WAAS Technical Report
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Pomona, New Jersey
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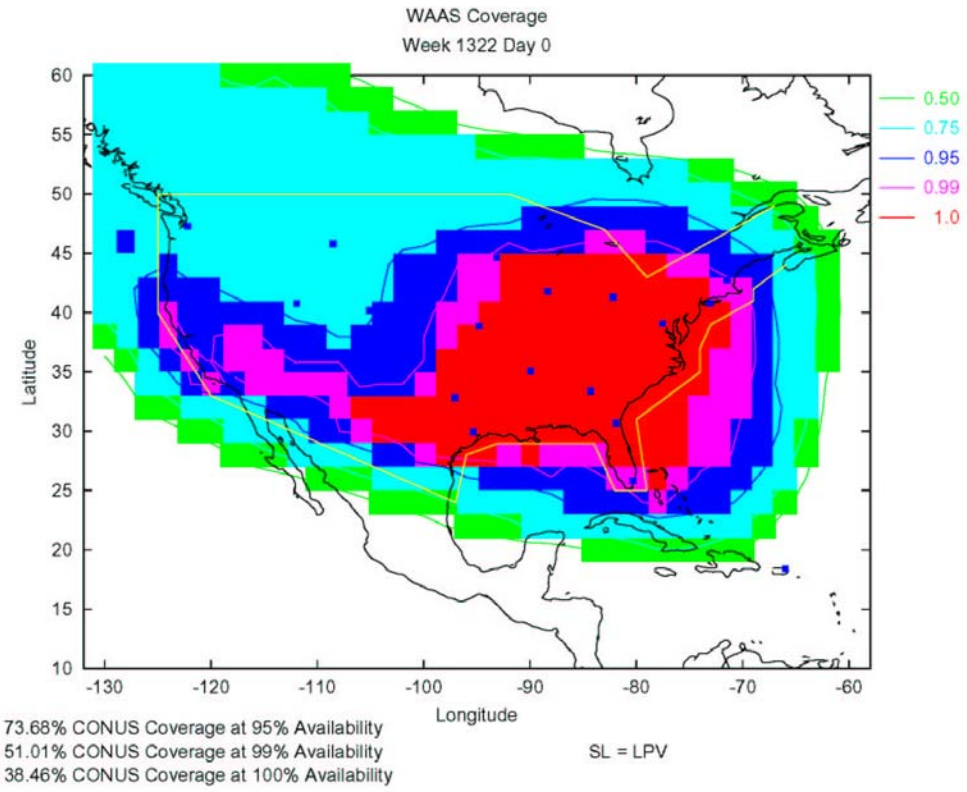
DR#3: Moderate Ionospheric storm caused loss of WAAS LPV service in the North West quadrant of CONUS for approximately 2 hours
GPS Week/Day: Week 1322 Day 0 (5/8/2005)

Discussion:
On May 8th 2005 (Day 0 of Week 1322) loss of LPV service availability was observed on daily coverage plots in the North West region of CONUS from Seattle Washington to Denver Colorado. The LPV service interruption was approximately 2 hours in the worst areas affected by ionospheric activity. The loss of LPV service started at 1:57:00 GMT (21:57 EST, or 7020 GPS time of Week) and service returned through out the region at 3:57:30 GMT (23:57 EST, or 14250 GPS time of Week).

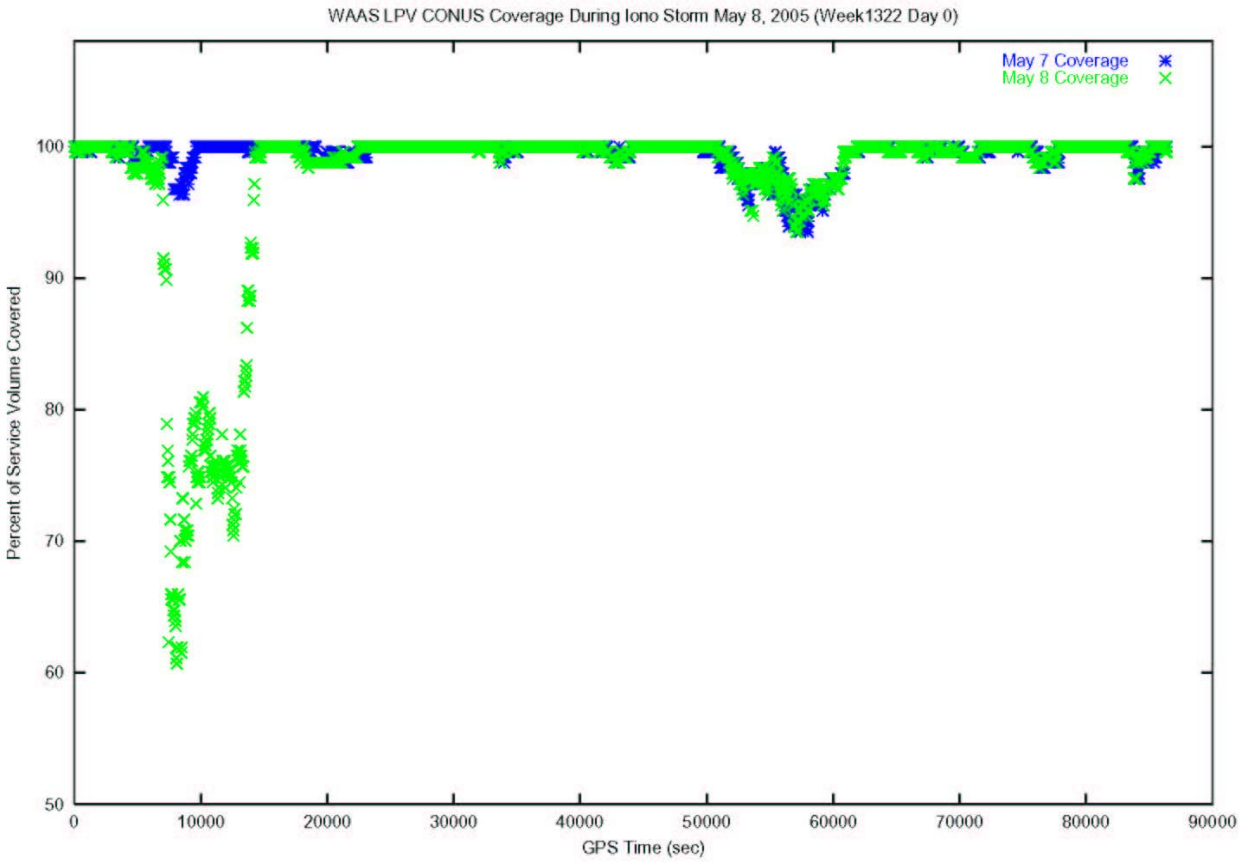
The loss of LPV service availability in the CONUS coverage volume can be observed in Figure 1.

Figure 1 – LPV Coverage, Week 1326 Day 0, 6/5/2005



As seen in the plot of the instantaneous LPV coverage area (Figure 2) the reduction in LPV service area on May 8th started at 7020 GPS time of Week. Instantaneous LPV coverage area for May 7th is also plotted, in blue, (Figure 2) as a reference to show normal (No ionospheric storm) WAAS LPV service during a 24hour period. LPV coverage returned too normal at approximately 14250 GPS time of Week where both plots show similar LPV coverage. WAAS LPV coverage movie also shows the affects of the ionospheric storm on May 8th and can be downloaded from the NSTB FTP site. (ftp://ftp.nstb.tc.faa.gov/pub/NSTB_data/Movies/coveragewaas_w1322d0.avi)

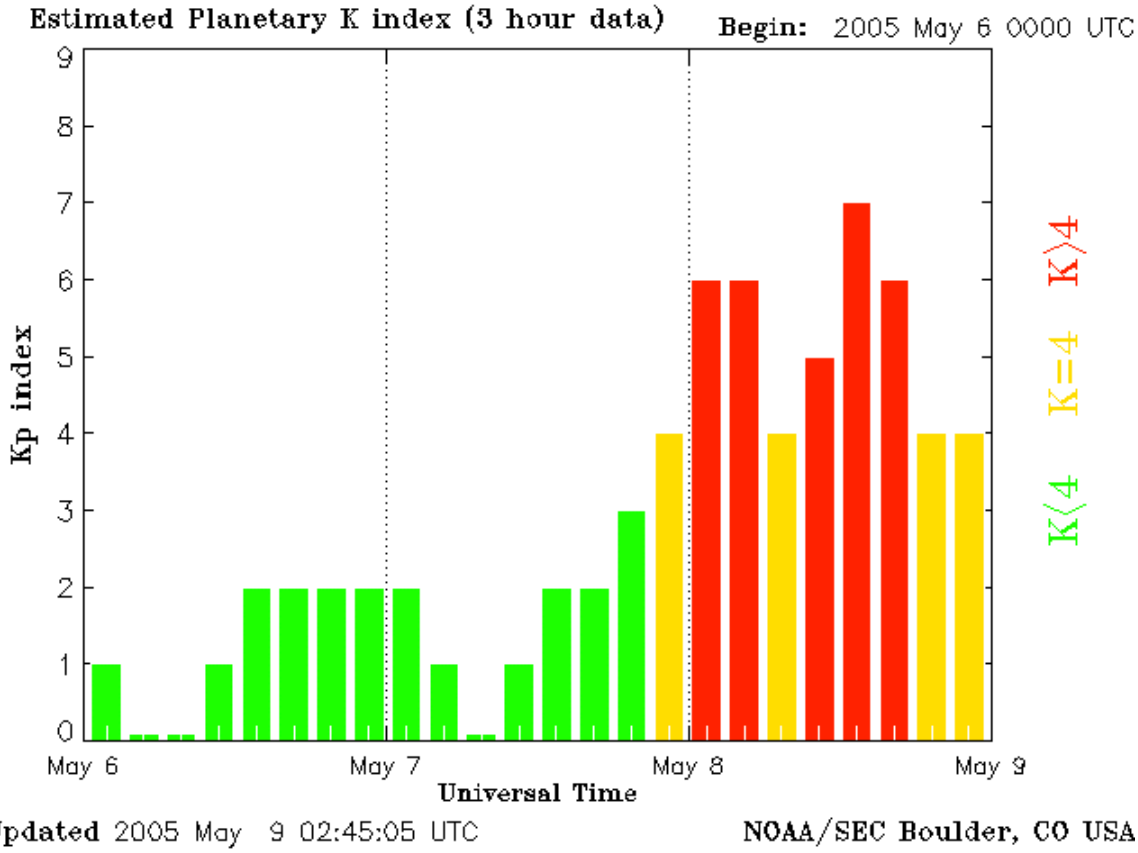
Figure 2 - LPV CONUS coverage verses time



The loss of LPV service was due to the ionospheric storm detected by the WAAS system during the early part of the GPS day. Moderate geomagnetic activity was observed this day, as shown in Figure 3, with the KP index reaching a maximum of 7 during the day. When rapid changes in the ionospheric delay occur WAAS ionospheric grid points (IGP's) in the affected area are set to storm state elevating their grid ionospheric vertical

error (GIVE) values to 45 meters. Normally GIVE values are between 4 to 15 meters. The large GIVE values are factored into the vertical and horizontal protection level (VPL, HPL) calculations raising the protection levels sharply and effectively turning off WAAS LPV service in the region.

Figure 3 – Kp Index, May 8th 2005 (Week 1322 Day 0)



A good example of the rapid changes in the ionosphere occurring during the storm is seen in Figure 4 & 5, which is a comparison of several satellites dual frequency slant ionospheric delays from Billings WRS during the storm and normal delays from the previous day May 7th 2005. Figure 4 shows that at relatively the same time of the storm on the normal day, May 7th, ionospheric delays change slowly with time, where as, on the storm day, Figure 5, ionospheric delays are perturbed and change 2 – 5 meters within short periods of time during the storm.

Figure 4 – Satellite Iono Delay, Normal, Billings May 7th 2005 (Week 1321 Day 6)

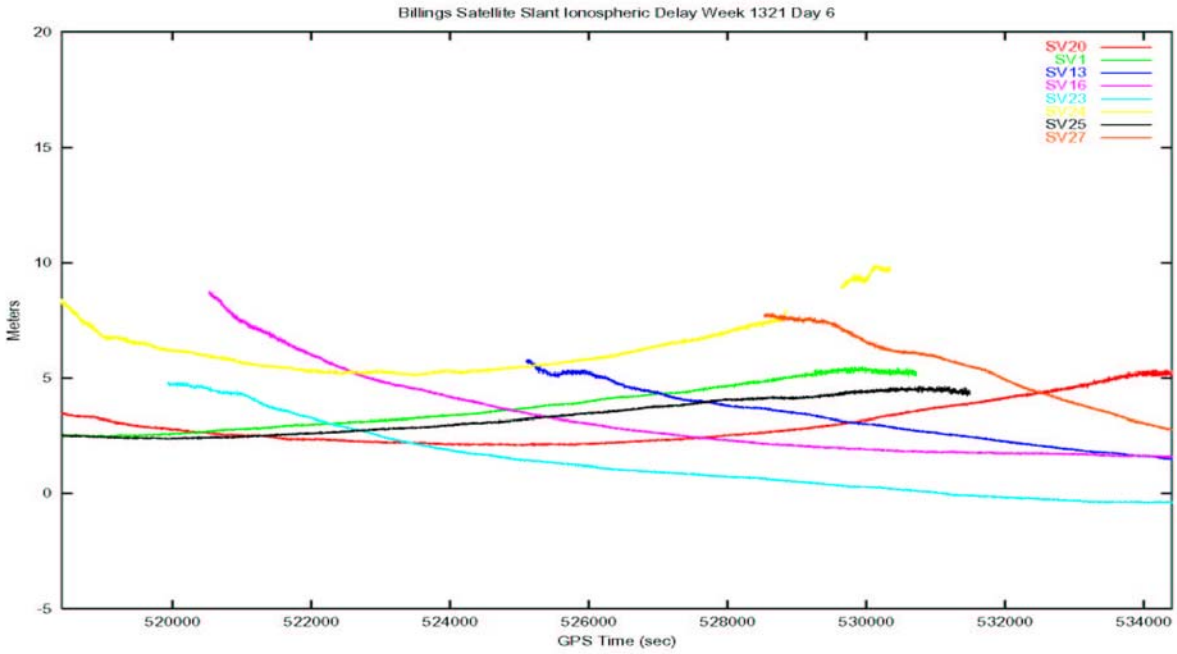
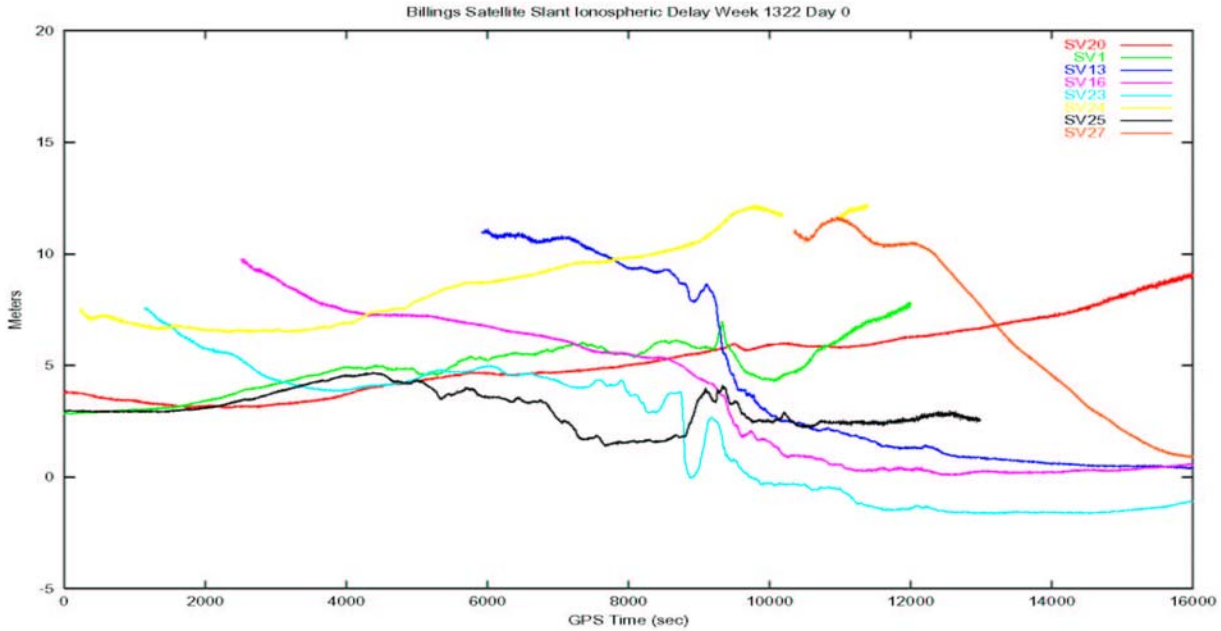
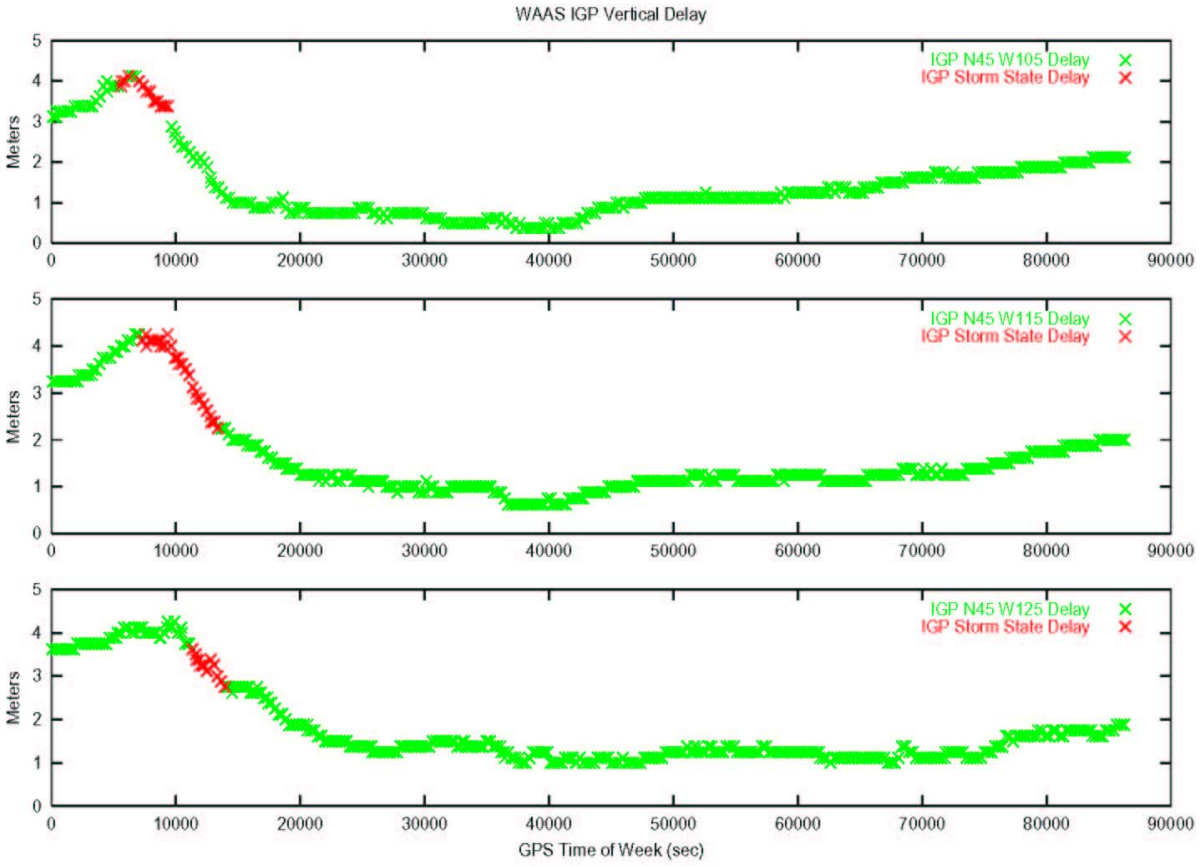


Figure 5 – Satellite Iono Delay, Storm, Billings May 8th 2005 (Week 1322 Day 0)



WAAS IGP's enter and leave storm state independently. This condition has various impacts on LPV availability in the region. Figure 6 shows the ionospheric vertical delay verses time for three IGP's (N45,W105), (N45,W115), and (N45,W125) set to ionospheric storm state. The vertical delays due to the ionosphere changed from approximately 4 meters down to 1 meter during the storm. Vertical delays plotted in red indicate that ionospheric storm state is activated. WAAS Ionospheric model movie also shows WAAS interpretation of the ionosphere over a wide area during the ionospheric storm on May 8th and can be downloaded from the NSTB FTP site. (ftp://ftp.nstb.tc.faa.gov/pub/NSTB_data/Movies/ionowaasw1322d0a.avi)

Figure 6 – WAAS IGP Vertical Delay verses Time



It is of interest to WAAS users what the affect of this ionospheric storm is on WAAS navigation accuracy in the region. Figures 7 to 9 shows the vertical position error (VPE) verses time at three WAAS Reference Stations (WRS) located at Billings Montana, Minneapolis Minnesota, and Kansas City Kansas. Also plotted with the VPE is the WAAS VPL divided by 5.33, which shows the one-sigma VPL vertical error bounding. When the one-sigma VPL exceeds 9.4 (VPL = 50) LPV service is not available at that location.

Figure 7 – WAAS Vertical Position Error at Billings

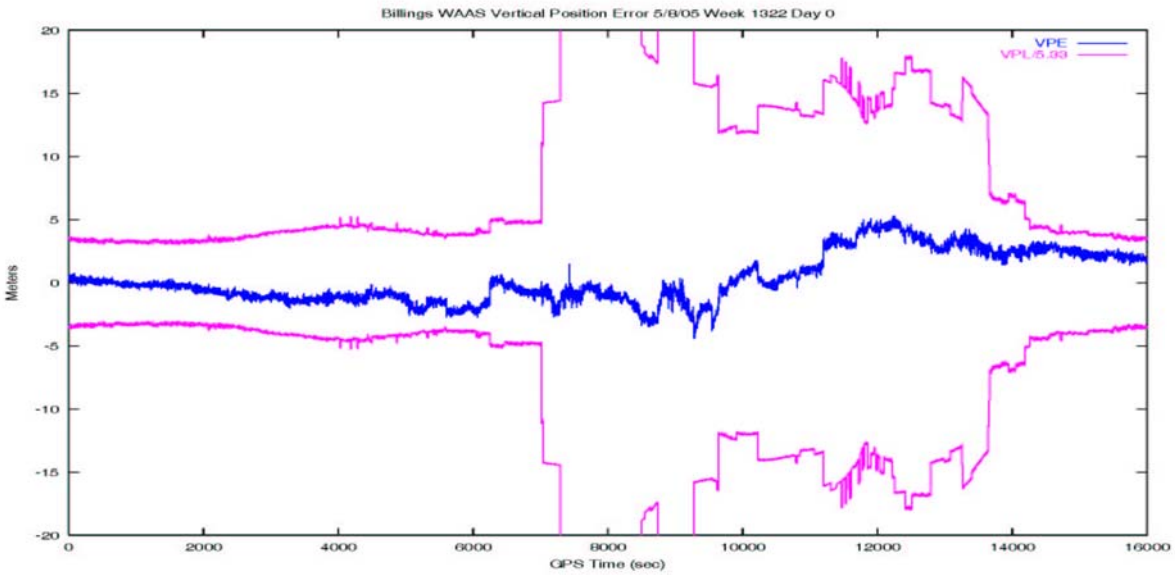


Figure 8 – WAAS Vertical Position Error at Minneapolis

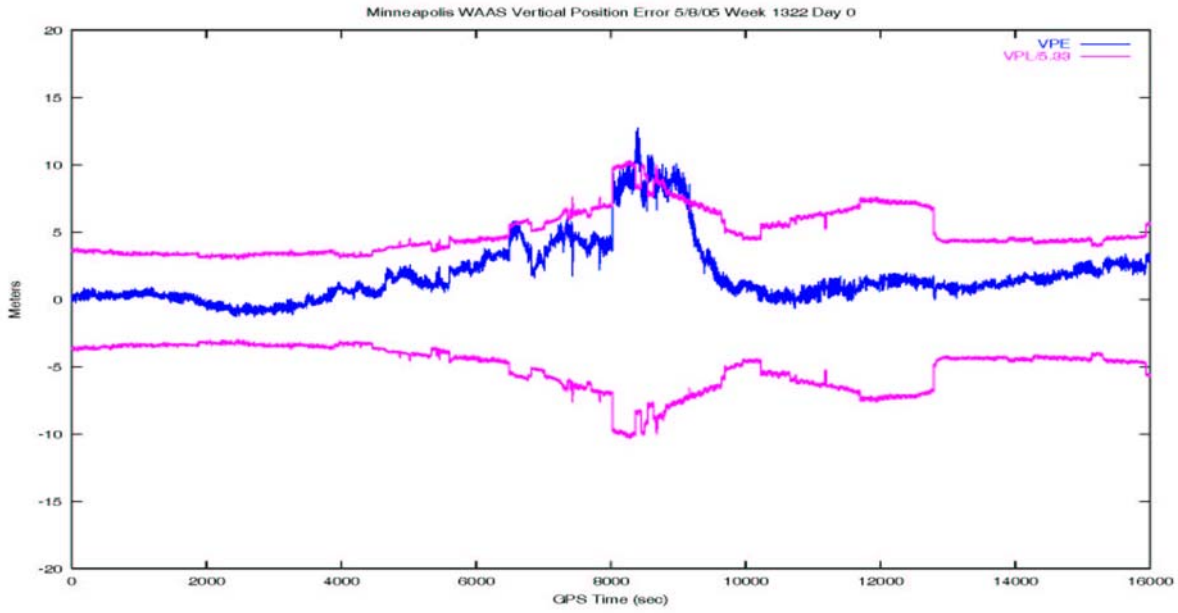
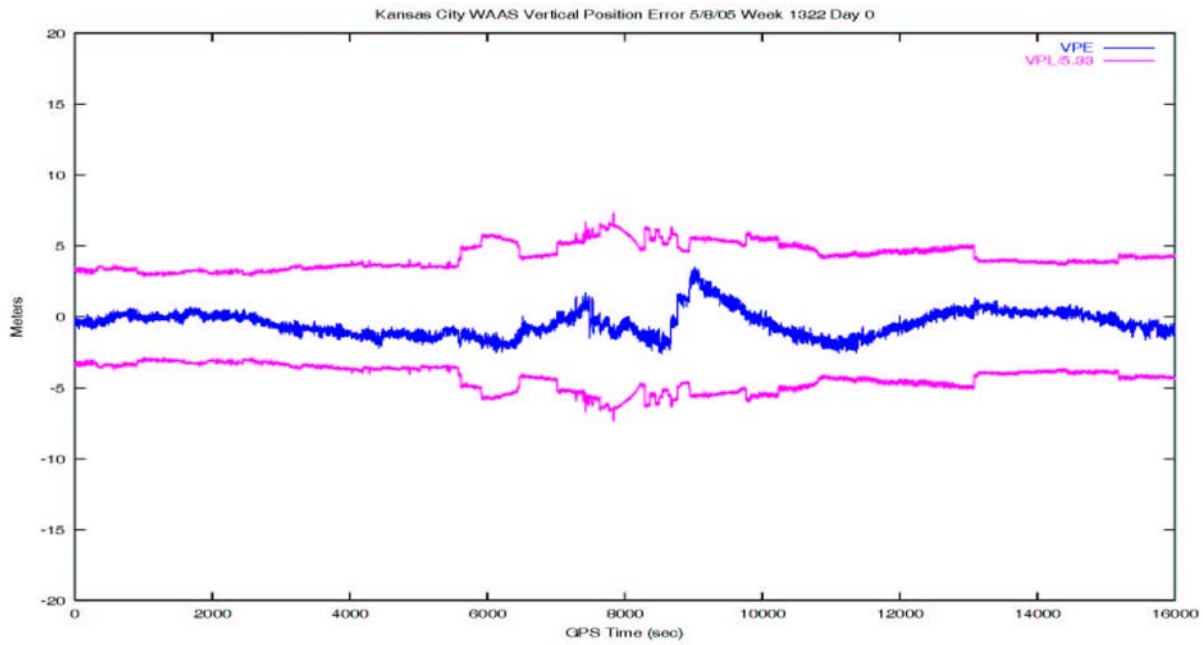


Figure 9 – WAAS Vertical Position Error at Kansas City



As seen in Figure 7 – 9 the VPE as a different profile during the time of the ionospheric storm (between 7020 and 14250 GPS time of week) depending on where the user is located. The maximum VPE at Billings was 5.2 meters with a VPL of 81.9 meters. During the storm LPV service was not available at Billings with VPL reaching as high as 120 meters. Even the one sigma protection levels always bounded vertical position errors at Billings (as seen in Figure 7). The maximum VPE at Kansas City was 3.3 meters with a VPL of 29.4 meters. During the storm LPV service was always available at Kansas City with the maximum VPL reaching only 33 meters. And as with Billings, the one sigma protection levels at Kansas City always bounded vertical position errors (as seen in Figure 9). The maximum VPE at Minneapolis was 12.7 meters with a VPL of 44.8 meters. During the storm LPV service was available except for 412 seconds at Minneapolis with the maximum VPL of 54 meters. Figure 8 shows that the one sigma protection level was exceeded by the vertical position error at Minneapolis from 8100 GPS time of week for approximately 1000 seconds. This is not an integrity failure since position errors do not exceeded 5.33 times the one sigma protection level.

Conclusion:

WAAS LPV service was not available on May 8th 2005 in the North West region of CONUS due to an ionosheric storm that was detected by the system. LPV service was unavailable for two hours at the worst locations affected. The small changes in the ionospheric delay of 2 – 5 meters during the storm created an amplified and unpredictable WAAS system response. For example, at the WRS the maximum vertical error was 5.2 meters and the VPL increased by 50 meters. However, at the Minneapolis WRS the maximum vertical error was 12.7 meters and the VPL increased by 20 meters.