Precise Point Positioning Accuracy Analysis for Integrated Surveys

By Ron Berg, M.A.Sc., O.L.S., and Trevor Holliday, B.E.S.

Introduction

Historically, GNSS (Global Navigation Satellite System) surveys required at least 2 geodetic-quality receivers, simultaneously tracking common satellites, to produce centimetre-level positioning results. This can be done by post-processing data from static surveys, or by operating a base station and rover receiver in a Real-time Kinematic (RTK) mode, which provides position corrections as the survey is being conducted.

A GNSS user can now compute high-accuracy geographic coordinates from a single receiver through Natural Resources Canada's (NRCan) on-line Precise Point Positioning (PPP) service. PPP may be used to correct both static and kinematic GNSS observations, and provides results in the NAD83 CSRS (North American Datum 1983, Canadian Spatial Reference System), and the ITRF (International Terrestrial Reference Frame).

The Ministry of Transportation Ontario (MTO) Geomatics Office submitted numerous control survey data files for PPP processing to analyze the accuracy of PPP-derived position solutions.

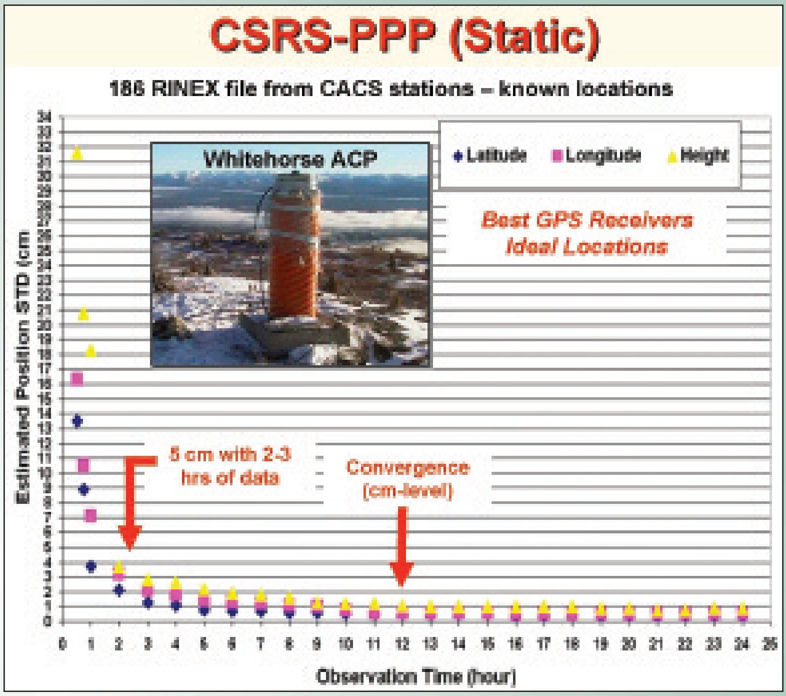

Figure 1 (Natural Resources Canada, 2010)

Precise Point Positioning Service Overview

NRCan provides two methods of obtaining PPP corrections. One is online through their CSRS Online Database Service. A free NRCan account must be set up in order to use the PPP corrections service. Go to:

http://www.geod.nrcan.gc.ca/online_data_e.php

A new version, called PPP Direct, allows the user to drag-and-drop multiple files onto a desktop icon that automatically submits the files for processing. The executable file can be installed from the CSRS Online Database Service. With either method, PPP returns results via e-mail. RINEX (Receiver INdependent EXchange) format files must be used for PPP processing.

The accuracy of PPP-derived coordinates is a function of the length of observation session, the type and quality of equipment used, and the availability and geometry of satellites during the session.

Figure 1 shows achievable accuracies at CACS (Canadian Actve Control System) stations, which are very stable, pillar-mounted, geodetic-quality receivers in locations with virtually unrestricted visibility to the sky.

NRCan has done limited testing with single-frequency receivers. Mapping-grade receivers can provide results accurate to approximately 20 cm under ideal conditions. Recreation-grade receivers are unreliable and are not recommended for sub-metre positioning. Users are advised to conduct independent testing with their receivers at known CSRS control monuments to determine achievable accuracies.

Accuracy of PPP Solutions

The Ministry of Transportation Ontario (MTO) Geomatics Office submitted numerous files for PPP processing to analyze the accuracy of PPP-derived position solutions. All sessions were submitted for PPP processing from March to July, 2010. Controlling factors for these submissions were that the original surveys used **dual-frequency, geodetic-quality** equipment and were conducted according to MTO specifications for GPS Control Surveys. Stations were chosen across a broad geographical area as shown on the accompanying map (Figure 2). Most stations have more than one session processed for comparison. The observations were from control surveys conducted between 2000 *cont'd on page 34*

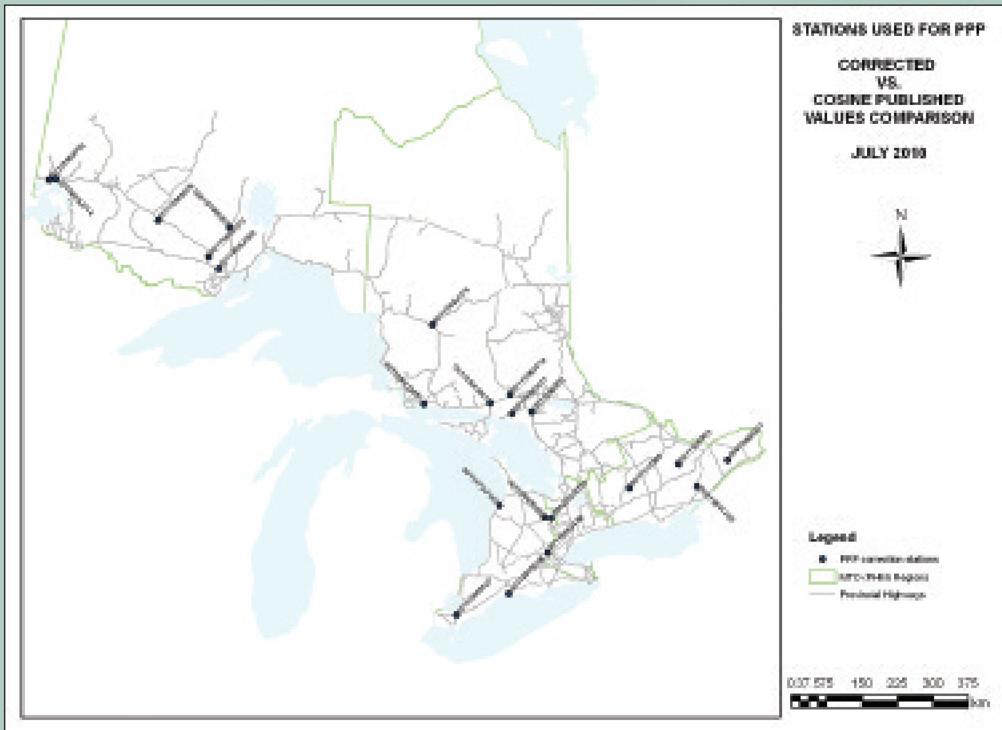

Figure 2

For sessions under one hour the Sigmas are generally far worse than the actual coordinate differences.

Of significant importance to the user is the fact that the PPP-derived positions were closer to the actual published NAD83 CSRS values than the Sigma values in almost all cases. Thus the Sigmas likely indicate a worst-case accuracy scenario and are not overly optimistic error estimates. Sigmas for sessions of 1 hour 30 minutes and longer were generally close to the calculated coordinate difference between PPP-derived and published CSRS values. Sigmas generally improve with increased observation time, provided no other problems exist during the session i.e. poor sky visibility, cycle slips, too few satellites, poor satellite geometry, and atmospheric interference.

and 2009 and range in length from 30 minutes to four hours.

When submitting files to NRCan for PPP processing, the user must select the reference system – either NAD83 CSRS or ITRF. Ontario's current published geodetic survey data is related to the NAD83 CSRS datum – 1997 epoch. The user must select **epoch "1997.0"** in order to derive values directly comparable to current **published NAD83 CSRS values in Ontario** available through MNR's COSINE database.

In the graphs below (Figures 3 and 4), the vertical bars show the 2-D coordinate difference between the PPP-derived UTM values and the published NAD83 CSRS UTM values in COSINE. The line graph represents the 2-D error estimate (Sigma) from the PPP processing software for each session. Sessions range from approximately 30 minutes to four hours. Figure 4 is an enlargement to clearly show the coordinate differences.

The coordinate differences generally decrease with increasing session length, although there are notable inconsistencies throughout the dataset. With a few exceptions, the coordinate differences are within 10 cm after 30 minutes and 5 cm after 60 minutes. There is a noticeable improvement in coordinate comparisons (PPP accuracy) and error estimates (PPP Sigma values) after about one hour of data collection.

There is good correlation between the coordinate differences and the Sigma values for the longer sessions, especially from 1 hour 41 minutes onward.

From these results the following minimum observation times are recommended:

Accuracy < 20 cm at least 30 minutes
Accuracy < 10 cm at least 60 minutes
Accuracy < 5 cm at least 120 minutes

This assumes good GNSS observation conditions. In all cases, redundant observations are required to independently verify the PPP results.

Carrier phase ambiguity resolution is the main factor affecting the convergence seen in the accuracy plots. Resolved ambiguities are the key to benefiting from the full positioning accuracy provided by the carrier phase measurements. Therefore it is essential to ensure the observation

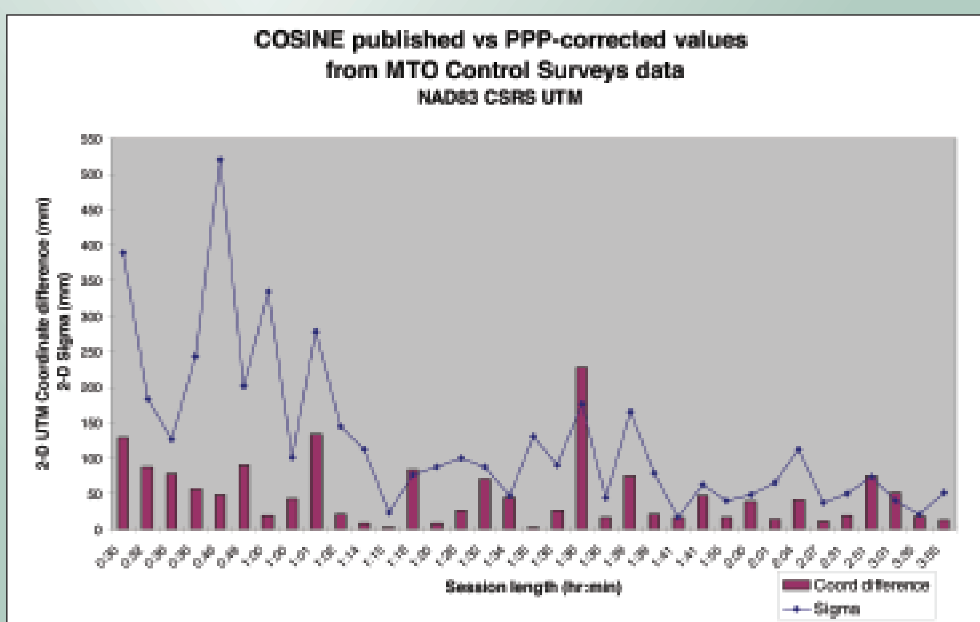

Figure 3

session is long enough for phase ambiguity resolution. Minimum observation times will depend on the accuracy required.

Testing Your Equipment

Users are advised to conduct independent testing with their receivers at known NAD83 CSRS control monuments to determine achievable accuracies. Ideally CBN (Canadian Base Network), OHPN (Ontario High Precision Network) or MTO Key Station monuments should be used since these are the highest-accuracy NAD83 CSRS stations available in Ontario. They are listed as Classes A, B and C in COSINE (COordinate Survey INformation Exchange – MNR's geodetic control database). Most of these monuments are in good locations for GNSS observations with few obstructions.

Testing should include different session lengths and different satellite constellations (observe at different times of the day) to get an idea of the accuracy that can be expected. All types of equipment (i.e. L1 only, L1 & L2) must be tested separately.

Users should test the accuracy of PPP-derived values by directly occupying geodetic control stations with published NAD83 CSRS values, and submitting those sessions for PPP processing to compare to the published values.

Collect several hours of data, carefully measure antenna heights, convert your raw GPS data to RINEX format, ensure that the correct antenna name is used and submit the RINEX files for PPP static processing using NAD83 CSRS epoch 1997.0. Compare the PPP results with published values. This will give an indication of achievable accuracy with your equipment at similar sites over similar time periods. The position difference plots are good indicators of the time needed for "convergence".

When to Use PPP

PPP does not replace a proper geodetic control survey since it does not provide direct ties to surrounding stations to verify integration accuracy with respect to the monumented Ontario NAD83 CSRS datum. The MTO Geomatics Office will continue to establish high order geodetic control through sufficient direct baseline ties to existing control in a geometrically strong network. Geodetic control surveys are governed by the "Ontario Specification for GPS Control Surveys", June 2004. Also, project control should be established from geodetic control by normal GNSS static or RTK surveys, not by PPP.

However PPP may be an option in other instances:

- to meet the cadastral survey integration requirements of Ontario Regulation 216/10 under the Surveyors Act
- in remote locations where no other control exists i.e. remote northern airports
- when NAD83 CSRS values are desired and no nearby published control exists
- to use in place of a local assumed coordinate system for other generic georeferencing needs i.e. pit surveys
- as a check on geodetic control coordinates

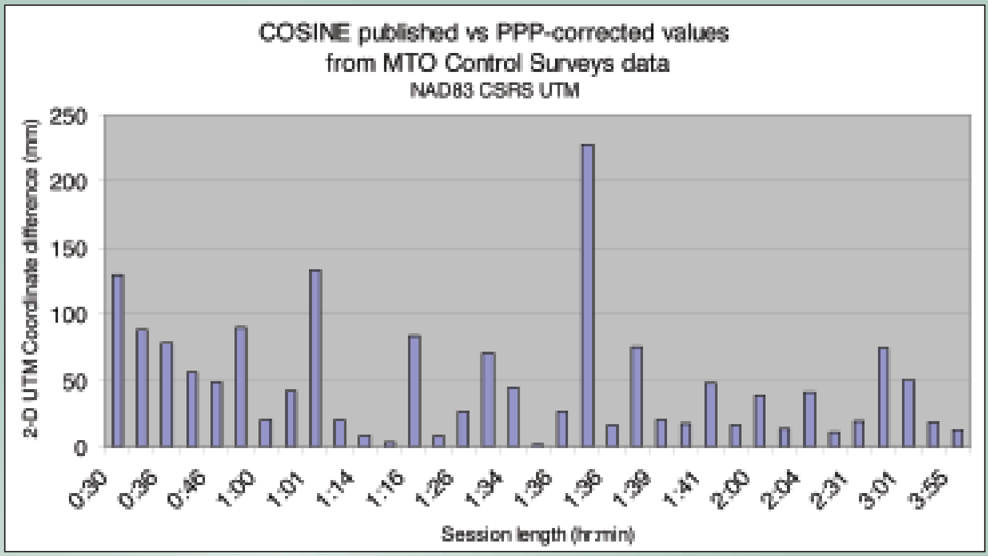

Figure 4

PPP use will increase, particularly for cadastral survey integration, as the observation time required to achieve a given accuracy decreases and as the NAD83 CSRS datum gains more widespread use.

Conclusions

A GNSS user can now compute high-accuracy geographic coordinates from a single receiver through Natural Resources Canada's (NRCan) on-line PPP service. The accuracy of PPP-derived coordinates is a function of the length of observation session, the type and quality of equipment used, and the availability and geometry of satellites during the session. Geodetic-quality, dual-frequency receivers must be used to obtain the best results.

MTO submitted numerous files for PPP processing to analyze the accuracy of PPP-derived position solutions. Results show that the 2-D coordinate differences between the PPP-derived UTM values and the published NAD83 CSRS UTM values in COSINE generally decrease with increasing session length, although there are notable inconsistencies throughout the dataset. With a few exceptions, the coordinate differences are within 10 cm after 30 minutes and 5 cm after 60 minutes. There is a noticeable improvement in coordinate comparisons (PPP accuracy) and error estimates (PPP Sigma values) after about one hour of data collection.

Of significant importance to the user is the fact that the PPP-derived positions were closer to the actual published NAD83 CSRS values than the Sigma values in almost all cases. Thus the Sigmas likely indicate a worst-case accuracy scenario and are not overly optimistic error estimates. Check the Sigma values of the estimated PPP position to ensure they meet the required survey accuracy.

Minimum observation times have been recommended for integrated survey accuracy requirements. Users are advised to conduct independent testing with their receivers at known NAD83 CSRS control monuments to determine achievable accuracies. Testing should include different session lengths and different satellite constellations (observe at different times of the day) to get an idea of the accuracy that can be expected. All types of equipment (i.e. L1 only, L1 & L2) must be tested separately.

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This article is derived from the research report **"User Guide to the Precise Point Positioning Service".** The complete report is available for download from the MTO Research Library Online Catalogue at **http://www.mto.gov.on.ca/english/transrd/.** See References.

References

Berg, Ron and Trevor Holliday, 2010. ***User Guide to the Precise Point Positioning Service.*** Ministry of Transportation Ontario Geomatics Office Report GEO-002. The Queen's Printer for Ontario, October, 2010.

Natural Resources Canada, 2010. ***CSRS-PPP Accuracy.*** **http://www.geod.nrcan.gc.ca/products-produits/ppp_acc_e.php** (May, 2010).

Further Reading

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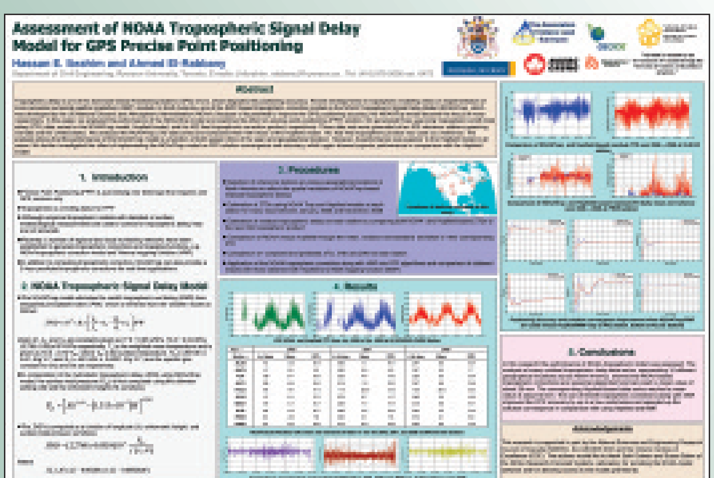
2. Natural Resources Canada. ***Online Global GPS Processing Service (CSRS-PPP).*** **http://www.geod.nrcan.gc.ca/products-produits/ppp_e.php** (2010).
3. Tetrault, Pierre and Pierre Sauve, 2010. ***CSRS-PPP: A web tool to facilitate NAD83(CSRS) integration.*** Ontario Professional Surveyor, Winter 2010, pp 26-31.

FIFTH Annual AOLS Graduate Student Geomatics Poster Session Award Winners

FIRST PLACE: **Hassan E. Ibrahim,** Ph.D. Candidate in the Department of Civil Engineering, Ryerson University, supervised by Dr. Ahmed El-Rabbany.



Assessment of NOAA Tropospheric Signal Delay Model for GPS Precise Point Positioning

ABSTRACT

Tropospheric delay is one of the dominant Global Positioning System (GPS) errors, which degrades the positioning accuracy. Recent developments in tropospheric modeling rely on implementation of more accurate Numerical Weather Prediction (NWP) models. In North America one of the NWP-based tropospheric correction models is the NOAA Tropospheric Signal Delay Model (NOAATrop), which has been developed by the US National Oceanic and Atmospheric Administration (NOAA). Because of its potential to improve the GPS positioning accuracy, the NOAATrop model became the focus of many researchers. In this paper, we analyzed the performance of the NOAATrop model and examined its effect on precise point positioning (PPP) solution. We generated a three-year-long tropospheric zenith total delay (ZTD) data series for the NOAATrop, Hopfield, and the IGS final tropospheric correction product, respectively. These data sets were generated at ten IGS reference stations spanning Canada and the United States. We analyzed the NOAA ZTD data series and compared them with those of the Hopfield model. The IGS final tropospheric product was used as a reference. The analysis shows that the performance of the NOAATrop model is a function of both season (time of the year) and geographical location. However, its performance was superior to the Hopfield model in all cases. We further investigated the effect of implementing the NOAATrop model on the PPP solution convergence and accuracy, which again showed superior performance in comparison with the Hopfield model. Email: hibrahim@ryerson.ca.

SECOND PLACE: **Wai Yeung Yan,** Ph.D. Candidate in the Department of Civil Engineering, Ryerson University, supervised by Dr. Ahmed Shaker.

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