Global Positioning System (GPS)

Standard Positioning Service (SPS)

Performance Analysis Report

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GPS Product Team

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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 #87, includes data collected from 1 July through 30 September 2014. The next quarterly report will be issued January 31, 2015.

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° 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 July and 30 September 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 eight outages were reported in the NANU's this quarter. Six outages were scheduled ahead of time while two outages were unscheduled NANU's sent out after the start of the event.

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 26.053 meters on Satellite PRN 12. 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 2.307 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 7.98 meters at Matera, Italy and 7.73 meters at Usuda, Japan.

From the analysis performed on data collected between 1 July and 30 September 2014, the GPS performance met all SPS requirements that were evaluated.

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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.

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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	✓
Constellation Coverage	**Conditions and Constraints**	
Terrestrial Service Volume: 100% Coverage Space Service Volume: No Coverage Performance Specified	• For any healthy or marginal SPS SIS	✓
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	Please see results in the WAAS PAN 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	✓
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	✓

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
$\geq$ 98% global PDOP of 6 or less $\geq$ 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° 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 2.975 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: $\geq$ 98%)	Worst-Case Point (Spec: $\geq$ 88%)
29 Jun – 5 Jul	2.920	100	99.931
6 – 12 Jul	2.933	100	99.861
13 – 19 Jul	2.937	100	99.861
20 – 26 Jul	2.925	100	100
27 Jul – 2 Aug	2.924	100	100
3 – 9 Aug	2.917	100	100
10 – 16 Aug	2.959	100	100
17 – 23 Aug	2.950	100	100
24 – 30 Aug	2.961	100	100
31 Aug – 6 Sept	2.972	100	100
7 – 13 Sept	2.974	100	100
14 – 20 Sept	2.975	100	99.931
21 – 27 Sept	2.948	100	99.931

Figure 2-1 World GPS Maximum PDOP

08/14/14 World GPS Maximum PDOP

Median 99.99% PDOP =2.9
Maximum PDOP =12.4
Color Scale is Position Dilution of Precision (PDOP)
(WJH FAA Tech. Cntr, NJ USA)
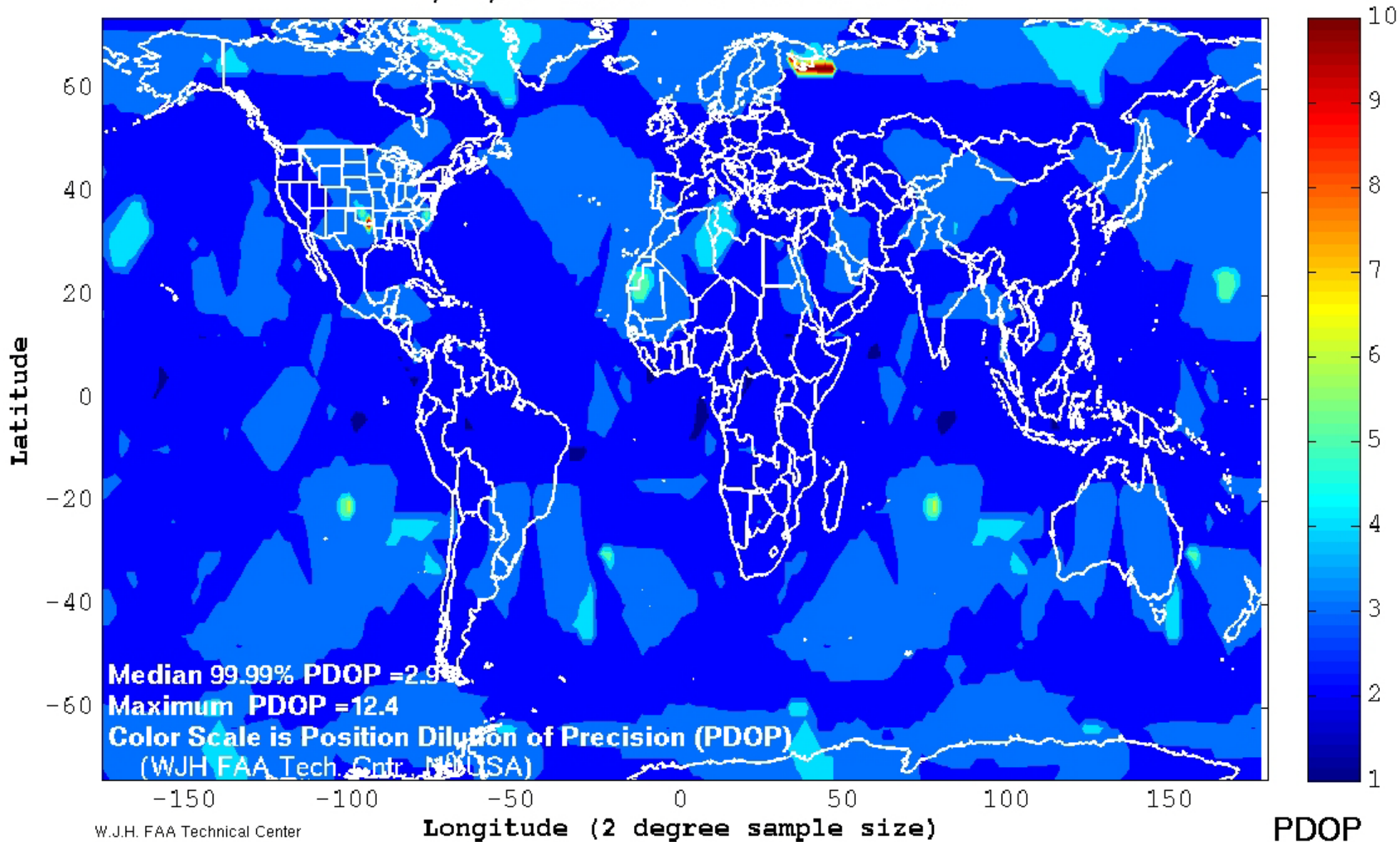
W.J.H. FAA Technical Center
WAAS Test Team

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

Worst-Case Point (Lat: 60, Long: 40)
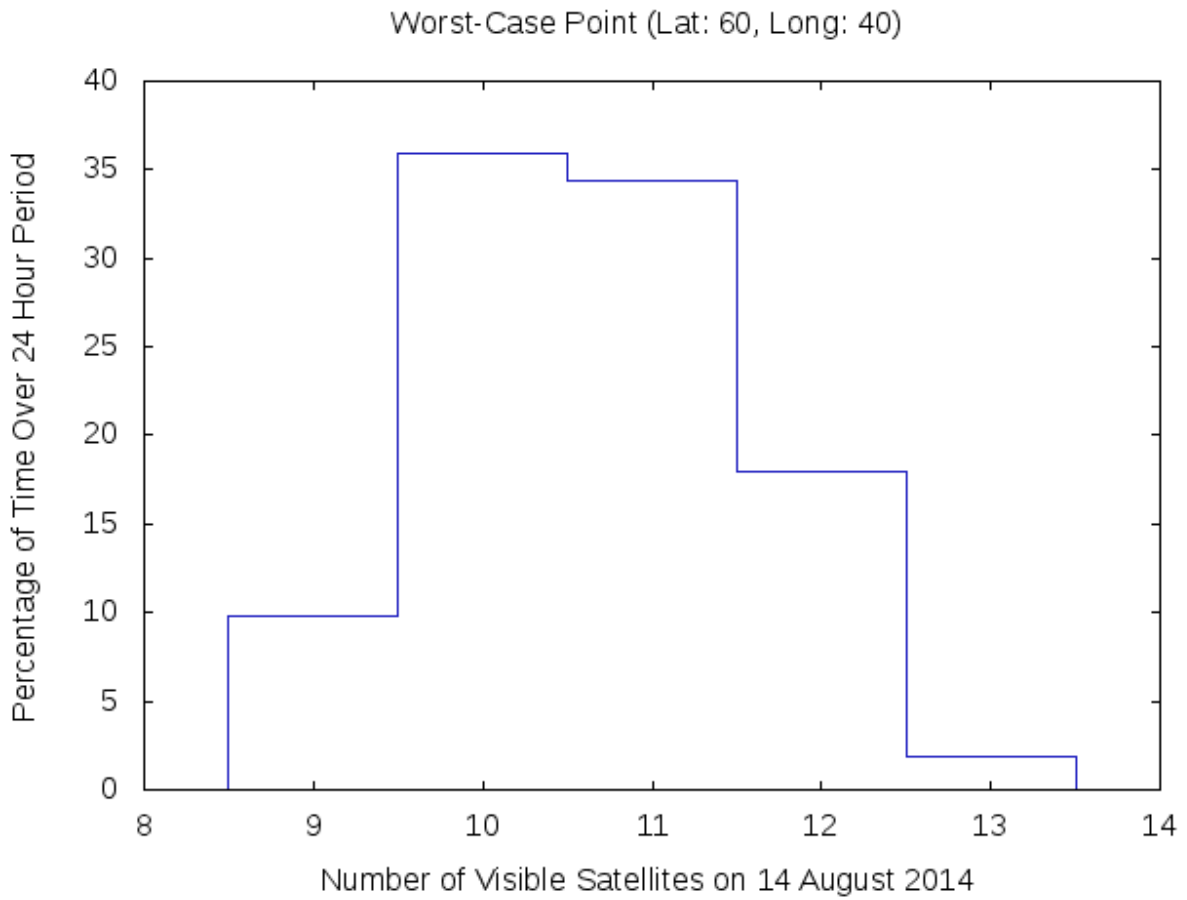
3 NANU Summary and Evaluation

> **NANU:** <u>N</u>otice <u>A</u>dvisory to <u>N</u>AVSTAR <u>U</u>sers – 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 July through 30 September 2014, there were a total of eight reported outages. Six of those outages were maintenance activities and were reported in advance. There were two unscheduled outages. 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 115.833 hours. The notification time met the 48-hour requirement. The maximum response time for a NANU issued for an unscheduled outage was 0.267 hours. Therefore the probability of continuity not being affected due to an unscheduled failure interruption was 100%, which met the specification requirement.

Table 3-1 NANUs Affecting Satellite Availability

NANU#	PRN	TYPE	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2014054	30	UNUSABLE	3-Jul-14	12:11	3-Jul-14	22:50	10.65		10.65
2014056	10	FCSTSUMM	10-Jul-14	11:52	10-Jul-14	17:41		5.82	5.82
2014057	6	FCSTSUMM	17-Jul-14	9:50	17-Jul-14	15:07		5.28	5.28
2014059	19	UNUSABLE	21-Jul-14	16:12	21-Jul-14	19:02	2.83		2.83
2014064	8	FCSTSUMM	7-Aug-14	12:52	7-Aug-14	18:56		6.07	6.07
2014067	4	FCSTSUMM	12-Aug-14	16:47	12-Aug-14	22:14		5.45	5.45
2014068	13	FCSTSUMM	14-Aug-14	7:33	14-Aug-14	13:30		5.95	5.95
2014072	13	FCSTSUMM	19-Sep-14	7:13	19-Sep-14	14:30		7.28	7.28
Totals of Unscheduled, Scheduled & Total Downtime							13.48	35.85	49.33

GENERAL NANUs

2014069 – Announced resumed transmission of L-band signal on PRN3/SVN35.

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2014052	30	UNUSUFN	3-Jul	12:11				2014054
2014053	10	FCSTDV	10-Jul	11:30	10-Jul	23:30	12	2014056
2014055	6	FCSTDV	17-Jul	9:30	17-Jul	21:30	12	2014057
2014058	19	UNUSUFN	21-Jul	16:12				2014059
2014061	8	FCSTDV	7-Aug	12:30	8-Aug	0:30	12	2014064
2014065	4	FCSTMX	12-Aug	16:00	13-Aug	4:00	12	2014067
2014066	13	FCSTDV	14-Aug	7:00	14-Aug	19:00	12	2014068
2014070	13	FCSTDV	19-Sep	7:00	19-Sep	19:00	12	2014072
					Total Forecasted Downtime		72	

Table 3-3 Cancelled NANUs

NANU#	PRN	Type	Start Date	Start Time	Comments
-	-	-	-	-	-

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-Apr-14 30-Jun-14	1-Jan-00 30-Jun-14
Total Forecast Downtime (hrs):	72	10248.82
Total Actual Downtime (hrs):	49.33	38304.96
Total Actual Scheduled Downtime (hrs):	35.85	5985.27
Total Actual Unscheduled Downtime (hrs):	13.48	32319.69
Total Satellite Observed MTTR (hrs):	6.17	48.3
Scheduled Satellite Observed MTTR (hrs):	5.98	9.56
Unscheduled Satellite Observed MTTR (hrs):	6.74	193.53
# Total Satellite Outages:	8	793
# Scheduled Satellite Outages:	6	626
# Unscheduled Satellite Outages:	2	167
Percent Operational -- Scheduled Downtime:	99.95	99.85
Percent Operational -- All Downtime:	99.93	99.04

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 July and 30 September 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	7948053	0	100%
Anchorage	7944668	0	100%
Atlanta	7948019	0	100%
Barrow	7947769	0	100%
Bethel	7945688	0	100%
Billings	7947944	0	100%
Boston	7947959	0	100%
Cleveland	7947959	0	100%
Cold Bay	7947923	0	100%
Fairbanks	7947931	0	100%
Gander	7936749	0	100%
Honolulu	7923213	0	100%
Houston	7946422	0	100%
Iqaluit	7942352	0	100%
Juneau	7939482	0	100%
Kansas City	7944820	0	100%
Kotzebue	7947759	0	100%
Los Angeles	7947839	0	100%
Merida	7942022	0	100%
Miami	7948036	0	100%
Minneapolis	7947949	0	100%
Oakland	7946854	0	100%
Salt Lake City	7947067	0	100%
San Jose Del Cabo	7237442	0	100%
San Juan	7946622	0	100%
Seattle	7945916	0	100%
Tapachula	7802108	0	100%
Washington, DC	7946290	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 26.053 meters on satellite PRN 12.

Table 4-0-1 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 Apr – 30 Jun 2014	**Boston**	66,753,985	0	100%
1 Apr – 30 Jun 2014	**Honolulu**	68,686,898	0	100%
1 Apr – 30 Jun 2014	**Los Angeles**	69,371,306	0	100%
1 Apr – 30 Jun 2014	**Miami**	66,125,051	0	100%
1 Apr – 30 Jun 2014	**Merida**	68,443,030	0	100%
1 Apr – 30 Jun 2014	**Juneau**	69,450,654	0	100%
1 Apr – 30 Jun 2014	**Global**	408,830,924	0	100%

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 July through 30 September 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	4.427	2.632	9.152	5.547
Anchorage	4.327	2.499	11.537	5.267
Atlanta	4.009	2.622	8.983	5.219
Barrow	4.482	2.393	11.731	4.073
Bethel	4.521	2.501	12.235	5.433
Billings	3.983	1.945	8.307	3.916
Boston	3.750	2.201	7.797	4.260
Cleveland	3.859	2.189	7.854	3.636
Cold Bay	4.598	2.027	12.210	4.560
Fairbanks	4.244	2.576	10.802	4.886
Gander	3.611	2.119	7.101	4.288
Honolulu	4.656	5.665	10.176	12.585
Houston	5.133	3.785	11.780	6.713
Iqaluit	3.914	2.215	8.430	4.158
Juneau	4.089	2.324	10.367	4.063
Kansas City	4.111	2.200	7.572	4.131
Kotzebue	4.484	2.763	11.184	4.884
Los Angeles	4.389	2.956	10.011	5.823
Merida	5.956	4.707	29.289	13.030
Miami	4.601	3.792	12.144	7.525
Minneapolis	3.993	2.010	8.131	3.495
Oakland	4.282	2.575	11.174	4.755
Salt Lake City	4.102	2.080	8.260	3.766
San Jose Del Cabo	6.344	4.777	19.566	12.460
San Juan	5.160	3.909	15.318	16.330
Seattle	4.187	1.862	9.634	3.563
Tapachula	6.657	5.384	22.583	12.428
Washington, DC	3.806	2.214	7.672	4.163

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-eight WAAS sites from 1 July to 30 September 2014.

Figure 5-1 Global Vertical Error Histogram

Vertical Position Error Histogram: 1 July - 30 September 2014

<- 95% Vertical Error
(4.457 m)

Number of Samples

Vertical Position Error (Meters)
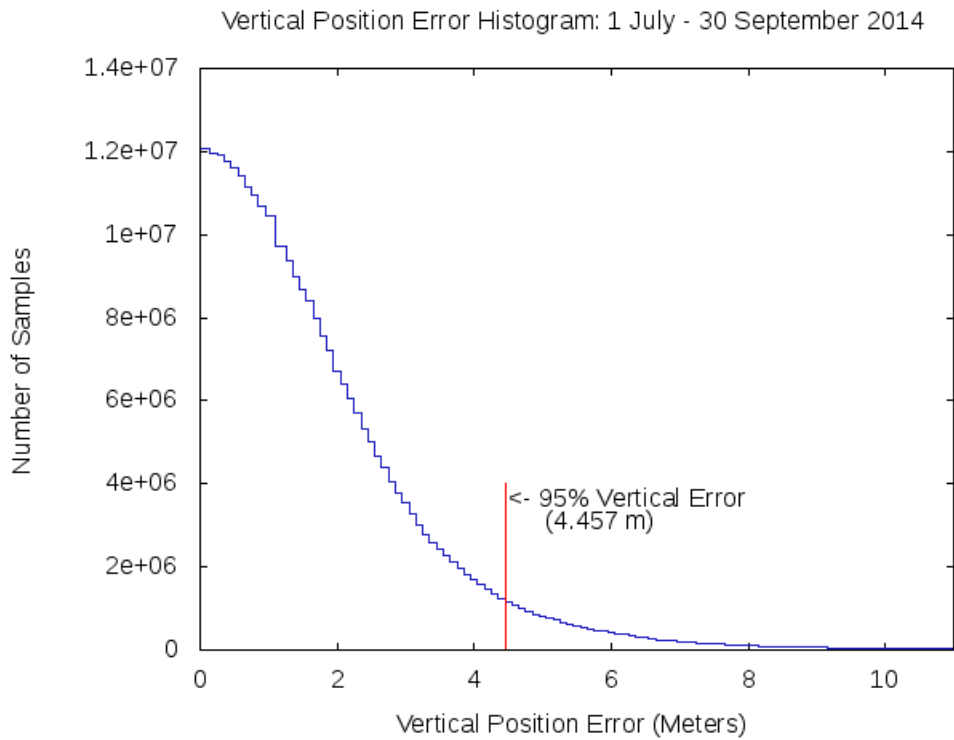
Figure 5-2 Global Horizontal Error Histogram

Horizontal Position Error Histogram: 1 July - 30 September 2014

<- 95% Horizontal Error
(2.849 m)

Number of Samples

Horizontal Position Error (Meters)

22
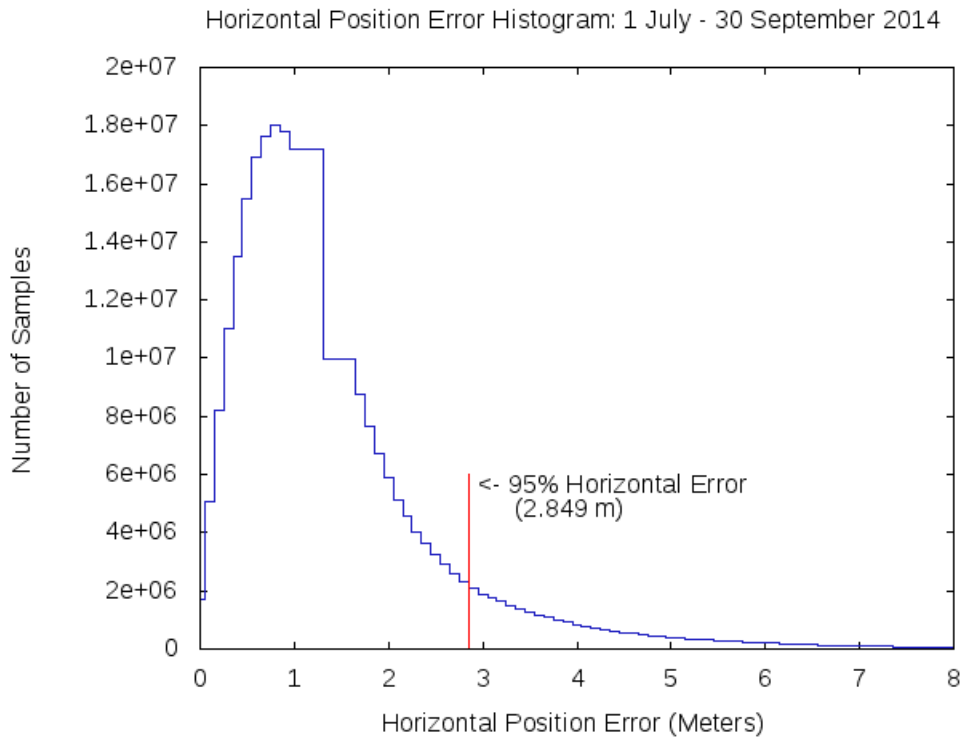
5.2   Time Transfer Accuracy

The GPS time error data between 1 July and 30 September 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 maximum instantaneous UTC offset error (UTCOE) for the quarter was 60.2 nanoseconds. The mean, standard deviation and 95% index of Time Transfer Error, and the maximum UTCOE are all within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Error
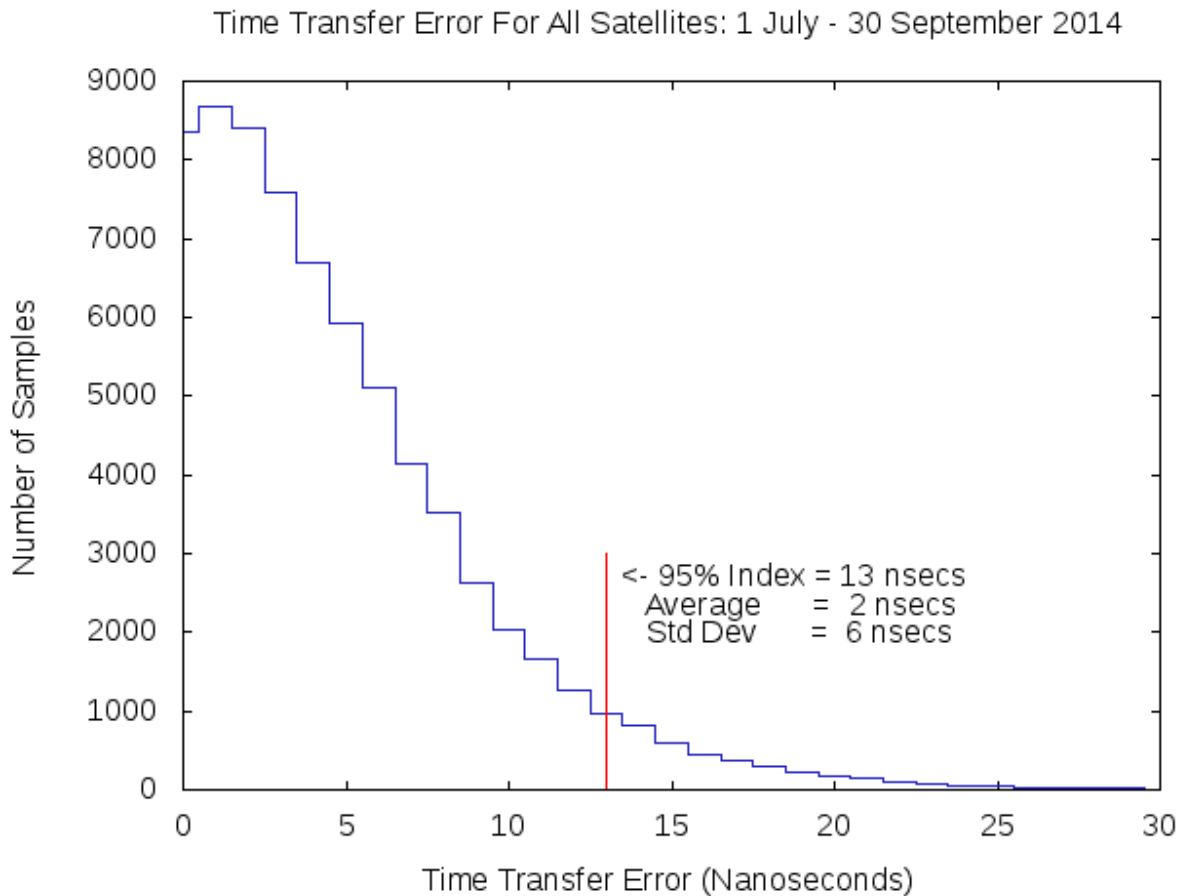
5.3   Range Domain Accuracy

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 July and 30 September 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	1.912	-0.850	1.501	3.792	13.700	13745663
2	1.905	-0.054	1.596	3.638	19.431	14630756
3	1.993	-0.350	1.536	3.478	13.830	4428846
4	2.174	-0.697	1.674	3.941	15.578	12682607
5	2.144	-0.680	1.858	3.897	21.857	13740714
6	2.296	-1.313	1.663	4.162	17.267	13829686
7	1.727	-0.546	1.423	3.269	23.565	12672544
8	2.141	-0.034	1.631	3.928	22.585	12898477
9	2.138	-1.040	1.694	4.217	16.770	1901824
10	2.307	0.681	1.728	4.231	17.345	12326910
11	1.802	0.001	1.451	3.466	19.665	12692005
12	2.006	-0.646	1.720	3.875	26.053	14213855
13	1.607	-0.016	1.429	3.211	20.559	12828057
14	1.772	0.430	1.493	3.422	22.015	14475174
15	1.692	-0.332	1.394	3.164	23.782	12821642
16	1.685	0.166	1.458	3.103	19.184	13298746
17	2.243	-0.992	1.723	4.130	16.639	14481842
18	1.857	0.193	1.511	3.390	15.471	13647336
19	1.883	0.529	1.533	3.569	18.712	12280963
20	1.811	0.376	1.605	3.482	20.207	14369043
21	1.904	0.047	1.542	3.442	12.738	13044800
22	2.129	0.912	1.475	3.764	16.002	12877483
23	1.522	0.180	1.334	3.040	19.936	12869167
24	2.051	-0.617	1.687	3.999	17.943	14116151
25	1.778	-0.218	1.601	3.560	26.038	14428888
26	1.698	-0.271	1.451	3.237	19.287	13518387
27	1.799	-0.296	1.577	3.548	20.887	13233333
28	2.110	-0.008	1.562	3.891	19.139	13688611
29	1.982	-0.735	1.613	3.634	24.115	13383431
30	1.625	-0.157	1.365	3.126	22.422	12608870
31	1.592	-0.239	1.414	3.149	17.183	14014258
32	1.807	0.695	1.376	3.494	17.346	13080855

Table 5-3 Range Rate Error Statistics

(Millimeters/ Second)

PRN	Range Rate Error RMS	95% Range Rate Error	Max Range Rate Error	Samples
1	3.048	3.514	241.640	13745663
2	3.446	4.334	212.010	14630756
3	3.335	3.814	199.500	4428846
4	3.401	3.885	218.330	12682607
5	3.366	4.229	201.700	13740714
6	3.439	4.051	221.200	13829686
7	2.672	3.569	192.650	12672544
8	3.089	3.781	212.960	12898477
9	2.590	3.369	128.700	1901824
10	3.564	4.171	273.000	12326910
11	3.080	3.648	231.850	12692005
12	3.487	4.345	213.810	14213855
13	2.561	3.469	209.690	12828057
14	2.360	3.387	267.990	14475174
15	2.835	3.840	200.560	12821642
16	2.865	3.472	180.030	13298746
17	3.442	4.309	207.350	14481842
18	2.498	3.566	212.390	13647336
19	2.928	3.635	253.710	12280963
20	2.999	3.699	230.890	14369043
21	2.987	3.958	274.750	13044800
22	2.385	3.366	217.460	12877483
23	2.259	3.207	213.360	12869167
24	3.679	4.135	300.230	14116151
25	3.382	3.980	280.620	14428888
26	3.298	3.844	280.760	13518387
27	2.802	3.479	185.160	13233333
28	3.355	4.006	196.460	13688611
29	3.324	4.120	239.630	13383431
30	2.737	3.605	195.710	12608870
31	2.592	3.261	216.490	14014258
32	2.458	3.093	285.170	13080855

Table 5-4 Range Acceleration Error Statistics

(Micrometers/Second^2)

PRN	Range Acceleration Error RMS ($\mu m/s^2$)	95% Range Acceleration Error ($\mu m/s^2$)	Max Range Acceleration Error ($\mu m/s^2$)	Samples
1	26.119	32.068	2410	13745663
2	29.404	38.540	2090	14630756
3	29.267	36.402	2000	4428846
4	29.318	36.690	2190	12682607
5	28.453	36.460	2010	13740714
6	29.484	38.264	2200	13829686
7	22.421	30.572	1930	12672544
8	25.903	32.111	2140	12898477
9	20.779	25.321	1250	1901824
10	29.934	38.174	2720	12326910
11	26.519	34.318	2320	12692005
12	29.797	38.121	2100	14213855
13	20.918	28.362	2140	12828057
14	18.871	26.634	2650	14475174
15	23.506	32.369	1980	12821642
16	24.707	31.302	1800	13298746
17	29.651	40.013	2070	14481842
18	20.568	29.079	2120	13647336
19	25.239	31.971	2530	12280963
20	25.546	32.639	2330	14369043
21	25.297	34.159	2760	13044800
22	19.410	26.307	2150	12877483
23	17.919	26.161	2080	12869167
24	31.883	36.733	2990	14116151
25	28.807	34.743	2800	14428888
26	28.397	34.198	2800	13518387
27	23.705	29.463	1860	13233333
28	28.975	38.281	1980	13688611
29	28.546	36.719	2390	13383431
30	22.665	31.103	1950	12608870
31	21.881	27.345	2130	14014258
32	20.429	25.408	2830	13080855

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 12 with an error of 26.053 meters. Satellite 21 had the lowest maximum range error of 12.738 meters.

Figure 5-4 Distribution of Daily Max Range Errors

Daily Max Range Error Histogram: 1 July - 30 September 2014
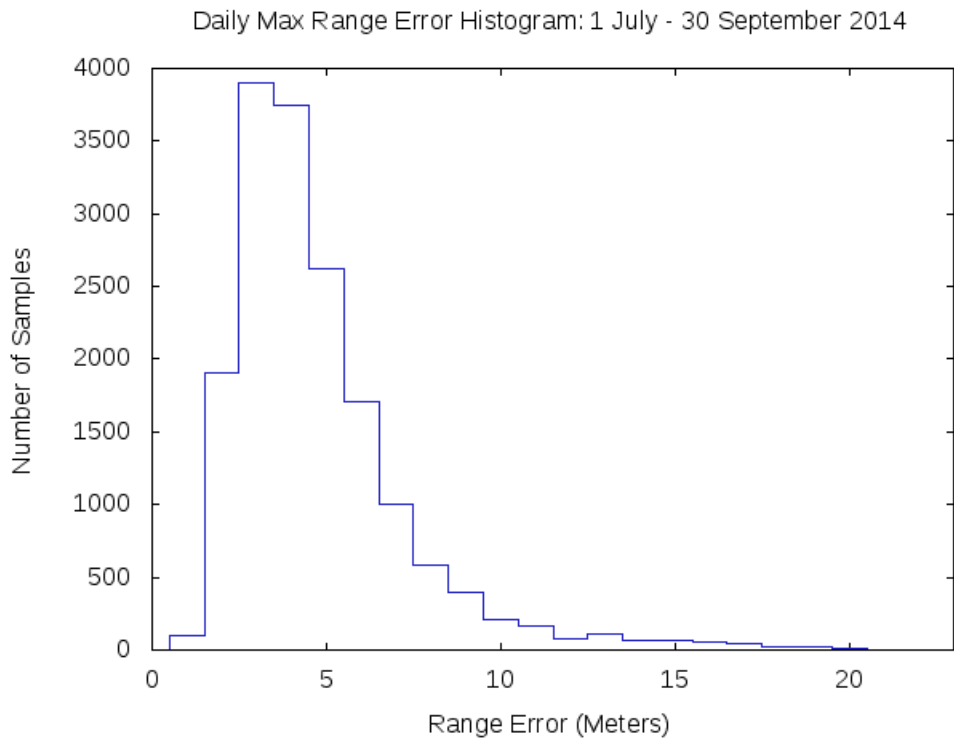
Figure 5-5 Distribution of Daily Max Range Rate Errors

Daily Max Range Rate Error Histogram: 1 July - 30 September 2014
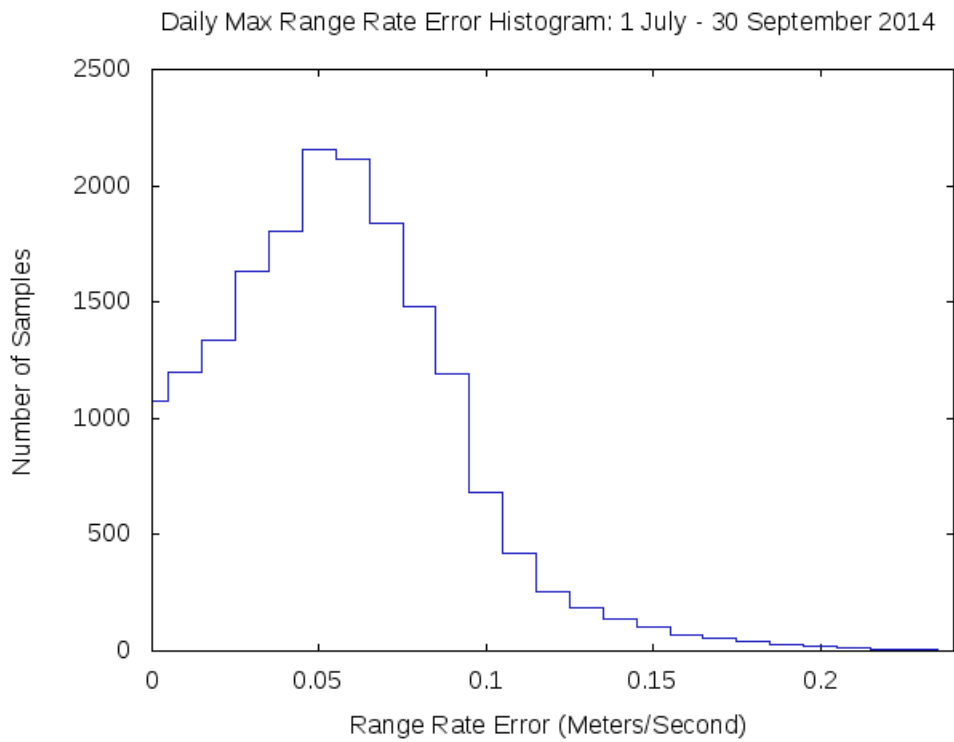
Figure 5-6 Distribution of Daily max Range Acceleration Errors

Daily Max Range Acceleration Error Histogram: 1 July - 30 September 2014
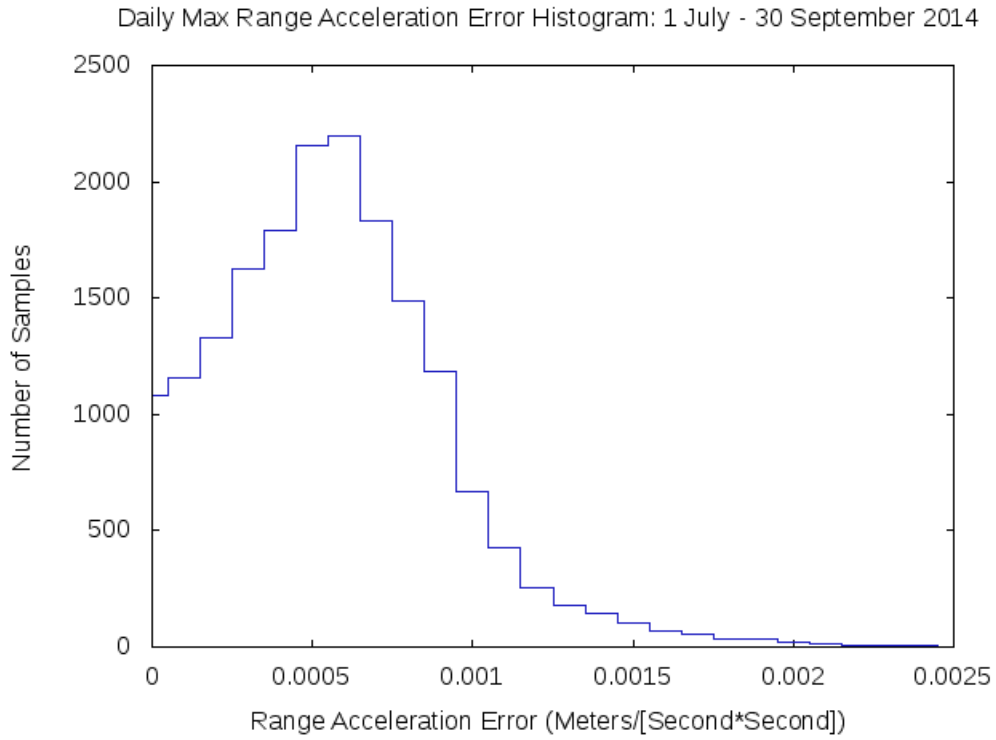
Figure 5-7 Range Error Histogram

Range Error Histogram: 1 July - 30 September 2014
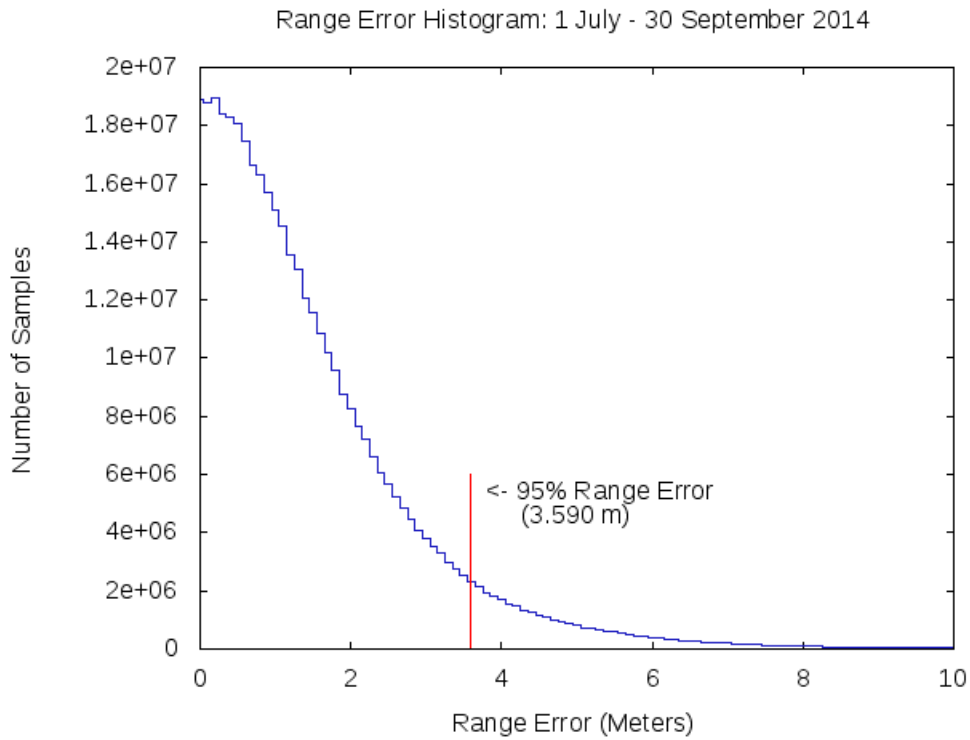
Figure 5-8 Maximum Range Error Per Satellite
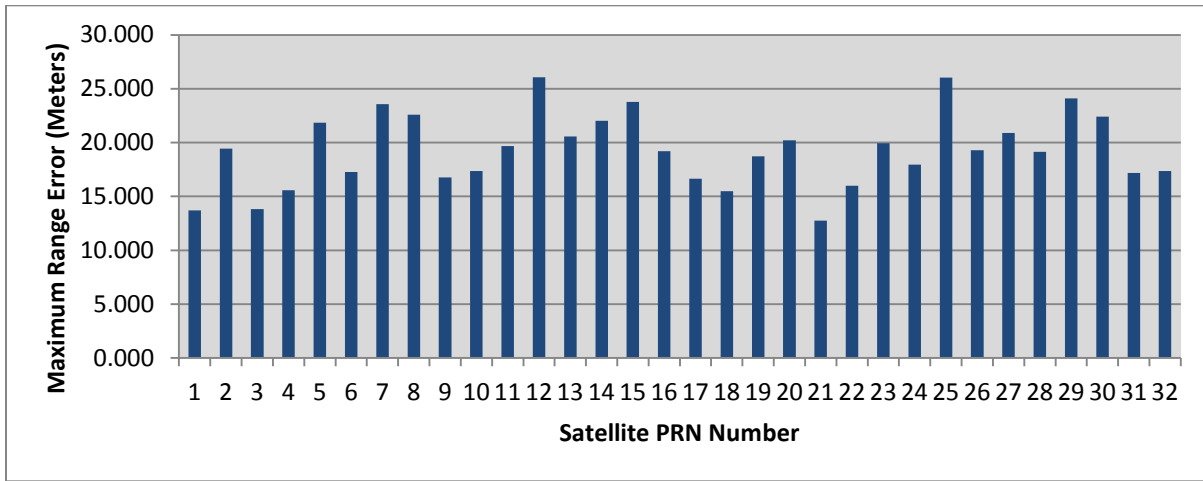
Figure 5-9 Maximum Range Rate Error Per Satellite
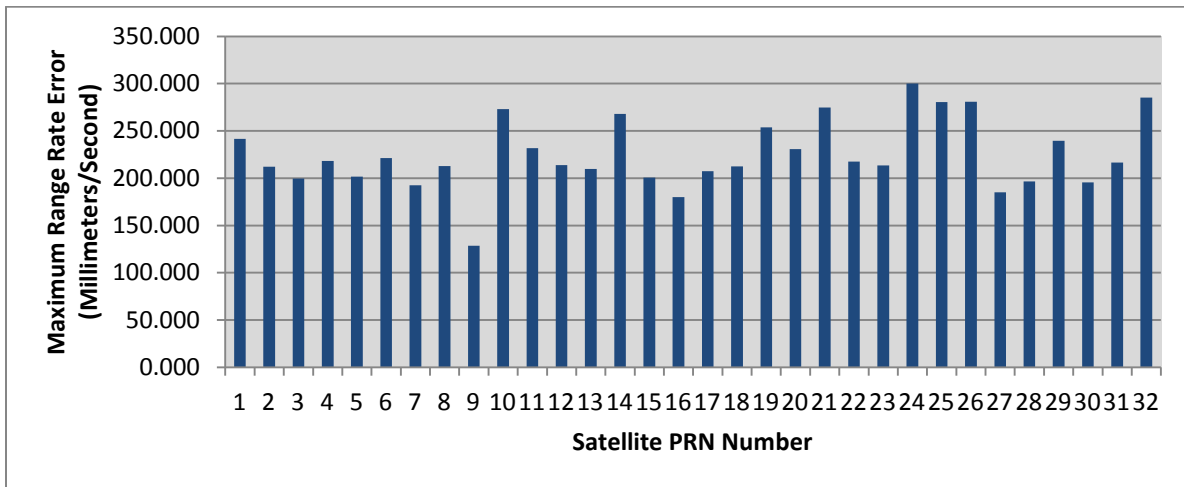
Figure 5-10 Maximum Range Acceleration Error Per Satellite
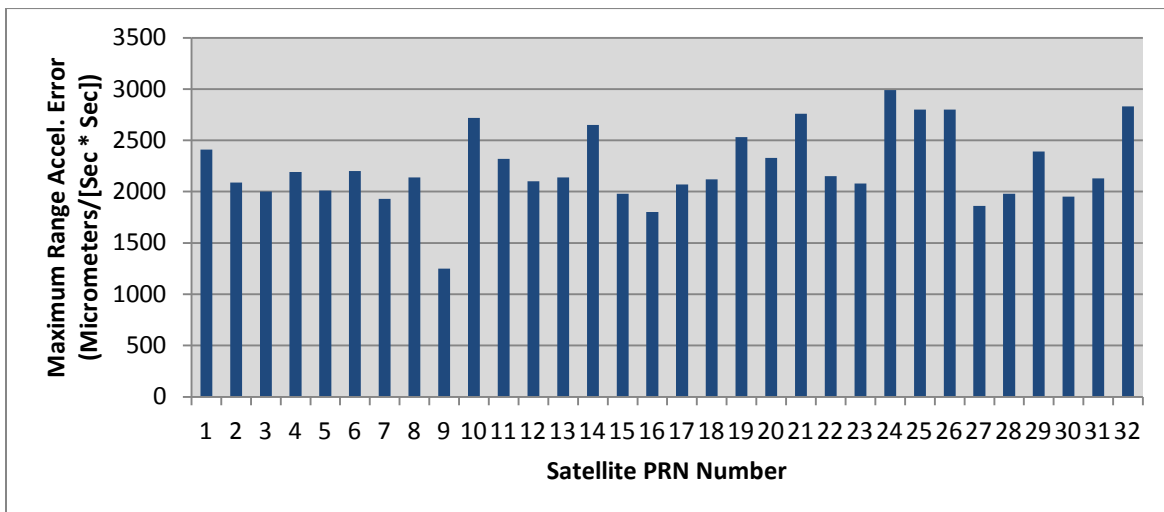
6   Solar Storms

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 11-13 September 2014
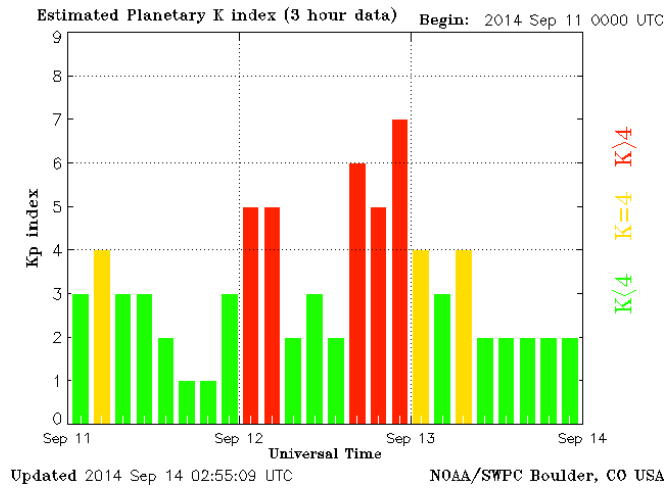
Figure 6-2 K-Index for 18-20 August 2014
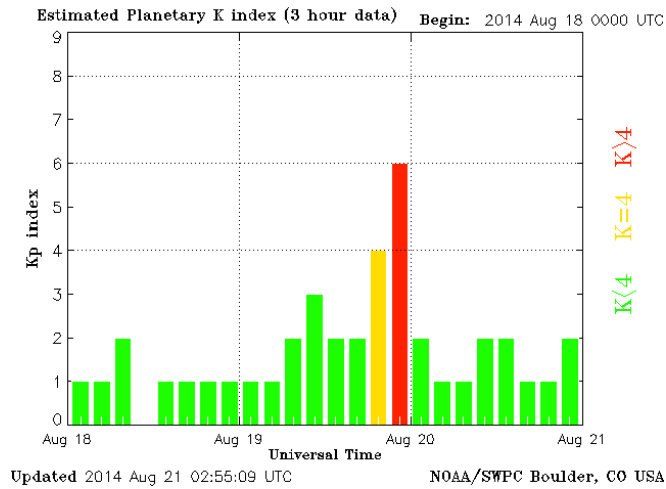
Figure 6-3 K-Index for 27-29 August 2014

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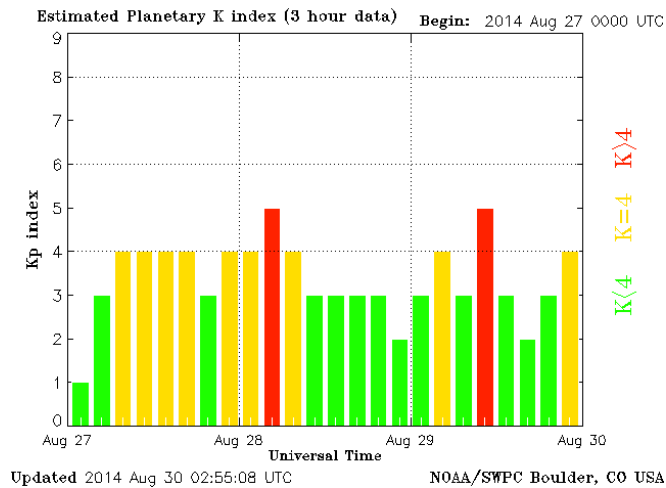
Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for September 12, 2014

Site	95% Horizontal (Meters)	95% Vertical (Meters)	Maximum Horizontal (Meters)	Maximum Vertical (Meters)
Albuquerque	2.323	5.116	2.874	6.225
Anchorage	2.418	4.149	3.932	5.796
Atlanta	2.517	3.112	3.654	4.736
Barrow	2.261	3.983	3.697	6.483
Bethel	2.607	5.376	3.653	7.152
Billings	3.049	4.240	4.093	6.050
Boston	3.068	2.853	4.341	5.777
Cleveland	2.513	2.866	2.870	5.544
Cold Bay	1.685	6.418	2.759	8.835
Fairbanks	2.310	4.200	4.699	6.681
Gander	2.686	2.636	4.899	3.382
Honolulu	5.371	3.511	6.477	5.102
Houston	2.510	3.314	3.499	5.019
Iqaluit	2.103	2.782	2.755	4.024
Juneau	2.049	3.809	3.631	5.544
Kansas City	3.004	3.573	3.564	5.495
Kotzebue	2.541	4.594	4.793	7.033
Los Angeles	1.939	5.485	3.070	5.937
Merida	4.163	5.600	6.186	12.174
Miami	3.022	3.391	4.103	5.153
Minneapolis	2.621	3.537	3.546	5.589
Oakland	2.273	5.655	2.846	6.420
Salt Lake City	2.682	5.151	3.379	7.075
San Jose Del Cabo	3.809	6.250	5.861	8.297
San Juan	2.890	3.885	3.589	6.761
Seattle	1.824	4.433	2.419	5.659
Tapachula	5.831	7.922	7.966	15.860
Washington, DC	2.256	2.406	2.813	4.279

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. Sites with high data rate (1 Hz) with good availability which are outside of the WAAS service area that also provide 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. These issues cause the outliers seen in the 99.99% statistics and are visible in the 95% accuracy trend plots. Examples of outliers in the 99.99% statistics are shown in Figure 7-4 and 7-5.   The POL2 site appears to have noisy tracking due to receiver or local environment issues. The UNSA site appears to have poor tracking due to scintillation from equatorial ionosphere. The UNSA issues increased towards the end of the quarter which coincides with the seasonal variations in the ionosphere. For this report small durations of data were removed (edited) for several sites where very short receiver glitches / tracking problems were observed. Table 7-3 contains the list of those edits. Figure 7-6 and 7-7 show examples of the data before the edits. High quality broadcast navigation data and Klobuchar 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.   The Russian Federation sites were unavailable for this reporting period. 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. The ramping error in the trend plots for the equatorial sites is due to seasonal variations in the ionosphere that cannot be corrected by the Klobuchar thin shell model of the ionosphere utilized by single frequency GPS SPS receivers.

(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

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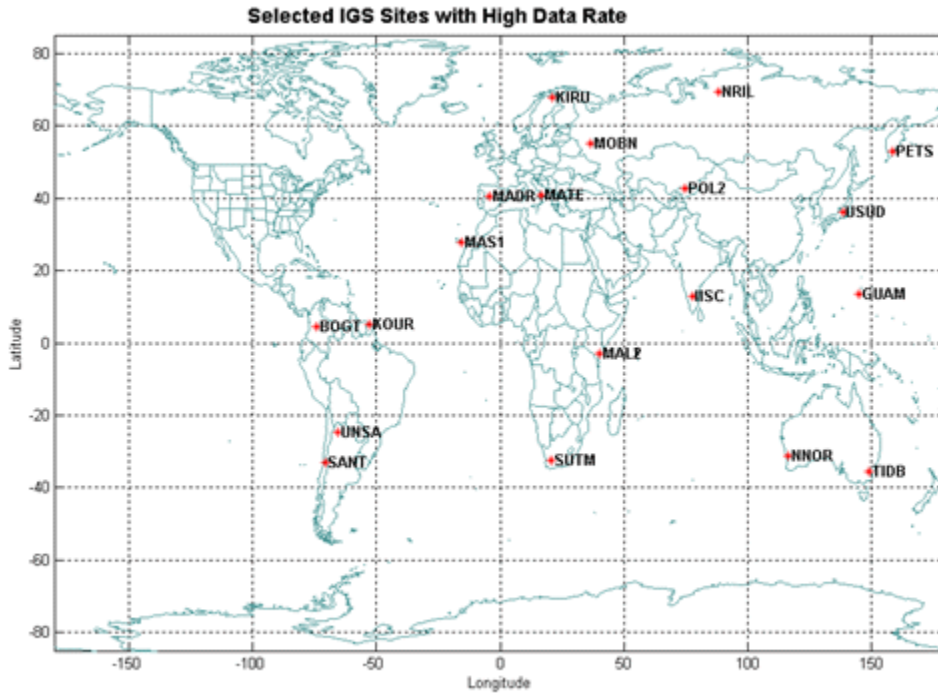
Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

Site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
BOGT	4.63	6.76	15.01	21.79	99.07%
GLPS	3.85	5.86	16.96	33.15	73.02%
GUAM	3.17	7.73	7.32	14.43	99.96%
IISC	2.56	7.66	5.86	15.11	67.80%
KIRU	2.19	3.99	5.01	9.79	100.00%
KOUR	4.16	5.46	12.30	16.26	100.00%
MAL2	3.25	4.47	10.40	17.96	98.46%
MAS1	4.16	5.77	10.24	13.40	99.43%
MATE	7.98	6.34	13.00	18.80	99.98%
MOBN	3.05	4.25	8.46	14.78	54.27%
NNOR	2.05	3.99	4.43	9.67	98.94%
NRIL	2.76	5.28	11.51	28.17	92.43%
PETS	2.10	3.97	4.65	7.30	95.86%
POL2	2.31	3.96	4.44	8.35	99.99%
SANT	5.28	7.47	18.66	46.65	97.40%
SUTM	3.76	4.92	11.39	17.37	78.70%
TIDB	4.63	6.76	15.01	21.79	99.07%
UNSA	3.85	5.86	16.96	33.15	73.02%
USUD	3.17	7.73	7.32	14.43	99.96%

Figure 7-2 GPS SPS 95% Horizontal Accuracy Trends at Selected IGS Sites
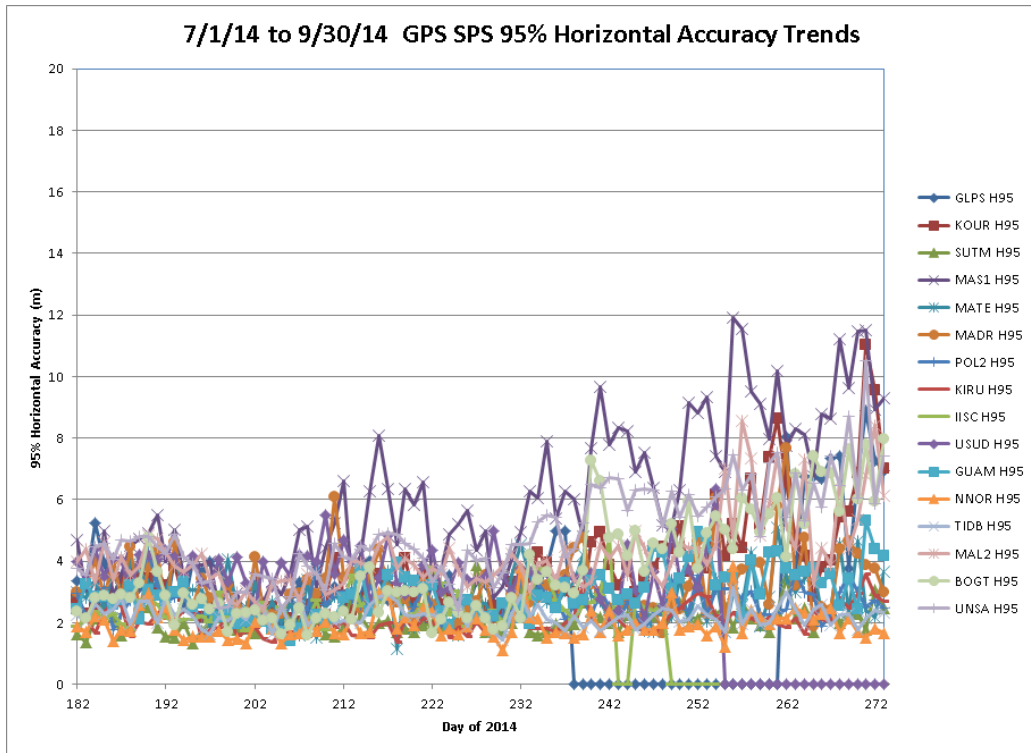
Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites

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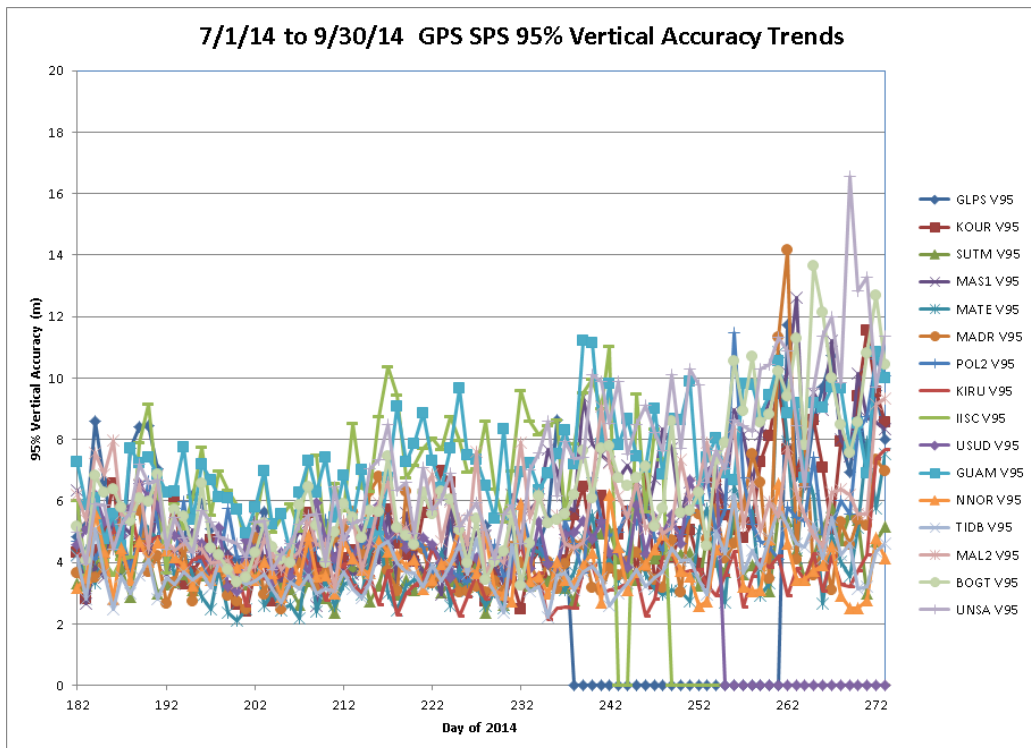
Figure 7-4 Example of Suspect Receiver Track Issues for POL2
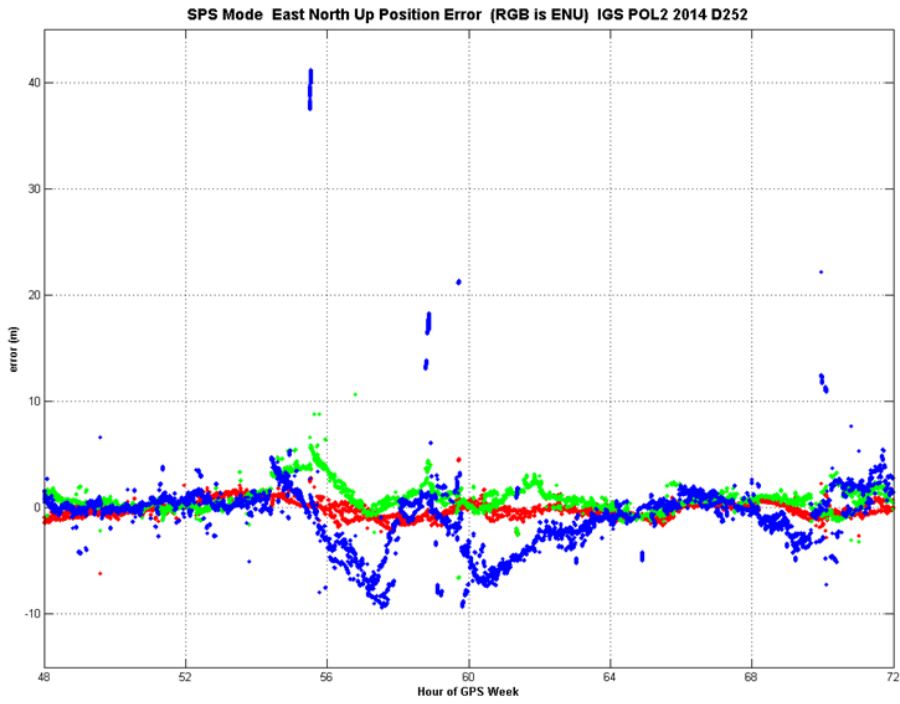
Figure 7-5 Example of Suspect Daily Scintillation Issues for UNSA
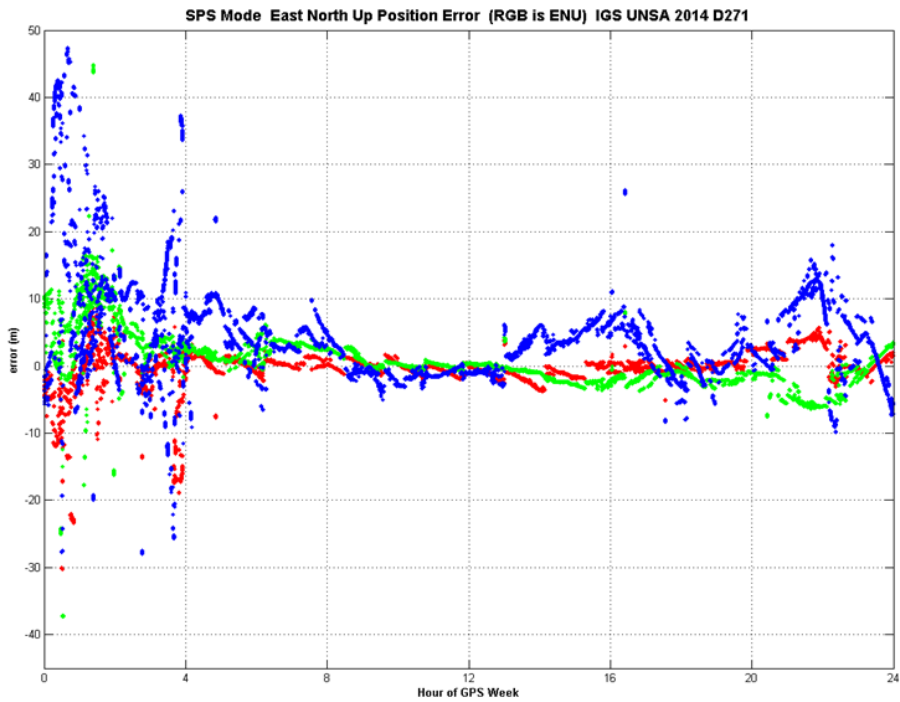
Table 7-3 Edited Data Points

Site	Day of 2014	GPS Week& Day	Edit Start GPS Week Sec	Edit End GPS Week Sec
MADR	D184	w1799d4	365345	365453
MADR	D186	w1799d6	602449	602983
USUD	D230	w1806d1	107820	108062
USUD	D231	w1806d2	194138	194308
MADR	D239	w1807d3	287306	287367
MADR	D240	w1807d4	373459	373615
MADR	D241	w1807d5	459608	459760
MADR	D242	w1807d6	545751	545804
MADR	D243	w1808d0	27106	27157
MADR	D246	w1808d3	285559	285612
MATE	D246	w1808d3	300875	324218

Figure 7-6 Example of Edited Data, MADR D246
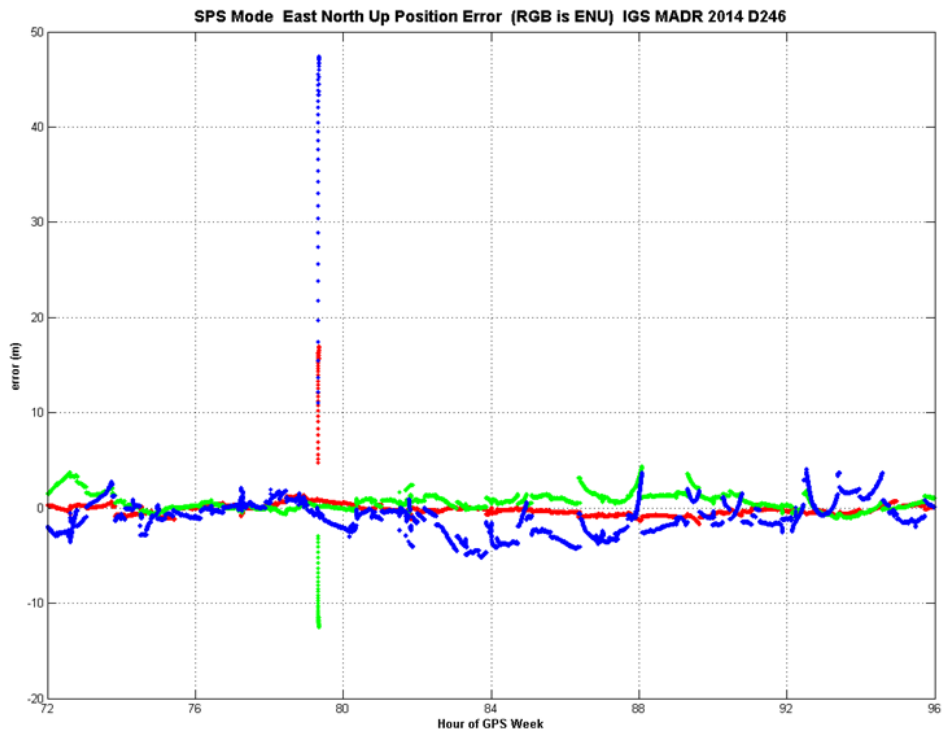
Figure 7-7 Example of Edited Data, MATE D246
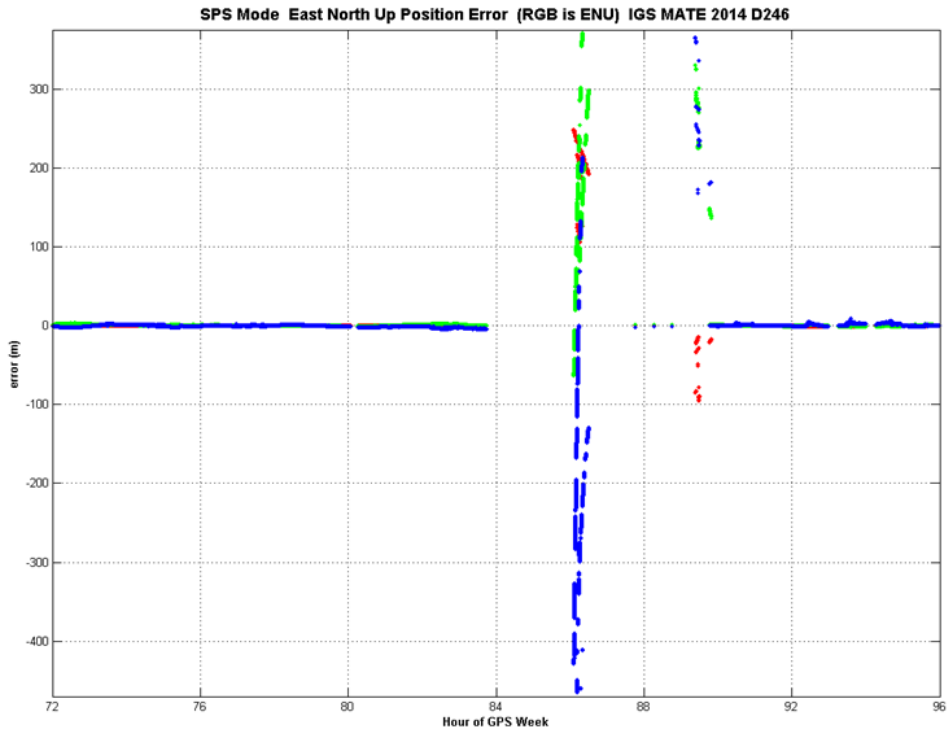
8   RAIM Performance

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 98.89% at Boston, Massachusetts. The minimum percent of time spent in RNP 0.3 mode was 100% at all sites. The maximum 99% HPL value was 197.03 meters at Boston, Massachusetts.

Table 8-1 RAIM Site Statistics

CITY	99% HPL	Percent RNP 0.1	Percent RNP 0.3
Albuquerque	117.961	100	100
Anchorage	141.586	100	100
Atlanta	142.432	99.44	100
Barrow	156.906	99.67	100
Bethel	162.254	100	100
Billings	124.272	100	100
Boston	197.031	98.89	100
Cleveland	169.703	100	100
Cold Bay	150.23	99.56	100
Fairbanks	137.305	99.90	100
Gander	140.079	100	100
Honolulu	145.979	99.99	100
Iqaluit	106.552	99.12	100
Juneau	154.149	100	100
Kansas City	129.866	99.86	100
Kotzebue	146.512	100	100
Los Angeles	139.625	99.48	100
Merida	122.995	99.83	100
Miami	92.925	99.99	100
Minneapolis	98.258	100	100
Oakland	147.106	99.99	100
Salt Lake City	130.434	99.94	100
San Jose Del Cabo	136.317	100	100
San Juan	100.961	99.71	100
Seattle	86.625	100	100
Tapachula	121.462	100	100
Washington DC	85.791	100	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 July and 30 September 2014.

Figure 8-1 RAIM RNP 0.1 Coverage

SPS RAIM RNP 0.1 (HAL = 185m) Availability
FD Only, SA Off, without Baro-Aiding
July 1 – September 30, 2014
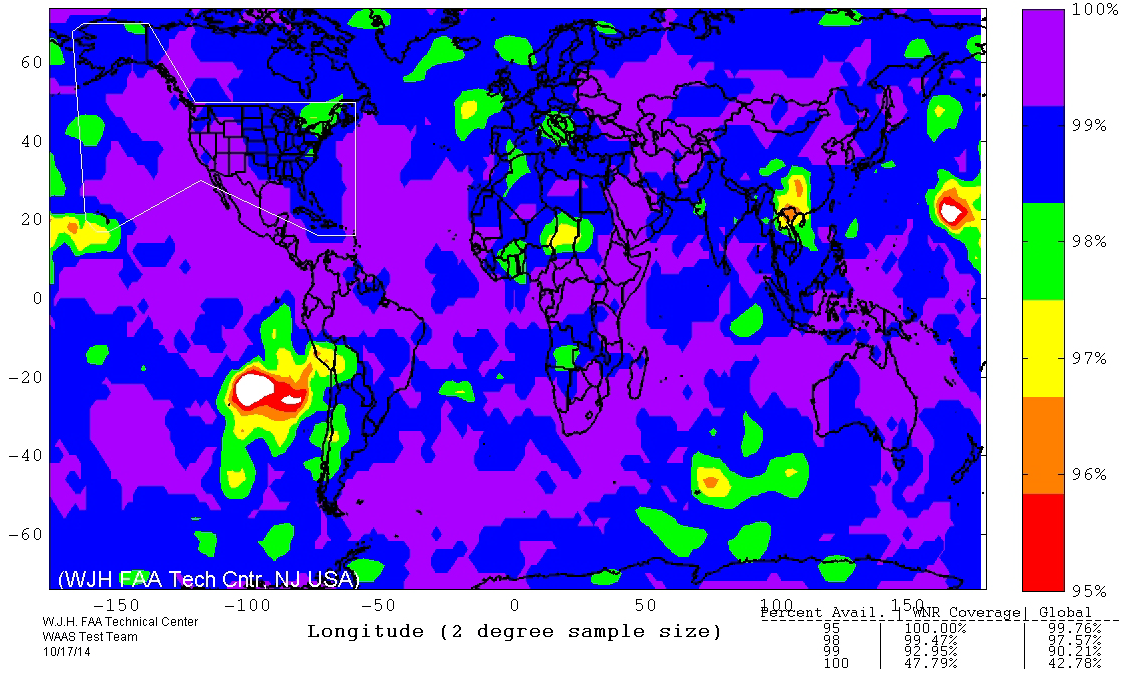
Figure 8-2 RAIM RNP 0.3 Coverage

SPS RAIM RNP 0.3 (HAL = 556m) Availability
FD Only, SA Off, without Baro-Aiding
July 1 – September 30, 2014

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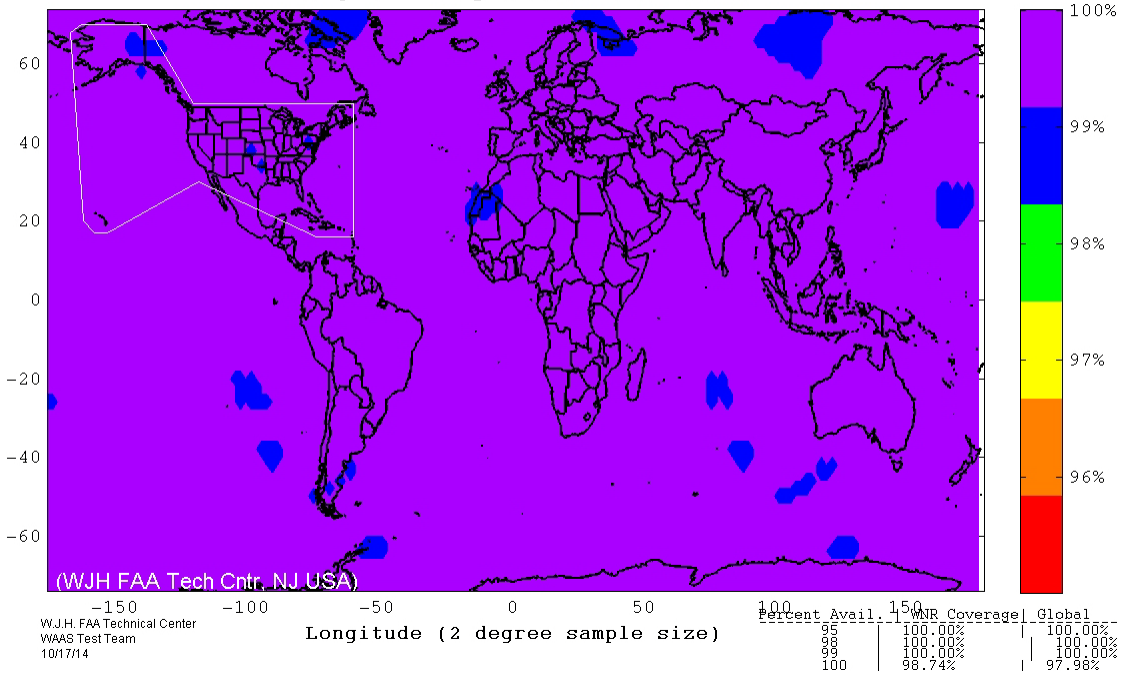
Figure 8-3 RAIM World Wide Coverage Trend
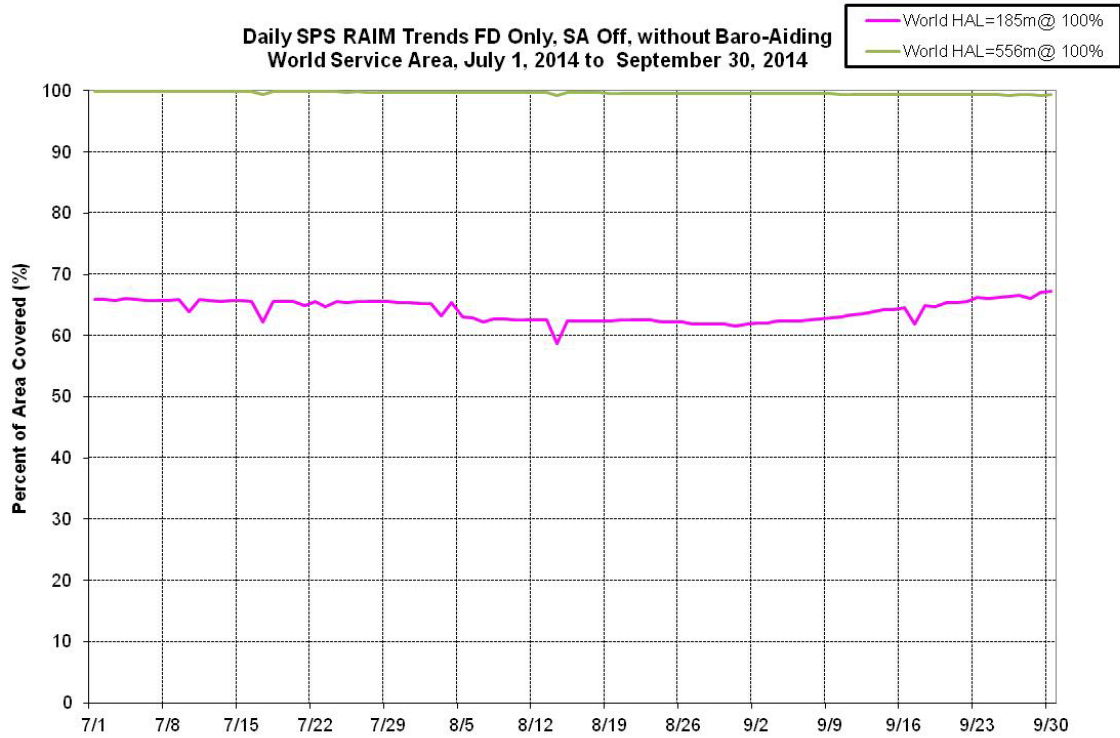
Figure 8-4 RAIM RNP Coverage Trend for WAAS NPA Service Area
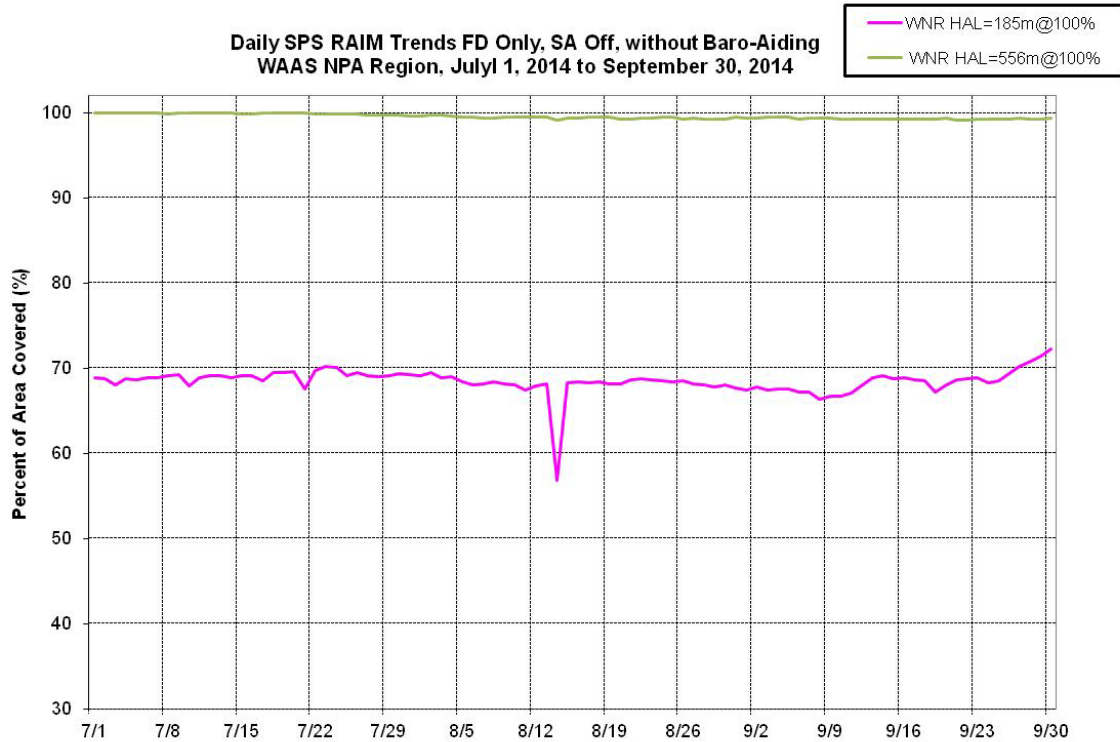
8.3   RAIM Airport Analysis

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
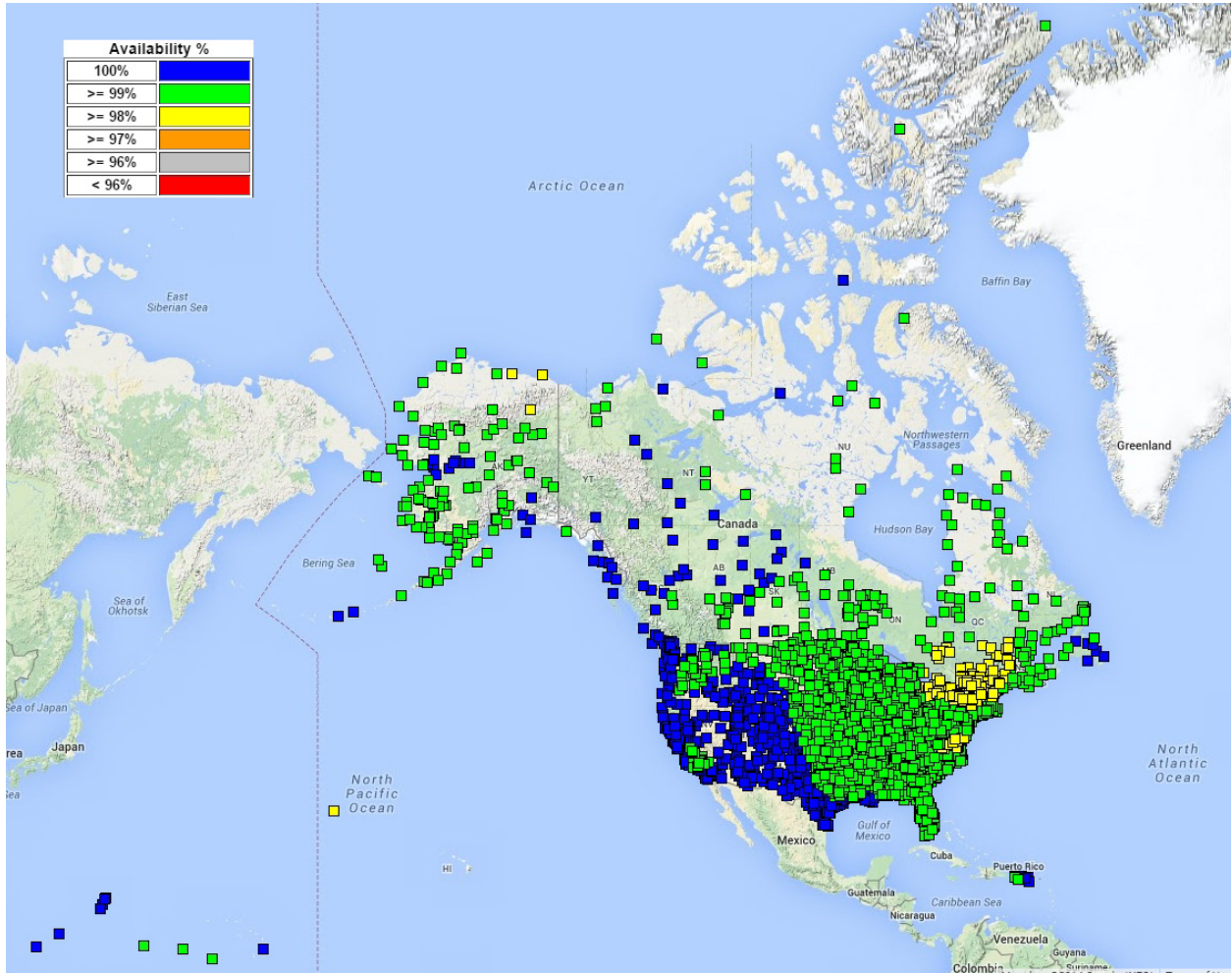
Figure 8-6 RAIM RNP 0.3 Airport Availability
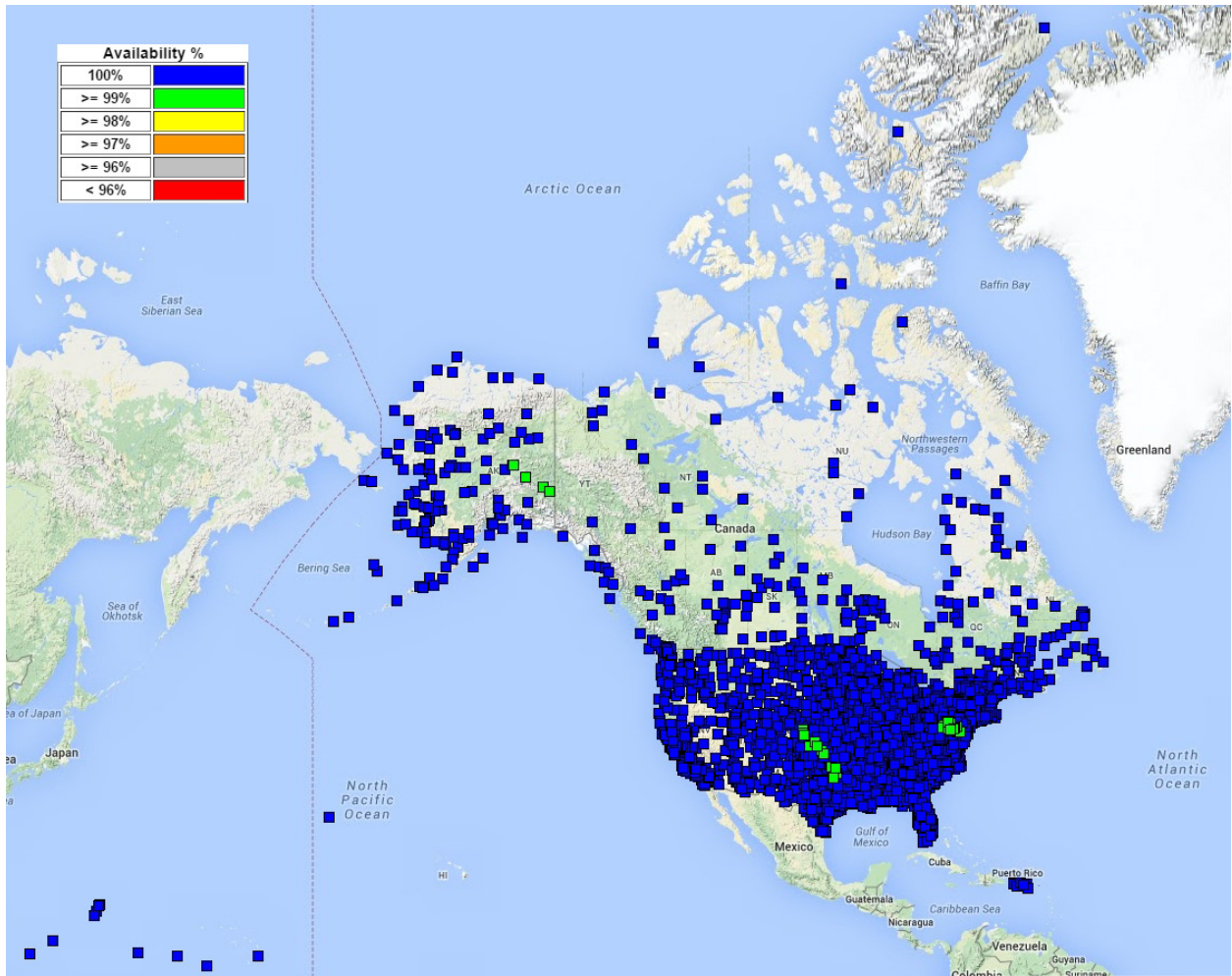
Figures 8-7 and 8-8 respectively show the number of RAIM RNP 0.1 and RAIM RNP 0.3 outages for every airport in the U.S. and Canada that have a RNAV (GPS) published approach or better.

Figure 8-7 RAIM RNP 0.1 Airport Outages
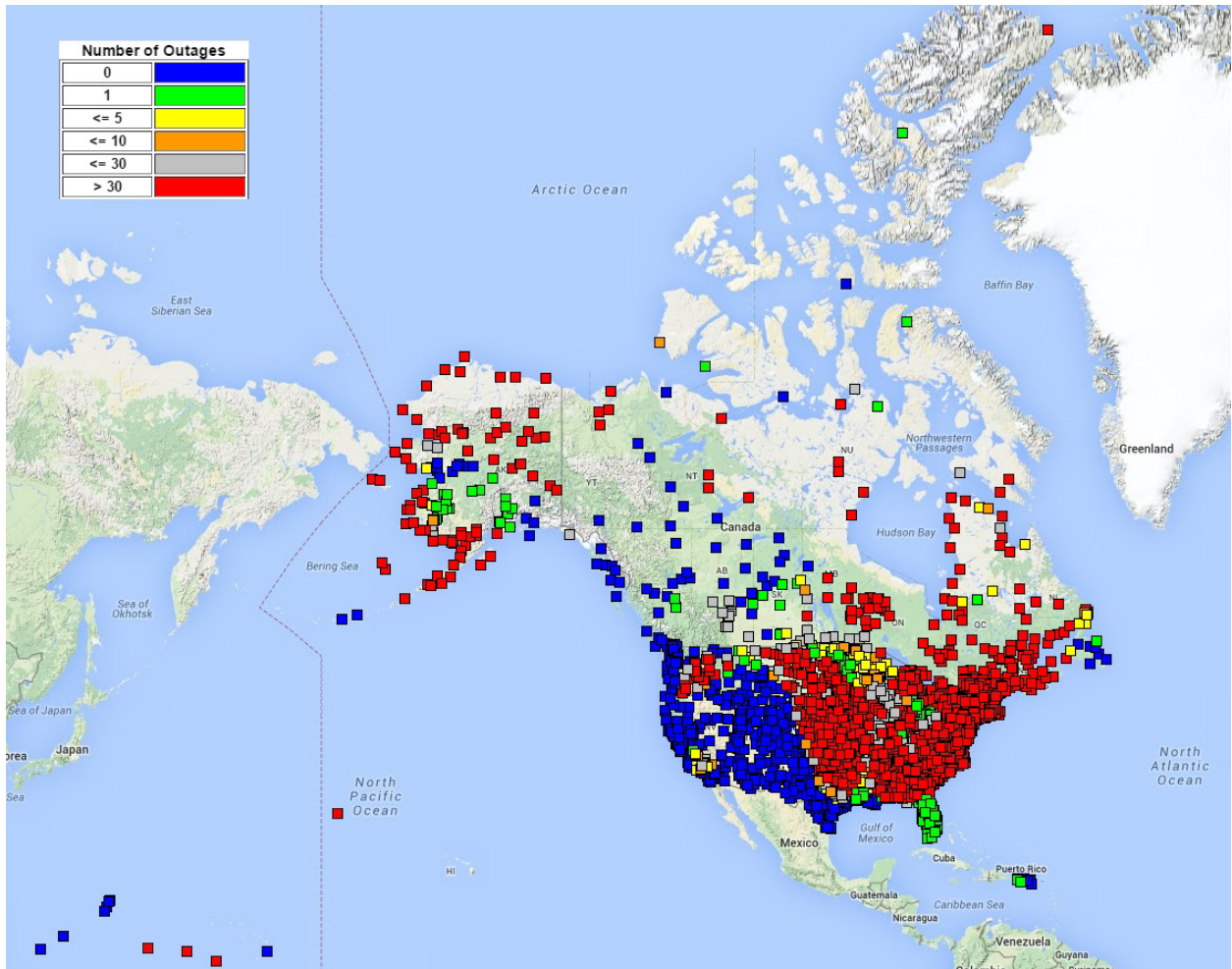
Figure 8-8 RAIM RNP 0.3 Airport Outages
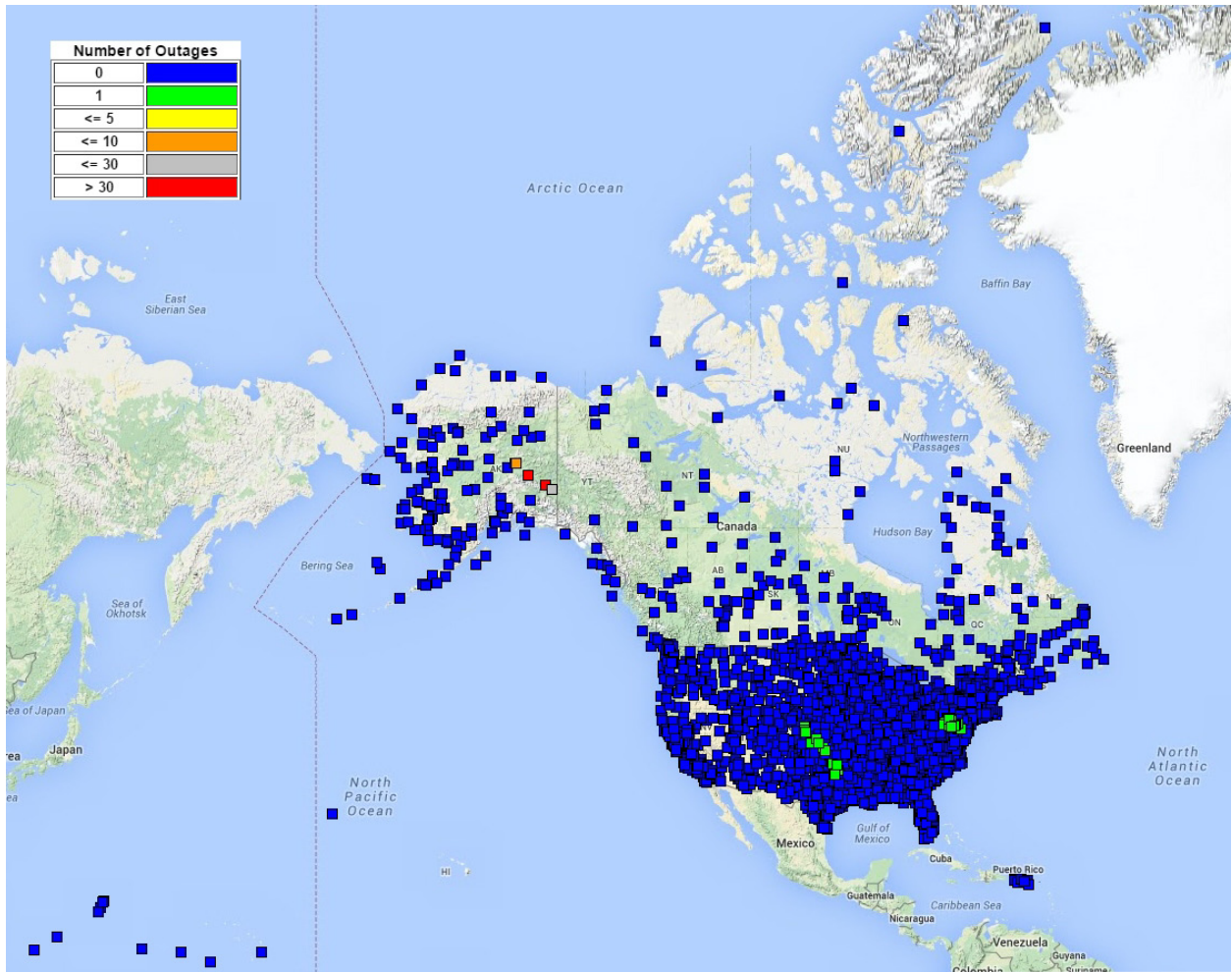
9   GPS Test NOTAMs Summary

> **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 July through 30 September 2014, there
were a total of 46 GPS test NOTAMs. The total number of days affected in this reporting period is 63. 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	211.85 hours
Minimum Duration	0.67 hours
Average Duration	4.61 hours
Maximum Duration	20.25 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	194,107	125,960	50,341	47,632	22,171
Average	572,425	444,993	264,885	235,385	160,775
Maximum	1,222,173	1,056,806	835,007	699,362	623,097

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
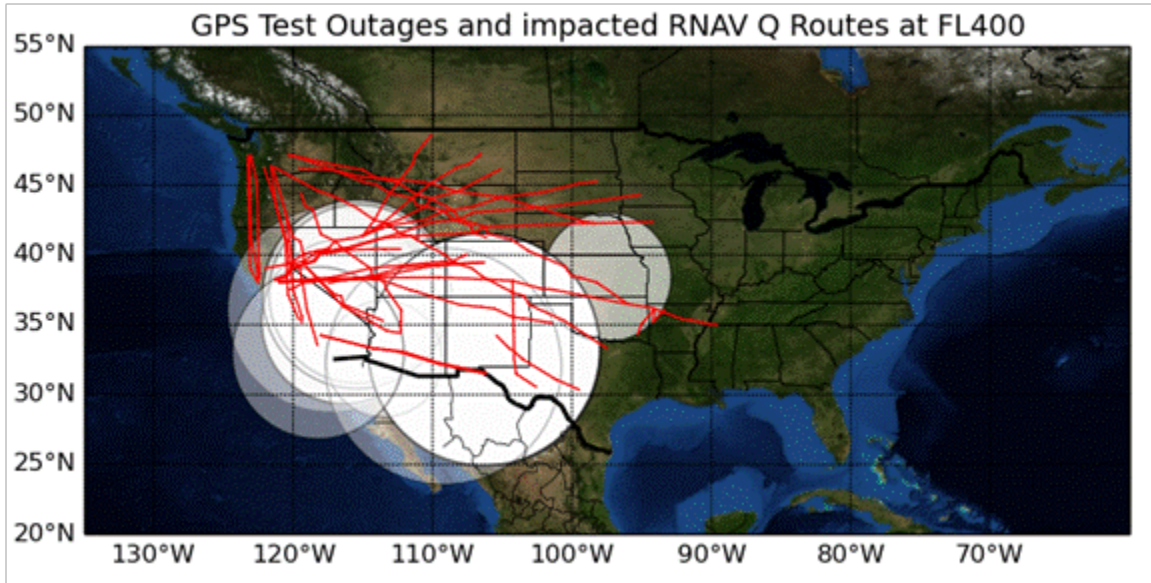
Figure 9-2 GPS NOTAMs @ FL250

Figure 9-3 GPS NOTAMs @ 10k Feet

Figure 9-4 GPS NOTAMs @ 4k Feet

Figure 9-5 GPS NOTAMs @ 50 Feet

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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.

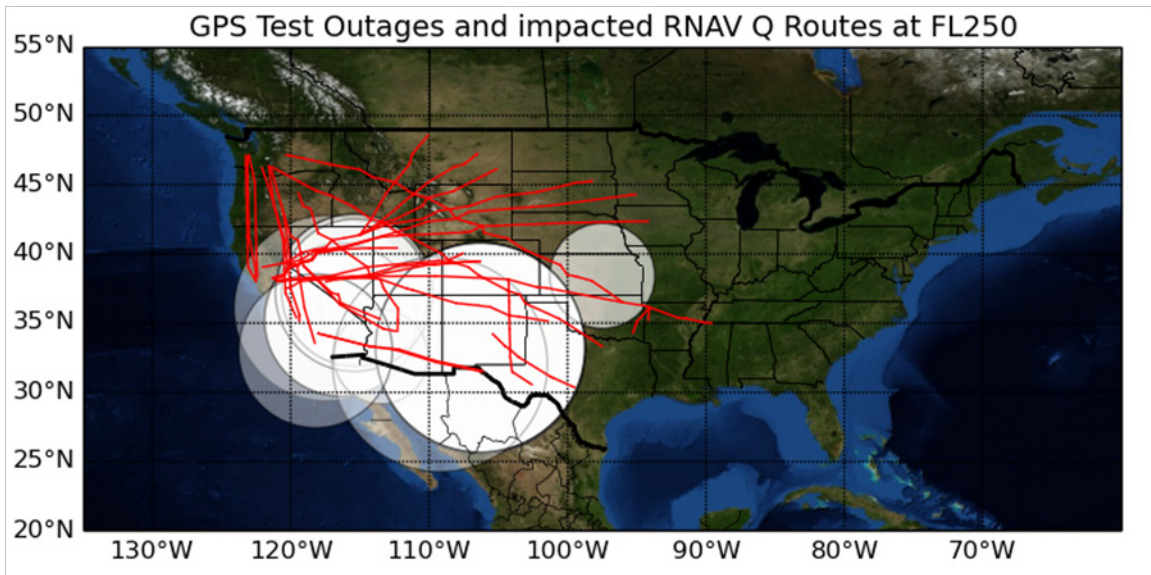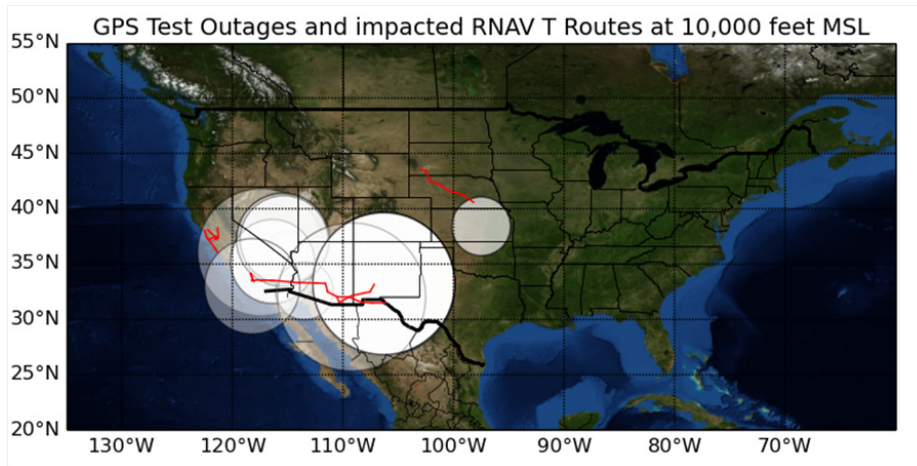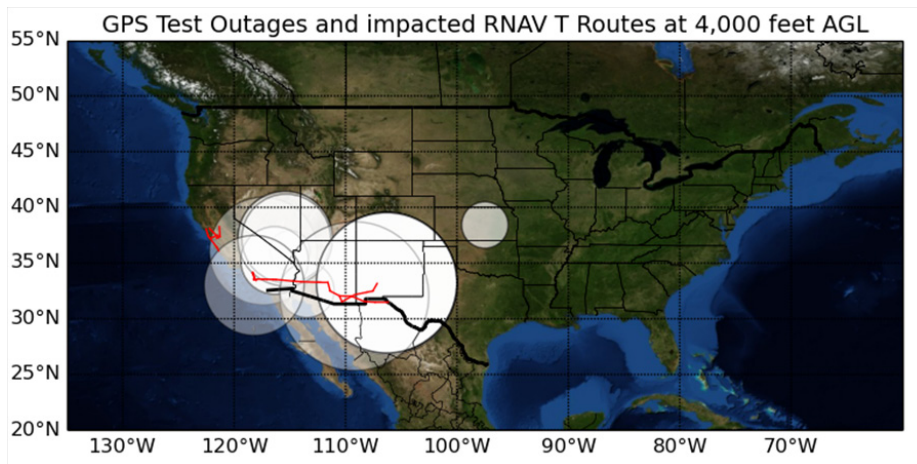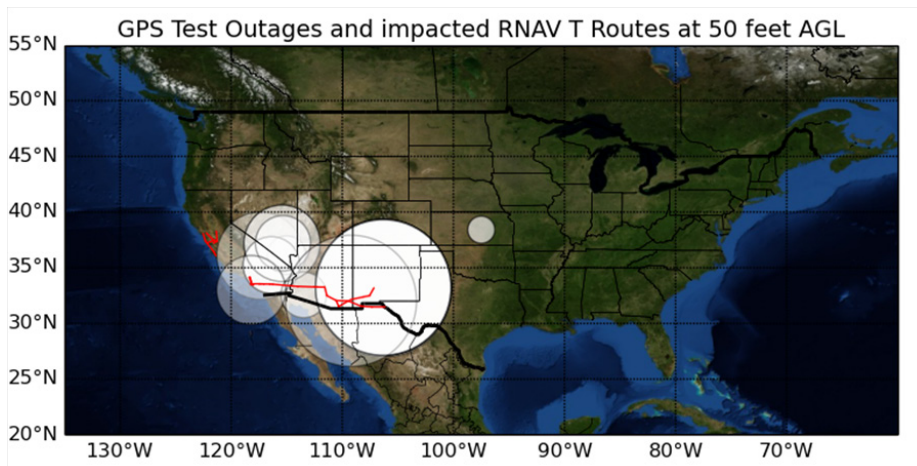### Table 9-3 NOTAM Impact to GPS Availability

Start Date	End Date	Latitude	Longitude	Percent Impact at each altitude				
				50	4000	10000	FL250	FL400
2014-07-01 03:00:00	2014-07-02 12:00:00	33.0702N	-106.2540W	11.87	12.59	12.80	17.23	20.23
2014-07-12 18:30:00	2014-07-13 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-07-14 14:00:00	2014-07-18 22:00:00	31.3548N	-110.1659W	0.00	0.00	0.00	0.00	0.00
2014-07-16 04:30:00	2014-07-19 07:00:00	37.2000N	-115.3330W	2.58	6.50	6.50	11.35	15.27
2014-07-17 18:00:00	2014-07-17 21:00:00	36.1307N	-115.0080W	1.14	1.14	1.34	3.30	5.26
2014-07-19 18:30:00	2014-07-20 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-07-21 14:00:00	2014-07-25 22:00:00	31.3548N	-110.1659W	0.00	0.00	0.00	0.00	0.00
2014-07-21 18:00:00	2014-07-21 21:00:00	36.1307N	-115.0080W	1.14	1.14	1.34	3.30	5.26
2014-07-22 03:00:00	2014-07-22 04:29:00	36.1307N	-115.0080W	1.14	1.14	1.34	3.30	5.26
2014-07-22 04:30:00	2014-07-25 07:00:00	37.2000N	-115.3330W	2.58	6.50	6.50	11.35	15.27
2014-07-22 18:30:00	2014-07-25 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-07-23 04:30:00	2014-07-25 07:00:00	37.2000N	-115.3330W	2.58	6.50	6.50	11.35	15.27
2014-07-24 18:30:00	2014-07-25 21:59:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-07-28 14:00:00	2014-08-01 22:00:00	31.3548N	-110.1659W	0.00	0.00	0.00	0.00	0.00
2014-07-29 04:00:00	2014-07-30 09:00:00	35.2401N	-116.3723W	2.58	3.61	5.37	9.29	10.22
2014-07-29 06:00:00	2014-08-25 14:00:00	22.4506N	-159.5839W	0.00	0.00	0.00	0.00	0.00
2014-08-11 17:50:00	2014-08-15 20:30:00	63.4714N	-145.5152W	0.00	0.00	0.00	0.00	0.00
2014-08-12 00:15:00	2014-08-15 01:15:00	63.4714N	-145.5152W	0.00	0.00	0.00	0.00	0.00
2014-08-13 15:30:00	2014-08-15 17:45:00	64.4048N	-147.0703W	0.00	0.00	0.00	0.00	0.00
2014-08-13 21:30:00	2014-08-15 23:59:00	64.4048N	-147.0703W	0.00	0.00	0.00	0.00	0.00
2014-08-16 00:15:00	2014-08-16 20:30:00	63.4714N	-145.5152W	0.00	0.00	0.00	0.00	0.00
2014-08-18 15:30:00	2014-08-20 17:45:00	61.1445N	-149.5041W	0.00	0.00	0.00	0.00	0.00
2014-08-18 17:50:00	2014-08-18 20:30:00	63.4714N	-145.5152W	0.00	0.00	0.00	0.00	0.00
2014-08-18 18:30:00	2014-08-18 22:30:00	35.2401N	-116.3723W	2.58	3.61	5.37	9.29	10.22
2014-08-18 21:30:00	2014-08-20 23:59:00	61.1445N	-149.5041W	0.00	0.00	0.00	0.00	0.00
2014-08-19 00:15:00	2014-08-21 01:15:00	63.4714N	-145.5152W	0.00	0.00	0.00	0.00	0.00
2014-08-19 13:00:00	2014-08-19 21:00:00	38.4130N	-97.4900W	0.41	2.06	2.89	6.19	9.29
2014-08-19 17:50:00	2014-08-21 20:30:00	63.4714N	-145.5152W	0.00	0.00	0.00	0.00	0.00
2014-08-21 03:00:00	2014-08-21 11:00:00	38.4130N	-97.4900W	0.41	2.06	2.89	6.19	9.29
2014-08-21 18:30:00	2014-08-21 22:30:00	35.2401N	-116.3723W	2.58	3.61	5.37	9.29	10.22
2014-08-22 00:15:00	2014-08-22 01:15:00	63.4714N	-145.5152W	0.00	0.00	0.00	0.00	0.00
2014-09-08 03:00:00	2014-09-09 12:30:00	32.5627N	-113.4710W	1.24	1.65	2.06	3.20	4.64
2014-09-10 20:00:00	2014-09-10 22:30:00	37.1934N	-115.4245W	4.75	7.33	6.91	12.59	16.10
2014-09-11 03:00:00	2014-09-12 12:30:00	32.5627N	-113.4710W	1.24	1.65	2.06	3.20	4.64
2014-09-12 20:00:00	2014-09-12 22:30:00	37.1934N	-115.4245W	4.75	7.33	6.91	12.59	16.10
2014-09-15 18:30:00	2014-09-15 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-09-16 03:00:00	2014-09-17 06:00:00	35.2401N	-116.3723W	2.58	3.61	5.37	9.29	10.22
2014-09-17 18:30:00	2014-09-17 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-09-18 05:30:00	2014-09-21 10:00:00	32.0300N	-109.2115W	8.77	11.04	11.04	14.45	17.13
2014-09-18 18:30:00	2014-09-18 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-09-20 18:30:00	2014-09-20 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-09-22 16:30:00	2014-09-22 22:30:00	36.0822N	-117.3846W	5.47	7.74	10.11	12.80	14.76
2014-09-23 18:30:00	2014-09-23 19:10:00	35.2401N	-116.3723W	2.58	3.61	5.37	9.29	10.22
2014-09-24 04:00:00	2014-09-24 08:00:00	33.0000N	-118.2000W	2.06	3.82	3.51	5.68	6.71
2014-09-24 18:30:00	2014-09-24 22:00:00	35.2401N	-116.3723W	2.58	3.61	5.37	9.29	10.22
2014-09-25 03:00:00	2014-09-27 12:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74

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	≤ 3.590 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	≤ 3.770 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	≤ 0.032 mm/s^2

Per-Satellite Coverage	Conditions and Constraints	Measured Performance
Terrestrial Service Volume: • 100% Coverage	• For any health or marginal SPS SIS	100%
Constellation Coverage	**Conditions and Constraints**	
Terrestrial Service Volume: • 100% Coverage	• For any health or marginal SPS SIS	100%
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	≥ 115.833 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	≤ 0.267 hours
Unscheduled Failure Interruption Continuity • ≥ 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.	100%
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.	≤ 2.849 m Horizontal ≤ 4.457 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.	≤ 5.665 m Horiz. ≤ 6.657 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.	≤ 13 nanoseconds
Instantaneous UTCOE Integrity • NTE ±120 nanoseconds 99.999% of time without a timely alert (SIS only)	• For any healthy SPS SIS • Worst case for delayed alert is 6 hours	≤ 45.3 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       High Latitude          Estimated
            - Fredericksburg -     ---- College ----     --- Planetary ---

     Date      A    K-indices       A    K-indices       A    K-indices
  2014 07 01   6  1 2 1 2 2 3 1 0   3  1 2 0 0 0 2 1 0   4  1 2 1 1 1 1 1 1
  2014 07 02   5  0 1 1 2 2 2 2 1   4  0 1 1 1 3 1 1 0   5  1 1 1 2 1 2 1 1
  2014 07 03   8  2 2 2 3 2 1 2 2  18  1 3 4 6 3 1 0 0   6  2 2 2 3 2 1 1 1
  2014 07 04   6  1 0 2 2 3 1 2 1   3  2 2 2 1 1 0 0 0   5  2 1 2 2 2 0 0 1
  2014 07 05   5  0 0 1 2 2 1 3 2   0  0 0 0 0 0 0 1 0   4  1 1 1 1 1 1 1 1
  2014 07 06   6  1 0 1 2 2 3 2 1   0  0 0 0 1 0 0 0 0   5  1 1 1 2 1 1 1 1
  2014 07 07   5  2 1 1 2 2 2 1 1   3  1 1 1 1 1 1 1 1   6  2 1 1 2 2 2 1 1
  2014 07 08   8  1 0 2 2 4 2 2 2   6  1 1 2 1 3 2 1 1   6  1 1 2 1 2 2 2 2
  2014 07 09   8  2 1 2 1 2 3 2 3   9  2 2 2 3 3 1 2 2   7  2 2 2 1 1 2 2 3
  2014 07 10  11  3 3 3 1 3 2 2 2   9  3 3 3 2 2 2 1 1   8  3 2 2 1 2 2 2 2
  2014 07 11   7  1 1 2 1 3 2 2 2   6  1 2 2 3 2 1 1 1   6  2 2 2 2 1 2 2 2
  2014 07 12   7  1 2 2 3 2 2 2 0  20  2 4 4 4 5 3 1 1   6  2 2 2 2 2 1 1 1
  2014 07 13   6  2 2 1 2 2 1 1 2   3  1 2 1 1 1 0 0 1   5  1 2 1 2 1 1 1 2
  2014 07 14  10  2 1 2 2 2 3 3 3   4  1 0 1 1 2 2 2 1   9  2 1 1 2 3 3 3 2
  2014 07 15  10  2 2 3 3 3 2 2 2   7  2 2 2 3 3 1 0 1   7  2 2 2 2 2 2 1 1
  2014 07 16   5  1 1 2 2 2 2 1 1   4  1 1 2 1 2 1 1 1   5  1 1 2 1 1 1 1 1
  2014 07 17   6  1 1 1 1 3 2 2 2   2  1 1 1 0 0 0 0 1   5  1 1 1 1 1 1 1 2
  2014 07 18   4  1 0 1 1 2 2 2 1   1  1 1 0 1 0 0 0 0   3  1 1 1 1 1 0 0 1
  2014 07 19   3  0 0 0 1 2 2 1 1   1  0 0 0 2 0 0 0 0   3  0 1 1 1 1 0 0 0
  2014 07 20   4  1 0 1 1 3 1 1 1   1  0 0 1 0 0 0 0 1   3  1 1 1 0 1 1 0 1
  2014 07 21   5  1 0 1 1 2 2 2 2   3  1 0 0 2 2 1 1 1   5  1 1 1 1 1 2 2 2
  2014 07 22   6  2 1 1 1 3 2 2 1   3  2 0 0 0 2 2 0 0   5  2 1 1 1 2 1 1 2
  2014 07 23   7  0 1 1 1 3 1 3 3   2  0 1 0 0 0 0 2 1   6  1 1 1 1 1 1 3 3
  2014 07 24   6  1 2 1 2 3 1 2 1   2  0 2 1 1 1 0 1 0   5  1 2 1 2 2 1 1 1
  2014 07 25   9  3 2 3 1 3 2 2 1   5  2 2 3 2 1 0 0 0   6  3 2 2 2 1 1 1 1
  2014 07 26   9  2 2 2 3 3 2 2 1  11  1 2 4 4 2 1 2 1   7  2 2 2 2 2 2 2 1
  2014 07 27   6  1 1 1 2 3 2 1 1   4  2 2 2 1 0 0 1 1   5  2 1 2 2 1 1 1 2
  2014 07 28  12  2 3 4 2 3 3 2 1  11  1 2 3 3 2 4 2 1   9  2 2 3 2 2 3 2 1
  2014 07 29   6  1 2 0 2 2 3 2 1   2  1 1 0 1 0 0 1 1   4  1 1 0 1 1 1 1 1
  2014 07 30   7  2 2 1 2 3 2 2 1   2  2 2 0 1 0 0 0 0   5  3 1 1 1 1 1 1 1
  2014 07 31   7  1 1 1 2 3 2 2 2   2  1 2 1 0 0 0 0 1   5  1 1 1 2 1 1 1 2
  2014 08 01  14  2 2 1 3 4 2 3 4  10  2 2 1 4 2 1 3 2  10  2 2 1 2 2 2 3 4
  2014 08 02  12  2 2 2 3 4 3 2 2  23  3 3 3 5 4 5 2 2  11  3 2 2 3 4 3 2 2
  2014 08 03   7  1 3 1 2 2 2 2 2   5  2 2 1 2 0 1 1 2   7  1 3 1 2 1 1 2 2
  2014 08 04  15  2 3 3 4 3 3 3 2  15  2 4 3 4 3 2 3 2  12  2 3 3 3 2 2 3 3
  2014 08 05  12  3 3 3 3 3 2 3 2  21  3 3 3 4 4 5 3 2  10  3 2 3 2 3 2 3 2
  2014 08 06   7  1 3 3 1 2 2 1 1  14  2 3 4 4 4 1 1 0   7  2 3 2 2 2 1 1 1
  2014 08 07   6  1 2 1 2 2 2 2 2  10  1 1 1 4 4 1 2 1   6  2 2 1 2 2 1 2 2
  2014 08 08   9  3 3 3 2 2 2 1 1  12  2 3 3 5 2 0 1 0   8  3 3 2 2 2 1 1 1
  2014 08 09   4  0 2 2 1 2 2 1 0   6  1 2 4 2 0 0 0 0   4  1 1 2 1 1 1 0 0
  2014 08 10   9  1 0 2 2 3 2 4 2   5  1 0 1 2 1 2 3 1   9  1 1 2 2 2 2 4 2
  2014 08 11   7  1 1 1 1 2 3 2 3   5  1 1 1 1 1 3 1 2   7  1 1 1 1 2 2 1 3
  2014 08 12  11  3 2 0 2 3 3 3 3   8  3 2 0 2 1 2 2 3  12  3 2 1 2 1 3 4 4
  2014 08 13   8  2 2 2 2 3 2 2 2  12  3 2 2 4 4 1 1 1   6  2 2 2 2 2 1 1 1
  2014 08 14   5  1 1 1 2 2 1 1 2   2  1 1 0 2 0 0 0 1   4  1 1 1 2 1 1 1 2
  2014 08 15   6  1 1 1 2 3 2 1 1   5  1 1 1 2 3 1 1 0   5  1 1 1 1 2 2 0 1
  2014 08 16   4  1 1 0 1 2 2 2 1   1  1 1 0 0 0 0 0 0   3  1 1 0 1 1 0 1 1
  2014 08 17   9  1 1 1 3 4 2 2 2   9  1 1 0 1 5 3 0 0   7  2 1 1 3 3 2 1 2
  2014 08 18   5  1 1 2 1 2 2 1 1   3  1 2 2 0 1 1 1 0   5  1 1 2 0 1 1 1 1
  2014 08 19  14  1 1 2 3 3 2 3 5  11  1 1 2 4 2 2 2 4  17  1 1 2 3 2 2 4 6
  2014 08 20   7  2 1 1 2 3 1 2 2   4  1 1 1 1 1 1 2 1   6  2 1 1 2 2 1 1 2
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2014 08 21    12   3 3 2 3 3 1 3 2    27   2 3 4 6 5 4 2 2    11   3 3 2 2 2 1 3 2
2014 08 22     4   2 2 1 1 2 1 1 0     3   2 2 0 0 2 0 0 1     4   1 3 1 0 1 0 0 1
2014 08 23     8   1 3 3 2 1 2 2 1     3   1 1 2 1 0 1 1 0     5   1 2 2 1 1 1 1 1
2014 08 24     5   1 0 2 2 2 2 2 1     1   0 0 1 2 0 0 0 0     4   1 1 1 1 2 1 1 1
2014 08 25     4   0 0 1 1 3 1 2 1     0   0 0 0 1 0 0 0 0     4   0 1 1 1 1 1 1 1
2014 08 26     5   0 0 1 2 3 1 2 2     2   0 0 0 2 2 0 0 0     4   1 1 1 2 1 1 1 1
2014 08 27    19   1 3 3 4 5 3 3 3    46   1 3 5 5 6 6 6 3    20   1 3 4 4 4 4 3 4
2014 08 28    17   3 5 4 3 2 3 2 1    39   3 5 5 6 5 5 3 2    21   4 5 4 3 3 3 3 2
2014 08 29    20   3 4 3 4 4 1 3 4    37   3 4 5 7 4 3 2 3    21   3 4 3 5 3 2 3 4
2014 08 30    11   3 4 2 2 3 1 2 2    30   3 4 3 6 6 2 2 2    15   4 4 2 3 4 2 3 2
2014 08 31    13   2 1 3 3 3 2 3 4    21   1 1 4 6 4 2 2 3    15   2 2 3 4 3 2 4 4
2014 09 01    12   3 3 3 3 3 2 2 2    27   3 3 3 6 5 4 2 2    11   3 3 3 3 3 2 2 3
2014 09 02    10   2 3 3 2 3 2 2 2    18   2 2 3 4 5 4 2 2    10   2 3 2 2 3 2 2 3
2014 09 03    11   3 3 3 2 3 1 2 2    17   2 3 5 5 2 2 1 1    10   3 3 3 2 2 1 1 2
2014 09 04     7   2 2 1 3 2 2 2 1    16   2 2 5 5 3 1 0 1     7   3 2 2 3 2 1 1 2
2014 09 05    10   1 1 3 3 3 3 1 2    16   1 2 3 5 4 3 2 1     8   2 2 2 2 2 2 2 2
2014 09 06     7   1 2 2 2 3 2 2 1     8   1 2 3 3 1 2 2 1     9   1 2 3 2 2 3 2 2
2014 09 07    10   3 3 3 2 3 2 1 0     4   2 3 2 0 0 0 0 0     8   3 3 3 1 1 1 0 0
2014 09 08     7   0 1 2 2 3 2 2 2     2   0 1 2 0 0 1 1 1     6   1 2 2 1 1 1 2 2
2014 09 09     8   2 2 1 2 3 2 2 2     4   2 1 1 2 1 1 1 1     8   3 2 2 2 2 2 2 3
2014 09 10     9   1 0 0 2 2 4 3 3     3   2 0 1 1 0 1 2 1     9   2 1 1 2 1 3 3 3
2014 09 11    16   3 4 3 4 3 2 2 3    20   2 3 5 5 4 1 1 2    12   3 4 3 3 2 1 1 3
2014 09 12    35   5 4 2 4 3 5 4 6    37   4 5 3 4 4 6 4 5    44   5 5 2 3 2 6 5 7
2014 09 13    13   4 2 3 2 3 2 3 2     8   3 2 2 1 2 2 2 2    13   4 3 4 2 2 2 2 2
2014 09 14     3   1 1 1 0 2 1 1 0     1   1 0 0 0 0 1 0 0     3   1 1 1 1 1 1 0 0
2014 09 15     2   0 0 0 1 2 1 1 1     1   0 0 0 0 0 1 1 1     3   1 1 1 1 1 1 1 1
2014 09 16     7   1 2 2 2 2 2 2 2     3   2 1 1 2 0 0 1 1     7   2 2 2 2 1 1 2 2
2014 09 17     4   2 0 0 1 2 1 2 2     2   1 1 0 0 0 1 1 2     6   3 1 0 0 1 2 2 2
2014 09 18     7   2 1 1 1 2 2 2 3     2   2 0 0 0 0 0 2 1     8   3 1 1 1 1 2 3 3
2014 09 19    23   4 5 4 3 4 3 3 2    32   3 5 5 4 5 4 4 3    22   4 5 4 3 3 4 3 2
2014 09 20     4   1 1 1 1 2 2 0 1     6   2 1 1 2 3 1 1 1     6   2 2 1 1 2 1 1 1
2014 09 21     7   1 3 2 2 2 2 2 1     3   1 2 1 1 0 1 1 1     7   2 3 2 1 1 1 2 1
2014 09 22     9   1 3 2 2 3 2 2 2    16   1 2 3 4 5 3 2 2     9   2 3 2 2 3 2 2 2
2014 09 23     9   3 1 2 2 2 2 2 3    18   1 1 3 5 5 3 2 2    11   3 2 2 2 3 3 3 3
2014 09 24    19   3 4 2 4 4 2 3 4    57   4 5 6 7 6 5 3 3    25   4 4 3 4 4 3 3 4
2014 09 25    13   4 2 3 2 3 2 2 3    18   3 3 3 5 4 2 2 2    13   4 3 3 3 2 2 2 3
2014 09 26    12   2 3 3 2 3 3 2 3    37   3 2 3 6 6 6 3 2    14   3 3 3 2 3 3 2 3
2014 09 27    12   4 3 3 2 3 2 2 1    32   3 5 6 5 4 4 2 2    15   4 4 3 3 3 2 2 1
2014 09 28     6   1 2 2 2 3 2 1 0    13   2 1 2 4 4 4 1 1     8   2 2 2 3 3 2 2 1
2014 09 29     7   2 1 1 2 2 2 3 2    22   1 1 4 6 5 1 2 2    10   2 2 2 2 2 2 4 3
2014 09 30    12   2 3 2 4 3 2 2 2    28   2 5 4 6 4 4 1 2    15   3 4 3 4 3 2 2 3
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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:

There were no problems this quarter.

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.