Global Positioning System (GPS)
Standard Positioning Service (SPS)
Performance Analysis Report

Submitted To

Federal Aviation Administration

GPS Product Team

1284 Maryland Avenue SW

Washington, DC 20024

Report #85

April 30, 2014

Reporting Period: 1 January – 31 March 2014

Submitted by

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Executive Summary

The GPS Product Team has tasked the Navigation Systems Verification and Monitoring Branch at the William J. Hughes Technical Center to document the Global Positioning System (GPS) Standard Positioning Service (SPS) performance in quarterly GPS Performance Analysis (PAN) Reports. The report contains the analysis performed on data collected at twenty-eight Wide Area Augmentation System (WAAS) Reference Stations. This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification (September 2008).

This report, Report #85, includes data collected from 1 January through 31 March 2014. The next quarterly report will be issued July 31, 2014.

Analysis of this data includes the following standards and categories: PDOP Availability, NANU Summary and Evaluation, Service Availability, Position and Range Accuracy and Solar Storm Effects on GPS SPS performance.

PDOP availability is based on Position Dilution of Precision (PDOP). Utilizing the weekly almanac posted on the US Coast Guard navigation web site, the coverage for every 5^o grid point between 180W to 180E and 80S and 80N was calculated for every minute over a 24-hour period for each of the weeks covered in the reporting period. For this reporting period, the global availability based on PDOP less than six for CONUS was 100%.

NANU summary and evaluation was achieved by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 January and 31 March 2014. Using this data, we compute a set of statistics that give a relative idea of constellation health for both the current and combined history of past quarters. A total of twelve outages were reported in the NANU's this quarter. Ten outages were scheduled while two were unscheduled.

The quarterly service availability standard was verified using 24-hour position accuracy values computed from data collected at one-second intervals. All of the sites achieved a 100% availability, which exceeds the SPS "average location" value of 99% and the "worst-case location" value of 90%.

Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error standard was verified for each satellite from 24-hour accuracy values computed using data collected at the following six sites: Boston, Honolulu, Los Angeles, Miami, San Juan and Juneau. This data was also collected in one-second samples. All sites achieved 100% reliability, meeting the SPS specification. The maximum range error recorded was 31.464 meters on Satellite PRN 10. The SPS specification states that the range error should never exceed 30 meters for less than 99.79% of the day for a worst-case point and 99.94% globally. The maximum RMS range error value of 2.918 was recorded on satellite PRN 10. The SPS specification states that RMS URE cannot exceed 6 meters in any 24-hour interval.

Geomagnetic storms had little to no effect on GPS performance this quarter. All sites met all GPS Standard Positioning Service (SPS) specifications on those days with the most significant solar activity.

The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products. During the evaluation period, the maximum 95% horizontal and vertical SPS errors were 10.32 meters at Matera, Italy and 11.36 meters at Bogota, Colombia respectively.

From the analysis performed on data collected between 1 January and 31 March 2014, the GPS performance met all SPS requirements that were evaluated. However, a couple issues were noted and discussed in the problem report in section 9.3 on page 49. Ionospheric activity caused increased range errors on two different satellites at Honolulu, Hawaii on 21 February. Although the range error exceeded 30 meters for a short time, it was not long enough duration to exceed the SPS specification. The analysis was included for completeness.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS and WAAS for IFR operations and is developing Local Area Augmentation (LAAS), which is an additional GPS augmentation system. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Analysis report. This report contains data collected at the following twenty-eight WAAS reference station locations:

- Bethel, AK
- Billings, MT
- Fairbanks, AK
- Cold Bay, AK
- Kotzebue, AK
- Juneau, AK
- Albuquerque, NM
- Anchorage, AK
- Boston, MA
- Washington, D.C.
- Honolulu, HI
- Houston, TX
- Kansas city, KS
- Los Angeles, CA
- Salt Lake City, UT
- Miami, FL
- Minneapolis, MI
- Oakland, CA
- Cleveland, OH
- Seattle, WA
- San Juan, PR
- Atlanta, GA
- Barrow, AK
- Merida, Mexico
- Gander, Canada
- Tapachula, Mexico
- San Jose Del Cabo, Mexico
- Iqaluit, Canada

The analysis of the data is divided into the four performance categories stated in the Standard Positioning Service Performance Specification (September 2008). These categories are:

- PDOP Availability Standard
- Service Availability Standard
- Service Reliability Standard
- Positioning, Ranging and Timing Accuracy Standard

The results were then compared to the performance parameters stated in the SPS.

1.2 Report Overview

Section 2 of this report summarizes the results obtained from the coverage calculation program developed by the WAAS test team at the William J. Hughes Technical Center. The SPS coverage area program uses the GPS satellite almanacs to compute each satellite position as a function of time for a selected day of the week. This program establishes a 5-degree grid between 180 degrees east and 180 degrees west, and from 80 degrees north and 80 degrees south. The program then computes the PDOP at each grid point (1485 total grid points) every minute for the entire day and stores the results. After the PDOP's have been saved the 99.99% index of 1-minute PDOP at each grid point is determined and plotted as contour lines (Figure 2-1). The program also saves the number of satellites used in PDOP calculation at each grid point for analysis.

Section 3 summarizes the GPS constellation performance by providing the "Notice: Advisory to Navstar Users" (NANU) messages to calculate the total time of forecasted and actual satellite outages. This section also evaluates the Service Availability Standard using 24-hour 95% horizontal and vertical position accuracy values.

Section 4 summarizes service reliability performance. It will be reported at the end of the first year of this analysis because the SPS standard is based on a measurement interval of one year. Data for the quarter is provided for completeness.

Section 5 provides the position accuracies based on data collected on a daily basis at one-second intervals. This section also provides the statistics on the range error, range error rate and range acceleration error for each satellite. The overall average, maximum, minimum and standard deviations of the range rates and accelerations are tabulated for each satellite.

In Section 6, the data collected during solar storms is analyzed to determine the effects, if any, of GPS SPS performance.

Section 7 provides an analysis of GPS-SPS accuracy performance from a selection of high rate IGS stations around the world.

Section 8 provides a summary of GPS Test NOTAMs.

Section 9 provides four appendices to summarize the data found in this report and provide further information.

Appendix A provides a summary of all the results as compared to the SPS specification.

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

Appendix D provides a glossary of terms used in this PAN report. This glossary was obtained directly from the GPS SPS specification document (September 2008).

1.3 Summary of Performance Requirements and Metrics

Table 1-1 over the next four pages lists the performance parameters from the SPS and identifies those parameters verified in this report.

Table 1-1 SPS SIS Performance Requirements Standards

Per-Satellite Coverage	**Conditions and Constraints**	**Evaluated in This Report**
Terrestrial Service Volume: 100% Coverage Space Service Volume: No Coverage Performance Specified	• For any health or marginal SPS SIS	**Future Report**
Constellation Coverage	**Conditions and Constraints**	
Terrestrial Service Volume: 100% Coverage Space Service Volume: No Coverage Performance Specified	• For any healthy or marginal SPS SIS	**Future Report**
User Range Error Accuracy	**Conditions and Constraints**	
Single Frequency C/A-Code • ≤ 7.8m 9%% Global Average URE during normal operations over All AODs • ≤ 6.0m 95% Global Average URE during operations at Zero AOD • ≤ 12.8m 95% Global Average URE during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1	✓
Single Frequency C/A-Code • ≤ 30m 99.94% Global Average URE during normal operations • ≤ 30m 99.79% Worst Case single point average during normal operations.	• For any healthy SPS SIS. • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 • Standard based on measurement interval of one year; average of daily values within service volume • Standard based on 3 service failures per year, lasting no more than 6 hours each	✓
User Range Rate Error Accuracy	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	✓

User Range Acceleration Error Accuracy	**Conditions and Constraints**	**Evaluated in This Report**
Single-Frequency C/A-Code: • ≤ 2 mm/sec^2 95% Global average URAE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	✓
Coordinated Universal Time Offset Error Accuracy		
• ≤ 40 nanoseconds 95% Global average UTCOE during normal operations at Any AOD.	• For any healthy SPS SIS	✓
Instantaneous URE Integrity	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 1x10^{-5} Probability over any hour of the SPS SIS Instantaneous URE exceeding the NTE tolerance without a timely alert during normal operations.	• For any healthy SPS SIS • SPS SIS URE NTE tolerance defined to be ±4.42 times the upper bound on the URA value corresponding to the URA index “N” currently broadcast by the satellite. • Given that the maximum SPS SIS instantaneous URE did not exceed the NTE tolerance at the start of the hour • Worst case for delayed alert is 6 hours. • Neglecting singe-frequency ionospheric delay model errors	**Future Report**
Instantaneous UTCOE Integrity	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 1x10^{-5} Probability over any hour of the SPS SIS Instantaneous UTCOE exceeding the NTE tolerance without a timely alert during normal operations.	• For any healthy SPS SIS • SPS SIS URE NTE tolerance defined	**Future Report**
Unscheduled Failure Interruption Continuity	**Conditions and Constraints**	
Unscheduled Failure Interruptions: • ≥ 0.9998 Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Given that the SPS SIS is available from the slot at the start of the hour	**Future Report**

Status and Problem Reporting	Conditions and Constraints	Evaluated in This Report
Scheduled event affecting service • Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	• For any SPS SIS	✓
Unscheduled outage or problem affecting service • Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	• For any SPS SIS	✓
Per-Slot Availability	**Conditions and Constraints**	
• ≥ 0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS • ≥ 0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a health SPS SIS	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard.	✓
Constellation Availability	**Conditions and Constraints**	
• ≥ 0.98 Probability that at least 21 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration • ≥ 0.99999 Probability that at least 20 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration	• Calculated as an average over all slots in the 24-slot constellation, normalized annually. • Applies to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.	✓
Operational Satellite Count	**Conditions and Constraints**	
• ≥ 0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not	• Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operation satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not.	✓

PDOP Availability	Conditions and Constraints	Evaluated in This Report
• ≥ 98% global PDOP of 6 or less • ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval	✓
Service Availability	**Conditions and Constraints**	
• ≥ 99% Horizontal Service Availability, average location • ≥ 99% Vertical Service Availability, average location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	✓
• ≥ 90% Horizontal Service Availability, worst-case location • ≥ 90% Vertical Service Availability, worst-case location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	✓
Position/Time Accuracy	**Conditions and Constraints**	
Global Average Position Domain Accuracy • ≤ 9m 95% Horizontal Error • ≤ 15m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	✓
Worst Site Position Domain Accuracy • ≤ 17m 95% Horizontal Error • ≤ 37m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	✓
Time Transfer Domain Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for a time transfer solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	✓

2 PDOP Availability Standard

PDOP Availability: The percentage of time over any 24-hour interval that the PDOP value is less than or equal to its threshold for any point within the service volume.

Dilution of Precision (DOP): The magnifying effect on GPS position error induced by mapping GPS range errors into position within the specified coordinate system through the geometry of the position solution. The DOP varies as a function of satellite positions relative to user position. The DOP may be represented in any user local coordinate desired. Examples are HDOP for local horizontal, VDOP for local vertical, PDOP for all three coordinates, and TDOP for time.

PDOP Availability Standard	Conditions and Constraints
≥ 98% global PDOP of 6 or less ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval

Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by the WAAS test team was used to calculate the PDOP at every 5^{o} point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 2.9767 or better 99.9% of the time for each of the 24-hour intervals.

Figure 2-1 is a contour plot of PDOP values over the entire globe. Inside each contour area, the PDOP value is greater than or equal to the contour value shown in the legend for that color line. That areas' value is also less than the next higher contour value, unless another contour line lies within the current area. A single "DOP hole" where the PDOP value is greater than 6 was evaluated for satellite visibility for one 24-hour interval from the week shaded in Table 2-1. The histogram in Figure 2-2 shows the satellite visibility at the DOP hole position for the 24 hour interval in question.

The GPS coverage performance evaluated met the specifications stated in the SPS.

Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value	Global Average (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
29 Dec – 4 Jan	2.9210	100	99.931
5 – 11 Jan	2.9242	100	99.931
12 – 18 Jan	2.9198	100	100
19 – 25 Jan	2.9198	100	100
26 Jan – 1 Feb	2.9190	100	100
2 – 8 Feb	2.9220	100	100
9 – 15 Feb	2.9247	100	100
16 – 22 Feb	2.9256	100	100
23 Feb – 1 Mar	2.9204	100	100
2 – 8 Mar	2.9767	100	99.861
9 – 15 Mar	2.9704	100	99.861
16 – 22 Mar	2.9622	100	99.861
23 – 29 Mar	2.9537	100	99.861

Figure 2-1 World GPS Maximum PDOP

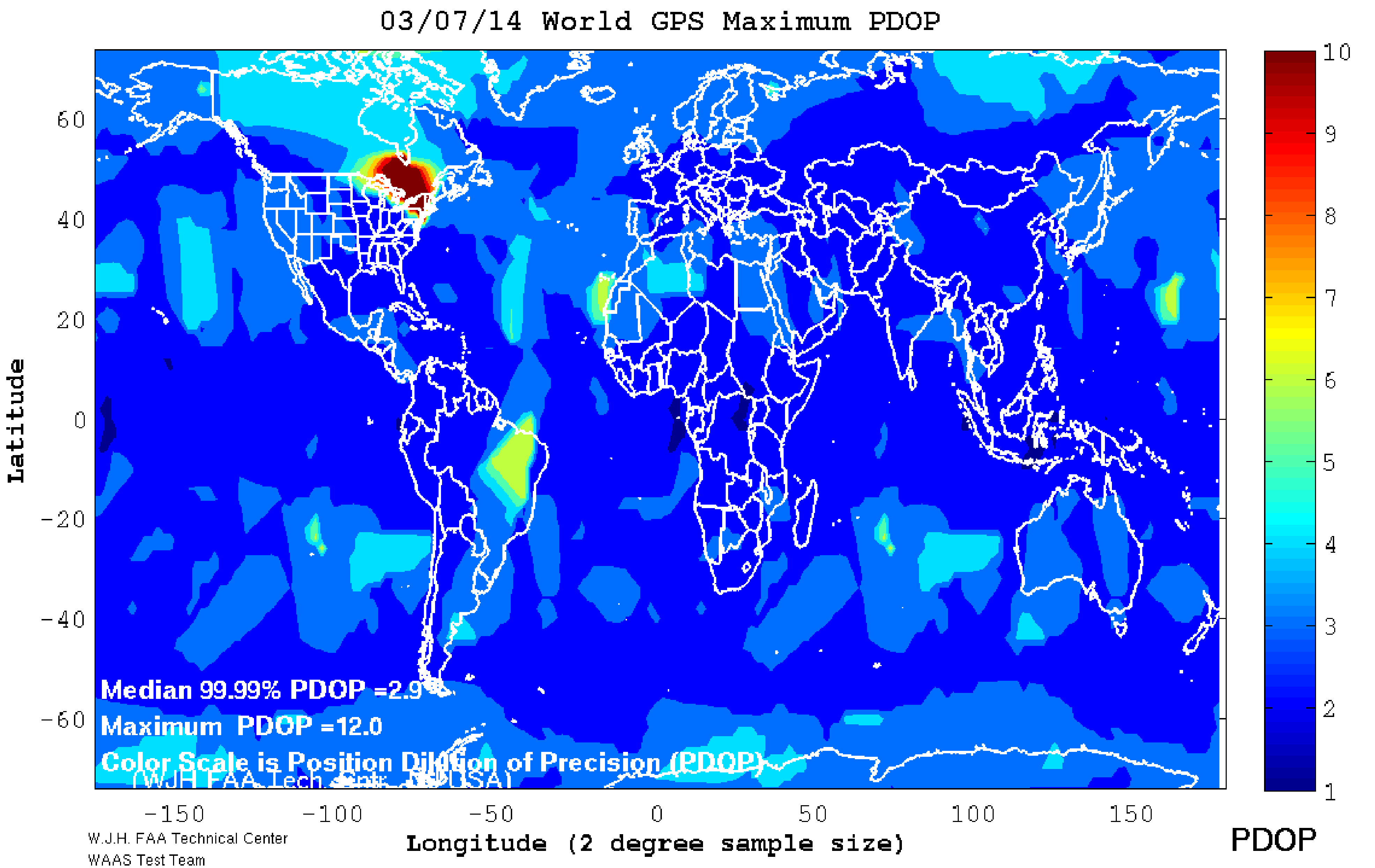
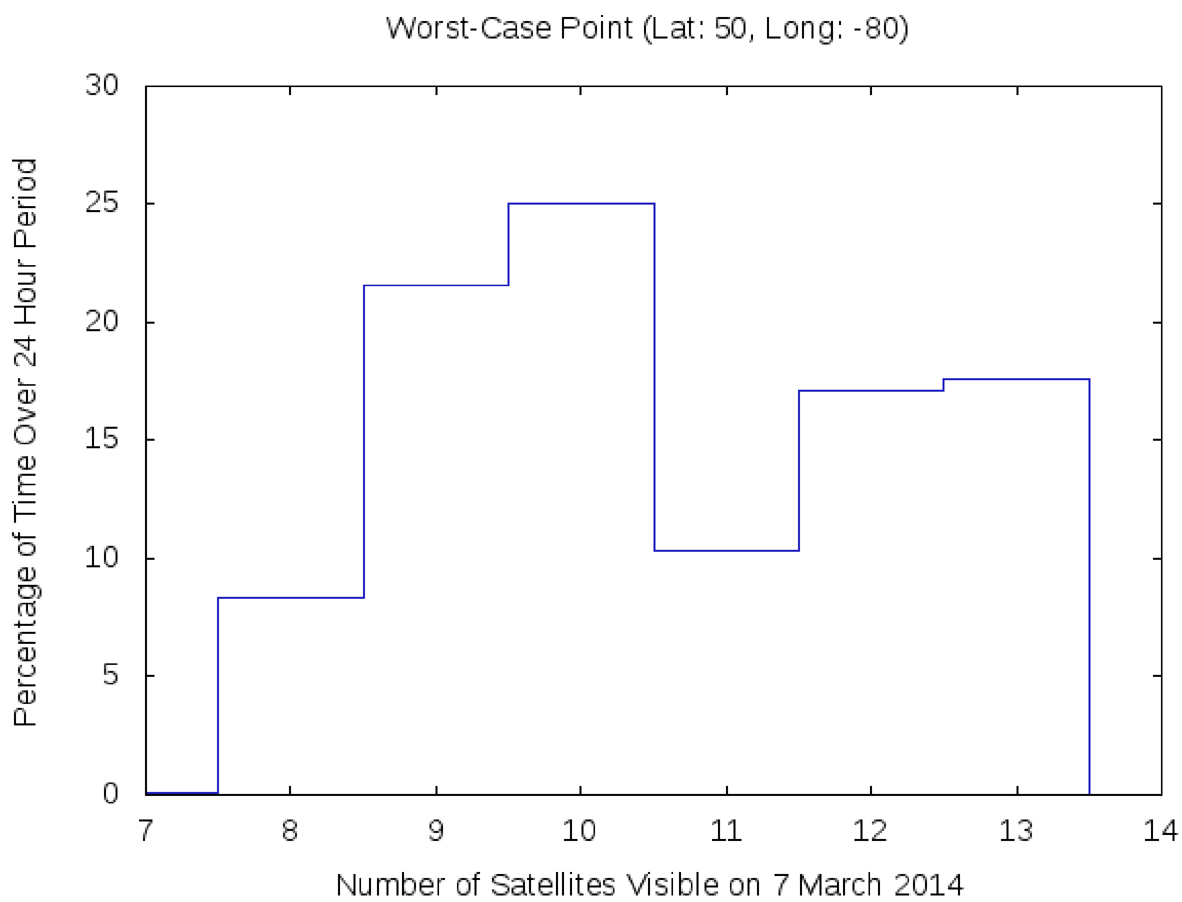


Figure 2-2 Satellite Visibility Profile for Worst-Case Point



3 NANU Summary and Evaluation

NANU: Notice Advisory to NAVSTAR Users – A periodic bulletin alerting users to changes in the satellite system performance.

Status and Problem Reporting	Conditions and Constraints
Scheduled event affecting service • Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	• For any SPS SIS
Unscheduled outage or problem affecting service • Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	• For any SPS SIS

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANU's). During this reporting period, 1 January through 31 March 2014, there were a total of twelve reported outages. Ten of those outages were maintenance activities and were reported in advance while two were unscheduled. A complete listing of outage NANU's for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-2. Canceled outage NANU's (if any) are provided in Table 3-3. The minimum duration a scheduled outage was forecasted ahead of time was 52.983 hours. The notification time met the 48-hour requirement. The maximum response time for a NANU issued for an unscheduled outage was 1.2 hours.

Table 3-1 NANUs Affecting Satellite Availability

NANU#	PRN	TYPE	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2014002	19	FCSTSUMM	9-Jan-14	20:58	10-Jan-14	2:50		5.87	5.87
2014004	22	FCSTSUMM	16-Jan-14	17:41	16-Jan-14	22:45		5.07	5.07
2014009	1	FCSTSUMM	3-Feb-14	16:16	3-Feb-14	21:32		5.27	5.27
2014011	21	FCSTSUMM	7-Feb-14	13:02	7-Feb-14	18:40		5.63	5.63
2014014	2	FCSTSUMM	14-Feb-14	9:41	14-Feb-14	15:07		5.43	5.43
2014016	16	FCSTSUMM	18-Feb-14	15:56	18-Feb-14	22:13		6.28	6.28
2014020	8	FCSTSUMM	27-Feb-14	1:01	27-Feb-14	6:31		5.50	5.50
2014023	5	FCSTSUMM	5-Mar-14	0:14	5-Mar-14	7:58		7.73	7.73
2014024	17	FCSTSUMM	7-Mar-14	3:55	7-Mar-14	9:46		5.85	5.85
2014026	9	UNUSABLE	7-Mar-14	15:08	7-Mar-14	15:48	0.67		0.67
2014028	1	UNUSABLE	14-Mar-14	5:02	14-Mar-14	6:48	1.77		1.77
2014030	24	FCSTSUMM	20-Mar-14	3:14	20-Mar-14	8:54		5.67	5.67
Totals of Unscheduled, Scheduled & Total Downtime							2.44	58.30	60.74

GENERAL NANUs

There were no GENERAL NANU's issued this quarter.

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2014001	19	FCSTDV	9-Jan	20:15	10-Jan	8:15	12	2014002
2014003	22	FCSTDV	16-Jan	17:00	17-Jan	5:00	12	2014004
2014005	16	FCSTDV	4-Feb	15:30	5-Feb	3:30	0	2014007
2014006	1	FCSTMX	3-Feb	16:00	4-Feb	4:00	12	2014009
2014008	21	FCSTDV	7-Feb	12:45	8-Feb	0:45	12	2014011
2014010	16	FCSTDV	11-Feb	15:15	12-Feb	3:15	0	2014013
2014012	2	FCSTDV	14-Feb	9:20	14-Feb	21:20	12	2014014
2014013	16	FCSTRESCD	18-Feb	15:15	19-Feb	3:15	12	2014016
2014017	8	FCSTDV	27-Feb	0:30	27-Feb	12:30	12	2014020
2014021	5	FCSTDV	5-Mar	0:00	5-Mar	12:00	12	2014023
2014022	17	FCSTDV	7-Mar	3:22	7-Mar	15:22	12	2014024
2014025	9	UNUSUFN	7-Mar	15:08				2014026
2014027	1	UNUSUFN	14-Mar	5:02				2014028
2014029	24	FCSTDV	20-Mar	3:00	20-Mar	15:00	12	2014030
						Total Forecasted Downtime	120	

Table 3-3 Cancelled NANUs

NANU#	PRN	Type	Start Date	Start Time	Comments
2014007	16	FCSTCANC	4-Feb	15:30	2014005

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published "Notice: Advisory to Navstar Users" messages (NANU's). This data has been summarized in Table 3-4. The "Total Satellite Observed MTTR" was calculated by taking the average downtime of all satellite outage occurrences. Scheduled downtime was forecasted in advance via NANU's. All other downtime reported via NANU was considered unscheduled. The "Percent Operational" was calculated based on the ratio of total actual operating hours to total available operating hours for every satellite.

Table 3-4 GPS Satellite Maintenance Statistics

Satellite Reliability/Maintainability/Availability (RMA) Parameter	1-Jan-14 31-Mar-14	1-Jan-00 31-Mar-14
Total Forecast Downtime (hrs):	120	10104.82
Total Actual Downtime (hrs):	60.74	38217.82
Total Actual Scheduled Downtime (hrs):	58.30	5911.61
Total Actual Unscheduled Downtime (hrs):	2.44	32306.21
Total Satellite Observed MTTR (hrs):	5.06	49.06
Scheduled Satellite Observed MTTR (hrs):	5.83	9.63
Unscheduled Satellite Observed MTTR (hrs):	1.22	195.80
# Total Satellite Outages:	12	779
# Scheduled Satellite Outages:	10	614
# Unscheduled Satellite Outages:	2	165
Percent Operational -- Scheduled Downtime:	99.91	99.85
Percent Operational -- All Downtime:	99.91	99.01

3.2 Service Availability Standard

Service Availability: The percentage of time over any 24-hour interval that the predicted 95% position error is less than the threshold at any given point within the service volume.

• **Horizontal Service Availability:** The percentage of time over any 24-hour interval that the predicted 95% horizontal error is less than its threshold for any point within the service volume.

• **Vertical Service Availability:** The percentage of time over any 24-hour interval that the predicted 95% vertical error is less than its threshold for any point within the service volume.

Service Availability Standard	Conditions and Constraints
• ≥ 99% Horizontal Service Availability, average location • ≥ 99% Vertical Service Availability, average location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.
• ≥ 90% Horizontal Service Availability, worst-case location • ≥ 90% Vertical Service Availability, worst-case location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.

To verify availability, the data collected from receivers at the twenty-eight WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-5. The data was collected at one-second intervals between 1 January and 31 March 2014.

Table 3-5 Accuracies Exceeding Threshold Statistics

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-hour Threshold Failures	Quarters Service Availability %
Albuquerque	7731151	0	100%
Anchorage	7736440	0	100%
Atlanta	7744979	0	100%
Barrow	7732198	0	100%
Bethel	7535342	0	100%
Billings	7707907	0	100%
Boston	7745046	0	100%
Cleveland	7740194	0	100%
Cold Bay	7744617	0	100%
Fairbanks	7744971	0	100%
Gander	7745035	0	100%
Honolulu	7600782	0	100%
Houston	7126764	0	100%
Iqaluit	7736484	0	100%
Juneau	7484727	0	100%
Kansas City	7745043	0	100%
Kotzebue	7053434	0	100%
Los Angeles	7742769	0	100%
Merida	7738070	0	100%
Miami	7742340	0	100%
Minneapolis	7735548	0	100%
Oakland	7221101	0	100%
Salt Lake City	7738274	0	100%
San Jose Del Cabo	7744927	0	100%
San Juan	7303278	0	100%
Seattle	7726191	0	100%
Tapachula	7732185	0	100%
Washington, DC	7743014	0	100%
Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)			

4 Service Reliability Standard

Service Reliability: The percentage of time over a specific time interval that the instantaneous SIS SPS URE is maintained within a specified reliability threshold at any given point within the service volume, for all healthy GPS satellites.

User Range Error Accuracy	Conditions and Constraints
Single Frequency C/A-Code • ≤ 30m 99.94% Global Average URE during normal operations • ≤ 30m 99.79% Worst Case single point average during normal operations.	• For any healthy SPS SIS. • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 • Standard based on measurement interval of one year; average of daily values within service volume • Standard based on 3 service failures per year, lasting no more than 6 hours each

Table 4-1 shows a comparison to the service reliability standard for range data collected at a set of six receivers across North America. Although the specification calls for yearly evaluations, we will be evaluating this SPS requirement at quarterly intervals. Additional range analysis results can be found in table 5-2. The maximum User Range Error recorded this quarter was 31.464 meters on satellite PRN 10.

Table 4-1 User Range Error Accuracy

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Percentage
1 Jan – 31 Mar 2014	**Boston**	65,194,691	0	100%
1 Jan – 31 Mar 2014	**Honolulu**	68,172,218	952	99.9986%
1 Jan – 31 Mar 2014	**Los Angeles**	67,556,378	0	100%
1 Jan – 31 Mar 2014	**Miami**	64,173,975	0	100%
1 Jan – 31 Mar 2014	**Merida**	66,991,425	0	100%
1 Jan – 31 Mar 2014	**Juneau**	66,588,846	0	100%
1 Jan – 31 Mar 2014	**Global**	398,677,533	952	99.9998%

5 Accuracy Standard

Positioning Accuracy: The statistical difference, at a 95% probability, between position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

• **Horizontal Positioning Accuracy**: The statistical difference, at a 95% probability, between horizontal position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

• **Vertical Positioning Accuracy**: The statistical difference, at a 95% probability, between vertical position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

Position/Time Accuracy	Conditions and Constraints
Global Average Position Domain Accuracy • ≤ 9m 95% Horizontal Error • ≤ 15m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.
Worst Site Position Domain Accuracy • ≤ 17m 95% Horizontal Error • ≤ 37m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.
Time Transfer Domain Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for a time transfer solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.

User Range Accuracy	Conditions and Constraints
Single Frequency C/A-Code • ≤ 7.8m 9%% Global Average URE during normal operations over All AODs • ≤ 6.0m 95% Global Average URE during operations at Zero AOD • ≤ 12.8m 95% Global Average URE during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1
Single-Frequency C/A-Code: • ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors
Single-Frequency C/A-Code: • ≤ 2 mm/sec^2 95% Global average URAE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors
Coordinated Universal Time Offset Error Accuracy	**Conditions and Constraints**
• ≤ 40 nanoseconds 95% Global average UTCOE during normal operations at Any AOD.	• For any healthy SPS SIS

5.1 Position Accuracy

The data used for this section was collected for every second from 1 January through 31 March 2014 at the selected WAAS locations. Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter. Every twenty-four hour analysis period this quarter passed both the worst-case and global position accuracy requirements set forth by the SPS specification.

Table 5-1 Horizontal & Vertical Accuracy Statistics for the Quarter

Site	95% Vertical (Meters)	95% Horizontal (Meters)	99.99% Vertical (Meters)	99.99% Horizontal (Meters)
Albuquerque	5.619	2.318	14.308	6.244
Anchorage	6.373	2.512	16.213	5.740
Atlanta	5.635	2.566	15.271	5.842
Barrow	7.326	2.956	18.183	6.973
Bethel	7.078	2.479	16.886	5.627
Billings	5.299	2.265	13.699	6.177
Boston	5.044	2.695	12.678	8.883
Cleveland	5.108	2.578	13.008	6.067
Cold Bay	6.618	2.376	15.235	8.230
Fairbanks	6.486	2.671	17.024	7.823
Gander	5.082	2.718	12.581	8.055
Honolulu	8.107	10.229	20.832	17.613
Houston	6.248	2.720	14.406	7.043
Iqaluit	6.435	3.260	19.702	8.474
Juneau	5.733	2.355	14.162	8.967
Kansas City	5.334	2.450	13.607	6.338
Kotzebue	6.806	2.886	17.747	5.994
Los Angeles	6.413	2.210	14.320	4.938
Merida	6.615	4.341	18.643	11.218
Miami	5.947	3.044	15.518	8.270
Minneapolis	5.051	2.398	13.086	11.491
Oakland	6.542	2.151	14.845	4.933
Salt Lake City	5.552	2.184	14.426	5.690
San Jose Del Cabo	7.375	4.826	21.716	13.072
San Juan	9.869	6.557	25.413	18.036
Seattle	5.518	2.172	14.252	6.497
Tapachula	8.191	6.909	19.089	15.506
Washington, DC	5.379	2.658	13.170	4.879

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-eight WAAS sites from 1 January to 31 March 2014.

Figure 5-1 Global Vertical Error Histogram

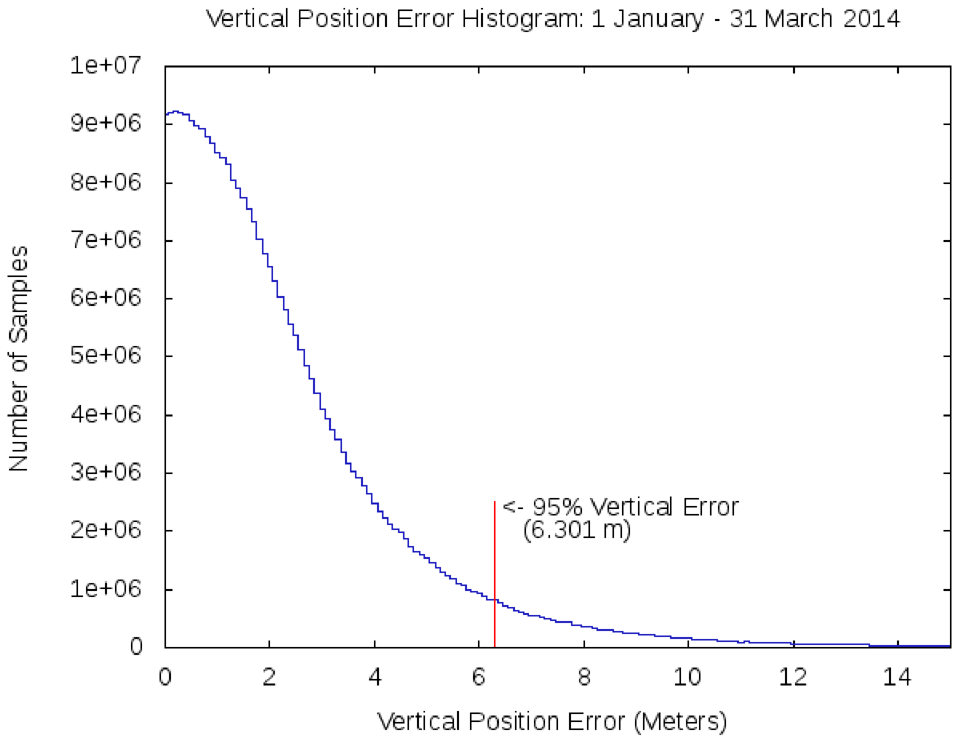
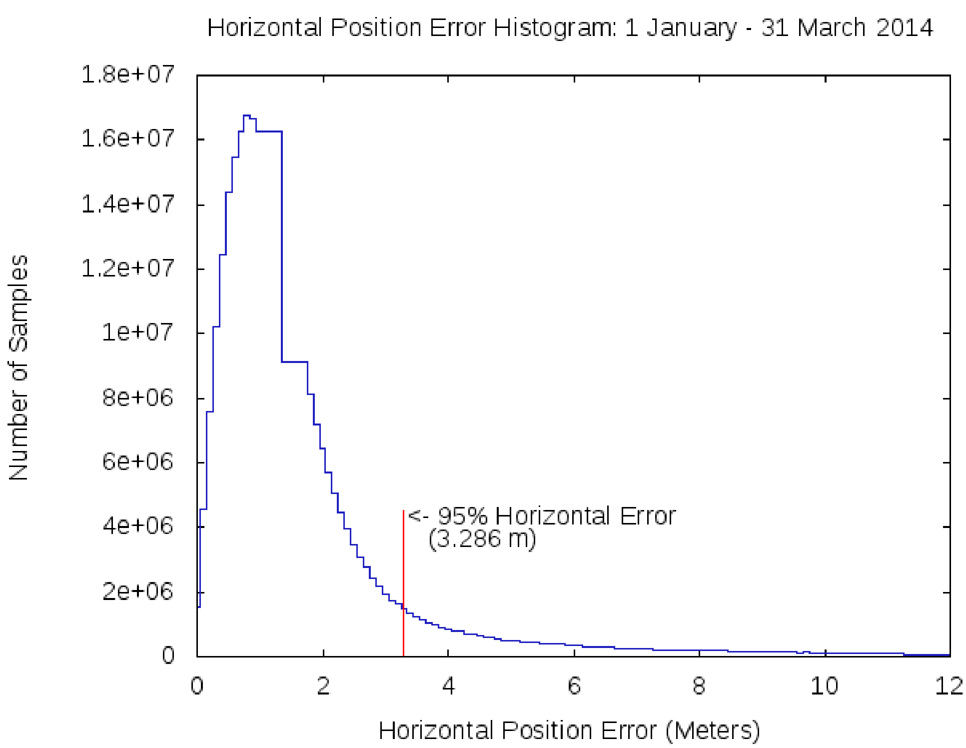


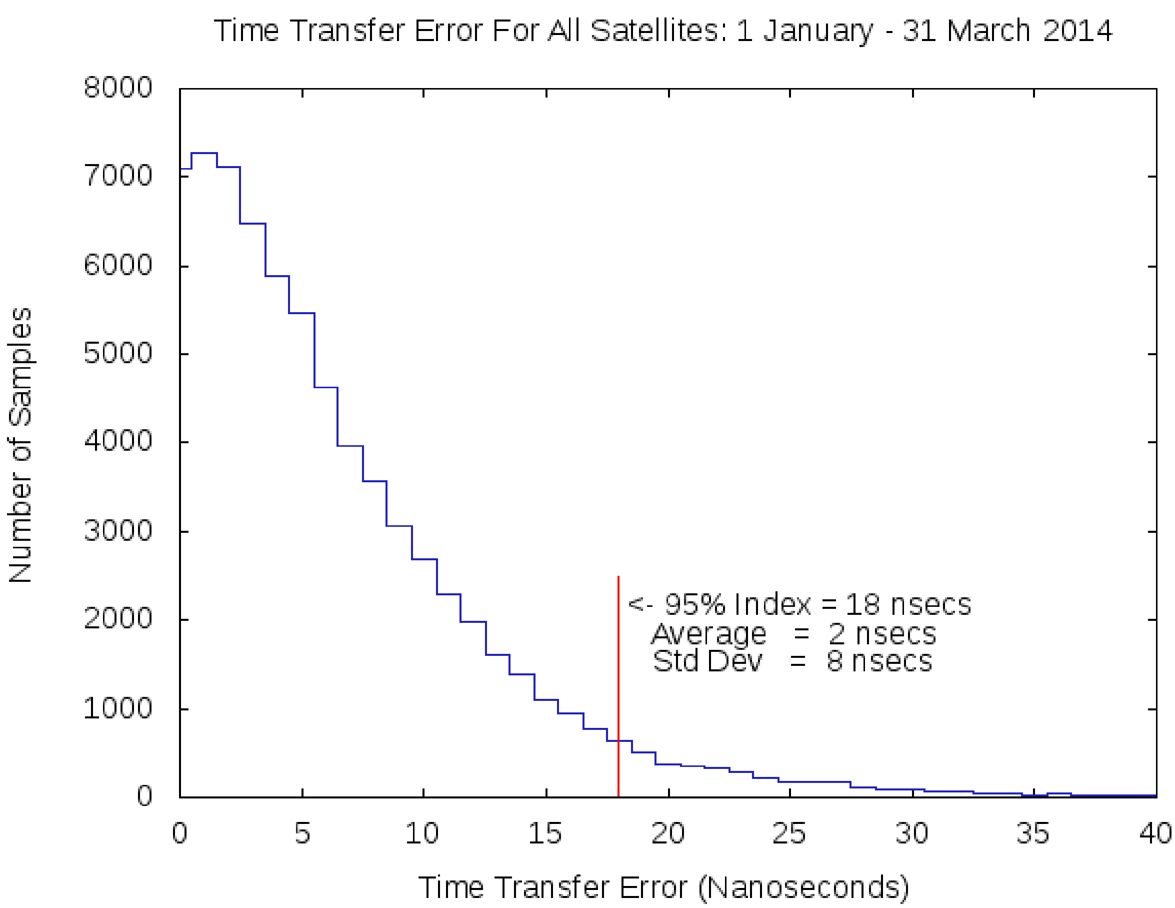
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 2014 was downloaded from USNO Internet site. The USNO data file contains the time difference between the USNO master clock and GPS system time for each GPS satellites during the time period. Over 10,000 samples of GPS time error are contained in the USNO data file. In order to evaluate the GPS time transfer error, the data file was used to create a histogram (Fig 5-3) to represent the distribution of GPS time error. The histogram was created by taking the absolute value of time difference between the USNO master clock and GPS system time, then creating data bins with one nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Fig 5-3. The mean, standard deviation, and 95% index are within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Error



5.3 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 January and 31 March 2014. A weighted average filter was used for the calculation of the range rate error and the range acceleration error. All Range Domain SPS specifications were met.

Table 5-2 Range Error Statistics

(Meters)

PRN	RMS Range Error (≤ 6 m)	Range Error Mean	1σ	95% Range Error	Max Range Error (SPS Spec. ≤ 30 m)	Samples
1	2.249	-0.033	1.806	4.190	18.951	12298503
2	2.462	1.129	1.950	4.701	30.567	14057867
3	2.256	0.851	1.666	4.119	17.417	12180788
4	2.399	0.289	2.075	4.568	27.591	13341733
5	2.174	0.230	1.953	4.165	26.278	13212961
6	2.201	1.272	1.527	4.098	18.831	7527580
7	2.477	-0.312	1.838	4.567	18.547	12654225
8	2.681	0.521	1.912	4.890	17.203	12735431
9	2.677	0.414	1.919	4.871	17.723	12322488
10	2.918	1.431	2.134	5.329	31.464	12022590
11	2.192	0.629	1.787	4.148	23.093	12577467
12	2.192	0.085	1.954	4.228	27.822	13871698
13	2.323	-0.003	1.719	4.259	24.940	12978817
14	2.630	0.642	1.844	4.792	24.098	14167579
15	2.017	0.260	1.715	3.814	23.415	12358700
16	2.463	0.637	1.963	4.676	29.799	13195698
17	2.453	0.359	2.074	4.736	21.998	14084783
18	2.163	1.108	1.456	3.896	19.909	13102313
19	2.321	1.262	1.669	4.313	24.395	12196603
20	2.485	0.839	1.925	4.637	21.829	14154447
21	2.139	1.085	1.508	3.876	22.169	12221915
22	2.682	1.708	1.549	4.595	20.109	12514260
23	2.516	0.161	1.823	4.551	23.936	12668995
24	2.233	-0.513	1.814	4.099	22.378	13859919
25	2.127	0.212	1.777	4.237	20.287	13961967
26	2.309	0.397	1.980	4.631	28.730	12895018
27	1.814	0.329	1.475	3.501	16.597	13010329
28	2.803	0.968	1.984	5.019	18.857	13496839
29	2.092	0.270	1.773	4.156	29.690	12590000
31	2.584	0.098	1.891	4.732	20.481	13588647
32	2.489	1.069	1.666	4.341	19.868	12827373

Table 5-3 Range Rate Error Statistics

(Millimeters/ Second)

PRN	Range Rate Error RMS	95% Range Rate Error	Max Range Rate Error	Samples
1	2.874	3.678	209.330	12298503
2	2.397	3.698	299.740	14057867
3	2.827	3.760	268.040	12180788
4	2.364	3.553	247.430	13341733
5	2.481	3.589	310.780	13212961
6	2.735	3.625	416.780	7527580
7	2.448	3.671	344.660	12654225
8	2.741	3.840	329.240	12735431
9	2.848	3.763	317.970	12322488
10	2.684	3.672	317.300	12022590
11	2.582	3.785	283.950	12577467
12	2.787	4.018	269.660	13871698
13	2.623	3.941	265.270	12978817
14	2.905	4.089	394.160	14167579
15	2.598	3.645	493.370	12358700
16	2.610	3.772	280.470	13195698
17	2.259	3.695	236.920	14084783
18	2.666	3.669	287.600	13102313
19	2.442	3.668	320.150	12196603
20	2.660	3.892	222.760	14154447
21	2.545	3.821	431.120	12221915
22	2.749	3.724	306.510	12514260
23	2.613	3.734	254.110	12668995
24	2.957	3.946	446.300	13859919
25	2.692	3.613	299.620	13961967
26	2.466	3.701	331.180	12895018
27	2.659	3.501	436.080	13010329
28	2.390	3.506	347.890	13496839
29	2.579	3.788	331.120	12590000
31	2.806	3.831	301.390	13588647
32	2.730	3.673	223.090	12827373

Table 5-4 Range Acceleration Error Statistics

(Micrometers/Second^2)

PRN	Range Acceleration Error RMS (μm/s^2)	95% Range Acceleration Error (μm/s^2)	Max Range Acceleration Error (μm/s^2)	Samples
1	23.144	29.189	2070	12298503
2	17.957	25.956	3000	14057867
3	22.729	29.711	2650	12180788
4	17.797	25.131	2470	13341733
5	19.493	27.974	3110	13212961
6	22.015	27.561	4110	7527580
7	18.904	28.372	3410	12654225
8	21.346	28.644	3280	12735431
9	22.644	28.556	3160	12322488
10	21.363	27.797	3180	12022590
11	19.997	29.034	2800	12577467
12	21.157	31.045	2680	13871698
13	20.834	31.547	2660	12978817
14	22.812	33.107	3880	14167579
15	20.447	29.816	4890	12358700
16	20.561	30.196	2760	13195698
17	16.412	25.734	2320	14084783
18	21.594	31.278	2870	13102313
19	18.783	27.988	3160	12196603
20	20.962	30.168	2240	14154447
21	19.836	31.525	4280	12221915
22	22.504	31.864	3070	12514260
23	20.783	30.301	2510	12668995
24	23.792	32.170	4410	13859919
25	21.456	29.172	2970	13961967
26	18.719	27.320	3310	12895018
27	21.632	28.581	4300	13010329
28	18.556	25.490	3430	13496839
29	19.806	27.498	3290	12590000
31	22.389	31.984	3010	13588647
32	21.866	30.595	2170	12827373

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the maximum range error, range rate error and range acceleration error for all satellites. The highest maximum range error occurred on satellite 10 with an error of 31.464 meters. Satellite 27 had the lowest maximum range error of 16.597 meters.

Figure 5-4 Distribution of Daily Max Range Errors

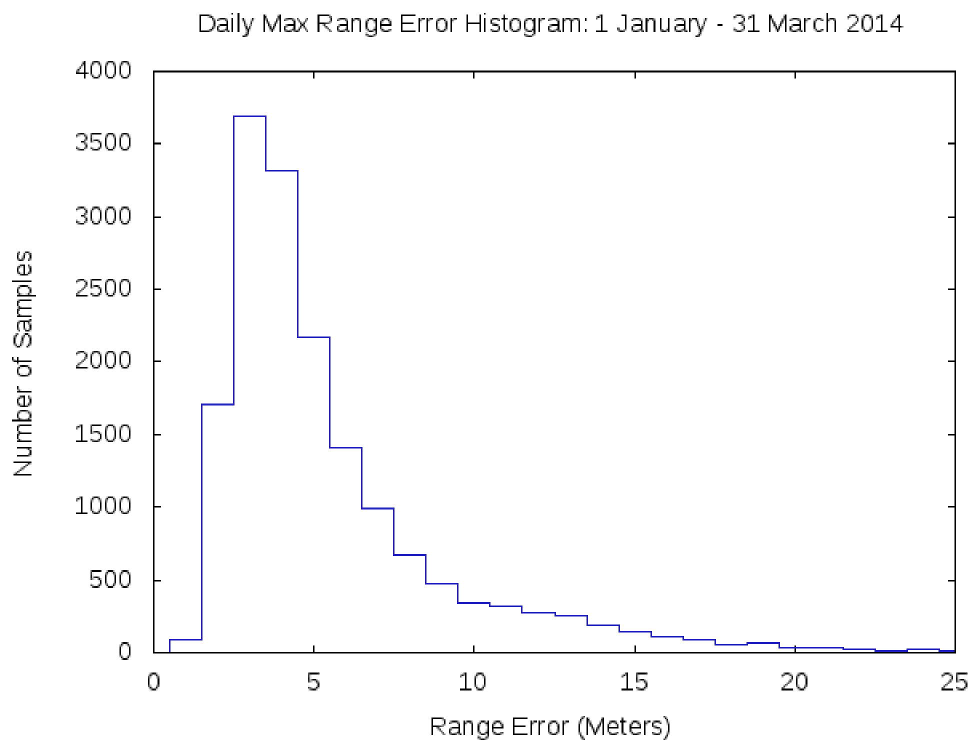


Figure 5-5 Distribution of Daily Max Range Rate Errors

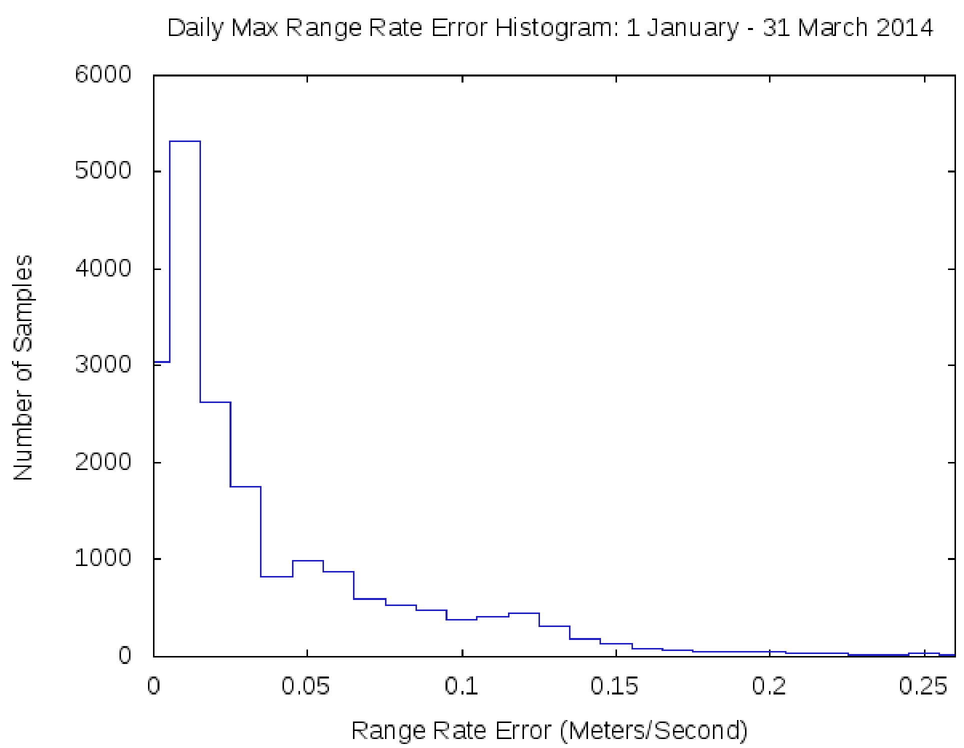


Figure 5-6 Distribution of Daily max Range Acceleration Errors

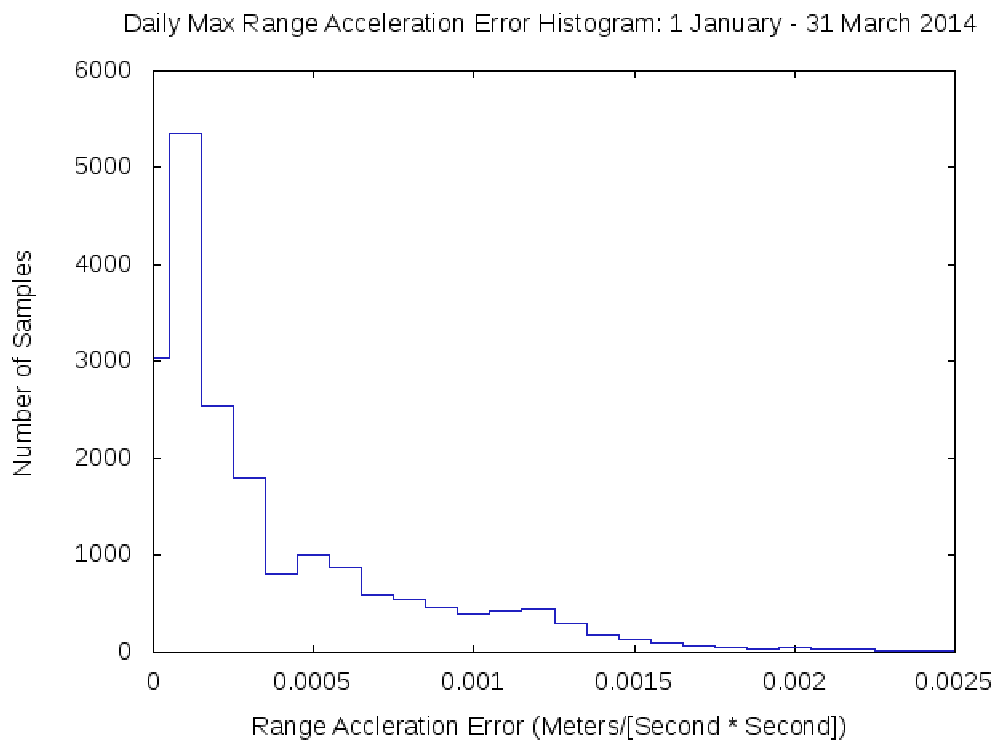


Figure 5-7 Range Error Histogram

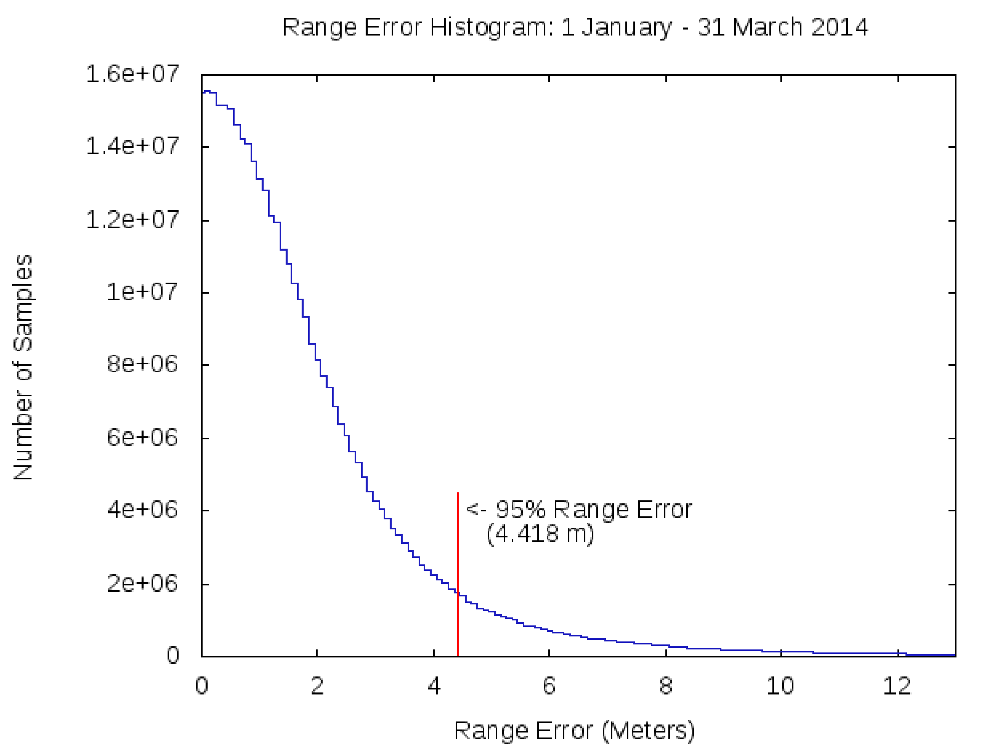


Figure 5-8 Maximum Range Error Per Satellite

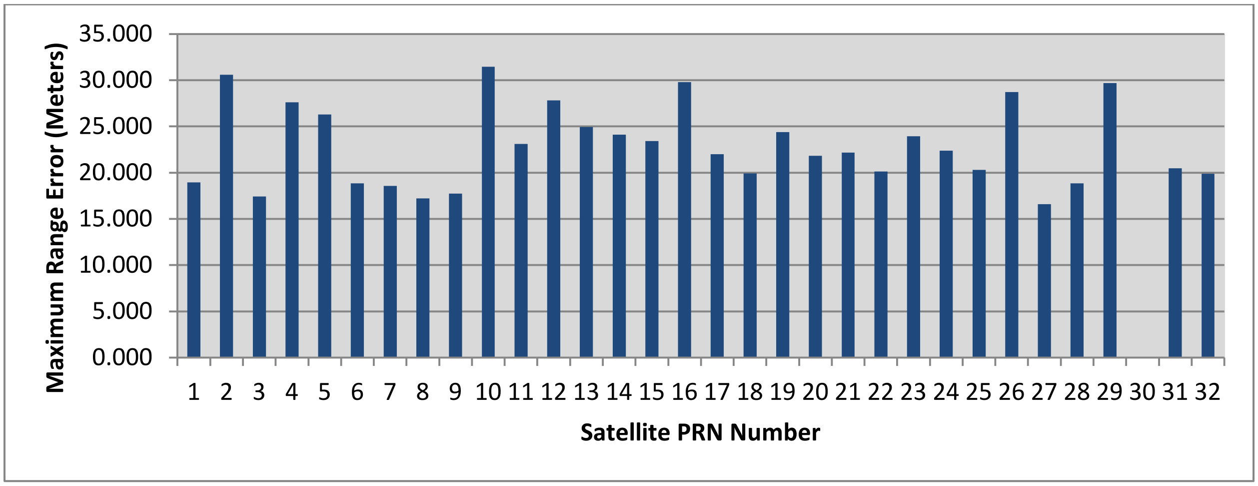


Figure 5-9 Maximum Range Rate Error Per Satellite

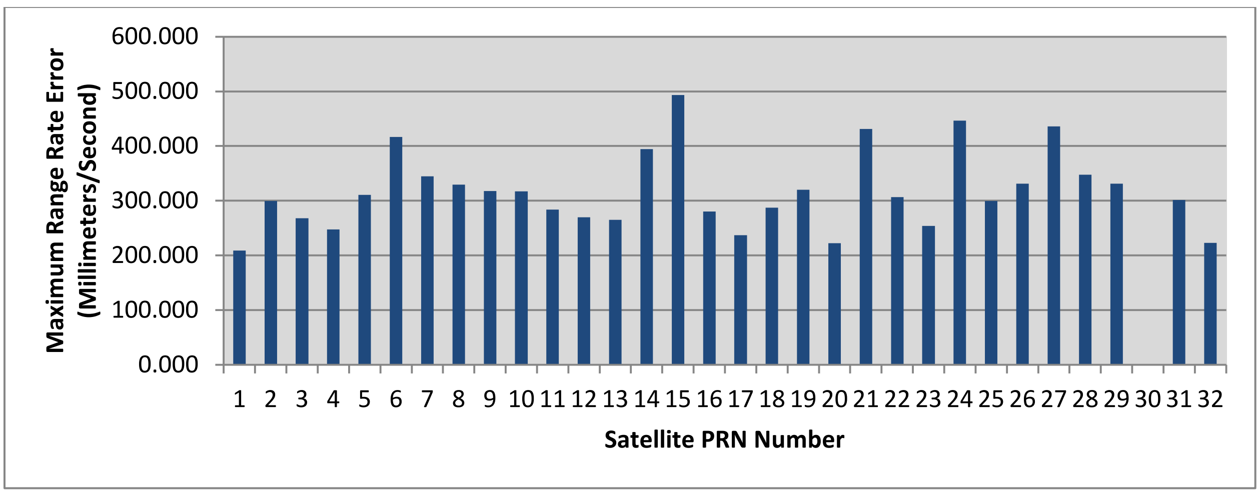
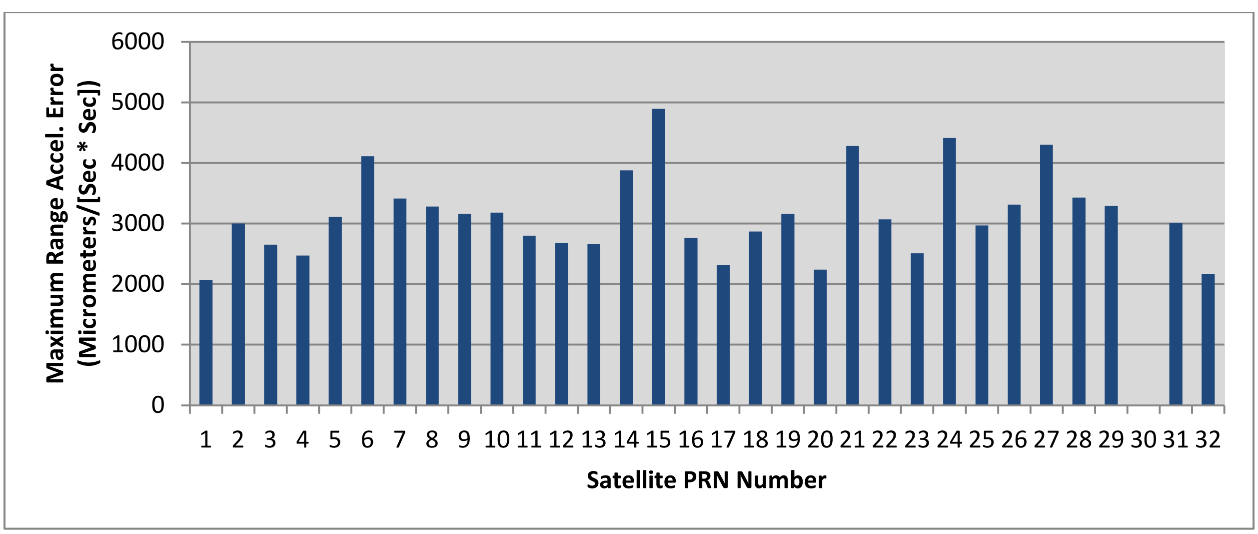


Figure 5-10 Maximum Range Acceleration Error Per Satellite



6 Solar Storms

Solar storm activity is being monitored in order to assess the possible impact on GPS SPS performance. Solar activity is reported by the Space Weather Prediction Center (SWPC) , a division of the National Oceanic and Atmospheric Administration (NOAA). When storm activity is indicated, ionospheric delays of the GPS signal, satellite outages, position accuracy and availability will be analyzed.

The following article was taken from the SEC web site http://swpc.noaa.gov. It briefly explains some of the ideas behind the association of the aurora with geomagnetic activity and a bit about how the 'K-index' or 'K-factor' works.

> *The aurora is caused by the interaction of high-energy particles (usually electrons) with neutral atoms in the earth's upper atmosphere. These high-energy particles can 'excite' (by collisions) valence electrons that are bound to the neutral atom. The 'excited' electron can then 'de-excite' and return back to its initial, lower energy state, but in the process it releases a photon (a light particle). The combined effect of many photons being released from many atoms results in the aurora display that you see.*
>
> *The details of how high energy particles are generated during geomagnetic storms constitute an entire discipline of space science in its own right. The basic idea, however, is that the Earth's magnetic field (let us say the 'geomagnetic field') is responding to an outwardly propagating disturbance from the Sun. As the geomagnetic field adjusts to this disturbance, various components of the Earth's field change form, releasing magnetic energy and thereby accelerating charged particles to high energies. These particles, being charged, are forced to stream along the geomagnetic field lines. Some end up in the upper part of the earth's neutral atmosphere and the auroral mechanism begins.*
>
> *An instrument called a magnetometer may also measure the disturbance of the geomagnetic field. At NOAA's operations center magnetometer data is received from dozens of observatories in one-minute intervals. The data is received at or near to 'real-time' and allows NOAA to keep track of the current state of the geomagnetic conditions. In order to reduce the amount of data NOAA converts the magnetometer data into three-hourly indices, which give a quantitative, but less detailed measure of the level of geomagnetic activity. The K-index scale has a range from 0 to 9 and is directly related to the maximum amount of fluctuation (relative to a quiet day) in the geomagnetic field over a three-hour interval.*
>
> *The K-index is therefore updated every three hours. The K-index is also necessarily tied to a specific geomagnetic observatory. For locations where there are no observatories, one can only estimate what the local K-index would be by looking at data from the nearest observatory, but this would be subject to some errors from time to time because geomagnetic activity is not always spatially homogenous.*
>
> *Another item of interest is that the location of the aurora usually changes geomagnetic latitude as the intensity of the geomagnetic storm changes. The location of the aurora often takes on an 'oval-like' shape and is appropriately called the auroral oval.*

Figures 6-1 through 6-3 show the K-index for three time periods with significant solar activity. Although there were other days with increased solar activity, these time periods were selected as examples. (See Appendix B for the actual geomagnetic data for this reporting period.)

Figure 6-1 K-Index for 18-20 February 2014

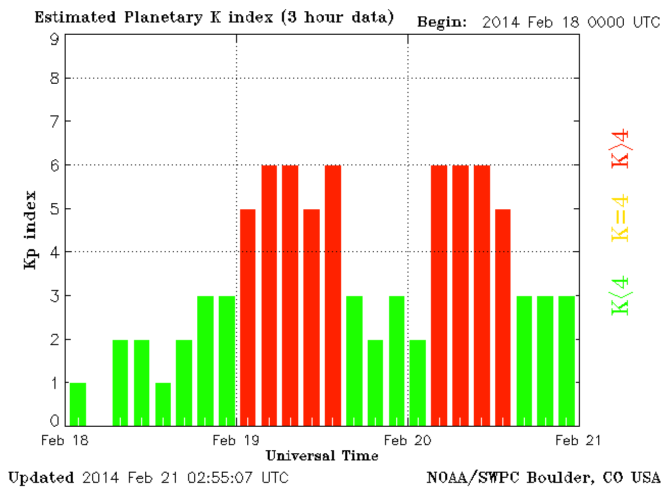


Figure 6-2 K-Index for 26-28 February 2014

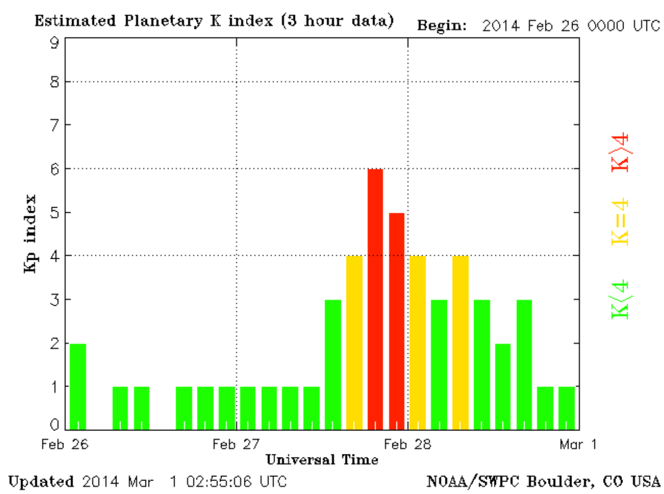


Figure 6-3 K-Index for 15-17 February 2014

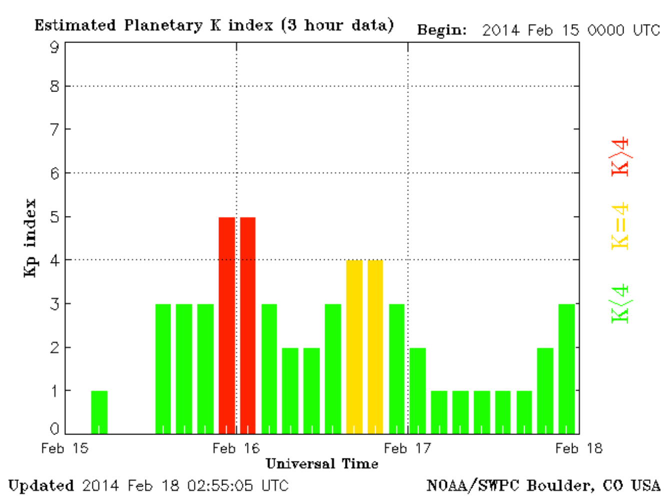


Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for February 19, 2014

Site	95% Horizontal (Meters)	95% Vertical (Meters)	Maximum Horizontal (Meters)	Maximum Vertical (Meters)
Albuquerque	3.624	4.059	5.106	5.307
Anchorage	4.517	5.290	5.383	6.566
Atlanta	4.581	4.037	5.912	5.517
Barrow	3.718	6.851	5.043	9.460
Bethel	3.227	5.072	4.181	6.202
Billings	3.682	3.889	6.292	5.146
Boston	2.513	4.598	3.472	6.229
Cleveland	2.908	4.606	4.382	6.049
Cold Bay	2.067	3.971	2.529	4.632
Fairbanks	3.963	5.673	5.020	7.646
Gander	2.852	4.874	4.208	5.994
Honolulu	12.614	12.278	15.102	17.432
Houston	4.423	4.131	7.051	8.549
Iqaluit	2.215	6.493	3.145	8.295
Juneau	3.680	4.902	5.386	5.829
Kansas City	4.218	3.991	5.103	4.860
Kotzebue	3.866	5.944	4.888	8.042
Los Angeles	3.095	5.051	3.972	7.142
Merida	4.449	5.242	5.476	8.360
Miami	6.119	4.880	7.269	7.254
Minneapolis	3.263	4.947	4.787	6.008
Oakland	3.481	4.367	5.149	6.928
Salt Lake City	4.064	3.406	5.874	4.411
San Jose Del Cabo	5.226	8.096	8.303	9.369
San Juan	3.602	4.799	5.125	7.815
Seattle	3.526	4.381	5.981	5.914
Tapachula	7.559	9.431	9.880	11.975
Washington, DC	2.920	4.369	5.022	5.475

7 IGS Data

GPS SPS accuracy performance was evaluated at a selection of high rate IGS stations[(1)]. The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products.

High data rate (1 Hz) sites with good availability that were outside of the WAAS service area, and provided a good geographic distribution have been selected. To facilitate differentiating between GPS accuracy issues and receiver tracking problems, an automatic data screening function excluded errors greater than 500 meters and or times when VDOP or HDOP were greater than 10. The remaining receiver tracking issues are still included in the processing and are forced into the 50.1 meter histogram bin and cause the outliers in the 99.99% statistics and are visible in the 95% accuracy trend plots. The 50.1 meter 99.99% Vertical Accuracy outliers for USNA and BOGT are examples. USNA has 25 days where the 50.1 m bin was overloaded, BOGT had 16 such days. The cause of the BOGT and USNA problems is suspected to be very strong scintillation associated with the equatorial geomagnetic anomalies, the season and the current point in the solar cycle. The USUD site also had a 50.01 m histogram bin overload on 1/14/14 that was due to an reinitialization of the receiver after that receiver was off line, that day for that receiver was manually removed.

High quality broadcast navigation data and Klobachar model data is created by voting across all available IGS high rate RINEX navigation data. Some manual review was necessary to recover missing navigation data where the number of IGS sites reporting navigation data was below the voting threshold (i.e. 4).

Table 7.1 and Figure 7-1 show the IGS site information and locations. Table 7.2 shows the GPS SPS Accuracy Performance observed at a selection of High Rate IGS sites. Figure 7-2 shows the 95% horizontal accuracy trends at these sites. Figure 7-3 shows the 95% vertical accuracy trends at these sites. A value of zero indicates no data.

Figures 7-4 and 7-5 show position accuracy data examples for BOGT and USNA. Both sites had multiple days with essentially the same symptoms. Other sites in the magnetic equatorial region also had availability and accuracy issues as evident by the 95% accuracy trends and the data availability percentages (although most unavailability is because data was not available for a receiver).

(1) J.M. Dow, R.E. Neilan, G. Gendt, "The International GPS Service (IGS): Celebrating the 10th Anniversary and Looking to the Next Decade," Adv. Space Res. 36 vol. 36, no. 3, pp. 320-326, 2005. Doi: 10.1016/j.asr.2005.05.125

Table 7-1 Selected IGS Site Information

ID	City	Country
BOGT	Bogota	Colombia
GUAM	Dededo	Guam
IISC	Bangalore	India
KIRU	Kiruna	Sweden
KOUR	Kourou	French Guyana
MADR	Robledo	Spain
MAL2	Malindi	Kenya
MAS1	Maspalomas	Spain
MATE	Matera	Italy
MOBN	Obninsk	Russian Federation
NNOR	New Norcia	Australia
NRIL	Norilsk	Russian Federation
PETS	Petropavlovsk-Kamchatka	Russian Federation
POL2	Bishkek	Kyrghyzstan
SANT	Santiago	Chile
SUTM	Sutherland	South Africa
TIDB	Tidbinbilla	Australia
UNSA	Salta	Argentina
USUD	Usuda	Japan

Figure 7-1 Selected IGS Site Locations

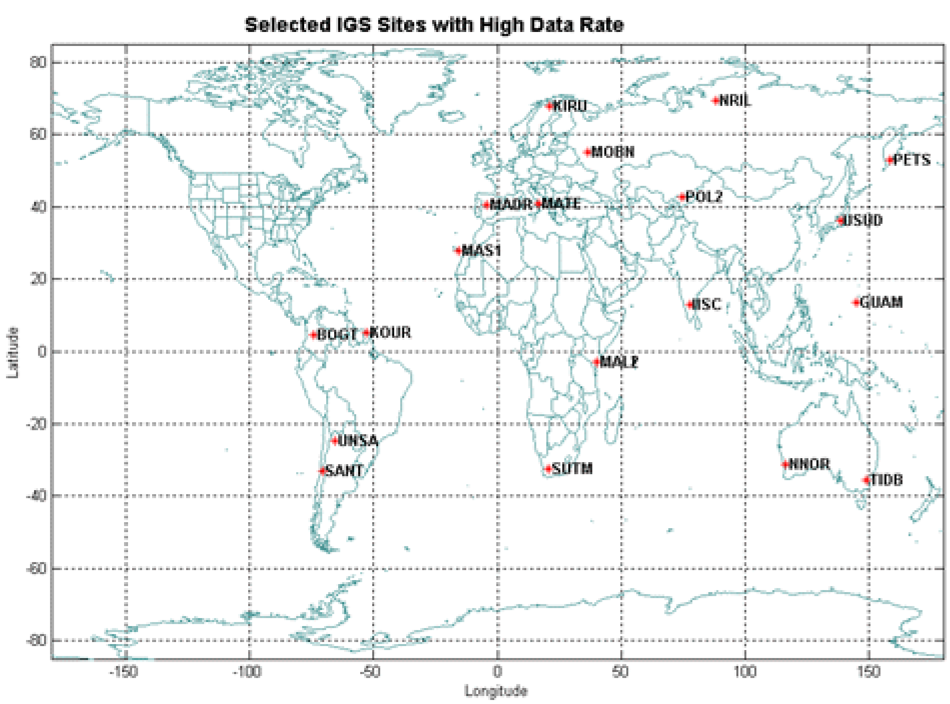


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

Site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
BOGT	7.87	11.36	26.65	50.01	91.62%
GLPS	6.47	7.89	17.27	27.37	92.93%
GUAM	4.31	9.27	10.12	23.00	32.06%
IISC	5.66	8.64	13.63	24.08	99.15%
KIRU	2.76	6.86	8.92	17.09	84.15%
KOUR	8.88	9.81	16.36	26.02	81.82%
MAL2	4.75	5.77	46.24	18.30	31.15%
MAS1	5.56	6.73	15.74	17.59	88.13%
MATE	10.32	8.88	23.44	32.36	68.65%
MOBN	3.40	6.87	13.10	20.17	68.89%
NNOR	2.69	6.45	6.83	17.59	98.46%
NRIL	2.41	4.64	10.85	24.04	38.00%
PETS	3.02	6.80	8.40	34.64	89.89%
POL2	2.75	7.22	5.80	17.06	99.97%
SANT	2.94	6.41	15.35	25.06	59.06%
SUTM	2.81	4.81	4.49	8.90	77.19%
TIDB	2.43	5.31	14.79	25.52	92.71%
UNSA	6.38	10.21	39.76	50.01	91.43%
USUD	5.74	7.99	16.87	30.98	98.46%

Figure 7-2 GPS SPS 95% Horizontal Accuracy Trends at Selected IGS Sites

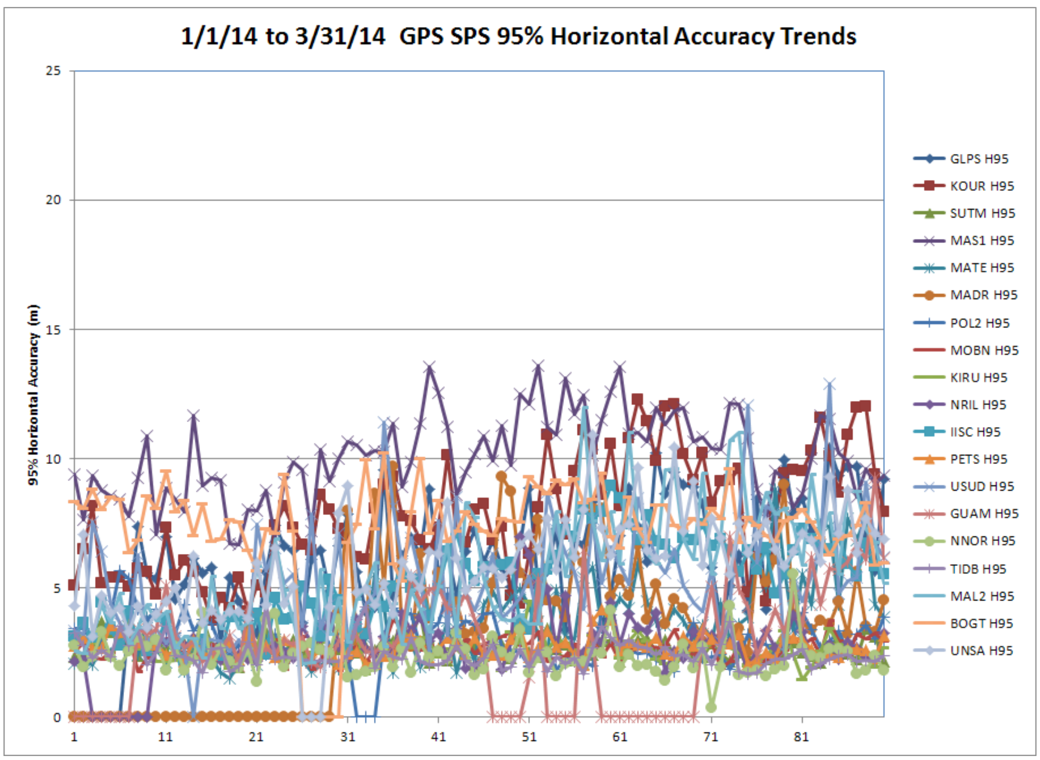


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites

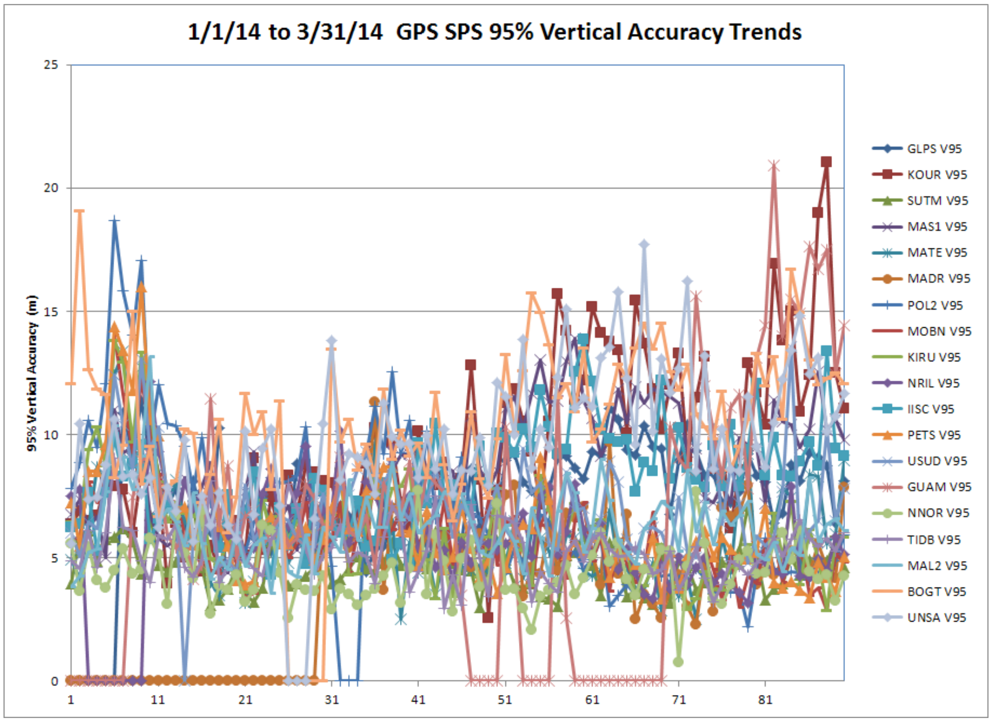


Figure 7-4 Example Receiver Tracking Problem

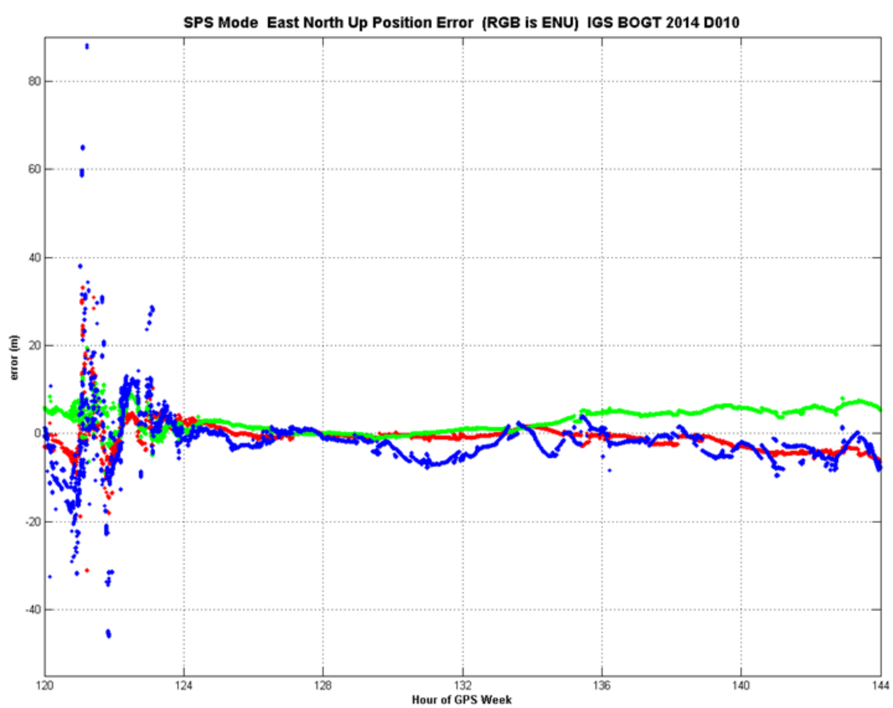
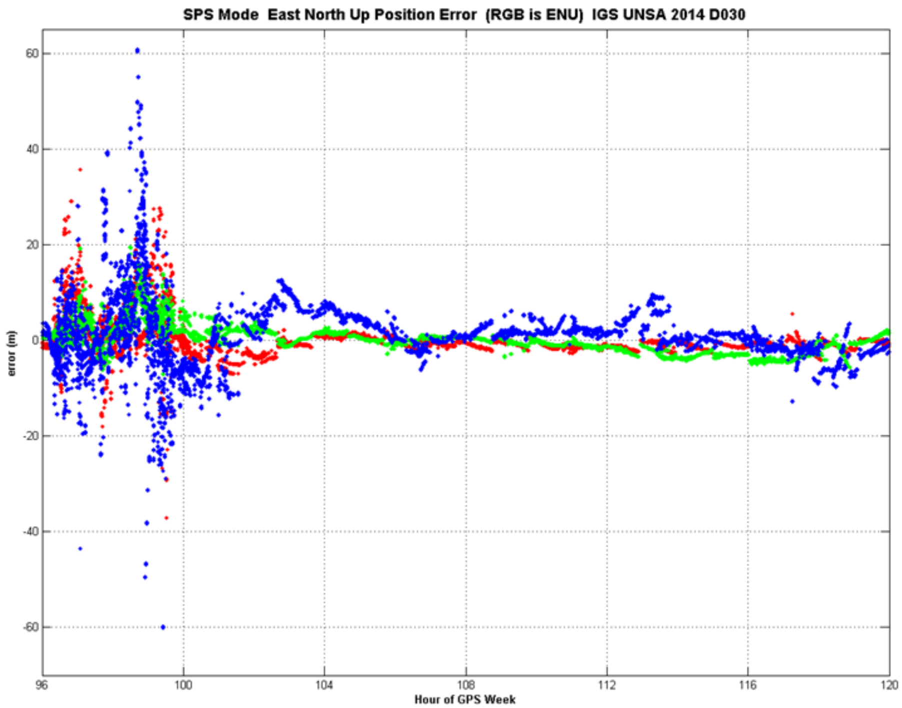


Figure 7-5 Example Large Ionospheric Error



8 RAIM Performance

Receiver autonomous integrity monitoring (RAIM) is a technology developed to assess the integrity of GPS signals in a GPS receiver system. It is especially important in safety critical GPS applications, such as aviation. In order for a GPS receiver to perform RAIM or fault detection (FD) function, a minimum of five visible satellites with satisfactory geometry must be visible. RAIM has various kinds of implementations; one of them performs consistency checks between all position solutions obtained with various subsets of the visible satellites. The receiver provides an alert to the pilot if the consistency checks fail.

Availability is a performance indicator of the RAIM algorithm. Availability is a function of the geometry of the constellation in view and of other environmental conditions. All the analysis performed here is utilizing the "Fault-Detection with no baro-aiding and SA off" RAIM implementation. Additional modes will be assessed at a future date. The test statistic used is a function of the pseudorange measurement residual (the difference between the expected measurement and the observed measurement) and the amount of redundancy. The test statistic is compared with a threshold value, and is determined based on the requirements for the probability of false alarm (Pfa), the probability of missed detection (Pmd), and the expected measurement noise. In aviation systems, the Pfa is fixed at 1/15000.

The horizontal protection limit (HPL) is a figure which represents the radius of a circle centered on the GPS position solution and is guaranteed to contain the true position of the receiver to within the specifications of the RAIM scheme (i.e. meets the Pfa and Pmd). The HPL is calculated as a function of the RAIM threshold and the satellite geometry at the time of the measurement. The HPL is compared with the horizontal alarm limit (HAL) to determine if RAIM is available. The RNP values shown here are measured in nautical miles, the computed HPL must be less than the RNP value for the service to be available.

8.1 Site Performance

Table 8-1 shows the RAIM performance for the twenty-eight sites evaluated. For all sites collected, the minimum percent of time in RNP 0.1 mode was 99.240% at Boston. The minimum percent of time spent in RNP 0.3 mode was 99.996% at Honolulu. The maximum 99% HPL value was 176.442 meters at Washington, DC.

Table 8-1 RAIM Site Statistics

CITY	99% HPL	Percent RNP 0.1	Percent RNP 0.3
Albuquerque	128.167	99.968	100
Anchorage	152.092	99.935	100
Atlanta	122.699	99.846	100
Barrow	142.253	99.976	100
Bethel	157.397	99.421	100
Billings	165.315	99.783	100
Boston	166.416	99.240	99.999
Cleveland	164.185	99.971	100
Cold Bay	146.831	99.803	100
Fairbanks	142.528	99.955	100
Gander	150.64	99.906	100
Honolulu	146.674	99.595	99.996
Iqaluit	155.572	99.551	100
Juneau	143.164	99.953	100
Kansas City	111.031	99.953	100
Kotzebue	160.897	99.437	100
Los Angeles	130.203	99.961	99.997
Merida	89.264	100	100
Miami	101.344	99.984	100
Minneapolis	124.227	99.949	100
Oakland	134.748	99.974	99.998
Salt Lake City	143.555	99.941	100
San Jose Del Cabo	102.929	99.986	100
San Juan	123.465	100	100
Seattle	117.009	99.831	100
Tapachula	97.579	100.000	100
Washington DC	176.442	99.570	100

8.2 RAIM Coverage

Figures 8-1 through 8-2 show the world wide RAIM coverage for both RNP 0.1 and RNP 0.3 respectively. Figures 8-3 through 8-4 show the daily RAIM coverage trends between 1 January and 31 March 2014.

Figure 8-1 RAIM RNP 0.1 Coverage

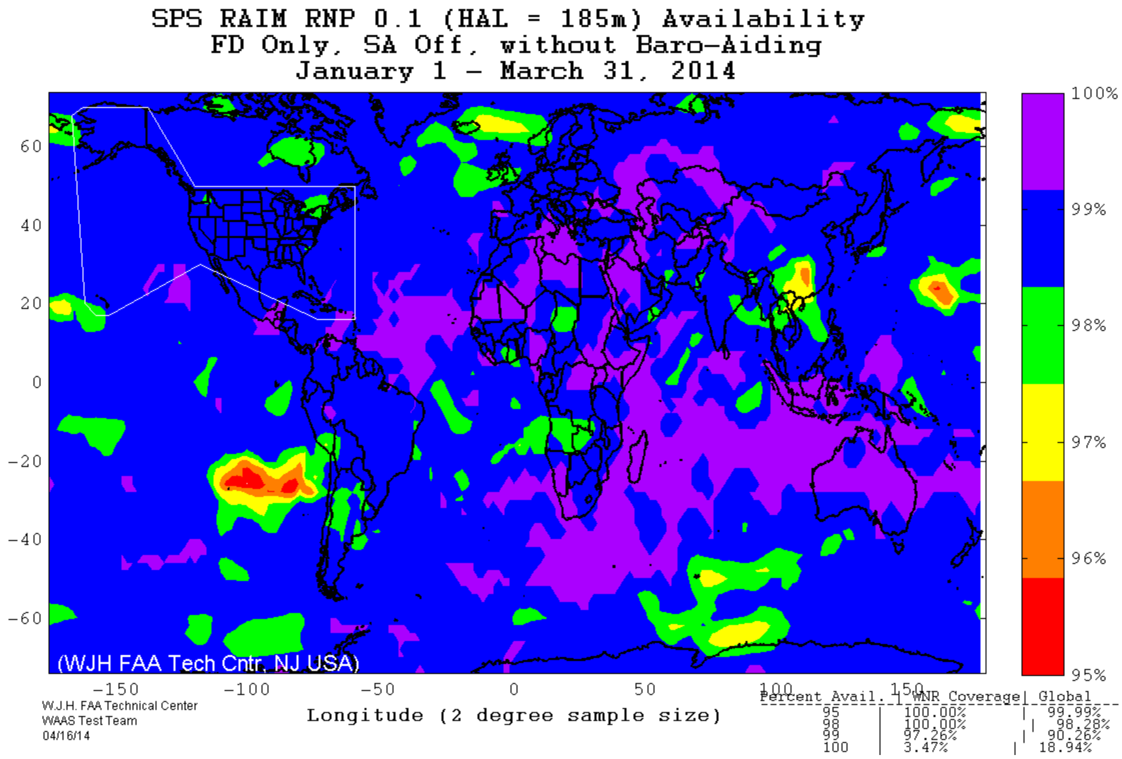


Figure 8-2 RAIM RNP 0.3 Coverage

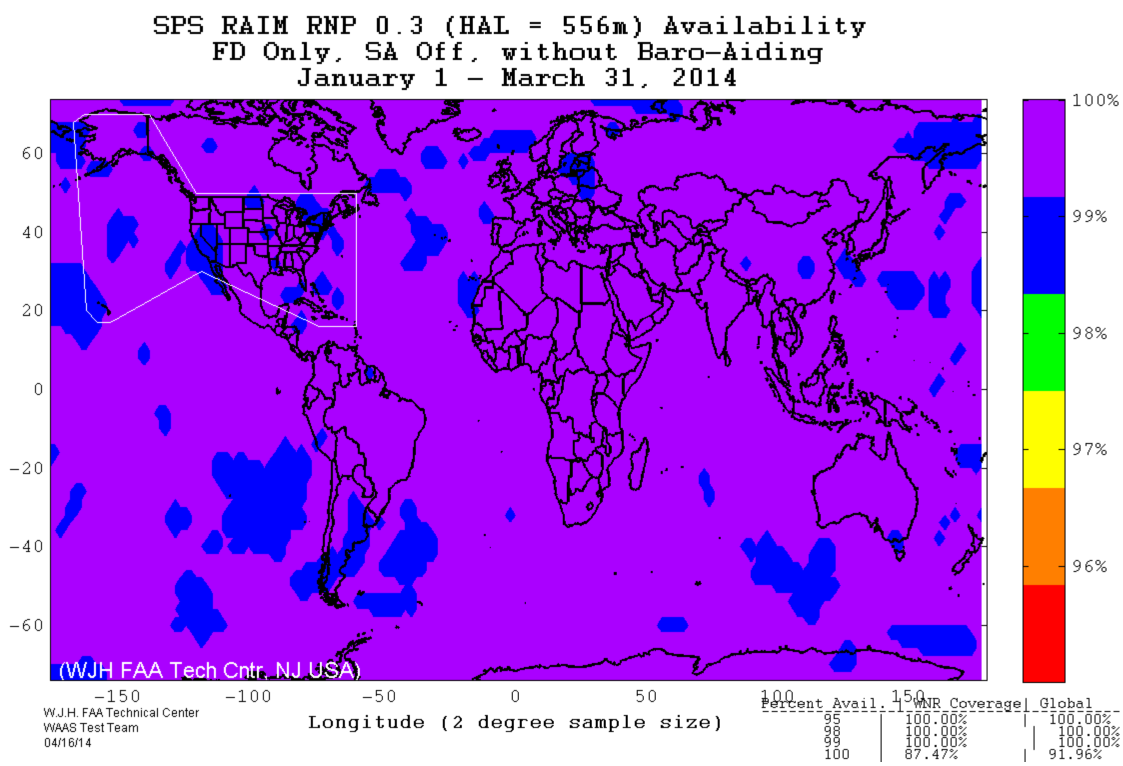


Figure 8-3 RAIM World Wide Coverage Trend

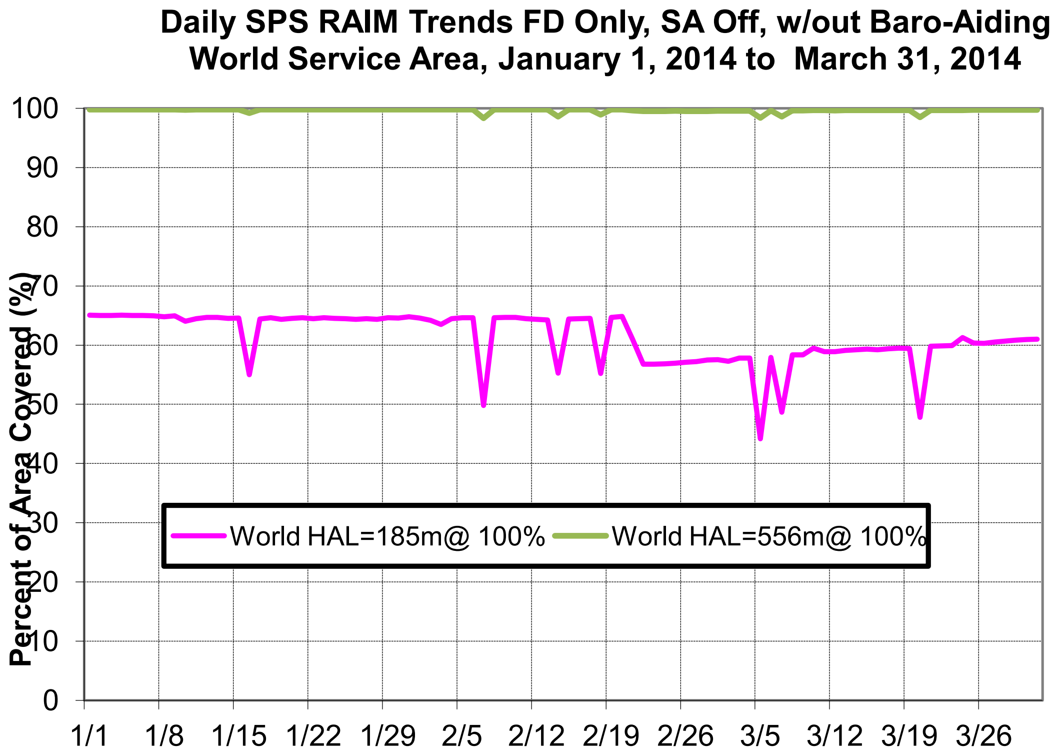
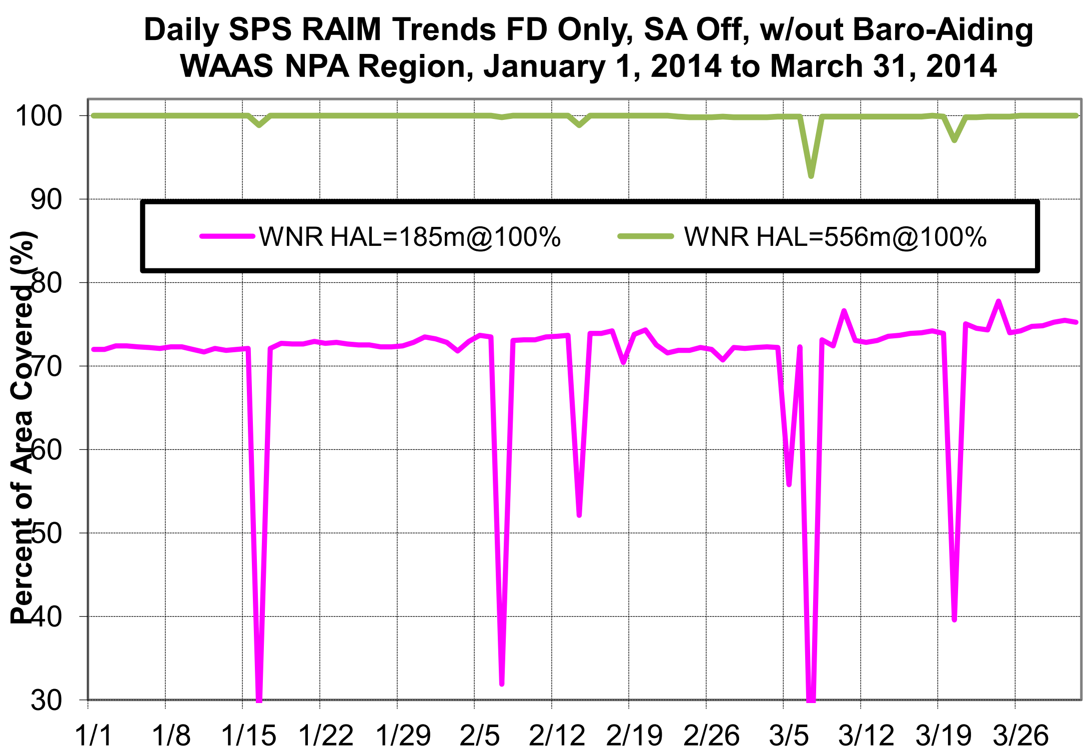


Figure 8-4 RAIM RNP Coverage Trend for WAAS NPA Service Area



8.3 RAIM Airport Analysis

Figures 8-5 and 8-6 shows RAIM RNP 0.1 and RNP 0.3 availability at all U.S. and Canadian airports that have an RNAV (GPS) published approach or better.

Figure 8-5 RAIM RNP 0.1 Airport Availability

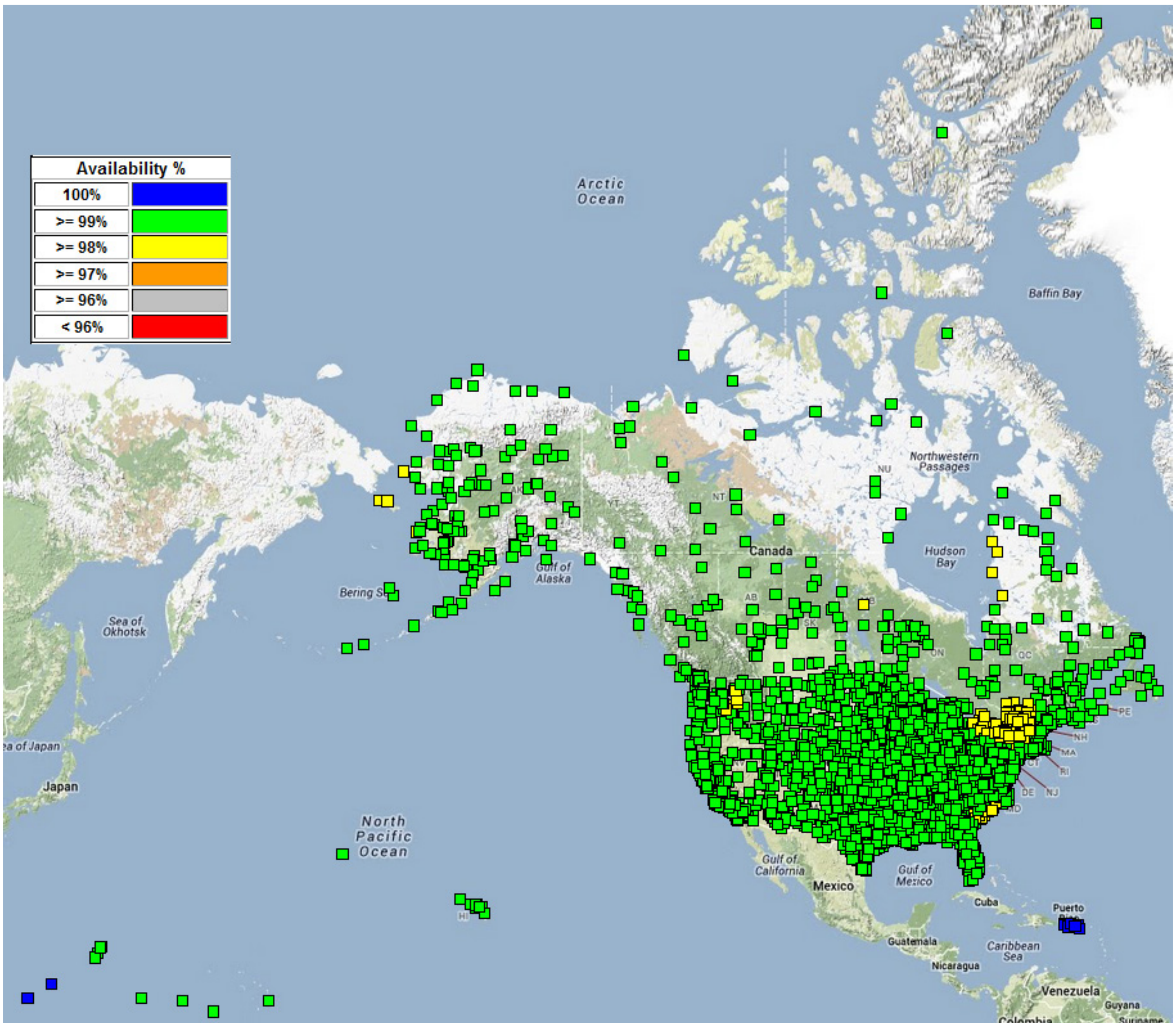
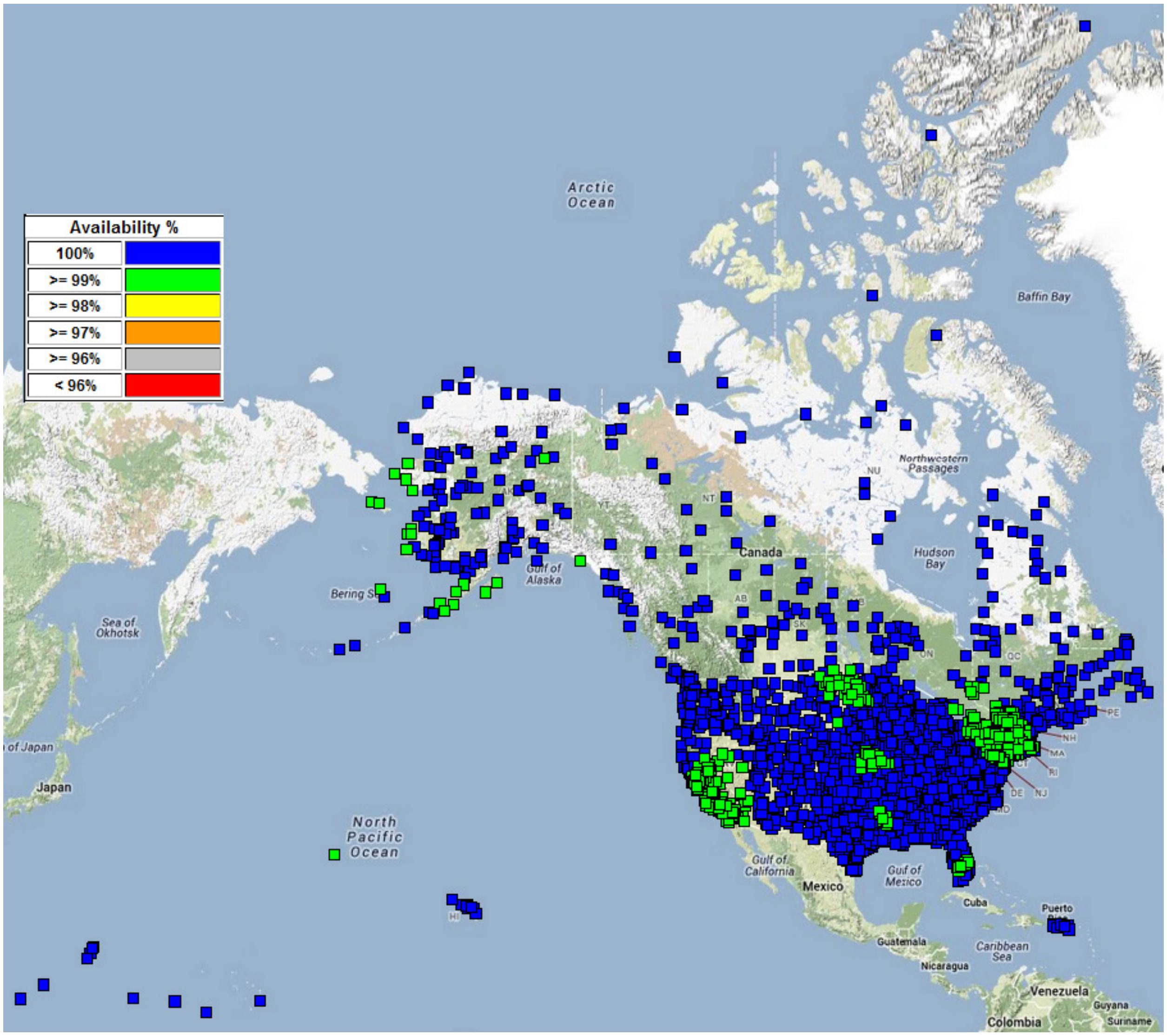


Figure 8-6 RAIM RNP 0.3 Airport Availability



Figures 8-7 and 8-8 respectively show the number of RAIM RNP 0.1 and RAIM RNP 0.3 outages for every airport in the U.S. and Canada that have a RNAV (GPS) published approach or better.

Figure 8-7 RAIM RNP 0.1 Airport Outages

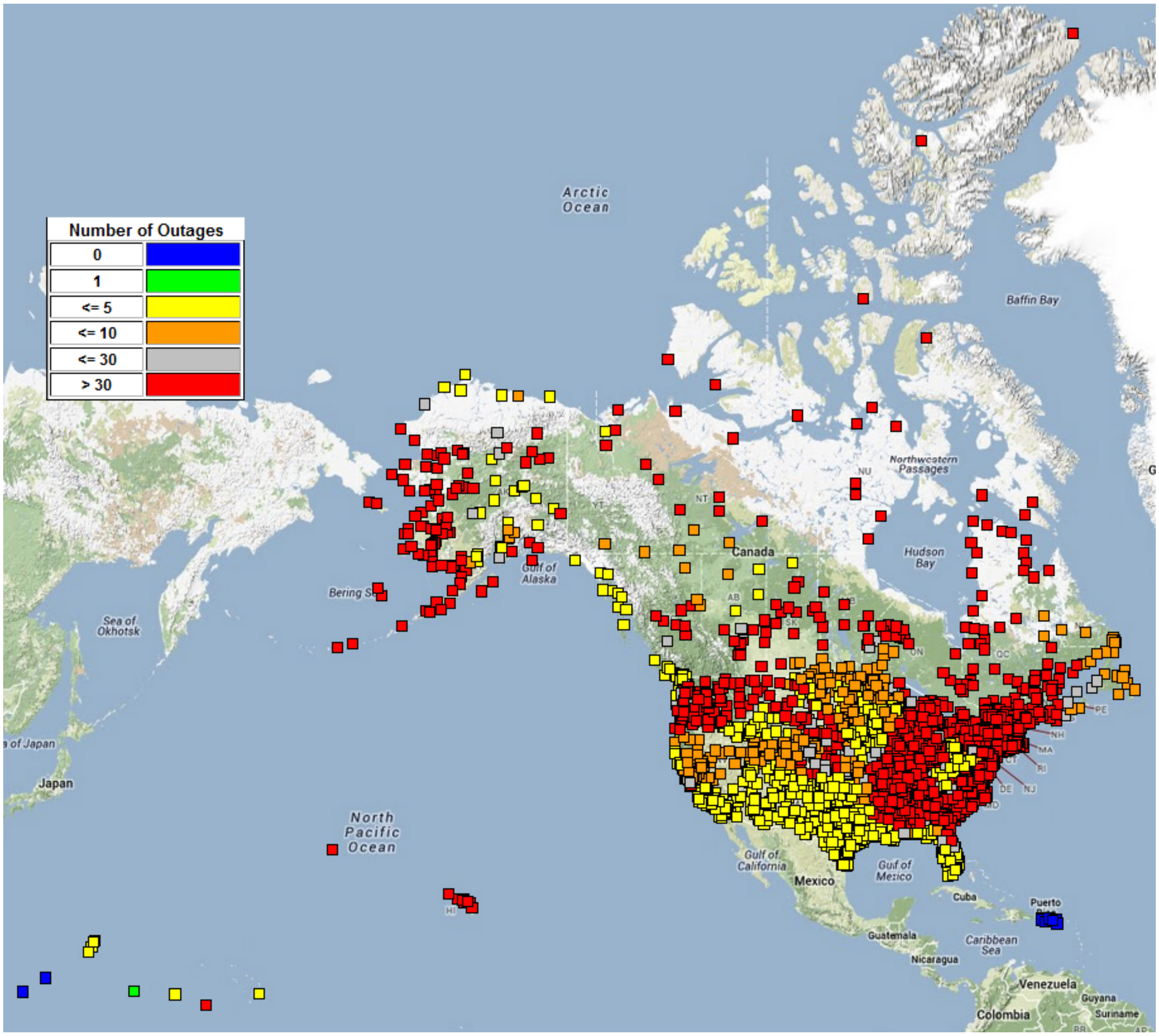
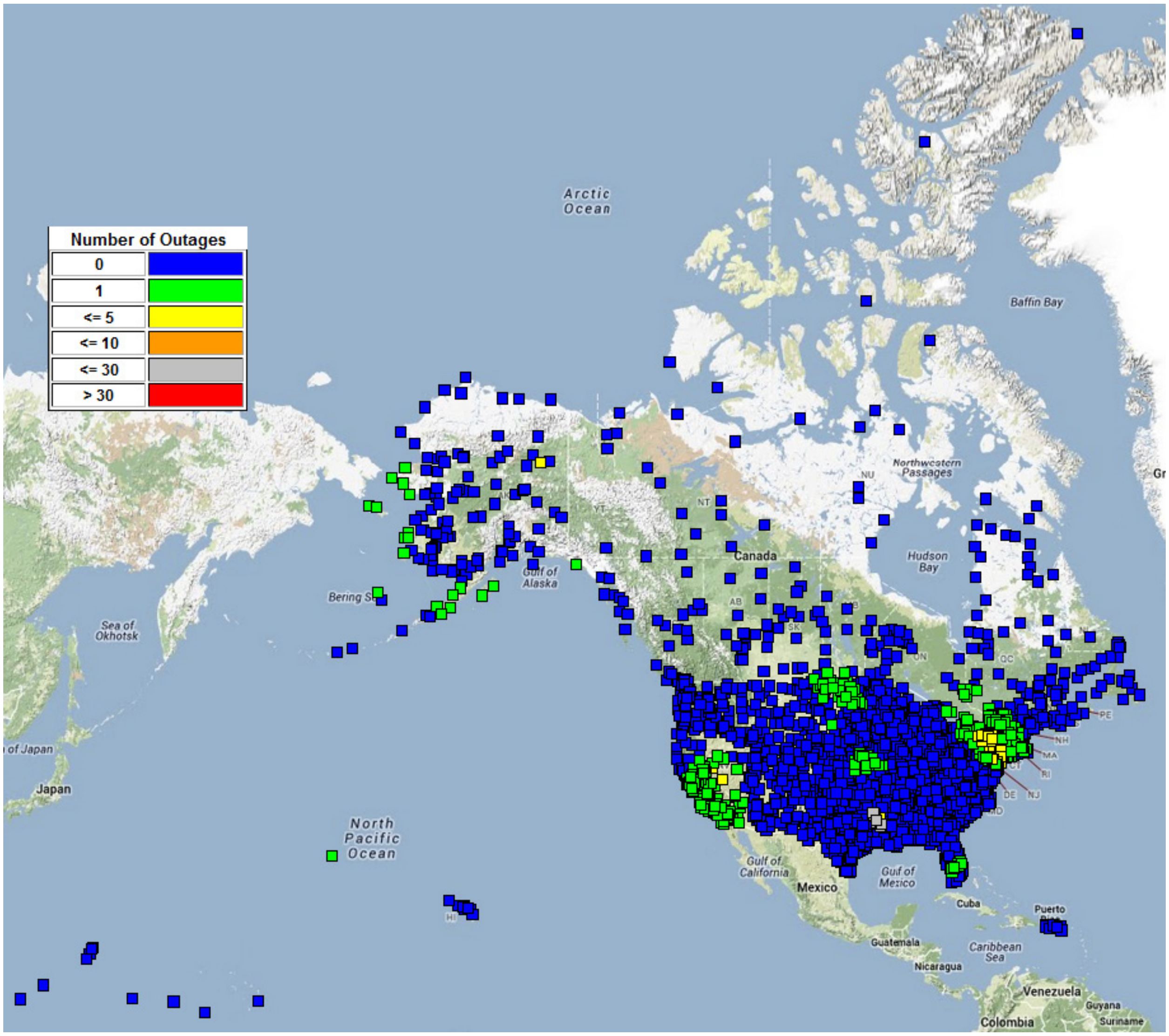


Figure 8-8 RAIM RNP 0.3 Airport Outages



9 GPS Test NOTAMs Summary

GPS test NOTAM: Global Positioning System test Notices to Airmen - GPS test NOTAMs are issued in the event that GPS is predicted to be unreliable and/or unavailable at a defined location for specific times, as indicated in the NOTAM, due to scheduled testing events.

Status and Problem Reporting	Conditions and Constraints
Scheduled event affecting service • Appropriate GPS Test NOTAM issued to the FAA at least 5 hours prior to the event	• For any SPS SIS

9.1 GPS Test NOTAMs Issued

GPS test NOTAMs were tracked and trended from GPS test NOTAMs posted on the FAA PilotWeb website (https://pilotweb.nas.faa.gov/PilotWeb/). During this reporting period, 1 January through 31 March 2014, there were a total of 40 GPS test NOTAMs. The total number of days affected in this reporting period is 42. Tables 8.1 and 8.2 below list the statistics of areas affected and durations. Note that the minimum, average, and maximum durations are on a per GPS test NOTAM basis.

Table 9-1 GPS test NOTAM Durations

Cumulative duration	153.8 hours
Minimum duration	0.5 hours
Average duration	3.84 hours
Maximum duration	11.0 hours

Table 9-2 GPS Test NOTAM Affected Areas (Square Miles) by Altitude

	40,000 feet	25,000 feet	10,000 feet	4,000 feet	50 feet
Minimum	99,953	99,953	50,341	22,171	10,821
Average	523,944	410,133	240,638	205,179	157,308
Maximum	1,258,518	1,056,806	755,011	616,674	512,564

9.2 Tracking and Trending of GPS Test NOTAMs

The GPS Test NOTAMs that are tracked and trended for this reporting period were done with a specialized software analysis tool that is designed to not only trend but also archive GPS Test NOTAMs. It is designed to trend archived GPS Test NOTAMs for any specified time frame. In addition to the data provided in this report, this tool will provide all data presented here along with airports with affected procedures via a web interface. The web interface is available at the following URL: http://waas.faa.gov/static/sog/notam/index.html.

The five plots below illustrate a visual depiction of the affected areas at their corresponding altitudes along with the impacted RNAV routes (indicated in red). Note that some GPS Test NOTAMs occupy the same area and position but differ in effective dates and/or durations.

Figure 9-1 GPS Test NOTAMs @ FL400

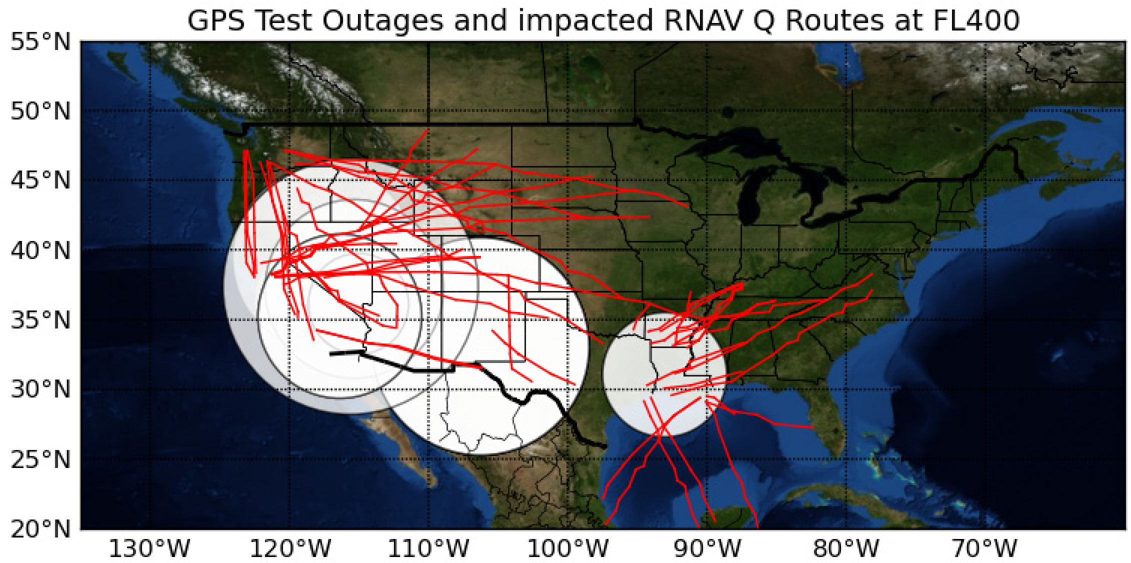


Figure 9-2 GPS NOTAMs @ FL250

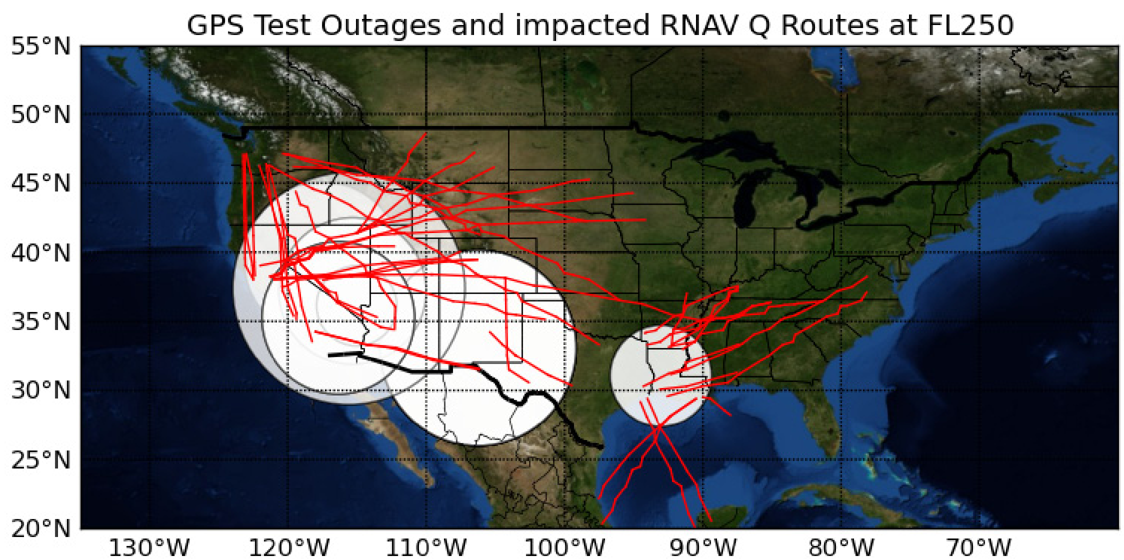


Figure 9-3 GPS NOTAMs @ 10k Feet

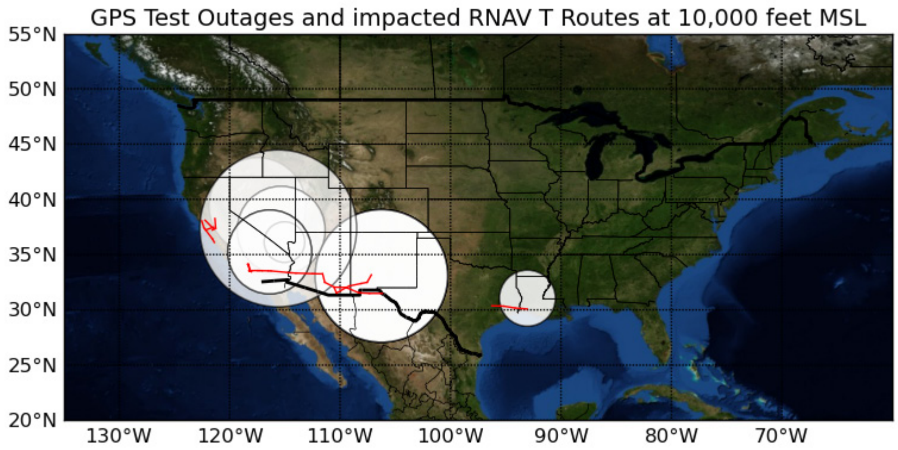


Figure 9-4 GPS NOTAMs @ 4k Feet

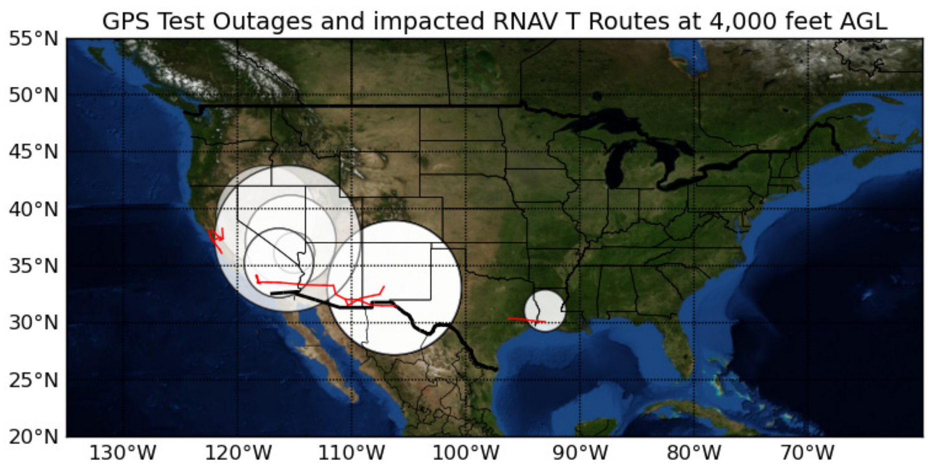
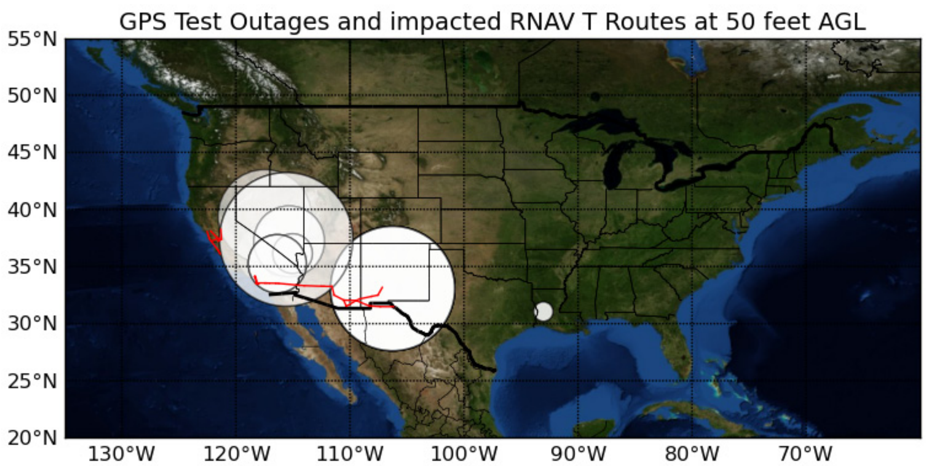


Figure 9-5 GPS NOTAMs @ 50 Feet



9.3 GPS Availability

The impacts to GPS availability are listed below for the corresponding locations and times. The percent impact to GPS availability over CONUS indicates that GPS is impacted for X % of the total area (total area of CONUS), centered at the indicated latitude/longitude. The last five columns in each table represent the impact to GPS availability at the corresponding altitude range. Altitudes 4,000 feet and under are with respect to above ground level (AGL), all remaining altitudes are with respect to MSL (mean sea level). Each row of the following table represents one GPS Test NOTAM. The remaining tables each represent one GPS Test NOTAM.

Table 9-3 NOTAM Impact to GPS Availability

				Percent Impact at each altitude				
Start Date	**End Date**	**Latitude**	**Longitude**	**50**	**4000**	**10000**	**FL250**	**FL400**
2014-02-04 03:00:00	2014-02-04 07:00:00	36.1307N	-115.0307W	1.14	1.14	1.24	3.30	5.26
2014-01-14 22:00:00	2014-01-15 22:30:00	35.1548N	-116.4005W	0.31	0.62	1.34	2.68	2.68
2014-01-20 20:00:00	2014-01-20 23:00:00	31.0535N	-93.0350W	0.21	1.14	2.17	4.85	6.81
2014-01-29 05:00:00	2014-02-01 07:59:00	37.3718N	-115.5946W	13.52	15.38	17.96	22.60	25.49
2014-02-04 19:00:00	2014-02-04 22:30:00	36.1307N	-115.0307W	1.14	1.14	1.24	3.30	5.26
2014-02-05 05:00:00	2014-02-08 07:59:00	37.3718N	-115.5946W	13.52	15.38	17.96	22.60	25.49
2014-02-11 03:00:00	2014-02-11 07:00:00	36.1307N	-115.0307W	1.14	1.14	1.24	3.30	5.26
2014-02-11 19:00:00	2014-02-11 22:30:00	36.1307N	-115.0307W	1.14	1.14	1.24	3.30	5.26
2014-02-12 06:00:00	2014-02-14 07:59:00	37.3718N	-115.5946W	13.52	15.38	17.96	22.60	25.49
2014-02-12 22:00:00	2014-02-12 22:29:00	35.1548N	-116.4005W	0.31	0.62	1.34	2.68	2.68
2014-02-22 22:00:00	2014-02-22 22:30:00	35.2400N	-116.3722W	2.58	3.61	5.37	9.29	10.22
2014-02-23 09:30:00	2014-02-23 13:30:00	35.2400N	-116.3722W	2.58	3.61	5.37	9.29	10.22
2014-02-24 19:30:00	2014-02-24 22:00:00	35.2400N	-116.3722W	2.58	3.61	5.37	9.29	10.22

Start Date	End Date	Latitude	Longitude	Percent Impact at each altitude				
				50	4000	10000	FL250	FL400
2014-02-26 08:00:00	2014-02-26 12:00:00	35.2400N	-116.3722W	2.58	3.61	5.37	9.29	10.22
2014-02-26 22:00:00	2014-02-26 23:30:00	35.2400N	-116.3722W	2.58	3.61	5.37	9.29	10.22
2014-02-27 11:00:00	2014-02-27 13:30:00	35.2400N	-116.3722W	2.58	3.61	5.37	9.29	10.22
2014-03-03 03:00:00	2014-03-03 14:00:00	33.0701N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2014-03-04 08:31:00	2014-03-08 14:00:00	33.0701N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2014-03-05 20:30:00	2014-03-05 22:29:00	36.1307N	-115.0308W	1.14	1.14	1.24	3.30	5.26
2014-03-06 05:30:00	2014-03-06 08:00:00	37.2000N	-115.3333W	4.02	6.50	6.50	11.35	15.27
2014-03-06 20:30:00	2014-03-06 22:29:00	36.1307N	-115.0307W	1.14	1.14	1.24	3.30	5.26
2014-03-07 05:30:00	2014-03-07 08:00:00	37.2000N	-115.3333W	4.02	6.50	6.50	11.35	15.27
2014-03-08 05:30:00	2014-03-08 08:00:00	37.2000N	-115.3333W	4.02	6.50	6.50	11.35	15.27
2014-03-09 03:00:00	2014-03-10 14:00:00	33.0701N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2014-03-10 19:30:00	2014-03-10 21:29:00	36.1307N	-115.0308W	1.14	1.14	1.24	3.30	5.26
2014-03-11 03:00:00	2014-03-11 04:29:00	36.1307N	-115.0308W	1.14	1.14	1.24	3.30	5.26
2014-03-11 07:31:00	2014-03-14 14:00:00	33.0701N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2014-03-12 04:30:00	2014-03-14 07:00:00	37.2000N	-115.3333W	4.02	6.50	6.50	11.35	15.27
2014-03-15 03:00:00	2014-03-16 14:00:00	33.0701N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2014-03-15 18:30:00	2014-03-16 22:30:00	33.0701N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2014-03-15 20:00:00	2014-03-15 23:00:00	31.0535N	-93.0350W	0.21	1.14	2.17	4.85	6.81
2014-03-17 03:00:00	2014-03-20 12:00:00	33.0701N	-106.2540W	9.80	10.94	11.35	15.27	17.96

Start Date	End Date	Latitude	Longitude	Percent Impact at each altitude				
				50	4000	10000	FL250	FL400
2014-03-17 19:00:00	2014-03-18 22:30:00	36.0911N	-117.3815W	2.68	3.72	3.41	7.12	8.57
2014-03-18 02:30:00	2014-03-18 04:00:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2014-03-18 16:00:00	2014-03-19 17:30:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2014-03-19 17:00:00	2014-03-19 20:00:00	31.0535N	-93.0350W	0.21	1.14	2.17	4.85	6.81
2014-03-21 07:31:00	2014-03-21 13:00:00	33.0701N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2014-03-21 17:00:00	2014-03-21 20:00:00	31.0535N	-93.0350W	0.21	1.14	2.17	4.85	6.81
2014-03-22 07:31:00	2014-03-22 14:00:00	33.0701N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2014-03-28 03:00:00	2014-03-28 12:00:00	33.0701N	-106.2540W	9.80	10.94	11.35	15.27	17.96

10 Appendices

10.1 Appendix A: Performance Summary

Table 10-1 Performance Summary

User Range Error Accuracy	**Conditions and Constraints**	**Measured Performance**
Single Frequency C/A-Code • ≤ 7.8m 95% Global Average URE during normal operations over All AODs • ≤ 6.0m 95% Global Average URE during operations at Zero AOD • ≤ 12.8m 95% Global Average URE during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1	≤ 4.418 m N/A N/A
Single Frequency C/A-Code • ≤ 30m 99.94% Global Average URE during normal operations • ≤ 30m 99.79% Worst Case single point average during normal operations.	• For any healthy SPS SIS. • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 • Standard based on measurement interval of one year; average of daily values within service volume • Standard based on 3 service failures per year, lasting no more than 6 hours each	100% Global 100% WCP
User Range Rate Error Accuracy	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	≤ 3.741 mm/sec
User Range Acceleration Error Accuracy	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 2 mm/sec^2 95% Global average URAE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	≤ 0.029 mm/s^2

Status and Problem Reporting	Conditions and Constraints	Measured Performance
Scheduled event affecting service • Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	• For any SPS SIS	≥ 52.983 hours Prior to event
Unscheduled outage or problem affecting service • Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	• For any SPS SIS	1.2 hours
Operational Satellite Count	**Conditions and Constraints**	
• ≥ 0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not	• Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operation satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not.	100%
PDOP Availability	**Conditions and Constraints**	
• ≥ 98% global PDOP of 6 or less • ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval	100 % 100 %
Service Availability	**Conditions and Constraints**	
• ≥ 99% Horizontal Service Availability, average location • ≥ 99% Vertical Service Availability, average location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	100% Horizontal 100% Vertical
• ≥ 90% Horizontal Service Availability, worst-case location • ≥ 90% Vertical Service Availability, worst-case location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	100% Horizontal 100% Vertical
Position/Time Accuracy	**Conditions and Constraints**	
Global Average Position Domain Accuracy • ≤ 9m 95% Horizontal Error • ≤ 15m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 3.286 m Horizontal ≤ 6.301 m Vertical
Worst Site Position Domain Accuracy • ≤ 17m 95% Horizontal Error • ≤ 37m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 10.23 m Horiz. ≤ 9.869 m Vert.
Time Transfer Domain Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for a time transfer solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 18 nanoseconds

Per-Slot Availability	Conditions and Constraints	
• ≥ 0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS • ≥ 0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a healthy SPS SIS	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard.	100% 100%
Constellation Availability	**Conditions and Constraints**	
• ≥ 0.98 Probability that at least 21 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration • ≥ 0.99999 Probability that at least 20 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration	• Calculated as an average over all slots in the 24-slot constellation, normalized annually. • Applies to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.	100% 100%

10.2 Appendix B: Geomagnetic Data

Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center

Current Quarter Daily Geomagnetic Data

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2014 01 01	11	0 1 1 3 4 3 3 2	33	0 0 2 5 7 5 2 3	12	1 2 2 3 4 3 3 3
2014 01 02	15	3 3 3 2 3 3 4 2	29	2 4 3 4 6 5 4 1	20	3 4 4 2 3 3 5 3
2014 01 03	7	2 2 2 2 2 2 2 1	13	1 1 3 4 4 3 2 1	10	3 2 2 3 3 3 3 2
2014 01 04	6	1 1 1 2 2 2 3 1	12	1 0 2 5 4 1 1 1	6	1 1 1 2 2 2 2 1
2014 01 05	4	1 1 2 1 1 2 2 0	2	0 0 2 2 1 0 0 0	4	1 1 2 1 1 1 1 0
2014 01 06	4	0 1 2 0 2 2 2 1	0	0 0 1 0 0 0 0 0	4	0 1 1 0 1 1 2 2
2014 01 07	7	0 2 0 1 2 3 3 2	4	0 1 0 1 0 3 2 1	8	1 2 0 1 1 3 3 3
2014 01 08	8	3 3 1 1 2 2 2 1	4	2 2 0 1 1 2 1 1	8	3 3 1 1 1 1 1 2
2014 01 09	7	2 2 2 1 2 2 3 1	10	2 1 3 3 3 1 3 1	10	3 3 2 2 1 1 3 2
2014 01 10	4	1 1 1 1 2 2 1 1	3	0 0 0 0 3 2 0 0	5	2 2 1 1 1 2 1 1
2014 01 11	3	0 0 0 0 2 2 2 1	2	0 0 0 0 0 1 2 1	4	0 0 0 0 1 1 3 2
2014 01 12	7	1 1 1 1 2 1 3 3	9	0 1 0 4 3 1 2 3	9	1 1 2 1 2 1 3 4
2014 01 13	6	2 2 2 1 2 2 1 1	5	3 1 1 2 2 0 0 1	7	3 3 2 1 1 1 0 1
2014 01 14	8	3 2 1 1 3 2 1 2	17	2 1 3 1 6 3 1 2	11	4 2 2 1 3 2 1 3
2014 01 15	3	1 1 1 0 1 2 1 0	3	1 1 1 2 0 1 1 0	4	2 1 1 1 0 1 1 1
2014 01 16	2	0 0 1 1 1 1 1 0	1	0 0 1 2 0 0 0 0	3	0 0 1 1 1 0 1 0
2014 01 17	2	0 0 0 0 1 2 1 1	1	0 0 0 0 2 0 0 0	4	1 1 1 0 1 1 1 2
2014 01 18	1	0 0 0 0 1 1 1 0	0	0 0 0 0 0 0 1 0	2	1 0 0 0 0 0 1 0
2014 01 19	2	0 0 0 0 2 2 1 0	0	0 0 0 0 0 0 0 0	2	1 0 0 0 1 1 1 0
2014 01 20	4	0 0 1 1 2 2 2 1	3	0 0 3 2 1 0 0 0	3	0 0 1 1 1 1 1 0
2014 01 21	6	2 1 1 1 2 2 2 2	11	0 0 2 4 4 3 2 1	8	3 1 2 2 2 2 2 2
2014 01 22	8	1 1 3 3 2 2 1 2	19	0 0 3 6 5 2 1 0	9	2 2 3 3 2 1 2 3
2014 01 23	5	2 1 2 1 1 2 2 1	3	1 1 2 2 1 1 0 0	6	3 2 2 1 1 1 2 1
2014 01 24	3	2 1 0 0 1 2 1 0	2	1 1 0 1 0 0 1 0	5	3 2 1 1 1 1 1 1
2014 01 25	-1	3 2 1 1 1 2-1-1	-1	0 0 0 1 2-1-1-1	8	3 2 2 1 1 2 2 3
2014 01 26	3	0 2 2 1 0 1 1 1	4	0 1 2 3 0 1 1 0	6	2 3 2 1 0 2 1 1
2014 01 27	3	0 1 1 0 2 2 0 1	1	0 0 0 0 1 1 0 0	4	1 1 1 0 1 1 1 1
2014 01 28	3	0 0 1 1 1 2 2 1	3	0 0 1 2 0 1 2 1	5	0 0 2 1 1 2 2 2
2014 01 29	6	1 2 2 2 2 2 2 1	10	0 1 3 4 3 3 1 0	7	2 2 2 2 2 2 2 2
2014 01 30	4	2 3 1 0 1 1 1 0	1	1 1 1 0 0 0 0 0	5	2 3 1 0 0 0 1 1
2014 01 31	2	0 0 0 1 1 1 1 0	0	0 0 0 1 0 0 0 0	3	0 0 1 1 1 0 1 1
2014 02 01	2	0 0 0 1 1 1 1 2	1	0 0 0 1 0 1 0 1	5	0 0 1 1 1 1 2 3
2014 02 02	4	1 1 1 0 2 2 2 0	1	1 1 0 0 0 0 1 0	4	1 2 1 0 1 1 2 1
2014 02 03	5	1 2 2 1 2 2 1 1	4	0 1 0 1 2 3 0 0	6	2 2 2 1 1 2 1 2
2014 02 04	4	1 1 1 0 2 2 1 1	0	0 0 0 0 0 0 0 0	5	2 2 1 1 1 1 1 1
2014 02 05	5	0 2 1 0 3 1 1 2	1	0 0 0 0 1 0 0 1	4	1 1 1 0 2 1 1 2
2014 02 06	5	1 2 1 2 2 2 1 1	14	1 1 1 4 5 4 1 0	9	2 3 2 2 3 2 2 1
2014 02 07	7	0 0 1 2 1 2 2 4	5	0 0 1 3 1 1 2 2	9	1 0 2 2 1 3 3 4
2014 02 08	19	4 4 3 2 3 1 2 5	24	3 3 5 4 5 3 3 2	23	4 4 4 2 2 2 4 5
2014 02 09	11	3 2 3 1 3 2 3 2	25	3 3 5 1 5 5 3 2	18	4 3 3 1 3 3 4 3
2014 02 10	9	2 2 1 2 1 1 4 3	8	2 1 2 3 1 1 3 2	12	3 2 2 2 1 1 4 4
2014 02 11	3	1 1 1 0 1 1 1 2	3	2 1 1 1 0 0 1 2	6	2 2 2 1 1 0 1 3
2014 02 12	5	3 2 1 1 1 2 1 0	6	3 0-1-1-1 2 1 1	9	3 3 2 1 1 2 2 1
2014 02 13	2	0 0 0 1 1 1 1 0	0	0 0 0 0 0 0 0 0	3	1 0 1 1 0 0 1 0
2014 02 14	4	0 0 1 1 3 2 1 1	0	0 0 0 0 0 0 0 0	4	0 0 1 1 2 1 1 1
2014 02 15	7	0 0 0 0 3 2 2 4	6	0 0 0 0 2 3 2 3	11	0 1 0 0 3 3 3 5
2014 02 16	14	4 3 2 2 3 3 3 2	16	3 2 2 3 3 5 3 2	22	5 3 2 2 3 4 4 3
2014 02 17	4	1 0 1 1 1 1 2 2	2	1 1 1 1 0 0 0 1	5	2 1 1 1 1 1 2 3
2014 02 18	6	1 0 1 1 2 2 2 3	8	1 0 2 1 3 3 3 2	7	1 0 2 2 1 2 3 3
2014 02 19	30	4 5 5 5 5 2 2 2	57	3 6 5 7 7 3 2 2	47	5 6 6 5 6 3 2 3
2014 02 20	27	1 5 5 5 5 2 2 2	59	1 5 5 8 6 4 3 2	39	2 6 6 6 5 3 3 3

2014 02 21	9	2	2	2	3	2	2	2	3	19	2	1	4	5	4	4	2	1	12	3	3	3	3	2	3	2	3
2014 02 22	11	4	3	2	3	2	2	2	1	19	4	2	3	5	4	3	2	1	14	4	3	2	3	2	3	2	2
2014 02 23	12	2	2	3	2	3	3	3	3	32	1	2	2	5	5	5	6	3	17	2	2	3	3	3	4	4	4
2014 02 24	5	1	1	2	2	2	2	2	0	8	1	2	2	4	2	2	1	0	7	2	2	2	3	2	2	2	1
2014 02 25	3	1	0	0	0	2	2	1	2	4	1	0	0	2	3	1	0	1	4	2	0	1	1	1	1	1	2
2014 02 26	3	2	0	0	1	2	2	1	0	0	1	0	0	0	0	0	0	0	4	2	0	1	1	0	1	1	1
2014 02 27	15	1	1	0	0	3	4	5	4	24	0	0	0	2	4	6	5	4	24	1	1	1	1	3	4	6	5
2014 02 28	10	3	2	3	3	2	3	1	1	-1	3	2	4	6	1	-1	-1	-1	13	4	3	4	3	2	3	1	1
2014 03 01	6	2	1	2	1	2	2	2	2	3	-1	-1	-1	-1	-1	-1	1	1	7	2	2	2	2	2	1	2	3
2014 03 02	3	2	1	0	1	2	1	1	0	2	2	1	0	0	1	0	0	0	5	3	2	1	1	1	0	1	1
2014 03 03	6	2	2	2	1	2	2	1	1	6	0	1	2	3	3	1	0	1	7	3	2	2	2	2	1	1	1
2014 03 04	8	2	2	0	3	3	2	1	2	7	1	0	0	4	3	2	1	1	8	2	1	0	2	3	2	2	3
2014 03 05	6	1	1	1	1	3	2	2	1	7	1	0	0	4	3	2	1	1	7	2	1	2	2	3	2	2	2
2014 03 06	5	1	0	0	1	2	3	2	1	5	0	0	0	1	4	2	1	0	6	1	1	1	2	2	2	3	1
2014 03 07	3	0	1	0	1	2	2	1	1	0	0	0	0	0	0	0	1	0	4	1	1	1	1	1	1	1	1
2014 03 08	5	1	1	1	1	2	2	1	2	1	0	0	0	2	0	0	0	0	4	1	1	1	1	1	1	1	1
2014 03 09	2	1	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	3	1	0	1	1	0	0	1	1
2014 03 10	4	1	1	1	2	2	1	1	0	7	0	0	0	5	2	0	0	0	6	1	1	1	3	2	0	1	1
2014 03 11	4	0	0	0	2	2	3	1	1	2	0	0	1	1	2	1	0	0	4	0	0	1	2	1	1	1	1
2014 03 12	-1	2	0	1	2	-1	-1	-1	-1	2	1	0	0	0	1	0	1	1	6	2	1	1	1	1	1	2	3
2014 03 13	-1	-1	-1	-1	-1	-1	-1	-1	-1	14	3	4	3	4	3	2	1	1	13	5	4	3	2	2	1	2	1
2014 03 14	5	1	2	2	1	2	1	1	1	11	0	-1	-1	4	4	2	1	0	6	1	2	2	1	2	2	1	1
2014 03 15	3	2	1	1	0	0	1	1	2	2	1	0	2	1	0	0	0	0	4	2	1	1	1	0	0	1	1
2014 03 16	1	1	1	1	0	0	0	0	0	1	0	0	2	0	0	0	0	0	3	1	1	1	0	0	0	1	0
2014 03 17	2	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	3	0	0	1	1	0	0	1	1
2014 03 18	5	1	2	2	1	2	2	2	0	11	0	0	5	3	3	2	1	0	6	1	1	2	2	2	1	2	1
2014 03 19	2	1	0	1	1	1	0	1	1	7	1	1	4	3	1	0	0	1	5	2	1	2	1	1	1	1	1
2014 03 20	4	1	2	1	1	1	1	1	1	3	1	1	0	3	1	0	1	0	6	1	2	2	2	1	0	1	1
2014 03 21	10	3	2	3	2	2	3	2	2	16	2	2	4	5	3	3	1	1	10	3	2	3	3	2	3	2	2
2014 03 22	7	2	1	1	2	3	2	2	1	5	1	0	0	0	4	1	1	0	6	2	1	1	2	2	1	1	2
2014 03 23	7	1	2	2	2	2	2	2	2	4	1	1	1	1	1	1	2	1	6	2	2	2	1	1	1	2	2
2014 03 24	4	1	0	1	2	2	2	1	0	1	1	0	0	1	0	0	0	0	5	2	1	1	2	1	1	1	1
2014 03 25	7	0	0	0	2	3	1	3	3	4	0	0	0	1	1	0	3	2	8	1	1	1	2	2	1	3	3
2014 03 26	7	3	1	3	2	2	1	1	1	8	3	1	4	3	0	1	1	0	9	4	1	4	2	1	1	2	1
2014 03 27	7	1	1	1	3	3	1	2	1	15	1	1	1	5	5	3	1	0	7	2	2	1	3	2	2	2	0
2014 03 28	9	1	1	1	2	3	2	3	3	7	0	0	1	2	4	1	2	2	8	1	1	1	2	2	1	3	3
2014 03 29	9	3	2	0	2	2	3	2	3	5	2	1	1	3	2	0	0	1	8	3	2	1	2	1	1	1	3
2014 03 30	5	2	0	1	2	2	2	1	1	2	1	0	0	2	0	1	1	0	5	2	1	1	2	1	1	1	1
2014 03 31	8	1	1	1	1	3	4	2	1	8	1	1	1	1	4	3	2	0	7	0	1	1	2	3	3	2	1

10.3 Appendix C: Performance Analysis (PAN) Problem Report

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS for IFR and is developing WAAS and LAAS, both of which are GPS augmentation systems. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Performance Analysis (PAN) report. The PAN report contains data collected at various National Satellite Test Bed (NSTB) and Wide Area Augmentation System (WAAS) reference station locations. This PAN Problem Report will be issued only when the performance data fails to meet the GPS Standard Positioning Service (SPS) Signal Specification.

Problem Description:

Although no GPS satellites failed specification limits, two GPS satellites (PRN's 2 and 10) did exceed 30 meter range errors for a short time at Honolulu, HI. The plots below show the range error plots for the satellites in both a single frequency and dual frequency navigation solution. The plots demonstrate that the major contributor to the range errors measured on these satellites was due to ionospheric error. This is evidenced by the fact that the dual frequency solution had a much smaller range error value. The gaps in the plots signify where scintillation was extreme enough for the solution to set the satellite as invalid and exclude it from the position solution.

Figure 10-1 Dual and Single Frequency Range Error on PRN2: 21 February 2014

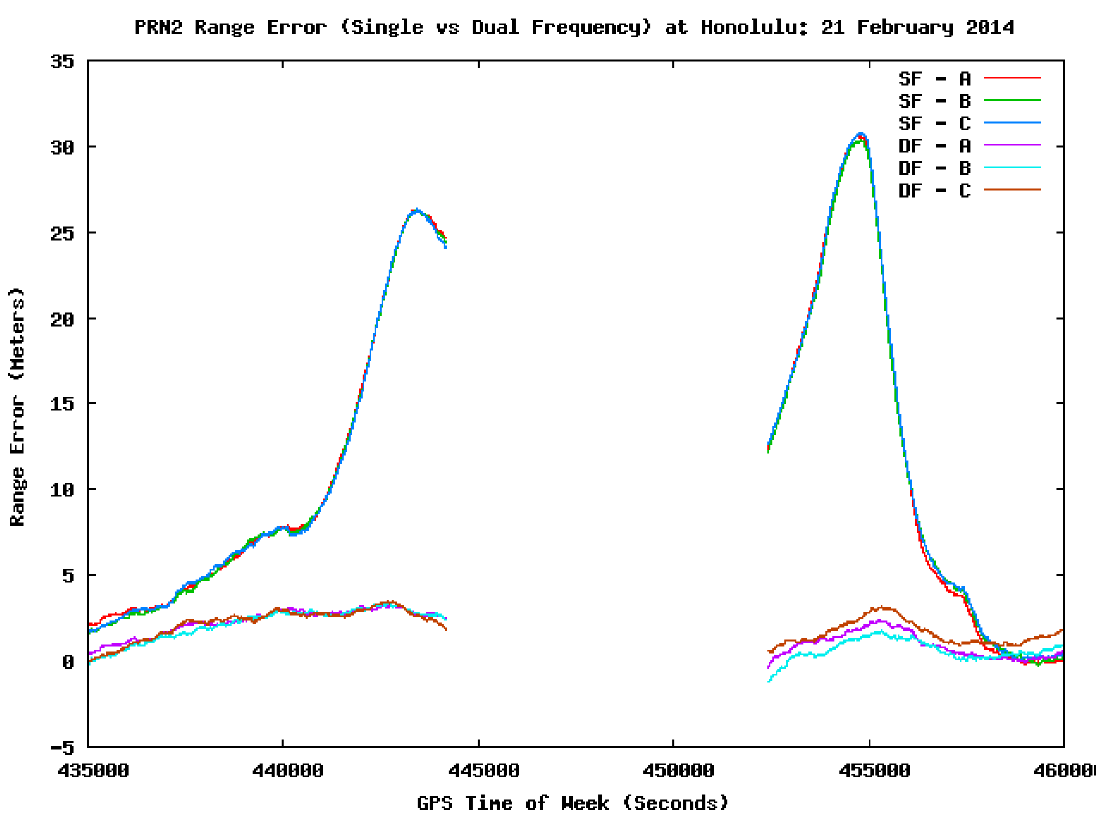
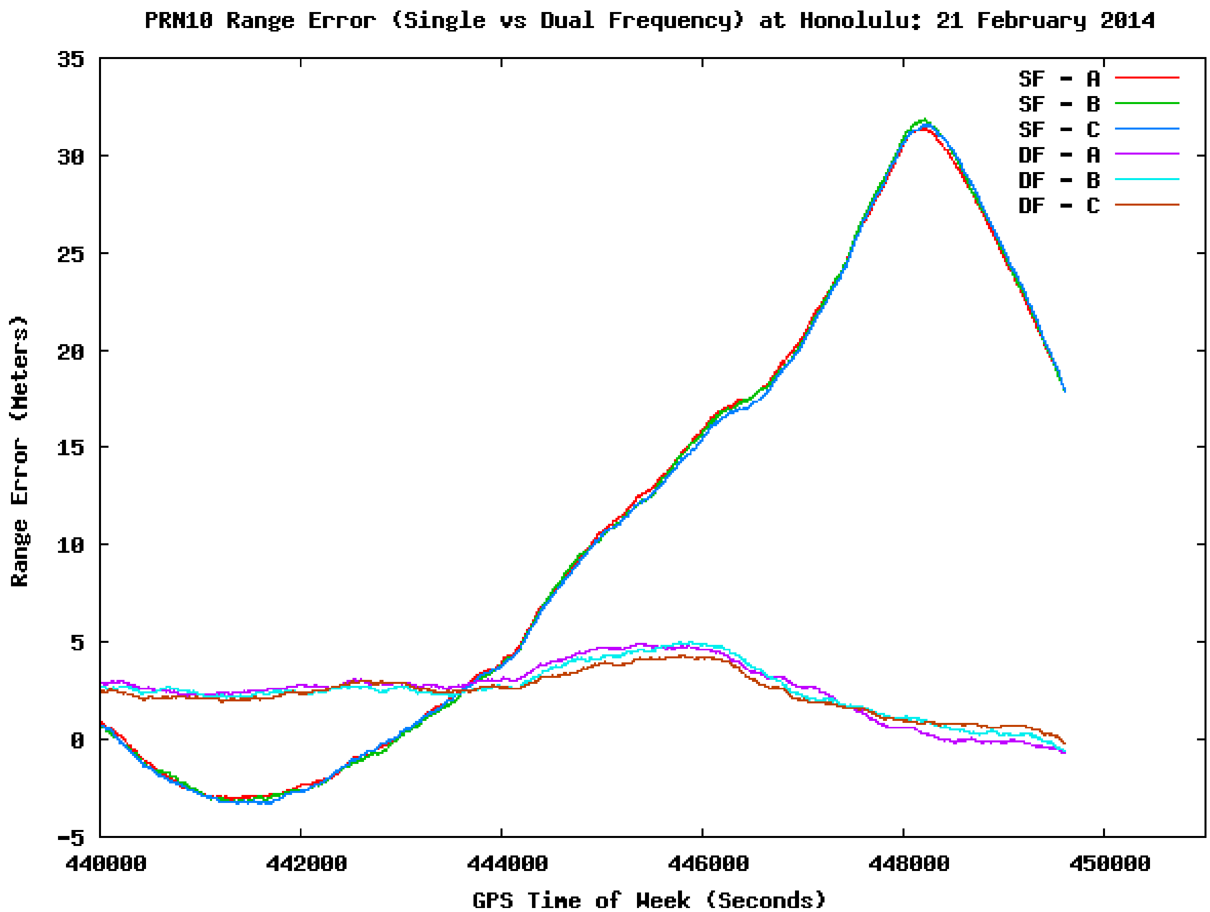


Figure 10-2 Dual and Single Frequency Range Error on PRN10: 21 February 2014



10.4 Appendix D: Glossary

The terms and definitions discussed below are taken from the Standard Positioning Service Performance Specification (September 2008). An understanding of these terms and definitions is a necessary prerequisite to full understanding of the Signal Specification.

General Terms and Definitions

Almanac Longitude of the Ascending Node (.o): Equatorial angle from the Prime Meridian (Greenwich) at the weekly epoch to the ascending node at the ephemeris reference epoch.

Coarse/Acquisition (C/A) Code: A PRN code sequence used to modulate the GPS L1 carrier.

Corrected Longitude of Ascending Node (Ωk) and Geographic Longitude of the Ascending Node (GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the ascending node, both at arbitrary time T_k.

Dilution of Precision (DOP): The magnifying effect on GPS position error induced by mapping GPS ranging errors into position within the specified coordinate system through the geometry of the position solution. The DOP varies as a function of satellite positions relative to user position. The DOP may be represented in any user local coordinate desired. Examples are HDOP for local horizontal, VDOP for local vertical, PDOP for all three coordinates, and TDOP for time.

Equatorial Angle: An angle along the equator in the direction of Earth rotation.

Geometric Range: The difference between the estimated locations of a GPS satellite and an SPS receiver.

Ground track Equatorial Crossing (GEC, λ, 2 SOPS GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the location a ground track intersects the equator when crossing from the Southern to the Northern hemisphere. GEC is equal to Ωk when the argument of latitude (Φ) is zero.

Instantaneous User Range Error (URE): The difference between the pseudo range measured at a given location and the expected pseudo range, as derived from the navigation message and the true user position, neglecting the bias in receiver clock relative to GPS time. A signal-in-space (SIS) URE includes residual orbit, satellite clock, and group delay errors. A system URE (sometimes known as a User Equivalent Range Error, or UERE) contains all line-of-sight error sources, to include SIS, single-frequency ionosphere model error, troposphere model error, multipath and receiver noise.

Longitude of Ascending Node (LAN): A general term for the location of the ascending node – the point that an orbit intersects the equator when crossing from the Southern to the Northern hemisphere.

Longitude of the Ground track Equatorial Crossing (GEC, λ, 2 SOPS GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the location a ground track intersects the equator when crossing from the Southern to the Northern hemisphere. GEC is equal to Ωk when the argument of latitude (Φ) is zero.

Mean Down Time (MDT): A measure of time required to restore function after any downing event.

Mean Time Between Downing Events (MTBDE): A measure of time between any downing events.

Mean Time Between Failures (MTBF): A measure of time between unscheduled downing events.

Mean Time to Restore (MTTR): A measure of time required to restore function after an unscheduled downing event.

Navigation Message: Data contained in each satellite's ranging signal and consisting of the ranging signal time-of-transmission, the transmitting satellite's orbital elements, an almanac containing abbreviated orbital element information to support satellite selection, ranging measurement correction information, and status flags. The message structure is described in Section 2.1.2 of the SPS Performance Standard.

Operational Satellite: A GPS satellite which is capable of, but is not necessarily transmitting a usable ranging signal.

PDOP Availability: Defined to be the percentage of time over any 24-hour interval that the PDOP value is less than or equal to its threshold for any point within the service volume.

Positioning Accuracy: Defined to be the statistical difference, at a 95% probability, between position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

- **Horizontal Positioning Accuracy:** Defined to be the statistical difference, at a 95% probability, between horizontal position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

- **Vertical Positioning Accuracy:** Defined to be the statistical difference, at a 95% probability, between vertical position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

Position Solution: An estimate of a user's location derived from ranging signal measurements and navigation data from GPS.

Position Solution Geometry: The set of direction cosines that define the instantaneous relationship of each satellite's ranging signal vector to each of the position solution coordinate axes.

Pseudo Random Noise (PRN): A binary sequence that appears to be random over a specified time interval unless the shift register configuration and initial conditions for generating the sequence are known. Each satellite generates a unique PRN sequence that is effectively uncorrelated (orthogonal) to any other satellite's code over the integration time constant of a receiver's code tracking loop.

Representative SPS Receiver: The minimum signal reception and processing assumptions employed by the U.S. Government to characterize SPS performance in accordance with performance standards defined in Section 3 of the SPS Performance Standard. Representative SPS receiver capability assumptions are identified in Section 2.2 of the SPS Performance Standard.

Right Ascension of Ascending Node (RAAN): Equatorial angle from the celestial principal direction to the ascending node.

Root Mean Square (RMS) SIS URE: A statistic that represents instantaneous SIS URE performance in an RMS sense over some sample interval. The statistic can be for an individual satellite or for the entire constellation. The sample interval for URE assessment used in the SPS Performance Standard is 24 hours.

Selective Availability: Protection technique formerly employed to deny full system accuracy to unauthorized users. SA was discontinued effective midnight May 1, 2000.

Service Availability: Defined to be the percentage of time over any 24-hour interval that the predicted 95% positioning error is less than its threshold for any given point within the service volume.

- **Horizontal Service Availability:** Defined to be the percentage of time over any 24-hour interval that the predicted 95% horizontal error is less than its threshold for any point within the service volume.

- **Vertical Service Availability:** Defined to be the percentage of time over any 24-hour interval that the predicted 95% vertical error is less than its threshold for any point within the service volume.

Service Degradation: A condition over a time interval during which one or more SPS performance standards are not supported.

Service Failure: A condition over a time interval during which a healthy GPS satellite's ranging signal exceeds the Not-to-Exceed (NTE) SPS SIS URE tolerance.

Service Reliability: The percentage of time over a specified time interval that the instantaneous SIS SPS URE is maintained within a specified reliability threshold at any given point within the service volume, for all healthy GPS satellites.

Service Volume: The spatial volume supported by SPS performance standards. Specifically, the SPS Performance Standard supports the terrestrial service volume. The terrestrial service volume covers from the surface of the Earth up to an altitude of 3,000 kilometers.

SPS Performance Envelope: The range of nominal variation in specified aspects of SPS performance.

SPS Performance Standard: A quantifiable minimum level for a specified aspect of GPS SPS performance. SPS performance standards are defined in Section 3.0.

SPS Ranging Signal: An electromagnetic signal originating from an operational satellite. The SPS ranging signal consists of a Pseudo Random Noise (PRN) C/A code, a timing reference and sufficient data to support the position solution generation process. A description of the GPS SPS signal is provided in Section 2. The formal definition of the SPS ranging signal is provided in ICD IS-GPS-200G.

SPS Ranging Signal Measurement: The difference between the ranging signal time of reception (as determined by the receiver's clock) and the time of transmission derived from the navigation signal (as defined by the satellite's clock) multiplied by the speed of light. Also known as the *pseudo range*.

SPS SIS User Range Error (URE) Statistic:

- A satellite SPS SIS URE statistic is defined to be the Root Mean Square (RMS) difference between SPS ranging signal measurements (neglecting user clock bias and errors due to propagation environment and receiver), and "true" ranges between the satellite and an SPS user at any point within the service volume over a specified time interval.

- A constellation SPS SIS URE statistic is defined to be the average of all satellite SPS SIS URE statistics over a specified time interval.

Time Transfer Accuracy Relative to UTC (USNO): The difference at a 95% probability between user UTC time estimates and UTC (USNO) at any point within the service volume over any 24-hour interval.

Transient Behavior: Short-term behavior not consistent with steady-state expectations.

Usable SPS Ranging Signal: An SPS ranging signal that can be received, processed, and used in a position solution by a receiver with representative SPS receiver capabilities.

User Navigation Error (UNE): Given a sufficiently stationary and ergodic satellite constellation ranging error behavior over a minimum sample interval, multiplication of the DOP and a constellation ranging error standard deviation value will yield an approximation of the RMS position error. This RMS approximation is known as the UNE (UHNE for horizontal, UVNE for vertical, and so on). The user is cautioned that any divergence away from the stationary and ergodic assumptions will cause the UNE to diverge from a RMS value based on actual measurements.

User Range Accuracy (URA): A conservative representation of each satellite's expected (1σ) SIS URE performance (excluding residual group delay) based on historical data. A URA value is provided that is representative over the curve fit interval of the navigation data from which the URA is read. The URA is a coarse representation of the URE statistic in that it is quantized to levels represented in ICD IS-GPS-200G.