CSRS-PPP: A web tool to facilitate NAD83(CSRS) integration

By Pierre Tétreault and Pierre Sauvé
Geodetic Survey Division, Earth Sciences Sector, Natural Resources Canada

Precise point positioning (PPP) was still a relatively new concept when the Geodetic Survey Division launched its GPS positioning web service, CSRS-PPP, in the fall of 2003. Simplified field logistics and not requiring accurate coordinates for a reference marker rapidly made CSRS-PPP a viable alternative to the traditional phase-differential positioning technique. The PPP approach, which relies on error correction instead of cancellation, has the added benefit of reducing the cost of maintaining networks of ground control needed for differential techniques. In essence, the PPP approach bypasses the traditional ground networks of monumented control points maintained by the federal and provincial governments and accesses the reference in space using the network formed by the various GNSS constellations (including GPS). The precise satellite positions and clock corrections listed in Table 1, which are updated several times a day, along with proper modelling of the effects listed in Table 2, make cm-level positioning accuracy possible.

Table 1: GPS precise satellites orbits and clock corrections used by CSRS-PPP

Products (15 min. orbits & 5 min. clocks)	Delay	Static CSRS-PPP Positioning Accuracy	
		Horizontal (cm)	Vertical (cm)
IGS Final	12 to 19 days (made available 1 GPS Week at a time 12 days after end of week)	0.67	1.13
IGS Rapid	19 hours (made available 1 GPS day at a time 19 hours after end of day)	0.69	1.14
NRCan Hourly	90 to 150 minutes (made available 1 hour at a time 90 minutes after end of hour)	0.89	1.41

Table 1: GPS precise satellites orbits and clock corrections used by CSRS-PPP.

Table 2: Dual-Frequency GPS PPP Estimation

Estimated Parameters	Modeled Effects	Cancelled Effects
Position of antenna phase centre Receiver clock Tropospheric delay Carrier-phase ambiguities	Antenna offsets and phase wind-up Solid earth and polar tides Ocean loading Earth rotation parameters	Ionospheric effects (by combining the two GPS observation frequencies)

Table 2: Dual-Frequency GPS PPP Estimation.

This article provides an overview of the current CSRS-PPP service along with information explaining its usage. While dual-frequency static positioning will be covered here, as it is the most appropriate for accurate survey integration, CSRS-PPP can also be used to process data from single-frequency (pseudo-ranges only observations) and dual-frequency (pseudo-range and carrier-phase observations) for either fixed (static) or moving (kinematic) receivers with expected accuracy as listed in Table 3.

Table 3: CSRS-PPP Accuracy

Receiver	Observations	PPP Mode	Precision (cm) Latitude	Longitude	Height
Dual Frequency	Code & Carrier (1)	Static	1	1	2
		Kinematic	5	4	10
Single Frequency	Code Only (2)	Static	10	10	100
		Kinematic	50	50	150

Notes (1): Quoted PPP code and carrier performance is after convergence.
(2): Quoted PPP code-only performance is for surveying grade receiver.

Table 3: CSRS-PPP Accuracy.

How can I submit data to CSRS-PPP?

Interface and Input

First, GPS observation data must be converted to the RINEX observation format (ftp://igscb.jpl.nasa.gov/pub/data/format/rinex212.txt) for submission to CSRS-PPP. Either single or multiple RINEX observation files containing up to seven days of tracking can be submitted. In the case of multiple RINEX observation files, they are submitted as a single zip file. In either case, the overall size of the uploaded file must be less than 300MB. Additional information on the various compression formats accepted by CSRS-PPP can be found in the CSRS-PPP online documentation.

Two mechanisms are available for data submission: the online web interface and a command line Perl cgi script. The script interface was developed to simplify automation of regular submissions such as daily processing of an RTK base station or analysis requiring PPP processing of a large number of RINEX observation files. Although the input and output content is the same for either mechanism, access to the output URL links differs slightly depending on the submission mode. While URL links are included in the email sent as a response to submissions made using the web interface, they are returned as direct output to the calling script in the case of the Perl cgi and can be accessed with an application such as wget.

The web interface is available at http://www.geod.nrcan.gc.ca/products-produits/ppp_e.php while the Perl cgi script is distributed upon request. Although the automation script was originally developed in Perl, it can be re-written in other cgi languages as long as they support the HTTP protocol and provide the required input to CSRS-PPP. Before using either access method, users will require a valid account for GSD online products. The account is free and can be obtained online at http://www.geod.nrcan.gc.ca/licence_e.php.

CSRS-PPP was designed to be simple to use and therefore requires minimum input. Users must specify the name of the RINEX observation file to process, the reference frame (NAD83(CSRS) or ITRF), and the processing mode (static or kinematic). The user's return e-mail address, as stored in our client database is appended by default, but can be modified. Finally, if coordinate estimates are required in NAD83(CSRS) the user is asked to select the epoch (observed epoch, 1997.0, 2002.0 or user specified).

Additional Input

In addition to the user input fields listed above, information on the antenna used to collect the data and initial coordinates are extracted from the RINEX file header during processing. Initial coordinates are not mandatory. They can, however, be useful since they are used to compute all output position differences (graphical time series of coordinate differences in pdf file or numerical values in pos file). For example, when evaluating CSRS-PPP performance for a GPS receiver and antenna at a survey marker with known coordinates, providing those coordinates in the RINEX header will facilitate the interpretation of the results. If no approximate coordinates are present in the header, differences will be calculated with respect to a position estimated from the first valid pseudo-range contained in the user dataset to initialize the PPP processing. The approximate coordinates in the RINEX header will also occasionally be replaced by the initial pseudo-range position estimate if they differ by more than 100m, to eliminate any gross user input errors. A comment near the bottom of the first page of the pdf report indicates if the RINEX header approximate position or a pseudo-range solution was used to initialize the solution.

The antenna information in the RINEX header, although not mandatory, is essential to reduce the computed position of the antenna phase centre to the survey marker. Two elements must be included in the header to ensure proper reduction of the phase centre position: the vertical height of the antenna above the marker ("ANTENNA: DELTA H/E/N" header record, note that horizontal offsets of that record are not used by CSRS-PPP), and the antenna model ("ANT # / TYPE" header record). The antenna model, which must conform to the International GNSS Service (IGS) naming convention (see ftp://igscb.jpl.nasa.gov/pub/station/general/rcvr_ant.tab) is used to extract the antenna phase centre position from the CSRS-PPP antenna database. It is also used to obtain the azimuthal corrections specific to that antenna (see http://www.ngs.noaa.gov/ANTCAL/images/summary.html). Figure 1 shows the various points used to reference antenna measurements and naming conventions used by CSRS-PPP. It should be noted that the Antenna Reference Point (ARP) used by CSRS-PPP corresponds to the lowest point of the antenna, the point that would normally touch the top of the tribrach or force centering plate when the antenna is attached. This point may differ from the manufacturer indicated reference point on some antenna. The bottom point is used in CSRS-PPP since it follows the convention used by the IGS to report antenna phase centre positions.

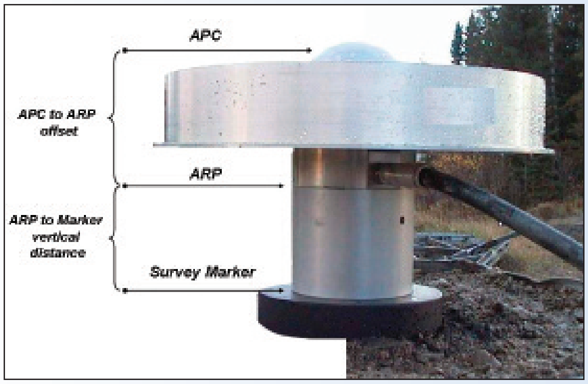

Figure 1: The Antenna Phase Centre (APC) to the Antenna Reference Point (ARP) is provided by CSRS-PPP based on antenna model listed on the "ANTENNA: DELTA H/E/N" RINEX header record while the ARP to the Survey Marker vertical distance is provided by the user on the "ANT # / TYPE" RINEX header record. The ARP is usually the bottom of the antenna mount .

NAD83(CSRS) Reference Epoch

CSRS-PPP estimated positions correspond to the epoch of the GPS data used in the processing, the current epoch. This is true for either the ITRF or NAD83(CSRS) reference frame. Because Canadian provinces and territories adopted versions of NAD83(CSRS) referring to either epoch 1997.0 or epoch 2002.0, CSRS-PPP estimated NAD83(CSRS) coordinates may not always be in agreement with published coordinates. In order to facilitate integration of CSRS-PPP estimated positions, a velocity model has recently been added to CSRS-PPP to transform current epoch NAD83(CSRS) coordinates to 1997.0 and 2002.0 epochs. Additional information on the velocity grid can be found here http://webapp.csrs.nrcan.gc.ca/field/nad83_epochs/PPP_Epoch_Transformation_e.pdf.

It should be noted that the velocity grid only captures the changes due to real displacement of the Earth's crust. In Canada, this is primarily a vertical displacement due to glacial isostatic adjustment and can reach 1cm per year in some regions of northern Ontario, particularly around Hudson's Bay. The model does not account for any differences between realizations of NAD83(CSRS) stemming from adjustment variations. Therefore, although CSRS-PPP will provide epoch specific coordinates such as 1997.0 or 2002.0, it will not provide adjustment versions specific coordinates such as v2.0 or v3.0. The velocity model used in CSRS-PPP is intended primarily to remove vertical displacement which can quickly accumulate when comparing coordinates at different epochs of NAD83 realizations.

How can I tell if my PPP solution is correct?

Output

In addition to the expected position estimates and associated standard deviations, CSRS-PPP provides several output reports. Four reports are output for each RINEX file processed — the pos file containing the estimated positions, the sum file with the analysis summary, the res file listing all observation residuals and the graphical pdf report for a quick assessment of the solution.

Because CSRS-PPP is an automated service, user validation of the CSRS-PPP output is important and should be seen as the final step in the PPP process. Although the standard deviations provide good indicators of the solution quality, other aspects also need consideration to ensure the solution is acceptable.

Why is proper convergence important?

In addition to validating some of the important details of the CSRS-PPP solution outputs such as those listed in

Table 4: Validation of CSRS-PPP solution

Validation	Function	Source
Standard deviation of position	To ensure it meets the required accuracy	Page 1 of PDF report or table 3.3 of sum file
Antenna information	To ensure antenna model properly entered in RINEX header and phase-centre offsets available in CSRS-PPP database	Page 1 of PDF report
Satellite coverage	To trouble-shoot weak PPP solutions	Page 2 of PDF report
Tropospheric delay	Could provide signs of possible processing problems	Page 5 of PDF report
Carrier-phase ambiguities	To ensure lock was maintained	Page 5 of PDF report
Start and stop time of processed data	To ensure that all collected data has been processed	Page 1 of PDF report or table 3.2 of sum file
Convergence	To ensure optimal accuracy was achieved	Page 4 of PDF report

Table 4: Validation of CSRS-PPP solution.

Table 4, it is critical to verify that convergence has been reached. Centimetre level PPP positioning accuracy is only possible if the full precision of the carrier-phase observations is achieved. A pseudo-range PPP solution without carrier-phase observations will provide decimetre level position accuracy at best. In order to fully realize the carrier-phase observation precision, ambiguities must be estimated which normally takes between 60 to 90 minutes of data, the so called convergence period. Initial convergence takes this long since all carrier-phase ambiguities along with several other parameters, such as tropospheric delay, must be estimated simultaneously from approximate initialization values. This requires sufficient change in geometry to properly separate the various effects.

Because carrier-phase ambiguities are initialized with pseudo-range observations, PPP estimated positions will vary in precision from decimetres, equivalent to a pseudo-range only solution, to one cm or better. How long you should observe is therefore a function of the accuracy to which your project requires, the environment in which you work (satellite coverage) and the precision of your GPS equipment. A few datasets collected over periods of a few hours using your GPS equipment in a typical field environment over survey markers with known and accurate coordinates should help you answer that question.

Although achieving initial convergence is critical, it is also important to ensure that the estimated carrier-phase ambiguities are stable. Normally each carrier-phase ambiguity remains fairly constant over a full arc — the period between the times a satellite rises and sets. Each new arc for

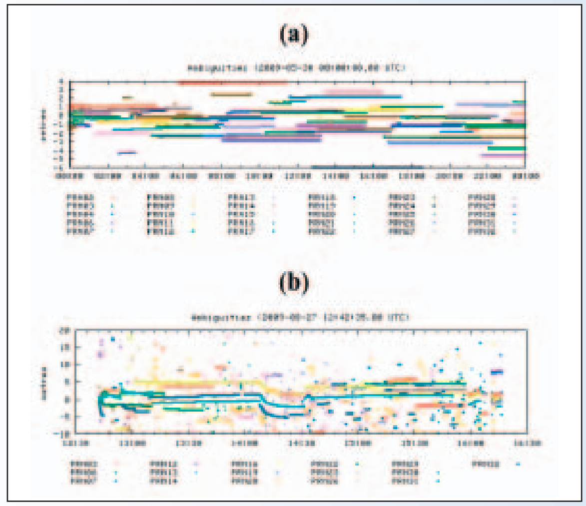

Figure 2: A strong PPP solution should have stable ambiguities such as those displayed in (a) while frequent ambiguity resets, such as those of (b), greatly weakens the PPP solution.

any given satellite will require the estimation of a new carrier-phase ambiguity. Following the initial convergence period, new ambiguities can usually be properly estimated with only a few epochs of observations once all other parameters, including other satellite ambiguities, are resolved. A strong PPP solution should have stable ambiguities such as those displayed in Figure 2(a) while frequent ambiguity resets, such as those of Figure 2(b), greatly weaken the PPP solution. In this particular instance, the multitude of ambiguity resets were caused by the receiver losing lock on the L2 signal resulting in PPP being unable to form the ionosphere-free L1-L2 observation combination, which is essential for a precise solution.

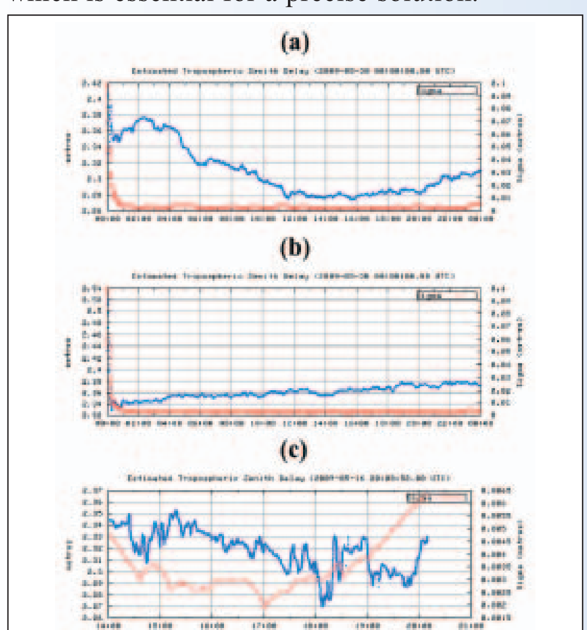

Figure 3: Smoothly varying tropospheric delay of (a) and (b) are indicative of normal PPP estimation while the rapid and large variations in (c) are indicative of possible estimation problems such as uncorrected cycle slips.

Tropospheric delay, normally a nuisance parameter which must be accounted for in PPP processing, can in fact be very useful in assessing the quality of a solution. Tropospheric delay normally varies slowly in time, in the order of 10cm or less per hour. Therefore, any large and rapid variations show signs of a weak or incorrect PPP solution, unless a severe weather front moved rapidly into the survey region. Figures 3(a) and (b) are examples of expected tropospheric behaviour while the large and rapid variations depicted on Figure 3(c) were caused by undetected cycle slips. While the CSRS-PPP observation filters are tuned to eliminate all possible cycle slips, users should keep in mind that higher sampling rates, practically to a rate of about once per second, is preferred as it usually translates to improved cycle slip detection. This becomes more important during periods of ionospheric irregularities such as those associated with solar cycle maxima.

As an alternate means of validation, it is also possible to use some of the other online GPS positioning services offered by various agencies such as OPUS from the U.S. National Geodetic Survey (NGS). Whenever comparing coordinates from various sources, however, it is important to ensure that the reference frames and epochs of the compared coordinates are compatible.

Conclusion

The establishment of integrated survey control can be time consuming and costly. CSRS-PPP, NRCan's online positioning service, can help on both counts by facilitating access to NAD83(CSRS) coordinates with cm accuracy by submitting a single RINEX observation file. This capability has proven to be an effective way of reducing both the field logistics and processing complexities normally associated with differential carrier-phase techniques. For further information contact the authors by email at: pierre.tetreault@nrcan.gc.ca and pierre.sauve@nrcan.gc.ca.

Further Reading

"Precise Point Positioning Using IGS Orbit and Clock Products" by J. Kouba and P. Héroux in GPS Solutions, Vol. 5, No. 2, 2001, pp. 12–28.

"CSRS-PPP: An Internet Service for GPS User Access to the Canadian Spatial Reference Frame" by Pierre Tétreault, Jan Kouba, Pierre Héroux and Patrick Legree in Geomatica, Vol 59, No. 1, 2005, pp 17-28.