GPS MULTIPATH ASSESSMENT OF THE HIBERNIA OIL PLATFORM

A study commissioned by Cougar Helicopters Ltd.

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EXECUTIVE SUMMARY

Cougar Helicopters Limited has contracted the Geodetic Research Laboratory of the Department of Geodesy and Geomatics Engineering, University of New Brunswick (UNB) to assess the GPS multipath environment at the Hibernia Oil Platform. In order to accomplish this task, UNB personnel, with the aid of NavCanada officials, visited the Hibernia construction site and collected two days of GPS data. Three potential sites for DGPS station antennas were chosen on the platform, as well as a low-multipath site on the shore. The platform sites were located as follows: on the south side of the platform, on level above the Weather Deck, (designated RIG1); on the north side of the Weather Deck, above an electrical room, between the Flare Boom support struts (designated RIG2); and, on the south side of the Weather Deck, on the meteorological/communications tower, adjacent to the Helideck (designated RIG3). The shore site was located on a barren hill near a platform access road. Dual frequency Ashtech Z-12 GPS receivers were used to collect data at a ten second recording interval. This data was processed at UNB in order to identify the potential magnitude of multipath induced error for a DGPS system to be located on the platform. Another goal of the project was to identify practical methods to mitigate the effects of this multipath.

The University Navstar Consortium's (UNAVCO) Quality Control (QC) software was used to determine the C/A-code pseudorange errors at each site. The average root mean square (r.m.s.) range error was computed, from two 21- to 24-hour data sets, to be approximately 5 m at RIG1, 7 m at RIG2, and 15 m at RIG3; and the maximum range error to be 155 m, 200 m, and 300 m, respectively. To infer how these pseudorange errors would affect position determinations, Ashtech, Inc.'s Precise Differential GPS Navigation and Surveying (PNAV) software was used to determine baseline lengths between the shore site and the platform sites. However, due to the fact that the platform was oscillating in its moored position, the pseudorange solutions had to be differenced from the more precise carrier phase solutions in order to realise a "stationary" baseline estimate time series. Also, the day-to-day multipath repeatability could not be analytically

compared because of this motion. The mean r.m.s. baseline length error, due predominately to multipath, was computed to be approximately 3 m at RIG1, 4 m at RIG2, and 6.5 m at RIG3; and the maximum range error to be 54 m, 41.5 m, and 72 m, respectively.

The final portion of the analysis deals with the satellite sky distribution. Signal blockages were observed to be primarily caused by the drilling derricks, but also from other parts of the platform superstructure. The simplest solution to this problem is to place the antennas on the south side of the platform, in its final drilling position, so as to allow the derricks to obstruct mainly the sparsely covered northern portion of the sky.

From these results, the site designated in this report as RIG1 appears to be the best antenna location. However, in its final drilling position the platform's superstructure will block a significant portion the GPS constellation from this site. Hence we consider the site designated as RIG2 in this report as an optimal site for the DGPS reference station antenna when the platform is in its final position.

In addition, the use of new receiver processing technology, and antenna choke-rings and microwave absorbing material would also provide some benefit to the mitigation of the multipath induced error. Another improvement would be the use of an array of antennas erected to improve the integrity of the system. Three potential sites are the locations used in these tests.

Finally, a second study should be contemplated when the platform is in its final drilling location. Such a follow-on study is envisioned to consist of two phases. First, to erect a temporary DGPS reference station array and to process the data to confirm the multipath induced errors at the three sites; and second, having established the preferred locations for the DGPS system antennas, to install the DGPS system and to assess the residual multipath error of the system. The *actual* magnitude of the DGPS positioning error due to multipath could then be assessed.

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ACKNOWLEDGEMENTS

The authors would like to thank NavCanada for their introduction of the Hibernia Oil Platform project to the Geodetic Research Laboratory, and for the transportation provided for our site visits. In particular, we would like to thank George Dewar for providing logistical support for the GPS campaign.

1. INTRODUCTION

The contract for providing helicopter services to the Hibernia Oil Platform was obtained by Cougar Helicopters Ltd. in 1997. As part of the contract it has been proposed to use the Global Positioning System (GPS) as the primary aviation navigation and landing aid system. In terms of the error sources that contribute to GPS, next to Selective Availability (SA), multipath can be the most significant, theoretically reaching 150 metres for C/A-code pseudorange measurements [Langley, 1997]. However, while differential GPS (DGPS) greatly reduces common-mode errors (atmosphere, ephemeris, satellite clock including SA), multipath is not reduced. In DGPS operation, multipath-induced errors at a reference receiver (i.e. on the platform) are propagated into the transmitted corrections that are applied at the mobile receiver (i.e. in the helicopter), resulting in lower positional accuracies. The Geodetic Research Laboratory, in consultation with NavCanada, proposed to undertake a study of the multipath environment on the platform and its potential effect on DGPS operations with the aim of identifying suitable locations for the antenna(s) of a DGPS reference station. Between the 18th and 21st of April, 1997 a 48 hour GPS campaign was carried-out at the Bull Arm, Newfoundland construction site of the Hibernia Oil Platform. Observations were made at three sites on the platform and one site on the shore. The data collected were processed with the University NAVSTAR Consortium's (UNAVCO) Quality Control (QC) software to estimate C/A-code pseudorange multipath and Ashtech, Inc.'s Precise Differential GPS Navigation and Surveying (PNAV) software to estimate baseline lengths.

The following subsection briefly describes the GPS multipath phenomenon. Section two identifies the sites chosen on the platform and the data collected by the GPS receivers. The primary data processing techniques are described in section three. Section four presents the results of the data processing undertaken. This includes determinations of site multipath and the effects of these errors on differential positioning. Finally, conclusions and recommendations are given in section five.

1.1. GPS MULTIPATH

Multipath is the phenomenon whereby a signal arrives at a receiving antenna via two or more different paths. The arriving signals, with different phases and amplitudes, interfere with each other at the antenna and contribute to the error in the pseudorange and carrier phase observations. Figure 1.1 illustrates the satellite–reflecting surface–antenna geometry.

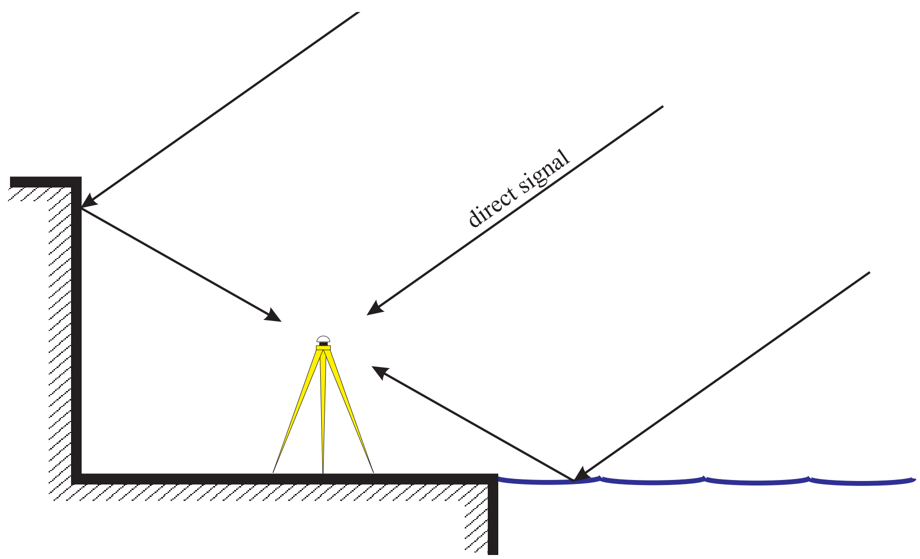

Figure 1.1. GPS satellite-reflecting surface-antenna multipath reflection geometry.

A surface in proximity to the receiving antenna will cause multipath if the receiver tracking loops are unable to distinguish between the direct and delayed signals. This occurs for the C/A-code if the difference (between the direct and delayed signals) is less than 1466 ns (1.5 chips of the C/A-code) for a standard-width correlator. This is the case because for a difference greater than this, the C/A-code tracking loop rejects any other signal. Therefore, reflecting surfaces that produce a multipath signal that arrives at the GPS antenna less than 1466 ns after the direct signal (which translates into a path-length difference of 440 m for the C/A-code, given that 1 chip is approximately 293.3 m long) will cause measurement errors due to multipath [Braasch, 1996, p. 559]. Note that reflecting surfaces greater than 440 m from the receiving antenna can still cause multipath, if the indirect signal travels along a path that is less than 440 m longer than the path of the direct signal.

Aside from the path length induced phase difference, the electromagnetic (EM) properties and texture of the reflecting object also influence the amplitude of the signal. The direct right-hand circularly polarised GPS signal becomes left-hand elliptically polarised if it is reflected from a near-planar surface with an incidence angle of less than a certain value (sometimes referred to as Brewster's angle). Such left-hand polarised signals are only partially attenuated by the antenna and less so if the reflecting surface is not smooth [Braasch, 1996, p. 559]. This signal attenuation is obtained by designing antennas to be insensitive to left-hand circularly polarised EM signals. The gain pattern of such antennas also allows for the attenuation of signals at or below the antenna's horizon, since as can be seen in Figure 1.1 signals arriving from these directions are multipath signals. However, multipath signals can also arrive at the antenna with elevation angles well above the horizon.

A number of other multipath reduction techniques have been designed. An obvious method is to place antennas in low multipath areas (i.e. away from reflecting objects). This is not a viable option for an oil platform. Extended ground planes, choke-rings, and microwave absorbing materials added to antenna hardware can reduce the effect of received multipath signals. Multiple antenna configurations can be used to remove the site specific multipath signals through spatial processing. Long-term single antenna observations take advantage of the repetitive GPS satellite-reflecting surface-antenna geometry for static sites to detect and through processing remove the site multipath. Finally, the most promising method for multipath reduction is real-time signal processing within the receiver [Weill, 1997].

The complex structure of the platform was expected to be a highly reflective environment for the GPS signals. The specific goals of the investigations described in this report were to verify that this is true, to indicate the level of multipath, to consider the impact on position determination, and to offer suggestions of countermeasures.

2. SITE SELECTION AND DATA COLLECTION

At the time of the GPS observations, the Hibernia platform was located in Bull Arm channel (refer to Figure 2.1), on the west side of Trinity Bay, Newfoundland. The TopSides and the Gravity Base Structure had already been mated. As can be seen in Figure 2.1, topography as high as a few hundred metres lies within 1 km of the platform (a 1 km grid is overlaid on the map). This raises the possibility that the off-platform multipath environment in Bull Arm is different than that at the Hibernia oilfield.

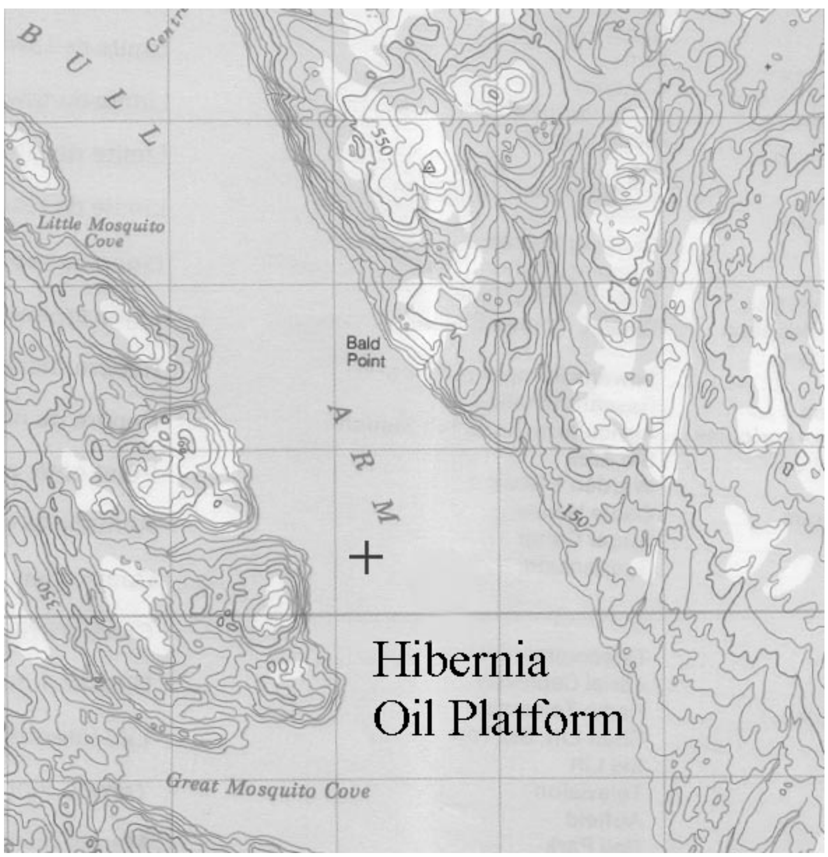

Figure 2.1. Location of the Hibernia Oil Platform in Bull Arm, Newfoundland (after Energy, Mines and Resources Canada [1981]).

Three platform (or "rig") sites were chosen, along with a nearby site on-shore. This latter station was chosen to be in a minimum multipath environment subject to the constraints of reconnaissance time and site accessibility. The site location was a near-barren hill adjacent to a platform access road. The criteria for choosing platform sites included: locations as far away as possible from the platform superstructure; locations with high "visibility" of the sky and GPS satellites; locations where GPS antennas could operate in the Hibernia oilfield working environment; locations that were accessible during the period of the GPS surveys; and the availability of three GPS receivers for the platform multipath assessment. The three sites chosen, denoted RIG1, RIG2, and RIG3 are identified in Figure 2.2. Given that the platform was azimuthally rotated almost 180° from its final orientation, it was decided that a pair of sites should be located on either side (south and north) of the platform. The rationale for this decision is further discussed in sub-section 4.3. These sites are RIG1 and RIG2, respectively. The third site, RIG3, was chosen because of the above criteria and also because it is already a GPS antenna (marine DGPS) location on the platform. It too was located on the southern side of the platform. Figure 2.3, Figure 2.4, and Figure 2.5 show the detailed locations and mounting apparatus of sites RIG1, RIG2, and RIG3, respectively. Of note, RIG2 lies between the support structure of the Flare Boom and RIG3 is located on a weather/communications tower. Refer to the above mentioned figures for detailed descriptions. Few other sites on the platform would, in the authors' opinion, be suitable for the locating of GPS antennas.

Figure 2.2. Locations of GPS sites RIG1, RIG2, and RIG3 on the Hibernia Oil Platform (after Hibernia [1997]).

Figure 2.3. GPS antenna location “RIG1”.

Figure 2.4. GPS antenna location “RIG2”.

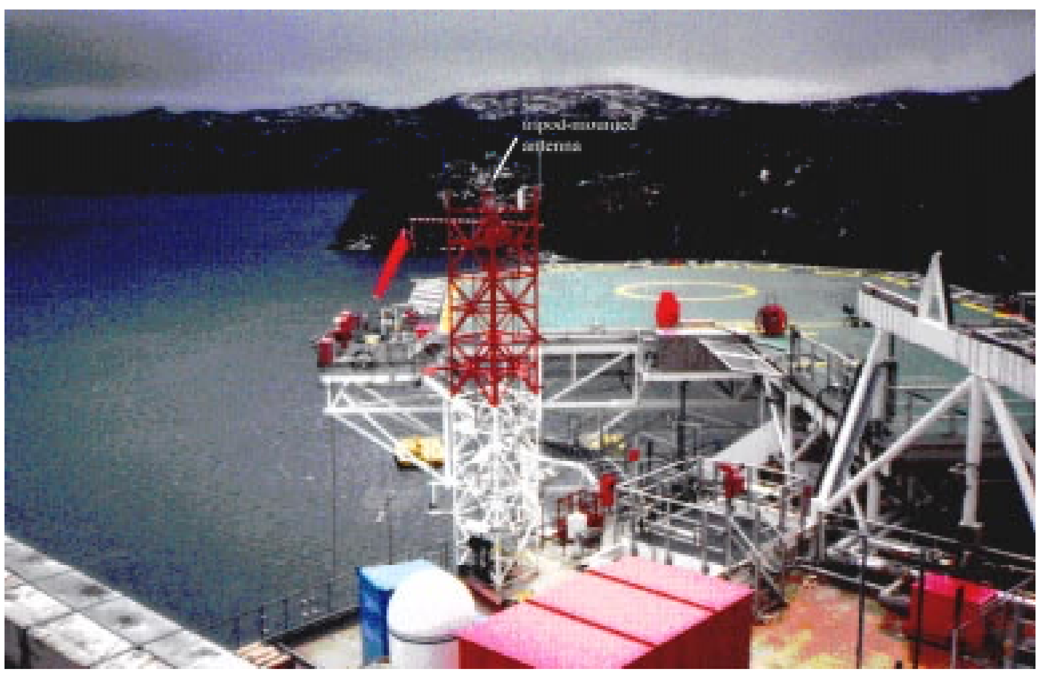

Figure 2.5. GPS antenna location “RIG3”.

An attempt was made to collect two consecutive 24 hour data sets at each site. The motives behind this procedure are firstly, that the GPS satellite constellation ground tracks repeat approximately every 24 hours — therefore all possible satellite-reflecting surface-antenna multipath reflection geometry can be observed And secondly, that through repeatability analysis, two days of data can be used to detect whether or not errors thought to be multipath really are in fact that phenomenon. Due to logistical problems data was not recorded for the full 48 hour period. Figure 2.6 shows a timeline of the recorded data, which is also summarised in Table 2.1. The data obtained before the first large gaps (caused by battery failure) is designated as session one. The data after these breaks is designated as session two. The shorter gaps in this session occurred when data from the first session was downloaded from the receivers.

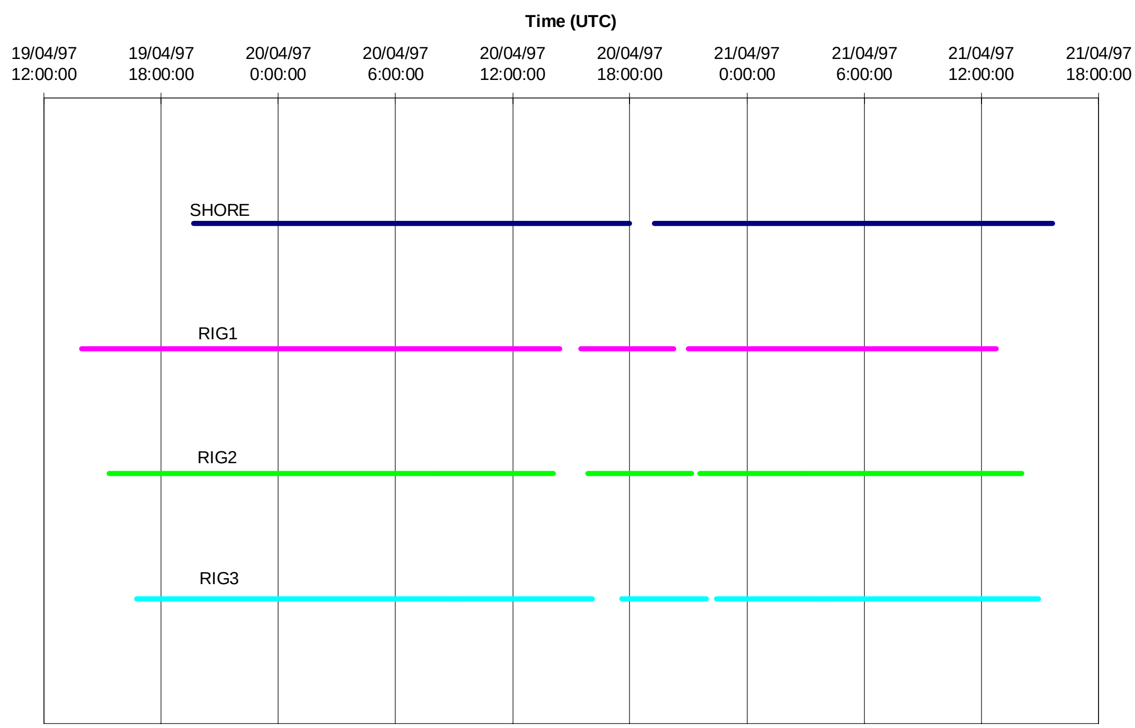

Figure 2.6.   Timeline of GPS data collected at the Hibernia Oil Platform.

Site	Session 1			Session 2		
	Start	Stop	Duration	Start	Stop	Duration
RIG1	19/04/97 13:54:00	20/04/97 14:32:40	$24^h38^m40^s$	20/04/97 15:24:50	21/04/97 12:47:50	$21^h23^m00^s$
RIG2	19/04/97 15:22:30	20/04/97 14:06:40	$22^h44^m10^s$	20/04/97 15:48:30	21/04/97 14:05:40	$22^h17^m10^s$
RIG3	19/04/97 16:47:00	20/04/97 16:04:40	$23^h17^m40^s$	20/04/97 17:34:20	21/04/97 14:56:50	$21^h22^m30^s$
SHORE	19/04/97 19:29:00	20/04/97 17:57:40	$22^h28^m40^s$	20/04/97 19:15:00	21/04/97 15:38:40	$20^h23^m40^s$

Table 2.1. Data collection periods in the GPS Time scale (approximately UTC).

The GPS equipment consisted of four, 12 channel ("all in view") Ashtech Z-12 receivers capable of recording the full complement of dual-frequency observations (L1 C/A-code, L1 and L2 P-code, and L1 and L2 carrier phase). Ashtech L1-L2 antennas, model number 700718.B — each a microstrip patch mounted on a circular aluminium platform (ground plane). The elevation angle mask was set to zero degrees, although all the processing undertaken so far has removed any data below five degrees, that being the minimum cut-off angle generally used (see e.g., the GPS interface control document [Rockwell International Corp., 1984]). As a compromise between a high data collection rate and the memory capacity of the receivers, a GPS data recording interval of ten seconds was used.

3. DATA PROCESSING TECHNIQUES

This section briefly describes the software used to process and to analyse the GPS data and where appropriate the primary algorithms used in the software are outlined.

3.1. Quality Check (QC) Software

The QC (version 3) software was developed by the University Navstar Consortium (UNAVCO) at Boulder, Colorado, U.S.A. The program is designed to check the quality of either static or kinematic GPS data. Linear combinations of the GPS observables are formed to compute the pseudorange multipath on L1 and L2 and the ionospheric phase delay of the L1 carrier phase. Summary files of these data are provided, as well as satellite elevation and azimuth data, and information about cycle slips and clock drift.

The main assumption of the QC program is that carrier phase multipath and noise are approximately two orders of magnitude smaller than the corresponding pseudorange multipath and noise. In addition, with dual frequency carrier phase data, the ionospheric delay can also be solved for to the first order. Hence, a linear combination can be formed of the pseudorange and carrier phases which is dominated by the pseudorange multipath and noise.

If we consider the C/A-code pseudorange (C_1) and carrier phases (Φ_1 and Φ_2 - subscript 1 will be used throughout for L1 and subscript 2 for L2) to be formulated as follows:

$$C_1 = \rho + c(dT - dt) + I_1 + T + m_{C_1} + n_{C_1} \qquad (3.1)$$

$$\Phi_1 = \rho + c(dT - dt) + \lambda_1 N_1 - I_1 + T + m_{\Phi_1} + n_{\Phi_1} \qquad (3.2)$$

$$\Phi_2 = \rho + c(dT - dt) + \lambda_2 N_2 - I_2 + T + m_{\Phi_2} + n_{\Phi_2} \qquad (3.3)$$

where ρ is the geometric distance between the satellite and receiver antenna phase centres; c is the speed of light in a vacuum; dT and dt are the receiver and satellite clock offsets respectively, from GPS Time; I is the ionospheric range delay; T is the tropospheric range delay; m is the effect of multipath; and any inherent receiver noise is represented by n. On each carrier phase observable, the biased distance caused by the unknown number of cycles is given by λN (the so-called carrier phase bias), where λ is the carrier wavelength and N is an integer number of cycles.

The difference between the pseudorange and carrier phase on L1 (both in units of distance) is:

$$C_1 - \Phi_1 = 2I_1 - \lambda_1 N_1 + m_{C_1} + n_{C1} - m_{\Phi_1} - n_{\Phi 1} \qquad (3.4)$$

which, under smoothly varying ionospheric conditions and no cycle slips will be dominated by the pseudorange multipath and noise components. However, by taking advantage of the dual frequency carrier phase observations and the fact that the ionospheric delays on L1 and L2 are related by:

$$I_2 = \alpha I_1; \quad \alpha = \left(\frac{f_1}{f_2}\right)^2 \qquad (3.5)$$

the ionospheric component can be solved for with:

$$2\frac{(\Phi_1 - \Phi_2)}{(\alpha - 1)} = 2I_1 + 2\frac{(\lambda_1 N_1 - \lambda_2 N_2)}{(\alpha - 1)} + 2\frac{(m_{\Phi_1} - m_{\Phi_2})}{(\alpha - 1)} + 2\frac{(n_{\Phi_1} - n_{\Phi_2})}{(\alpha - 1)} \qquad (3.6)$$

which can be subtracted from (3.4). The final equation for the C/A-code "multipath" observable is usually written as:

$$C_1 - \left(1 + \frac{2}{\alpha - 1}\right)\Phi_1 + \left(\frac{2}{\alpha - 1}\right)\Phi_2 = m_{C_1} + n_{C_1} + B + M_\Phi + N_\Phi \qquad (3.7)$$

$$\text{or} \quad C_1 - 4.0915\Phi_1 + 3.0915\Phi_2 = m_{C_1} + n_{C_1} + B + M_\Phi + N_\Phi \qquad (3.8)$$

where the carrier phase integer bias, multipath and noise combinations are represented by B, M_Φ and N_Φ, respectively. Again, this observable will be dominated by the C/A-code pseudorange multipath and noise (M_Φ and N_Φ being very small in comparison). The bias component represented by B can be estimated and removed from the time series to produce the C/A-code pseudorange multipath variation over time.

3.2. Precise Differential GPS Navigation and Surveying (PNAV) Software

The Ashtech PNAV software has been used to compute the baseline solutions. PNAV is a subset of the Ashtech Precision GPS Surveying software suite — Prism. Precise relative positions can be determined between a static base receiver and a static or moving remote receiver. This software was found to be the most appropriate for processing the data. Other software packages mentioned in the original contract proposal were not used. Processing GPS data over the end-of-week boundary caused errors in the GIMP software. The actual movement of the rig itself precluded the use of UNB's DIPOP software and the KARS software was unable to adequately resolve the carrier phase ambiguities.

A significant feature of PNAV is its ability to resolve carrier phase ambiguities while the receiver is in motion (on-the-fly [OTF] ambiguity resolution). The OTF algorithm initially approximates positions of the moving receiver by processing the pseudoranges. Then these results serve as initialisation points for the carrier phase processing to update the position determinations. Finally, the software searches for an optimal carrier phase ambiguity combination and attempts to derive a fixed integer ambiguity solution.

PNAV uses a Kalman filter, meaning that the software compares predicted positions based on previous position estimates with positions derived from the current measurements, and obtains final position estimates by using the covariance matrix of the predictions and the measurements. This use of a Kalman filter allows for potential dynamic movement of the platform to be modelled, which in the present case turned out to be somewhat significant. This procedure in turn allowed the integer ambiguities to be resolved in the short baseline processing.

4. PROCESSING RESULTS

The results are presented in three sections: first, the output from QC; second the results of the baseline processing; and finally some considerations of the satellite sky coverage from the platform sites.

4.1. SITE MULTIPATH ESTIMATION

The time series of C/A-code multipath observations computed from the raw data collected at each site are presented in Figure 4.1 and Figure 4.2 and summarised in Table 4.1. It can be seen immediately that there are significant differences among the three platform sites. RIG3 has the largest mean r.m.s. multipath over all satellites — approximately 15 m — more than twice as much as the RIG1 site — approximately 7 m — and approximately three times as much as the RIG2 site — approximately 5 m. The peak-to-peak ranges can reach the 300 m level, as is the case at site RIG3. However, it is possible that some of these peaks are due to QC's method of dealing with cycle slips. Note the similar mean r.m.s. magnitudes between days for each site. The results obtained for the shore station show a lower level of multipath. This result can be used in the baseline processing.

Site	Session 1		Session 2	
	Mean r.m.s. (m)	Range (m)	Mean r.m.s. (m)	Range (m)
SHORE	2.1	17.9	2.0	13.3
RIG1	4.9	155.2	4.5	98.4
RIG2	7.0	185.5	7.0	198.9
RIG3	15.0	300.0	14.4	292.9

Table 4.1. Multipath error in the C/A-code pseudoranges.

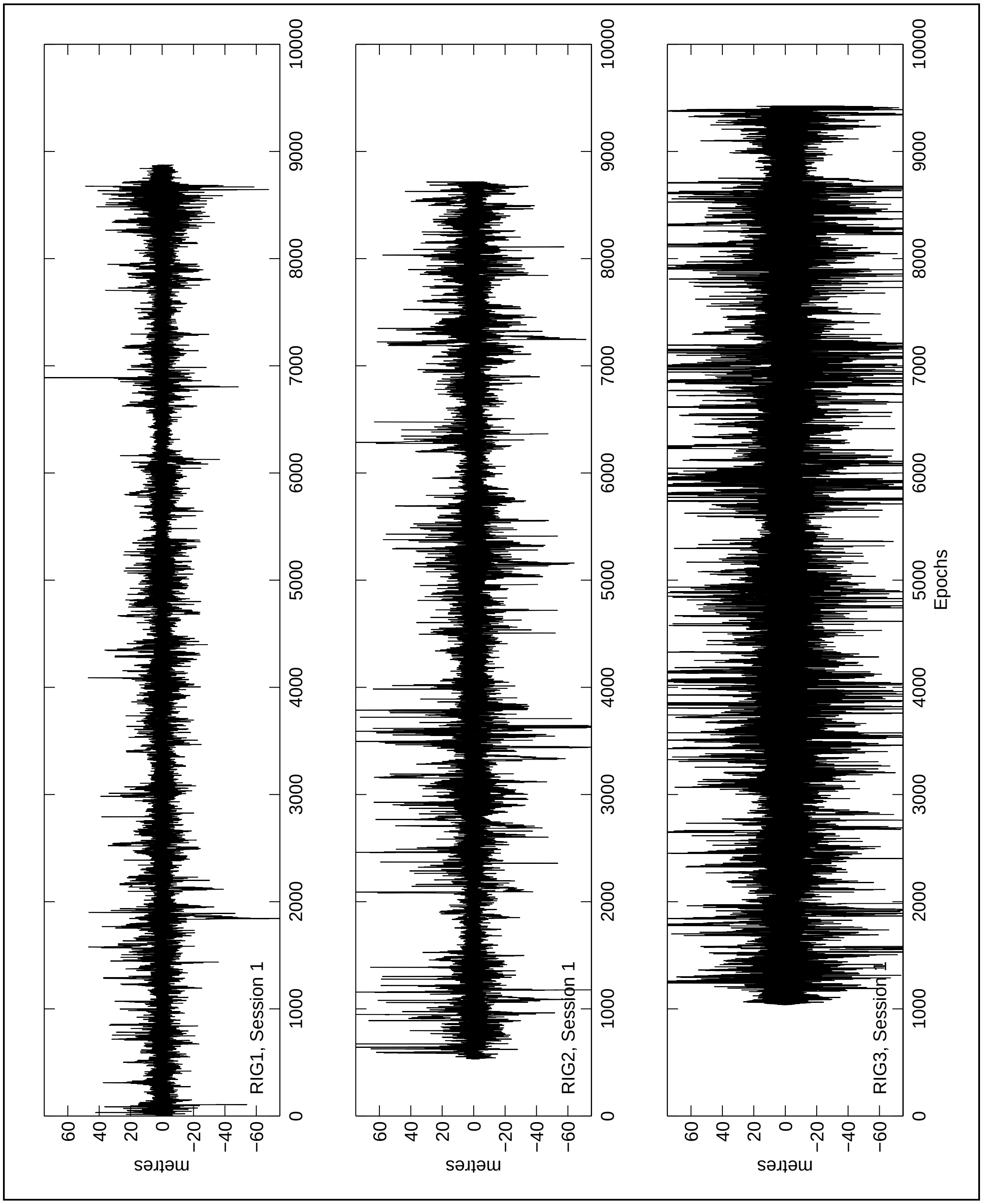

Figure 4.1. C/A-code multipath, session one (1000 epochs ≈ 2.8 hours).

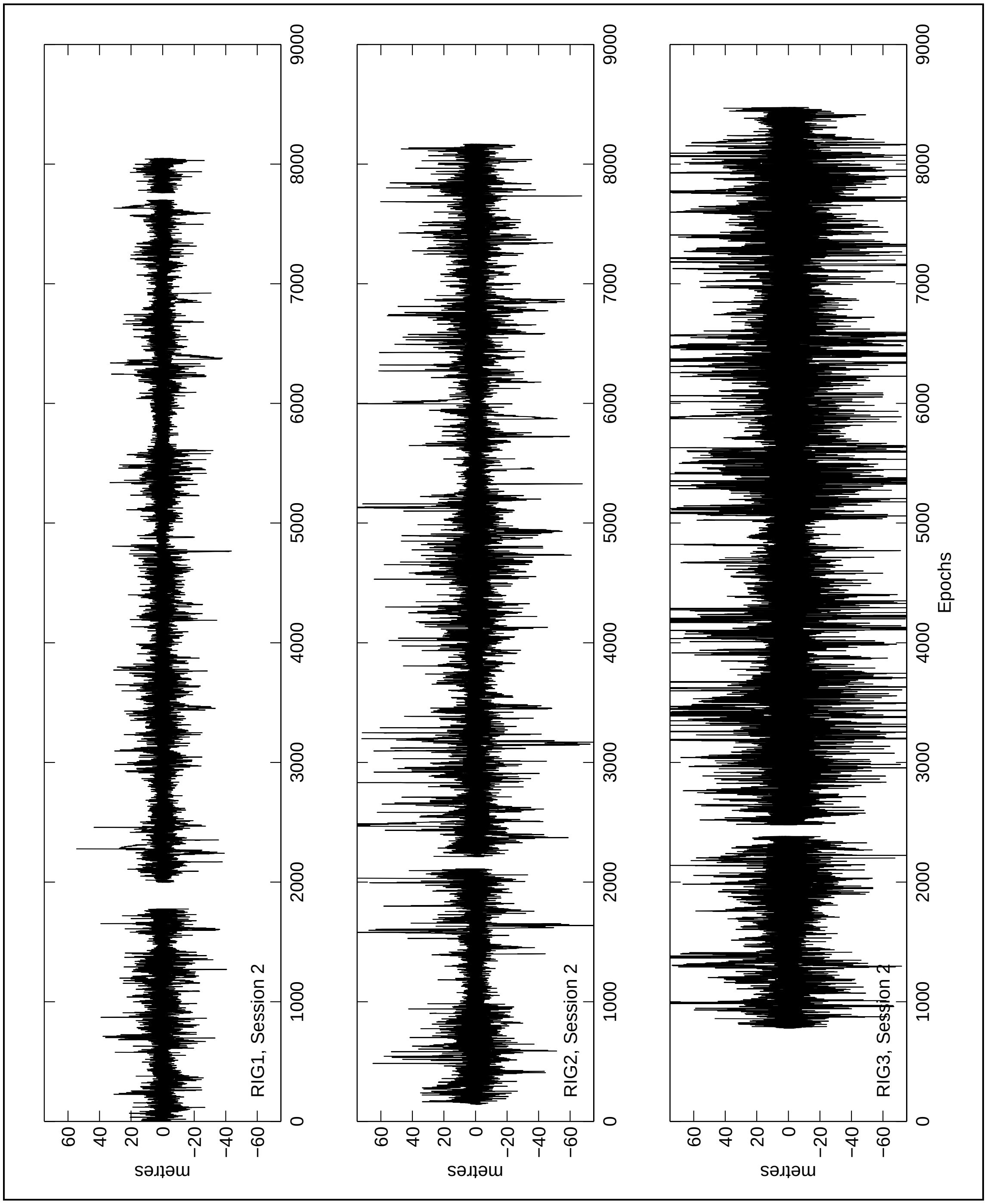

Figure 4.2. C/A-code multipath, session two (1000 epochs ≈ 2.8 hours).

The "multipath" observable also includes the contribution of C/A-code pseudorange measurement noise. To investigate whether noise, rather than multipath, was dominating the "multipath" time series, particularly that for RIG3, the time series of the measurement signal to noise ratios (SNRs) recorded by the receivers were examined. Figure 4.3 and Figure 4.4 show the SNR values for satellite PRN 31, for a portion of session one at sites RIG3 and RIG2, respectively. As can be seen, the SNR values at each site are not significantly different. Therefore, the noise level of the receiver at RIG3 can not be said to be significantly higher than that of the receiver at RIG2, and hence the QC output of multipath and noise in Figure 4.1 and Figure 4.2 for RIG3 is in fact predominately due to multipath. Note that the SNR values for the L1 P-code and the L2 P-code are almost identical due to the high correlation between these synthesised observables.

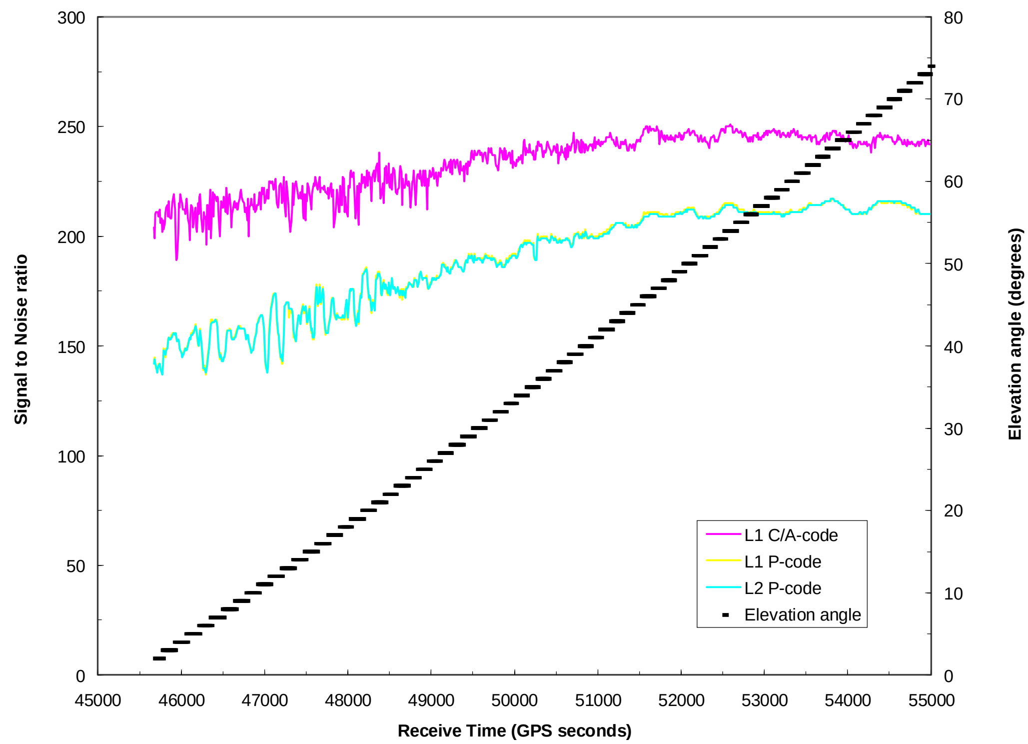

Figure 4.3. Elevation angle of satellite PRN 31 and signal to noise values for each observable at site RIG 3, session one.

The quasi-sinusoidal variations in SNR at the lower elevation angles in Figure 4.3 (particularly evident in the P-code values) are characteristic of multipath from a horizontal planar surface. By observing the frequency of the observable's SNR, the elevation angle and the rate of change of elevation angle with time, it has been estimated that the reflecting horizontal surface at site RIG3 is approximately 5 metres below the antenna.

This would suggest reflection from the Helideck, given that the satellite azimuth indicates that the satellite was rising with respect to RIG3 in line with the Helideck and that the Helideck is approximately 6 metres below the antenna at RIG3. However more study is required to definitively identify the multipath-inducing surfaces both on and off the platform.

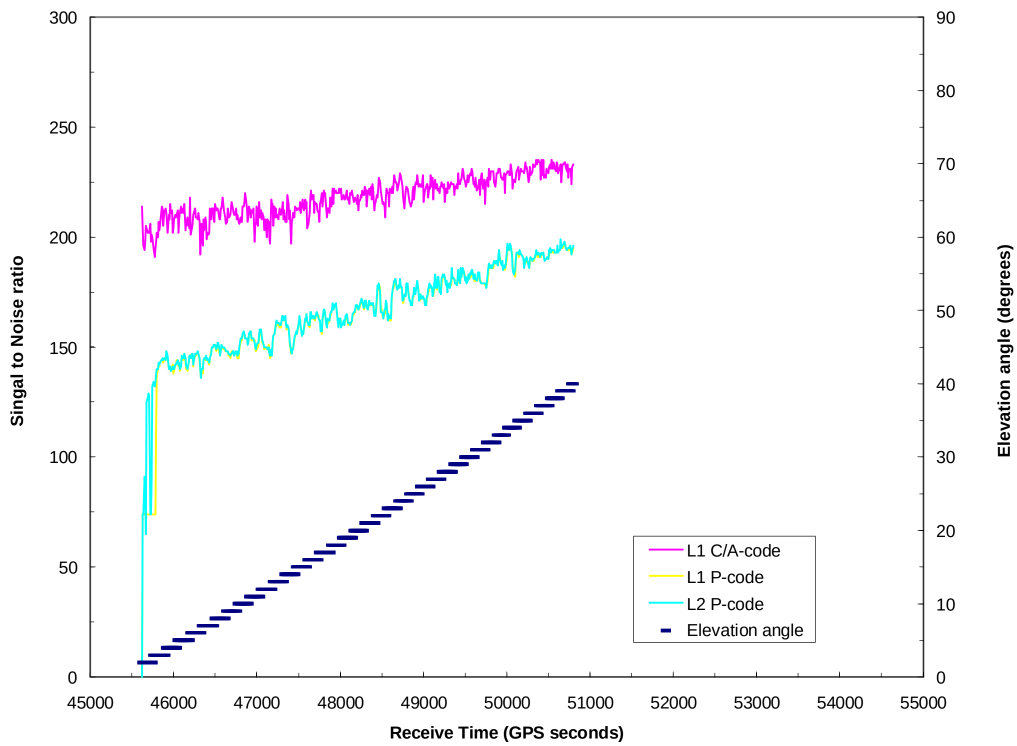

Figure 4.4. Elevation angle of satellite PRN 31 and signal to noise values for each observable at site RIG 2, session one.

Two activities could have potentially affected the observed multipath. The first involved the platform cranes. sites RIG1 and RIG3. Figure 4.5 illustrates the situation at RIG1. During helicopter approaches and landings these cranes must be in their rest positions. This raised the question of how would the observed magnitude of multipath error change during these times when the position information is most crucial. From initial investigations, using the data displayed in Figure 4.1, Figure 4.2 and Table 4.1, there is no indication that the presence of the resting cranes significantly increased the multipath errors at sites RIG1 and RIG3.

Figure 4.5. Crane in rest position adjacent to site RIG1.

The second activity that may have possible adverse effects were the transmitting antennas located on the same tower as RIG3 (refer to Figure 2.5). The transmitters consist of aeronautical (130 MHz), marine VHF (156 MHz), and trunk (approximately 850 MHz) radios, the last of which was not operational at the time of the GPS data collection. The aeronautical and marine VHF radios transmitted for approximately two minutes each, beginning at approximately epoch 7860, session two. No significant change to the magnitude of the C/A-code multipath (plus noise) can be observed in Figure 4.2 as a result of the radio transmissions.

4.2. BASELINE ESTIMATION

The objective for the baseline processing was to determine the effect that the previously determined C/A-code pseudorange multipath at each platform site has on relative position determination. The methodology used was to process the baselines from the shore to the platform sites, holding the coordinates of the shore station fixed. Because the shore station has relatively low multipath (see section 4.1), the solution "errors" should be dominated by the multipath at the platform sites. The PNAV software has been used for this task.

Preliminary processing with the pseudorange data revealed that there was some movement of the anchored platform. To avoid possible confusion with multipath induced position differences, this movement was confirmed by processing the carrier phase data. This analysis revealed horizontal movement during session one to be of the order of twenty metres (refer to Figure 4.6), while the vertical movement is almost one metre, dominated by the tide (refer to Figure 4.7). This provides an extra challenge to the multipath determination because the platform's position is not fixed and hence the multipath geometry is constantly changing.

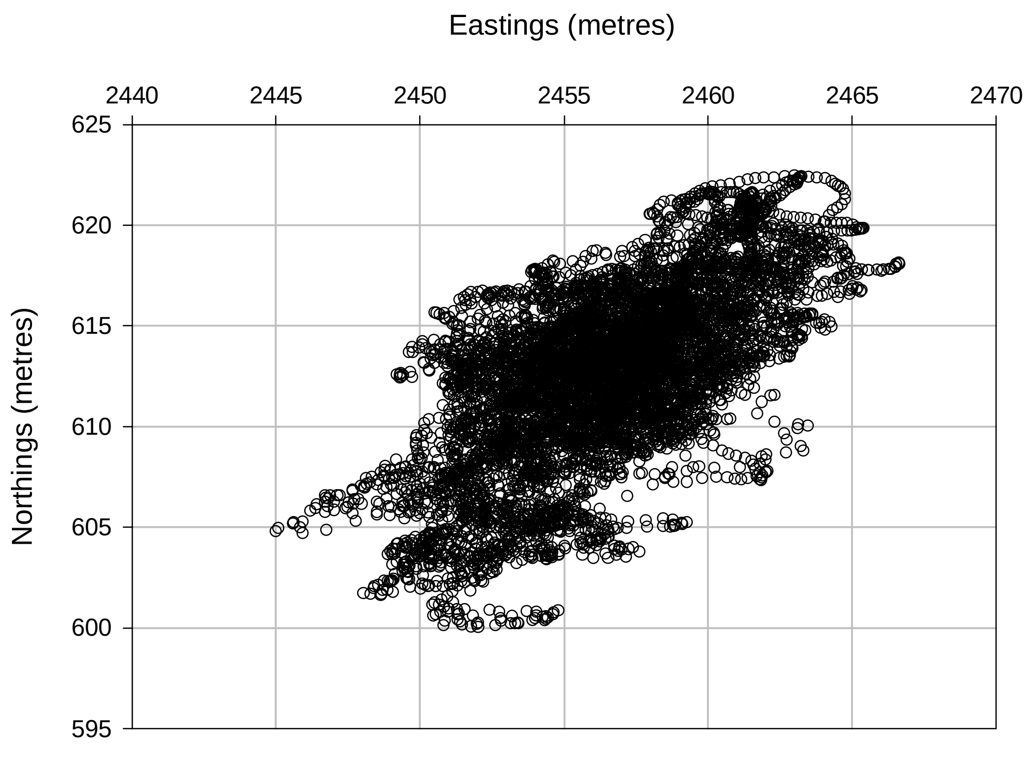

Figure 4.6. Horizontal movement of the Hibernia Oil Platform (relative to the origin shore station) during session one, using data from RIG3.

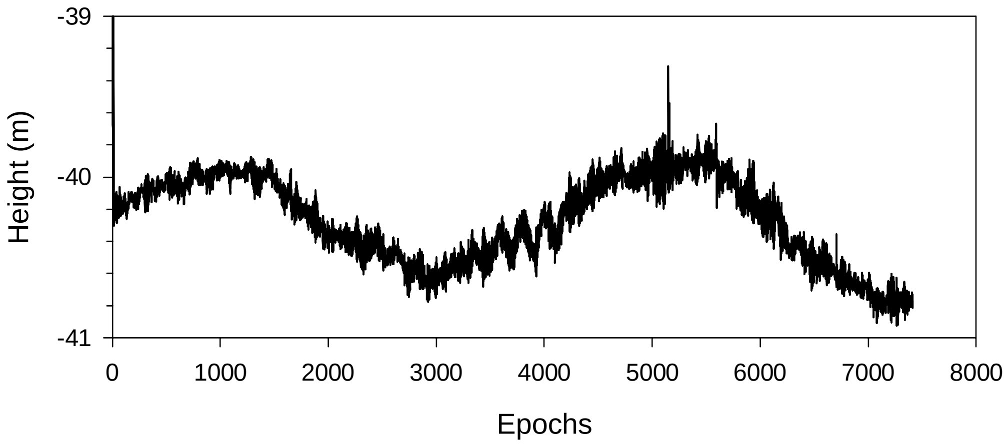

Figure 4.7. Vertical movement of the Hibernia Oil Platform (relative to the shore station) during session one, using data from RIG3.

Examination of Figure 4.7 in particular, reveals that, despite the much lower noise level and susceptibility to multipath of the carrier phase solution, there are possible periodic multipath trends visible (the high frequency structures). Even so, the Hibernia DGPS system will be using pseudoranges and therefore this study concentrated on solutions computed with this observable but will utilise the accuracy of the carrier phase solutions. Note that the spike after epoch 5000 may be due to an uncorrected cycle slip.

Figure 4.8, Figure 4.9, and Figure 4.10 show the results for the estimation of the baseline lengths with the session one data. Two traces are shown on each plot, one showing the baseline length as computed using the C/A-code pseudoranges and the other the length computed using the carrier phases. Note that for plotting purposes, the end-of-week crossover at 604800 seconds has been ignored on these plots.

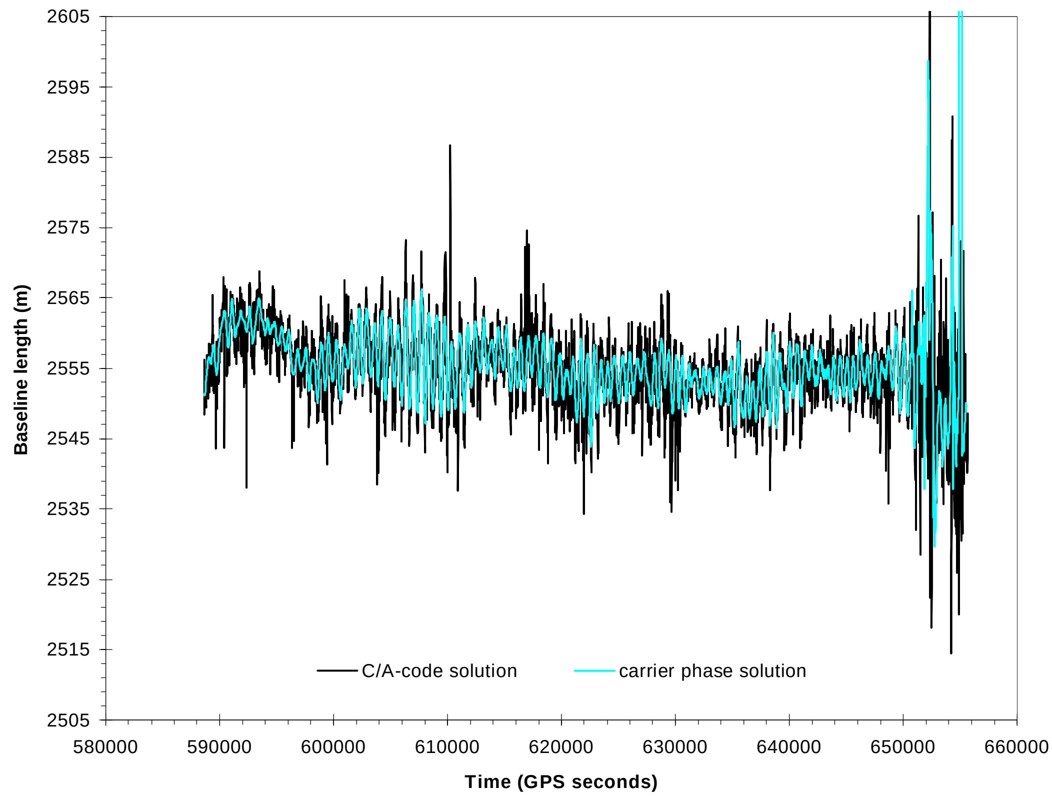

Figure 4.8. C/A-code and carrier phase solutions of baseline SHORE to RIG1, session one.

According to Figure 4.8, there appears to be some kind of problem at the end of session one. As this appears only in this plot, it can be concluded that there is a problem with the RIG1 data, possibly some form of data corruption. Whether this is a multipath induced problem, or an internal receiver problem requires further investigation. Also each plot has a vertical scale that spans 100 metres so that general visual intercomparisons can be made. The greater variations associated with the baseline solutions for site RIG3 are readily apparent.

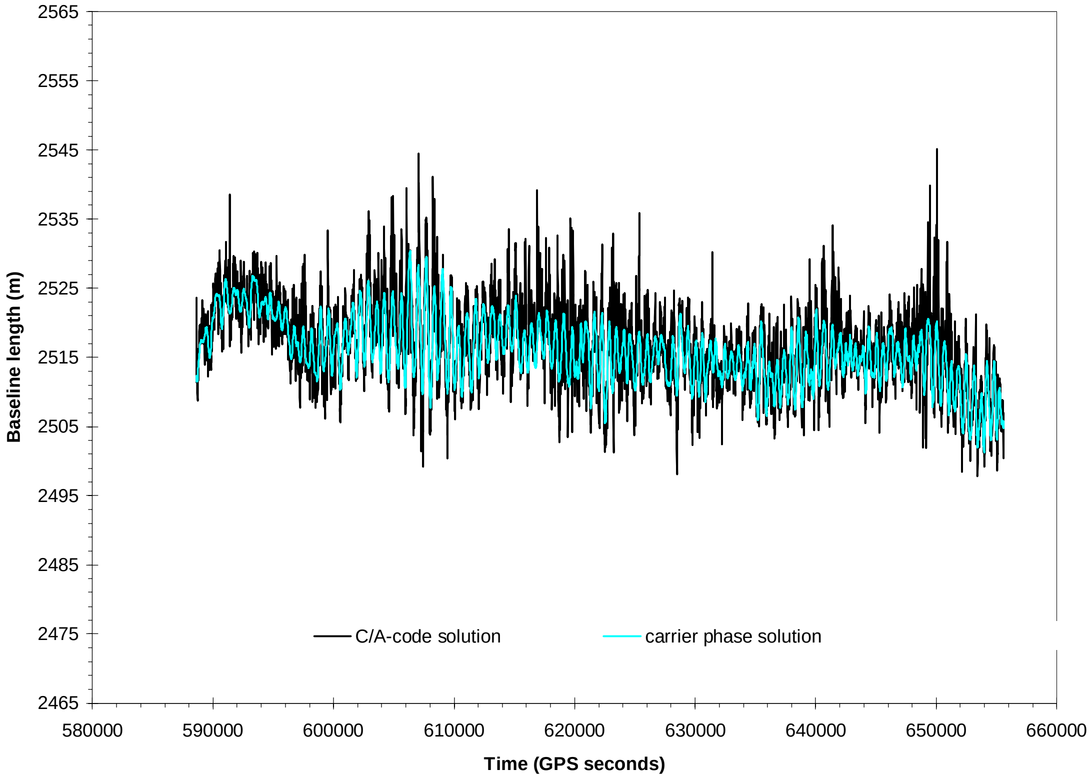

Figure 4.9. C/A-code and carrier phase solutions of baseline SHORE to RIG2, session one.

The movement of the platform can be clearly seen in these plots. To examine the effect of the C/A-code multipath, this movement must be removed from the baseline solutions. This can be accomplished by subtracting the carrier phase solutions from the C/A-code solutions. As long the correct fixed integers are used in carrier phase processing, the carrier-phase solutions should be accurate to at least 10 cm. The QC results show that the multipath effect on the pseudoranges is up to three orders of magnitude greater than this level, so any difference between the two will predominantly be due to pseudorange multipath.

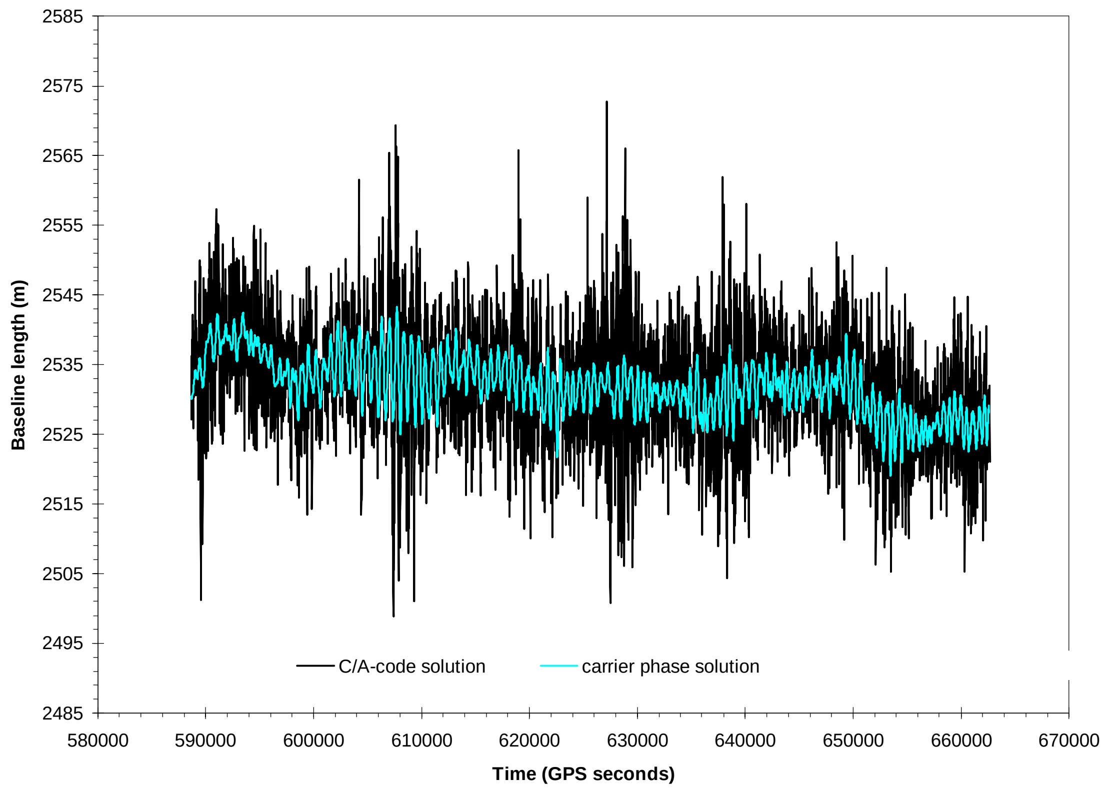

Figure 4.10. C/A-code and carrier phase solutions of baseline SHORE to RIG3, session one.

These differences are shown in Figure 4.11, Figure 4.12 and Figure 4.13, with associated statistics summarised in Table 4.2. The results confirm the QC site multipath results in that the multipath effects on position determinations at sites RIG1 and RIG2 are less than those at site RIG3. The variation in baseline length reached 72 m for the RIG3 - SHORE baseline.

Baseline	Solution Difference	
	Mean r.m.s. (m)	Range (m)
RIG1 – SHORE	2.9	54.0
RIG2 – SHORE	3.8	41.5
RIG3 – SHORE	6.5	72.0

Table 4.2. Session one solution statistics for C/A-code solution minus carrier phase solution.

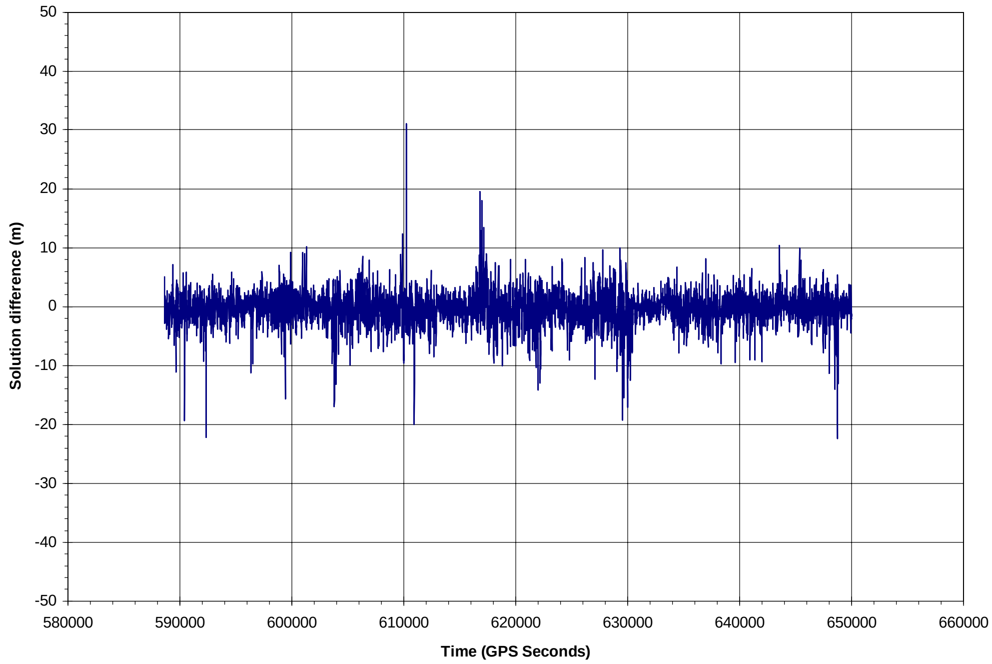

Figure 4.11. Multipath effect on baseline SHORE to RIG1, session one.

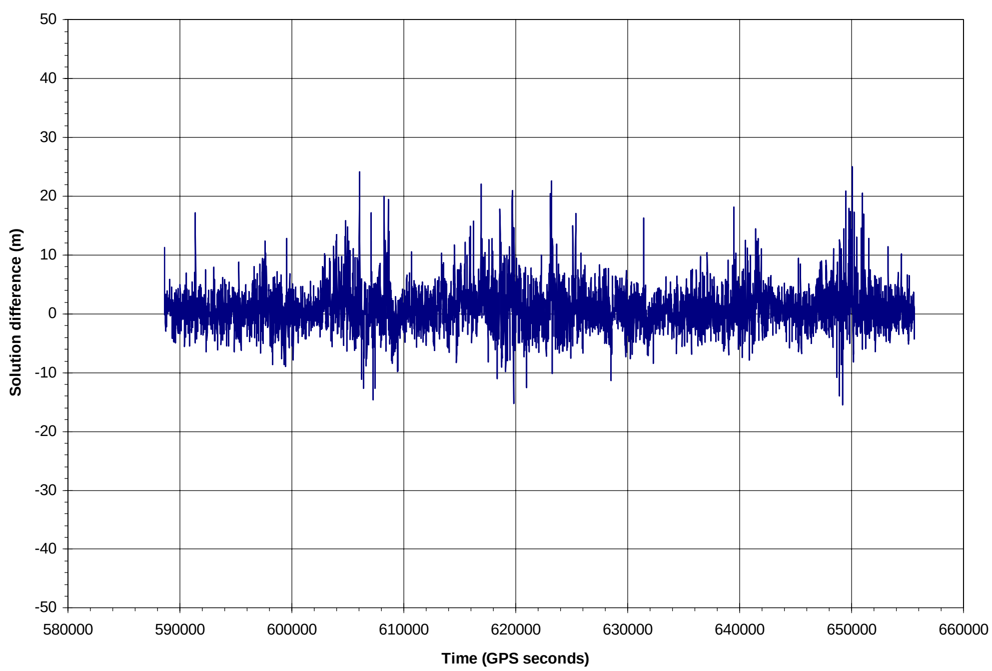

Figure 4.12. Multipath effect on baseline SHORE to RIG2, session one.

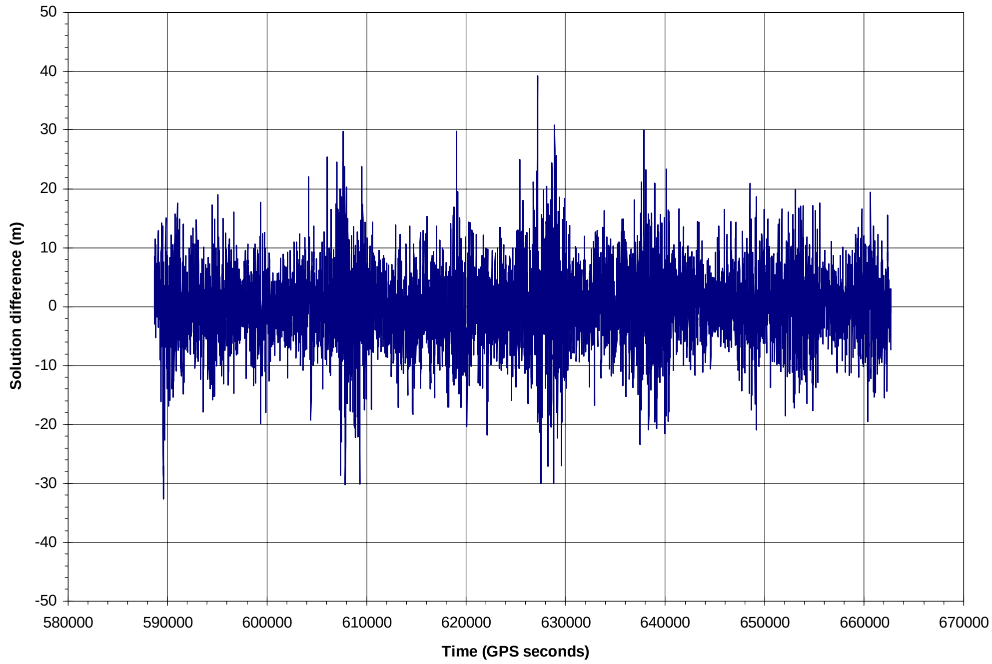

Figure 4.13. Multipath effect on baseline SHORE to RIG3, session one.

Overall, these results appear to indicate that RIG3 is a relatively poor reference site in comparison to RIG1 and RIG2 in terms of its susceptibility to multipath. This could be due to several factors. The antenna at this site was located approximately 11 metres above the support deck on a steel-frame tower. It is likely that it is susceptible to multipath from signals reflected from the adjacent Helideck — “ground-bounce” multipath. Sites RIG1 and RIG2 are only several metres above their respective decks and hence the multipath from ground reflectors should be less since the occurrence of reflection angles less than or equal to Brewster’s angle are less likely. In addition, RIG3 is located at the edge of the platform, and hence it is possible that some reflection could be coming from the water’s surface as well. Of the other two sites, RIG1 is set back several tens of metres from the edge of the platform and hence is more protected from this source of multipath.

4.3. SKY COVERAGE

An important consideration in placing the antennas onboard the platform is that of overall sky coverage. It is not possible to place a receiver at any great distance from the drilling derricks and cranes, and hence these will always block a portion of the sky. Due to the configuration of the GPS constellation however, there is a portion of the sky through which no satellites pass. (Actually, there are two regions, one over the North Pole and one over the South Pole). It would therefore be advantageous to position an antenna so that the derricks are in view at this portion of the sky coverage gap. At the time of the campaign this was the case for sites RIG1 and RIG3. It is important to stress again that at the time of the test, the platform did not have the orientation that it will have when in its production environment. Hence the sky visibility of a site in the vicinity of the helicopter pad in the platform's final orientation is more likely to be represented by site RIG2 in these tests.

To illustrate this, Figure 4.14, Figure 4.15 and Figure 4.16 represent the skyplots of the satellites in view from the first session produced by QC. Due to an error in the QC software, there are some spurious traces in these plots where the satellite azimuth changes from +/- 180°. Regardless, in addition to the "hole" towards the north, it is possible to clearly see the outline of two gaps from RIG2, session one data between 80° and 180° azimuth where the derricks were located. RIG1 has an apparently similar pattern (between -90° to -60° and from -40° up to 0°), although these blockages must have been caused by other features, and RIG3 has almost no large blockages, although there is a blockage around -40°, which is likely to be one of the cranes.

Careful examination of these plots reveals other gaps, some significant. It is likely that these blockages are due to other large plant scattered around the platform and also possibly due to the movement of the cranes.

In an attempt to emphasise the problem of sky coverage, further results from the baseline processing are presented. The Position Dilution of Precision (PDOP) is an indication of the overall satellite geometry and therefore of the solution quality. Figure 4.17, Figure 4.18 and Figure 4.19 represent the PDOP and the total number of satellite vehicles (SV's) used in the position determinations for the three baselines for session one.

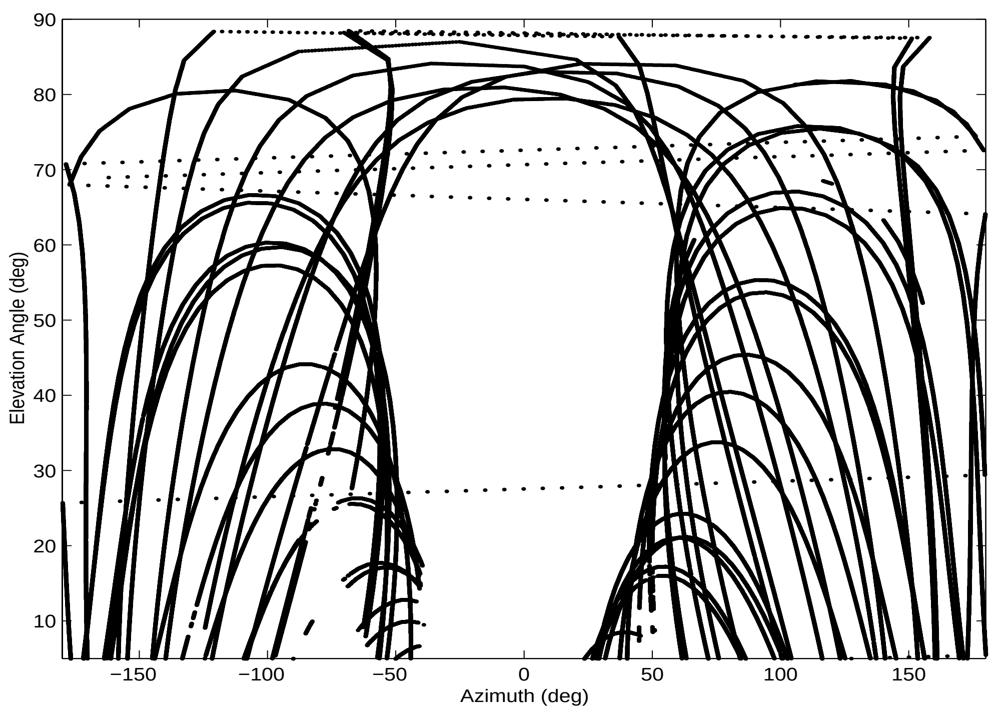

Figure 4.14. Satellite sky coverage at site RIG1, session one.

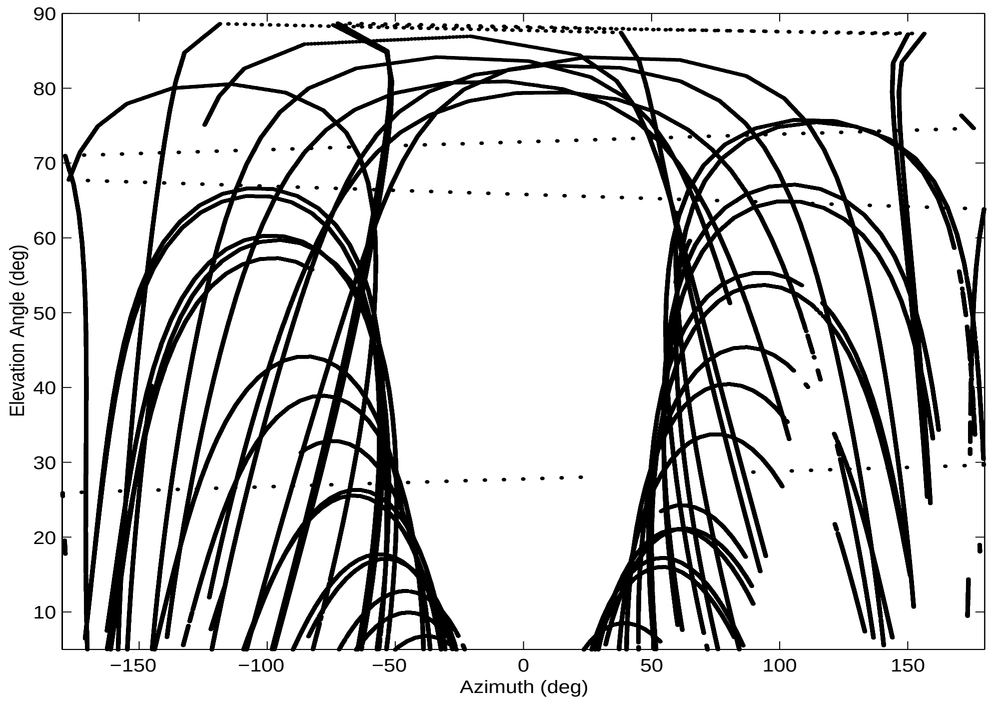

Figure 4.15. Satellite sky coverage at site RIG2, session one.

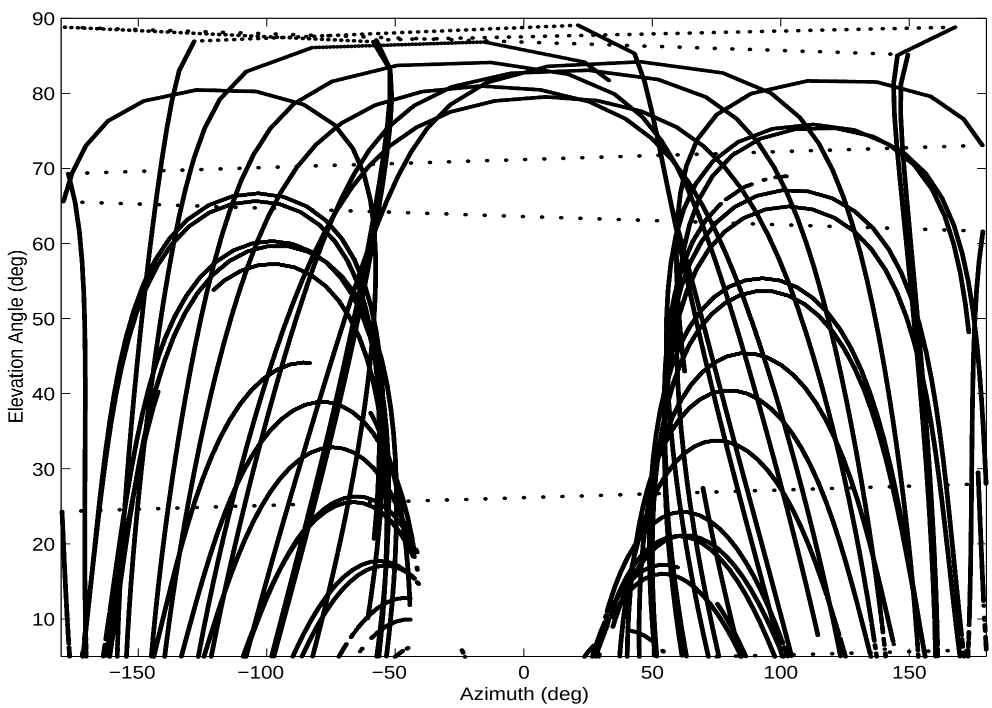

Figure 4.16. Satellite sky coverage at site RIG3, session one.

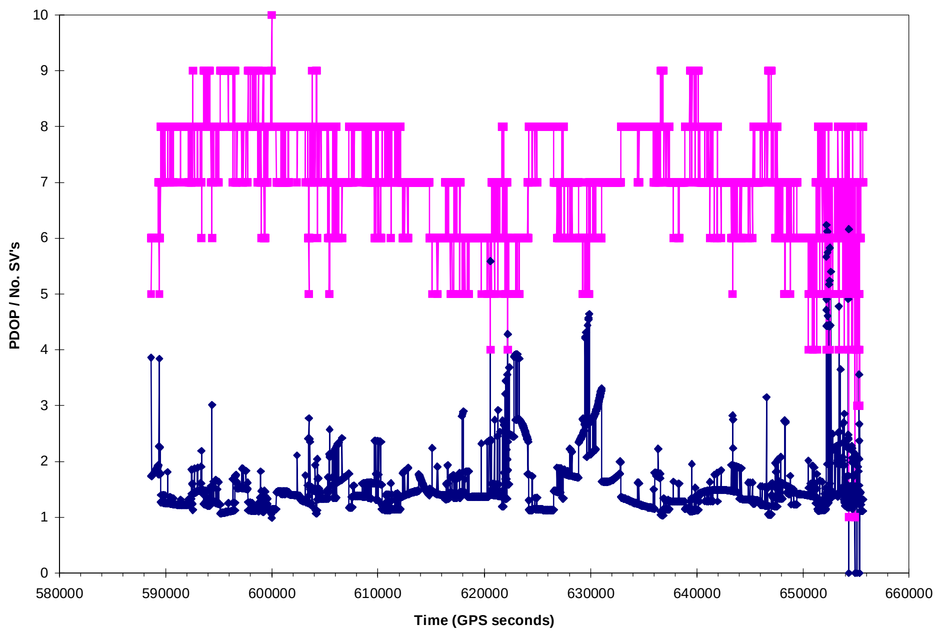

Figure 4.17. PDOP and number of SV's for the SHORE–RIG1 baseline, session one.

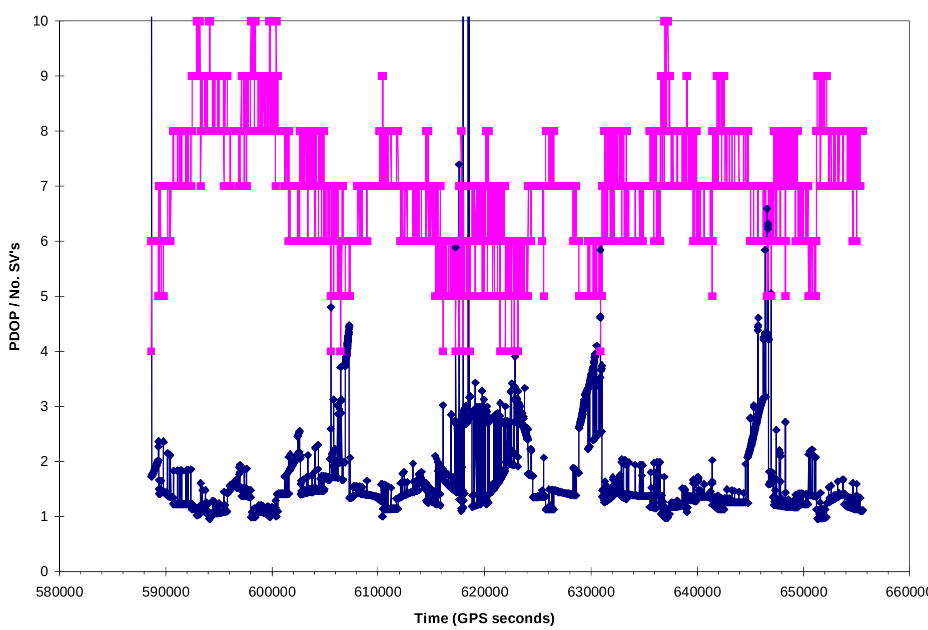

Figure 4.18. PDOP and number of SV's for the SHORE–RIG2 baseline, session one.

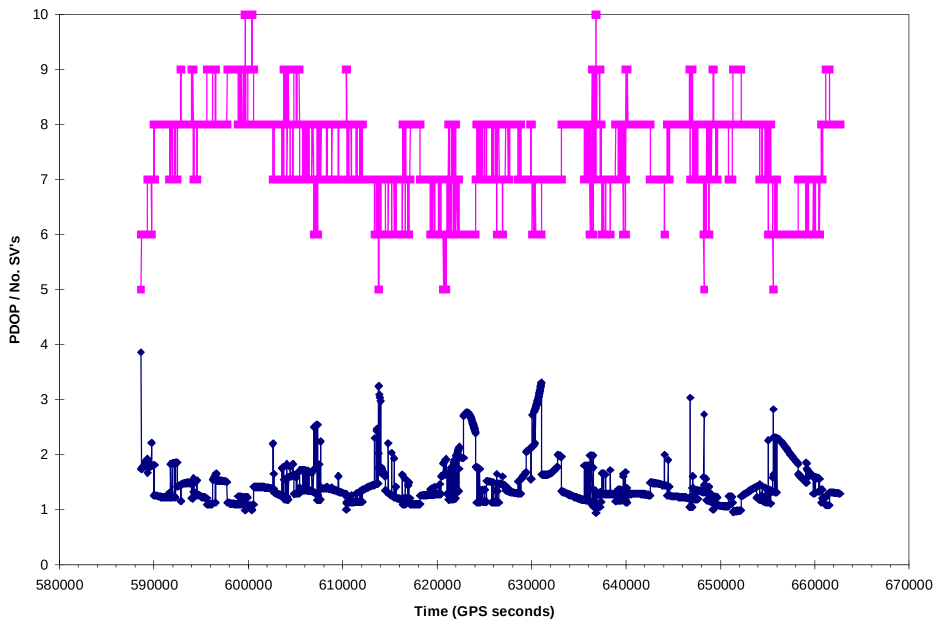

Figure 4.19. PDOP and number of SV's for the SHORE–RIG3 baseline, session one.

As might be expected, the site furthest from the derricks on the south side of the platform has the best coverage, i.e. RIG3. Unlike the other two sites, there are no large PDOP spikes, and the number of satellites never drops below 5 and only occasionally below 6. For sites RIG1 and RIG2 however, there are potential problems with large PDOP spikes (extreme in the case of RIG2). The possible data corruption at the end of the RIG1 session one data (Figure 4.8) can also be seen. However, in the remaining portion of the plot there are only two spikes, corresponding to the low SV coverage of four satellites. RIG2 is the most problematic. Several PDOP spikes are off the scale of the graph and there are many instances of low satellite coverage. This is almost certainly due to the fact that the derricks are to the south of this site, obscuring the most densely populated part of the GPS constellation.

5. CONCLUSIONS AND RECOMMENDATIONS

The task of studying the potential multipath problems on the Hibernia Oil Platform has proven particularly challenging for several reasons. As well as all the logistical problems of actually recording data aboard the platform, the multipath environment and the GPS satellite observing conditions were different from the case when the platform is in its final drilling position and orientation. Another problem for this study was the fact that the platform was not stationary during the data collection period, but had a quasi-periodic motion due to tides, wind, and wave action. This motion precludes the repeatability that is normally invoked by multiple days of data collection to conclusively prove the presence of multipath and to assess the actual magnitude of the error it contributes.

The results presented here however, are substantial enough to infer some important conclusions. The levels of the mean r.m.s. multipath for the C/A-code pseudorange measurements at the three sites tested are approximately 5 m for site RIG1, 7 m for site RIG2, and 15 m for site RIG3. The error range reached 300 m for the RIG3 site. The higher multipath at RIG3 over RIG1 and RIG2 is most probably due to reflections from the Helideck. To study the effect that these pseudorange errors would have on position determinations, baseline lengths to the platform sites were processed holding the coordinates of the low-multipath shore station fixed. However, due to platform movement (approximately 20 m horizontally and 1 metre vertically), the carrier phase baseline solutions had to be differenced from the pseudorange solutions to remove most of the movement. The approximate r.m.s. solution differences are for the RIG1 baseline 3 m, RIG2 baseline 4 m, and RIG3 baseline 6.5 m. The maximum range in position was 72 m for site RIG3. These results corroborate the individual platform site C/A-code pseudorange multipath results. These positional errors are an indicator of the magnitude of reference station positional error due to multipath for C/A-code observations on the Hibernia Oil Platform with the equipment used in the tests.

The final portion of the analysis dealt with the satellite sky distribution. Signal blockages were observed to be primarily caused by the drilling derricks, but also from other parts of the platform superstructure. The simplest solution to this problem is to place the antenna on the south side of the platform, in its final drilling position, so as to allow the derricks to obstruct mainly the sparsely covered northern portion of the sky.

Hence, if only one antenna were to be mounted on the Hibernia Platform, it should be placed on the south side. In the final platform position this will be on the opposite side from the Helideck, behind the flare boom (i.e. the RIG2 site of these tests). This structure will cause some signal blockage, but not as much as the derricks. On the north side of the platform (in its operating orientation) an antenna located on the meteorological and communications tower (i.e. the RIG3 site) would probably be the best site, because it is furthest from the derricks. This recommendation requires that both antennas be equipped with choke-rings and possibly microwave absorbing material. This should greatly improve performance, especially at the sensor tower site.

Depending on the availability of funds, an array of antennas should be erected to improve the integrity of the system. Three potential sites for the antennas are the locations used in these tests. The use of new receiver processing technology would also benefit in the mitigation of the multipath-induced error.

Finally, to resolve some of the lingering questions from this study, a second study should be contemplated when the platform is in its static drilling location. The *actual* magnitude of the positioning error due to multipath could then be assessed. Additional processing could then be performed, for example inter-day multipath error comparisons and signal reflector determinations. For this study, choke-ring antennas should be used.

Such a follow-on study is envisioned to consist of two phases. First, erecting a temporary DGPS reference station array and processing data from this array, allowing for a more thorough investigation to confirm the multipath induced errors at the three sites and possibly others. And second, installing the DGPS reference station antennas in the preferred locations specified from the first phase and assessing and mapping the residual, multipath error of the permanent DGPS system.

6. REFERENCES

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