Observed Differential Carrier Phase Float Accuracies on three Kinematic Surveys using a u-blox Antaris GPS Receiver under Open Sky Conditions

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Three kinematic tests were conducted on separate days, the 6th, 18th, and 20th of May 2005. All tests were conducted under near prairie-like conditions in rural areas of South-East Calgary, Alberta. Tests #1 and #2 were conducted in the same location, with baseline distances at a maximum of 4 kilometers. The baseline distances in test #3 ranged from 9.3 km to 16.5 km.

A Novatel 3151 provided base station data for all tests, which was logging data from an antenna on the roof of Waypoint's office building. All remote data was flagged as kinematic and processed with GrafNav 7.50 at 1 Hz with a 10 degree elevation mask. The antenna used at the remote was a high quality Novatel GPS 600-LB.

On all baselines, a float solution is processed which does not attempt to fix satellite ambiguities to integer values. However, techniques that resolve satellite ambiguities with single frequency data such as Kinematic Ambiguity Resolution (KAR) or a fixed static initialization were used to establish a truth trajectory. This was possible only because the surveys were performed under open skies and otherwise good field procedures were used to allow these techniques to succeed. The truth trajectory is in each case compared to Waypoint's combined forward/reverse float solution.

GrafNav processes GPS data both forward and backwards in time. Forward and reverse processing can be considered independent provided the available satellite constellation is sufficiently different at the start and end times of the survey.

Plots presented for each kinematic survey are as follows:

- Number of satellites used in solution
- C/A code RMS
- L1 phase RMS
- Forward/reverse solution separation
- Comparison of float trajectory to truth trajectory

The number of satellites used in the solution summarizes the degree to which signal obstructions were a factory in the survey. This plot shows at a glance where and for approximately how long any satellite drop-out's occurred. The C/A code and L1 phase RMS plots summarize the raw measurement quality output by the receiver. The forward/reverse solution separation is an indication of both accuracy and solution reliability. If both independent solutions agree closely you can be confident your solution is reliable. This plot is also a conservative estimate of accuracy as the final trajectory output by GrafNav is weighted between both solutions.

In order to best see the accuracy of the float solution, it is desirable to compare with a truth solution. The conditions of all the surveys were such that a fixed integer solution was successfully processed, and this trajectory was used as the truth solution. Note that these techniques should only be used under open sky conditions and short master-remote separations.

Kinematic Post Processing Analysis

Kinematic Test #1

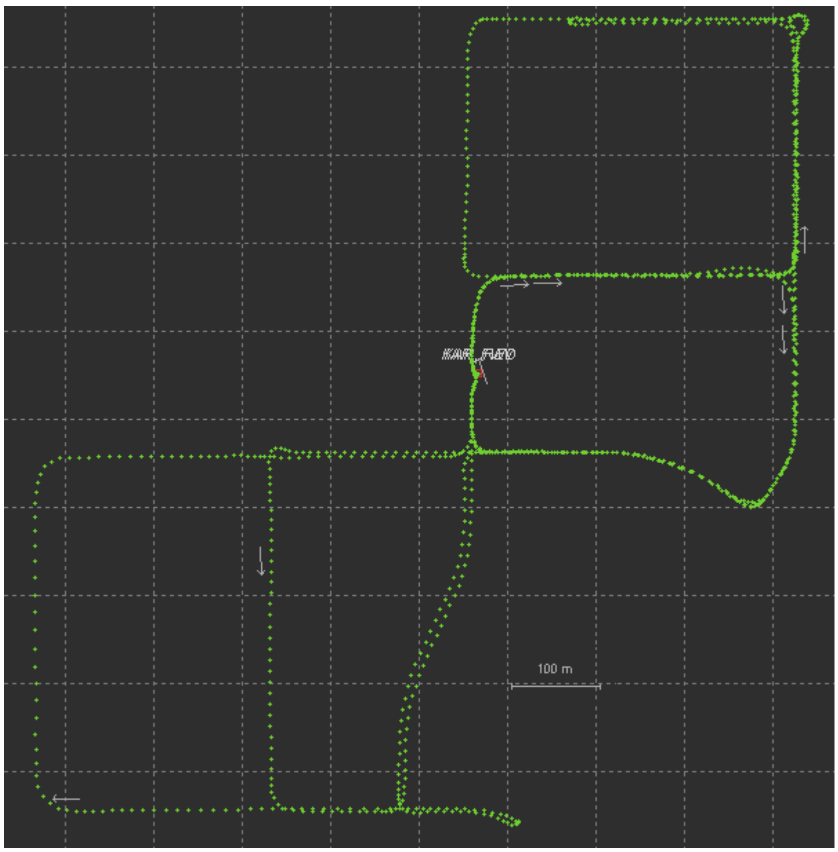

Figure 1: Trajectory for Kinematic Test #1

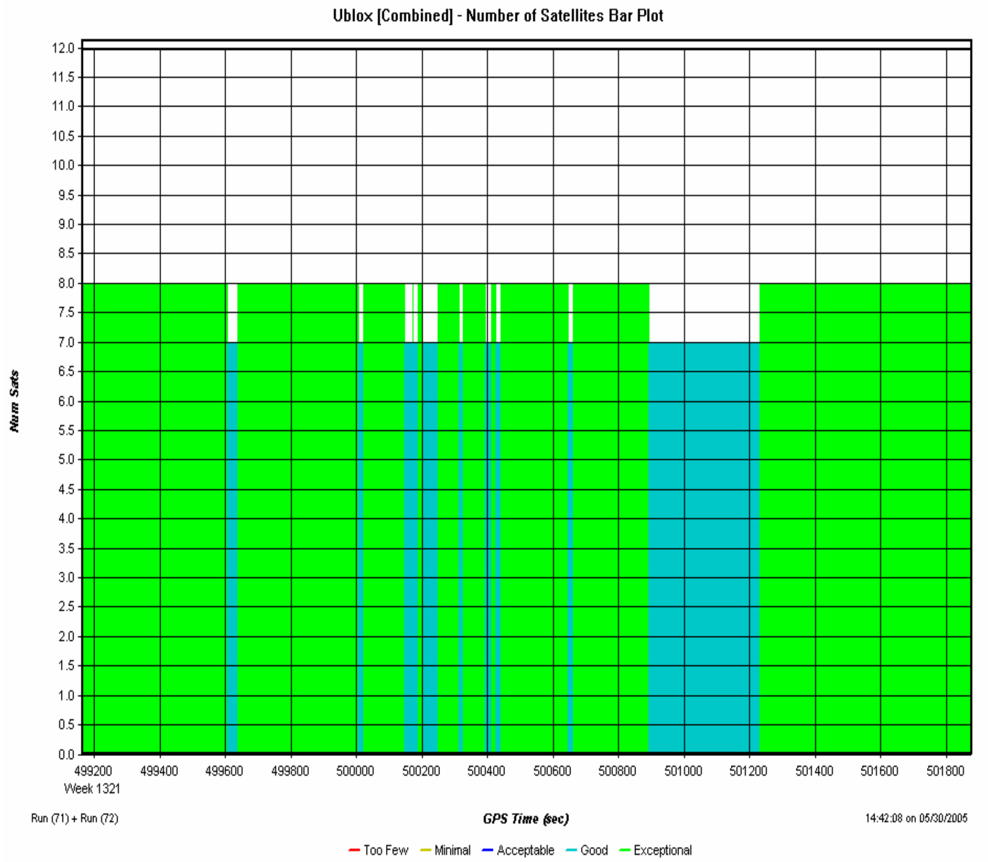

Figure 2: Number of SV's used in Solution for Kinematic Test #1

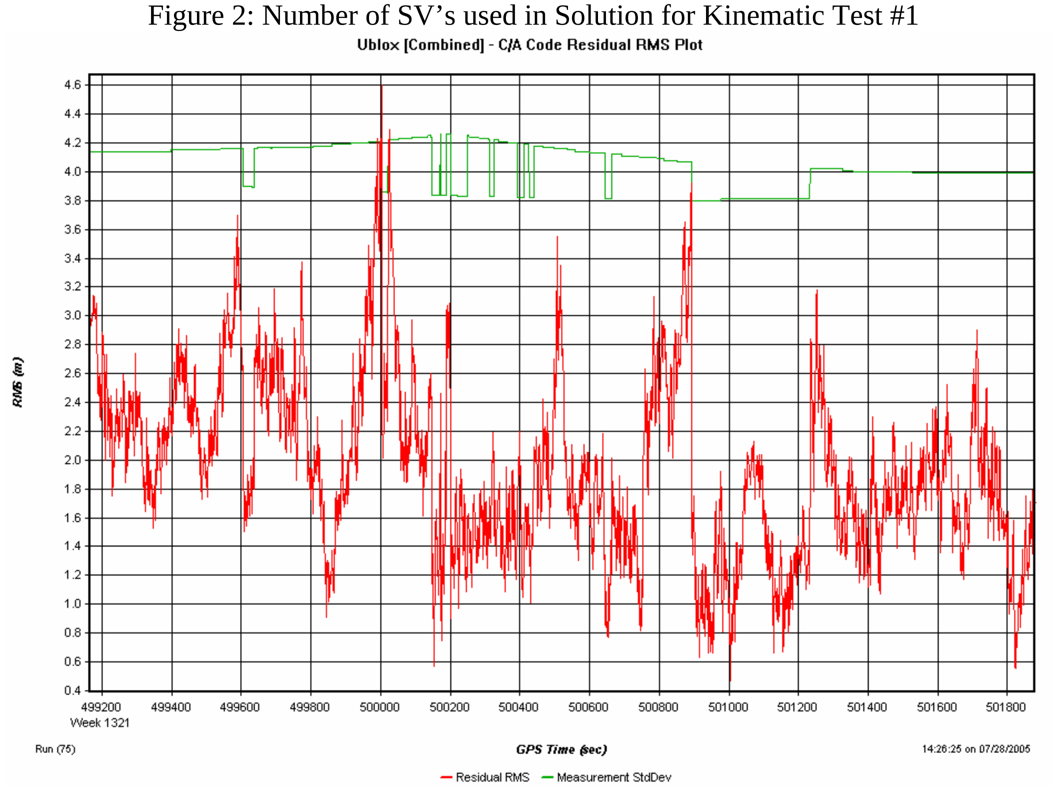

Figure 3: C/A code RMS during Kinematic Test #1

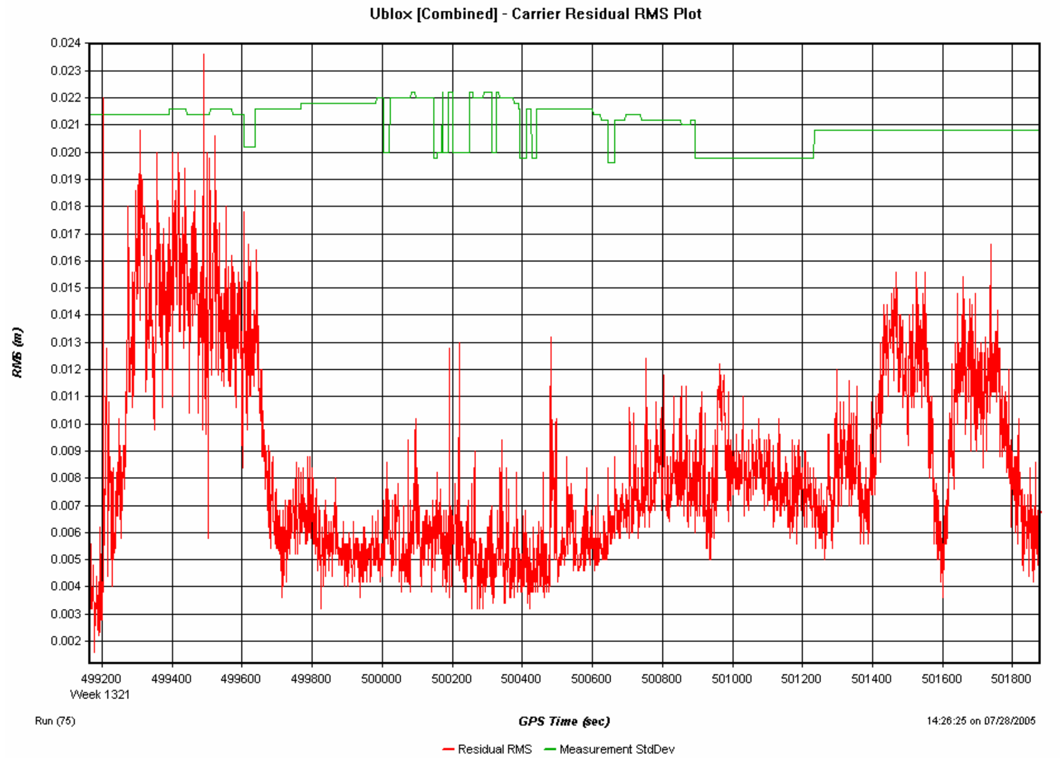

Figure 4: L1 Phase RMS during Kinematic Test #1

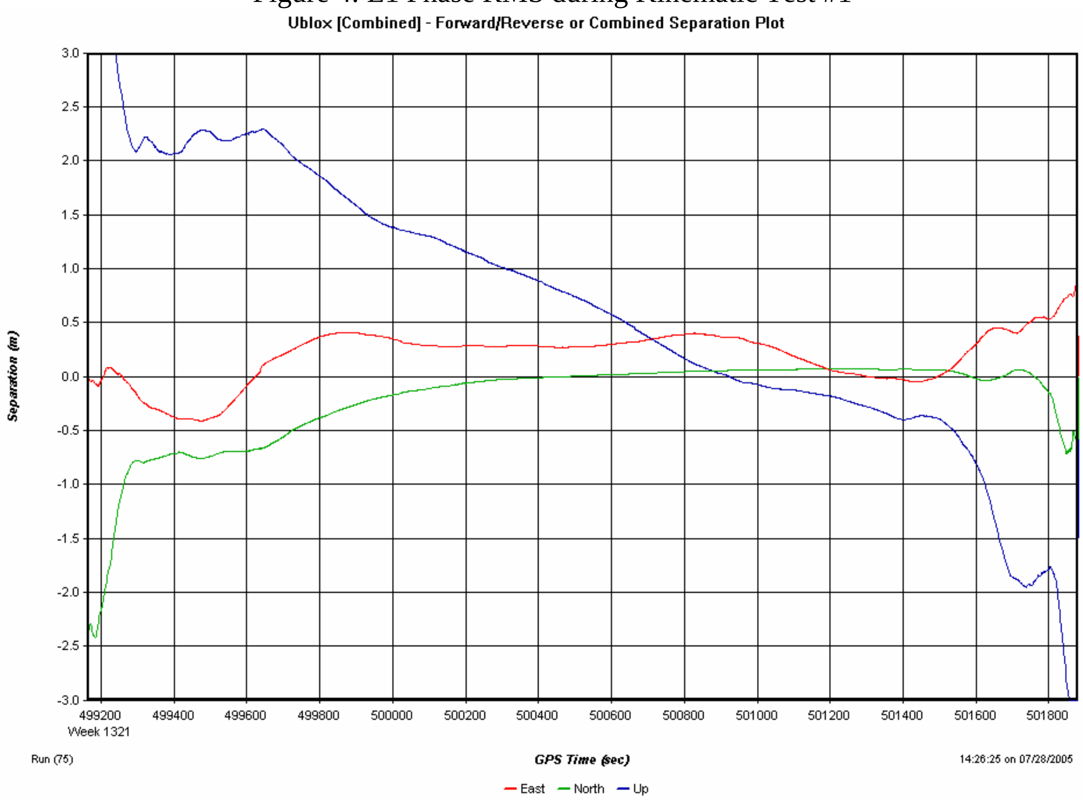

Figure 5: Forward/Reverse Separation for Kinematic Test #1

The C/A code RMS plot (figure 7) shows distinct ramping effects, the largest occurring at the beginning of the survey. A ramping trend is also apparent in the L1 phase residuals, especially at the beginning of the data set. This is an indication of multipath, likely caused by GPS signal reflections from a large truck that was temporarily parked nearby. There were also several cars and trucks parked nearby belonging to construction crews working in the area.

The separation shown in figure 5 is considerably larger at the beginning and end of the survey than in the middle. This is because float solution accuracy improves with time providing a simultaneous loss of lock is not observed on all satellites. Therefore at the ends of the data, a very well converged solution is being compared with a solution that has just begun to converge. These solutions are combined in GrafNav to produce a weighted final trajectory.

A truth solution was processed using KAR, the difference in this weighted solution and the truth solution is as follows.

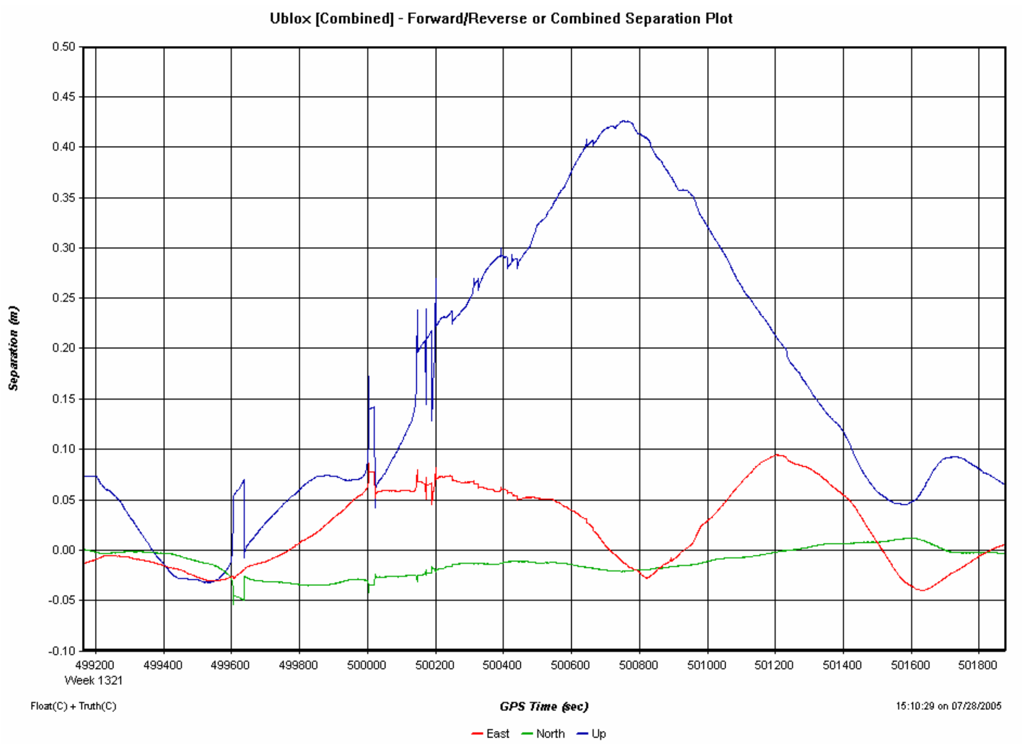

Figure 6: Accuracy of Float Solution for Kinematic Test #1

Horizontally, the float solution appears to be within 10 cm from the truth trajectory for the entire duration of the survey. Vertically, the solution agrees quite well at the beginning and end of the survey, but this is expected as the float solution is well converged at the end of the survey in both processing directions. The error in height is at most observed to be approximately 43 cm.

Kinematic Test #2

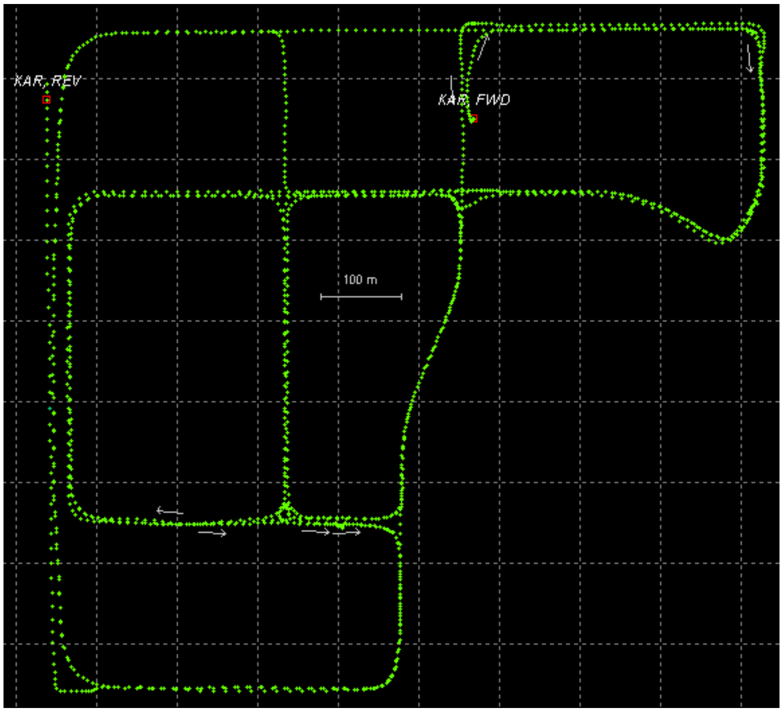

Figure 7: Trajectory for Kinematic Test #2

Figure 8: Number of SV's used in u-blox Solution during Kinematic Test #2

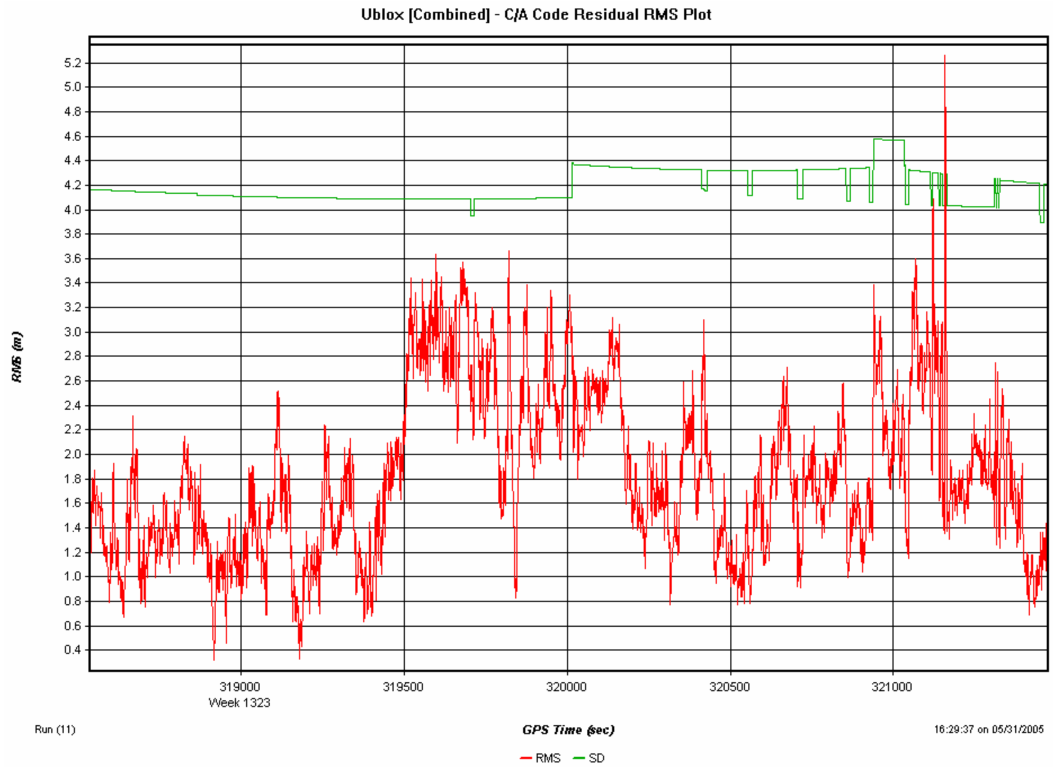

Figure 9: Code RMS during Kinematic Test #2

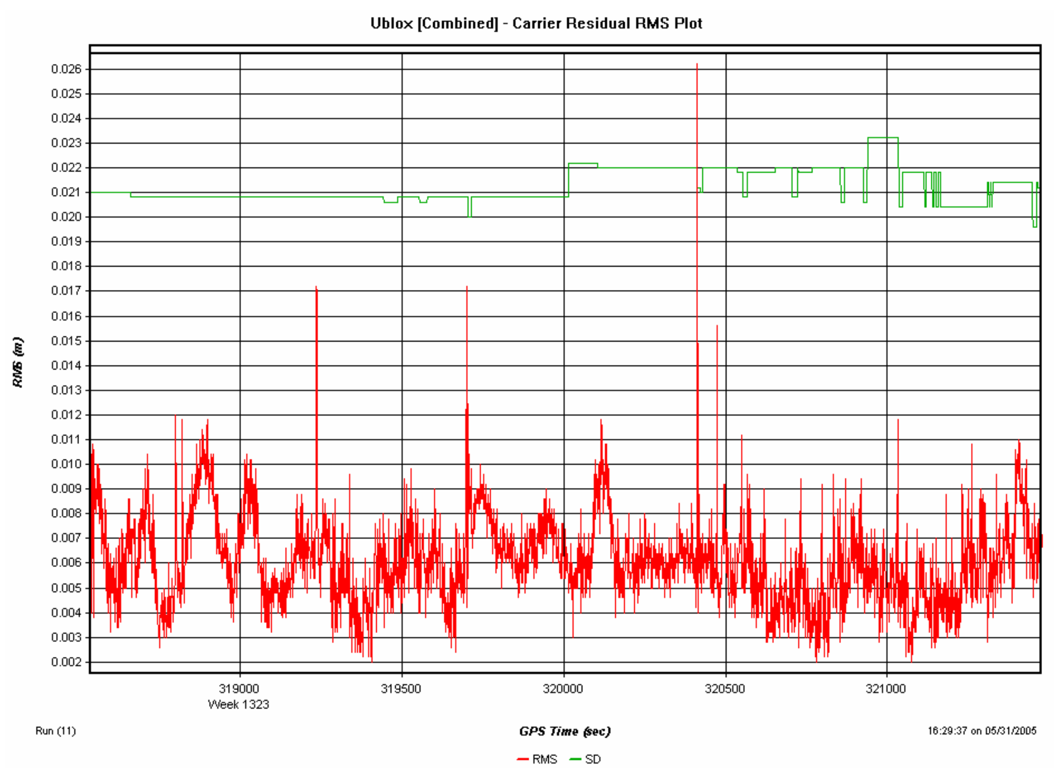

Figure 10: L1 Phase RMS during Kinematic Test #2

The ramping effects shown in figure 9 is an indication of multi-path, however values such as these are not unusual for this type of survey. As well, there are several spikes in the phase plot indicating periods of elevated noise. There are again however not out of the ordinary for any typical ground survey.

The survey was conducted under favourable GPS conditions as figure 8 indicates. This graph shows a minimum of eight satellites were observed for most of the survey, although there were brief periods where only 6 and 7 satellites were observed due to passing signal obstructions such as large trucks. Shown below is the forward/reverse separation of the float solution.

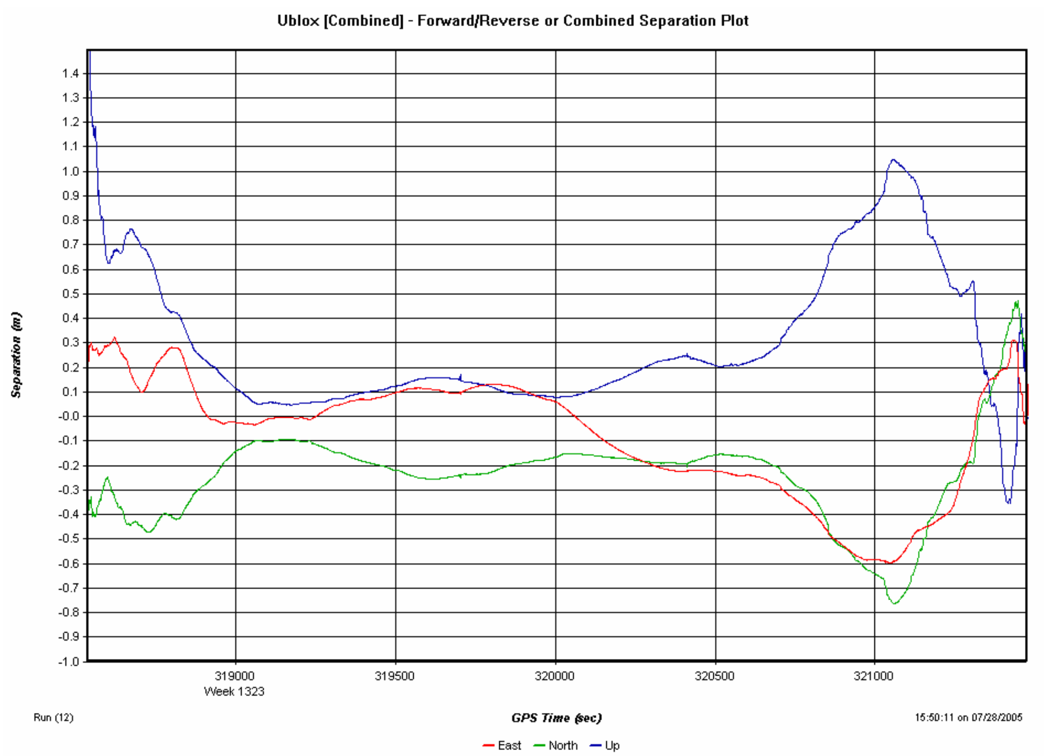

Figure 11: Forward/Reverse Separation of Float Solution for Kinematic Test #2

As in kinematic test #1, a truth solution was processed and used to show the absolute accuracy of the GrafNav forward/reverse weighted float solution, which is shown below.

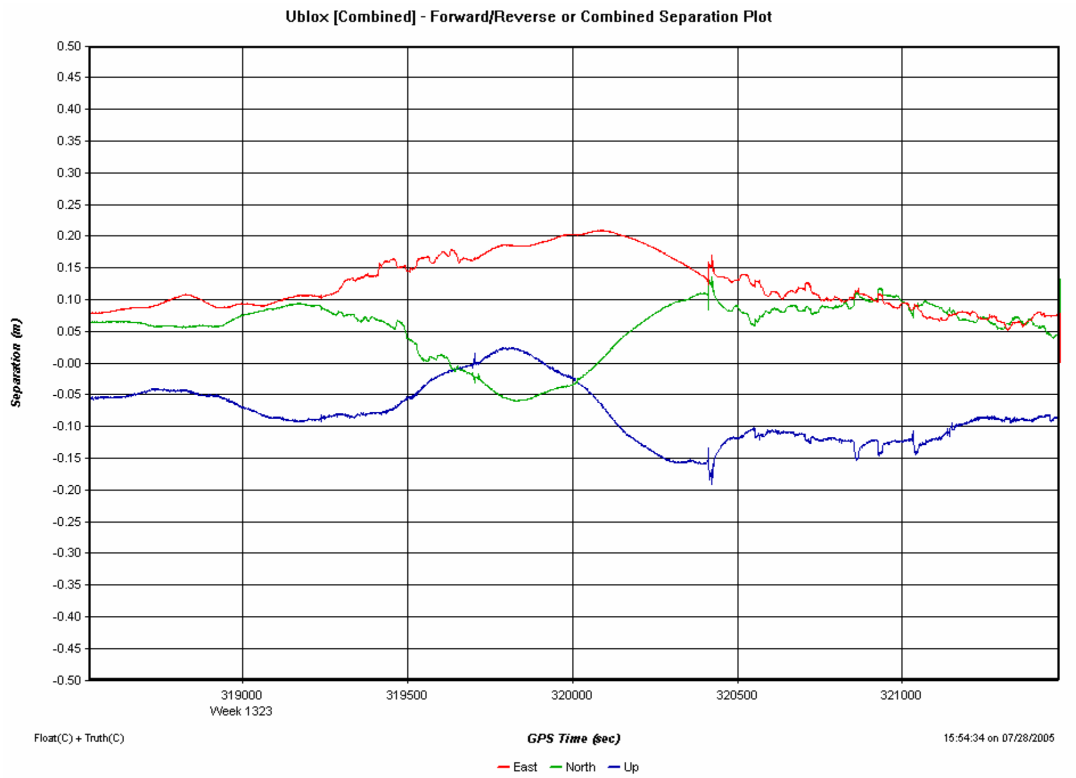

Figure 12: Accuracy of Float Solution for Kinematic Test #2

Horizontally, the accuracy of the float solution is again best at the beginning and end of the survey. This was seen in kinematic test #1 as well and is expected. The general quality of this survey was better, however, as the height is at most in error of about 20 cm.

Kinematic Test #3

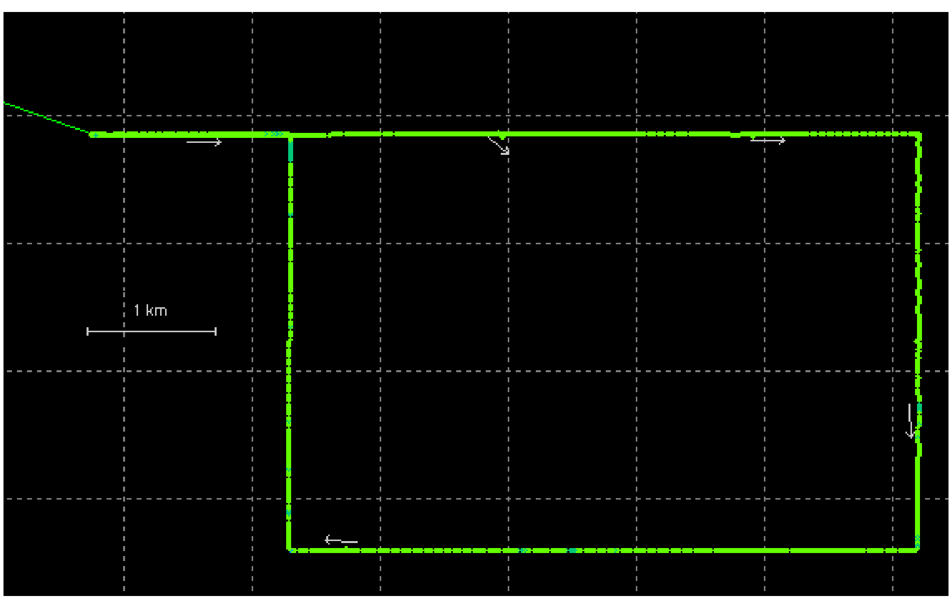

Figure 13: Trajectory for Kinematic Test #3

Kinematic test #3 differed from #1 and #2 in that the baseline lengths were much longer. The kinematic survey began 9.3 km from the base station and was approx 16.5 km away at its farthest point.

The following graphs summarize the GPS quality, raw measurement quality and forward/reverse separation of the float solution.

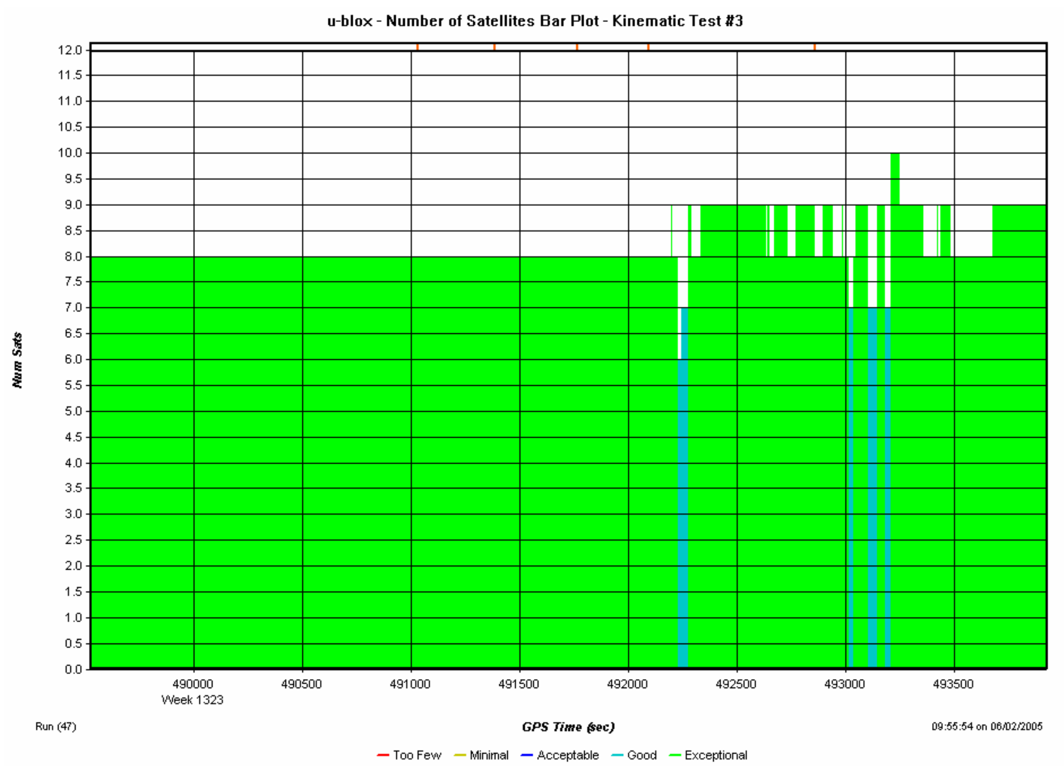

Figure 14: Number of SV's in Solution for Kinematic #3

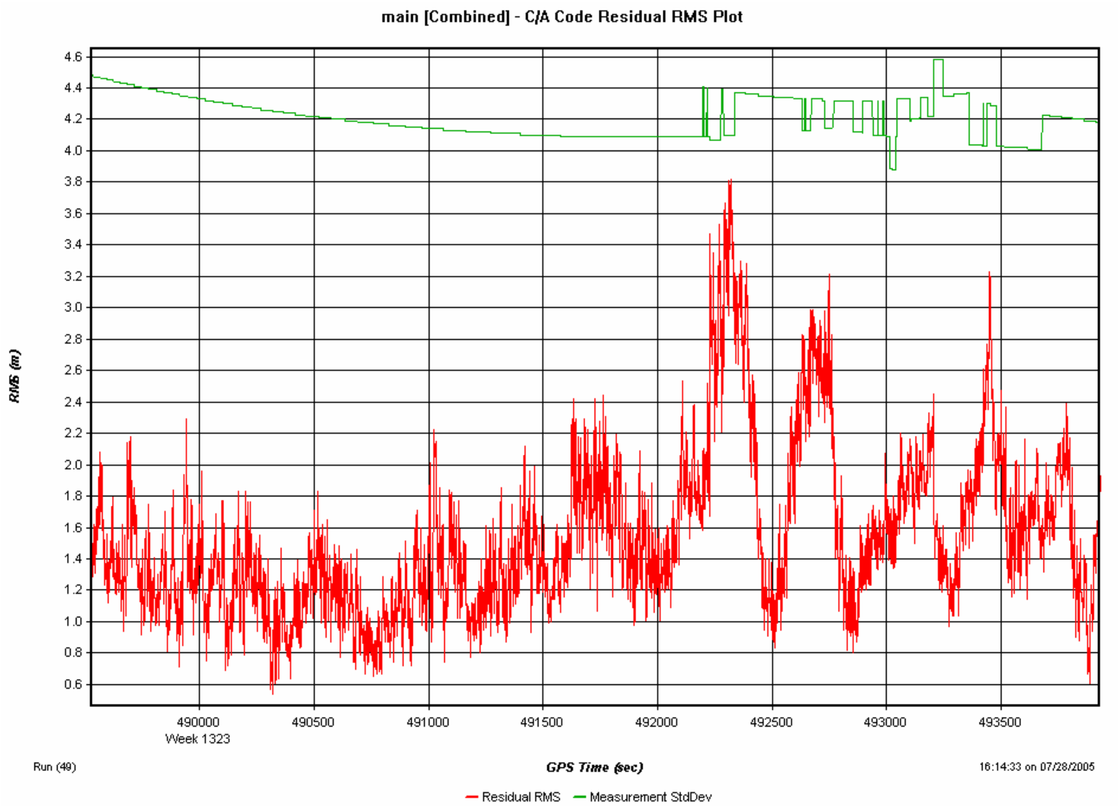

Figure 15: C/A code RMS during Kinematic Test #3

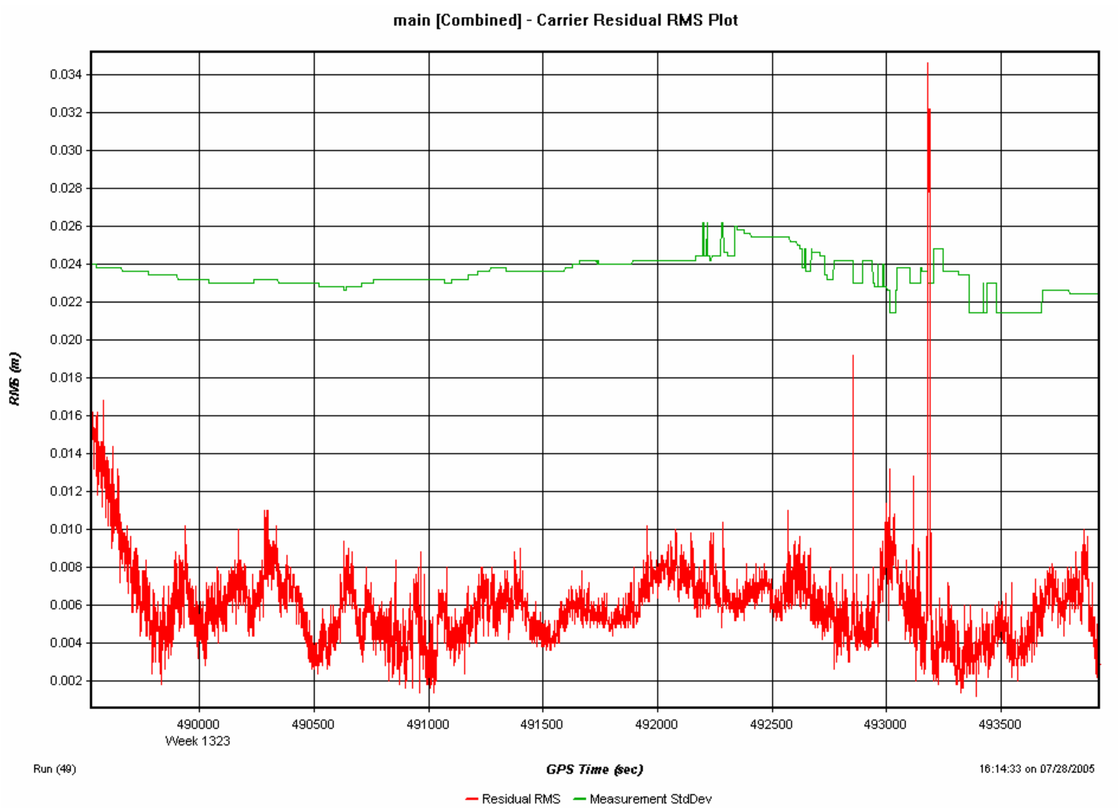

Figure 16: L1 Phase RMS during Kinematic Test #3

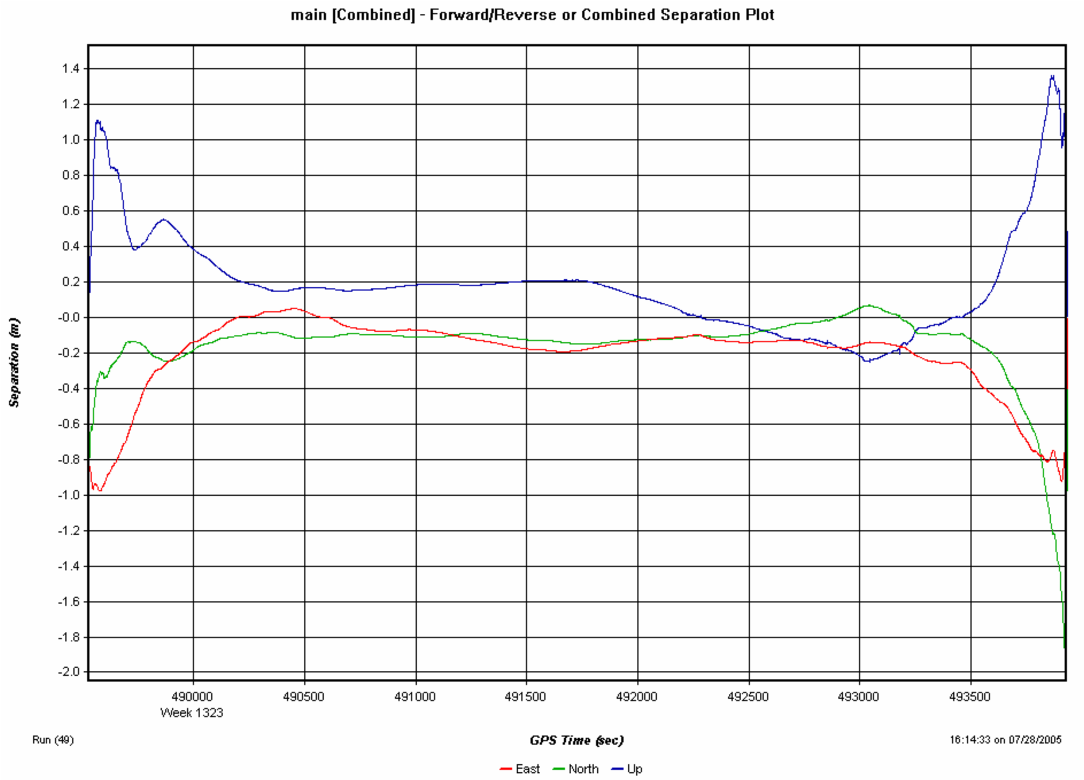

Figure 17: FWD/REV Separation of Float Solution in Kinematic Test #3

Once again, the code and phase RMS plots do not show anything particularly a-typical for this kind of survey. The survey was conducted under open skies and generally very good GPS conditions. There were brief periods of satellite drop outs due to passing near large trees, however simultaneous lock was maintained on a minimum of six satellites at all times.

As in tests #1 and #2, a truth solution was processed. This truth solution was not performed using KAR, as single frequency KAR is very unreliable at these baseline distances. Rather, static data was collected at the beginning and end of the data and a fixed static initialization was processed. This solution was compared to the float solution below.

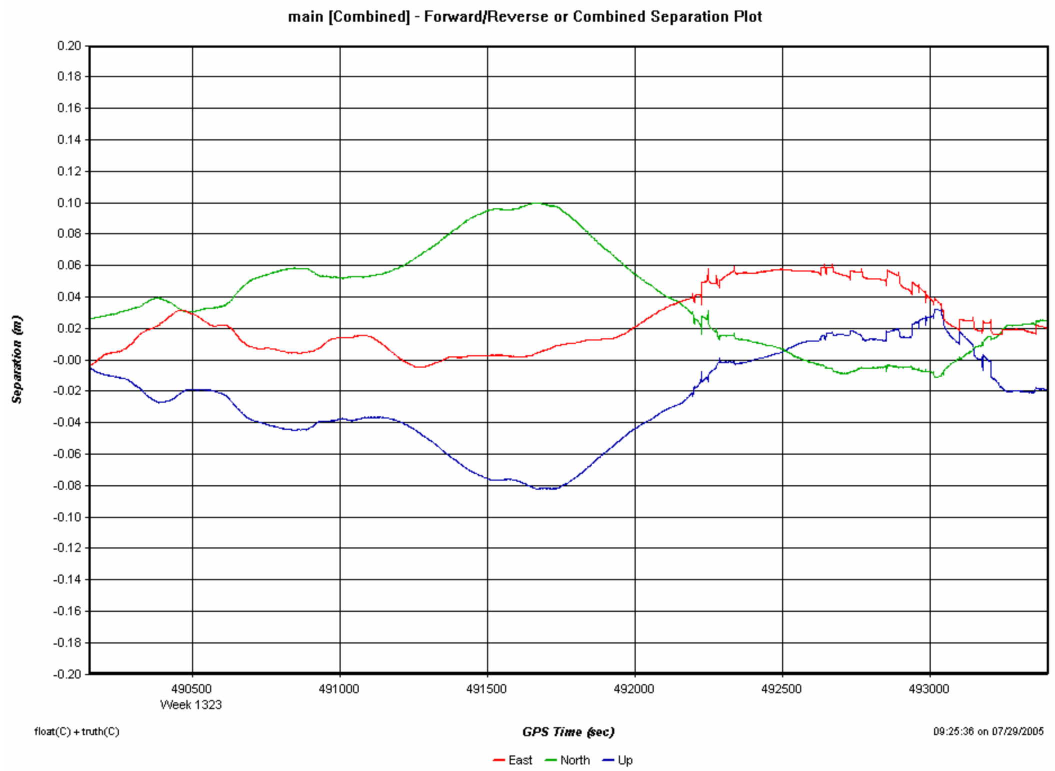

Figure 18: Accuracy of Float Solution for Kinematic Test #3

Horizontally, accuracies were largely within 10 cm for the duration of the kinematic survey and vertically the float solution is in error at most about 8 cm.

Conclusions

Results obtained from the three kinematic surveys are considered to be very good, especially considering the low cost of the u-blox Antaris. It should be remembered that these surveys were conducted under very open conditions with only a few signal obstructions such as large trucks and trees on the side of the road. It is also important to stress that high quality base station data was used (Novatel 3151) and a high quality antenna was used at the remote location.

The raw measurements output by the receiver were typical of marine or prairie surveys, and of sufficiently high quality to allow ambiguities to be fixed and used as truth solutions. Ambiguities would not have been likely resolved in Freeway or treed data, and the same accuracies would not have been seen. Float accuracies for the surveys were found be at worst 43 cm in height in kinematic test #1, however the other two tests saw maximum errors in height not exceeding 20 cm. The float trajectory computed by GrafNav is a weighted solution from both forward and reverse processing and thus is of higher accuracy than would be observed in an RTK solution or forward only post-processing. Further tests would be useful in a variety of GPS environments, including those in more urban environments.