CSRS-PPP Version 3: Tutorial

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Motivation

The Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service was launched in 2003. It allows users of global navigation satellite systems (GNSS) to collect data in the field and upload this data to Natural Resources Canada (NRCan) servers. Within minutes, users receive an estimate of their position, or trajectory, along with quality estimates and a report for visual quality control.

CSRS-PPP uses precise satellite orbit, clock and bias corrections derived from a global network of receivers to determine accurate user positions. This strategy differs from other online positioning services based on differential positioning, i.e., using nearby base stations. CSRS-PPP enables up to millimeter-level accuracies for long observation sessions (24+ hours) in static mode, but an accuracy of a few centimeters can typically be achieved in an hour.

On 16 August 2018, a new version of the software supporting CSRS-PPP was launched. This software replacement was the first step in the CSRS-PPP modernization plan which includes PPP with ambiguity resolution (PPP-AR), faster convergence using external ionospheric information and processing of multi-GNSS observations. CSRS-PPP version 3, described in this document, implements PPP-AR.

In the past decade, PPP-AR algorithms have matured from experimental to operational solutions. Ambiguity resolution offers significant benefits for users by transforming ambiguous carrier-

phase observations into precise ranges. As a result, centimeter-level accuracies can often be obtained more rapidly. Furthermore, due to satellite geometry, resolving carrier-phase ambiguities results in improved estimates for the longitude (east) component.

This document guides the user through the new features of this software. It explains basic principles of ambiguity resolution and presents, through examples, what CSRS-PPP version 3 users should expect in terms of performance.

New Features

The main novelty of CSRS-PPP version 3 is the implementation of PPP-AR algorithms. Apart from this substantial change, other modifications could impact results with respect to CSRS-PPP version 2, such as:

- New products available: to perform ambiguity resolution, satellite phase biases consistent with satellite orbit and clock corrections must be available. For this purpose, NRCan now generates its own PPP-AR products:
  - DCU: ultra-rapid products
  - DCR: rapid products
  - DCF: final products, using combined orbits from the International GNSS Service (IGS) and an in-house clock combination

- Changes to outputs: the tropospheric zenith delay and receiver clock estimates were moved from the '.pos' file to the '.tro' and '.clk' files, respectively. The '.tro' and '.clk' files are IGS standards.

- In static mode *only*, the reported standard deviations for the receiver clock and tropospheric zenith delay estimates are scaled to obtain more realistic values. The applied scale factor is the same as for position standard deviations, which were already being scaled in CSRS-PPP version 2. As a consequence of this scaling, it is possible that reported sigma values in static mode are larger than in kinematic mode.

- The use of observable-specific satellite biases: to minimize errors that could impact ambiguity resolution, CSRS-PPP version 3 only accepts signals for which it has explicit code-bias corrections. For this reason, it is strongly suggested that users submit GNSS data in RINEX 3 format.

- Improved day boundary crossing: when observations spanned more than one GPS day, users of CSRS-PPP experienced a discontinuity at midnight due to clock alignment issues between days. These discontinuities have been reduced in CSRS-PPP version 3, although they could still occur (see section Day Boundaries).

- Modified cycle-slip detection thresholds: tighter thresholds are now used to improve detection of half-cycle-slips. As a natural consequence of this change, more cycle slips could be reported in CSRS-PPP version 3.

Ambiguity Resolution

CSRS-PPP version 3 introduces ambiguity resolution capabilities for data collected on or after 1-January 2018. This section first describes, at a high level, the basic principles of this feature. Then, examples are provided to guide users through a better understanding of their results.

Principles

When applying a specific set of corrections to carrier-phase observations and estimating phase-bias parameters, the ambiguity parameters set up in the PPP filter have an integer nature. This means that, using sophisticated algorithms, it is possible to identify these integers and constrain their values. Adding this additional information to the solution typically improves accuracy and reduces reported uncertainties.

In CSRS-PPP version 3, ambiguity resolution is performed on the backward run. This means that epochs are first processed in a chronological order to ensure that all information is available prior to resolving ambiguities. Then, starting with the last epoch successfully processed, ambiguity resolution is attempted. This process is repeated for all epochs in reverse order (from last to first epoch). It should be noted that this sequential algorithm is not theoretically optimal. While attempting ambiguity resolution on all ambiguities simultaneously should yield better results, it is subject to significant computational load constraints for datasets with several hundred ambiguity parameters. The sequential algorithm implemented is fast and often provides results identical to the optimal algorithm.

Once the backward run is completed, a final back-substitution is performed to obtain the final values for all parameters: tropospheric zenith delays, receiver clocks and positions (in kinematic mode).

What to Expect

While successfully resolving ambiguities is beneficial for the solution, incorrectly resolving some or several ambiguities can have disastrous consequences. For this reason, several mechanisms were implemented to reduce the risks of incorrectly resolving ambiguities:

- Ambiguities associated with less than 5 minutes of data are not resolved.

- No attempt is made at resolving GLONASS ambiguities.

- Partial ambiguity resolution is performed, meaning that not all ambiguities need to be resolved.

- However, ambiguity validation is only successful when a minimum of 4 satellites have resolved ambiguities simultaneously.

- The validity of the stochastic model is taken into consideration in the ambiguity validation process. This check implies that if ambiguity residuals (i.e., the difference between the float and integer estimates) are much larger than their precision, the process is aborted.

- Due to the inconsistency of equipment delays associated with code observations, ambiguity resolution is deactivated for cross-correlation receivers:
  - AOA ICS-4000Z
  - ROGUE SNR-12
  - ROGUE SNR-12 RM
  - ROGUE SNR-8
  - ROGUE SNR-800
  - ROGUE SNR-8000
  - ROGUE SNR-8100
  - ROGUE SNR-8C
  - SPP GEOTRACER100
  - TOPCON GP-DX1
  - TOPCON TT4000SSI
  - TRIMBLE 4000SSE
  - TRIMBLE 4000SSI
  - TRIMBLE 4000SST

  CSRS-PPP uses the "REC # / TYPE / VERS" field in the RINEX header to determine the receiver type.

While ambiguity resolution can sometimes be successful with as little as 15 minutes of data, longer observation sessions are usually associated with more ambiguities being resolved.

The '.sum' file contains a tag called "IAR", reporting the percentage of fixed ambiguities. This value is computed by considering carrier-phase observations with fixed ambiguities rather than arcs with fixed ambiguities. For example, let us consider a simplistic example with two satellite arcs:
- Satellite G01 is observed for 90 epochs and has its ambiguities resolved
- Satellite G02 is observed for 10 epochs but ambiguities could not be resolved

In this case, the ambiguity success rate is 90% since it represents the percentage of carrier-phase observations with fixed ambiguities.

The percentage of fixed ambiguities is also reported on the front page of the PDF report, as shown in Figure 1.

Figure 1: PDF report showing the percentage of fixed ambiguities

Ambiguity Status Plot

The PDF report of CSRS-PPP version 3 now includes an ambiguity status plot. This plot indicates, for all satellites at each epoch, the status of the estimated parameters:

- **Olive**: float ambiguity. This ambiguity could not be resolved to an integer, either because the software could not do it with enough confidence or because ambiguity resolution is not activated for a system (e.g., GLONASS).

- **Cyan**: datum ambiguity. CSRS-PPP version 3 implements the ambiguity datum concept of Collins et al (2010). To estimate the additional receiver phase-bias parameters set up in the PPP filter, the filter must fix _a priori_ a certain number of ambiguities. These selected ambiguities are called _datum ambiguities_.

- **Green**: fixed ambiguity. Integer ambiguities that were validated by the software's algorithms are indicated in green.

- **Red**: new ambiguity/arc. When an ambiguity parameter is first observed, it is plotted in red.

Let us look at a few examples of the ambiguity status plot to learn how to interpret them.

Example 1

This example shows data from a 24-hour static session collected by high-quality geodetic instruments. As expected, most GPS ambiguities have been resolved (98.52%) and are indicated in green. Since ambiguity resolution is not enabled for GLONASS, all ambiguities are float and plotted in olive. If your ambiguity status plot looks like this, it is quite likely that the PPP-AR solution is of good quality.
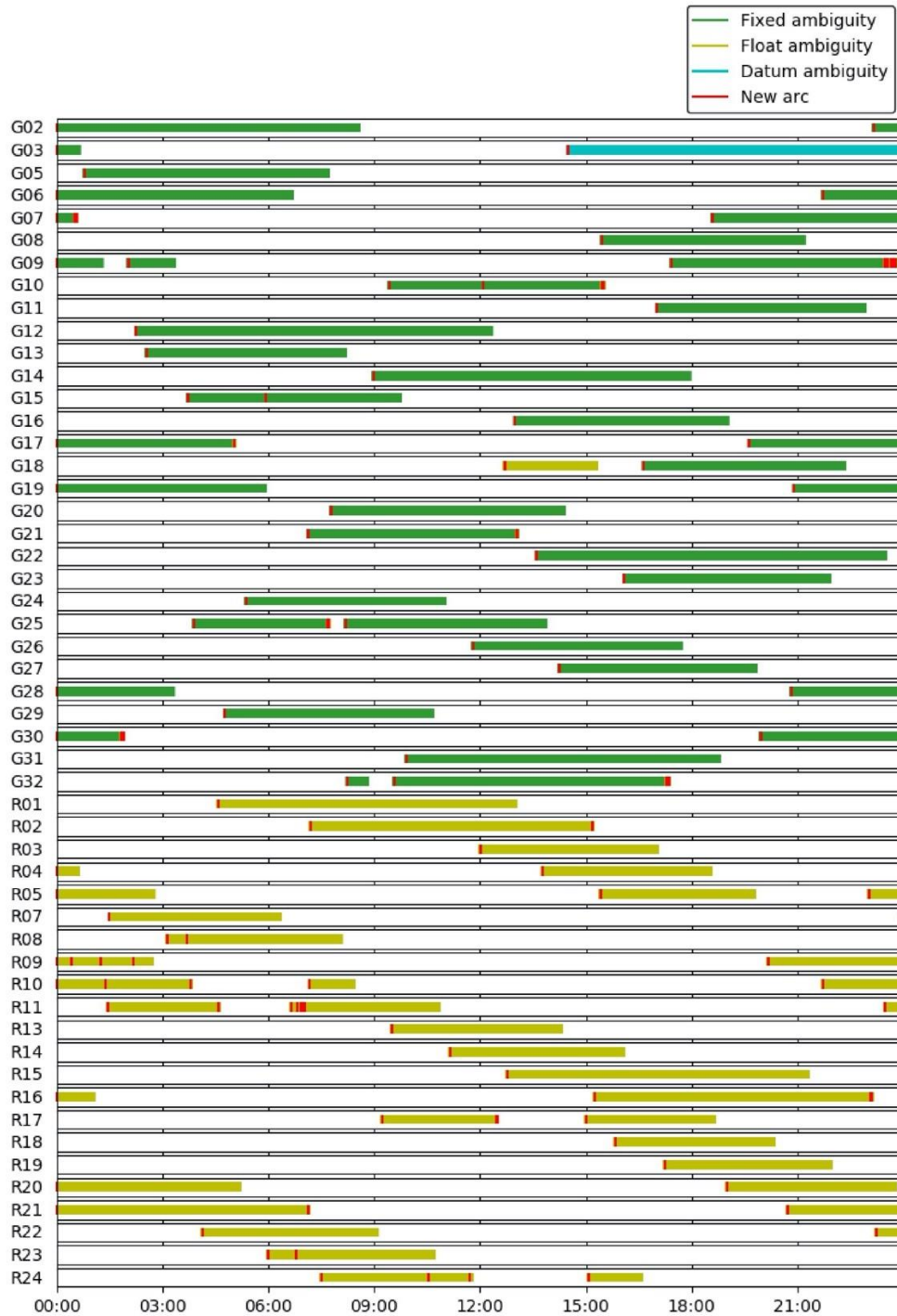

Figure 2: Ambiguity status plot for 24-hour static dataset

Example 2

This example shows a short observation session lasting 15 minutes in which ambiguity resolution was successful. Since CSRS-PPP version 3 performs partial ambiguity resolution, not all ambiguities were resolved. The PDF report indicates that 68.54% of ambiguities were resolved. Even though this number may seem low, there is no reason to believe that the solution experienced any issues. Satellite G06 was not observed for the whole session, resulting in too short an observation period to confidently resolve its ambiguities. While G31 was observed for the whole session, this satellite was tracked at a low elevation angle and its ambiguities could, again, not be resolved confidently.
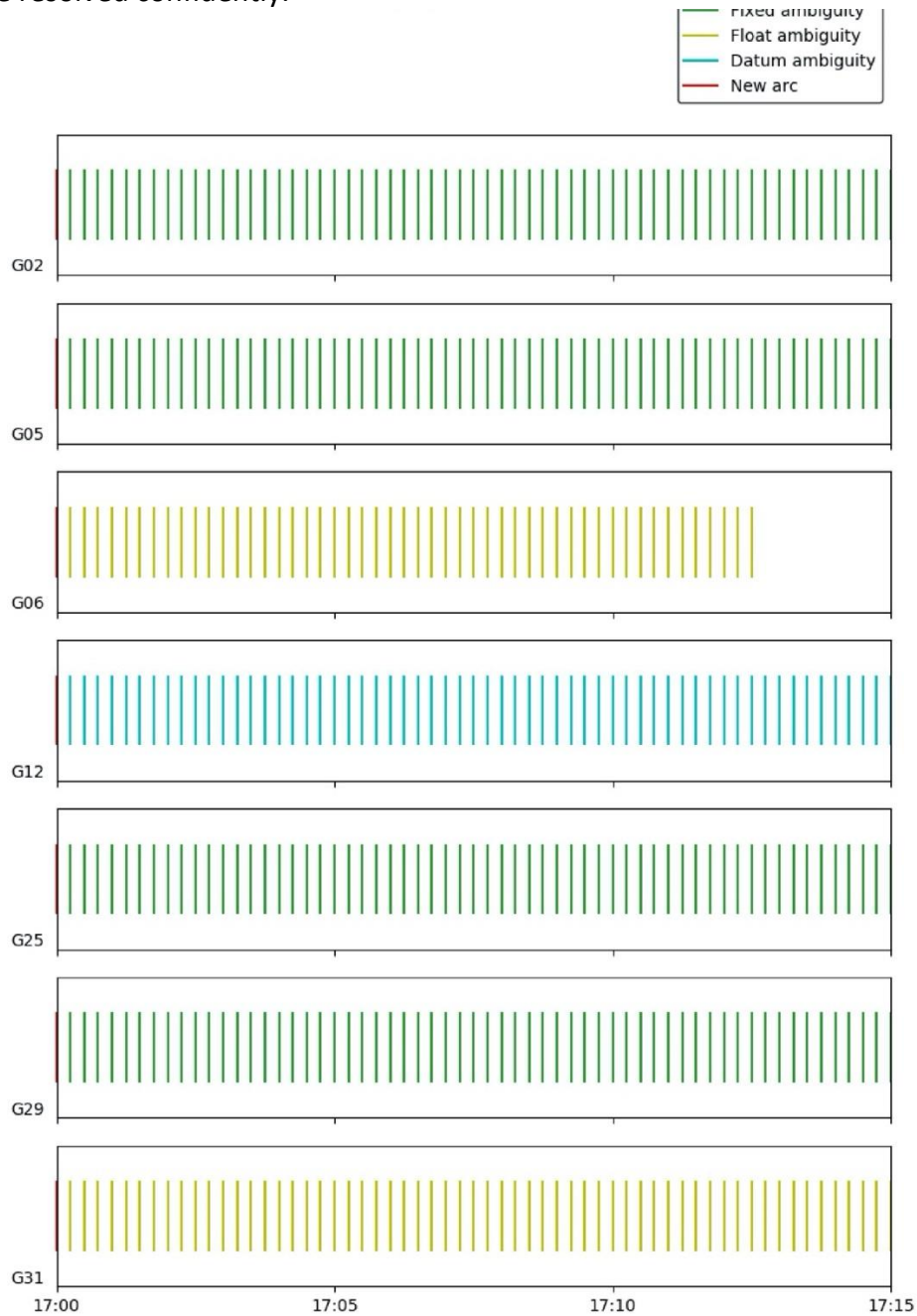

Figure 3: Ambiguity status plot for a shorter observation session

Example 3

This example shows a 30-minute observation session in which no ambiguities were resolved. The reason should be obvious when looking at the ambiguity status plot: many cycle slips (indicated in red) contaminated the data which resulted in very short arcs. In this case, the software could not confidently resolve ambiguities and provided a float solution.
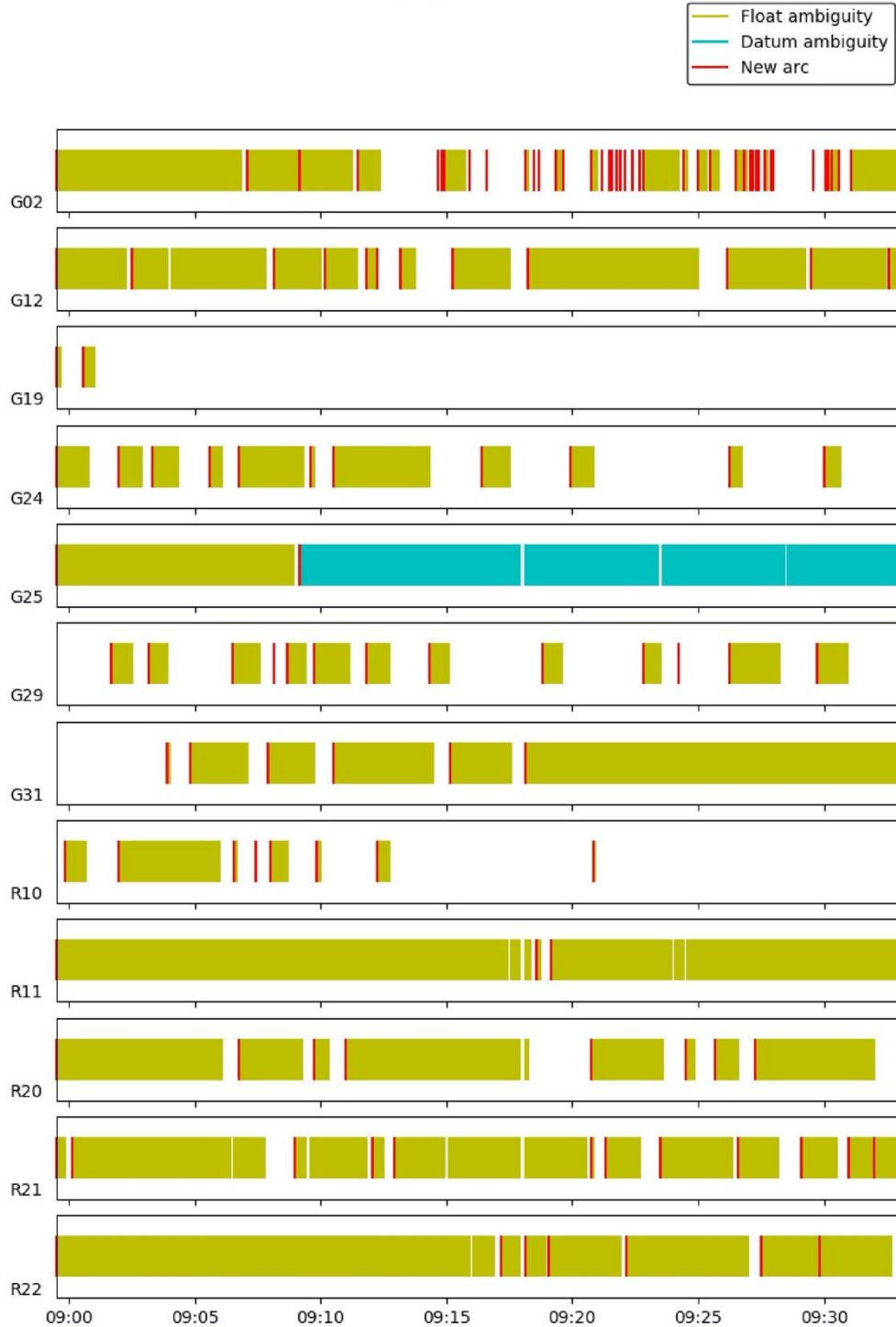

Figure 4: Ambiguity status plot for a session with several cycle slips

Day Boundaries

A benefit of the "integer" satellite clock corrections used in PPP-AR solutions is that they can be precisely aligned from day to day. As a consequence, position jumps occurring when observations span two GPS days can be minimized. As an example, data from station ALGO located in Canada was processed from 2019-08-14 23:00:00 to 2019-08-15 01:00:00 using CSRS-PPP version 2 (Figure 5) and version 3 (Figure 6).
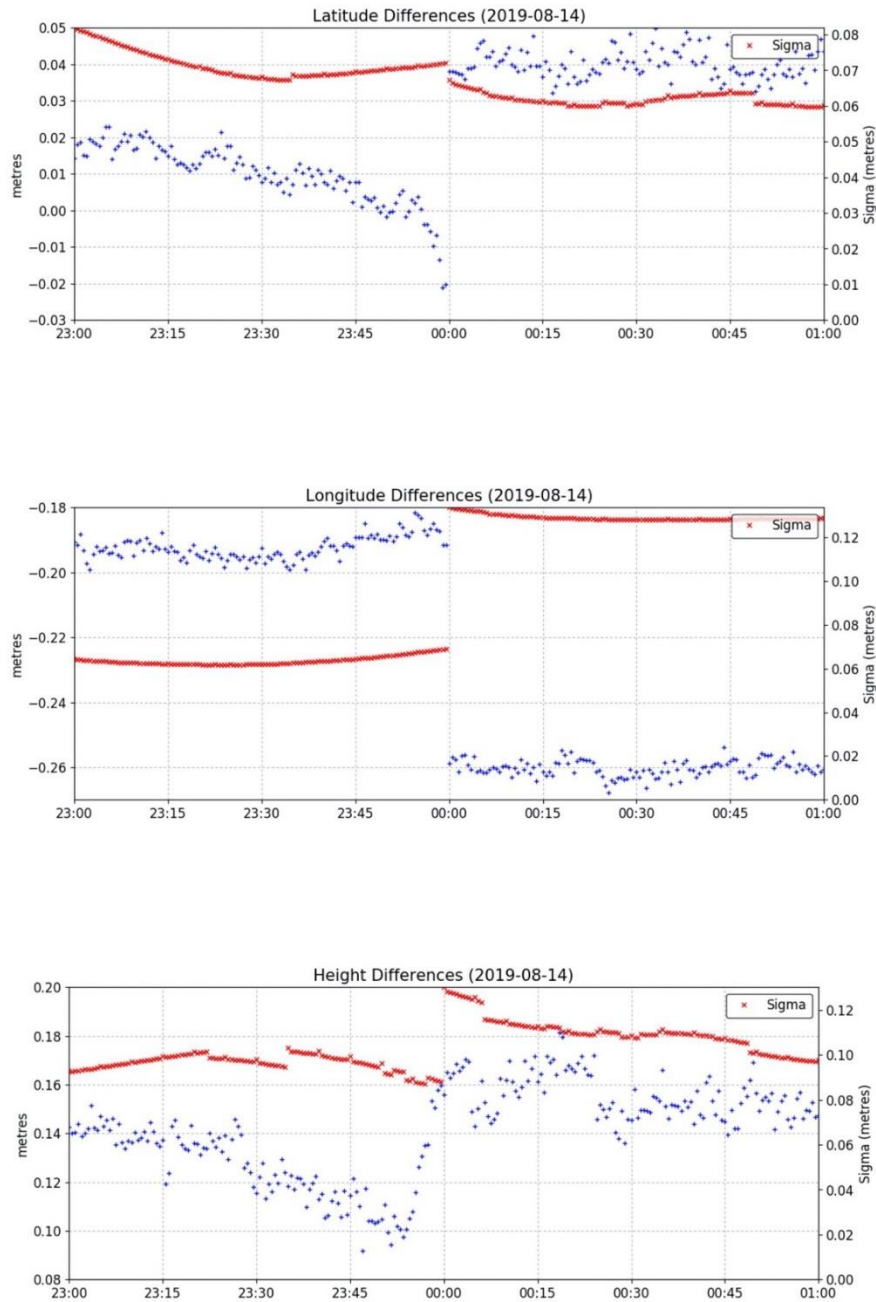

Figure 5: CSRS-PPP version 2 position estimates during a day boundary crossing

With CSRS-PPP version 2, position jumps of approximately 6 cm in latitude and 7 cm in longitude can be noticed, even though the receiver maintained continuous lock on all satellites. This is a consequence of IGS clock products not being aligned between two consecutive days. With CSRS-PPP version 3, no jump can be seen in latitude and the discontinuity in longitude has been reduced to 1.5 cm. The latter is caused by satellite orbit interpolation errors associated with the use of two orbit (SP3) files. Still, the benefits of PPP-AR (and the products used) are obvious.
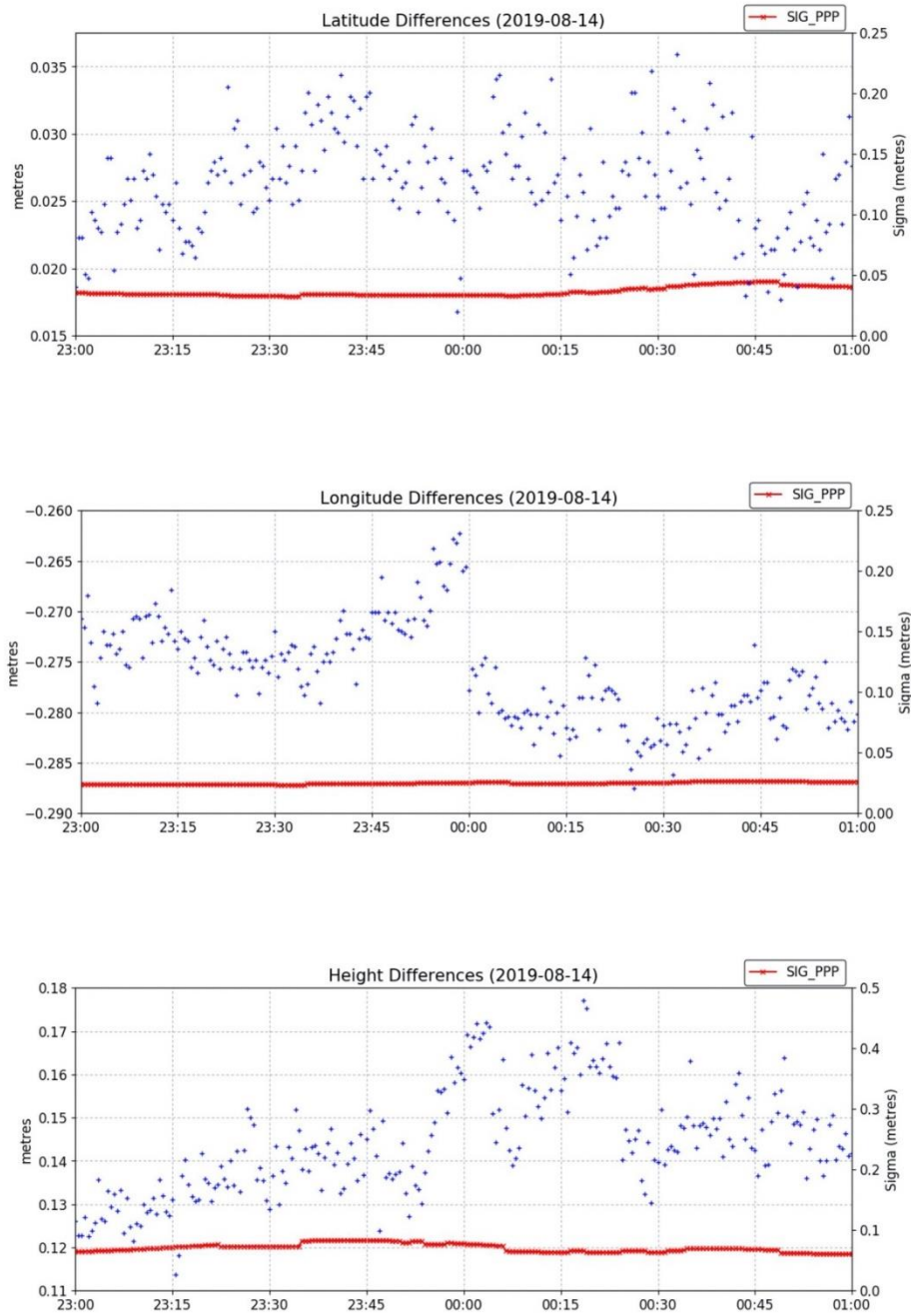

Figure 6: CSRS-PPP version 3 position estimates during a day boundary crossing

References

Collins P, Bisnath S, Lahaye F, Héroux P (2010) Undifferenced GPS ambiguity resolution using the decoupled clock model and ambiguity datum fixing. Navigation 57(2):123–135