Canadian Active Control System Real-Time GPS* Correction Service Performance Review

F. Lahaye, M. Caissy, P. Héroux, K. MacLeod, J. Popelar
Geodetic Survey Division, Geomatics Canada
Natural Resources Canada
615 Booth Street
Ottawa, Ontario
K1A 0E9
information@geod.nrcan.gc.ca

BIOGRAPHY

François Lahaye, Pierre Héroux, Mark Caissy and Ken MacLeod are Research Officers in the Active Control System Section, Geodetic Survey Division of Geomatics Canada.

Dr. Josef Popelar is the Chief of the Active Control System Section, Geodetic Survey Division of Geomatics Canada.

ABSTRACT

The Canadian Active Control System (CACS) was established to improve the accuracy and efficiency of GPS positioning and to provide a direct access to the Canadian Spatial Reference System (CSRS). Precise GPS satellite ephemerides, clock corrections and earth orientation parameters are produced on a daily basis since 1992 with precisions of about 10 cm, 1 ns and 0.2 mas respectively. In 1996, the infrastructure for real-time CACS data acquisition and processing at a central site was put in place to facilitate real-time computation and distribution of GPS corrections which is known as the GPS•C service.

Recent point positioning results, using the GPS•C service satellite orbit and clock corrections, for stations located in central and western Canada show RMS differences with respect to ground truth better than 0.5 meter in horizontal components and better than 1 meter in the vertical.

I INTRODUCTION

The Canadian Active Control System (CACS) was established to improve the accuracy and efficiency of GPS positioning and to provide a direct access to the Canadian Spatial Reference System (CSRS). Precise GPS satellite ephemerides, clock corrections, and earth orientation parameters have been produced on a daily basis since 1992 with current precision of about 10 cm, 1 ns and 0.2 mas respectively. These CACS products facilitate geodetic positioning at the centimeter level and single point positioning at the meter level in post-processing with several days delay, depending on receiver characteristics.

The Geodetic Survey Division (GSD) of Geomatics Canada, has implemented a prototype real-time GPS Correction Service (GPS•C) based on the CACS. Figure 1 shows the current configuration of the real-time CACS network. The system uses Hewlett-Packard UNIX servers, frame relay data communications and the Real-Time Application Platform (RTAP) enabling technology. The viability of the system architecture, the selected platforms, data communication infrastructure and the application software technologies was described in [Caissy *et al*, 1996].

The physical system performs the following functions:

1. data collection, validation and communication, at Real-Time Active Control Points (RTACPs);

2. network control, data management, generation and multicasting of GPS•C corrections, at the Real-Time Master Active Control Station (RTMACS);

3. GPS•C user interface, at Virtual Active Control Points (VACPs), and

4. GPS•C data integrity monitoring, at Integrity Monitoring Stations (IMSs).

This paper reviews the present status of the real-time CACS operations and summarizes the precision of positioning obtained with the GPS•C service to date.

*Presented at the 1997 National Technical Meeting of the Institute of Navigation, January 14-16, 1997, Santa Monica, CA.

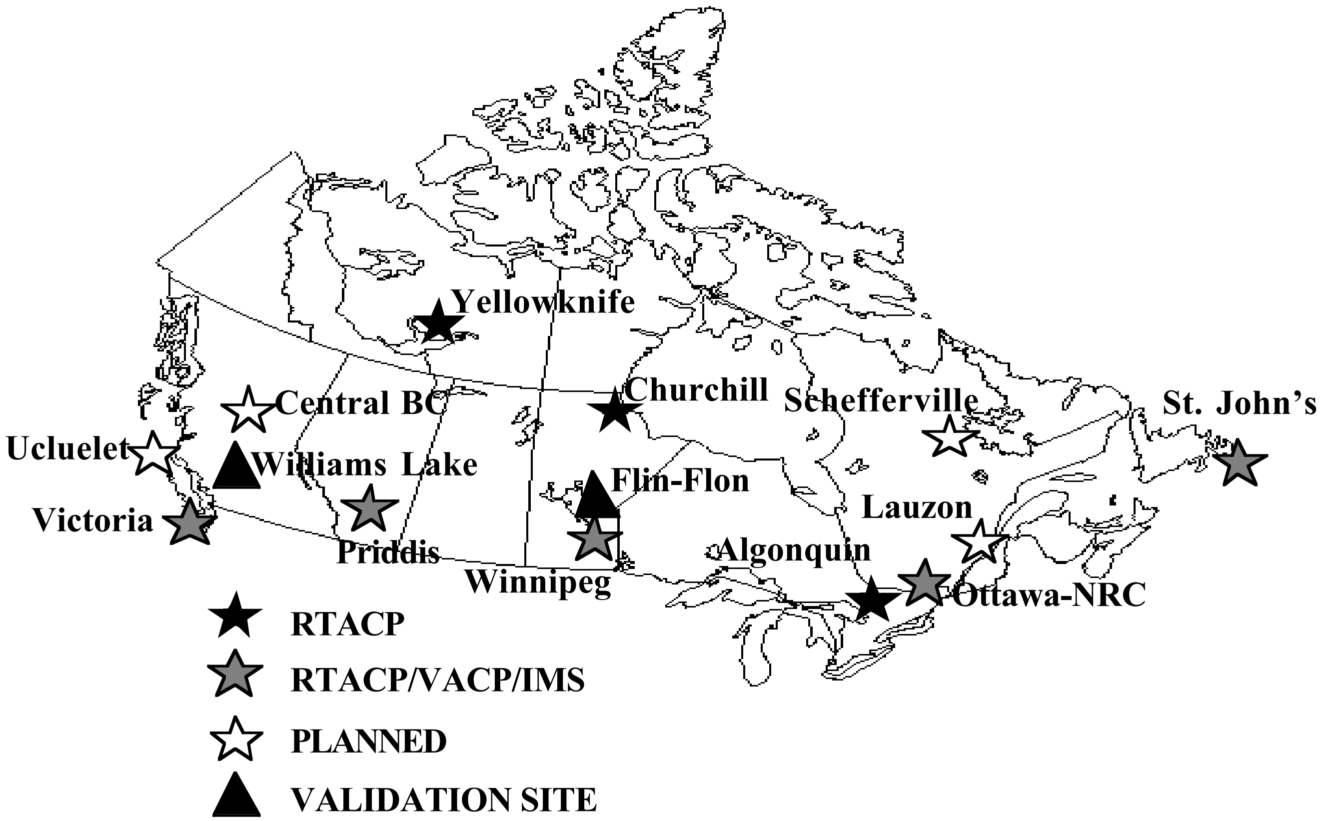

Figure 1: Real-time CACS network

Site	Installation	Functionality	Communication	Instrumentation
Victoria	March, 1996	RTACP,VACP,IMS	Land	SNR-12RM Rb Met
Yellowknife	March, 1996	RTACP	Satellite	SNR-12RM Hm Met
Priddis	March, 1996	RTACP,VACP,IMS	Land	SNR-12RM Rb Met
Churchill	October, 1996	RTACP	Satellite	SNR-8000 Cs
Winnipeg	October, 1996	RTACP,VACP,IMS	Land	SNR-8100 Rb
Algonquin	October, 1996	RTACP	Satellite	SNR-8000 Hm
Ottawa-NRC	March, 1996	RTACP,VACP,IMS	Land	SNR-12RM Hm Met
St-John's	March, 1996	RTACP,VACP,IMS	Land	SNR-8000 Cs Met
Central BC	1997		Land	-
Lauzon	1997		Land	-
Ucluelet	1997		Satellite	-
Schefferville	1997		Satellite	-

SNR-xxxx: Turbo Rogue GPS receiver models   Met: Met data unit
Hm: Hydrogen Maser clock   Cs: Cesium clock   Rb: Rubidium clock

Table 1: Real-time CACS sites

II REAL-TIME CACS NETWORK

Since the publication of [Caissy *et al*, 1996], three additional sites have been put into operation: Winnipeg, Manitoba, Churchill, Manitoba and Algonquin, Ontario, for a total of eight RTACPs across Canada. A test site located at the Geodetic Survey in Ottawa is used for development. Table 1 lists all the real-time CACS sites, their time of installation, functionality, communication and instrumentation. The maximum data communication delays for land lines are generally less than 0.5 second whereas for the satellite links they can amount to 1.5 seconds.

III GPS∑C SERVICE PRODUCTS

According to the [Mueller, 1994] classifications of WADGPS systems, the GPS∑C service represents a new approach using a state-space domain algorithm. The GPS∑C service products comprise estimates of satellite orbit corrections, satellite clock corrections and atmospheric delay corrections. These corrections must be combined taking into account approximate receiver location and local meteorological data to form measurement corrections. This can be performed at a VACP and the resulting measurement corrections can be transmitted to users within appropriate range using the RTCM-104 standard. The following sub-sections outline the GPS∑C approach.

III.1 ORBIT CORRECTIONS

The orbit corrections are determined from orbit predictions based on several daily global solutions. NRCan contributes these daily global solutions to the IGS Rapid Orbit Service [Tétreault *et al*, 1995] where it is combined with independent determinations from other analysis centers. The statistics of the IGS combination are used to exclude problematic orbit data from the prediction process. However this scheme can not accommodate sudden changes in satellite orbital dynamics and thus when broadcast orbits differ from the predicted by more than 15 m, the real-time corrections are based on broadcast orbits and the orbit corrections for the corresponding satellite are zero. The orbit predictions are updated daily as soon as new global solutions are available.

III.2 CLOCK CORRECTIONS

The satellite clock corrections are derived from dual frequency tracking data collected in real-time from the RTACPs. Ionosphere-free, carrier-phase smoothed pseudorange data at 2 second intervals are combined with latest satellite orbit predictions and RTACP coordinates in a least-squares adjustment to determine satellite and station clock corrections with respect to a virtual reference clock (VRC). The VRC is maintained as a mean of the ensemble of the RTACP station atomic time standards using appropriate consistency algorithm. This approach mitigates the effects of instabilities of individual station clocks, eliminates clock discontinuities and presently provides VRC stabilities at the 10^{-14} level.

III.3 ATMOSPHERIC DELAYS

Vertical ionospheric delays between the RTACP receivers and observed satellites, computed from L1 and L2 carrier-phase smoothed pseudoranges, are used to update a latitude versus local solar time grid for a single layer ionosphere model. The ionospheric delay grid computation requires prior calibration of GPS satellite and RTACP receiver delays to eliminate the inter-frequency instrumental biases. These instrumental biases result from hardware delays in receiver and satellite L1 and L2 signal paths and can be estimated with ±0.5 nanosecond precision [Gao *et al*, 1994].

Tropospheric delay corrections are computed using the Hopfield model and standard or measured meteorological parameters at the VACPs.

IV PERFORMANCE ASSESSMENT

From December 24, 1996 to January 5, 1997, the GPS∑C satellite orbit and clock corrections were collected in real-time at a sampling rate of 30 seconds. These were used for point positioning, using the ionosphere free carrier-phase smoothed pseudoranges from independent stations at Williams Lake, B.C. and Flin-Flon, Manitoba (see Figure 1). The daily RMS values for the GPS∑C based positions with respect to ground truth for these stations are shown in Figure 2. Satellite tracking data above 15 degree elevation with GDOP less than 10 have been used. These results are obtained with dual frequency geodetic quality receivers without latency effects.

The daily RMS of position differences based on precise IGS products for Williams Lake obtained from the IGS reports (Table 3 of IGS Rapid Service Reports) are plotted in Figure 3. These results represent the current precision limits of the point positioning technique based on geodetic quality dual frequency pseudo-range data.

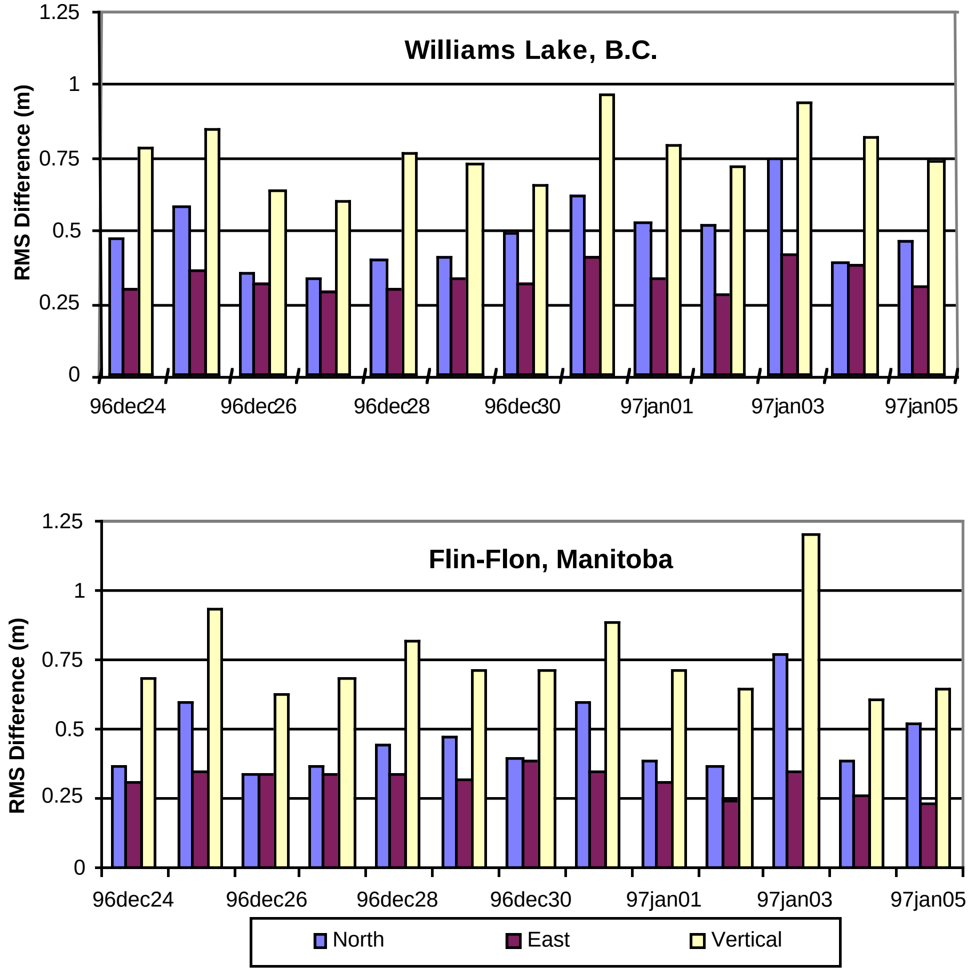

Figure 2: Point-positioning results based on the GPS•C real-time products.

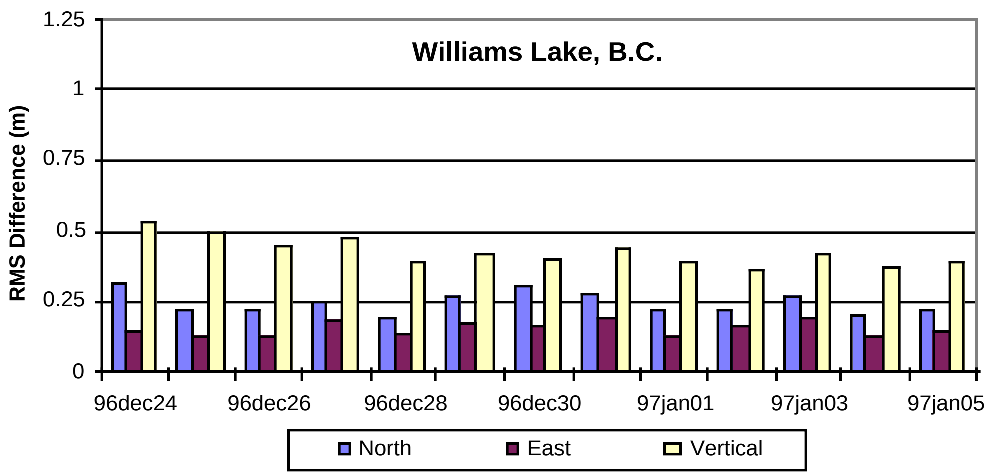

Figure 3: Point-positioning results based on the IGS post-processing products.

V CONCLUSION

The GPS•C service of the Canadian Active Control System has been implemented in 1996 to facilitate real-time positioning and navigation with better than 1 meter precision for Canada and adjacent regions. The GPS•C satellite orbit, clock and ionosphere corrections are presently based on GPS data from 8 RTACPs connected with the RTMACS in Ottawa by a frame relay network using land and satellite data communications facilities. Recent point positioning results from stations located in central and western Canada show daily RMS differences with respect to the ground truth better than 0.5 meter in horizontal components and better than 1 meter in the vertical. It is expected that this performance will improve by about 40% when planned enhancements are implemented and the real-time CACS network completed in 1997.

ACKNOWLEDGMENTS

The authors wish to acknowledge the important contributions to this work by their colleagues at the Geodetic Survey Division and R. Fong at tesserNet Systems Inc.

REFERENCES

1. Caissy M., P. Héroux, F. Lahaye, K. MacLeod, J. Popelar, J. Blore, D. Decker, R. Fong, "Real-Time GPS Correction Service of the Canadian Active Control System", Proceedings of the 9th International Technical Meeting of The Satellite Division of the Institute of Navigation, ION GPS-96, September 17-20, 1996, pp 1787-1791 .

2. Gao, Y., P. Héroux and J. Kouba, "Estimation of GPS Receiver and Satellite L1/L2 Signal Delay Biases Using Data from CACS", Proceedings of the International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, Banff, Canada, August 30-September 2, 1994, pp. 109-117.

3. Mueller, T., "Wide Area Differential GPS", GPS World, June 1994, pp 36-44.

4. Tétreault, P., R. Ferland, J. Kouba and J. Popelar, "NRCan (EMR) Analysis Center 1995 Annual Report to the IGS", in "1995 Annual Report", International GPS Service for Geodynamics, IGS Central Bureau at Jet Propulsion Laboratory, September 1996, pp. 175-180.