WAAS Technical Report
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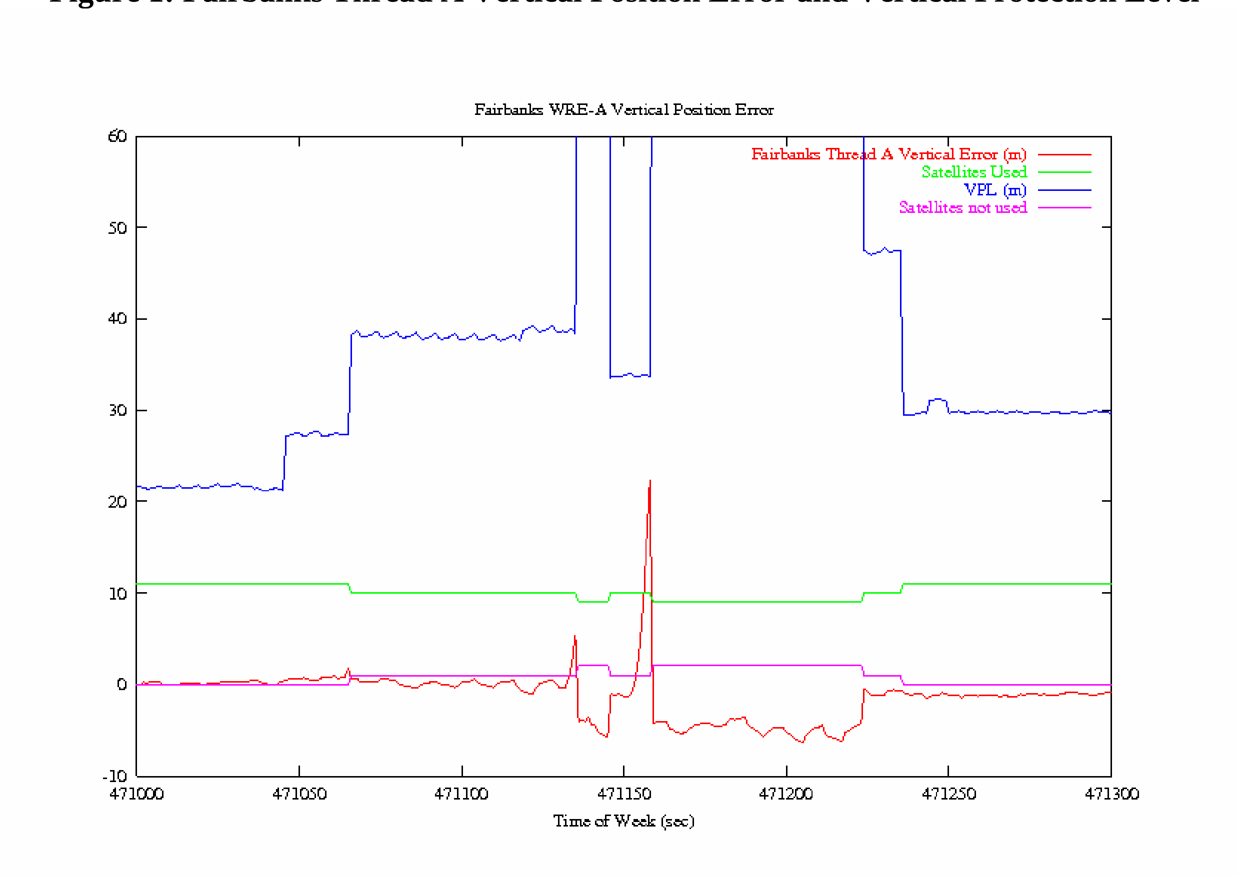
DR#52: Ionospheric Scintillation caused High Position Errors at Fairbanks
GPS Week/Day: Week 1420 Day 5 (March 30, 2007)

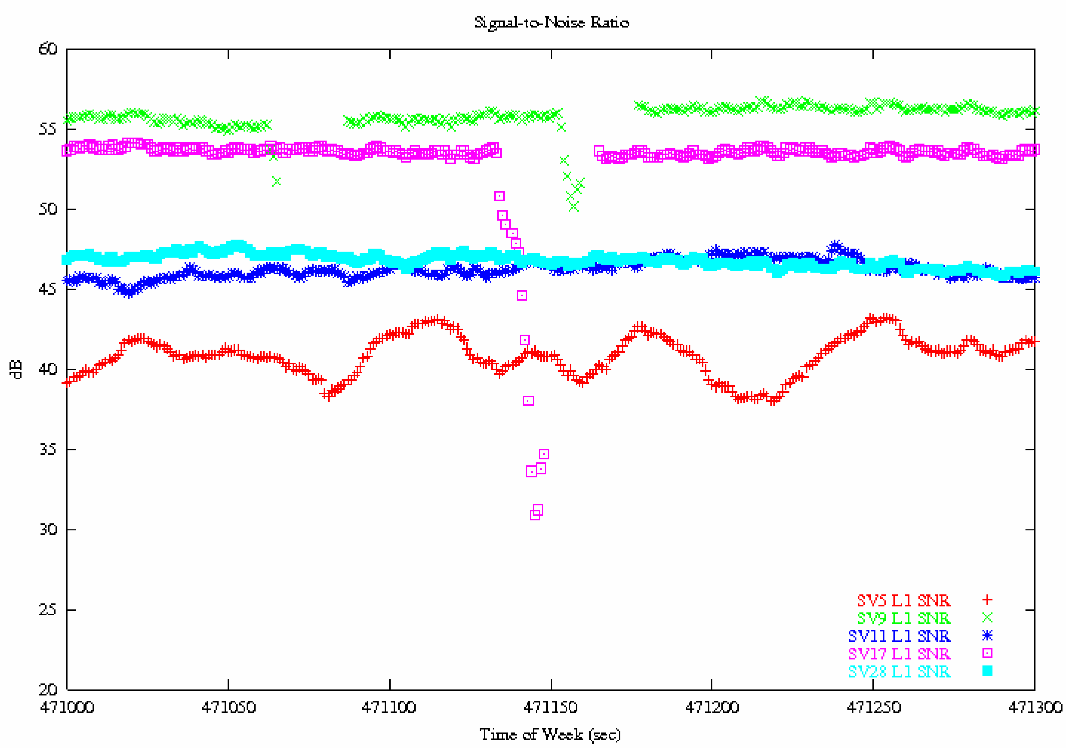
Discussion: On March 30, 2007 (GPS Week 1420 Day 5), large vertical position errors (VPE) were observed at Fairbanks WAAS reference receiver thread A (WRE-A). The vertical errors occurred when WAAS vertical protection levels (VPL) were less than 50 meters, which would allow LPV operations. The maximum vertical error during the event that lasted five seconds was 22.492 meters at 471158 GPS time of week (GMT 10:52:38) and is shown as the red trace on Figure 1. It should be noted that the VPE did not exceed the VPL at any period. The horizontal errors were unaffected during the event reaching a maximum error 1.879 meters. The ratio of the vertical position error (VPE) divided by the VPL was also high (0.669) indicating the VPL (blue trace in figure 1) did not increase at the time of the event. The VPL increased when satellite measurements were rejected from the navigation solution or dropped from receiver tracking.

Figure 1: Fairbanks Thread A Vertical Position Error and Vertical Protection Level



The sharp increase in VPE was incidental to satellite tracking interruptions of PRN 9 and PRN 17, which were at relatively high elevations of 64 degrees and 55 degrees respectively. The L1 signal strength of carrier to noise (C/No) for the satellites are shown on Figure 2 and sharply decrease for PRN 9 & 17 before and during the time of the anomalous VPE. The signal strength of other satellites tracked remained unaffected with a subset of receiver satellite C/No shown on figure 2 for reference.

Figure 2: Signal-to-Noise ratio of several satellites



Fairbanks threads B and C reference receivers also experienced high vertical errors and maximum VPL/VPE ratios. Thread B had a maximum vertical error of 21.456 and a maximum ratio of 0.638 shown in Figure 3. Thread C had a maximum vertical error of 15.665 and a maximum ratio of 0.461 shown in figure 4.

The satellite tracking problems were consistent at all three receivers at Fairbanks at the time of the maximum VPE. Figures 3 and 4 show the Vertical Position Errors and VPL for threads B and C respectively. The plots also indicate the number of satellites in use (green trace) during this time period. As can be seen from the plots, the vertical errors and VPL's on all three threads did not vary significantly during this time period. Thread C had a lower maximum vertical error than threads A and B because satellite 9 was dropped one second earlier on thread C than on the other threads.

Figure 3: Fairbanks Thread B Vertical Position Error and Vertical Protection Level

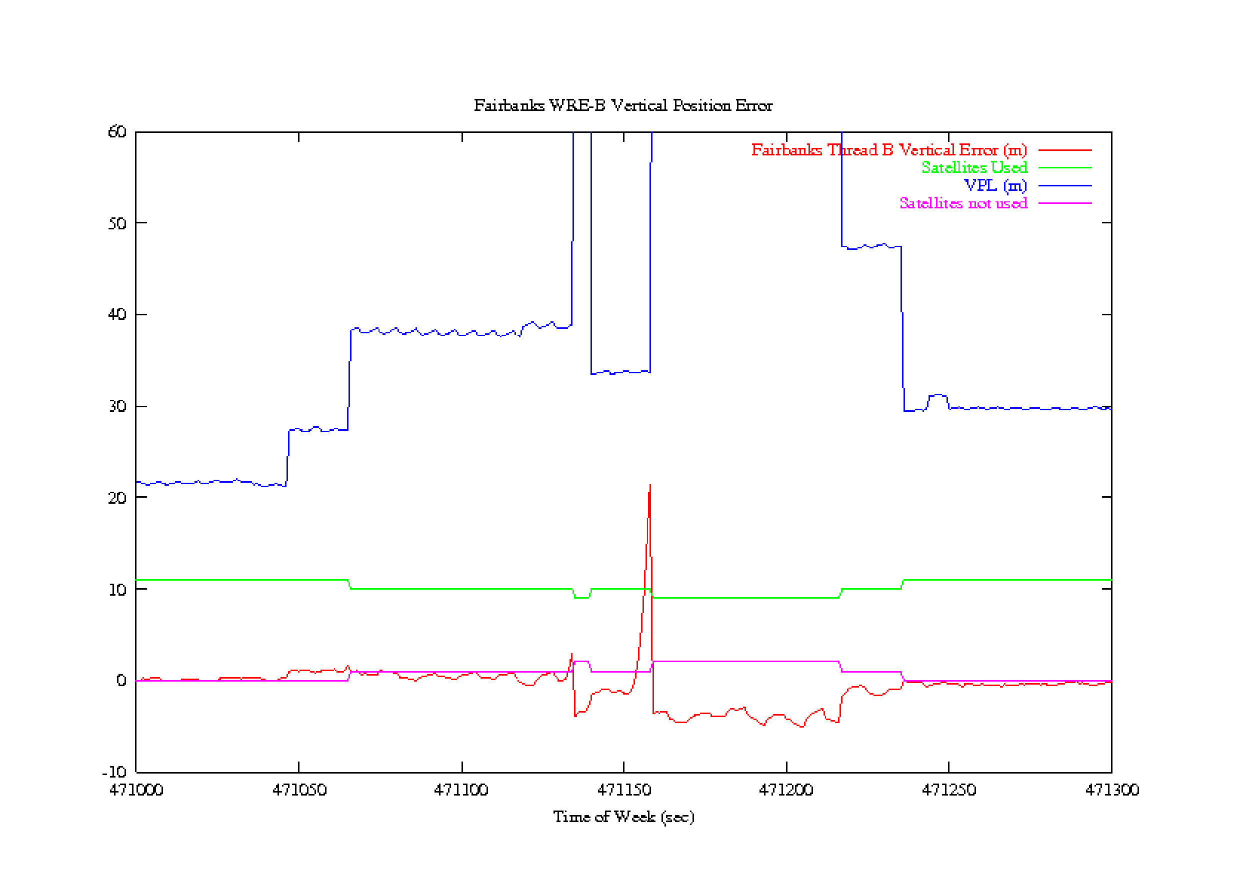


Figure 4: Fairbanks Thread C Vertical Position Error and Vertical Protection Level

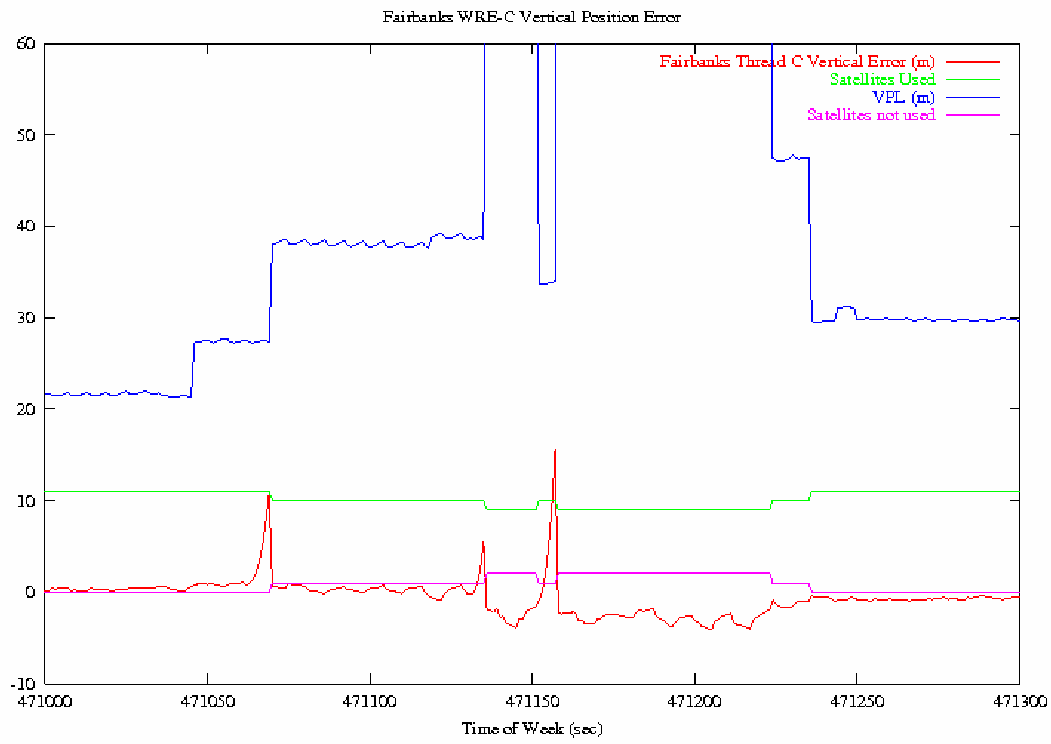


Figure 5 shows the range errors of several satellites tracked and used in the navigation solution during the VPE anomaly. The figure shows PRN 9 range error (shown as the green trace) magnitude increasing to –16 meters at the same time of the maximum vertical errors were observed. PRN 9 was subsequently dropped from the receiver track list and removed from the navigation solution, at which time the magnitude of the vertical error dropped to less than 5 meters and the VPL jumped from 33 meters to 110 meters (Figure 1). Independent data analysis at other Alaska reference receivers showed that WAAS satellite and ionospheric corrections did not contribute to the satellite PRN 9 range error.

Satellite PRN 17 (magenta trace) also experienced increasing range errors and was dropped from the navigation solution due to L1 carrier cycle slip detection at 471135 GPS time of week and did not significantly affect navigation performance. The range errors for the other satellites used in the navigation solution were unchanged during this time period and a subset are shown in Figure 5 for reference.

Figure 5 Satellite Range Error at Fairbanks WRE-A

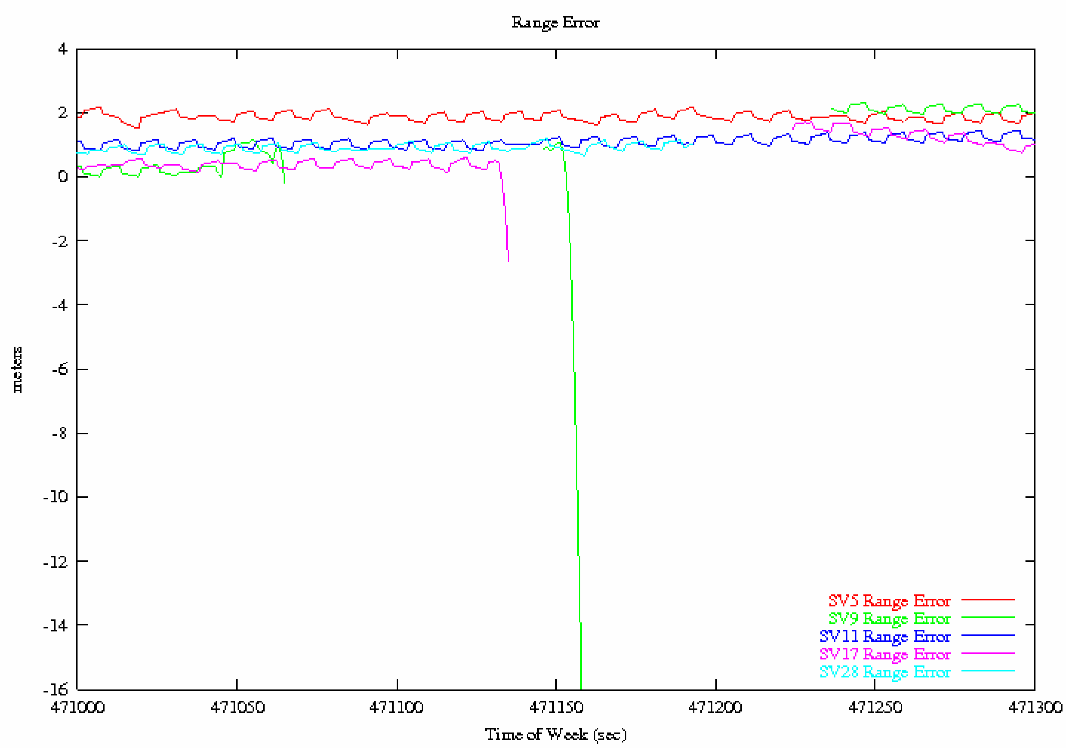


Figure 6 shows the dual frequency ionospheric slant delay observed by several satellites tracked during the same time period. The total electron content (TEC) was relatively small producing 1 – 2 meters of delay at the L1 frequency for the satellites shown in Figure 6. The ionospheric delay of satellites PRN9, PRN 17 and PRN 28 experienced moderate sinusoidal fluctuations before L1 and L2 loss of code and carrier lock by the receiver indicating ionospheric scintillation may have contributed to the poor receiver tracking of these high elevation satellites. After satellite reacquisition there is typically more noise on L1 and L2 receiver measurements as seen on satellite PRN 9 (aqua trace), which was most affected by scintillation and dropped from receiver tracking twice during the period.

Figure 6: Dual Frequency Ionospheric Delay

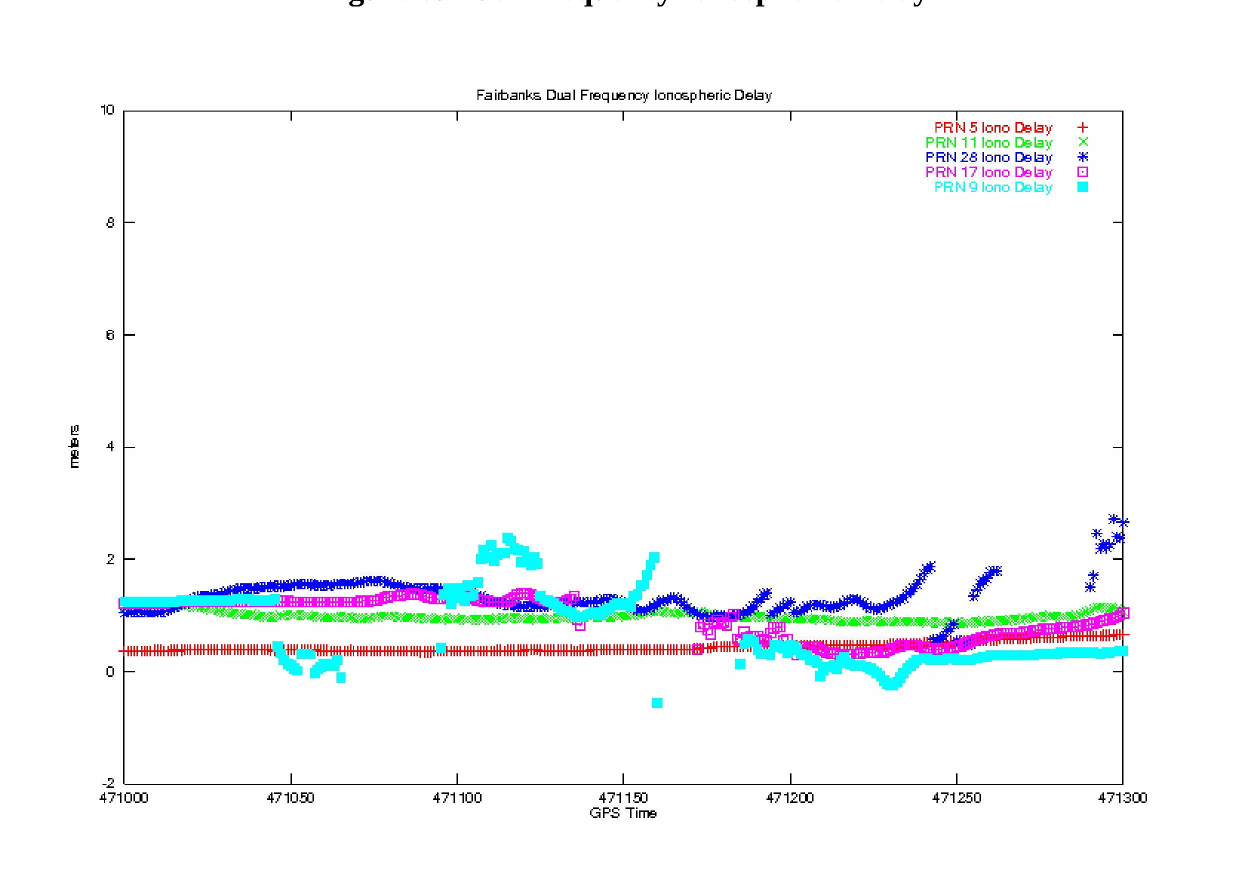
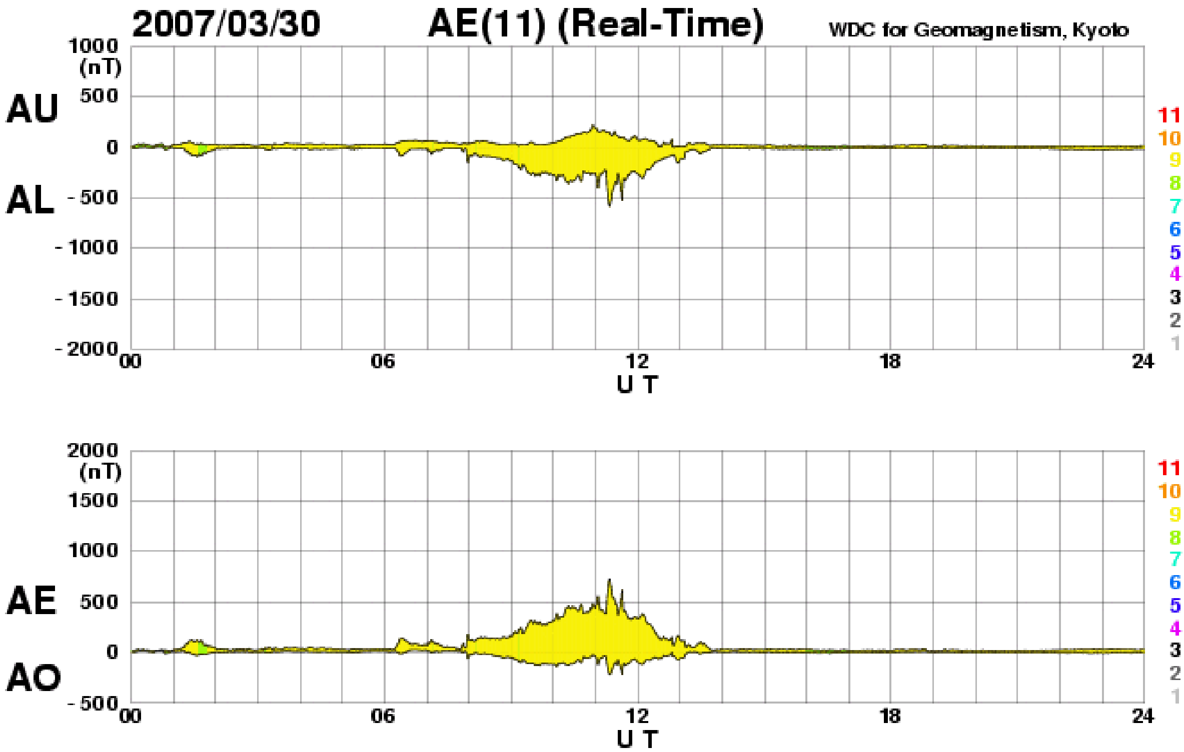


Figure 7 is a plot of the Auroral Electrojet Index, which shows the aurora's effects on Earth's magnetic field. The times of increased activity correspond to the times when high errors were reported at Fairbanks.

Figure 7: Auroral Electrojet Index



Figures 8 and 9 show the code (red trace) and carrier (green trace) measurement errors for satellites 9 and 17 respectively. The measurement error of the 100 seconds carrier smooth code is shown as the blue trace and is the measurement used in the least square navigation function, which determines the user position. As Figure 8 shows, after satellite PRN 9 is reacquired at 471085 GPS time of week it was tracked for only 68 seconds before large carrier measurement errors grew to 30 meters within 7 seconds before the receiver lost track of the satellite signal. The receiver measurements for PRN 9 and PRN 17 (Figure 9) both had common error signatures before the loss of tracking occurred, however the validity of PRN 17 receiver measurements was flagged as invalid due to carrier cycle slip, which minimized the vertical position error to 4.9 meters at 471135 GPS time of week. PRN 9 measurement errors were not detected by the receiver or signal processing functions and were introduced into the navigation solution causing the vertical error to grow to 22 meters before the satellite measurements were eventually flagged invalid.

Figure 8: Satellite PRN 9 L1 Code and Carrier Measurement Errors

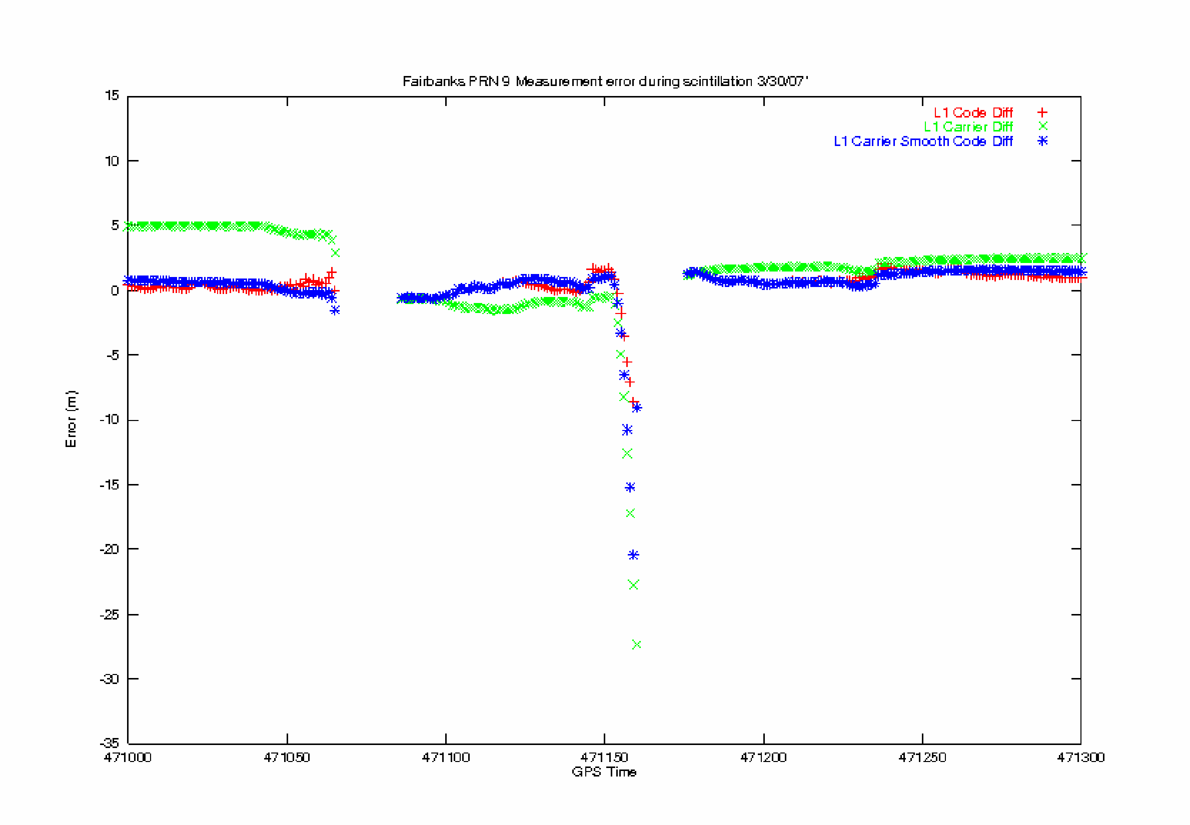
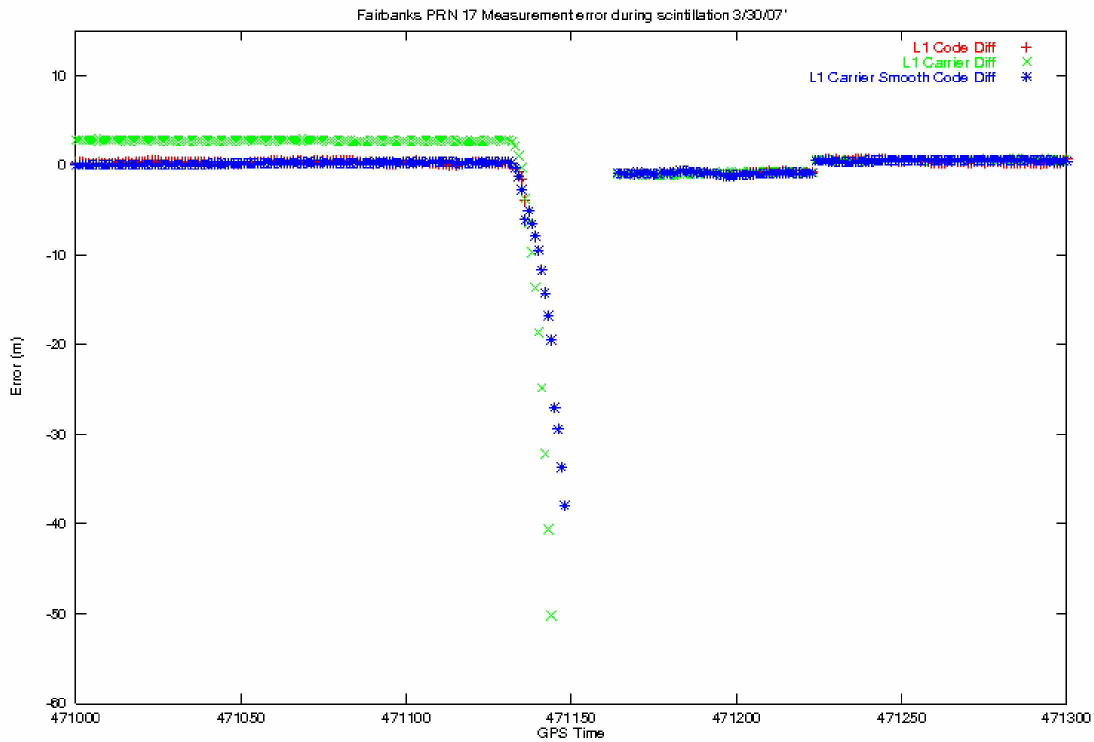


Figure 9: Satellite PRN 17 L1 Code and Carrier Measurement Errors



Electrojet Index showed increased auroral activity at the time maximum errors occurred. Satellites PRN 9, PRN 17, and PRN 28 were the satellites that were highest elevation at Fairbanks during the time under investigation, and were most affected by scintillation. Satellites PRN 9 and PRN 17 previously had strong signal-to-noise ratios and were briefly dropped from the track list as ionospheric perturbations increased. The undetected receiver code and carrier measurement errors on PRN 19 increased significantly within 7 seconds and caused the vertical error to increase to 22 meters. When ionospheric perturbations lessened, satellites PRN 9 and PRN 17 returned to the track list and vertical position errors, and vertical protection levels resumed to normal.

More study is planned since this effect has been observed on other occasions. The focus of the study will be the evaluation of data from a certified avionics receiver installed at a location in Alaska to see the tracking performance in this type of environment.