Geomatics Canada
Geodetic Survey of Canada

GPDP PROJECT REPORT

Application of Canadian Active Control System Products for Spatial Referencing of Local Surveys

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EXECUTIVE SUMMARY

With the increasing use of GPS techniques for Legal Surveys, CACS products are available as an alternative to spatial referencing with traditional survey control. In the spring of 1995, the document "Application of Canadian Active Control System Products for the Integration of Local Survey Networks" (GSD, 1995) was prepared to serve as an aid to those wishing to employ CACS products and has been used as an Appendix for some Legal Surveys Land Claims contracts over the past two field seasons. The document recommends two spatial referencing approaches using CACS products: (1) precise point positioning (single point positioning using precise orbits and clocks) and (2) long baselines (processing of observations from a survey site with those from an Active Control Point). The purpose of this project was to test a these spatial referencing approaches and assess their accuracy.

Results from precise point positioning tests showed that 'absolute' horizontal positions with sub-metre accuracy (rms) were achievable using dual frequency observations. Results from long baseline tests using commercial GPS processing software and dual frequency observations showed that sub-decimetre accuracy (rms) was achievable using 3 hours of data and better than two decimetre accuracy was achievable with 30 minutes of data.

Based on the results herein, it is strongly recommended that dual frequency receivers be used to ensure the 2 m or better 'absolute' accuracy (95% confidence level), usually required for spatial referencing of northern land claim surveys.

Tests carried out on one data set collected under severe ionospheric conditions showed precise point positioning accuracies better than 0.5 m (rms) regardless of the session length, while accuracies worse than 1.5 m were achieved for long baselines when session lengths were one hour or less. Precise point positioning may therefore be considered as a check on long baseline solutions in situations where high ionospheric activity may be suspected. Further investigations into this is warranted.

INTRODUCTION

This document presents the activities performed during my fourth and last project in the Geomatics Professional Development Program (GPDP). This project, Application of Canadian Active Control System (CACS) Products for Spatial Referencing of Local Surveys, was accomplished under the direction of Caroline Erickson, in the Positioning Systems Integration Team of the Geodetic Survey Division.

With the increasing use of GPS techniques for Legal Surveys, CACS products are available as an alternative to spatial referencing with traditional survey control. In the spring of 1995, the document "Application of Canadian Active Control System Products for the Integration of Local Survey Networks" (GSD, 1995) was prepared to serve as an aid to those wishing to employ CACS products and has been used as an Appendix for some Legal Surveys Land Claims contracts over the past two field seasons.

The main purpose of this project was to test and demonstrate the spatial referencing approaches presented in GSD (1995). This report describes results of an accuracy assessment of the two approaches for using CACS products. Alternatives for the integration of local surveys using these techniques are left for a follow-up investigation.

I wish to express my sincere appreciation to all of those who have contributed to this project. Thanks also go to Mike Strutt for use of Trimble GPSurvey software; and Lina Mancuso for her work with data handling and processing. Special recognition is due to Caroline Erickson for her patient understanding and guidance.

APPROACH and METHODOLOGY

TEST SITES and DATA

Test Sites

Two Canadian Base Network (CBN) sites were used for testing. CBN sites provided the high accuracy coordinates to serve as 'truth' and GPS data was readily available for these sites. These two northern CBNs were chosen because their location best represented the location of most land claim surveys. Four Active Control Points (ACPs) were also used (Churchill (CHUR), Penticton (DRAO), Prince-Albert (PRAL), and Yellowknife (YELL)). Figure 1 shows the location of all test sites.

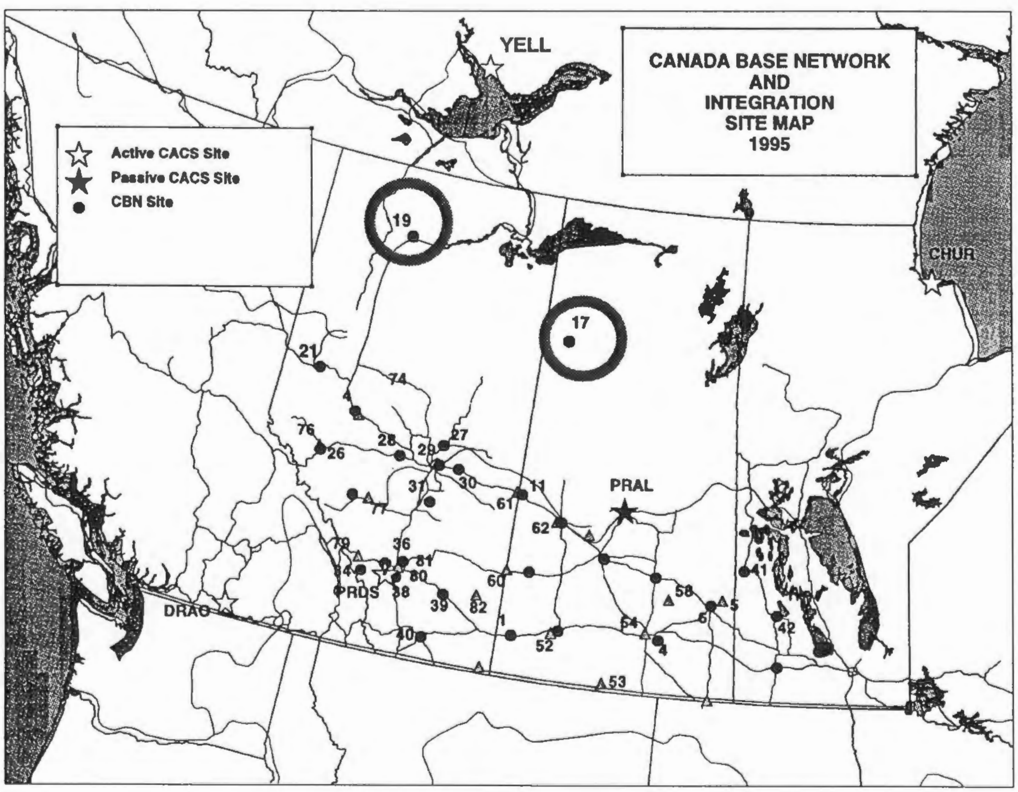


Figure 1: ACP and test site locations (CBN 17 & 19)

The ACPs were selected such that when used with the test sites, they would represent typical distances between survey sites and ACPs found in northern land claim surveys. Table 1 shows the distance between various ACPs and possible land claim locations. Table 2 shows the distance between ACPs and the sites used for testing.

ACPs	YUKON	NWT	NUNAVUT
	Average Distance	Average Distance	Average Distance
Churchill (CHUR)	2100	1280	1230
Whitehorse (WHI)	375	1250	—
William's Lake (WILL)	1050	430	1500
Yellowknife (YELL)	1050	430	1500

Distances are approximate (km)

Table 1: Distance between ACPs and possible land claim locations

ACPs	CBNs	
	Distance to site 17	Distance to site 19
Churchill (CHUR)	900	1300
Penticton (DRAO)	1100	1050
Prince Albert (PRAL)	450	900
Yellowknife (YELL)	700	450

Distances are approximate (km)

Table 2: Distance between ACPs and test sites

Data

Data from four different days were used for testing; GPS Days 264, 268, 269, and 270. Day 270 was specifically chosen because it was the only day within two months of CBN observations identified as having data adversely affected by ionospheric conditions. This day was analyzed to help determine the impact of such exceptional occurrences on spatial referencing accuracy. The GPS observations on days 264, 268, and 269 provided typical data.

The GPS data for the two test sites came from the 1995 Canadian Base Network Project (Brookes, 1995). For each day, a full 24 hours of data were collected with Ashtech Z-XII receivers and Dorne Margolin antennas. The ACPs were equipped with Turborogue receivers and Dorne Margolin antennas.

PROCESSING TECHNIQUES

The two approaches for using CACS products are described in the document "Application of Canadian Active Control System Products for the Integration of Local Survey Networks" (GSD, 1995). As mentioned in this document the two techniques "provide efficient ways to integrate a local survey without the requirement of occupying geodetic control stations. In most cases, no additional observations to those required to perform a reliable local survey are needed. The first approach uses precise point positioning that can provide "absolute" horizontal positions with an accuracy of 2 metres at the 95% confidence level. The second approach is to position the local network relative to stations of the CACS. Both methods should greatly reduce data collection costs and in most cases produce results that are more accurate and more consistent." In this report the first approach is referred to as 'precise point positioning' and the second approach as 'long baselines'.

Precise Point Positioning

Precise point positioning uses CACS precise orbits and clocks to improve point positioning accuracy. Several reports on this technique and its application have been written and may be referred to for further information (e.g. Héroux and Kouba, 1995; Erickson and Héroux, 1994; Lachapelle et al., 1994; Shreenan et al., 1996). GPSPace version 3.2 (GPS Positioning from ACS Clocks and Ephemerides) software was used in the testing (GSD, 1997).

Solutions accurate at the sub-metre level (rms) are achievable with only a single measurement (epoch) of data using precise point positioning with geodetic quality dual frequency receivers (Shreenan et al., 1996). Some improvements in accuracy may be realized by averaging several single epoch solutions collected over a period of time. In this project, test results 'averaged' over time were examined.

Long Baselines

The long baseline technique involves positioning some stations within the local survey network relative to one or more ACPs included in the CACS network, by computing the baselines to the ACPs using carrier phase observations. (See Duval et al., 1996 for more information on CACS.) Initially the following packages were to be tested: ASHTECH - GPPS, LEICA - SKI v2.11, and TRIMBLE - GPSurvey v2.20. Testing with the ASHTECH - GPPS was discontinued due to difficulties encountered when using precise ephemerides. (A newer release of Ashtech software, AOSS, has not yet been tested.)

PROCESSING VARIABLES

Session Length

Different observation periods within the 24 hour data sets were extracted to help determine the impact of session length on spatial referencing accuracy. Following GSD (1995) the longest session tested was 6 hours. Other session lengths tested were 3 hours, 1 hour, 30, 15, and 5 minutes. The most extensive testing was carried out for 30 minute sessions, as this seemed to give satisfactory results and was deemed practical for most land claim applications.

Note that for precise point positioning, the 'session length' is the length of time over which numerous single epoch solutions were determined and then averaged, while for long baselines, the 'session length' is the time span for which carrier phase measurements and satellite arcs were used in a least squares adjustment to arrive at a single solution.

Single Frequency Versus Dual Frequency

Processing was carried out with single frequency (L1 only) and dual frequency (L1 and L2) measurements of the described data set to assess the impact of single frequency versus dual frequency on the results. In this report, use of dual frequency data is indicated by the expressions L1 + L2, and occasionally by the expression L3.

Software Parameter Settings

Processing with the commercial software was mostly automated, with very little user intervention. Figures 2, 3, and 4 list the parameters used during processing. In all cases, NRCan precise orbits were used in place of broadcast orbits.

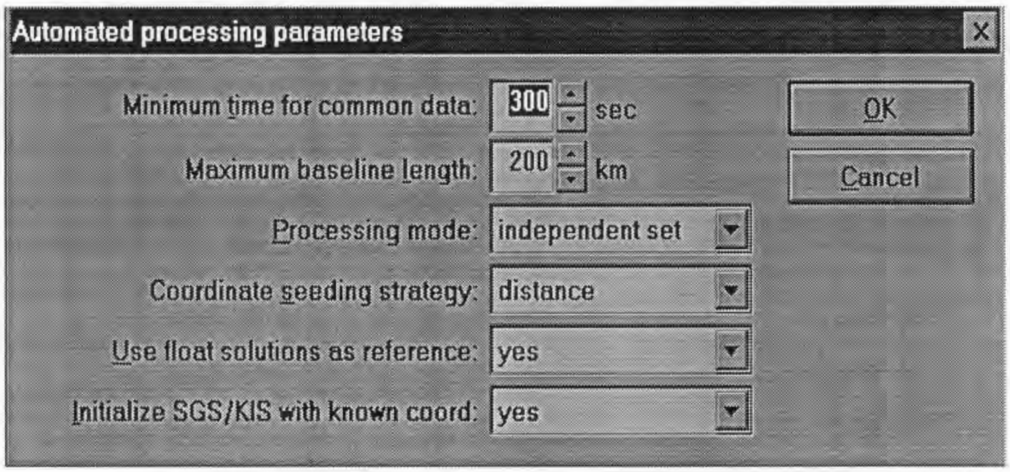


Figure 2: Long Baseline Processing Parameters - LEICA (Automated Processing Parameters)

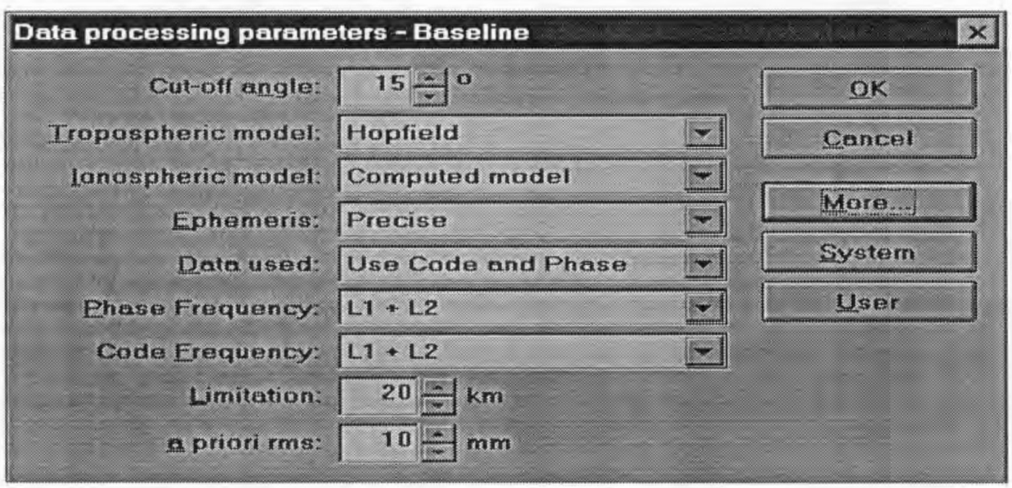


Figure 3: Long Baseline Processing Parameters - LEICA (Data Processing Parameters)

CATEGORY	OPTIONS	SETTINGS
General	Elevation mask (deg)	15
	Maximum iterations	10
	Maximum fixable cycle slip (sec)	600
	Ephemeris	Precise
	Generate residuals	Yes
	Enable antenna phase correction	Yes
Observables	L1 phase	Yes
	L2 full phase	Yes
	L1 P- code	Yes
	L2 P- code	Yes
	L1 C/A - code	Yes
	L2 code (encrypted)	Yes
Static Network	Minimum baseline observation time (s)	120
Kinematic Network	N/A	
OTF Search	N/A	
Events	N/A	
Quality	Observation editing	Level of confidence 95%
	Ratio test	Level of confidence 95%
	Reference variance test	Level of confidence 95%
Tropo Correction	Model	Hopfield
	Estimated zenith delay interval (hr)	0
	Use observed met data	No
Iono Correction	Ambiguity resolution pass	Iono free (10 km)
	Final pass	Iono free (5 km)
Final Solution	Solution type	Float

Table 3: Trimble Advanced Controls

TESTING SUMMARY

A summary of the testing conducted, including a description of the session lengths, processing software and whether single or dual frequency was used, is provided in Table 4.

SESSION LENGTH	SITE 17 DAY 264	SITE 17 DAY 268	SITE 19 DAY 268	SITE 19 DAY 269	SITE 19 DAY 270
6 hr. (14:00 - 20:00)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)		GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)
3 hr. (14:00 - 17:00)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)		GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)
1 hr (14:00 - 15:00)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)		GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)
30 min (14:00 - 14:30)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)		GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)
30 min (16:00 - 16:30)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)		GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)
30 min (18:00 - 18:30)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)		GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)
30 min (20:00 - 20:30)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)		GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)
30 min (22:00 - 22:30)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)		GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)
30 min (2:00 - 2:30)				LEICA (L1+L2) TRIMBLE (L1+L2)	
30 min (6:00 - 6:30)				LEICA (L1+L2) TRIMBLE (L1+L2)	
30 min (8:00 - 8:30)				LEICA (L1+L2) TRIMBLE (L1+L2)	
30 min (10:00 - 10:30)				LEICA (L1+L2) TRIMBLE (L1+L2)	
15 min (14:00 - 14:15)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)		GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)
5 min (14:00 - 14:05)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1+L2) TRIMBLE (L1+L2)	GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)		GPSPACE (L1) GPSPACE (L3) LEICA (L1) LEICA (L1+L2) TRIMBLE (L1) TRIMBLE (L1+L2)

Table 4: Testing Summary

ANALYSIS / RESULTS

PRECISE POINT POSITIONING

The following two tables (Tables 5 and 6) present a summary of the differences between the precise point positioning results and the 'truth'. Table 5 summarizes dual frequency (L1 + L2) results, while Table 6 summarizes L1 only results.

Table 5 is divided into two sections. The first section shows results for the three test data sets with standard observations, while the second shows results for a data set (Day 270) which was collected under severe ionospheric conditions. Table 6 includes only one section with standard observations.

Each section includes 5 columns. The first indicates the session length used to compute the solution, the second contains the number of individual solutions (n) used to compute the root mean square (rms) and the following four represent the rms differences between the test results and the 'truth' in latitude (Lat.), longitude (Long.), horizontal position (Hor.) and ellipsoidal height (Hght.).

	Days 264, 268 & 269					Day 270				
Averaging Time	Difference from truth, rms (m)					Difference from truth, rms (m)				
	n	Lat.	Long.	Hor.	Hght.	n	Lat.	Long.	Hor.	Hght.
6 hr.	3	0.07	0.11	0.13	0.50	1	0.12	0.14	0.18	0.28
3 hr.	3	0.21	0.23	0.31	0.30	1	0.16	0.02	0.16	0.12
1 hr	3	0.54	0.06	0.55	0.36	1	0.34	0.02	0.34	0.64
30 min	15	0.39	0.21	0.44	0.88	5	0.27	0.29	0.40	0.60
15 min	3	0.64	0.13	0.65	0.68	1	0.37	0.28	0.47	1.33
5 min	3	0.62	0.26	0.67	1.08	1	0.25	0.01	0.25	0.82

Table 5: Precise point positioning results using dual frequency data

	Days 264, 268 & 269				
Averagin g Time	Difference from truth, rms (m)				
	n	Lat.	Long.	Hor.	Hght.
6 hr.	3	0.77	0.39	0.86	2.08
3 hr.	3	0.62	0.57	0.84	1.61
1 hr.	3	0.50	0.50	0.71	0.36
30 min	3	0.73	0.34	0.81	0.42
15 min	3	0.79	0.32	0.85	0.5
5 min	3	0.75	0.27	0.80	0.75

Table 6: Precise point positioning results using L1 only

Impact of Single Versus Dual Frequency

Figure 4 shows the impact of single frequency versus dual frequency data on precise point positioning horizontal accuracy for Days 264, 268 and 269. Smaller rms values resulted when using L1+L2 compared to L1 only.

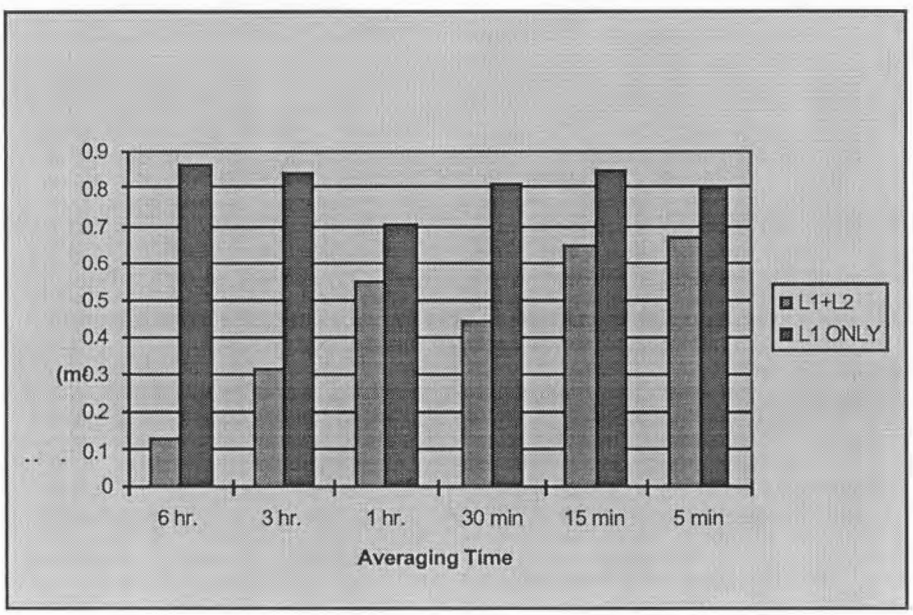


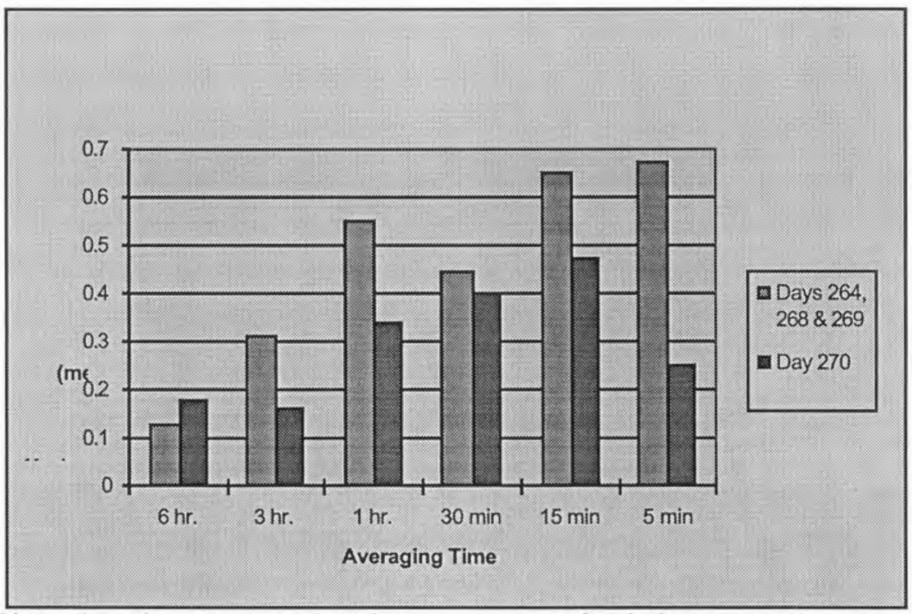
Figure 4: Precise point positioning results for Days 264, 268 and 269, comparing dual versus single frequency data

All rms values are at the sub-metre level. For sessions processed using L1+L2, the rms values decreased with the averaging time (session length). Session length did not appear to influence solutions determined using L1 only. When processing using L1+L2, 30 minute sessions gave an accuracy of ~0.4 m rms (based on 15 independent solutions).

The impact of processing observations adversely affected by severe ionospheric conditions with single frequency versus dual frequency will be treated in the next section.

Impact of Severe Ionospheric Conditions

Figure 5 shows the impact of the severe ionospheric conditions from Day 270 on the precise point positioning horizontal accuracy when using dual frequency data.



Note: 30 min. rms based on larger number of solutions than the others

Figure 5: Precise point positioning results using dual frequency data, comparing days 264, 268 and 269 with Day 270

With the exception of the 6 hour session, rms values were smaller for Day 270 than Day 264, 268 and 269. Further investigation is required before drawing any conclusions from this trend since, with the exception of the 30 minute session, only one solution was attained for Day 270 for each session length, whereas three were attained for Days 264, 268 and 269 (as summarized in Table 5). However it appears that the accuracy of the precise point positioning approach was unaffected by the ionospheric conditions.

LONG BASELINES

The following two tables (Tables 7 and 8) present a summary of the differences between the long baseline processing results and the 'truth'. Solutions from each of the four ACPs listed in Table 2 were individually processed using both Trimble and Leica software. All solutions were used in calculating the rms differences shown in Tables 7 and 8. Table 7 summarizes L1+L2 results and Table 8 summarizes L1 only results. Both tables are divided in two sections; Days 264, 268 & 269 and Day 270. Each section includes 5 columns, the first indicates the session length used to compute the solution, the second contains the number of individual solutions (n) used to compute the rms and the following four represent the rms differences between the test results and the 'truth' in latitude (Lat.), longitude (Long.), horizontal position (Hor.) and ellipsoidal height (Hght.).

The section for Day 270 in Table 8 includes separate results for the two software packages used (referred to as A and B). This was done due to the magnitude of the difference between these results. In all other cases the two software packages used had produced very similar results and results for both packages were included when the rms' were calculated.

	Days 264, 268 & 269					Day 270				
Session	Difference from truth, rms (m)					Difference from truth, rms (m)				
Length	n	Lat.	Long.	Hor.	Hght.	n	Lat.	Long.	Hor.	Hght.
6 hr.	24	0.03	0.04	0.05	0.06	7	0.08	0.27	0.28	0.16
3 hr.	24	0.05	0.05	0.07	0.06	8	0.09	0.51	0.51	0.22
1 hr.	24	0.06	0.18	0.19	0.05	7	0.37	1.48	1.53	0.37
30 min	152	0.09	0.13	0.15	0.12	40	0.60	1.73	1.83	0.75
15 min	24	0.11	0.49	0.50	0.11	8	0.66	1.00	1.19	0.45
5 min	24	0.19	0.72	0.75	0.22	8	2.11	3.49	4.08	1.68

Table 7: Long baseline results using dual frequency data

	Days 264, 268 & 269					Day 270					
Session	Difference from truth, rms (m)					Difference from truth, rms (m)					
Length	n	Lat.	Long.	Hor.	Hght.		n	Lat.	Long.	Hor.	Hght.
6 hr.	8	1.04	1.45	1.78	1.03	A	4	16.58	12.43	20.72	33.01
						B	4	0.56	0.73	0.92	1.25
3 hr.	8	1.04	1.47	1.8	1.07	A	4	4.88	3.79	6.17	33.93
						B	4	1.21	2.73	3.00	2.01
1 hr.	7	0.37	1.48	1.53	0.37	A	1	8.18	6.75	10.61	4.21
						B	4	1.21	3.22	3.44	0.68
30 min	8	1.39	2.06	2.49	1.07	A	4	5.73	3.88	6.92	34.12
						B	4	0.46	3.91	3.93	0.69
15 min	8	1.73	1.60	2.36	1.26	A	4	6.05	1.18	6.16	34.43
						B	4	3.37	4.35	5.60	1.10
5 min	8	2.89	5.63	6.33	2.20	A	2	0.86	6.84	6.90	1.04
						B	4	3.33	11.45	12.28	8.05

Table 8: Long baseline results using single frequency data

Impact of Single Versus Dual Frequency

Figure 6 shows the impact of single frequency versus dual frequency data on horizontal accuracy based on long baseline solutions for Days 264, 268 and 269.

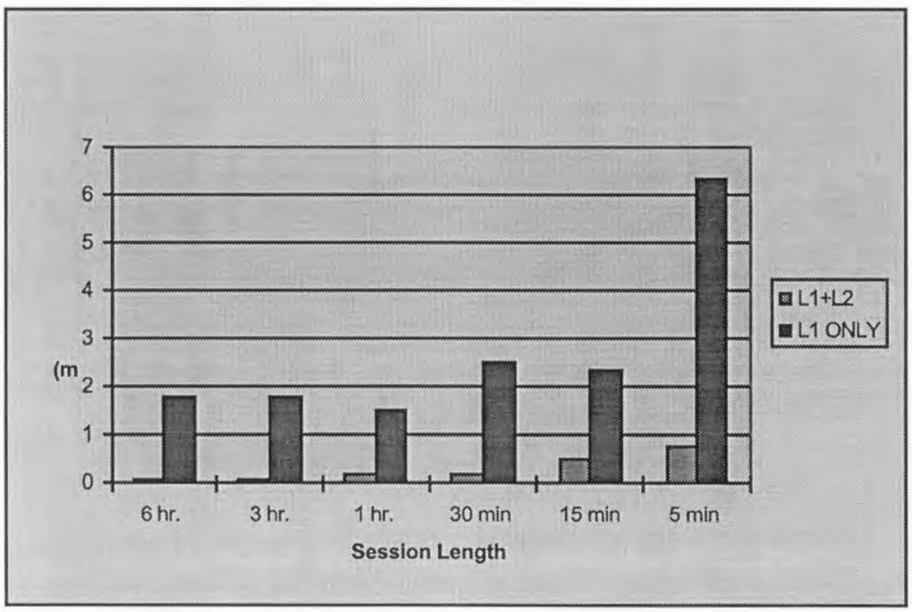


Figure 6: Long baseline results for Days 264, 268 and 269 comparing dual versus single frequency data.

All sessions processed have smaller rms values processing L1+L2 compared to processing L1 only. For sessions processed using L1+L2, the rms values are at a few decimetres. The 3 and 6 hours sessions are at the sub-decimetre level.

Impact of Severe Ionospheric Conditions

Figure 7 shows the impact of severe ionospheric conditions from Day 270 on the long baseline horizontal accuracy when using dual frequency data. Results from Days 264, 268 and 269 have significantly smaller rms values. For example, the horizontal rms for the 30 minute session is 15 cm for Days 264, 268 and 269; and 1.83 m for Day 270 which was subject to extreme ionospheric conditions. The rms values for Days 264, 268 & 269 are all below a decimetre for three hours or more of observations, and sub-metre level for shorter sessions. For Day 270, only the 6 and 3 hour sessions are at the sub-metre level.

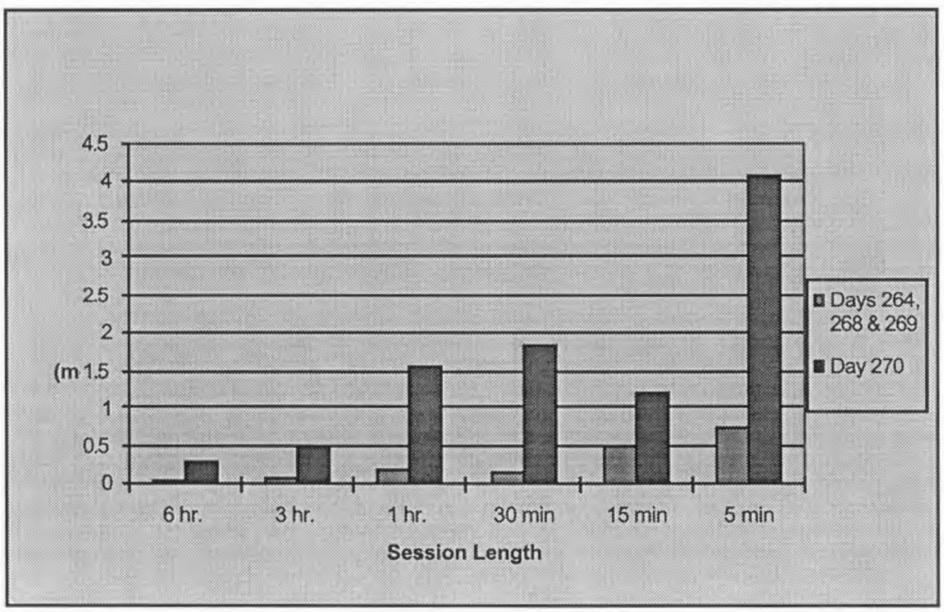


Figure 7: Long baseline results using dual frequency data, comparing Days 264, 268 and 269 with Day 270

Impact of Baseline Length

Figures 8 and 9 represent the impact the length of the baselines between the ACP and local sites have on the accuracy. They show the horizontal rms differences at sites 17 and 19 for L1+L2 processing, over 30 minute sessions, based on results from Days 264, 268 and 269. The baseline length increases from left to right. Results indicate that, for the range of baselines under consideration here (450 - 1300 km), the baseline lengths do not appear to influence horizontal accuracy.

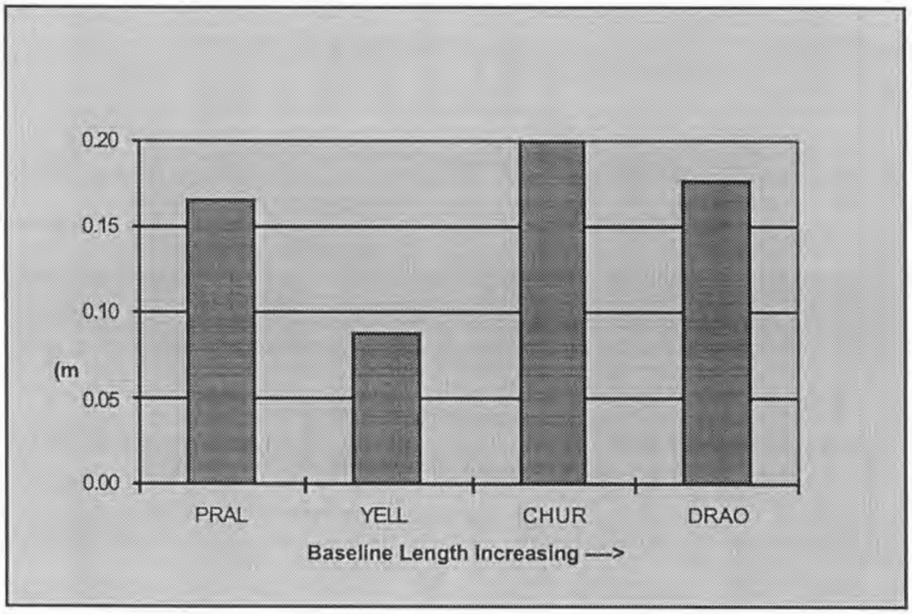


Figure 8: Comparison of long baseline results from site 17 to ACPs using dual frequency data from Days 264, 268 and 269 in 30 minute sessions

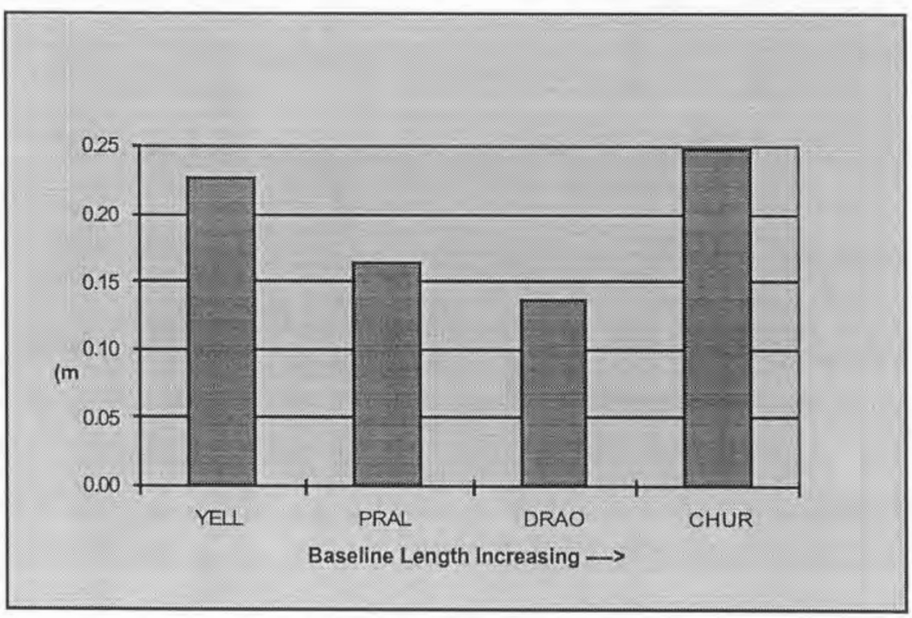


Figure 9: Comparison of long baseline results from site 19 to ACPs using dual frequency data from Days 264, 268 and 269 in 30 minute sessions

Impact of Session Length

Figure 10 indicates the impact of session length on horizontal accuracy using L1+L2 processing for Days 264, 268 & 269. As expected, the longer the session length, the smaller the rms values. The horizontal accuracy obtained with 30 minute session is 15 cm. (Note that rms values for the 30 minute sessions were based on 152 solutions, while for other session lengths shown in Figure 10, they were based on 24 solutions.)

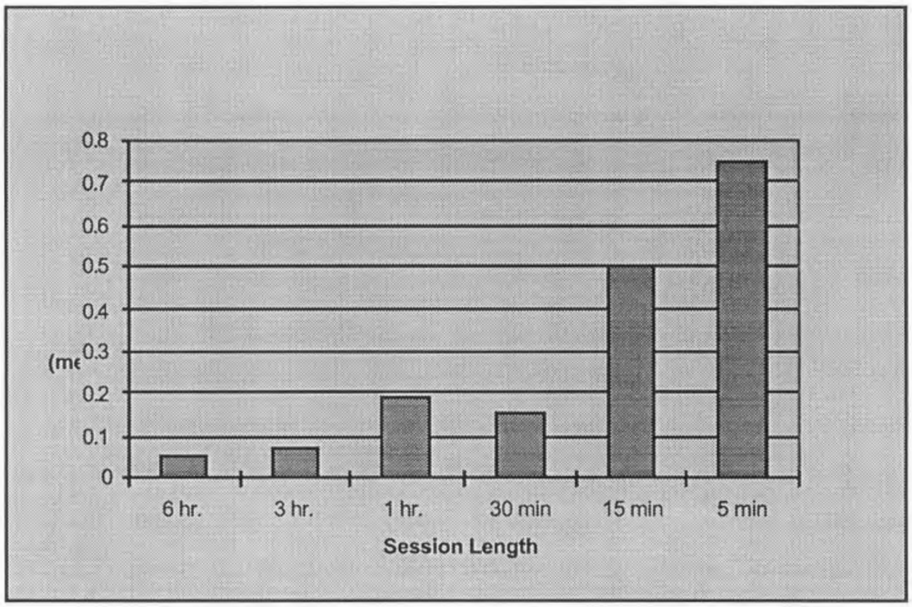


Figure 10: Long baseline results for Days 264, 268 & 269 using dual frequency data

Precise Point Positioning Versus Long Baselines

Figures 11, 12, and 13 compare the horizontal accuracy achieved using precise point positioning and long baseline techniques. The highest horizontal accuracy was achieved from the long baseline technique using L1+L2 processing with Days 264, 268 & 269 (Figure 11). With the 6 hour session length, 0.05 m was attained using the long baseline technique whereas 13 cm was attained using the precise point positioning technique. With 30 minute sessions, 0.15 m was attained using the long baseline approach while 0.44 cm was attained using precise point positioning.

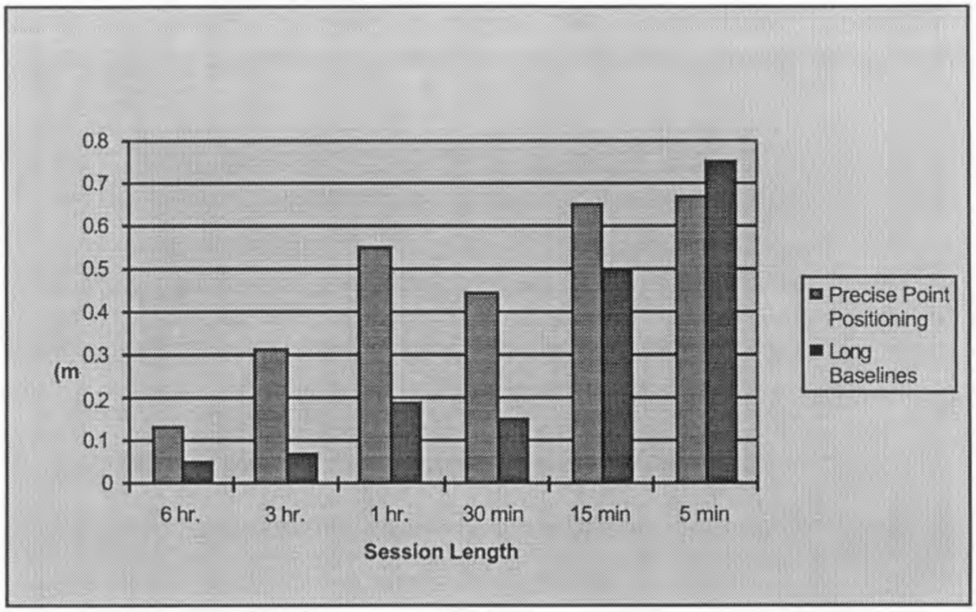


Figure 11: Comparison of precise point positioning and long baseline results for Days 264, 268 & 269 using dual frequency data

For shorter sessions, the two techniques provided comparable results (0.50 m for long baselines and 0.67 m for precise point positioning over 15 minutes and 0.75 m for long baselines and 0.67 m for precise point positioning over 5 minutes).

The results shown in Figure 12 indicate that with L1+L2, precise point positioning is less affected than long baselines by the ionospheric conditions of Day 270. This is likely due to discontinuities (cycle slips) remaining in the carrier phase data after processing causing degradation of the long baseline results. Precise point positioning, which is based on code measurements, is solely an average of individual solutions and does not depend on continuity over time.

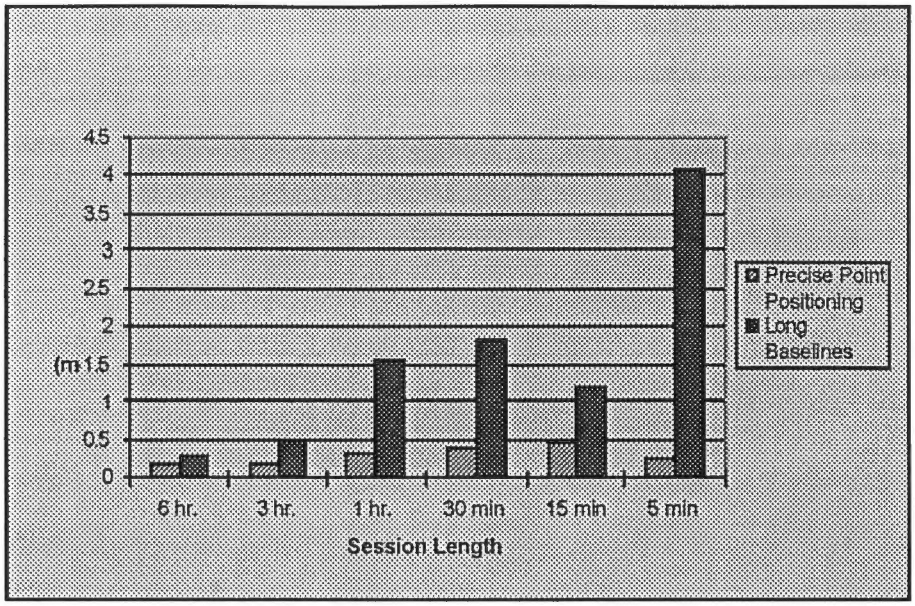


Figure 12: Comparison of Precise Point Positioning and Long Baseline Results for Day 270 using Dual Frequency Data

In Figure 13, results using L1 only are shown. Long baseline processing with L1 only gave very poor results, with the all solutions worse than 1.5 m. Precise point positioning results gave sub-metre accuracy, independent of the averaging time.

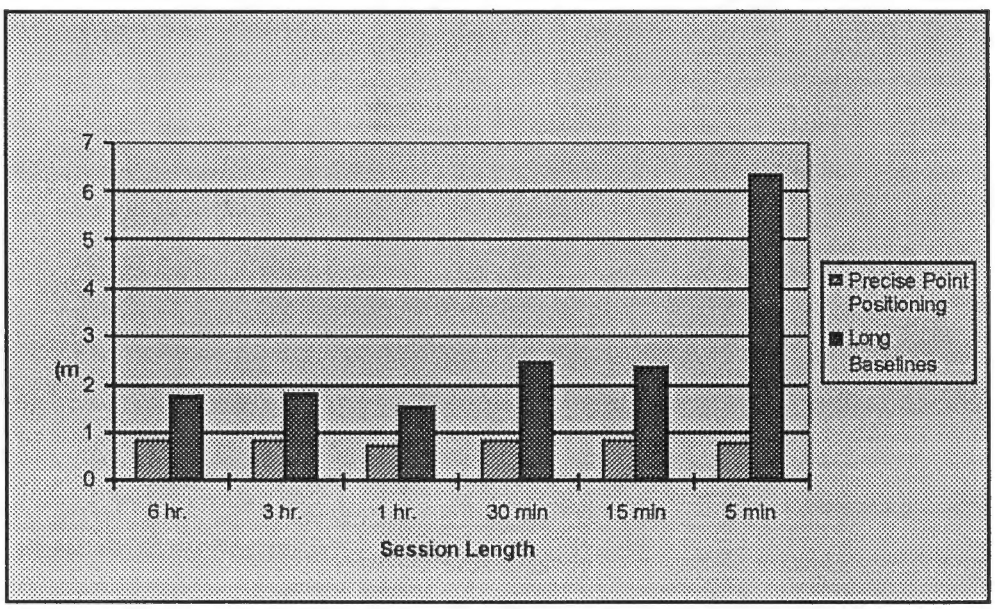


Figure 13: Comparison of Precise Point Positioning and Long Baseline Results for Days 264, 268 and 269 using L1 data only.

30 Minute Session Summary

As mentioned in the Approach and Methodology section, more testing was done with the 30 minutes session than other session lengths. Table 9 shows the results of all testing with the 30 minute session length. This table is divided into 5 columns. The first describes the testing used to compute the solution, the second contains the number of individual solutions (n) used to compute the rms and the following three represent the rms differences between the test results and the 'truth'.

Testing	Difference from truth, rms (m)			
	n	Lat.	Long.	Hor.
Precise Point Positioning - L1+L2 - Days 264, 268 & 269	15	0.39	0.21	0.44
Precise Point Positioning - L1+L2 - Day 270	5	0.27	0.29	0.40
Precise Point Positioning - L1 Only - Days 264, 268 & 269	3	0.73	0.34	0.81
Precise Point Positioning - L1 Only - Day 270	0	---	---	---
Long Baseline - L1+L2 - Days 264, 268 & 269	152	0.09	0.13	0.15
Long Baseline - L1+L2 - Day 270	40	0.60	1.73	1.83
Long Baseline - L1 Only - Days 264, 268 & 269	8	1.39	2.06	2.49
Long Baseline - L1 Only - Day 270 - software A	4	5.73	3.88	6.92
Long Baseline - L1 Only - Day 270 - software B	4	0.46	3.91	3.93
Total:	231			

Table 9: Horizontal accuracy summary (30 minute sessions)

Figure 14 shows the difference in horizontal accuracy achieved between different types of testing for the 30 minute sessions. The values range from 15 cm (long baselines - L1+L2 - Days 264, 268 & 269) to ~7m (long baselines - L1 Only - Day 270). All values obtained with precise point positioning are at the sub-metre level. The best values are obtained with the long baseline techniques using L1+L2 with Days 264, 268 and 269.

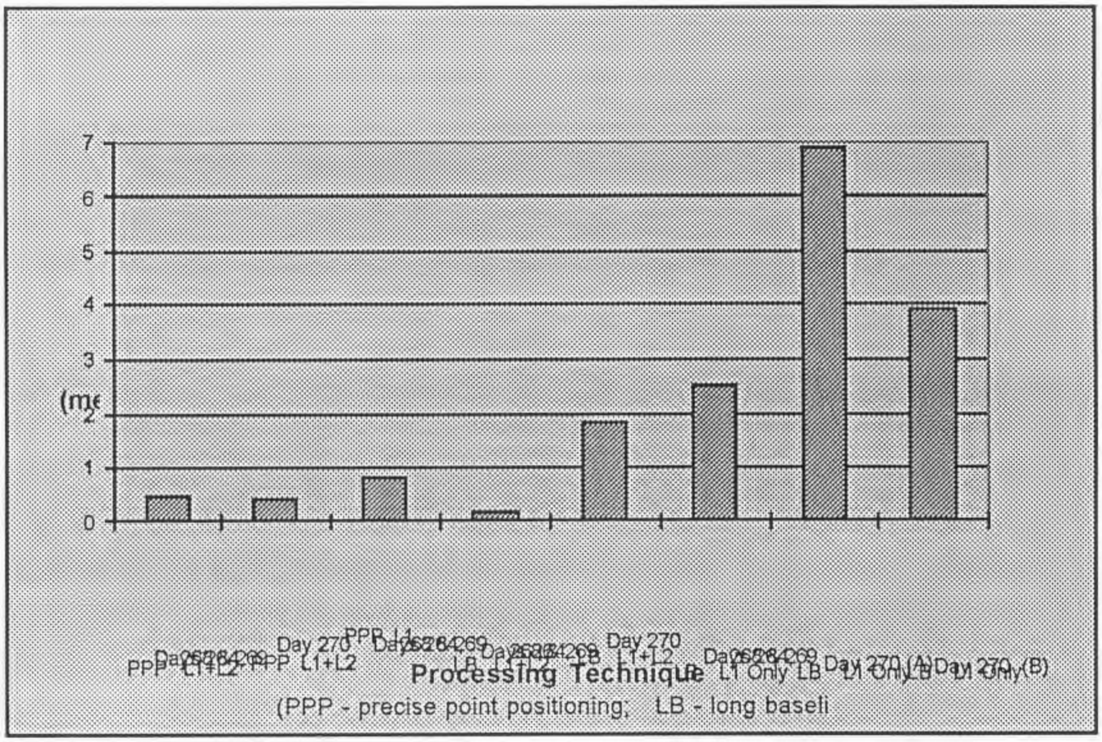


Figure 14: Comparison of processing techniques - 30 minute sessions

LIMITATIONS

It is important to note the conditions of the tests carried out and limitations in their applicability for some field situations.

- The CBN points were 'forced centering pillars'. Therefore the results from the above tests do not include tripod set-up error.
- The CBN sites were specifically located to be suitable for GPS (i.e. unobstructed line of sight to satellites, multipath sources avoided).
- The antenna used for data collection at sites 17 and 19 was identical to those used at the ACPs. For long baseline solutions, if different antenna types are used at the ACP and survey site and these differences are not accounted for in the GPS data processing, then additional errors may be introduced into the solution. Usually these errors will be at the sub-cm level horizontally, but can range up to several cm vertically (e.g. 10 cm).

- The 'rms' values above are based on different sample sizes, ranging from 1 to 152, as noted in Tables 5 to 9, and include some solutions computed with the same data but using different software. Therefore, although they provide very valuable information, they are not suited for strict statistical applications.
- The rms values shown above roughly (due to small sample sizes) approximate 68% probability. To roughly approximate 95% probability, they would have to be doubled.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Results show that both precise point positioning and long baseline ties to ACPs can satisfy spatial referencing accuracy requirements for local surveys. However, it is very important to recognize that the results are dependent on the hardware, software and GPS observing conditions specific to the test data set. (See 'limitations' in the previous section.) Since differences in GPS receivers and software can have a major influence on results, it is recommended that user equipment, software and procedures be validated on a GPS validation network.

Results from precise point positioning showed that 'absolute' horizontal position with a sub-metre accuracy is achievable using L1+L2 processing for all session lengths, with improvements realized with longer averaging time. Sub-metre accuracy was even achieved for data that was affected by severe ionospheric conditions. All precise point positioning results are consistent with the analysis found in "Capabilities of Currently Available GPS Receivers for Precise Single Point Positioning" (Shreenan et al., 1996).

The best horizontal accuracy was achieved using the long baseline approach when processing with dual frequency data. With 3 hours of data, 0.07 m rms was achieved, while with 30 minute of data 0.15 m rms was achieved. This method was adversely affected by severe ionospheric conditions, with accuracy reduced to 0.51 m for 3 hour data sets and 1.83 m for 30 minute data sets.

Using the long baseline technique, for baseline lengths ranging from 450 to 1300 km, the distance between the local survey area and the ACPs did not affect the horizontal accuracy.

When processing Day 270, which was subject to severe ionospheric conditions, the precise point positioning method was less affected than the long baselines approach.

Recommendations

1. For spatial referencing of local surveys requiring 2 m accuracy at the 95% confidence level, it is recommended that dual frequency receivers be used.
2. A 30 minute session length should satisfy spatial referencing accuracy requirements of many northern land claim surveys (at the 1 - 2 m level). However, longer sessions should give much better results for long baseline ties.
3. Further investigations are required to:

   a) gain knowledge on the capabilities and performance of commercially available software in computing long baseline ties to ACPs;

   b) better understand the implications of severe ionospheric conditions on long baseline and precise point positioning solution accuracy;

   c) assess the precision estimates associated with the precise point positioning and long baseline techniques, and

   d) develop recommendations on the integration of local surveys using CACS products.

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