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

Submitted To

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Submitted by

William J. Hughes Technical Center

WAAS T&E Team

Atlantic City International Airport, NJ 08405

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 #88, includes data collected from 1 October through 31 December 2014. The next quarterly report will be issued April 30, 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 October and 31 December 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. All eight outages were scheduled ahead of time while no 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 31.556 meters on Satellite PRN 20. 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 3.897 was recorded on satellite PRN 22. 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 12.62 meters at Maspalomas and 11.97 meters at Bogota.

From the analysis performed on data collected between 1 October and 31 December 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
≥ 98% global PDOP of 6 or less ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval

Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by the WAAS test team was used to calculate the PDOP at every 5° 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 3.061 or better 99.9% of the time for each of the 24-hour intervals.

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

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

Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value	Global Average (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
28 Sep – 4 Oct	2.925	99.999	99.722
5 – 11 Oct	2.917	100	99.722
12 – 18 Oct	2.924	100	99.722
19 – 25 Oct	2.932	99.999	99.514
26 Oct – 1 Nov	3.061	99.999	99.375
2 – 8 Nov	3.003	99.999	99.444
9 – 15 Nov	2.990	99.999	99.514
16 – 22 Nov	2.982	99.999	99.583
23 – 29 Nov	2.978	100	99.653
30 Nov – 6 Dec	2.968	100	99.722
7 – 13 Dec	2.968	100	99.792
14 – 20 Dec	2.871	100	99.792
21 – 27 Dec	2.884	100	99.792

Figure 2-1 World GPS Maximum PDOP

10/02/14 World GPS Maximum PDOP

Median 99.99% PDOP =2.8
Maximum PDOP =283.7
Color Scale is Position Dilution of Precision (PDOP)
(WJH FAA Tech. Cntr., NJ USA)

W.J.H. FAA Technical Center
WAAS Test Team

Longitude (2 degree sample size)

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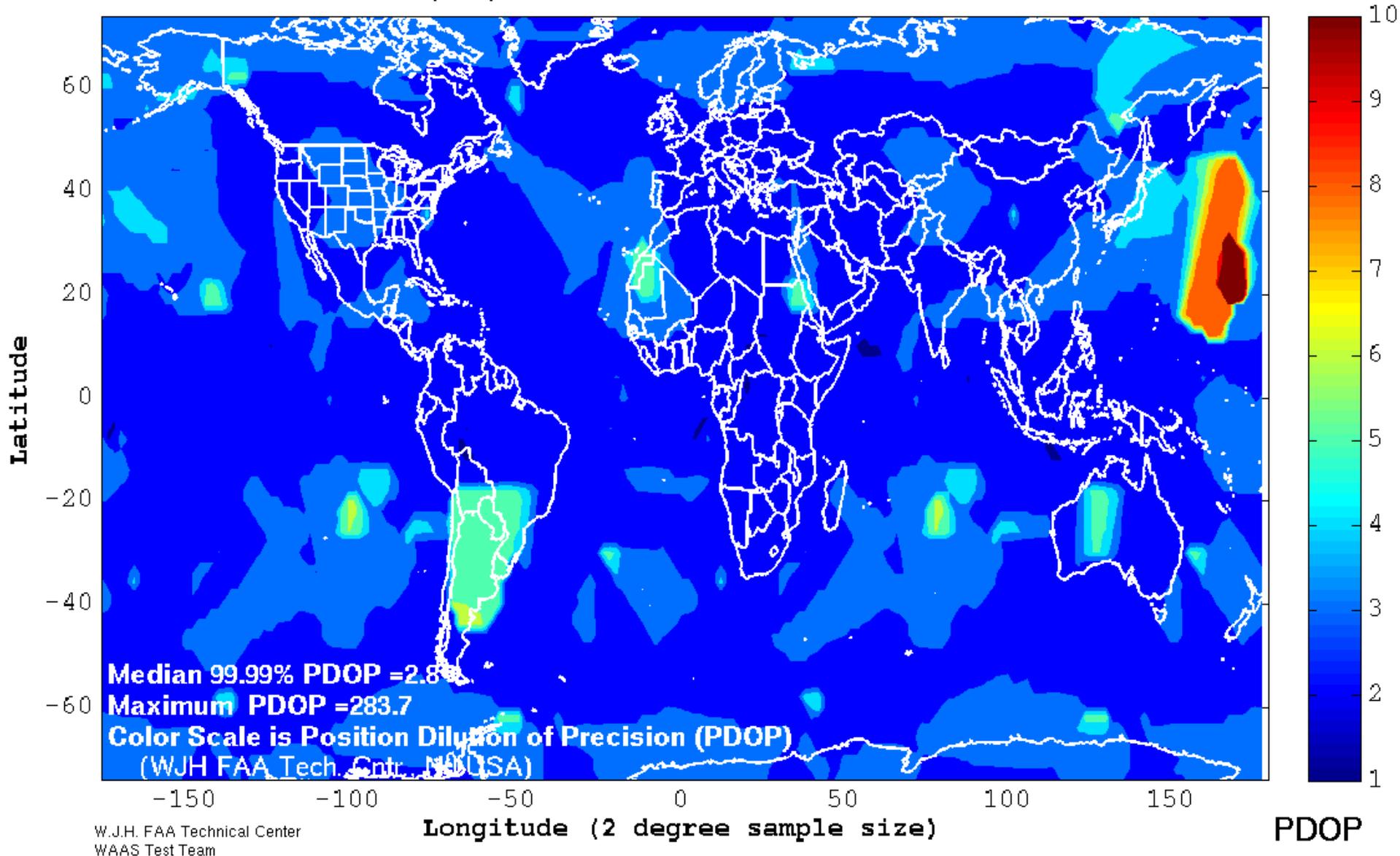
Figure 2-2 Satellite Visibility Profile for Worst-Case Point

Worst-Case Point (Lat: 25, Long: 165)
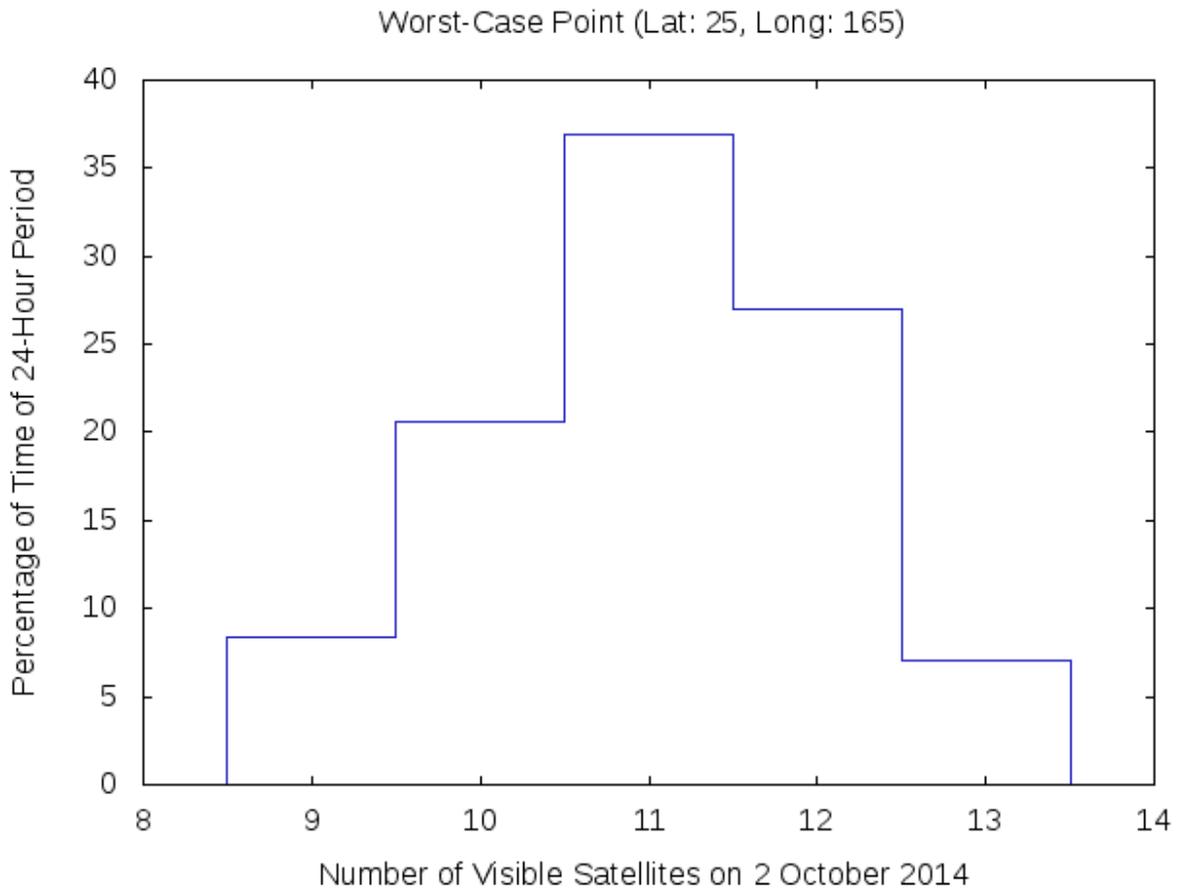
3   NANU Summary and Evaluation

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

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

3.1   Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANU's). During this reporting period, 1 October through 31 December 2014, there were a total of eight reported outages. All eight of those outages were maintenance activities and were reported in advance. There were no 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 80.133 hours. The notification time met the 48-hour requirement. The maximum response time for a NANU issued for an unscheduled outage was not applicable. 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
2014074	25	FCSTSUMM	2-Oct-14	16:00	2-Oct-14	21:43		5.72	5.72
2014077	12	FCSTSUMM	23-Oct-14	13:54	23-Oct-14	17:52		3.97	3.97
2014080	1	FCSTSUMM	27-Oct-14	18:44	27-Oct-14	23:05		4.35	4.35
2014081	12	FCSTSUMM	28-Oct-14	4:44	28-Oct-14	10:44		6	6
2014085	4	FCSTSUMM	21-Nov-14	16:14	21-Nov-14	23:52		7.63	7.63
2014089	15	FCSTSUMM	11-Dec-14	15:38	11-Dec-14	20:54		5.27	5.27
2014091	20	FCSTSUMM	16-Dec-14	17:19	16-Dec-14	23:48		6.48	6.48
2014092	7	FCSTSUMM	19-Dec-14	1:13	19-Dec-14	6:54		5.68	5.68
Totals of Unscheduled, Scheduled & Total Downtime							0	45.10	45.10

GENERAL NANUs

No General NANU's issued this quarter.

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2014073	25	FCSTDV	2-Oct	16:00	3-Oct	4:00	12	2014074
2014075	12	FCSTDV	23-Oct	13:30	24-Oct	1:30	12	2014077
2014076	1	FCSTMX	27-Oct	16:00	28-Oct	4:00	12	2014080
2014079	12	FCSTDV	28-Oct	4:15	28-Oct	16:15	12	2014081
2014084	4	FCSTDV	21-Nov	16:00	22-Nov	4:00	12	2014085
2014086	15	FCSTDV	11-Dec	14:00	12-Dec	2:00	12	2014089
2014087	20	FCSTDV	16-Dec	17:00	17-Dec	5:00	12	2014091
2014088	7	FCSTDV	19-Dec	1:00	19-Dec	13:00	12	2014092
					Total Forecasted Downtime		96	

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-Oct-14 31-Dec-14	1-Jan-00 31-Dec-14
Total Forecast Downtime (hrs):	96	10344.82
Total Actual Downtime (hrs):	45.1	3835.06
Total Actual Scheduled Downtime (hrs):	45.10	6030.37
Total Actual Unscheduled Downtime (hrs):	0	32319.69
Total Satellite Observed MTTR (hrs):	5.64	47.88
Scheduled Satellite Observed MTTR (hrs):	5.64	9.51
Unscheduled Satellite Observed MTTR (hrs):	N/A	193.53
# Total Satellite Outages:	8	801
# Scheduled Satellite Outages:	8	634
# Unscheduled Satellite Outages:	0	167
Percent Operational -- Scheduled Downtime:	99.93	99.85
Percent Operational -- All Downtime:	99.93	99.06

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 October and 31 December 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	7948787	0	100%
Anchorage	7948553	0	100%
Atlanta	7946140	0	100%
Barrow	7948538	0	100%
Bethel	7948095	0	100%
Billings	7937649	0	100%
Boston	7948601	0	100%
Cleveland	7938132	0	100%
Cold Bay	7940947	0	100%
Fairbanks	7948678	0	100%
Gander	7946552	0	100%
Honolulu	7846921	0	100%
Houston	7945539	0	100%
Iqaluit	7852770	0	100%
Juneau	7943893	0	100%
Kansas City	7946459	0	100%
Kotzebue	7947635	0	100%
Los Angeles	7945659	0	100%
Merida	7946650	0	100%
Miami	7948711	0	100%
Minneapolis	7947164	0	100%
Oakland	7947224	0	100%
Salt Lake City	7948434	0	100%
San Jose Del Cabo	7917616	0	100%
San Juan	7628770	0	100%
Seattle	7948647	0	100%
Tapachula	7945098	0	100%
Washington, DC	7878358	0	100%
Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)			

4   Service Reliability Standard

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

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

Table 4-1 shows a comparison to the service reliability standard for range data collected at a set of six receivers across North America. Although the specification calls for yearly evaluations, we will be evaluating this SPS requirement at quarterly intervals. Additional range analysis results can be found in table 5-2. The maximum User Range Error recorded this quarter was 31.556 meters on satellite PRN 20.

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**	67,787,057	0	100%
1 Apr – 30 Jun 2014	**Honolulu**	70,425,886	1,140	99.998%
1 Apr – 30 Jun 2014	**Los Angeles**	69,138,312	0	100%
1 Apr – 30 Jun 2014	**Miami**	67,632,484	0	100%
1 Apr – 30 Jun 2014	**Merida**	69,701,081	0	100%
1 Apr – 30 Jun 2014	**Juneau**	69,525,666	0	100%
1 Apr – 30 Jun 2014	**Global**	414,210,486	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 October through 31 December 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	7.188	2.228	14.061	4.523
Anchorage	9.132	2.655	18.221	6.080
Atlanta	6.905	2.533	14.532	4.439
Barrow	9.689	2.957	20.542	6.438
Bethel	9.488	2.512	16.694	5.412
Billings	6.619	2.327	13.340	7.155
Boston	5.711	2.695	11.194	4.826
Cleveland	6.076	2.612	12.816	4.778
Cold Bay	9.146	2.306	15.875	5.852
Fairbanks	9.139	2.849	18.736	5.652
Gander	6.049	2.633	12.173	6.345
Honolulu	7.501	9.262	15.328	14.133
Houston	7.364	2.493	15.915	4.434
Iqaluit	6.992	4.059	15.226	7.928
Juneau	8.117	2.617	17.734	5.961
Kansas City	6.465	2.407	13.581	5.335
Kotzebue	9.513	2.749	17.511	5.408
Los Angeles	7.994	2.249	15.996	4.780
Merida	7.707	3.620	22.625	14.047
Miami	7.202	2.878	13.110	6.736
Minneapolis	6.153	2.435	12.935	5.500
Oakland	8.042	2.203	17.455	4.874
Salt Lake City	7.159	2.213	14.010	4.768
San Jose Del Cabo	7.988	4.321	17.977	13.388
San Juan	8.504	7.427	22.596	22.642
Seattle	7.340	2.232	16.732	7.105
Tapachula	8.429	7.085	20.028	15.206
Washington, DC	6.230	2.619	11.810	4.510

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

Figure 5-1 Global Vertical Error Histogram

Vertical Position Error Histogram: 1 October - 31 December 2014
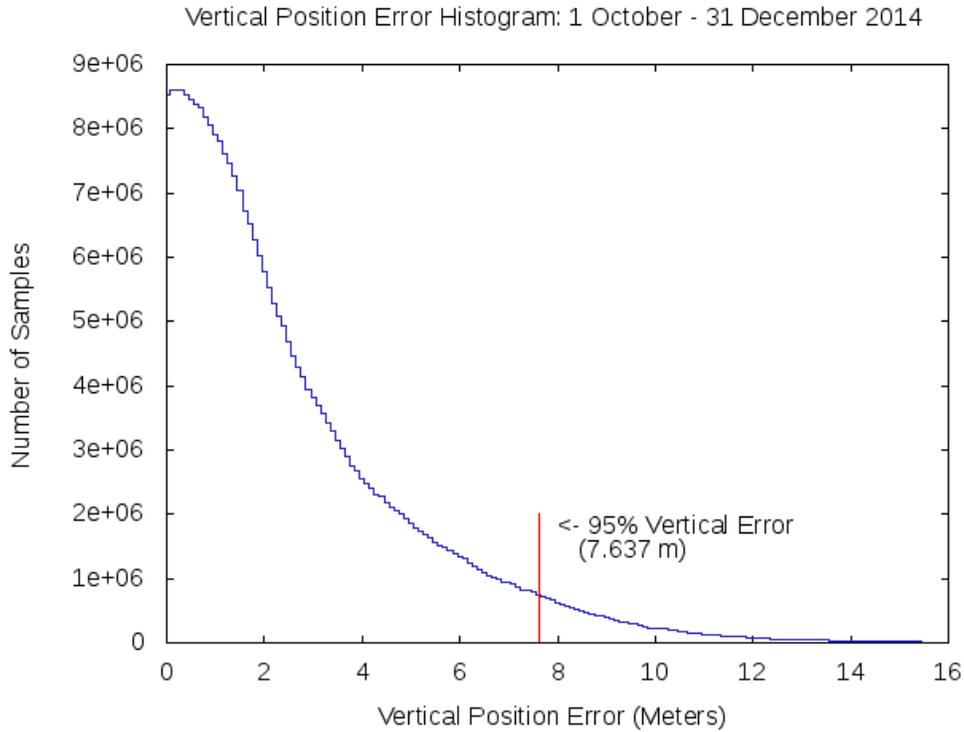
Figure 5-2 Global Horizontal Error Histogram

Horizontal Position Error Histogram: 1 October - 31 December 2014
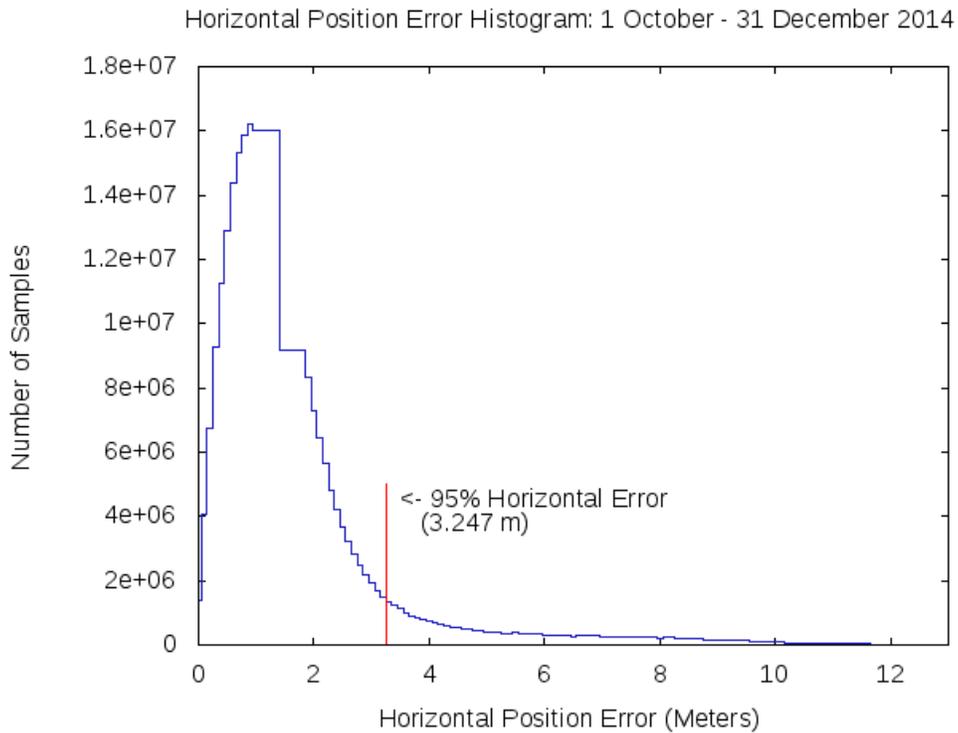
5.2   Time Transfer Accuracy

The GPS time error data between 1 October and 31 December 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 47.9 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
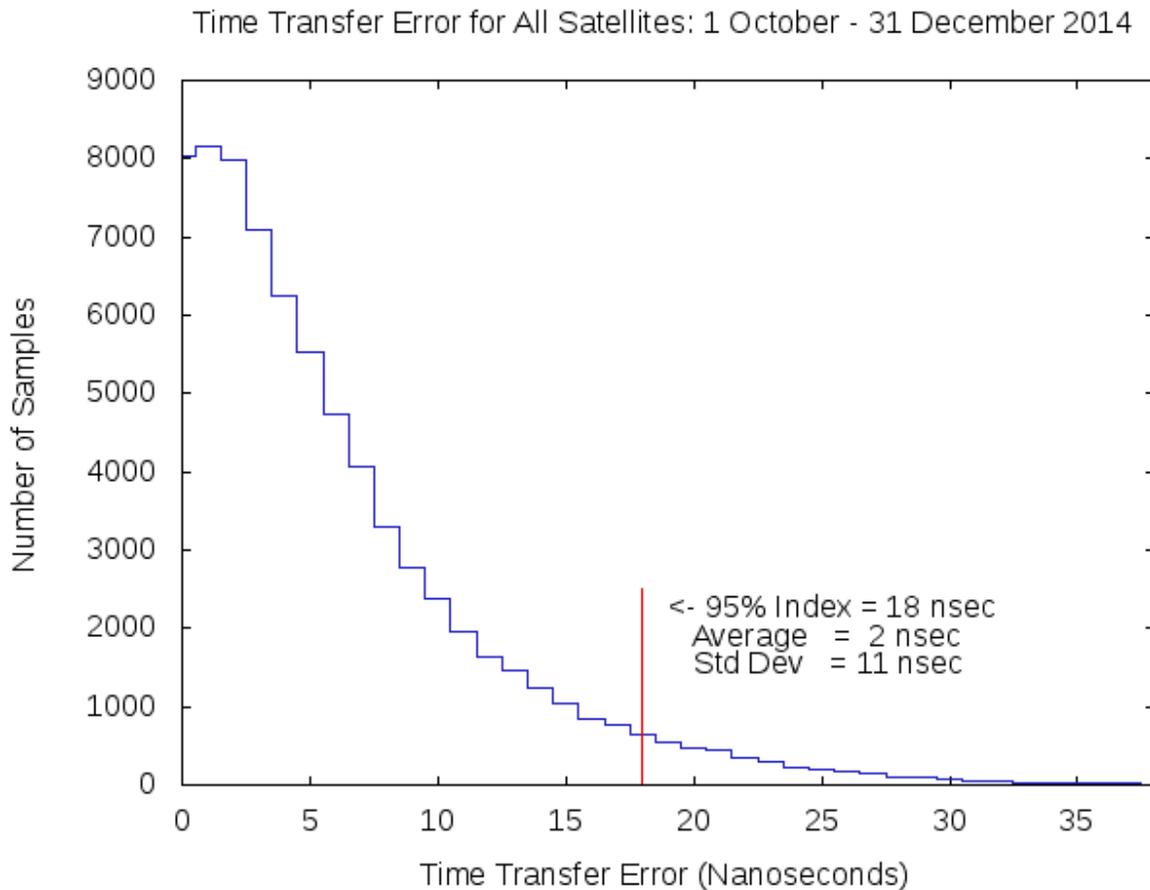
5.3   Range Domain Accuracy

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 October and 31 December 2014. A weighted average filter was used for the calculation of the range rate error and the range acceleration error. All Range Domain SPS specifications were met.

Table 5-2 Range Error Statistics

(Meters)

PRN	RMS Range Error (≤ 6 m)	Range Error Mean	1σ	95% Range Error	Max Range Error (SPS Spec. ≤ 30 m)	Samples
1	2.617	0.424	2.207	4.805	29.932	13773861
2	2.206	0.793	1.561	4.115	22.065	14562079
3	2.652	-0.777	2.106	4.646	18.074	2990706
4	2.673	0.708	2.136	5.101	28.379	14134427
5	2.176	-0.066	1.752	3.967	16.721	13674702
6	2.378	-0.251	2.027	4.742	21.416	13869223
7	2.194	0.710	1.850	4.433	25.536	12652451
8	2.511	0.733	2.074	4.864	24.387	4413894
9	2.184	0.428	1.827	4.480	22.253	13521332
10	2.829	1.649	1.835	4.971	19.175	12235346
11	2.953	1.280	2.288	5.745	28.944	12825500
12	1.972	0.461	1.611	3.613	23.744	14082615
13	1.867	0.238	1.679	3.834	28.970	14225496
14	3.401	1.986	2.123	5.872	18.775	14661785
15	2.036	0.577	1.479	3.642	26.611	12815061
16	2.740	1.091	2.141	5.167	19.577	13343254
17	2.381	0.451	1.998	4.751	24.341	14525326
18	3.120	1.700	1.939	5.231	16.217	13794403
19	2.765	1.422	1.979	5.035	22.854	12427045
20	2.922	1.489	2.176	5.444	31.556	14353668
21	3.061	1.287	2.020	5.172	17.738	13120655
22	3.897	2.360	2.148	6.253	18.012	13011898
23	2.477	1.037	1.942	4.782	21.198	12907904
24	2.214	0.213	1.806	4.107	18.895	14146460
25	2.375	1.142	1.782	4.430	24.479	14307151
26	2.074	0.469	1.658	3.963	22.241	13509337
27	2.364	0.529	2.005	4.720	24.964	13350761
28	2.608	1.280	1.830	5.164	30.388	13751867
29	2.346	0.374	1.723	4.183	27.713	13296681
30	2.271	0.902	1.869	4.930	29.559	12809785
31	3.085	1.287	2.354	5.692	21.006	14096875
32	3.340	1.893	2.042	5.684	20.078	13018938

Table 5-3 Range Rate Error Statistics

(Millimeters/ Second)

PRN	Range Rate Error RMS	95% Range Rate Error	Max Range Rate Error	Samples
1	2.285	3.479	194.790	13773861
2	2.426	3.622	309.690	14562079
3	2.057	3.459	94.830	2990706
4	2.420	3.561	199.920	14134427
5	2.597	3.774	338.070	13674702
6	2.297	3.392	259.270	13869223
7	1.977	3.279	335.660	12652451
8	2.896	3.587	268.740	4413894
9	2.304	3.464	311.360	13521332
10	2.713	3.742	296.330	12235346
11	2.365	3.619	195.290	12825500
12	2.498	3.795	255.940	14082615
13	2.578	3.851	313.430	14225496
14	2.484	3.874	159.420	14661785
15	2.718	3.863	251.640	12815061
16	2.307	3.711	246.940	13343254
17	2.493	3.701	299.520	14525326
18	2.747	3.944	241.980	13794403
19	2.291	3.577	241.340	12427045
20	2.339	3.772	181.310	14353668
21	2.734	3.878	211.320	13120655
22	2.738	3.949	270.280	13011898
23	2.191	3.428	271.810	12907904
24	2.942	3.842	264.040	14146460
25	2.384	3.497	184.990	14307151
26	2.668	3.605	357.170	13509337
27	2.478	3.637	334.310	13350761
28	2.395	3.367	259.110	13751867
29	2.565	3.748	313.420	13296681
30	2.033	3.406	323.880	12809785
31	2.343	3.706	264.140	14096875
32	2.466	3.667	243.170	13018938

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	17.742	25.081	1940	13773861
2	18.780	27.379	3090	14562079
3	15.109	23.346	910	2990706
4	18.827	26.712	1970	14134427
5	20.281	29.851	3360	13674702
6	17.760	25.138	2610	13869223
7	14.236	22.688	3330	12652451
8	24.124	25.400	2650	4413894
9	17.041	24.301	3110	13521332
10	21.186	28.275	2910	12235346
11	18.006	26.996	1940	12825500
12	19.317	29.767	2580	14082615
13	19.951	29.781	3130	14225496
14	19.481	28.123	1510	14661785
15	21.457	30.286	2470	12815061
16	17.007	27.639	2430	13343254
17	19.206	26.720	2960	14525326
18	22.082	31.814	2370	13794403
19	17.526	26.452	2370	12427045
20	17.202	26.237	1810	14353668
21	21.964	31.748	2100	13120655
22	21.467	30.237	2650	13011898
23	16.549	24.435	2710	12907904
24	24.063	31.177	2640	14146460
25	18.882	26.677	1880	14307151
26	21.354	28.528	3580	13509337
27	19.389	25.910	3290	13350761
28	18.612	23.836	2580	13751867
29	20.129	29.344	3110	13296681
30	14.558	22.619	3190	12809785
31	17.601	25.869	2640	14096875
32	18.875	26.071	2430	13018938

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 20 with an error of 31.556 meters. Satellite 5 had the lowest maximum range error of 16.721 meters.

Figure 5-4 Distribution of Daily Max Range Errors

Daily Max Range Error Historgram: 1 October - 31 December 2014
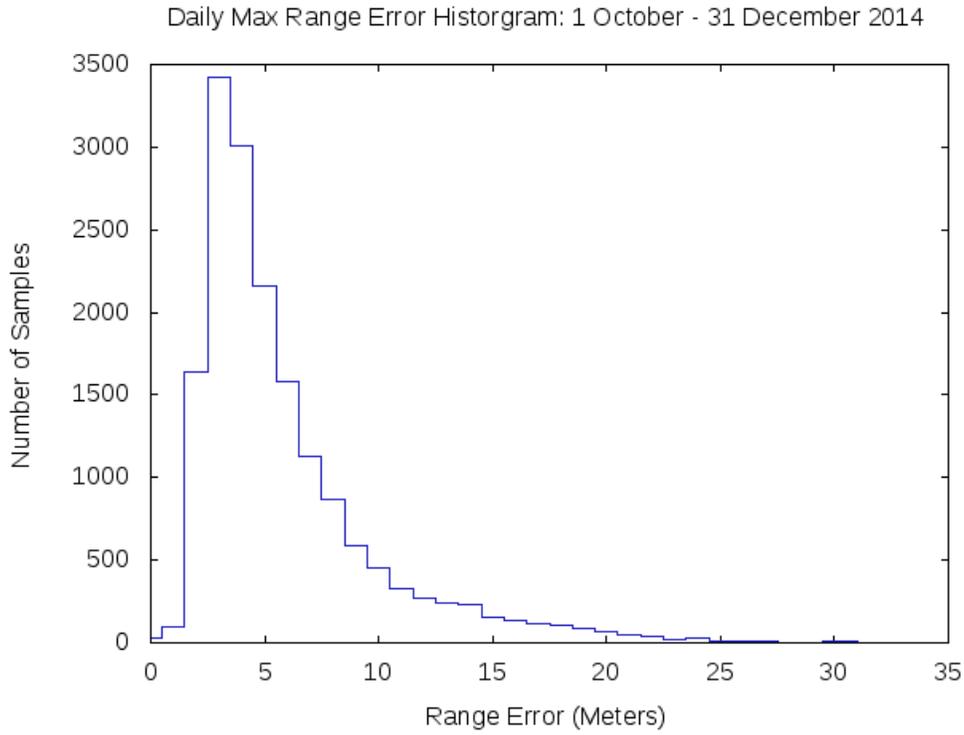
Figure 5-5 Distribution of Daily Max Range Rate Errors

Daily Max Range Rate Error Historgram: 1 October - 31 December 2014
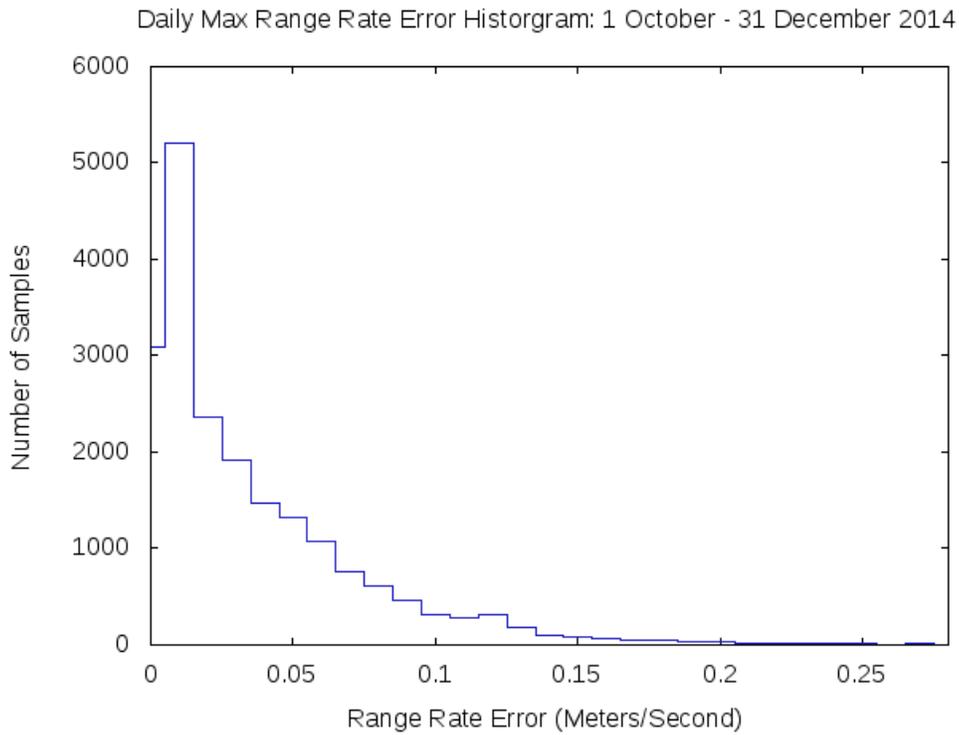
Figure 5-6 Distribution of Daily max Range Acceleration Errors

Daily Max Range Accel Error Historgram: 1 October - 31 December 2014
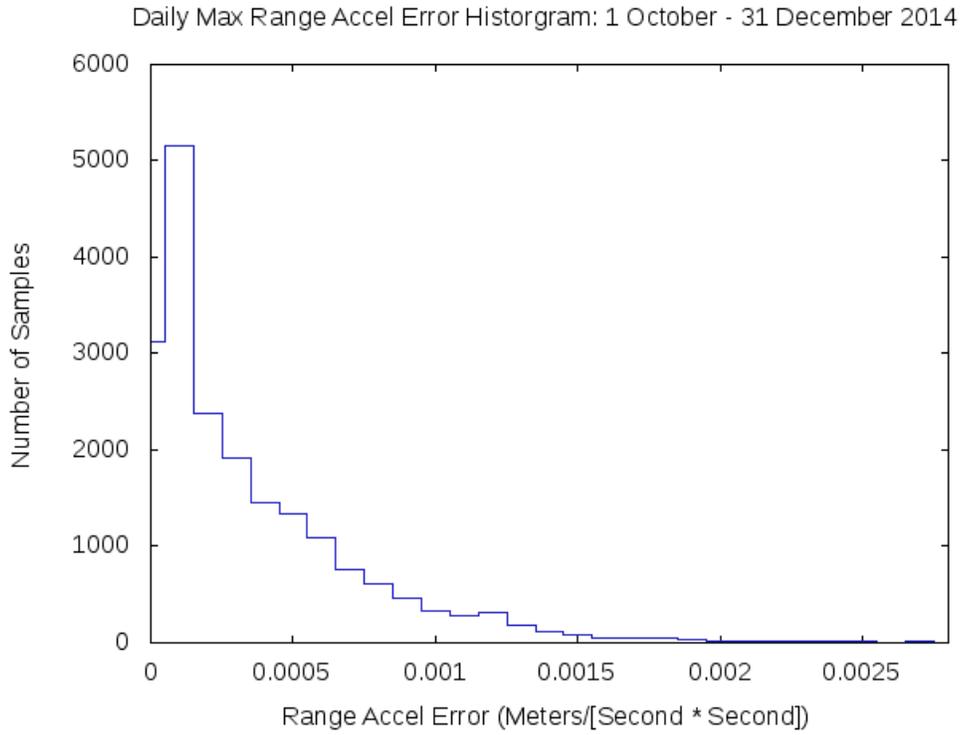
Figure 5-7 Range Error Histogram

Range Error Histogram: 1 October - 31 December 2014
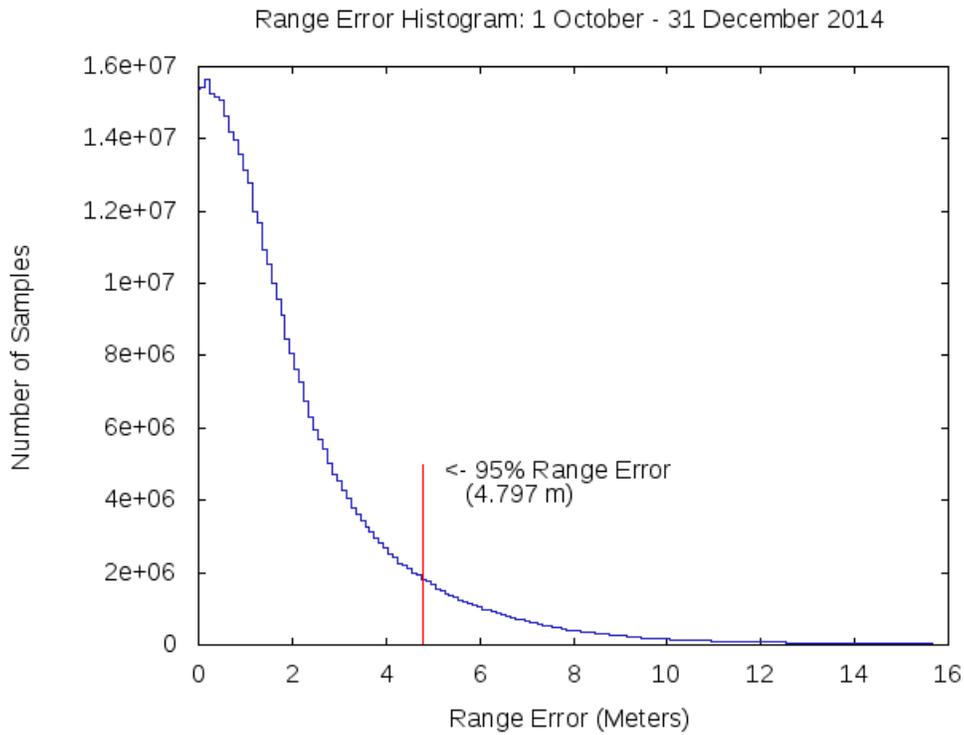
Figure 5-8 Maximum Range Error Per Satellite
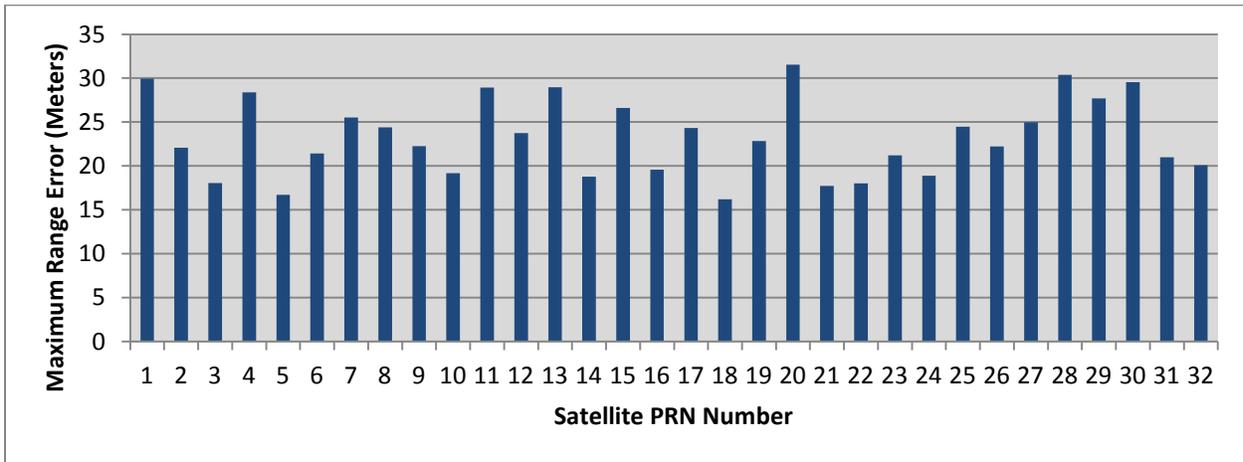
Figure 5-9 Maximum Range Rate Error Per Satellite
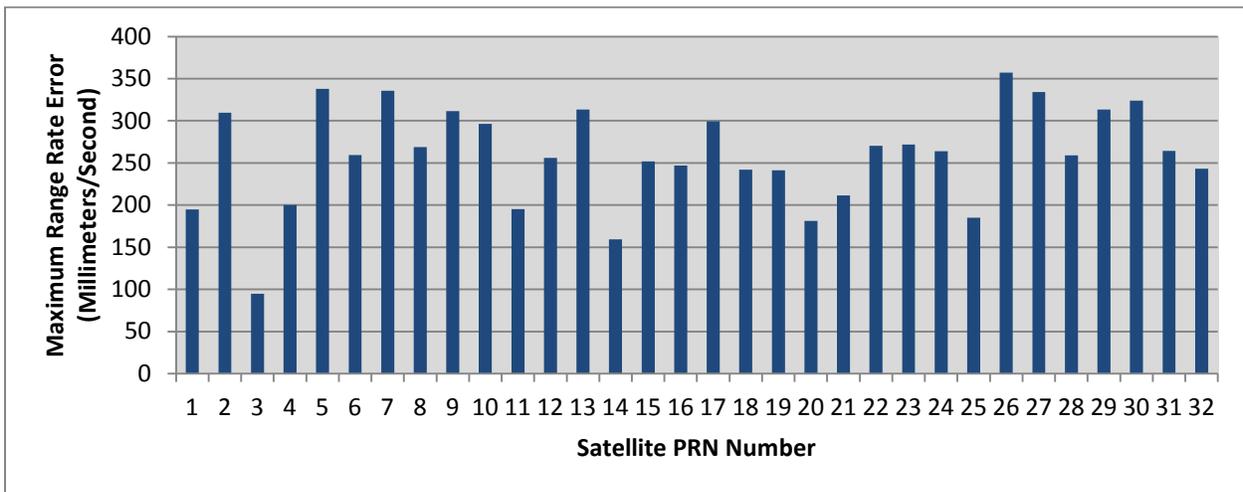
**Figure 5-10 Maximum Range Acceleration Error Per Satellite**
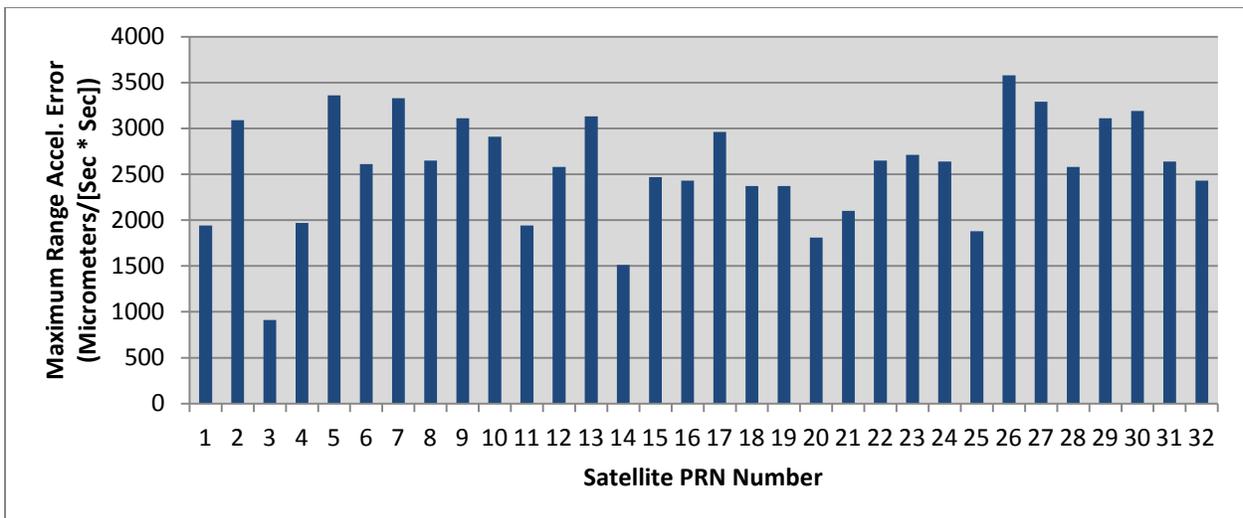
6   Solar Storms

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 13-15 October 2014
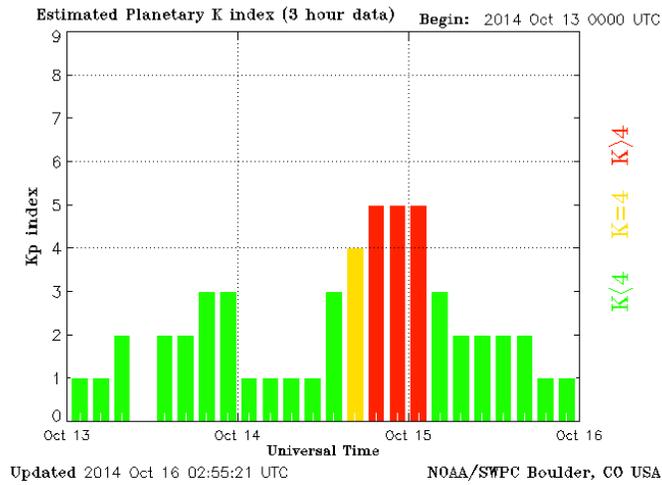
Figure 6-2 K-Index for 21-23 December 2014
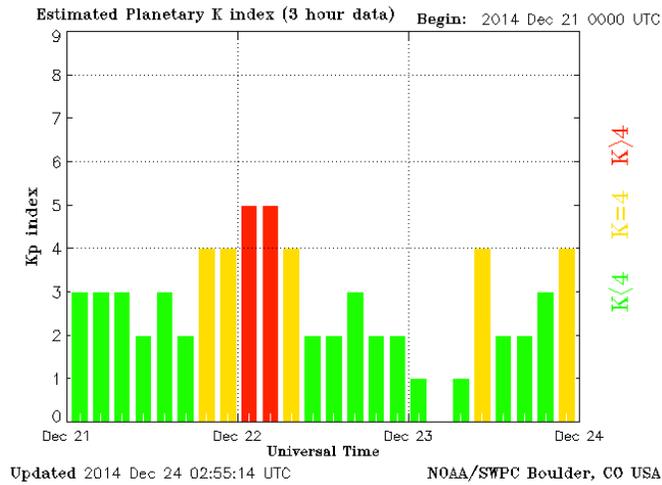
Figure 6-3 K-Index for 28-30 December 2014

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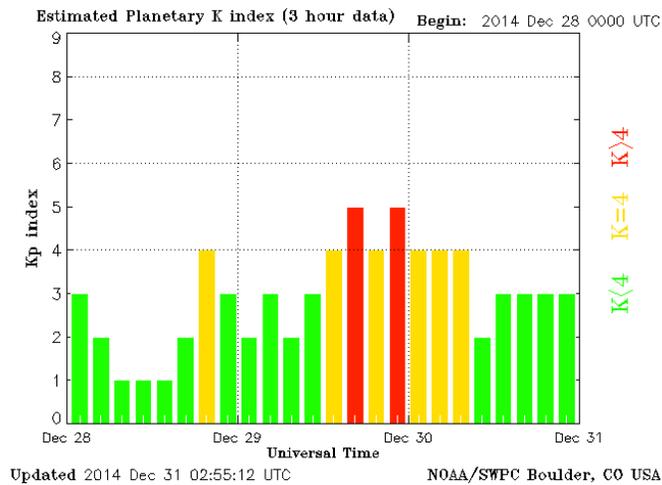
Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for October 14, 2014

Site	95% Horizontal (Meters)	95% Vertical (Meters)	Maximum Horizontal (Meters)	Maximum Vertical (Meters)
Albuquerque	1.695	5.236	2.029	6.304
Anchorage	2.093	3.155	3.167	4.366
Atlanta	2.078	5.845	2.332	7.216
Barrow	1.874	3.299	2.658	4.827
Bethel	2.264	3.445	2.998	4.482
Billings	2.150	6.125	2.939	7.994
Boston	2.257	6.548	2.782	7.249
Cleveland	2.643	6.762	3.704	7.992
Cold Bay	2.307	3.549	2.651	5.087
Fairbanks	2.135	3.315	3.609	4.234
Gander	2.779	5.576	3.488	7.438
Honolulu	3.963	3.784	5.048	5.802
Houston	1.790	5.105	1.989	5.687
Iqaluit	4.346	6.405	6.041	10.433
Juneau	2.024	3.466	3.475	5.064
Kansas City	2.360	5.826	3.023	6.315
Kotzebue	2.084	3.255	2.574	6.395
Los Angeles	1.588	4.918	2.301	5.577
Merida	2.337	6.471	2.625	8.031
Miami	1.951	5.040	2.521	6.248
Minneapolis	2.534	6.431	3.341	7.327
Oakland	1.590	5.044	2.191	6.257
Salt Lake City	1.786	5.248	2.047	6.428
San Jose Del Cabo	2.015	4.872	4.314	8.497
San Juan	5.353	8.257	9.341	17.908
Seattle	2.638	4.898	3.333	7.449
Tapachula	3.199	8.630	4.403	14.907
Washington, DC	2.510	6.289	3.307	7.597

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. The 3 Russian Federation sites, MOBN, NRIL, and PETS, have not yet been returned to service. 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.

Equatorial sites experienced higher than norm errors this quarter due to increased errors in the Klobuchar ionosphere model used by SPS receivers. The errors are due to increased solar activity and the seasonal tilt of the earths axis with respect to the sun. Figures 7-4 and 7-5 show the accuracy trends with the equatorial sites excluded. Figure 7-6 shows an example of the impact of the poor Klobuchar model performance. Figure 7-7 shows the NNOR outlier visible in Figure 7-4. This event appears to be receiver maintenance. Figure 7-8 shows an example of the daily scintillation errors seen at the BOGT site which cause it to be an outlier if Figure 7-5.

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	Columbia
GLPS	Puerto Ayora	Ecuador
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
SUTM	Sutherland	South Africa
TIDB	Tidbinbilla	Australia
UNSA	Salta	Argentina
USUD	Usuda	Japan

Figure 7-1 Selected IGS Site Locations

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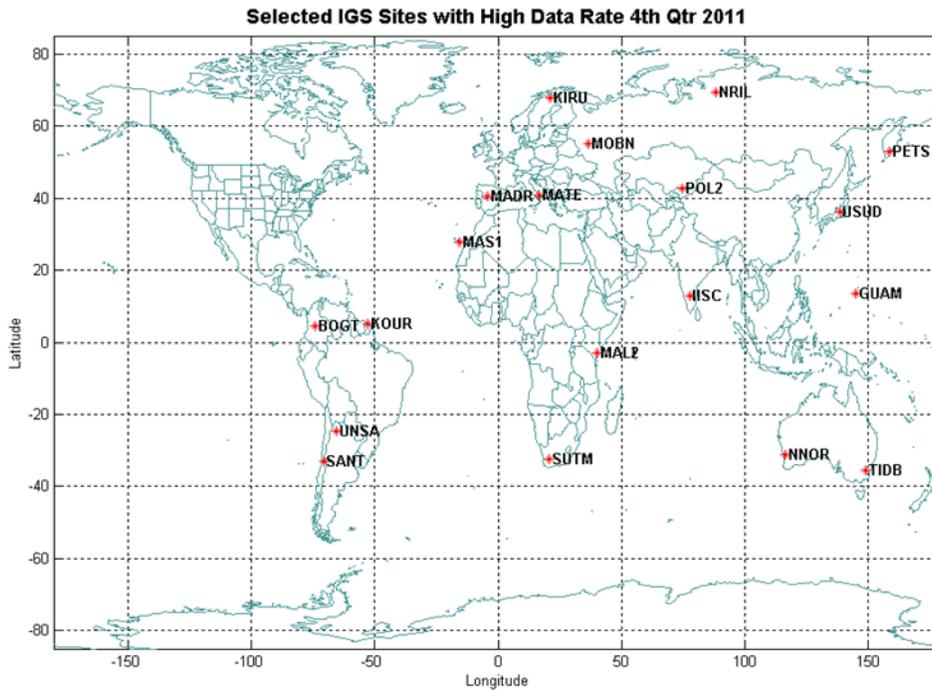
Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

Site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
BOGT	9.12	11.97	24.83	48.64	96.48%
GLPS	7.79	8.36	21.37	28.53	98.83%
GUAM	4.28	8.11	8.10	18.12	98.00%
IISC	6.20	8.49	14.84	23.23	86.25%
KIRU	3.19	9.09	8.02	15.19	99.88%
KOUR	9.09	9.31	24.67	28.00	94.64%
MADR	3.63	7.54	10.45	20.25	99.88%
MAL2	5.40	7.73	13.55	17.55	99.93%
MAS1	12.62	9.70	21.62	22.96	99.98%
MATE	2.54	7.55	10.47	14.74	42.36%
MOBN	-	-	-	-	N/A
NNOR	2.75	5.87	11.61	16.39	99.99%
NRIL	-	-	-	-	N/A
PETS	-	-	-	-	N/A
POL2	2.56	10.28	15.78	31.49	81.96%
SANT	4.64	6.36	7.86	13.23	12.09%
SUTM	3.11	5.85	5.49	9.18	54.27%
TIDB	2.45	5.55	7.32	18.80	98.73%
UNSA	6.32	11.38	32.90	50.01	47.88%
USUD	4.18	8.93	15.05	27.26	76.06%

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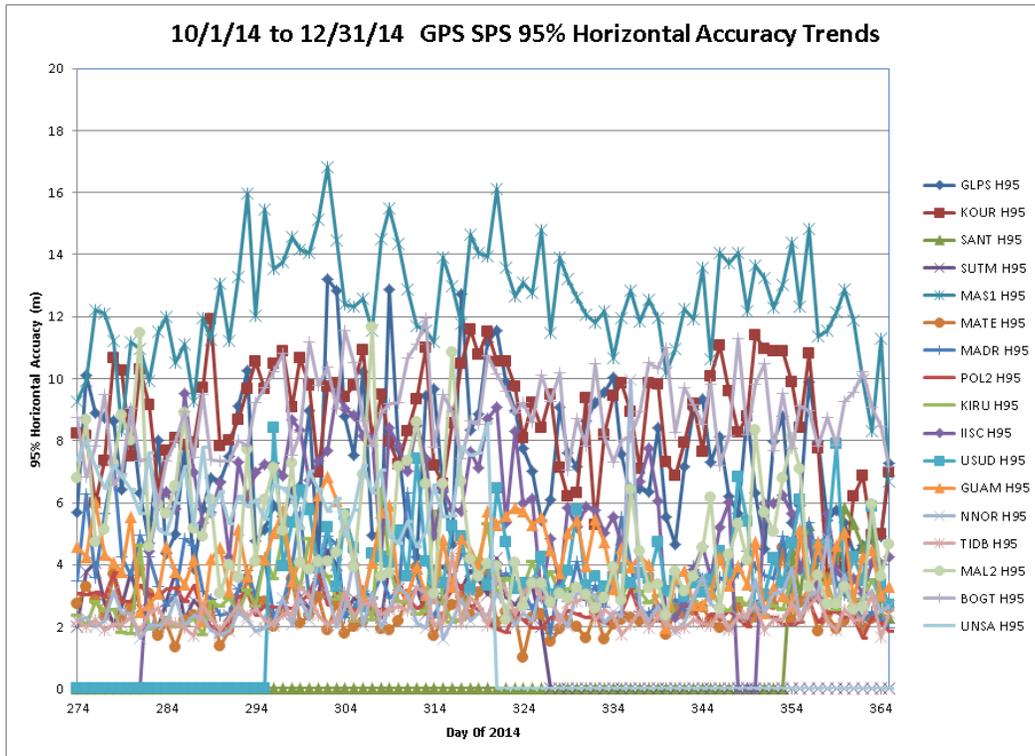
Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites

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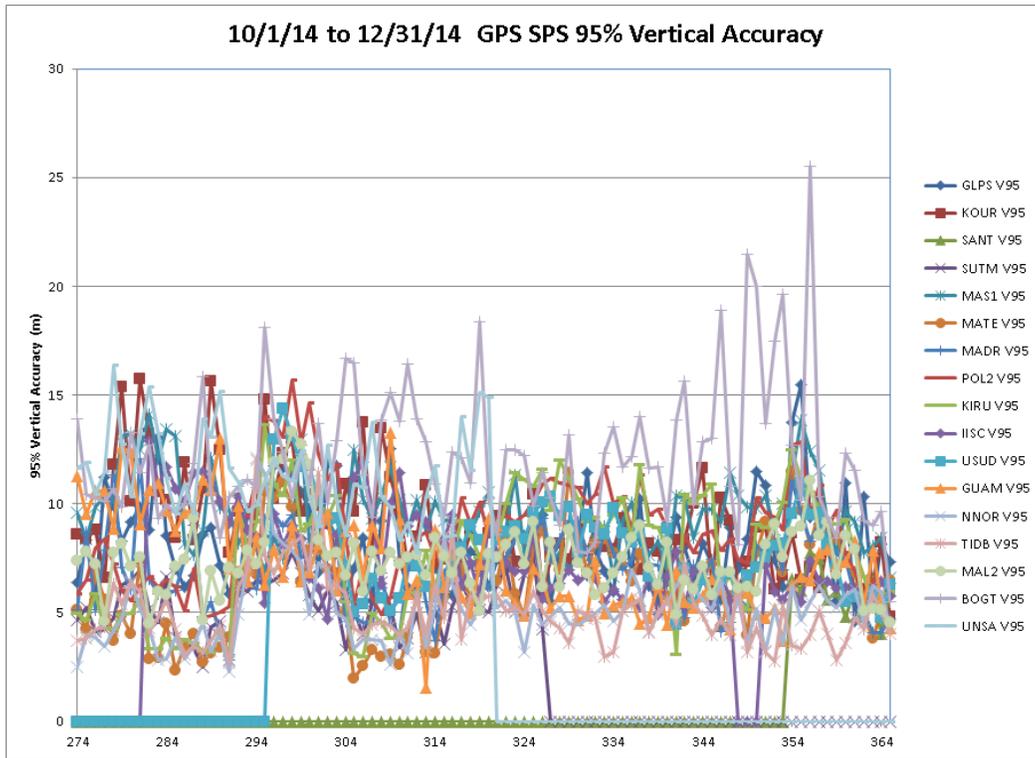
**Figure 7-4 GPS SPS 95% Horizontal Accuracy Excluding Equatorial Sites**
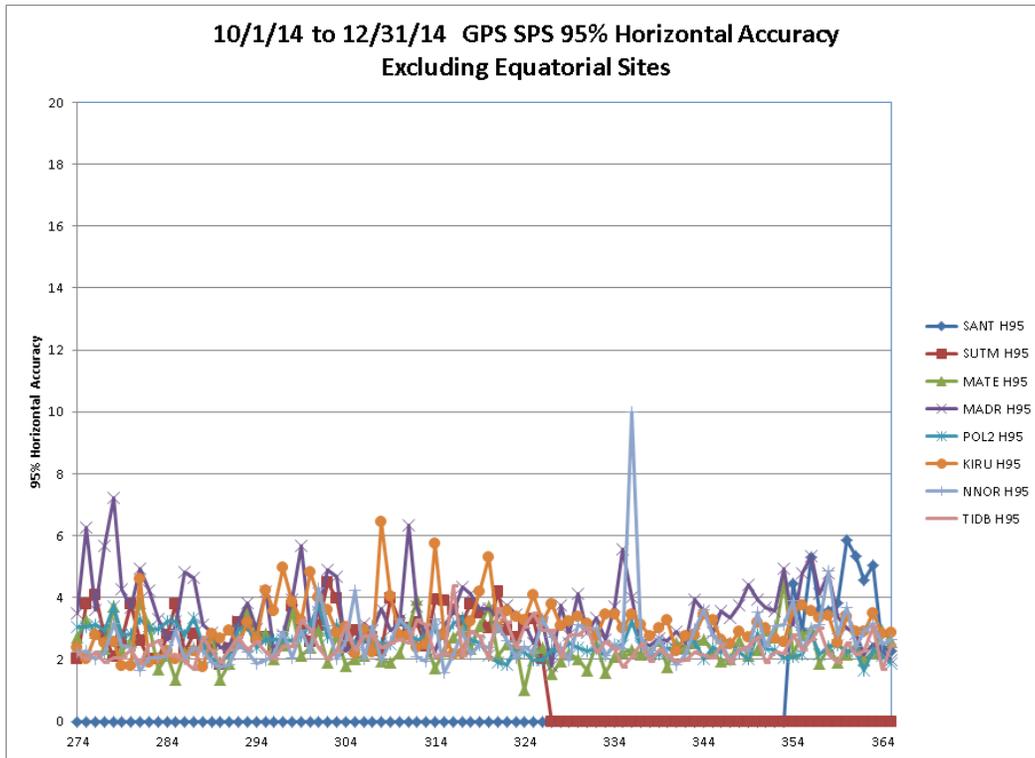
Figure 7-5 GPS SPS 95% Vertical Accuracy Excluding Equatorial Sites
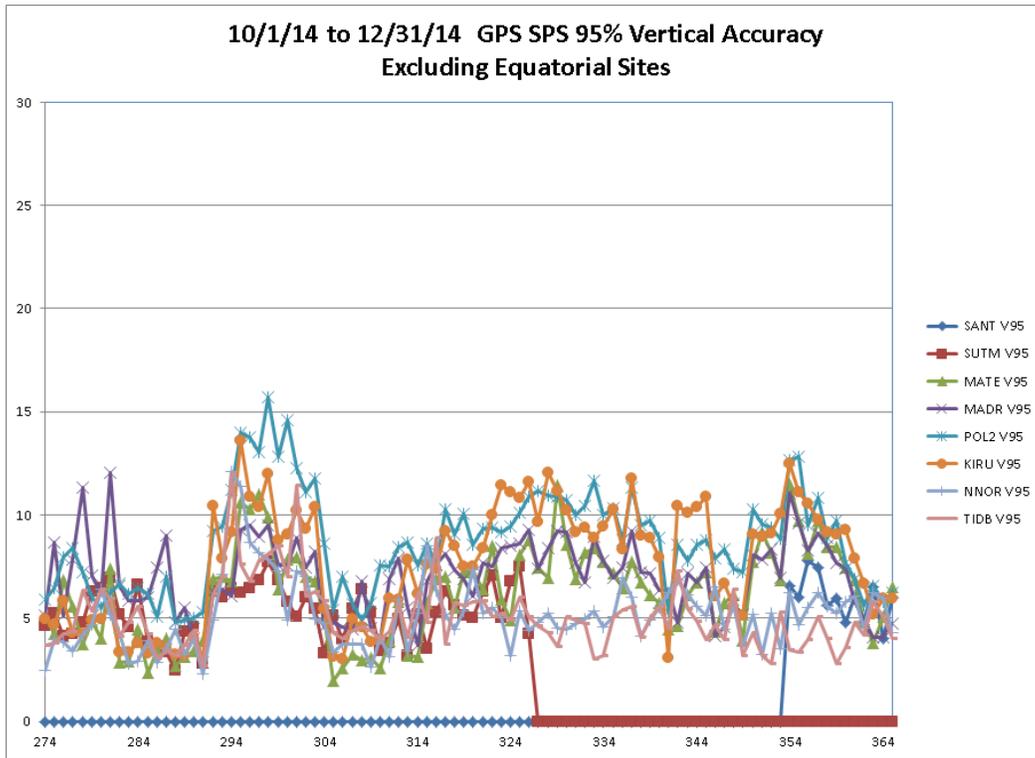
**Figure 7-6 Example of Poor Klobuchar Model Performance**

SPS Mode East North Up Position Error (RGB is ENU) IGS MAS1 2014 D301
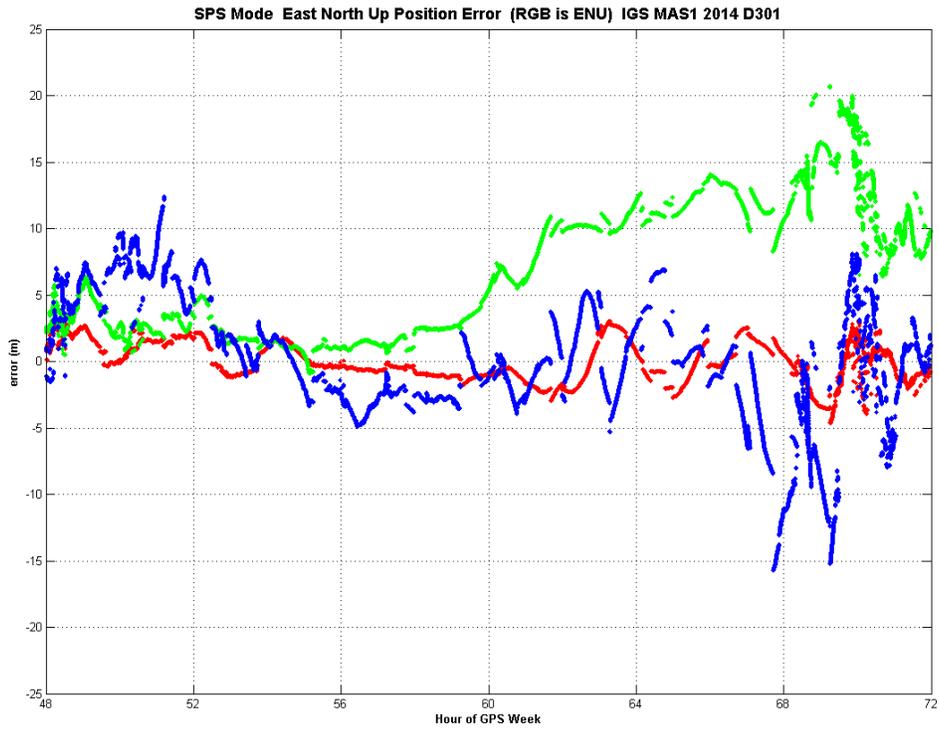
Figure 7-7 Day 336 Outlier at NNOR

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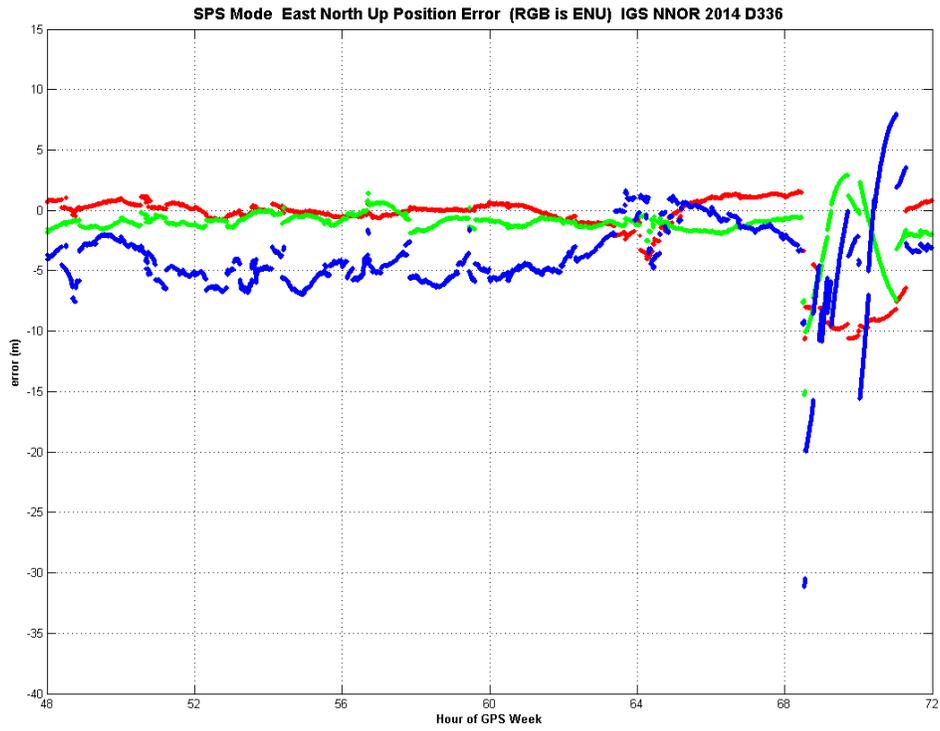
Figure 7-8 Example of Suspect Daily Scintillation Issues for BOGT
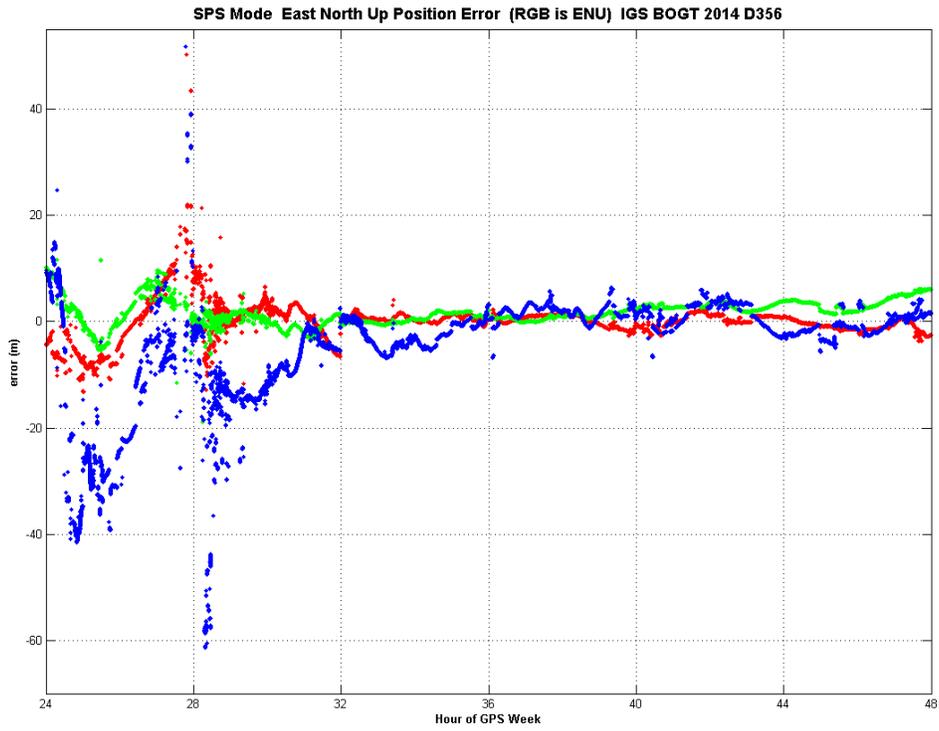
8   RAIM Performance

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

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

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

8.1   Site Performance

Table 8-1 shows the RAIM performance for the twenty-eight sites evaluated. For all sites collected, the minimum percent of time in RNP 0.1 mode was 99.17% at Honolulu, Hawaii. The minimum percent of time spent in RNP 0.3 mode was 99.99% at Seattle, Washington. The maximum 99% HPL value was 156.751 meters at Kansas City, Kansas.

Table 8-1 RAIM Site Statistics

CITY	99% HPL	Percent RNP 0.1	Percent RNP 0.3
Albuquerque	111.675	99.992	100
Anchorage	128.662	99.972	100
Atlanta	125.712	99.605	100
Barrow	138.865	99.894	100
Bethel	156.605	99.746	100
Billings	145.277	99.771	100
Boston	138.005	99.668	100
Cleveland	150.5	99.978	100
Cold Bay	138.163	99.805	100
Fairbanks	131.936	99.715	100
Gander	149.517	99.978	99.997
Honolulu	149.165	99.173	100
Houston	94.799	100	100
Iqaluit	143.264	99.982	100
Juneau	145.924	99.971	100
Kansas City	156.751	99.714	100
Kotzebue	154.459	99.741	100
Los Angeles	122.407	99.854	100
Merida	92.238	99.998	100
Miami	96.444	99.998	100
Minneapolis	151.399	99.909	100
Oakland	126.23	99.999	100
Salt Lake City	127.027	99.998	100
San Jose Del Cabo	99.436	100	100
San Juan	84.517	100	100
Seattle	110.115	99.983	99.996
Tapachula	91.657	100	100
Washington DC	132.257	99.868	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 October and 31 December 2014.

Figure 8-1 RAIM RNP 0.1 Coverage

SPS RAIM RNP 0.1 (HAL = 185m) Availability
FD Only, SA Off, without Baro-Aiding
October 1 – December 31, 2014

Percent Avail.	WNR Coverage	Global
95	100.00%	99.80%
98	99.58%	97.36%
99	97.47%	90.40%
100	20.32%	28.21%
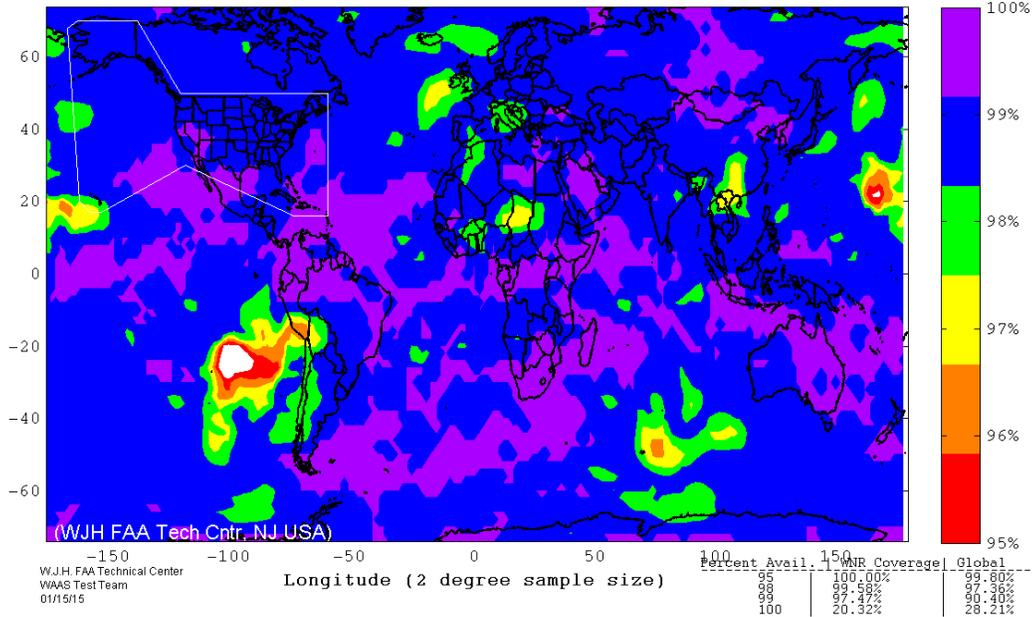
Figure 8-2 RAIM RNP 0.3 Coverage

SPS RAIM RNP 0.3 (HAL = 556m) Availability
FD Only, SA Off, without Baro-Aiding
October 1 – December 31, 2014

Percent Avail.	WNR Coverage	Global
95	100.00%	100.00%
98	100.00%	100.00%
99	100.00%	100.00%
100	83.26%	87.38%

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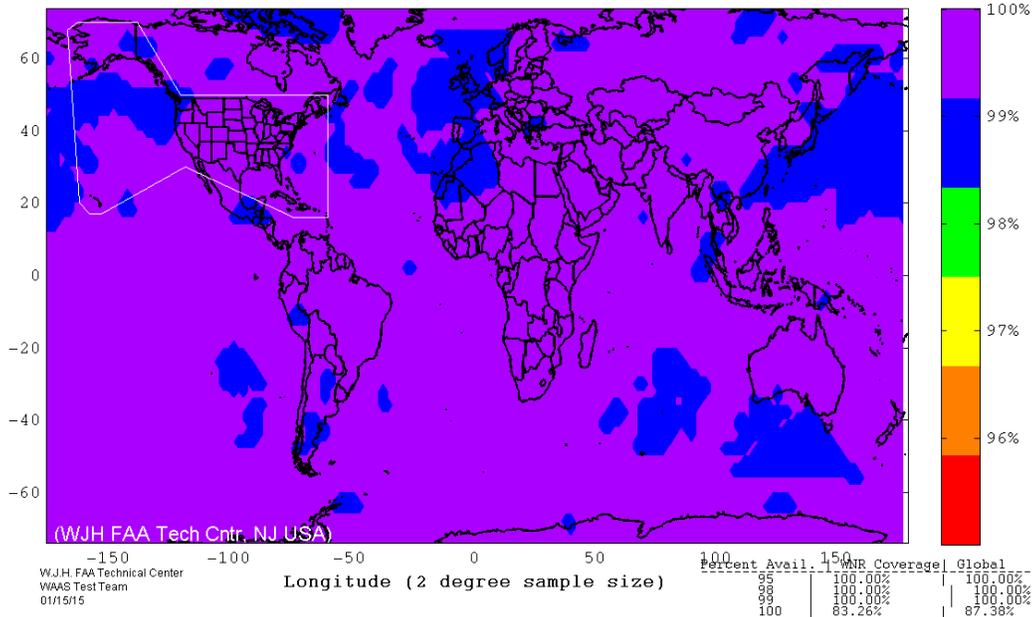
Figure 8-3 RAIM World Wide Coverage Trend
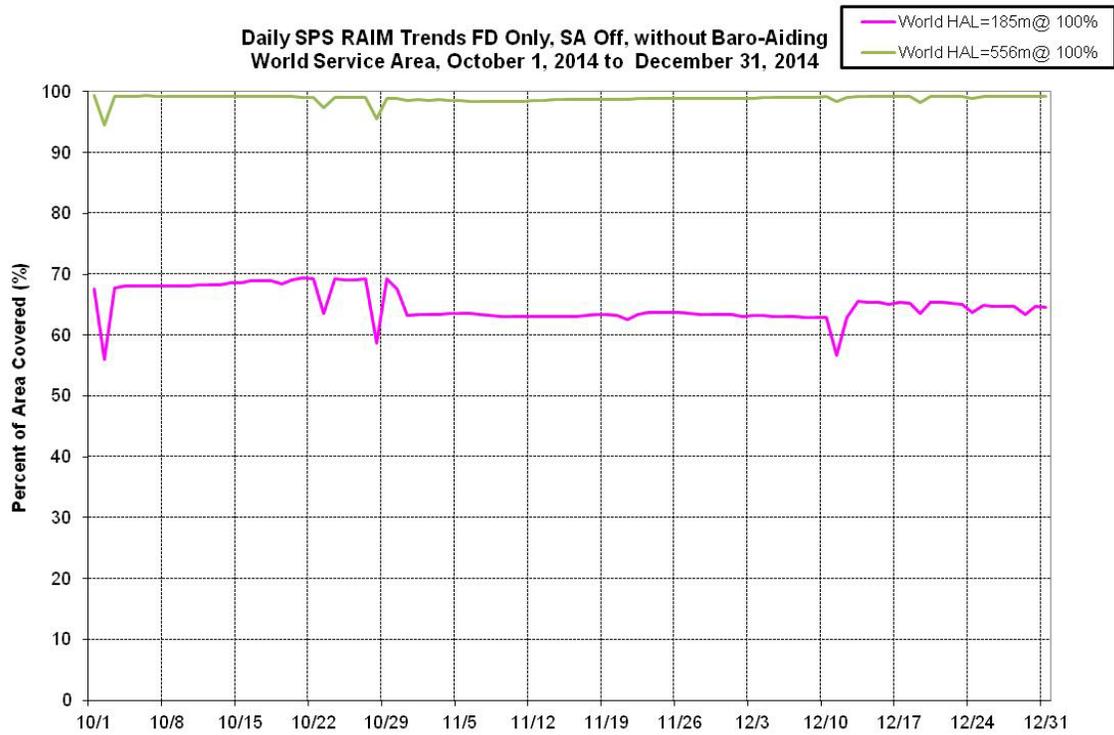
Figure 8-4 RAIM RNP Coverage Trend for WAAS NPA Service Area
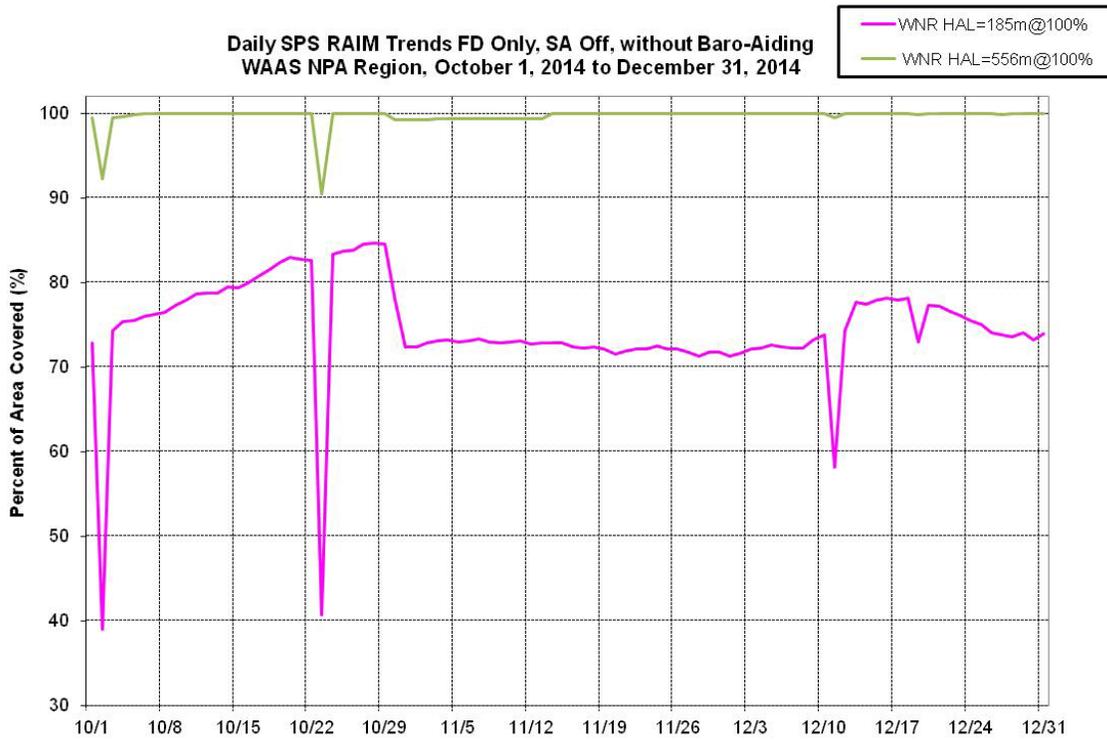
8.3   RAIM Airport Analysis

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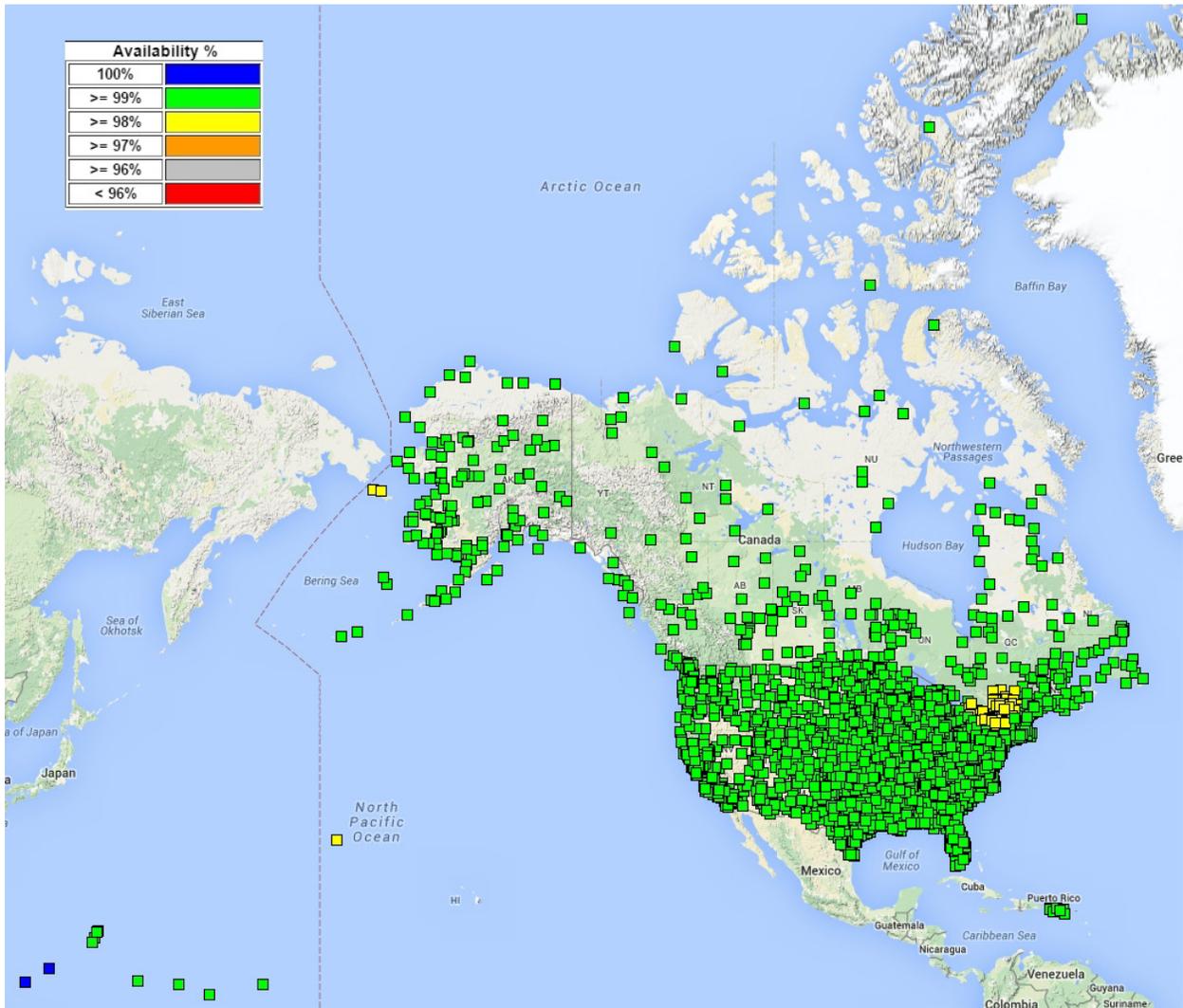
Figure 8-6 RAIM RNP 0.3 Airport Availability
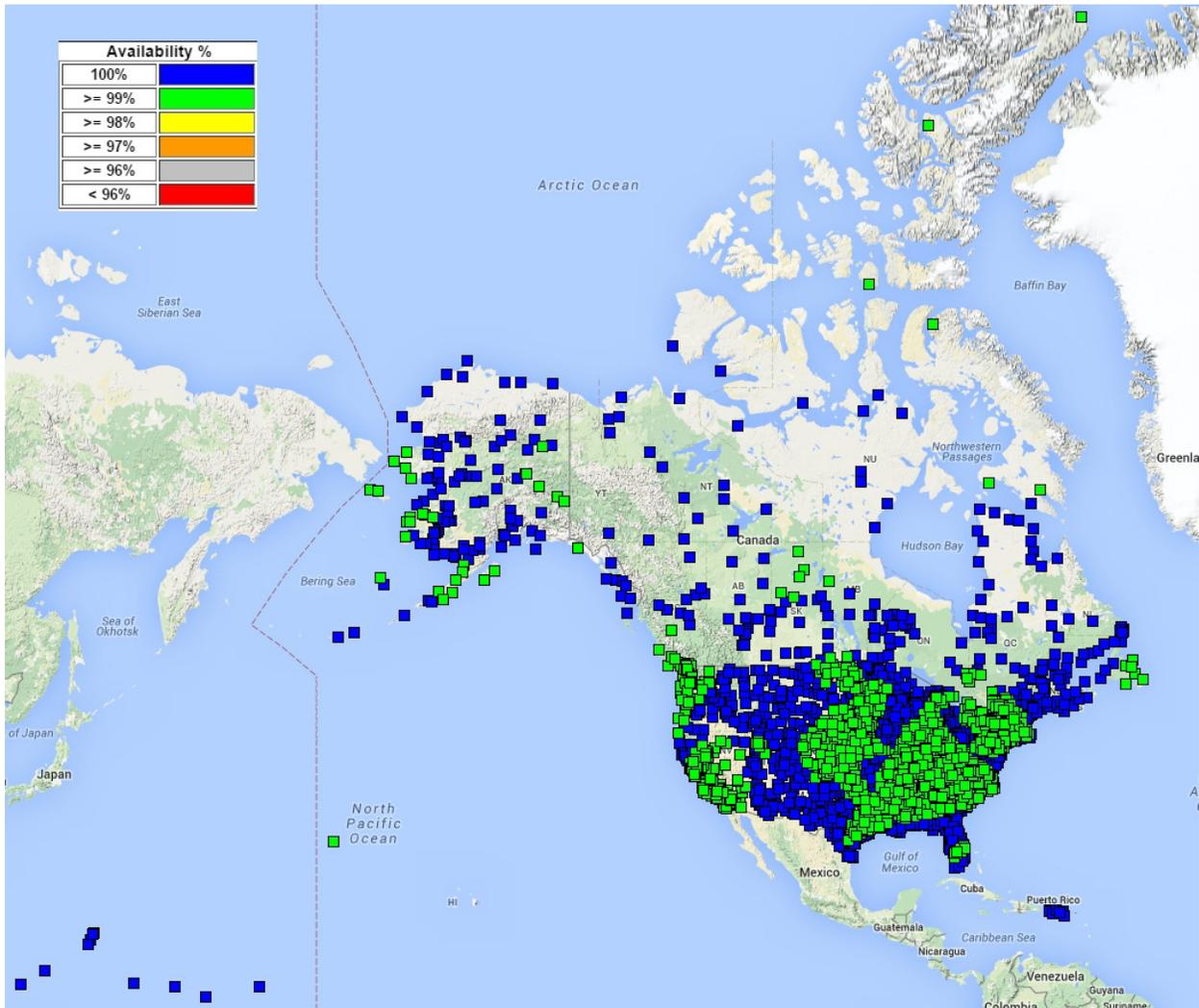
Figures 8-7 and 8-8 respectively show the number of RAIM RNP 0.1 and RAIM RNP 0.3 outages for every airport in the U.S. and Canada that have a RNAV (GPS) published approach or better.

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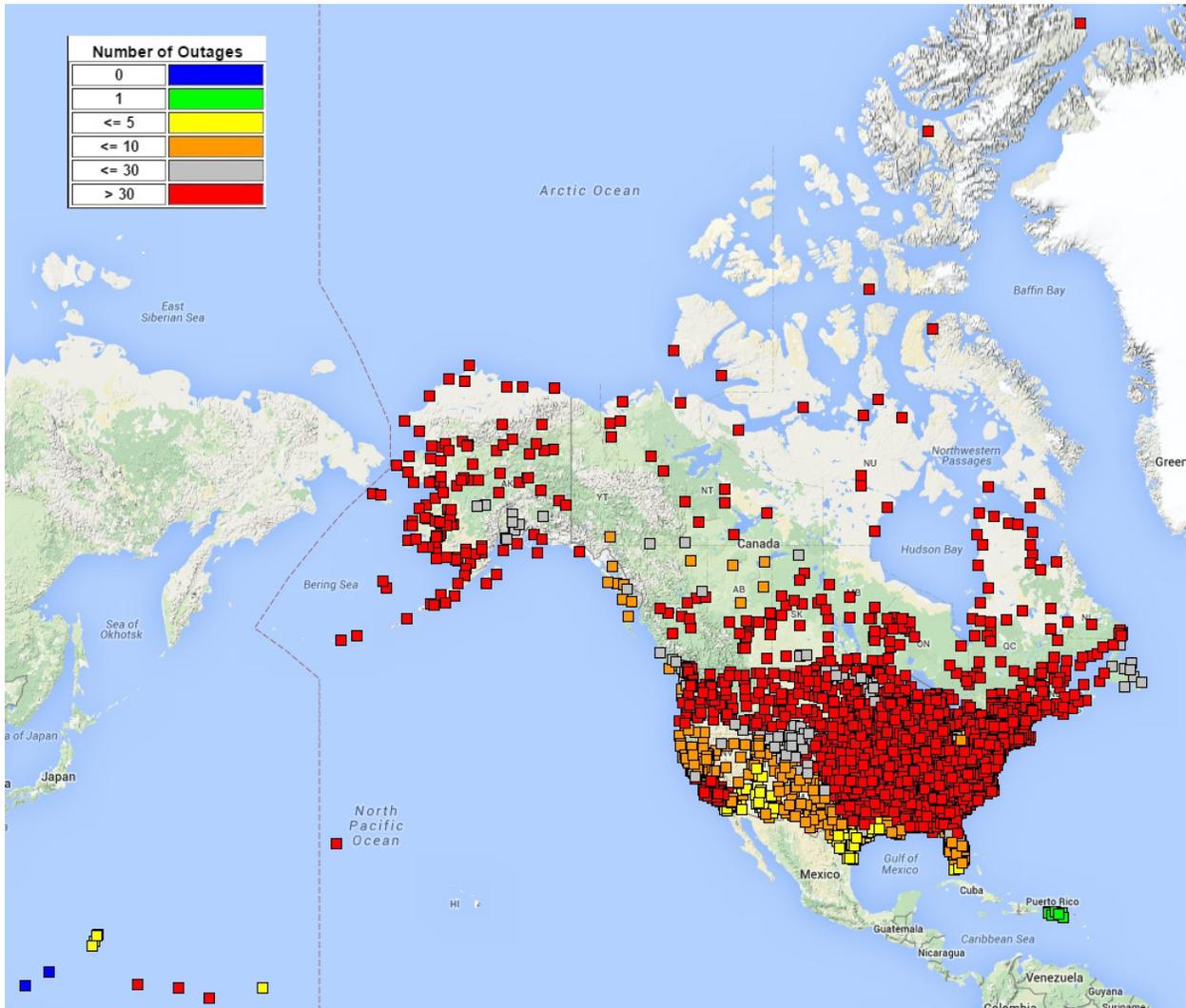
Figure 8-8 RAIM RNP 0.3 Airport Outages
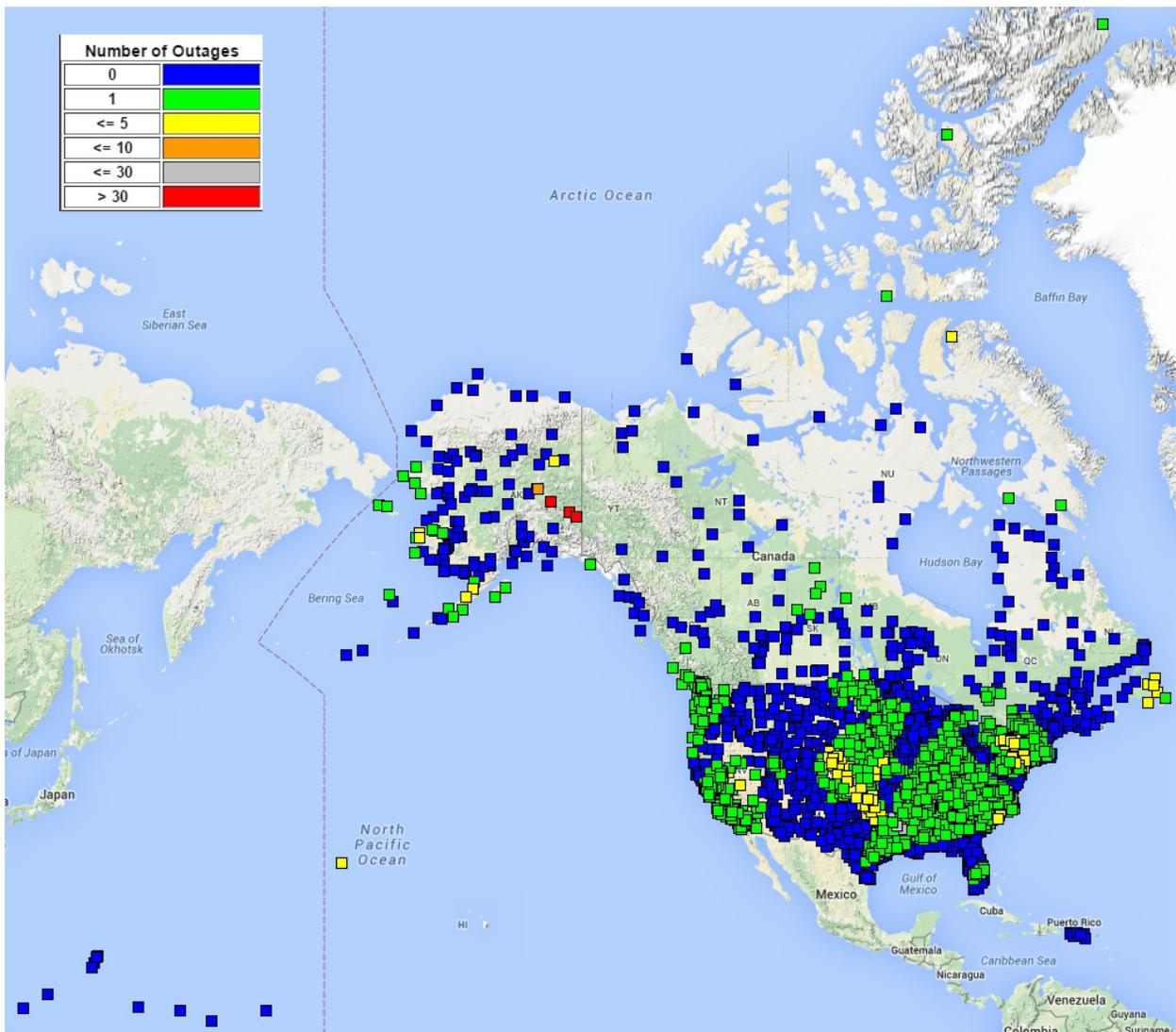
9   GPS Test NOTAMs Summary

> **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 October through 31 December 2014, there were a total of 35 GPS test NOTAMs. The total number of days affected in this reporting period is 47. 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	150.48 hours
Minimum Duration	1.50 hours
Media Duration	4.00 hours
Average Duration	4.43 hours
Maximum Duration	9.00 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	685,782	483,774	264,201	270,529	176,550
Average	1,079,249	912,486	602,901	564,588	523,618
Maximum	1.231,209	1,094,886	675,685	603,926	578,831

9.2   Tracking and Trending of GPS Test NOTAMs

The GPS Test NOTAMs that are tracked and trended for this reporting period were done with a specialized software analysis tool that is designed to not only trend but also archive GPS Test NOTAMs. It is designed to trend archived GPS Test NOTAMs for any specified time frame. In addition to the data provided in this report, this tool will

provide all data presented here along with airports with affected procedures via a web interface. The web interface is available at the following URL: http://waas.faa.gov/static/sog/notam/index.html.

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

Figure 9-1 GPS Test NOTAMs @ FL400
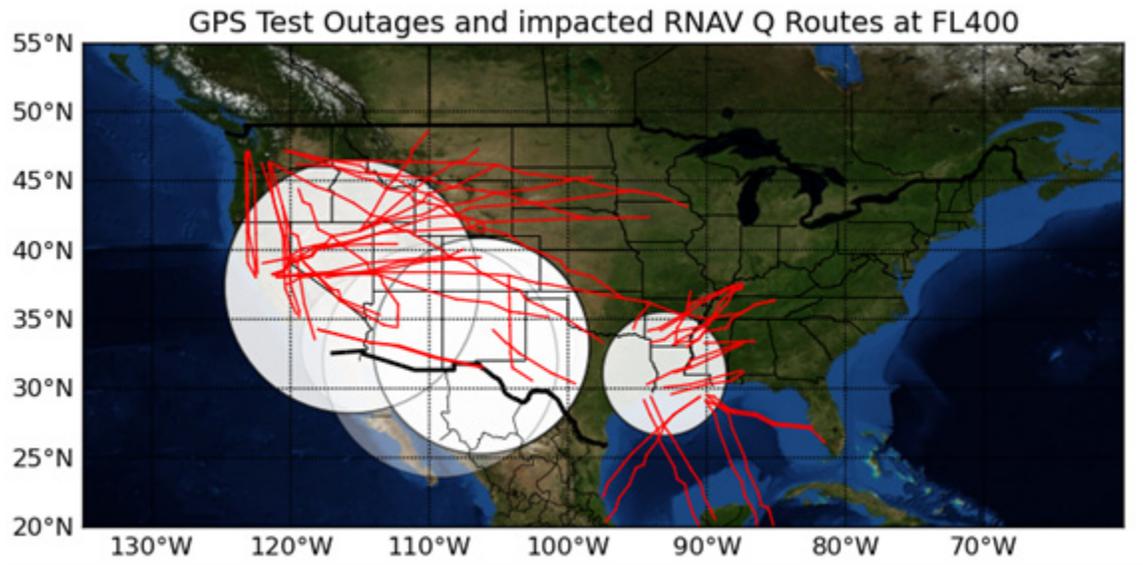
Figure 9-2 GPS NOTAMs @ FL250
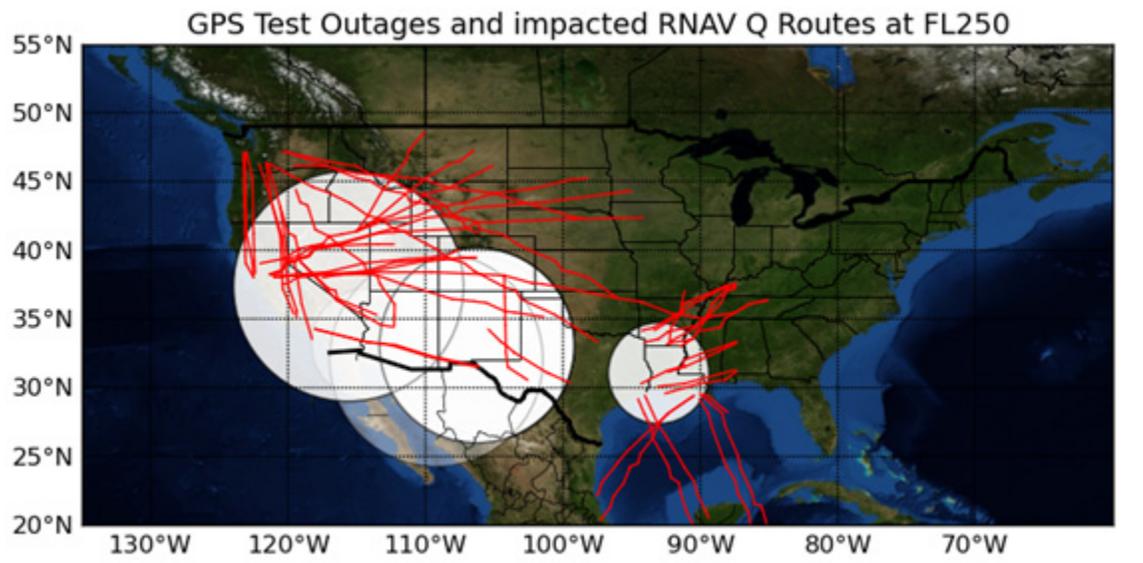
Figure 9-3 GPS NOTAMs @ 10k Feet
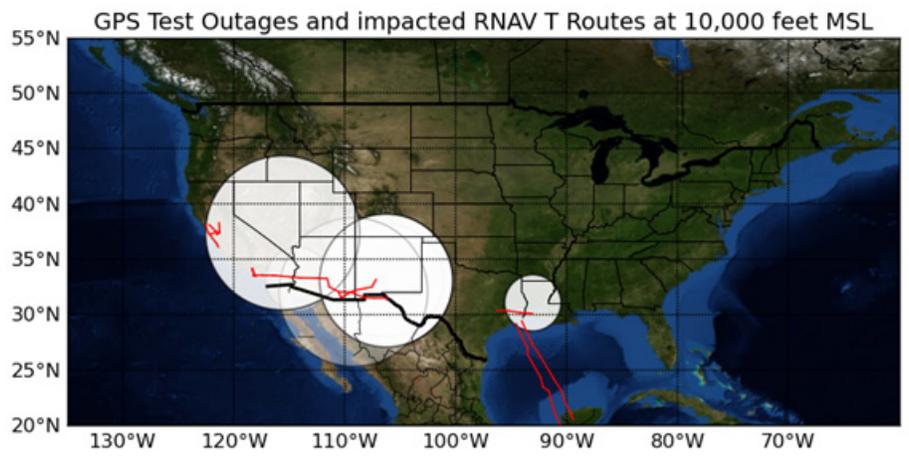
Figure 9-4 GPS NOTAMs @ 4k Feet
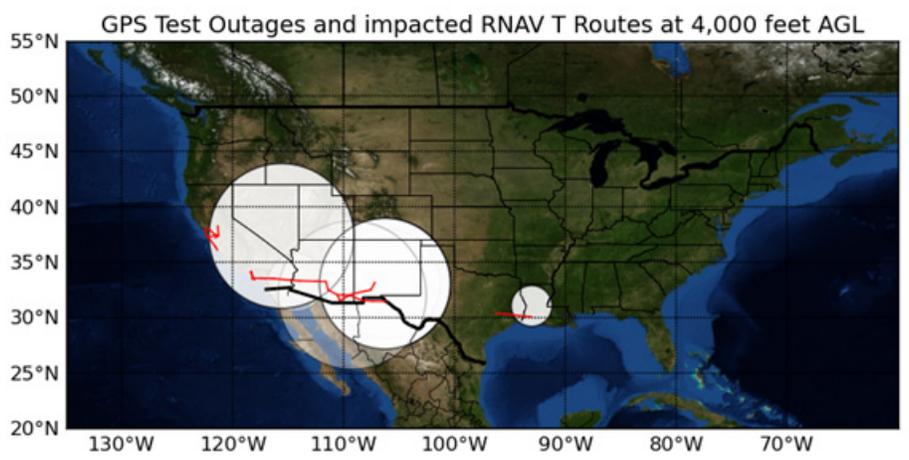
Figure 9-5 GPS NOTAMs @ 50 Feet
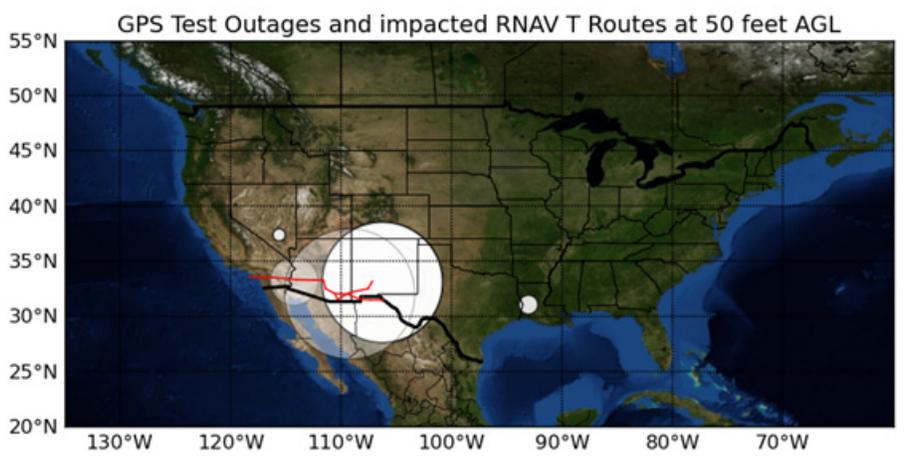
9.3   GPS Availability

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

Table 9-3 NOTAM Impact to GPS Availability

				Percent Impact at each altitude				
Start Date	End Date	Latitude	Longitude	50	4000	10000	FL250	FL400
2014-10-04 04:00:00	2014-10-04 10:00:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-08 18:30:00	2014-10-11 22:30:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-09 06:00:00	2014-10-09 12:00:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-10 03:00:00	2014-10-10 07:00:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-11 03:00:00	2014-10-11 07:00:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-11 18:30:00	2014-10-11 20:00:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-12 03:00:00	2014-10-12 07:00:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-14 20:00:00	2014-10-14 22:30:00	37.1934N	-115.4249W	4.75	7.33	6.91	12.59	16.10
2014-10-16 03:00:00	2014-10-24 07:00:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-16 18:15:00	2014-10-21 18:15:00	36.0728N	-86.4041W	0.10	0.10	0.10	0.10	0.10
2014-10-16 18:30:00	2014-10-18 22:30:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-18 18:30:00	2014-10-23 22:30:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-24 18:30:00	2014-10-26 22:30:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-25 03:00:00	2014-10-25 09:00:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-26 03:00:00	2014-11-01 07:00:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-10-29 18:30:00	2014-10-30 22:30:00	32.4440N	-106.0817W	11.56	11.76	12.80	19.81	22.39
2014-11-07 04:00:00	2014-11-07 09:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-08 18:30:00	2014-11-08 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-10 18:30:00	2014-11-10 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-11 18:30:00	2014-11-11 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-12 18:30:00	2014-11-12 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-13 18:30:00	2014-11-13 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-14 18:30:00	2014-11-14 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-15 18:30:00	2014-11-15 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-17 18:30:00	2014-11-17 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-18 18:30:00	2014-11-23 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-19 03:00:00	2014-11-19 12:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-20 04:31:00	2014-11-20 12:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-11-21 04:00:00	2014-11-21 09:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-12-01 18:30:00	2014-12-01 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-12-03 18:30:00	2014-12-03 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-12-05 18:30:00	2014-12-05 22:30:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2014-12-06 18:30:00	2014-12-06 22:30:00	37.1934N	-115.4249W	4.75	7.33	6.91	12.59	16.10
2014-12-08 04:00:00	2014-12-10 09:00:00	37.1934N	-115.4249W	4.75	7.33	6.91	12.59	16.10
2014-12-19 04:00:00	2014-12-19 09:00:00	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	≤ 4.797 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	≤ 3.650 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	≤ 0.027 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	$\geq$ 80.133 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	Not Applicable
Unscheduled Failure Interruption Continuity • $\geq$ 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**	
• $\geq$ 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**	
• $\geq$ 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	100 % 100 %
Service Availability	**Conditions and Constraints**	
• $\geq$ 99% Horizontal Service Availability, average location • $\geq$ 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
• $\geq$ 90% Horizontal Service Availability, worst-case location • $\geq$ 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

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Position/Time Accuracy	Conditions and Constraints	
Global Average Position Domain Accuracy • ≤ 9m 95% Horizontal Error • ≤ 15m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 3.247 m Horizontal ≤ 7.637 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.	≤ 9.262 m Horiz. ≤ 9.689 m Vert.
Time Transfer Domain Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for a time transfer solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 18 nanoseconds
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	≤ 47.9 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

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                  Current Quarter Daily Geomagnetic Data

             Middle Latitude        High Latitude            Estimated
            - Fredericksburg -      ---- College ----      --- Planetary ---

    Date        A    K-indices         A    K-indices        A    K-indices
2014 10 01     10  3 3 3 2 2 2 2 2    21  3 2 3 6 3 4 2 1   10  4 3 3 2 2 2 2 2
2014 10 02     13  2 2 2 5 2 2 3      10  2 2 2 4 3 2 1 1    8  2 2 2 2 2 2 1 3
2014 10 03      3  2 0 1 1 1 1 0 1     2  1 1 1 1 0 0 0 0    4  2 1 1 1 0 1 1 1
2014 10 04      5  1 1 2 2 1 1 1 2     4  1 2 3 2 0 0 0 1    6  1 2 2 2 1 1 1 2
2014 10 05      5  2 1 2 1 2 1 1 1     2  1 1 0 0 0 1 1 1    6  2 2 2 1 2 1 1 1
2014 10 06      6  2 2 0 2 2 2 2 2     3  1 2 0 0 2 0 1 1    6  3 2 1 1 1 1 1 2
2014 10 07      5  2 3 0 1 1 2 1 1     2  2 1 0 0 1 0 0 0    6  2 3 1 1 1 1 1 1
2014 10 08      6  1 1 2 2 2 2 2 2    16  1 0 0 5 5 3 2 2    9  1 1 2 3 2 2 2 3
2014 10 09     10  2 3 3 2 3 2 2 2     8  3 0-1-1 3 3 1 0   14  3 4 4 3 3 2 2 2
2014 10 10      7  3 3 1 1 2 2 1 1     5  1 3 1 1 1 2 1 1    8  3 3 1 1 1 1 2 1
2014 10 11      8  2 3 3 2 3 1 1 0    13  1 3 4 4 4 1 0 0   10  3 3 3 3 3 1 1 1
2014 10 12      2  0 0 1 1 1 1 1 1    13  0 1 0 5 5 2 0 0    5  1 1 1 2 2 1 1 1
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2014 10 14     12  1 1 1 1 3 4 3 4    21  0 1 0 1 5 5 5 3   18  1 1 1 1 3 4 5 5
2014 10 15      8  4 2 2 2 2 1 1 1    15  3 2 3 3 4 4 2 1   11  5 3 2 2 2 2 1 1
2014 10 16      5  2 1 0 1 2 1 1 3     9  1 1 0 4 4 1 1 1    7  2 1 1 2 2 2 1 3
2014 10 17      6  1 3 1 2 1 2 1 2     7  2 2 1 3 2 1 1 2    8  2 3 2 2 1 1 2 3
2014 10 18     11  3 3 2 2 3 2 2 3    20  3 3 3 5 4 4 2 2   15  4 3 2 2 3 4 2 3
2014 10 19      9  3 3 2 3 2 1 1 1    18  2 3 5 4 4 2 2 2   11  3 3 3 3 2 1 2 2
2014 10 20     17  3 2 3 3 3 4 4 3    48  1 3 6 6 6 6 4 3   26  3 3 4 4 4 5 4 4
2014 10 21     11  2 2 3 2 3 3 3 2    28  3 2 3 5 5 5 4 3   15  3 2 3 3 4 3 4 3
2014 10 22     10  3 2 3 2 3 2 2 2    23  3 3 3 5 5 4 2 2   14  4 3 3 2 3 3 3 2
2014 10 23      8  2 2 2 2 2 2 3 2    19  1 1 3 5 5 3 3 2   11  2 2 2 2 3 2 4 2
2014 10 24      9  2 1 1 3 3 3 2 1    18  2 1 3 4 4 5 2 2   11  3 1 2 2 2 4 2 2
2014 10 25      9  3 2 2 2 2 3 2 1    16  2 2 2 4 5 3 2 2   10  3 2 2 2 2 3 2 1
2014 10 26     11  3 2 3 3 3 2 2 1    20  1 2 3 4 5 5 2 1   12  3 3 3 3 3 2 2 1
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2014 11 03      5  2 1 2 1 2 1 0 2     2  1 0 2 1 0 0 0 1    6  3 2 2 2 1 1 0 2
2014 11 04     12  1 1 2 3 4 2 3 3    35  0 0 4 6 6 5 4 3   21  2 1 3 4 4 3 4 4
2014 11 05     13  4 3 2 3 3 2 2 2    18  3 3 2 5 4 3 2 2   16  4 4 3 4 3 2 3 3
2014 11 06     -1  1 2 2 1 2 2 3-1     9  2 2 3 1 4 1 1 1    9  2 2 2 2 2 1 2 3
2014 11 07     10 -1-1-1-1 1 3 2 3    13  2 2 4 4 4 1 1 1   12  3 3 2 3 2 2 2 3
2014 11 08      8  1 1 2 2 3 2 1 3     6  1 0 2 3 3 2 0 1    8  2 1 2 2 2 2 1 3
2014 11 09      8  3 2 2 1 2 2 2 2     7  3 2 3 1 1 2 1 1    9  3 2 2 1 1 2 2 3
2014 11 10     16  4 3 2 4 3 3 3 2    41  3 2 2 7 5 6 4 2   23  4 3 3 5 4 4 4 2
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2014 11 14      9  3 2 3 1 2 2 2 2     9  1 2 2 2 4 2 2 2   12  3 3 3 2 2 2 3 3
2014 11 15     13  2 3 2 3 3 2 2 4    28  2 3 5 6 5 1 2 3   17  3 3 3 3 3 2 2 4
2014 11 16     18  4 4 3 3 4 3 2 2    48  3 4 5 7 6 5 3 2   22  4 4 4 3 4 4 3 3
2014 11 17      8  2 1 1 2 3 2 3 2    16  1 1 0 5 5 3 2 2   12  3 2 1 2 3 3 3 3
2014 11 18      9  2 2 2 3 3 2 1 2    20  2 2 3 5 5 4 2 1   11  3 3 2 3 3 3 2 2
2014 11 19      6  2 1 1 1 2 2 3 1     9  2 1 1 3 4 2 1 1    8  4 1 2 2 2 1 2 1
2014 11 20      8  2 2 2 3 2 2 2 1    19  2 2 3 5 4 4 3 1   11  4 2 2 3 1 2 3 2
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2014 11 21    10   3 3 1 2 3 2 2 2    26   3 3 3 6 4 5 2 1    15   4 4 2 3 3 3 3 3
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2014 11 23     9   1 1 3 3 3 2 2 1    24   2 2 3 6 5 3 3 1    10   2 2 3 3 3 2 3 2
2014 11 24     5   3 1 1 1 2 1 1 0    14   1 1 2 2 5 4 2 2     7   3 2 1 2 2 2 2 1
2014 11 25     4   1 2 0 2 2 1 1 1     5   0 0 0 3 3 2 1 0     5   1 2 1 2 1 2 2 1
2014 11 26     4   1 1 1 1 2 1 1 1     8   0 0 1 4 4 1 0 0     5   1 1 2 1 2 1 0 1
2014 11 27     7   1 3 1 1 2 2 2 2     4   0 1 1 2 2 2 1 1     8   2 3 2 1 2 2 2 2
2014 11 28     5   1 1 0 0 3 2 2 1     5   1 0 0 0 4 2 1 0     5   1 1 0 1 3 2 1 1
2014 11 29     5   1 1 1 1 2 2 2 1     2   0 0 0 0 2 1 1 0     5   1 1 2 1 2 2 2 1
2014 11 30     6   1 1 2 2 2 2 2 2     3   0 1 1 1 0 2 1 2     9   1 2 2 2 1 3 3 3
2014 12 01     9   1 2 2 1 2 2 2 4     8   1 2 2 1 3 1 2 3    10   2 2 2 1 2 2 2 4
2014 12 02     9   3 2 2 2 3 2 2 2    17   3 2 3 3 5 3 3 1    12   3 3 3 2 3 3 2 3
2014 12 03     7   3 2 1 2 1 2 2 2     5   2 1 1 0 1 2 2 2     8   3 2 1 2 2 2 3 2
2014 12 04     8   2 1 1 1 2 2 2 4    15   1 2 2 3 4 5 1 2    11   3 2 1 1 2 3 2 4
2014 12 05     8   2 3 2 2 2 1 2 2    26   2 4 4 6 5 3 1 1    11   2 3 2 3 3 2 2 2
2014 12 06    10   1 2 2 2 2 2 3 4    13   1 1 4 4 2 2 3 3    13   2 2 3 2 2 2 4 4
2014 12 07    19   4 2 2 3 4 4 4 3    53   4 3 3 6 7 6 5 3    28   5 3 3 3 5 4 4 4
2014 12 08    11   3 2 2 2 3 3 2 3    29   3 3 3 5 5 5 4 3    17   4 3 3 2 3 4 3 3
2014 12 09    12   4 2 3 2 2 1 3 3    23   3 2 4 5 5 3 3 2    15   4 3 3 2 3 2 4 3
2014 12 10     6   2 2 1 3 1 2 1 1     9   2 2 3 4 2 2 0 1     9   3 3 2 3 2 1 1 1
2014 12 11     4   2 0 1 1 1 2 1 2     2   0 0 1 1 0 1 2 0     6   2 1 1 1 1 1 2 3
2014 12 12    15   2 2 3 2 5 3 3 2    43   2 2 6 5 6 6 4 3    21   3 3 4 3 5 4 4 3
2014 12 13     6   1 2 0 1 2 3 2 2    -1   2 2 3 2 -1 -1 -1 -1    11   2 3 2 2 2 3 3 3
2014 12 14     9   1 2 2 2 3 2 3 2    21   2 2 4 4 5 4 3 2    11   2 3 2 2 3 3 3 2
2014 12 15    11   1 2 2 3 3 3 2 3    29   1 2 5 5 6 4 3 1    15   2 3 3 3 3 3 3 3
2014 12 16     7   1 1 0 1 3 2 2 3    18   1 1 2 4 6 3 2 1     8   1 1 1 2 3 2 2 3
2014 12 17     6   2 2 2 1 2 2 1 1     7   2 3 3 2 1 2 1 0     8   3 3 2 1 1 2 2 1
2014 12 18     5   1 1 0 2 2 2 1 2     3   1 0 0 1 2 2 1 1     5   1 1 1 1 1 2 2 2
2014 12 19     6   2 1 2 2 2 2 1 1     8   0 1 2 4 2 3 1 1     8   3 2 2 2 1 2 2 2
2014 12 20     6   2 2 1 2 2 2 1 2     2   0 -1 -1 -1 -1 1 0 1     9   3 2 2 2 2 2 1 3
2014 12 21    10   2 2 2 2 3 2 3 3    28   1 4 4 4 6 4 3 3    14   3 3 3 2 3 2 4 4
2014 12 22    13   4 3 4 2 2 3 1 1    28   5 5 5 5 2 3 1 1    20   5 5 4 2 2 3 2 2
2014 12 23     8   1 0 0 4 2 2 2 3    10   0 0 1 3 2 1 2 5    13   1 0 1 4 2 2 3 4
2014 12 24    12   3 3 2 2 3 2 3 3    24   3 2 4 4 5 5 3 2    17   4 3 2 2 4 3 3 3
2014 12 25     9   2 1 1 0 3 3 3 3    16   1 1 1 0 5 4 3 4    13   2 2 2 1 3 3 4 4
2014 12 26    15   4 3 2 2 2 3 4 3    22   3 5 4 3 2 2 4 4    17   4 4 2 2 2 2 4 3
2014 12 27     5   2 2 1 2 1 2 1 1    10   3 2 3 3 3 2 1 0     7   3 2 2 2 2 1 1 1
2014 12 28     8   2 2 2 1 2 2 3 2     9   0 1 2 2 3 2 4 2    11   3 2 1 1 1 2 4 3
2014 12 29    15   1 2 2 3 3 4 3 4    34   1 2 3 5 6 6 3 4    23   2 3 2 3 4 5 4 5
2014 12 30    14   3 4 4 2 3 2 2 2    36   3 4 5 5 5 5 5 2    18   4 4 4 2 3 3 3 3
2014 12 31     7   2 2 2 1 2 3 1 1    17   2 2 2 2 5 5 2 1     8   2 2 2 2 2 3 2 2
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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.