THE CANADIAN GOTEX CAMPAIGN: AN ACTIVE CONTROL SYSTEM EMULATION STUDY

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In the fall of 1988, as part of the Global Orbit Tracking Experiment (GOTEX), data was continuously collected for twenty-one days at six Canadian sites. During that time, data was also collected from an additional twenty-two sites for periods ranging from five to ten days. A portion of this data has been analyzed with special emphasis on array geometry and efficient data processing, in order to emulate the operation of Canada's Active Control System. Results in terms of satellite orbit solutions and differential baseline component repeatabilities are presented.

INTRODUCTION

In 1988 the Geodetic Survey of Canada (GSC) contributed to the international Global Orbit Tracking Experiment (GOTEX), providing data from six sites across Canada. During this experiment, data was also gathered at twenty-two additional sites, in Canada, chosen as likely candidates for permanent stations of the Active Control System currently under development. The GSC is using the GIPSY (GPS Inferred Positioning System) software package, developed at the Jet Propulsion Laboratory (JPL), to process this data. The results presented in this paper are a part of the continuing efforts to gain more experience in processing a national data set. Our goal is to develop efficient data processing procedures and to assist in planning the expansion of ACS stations.

THE ACTIVE CONTROL SYSTEM

The ACS will consist of a nation wide network of continuously operating satellite (GPS and others) tracking stations coupled with a central data management site. The ACS will enable the GSC to fulfill it's mandate of maintaining a geodetic framework across Canada, and will be a valuable tool in the field of geodynamics studies as well as air, sea and land navigation [Delikaraoglou et al, 1990]. Since it's conception in 1985, the ACS has been in various stages of development consisting of early planning [Delikaraoglou et al., 1986], prototype development [Quek et al, 1988], and cost effectiveness studies [Lapp, 1989]. To date, the system consists of four prototype stations, Yellowknife, Pacific Geoscience Centre (PGC), Algonquin Radio Observatory (ARO) and Ottawa all shown on Figure 1. Data from these sites is transferred directly to monitoring and controlling stations located in Ottawa.

The Geodynamics Section of the Geological Survey of Canada, has been analyzing data from two of these sites, ARO and PGC, monitoring the baseline repeatability and more recently, the degradation of the satellite signal as a result of selective availability. [Kouba et al, 1990]. At the Systems Development Section (SDS) of the Geodetic Survey of Canada, one emphasis has been on data management. Key elements of the satellite's data life span are being examined including data gathering and transmission, storage, processing, product dispersal and archiving. [Delikaraoglou et al, 1990]

THE CANADIAN GOTEX DATA SET

The international GOTEX campaign took place between October 30 and November 20 1988. During this time a total of twenty-eight sites in Canada were occupied as part of a locally organized national campaign. These sites were chosen as likely locations for future ACS stations. Six of these sites were occupied for the entire twenty-one days of the experiment and provided data for part of the international GOTEX data set. The remaining twenty-two sites were occupied for periods ranging from five to ten days. This national data set will provide first epoch measurements for many future ACS stations. Figure 1 shows the locations of all twenty-eight stations making up the national data set.

All data was collected using dual frequency TI-4100 GPS receivers. Receivers at Iqaluit, Penticton, Yellowknife and St. John's used cesium frequency standards while a rubidium standard was used at Algonquin. Other receivers used internal quartz standards. Both carrier phase and pseudo-range measurements were made using a data collection rate of thirty seconds at all sites.

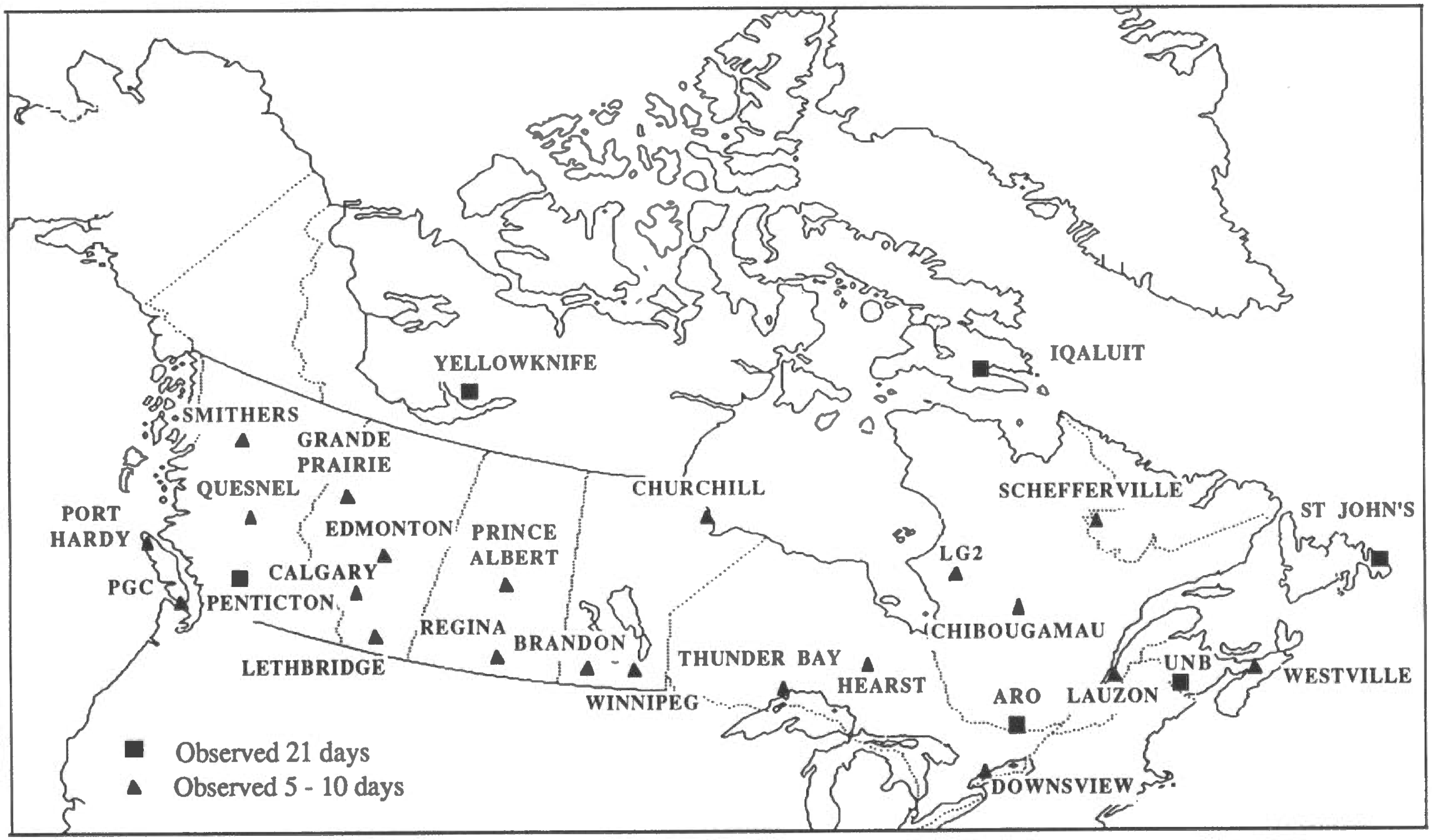


Figure 1

Sites Within The Canadian National Data Set

Observation windows during the campaign were typically between 11:30 UT and 18:30 UT. A slightly longer window was observed at the more northern sites. Seven satellites formed the GPS constellation at that time; they were PRNs 3, 6, 8, 9, 11, 12, and 13. Due to the crystal clock in PRN 8, it was only used when required to complete the requirement of tracking four satellites. [Duval, 1988]

ANALYSIS

The first seven days of observations, October 30th to November 5th, of the Canadian GOTEX data set as well as data collected at two Cooperative International GPS Network (CIGNET) sites: Mojave, California and Richmond, Florida, have been used for the purpose of this analysis. Table 1 shows the observation window at these sites. Reliable position estimates were available for few of the sites including Mojave, Richmond, Yellowknife and Algonquin. Most sites had been established just prior to the campaign including a new site at Yellowknife. Both the old and new Yellowknife sites were occupied during the campaign, but only data from the older station was included in this analysis.

The analysis was performed with the GIPSY software package. The fiducial station method was used to solve simultaneously for both station and satellite parameters. The VLBI colocated sites of Mojave, Richmond, Yellowknife and Algonquin served as the fiducials. Figure 2 depicts the geometry provided by these four sites.

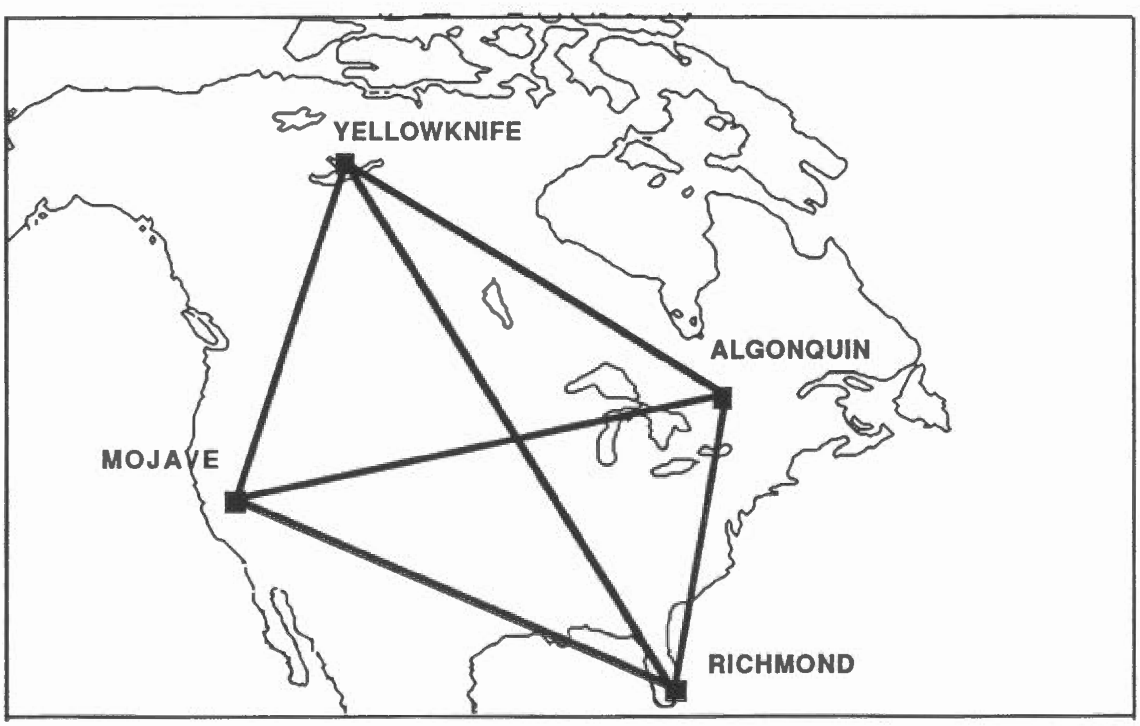


Figure 2

North American Fiducial Network Used In The Analysis

Cycle slip editing was performed in an automated way using a combination of pseudo-range and carrier phase data [Blewitt, 1990]. Station coordinates and satellite state vectors, including solar pressure parameters, were estimated using a modified Kalman filter [Lichten, 1990]. A residual tropospheric effect was estimated as process noise. The bulk of the tropospheric effect was modelled [Sovers, 1988]. Satellites and receiver clocks were estimated as white noise. In this analysis, both pseudo range and carrier phase ionospheric free combinations compressed to six minute normal points were used.

The primary goal of the analysis was to investigate station distributions and orbital solutions based on short (daily) and longer (five day) satellite arcs. Station position repeatability was used as a measure of precision. No comparison of known baseline lengths was performed as a measure of accuracy. The effect of satellite arc length was analyzed by comparing results from five independent daily solutions to a five day arc solution. Comparison of results from five independent daily solutions for a continental network and a regional one was used to analyze the effect of station distribution.

Daily Solutions of Continental Network

A thirteen station network described in Table 1 was selected as a representative continental network. Five independent daily solutions, using Mojave, Richmond, Yellowknife and Algonquin as fiducials, were obtained for both the station positions and satellite orbits. The distribution of baseline lengths for this network is given in Figure 3; not all of these baselines were observed for the five days. Figure 4 shows the horizontal position repeatability of the 438 km baseline between Hearst and Thunder Bay. Resolution of double differenced integer phase ambiguities [Blewitt, 1989] was performed. The lack of short baselines coupled with a large number of long baselines made ambiguity resolutions difficult. At most 62% of the ambiguities were resolved at a 99% level of confidence. On some days as little as 12% of the ambiguities were resolved.

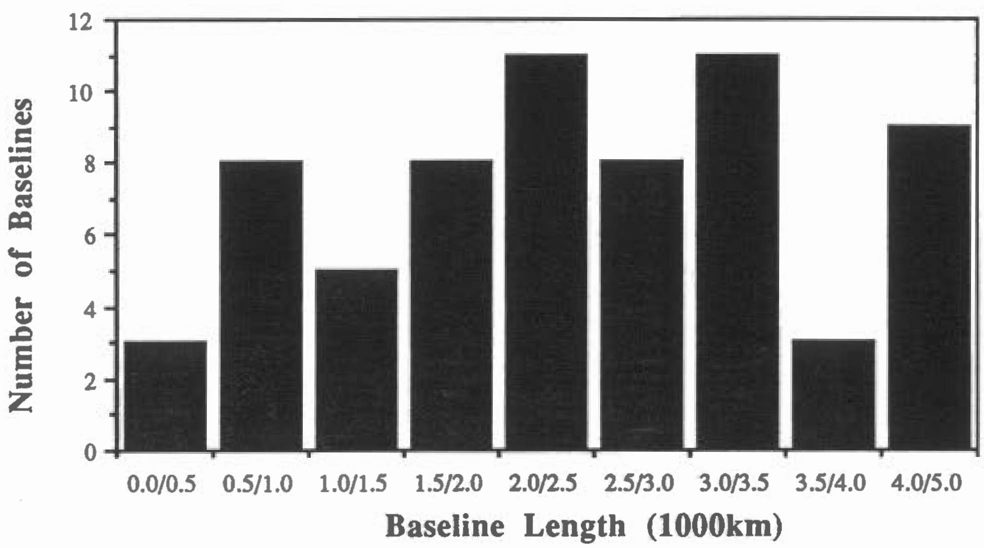


Figure 3
Baseline Length Distribution

Figures 5 (a) and (b) show the rms daily repeatability for both the north-south and east-west baseline components and baseline lengths respectively as a function of baseline length. Baselines including a fiducial station were excluded from this analysis. Two especially noisy sites, Iqaluit and Chibougamau, were also excluded. Neither the horizontal components nor the baseline length repeatabilities show large correlations to baseline length. This is likely the result of a lack of short baselines and also especially noisy data at several of the sites. Figures 6 (a) and (b) depict a 5.4 cm wavelength combination of carrier phase and pseudo range data. The data from Iqaluit , Figure 6(b), is likely contaminated by ionospheric noise. The combination for Thunder Bay, figure 6(a) shows data having less noise.

station	oct 30	oct 31	nov 01	nov 02	nov 03	nov 04	nov 05
Yellowknife	X	X	X	X	X	X	X
Iqaluit	X	X	X	X	X	X	X
Penticton	X	X	X	X	X	X	X
Algonquin	X	X	X	X	X	X	X
St. John's	X	X	X	X	X	X	X
UNB		X	X	X	X	X	X
PGC	X	X	X	X	X	X	X
Thunder Bay	X	X	X	X	X		
Downsview	X	X	X	X	X	X	X
Hearst	X	X	X	X	X		
Chibougamau	X	X	X	X	X	X	X
Mojave	X	X	X	X	X	X	X
Richmond	X	X	X	X	X	X	X

Table 1
Station Observation Dates

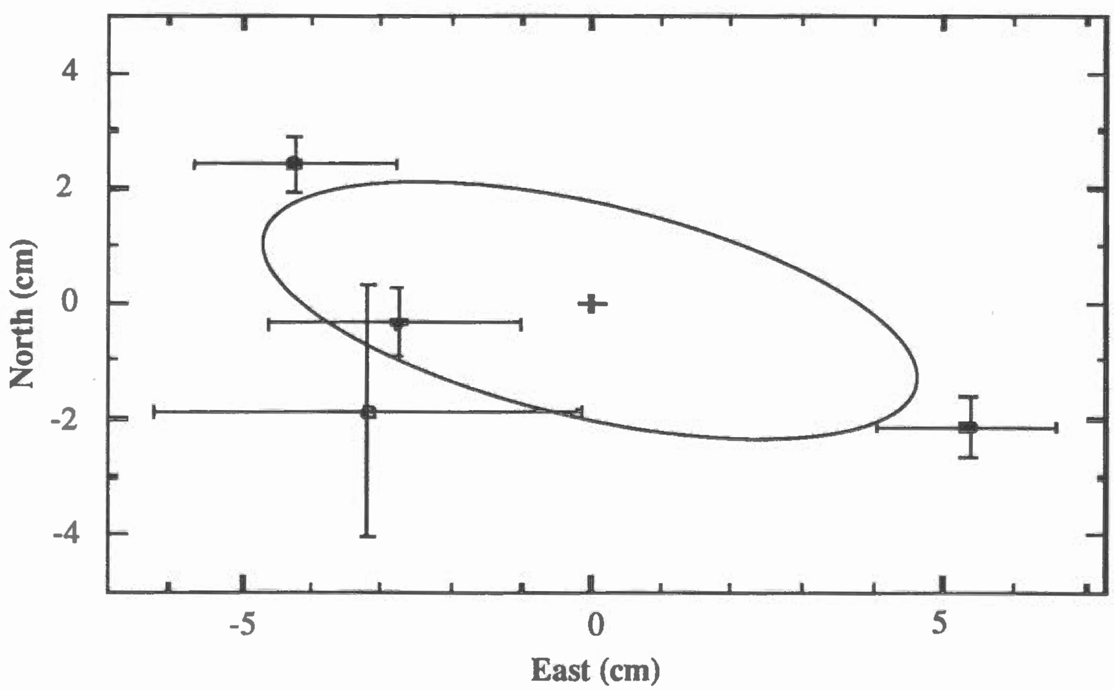


Figure 4
Daily Repeatability for Hearst-Thunder Bay (438 km)

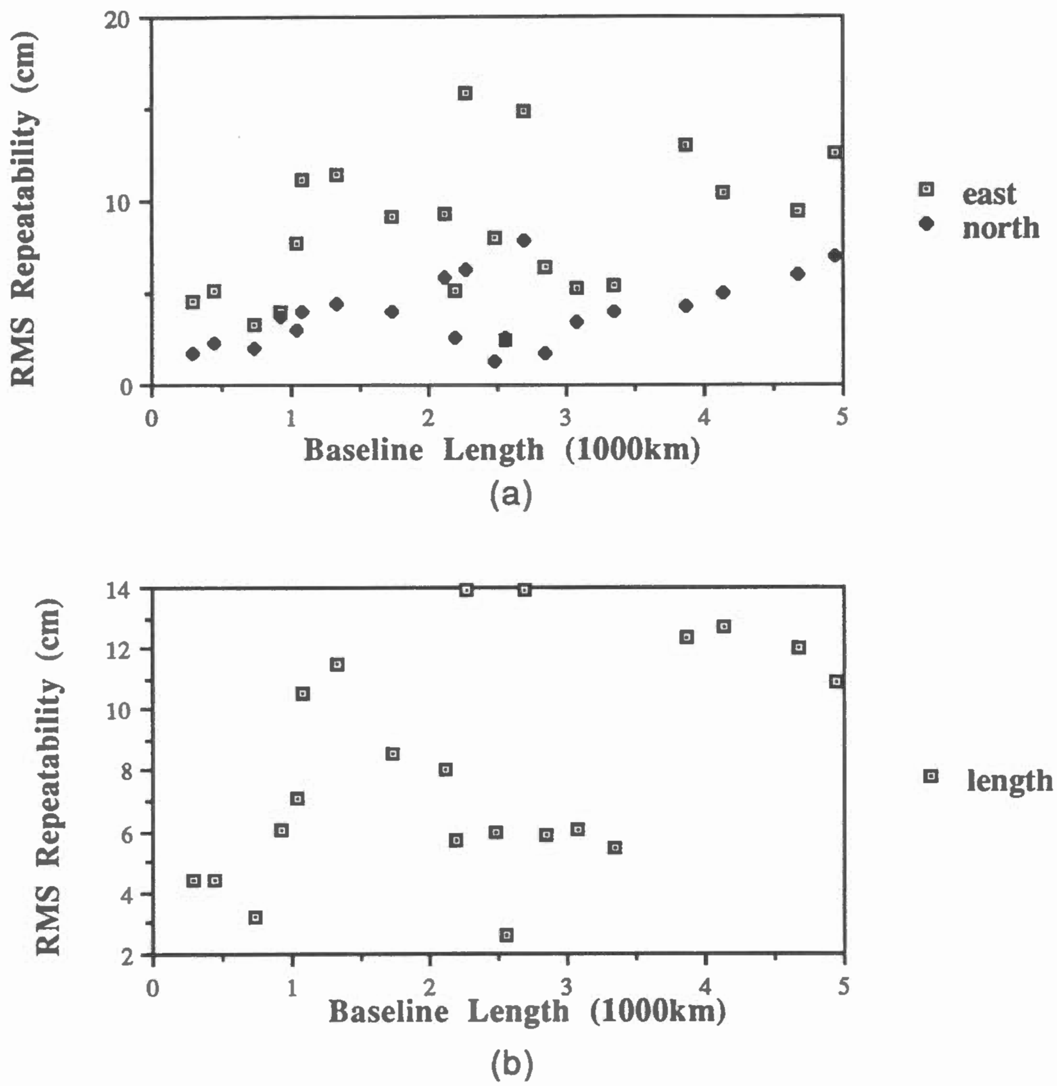
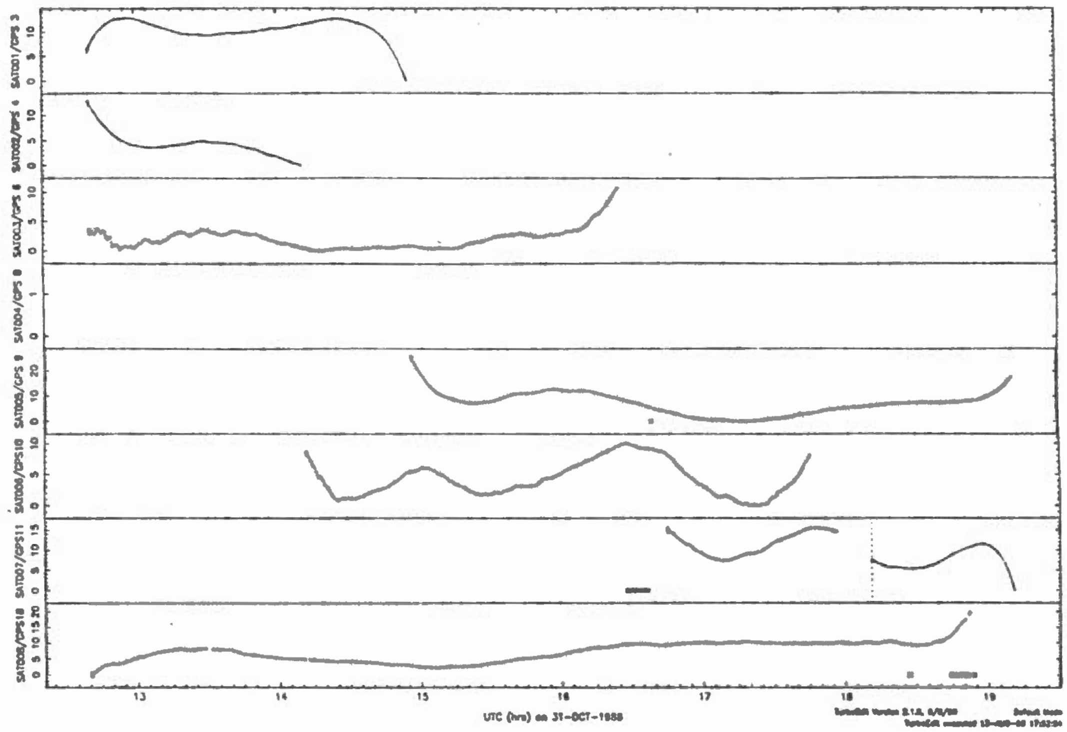


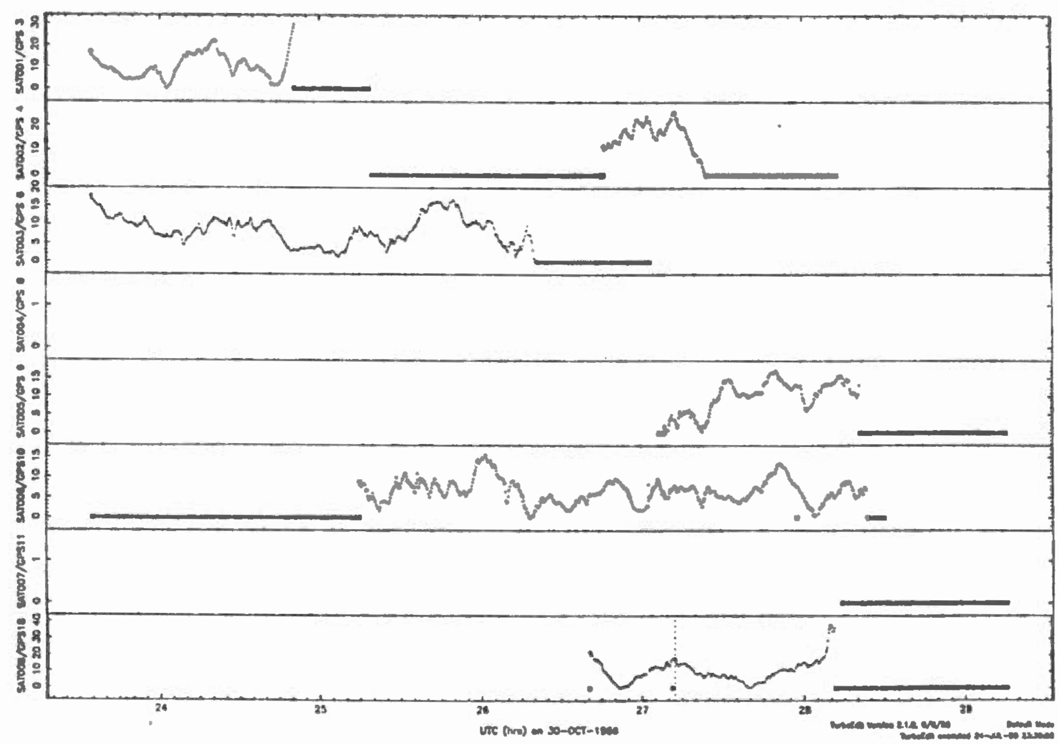
Figure 5
Daily Repeatability for North-South, East-West (a) and Length (b) Components

Comparison Between the Multi-Day Arc Solution and Daily Solutions

A five day arc solution was obtained using an eight station subset of the continental network. Table 2 lists the stations used. The station positions were solved for independently each day while the satellites orbits were solved for as a single five day arc. Figure 7 depicts the rms daily repeatability of the baseline length for both the daily solutions and the five day arc solution. The rms repeatability of the five day arc solution compares quite favorably even though a less dense tracking network was used.



(a) THUNDER BAY



(b) IQALUIT

Figure 6

5.4cm wavelength combination of carrier phase and pseudo range data

station	oct 30	oct 31	nov 01	nov 02	nov 03	nov 04	nov 05
Yellowknife	X	X	X	X	X	X	X
Iqaluit	X	X	X	X	X	X	X
Penticton	X	X	X	X	X	X	X
Algonquin	X	X	X	X	X	X	X
St. John's	X	X	X	X	X	X	X
UNB		X	X	X	X	X	X
Mojave	X	X	X	X	X	X	X
Richmond	X	X	X	X	X	X	X

Table 2
Stations Used for Five Day Arc Solutions

A much more significant improvement was obtained for the formal error of the satellites three dimensional position. Figures 8 (a) and (b) show the mean standard deviations and final standard deviation of the satellite positions for the daily solutions and five day arc solutions respectively.

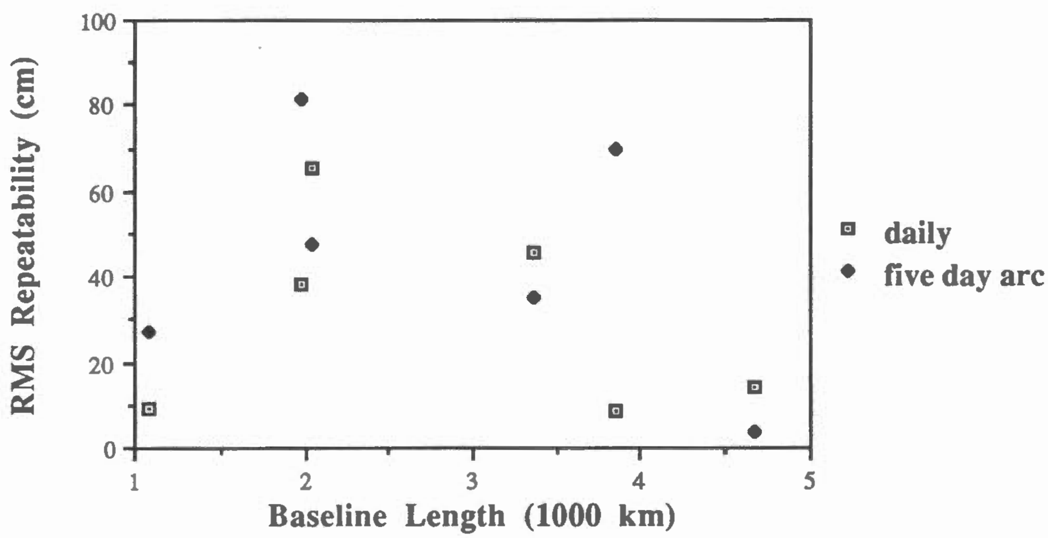
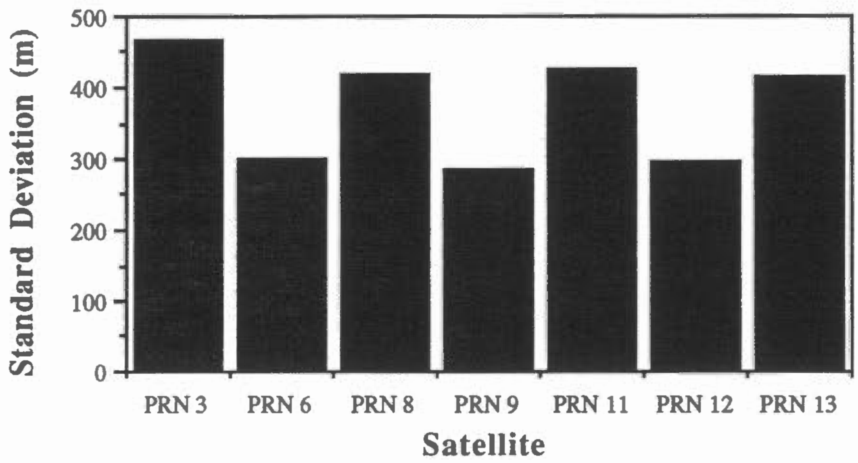


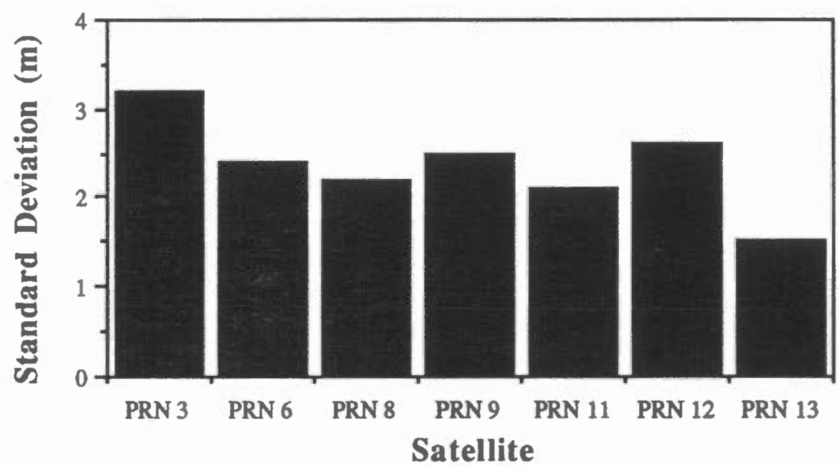
Figure 7
Baseline Length Repeatability

Comparison Between a Continental Network and a Regional Network

A comparison of the daily repeatability for the length of six baselines common to both a continental network and a regional network was performed. Five independent daily solutions were obtained for the regional network using a single fiducial station and fixed orbits. The orbits used were derived from a twenty one day fit to broadcast ephemerides. Figure 9 shows the rms repeatability of the baseline length as a function of baseline length. The higher precision depicted by the regional network highlights the weakness of the daily orbit solution derived from the continental network.



(a)



(b)

Figure 8
Standard Deviation of Satellite Position for the Mean of Daily Solutions (a) and Five Day Arc Solution (b)

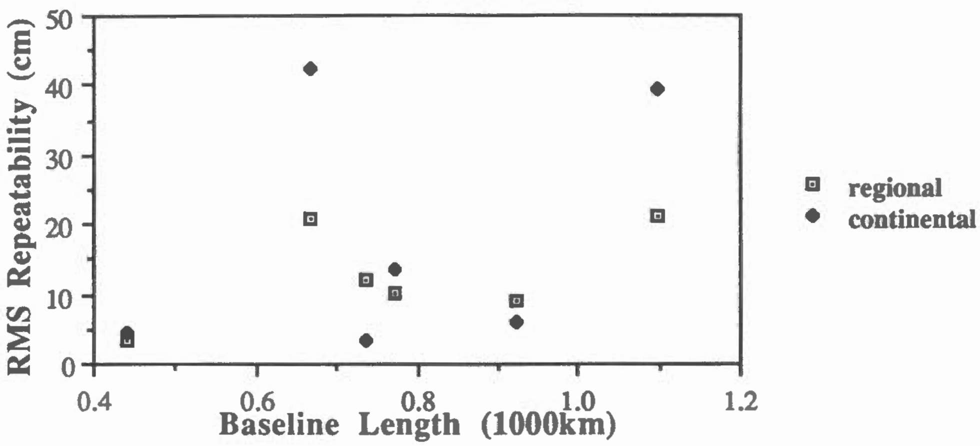


Figure 9
Baseline Length Repeatability

CONCLUSIONS

This limited analysis of a portion of the GOTEX data set demonstrates that in order to resolve orbits with a high degree of precision a multi-day arc solution derived from a continental fiducial network is required. It is also interesting to see that good precision can be achieved, for station positions, using data from a small tracking network and good a priori orbits. This is of particular importance when one considers the benefits of having an ACS which can provide not only precise orbital information but also data from a regional tracking networks useful to all GPS users.

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