***WAAS Technical Report***
***William J. Hughes Technical Center***
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***DR#3: Moderate Ionospheric storm caused loss of WAAS LPV service in the Northern region CONUS for approximately 4 hours***
***GPS Week/Day: Week 1327 Day 0 & Day 1 (6/12 & 6/13 2005)***

**Discussion:**
On June 12th 2005 (Day 0 of Week 1327) loss of LPV service availability was observed on daily coverage plots in the Northern region of CONUS from Boston Massachusetts to Denver Colorado. The LPV service interruption was approximately 4 hours in the worst areas affected by ionospheric activity. The loss of LPV service started at 20:09:30 GMT on June 12th (16:09 EST June 12th, or 72570 GPS time of Week) and service returned through out the CONUS at 1:26:00 GMT on June 13 (21:26 EST June 13th, or 91560 GPS time of Week).

The loss of LPV service availability in the CONUS coverage volume can be observed in Figure 1 for June 12th and Figure 2 for June 13th.

**Figure 1 – LPV Coverage, Week 1327 Day 0, 6/12/2005**

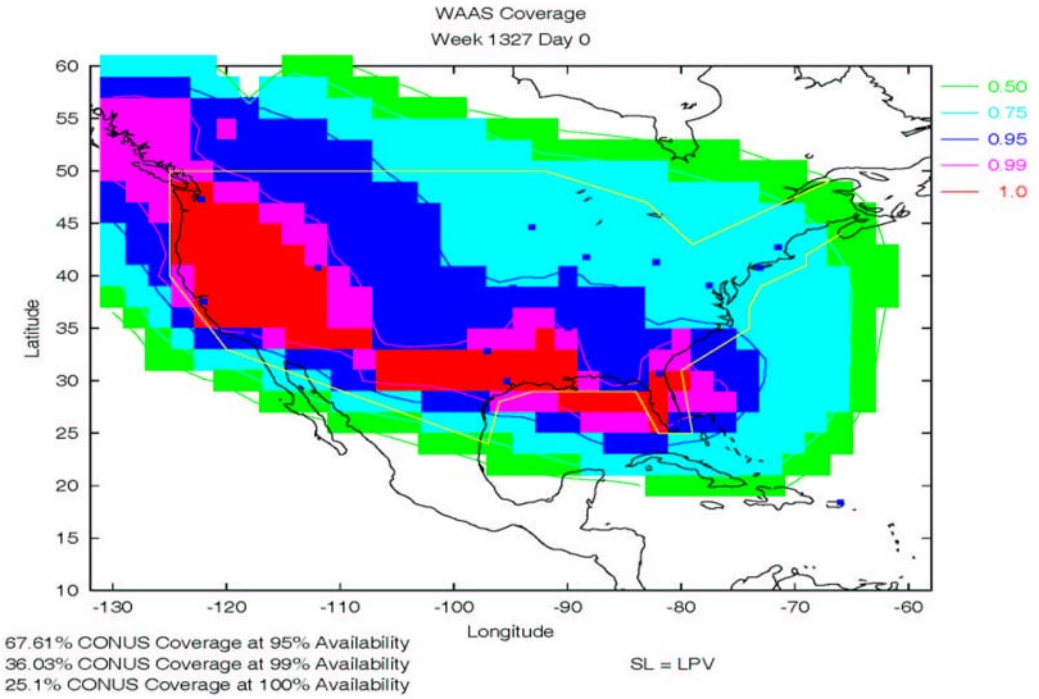
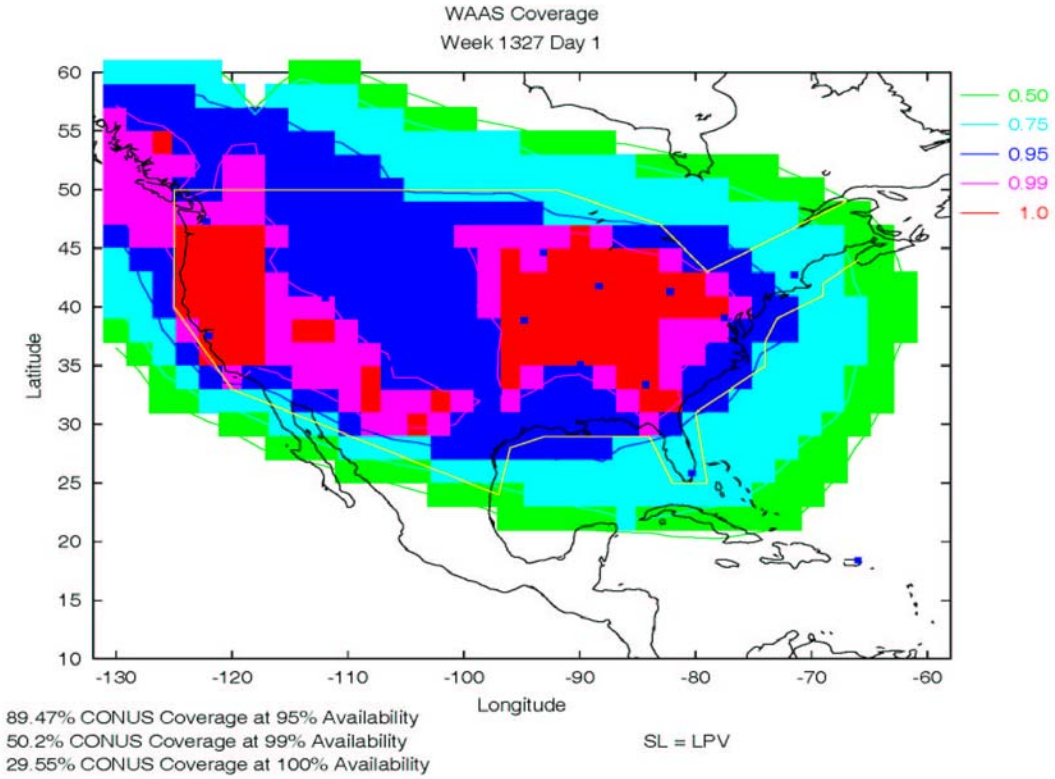
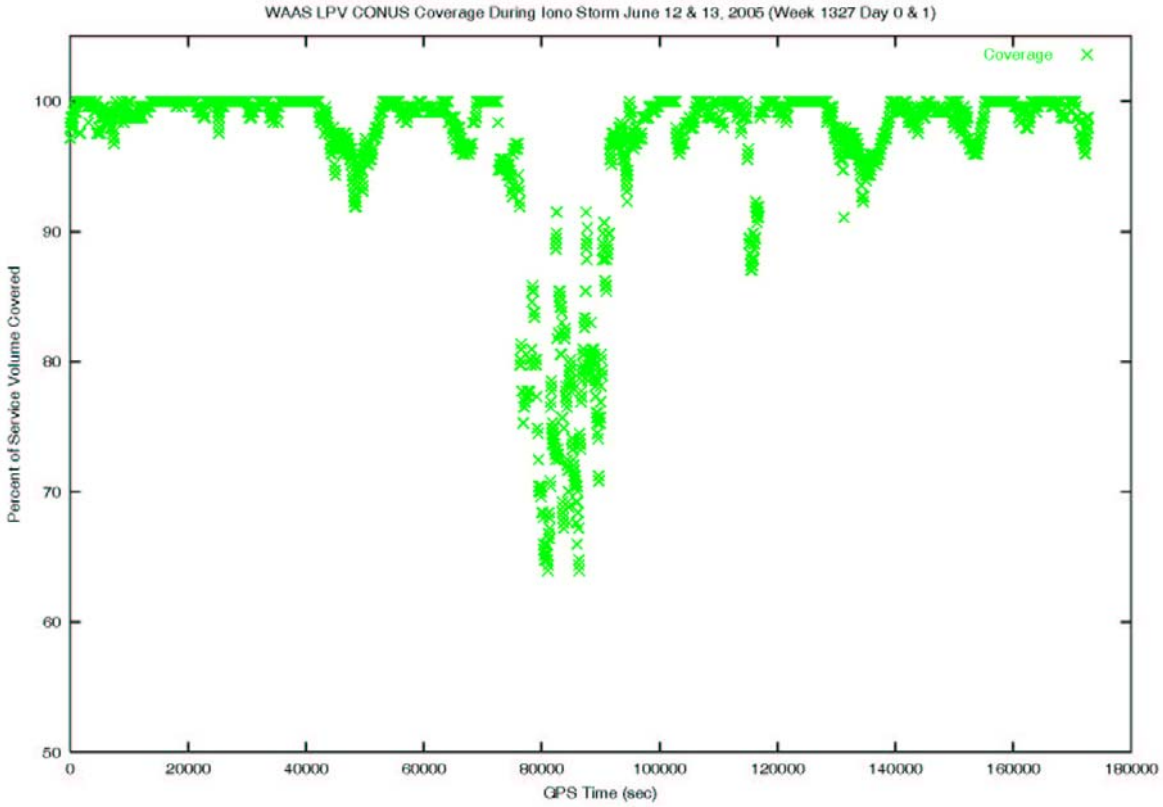


**Figure 2 – LPV Coverage, Week 1327 Day 1, 6/13/2005**



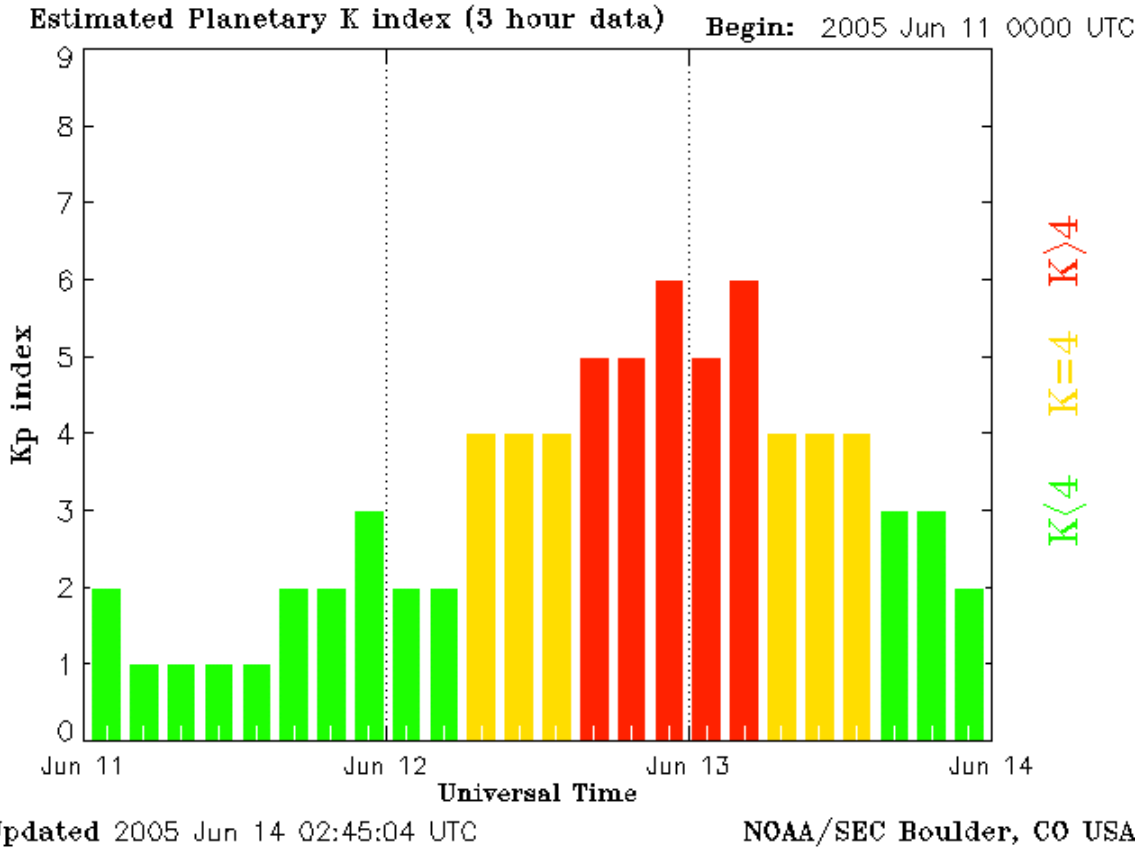
As seen in the plot of the instantaneous LPV coverage area (Figure 3) the reduction in LPV service area on June 12th started at 72570 GPS time of Week and LPV coverage returned to normal at approximately 91560 GPS time of Week. WAAS LPV coverage movie also shows the affects of the ionospheric storm on June 12th & 13th, and can be viewed at the following location:
ftp://ftp.nstb.tc.faa.gov/pub/NSTB_data/Movies/coveragewaas_w1327d0_d1.avi

**Figure 3 - LPV CONUS Coverage verses Time June 12th & 13th**



The loss of LPV service was due to the ionospheric storm detected by the WAAS system during the end of the GPS day. Moderate geomagnetic activity was observed on June 12th & 13th, as shown in Figure 4, with the KP index reaching a maximum of 6 on both days. 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 and 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 affected region.

**Figure 4 – Kp Index, June 12th & 13th 2005 (Week 1327 Day 0 & Day 1)**




A good example of the rapid changes in the ionosphere occurring during the storm is seen in Figure 5 & 6, which is a comparison of several satellites dual frequency slant ionospheric delays from Minneapolis WRS during the storm and normal delays from the previous day June 10th 2005. Figure 5 shows that at relatively the same time of the storm on the normal day, June 10th, ionospheric delays change slowly with time, where as, on the storm day, Figure 6, ionospheric delays are perturbed and change 2 – 7 meters within short periods of time during the storm.

**Figure 5 – Satellite Iono Delay, Normal, Minneapolis June 10th 2005**

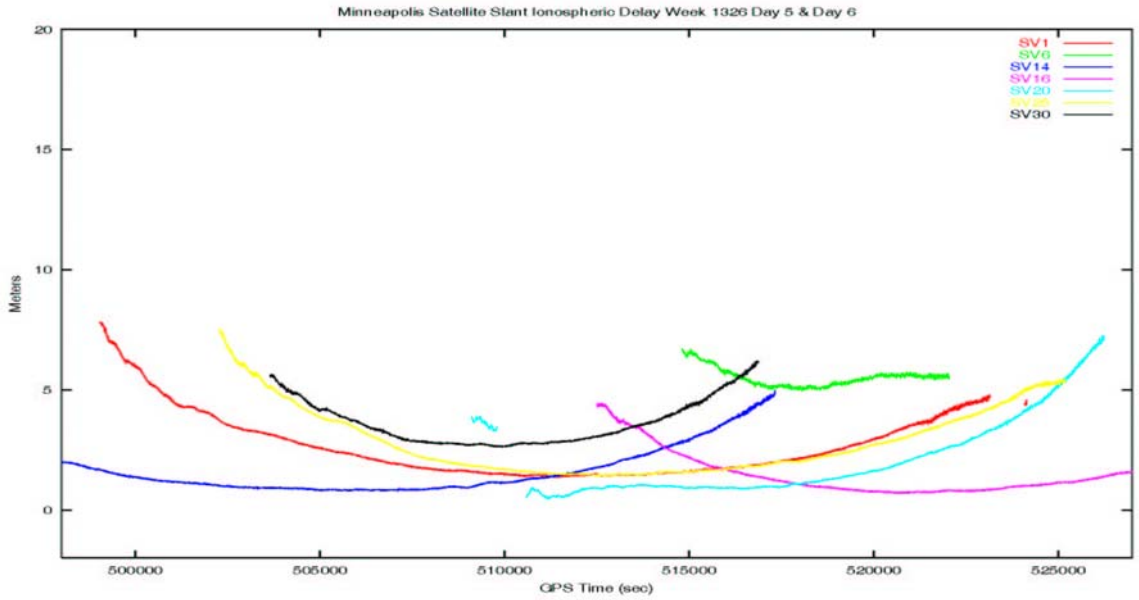
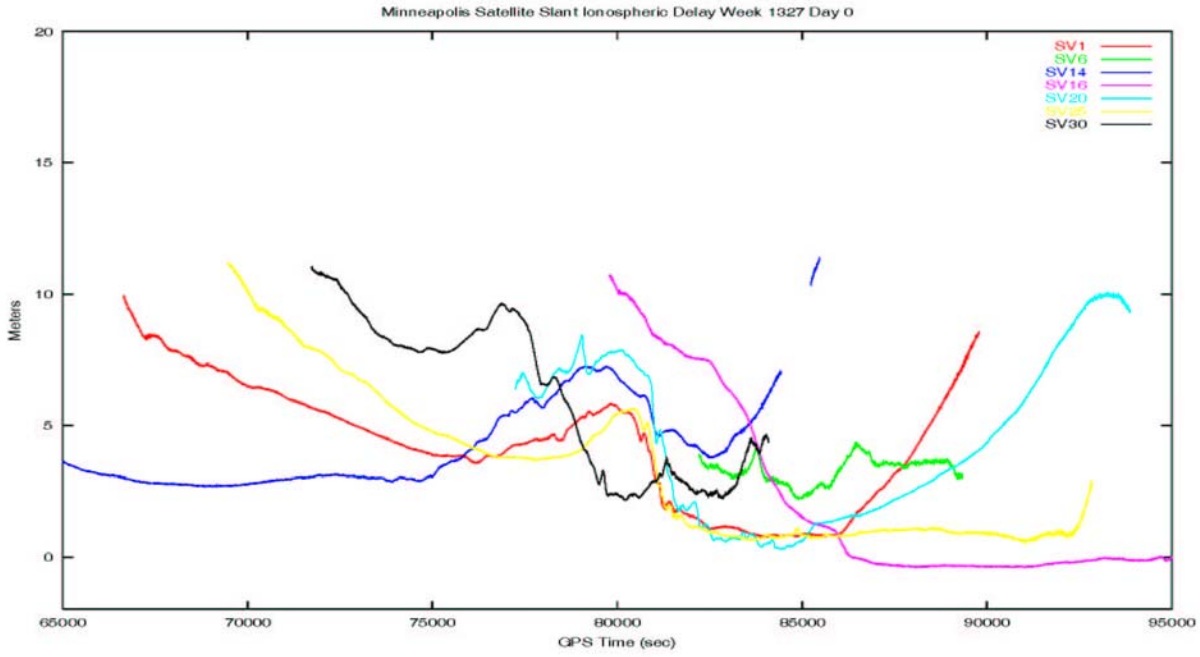
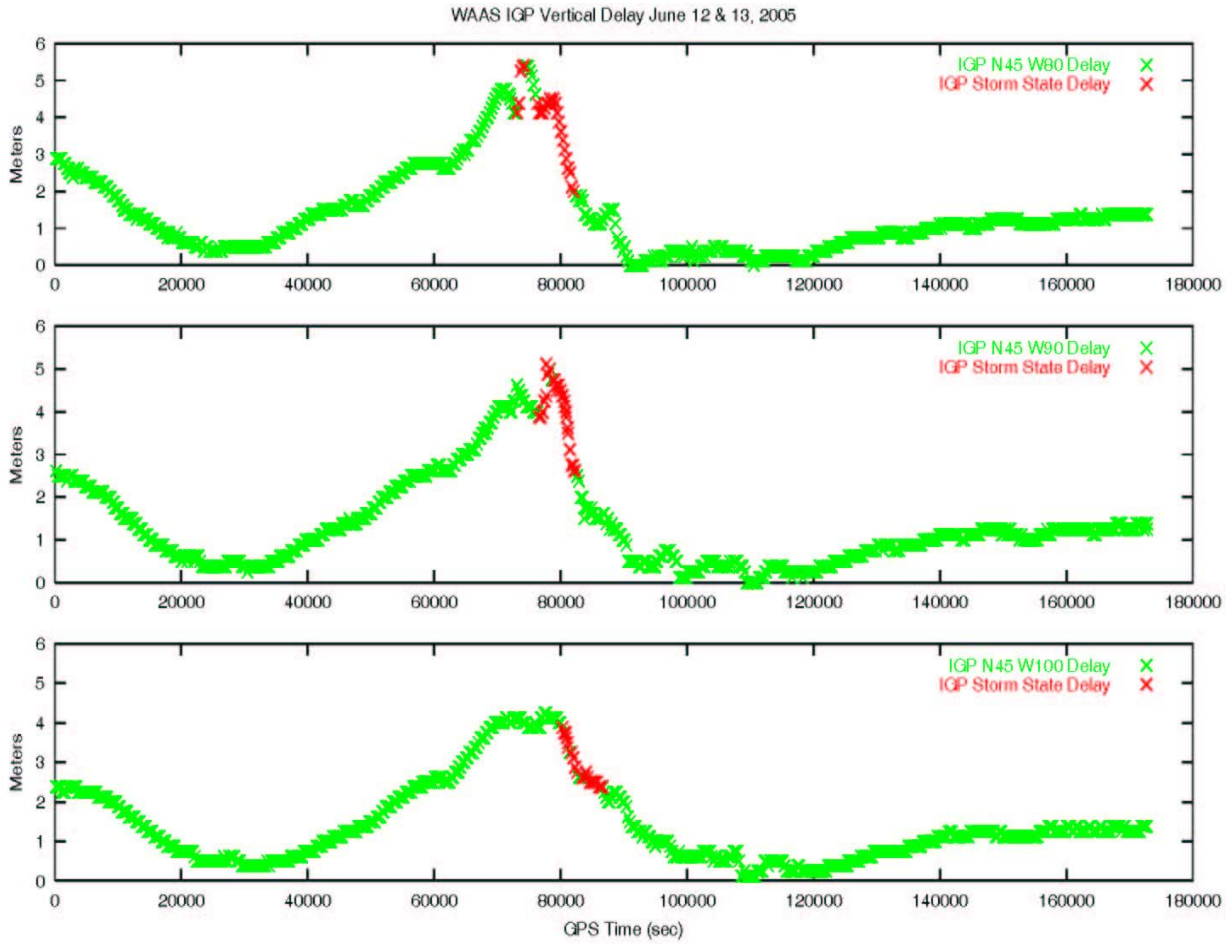



**Figure 6 – Satellite Iono Delay, Storm, Minneapolis June 12th 2005**



WAAS IGP's enter and leave storm state independently. This condition has various impacts on LPV availability in the region. Figure 7 shows the ionospheric vertical delay verses time for three IGP's (latitude/longitude coordintes: N45/W80, N45/W90, and N45/W100) set to ionospheric storm state. The vertical delays due to the ionosphere changed from approximately 5 meters down to 0 meters during the storm. Vertical delays plotted in red indicate that ionospheric storm state is activated for that IGP. The WAAS Ionospheric model movie shows WAAS interpretation of the ionosphere over a wide area during the ionospheric storm on June 12$^{th}$ & 13$^{th}$, and can be viewed at the following location:
ftp://ftp.nstb.tc.faa.gov/pub/NSTB_data/Movies/ionowaasw1327d0_d1.avi

**Figure 7 – 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 8 to 10 shows the vertical position error (VPE) verses time at three WAAS Reference Stations (WRS) located at Boston Massachusetts, Washington DC, and Minneapolis Minnesota. 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 8 – WAAS Vertical Position Error at Boston**

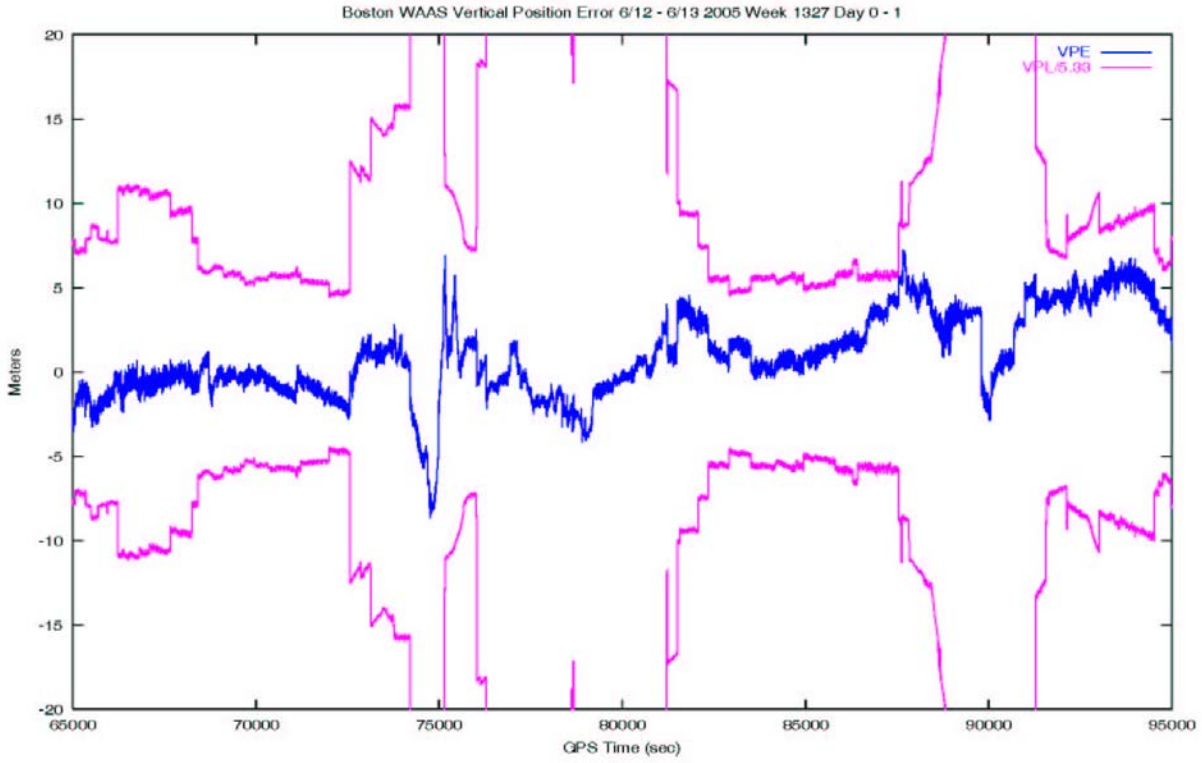


**Figure 9 – WAAS Vertical Position Error at Washington DC**

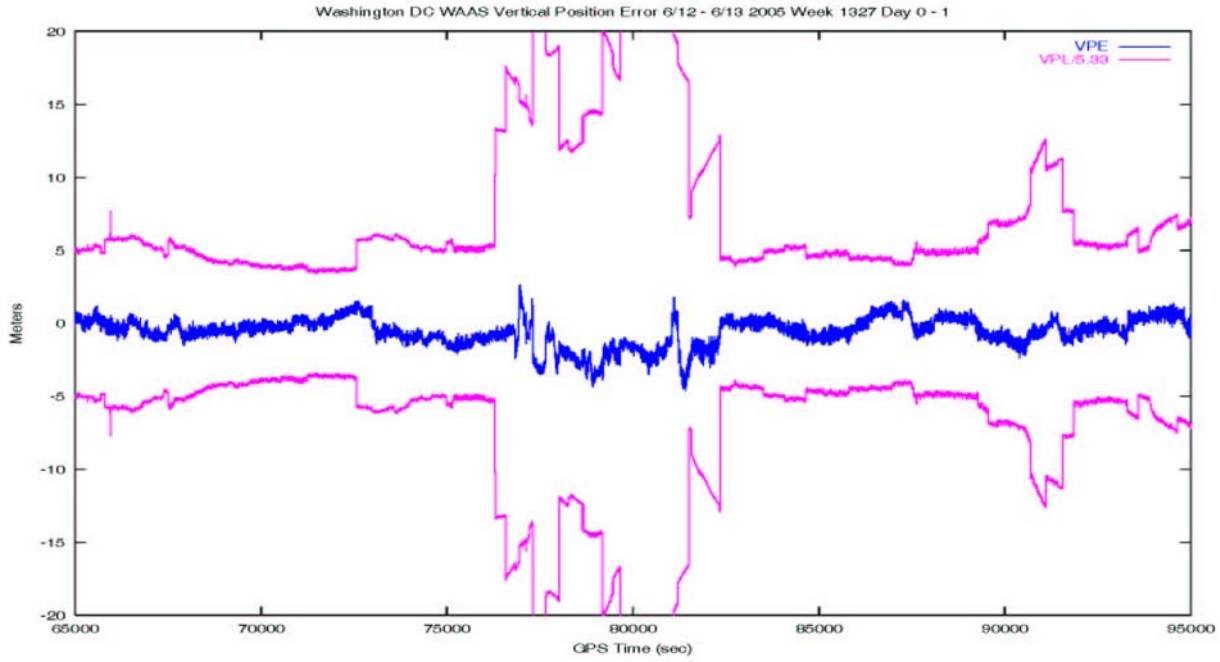
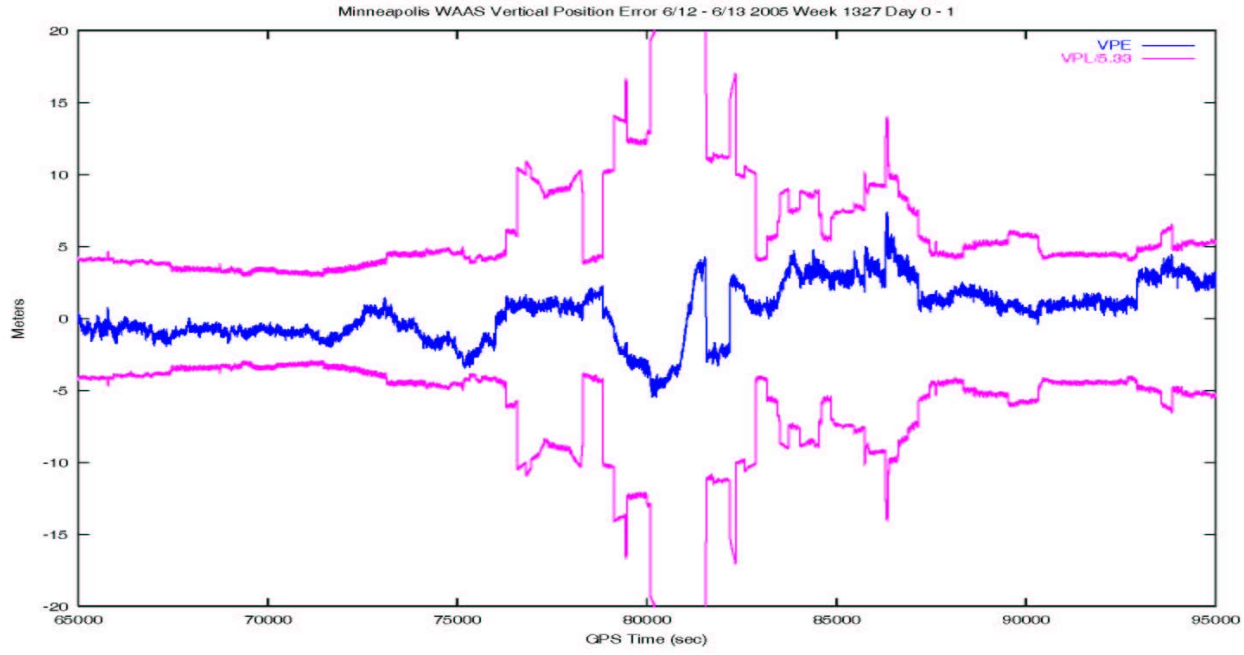



**Figure 10 – WAAS Vertical Position Error at Minneapolis**



As seen in Figure 8 – 10 the VPE as a different profile during the time of the ionospheric storm (between 72570 and 91560 GPS time of week) depending on where the user is located. The maximum VPE at Boston was 8.6 meters with a VPL of 111.8 meters. During the storm LPV service was not available at Boston with VPL reaching as high as 183 meters. Even the one sigma protection levels always bounded vertical position errors at Boston (as seen in Figure 8). The maximum VPE at Washington DC was 4.6 meters with a VPL of 90.5 meters. During the storm LPV service was not available at Washington DC with VPL reaching as high as 168 meters. And as with Boston, the one sigma protection levels at Washington DC always bounded vertical position errors (as seen in Figure 9). The maximum VPE at Minneapolis was 7.4 meters with a VPL of 72.8 meters. During the storm LPV service was not available at Minneapolis with VPL reaching as high as 125 meters. And as with Boston and Washington DC, the one sigma protection levels at Minneapolis always bounded vertical position errors (as seen in Figure 10).

**Conclusion:**

WAAS LPV service was not available on June 12$^{th}$ & 13$^{th}$ 2005 in the Northern region of CONUS due to an ionosheric storm that was detected by the system. LPV service was unavailable for four hours at the worst locations affected. The small changes in the ionospheric delay of 2 – 7 meters during the storm created an amplified WAAS system response, which created long LPV service outages through out CONUS. For example, at the Washington DC WRS the maximum vertical error was 4.6 meters during the storm and LPV service was not available at Washington DC for approximately 1.5 hours.