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

Submitted To

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GPS Product Team

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Executive Summary

The GPS Product Team has tasked the Navigation 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 #84, includes data collected from 1 October through 31 December 2013. The next quarterly report will be issued April 30, 2014.

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

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

NANU summary and evaluation was achieved by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 October and 31 December 2013. 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 ten outages were reported in the NANU’s this quarter. Seven outages were scheduled while three were unscheduled.

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

Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error standard was verified for each satellite from 24-hour accuracy values computed using data collected at the following six sites: Boston, Honolulu, Los Angeles, Miami, San Juan and Juneau. This data was also collected in one-second samples. All sites achieved 100% reliability, meeting the SPS specification. The maximum range error recorded was 31.051 meters on Satellite PRN 11. 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 4.008 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 10.98 meters at Maspalomas, Spain and 10.51 meters at Bogota, Colombia respectively.

From the analysis performed on data collected between 1 October and 31 December 2013, the GPS performance met all SPS requirements that were evaluated. However, a couple issues were noted and discussed in the problem report in section 9.3 on page 50. Ionospheric activity caused increased range errors on two different satellites at Honolulu, Hawaii on two different days. Although the range error exceeded 30 meters for a short time, it was not a long enough duration to exceed the SPS specification. We included this discussion for completeness.

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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.

1.2 Report Overview

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

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

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

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

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

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

Section 8 provides a summary of GPS Test NOTAMs.

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

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

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

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

1.3 Summary of Performance Requirements and Metrics

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

Table 1-1 SPS SIS Performance Requirements Standards

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

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

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

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

2 PDOP Availability Standard

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

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

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

Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by the GPS test team was used to calculate the PDOP at every 5^{o} point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.558 or better 99.9% of the time for each of the 24-hour intervals.

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

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

Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value	Global Average (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
29 Sept – 5 Oct	2.938	100	100
6 – 12 Oct	2.941	100	100
13 – 19 Oct	2.941	100	100
20 – 26 Oct	2.941	100	100
27 Oct – 2 Nov	2.941	100	100
3 – 9 Nov	2.937	100	100
10 – 16 Nov	2.940	100	100
17 – 23 Nov	2.937	100	99.931
24 – 30 Nov	3.558	99.987	98.681
1 – 7 Dec	2.933	100	99.931
8 – 14 Dec	2.928	100	99.931
15 – 21 Dec	2.926	100	99.931
22 – 28 Dec	2.922	100	99.931

Figure 2-1 World GPS Maximum PDOP

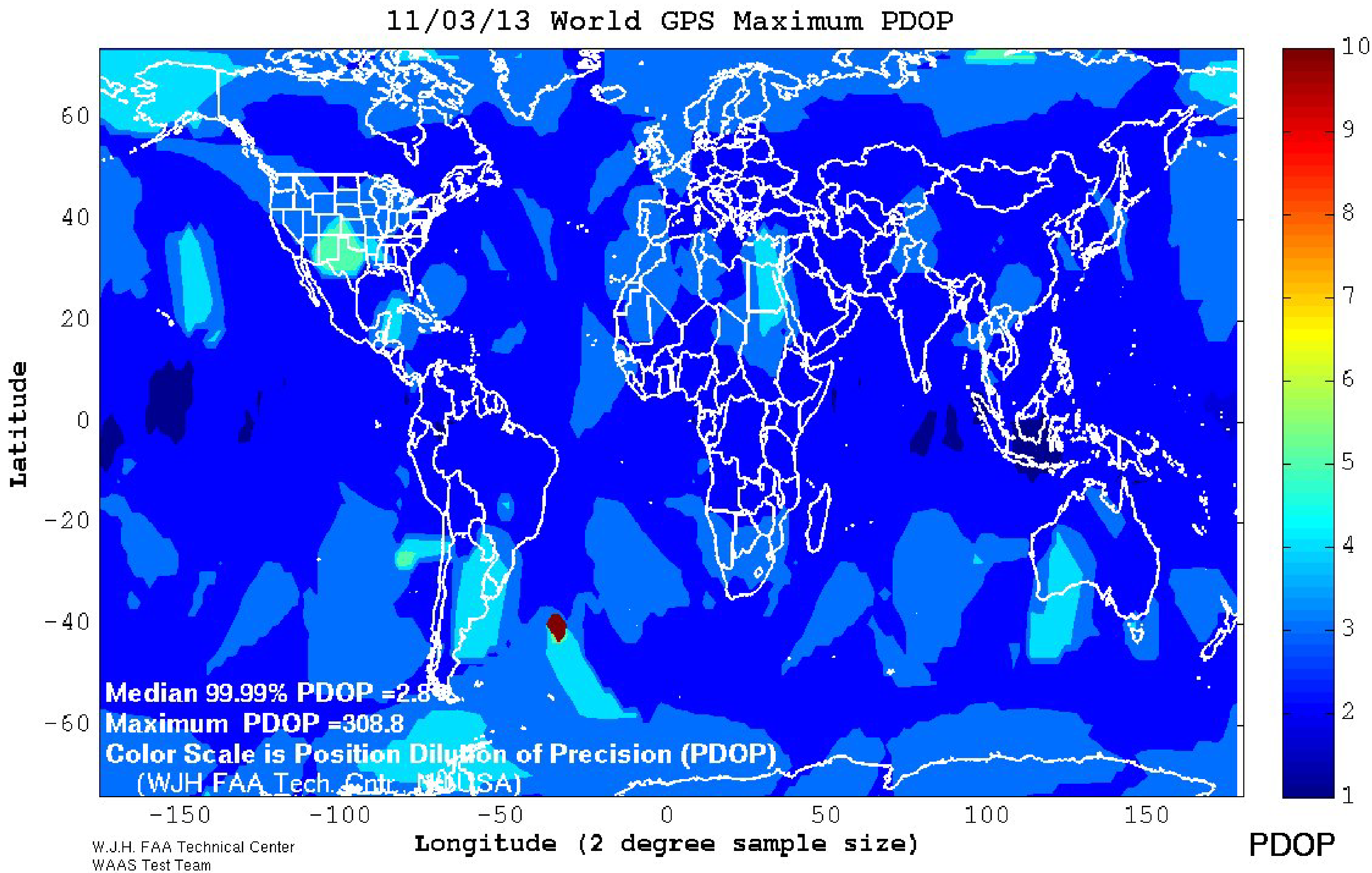
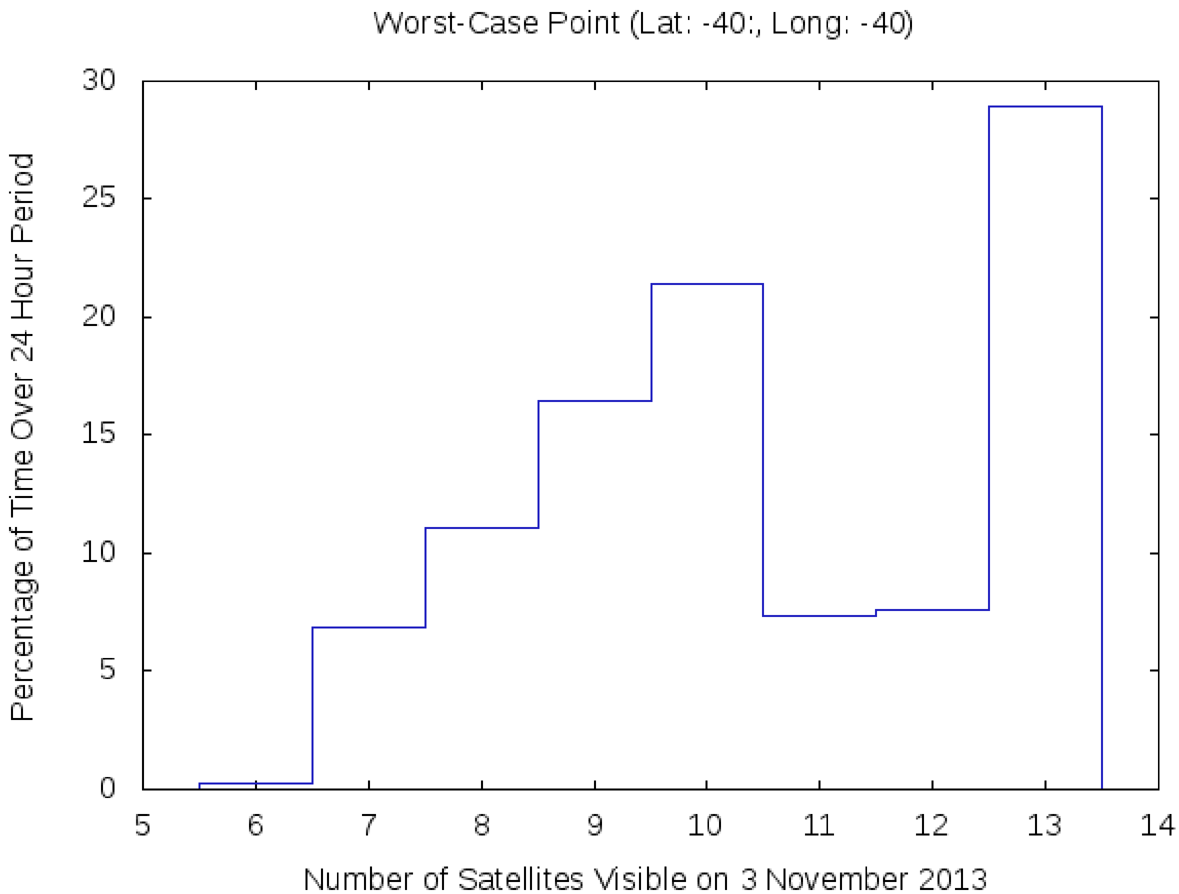


Figure 2-2 Satellite Visibility Profile for Worst-Case Point



3 NANU Summary and Evaluation

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

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

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANU's). During this reporting period, 1 October through 31 December 2013, there were a total of ten reported outages. Seven of these outages were maintenance activities and were reported in advance while three were unscheduled. A complete listing of outage NANU's for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-2. Canceled outage NANU's (if any) are provided in Table 3-3. The minimum duration a scheduled outage was forecasted ahead of time was 101.833 hours. The response time meet the 48-hour requirement. The maximum response time for a NANU issued for an unscheduled outage was 0.433 hours.

Table 3-1 NANUs Affecting Satellite Availability

NANU#	PRN	TYPE	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2013058	10	UNUSABLE	20-Oct-13	21:57	21-Oct-13	1:19	3.37		3.37
2013060	26	FCSTSUMM	29-Oct-13	18:38	29-Oct-13	20:31		1.88	1.88
2013062	2	UNUSABLE	3-Nov-13	17:04	5-Nov-13	15:08	46.07		46.07
2013065	27	FCSTSUMM	18-Nov-13	21:37	19-Nov-13	1:18		3.68	3.68
2013066	29	FCSTSUMM	19-Nov-13	12:56	19-Nov-13	17:57		5.02	5.02
2013069	32	UNUSABLE	23-Nov-13	8:47	23-Nov-13	9:19	0.53		0.53
2013070	1	FCSTSUMM	25-Nov-13	18:34	26-Nov-13	1:42		7.13	7.13
2013073	24	FCSTSUMM	2-Dec-13	23:59	3-Dec-13	3:29		3.5	3.5
2013075	25	FCSTSUMM	5-Dec-13	1:50	5-Dec-13	8:16		6.43	6.43
2013077	1	FCSTSUMM	12-Dec-13	14:22	12-Dec-13	20:13		5.85	5.85
Totals of Unscheduled, Scheduled & Total Downtime							49.97	33.49	83.46

GENERAL NANUs

NANU 2013074 stated that the L-band signal would resume transmitting from PRN30 (SVN 27) on December 3, 2013. The satellite would not be included in the almanac.

NANU 2013080 stated that the L-band signal would resume transmitting from PRN30 (SVN 49) on December 19, 2013. The satellite would not be included in the almanac.

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2013057	10	UNUSUFN	20-Oct	21:57				2013058
2013059	26	FCSTMX	29-Oct	18:00	30-Oct	6:00	12	2013060
2013061	2	UNUSUFN	3-Nov	17:04				2013062
2013063	27	FCSTMX	18-Nov	21:00	19-Nov	9:00	12	2013065
2013064	29	FCSTDV	19-Nov	12:15	20-Nov	0:15	12	2013066
2013067	1	FCSTMX	25-Nov	18:00	26-Nov	6:00	12	2013070
2013068	32	UNUSUFN	23-Nov	8:47				2013069
2013071	24	FCSTMX	2-Dec	22:30	3-Dec	10:30	12	2013073
2013072	25	FCSTMX	5-Dec	1:30	5-Dec	13:30	12	2013075
2013076	1	FCSTMX	12-Dec	14:00	13-Dec	14:00	24	2013077
2013078	1	FCSTMX	18-Dec	17:00	20-Dec	17:00	0	2013079
						Total Forecasted Downtime	96	

Table 3-3 Cancelled NANUs

NANU#	PRN	Type	Start Date	Start Time	Comments
2013079	1	FCSTCANC	18-Dec	17:00	2013078

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-13 31-Dec-13	1-Jan-00 31-Dec-13
Total Forecast Downtime (hrs):	96	9984.82
Total Actual Downtime (hrs):	83.46	38157.08
Total Actual Scheduled Downtime (hrs):	33.49	5853.31
Total Actual Unscheduled Downtime (hrs):	49.97	32303.77
Total Satellite Observed MTTR (hrs):	8.35	49.75
Scheduled Satellite Observed MTTR (hrs):	4.78	9.69
Unscheduled Satellite Observed MTTR (hrs):	16.66	198.18
# Total Satellite Outages:	10	767
# Scheduled Satellite Outages:	7	604
# Unscheduled Satellite Outages:	3	163
Percent Operational -- Scheduled Downtime:	99.95	99.85
Percent Operational -- All Downtime:	99.88	99.01

3.2 Service Availability Standard

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

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

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

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

To verify availability, the data collected from receivers at the twenty-eight WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-5. The data was collected at one-second intervals between 1 October and 31 December 2013.

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	7931651	0	100%
Anchorage	7898403	0	100%
Atlanta	7933321	0	100%
Barrow	7933025	0	100%
Bethel	7930573	0	100%
Billings	7919276	0	100%
Boston	7928343	0	100%
Cleveland	7933311	0	100%
Cold Bay	7917845	0	100%
Fairbanks	7427454	0	100%
Gander	7929948	0	100%
Honolulu	7761917	0	100%
Houston	7933355	0	100%
Iqaluit	7914889	0	100%
Juneau	7921171	0	100%
Kansas City	7924740	0	100%
Kotzebue	7395780	0	100%
Los Angeles	7933303	0	100%
Merida	7919687	0	100%
Miami	7922644	0	100%
Minneapolis	7929877	0	100%
Oakland	7932421	0	100%
Salt Lake City	7930093	0	100%
San Jose Del Cabo	7926131	0	100%
San Juan	7933055	0	100%
Seattle	7907659	0	100%
Tapachula	7709629	0	100%
Washington, DC	7933184	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 31.051 meters on satellite PRN 11.

Table 4-1 User Range Error Accuracy

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Percentage
1 Oct – 31 Dec 2013	**Boston**	68,175,202	0	100%
1 Oct – 31 Dec 2013	**Honolulu**	70,875,038	545	99.999999%
1 Oct – 31 Dec 2013	**Los Angeles**	70,737,380	0	100%
1 Oct – 31 Dec 2013	**Miami**	66,731,481	0	100%
1 Oct – 31 Dec 2013	**Merida**	69,240,351	0	100%
1 Oct – 31 Dec 2013	**Juneau**	70,505,812	0	100%
1 Oct – 31 Dec 2013	**Global**	416,265,264	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 2013 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	7.149	2.059	12.047	4.641
Anchorage	8.798	2.195	14.120	5.678
Atlanta	7.381	2.355	12.850	5.688
Barrow	9.254	2.572	17.377	4.679
Bethel	9.077	2.102	13.808	5.387
Billings	6.519	2.242	12.074	4.388
Boston	6.226	2.599	10.205	5.098
Cleveland	6.488	2.478	11.267	4.832
Cold Bay	8.740	2.083	13.290	4.867
Fairbanks	8.512	2.242	14.178	4.837
Gander	6.126	2.526	11.210	4.502
Honolulu	6.555	8.068	13.345	14.028
Houston	7.636	2.230	13.159	4.252
Iqaluit	6.563	3.144	12.957	6.576
Juneau	8.188	2.190	13.208	4.428
Kansas City	6.771	2.249	12.879	4.958
Kotzebue	8.800	2.269	15.211	5.058
Los Angeles	8.142	2.089	12.191	3.688
Merida	7.659	3.165	26.586	10.413
Miami	7.302	2.512	11.918	4.597
Minneapolis	6.296	2.281	11.674	4.579
Oakland	8.297	2.066	13.338	3.800
Salt Lake City	7.044	2.135	11.562	3.698
San Jose Del Cabo	7.895	3.562	19.208	12.216
San Juan	7.172	5.923	23.194	20.133
Seattle	7.484	2.152	12.060	4.062
Tapachula	7.190	5.982	18.264	13.898
Washington, DC	6.809	2.573	11.160	4.963

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 2013.

Figure 5-1 Global Vertical Error Histogram

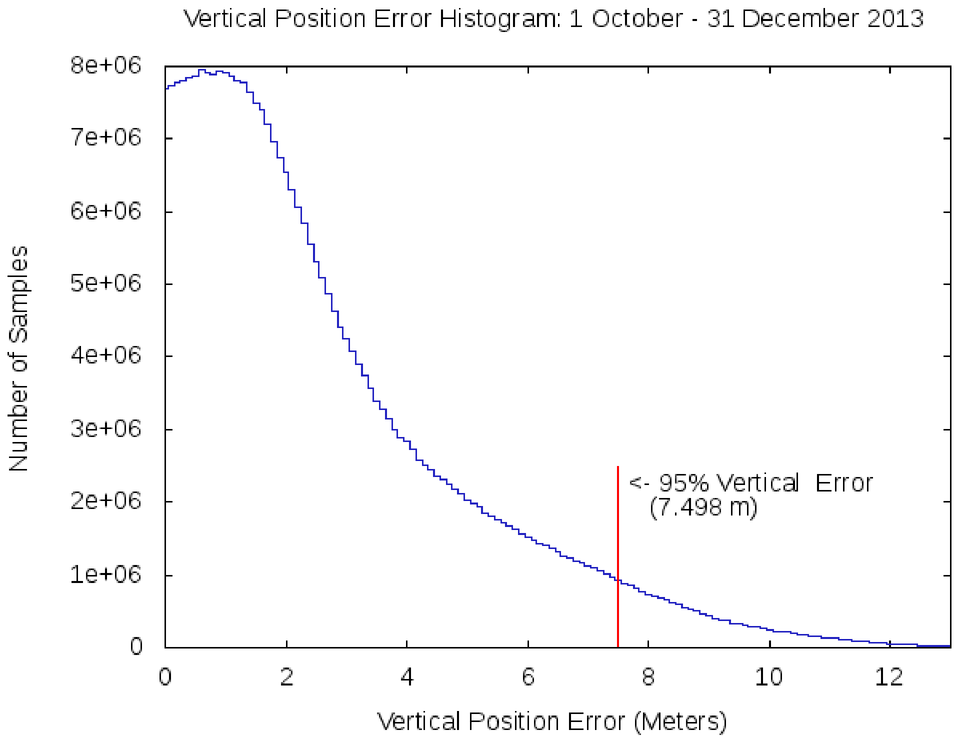
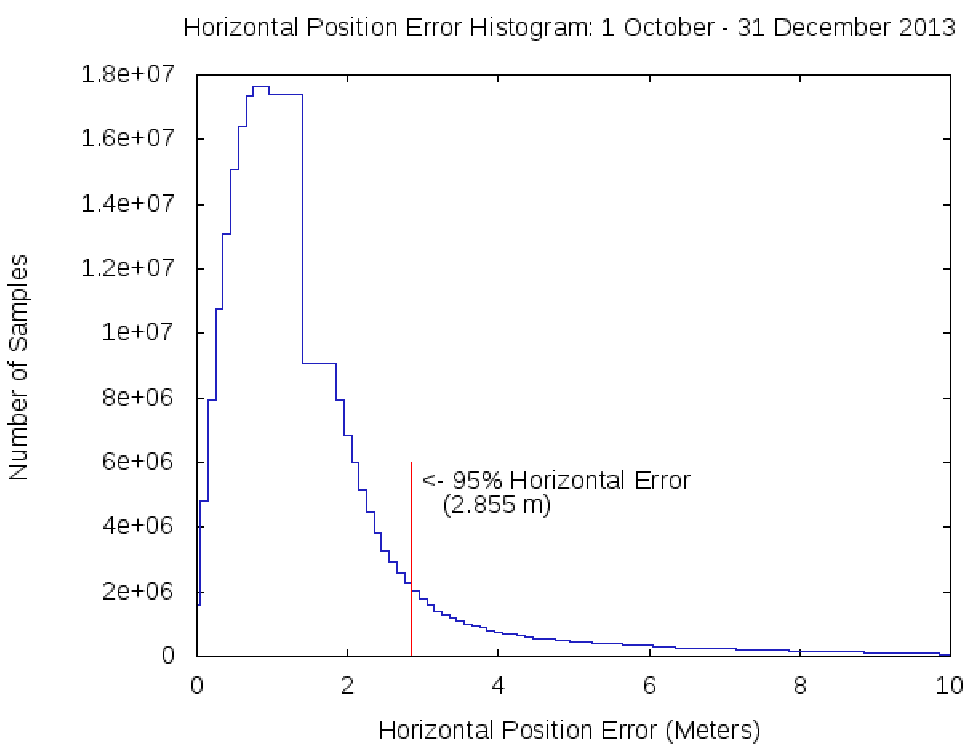


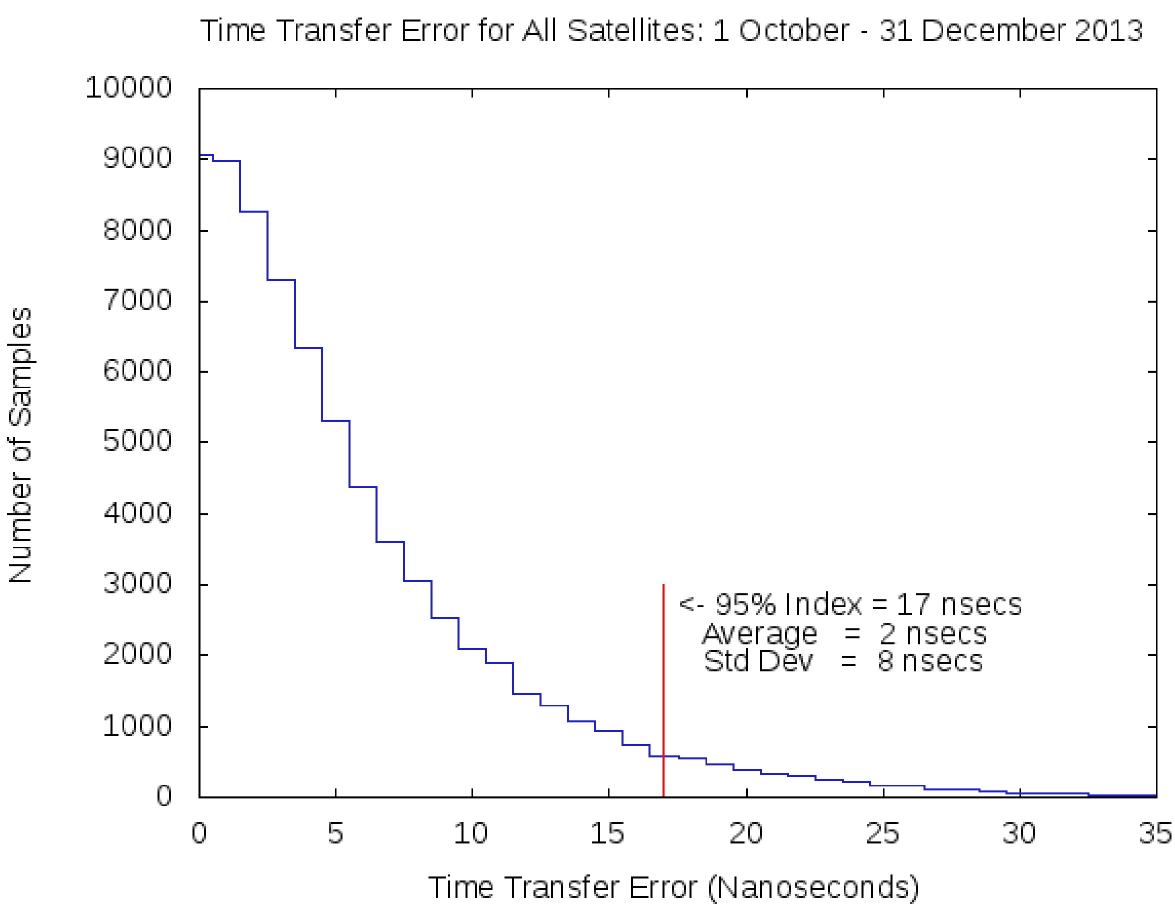
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 October and 31 December 2013 was downloaded from USNO Internet site. The USNO data file contains the time difference between the USNO master clock and GPS system time for each GPS satellites during the time period. Over 10,000 samples of GPS time error are contained in the USNO data file. In order to evaluate the GPS time transfer error, the data file was used to create a histogram (Fig 5-3) to represent the distribution of GPS time error. The histogram was created by taking the absolute value of time difference between the USNO master clock and GPS system time, then creating data bins with one nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Fig 5-3. The mean, standard deviation, and 95% index are within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Error



5.3 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 October and 31 December 2013. 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	2.664	1.167	2.068	4.725	28.534	12998084
2	2.195	0.791	1.503	3.945	17.034	14189917
3	2.626	1.273	1.961	4.918	23.310	12401033
4	2.093	0.371	1.649	4.001	17.604	13664369
5	2.034	0.411	1.549	3.624	17.703	13689556
6	2.376	1.063	1.871	4.673	25.526	13638577
7	2.026	0.591	1.701	4.362	24.604	12922515
8	2.481	1.059	1.852	4.846	30.081	13137968
9	2.325	0.617	1.798	4.474	26.507	12549055
10	2.674	1.505	1.664	4.550	14.939	12342431
11	2.774	1.185	2.223	5.387	31.051	12825740
12	2.080	0.827	1.558	3.744	28.169	14274366
13	1.950	0.826	1.601	3.846	22.129	13231713
14	3.410	2.191	2.062	5.861	16.724	14548963
15	2.178	1.290	1.392	3.731	25.469	12879959
16	2.254	1.075	1.750	4.256	16.677	13435527
17	1.988	0.358	1.597	3.891	21.456	14491404
18	3.421	2.422	1.934	5.603	16.174	13671900
19	2.877	1.779	2.007	5.595	28.142	12509567
20	2.529	1.513	1.793	4.625	24.813	14393667
21	3.231	1.874	2.100	5.410	13.536	12987564
22	4.008	2.853	2.106	6.427	18.639	13076974
23	2.272	1.323	1.682	4.454	21.749	12876256
24	2.292	0.823	1.835	4.192	12.710	14232385
25	2.320	1.174	1.733	4.412	25.351	14483872
26	2.102	0.919	1.592	3.807	23.932	13465822
27	2.149	0.740	1.822	4.342	20.467	13271581
28	2.231	1.206	1.525	4.175	24.477	13777029
29	2.193	0.751	1.566	3.803	23.701	12978267
31	2.705	1.175	2.084	5.029	20.080	14033665
32	2.988	2.046	1.815	5.336	20.383	13285538

Table 5-3 Range Rate Error Statistics

(Millimeters/ Second)

PRN	Range Rate Error RMS	95% Range Rate Error	Max Range Rate Error	Samples
1	2.176	3.303	202.400	12998084
2	2.495	3.637	260.660	14189917
3	2.629	3.645	222.880	12401033
4	2.319	3.400	230.040	13664369
5	2.698	3.814	304.680	13689556
6	2.646	3.634	237.460	13638577
7	2.026	3.261	341.890	12922515
8	2.626	3.699	313.590	13137968
9	2.610	3.605	323.580	12549055
10	2.706	3.668	217.570	12342431
11	2.198	3.509	207.270	12825740
12	2.559	3.774	189.420	14274366
13	2.202	3.471	260.920	13231713
14	2.340	3.658	189.360	14548963
15	2.777	3.927	237.140	12879959
16	2.228	3.520	208.240	13435527
17	2.361	3.579	198.370	14491404
18	2.784	3.904	200.300	13671900
19	2.217	3.592	225.380	12509567
20	2.151	3.520	189.210	14393667
21	2.815	3.946	210.320	12987564
22	2.768	3.835	203.110	13076974
23	1.981	3.283	261.180	12876256
24	2.881	3.769	223.990	14232385
25	2.570	3.519	210.700	14483872
26	2.680	3.616	293.150	13465822
27	2.348	3.443	221.320	13271581
28	2.351	3.282	268.420	13777029
29	2.692	3.756	211.130	12978267
31	2.143	3.490	210.630	14033665
32	2.223	3.432	228.280	13285538

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	16.963	24.218	2000	12998084
2	20.231	29.574	2610	14189917
3	21.417	27.316	2210	12401033
4	18.805	26.911	2310	13664369
5	22.307	32.153	3040	13689556
6	21.533	26.384	2320	13638577
7	15.447	23.512	3410	12922515
8	20.671	25.624	3140	13137968
9	20.622	25.547	3230	12549055
10	22.375	29.415	2180	12342431
11	17.070	25.050	2060	12825740
12	20.707	30.380	1890	14274366
13	17.231	25.815	2610	13231713
14	18.507	26.309	1870	14548963
15	22.719	31.382	2380	12879959
16	17.592	26.859	2090	13435527
17	19.218	26.986	1970	14491404
18	22.847	31.239	1990	13671900
19	17.193	25.765	2260	12509567
20	16.660	25.290	1880	14393667
21	23.181	32.456	2060	12987564
22	22.499	29.167	1980	13076974
23	15.161	24.245	2600	12876256
24	24.280	31.001	2220	14232385
25	21.033	28.029	2110	14483872
26	21.784	29.512	2890	13465822
27	18.725	25.481	2190	13271581
28	19.207	24.574	2690	13777029
29	22.355	31.773	2100	12978267
31	16.586	24.671	2100	14033665
32	16.965	24.134	2240	13285538

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 11 with an error of 31.051 meters. Satellite 24 had the lowest maximum range error of 12.710 meters.

Figure 5-4 Distribution of Daily Max Range Errors

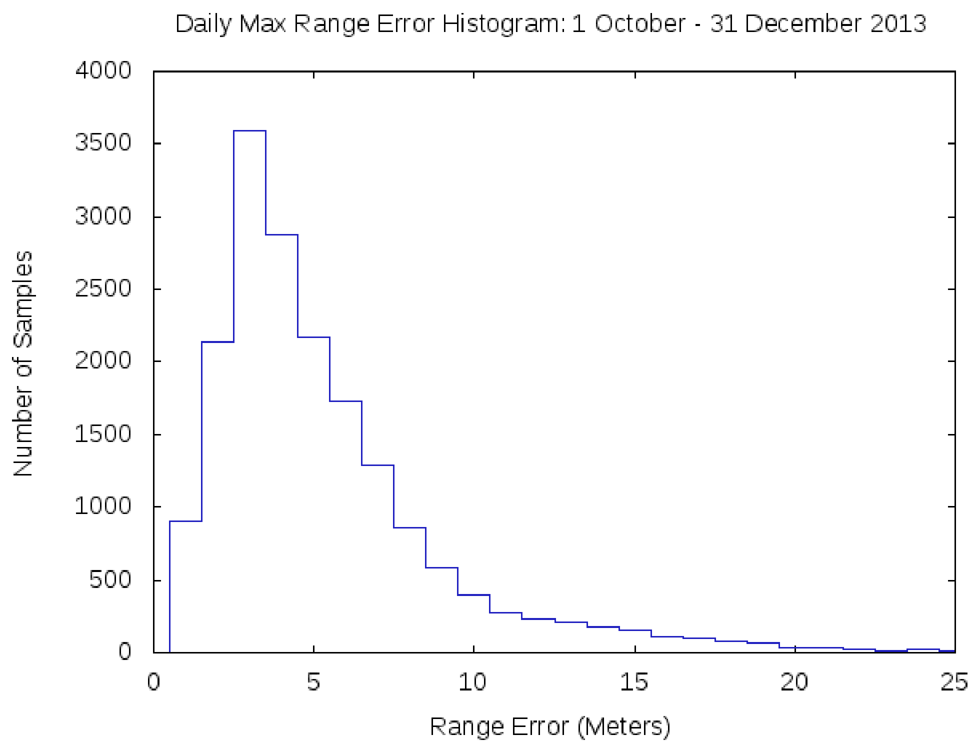


Figure 5-5 Distribution of Daily Max Range Rate Errors

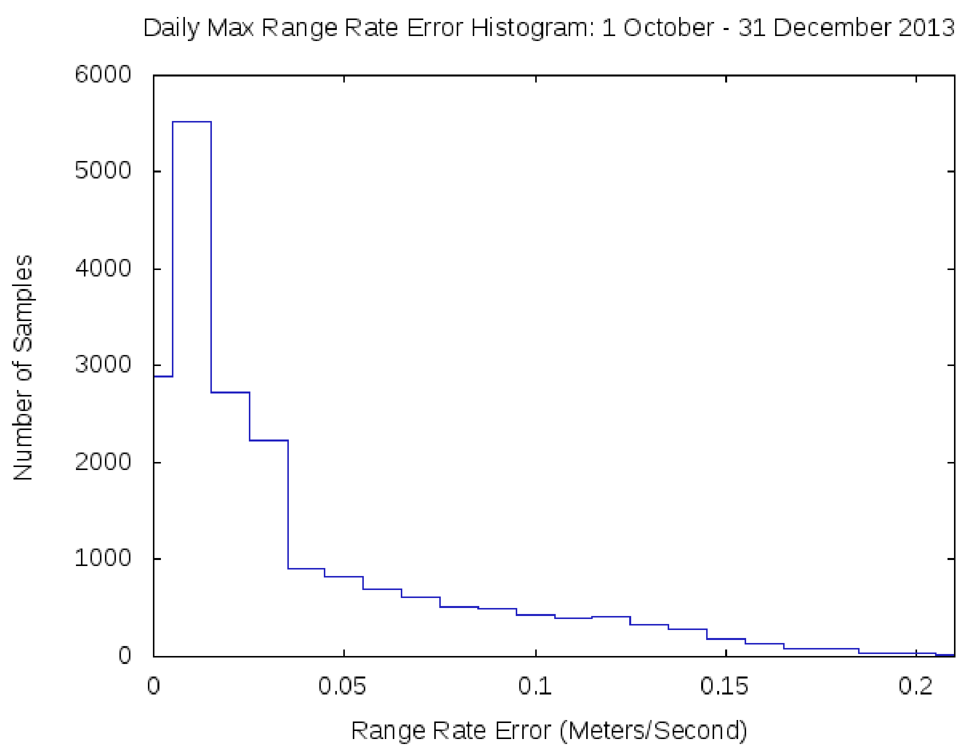


Figure 5-6 Distribution of Daily max Range Acceleration Errors

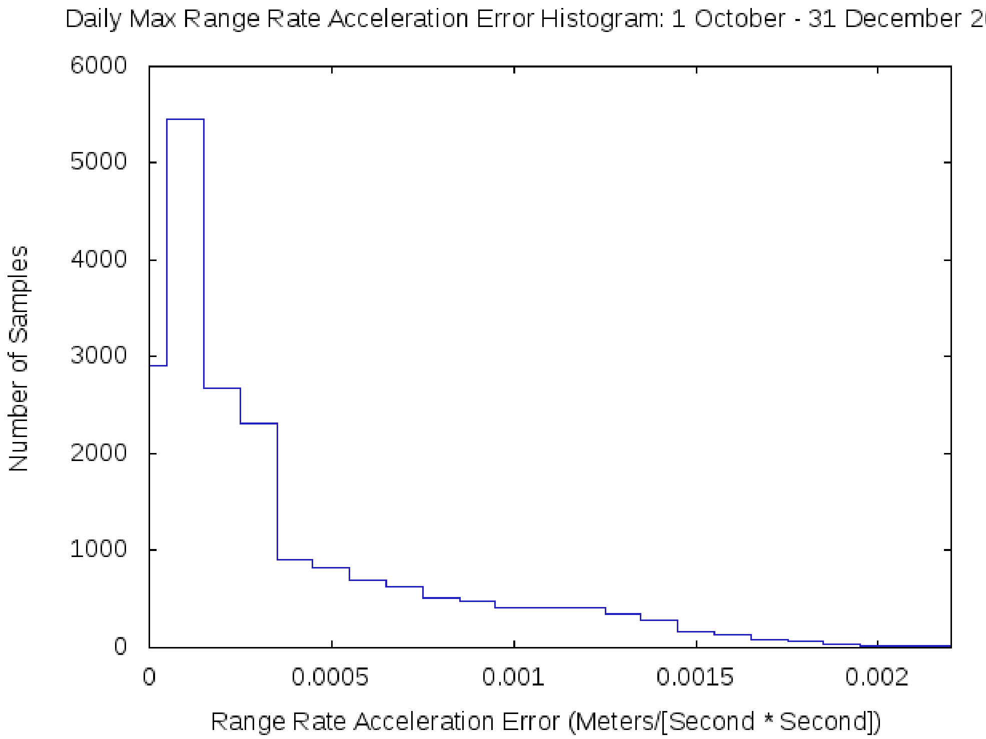


Figure 5-7 Range Error Histogram

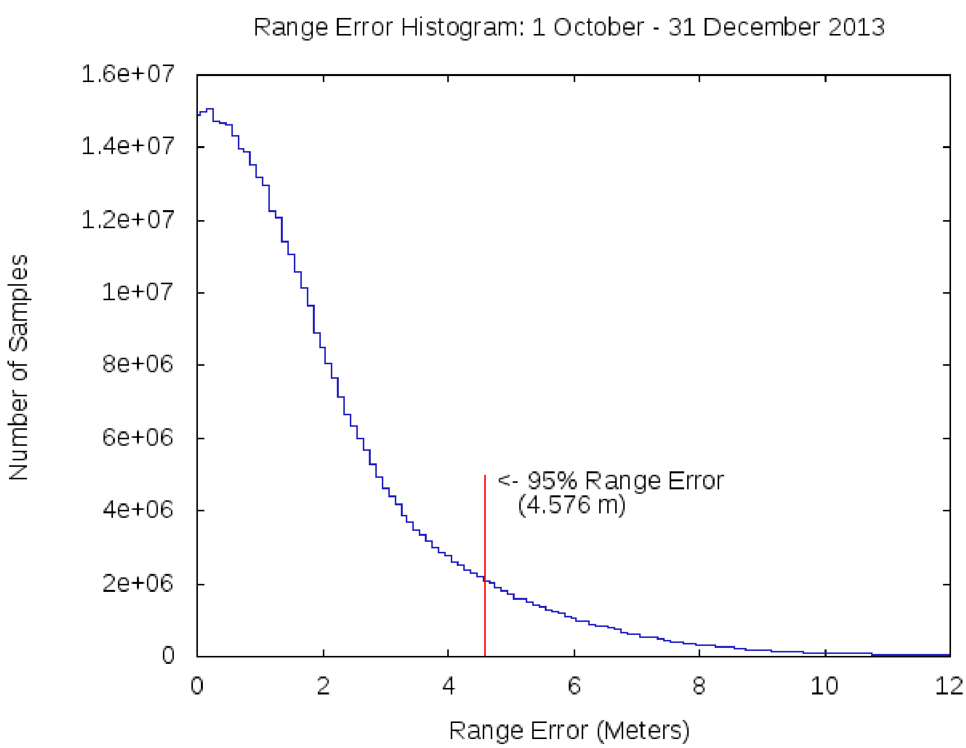


Figure 5-8 Maximum Range Error Per Satellite

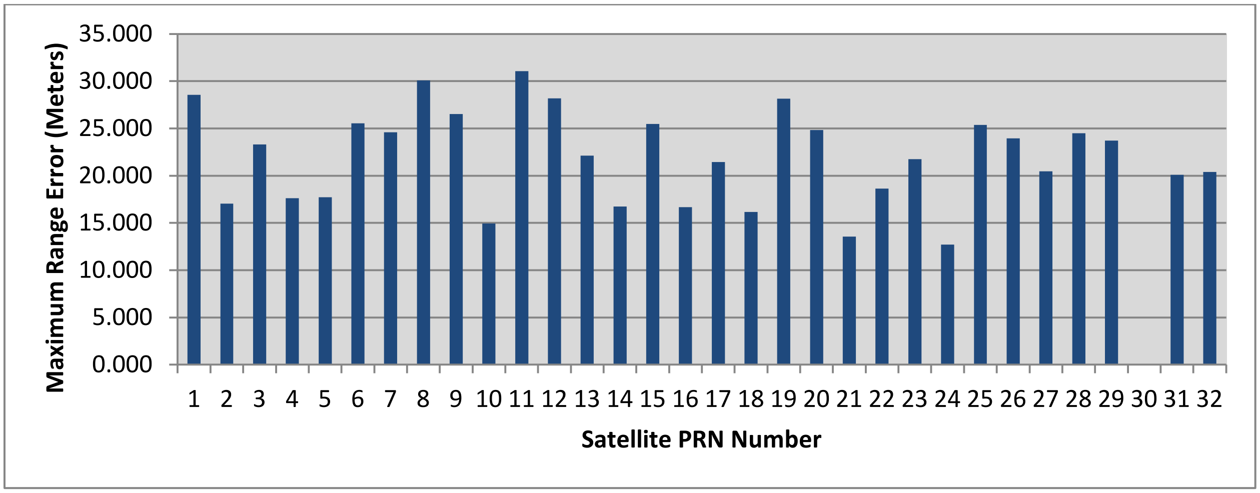


Figure 5-9 Maximum Range Rate Error Per Satellite

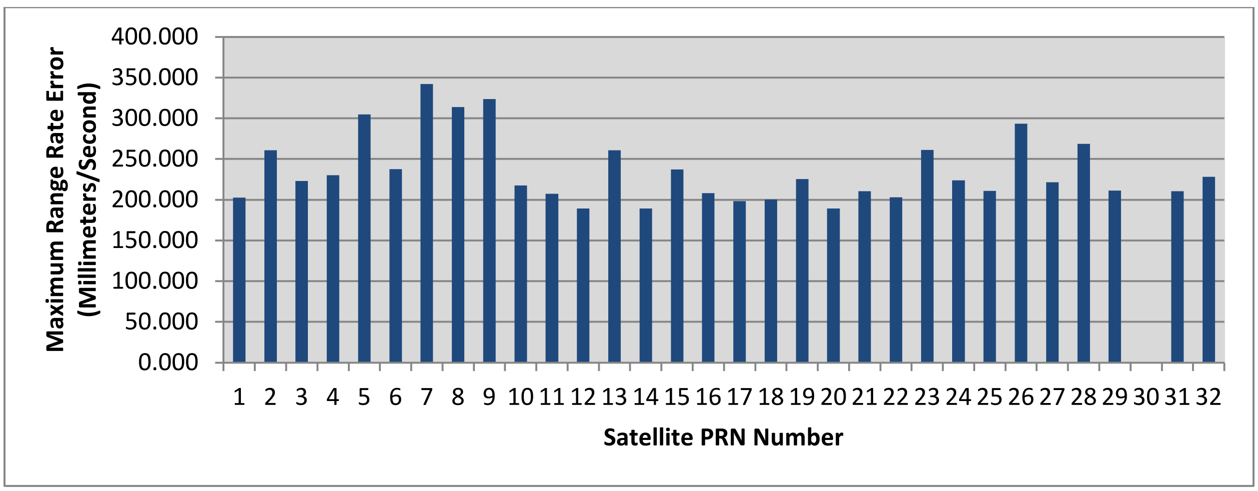
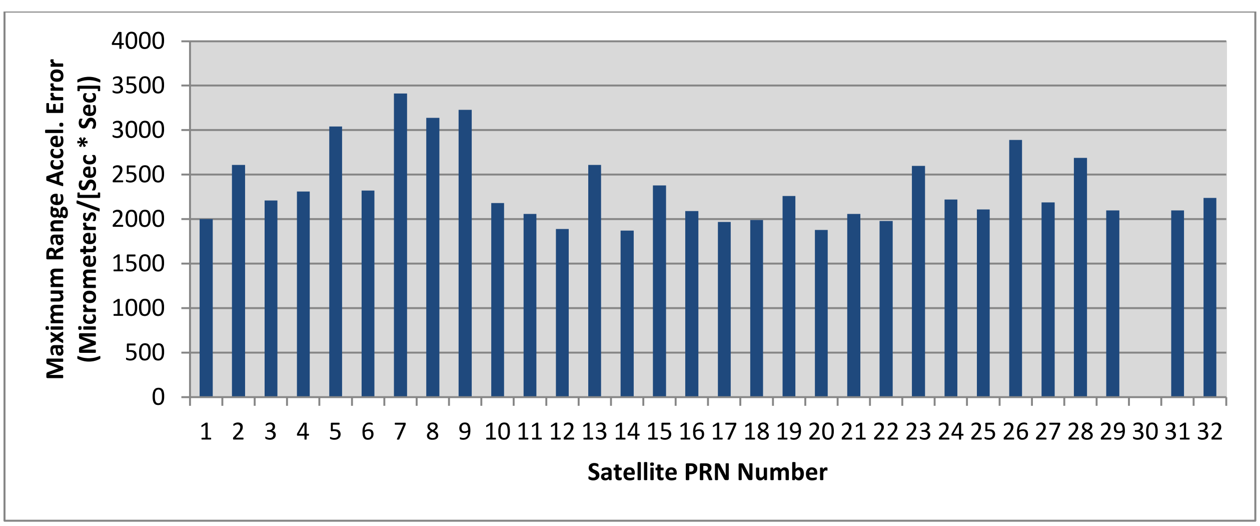


Figure 5-10 Maximum Range Acceleration Error Per Satellite



6 Solar Storms

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

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

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

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

Figure 6-1 K-Index for 1-3 October 2013

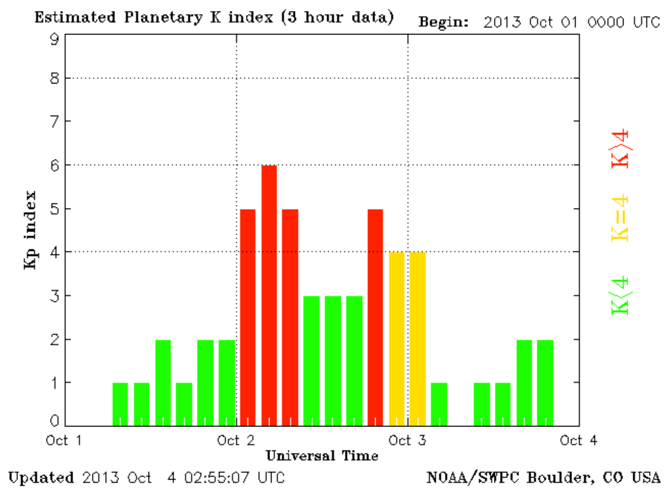


Figure 6-2 K-Index for 7-9 December 2013

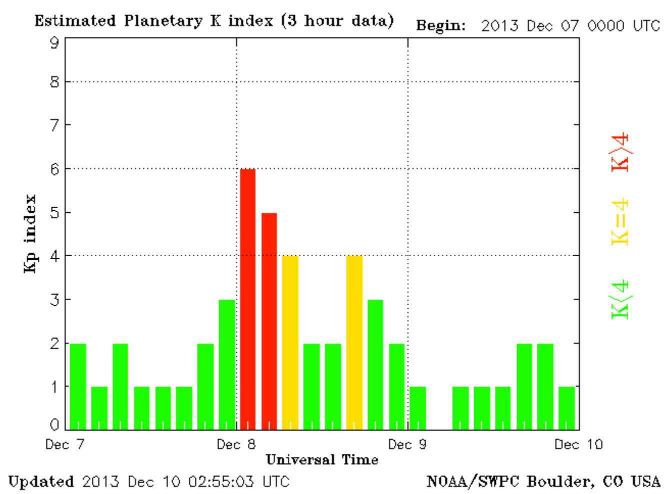


Figure 6-3 K-Index for 8-10 October 2013

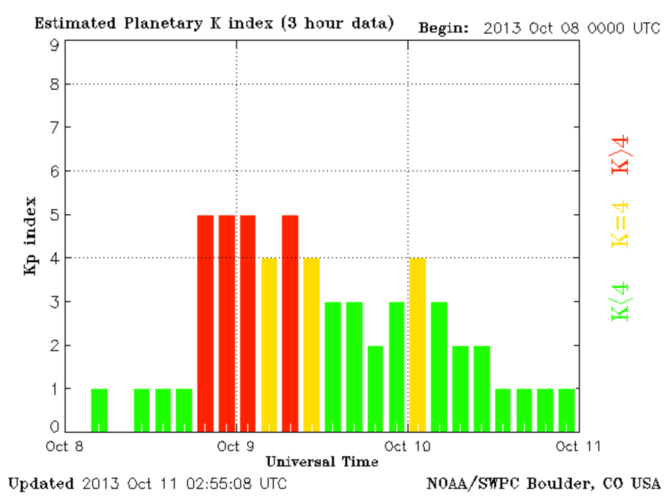


Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for October 2, 2013

Site	95% Horizontal (Meters)	95% Vertical (Meters)	Maximum Horizontal (Meters)	Maximum Vertical (Meters)
Albuquerque	2.702	4.034	3.401	5.754
Anchorage	2.017	3.808	2.933	4.587
Atlanta	2.320	6.782	2.876	8.162
Barrow	1.987	3.677	2.532	6.367
Bethel	1.975	3.402	3.156	3.955
Billings	2.233	3.201	3.255	4.141
Boston	2.320	4.034	2.797	5.693
Cleveland	2.460	4.852	3.002	8.313
Cold Bay	2.090	3.590	2.699	4.862
Fairbanks	1.949	3.790	3.768	7.664
Gander	2.006	3.135	2.421	4.274
Honolulu	7.391	7.561	8.923	8.945
Houston	2.723	7.184	3.506	8.995
Iqaluit	2.501	2.485	3.940	5.020
Juneau	2.256	3.382	3.606	4.862
Kansas City	2.215	4.397	3.248	6.716
Kotzebue	1.735	3.978	2.635	6.066
Los Angeles	1.941	3.758	3.348	5.798
Merida	6.105	8.897	8.438	16.19
Miami	2.666	8.492	4.819	10.717
Minneapolis	2.247	3.885	2.785	5.898
Oakland	1.843	4.001	2.690	6.431
Salt Lake City	1.758	3.718	2.113	4.592
San Jose Del Cabo	3.760	5.287	7.366	10.452
San Juan	3.877	7.159	6.750	8.131
Seattle	1.796	3.307	2.384	4.726
Tapachula	7.818	11.045	12.267	12.755
Washington, DC	2.289	4.551	2.796	6.964

7 IGS Data

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

High data rate (1 Hz) sites with good availability that were outside of the WAAS service area, and provided a good geographic distribution have been selected. To facilitate differentiating between GPS accuracy issues and receiver tracking problems, an automatic data screening function excluded errors greater than 500 meters and or times when VDOP or HDOP were greater than 10. The remaining receiver tracking issues are still included in the processing and are forced into the 50.1 meter histogram bin and cause the outliers in the 99.99% statistics and are visible in the 95% accuracy trend plots. The 50.1 meter 99.99% Vertical Accuracy and Horizontal outliers for USNA are an example. USNA has about 20 days when there are tracking problem. The cause of the USNA problem is unknown, but scintillation, or RFI, or a degraded receiver, or a combination of any of those three could cause the symptoms. The geomagnetic latitude of USNA and the time of day signature of the errors reinforces the scintillation speculation.

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

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

Figures 7-4 and 7-5 show position accuracy data for USNA on two of the problematic days. TIDB also had a day with content in the 50.1 meter histogram bin. The cause of the TIBD was problems tracking GPS satellites. At the time of the ramping error, tracking dropped from 12 GPS tracked to only 5 GPS tracked. Of those 5, one was at 25 degrees elevation and the other 4 were all above 52 degrees elevation. The problem ended when tracking dropped below 4 GPS. See Figure 7-6.

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

Table 7-1 Selected IGS Site Information

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

Figure 7-1 Selected IGS Site Locations

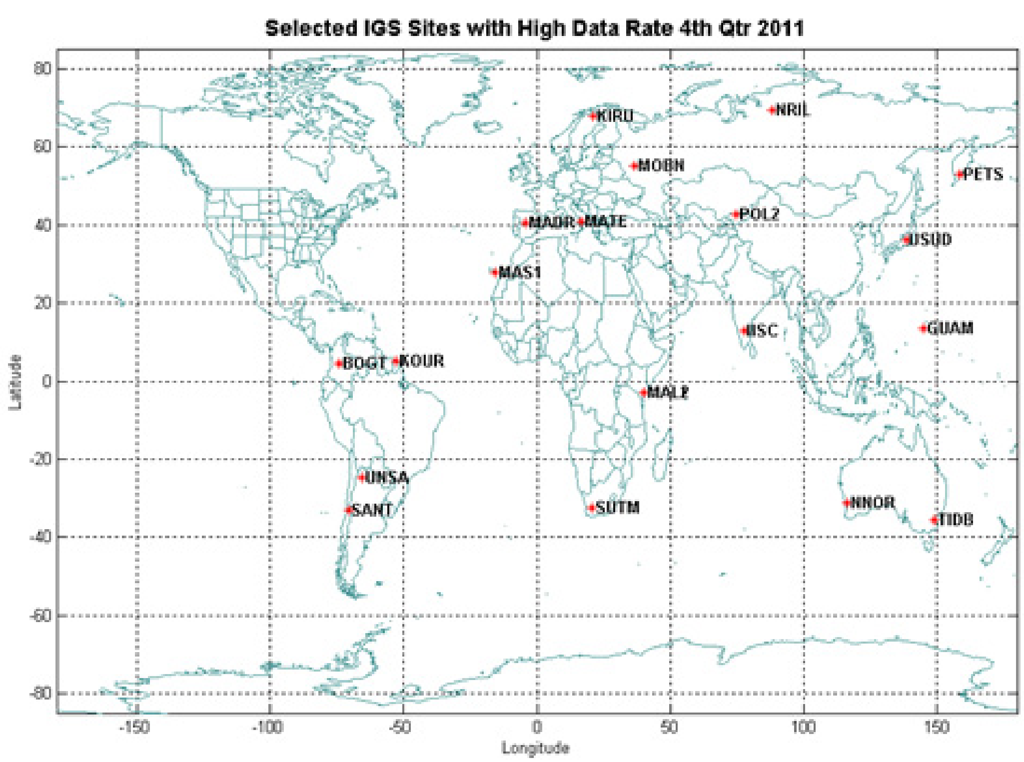


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

Site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
BOGT	8.42	10.51	20.94	38.50	97.71%
GLPS	6.26	7.27	14.63	22.08	95.49%
GUAM	3.84	7.70	33.05	39.84	54.61%
IISC	4.81	7.40	19.51	23.98	67.15%
KIRU	2.72	8.91	6.79	18.83	86.26%
KOUR	5.02	6.16	12.80	15.57	77.89%
MAL2	5.56	6.38	11.40	11.68	81.41%
MAS1	10.98	8.27	17.95	21.50	68.10%
MATE	2.62	7.31	11.14	13.07	92.63%
MOBN	2.74	8.54	9.35	17.12	97.26%
NNOR	2.85	4.95	16.16	29.53	40.20%
NRIL	2.92	9.63	9.50	36.10	98.38%
PETS	2.78	9.94	10.92	19.66	99.94%
POL2	2.74	9.67	14.19	45.67	66.89%
SANT	3.22	5.32	5.48	9.77	77.65%
SUTM	2.74	5.73	50.01	50.01	90.25%
TIDB	5.35	9.13	32.61	50.01	94.42%
UNSA	3.46	8.73	17.66	27.63	98.87%
USUD	8.42	10.51	20.94	38.50	97.71%

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

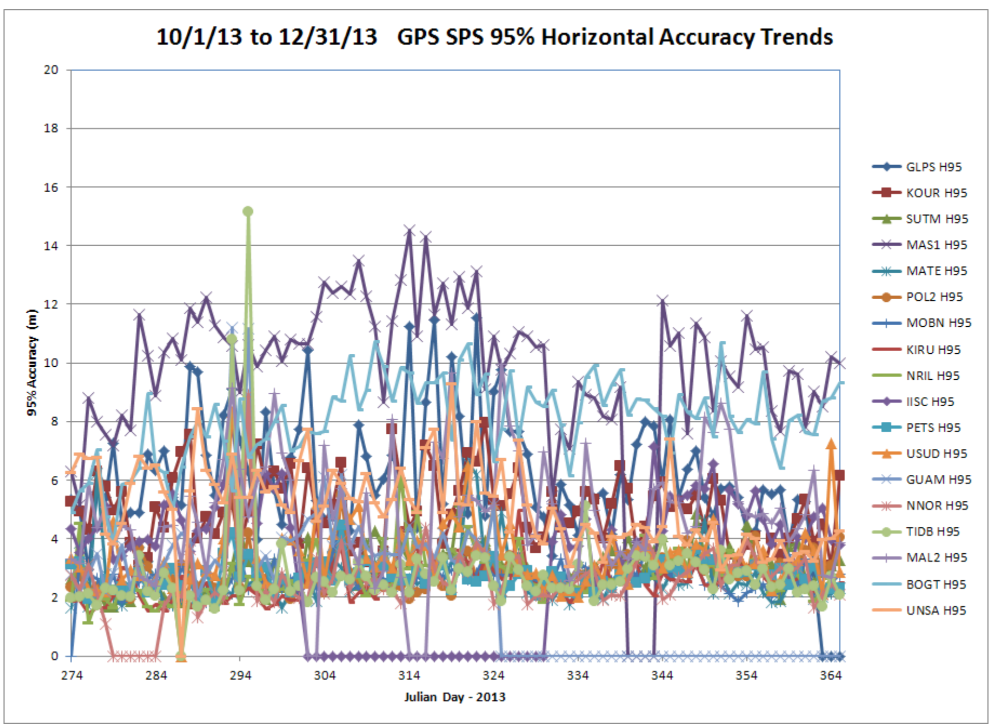


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites

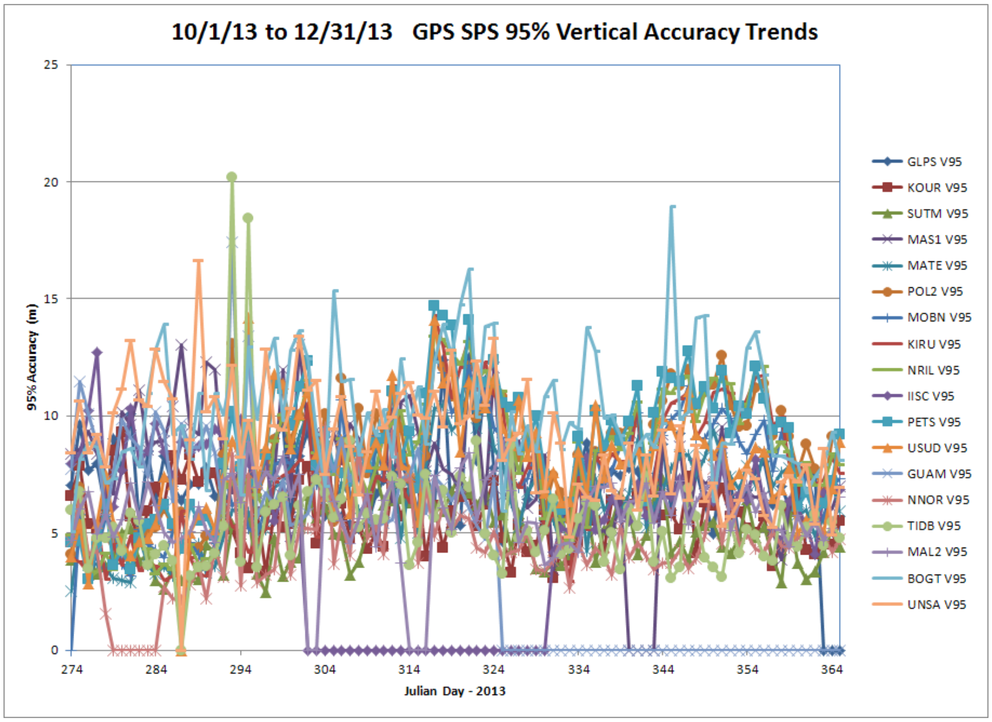


Figure 7-4 Example Receiver Tracking Problem

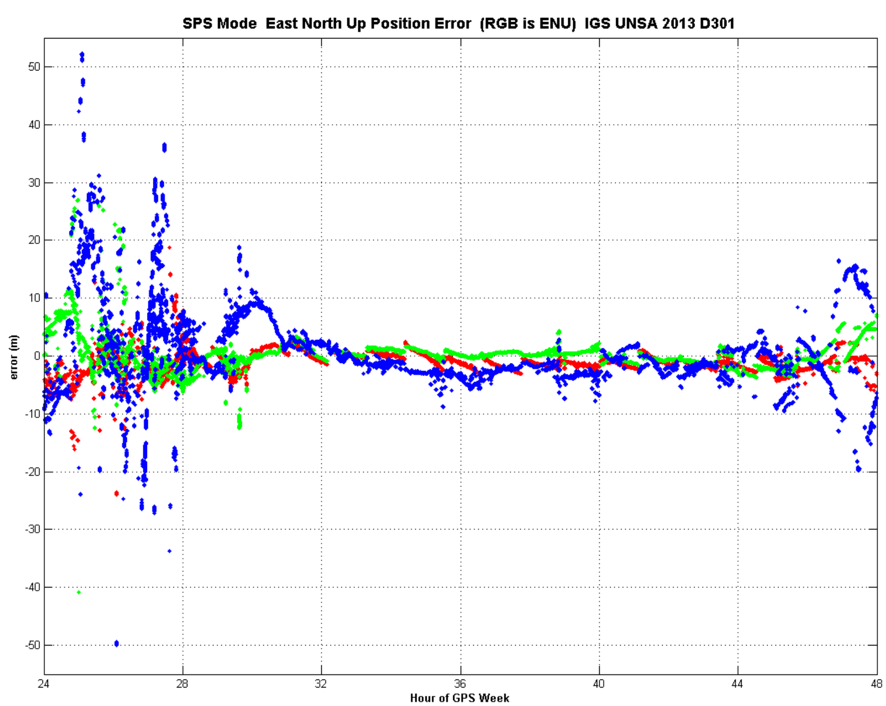
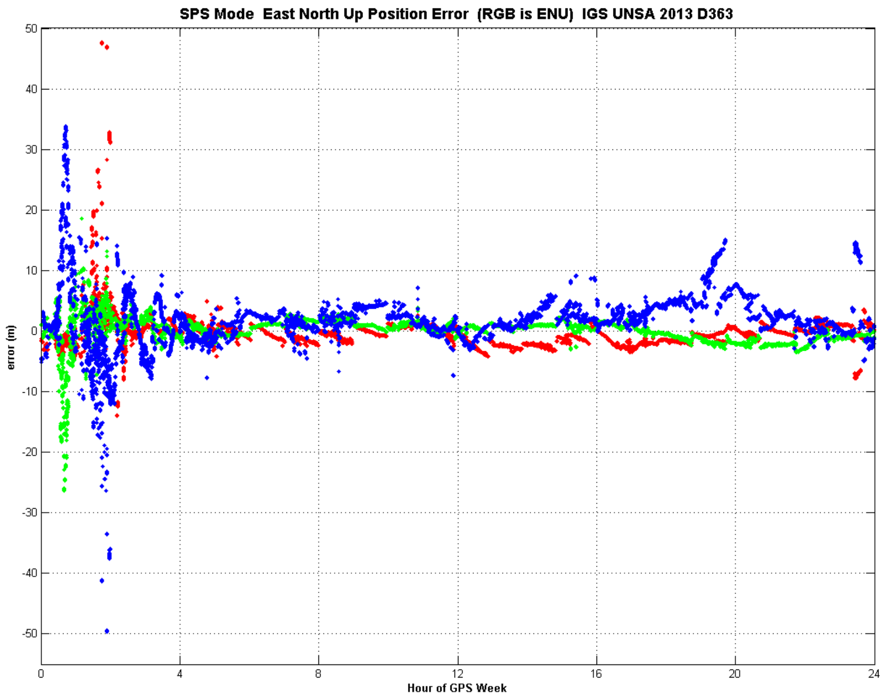


Figure 7-5 Example Large Ionospheric Error



8 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

8.1 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 2013, there were a total of 60 GPS test NOTAMs. The total number of days affected in this reporting period is 48. 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 8-1 GPS test NOTAM Durations

Cumulative duration	352.4 hours
Minimum duration	0.5 hours
Average duration	5.38 hours
Maximum duration	24.0 hours

Table 8-2 GPS Test NOTAM Affected Areas (Square Miles) by Altitude

	40,000 feet	25,000 feet	10,000 feet	4,000 feet	50 feet
Minimum	22,171	22,171	2,014	19,238	599
Average	622,096	478,618	296,837	287,090	209,830
Maximum	1,035,941	857,523	616,674	594,453	557,309

8.2 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 8-1 GPS Test NOTAMs @ FL400

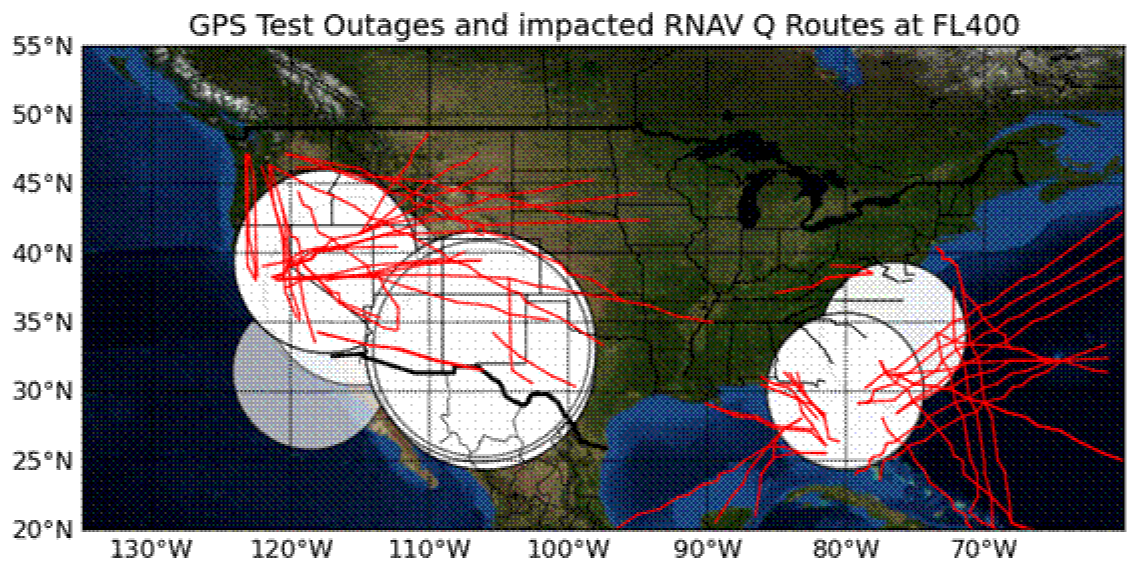


Figure 8-2 GPS NOTAMs @ FL250

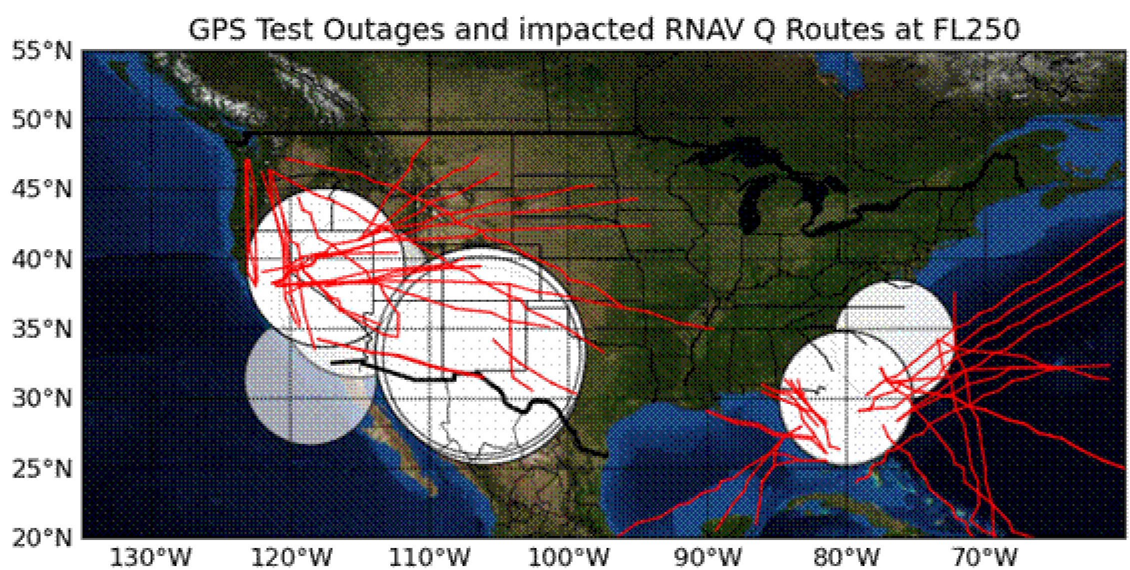


Figure 8-3 GPS NOTAMs @ 10k Feet

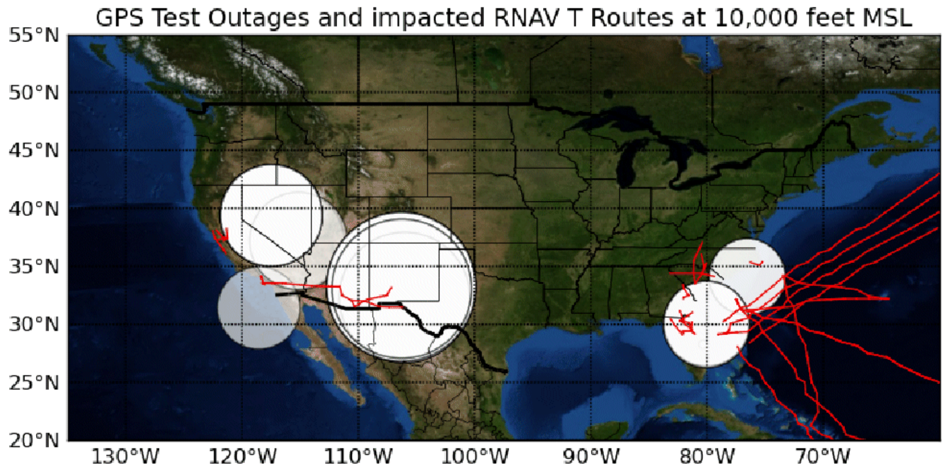


Figure 8-4 GPS NOTAMs @ 4k Feet

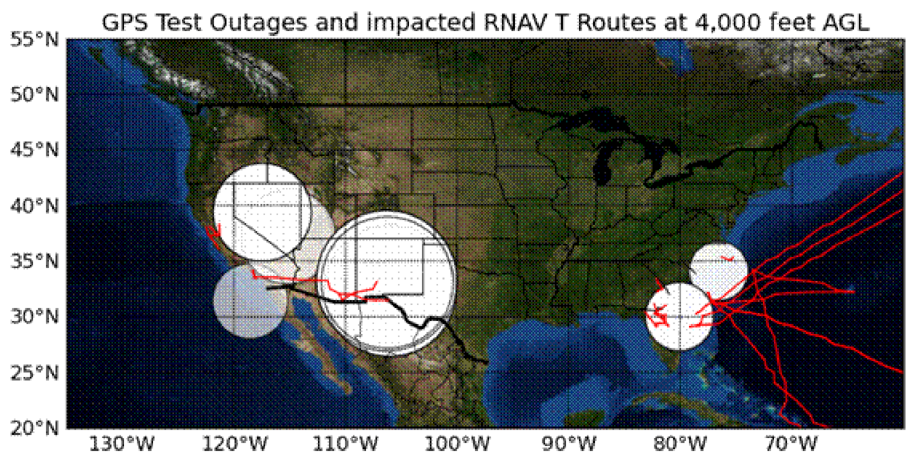
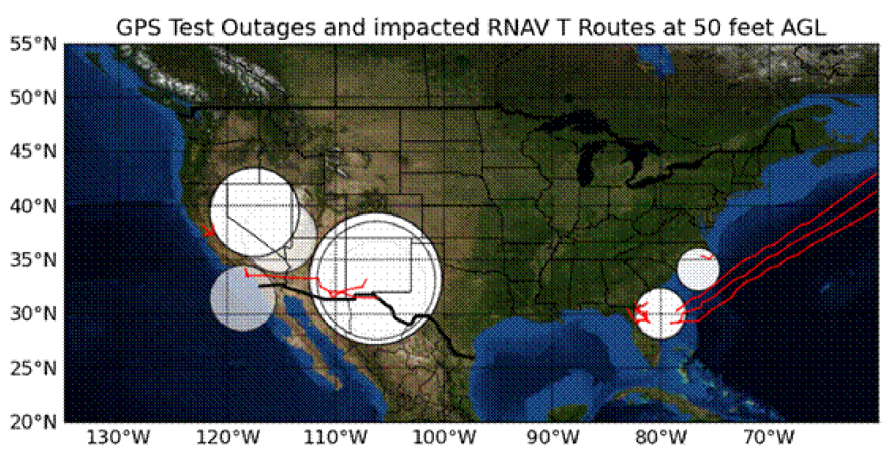


Figure 8-5 GPS NOTAMs @ 50 Feet



8.3 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 8-3 NOTAM Impact to GPS Availability

Start Date	End Date	Latitude	Longitude	Percent Impact at each altitude				
				50	4000	10000	FL250	FL400
2013-10-04 03:00:00	2013-10-04 06:30:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-07 02:15:00	2013-10-07 04:00:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-07 18:30:00	2013-10-07 22:30:00	32.3259N	-106.0123W	6.19	10.01	9.18	14.24	17.44
2013-10-08 00:00:00	2013-10-11 23:59:00	28.2814N	-80.3448W	0.00	0.41	0.00	0.41	0.41
2013-10-08 03:00:00	2013-10-11 09:00:00	32.3259N	-106.0123W	6.19	10.01	9.18	14.24	17.44
2013-10-08 16:00:00	2013-10-09 18:00:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-08 19:15:00	2013-10-09 21:00:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-10 02:15:00	2013-10-10 04:00:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-10 16:00:00	2013-10-10 18:00:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-10 19:15:00	2013-10-10 21:00:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-11 03:00:00	2013-10-11 04:30:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-16 06:00:00	2013-10-17 12:00:00	32.3259N	-106.0123W	6.19	10.01	9.18	14.24	17.44
2013-10-16 16:45:00	2013-10-16 18:30:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00

2013-10-16 21:30:00	2013-10-16 23:00:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-17 02:15:00	2013-10-17 05:30:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-18 03:00:00	2013-10-18 14:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2013-10-22 23:00:00	2013-10-22 23:59:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-23 01:00:00	2013-10-23 01:30:00	39.3835N	-117.4702W	7.02	8.05	7.95	12.80	16.00
2013-10-23 03:00:00	2013-10-25 08:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2013-10-24 10:00:00	2013-10-24 23:59:00	28.2814N	-80.3448W	0.00	0.41	0.00	0.41	0.41
2013-10-25 00:00:00	2013-10-26 23:59:00	28.2814N	-80.3448W	0.00	0.41	0.00	0.41	0.41
2013-10-27 11:00:00	2013-10-27 16:30:00	34.1000N	-76.5500W	1.03	1.55	2.48	3.92	5.16
2013-10-28 18:30:00	2013-10-28 23:59:00	34.1000N	-76.5500W	1.03	1.55	2.48	3.92	5.16
2013-10-29 00:00:00	2013-10-29 00:30:00	34.1000N	-76.5500W	1.03	1.55	2.48	3.92	5.16
2013-10-29 17:00:00	2013-10-29 23:00:00	34.1000N	-76.5500W	1.03	1.55	2.48	3.92	5.16
2013-10-30 11:00:00	2013-10-31 17:00:00	34.1000N	-76.5500W	1.03	1.55	2.48	3.92	5.16
2013-10-30 18:30:00	2013-10-31 22:30:00	32.3259N	-106.0123W	6.19	10.01	9.18	14.24	17.44
2013-11-03 11:00:00	2013-11-03 16:00:00	30.0000N	-80.0500W	1.24	1.96	3.10	4.85	6.71
2013-11-04 11:00:00	2013-11-04 17:00:00	30.0000N	-80.0500W	1.24	1.96	3.10	4.85	6.71
2013-11-05 03:00:00	2013-11-10 15:00:00	32.3259N	-106.0123W	6.19	10.01	9.18	14.24	17.44
2013-11-05 19:00:00	2013-11-05 23:59:00	30.0000N	-80.0500W	1.24	1.96	3.10	4.85	6.71
2013-11-06 00:00:00	2013-11-06 02:00:00	30.0000N	-80.0500W	1.24	1.96	3.10	4.85	6.71
2013-11-06 13:30:00	2013-11-06 20:00:00	30.0000N	-80.0500W	1.24	1.96	3.10	4.85	6.71

2013-11-11 03:00:00	2013-11-11 15:00:00	32.3259N	-106.0123W	6.19	10.01	9.18	14.24	17.44
2013-11-12 03:00:00	2013-11-12 15:00:00	32.3259N	-106.0123W	6.19	10.01	9.18	14.24	17.44
2013-11-12 17:00:00	2013-11-13 22:30:00	31.4115N	-118.5500W	0.93	1.14	1.24	2.58	3.72
2013-11-13 17:00:00	2013-11-13 22:30:00	31.4115N	-118.5500W	0.93	1.14	1.24	2.58	3.72
2013-11-13 18:30:00	2013-11-14 22:30:00	33.0702N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2013-11-18 13:00:00	2013-11-19 15:00:00	33.0702N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2013-11-18 18:30:00	2013-11-19 22:30:00	33.0702N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2013-11-21 13:00:00	2013-11-21 15:00:00	33.0702N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2013-11-21 18:30:00	2013-11-21 22:30:00	33.0702N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2013-11-22 13:00:00	2013-11-22 15:00:00	33.0702N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2013-11-22 18:30:00	2013-11-22 22:30:00	33.0702N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2013-11-23 04:00:00	2013-11-23 06:59:00	33.0702N	-106.2540W	9.80	10.94	11.35	15.27	17.96
2013-12-06 06:00:00	2013-12-06 13:30:00	37.1934N	-115.1330W	4.95	7.43	7.33	12.49	16.72
2013-12-07 14:00:00	2013-12-07 18:00:00	30.0500N	-80.0500W	1.24	1.86	3.10	4.85	6.71
2013-12-07 20:00:00	2013-12-07 23:59:00	30.0500N	-80.0500W	1.24	1.86	3.10	4.85	6.71
2013-12-08 13:00:00	2013-12-08 18:00:00	30.0500N	-80.0500W	1.24	1.86	3.10	4.85	6.71
2013-12-09 14:00:00	2013-12-09 19:00:00	30.0500N	-80.0500W	1.24	1.86	3.10	4.85	6.71
2013-12-10 03:00:00	2013-12-10 06:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2013-12-10 06:00:00	2013-12-10 13:30:00	37.1934N	-115.1330W	4.95	7.43	7.33	12.49	16.72

2013-12-11 03:00:00	2013-12-11 15:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2013-12-12 03:00:00	2013-12-12 15:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2013-12-13 04:00:00	2013-12-13 06:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2013-12-13 06:00:00	2013-12-13 13:30:00	37.1934N	-115.4250W	4.75	7.33	6.91	12.59	16.10
2013-12-14 04:00:00	2013-12-14 15:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2013-12-15 03:00:00	2013-12-15 15:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2013-12-18 03:00:00	2013-12-18 12:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74
2013-12-19 03:00:00	2013-12-19 12:00:00	33.2339N	-106.3058W	11.87	12.69	13.00	17.23	20.74

9 Appendices

9.1 Appendix A: Performance Summary

Table 9-1 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	≤ 4.576 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	≤ 3.596 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	≤ 27.444 mm/s^2

Status and Problem Reporting	Conditions and Constraints	Measured Performance
Scheduled event affecting service • Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	• For any SPS SIS	≥ 101.833 hours Prior to event
Unscheduled outage or problem affecting service • Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	• For any SPS SIS	0.433 hours
Operational Satellite Count	**Conditions and Constraints**	
• ≥ 0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not	• Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operation satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not.	100%
PDOP Availability	**Conditions and Constraints**	
• ≥ 98% global PDOP of 6 or less • ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval	100 % 100 %
Service Availability	**Conditions and Constraints**	
• ≥ 99% Horizontal Service Availability, average location • ≥ 99% Vertical Service Availability, average location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	100% Horizontal 100% Vertical
• ≥ 90% Horizontal Service Availability, worst-case location • ≥ 90% Vertical Service Availability, worst-case location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	100% Horizontal 100% Vertical
Position/Time Accuracy	**Conditions and Constraints**	
Global Average Position Domain Accuracy • ≤ 9m 95% Horizontal Error • ≤ 15m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 2.855 m Horizontal ≤ 7.498 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.	≤ 8.068 m Horiz. ≤ 9.254 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.	≤ 17 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%

9.2 Appendix B: Geomagnetic Data

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

Current Quarter Daily Geomagnetic Data

Date	Middle Latitude - Fredericksburg - A	K-indices	High Latitude ---- College ---- A	K-indices	Estimated --- Planetary --- A	K-indices
2013 10 01	6	0 1 1 2 3 1 2 2	2	0 0 0 0 2 0 1 1	5	0 0 1 1 2 1 2 2
2013 10 02	29	5 5 5 3 3 3 4 3	64	6 8 5 5 5 3 3 3	39	5 6 5 3 3 3 5 4
2013 10 03	5	3 1 0 1 1 2 2 0	9	5 2 1 1 0 2 2 0	6	4 1 0 1 1 2 2 0
2013 10 04	2	0 0 0 1 1 1 1 0	0	0 0 0 0 0 0 0 0	2	0 0 0 0 1 1 1 0
2013 10 05	2	0 0 0 1 2 1 1 0	0	0 0 0 0 0 0 0 0	1	0 0 0 1 1 1 0 0
2013 10 06	3	0 0 0 2 1 2 1 1	0	0 0 0 1 0 0 0 0	2	0 0 0 1 1 1 0 1
2013 10 07	8	1 3 3 2 2 2 1 1	4	0 1 3 2 1 1 0 0	6	1 3 2 1 1 1 1 1
2013 10 08	12	0 1 0 1 2 2 4 5	14	0 0 1 3 3 0 4 5	16	0 1 0 1 1 1 5 5
2013 10 09	21	4 4 5 3 3 3 2 3	40	3 4 7 5 5 4 2 2	24	5 4 5 4 3 3 2 3
2013 10 10	7	3 3 2 1 2 1 1 0	12	2 3 2 5 2 2 1 1	9	4 3 2 2 1 1 1 1
2013 10 11	3	1 1 2 1 1 1 1 0	7	1 2 2 3 4 0 0 0	5	1 2 2 1 2 1 1 1
2013 10 12	3	0 1 0 2 1 2 1 1	4	0 0 1 3 1 0 2 1	5	0 1 1 2 1 1 2 2
2013 10 13	2	1 0 0 1 1 2 1 0	1	1 0 0 0 1 0 0 0	2	1 0 0 0 0 1 0 0
2013 10 14	10	0 2 2 3 3 2 3 3	31	0 1 5 6 5 5 3 2	13	0 2 2 3 3 3 4 3
2013 10 15	14	3 4 3 3 3 1 1 3	27	4 4 5 6 3 1 2 2	14	4 4 3 3 2 1 1 3
2013 10 16	9	3 2 1 2 3 2 2 2	10	2 1 1 3 4 3 1 1	9	4 2 2 1 2 2 2 2
2013 10 17	10	2 3 3 2 3 2 2 1	16	2 2 4 5 4 2 1 1	9	2 3 3 2 2 2 1 1
2013 10 18	3	0 0 0 1 2 0 2 1	1	0 0 1 1 0 0 1 0	3	0 0 1 1 1 1 2 0
2013 10 19	3	0 0 0 1 2 2 2 1	0	0 0 0 1 0 0 0 0	3	0 0 0 1 1 1 0 0
2013 10 20	3	0 0 1 1 2 1 1 1	0	0 0 0 1 0 0 0 0	3	0 0 1 1 1 1 1 1
2013 10 21	2	0 0 1 0 2 1 1 1	0	0 0 0 0 0 0 0 0	2	0 0 0 0 1 1 0 0
2013 10 22	3	0 0 2 1 1 1 2 1	1	0 0 0 2 0 0 1 0	5	0 0 2 2 1 1 2 2
2013 10 23	3	0 1 1 1 1 1 1 1	4	0 2 2 3 0 0 0 0	4	1 2 1 1 1 1 1 0
2013 10 24	2	0 1 0 1 2 1 1 0	0	0 0 0 0 0 0 0 0	3	1 1 0 1 1 1 0 0
2013 10 25	3	0 0 0 0 2 2 1 1	0	0 0 0 0 0 0 0 0	3	0 0 1 0 1 2 1 1
2013 10 26	3	0 0 0 1 2 1 1 2	0	0 0 0 0 0 0 0 0	3	0 0 0 1 1 1 1 1
2013 10 27	2	0 0 1 1 2 1 1 0	0	0 0 0 0 0 0 0 0	3	0 0 1 1 1 1 1 0
2013 10 28	2	1 1 1 1 1 0 0 0	0	0 0 0 0 0 0 0 0	3	1 1 1 0 1 1 0 0
2013 10 29	3	0 0 0 2 2 1 2 1	9	0 0 0 5 3 0 1 1	6	0 0 0 3 2 1 2 2
2013 10 30	10	0 1 3 2 3 3 2 3	31	0 0 4 6 5 6 2 2	12	0 1 3 3 3 3 3 3
2013 10 31	6	2 1 1 2 2 2 2 2	3	1 0 0 1 1 2 1 1	6	2 1 0 2 2 2 2 2
2013 11 01	4	2 1 0 1 1 1 2 1	10	1 2 3 4 4 0 0 0	5	2 2 1 1 1 0 1 0
2013 11 02	3	1 1 1 1 1 0 1 1	1	1 1 0 1 0 0 0 0	3	1 1 0 1 0 1 0 1
2013 11 03	7	3 3 2 1 2 0 1 1	7	1 3 3 3 1 0 0 1	6	2 3 2 1 1 1 2 1
2013 11 04	4	0 1 1 1 2 2 1 1	7	0 2 1 3 2 3 2 0	5	0 1 1 2 1 2 2 1
2013 11 05	4	1 1 1 1 2 2 1 0	2	0 0 2 1 1 1 0 0	5	1 1 1 1 1 1 0 2
2013 11 06	3	0 0 1 1 2 2 1 1	0	0 0 0 0 0 0 1 0	4	0 0 1 1 1 1 1 1
2013 11 07	11	1 3 2 4 3 2 2 1	23	0 4 3 6 5 0 2 1	11	1 3 3 4 3 2 2 1
2013 11 08	3	2 1 1 1 1 1 1 0	1	1 1 1 0 0 0 0 0	4	2 1 1 1 0 1 0 0
2013 11 09	14	2 3 3 4 4 2 2 1	40	1 6 5 6 6 3 2 1	16	2 4 4 4 4 2 2 1
2013 11 10	9	2 3 1 3 2 2 2 2	15	2 2 3 4 3 3 3 3	10	2 2 2 2 2 2 3 3
2013 11 11	13	3 3 3 3 3 3 2 1	30	4 4 6 5 4 4 2 0	16	4 4 4 3 3 3 2 1
2013 11 12	2	1 2 0 1 1 0 0 0	1	1 1 0 0 1 0 0 0	2	1 1 0 0 1 0 0 0
2013 11 13	2	0 1 0 1 1 1 1 0	5	0 0 1 2 4 1 0 0	3	0 1 1 1 2 1 0 0
2013 11 14	2	0 0 0 1 2 1 0 0	0	0 0 0 1 0 0 0 0	2	0 0 0 1 1 1 0 1
2013 11 15	6	1 2 1 0 1 2 2 3	10	0 1 2 3 3 4 2 2	8	1 2 1 1 1 2 2 4
2013 11 16	11	3 3 2 3 3 2 1 2	12	2 1 2 4 4 3 1 2	9	3 3 2 3 3 2 1 2
2013 11 17	5	2 2 2 2 2 1 1 0	9	1 1 4 4 2 0 1 0	6	2 2 3 2 1 1 1 1
2013 11 18	2	2 0 0 0 0 1 1 1	1	0 0 1 1 1 0 0 0	3	1 0 1 1 1 1 1 1
2013 11 19	3	0 0 0 0 1 2 2 1	1	0 0 0 0 1 1 1 0	3	0 0 0 0 1 1 2 1
2013 11 20	3	1 1 1 1 2 1 1 0	5	0 1 1 2 4 0 0 0	4	1 1 1 1 2 0 1 0

2013	11	21	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	1	0	0	1	1
2013	11	22	2	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	3	1	1	0	0	0	0	1	2
2013	11	23	6	1	2	3	2	2	2	1	0	11	0	1	3	5	3	2	0	0	8	1	3	3	3	2	1	1	0
2013	11	24	2	0	0	0	1	1	1	1	0	1	0	0	0	2	0	0	0	0	2	0	0	0	1	0	0	1	0
2013	11	25	2	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	1	0
2013	11	26	2	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	1
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2013	12	04	3	1	1	1	1	1	1	1	1	2	1	0	1	0	1	0	1	2	4	2	2	1	0	0	1	1	1
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2013	12	07	4	1	1	2	0	1	1	1	2	3	0	1	2	1	1	0	0	2	6	2	1	2	1	1	1	2	3
2013	12	08	14	4	4	3	2	2	3	2	1	23	4	4	4	3	3	5	3	2	26	6	5	4	2	2	4	3	2
2013	12	09	2	1	0	0	1	1	1	1	1	4	0	0	0	1	3	2	1	0	5	1	0	1	1	1	2	2	1
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2013	12	13	3	0	1	0	0	2	2	1	1	0	0	1	0	0	0	0	0	0	3	0	1	0	0	2	2	1	1
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2013	12	15	5	1	1	1	1	1	1	3	1	1	8	1	1	2	3	3	3	1	0	7	2	1	1	1	1	3	1	1
2013	12	16	5	2	2	2	0	2	2	1	1	6	1	1	1	3	3	1	0	1	7	3	3	2	1	1	1	2	2
2013	12	17	3	1	0	0	0	0	2	2	1	1	0	0	0	1	0	0	2	0	3	2	1	0	0	0	1	2	1
2013	12	18	3	0	1	1	1	1	2	1	1	2	0	0	3	1	0	0	0	0	4	1	1	2	1	0	1	1	2
2013	12	19	4	1	1	0	0	2	2	1	2	3	0	1	0	0	2	2	1	1	5	2	2	0	0	1	2	2	2
2013	12	20	6	2	2	0	2	2	3	1	1	2	1	1	1	1	1	1	0	0	6	2	3	0	1	1	2	2	1
2013	12	21	4	1	1	2	1	2	1	1	0	1	1	0	2	0	0	0	0	0	4	1	1	2	1	0	0	1	0
2013	12	22	2	0	1	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	3	0	1	1	1	0	0	1	0
2013	12	23	2	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	3	1	1	1	0	0	0	1	1
2013	12	24	2	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	1
2013	12	25	6	2	1	2	3	2	1	1	0	16	0	0	3	5	4	4	2	0	7	2	1	2	3	3	2	1	1
2013	12	26	2	1	1	1	0	1	1	0	0	4	0	0	2	3	2	1	0	0	3	1	1	1	1	1	0	0	0
2013	12	27	3	0	0	0	0	2	1	2	1	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	0	2	1
2013	12	28	4	0	0	0	1	2	2	2	2	0	0	0	0	0	0	0	0	0	3	0	0	0	1	1	1	1	1
2013	12	29	4	1	1	0	2	1	2	2	0	5	0	0	0	4	2	1	0	0	5	1	1	1	2	1	1	2	1
2013	12	30	2	0	0	1	0	1	2	1	1	1	0	0	2	1	0	0	0	0	3	0	0	1	1	1	1	1	1
2013	12	31	6	1	1	2	2	2	2	2	1	4	0	0	2	3	1	1	1	0	6	2	1	2	2	2	1	2	1

9.3 Appendix C: Performance Analysis (PAN) Problem Report

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

Problem Description:

Although no GPS satellites failed specification limits, two GPS satellites (PRN's 8 and 11) did exceed 30 meter range errors for a short time. The plots below show the range error plots for the satellites in both a single frequency and dual frequency navigation solution. The plots demonstrate that the major contributor to the range errors measured on these satellites was due to ionospheric error. This is evidenced by the fact that the dual frequency solution had a much smaller range error value.

Figure 9-1 Dual and Single Frequency Range Error on PRN8: 25 October 2013

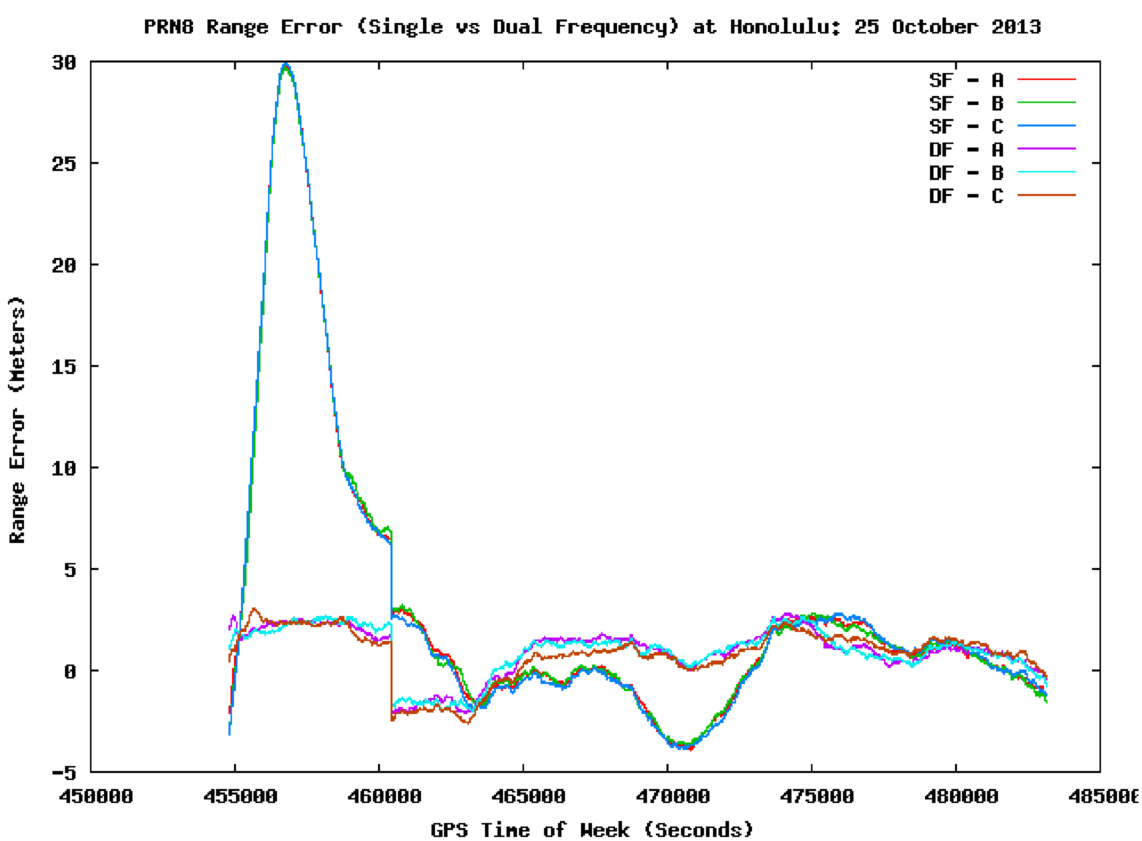
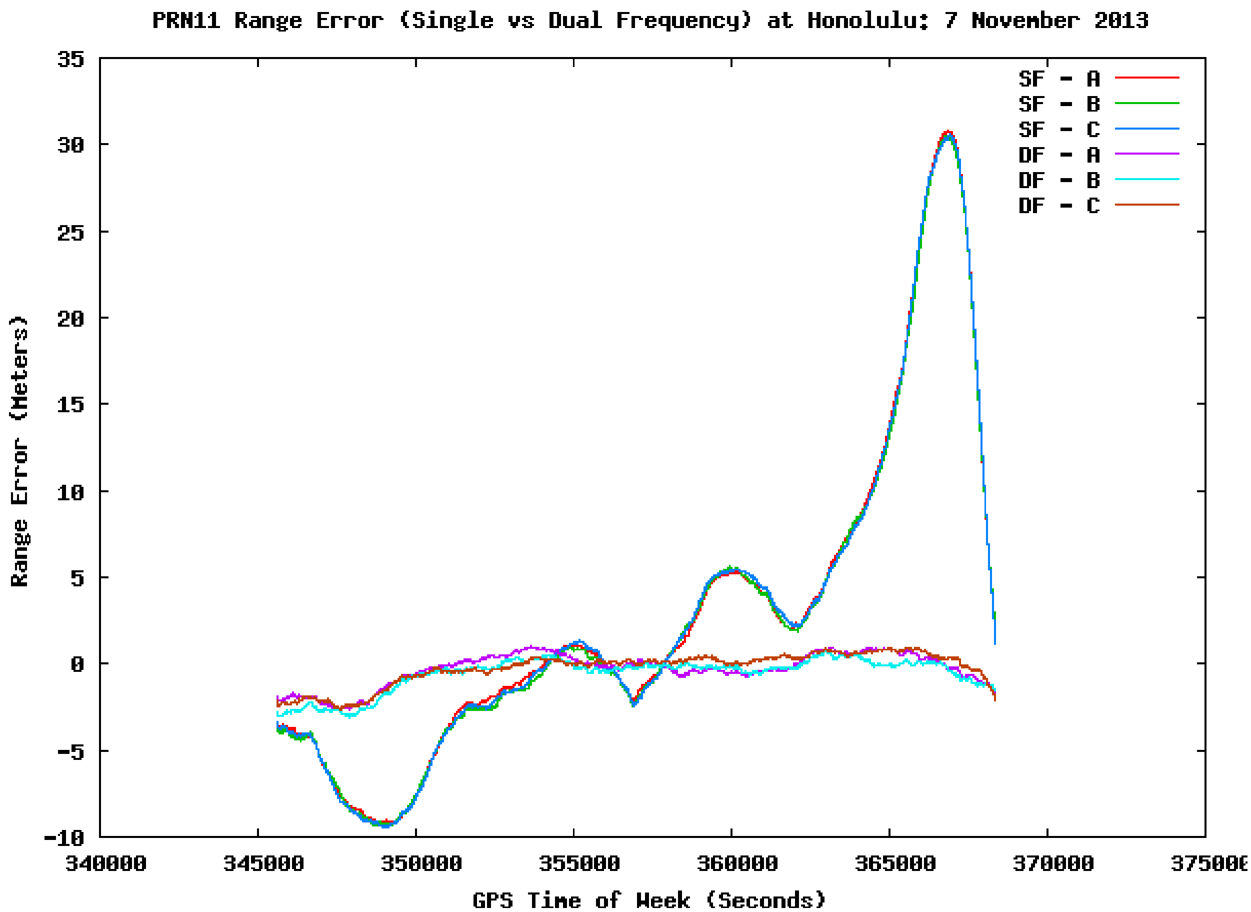


Figure 9-2 Dual and Single Frequency Range Error on PRN11: 7 November 2013



9.4 Appendix D: Glossary

The terms and definitions discussed below are taken from the Standard Positioning Service Performance Specification (October 2001). 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 ICDGPS-200C.

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 ICDGPS200C.