WAAS Technical Report
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DR# 53: Ionospheric Scintillation at Juneau
GPS Week/Day: Week 1419 Day 6 (3/24/07)

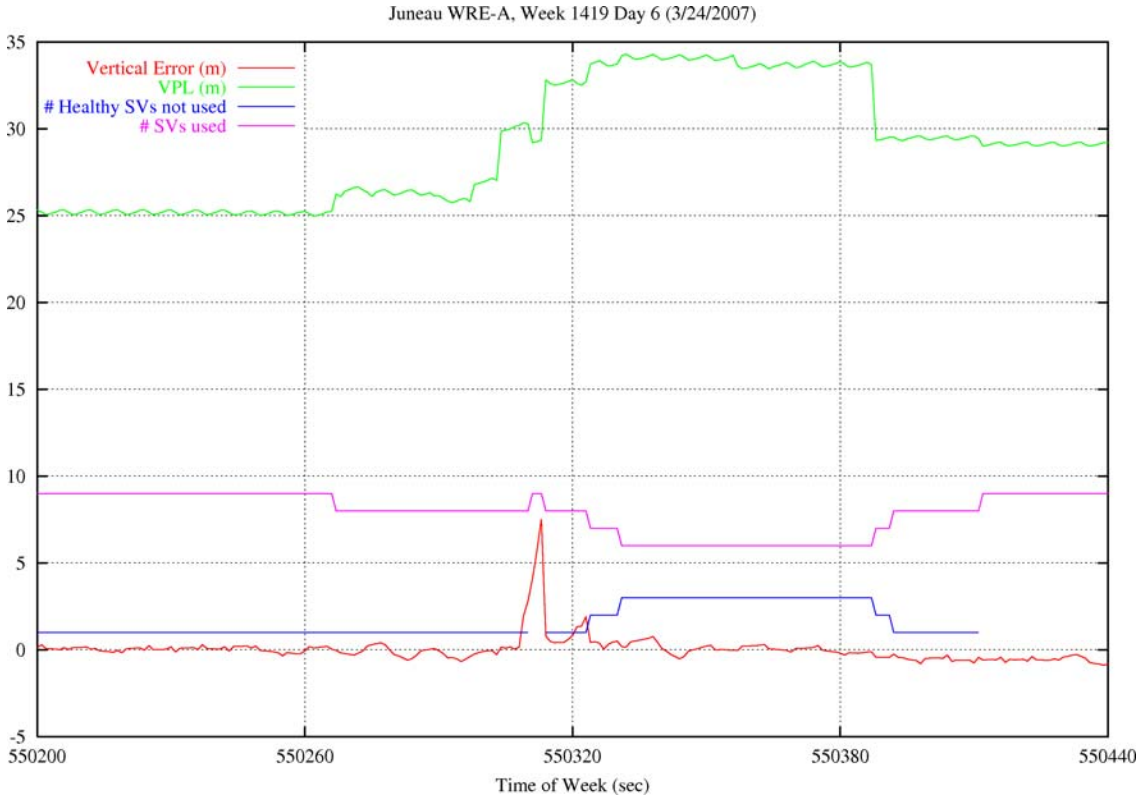
Discussion:

On March 24, 2007 (GPS Week 1419 Day 6), large vertical position errors (VPE) were observed at the Juneau WAAS reference receiver thread A (WRE-A). With the user position solution in PA mode, the maximum vertical error was 7.541 meters, which occurred at GPS time of week 550313 (08:51:39 GMT). The maximum ratio of the vertical position error divided by the vertical protection level (VPL) at a given time was 0.257. This is above the one-sigma value (1/5.33 = 0.188), but still bounded by the actual VPL.

Figure 1 shows the vertical position errors and VPL bounding. The VPL remained below 50 meters, so LPV service availability was maintained. Notice the sharp, sudden, brief increase in VPE.

Also included in Figure 1 is the number of in-view satellites not used in the solution. This indicates that there was a problem with satellite tracking at the time. VPL rose by no more than 10 meters, even with four satellites dropped from the solution.

Figure 1. Juneau Thread A Vertical Position Error, Vertical Protection Level, SV's used



As with the thread A reference receiver, threads B and C (shown in Figures 2 and 3) lost track of 3 – 4 satellites within the same time period. They stopped tracking PRN 8 before thread A did, so their VPE's did not climb as high as thread A's. Even so, the fact that the tracking interruptions are similar across all three threads suggests that a common cause induced receiver tracking problems.

Figure 2. Juneau Thread B Vertical Position Error, Vertical Protection Level, SV's used

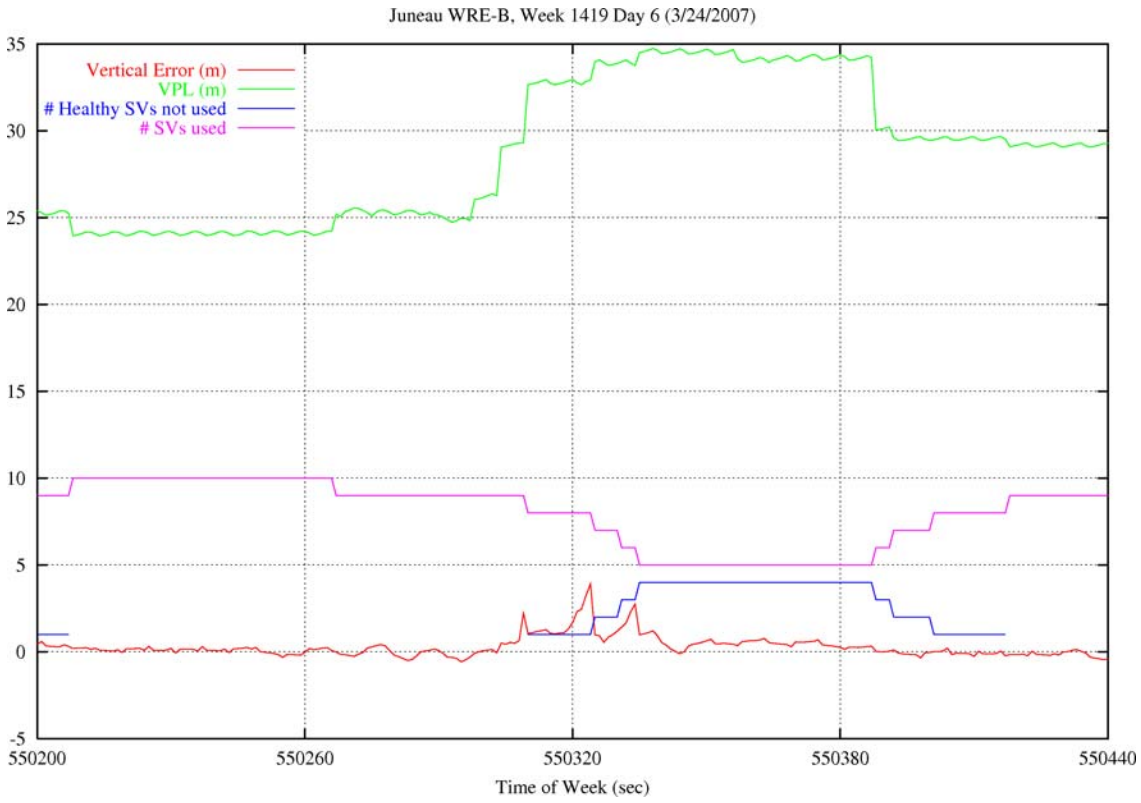


Figure 3. Juneau Thread C Vertical Position Error, Vertical Protection Level, SV's used

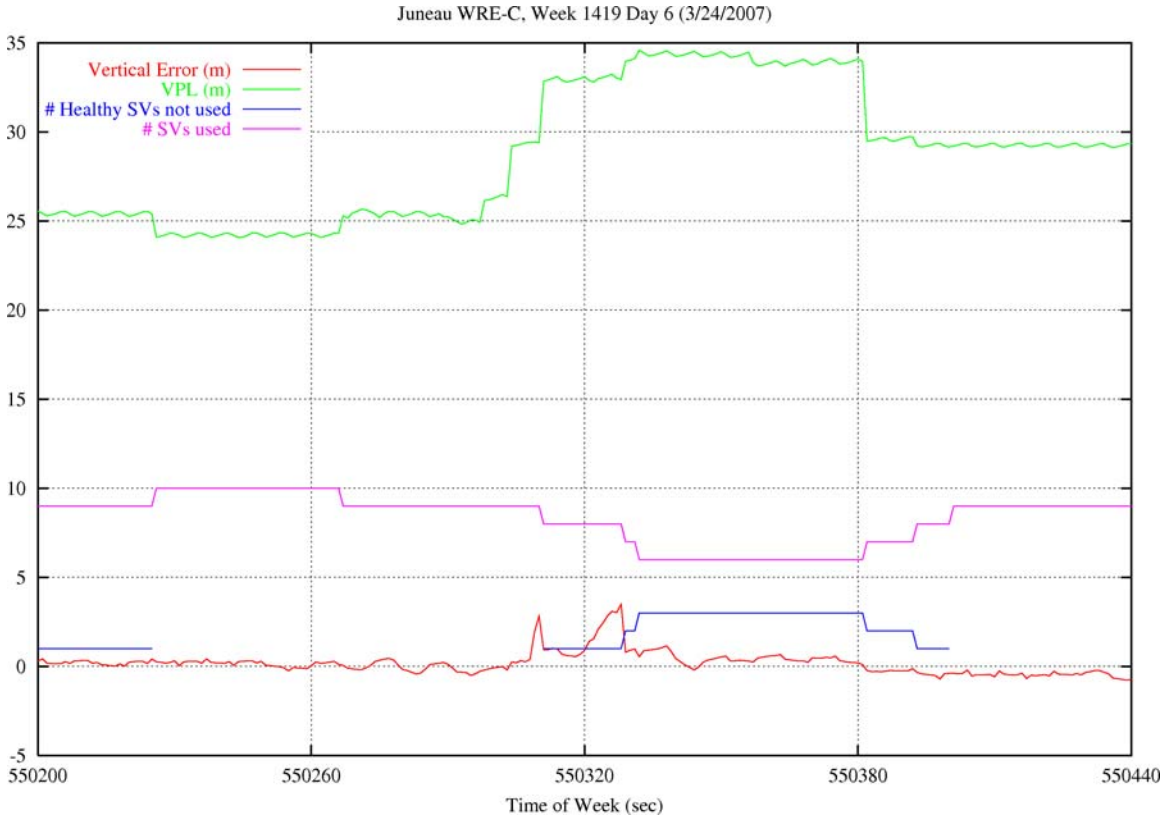


Figure 4 shows the signal to noise ratio of the L1 signal for several satellites as received at Juneau Thread A. Satellite PRN 8 was dropped from receiver tracking immediately after the maximum VPE. Satellite PRN's 27 and 29 were dropped within 20 seconds after the maximum VPE. Satellite PRN 10 was not dropped, and is shown as a baseline for comparison. Notice that the carrier-to-noise ratios (C/N_0) of the affected satellites each decreased sharply before the receiver lost track of them. Threads B and C performed similarly. This is consistent with ionospheric scintillation.

Figure 4. Juneau Thread A, L1 Carrier-to-Noise Ratio (C/N_0)

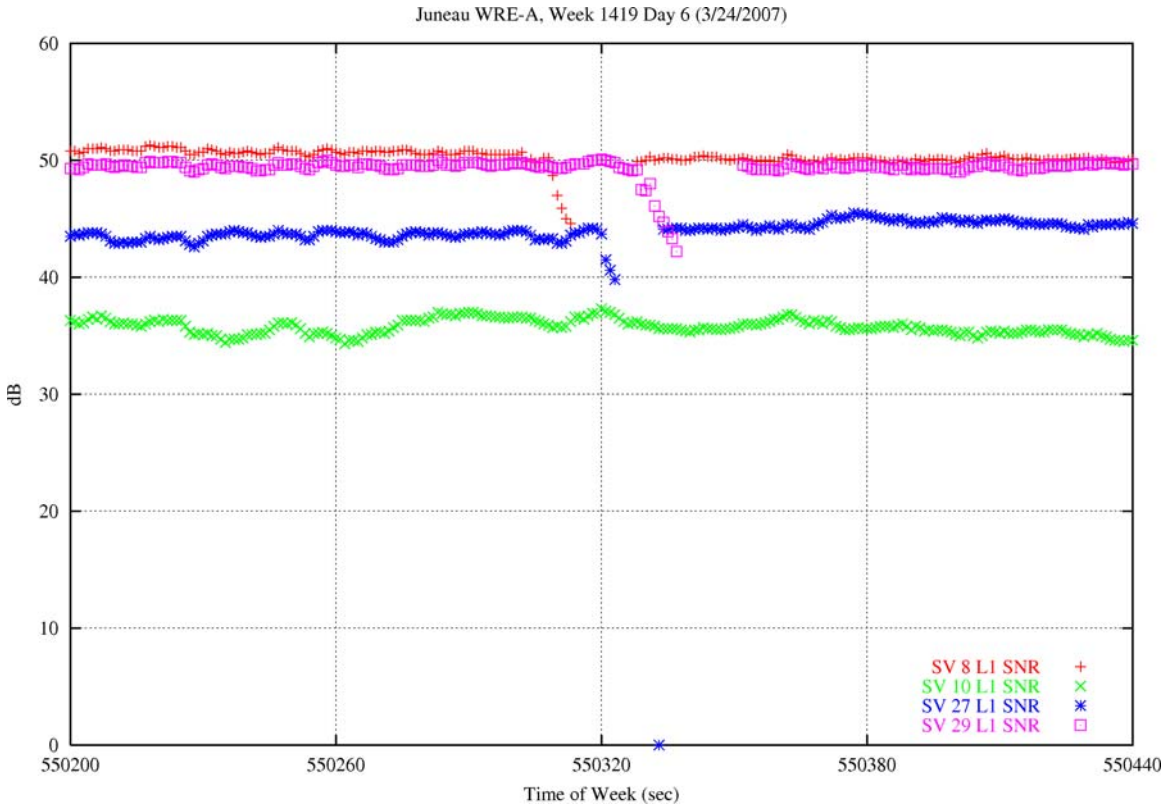


Figure 5 shows the range errors from receiver thread A for the same set of satellites during the VPE anomaly. The magnitude of PRN 8's range error (shown as the red points) increased to –12.0 meters at the time that the maximum vertical errors were observed. PRN 8 was subsequently dropped from the receiver track list and removed from the navigation solution, at which time the magnitude of the vertical error dropped to less than a meter, and the VPL rose to 33 meters (Figure 1).

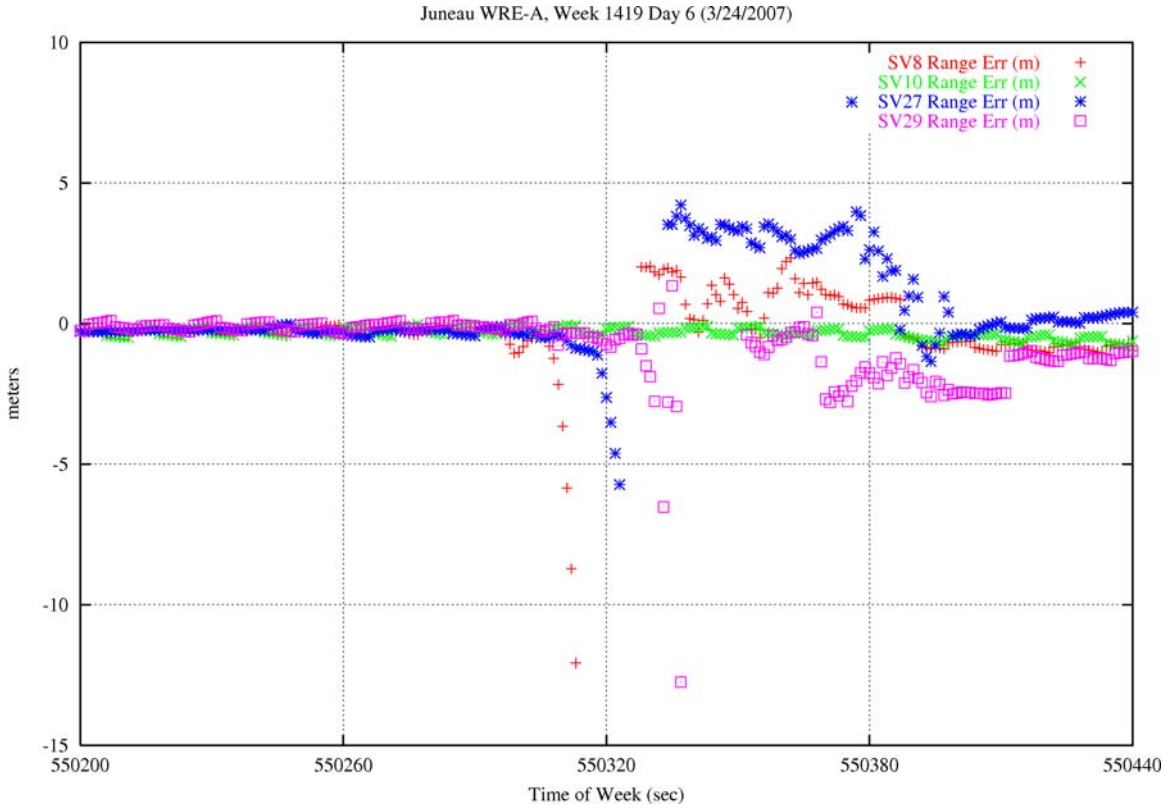
Satellite PRN 27 (blue points) experienced increasing range errors and was dropped from the receiver track list. At this time of its maximum range error (–6 meters), the VPE only increased to 1.9 meters. The VPL rose to 34 meters once it was dropped from the receiver track list.

Satellite PRN 29 (magenta points) also experienced increasing range errors, but it was dropped from the navigation solution due to L1 carrier cycle slip detection before the range errors exceeded 2 meters. Neither the PRN 29 range errors nor its exclusion from the solution caused significant effects to navigation performance.

The range errors for the other satellites used in the navigation solution were unchanged throughout this time period. PRN 10 range errors (green points) are shown in Figure 5 for reference.

Independent data analysis at other Alaska reference receivers indicates that WAAS satellite and ionospheric corrections did not contribute to the ranging errors of satellite PRN's 8, 27, or 29. As with the carrier-to-noise ratios, the range errors and satellite tracking were similar among all three threads.

Figure 5. Juneau Thread A, Range Error



Figures 6 through 8 show the code and carrier ranging errors for satellite PRN's 8, 27, and 29, respectively. The errors are calculated by subtracting the true range (distance between the satellite and the surveyed antenna) from the pseudorange measurement, and correcting for clock biases. The plots show that for all of these satellites, the carrier-smoothed code measurements, which are used in the position solution, ran off together with the range error—i.e. it is the main contributor to the ranging errors. Furthermore, the code and carrier errors are shown separately, demonstrating that there were measurement problems with both, though more so the carrier than the code. The bias on the carrier measurements prior to losing track of the satellites is due to the ambiguity of the carrier measurement. The key thing to note is the sharp deviation from the bias value, which correlates with the range error. The ionospheric scintillation caused code measurement errors, and carrier cycle slips that went undetected by the receivers.

Figure 6. Juneau Thread A, PRN 8 Code & Carrier Errors

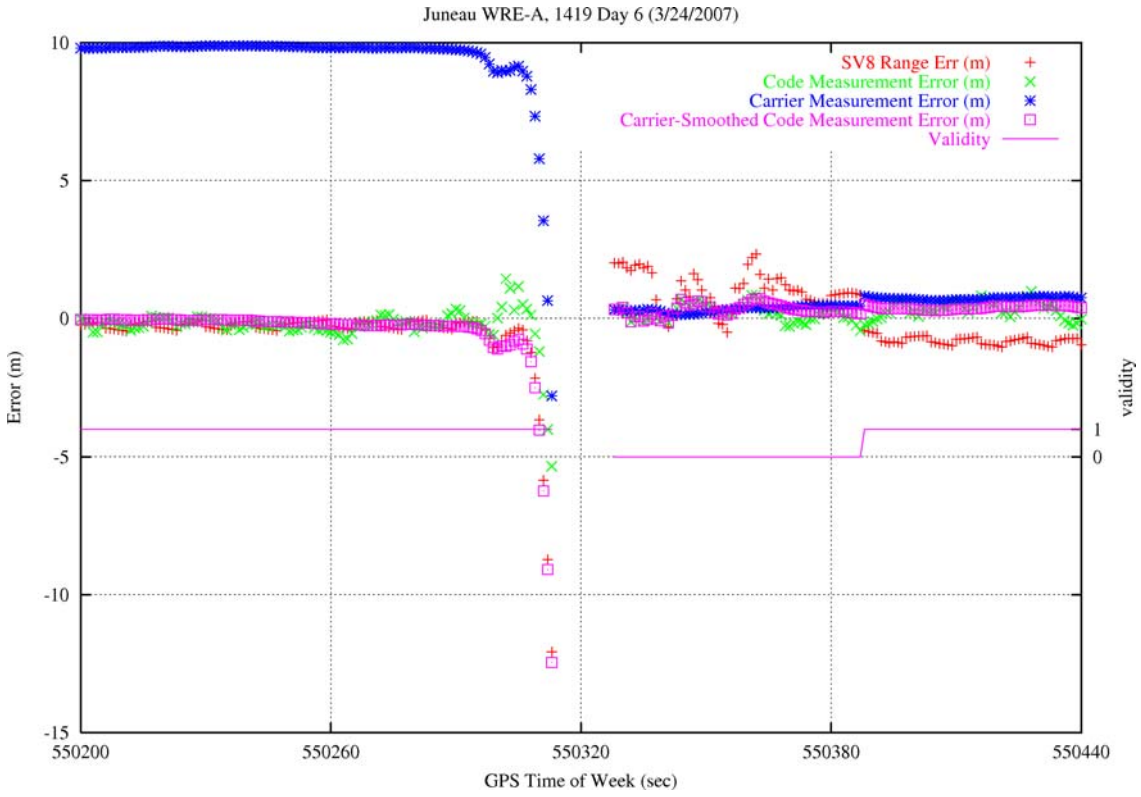


Figure 7. Juneau Thread A, PRN 27 Code & Carrier Errors

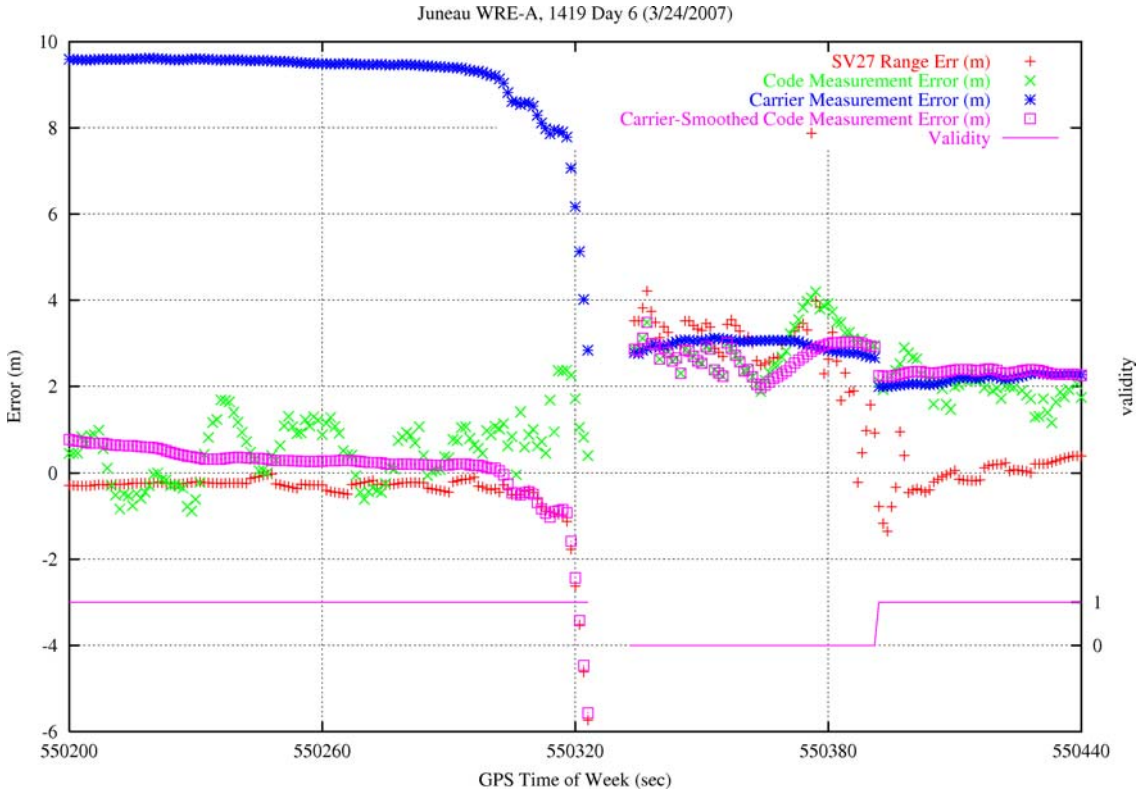
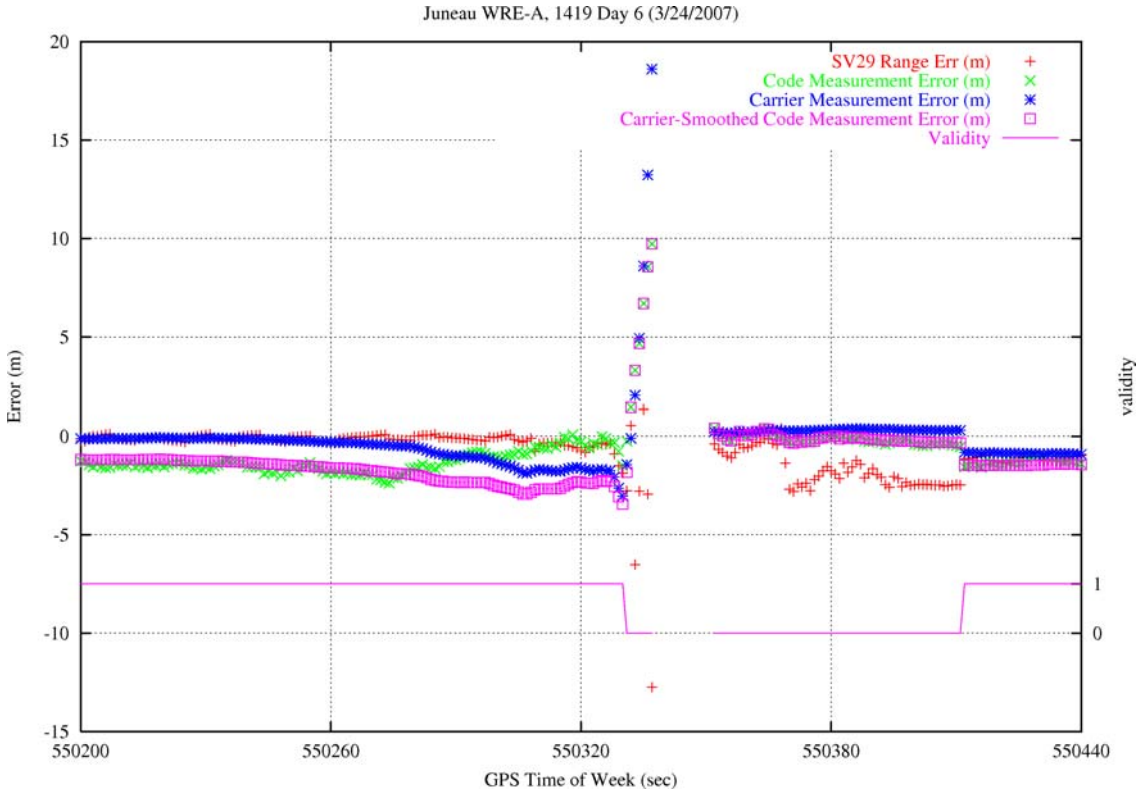


Figure 8. Juneau Thread A, PRN 29 Code & Carrier Errors



Conclusions:

On GPS Week 1419 Day 6, relatively localized ionospheric scintillation caused code measurement problems, and undetected carrier cycle slips, resulting in a loss of GPS satellite tracking at the Juneau WRS. Up to three satellites were dropped from each WRE's position solution during the anomaly. Though the vertical error did briefly exceed the one-sigma protection levels, at no point did they exceed the actual protection levels.