Performance Analysis of *a Narrow Cowelator Spacing Receiver for Precise Static GPS Positioning*

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ABSTRACT

The performance of narrow correlator spacing C/A code GPS receiver technology was assessed for static GPS surveying using lo-channel, single frequency GPSCard™ receivers. A series of surveys was conducted in the Eastern United States in December 1992 in support of this assessment. Baselines of 0.5 to 320 km were observed over several days to analyse repeatability and agreement with reference coordinates. The carrier phase measurements were post-processed using double and triple difference approaches. Precise orbits were used to isolate the atmospheric and receiver error sources. The effect of multipath on carrier phase measurements is demonstrated. In order to determine the effect of the ionosphere on long baseline (> 200 km) solutions, the ionospheric effect was estimated using a single frequency code/carrier phase divergence approach. This method is particularly well suited in this case in view of the high C/A code accuracy of the GPSCard™. The effect of the ionosphere on the baselines was found to reach several ppm. The repeatability of the baselines varies between 1.2 and 3.0 ppm. The agrement of the reference coordinates with the Ll baseline solutions is 3.7 ppm while that with the ionospherically corrected long baseline solutions is 1.1 ppm.

INTRODUCTION

The objective of the project described herein was to test the static GPS performance of the NovAtel GPSCard™ receiver over short and long baselines. The GPSCard™ is a lo-channel single frequency C/A code receiver equipped with a temperature compensated oscillator. Its narrow correlator spacing characteristic results in lower C/A code noise and multipath (Fenton et al 1991, Van Dierendonck et al 1992, Cannon & Lachapelle 1992). The noise and multipath level is similar to that of P code measurements, as determined from numerous field experiments (e.g., Lachapelle et al 1992). Although this is advantageous for rapid static and kinematic surveying to isolate the integer carrier phase ambiguities more effectively, the advantages for conventional GPS static surveying are less obvious since the narrow correlator spacing method has no advantage in terms of carrier phase measurement accuracy. Over long baselines, however, one significant advantage might be the recovery of the relative ionospheric effect through the code-carrier phase divergence method.

The antenna type used during the tests was the NovAtel Model 501 which has a high gain at low elevation. The use of chokering groundplanes has been shown to decrease multipath significantly in such a case (e.g., Cannon & Lachapelle 1992). Such groundplanes were not used regrettably during the test.

FIELD MEASUREMENTS AND DATA POST-PROCESSING METHOD

Field measurements were made in the Eastern part of the United States during the period December 7-11,1992. Four receivers were used and the short and long baselines shown in Figures 1 and 2 were observed. During the field observations, some five to seven satellites were available with an elevation above 15” and the PDOP ranged from approximately 2 to 4. Each GPSCard™ sensor was housed in a laptop computer. The carrier phase tracking

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bandwidth was set at 15 Hz, as suggested by the manufacturer.

The data were processed by The University of Calgary using SEMIKIN™ (Cannon 1990, Cannon et al 1991). A double difference approach with fixed integer ambiguities for short baselines (< 12 km) and float ambiguities for the other baselines was used. The data were also reduced by the U.S. National Geodetic Survey (NGS) using a triple difference approach and the results were comparable. NGS triple difference results were based on NGS precise orbits. SEMIKIN™ baseline results were derived using precise orbits generated by Geodetic Survey of Canada, Energy,Mines and Resources Canada (EMR). These precise orbits are based on CIGNET (Cooperative International GPS Network) stations and their agreement with precise orbits generated by other organizations is at the sub-meter level.

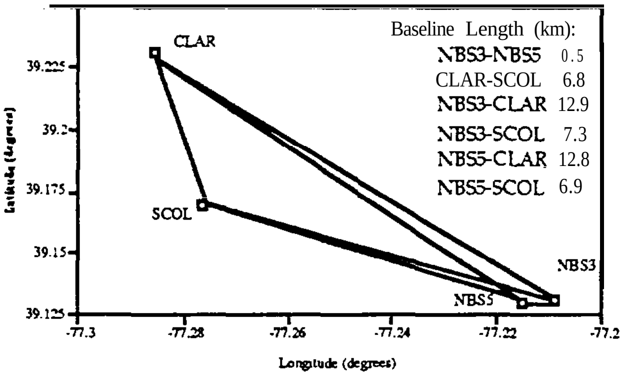

Figure 1: Stations Observed on Day 342

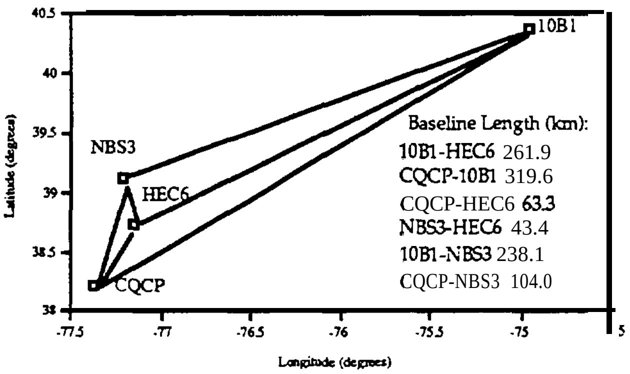

Figure 2: Stations Observed on Day 343,344,345, and 346

A modified Hopfield tropospheric model was used to correct all measurements for tropospheric effects. Measured meteorological data were used except at a few stations where standard atmosphere parameters (P = 1010.00 mbar, T=293.0° K, and humidity = 50%) corrected for altitude were applied because surface meteorological data were not collected. The carrier phase data interval used during processing was 20 seconds (ambiguities fixed) for the short baselines (ℓ < 15 km) and 30 seconds (ambiguities float) for the long baselines.

All the baselines were reduced using L1 carrier phase measurements. The baselines over 200 km were also reduced with ionospherically corrected data. The relative ionospheric L1 carrier phase advance was derived using two code/carrier phase divergence estimation techniques. The University of Calgary method is based on Cohen et al 's approach (1992) (Qiu et al 1993) while the NGS method is based on a new approach being developed and tested. No ionospherically corrected solutions were obtained for baselines less than 200 km because it becomes more difficult in this case to separate the smaller effect of the ionosphere from other effects such as multipath.

The observation time of each baseline varied between 2.5 and 4 hours. Observation sessions were mostly free from cycle slips, except for station CQCP on Day 346. The cause for the numerous cycle slips detected at that station remains unknown. The reference NAD83 horizonal geodetic coordinates and ellipsoidal heights used for comparison with the GPS results derived with the above measurements were obtained from NGS and these coordinates are listed in Table 1.

Table 1: Reference Geodetic Coordinates Used for Comparison

Station ID	Latitude (°, ', ")	Longitude (°, ', ")	Ellipsoid Height (m)
CQCP	N38-12-08.52187	W77-22-24.53286	35.585
SCOL	N39-10-13.165	W77-16-35.839	121.63
NBS3	N39-0751.00898	W77-12-32.76732	105.453
NBS5	N39-07-48.36530	W77-12-54.11362	105.604
CLAR	N39-13-53.039	W77-17-07.262	168.22
HEC6	N38-44-36.19398	W77-08-40.01902	-5.36
10B1	N40-22-57.97463	W74-57-08.89801	-7.163

ANALYSIS OF RESULTS

The GPS baseline components derived from the above measurements were analysed as follows:

- GPS L1 and ionospherically (k-200 km)corrected versus reference geodetic coordinates
- Repeatability of GPS L1 and ionospherically corrected solutions on different days
- Triangle misclosure
- Precise versus broadcast orbits
- Carrier multipath analysis
- Double difference ($\nabla\Delta\Phi$) versus triple difference ($\delta\nabla\Delta\Phi$) solution comparison

The 3D difference (δ3D) accuracy measure used in the tables described below is defined as

$$\delta 3D = (\Delta x^2 + \Delta y^2 + \Delta z^2)^{1/2} = (\Delta\phi^2 + \Delta\lambda^2 + \Delta h^2)^{1/2}$$

The corresponding accuracy, in terms of parts per million of the baseline ℓ, is $\delta 3D / \ell$.

Agreement with Reference Coordinates

The differences between the double difference L1 and ionospherically corrected (ℓ>200 km) solutions with the reference coordinates are shown in Figure 3. The corresponding 3D differences for the short and other baselines are given in Tables 2 and 3, respectively. The repeatability of the GPS solutions, for the baselines which were observed on different days, is given in Table 4.

Table 2: Comparison of L1 Short Baseline Solutions with Reference Coordinates for Day 342

Baseline	3D Diff (cm)
NBS3-NBS5 (0.5 km)	0.8
NBS3 - SCOL (7.3 km)	2.8
NBS5-SCOL (6.9 km)	2.0

The integer ambiguities were resolved for the short baseline solutions and the 3D differences shown in Table 2 are within expected limits. Figure 4 shows the double difference carrier residuals for SV pair 03-17 on baseline NBS3-NBS5. Since this baseline is only 500 m, most of the errors are eliminated by double differencing except carrier phase multipath and receiver noise, which is at the millimeter level. The residual amplitude reaches 4 cm and the pattern is typical of strong carrier phase multipath, caused largely in this case by the high gain of the antenna at low elevation.

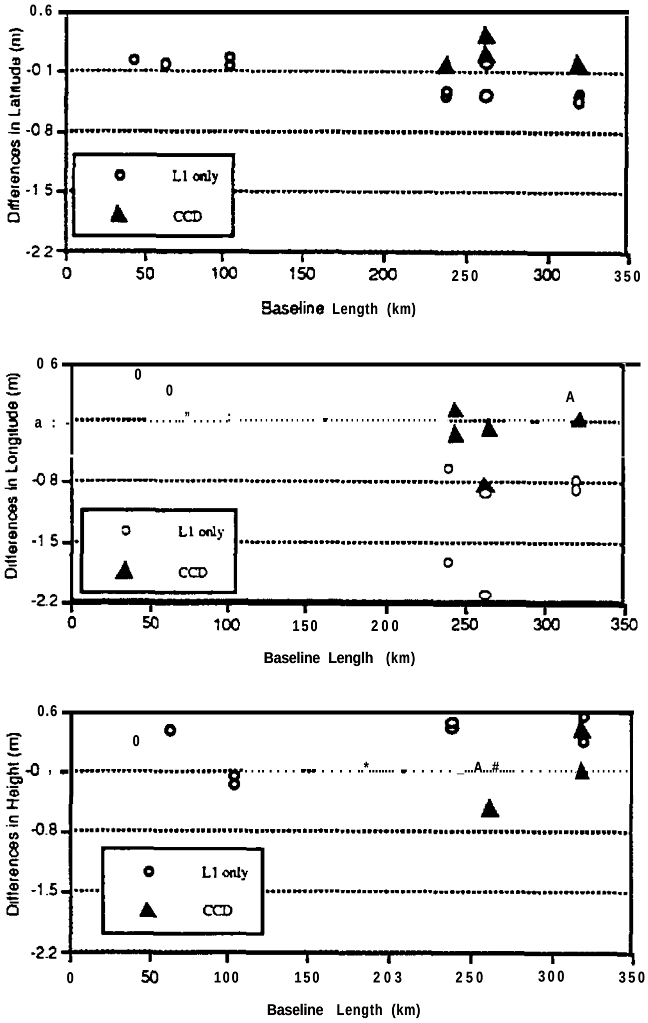

Figure 3: Coordinate Differences Between GPS L1 and Ionospherically Corrected Solutions and Reference Geodetic Coordinates

The 3D differences between the L1 solutions and the reference coordinates for the long baselines vary between 2.1 and 7.6 ppm, with an average of 3.7 ppm. The corresponding 3D differences for the baselines longer than 200 km using ionospherically corrected solutions vary between 0.2 and 2.0 ppm, with an average of 1.1 ppm. The average improvement of the ionospherically corrected solutions is of the order of 2.5 ppm, which demonstrates the capability of the code-carrier divergence technique. The 3D differences between the GPS solutions obtained on different days and given in Table 4 are also interesting because these values are independent from possible errors in the reference coordinates. The average repeatability level for the Ll and ionospherically corrected solutions is 2.9 ppm and 2.0 ppm, respectively. The improvement in repeatability of the ionospherically corrected solutions over the Ll solutions is about 1 ppm in this case.

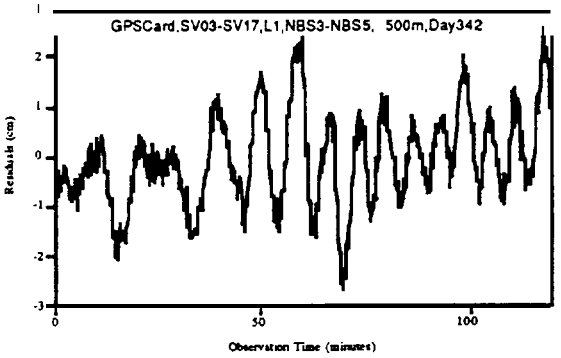

Figure 4: Sample Short Baseline Double Difference Residuals

Triangle Misclosure

It is also useful to examine the misclosure of a triangle formed by baselines observed on three different days. These baselines are NBS3-HEC6 (Day 346), lOBl-HEC6 (Day 345), and lOBI-NBS3 (Day 344), as shown in Figure 2. The misclosure of this triangle in each of the X, Y and Z components is 12, 29 and 20 cm, respectively, using Ll solutions. The 3D misclosure is therefore 37 cm or 0.7 ppm of the perimeter of the triangle (543 km), which is well within the expected error bounds.

Precise Versus Broadcast Orbits

To assess the effect of using precise versus broadcast ephemerides, satellite positions were computed using both broadcast and precise ephemerides. The differences between precise and broadcast ephemerides reached 25 m. The 320-km baseline between CQCP and lOB1 was selected to assess this effect on the position vector. The differences are given in Table 5. The 3D differences between the two solutions are 0.2 ppm.

Double Versus Triple Difference Solutions

The University of Calgary Ll double difference solutions were compared to the Ll triple difference solutions obtained by NGS for all baselines greater than 15 km. The results are summarized in Table 6. The 3-D differences range between 0.3 and 1.8 ppm and are within the level anticipated for such baseline lengths. The differences between ionospherically corrected solutions using different code/carrier divergence approaches are of the same order of magnitude or slightly lower.

Table 3: Comparison of Ll and Ionospherically Corrected Solutions with Reference Coordinates

Date	Baseline	3D Diff (m)	
		L1	Ion. Corr. (CCD)
Day 343	NBS3-CQCP (104 km)	0.26/2.5ppm	not calculated
Day 344		0.22/2.1ppm	not calculated
Day 344	NBS3-10B1 (238 km)	0.84/3.5ppm	0.05/0.2ppm
Day 346		1.80/7.6ppm	0.23/1.0ppm
Day 344	CQCP-10B1 (320 km)	1.10/3.4ppm	0.26/0.8ppm
Day 345		0.89/2.8ppm	0.39/1.2ppm
Day 345	CQCP-HEC6 (63 km)	0.18/2.9ppm	not calculated
Day 345	HEC6-10B1 (262 km)	0.54/2.1ppm	0.39/1.5ppm
Day 346		1.76/6.7ppm	0.52/2.0ppm
Day 346	NBS3-HEC6 (43 km)	0.15/3.5ppm	not calculated

Table 4: Repeatability of GPS Solutions

Date	Baseline	3D Diff (m)	
		L1	Ion. Corr. (CCD)
Days 343 & 344	NBS3-CQCP (104 km)	0.24/2.3ppm	not calculated
Days 344 & 346	NBS3-10B1 (238 km)	1.01/4.2ppm	0.28/1.2ppm
Days 344 & 345	CQCP-10B1 (320 km)	0.33/1.0ppm	0.57/1.8ppm
Days 345 & 346	HEC6-10B1 (262 km)	1.05/4.0ppm	0.78/3.0ppm

Table 5: Baseline Solutions for CQCP-10B1
Using Broadcast and Precise Ephemerides

Baseline	ΔX (m)	ΔY (m)	ΔZ (m)	Distance	3D Diff
Broadcast - Precise, Day 344	0.046	0.001	0.017	0.015	5 cm/0.2 ppm
Broadcast - Precise, Day 345	0.074	0.007	0.030	0.025	8 cm/0.2 ppm

Table 6: Comparison of UofC $\nabla\Delta\Phi$ Versus NGS $\delta\nabla\Delta\Phi$ L1 Solutions

Date	Baseline	3D Diff (m)
Day 343	NBS3-CQCP	0.19/1.8ppm
Day 344	NBS3-CQCP	0.08/0.8ppm
Day 344	NBS3-10B1	0.29/1.2ppm
Day 344	CQCP-10B1	0.18/0.6ppm
Day 345	CQCP-10B1	0.23/0.7ppm
Day 345	CQCP-HEC6	0.02/0.3ppm
Day 345	HEC6-10B1	0.10/0.4ppm
Day 346	NBS3-10B1	0.39/1.6ppm
Day 346	NBS3-HEC6	0.19/4.4ppm
Day 346	HEC6-10B1	0.19/0.7ppm

CONCLUSIONS

The static differential results obtained herein with the GPSCard™ are within the accuracy levels expected for this type of single frequency receiver. The NovAtel Model 501 antenna used herein is designed for multi-purpose applications and has a relatively high gain at low elevation. When no chokering groundplanes are used, as in this case, the carrier phase measurements are relatively susceptible to multipath as shown herein for a short baseline. The use of chokering groundplanes would have likely improved the short baseline L1 results significantly. Nevertheless, the use of the code-carrier phase divergence method to recover the relative effect of the ionosphere on the L1 measurements was shown to produce significantly better results, thereby demonstrating the capability of narrow correlator spacing single frequency equipment for ionospheric effect recovery.

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