

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

Submitted To

**Federal Aviation Administration
GPS Product Team**

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Submitted by

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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 (October 2001).

This report, Report #64, includes data collected from 1 October through 31 December 2008. The next quarterly report will be issued 30 April 2009.

Analysis of this data includes the following standards and categories: PDOP Availability, NANU Summary and Evaluation, Service Availability, Service Reliability, 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 the CONUS was 99.993% or better.

NANU summary and evaluation was achieved by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 October and 31 December 2008. 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 fourteen outages were reported in the NANU’s this quarter. Twelve outages were scheduled while two were unscheduled.

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

Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error and Service Reliability standards were 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 13.610 meters on Satellite PRN 13. The SPS specification states that the range error should never exceed 30 meters for less than 99.79% of the day for a worst-case point and 99.94% globally. The maximum RMS range error value of 2.557 recorded on satellite 10. The SPS specification states that RMS URE cannot exceed 6 meters in any 24-hour interval.

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

This quarter we’ve added a new section covering the GPS-SPS accuracy performance of IGS stations from around the world. 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 are 3.56 meters at Maspalomas and 6.14 meters at Usuda, respectively.

From the analysis performed on data collected between 1 October and 31 December 2008, the GPS performance met all SPS requirements that were evaluated. There were no significant problems to report for the duration of the quarter.

TABLE OF CONTENTS

1.0 INTRODUCTION.....5

 1.1 Objective of GPS SPS Performance Analysis Report.....5

 1.2 Summary of Performance Requirements and Metrics.....6

 1.3 Report Overview.....6

2.0 PDOP Availability Standard.....9

3.0 NANU Summary and Evaluation.....12

 3.1 Satellite Outages from NANU Reports.....12

 3.2 Service Availability Standard.....14

4.0 Service Reliability Standard.....16

5.0 Accuracy Standard.....17

 5.1 Position Accuracy.....18

 5.2 Time Transfer Accuracy.....20

 5.3 Range Domain Accuracy.....21

6.0 Solar Storms.....27

7.0 IGS Data.....30

Appendix A: Performance Summary.....34-35

Appendix B: Geomagnetic Data.....36-37

Appendix C: Performance Analysis (PAN) Problem Report.....38

Appendix D: Glossary.....39

LIST OF FIGURES

Figure 2-1 PDOP Availability (24-Hour Period: 15 December 2008).....	10
Figure 2-2 Satellite Visibility Profile for Worst-Case Point: 15 December 2008.....	11
Figure 5-1 Global Vertical Error Histogram.....	19
Figure 5-2 Global Horizontal Error Histogram.....	19
Figure 5-3 Time Transfer Error.....	20
Figure 5-4 Distribution of Daily Max Range Errors: 1 October – 31 December 2008.....	24
Figure 5-5 Distribution of Daily Max Range Error Rates: 1 October – 31 December 2008....	24
Figure 5-6 Distribution of Daily Max Range Acceleration Error: 1 October – 31 December 2008.....	25
Figure 5-7 Combined Range Error Histogram: 1 October – 31 December 2008.....	25
Figure 5-8 Maximum Range Error Per Satellite.....	26
Figure 5-9 Maximum Range Rate Error Per Satellite.....	26
Figure 5-10 Maximum Range Acceleration Per Satellite.....	26
Figure 6-1 K-Index for 10-12 October 2008.....	28
Figure 6-2 K-Index for 3-5 October 2008.....	28
Figure 6-3 K-Index for 7-9 November 2008.....	28
Figure 7-1 Selected IGS Site Locations.....	31
Figure 7-2 GPS-SPS 95% Horizontal Accuracy at Selected IGS Sites.....	32
Figure 7-3 GPS-SPS 95% Vertical Accuracy at Selected IGS Sites.....	32

LIST OF TABLES

Table 1-1	SPS Performance Requirements.....	7-8
Table 2-1	PDOP Availability Statistics.....	10
Table 3-1	NANU’s Affecting Satellite Availability.....	12
Table 3-2	NANU’s Forecasted to Affect Satellite Availability.....	13
Table 3-3	NANU’s Canceled to Affect Satellite Availability.....	13
Table 3-4	GPS Block II/IIA Satellite RMA Data.	13
Table 3-5	Accuracies Exceeding Threshold Values.....	15
Table 4-1	Service Reliability Based on User Range Error.....	16
Table 5-1	Horizontal & Vertical Accuracy Statistics.....	18
Table 5-2	Range Error Statistics.....	21
Table 5-3	Range Rate Error Statistics.....	22
Table 5-4	Range Acceleration Error Statistics.....	23
Table 6-1	Horizontal & Vertical Accuracy Statistics: 11 October 2008.....	29
Table 7-1	Selected IGS Site Information.....	30
Table 7-2	GPS-SPS Performance at a Selection of High Rate IGS Sites.....	31

1.0 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 (October 2001). 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 Summary of Performance Requirements and Metrics

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

1.3 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.

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 (October 2001).

Table 1-1 SPS Performance Requirements

PDOP Availability Standard	Conditions and Constraints	Evaluated in This Report
<p>≥ 98% global Position Dilution of Precision (PDOP) of 6 or less</p> <p>≥ 88% worst site PDOP of 6 or less</p>	<ul style="list-style-type: none"> Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. Based on using only satellites transmitting standard code and indicating “health” in the broadcast navigation message (sub-frame 1). 	✓
Service Availability Standard	Conditions and Constraints	
<p>≥ 99% Horizontal Service Availability average location</p> <p>≥ 99% Vertical Service Availability average location</p>	<ul style="list-style-type: none"> 36 meter horizontal (SIS only) 95% threshold. 77 meter vertical (SIS only) 95% threshold. Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. 	✓
<p>≥ 95.87% global average on worst-case day</p>	<ul style="list-style-type: none"> Based on using only satellites transmitting standard code and indicating “healthy” in the broadcast navigation message (sub-frame 1). 	✓
Service Reliability Standard	Conditions and Constraints	
<p>≥ 99.94% global average</p>	<ul style="list-style-type: none"> 30-meter Not-to-Exceed (NTE) SPS SIS URE. Standard based on a measurement interval of one year; average of daily values within the service volume. Standard based on 3 service failures per year, lasting no more than 6 hours each. 	✓
<p>≥ 99.79% single point average</p>	<ul style="list-style-type: none"> 30-meter Not-to-Exceed (NTE) SPS SIS URE. Standard based on a measurement interval of one year; average of daily values from the worst-case point within the service volume. Standard based on 3 service failures per year, lasting no more than 6 hours each. 	✓

Accuracy Standard	Conditions and Constraints	
Global Average Positioning Domain Accuracy • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only)	<ul style="list-style-type: none"> • Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume. 	✓
Worst Site Positioning Domain Accuracy • ≤ 36 meters 95% All-in-View Horizontal Error (SIS only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS only)	<ul style="list-style-type: none"> • Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours for any point within the service volume. 	✓
Time Transfer Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	<ul style="list-style-type: none"> • Defined for time transfer solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume. 	✓
SPS SIS URE STANDARD	Conditions and Constraints	
≤ 6 meters RMS SIS SPS URE across the entire constellation	<ul style="list-style-type: none"> • Average of the constellation's individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point within the service volume. 	✓

2.0 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 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. .*

PDOP Availability Standard	Conditions and Constraints
<p>≥ 98% global Position Dilution of Precision (PDOP) of 6 or less</p> <p>≥ 88% worst site PDOP of 6 or less</p>	<ul style="list-style-type: none"> • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. • Based on using only satellites transmitting standard code and indicating “health” in the broadcast navigation message (sub-frame 1).

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° 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 3.18693 or better 99.9% of the time for each of the 24-hour intervals.

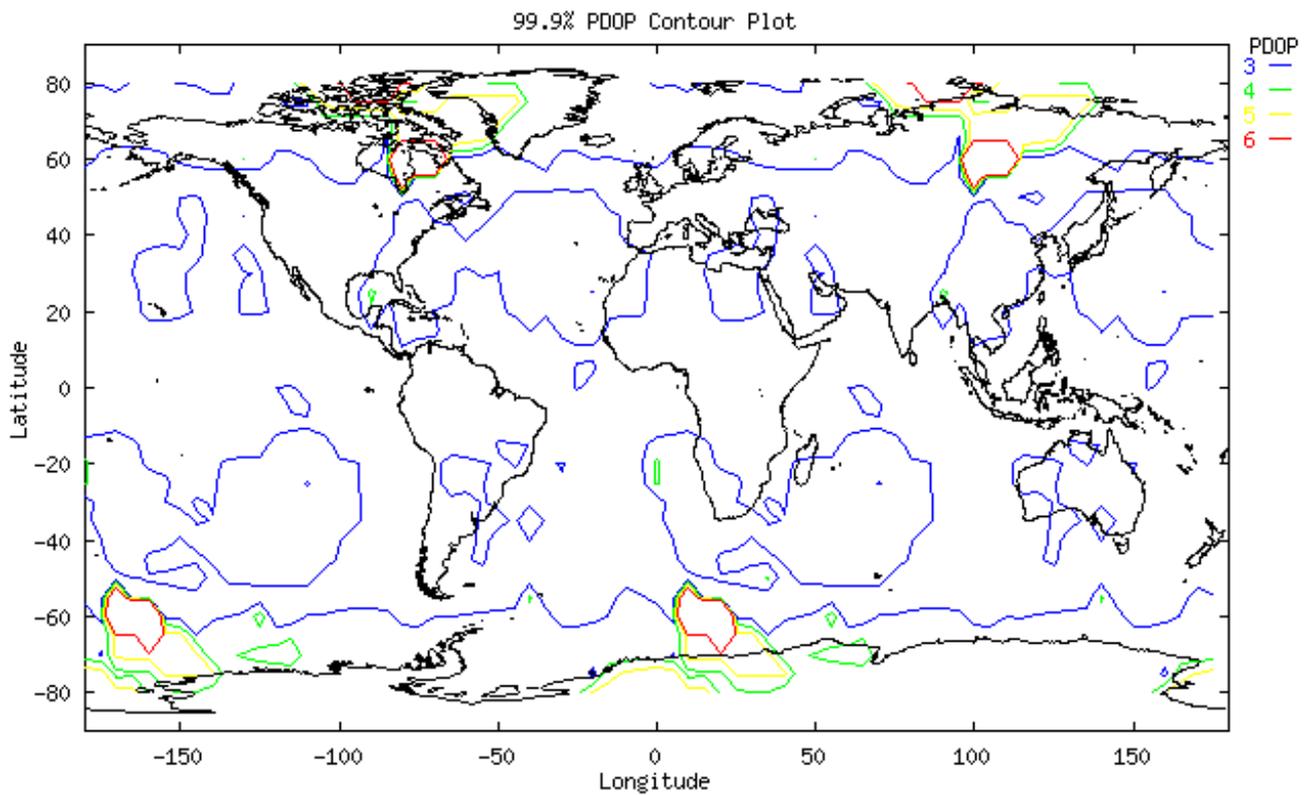
Figure 2-1 is a contour plot of PDOP values over the entire globe. Inside each contour area, the PDOP value is greater than or equal to the contour value shown in the legend for that color line. That areas’ value is also less than the next higher contour value, unless another contour line lies within 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.

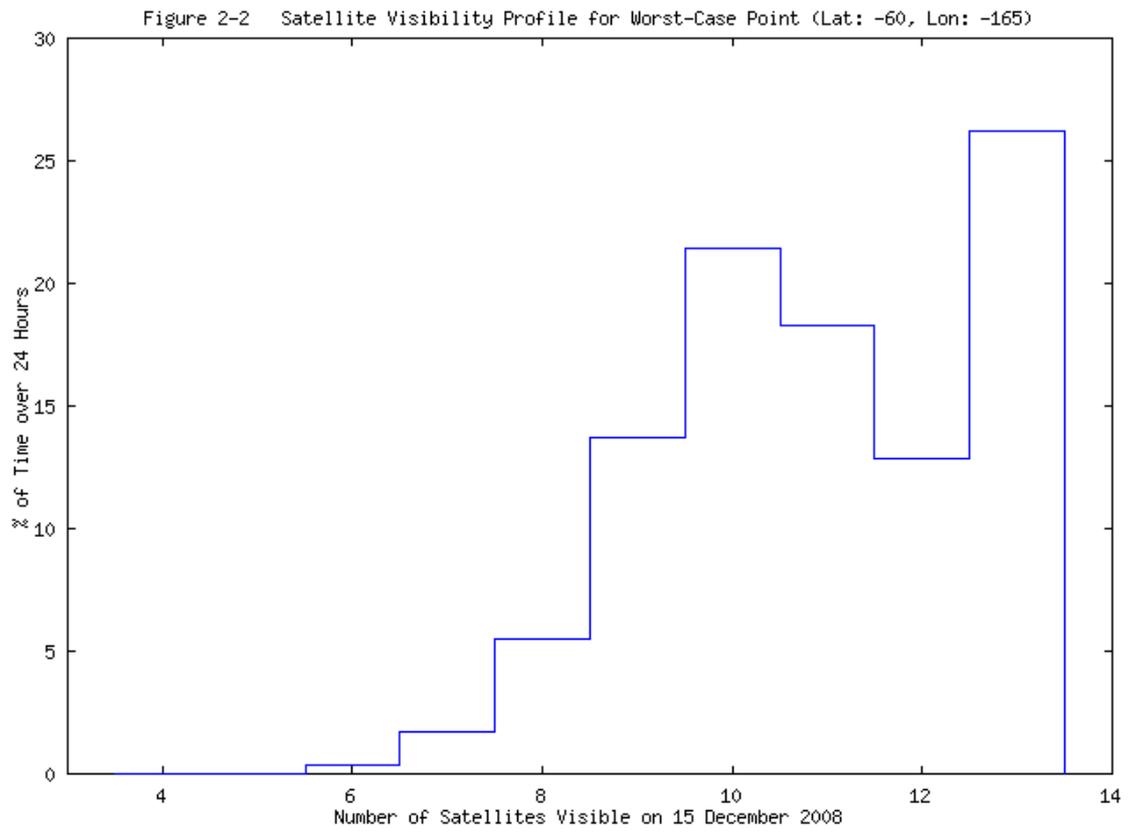
Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
28 Sept – 4 Oct	3.09004	99.993	99.236
5 – 11 Oct	3.07419	99.996	99.306
12 – 18 Oct	3.05207	99.993	99.236
19 – 25 Oct	3.07452	99.993	99.167
26 Oct – 1 Nov	3.06909	99.993	99.236
2 – 8 Nov	3.08372	99.993	99.167
9 – 15 Nov	3.08173	99.993	99.167
16 – 22 Nov	3.11738	99.993	99.167
23 – 29 Nov	3.13041	99.994	99.097
30 Nov – 6 Dec	3.12674	99.994	99.028
7-13 Dec	3.13445	99.994	99.028
14-20 Dec	3.17132	99.994	99.028
21-27 Dec	3.18693	99.994	98.958

Figure 2-1 PDOP Availability Plot (24-Hour Period: 15 December 2008)



Developed by FAA William J. Hughes Technical Center



3.0 NANU Summary and Evaluation

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

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 2008, there were a total of fourteen reported outages. Twelve of these outages were maintenance activities and were reported in advance. Two were 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 are provided in Table 3-3.

Table 3-1 NANUs Affecting Satellite Availability									
NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total		Total
							Unscheduled	Scheduled	
2008116	2	FCSTSUMM	30-Sep	16:30	30-Sep	19:37			3.12
2008117	12	FCSTSUMM	2-Oct	17:51	2-Oct	20:49			2.97
2008121	13	FCSTSUMM	7-Oct	14:45	7-Oct	17:32			2.78
2008122	5	UNUSABLE	5-Aug	23:38	7-Oct	20:49	1509.18		1509.18
2008123	26	FCSTSUMM	8-Oct	13:07	8-Oct	18:36			5.48
2008129	29	FCSTSUMM	15-Oct	20:06	16-Oct	3:16			7.17
2008132	15	FCSTSUMM	16-Oct	18:41	16-Oct	22:02			3.35
2008135	29	FCSTSUMM	24-Oct	19:29	24-Oct	22:26			2.95
2008136	2	FCSTSUMM	28-Oct	20:31	29-Oct	2:55			6.40
2008138	27	UNUSABLE	14-Nov	4:48	14-Nov	11:55	7.12		7.12
2008140	27	FCSTSUMM	20-Nov	12:04	20-Nov	18:58			6.90
2008143	13	FCSTSUMM	11-Dec	16:17	11-Dec	22:32			6.25
2008146	5	FCSTSUMM	17-Dec	19:17	17-Dec	21:21			2.07
2008147	14	FCSTSUMM	19-Dec	2:37	19-Dec	9:05			6.47
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							1516.30	55.90	1572.20

Table 3-2 NANUs Forecasted to Affect Satellite Availability								
NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2008118	29	FCSTDV	9-Oct	20:15	10-Oct	11:00	14.75	See Nanu 2008124
2008119	26	FCSTMX	8-Oct	13:00	9-Oct	1:00	12	See Nanu 2008123
2008120	13	FCSTMX	7-Oct	14:00	8-Oct	2:00	12	See Nanu 2008121
2008124	29	FCSTRESCD	15-Oct	20:00	16-Oct	11:00	15	See Nanu 2008129
2008125	29	FCSTMX	14-Oct	19:30	14-Oct	23:30	4	See Nanu 2008127
2008126	15	FCSTMX	16-Oct	18:30	17-Oct	6:30	12	See Nanu 2008132
2008127	29	FCSTRESCD	14-Oct	19:30	15-Oct	7:30	12	CANC
2008133	29	FCSTMX	24-Oct	19:00	25-Oct	7:00	12	See Nanu 2008135
2008134	2	FCSTDV	28-Oct	20:30	29-Oct	11:00	14.5	See Nanu 2008136
2008137	27	UNUSUFN	14-Nov	4:48	N/A	N/A	N/A	See Nanu 2008138
2008139	27	FCSTDV	20-Nov	12:00	21-Nov	14:00	26	See Nanu 2008140
2008142	13	FCSTDV	11-Dec	16:00	12-Dec	6:30	14.5	See Nanu 2008143
2008144	14	FCSTDV	19-Dec	2:30	19-Dec	17:00	14.5	See Nanu 2008147
2008145	5	FCSTMX	17-Dec	19:00	18-Dec	7:00	12	See Nanu 2008146
Total Forecast Downtime							175.25	

Table 3-3 NANUs Canceled					
NANU#	PRN	Type	Start Date	Start Time	Comments
2008128	29	FCSTCANC	14-Oct	19:22	See Nanu 2008127

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. Schedule 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 Block II/IIA Satellite RMA Data		
Satellite Reliability/Maintainability/Availability (RMA) Parameter	1-Oct-08	1-Oct-99
	31-Dec-08	31-Dec-08
Total Forecast Downtime (hrs):	175.25	7514.80
Total Actual Downtime (hrs):	1572.20	27404.09
Total Actual Scheduled Downtime (hrs):	55.90	3847.88
Total Actual Unscheduled Downtime (hrs):	1516.30	23556.21
Total Satellite Observed MTTR (hrs):	112.30	45.98
Scheduled Satellite Observed MTTR (hrs):	4.66	8.85
Unscheduled Satellite Observed MTTR (hrs):	758.15	146.31
# Total Satellite Outages:	14	596
# Scheduled Satellite Outages:	12	435
# Unscheduled Satellite Outages:	2	161
Percent Operational -- Scheduled Downtime:	99.92	99.83
Percent Operational -- All Downtime:	99.93	98.79

3.2 Service Availability Standard

Service Availability: 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:** 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
<p>≥ 99% Horizontal Service Availability average location</p> <p>≥ 99% Vertical Service Availability average location</p>	<ul style="list-style-type: none"> • 36 meter horizontal (SIS only) 95% threshold. • 77 meter vertical (SIS only) 95% threshold. • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.
<p>≥ 95.87% global average on worst-case day</p>	<ul style="list-style-type: none"> • Based on using only satellites transmitting standard code and indicating “healthy” in the broadcast navigation message (sub-frame 1).

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 2008.

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	7940098	0	100%
Anchorage	7940404	0	100%
Atlanta	7938934	0	100%
Barrow	7923726	0	100%
Bethel	7932618	0	100%
Billings	7936131	0	100%
Boston	7787270	0	100%
Cleveland	7941817	0	100%
Cold Bay	7889934	0	100%
Fairbanks	7935209	0	100%
Gander	7936963	0	100%
Honolulu	7923957	0	100%
Houston	7932202	0	100%
Iqaluit	7930277	0	100%
Juneau	7237385	0	100%
Kansas City	7941087	0	100%
Kotzebue	6200642	0	100%
Los Angeles	7941496	0	100%
Merida	7934932	0	100%
Miami	7939891	0	100%
Minneapolis	7934883	0	100%
Oakland	7940248	0	100%
Salt Lake City	7940811	0	100%
San Jose Del Cabo	7628056	0	100%
San Juan	7939576	0	100%
Seattle	7941028	0	100%
Tapachula	7928623	0	100%
Washington, DC	7481252	0	100%
Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)			

4.0 Service Reliability Standard

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 Reliability Standard	Conditions and Constraints
≥ 99.94% global average	<ul style="list-style-type: none"> • 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.
≥ 99.79% single point average	<ul style="list-style-type: none"> • 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values from the worst-case point within the 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 on page 21. The maximum User Range Error recorded this quarter was 13.610 meters on satellite PRN 13.

Table 4-1 Service Reliability Based on User Range Error

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Service Reliability Percentage
1 Oct – 31 Dec 2008	Boston	65,544,533	0	100%
1 Oct – 31 Dec 2008	Honolulu	69,753,235	0	100%
1 Oct – 31 Dec 2008	Los Angeles	69,329,731	0	100%
1 Oct – 31 Dec 2008	Miami	67,445,621	0	100%
1 Oct – 31 Dec 2008	San Juan	69,846,780	0	100%
1 Oct – 31 Dec 2008	Juneau	63,364,403	0	100%
1 Oct – 31 Dec 2008	Global	405,284,303	0	100%

5.0 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 horiz 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.

Accuracy Standard	Conditions and Constraints
Global Average Positioning Domain Accuracy <ul style="list-style-type: none"> • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only) 	<ul style="list-style-type: none"> • Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.
Worst Site Positioning Domain Accuracy <ul style="list-style-type: none"> • ≤ 36 meters 95% All-in-View Horizontal Error (SIS only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS only) 	<ul style="list-style-type: none"> • Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours for any point within the service volume.
Time Transfer Accuracy <ul style="list-style-type: none"> • ≤ 40 nanoseconds time transfer error 95% of time (SIS only) 	<ul style="list-style-type: none"> • Defined for time transfer solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.
SPS SIS URE STANDARD	Conditions and Constraints
≤ 6 meters RMS SIS SPS URE across the entire constellation	<ul style="list-style-type: none"> • Average of the constellation's individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point within the service volume.

5.1 Position Accuracy

The data used for this section was collected for every second from 1 October through 31 December 2008 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% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Albuquerque	2.043	4.242	3.895	9.127
Anchorage	1.942	5.256	3.751	9.497
Atlanta	2.255	4.751	5.209	10.528
Barrow	1.639	5.591	3.093	9.970
Bethel	2.028	5.306	4.199	8.815
Billings	2.227	4.371	3.901	9.792
Boston	2.445	4.604	4.985	10.997
Cleveland	2.392	4.532	5.783	10.491
Cold Bay	2.239	5.240	5.053	8.168
Fairbanks	1.771	5.379	3.743	10.325
Gander	2.516	4.158	4.440	9.169
Honolulu	3.299	4.707	6.402	11.172
Houston	2.051	4.697	5.057	10.593
Iqaluit	1.967	4.767	8.053	20.349
Juneau	2.064	4.943	3.983	9.761
Kansas City	2.278	4.508	5.319	9.323
Kotzebue	1.759	5.160	3.404	8.679
Los Angeles	2.064	4.867	3.952	10.100
Merida	2.000	5.035	4.810	10.852
Miami	2.123	5.267	4.708	11.479
Minneapolis	2.323	4.558	4.754	9.230
Oakland	2.109	4.890	4.984	9.827
Salt Lake City	2.128	4.380	3.866	10.629
San Jose Del Cabo	2.163	4.743	5.511	9.103
San Juan	1.955	5.194	5.199	12.913
Seattle	2.226	4.420	4.294	9.520
Tapachula	2.482	4.761	6.727	9.948
Washington, DC	2.430	4.594	5.383	11.474

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 2008.

Figure 5-1 Global Vertical Error Histogram

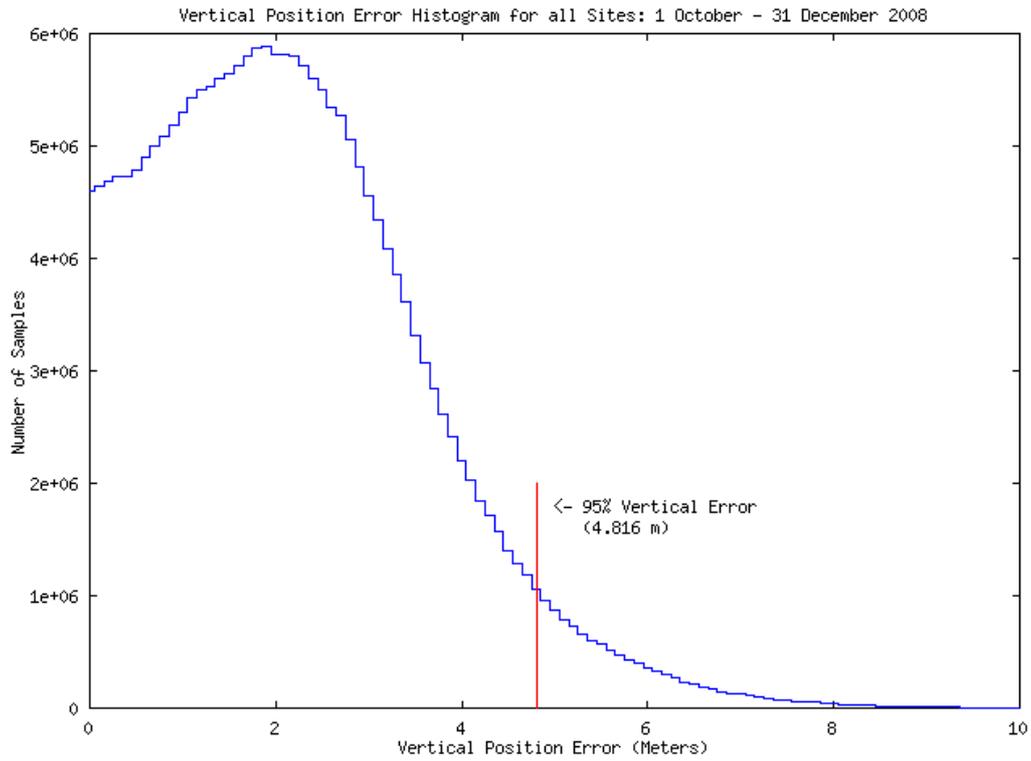
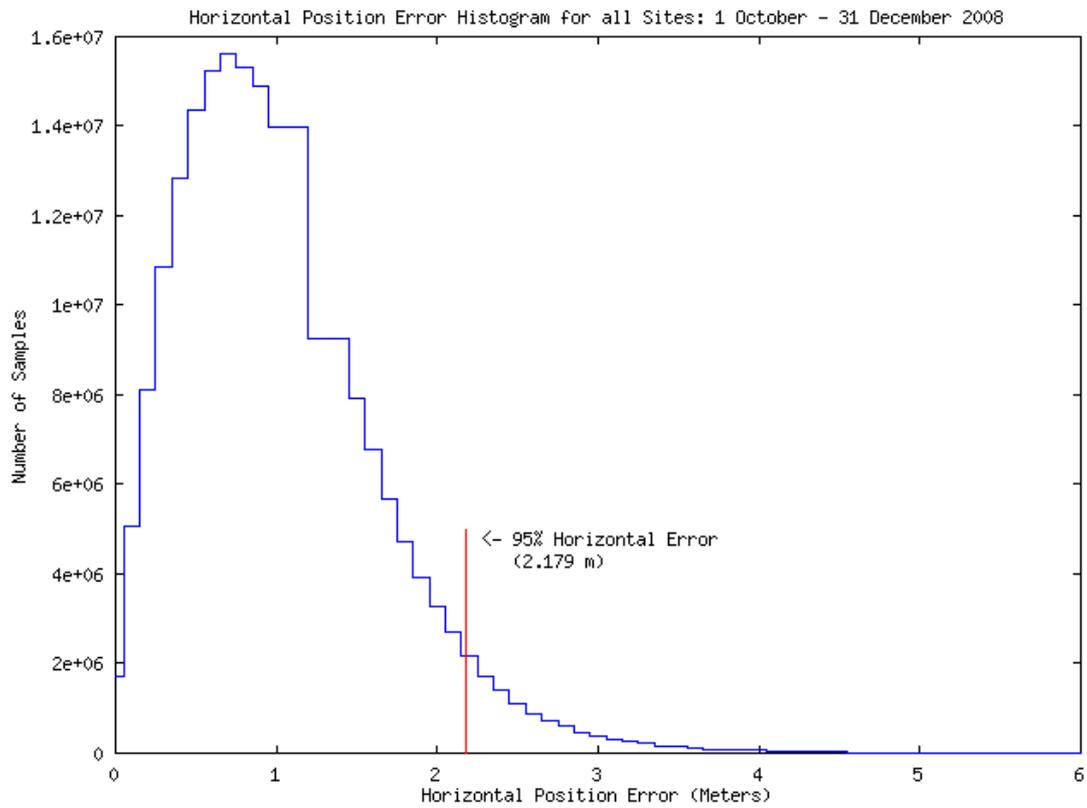


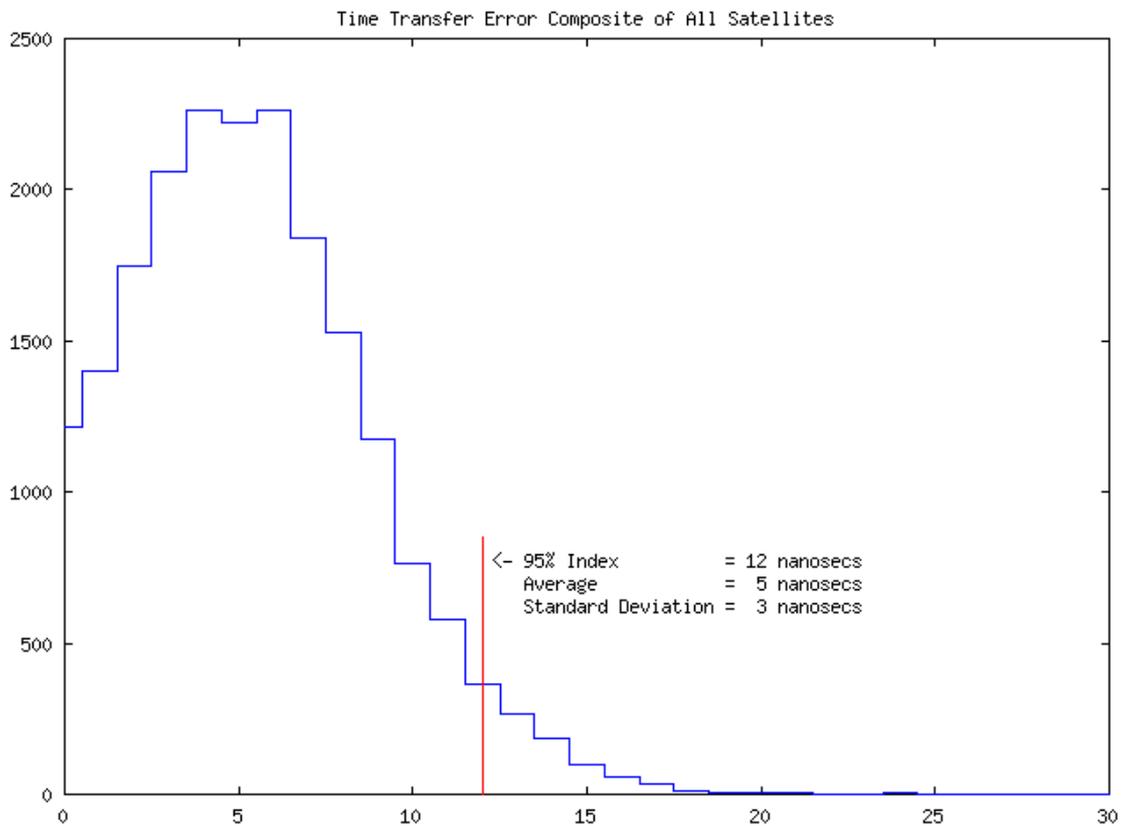
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 October and 31 December 2008 was down loaded 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 Errors



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 2008. The WAAS receiver at Houston was used to collect range measurement.

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
2	1.9249	1.3563	1.1854	3.3178	6.734	13661563
3	2.1143	1.3352	1.3147	3.4944	11.446	12338952
4	1.8069	1.1339	1.1447	3.2284	10.557	13958488
5	2.2534	1.6518	1.3653	3.8547	12.029	12953139
6	1.6285	0.7993	1.2674	2.7698	6.189	12923248
7	1.2672	0.3863	0.9969	2.3390	8.184	12031788
8	2.1287	1.1194	1.4799	3.8308	12.327	12867753
9	1.8049	0.7658	1.3836	3.3168	10.553	12880884
10	2.5575	1.8911	1.5751	4.4360	10.292	13744440
11	1.8580	1.3340	1.1484	3.1209	7.682	12288640
12	1.5611	0.7285	1.2034	2.8431	8.727	14430688
13	1.2532	0.6626	0.9422	2.2457	13.610	13705802
14	2.0303	1.6640	1.0813	3.4217	9.420	14015617
15	1.4425	0.6953	1.1344	2.7145	7.990	12732931
16	1.7886	1.3220	1.1123	3.0422	7.026	12996993
17	1.6901	0.8188	1.2069	3.1041	8.834	14048319
18	2.1560	1.6697	1.2785	3.6566	9.895	13071859
19	1.9775	1.5444	1.1481	3.2454	7.829	12574215
20	1.8993	1.4917	1.0993	3.2946	8.941	14195254
21	2.1515	1.6473	1.2372	3.5170	8.260	12243134
22	2.2153	1.7275	1.1948	3.6911	9.506	12511653
23	1.5488	1.0859	1.0238	2.6271	13.017	12922159
24	2.5115	1.8872	1.3678	4.1521	10.836	12560596
25	1.4990	0.6375	1.0142	2.6042	8.606	12302696
26	1.6327	0.9114	1.1907	3.0158	9.087	12309661
27	1.8724	0.7139	1.4579	3.4028	9.773	12729530
28	2.1841	1.2730	1.3788	3.7959	11.417	12330964
29	1.6302	0.8532	1.1216	2.9136	7.837	13413155
30	1.8384	0.3869	1.4982	3.3669	10.493	13077613
31	1.3779	0.6814	1.0563	2.6037	8.930	13614007
32	1.8202	1.3743	1.0848	3.1278	8.646	13848562

Table 5-3 Range Rate Error Statistics (meters/second)

PRN	Range Rate Error RMS	Range Rate Error Mean	Range Rate Error 1σ	95% Range Rate Error	Max Range Rate Error	Samples
2	0.001333	-0.000023	0.001330	0.002555	0.001333	13661563
3	0.001635	-0.000028	0.001632	0.002776	0.001635	12338952
4	0.001364	-0.000074	0.001358	0.002465	0.001364	13958488
5	0.001891	-0.000024	0.001886	0.002523	0.001891	12953139
6	0.001296	-0.000034	0.001291	0.002325	0.001296	12923248
7	0.001321	0.000000	0.001319	0.002445	0.001321	12031788
8	0.001766	-0.000050	0.001762	0.002875	0.001766	12867753
9	0.001802	0.000013	0.001798	0.002836	0.001802	12880884
10	0.001829	0.000027	0.001826	0.002915	0.001829	13744440
11	0.001343	-0.000022	0.001340	0.002521	0.001343	12288640
12	0.001366	-0.000020	0.001363	0.002689	0.001366	14430688
13	0.001350	0.000030	0.001347	0.002570	0.001350	13705802
14	0.001316	0.000000	0.001314	0.002519	0.001316	14015617
15	0.001321	-0.000040	0.001318	0.002561	0.001321	12732931
16	0.001287	-0.000001	0.001284	0.002474	0.001287	12996993
17	0.001411	0.000001	0.001408	0.002577	0.001411	14048319
18	0.001339	-0.000035	0.001334	0.002599	0.001339	13071859
19	0.001263	0.000005	0.001260	0.002437	0.001263	12574215
20	0.001296	0.000016	0.001294	0.002525	0.001296	14195254
21	0.001390	0.000001	0.001386	0.002702	0.001390	12243134
22	0.001660	-0.000011	0.001656	0.002805	0.001660	12511653
23	0.001224	0.000009	0.001221	0.002345	0.001224	12922159
24	0.001770	-0.000045	0.001765	0.002661	0.001770	12560596
25	0.001312	0.000024	0.001308	0.002136	0.001312	12302696
26	0.001368	-0.000005	0.001365	0.002435	0.001368	12309661
27	0.001976	-0.000016	0.001974	0.002679	0.001976	12729530
28	0.001613	-0.000004	0.001611	0.002598	0.001613	12330964
29	0.001427	-0.000014	0.001425	0.002521	0.001427	13413155
30	0.001810	0.000011	0.001805	0.002878	0.001810	13077613
31	0.001427	0.000022	0.001424	0.002461	0.001427	13614007
32	0.001276	0.000010	0.001273	0.002310	0.001276	13848562

Table 5-4 Range Acceleration Error Statistics (meters/second²)

PRN	Range Acceleration Error RMS	Range Acceleration Error Mean	Range Acceleration 1 σ	Max Range Acceleration Error	Samples
2	0.00133334	-0.00002275	0.00133001	0.00255466	13661563
3	0.00163490	-0.00002847	0.00163199	0.00277583	12338952
4	0.00136389	-0.00007438	0.00135849	0.00246544	13958488
5	0.00189112	-0.00002425	0.00188642	0.00252274	12953139
6	0.00129564	-0.00003377	0.00129074	0.00232526	12923248
7	0.00132104	0.00000027	0.00131892	0.00244513	12031788
8	0.00176568	-0.00004989	0.00176246	0.00287452	12867753
9	0.00180221	0.00001342	0.00179761	0.00283593	12880884
10	0.00182918	0.00002728	0.00182616	0.00291457	13744440
11	0.00134337	-0.00002226	0.00134004	0.00252125	12288640
12	0.00136579	-0.00002017	0.00136257	0.00268888	14430688
13	0.00134982	0.00002975	0.00134729	0.00256984	13705802
14	0.00131584	0.00000028	0.00131374	0.00251897	14015617
15	0.00132114	-0.00003965	0.00131767	0.00256072	12732931
16	0.00128749	-0.00000099	0.00128433	0.00247399	12996993
17	0.00141119	0.00000130	0.00140841	0.00257701	14048319
18	0.00133915	-0.00003493	0.00133393	0.00259940	13071859
19	0.00126343	0.00000534	0.00125990	0.00243716	12574215
20	0.00129568	0.00001630	0.00129357	0.00252464	14195254
21	0.00139041	0.00000091	0.00138626	0.00270227	12243134
22	0.00165964	-0.00001092	0.00165613	0.00280492	12511653
23	0.00122359	0.00000869	0.00122065	0.00234538	12922159
24	0.00176990	-0.00004481	0.00176540	0.00266074	12560596
25	0.00131162	0.00002351	0.00130827	0.00213615	12302696
26	0.00136792	-0.00000494	0.00136483	0.00243507	12309661
27	0.00197636	-0.00001572	0.00197353	0.00267933	12729530
28	0.00161315	-0.00000415	0.00161071	0.00259837	12330964
29	0.00142727	-0.00001405	0.00142477	0.00252103	13413155
30	0.00181011	0.00001111	0.00180535	0.00287782	13077613
31	0.00142681	0.00002213	0.00142429	0.00246138	13614007
32	0.00127573	0.00000965	0.00127273	0.00231041	13848562

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 13 with an error of 13.610 meters. Satellite 6 had the lowest maximum range error of 6.189 meters.

Figure 5-4 Distribution of Daily Max Range Errors

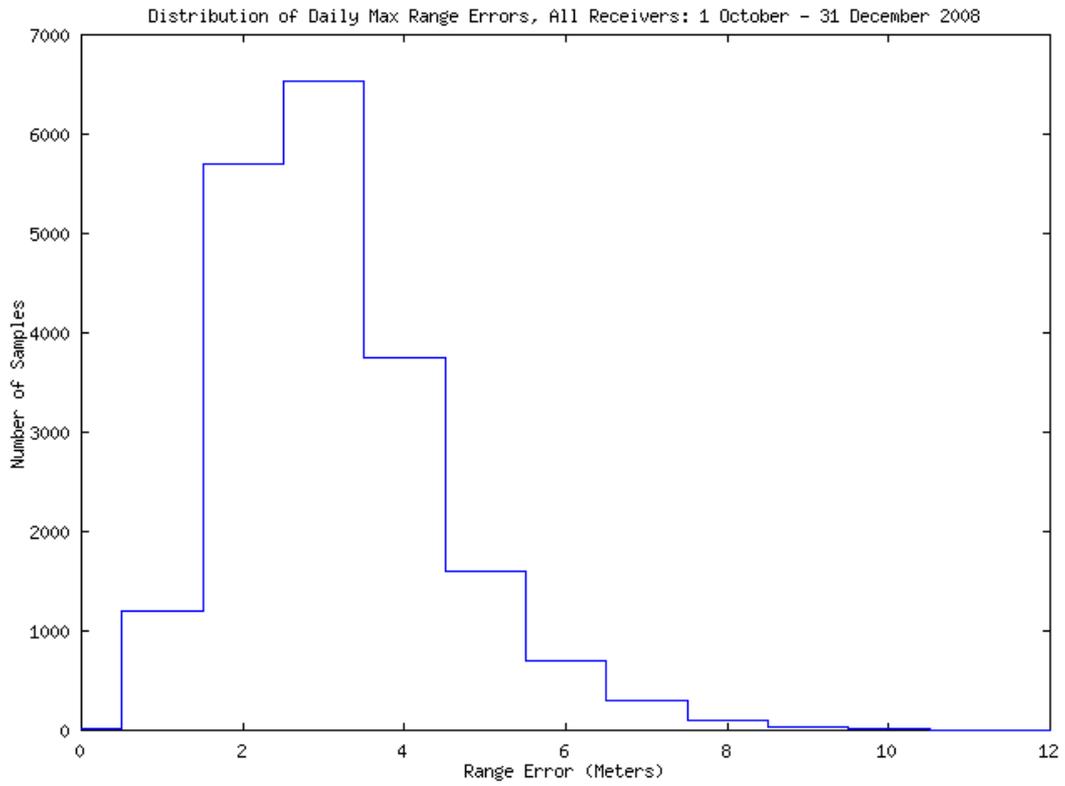


Figure 5-5: Distribution of Daily Max Range Rate Errors

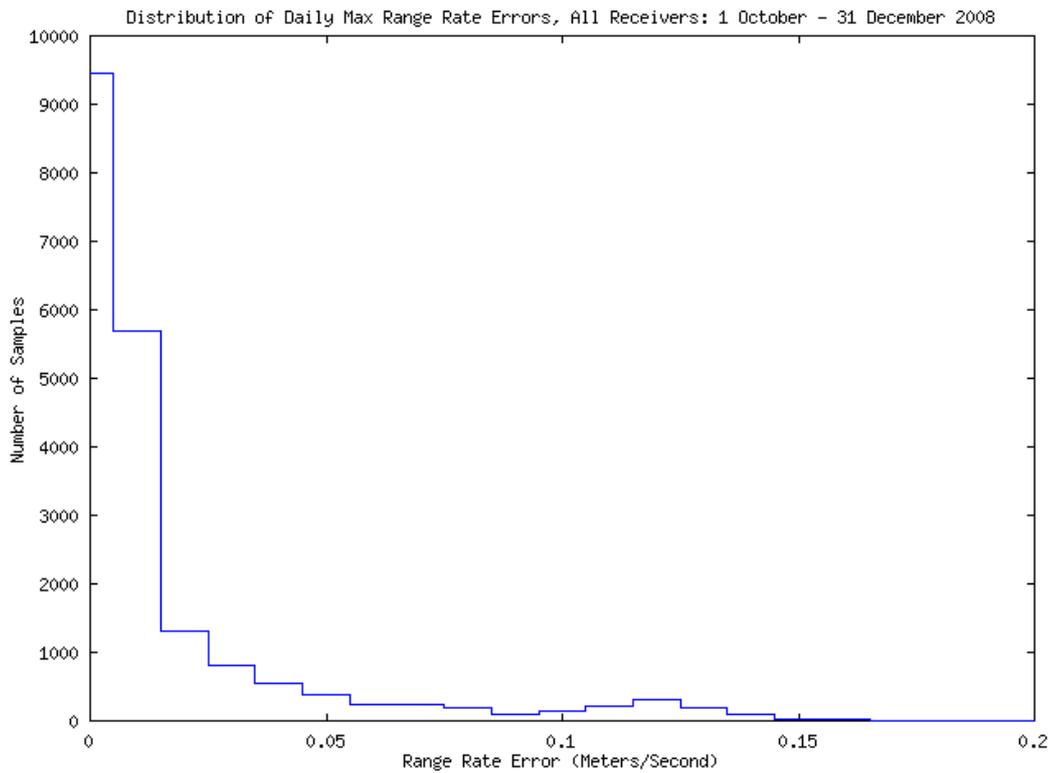


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

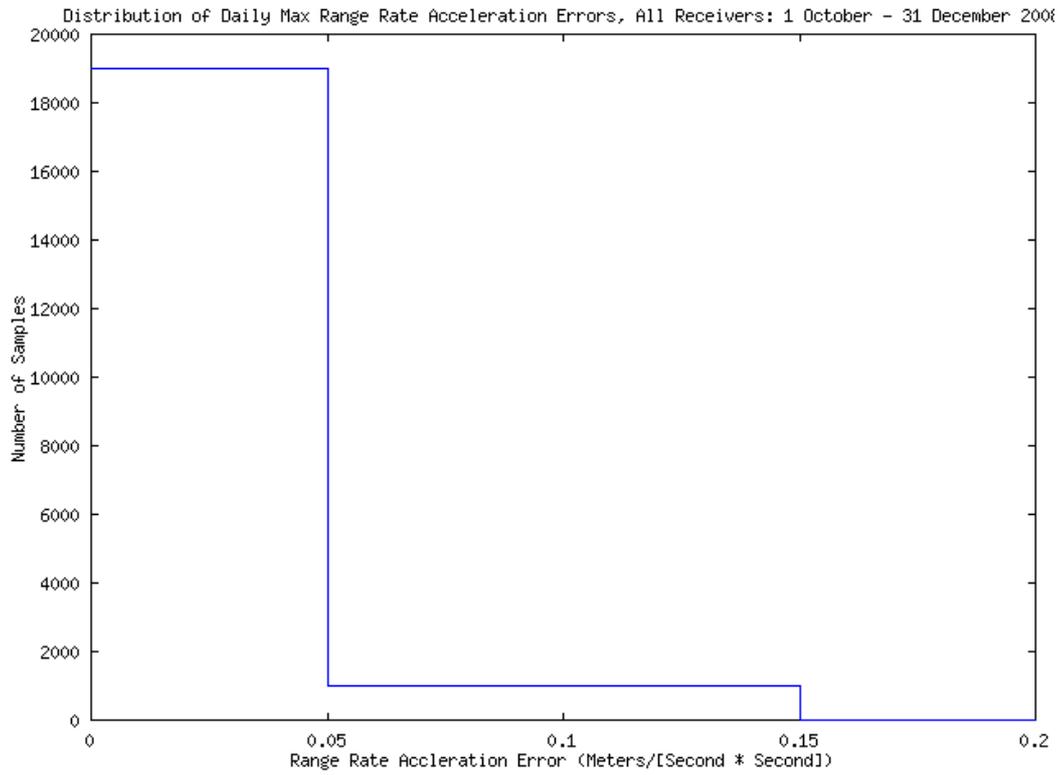
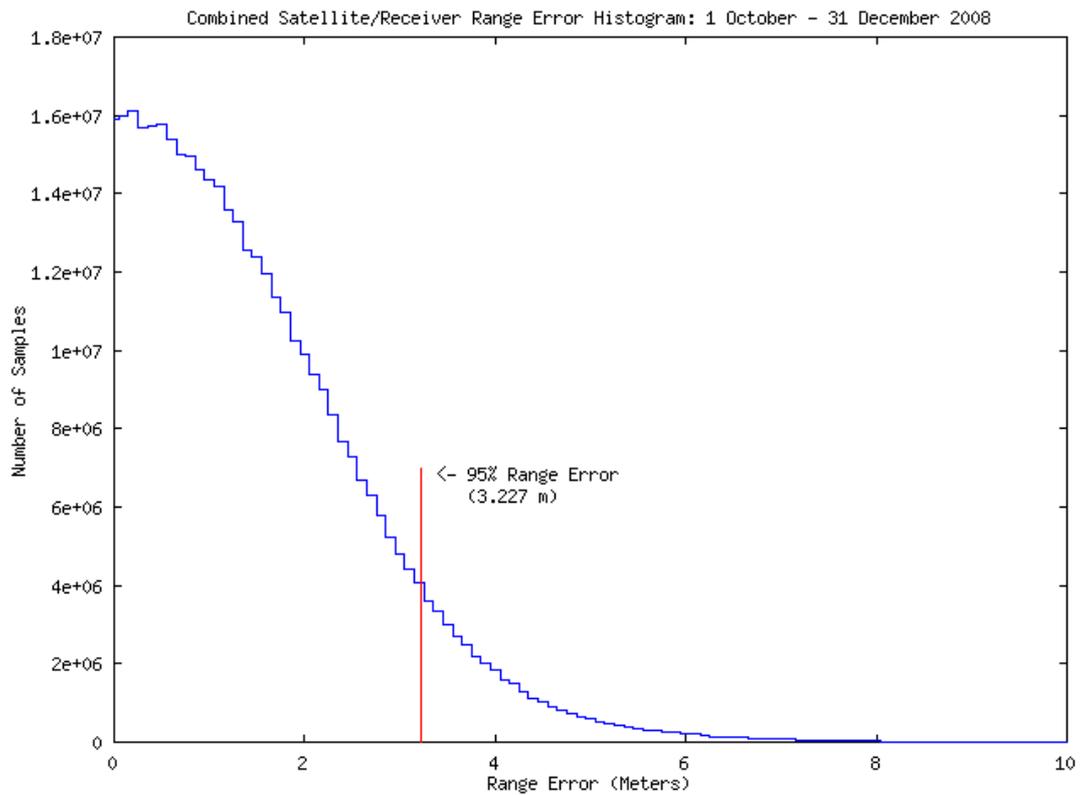
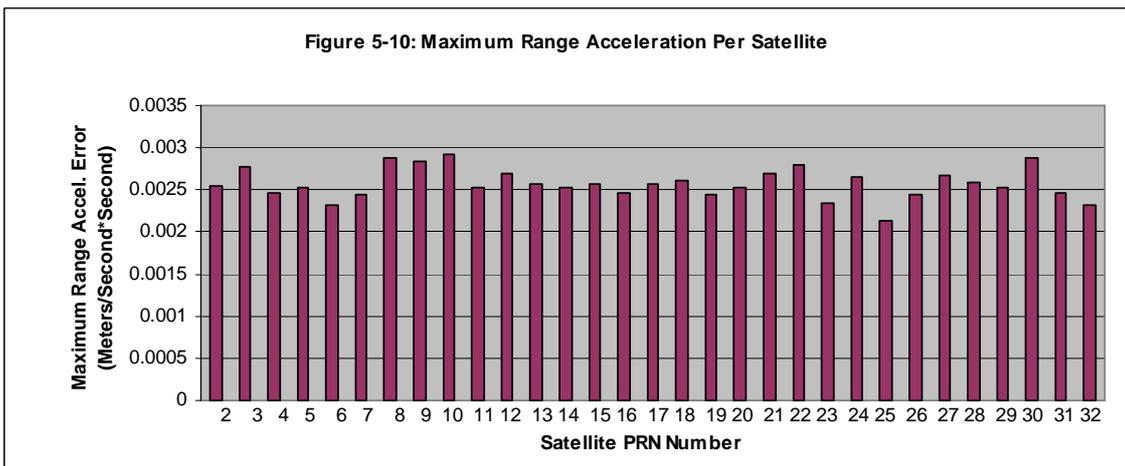
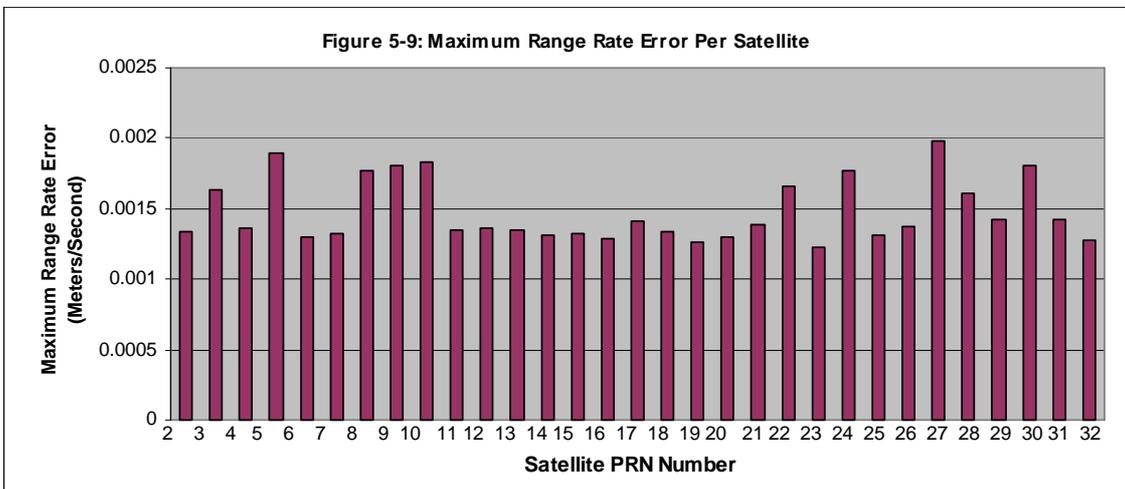
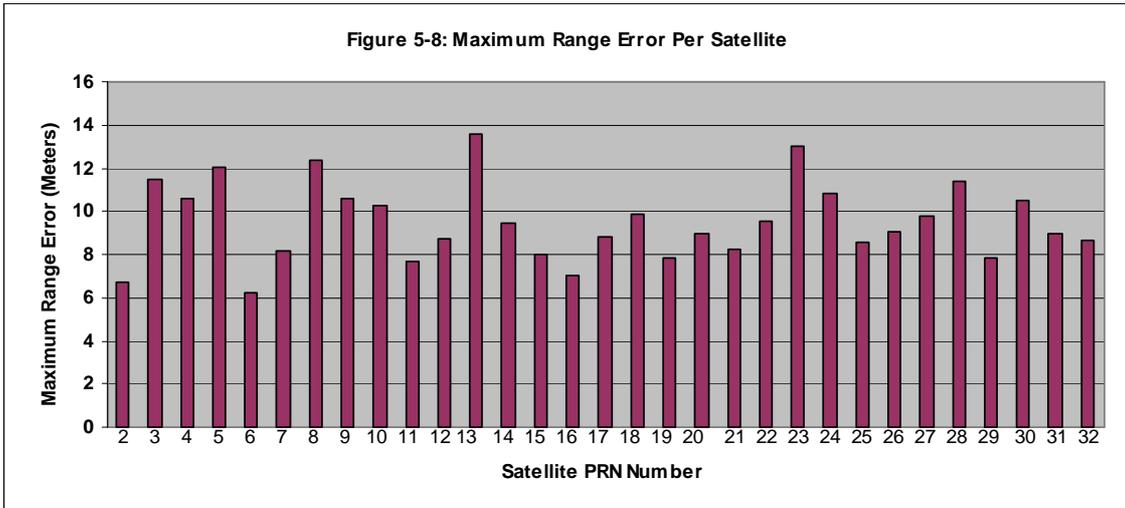


Figure 5-7: Range Error Histogram





6.0 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 Environment Center (SEC), 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://sec.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 10-12 October 2008

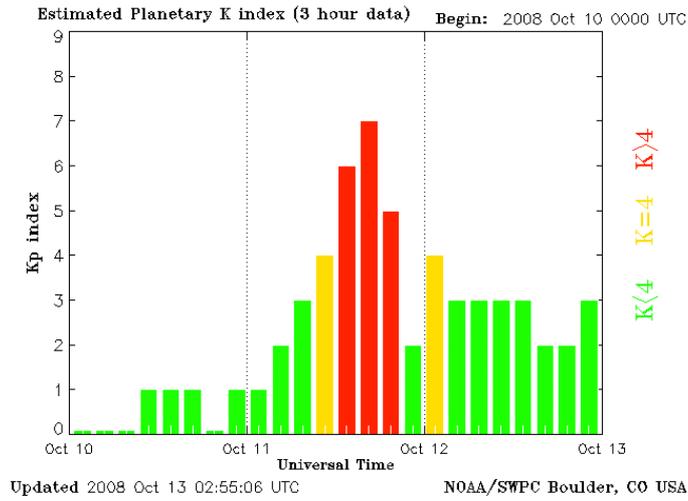


Figure 6-2 K-Index for 3-5 October 2008

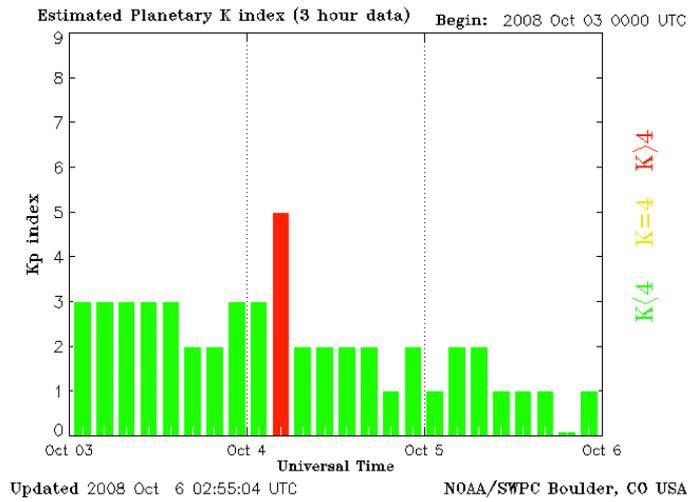


Figure 6-3 K-Index for 7-9 November 2008

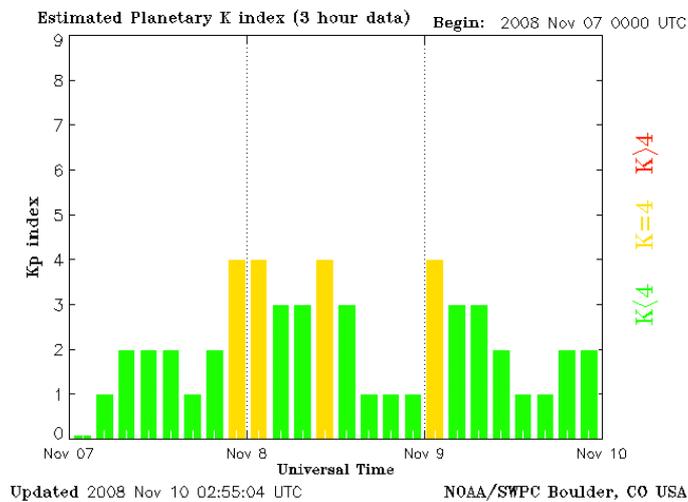


Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for 11 October 2008

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Albuquerque	3.286	3.877	4.371	6.833
Anchorage	1.748	3.920	2.513	4.929
Atlanta	3.837	5.367	4.444	10.41
Barrow	1.890	4.165	4.985	6.919
Bethel	1.770	4.263	2.763	4.890
Billings	2.473	3.585	3.596	6.570
Boston	2.837	5.163	3.768	6.386
Cleveland	2.914	4.570	3.461	8.488
Cold Bay	1.911	4.435	2.640	5.339
Fairbanks	1.856	3.817	2.254	5.629
Gander	2.557	4.869	3.141	7.190
Honolulu	2.813	4.957	3.487	6.812
Houston	4.629	6.383	5.235	9.444
Iqaluit	2.251	4.120	3.284	10.862
Juneau	1.735	3.233	2.509	4.308
Kansas City	3.026	4.588	4.053	9.045
Kotzebue	1.911	4.077	3.728	16.133
Los Angeles	2.848	4.773	4.135	5.861
Merida	2.511	6.837	3.862	11.149
Miami	3.451	5.849	4.762	10.212
Minneapolis	3.167	4.702	4.051	7.742
Oakland	2.339	5.074	4.060	6.608
Salt Lake City	2.622	4.542	3.935	7.253
San Jose Del Cabo	3.316	4.788	3.833	6.662
San Juan	1.900	5.734	2.369	8.290
Seattle	2.177	3.650	3.108	5.852
Tapachula	2.306	6.647	3.310	8.300
Washington, DC	3.090	5.240	3.836	8.259

7.0 IGS Analysis

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 that had high availability in 2006, were outside of the WAAS service area, and provided a good geographic distribution were 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 statistics and are forced into the 50.1-meter histogram bin and are believed to influence the outliers in the 99.99% statistics.

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.

During the evaluation period, the maximum 95% horizontal and vertical SPS errors are 3.56 meters at Maspalomas and 6.14 meters at Usuda. The minimum 95% horizontal and vertical SPS errors are 1.65 meters at Norilsk and 4.21 meters at Maspalomas. The maximum 99.99% horizontal and vertical SPS errors are 12.62 meters at Maspalomas and 39.25 meters at Guam.

(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
GLPS	Puerto Ayora	Ecuador
GUAM	Dededo	Guam
IISC	Bangalore	India
KIRU	Kiruna	Sweden
KOUR	Kourou	French Guyana
MADR	Robledo	Spain
MALI	Malindi	Kenya
MAS1	Maspalomas	Spain
MOBN	Obninsk	Russian Federation
NNOR	New Norcia	Australia
NRIL	Norilsk	Russian Federation
PETS	Petropavlovsk-Kamchatka	Russian Federation
POL2	Bishkek	Kyrgyzstan
SANT	Santiago	Chile
SUTM	Sutherland	South Africa
TIDB	Tidbinbilla	Australia
USUD	Usuda	Japan

Figure 7-1 Selected IGS Site Locations

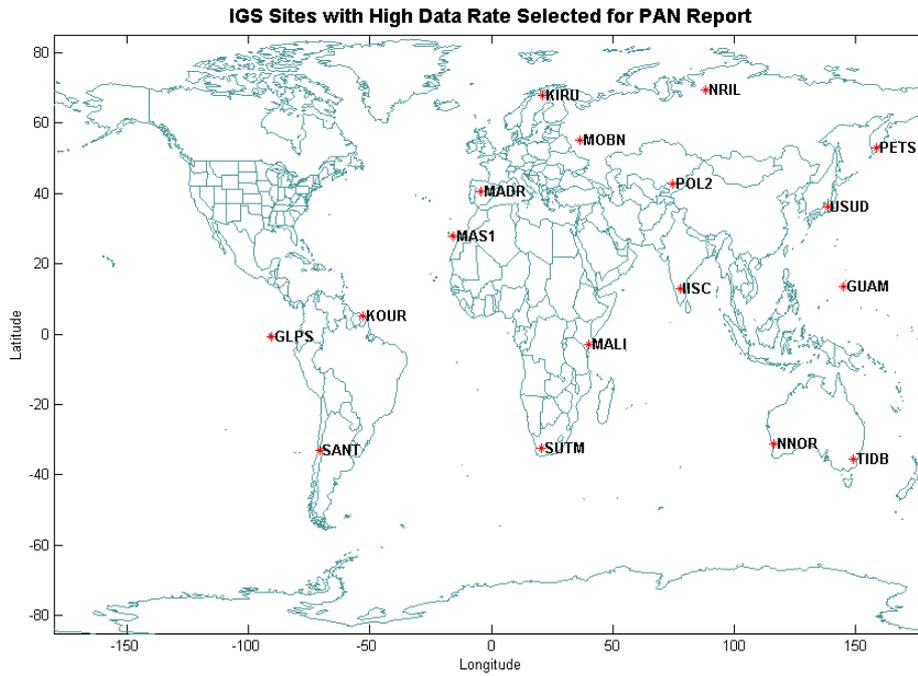


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

Site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
GLPS	2.31	5.30	4.19	11.85	74.45%
GUAM	2.05	5.32	5.46	39.25	99.02%
IISC	1.97	4.82	4.05	9.23	97.21%
KIRU	1.91	4.94	8.15	17.66	99.79%
KOUR	2.21	4.54	7.74	13.14	98.18%
MADR	2.08	4.40	6.52	10.15	99.60%
MAS1	3.56	4.21	12.62	26.29	99.89%
MATE	2.03	4.30	6.81	11.54	89.73%
MOBN	2.56	4.60	6.13	8.58	99.95%
NNOR	2.45	5.71	5.26	18.03	99.99%
NRIL	1.65	5.01	7.99	18.77	69.90%
PETS	2.44	5.27	7.35	13.86	98.55%
POL2	2.10	4.81	4.28	9.55	99.56%
SANT	3.00	5.23	6.25	13.11	99.95%
SUTM	2.01	4.95	5.90	9.82	97.20%
TIDB	2.57	5.15	12.26	27.04	92.20%
USUD	2.30	6.14	5.94	11.38	83.29%

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

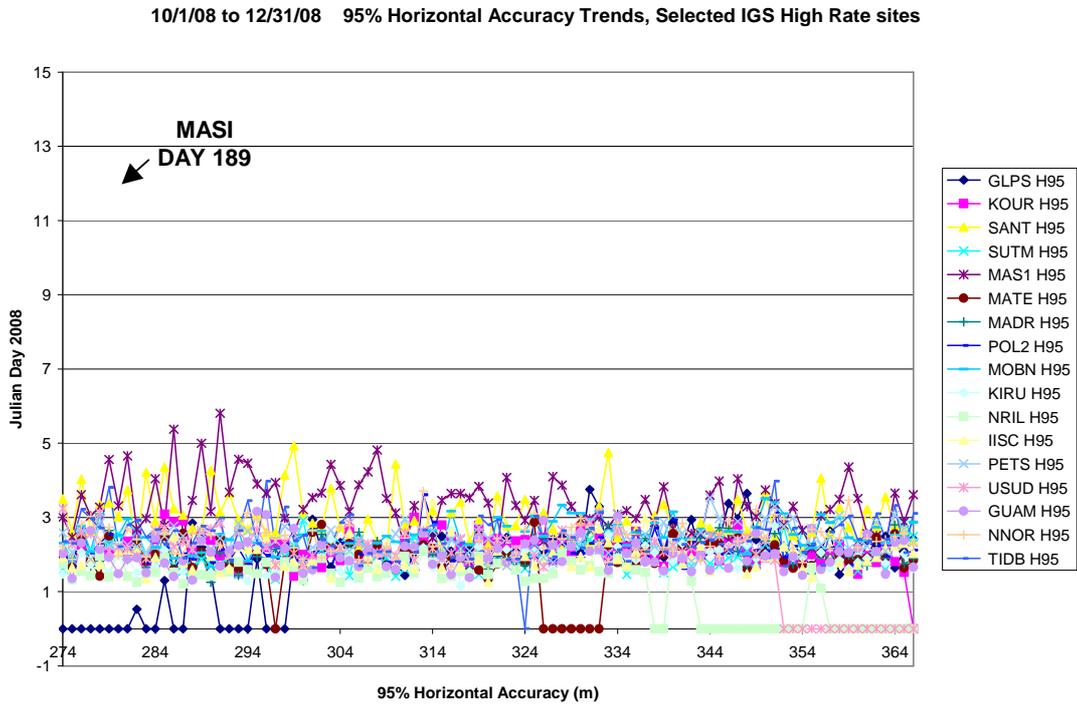
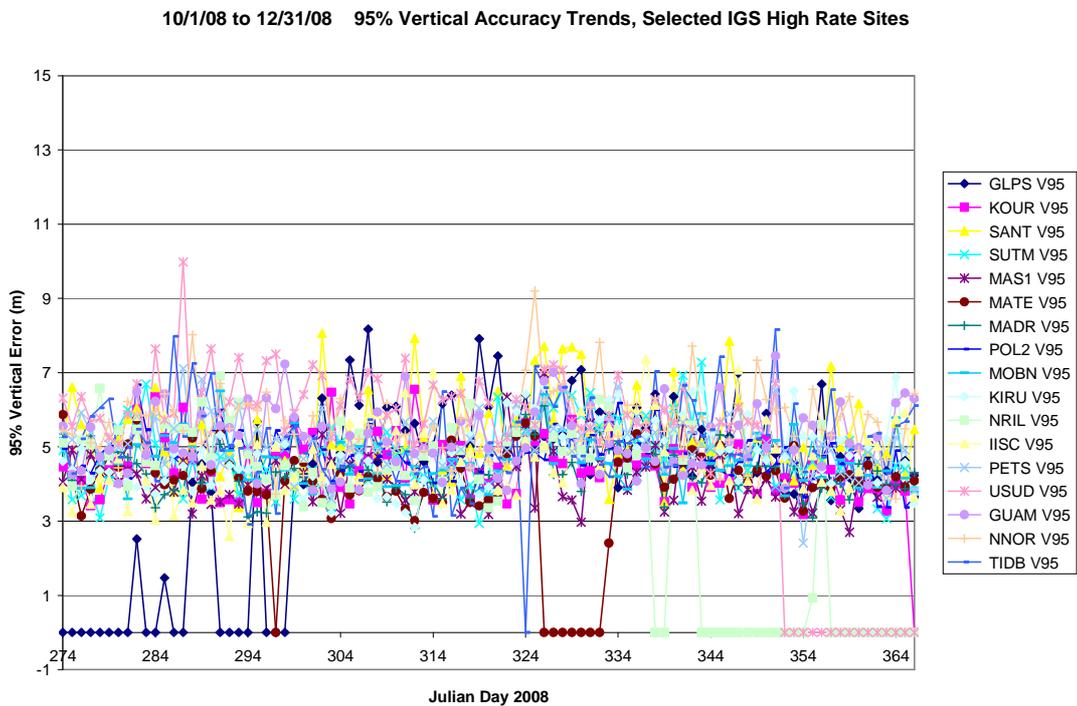


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites



APPENDICES A – D

Appendix A Performance Summary

<i>Conditions and Constraints</i>	<i>PDOP Availability Standard</i>	<i>Measured Performance</i>
<ul style="list-style-type: none"> • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. • Based on using only satellites transmitting standard code and indicating “health” in the broadcast navigation message (sub-frame 1). 	<p>≥ 98% global Position Dilution of Precision (PDOP) of 6 or less</p> <p>≥ 88% worst site PDOP of 6 or less</p>	<p>≥ 99.993%</p> <p>≥ 99.028%</p>
<i>Conditions and Constraints</i>	<i>Service Availability Standard</i>	<i>Measured Performance</i>
<ul style="list-style-type: none"> • 36 meter horizontal (SIS only) 95% threshold. • 77 meter vertical (SIS only) 95% threshold. • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. 	<p>≥ 99% Horizontal Service Availability average location</p> <p>≥ 99% Vertical Service Availability average location</p>	<p>100%</p>
<ul style="list-style-type: none"> • Based on using only satellites transmitting standard code and indicating “healthy” in the broadcast navigation message (sub-frame 1). 	<p>≥ 95.87% global average on worst-case day</p>	<p>100%</p>
<i>Conditions and Constraints</i>	<i>Service Reliability Standard</i>	<i>Measured Performance</i>
<ul style="list-style-type: none"> • 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each. 	<p>≥ 99.94% global average</p>	<p>100%</p>
<ul style="list-style-type: none"> • 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values from the worst-case point within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each. 	<p>≥ 99.79% single point average</p>	<p>100%</p>

<i>Conditions and Constraints</i>	<i>Accuracy Standard</i>	<i>Measured Performance</i>
<ul style="list-style-type: none"> • Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume. 	Global Average Positioning Domain Accuracy <ul style="list-style-type: none"> • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only) 	2.179 m 4.816 m
<ul style="list-style-type: none"> • Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours for any point within the service volume. 	Worst Site Positioning Domain Accuracy <ul style="list-style-type: none"> • ≤ 36 meters 95% All-in-View Horiz Error (SIS only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS only) 	3.299 m 5.591 m
<ul style="list-style-type: none"> • Defined for time transfer solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume. 	Time Transfer Accuracy <ul style="list-style-type: none"> • ≤ 40 nanoseconds time transfer error 95% of time (SIS only) 	12 nanoseconds 95%
<ul style="list-style-type: none"> • Average of the constellation's individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point in the service volume. 	≤ 6 meters RMS SIS SPS URE across the entire constellation	2.557 meters

Appendix B Geomagnetic Data

Prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center.
 # Please send comment and suggestions to SEC.Webmaster@noaa.gov
 #
 # Current Quarter Daily Geomagnetic Data
 #

Date	Middle Latitude - Fredericksburg -							High Latitude ---- College ----							Estimated --- Planetary ---											
	A	K-indices						A	K-indices						A	K-indices										
2008 10 01	7	2	1	2	2	2	2	2	8	2	1	3	1	3	2	2	1	6	1	1	2	1	2	2	2	2
2008 10 02	11	2	2	2	3	3	2	3	26	2	2	2	6	6	3	2	2	12	2	2	2	4	4	2	3	2
2008 10 03	10	3	2	2	3	2	2	2	32	3	2	5	6	6	3	2	2	13	3	3	3	3	3	2	2	3
2008 10 04	8	2	4	2	2	2	1	1	17	3	4	2	5	4	1	1	2	11	3	5	2	2	2	2	1	2
2008 10 05	3	0	1	2	0	1	2	1	4	1	1	2	1	2	0	1	1	4	1	2	2	1	1	1	0	1
2008 10 06	3	1	3	0	0	0	1	0	3	1	1	1	3	0	0	0	1	4	0	2	0	1	2	1	0	1
2008 10 07	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	0	3	0	0	0	0	2	2	1	1
2008 10 08	2	1	1	0	0	2	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	1	0	0	1
2008 10 09	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	1	1	1
2008 10 10	2	0	0	0	1	2	1	0	1	2	0	0	1	2	1	0	0	3	0	0	0	1	1	1	0	1
2008 10 11	20	1	3	3	3	4	5	4	2	40	1	1	5	5	6	6	5	37	1	2	3	4	6	7	5	2
2008 10 12	10	4	2	3	2	2	2	1	2	26	3	2	5	5	5	4	2	13	4	3	3	3	3	2	2	3
2008 10 13	7	2	3	2	2	1	1	2	2	15	2	2	5	5	2	1	1	9	3	3	2	2	1	3	1	2
2008 10 14	3	0	0	1	2	2	1	1	1	7	0	0	3	4	2	1	1	4	1	0	1	2	2	1	1	1
2008 10 15	7	2	3	3	1	1	2	1	1	15	1	3	4	4	4	2	0	8	2	3	3	2	1	2	1	2
2008 10 16	5	1	1	1	3	1	1	1	1	5	0	0	3	3	1	1	0	4	2	1	1	2	1	0	0	1
2008 10 17	1	0	1	0	0	1	0	0	0	1	0	0	0	1	2	0	0	2	0	1	0	0	2	1	0	0
2008 10 18	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
2008 10 19	5	1	1	0	2	2	1	2	2	6	0	0	1	3	3	2	2	6	1	1	0	1	2	2	3	2
2008 10 20	2	1	0	0	0	1	1	1	1	1	1	0	0	0	0	1	0	2	2	0	0	0	1	1	0	1
2008 10 21	3	1	1	0	1	1	1	1	1	3	2	1	1	2	1	0	0	3	1	2	0	1	1	1	0	1
2008 10 22	5	0	0	0	1	1	2	3	3	5	0	0	0	0	2	3	3	5	0	0	0	0	1	2	3	3
2008 10 23	3	1	1	2	1	0	1	1	0	0	0	0	0	0	0	0	0	3	1	1	2	0	0	1	0	0
2008 10 24	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	1	1	0	1
2008 10 25	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1
2008 10 26	3	1	2	1	0	2	1	0	1	3	0	0	0	2	2	2	0	4	0	2	1	1	1	1	0	1
2008 10 27	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
2008 10 28	5	0	0	2	2	1	2	2	2	2	0	0	0	1	0	1	2	4	0	0	1	1	1	2	2	2
2008 10 29	16	2	3	4	1	4	3	3	3	19	1	3	5	2	4	4	3	11	2	2	4	1	2	2	3	3
2008 10 30	11	3	2	2	2	2	4	2	2	18	3	2	2	5	4	4	2	11	3	2	2	3	2	4	3	2
2008 10 31	5	1	2	1	1	0	1	3	1	7	2	2	3	2	1	1	1	6	1	3	2	1	1	1	1	2
2008 11 01	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1
2008 11 02	2	0	0	0	1	2	1	1	1	4	0	0	0	3	3	0	0	2	0	0	0	1	1	0	0	1
2008 11 03	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
2008 11 04	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0
2008 11 05	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008 11 06	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1
2008 11 07	7	0	2	2	2	2	1	2	3	13	0	0	3	5	2	1	1	8	0	1	2	2	2	1	2	4
2008 11 08	11	4	3	3	2	2	2	2	1	30	4	3	5	6	5	3	2	14	4	3	3	4	3	1	1	1
2008 11 09	10	4	3	3	2	1	1	1	2	15	2	4	3	5	2	2	1	12	4	3	3	2	1	1	2	2
2008 11 10	3	1	2	1	1	1	1	0	1	4	0	1	3	1	2	1	0	3	1	2	1	1	1	1	0	0
2008 11 11	1	0	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0
2008 11 12	4	0	0	1	1	1	0	3	1	2	0	0	2	1	1	0	1	2	0	1	1	1	0	0	0	1
2008 11 13	2	0	1	0	0	1	2	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0
2008 11 14	1	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
2008 11 15	3	1	1	0	0	0	0	2	2	1	0	1	0	0	0	0	1	6	2	2	0	1	2	2	2	2
2008 11 16	7	3	4	1	1	1	0	1	1	11	3	4	2	2	4	1	1	8	4	4	1	0	1	0	0	1
2008 11 17	2	2	1	0	0	0	0	1	0	1	0	1	0	0	0	0	1	2	2	1	0	0	0	0	0	0
2008 11 18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
2008 11 19	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0
2008 11 20	1	0	1	0	0	2	0	1	2	0	0	0	0	0	0	0	1	2	0	1	0	0	0	1	1	1
2008 11 21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2008 11 22	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
2008 11 23	1	1	2	0	0	0	0	0	0	1	0	1	0	1	0	0	0	3	1	2	0	0	0	1	1	0
2008 11 24	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008 11 25	11	3	3	3	2	3	2	2	2	17	1	3	5	2	5	2	1	10	3	3	3	2	3	2	2	2
2008 11 26	11	4	4	2	1	1	1	2	2	11	2	3	4	3	1	2	1	8	2	3	2	1	1	1	1	2
2008 11 27	5	2	1	1	1	1	1	2	2	6	2	1	2	2	2	1	2	7	3	2	1	1	2	0	2	2

GPS SPS Performance Analysis Report

January 31, 2009

2008 11 28	3	0	2	1	0	0	1	0	2	1	0	1	0	0	0	0	1	1	4	1	2	0	0	0	0	1	2
2008 11 29	2	0	1	1	1	0	1	0	0	1	0	0	1	2	0	0	0	0	2	0	0	1	1	1	0	0	1
2008 11 30	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
2008 12 01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008 12 02	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008 12 03	4	1	1	1	1	1	1	1	2	4	0	0	0	0	2	3	1	1	4	0	1	1	0	1	2	1	2
2008 12 04	4	1	2	1	2	2	1	0	0	20	1	3	2	6	5	2	1	0	6	1	3	1	2	2	1	0	1
2008 12 05	7	1	1	1	3	2	2	1	3	24	0	1	5	6	3	4	3	2	10	1	1	2	4	2	3	2	1
2008 12 06	14	4	4	3	2	2	3	2	1	26	3	3	4	6	4	4	3	1	7	2	3	3	3	0	2	1	0
2008 12 07	6	1	2	1	3	2	2	1	0	11	1	2	1	5	3	2	2	0	6	0	2	1	3	2	2	1	1
2008 12 08	1	1	1	0	0	0	0	0	0	1	1	0	0	2	0	0	0	0	5	0	1	1	1	2	3	2	0
2008 12 09	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008 12 10	2	0	0	0	0	1	1	1	2	2	0	0	0	1	1	0	1	1	2	0	0	0	0	1	1	0	2
2008 12 11	4	1	1	1	1	1	2	1	1	4	0	0	1	1	2	2	1	0	3	1	1	1	1	1	1	0	1
2008 12 12	2	1	0	0	1	2	1	0	1	3	0	0	0	2	3	0	0	0	2	1	0	0	1	1	1	0	1
2008 12 13	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0
2008 12 14	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
2008 12 15	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1
2008 12 16	4	1	1	0	1	1	1	2	2	2	0	0	0	1	1	1	1	1	4	0	1	1	0	1	0	1	2
2008 12 17	3	2	2	1	0	1	1	1	0	6	1	1	2	1	3	3	0	0	5	2	2	1	0	1	2	1	1
2008 12 18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	1	1
2008 12 19	2	0	0	0	2	1	1	0	1	3	0	0	1	2	2	1	0	0	3	0	0	1	1	1	1	0	1
2008 12 20	2	0	0	1	1	1	0	1	0	3	0	0	1	1	2	2	0	0	2	1	0	0	0	1	0	0	1
2008 12 21	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0
2008 12 22	3	0	1	0	0	0	3	1	1	4	0	0	0	0	0	3	3	1	4	0	1	0	0	0	3	2	1
2008 12 23	8	1	3	1	2	2	2	2	3	11	1	3	1	3	3	4	2	2	9	2	3	1	2	2	2	3	2
2008 12 24	5	2	2	2	2	1	1	1	0	5	2	1	2	3	1	1	0	0	5	2	3	1	2	1	1	1	1
2008 12 25	2	0	0	0	1	1	1	1	1	3	0	0	0	1	3	1	1	1	3	0	0	0	1	2	1	1	1
2008 12 26	2	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
2008 12 27	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1
2008 12 28	1	1	0	0	0	0	1	0	0	1	0	0	0	2	1	0	0	0	2	1	0	0	0	1	1	0	0
2008 12 29	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2008 12 30	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2
2008 12 31	8	3	2	3	2	2	2	1	1	13	1	3	3	5	2	2	1	2	10	3	3	3	3	2	1	2	2

Appendix C Performance Analysis (PAN) Problem Report

Background:

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 to report for the quarter.

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 (Ω_k) 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 Ω_k 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 Ω_k 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 (1 σ) 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.