NovAtel's Waypoint PPP-AR Performance Analysis

Abstract

Version 8.90 of Waypoint Post-Processing products introduces support for PPP-AR (Precise Point Positioning with Ambiguity Resolution), which significantly improves PPP convergence. PPP-AR is based on the same technology that powers NovAtel's TerraStar-C PRO service. PPP-AR requires NovAtel GNSS data and a Waypoint Near-Real Time (NRT) subscription in order to access precise orbit and clock data with satellite code and phase biases from TerraStar.

The objective of this testing is to compare static and kinematic PPP performance of Waypoint's existing float PPP filter and the PPP-AR filter. For the static evaluation, 70 static surveys were processed using occupation lengths ranging between 15 minutes and 24 hours. The PPP-AR filter saw a reduced 3D RMS error at all occupation lengths, and particularly faster horizontal convergence. In the kinematic test a two-hour vehicle survey was collected in light urban, mixed GNSS signal conditions where over 76 km of distance was travelled. In the kinematic tests, tightly coupled PPP-AR results improved by a factor of four relative to results with the PPP Tightly Coupled (TC) float filter.

Introduction

TerraStar NRT corrections have multiple advantages over common correction services that offer precise satellite clock and orbit data. All users with a Waypoint NRT license may benefit from the following features:

- Fast availability (15 minute latency)
- High reliability and redundancy
- Multi-constellation (GPS, GLONASS, BeiDou, Galileo, QZSS)
- High rate corrections (good for low noise kinematic trajectories)

Users with a NovAtel GNSS receiver also benefit from

- Satellite code and phase biases (required for faster PPP convergence)

For an in-depth comparison of NRT vs common corrections refer to our performance analysis published January 2019.

Test Description

Seventy permanently operating reference stations from the Continuously Operating Reference Station (CORS) network were used to test static PPP accuracy using Waypoint's float PPP filter and the PPP-AR filter. The stations used in this test were chosen based on their receiver type (NovAtel receivers), data quality, and completeness over a 24 hour period (November 7, 2019). The National Geodetic Survey (NGS) provides published positions and station velocities, which were used to compute the processing errors. A map of the stations used is shown in Figure 1, which were well distributed throughout the continental USA, Alaska and Mexico.

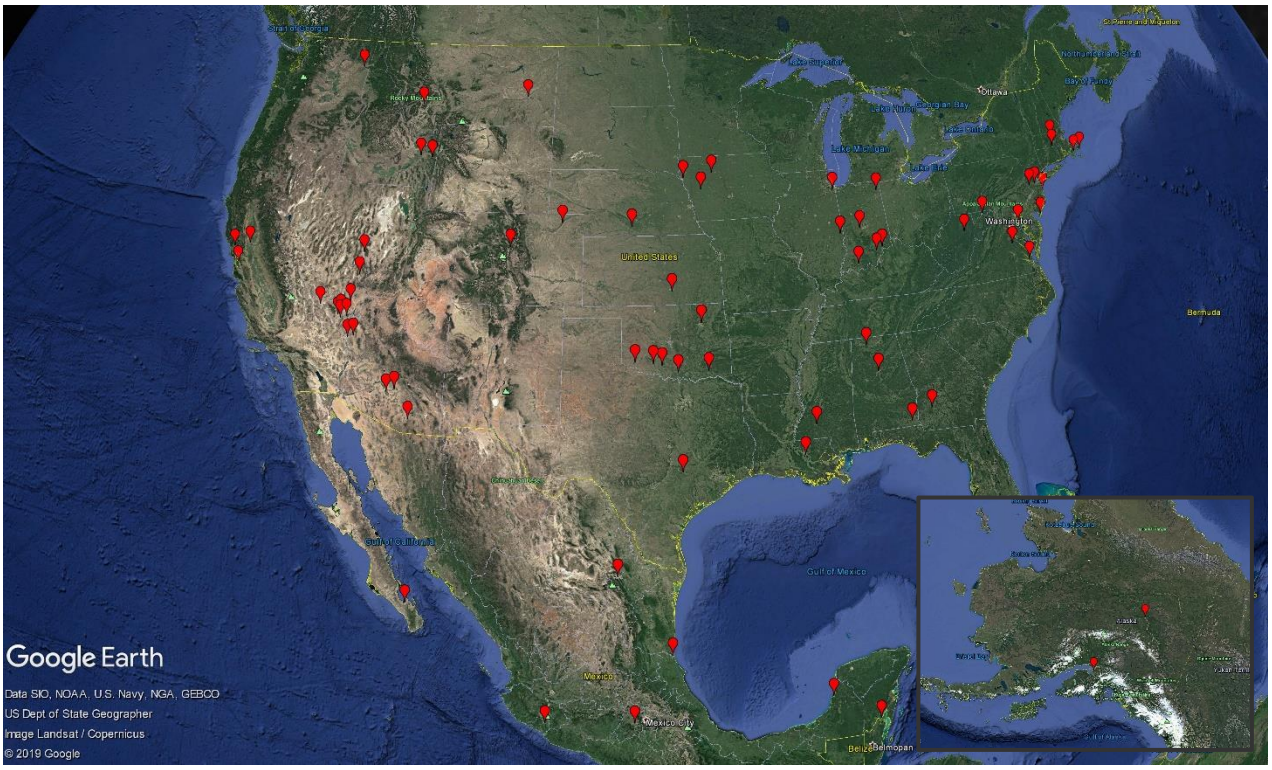

Figure 1: Permanently Operating Reference Stations used in Static PPP Testing. Map data: Google Earth; SIO, NOAA, U.S. Navy, NGA, GEBCO. US Dept of State Geographer, IBCAO, Landsat / Copernicus, Google 2019.

Each 24 hour dataset was processed using occupation times from 15 minutes to 24 hours. Multiple equally spaced processing runs were done on the shorter occupation lengths to help ensure many samples with a high variability in satellite geometry were represented in the results. In total, over 2,500 processing runs were used to generate results for each PPP filter. All data was processed using TerraStar NRT precise products. Processing and analysis were automated with the Waypoint Software Developers Kit (SDK).

Results

Figure 2 illustrates the 3D RMS errors of each filter as a function of occupation length.
Table 1 tabulates the horizontal and vertical components of the RMS error for each filter.

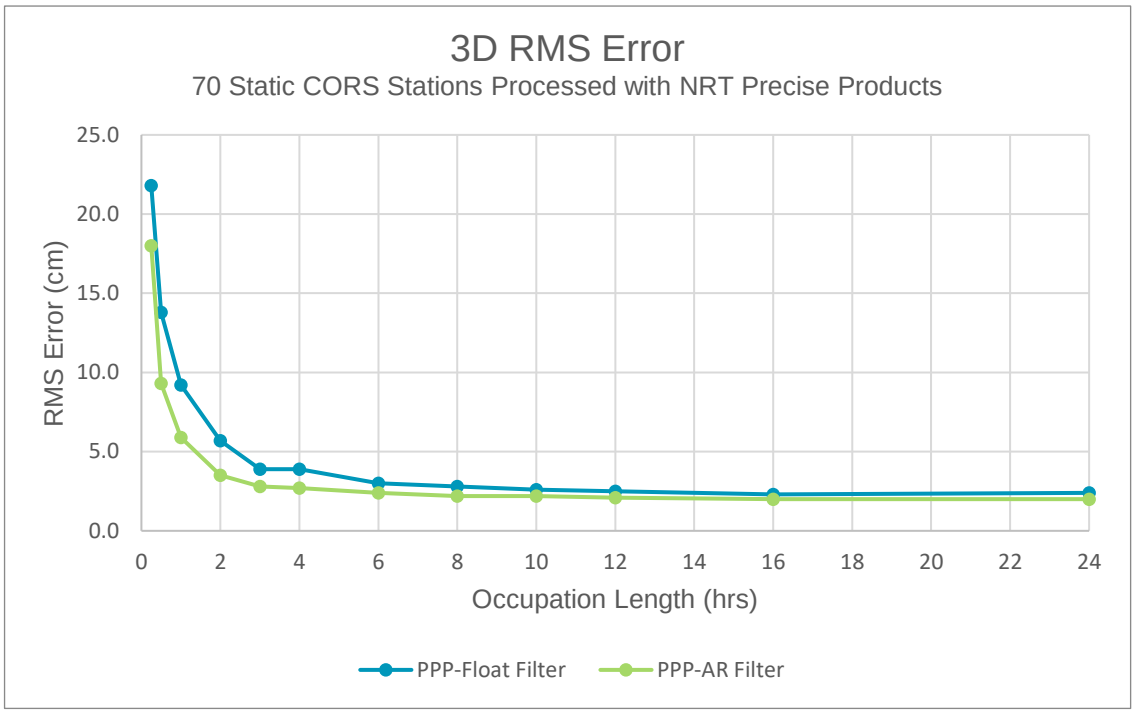

Figure 2: 3D RMS error using 70 CORS stations in the existing PPP-Float filter and the new PPP-AR filter, both using TerraStar NRT precise products.

Table 1: Horizontal, vertical and 3D RMS error using 70 CORS stations (static) in the existing PPP-Float filter and the new PPP-AR filter, both using TerraStar NRT precise products.

Occupation Length (hrs)	**PPP-Float Filter** Using NRT Precise Products			**PPP-AR Filter** Using NRT Precise Products		
	Horizontal RMSE (cm)	Vertical RMSE (cm)	3D RMSE (cm)	Horizontal RMSE (cm)	Vertical RMSE (cm)	3D RMSE (cm)
0.25	17.5	13.0	21.8	9.8	15.1	18.0
0.5	11.1	8.2	13.8	5.0	7.9	9.3
1	6.6	6.3	9.2	2.9	5.1	5.9
2	3.9	4.1	5.7	1.4	3.2	3.5
3	2.9	2.6	3.9	1.3	2.5	2.8
4	2.8	2.7	3.9	1.1	2.4	2.7
6	1.9	2.4	3.0	1.0	2.2	2.4
8	1.8	2.1	2.8	0.9	2.1	2.2
10	1.5	2.1	2.6	0.9	2.0	2.2
12	1.4	2.0	2.5	0.8	1.9	2.1
16	1.2	1.9	2.3	0.8	1.9	2.0
24	1.2	2.0	2.4	0.7	1.9	2.0

Figure 3 illustrates the improvement in accuracy provided by PPP-AR vs PPP-Float at various occupation times. The results show that most of the benefit of the PPP-AR filter is delivered in occupation times of less than six hours, during which PPP-AR reduced the 3D error by up to 4.5 cm, and the horizontal error by up to 7.7 cm.

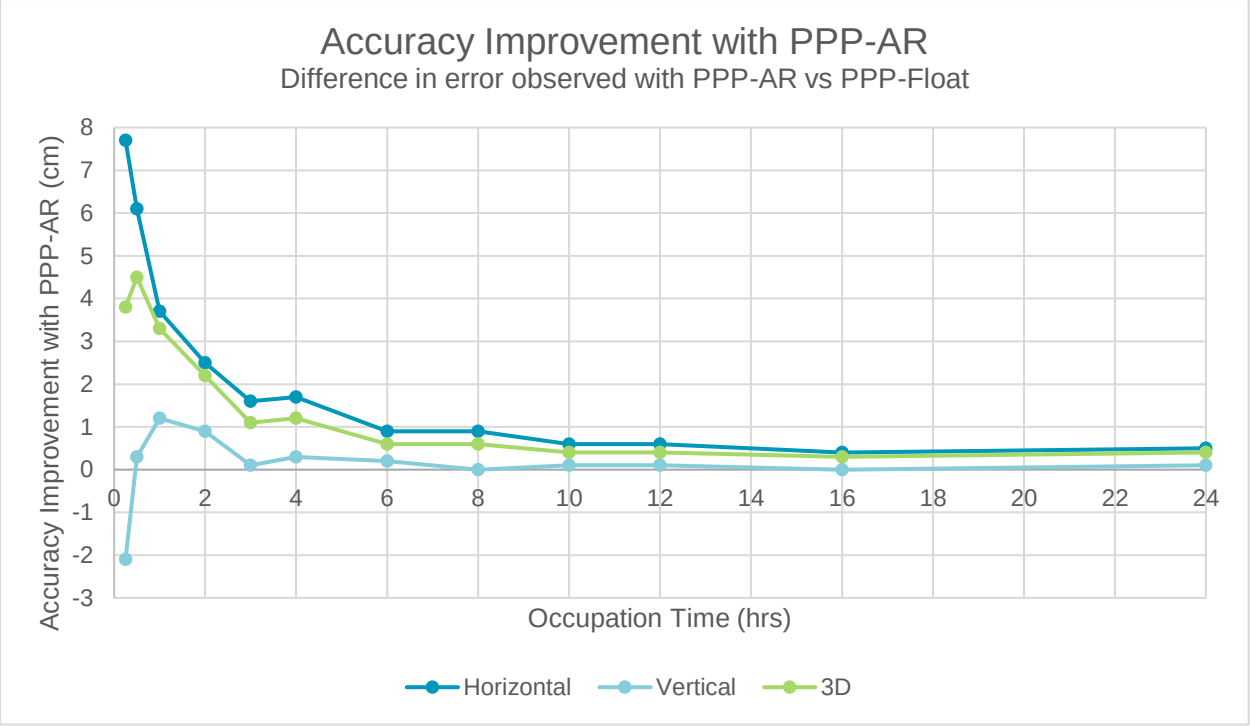

Figure 3: Horizontal, vertical and 3D accuracy improvement observed with PPP-AR filter compared to existing PPP-Float filter.

Kinematic Test

On January 10, 2020 a two hour survey was collected covering over 76 km of a light urban test route. Residential neighbourhoods and roadways with occasional overpasses made up most of the survey, which avoided completely open areas for extended periods but also avoided the downtown core. A map of the test route is shown in Figure 4.

GNSS+INS data was collected with a NovAtel SPAN PwrPak7-E1, which contains an Epson G320 MEMS IMU. The total number of satellites used in the solution and the satellite lock/cycle slip plot of the GPS L1 signals is given in Figure 5.

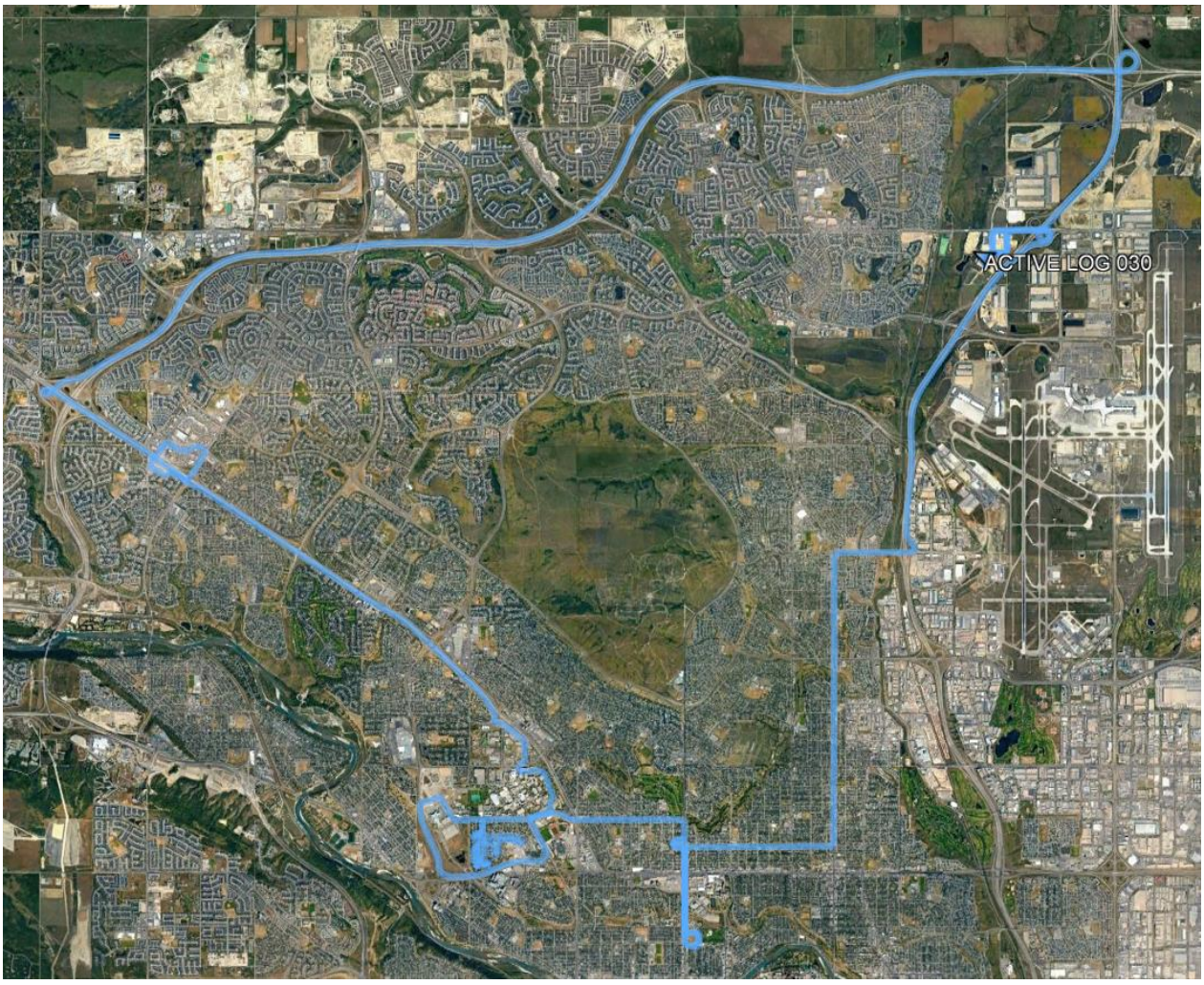

Figure 4: Light Urban Test Route for Kinematic PPP-AR test. Map data: Google Earth; SIO, NOAA, U.S. Navy, NGA, GEBCO. US Dept of State Geographer, IBCAO, Landsat / Copernicus, Google 2019.

The maximum distance to a base station operating on the roof of the NovAtel Hexagon Calgary Campus was just over 14 km, which was used to generate a differential tightly coupled reference solution. An average of 8.6 GPS, 6.2 Galileo, 5.5 GLONASS, and 1.5 BeiDou satellites were used in the post-processed trajectory. The reference trajectory achieved fixed integer status on 96.2% of the survey, and over 95% of the dual fixed integer solutions had a 3D forward/reverse processing difference under 5 cm.

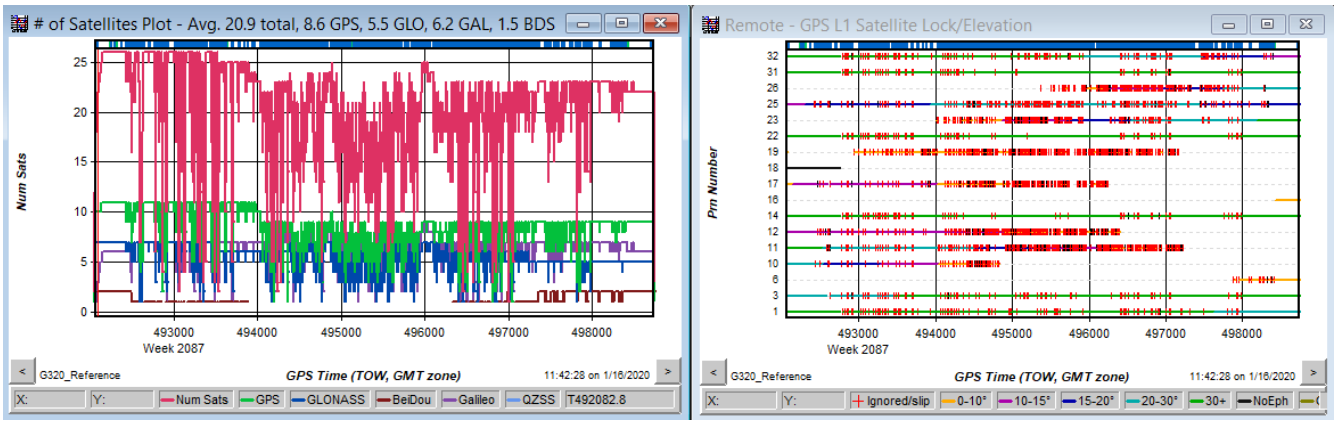

Figure 5: Number of Satellite Plot, GPS L1 Satellite Lock/Cycle Slip Plot of Kinematic Test

A Tightly Coupled PPP solution was processed using the Waypoint PPP Float filter and the PPP-AR filter. Both filters used near real-time precise satellite clock and orbit corrections from TerraStar, which Waypoint users can access with an NRT license. The satellite code and phase bias data contained in the NRT precise products is used by the PPP-AR filter to improve convergence/re-convergence in mixed GNSS signal conditions. Figure 6 and Figure 7 show the position difference between the PPP TC solutions and the reference trajectory at the same scale, and the results are summarized in Table 2.

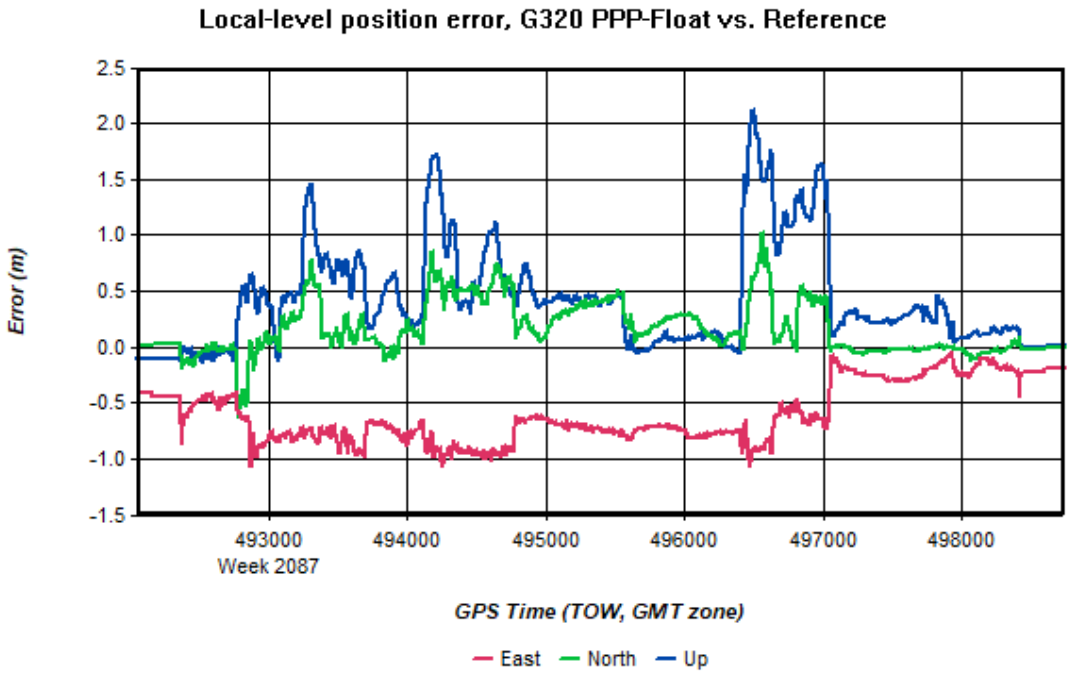

Figure 6: Position Error of TC PPP-Float Solution in Kinematic Test

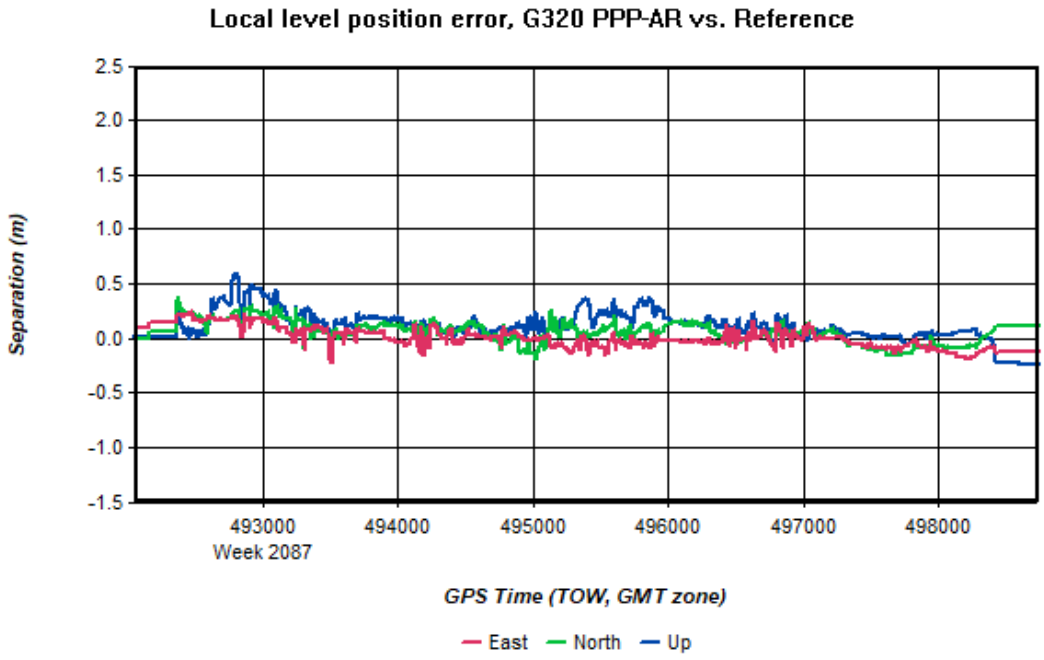

Figure 7: Position Error of TC PPP-AR Solution in Kinematic Test

Table 2: Horizontal, vertical and 3D RMS error of PPP TC Solutions

TC PPP-Float Filter Using NRT Precise Products			**TC PPP-AR Filter** Using NRT Precise Products		
Horizontal RMS (cm)	Vertical RMS (cm)	3D RMS (cm)	Horizontal RMS (cm)	Vertical RMS (cm)	3D RMS (cm)
71.3	62.9	95.0	14.9	17.8	23.2

Conclusions

The static and kinematic test results show significant improvement in PPP convergence using the PPP-AR filter. Users with NovAtel GNSS receivers may now benefit from both the low latency of the TerraStar NRT precise orbit and clock data (~15 minutes) and improved convergence on shorter surveys and when surveying in mixed GNSS signal conditions. This new filter will help maximize the post processing value delivered to NovAtel and Waypoint customers.

Acknowledgments

NovAtel would also like to thank the National Oceanic and Atmospheric Administration (NOAA) and the National Geodetic Survey (NGS) for the publicly available base station data used.