An Evaluation of C-NAV, NovAtel and NRCan Real-Time PPP Services

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Abstract

High-precision GNSS positioning is essential for ellipsoidally referenced surveying (ERS). Until recently, Real-Time (RTK) or Post-Processed Kinematic (PPK) solutions provided the most reliable results. The primary limitation of these systems is the need to be within range of reference stations. Precise point positioning (PPP) methods do not require local reference stations, which has made these services very attractive hydrographic operation, especially in remote areas like the Arctic. There have been two major drawbacks to the use of PPP; higher uncertainty (~30 cm) and longer solution convergence times (10s of minutes). Recent improvements in hardware and software have made PPP systems more viable for ERS.

The Canadian Hydrographic Service evaluated three real-time PPP services; C-NAV (provided by C&C technologies), TerraStar (provided by NovAtel) and HP-GPS*C (provided by NRCan). These systems were compared to each other as well as to short range (few KMs) RTK and PPK solutions. This paper describes the evaluation methodology, which includes both static and dynamic tests, and summarizes the results.

The CNAV PPP solution provided consistent results throughout, with an average uncertainty of ~13 cm (2σ). The NovAtel TerraStar PPP solution performed equally as well with an average uncertainty of ~13 cm (2σ). The NovAtel NRCan HPC PPP solution was not as consistent. While underway it was comparable to the other two PPP solutions, as seen in the Salt Spring Island survey results. However, while tied up at the dock, the solution tended to wander, with uncertainties reaching to 30 cm (2σ).

Introduction

Ellipsoidally Referenced Surveying (ERS) is a method used in hydrography to measure depths relative to the ellipsoid and translate those depths to a geoid or tidal datum. The vertical uncertainty necessary for this method can only be achieved through the use of high-precision Global Navigation Satellite Systems (GNSS). High-precision differential GNSS techniques used in Real-time Kinematic (RTK) and Post-processed Kinematic (PPK) are the most common methods used to meet the stringent vertical ERS requirements. High-precision Precise Point Positioning (PPP) methods (both real-time and post-processed) are becoming more widely accepted as their vertical uncertainty is reduced with more satellite availabilty (including GLONASS) and new hardware and processing methods.

The Canadian Hydrographic Service (CHS), in partnership with Natural Resources Canada (NRCan), Canadian Coast Guard and NovAtel Inc, with funding from the Canadian Safety and Security Program, conducted tests of the NRCan real-time PPP service in the Canadian Arctic and Pacific Coast. An overview of the project and results from the Artic can be found in Lévesque et al (2014). The following discussion looks at the testing methodology and results from the CHS Pacific region.

Approximately 40 days of testing took place over four months in late 2013 and early 2014, at the Institute of Ocean Science (IOS) and in the area of Patricia Bay on Vancouver Island (see Figure 1). GNSS equipment was mounted on the CHS launch Shoal Seeker and multiple positioning methods used for comparison with the NRCan service. Tests took place while the vessel was at dockside and underway to evaluate uncertainty. This paper describes the various systems used in the evaluation; the method used for the assessment, and presents the results.

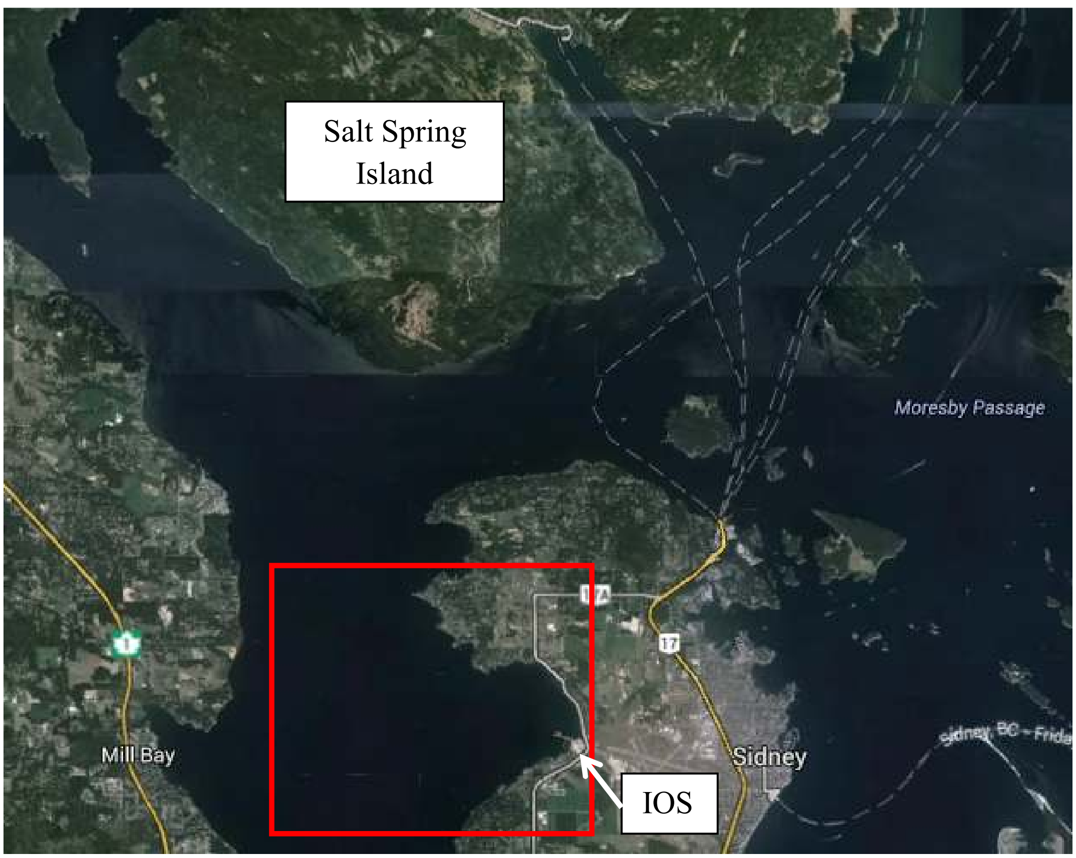

Figure 1: Test Area Near the Institue of Ocean Science

Background

Four high-precision GNSS methods associated with ERS are PPK, RTK, post-processed PPP and real-time PPP. PPK and RTK use differential techniques where uncertainties associated with satellite clocks; satellite positions (from ephemeris) and atmospheric effects are mitigated by comparing GNSS measurements observed by a roving receiver to those observed by a stationary receiver, at a known station (base station) or network of stations. This method can typically provide positions with uncertainties at the cm level. Uncertainties increase with the distance between the base stations and roving receivers.

PPP techniques use precise satellite ephemeris and clocks to mitigate uncertainties associated with the satellites, and algorithms and signal processing to deal uncertainties associated with the atmosphere. The precise ephemeris and clocks are estimated by global control stations and provided to the user in real-time (using predictions) or within few days for use in post-processing. PPP does not require local base stations.

Real-time services (both for differential and PPP techniques) require communication between a service provider and the user, which can be through cellular modem, radio or satellite link. Post-processed techniques do not require this link and have the advantage of processing the GNSS measurements in both forward and backward (time wise) directions.

One significant difference between the PPP and differential methods is the time-to-convergence. PPK and RTK tend to converge to an acceptable solution within a few seconds or minutes. PPP solutions tend to take 10s of minutes to converge. It is essential to ensure that the solution has converged (or has enough time to converge) prior to starting ERS operations. And, should the PPP system reset during a survey (e.g. going under a bridge), then it must be given time to reacquire before proceeding.

This evaluation looked at the vertical uncertainty associated with real-time PPP services, using short baseline PPK techniques, as well as water level gauge measurements, to provide the "true" solution.

The real-time PPP systems included:

- C-NAV 3050 receiver using the Net 2 service (Inmarsat) provided by C&C technologies
- NovAtel Flex 6 receiver using the TerraStar service (Inmarsat) provided by NovAtel
- NovAtel Flex 6 receiver using the NRCan HP-GPS*C service through the internet. The internet link was established through a cellular modem or an Inmarsat terminal.

Comparison measurements came from:

- Water level observations from the Patricia Bay permanent gauge
- PPK positions determined through RTKLib (freeware)
- PPK positions determined through POSPac.

All receivers used in these tests were capable of receiving both GPS and GLONASS. The C-NAV and NovAtel TerraStar services provided corrector information for both GPS and

GLONASS, and satellites measurement from both systems were used in the PPP derived solutions. GPS and GLONASS measurements were also used in the PPK solutions. Only GPS correctors were provided with the NRCan real-time PPP service.

Methodology

The roving GNSS systems were mounted on the CHS launch “Shoal Seeker” (see Figure 2). A Trimble NetR8 was established as a base station outside the CHS offices at the IOS. Much of the testing data was collected with the Shoal Seek at the dock, acting as a tide gauge (see Figure 3). The baseline distance between the reference base station and the Shoal Seeker while at dock was ~250m.

Figure 2: Shoal Seeker

The systems on the Shoal Seeker included a C-NAV 3050, NovAtel Flex 6 and a Trimble Net R8. The C-NAV system included an L-Band antenna capable of receiving GNSS signals as well as correctors from the Inmarsat communication satellite. The NovAtel flex 6 also included an L-Band antenna for use with the TerraStar service. The same NovAtel receiver/antenna configuration were used for the NRCan HP-GPS*C evaluation; however, the correctors were obtained through a link to the internet (cellular modem or Inmarsat terminal). Because the same equipment was used to test the TerraStar service and the NRCan HP-GPS*C service, no head-to-head comparison was possible and each test used either the TerraStar or NRCan service. A Trimble Net R8 receiver was also established on the vessel as a rover and it shared the NovAtel antenna through a signal splitter. A schematic of the Shoal Seeker configuration can be seen in Figure 4. Raw GNSS observations as well as real-time position solutions were recorded from all systems. The raw observations were used with the Trimble base station to derive the PPK solutions. The Shoal Seeker was equipped with a POS MV system (version 5). Unlike the other systems, data from the POS MV was not continually recorded throughout the testing period.

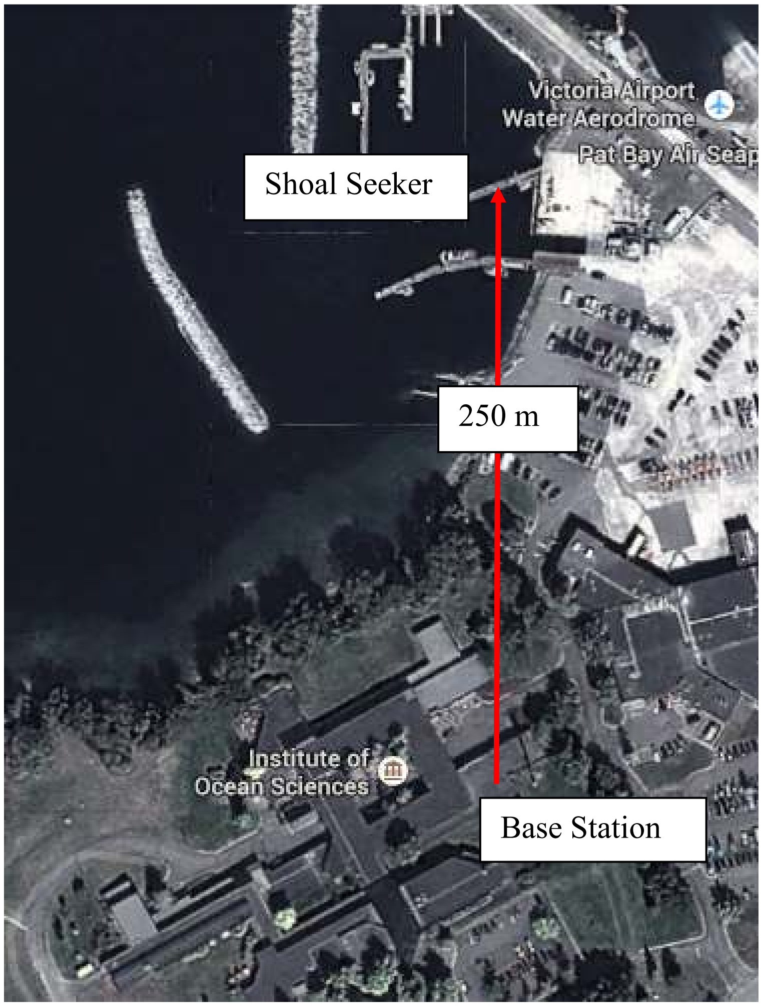

Figure 3: Base Station and Shoal Seeker docking location at the IOS.

For data collected at the dock in Patricia Bay, the tide observation was used as the reference; therefore, the uncertainty included short period wave action, which was usually minimal. While underway in Patricia Bay, the POS MV PPK solution or the Trimble PPK solution was used as the reference. For the Salt Spring Island survey, the POS MV PPK solution was used as the reference.

Statistics includes the difference mean, standard deviation (1σ) and 2σ ordered statistic (OS). The OS is derived by sorting the absolute values of the differences and selecting the difference that is greater than 95% of the entire set. The OS represents the 2σ uncertainty of one data set with respect to the data set it is being compared to. Therefore, it includes the uncertainties in both sets of observations. The data sets that have been determined to have the least uncertainty have been used as the reference.

There were approximately 35 days of tests over a 40 day span. Tests ran 24 hours a day, 7 days a week. The vast majority of testing took place with the Shoal Seeker tied to the dock, effectively acting as a tide gauge. Several short 2-hour trips in the area of Patricia Bay, and one 7 hour survey near Salt Spring Island were used to evaluate the systems in a more dynamic environment.

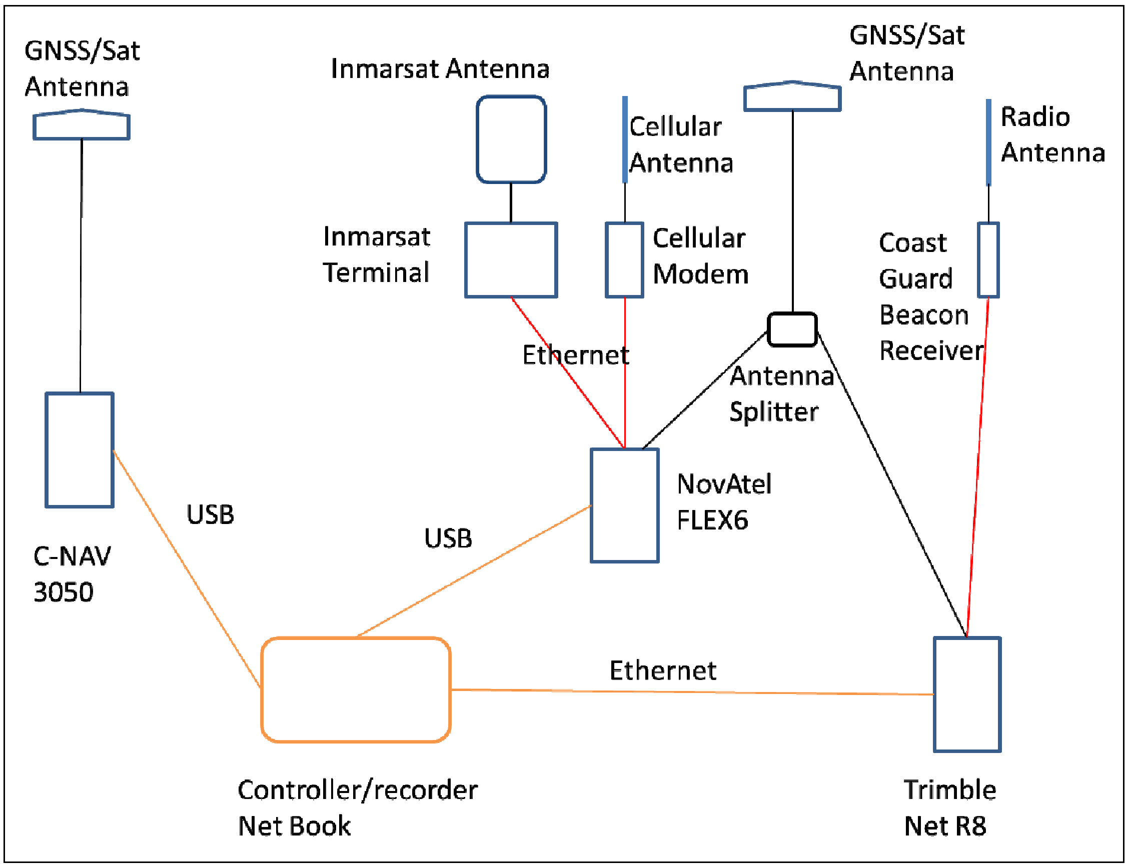

Figure 4: Shoal Seek GNSS Test Configuration

Results

This section is divided into three parts; the first looks at the height comparison (at dock and underway), the second looks at a horizontal comparison, and the third looks at the time it takes for the solutions to converge.

Vertical

The following sub-section includes the vertical evaluation results from four tests. The first two are from when the Shoal Seeker was at the dock and the second two from while the shoal seeker was underway. Each set of results contains two plots (ellipsoid heights and height differences) and one table with the difference statistics.

Figure 5 shows approximately 20 hours of observations with the Shoal Seeker at the dock. Plot displays time versus ellipsoid height (NAD83). Plots include the NovAtel real-time PPP (TerraStar) service, the NovAtel PPK results (from RTKLib), the CNAV real-time PPP, the POS PPK (from POSPac) and the tide. Figure 6 shows the difference between all of these systems and the tide, and Table 1 shows the associate statistics.

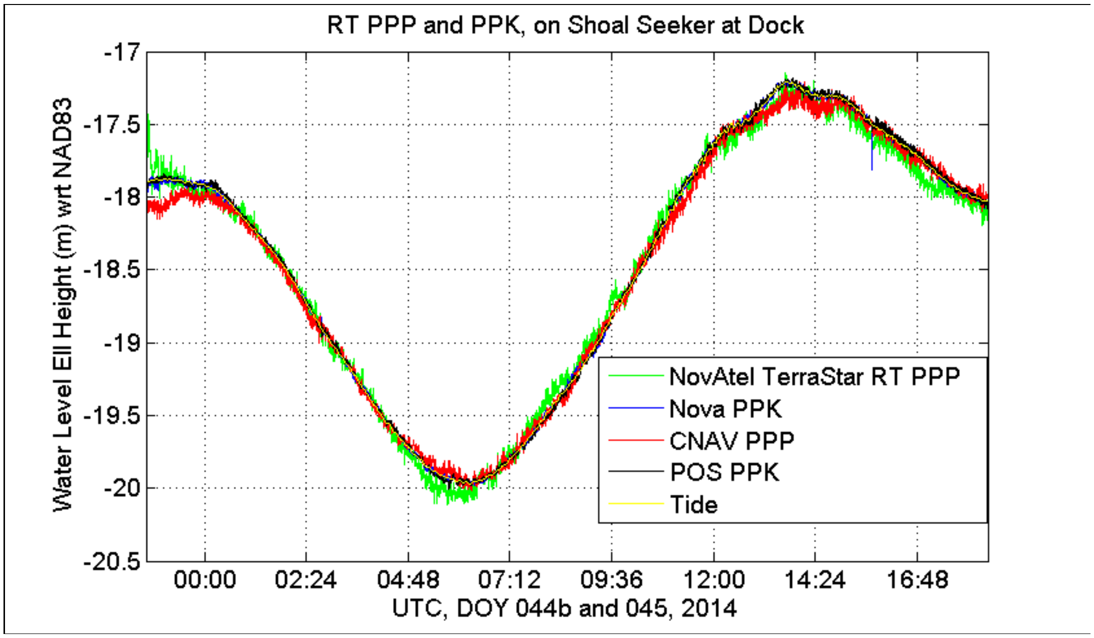

Figure 5: DOY 044b, Water Level Height, NovAtel PPP (TerraStar), Nova PPK, CNAV PPP, POS PPK and Tide

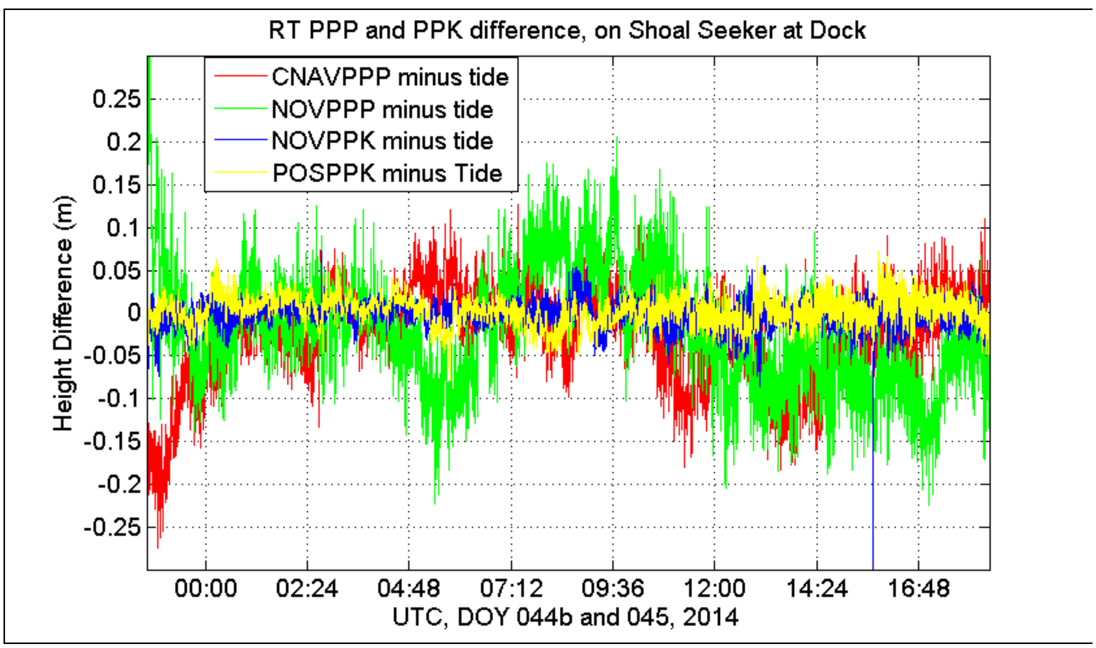

Figure 6: DOY 044b, Water Level Height Difference, NovAtel PPP (TerraStar), Nova PPK, CNAV PPP, POS PPK and Tide

Solutions	Mean (m)	1σ Stdev (m)	2σ OS (m)
Nova PPK minus Nova PPP	0.019	0.071	0.134
Nova PPK minus POS PPK	0.004	0.019	0.039
Nova PPK minus Tide	-0.001	0.014	0.029
Nova PPP minus Tide	-0.021	0.070	0.133
CNAV PPP minus Tide	-0.025	0.055	0.131
POS PPK minus Tide	0.000	0.018	0.035

Table 1: DOY 044b, Water Level Height Difference Statistics, NovAtel PPP (TerraStar), Nova PPK, CNAV PPP, POS PPK and Tide

The mean difference shows vertical offsets between the systems being compared, which are minimal, indicating the 2σ OS uncertainty is made-up mostly of noise and not systematic biases. The 2σ OS indicates the uncertainty associated with each system as compared to the reference. In this case, the NovAtel PPK and the POS PPK agree with each other to within 39 mm uncertainty at 95%. Both agree with the tide to 29 mm and 35 mm, respectively. The NovAtel PPP (TerraStar) agrees with the tide with 133 mm uncertainty and the CNAV agrees with the tide with 131 mm uncertainty. This indicates that both the NovAtel PPK (from RTKLib) and the POS PPK (from POSPac) are suitable references for the real-time PPP evaluation. And that the tide is a suitable reference to evaluate all systems while the Shoal Seeker is at the dock.

Figure 7, Figure 8 and Table 2 provide the results of approximately 24 hours of observations while the Shoal Seeker was at the dock. The NovAtel real-time PPP was using the NRCan HP-GPS*C service. The Trimble PPK results (from RTKLib) agreed with the tide to 27 mm, and the NovAtel real-time PPP results agreed with the tide to 233 mm. It is apparent from the plots that the real-time PPP solution occasionally drifted away from the tidal observations.

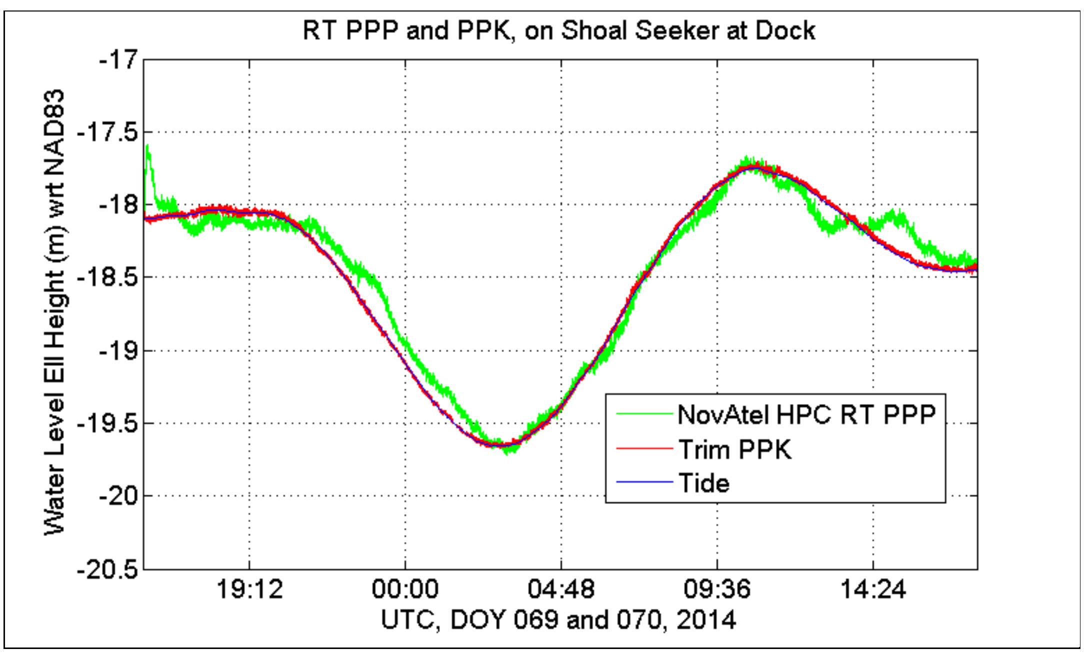

Figure 7: DOY 069, Water Level Height, NovAtel PPP (NRCan HP), Trim PPK and Tide

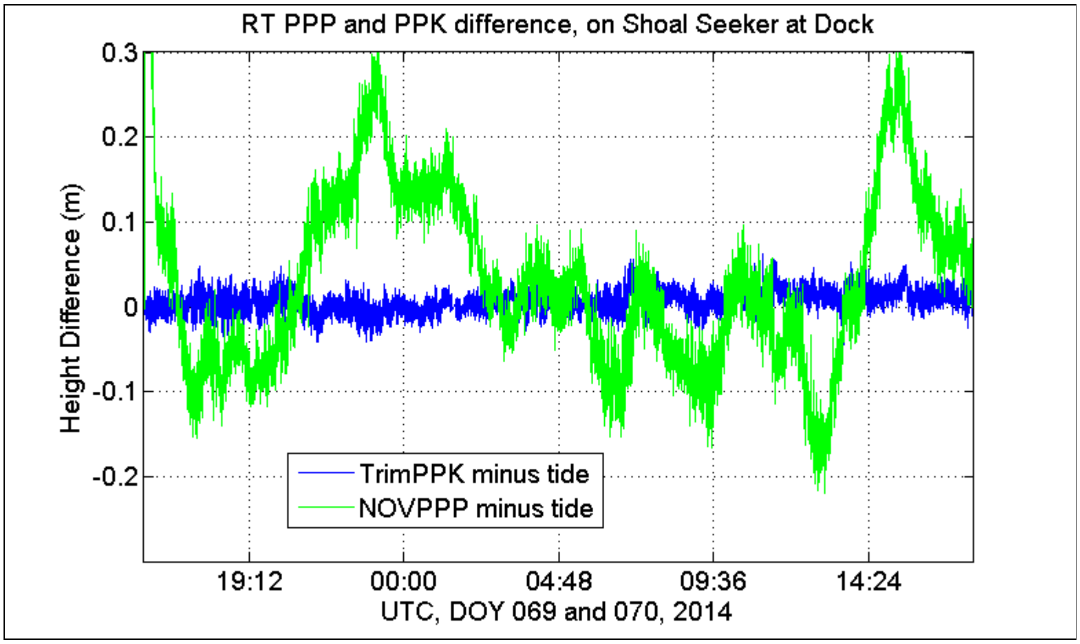

Figure 8: DOY 069, Water Level Height Difference, NovAtel PPP (NRCan HP-GPS*C), Trim PPK and Tide

Solutions	Mean (m)	1σ Stdev (m)	2σ OS
Trim PPK minus Nova PPP	-0.028	0.109	0.224
Trim PPK minus Tide	0.006	0.012	0.027
Nova PPP minus Tide	0.031	0.123	0.233

Table 2: DOY 069, Water Level Height Difference Statistics, NovAtel PPP (NRCan HP-GPS*C), Trim PPK and Tide

Figure 9, Figure 10 and Table 3 show the heights and height differences for approximately 40 minutes of measurements from the NovAtel real-time PPP (NRCan HP-GPS*C), NovAtel PPK (RTKLib), CNAV real-time PPP and tide, while the Shoal Seeker was underway in Patricia Bay. The vertical shifts seen in Figure 9 were due to changes in vessel speed. The slope and change in slope shown in Figure 9 were due to the change in ellipsoid/geoid separation.

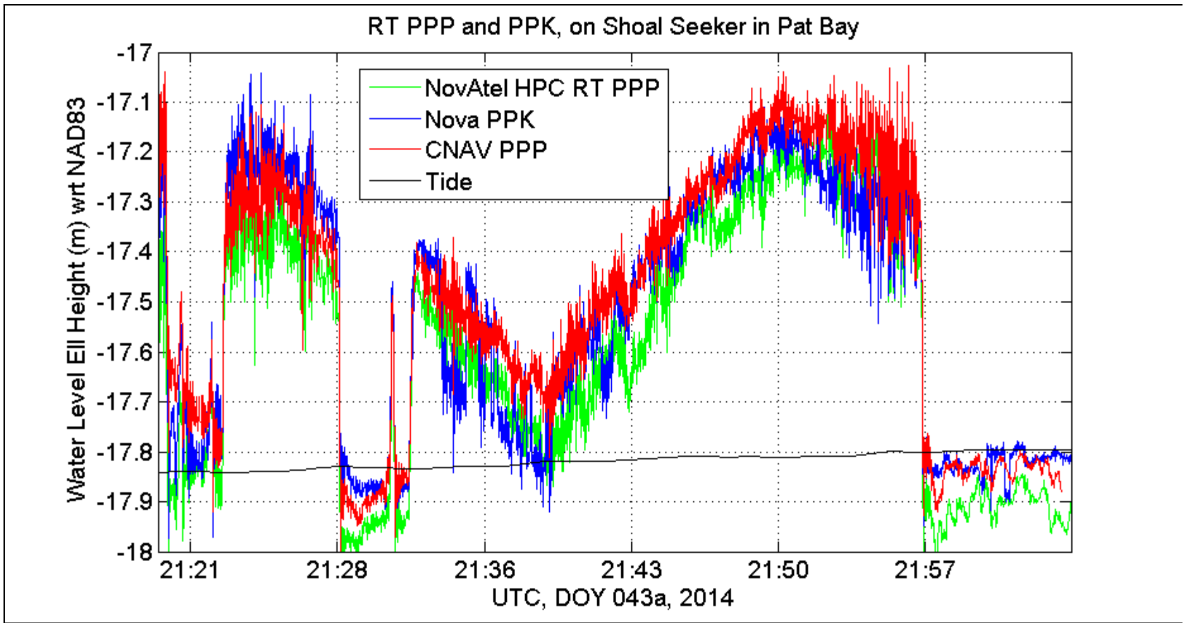

Figure 9: DOY 043A, Water Level Height, NovAtel PPP (HPC), Nova PPK, CNAV PPP and Tide

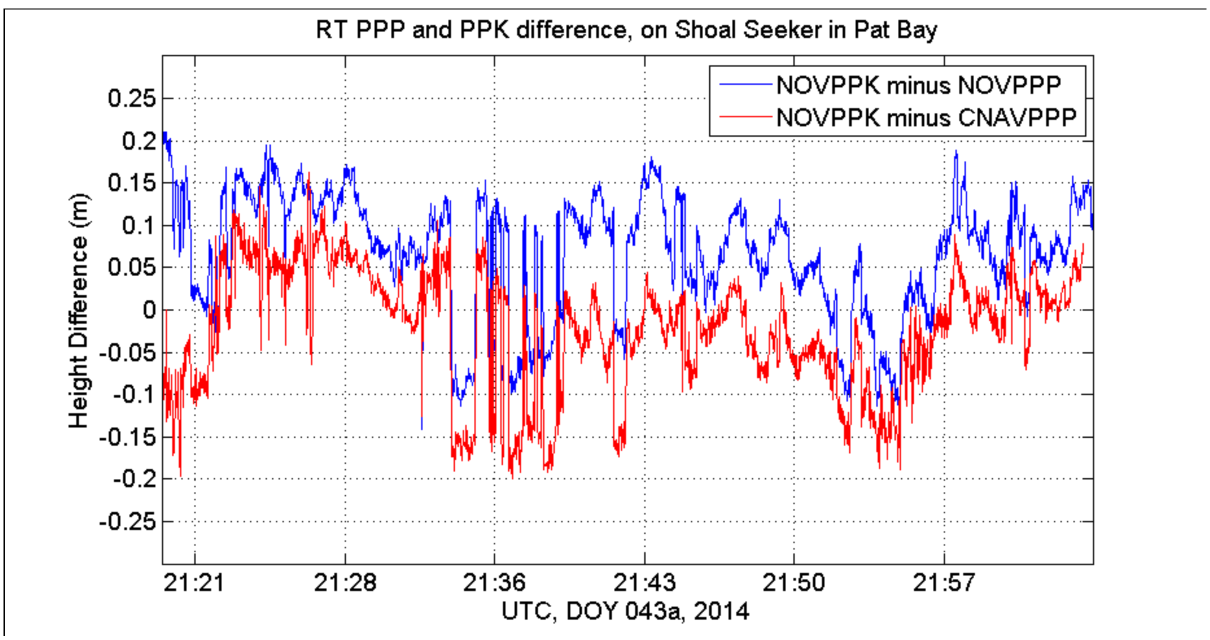

Figure 10: DOY 043A, Water Level Height Difference, NovAtel PPP (NRCan HPC), Nova PPK, CNAV PPP

Solutions	Mean (m)	1σ Stdev (m)	2σ OS
Nova PPK minus Nova PPP	0.067	0.072	0.161
Nova PPK minus CNAV PPP	-0.023	0.073	0.159

Table 3: DOY 043a, Water Level Height Difference Statistics, NovAtel PPP (NRCan HPC), Nova PPK, CNAV PPP

Figure 10 and the statistics in Table 3 showed that the CNAV real-time PPP and NovAtel real-time PPP (NRCan HP-GPS*C) produced very similar results.

Figure 11, Figure 12 and Table 4 depict the results from approximately 7 hours of measurements on the Shoal Seeker, underway near Salt Spring Island. The tide shown in Figure 11 is from the Patricia Bay gauge and deviations from the GNSS heights are due to the spatial separation and vessel speed through the water. The NovAtel real-time PPP (NRCan HP-SGP*C) compared very well with the CNAV real-time PPP solution and both agreed with the POS PPK solution to 110 mm and 104 mm, respectively.

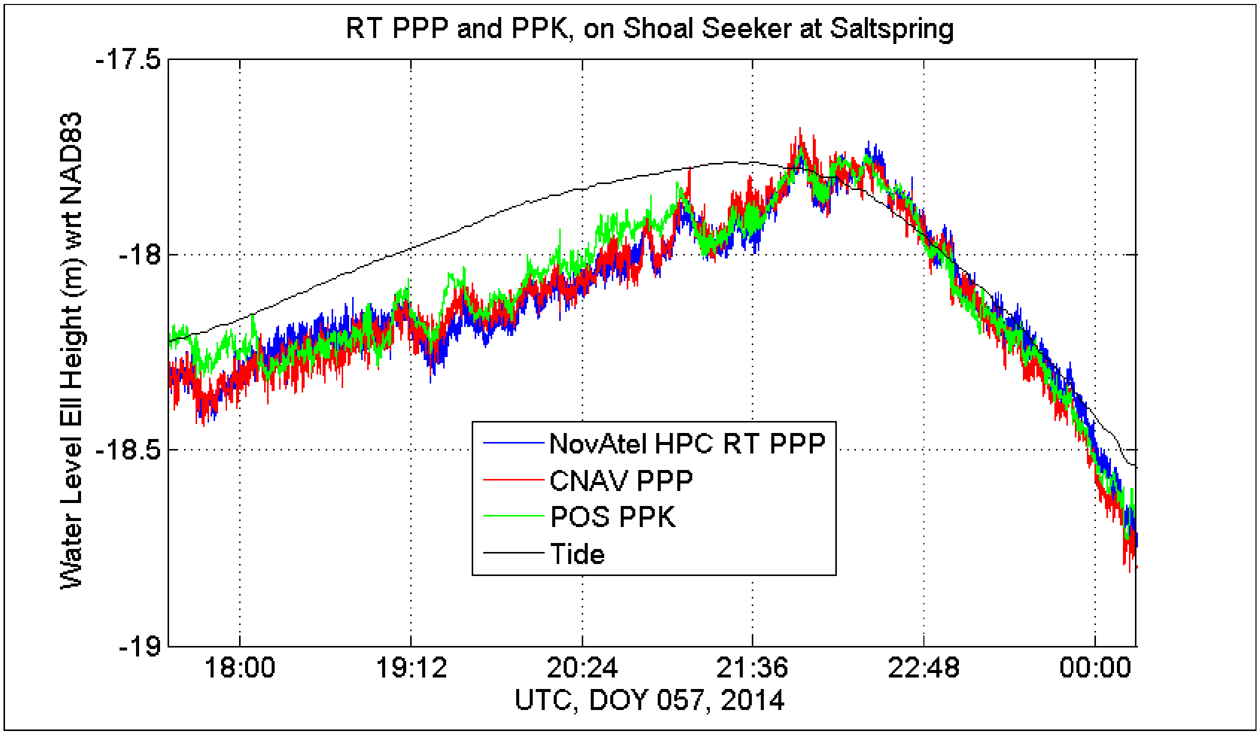

Figure 11: DOY 057, Water Level Height, NovAtel PPP (NRCan HPC), CNAV PPP, POS PPK and Tide

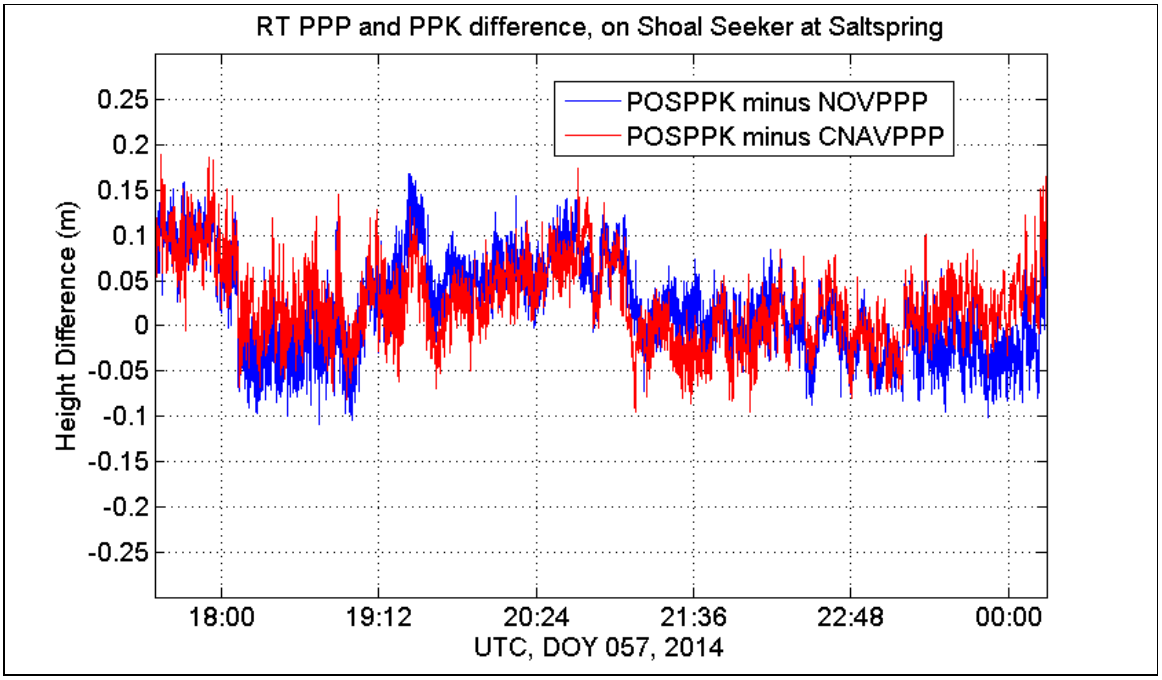

Figure 12: DOY 057, Water Level Height Difference, NovAtel PPP (NRCan HPC), CNAV PPP, POS PPK and Tide

Solutions	**Mean (m)**	1σ **Stdev (m)**	**2σ OS**
POS PPK minus Nova PPP	0.020	0.053	0.110
POS PPK minus CNAV PPP	0.025	0.045	0.104

Table 4: DOY 057, Water Level Height Difference Statistics, NovAtel PPP (NRCan HPC), CNAV PPP, POS PPK

Table 5 summarizes the vertical uncertainty results while the Shoal Seeker was at the dock and when it was underway. The first column describes the GNSS system, the second column shows the HP GNSS services used (GLONASS and/or GNSS) and the HP GNSS mode (RT PPP or PPK). The third and fourth columns show the 2σ vertical uncertainty (in mm) and the approximate number of hours of measurement used for the evaluation, while the vessel was at dock and underway. The NovAtel real-time PPP solution was determined from either the NRCan HP-GPS*C service or the NovAtel TerraStar service. At dock testing periods lasted from 24 to 72 hours in duration and tests were switched between HP-GPS*C and TerraStar service on a regular basis. Most systems showed increased uncertainty while underway, except the NovAtel real-time PPP with the NRCan HP-GPS*C service. This does not appear to be the case for the NovAtel real-time PPP when using the TerraStar service or the CNAV real-time PPP solution. The reason for this will require further investigation. The primary difference between HP-GPS*C and the other two real-time PPP service is the inclusion of GLONASS.

System	HP GNSS Mode	At Dock 2σ OS (mm)/hours of measurements	Underway 2σ OS (mm)/hours of measurements
RTKLib PPK	GPS and GLONASS PPK	27 mm/740 hr.	110 mm/4 hr.
POSPac PPK	GPS and GLONASS PPK	35 mm/72 hr.	110 mm/10 hr.
CNAV PPP	GPS and GLONASS RT PPP	113 mm/240 hr.	132 mm/10 hr.
NovAtel TerraStar	GPS and GLONASS RT PPP	122 mm/300 hr.	
NovAtel NRCan HPC	GPS RT PPP	197 mm/440 hr.	156 mm/10 hr.

Table 5: Summary of Vertical Uncertainty

Horizontal

A horizontal position comparison was made between the Trimble PPK solution, the NovAtel real-time PPP solution (TerraStar) and the Trimble coast guard DGPS solution, with the Shoal Seeker at the dock. The Trimble receiver on board the Shoal Seek was equipped with a Coast Guard Beacon receiver. The Coast Guard DGPS horizontal solution was found to have an uncertainty of less than 1 m (2σ) when compared to the Trimble PPK (RTKLib) solution. Figure 13 shows approximately 24 hours of horizontal position measurement differences between the Trimble PPK solution, the NovAtel real-time PPP solution and the Trimble DGPS solution. All systems shared the same antenna; therefore, there were no offsets to consider.

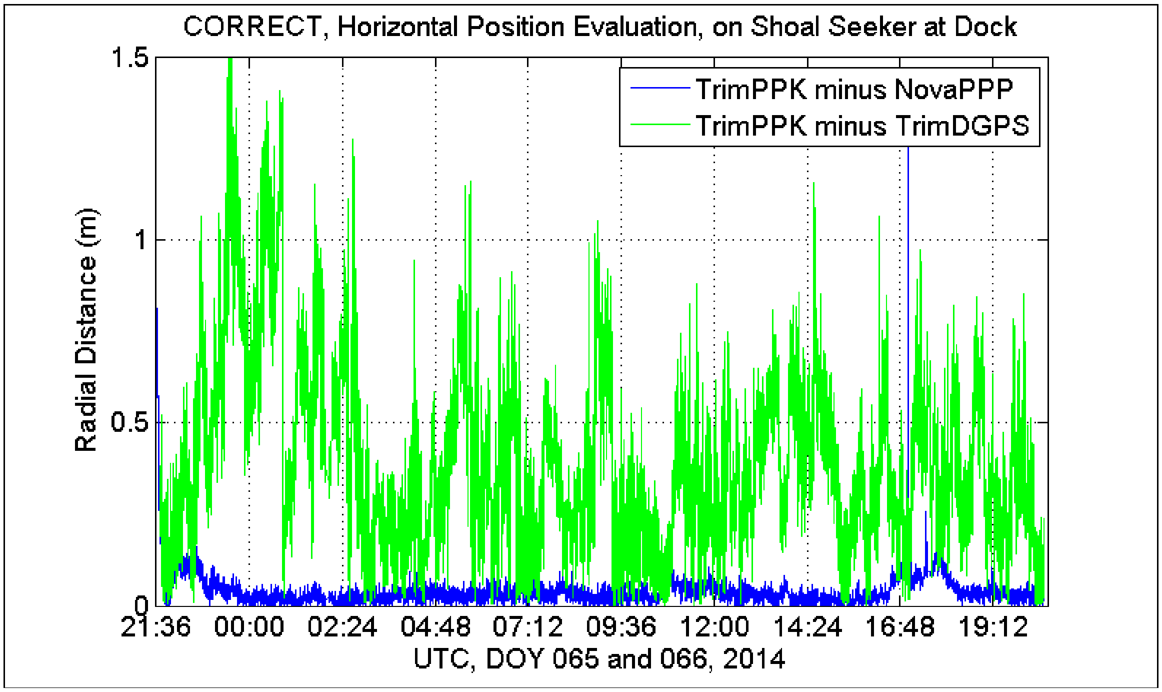

Figure 13: JD065, Horizontal Evaluation. Trimble PPK, Trimble DGPS and NovAtel TerraStar PPP

Table 6 shows the mean, standard deviation and 2σ OS uncertainty of the NovAtel real-time PPP (using TerraStar) as compared to the Trimbe PPK (RTKLib) positions. This indicates that the horizontal positions agree to within 10 cm at 2σ.

	Mean (m)	**Stdev (m)**	**2σ OS (m)**
Latitude	0.000	0.053	0.059
Longitude	0.000	0.049	0.086
Height	0.000	0.081	0.152
Horizontal Radial	0.004	0.059	0.104

Table 6: JD065, Horizontal Evaluation Statistics, Trimble PPK and NovAtel TerraStar PPP

Table 7 shows a similar comparison between The Trimble PPK and Trimble real-time DGPS (coast guard DGPS service). The horizontal positions agree to within 89 cm at 2σ.

	Mean	**Stdev**	**2σ OS**
Latitude	0.182	0.343	0.829
Longitude	-0.178	0.176	0.463
Height	-0.212	0.573	1.208
Horizontal Radial	0.389	0.249	0.885

Table 7: JD065, Horizontal Evaluation Statistics, Trimble PPK and Trimble DGPS (m)

Time to Convergence

The time it takes for a solution to converge to the “correct” answer can be a significant issue, especially is areas where the solution may reset due to satellite obstruction. For real-time techniques, RTK typically converges within a few minutes, where PPP converges in 10s of minutes. The situation is less critical in post-processing because raw data can be processed both forward and backward in time, which can provide a converged solution for the first epoch.

For this discussion, the solution is considered to be converged once the vertical is within 0.15 m of the reference. In this section, the time-to-convergence is evaluated for the NovAtel real-time PPP solutions.

The NovAtel real-time PPP (TerraStar) solutions converged in less than 14 minutes. Figure 14 shows an example of the first two hours of height differences comparing the Trimble PPK and the NovAtel real-time PPP with the tide, while the Shoal Seek was at the dock.

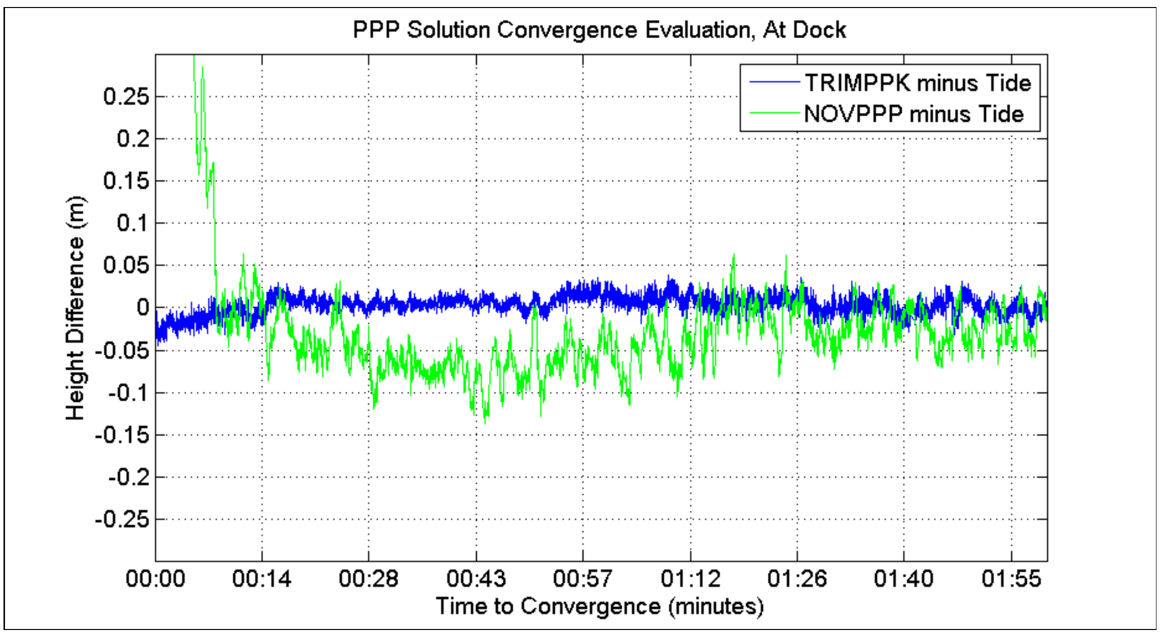

Figure 14: DOY 065 (at dock) NovAtel PPP (TerraStar) Time to Convergence.

Figure 15 Shows a similar comparison, except with the NovAtel real-time PPP service coming from NRCan HP-GPS*C. In this example the solution converged in approximately 20 minutes. Overall, the solution convergence with the NRCan service varied from 14 to 28 minutes, averaging approximately 22 minutes.

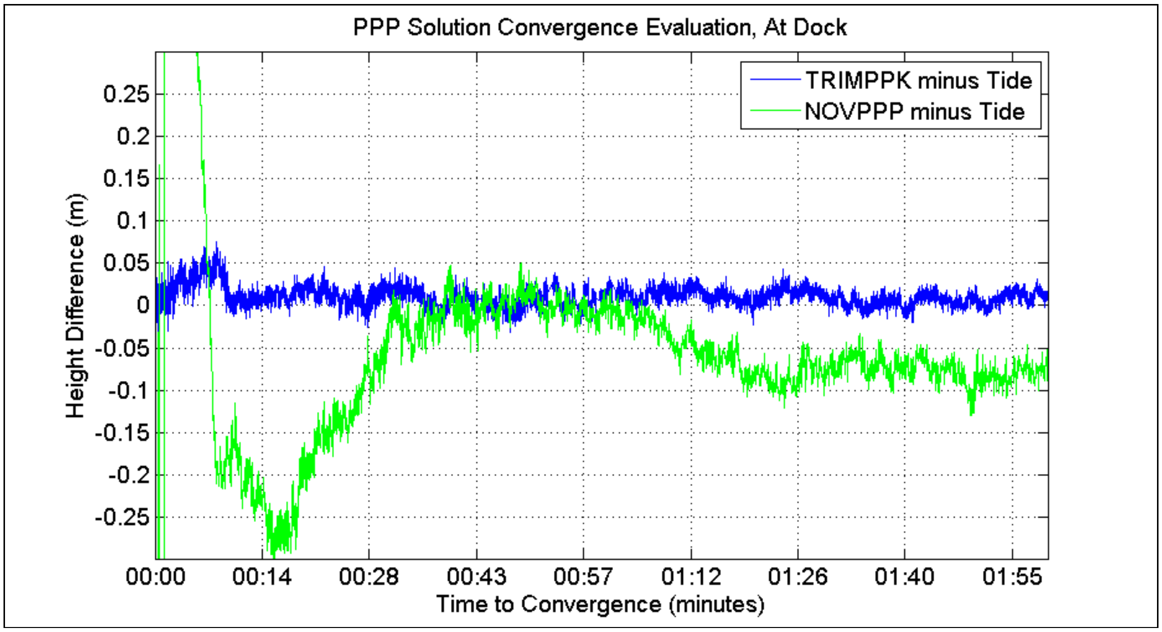

Figure 15: DOY 070 (at dock) NovAtel PPP (NRCan HPC) Time to Convergence.

Figure 16 shows an example of convergence with the Shoal Seeker underway. The CNAV and NovAtel real-time PPP (NRCan service) both converged in less than 14 minutes. This is another indication that the NovAtel real-time PPP, with the NCRCan service, performed better in a more dynamic environment.

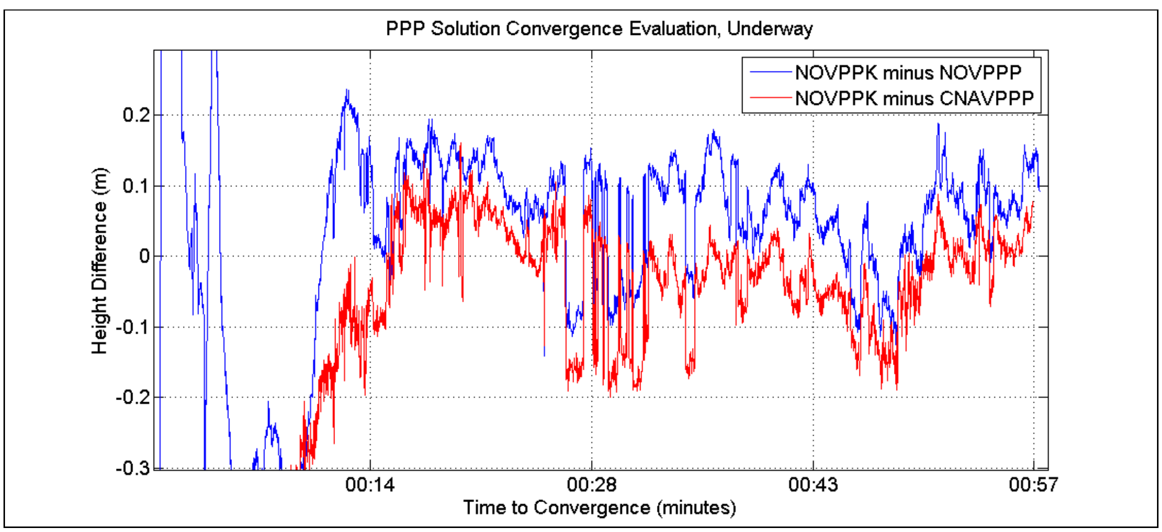

Figure 16: DOY 043a (underway) CNAV and NovAtel PPP (NRCan HPC) Time to Convergence

Conclusions and Recommendations

The CNAV real-time PPP and the NovAtel real-time PPP (with the TerraStar service), produced heights with vertical uncertainties of less than 14 cm (2σ). The NovAtel real-time PPP with the

NRCan service produced heights with uncertainties less than 16 cm while underway, and 20 cm while at the dock. The solution's tendency to wander and the longer time-to-convergence while the vessel was tied up may have been due to an issue with low dynamics coupled with the lack of GLONASS satellites.

It is suggested improvement of results with GLONASS be investigated. This can be done with the existing data and post-processing PPP software.

References

Lévesque S., K. MacLeod, R. Pike, J. Bartlett, S. Youngblut, C. Ellum, K. Fadaie and D. Hains (2014). "Assessing the feasibility and benefits of the real-time HP-GPS*C service to support high precision surveys and positioning in the Arctic." Proceeding of the 2014 Canadian Hydrographic Conference. April 14-17, St. John's, Canada.

Author Biography

David Dodd joined the CHS Pacific region on a two-year industry exchange in August 2013. His previous position was with the University of Southern Mississippi's Hydrographic Science Research Center as a research scientist and lecturer. Dr. Dodd spent 8 years as the director of the USM Master's in hydrographic science program before moving to the research center. He has a B.Sc. and M.Sc. in Surveying Engineering from the University of New Brunswick and a PhD in Marine Science from the University of Southern Mississippi.

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