WAAS Technical Report
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5/20/13

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DR #113: Ionospheric Scintillation Causes Elevated Vertical Errors at Higher Latitude WAAS Reference Stations
GPS Week/Day: Week 1733 Day 5 (Mar 29, 2013)

Discussion:

On March 29, 2013 the maximum vertical errors while in Precision Approach (PA) mode were higher than expected at several WAAS Reference Stations in Alaska and Canada.

There were several Alaska reference stations which had a higher than expected vertical errors and ratios. Performance was consistent across all three threads, as detailed on page 2 of this report.

Table 1 lists the times, maximum vertical errors (VPEs), the corresponding vertical protection levels (VPLs) at the time of the maximum errors, and the vertical ratio (VPE/VPL) for the WAAS reference stations which experienced high errors on March 29th,. Statistics listed in Table 1 express receiver performance realized while receiver tracking problems were evident. After additional analysis, it was determined that receiver tracking problems on a single satellite caused unexpected increases in vertical error at Fairbanks, Kotzebue, and Iqaluit.

Table 1: WRS Locations with Elevated Vertical Errors (with receiver tracking problems included) on March 29, 2013

WRS Location	Time of Max Error	Max Vertical Error	VPL at Time of Max Error	Vertical Ratio
Fairbanks-A	**9:54:32**	**20.961**	**18.144**	**1.155**
Fairbanks-B	**9:54:28**	**8.726**	**17.911**	**0.487**
Fairbanks-C	**9:54:26**	**5.786**	**18.14**	**0.319**
Barrow-A	**8:12:04**	**5.428**	**25.885**	**0.210**
Barrow-B	**8:12:03**	**4.711**	**25.888**	**0.182**
Barrow-C	**8:12:03**	**4.587**	**25.888**	**0.177**
Kotzebue-A	**10:22:09**	**4.238**	**24.925**	**0.170**
Kotzebue-B	**10:22:08**	**3.582**	**24.925**	**0.144**
Kotzebue-C	**10:22:08**	**4.021**	**24.924**	**0.161**
Iqaluit-A	**18:15:46**	**6.399**	**29.833**	**0.214**
Iqaluit-B	**18:15:51**	**9.798**	**29.838**	**0.328**
Iqaluit-C	**18:15:51**	**10.149**	**29.84**	**0.340**
Gander-A	**17:07:58**	**4.416**	**44.95**	**0.098**

Gander-B	**17:07:57**	**3.858**	**44.947**	**0.086**
Gander-C	**17:01:33**	**3.858**	**43.298**	**0.089**

Geomagnetic Activity

The maximum Kp index value on March 29th was 5. Elevated solar wind caused by an earth-directed coronal hole allowed more energy to flow into the Earth's upper atmosphere, leading to elevated geomagnetic activity. According to the Space Weather Prediction Center, "...unsettled to minor storm conditions were observed on 29-30 March due to effects from a second CH HSS. During that period, solar wind speed remained fairly steady averaging about 550 km/s." CH HSS stands for Coronal Hole High Speed Stream.

Alaska Reference Stations which experienced elevated vertical errors:

At Barrow, all satellites being tracked were used in the navigation solution at the time of the maximum vertical errors. All WREs at Barrow had similar vertical errors and ratios. The vertical ratios realized at Barrow on March 29th were higher than typical ratios. There was no receiver tracking problems at Barrow.

At both Fairbanks and Kotzebue, code and carrier measurements drifted sharply before a cycle slip was detected on PRN 29. The sharp drift in both the code and carrier measurements is a manifestation of WAAS G-2 tracking problems. The range error on PRN 29 increased before the satellite finally cycle slipped. Data will be excluded from statistics when the drift in code and carrier measurement caused high errors at Fairbanks and Kotzebue. Four seconds of data will be excluded from Kotzebue, and 10 seconds of data will be excluded from Fairbanks.

Canada Reference Stations which experienced elevated vertical errors:

At Gander, there were no dropped satellites or cycle slips. Vertical errors and protection levels were similar on all three threads. Vertical errors were higher than typically seen, although vertical ratios were within normal expectations. No receiver tracking problems were detected at Gander.

At Iqaluit, all three threads had higher than expected vertical errors. The maximum vertical error on thread A was lower than the other two threads.

After closely examining the performance of Iqaluit, it was determined that maximum errors were due to receiver tracking problems. The L2 signal was unexpectedly lost on PRN 14 near the time of maximum errors. The receiver kept tracking L1 throughout the event even though L2 was lost. Also, the receiver reported that PRN 14 was valid, when, in fact, code and carrier measurements were diverging. Eleven seconds of data will be excluded from Iqaluit statistics.

Thread A Reference Station Statistics Following Detailed Analysis

Table 2 shows the performance at several Alaska sites after exclusion of data when the receiver was experiencing tracking problems. Recomputed maximum vertical errors and ratios are shown below.

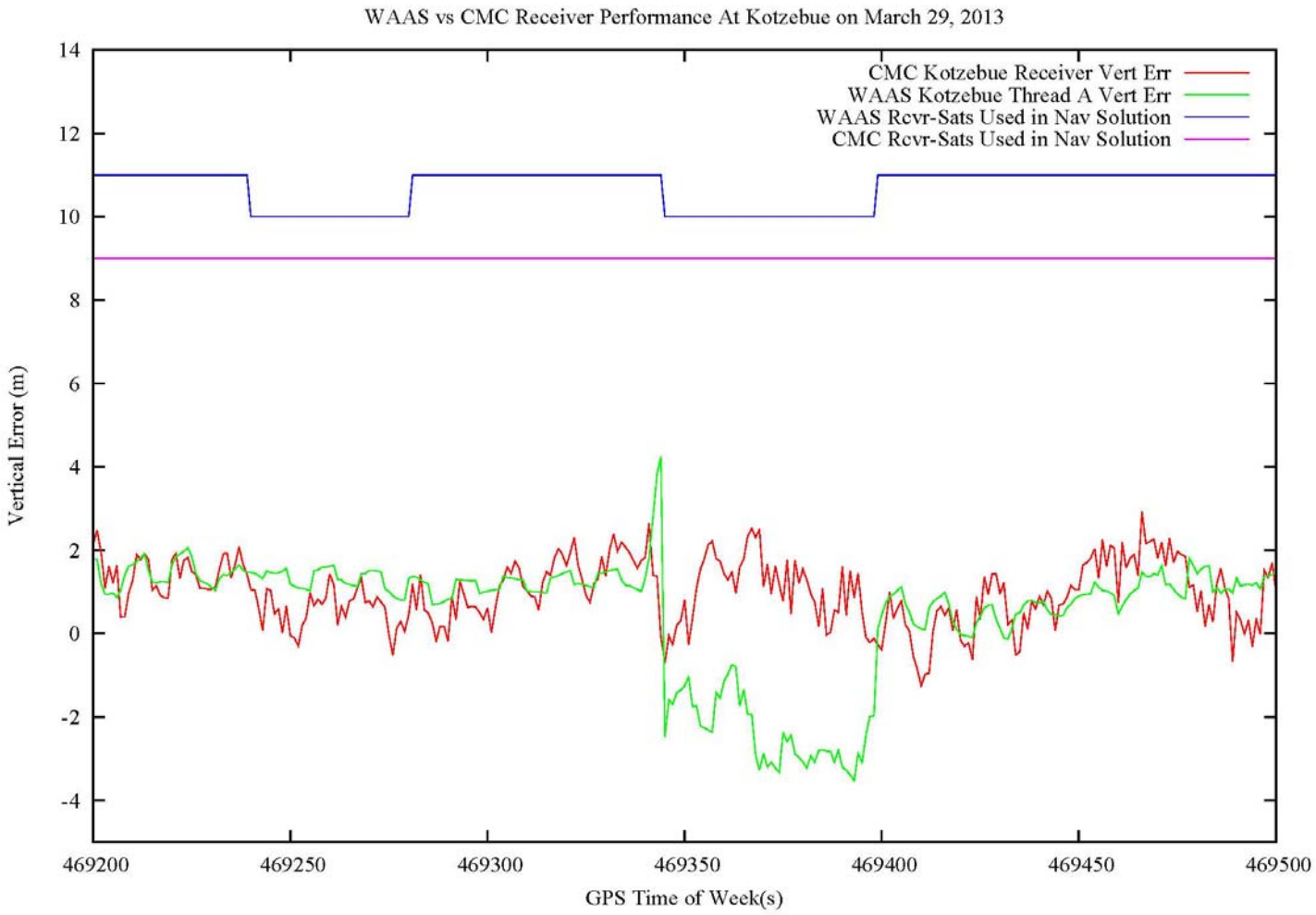
WRS Location	Time of Max Error	Max Vertical Error	VPL at Time of Max Error	Vertical Ratio
Fairbanks-A	**9:53:53**	**3.798**	**17.828**	**0.213**
Barrow-A	**8:12:04**	**5.428**	**25.885**	**0.210**
Kotzebue-A	**14:06:46**	**3.45**	**21.131**	**0.163**
Iqaluit-A	**2:45:11**	**3.155**	**29.864**	**0.106**
Gander-A	**17:07:58**	**4.416**	**44.95**	**0.098**

Performance of CMC WAAS Certified Aviation Receiver at Kotzebue, AK

A WAAS Certified Aviation receiver (CMC Electronics-CMA-5024 GLSSU) has been running real-time at Kotzebue, AK in addition to the three WAAS G-2 receivers. The CMC receiver operates solely on the L1 frequency. The data from the CMC receiver on March 29, 2013 was collected, processed and analyzed in detail.

Figure 1 shows a plot which compares differences between the CMC receiver performance and the WAAS G-2 receiver performance. Note that the WAAS G-2 receiver operates on both the L1 and L2 frequency. The vertical error and number of satellites used in the navigation solution for both receivers is plotted.

Figure 1: WAAS vs CMC Receiver Performance at Kotzebue on March 29, 2013



The CMC receiver utilized nine satellites in the navigation solution throughout the time when errors were elevated at Kotzebue. Vertical errors changed little at the time when high errors were reported from the WAAS G-2 receiver.

The WAAS G-2 receiver utilized between ten and eleven satellites in the navigation solution throughout the time shown. PRN 5 was excluded from the navigation solution at GPS Time of Week 469240 (10:20:24 GMT) due to a cycle slip. PRN 5 returned to the navigation solution at GPS TOW 469281 (10:21:05 GMT). PRN 29 was dropped from the track list at GPS TOW 469345 (10:22:09). When PRN 29 was lost, the vertical error changed sharply. PRN 29 was included in the navigation solution following initialization at 469399 (10:23:03 GMT). Vertical errors changed quickly for four seconds before PRN 29 was dropped from the track list.

The CMC receiver did not exhibit cycle slips or tracking difficulties during the time of interest.

This independently validates that tracking problems with the WAAS G-2 receiver caused high vertical errors.

Conclusion:

Elevated vertical errors at Gander and Barrow were caused by elevated geomagnetic activity. At Fairbanks, Iqaluit and Kotzebue, high vertical errors were due to WAAS G-2 receiver tracking problems during ionospheric scintillation. Invalid data will be excluded from statistics at Fairbanks, Kotzebue, and Iqaluit.