

Improvements in Position, Velocity and Attitude when using Waypoint Consulting's RTS Smoother during Periods of GPS Data Outages

Waypoint Consulting
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Introduction

Waypoint Consulting introduces a new feature to their GPS/INS software, Inertial Explorer, in version 7.60. This new feature is an RTS (Rauch-Tung-Striebel) smoother which has been shown to greatly improve positioning accuracy through periods of GPS data outages.

GPS/INS data is processed within Inertial Explorer both forward and backwards in time. This in itself is a significant advantage over processing in the forward direction only and has large implications for quantitative analysis of errors in attitude, position and velocity. The final trajectory is a weighted solution of both processing directions. Until recently, the combined forward/reverse solution was the final output from Inertial Explorer. Users now have the option of applying the RTS smoother in both processing directions, and again combining the results in the final trajectory.

This report shows the level of improvement in position, velocity and attitude the filter offers given GPS outages of 10 minutes, 5 minutes, 100 seconds and 30 seconds. Errors in forward only processing, combined forward/reverse, and RTS smoothed forward/reverse are presented. The improvement is easily quantified by comparing the truth trajectory to results obtained when ignoring all GPS data for the specified time intervals.

The test data was collected with a NovAtel SPAN Technology system that comprised the OEM4 dual frequency GPS receiver and an IMU with 1 degree per hour gyro bias stability. The SPAN system permits writing of the GPS and IMU raw data onto removable Compact Flash for transfer to an office computer for post processing. The data was collected under medium dynamics (maximum speed 100 km/hr, maximum acceleration 3 m/s^2) on a test run in Calgary, AB. The survey was performed under open conditions in order to establish a very reliable truth trajectory to compare results when ignoring specific amounts of GPS data

GPS/INS – very brief overview

GPS/INS integration is becoming more popular in industry. Some examples of this are airborne photogrammetry, laser profiling, high dynamic trajectory tracking and airborne geophysical applications. These applications all require high accuracy position and/or velocity data.

The individual nature of GPS and INS systems are complimentary. GPS provides accurate position and velocity information which do not drift over time. A major limitation to GPS is that the output data rate is not sufficient for many applications. As well, a single GPS receiver cannot provide attitude information. An INS system can provide attitude, position and velocity information at extremely high data rates. A major disadvantage is that these measurements are subject to large errors if not aided by some external source, such as GPS. Thus, an integrated GPS/INS system can provide a user with highly accurate attitude, position and velocity information at very high data rates.

There are principally two ways GPS and INS data can be combined. They are commonly known as loosely and tightly coupled systems. In a loosely coupled system, two processes must be performed sequentially. Firstly, the GPS data must be processed in its own Kalman filter. The output position and velocity information can then be used in a separate filter when processing the inertial data, and is used to bind the INS measurement error growth. The major advantage to a loosely coupled system is its design simplicity relative to a tightly coupled system.

A tightly coupled system integrates both GPS and INS measurements into a single Kalman filter. This has several theoretic advantages over a loosely coupled system. Firstly, any number of GPS measurements may be used in the filter, therefore even if just one satellite is being tracked, that data can be used within the filter to help bind INS error growth. Additionally, it is possible that both cycle slips may be fixed in GPS data and ambiguity states preserved through periods of GPS signal masking/blockages. The disadvantage to such a system is the complexity of the design and the ability to make such a system functional in practice.

Currently, Waypoint's GPS/INS processing software, Inertial Explorer, is a loosely coupled system. GrafNav is first used to process the GPS data, after which the position and velocity updates are used to update the IMU Kalman filter. More information on GPS/INS integration is available on Waypoint's website www.waypnt.com.

600 second data gap

Position Error during 600 second GPS outage

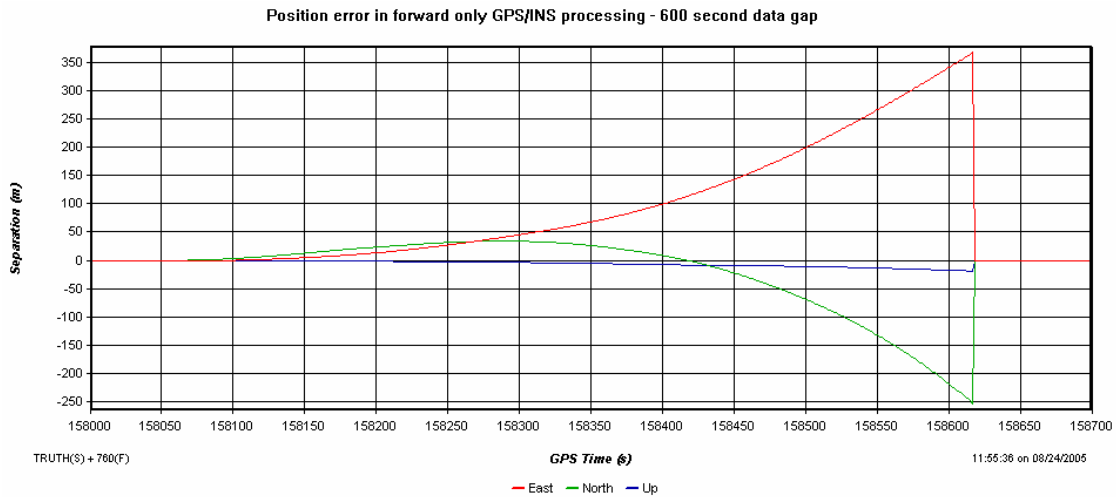


Figure 1: Position error in forward only processing during 600 second GPS outage

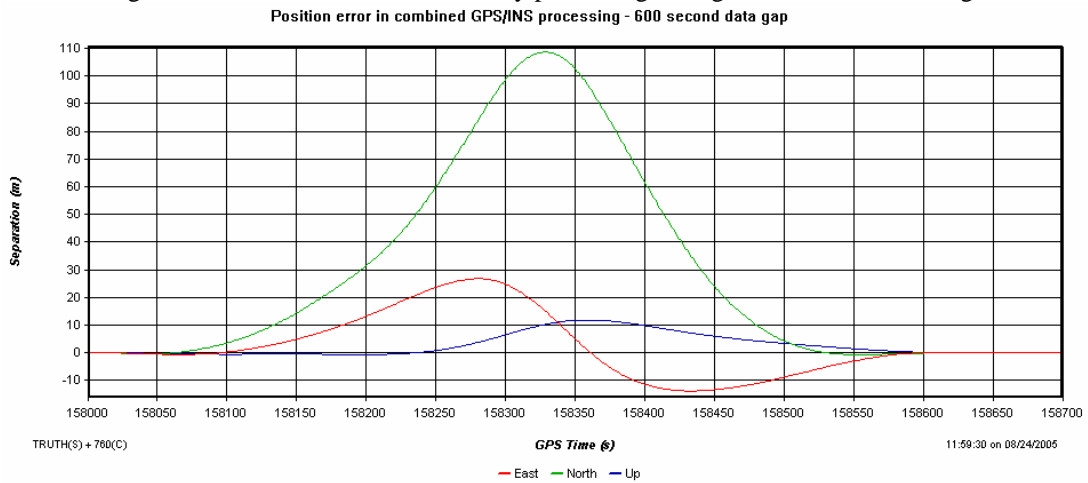


Figure 2: Position error in combined processing during 600 second GPS outage

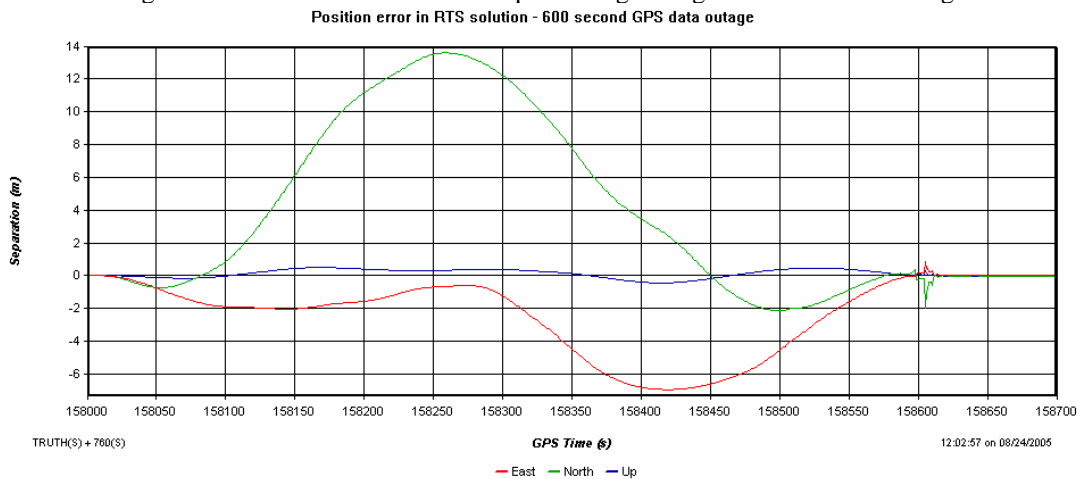


Figure 3: Position error in combined RTS processing during 600 second GPS outage

Velocity Error during 600 second GPS outage

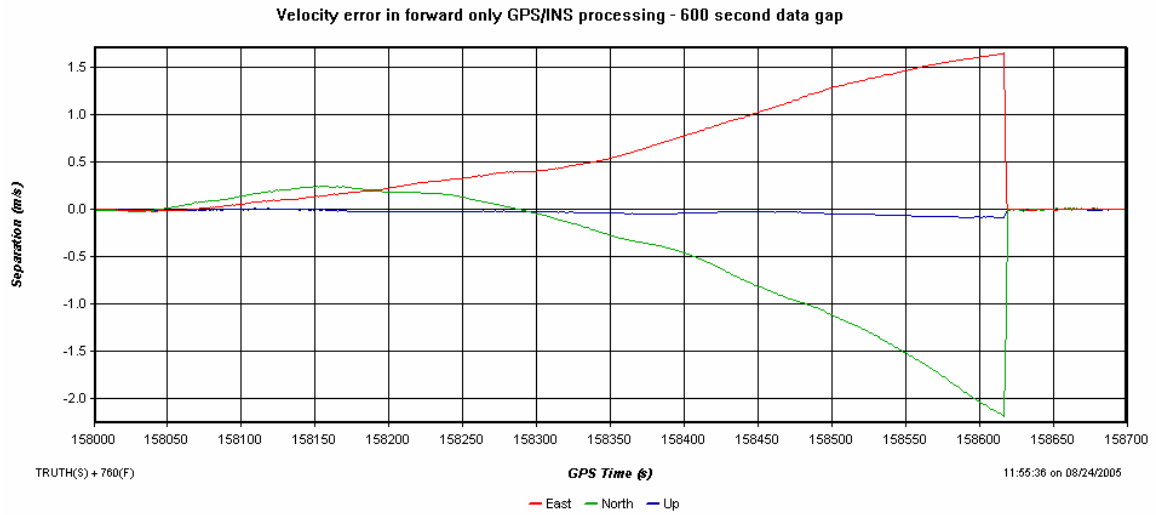


Figure 4: Velocity error in forward only processing during 600 second GPS outage

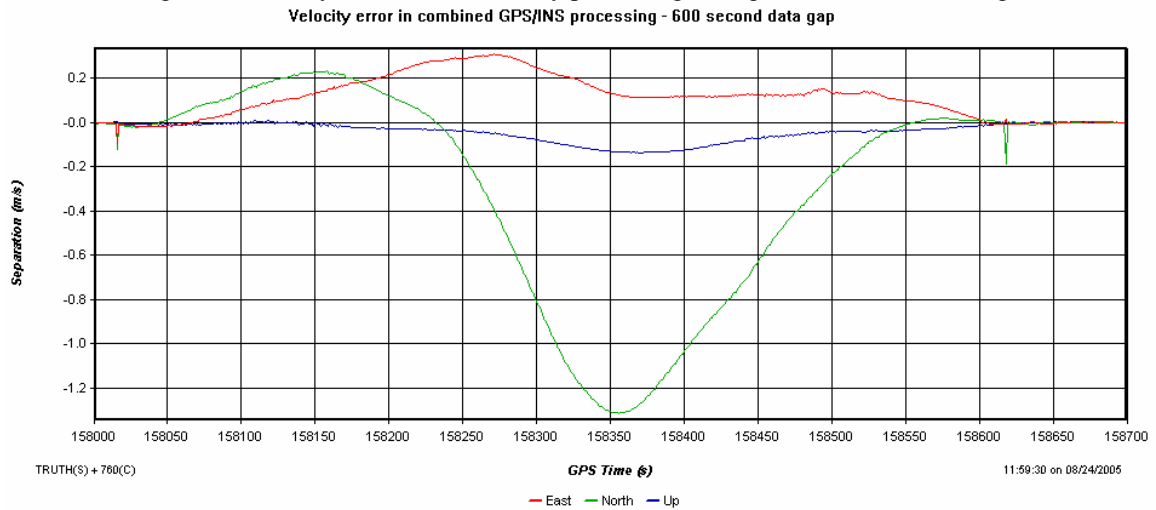


Figure 5: Velocity error in combined processing during 600 second GPS outage

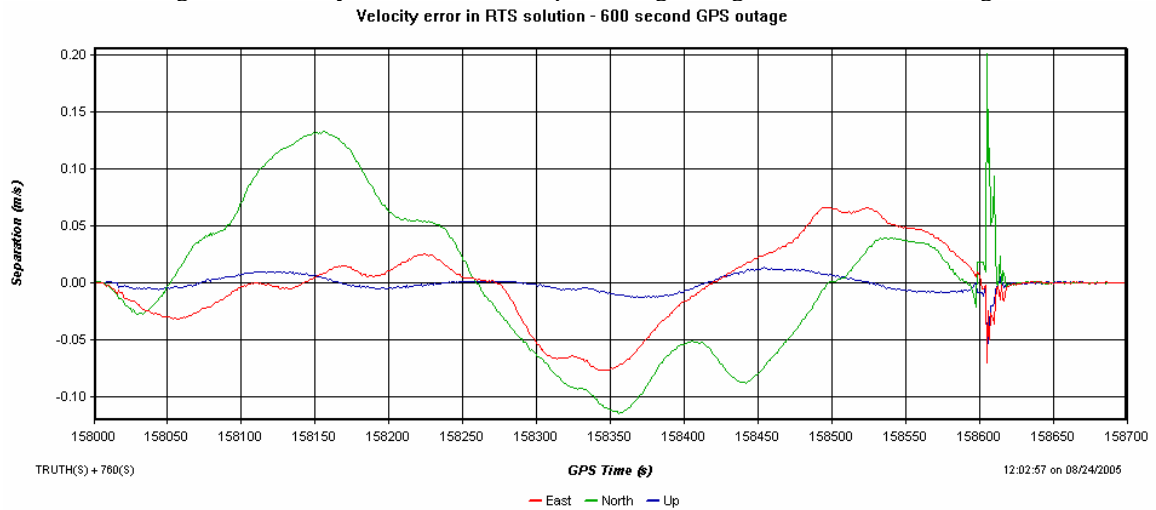


Figure 6: Velocity error in combined RTS processing during 600 second GPS outage

Attitude Error during 600 second GPS outage

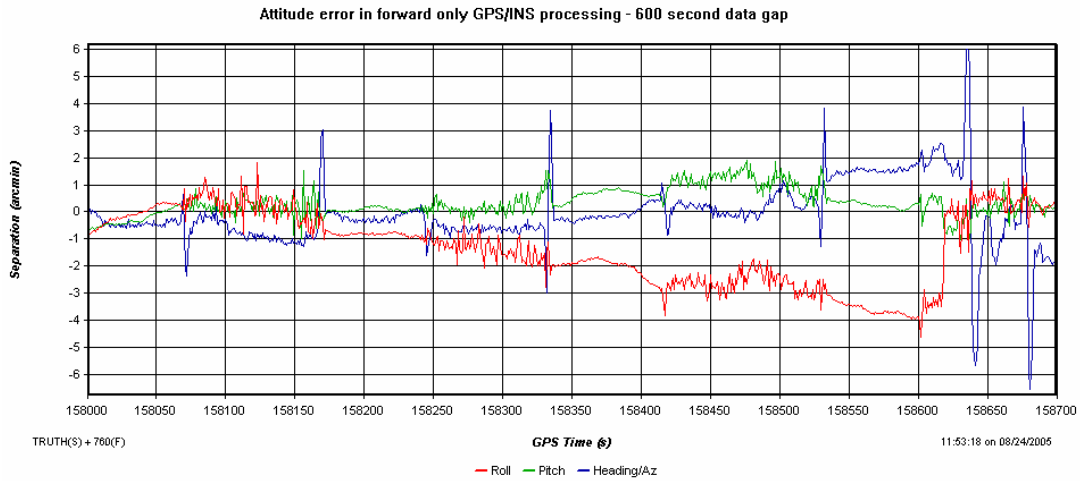


Figure 7: Attitude error in forward only processing during 600 second GPS outage

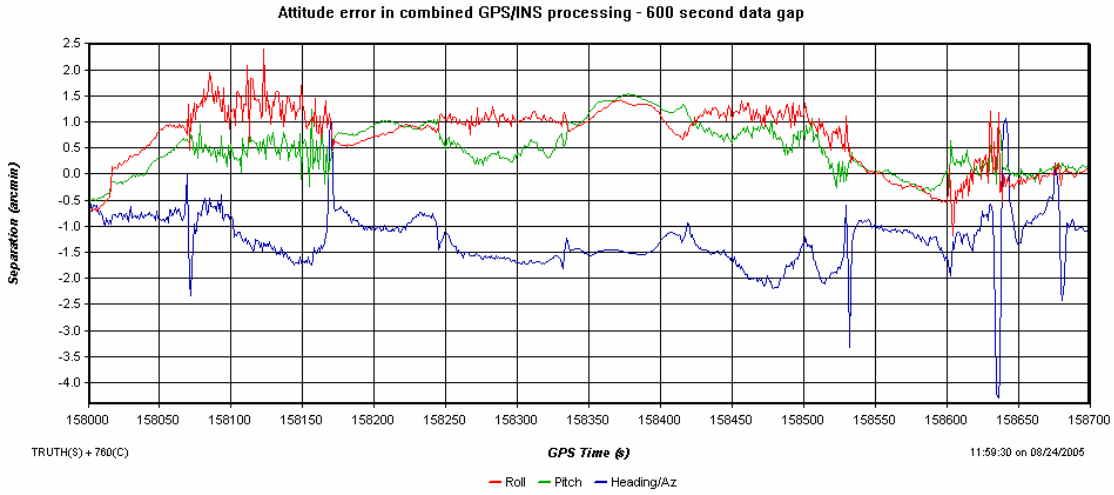


Figure 8: Attitude error in combined processing during 600 second GPS outage

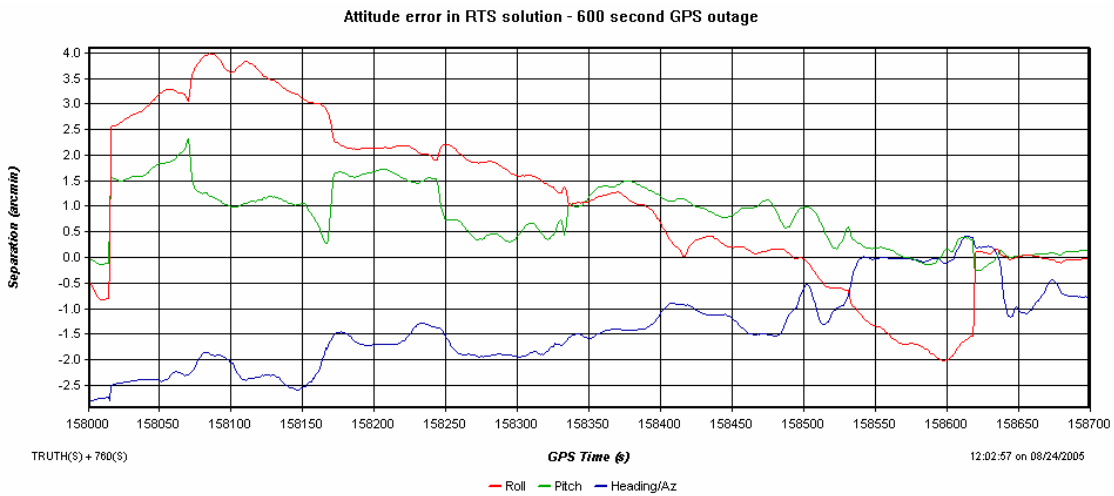


Figure 9: Attitude error in combined RTS processing during 600 second GPS outage

300 second GPS outage

Position Error during 300 second GPS outage

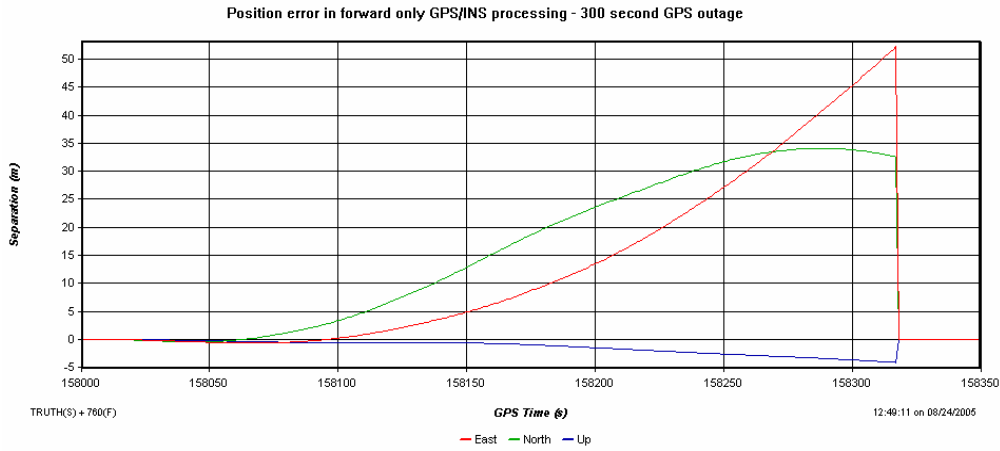


Figure 10: Position error in forward only processing during 300 second GPS outage

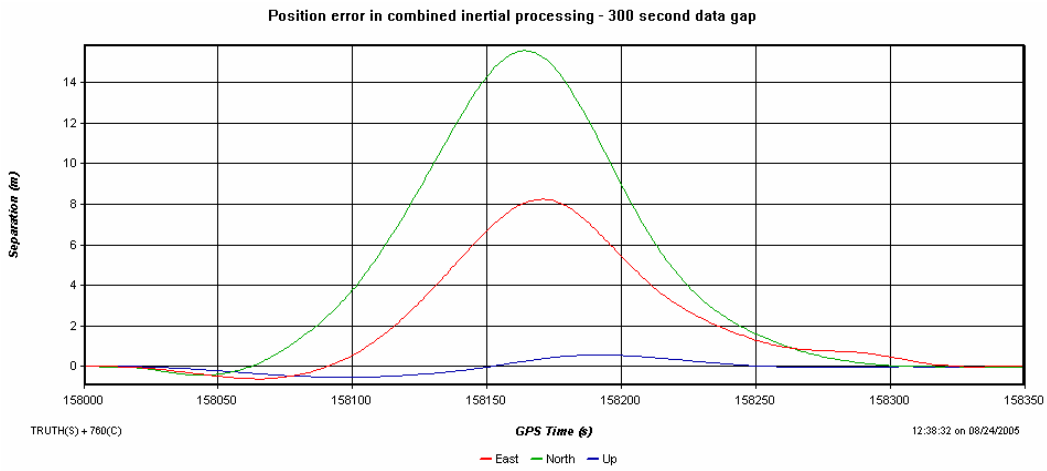


Figure 11: Position error in combined processing during 300 second GPS outage

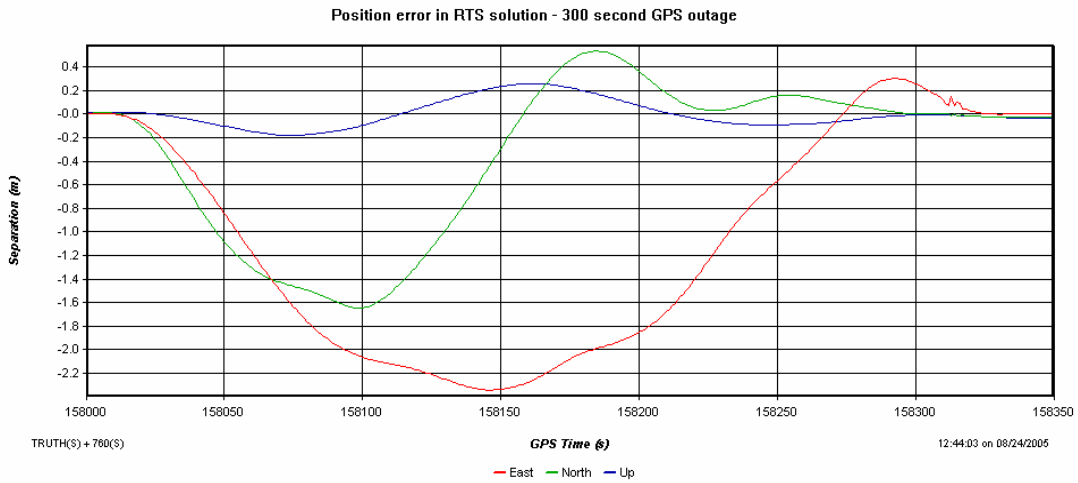


Figure 12: Position error in combined RTS processing during 300 second GPS outage

Velocity Error during 300 second GPS outage

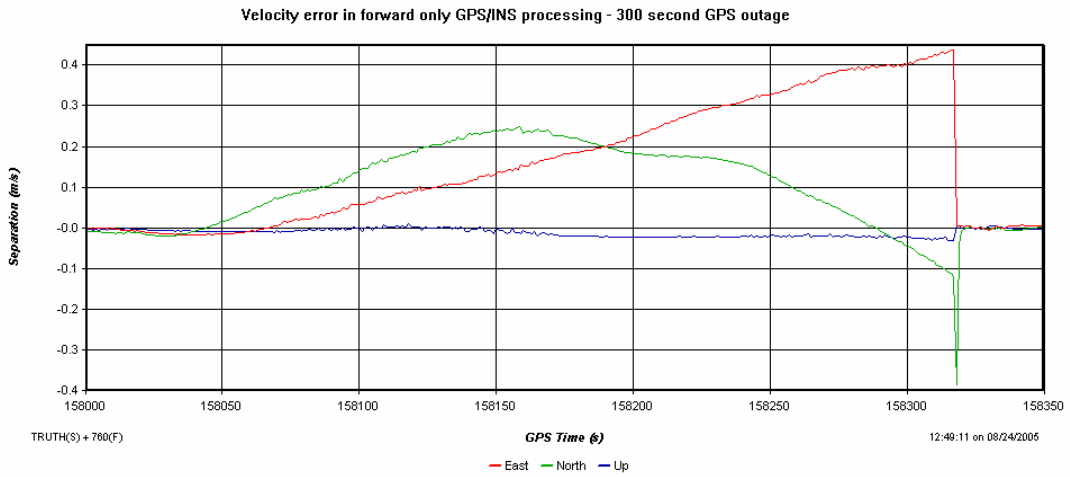


Figure 13: Velocity error in forward only processing during 300 second GPS outage

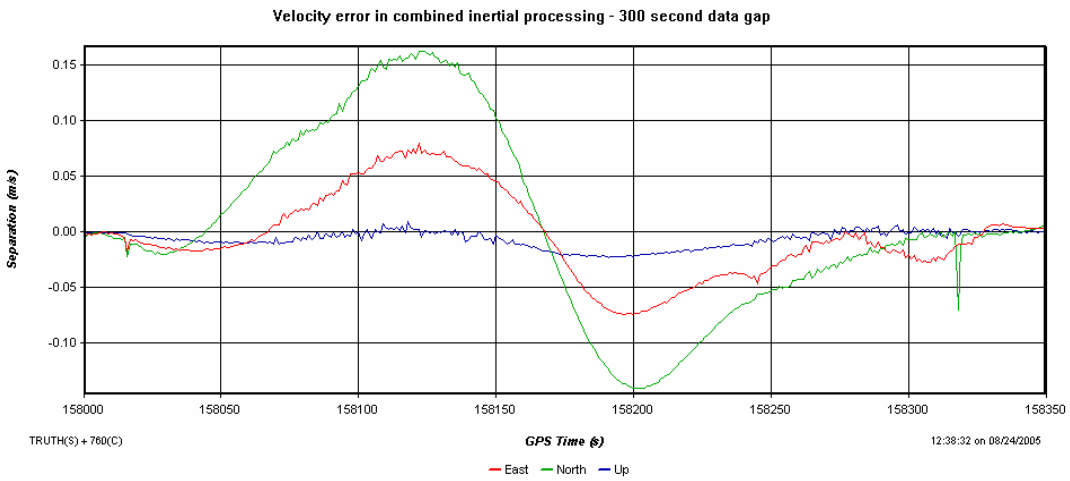


Figure 14: Velocity error in combined processing during 300 second GPS outage

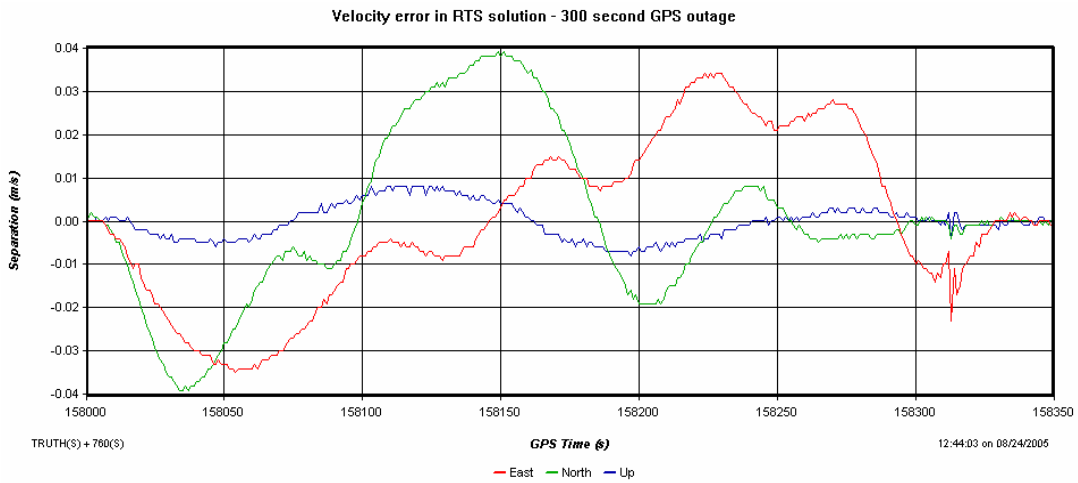


Figure 15: Velocity error in combined RTS processing during 300 second GPS outage

Attitude Error during 300 second GPS outage

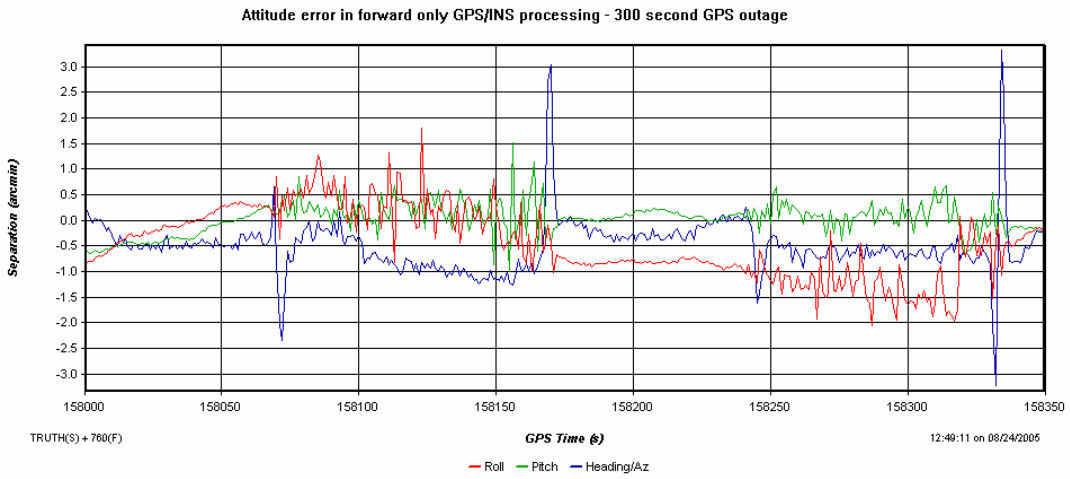


Figure 16: Attitude error in forward only processing during 300 second GPS outage

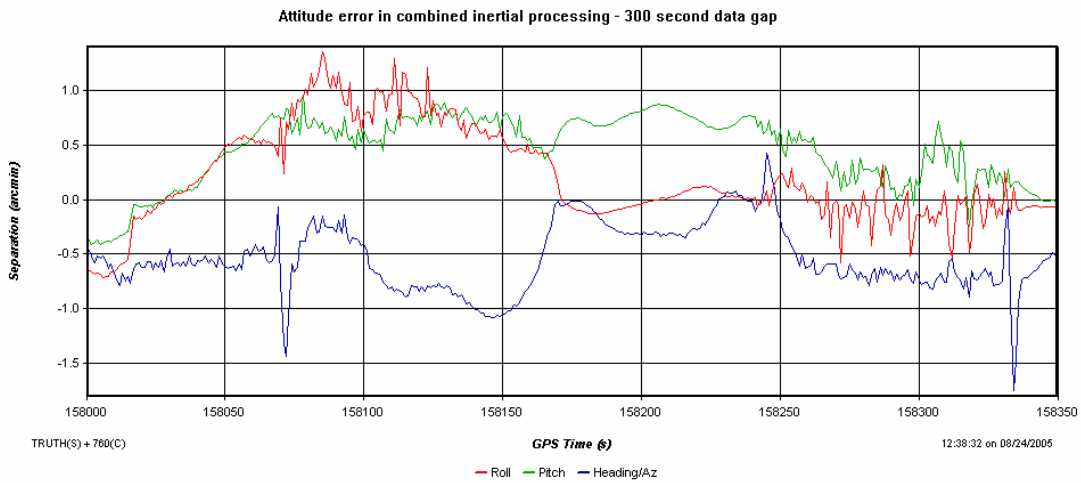


Figure 17: Attitude error in combined processing during 300 second GPS outage

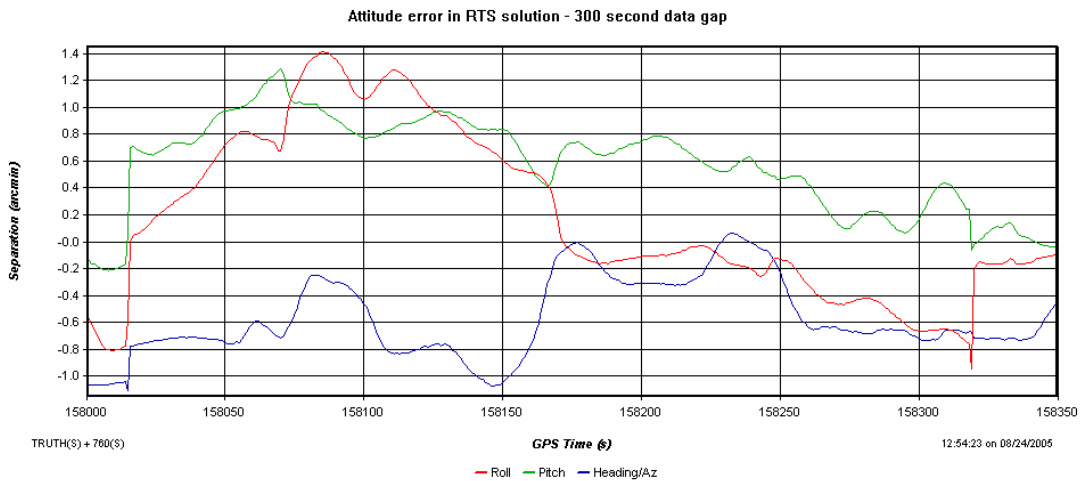


Figure 18: Attitude error in combined RTS processing during 300 second GPS outage

100 Second GPS outage

Position Error during 100 second GPS outage

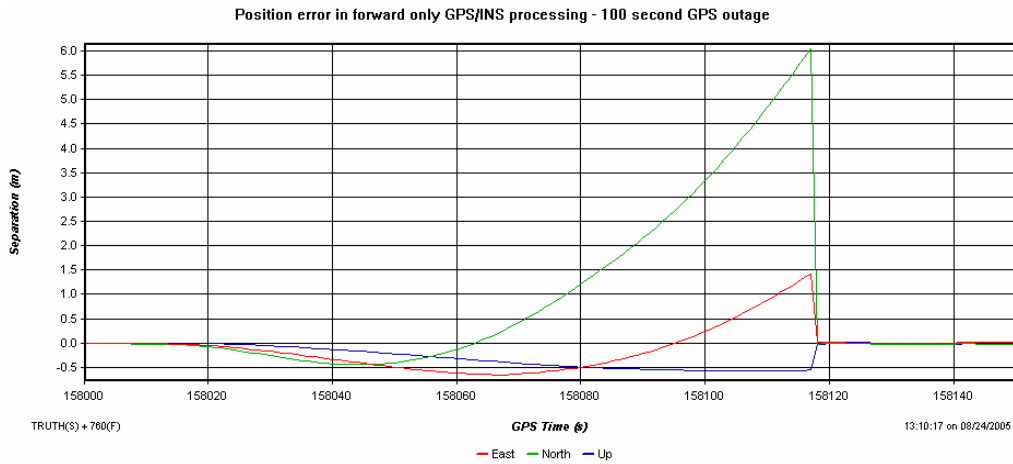


Figure 19: Position error in forward only processing during 100 second GPS outage

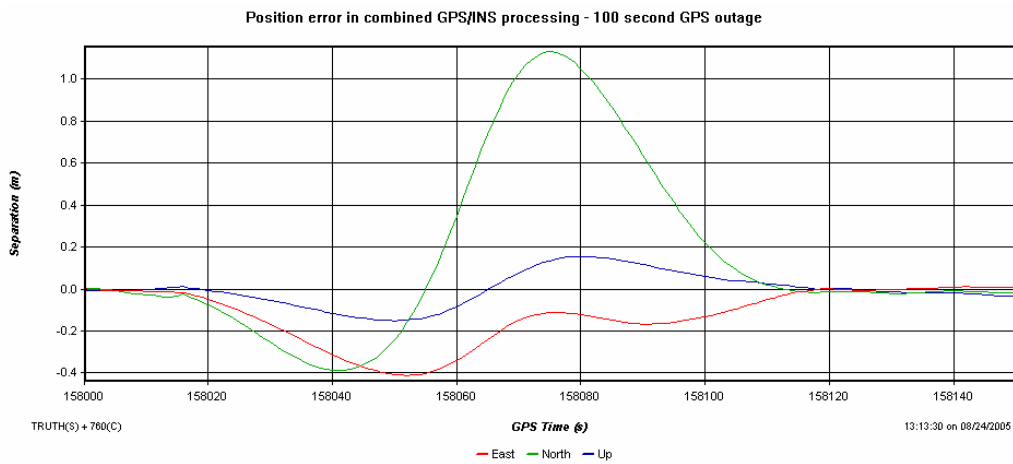


Figure 20: Position error in combined processing during 100 second GPS outage

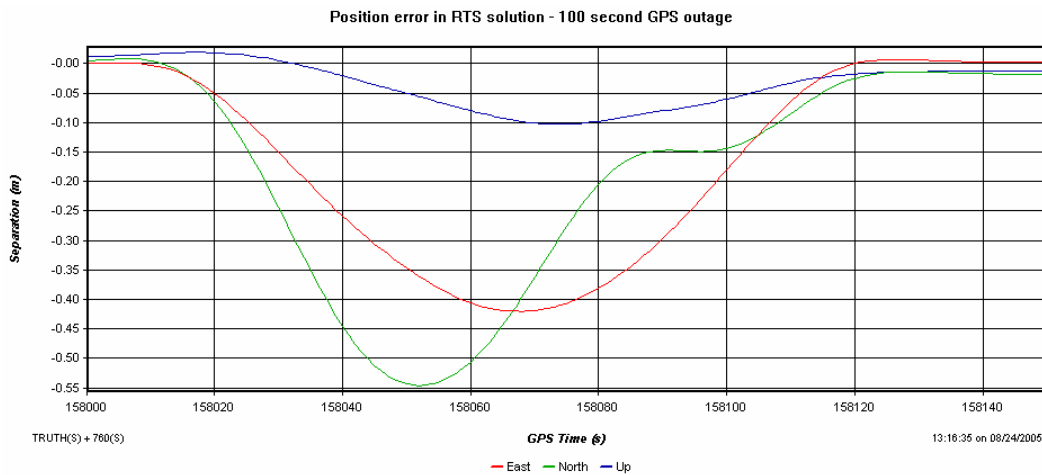


Figure 21: Position error in combined RTS processing during 300 second GPS outage

Velocity Error during 100 second GPS outage

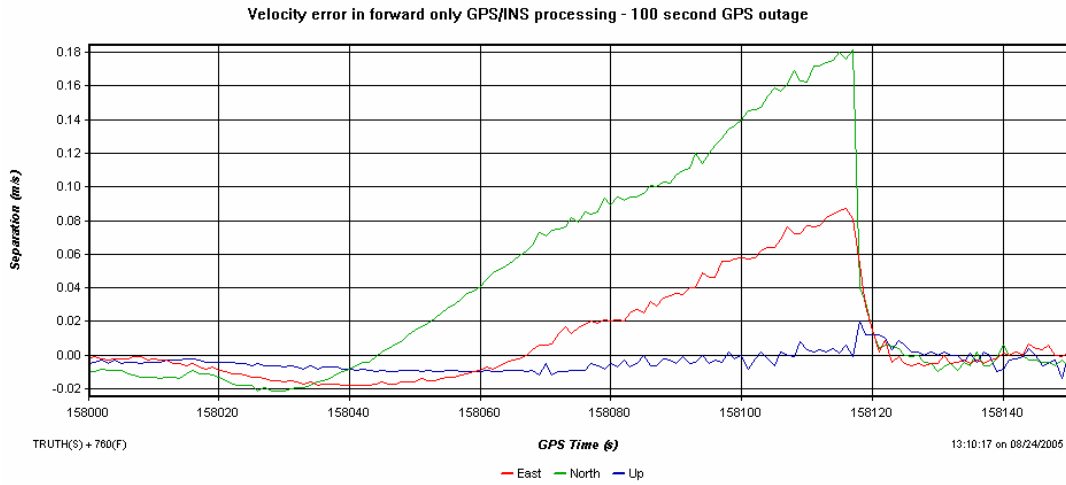


Figure 19: Velocity error in forward only processing during 100 second GPS outage

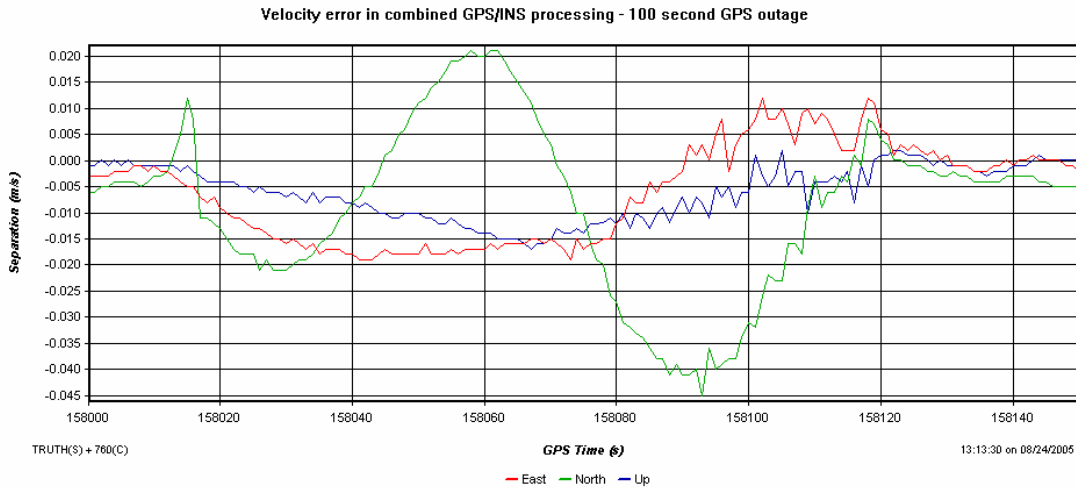


Figure 20: Velocity error in combined processing during 100 second GPS outage

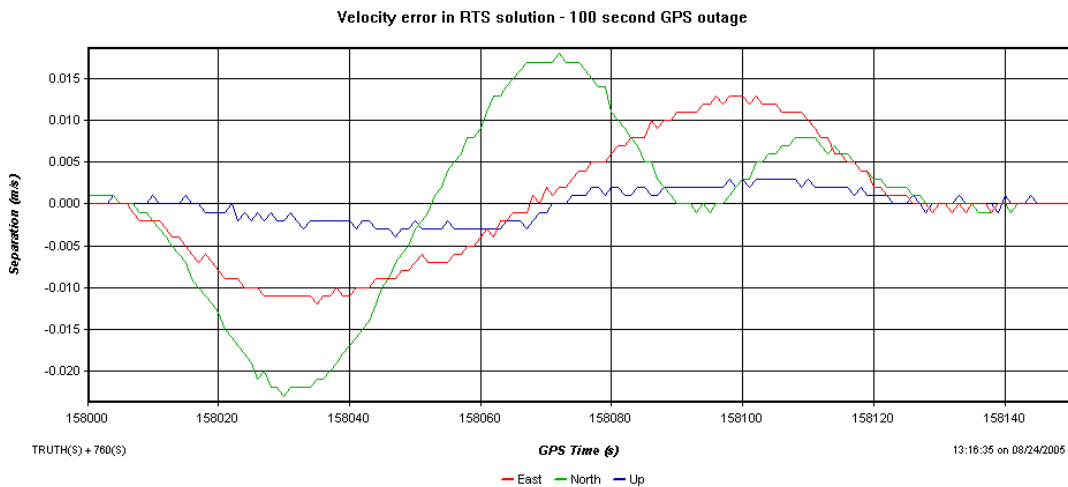


Figure 21: Velocity error in combined RTS processing during 100 second GPS outage

Attitude Error during 100 second GPS outage

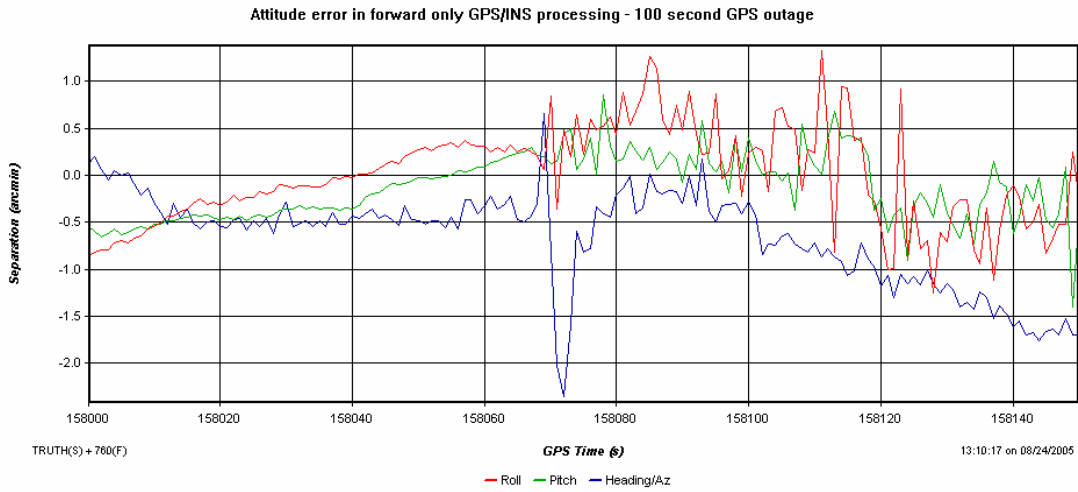


Figure 22: Attitude error in forward only processing during 100 second GPS outage

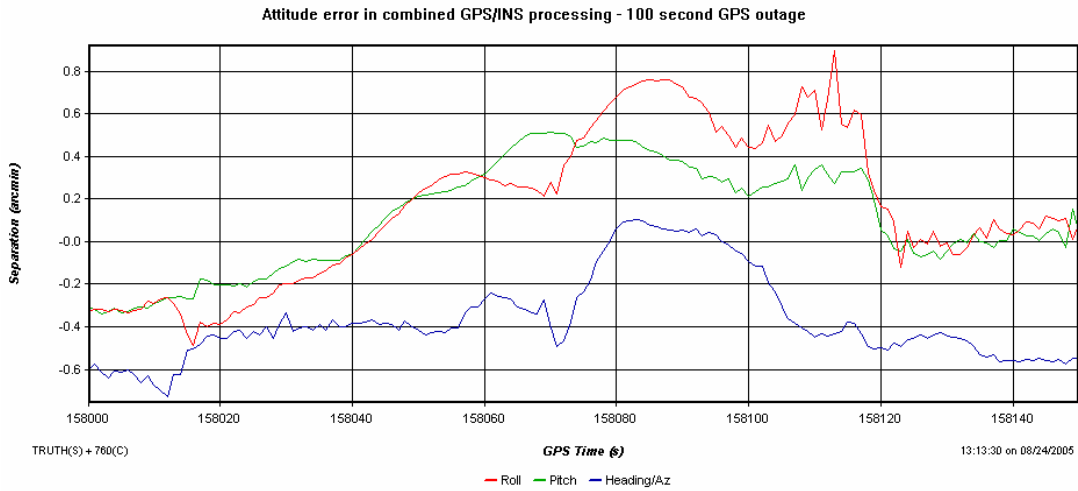


Figure 23: Attitude error in combined processing during 100 second GPS outage

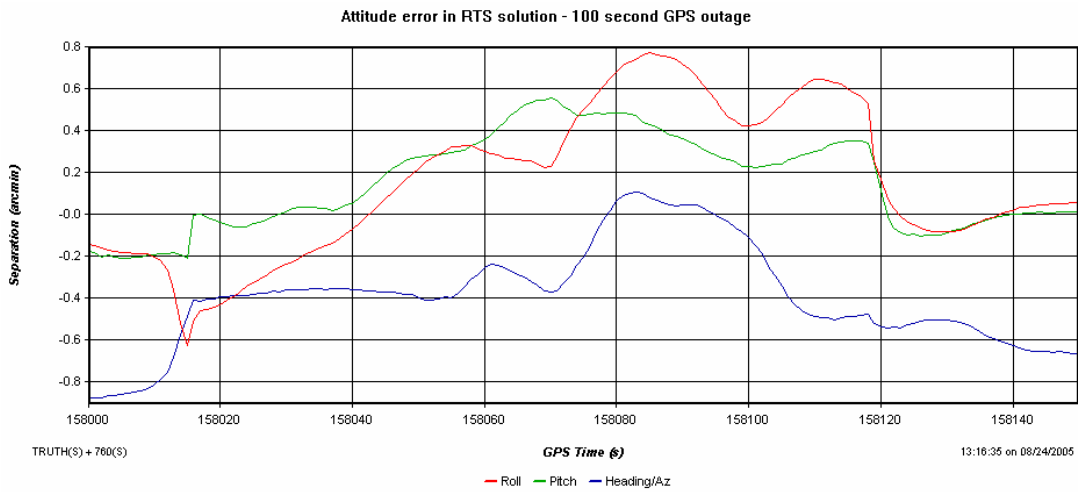


Figure 24: Attitude error in combined RTS processing during 100 second GPS outage

30 second GPS outage

Position Error during 30 second GPS outage

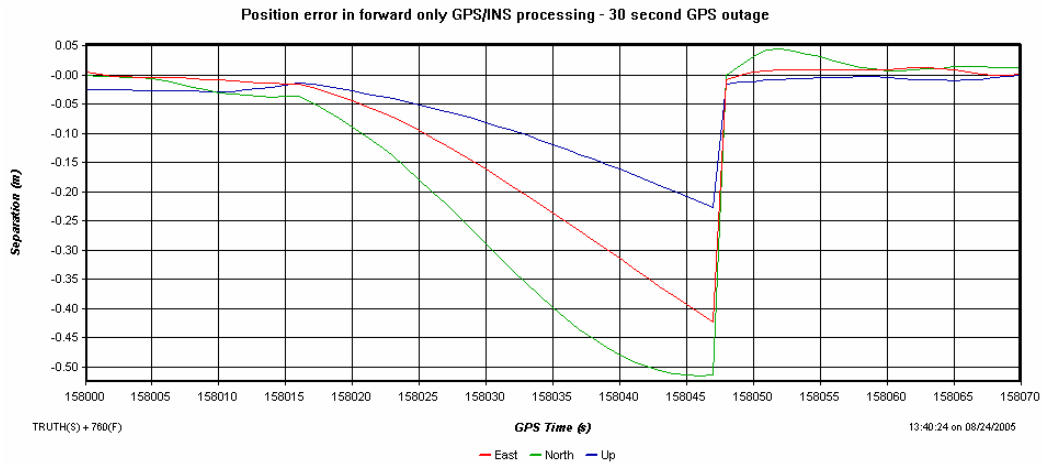


Figure 25: Position error in forward only processing during 30 second GPS outage

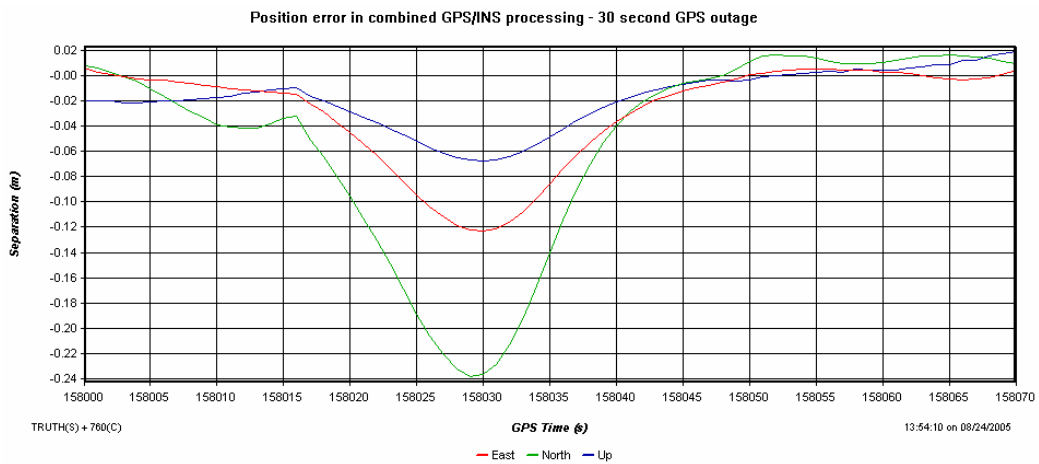


Figure 26: Position error in combined processing during 30 second GPS outage

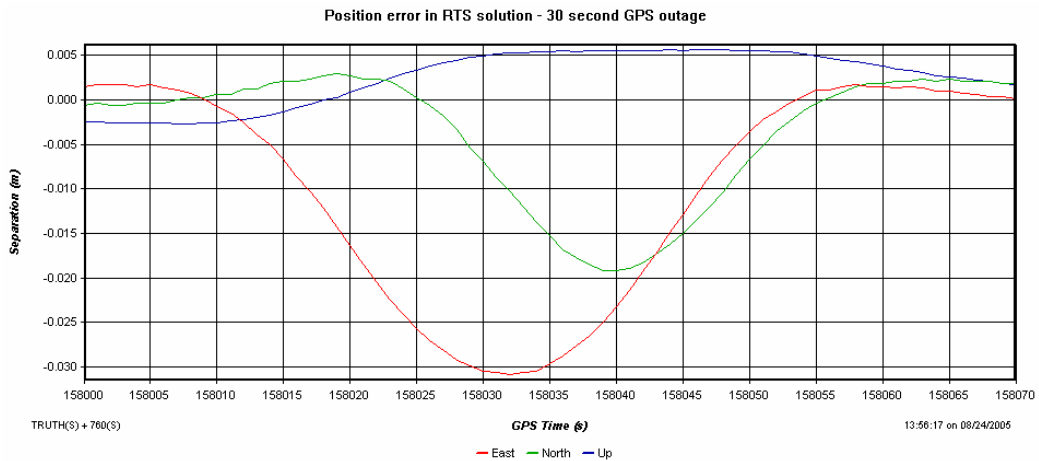


Figure 27: Position error in combined RTS processing during 30 second GPS outage

Velocity Error during 30 second GPS outage

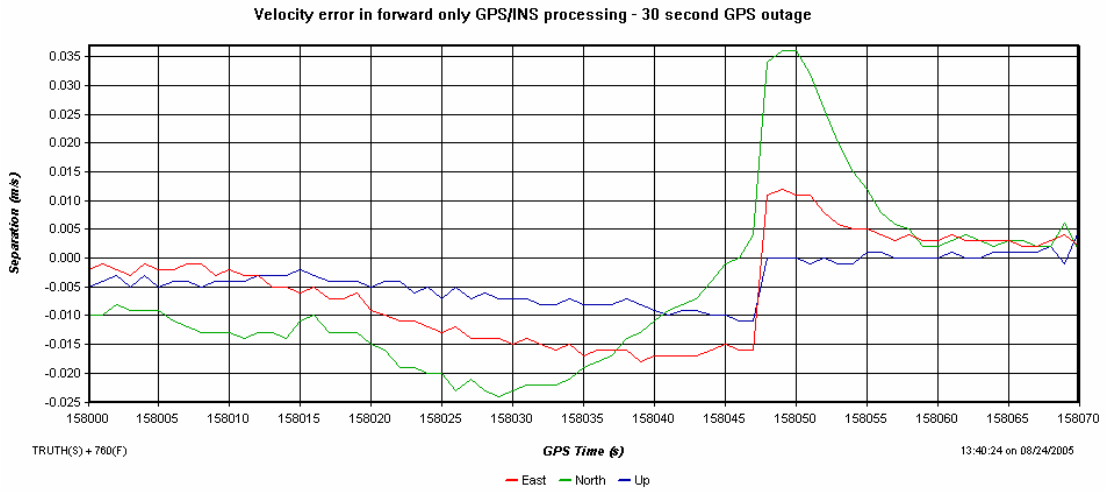


Figure 28: Velocity error in forward only processing during 30 second GPS outage

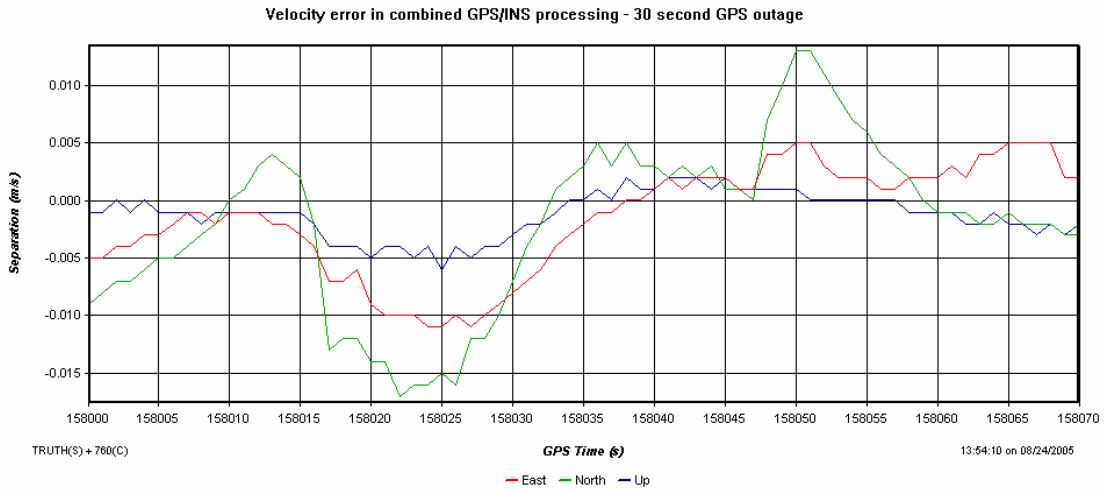


Figure 29: Velocity error in combined processing during 30 second GPS outage

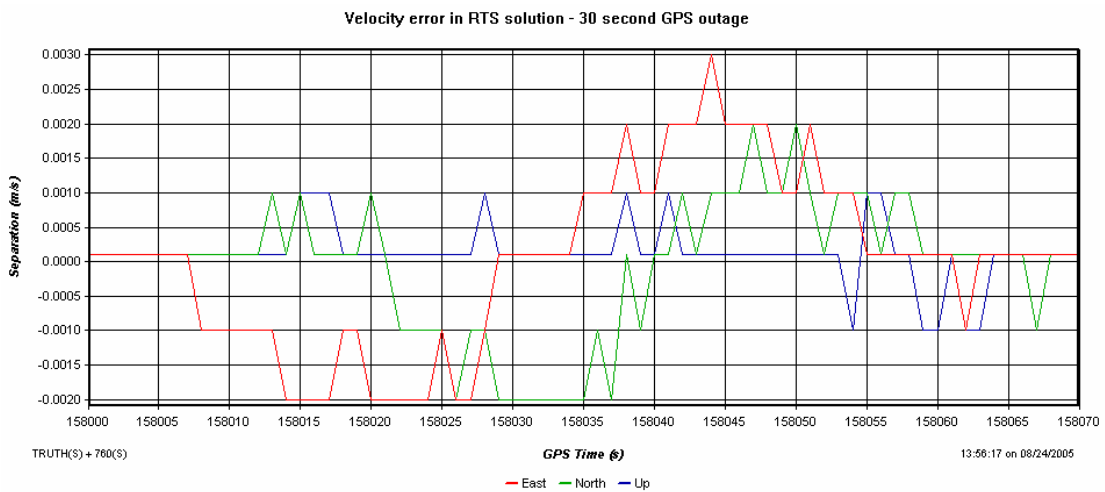


Figure 30: Velocity error in combined RTS processing during 30 second GPS outage

Attitude Error during 30 second GPS outage

Attitude error in forward only GPS/INS processing - 30 second GPS outage

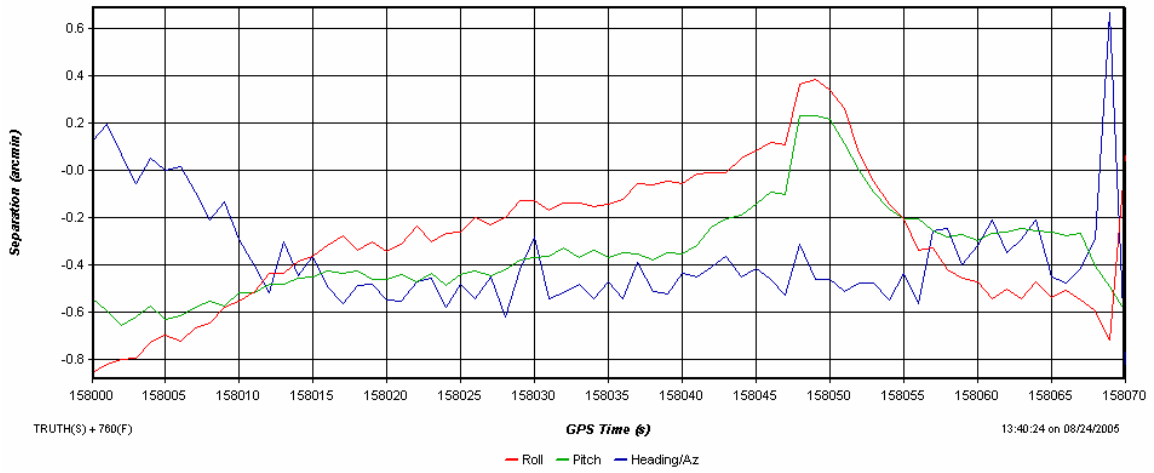


Figure 31: Attitude error in forward only processing during 30 second GPS outage

Attitude error in combined GPS/INS processing - 30 second GPS outage

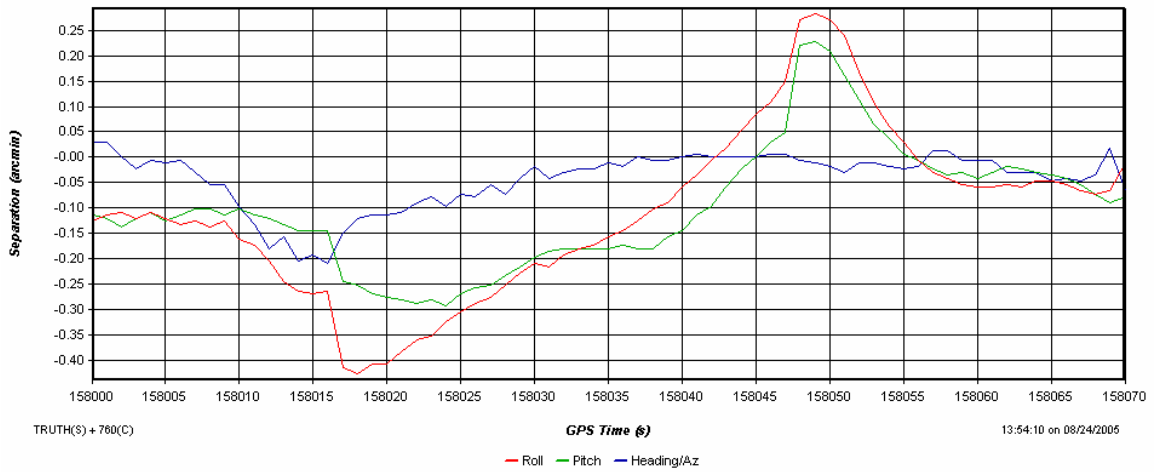


Figure 32: Attitude error in combined processing during 30 second GPS outage

Attitude error in RTS solution - 30 second GPS outage



Figure 31: Attitude error in combined RTS processing during 30 second GPS outage

Conclusions

The RTS smoother implemented by Waypoint Consulting in its newest version of Inertial Explorer (v7.60) has been shown to dramatically increase positional accuracy during periods of GPS data gaps. The effect is most pronounced in the 10 minute GPS data gap, where errors exceeded 350 meters in just the easting component in forward only processing. The largest error in the combined forward/reverse processing approached 110 meters in northing. In the RTS solution, the component with the largest error was the northing with less than 14 meters error. The RTS smoother thus improved the position accuracy by approximately 79% from what was previously possible in Inertial Explorer for this 10 minute data gap.

Large improvements are also seen in velocity. During the 10 minute data gap, the largest component error in velocity was just over two meters in northing. The combined forward/reverse solution reduced this error to just over 1.2 meters. The RTS smoother further reduced the error in velocity to a maximum of about 0.13 m/s for the majority of the test period, however one short spike of 0.20 m/s is also observed.

The effect of the RTS smoother on attitude is less obvious than its effect on position and velocity. The effect of GPS updates (position, velocity) is not directly related to attitude, and thus there is no strong correlation. The smoother has the effect of simply adding noise and thus either a very similar or slightly worse attitude solution is generally seen.

The RTS smoother is likely to be of most interest to users who conduct GPS/INS surveys under very difficult GPS conditions and require accuracies on the order of meters. In the five minute GPS data gap test, maximum total horizontal errors of approximately 61 meters were observed in forward only processing, 18 meters in combined forward and reverse processing, and 2.5 meters when using the RTS smoother. This is a major improvement and is likely to benefit many applications.