Airborne Precise Point Positioning (PPP) in GrafNav 7.80 with Comparisons to Canadian Spatial Reference System (CSRS) Solutions

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Introduction

GrafNav 7.80 is scheduled for release March 15 2007. A major new feature included in this release is a Precise Point Positioning (PPP) processor. PPP requires dual frequency measurements as well as precise orbit and clock files which can be downloaded via the internet. Tests have shown that post-processed accuracies of 10-20 cm can be achieved on typical airborne surveys provided high quality data is collected, i.e. minimal loss of GPS signal lock.

For applications which do not require the absolute highest of accuracies (i.e. fixed integers), PPP offers attractive savings in time and cost by providing relatively high accuracies without base station data. This is especially true for remote areas that do not have dense reference station coverage (such as Continuously Operating Reference Stations - CORS). Dense CORS coverage is common in some areas of the United States.

Presently, real-time PPP solutions are available through subscription services such as Navcom's StarFire and Omnistar XP. GrafNav's new PPP processor offers an alternative method, or additional level of security, to these services for those who do not require a real-time solution. GrafNav's new PPP will be a standard tool in future versions of GrafNav.

Final precise orbits and clocks have a latency of approximately 2 weeks. Prior to this, rapid orbits and rapid clocks are available for download by the IGS (International GNSS Service). Rapid orbits and clocks have a latency of approximately one day. Testing has shown that there is no significant difference in PPP accuracy when using the rapid orbits and clocks as apposed to the final products. Final and rapid ephemeris and clock files can be easily downloaded through the existing "Download Service Data" program included in GrafNav.

This report shows GrafNav's PPP results from three aerial surveys in which a reliable differential trajectory has been processed in GrafNav. A solution from the internet based CSRS service is also shown, which is explained below.

GrafNav and the CSRS

At the time of this writing, the Canadian Spatial Reference System (CSRS) provides an online PPP service at http://www.geod.nrcan.gc.ca/online_data_e.php. Firstly, a RINEX file is first uploaded through their website. The user has a choice of two datums, NAD83-CSRS or ITRF, and can specify whether the data is static or kinematic. When processing is complete, results are emailed to the user.

CSRS and GrafNav's PPP differ in a fundamental way. Both process a solution forwards and backwards in time, however GrafNav's forward and reverse solutions are completely independent of each other. The combined solution is then a weighted average of both processing directions. CSRS takes the converged Kalman Filter states from forward processing and applies them to reverse processing. Therefore the "best" CSRS solution is not a weighted average of the two, but rather the reverse processing results. Both of these methods have their advantages.

The advantage of processing two independent (forward and reverse) solutions is that it is a powerful quality control tool in order to gauge the accuracy of the solution. This can be done by comparing the difference in the solutions after convergence in both directions has been achieved (which takes roughly 30 minutes in a typical airborne environment). Secondly, multiple losses of lock are well handled in the combining process when using two independent solutions.

As long as an effective weighting strategy is applied to the forward and reverse results, the periods where each solution is converging will have little weight on the final solution.

One advantage to preserving the Kalman Filter states (which include a tropospheric state and ambiguity states) from forward processing and applying them to reverse processing is that for short data sets (less than 1 hour) an improved estimate of the troposphere is possible.

Another difference between the two PPP solutions is the source used for precise satellite clock corrections. The CSRS currently uses IGS precise clock files containing updates every 5 minutes (http://igscb.jpl.nasa.gov/components/prods_cb.html). This is adequate for static applications, however kinematic surveys benefit from higher rate satellite clock corrections. GrafNav's download utility supports a precise clock file containing corrections every thirty seconds from CODE (Center for Orbit Determination).

GrafNav also includes many other quality control tools, such as the ability to plot code and phase measurement residuals, the number of satellites used, the remote locktime plot, and access to 29 other plots. GrafNav also includes flexible export capabilities and the ability to load digital elevation models. For more information on GrafNav/Net, please see http://www.novatel.com/products/waypoint_pps.htm

The following sections present PPP results from three airborne surveys. All surveys have a high quality differential solution processed in GrafNav 7.60 which is used as truth. Any difference in the differential and single point solutions is considered error in the latter.

For flight 1, results from GrafNav's forward and reverse PPP processing are presented in addition to the combined solution. For brevity, the remaining runs show only the error in the combined GrafNav PPP solution. The errors in the CSRS solution are also shown for each run.

Flight 01

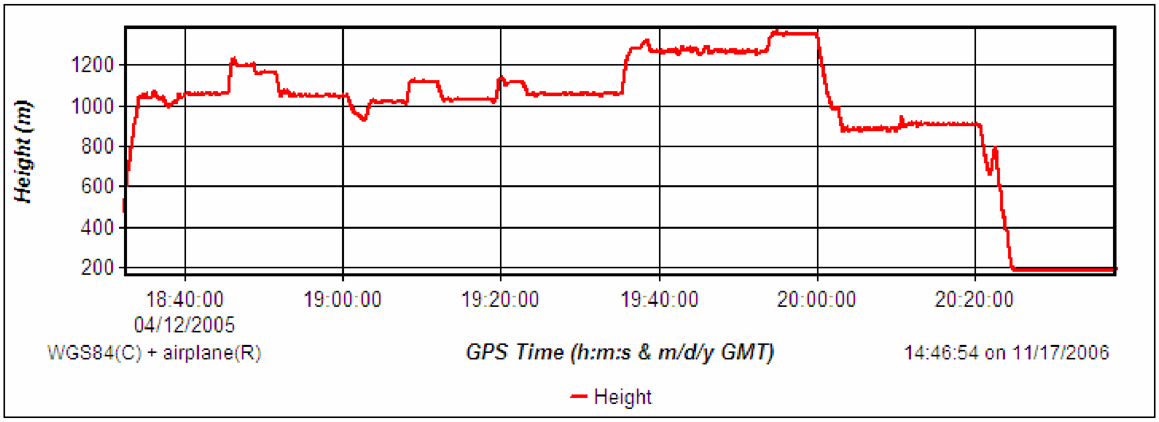

Figure 1: Height Profile for Flight 01

Flight 1 reaches a maximum elevation of approximately 4000 ft and the entire survey lasts two hours and five minutes. The receiver (a dual frequency NovAtel OEM3) began collecting data while the aircraft was climbing to elevation and was left on for approximately 12 minutes after landing. All data was processed in kinematic mode.

The results presented for this flight, and for all flights to follow in this report, were obtained by using an elevation mask of five degrees and a C/A code standard deviation of 7.0 meters. Using a low elevation mask benefits GrafNav's PPP as the ambiguity states of risings satellites will converge sooner, as more data is used, than if using a 10 or 12 degree elevation mask. Further, these measurements do not tend to contaminate the position solution due to the satellite weighting scheme in GrafNav's PPP processor. A five degree elevation mask is not recommended for differential processing.

Using a C/A standard deviation of 7.0 meters produces more appropriate standard deviations in PPP processing than when using GrafNav's default of 4.0 meters. The solution standard deviation is important as it affects how the forward and reverse solutions are combined. When using a 7.0 meter standard deviation, higher standard deviations are placed on converging solutions, thus de-weighting their effect in the combining process. The errors in the forward, reverse, and combined PPP solutions are shown in figures 2 through 4.

GrafNav's PPP solution takes approximately 48 minutes for all three components to converge within 20 cm of the benchmarked solution in flight 1, and reverse processing takes approximately 39 minutes. It is likely that forward processing took longer to converge as the receiver began collecting data while already traveling at high speeds in the aircraft.

The variance based combining process used by GrafNav produces a trajectory within (RMS) 6.1 cm horizontal and 5.8 cm vertical from the truth solution. The CSRS solution, shown in figure 5, had RMS errors of 7.0 cm horizontal and 10.4 cm vertical.

Comparing figures 4 and 5 below, it is obvious that a higher level of noise exists in the CSRS solution. The difference in the noise level can at least partially be attributed to the difference in the source used for precise clock corrections as described earlier.

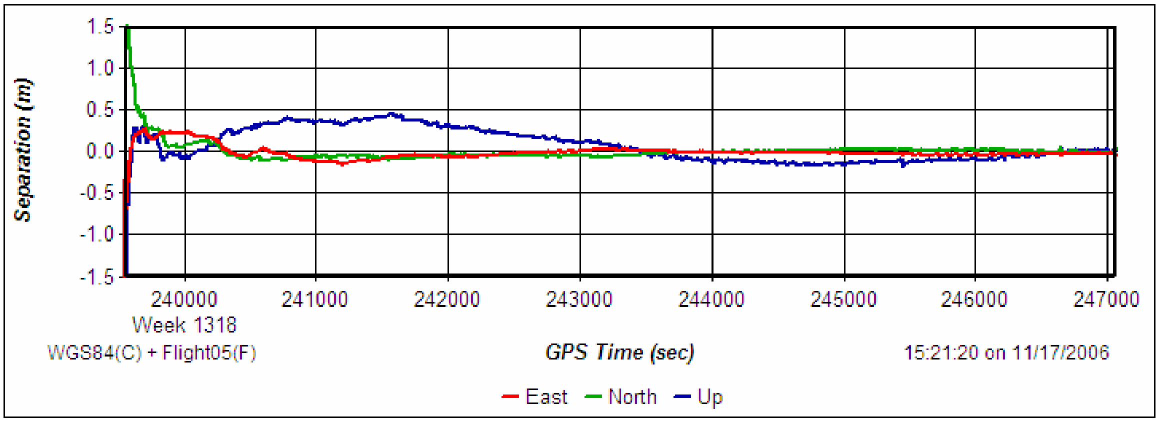

Figure 2: Forward GrafNav PPP vs Differential Truth Solution for Flight 01

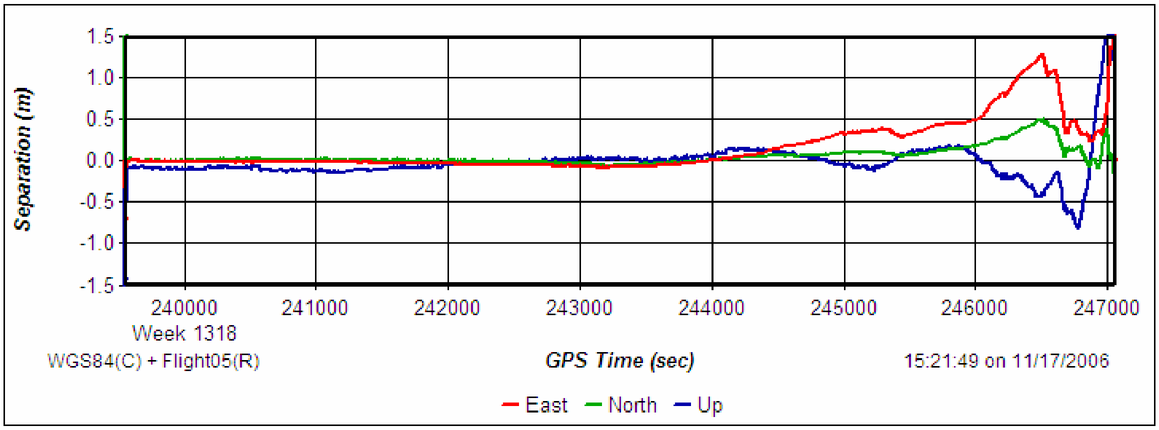

Figure 3: Reverse GrafNav PPP vs Differential Truth Solution for Flight 01

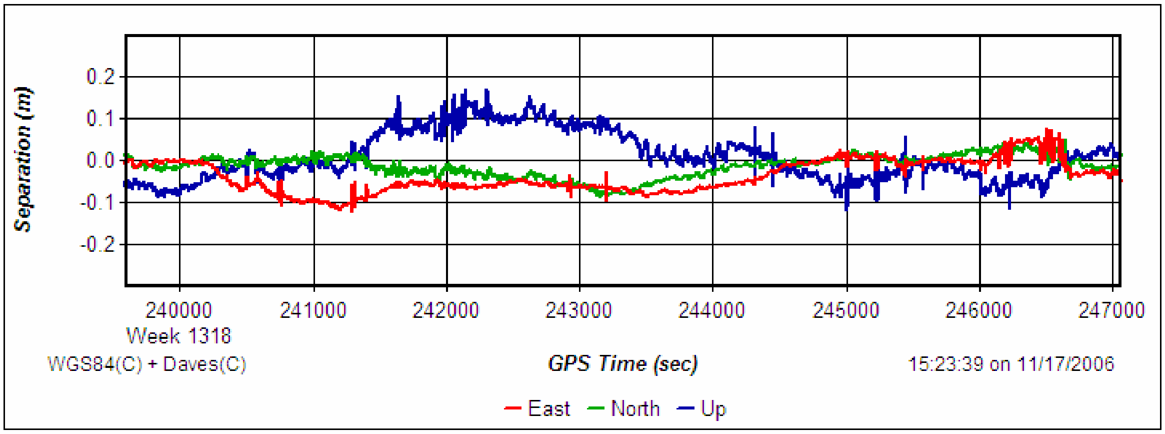

Figure 4: Combined GrafNav PPP vs Differential Truth Solution for Flight 01

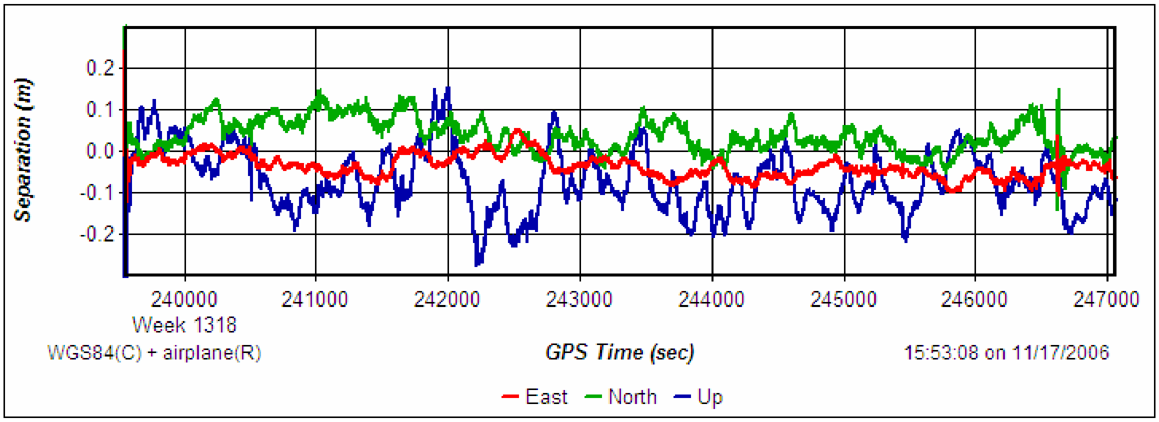

Figure 5: CSRS Solution vs Differential Truth Solution for Flight 01

Flight 02

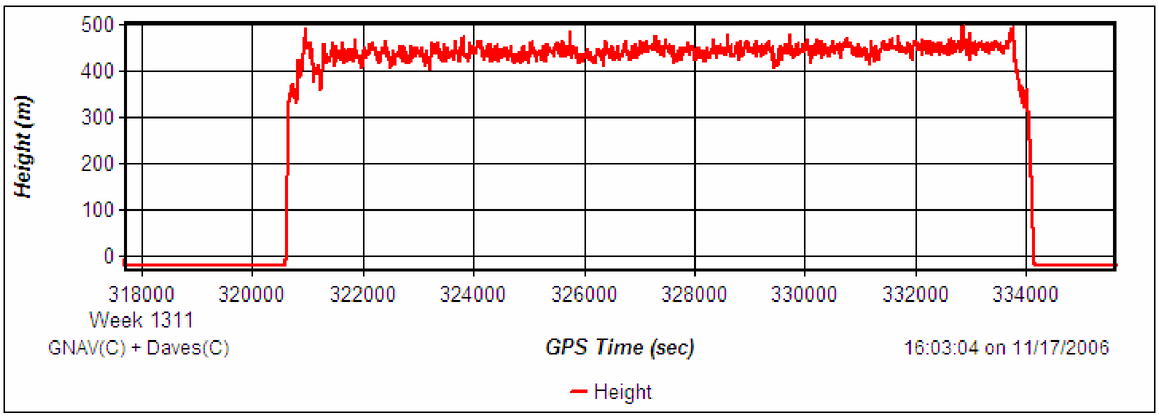

Figure 6: Height Profile for Flight 02

Flight 2 begins with approximately 40 minutes of data collection prior to the flight. As in flight 1, all data was processed as kinematic. The receiver used was a dual frequency Ashtech. Approximately four hours of data was then collected in the air at a maximum elevation of 1700 feet, and approximately 20 minutes of data (again not all of which is actually static) was logged at the end of the flight. The same processing options used and explained in flight 1 were also used to generate the results for flight 2.

There is a strong periodic effect in the CSRS solution which is most obviously seen in the easting in figure 7 between times 320000 and 326000. The period of this effect is five minutes, which is the same rate at which the precise satellite clock corrections are applied. Therefore the benefit of using a file with precise clock corrections every 30 seconds is clearly evident in this flight.

GrafNav's PPP errors (RMS) for flight 2 are 4.3 cm (horizontal) and 5.5 cm (vertical). The CSRS PPP solution produces accuracies of 9.2 cm (horizontal) and 12.9 cm (vertical).

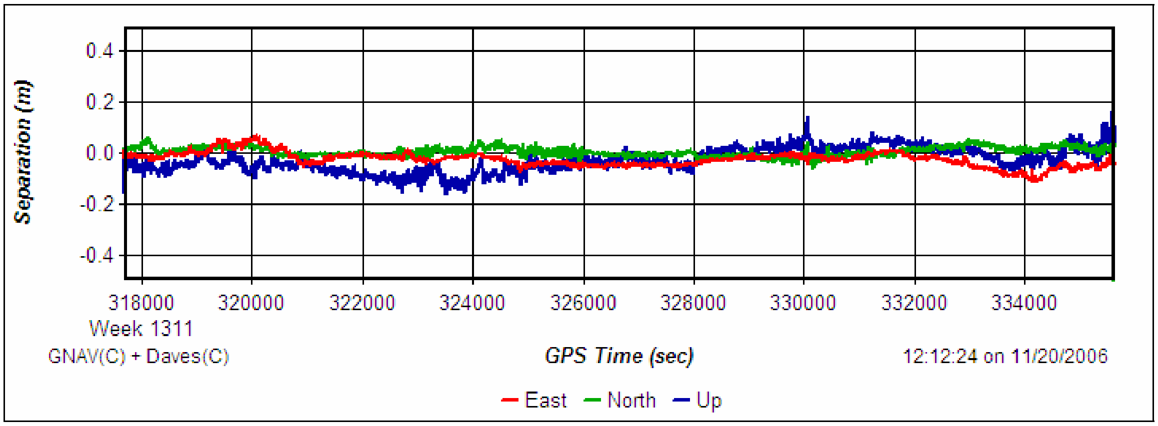

Figure 7: Combined GrafNav PPP vs Differential Truth Solution for Flight 02

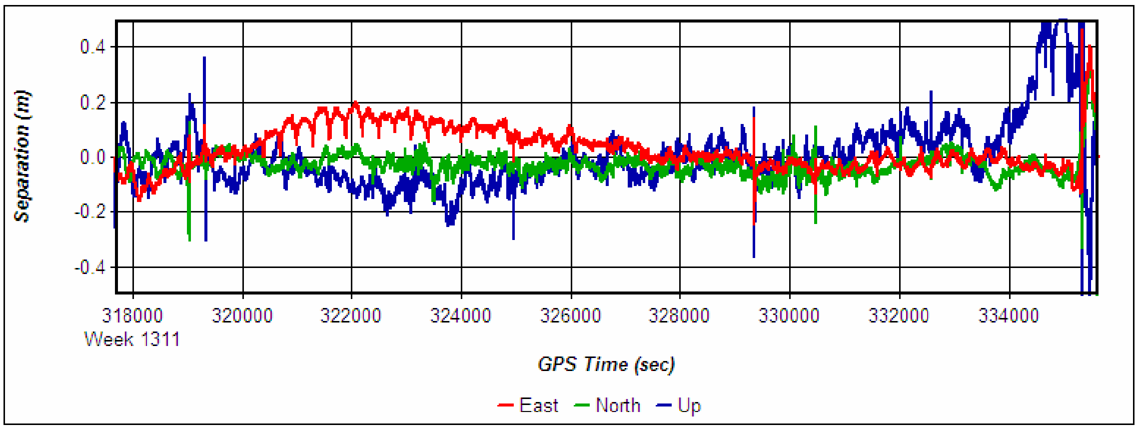

Figure 8: CSRS PPP Solution vs Differential Truth Solution for Flight 02

Flight 03

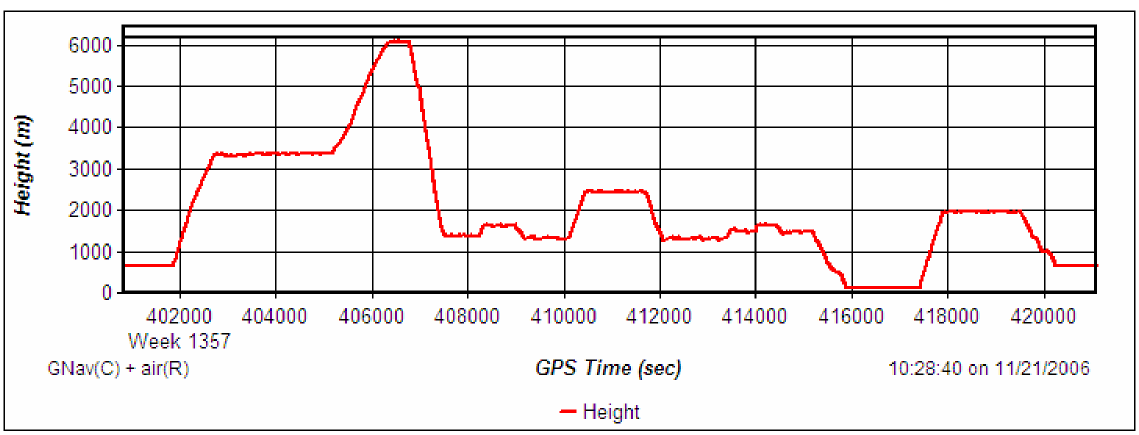

Figure 9: Height Profile for Flight 03

In flight 03, approximately 15 minutes of data was collected prior to take off, followed by a four hour flight. The plane then landed for refueling for approximately 20 minutes before conducting another flight of approximately 1 hour in length. Nine minutes of data was collected at the end of the flight. Therefore in total, over five and a half hours of data was collected.

Flight 3 differs from the previous flights in that it is flown at much higher altitudes than the previous two flights. While much of the survey is flown at altitudes of less than 6,000 feet, the maximum altitude reaches approximately 18,000 feet.

The error (RMS) in the GrafNav PPP solution, as compared with a multi-base station differential post-processed trajectory, is 5.5 cm (horizontal) and 6.9 cm (vertical). The CSRS solution shows errors (RMS) of 7.1 cm (horizontal) and 10.1 cm (vertical).

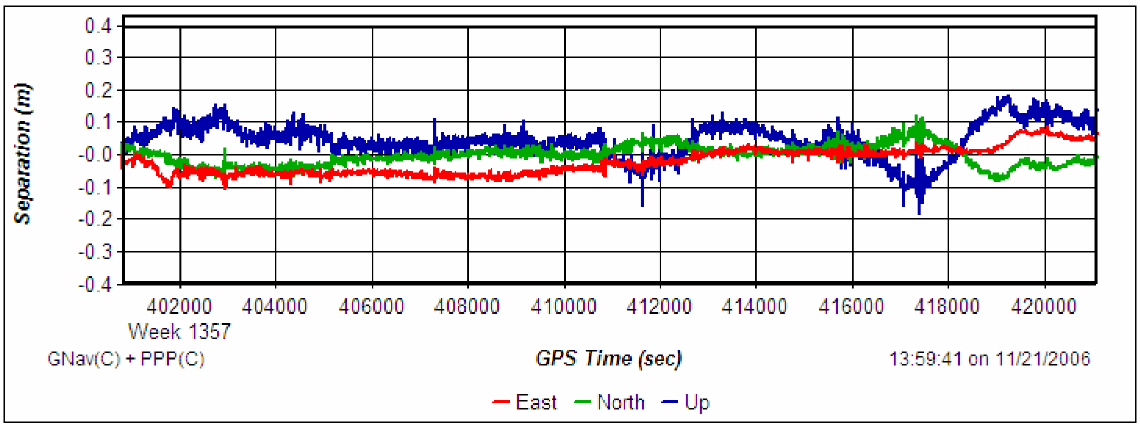

Figure 10: GrafNav PPP Solution vs Differential Truth Solution for Flight 03

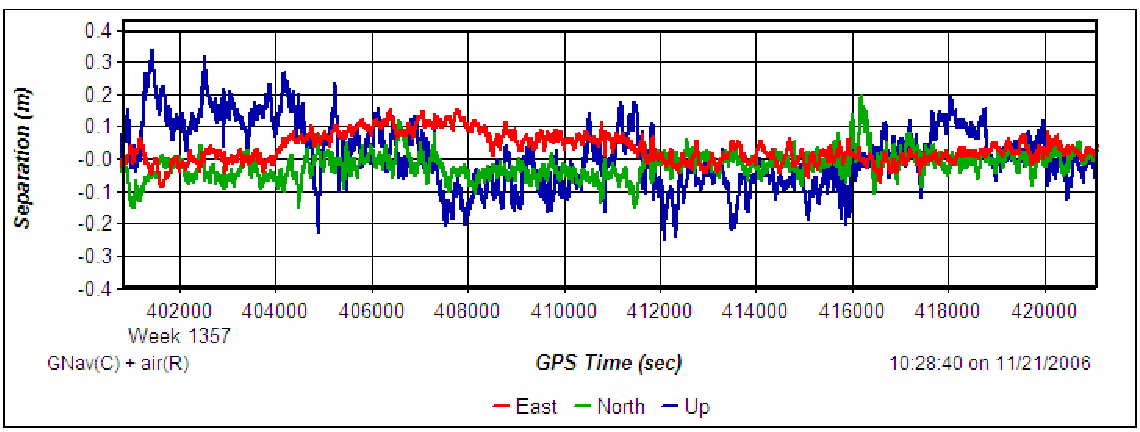

Figure 11: CSRS PPP Solution vs Differential Truth Solution for Flight 03

Summary

Table 1: Errors (RMS) of GrafNav PPP and CSRS PPP Solutions

	GrafNav PPP			CSRS PPP		
Errors (cm RMS)	Flight 01	Flight 02	Flight 03	Flight 01	Flight 02	Flight 03
Horizontal	6.1	4.3	5.5	7.0	9.2	7.1
Vertical	5.8	5.5	6.9	10.4	12.9	10.1

Summarized in this report are three flights, all with reliable differential post-processed trajectories. Each flight was processed with GrafNav's new PPP processor as well as with the internet based PPP solution available by the CSRS. GrafNav's PPP solutions are all within 10 cm (RMS) of the truth solution for both horizontal and vertical components in each flight. The CSRS solutions in each case show larger RMS errors than the GrafNav solution, especially in height.

All of the flights were processed entirely in kinematic mode. Static data collection, if properly flagged in GrafNav, at the beginning and end of flights would be expected to improve the speed of convergence in forward and reverse processing, respectively. All flights were processed with a five degree elevation mask and a 7.0 meter C/A code standard deviation. These options, which are not recommended if processing differentially, have been shown to produce good PPP results.

A five degree elevation mask allows the ambiguity states to converge more quickly for rising satellites as more data is used, and these measurements are heavily de-weighted so as to not overly influence the position solution. A 7.0 meter standard deviation produces more appropriate PPP weighting during solution convergence than the default 4.0 meter standard deviation.

It should be noted that all the flights presented in this report are in excess of two hours in length and were all collected without complete losses of signal lock at any time during the survey. Thus under similar conditions, GrafNav's PPP processor offers an attractive time and cost savings solution for applications requiring post-processed accuracies in the range of 10-20 cm.

There are additional benefits to PPP processing for very high altitude flights. Correctly resolving integer ambiguities is sometimes very challenging on such flights when processing a differential solution. This is because the actual difference in the troposphere between the high altitude rover and the ground base station can be significantly different than that modeled through the Saastamoinen model used in GrafNav. This limitation does not apply to a PPP solution as measurements are not being differenced with others at ground level. Thus very high altitude flights may actually be more accurately processed with a PPP solution than the traditional double differenced method.