WAAS Technical Memorandum
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Pomona, New Jersey
4/20/10
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DR #93: Ionospheric Storm Caused Alaska Coverage Drop
GPS Week/Day: Week 1578 Day 1 (4/5/10)

Discussion:

On April 5, 2010, a geomagnetic storm caused an Alaska coverage drop when serveral IGPs in the Alaska region were set to "storm state" (GIVE or Grid Ionospheric Vertical Error is 45) from about 09:07 GMT to 09:41 GMT. When the GIVE values were set to "storm state" the protection levels in the Alaska region increased, which caused a loss of LPV and LPV200 service. Position errors at several Alaska reference stations increased dramatically during the storm due to poor satellite tracking.

Actual IGP delays during the time of the event were less than two meters. There were a total of 40 IGPs that tripped on the WAAS GIVE Monitor between 09:04:12 and 09:07:18 GMT.

According to the NOAA Space Weather Prediction Center, the most likely cause of the geomagnetic storm was a halo Coronal Mass Ejection which was observed on April 3 at 09:54 UTC by the ACE spacecraft. The ACE (Advanced Composition Explorer) spacecraft, which is orbiting at at the point of Earth-Sun gravitational equilibrium, is tasked with studying accelerated particles as they stream towards the Earth. On April 5, the ACE spacecraft observed wind speeds between 720-800 km/s and Bz reaching values around -15nT. Bz is the vertical component of the solar wind magnetic field. Both values were elevated due to the geomagnetic storm. The estimated planetary K index (Kp index), which quantifies disturbances in the horizontal component of earth's magnetic field, had a measurement of 7.

Figures 1 and 2 show the WAAS Ionospheric Grid Point Status and a WAAS Service Snapshot during the time of the geomagnetic storm. There are several IGPs set to "Storm State" in and around the Alaska region.

Figure 1: WAAS Ionospheric Grid Point Status at 09:14 GMT. The pink dots indicate gridpoints which are set to "storm state."

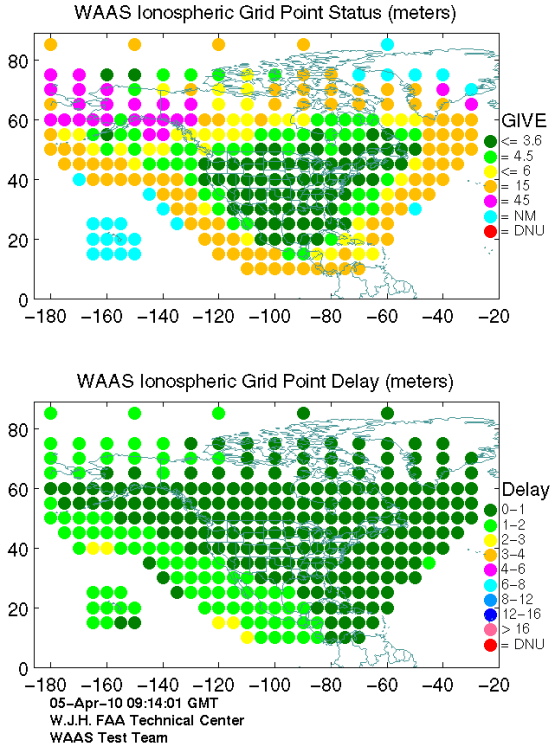


Figure 2: WAAS Service Snapshot at 09:14 GMT

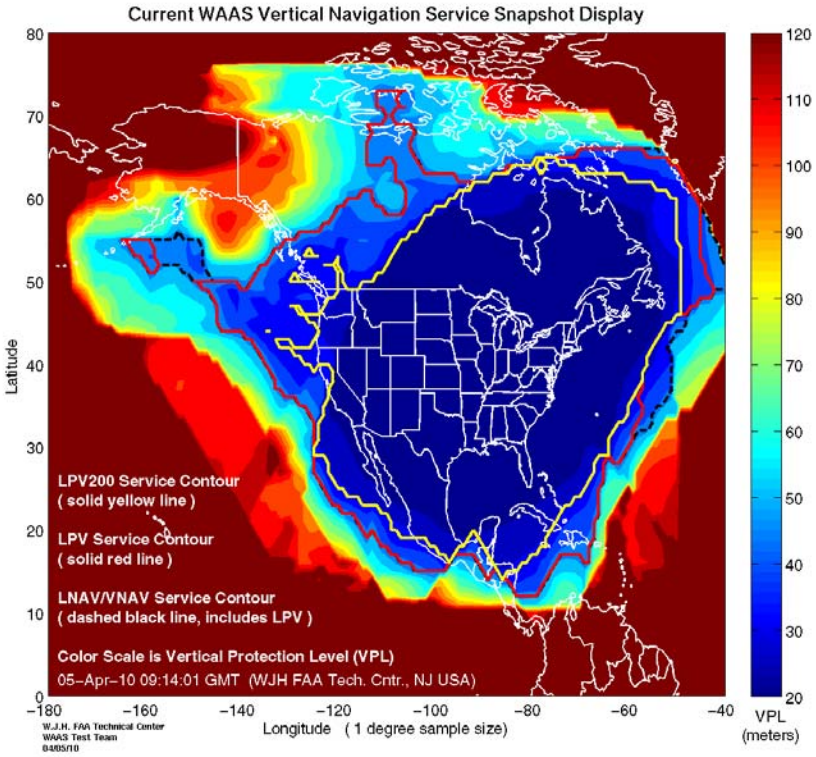


Figure 3 shows a plot of the Meridan Scanning Photometer which is installed at the Poker Flat Research Range, located near Fairbanks, Alaska. The instrument determines the intensity of light along a line between the north and south magnetic poles. The field of view is approximately 1 degree by 180 degrees. This covers a narrow band of the sky from the magnetic north horizon to the magnetic south horizon. As can be seen from the plot, auroral activity was high across the entire north-south slice of the sky when the GIVE monitor trips occurred (around 0900 GMT).

Figure 3: Meridian Scanning Photometer at the Poker Flat Research Range

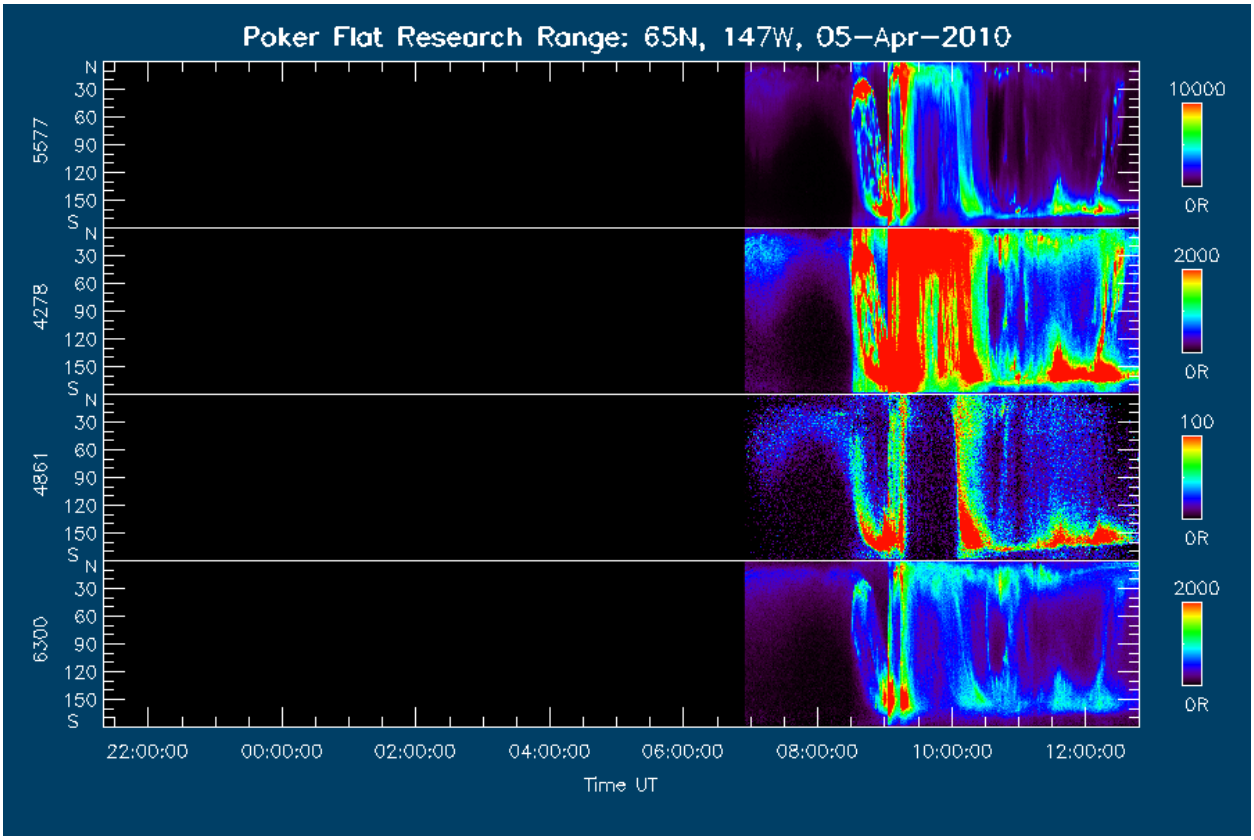


Figure 4 shows a plot of auroral intensity vs time on April 5, 2010. At the time of the GIVE monitor trips, auroral intensity spiked. Intensity was also high just after 13:00 GMT.

Figure 4: Auroral Activity vs Time – April 5, 2010

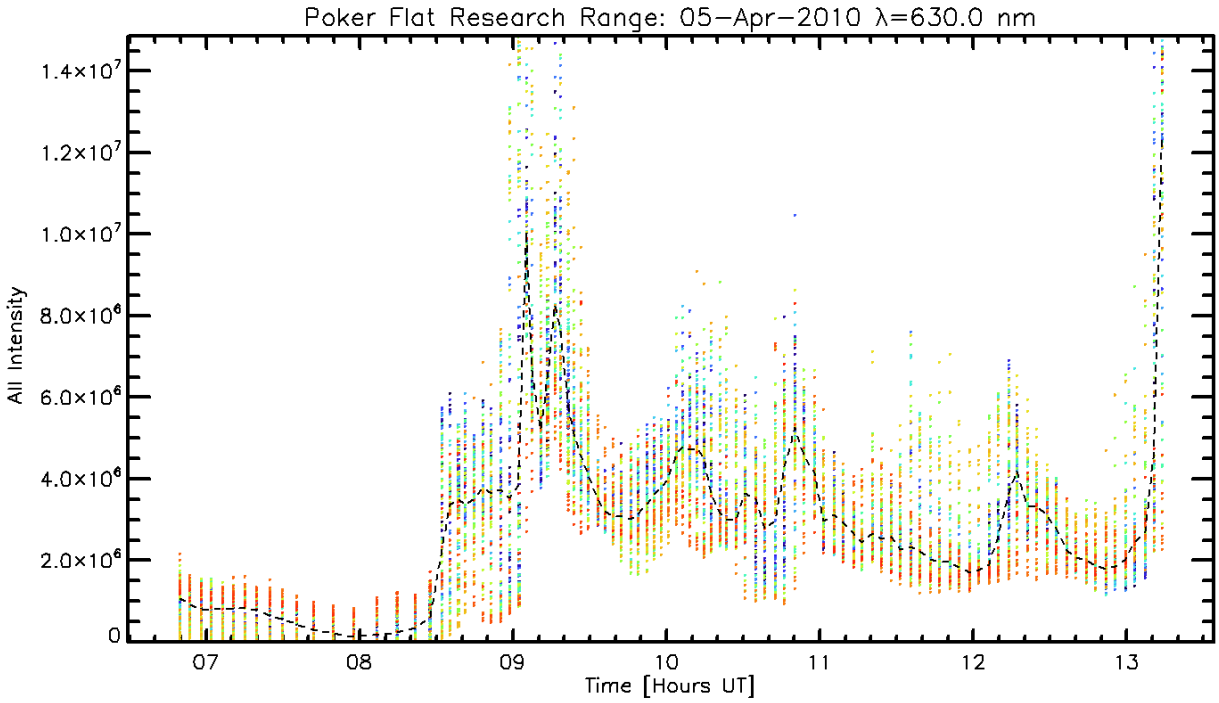


Figure 5 shows a visual representation of auroral intensity plots as seen from the Poker Flats Research Range. Starting at 08:55 GMT, the auroral intensity was high until about 09:26 GMT. There was also increased activity around 13:11 GMT.

Figure 5: Auroral Intensity throughout the day on April 5, 2010

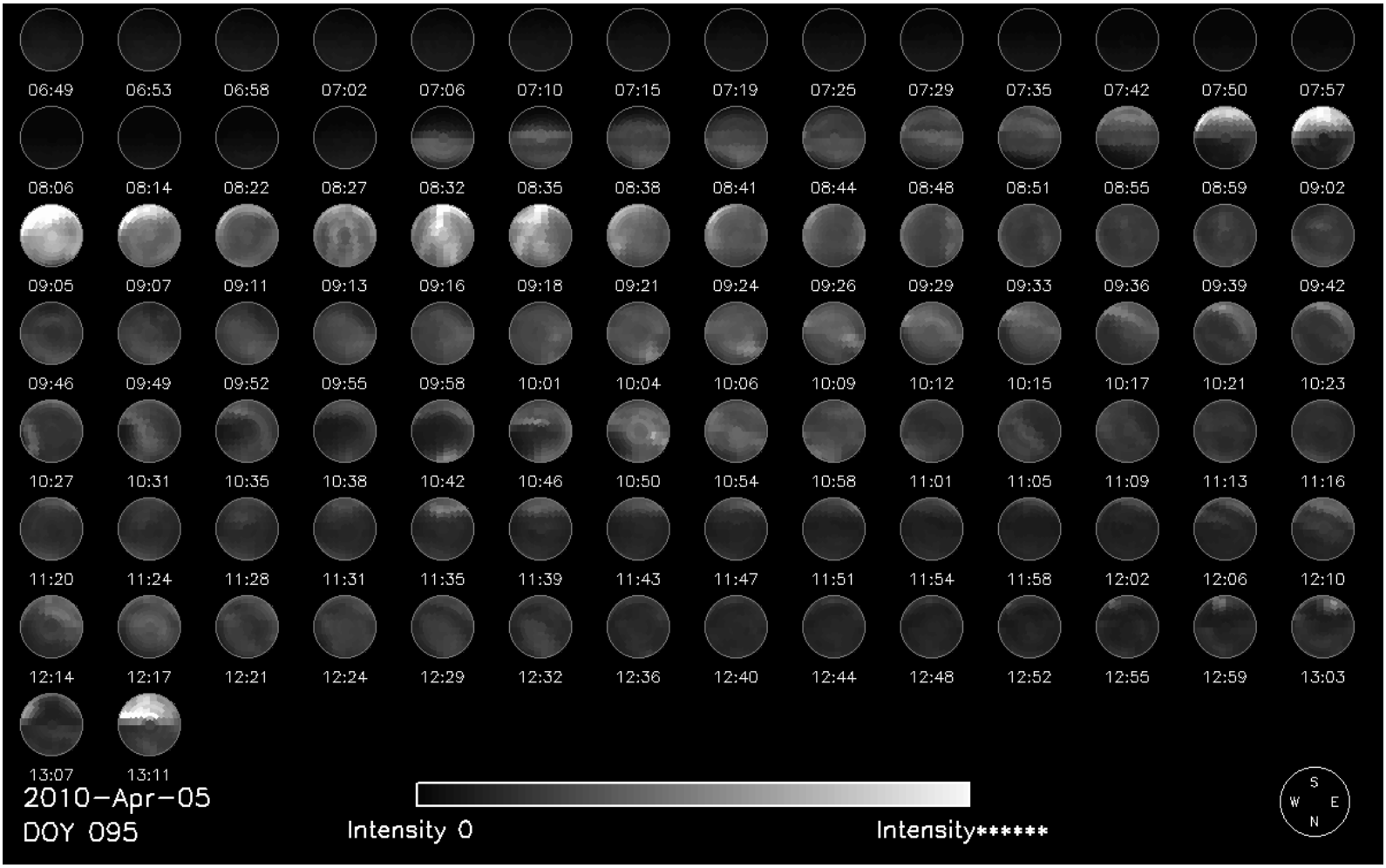
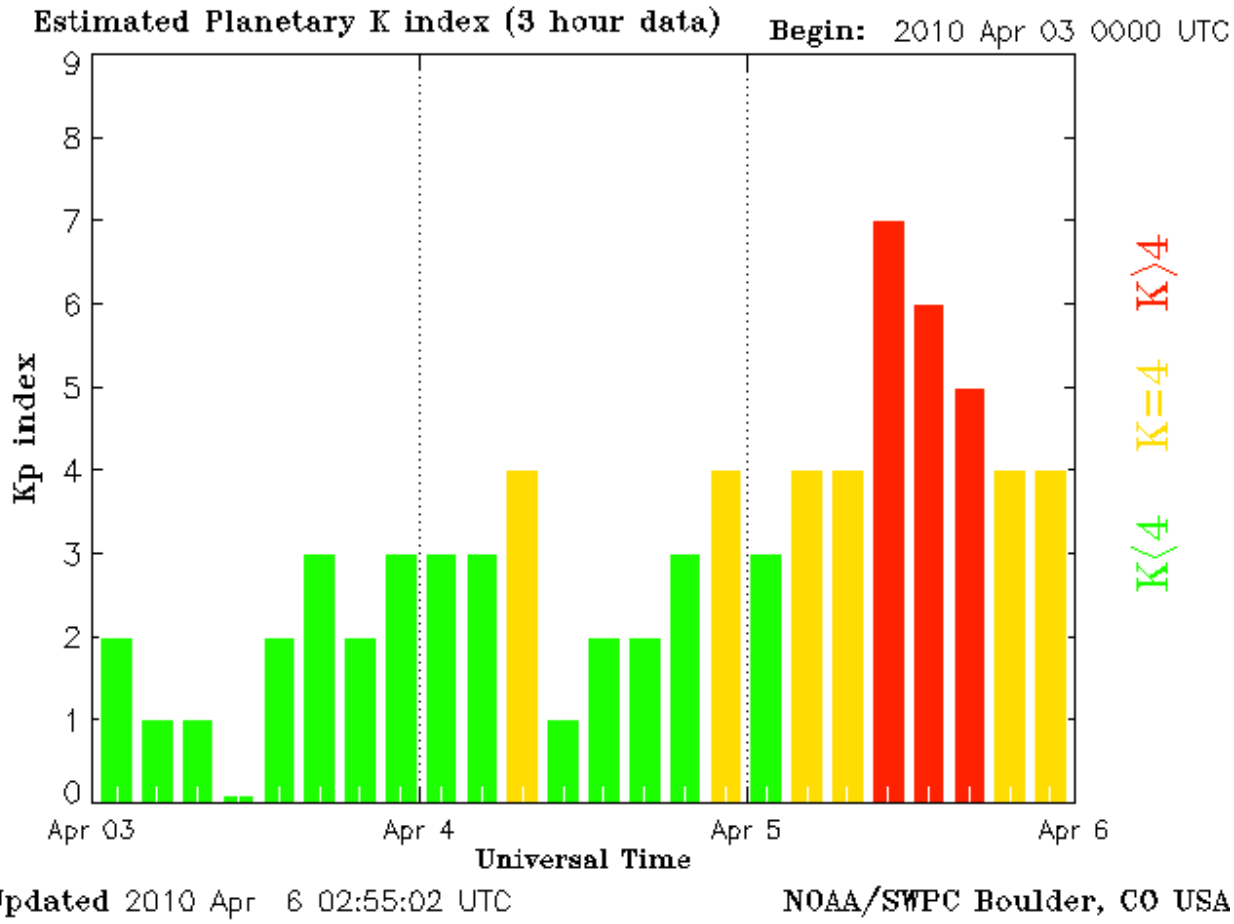


Figure 6 shows the planetary Kp index plot for April 5, 2010. The Kp index had a maximum value of 7 during the three hour period from 0900 GMT to 1200 GMT. According to the NOAA Space Weather Scale for Geomagnetic Storms, this indicates a G3, or “Strong” Geomagnetic Storm.

Figure 6: Kp index plot for April 5, 2010



The geomagnetic storm had significant effects on the tracking of satellites and caused increased position errors at several sites in Alaska. Table 1 lists the maximum vertical and horizontal errors and the protection levels at the time of those maximum errors. The horizontal and vertical maximum errors may have occurred at different times. The maximum errors did not exceed the protection levels at any Alaska site on April 5, 2010.

Table 1: Maximum Vertical and Horizontal Position Errors at Several Alaska Locations

Location	Vertical Error	Horizontal Error	VPL	HPL
Anchorage	3.873	2.581	26.753	47.923
Bethel	2.939	2.747	30.475	15.135
Barrow	10.601	2.081	79.570	20.190
Cold Bay	2.451	1.987	50.121	33.422
Fairbanks	3.588	2.408	139.145	55.841
Juneau	2.727	1.621	27.605	33.161
Kotzebue	29.253	18.777	120.848	230.875

At Kotzebue, AK, the geomagnetic storm caused especially poor satellite tracking, which caused the receivers at the WRS to lose lock for a short time during the height of the geomagnetic storm.

Starting at about 09:02 GMT, the Kotzebue WRS experienced significant drops in the Signal-to-Noise ratios and a significant increase in the relative carrier tracking error of all satellites. Over a period of about 80 seconds, the three Kotzebue receivers were unable to compute a navigation solution because less than four satellites were flagged as usable for navigation processing. As satellites were dropped from tracking due to the geomagnetic storm, position errors increased due to poor geometry of remaining satellites and increased range errors. At 09:07:31 GMT, the WAAS system set IGPs in the Alaska region to “Storm State, ” which raised the protection levels and caused a loss of LPV and LPV200 service until 09:41 GMT.

Figure 7 shows the L1 and L2 Signal-to-Noise ratio of PRN 12 and PRN 30 in Kotzebue during the time of the geomagnetic storm. Both the L1 and L2 signals dropped sharply during this period. The L2 signal tracking was especially unreliable during this time.

Figure 7: Kotzebue Signal-to-Noise Ratio during part of the ionospheric storm

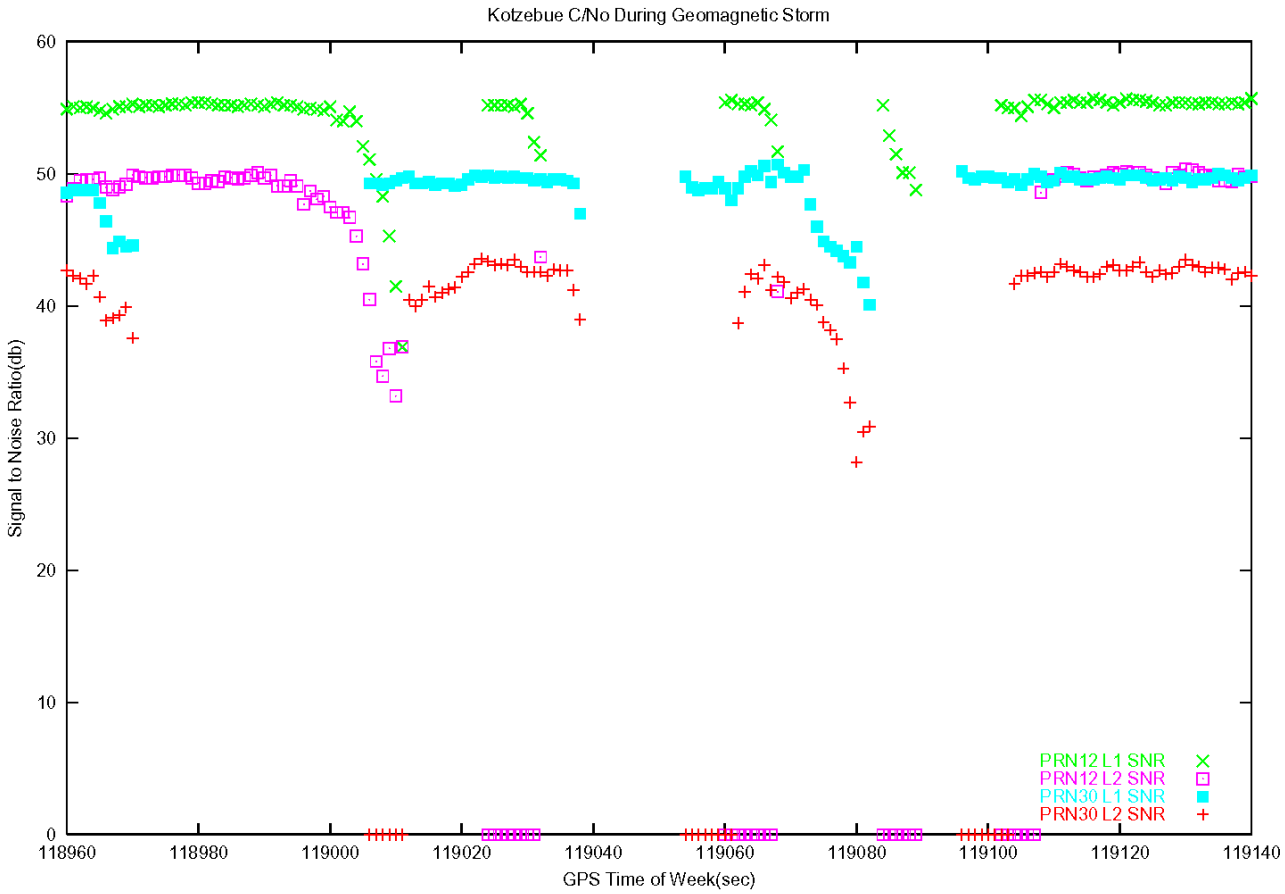


Figure 8 shows a plot of the WAAS vertical and horizontal protection levels on Kotzebue Thread 1 during the geomagnetic storm.

Figure 8: Protection Levels and Number of Satellites Tracked by Kotzebue Thread 1

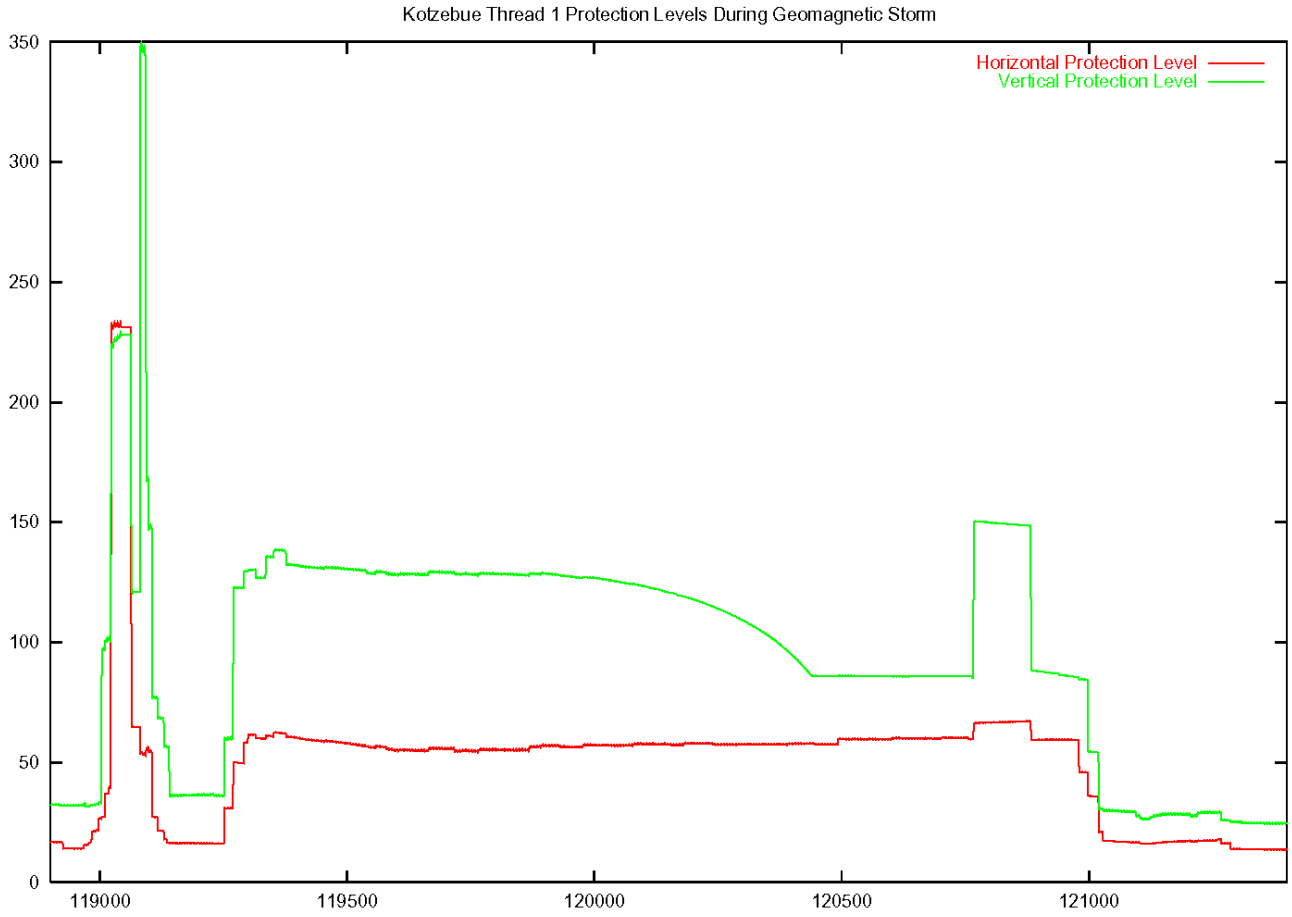
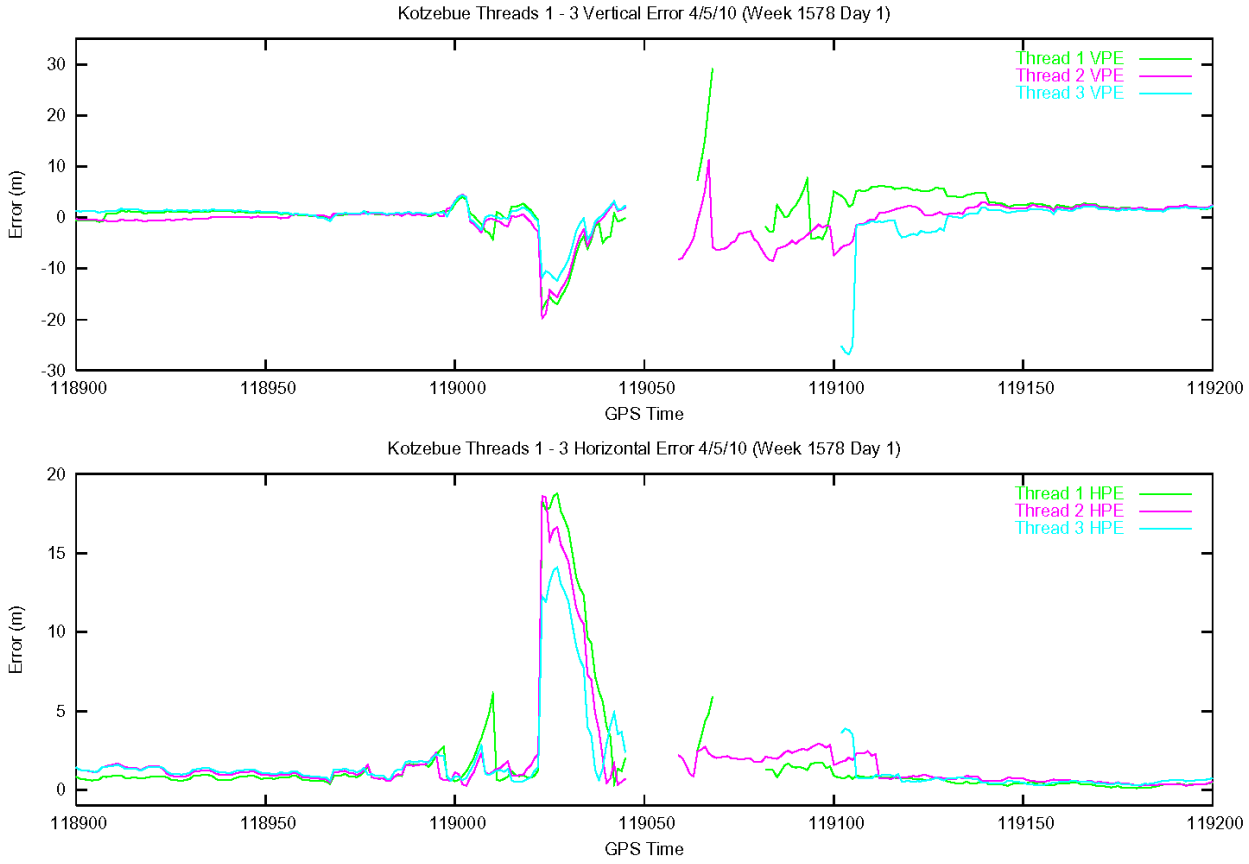


Figure 9 shows the vertical error and horizontal error at Kotzebue during a short duration of the geomagnetic storm. Gaps in the position errors indicate times when the receivers were unable to calculate a position solution due to loss of satellite tracking.

Figure 9: Vertical and Horizontal Error at Kotzebue during part of the ionospheric storm



The elevated GIVE values in the Alaska region reduced LPV and LPV200 coverage in Alaska as shown in. Figures 10 and 11 for April 5, 2010.

Figure 10: LPV Coverage on April 5, 2010

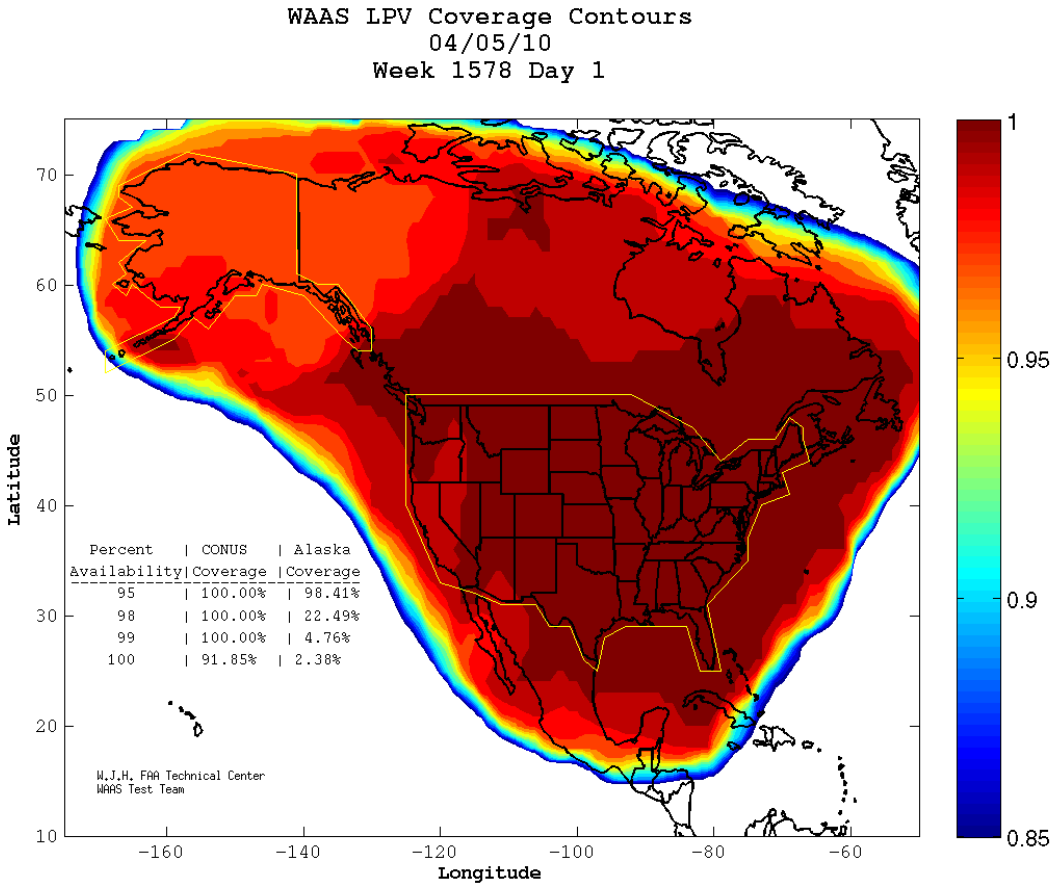
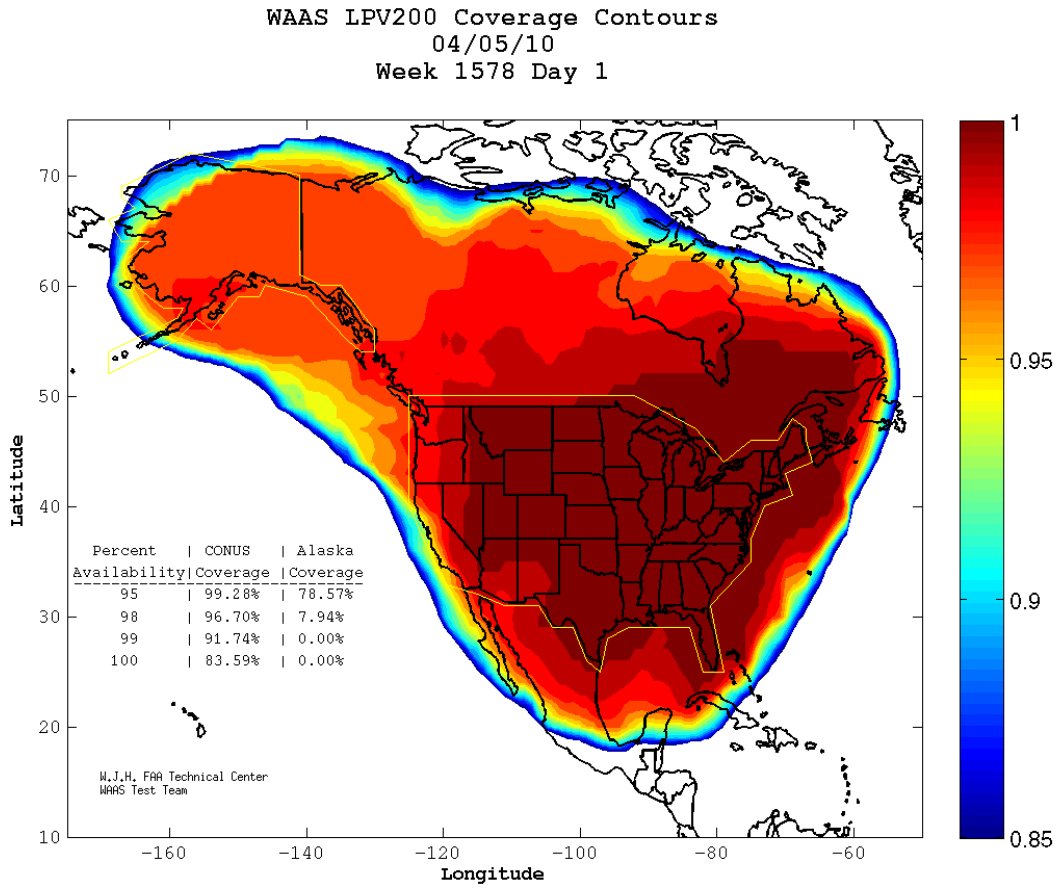


Figure 11: LPV200 Coverage Contours for April 5, 2010



Conclusion:

Several IGPs in the Alaska region were set to “storm state” (GIVE=45) on April 5, 2010. This was due to increased auroral activity at the time. The IGPs being set to “storm state” caused increased protection levels, leading to a reduction in Precision Approach coverage in Alaska for approximately 34 minutes. Drops in signal-to-noise ratios and increased carrier tracking errors caused the WAAS reference receivers at Kotzebue to declare cycle slips on several satellites, which led to increased position errors and caused the WAAS receivers to “lose lock” for a short period of time. The WAAS system performed as it was designed during the times of the geomagnetic storm by declaring a Precision Approach service outage for users in the area affected by ionospheric activity.