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-two 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 #59, includes data collected from 1 July through 30 September 2007. The next quarterly report will be issued 31 January 2007.

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^{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 the CONUS was 99.987% or better.

NANU summary and evaluation was achieved by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 July and 30 September 2007. Using this data, we compute a set of statistics that give a relative idea of constellation health for the both the current and a combined history of past quarters. A total of ten outages were reported in the NANU’s this quarter. Six outages were scheduled while four 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%.

Accuracy standards were verified by calculating the 24-hour 95% horizontal and vertical position error values. 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. Although some of the sites did not achieve 100% reliability, all sites met the SPS specification. The maximum range error recorded was 13.154 meters on Satellite PRN 9. 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 2.353 was 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.

From the analysis performed on data collected between 1 July and 30 September 2007, 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

LIST OF FIGURES

LIST OF TABLES

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-two 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

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 called SPS_CoverageArea developed by the GPS test team. The SPS_CoverageArea 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.

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
≥ 98% global Position Dilution of Precision (PDOP) of 6 or less ≥ 88% worst site PDOP of 6 or less	• 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**	
≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	• 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.	✓
≥ 95.87% global average on worst-case day	• 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**	
≥ 99.94% global average	• 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	• 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)	• 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)	• 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)	• 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	• Average of the constellation's individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point thing 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
≥ 98% global Position Dilution of Precision (PDOP) of 6 or less ≥ 88% worst site PDOP of 6 or less	• 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^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 3.31729 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%)
1-7 July	3.00496	99.996	99.306
8-14 July	3.00007	99.996	99.306
15-21 July	3.00280	99.995	99.236
22-28 July	3.00009	99.994	99.236
29 July-4 Aug	2.99984	99.994	99.236
5-11 Aug	2.99155	99.994	99.236
12-18 Aug	2.97424	99.993	99.236
19-25 Aug	2.98539	99.994	99.236
26 Aug – 1 Sep	3.30774	99.990	99.236
2-8 Sep	3.30653	99.990	99.167
9-15 Sep	3.31040	99.987	99.097
16-22 Sep	3.31729	99.987	99.097
23-30 Sep	2.98975	99.989	99.028

Figure 2-1 PDOP Availability Plot (24-Hour Period: 17 September 2007)

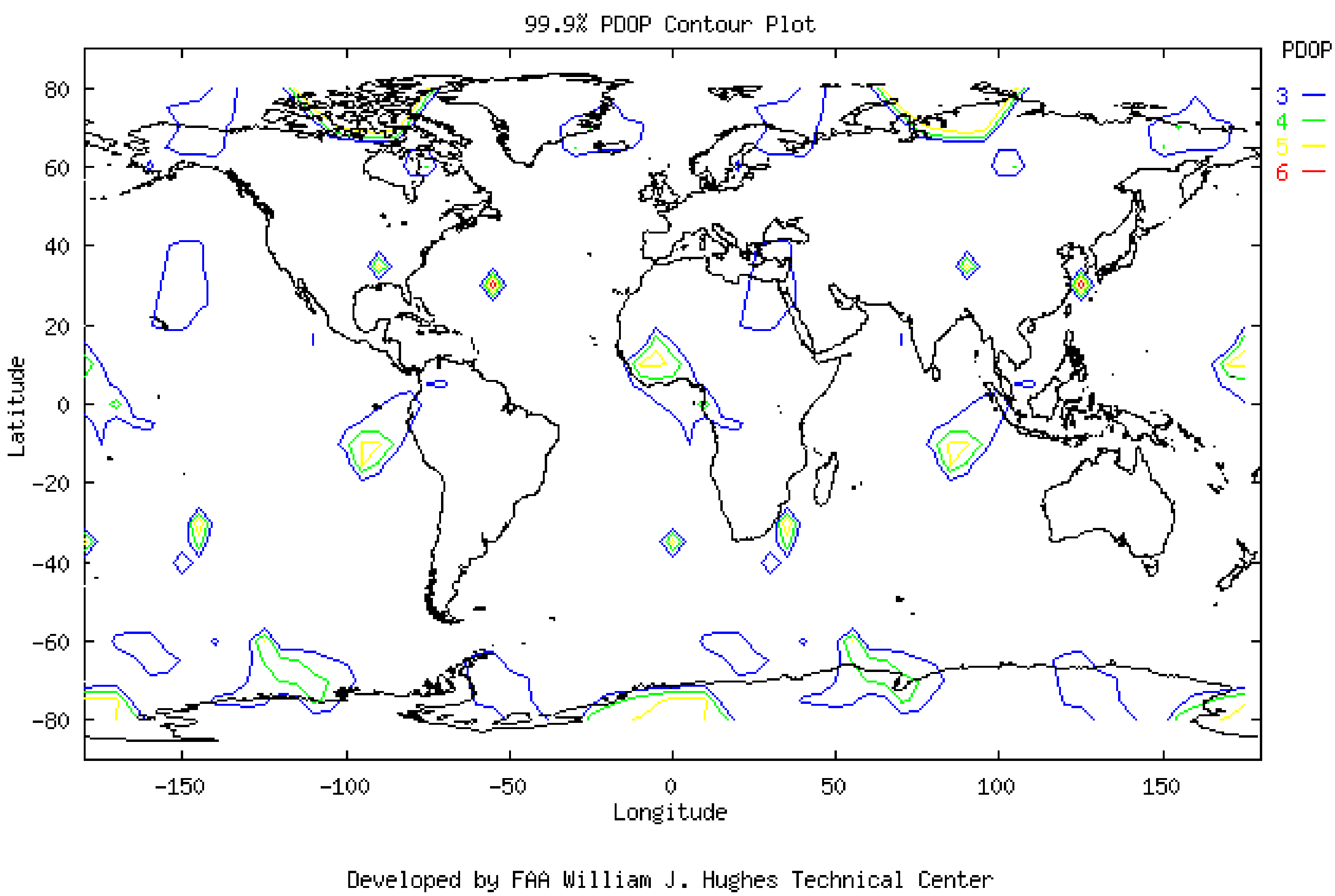
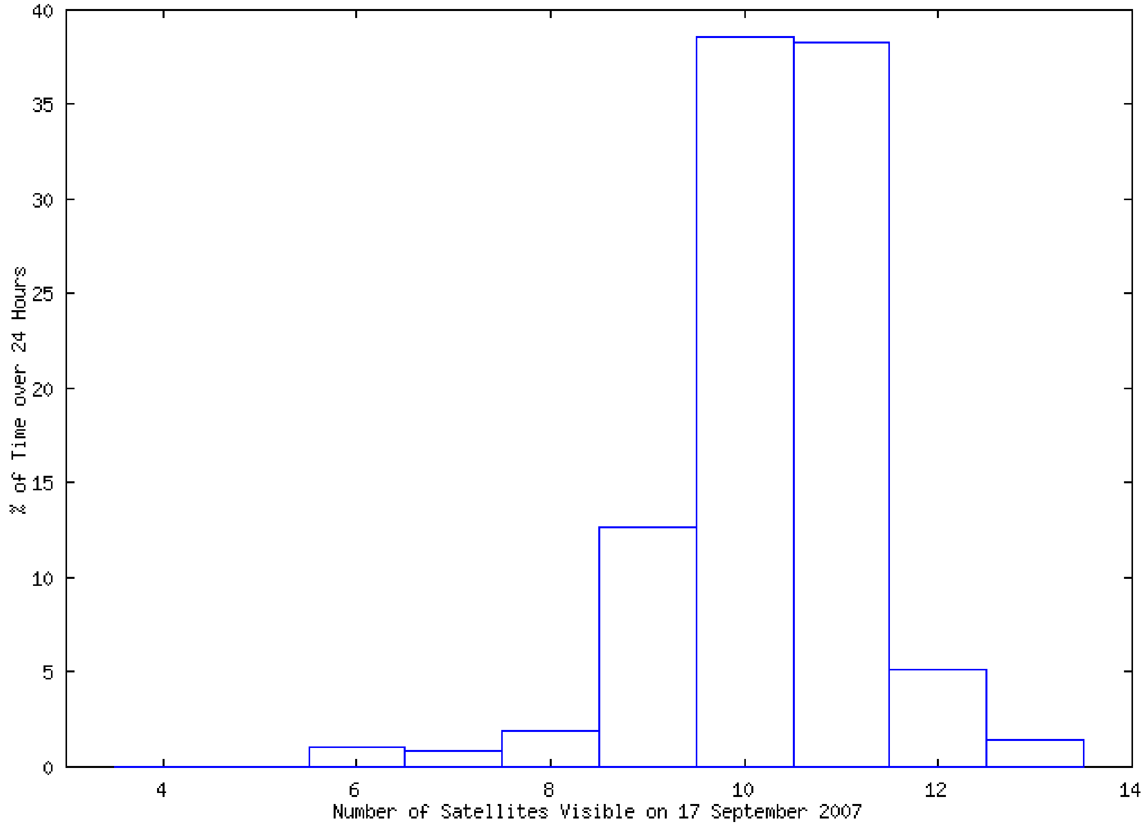


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lat: -90, Lon: 75)



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 July through 30 September 2007, there were a total of ten reported outages. Six of these outages were maintenance activities and were reported in advance. Four 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 Unscheduled	Total Scheduled	Total
2007090	31	FCSTSUMM	14-Aug	14:24	14-Aug	21:30		7.10	7.10
2007093	13	FCSTSUMM	16-Aug	15:03	16-Aug	22:09		7.10	7.10
2007097	19	FCSTSUMM	18-Aug	12:14	18-Aug	19:03		6.82	6.82
2007098	8	FCSTSUMM	20-Aug	21:04	20-Aug	21:47		0.72	0.72
2007099	26	FCSTSUMM	22-Aug	5:49	22-Aug	10:37		4.80	4.80
2007101	12	FCSTSUMM	23-Aug	20:52	24-Aug	8:45		11.88	11.88
2007107	17	UNUSABLE	15-Sep	12:50	15-Sep	16:13	3.38		3.38
2007108	7	UNUSABLE	17-Aug	7:48	17-Sep	21:22	757.57		757.57
2007111	10	UNUSABLE	24-Aug	17:51	18-Sep	20:28	602.62		602.62
2007115	1	UNUSABLE	27-Sep	16:14	27-Sep	19:20	3.10		3.10
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**1366.67**	**38.42**	**1405.08**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2007086	31	FCSTDV	14-Aug	14:00	15-Aug	4:00	14	See Nanu 2007090
2007088	13	FCSTDV	16-Aug	14:30	17-Aug	5:00	14.5	See Nanu 2007093
2007089	19	FCSTDV	18-Aug	11:30	19-Aug	1:00	13.5	See Nanu 2007097
2007091	8	FCSTMX	20-Aug	20:30	21-Aug	8:30	12	See Nanu 2007098
2007092	26	FCSTMX	22-Aug	5:30	22-Aug	17:30	12	See Nanu 2007099
2007095	7	UNUSUFN	17-Aug	7:48	N/A	N/A	N/A	See Nanu 2007108
2007096	12	FCSTDV	23-Aug	20:00	24-Aug	15:00	19	See Nanu 2007101
2007102	10	UNUSUFN	24-Aug	17:51	N/A	N/A	N/A	See Nanu 2007111
2007103	18	FCSTMX	31-Aug	1:30	31-Aug	3:30	2	See Nanu 2007104
2007106	17	UNUSUFN	15-Sep	12:50	N/A	N/A	N/A	See Nanu 2007107
2007110	7	FCSTDV	25-Sep	2:00	25-Sep	16:00	14	See Nanu 0
2007114	1	UNUSUFN	27-Sep	16:14	N/A	N/A	N/A	See Nanu 2007115
						Total Forecast Downtime	**101**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
2007104	18	FCSTCANC	31-Aug	1:30	See Nanu 2007103

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 Jul -**	**1 October,**
	30 Sep, 2007	**1999- 30 Sep. 2007**
Total Forecast Downtime (hrs):	101.00	6660.48
Total Actual Downtime (hrs):	1405.08	24859.36
Total Actual Scheduled Downtime (hrs):	38.42	3541.19
Total Actual Unscheduled Downtime (hrs):	1366.67	21318.17
Total Satellite Observed MTTR (hrs):	100.36	47.90
Scheduled Satellite Observed MTTR (hrs):	3.84	9.47
Unscheduled Satellite Observed MTTR (hrs):	341.67	147.02
# Total Satellite Outages:	10	519
# Scheduled Satellite Outages:	6	374
# Unscheduled Satellite Outages:	4	145
Percent Operational -- Scheduled Downtime:	99.94	99.82
Percent Operational -- All Downtime:	99.93	98.71

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
≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	• 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.
≥ 95.87% global average on worst-case day	• 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-two WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-5. The data was collected at one-second intervals between 1 July and 30 September 2007.

Table 3-5 Accuracies Exceeding Threshold Statistics

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-hour Threshold Failures	Quarters Service Availability %
Billings	7615200	0	100%
Albuquerque	7609314	0	100%
Anchorage	7183660	0	100%
Boston	7611706	0	100%
Washington, DC	7604213	0	100%
Honolulu	7591041	0	100%
Houston	7605647	0	100%
Kansas City	7508024	0	100%
Los Angeles	7508024	0	100%
Salt Lake City	7613514	0	100%
Miami	7603548	0	100%
Minneapolis	7610241	0	100%
Oakland	7465906	0	100%
Cleveland	7366931	0	100%
Seattle	7621490	0	100%
San Juan	7621490	0	100%
Atlanta	7150254	0	100%
Juneau	7590325	0	100%
Cold Bay	7613184	0	100%
Fairbanks	7567992	0	100%
Bethel	7469894	0	100%
Kotzebue	7582813	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	• 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	• 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 receiver in Billings, Montana. 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 13.154 meters at Boston on satellite PRN 9.

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 July – 30 Sept 2007	**Boston**	59,906,057	0	100%
1 July – 30 Sept 2007	**Honolulu**	61,742,452	0	100%
1 July – 30 Sept 2007	**Los Angeles**	61,869,355	0	100%
1 July – 30 Sept 2007	**Miami**	61,467,245	0	100%
1 July – 30 Sept 2007	**San Juan**	62,913,987	0	100%
1 July – 30 Sept 2007	**Juneau**	60,856,948	0	100%
1 July – 30 Sept 2007	**Global**	368,756,044	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 • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only)	• 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)	• 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)	• 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	• Average of the constellation’s individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point thing the service volume.

5.1 Position Accuracy

The data used for this section was collected for every second between 1 July through 30 September 2007 at the NSTB and WAAS selected 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)
Billings	2.026	3.344	3.991	7.252
Albuquerque	2.032	3.215	3.892	6.869
Anchorage	1.904	3.755	4.929	8.185
Boston	2.064	3.671	5.506	9.057
Washington, DC	2.07	4.027	5.813	9.651
Honolulu	3.216	4.349	6.378	11.747
Houston	2.114	3.392	4.650	8.347
Kansas City	2.017	3.479	4.425	7.761
Los Angeles	2.147	3.770	4.331	7.855
Salt Lake City	2.236	3.968	5.358	8.737
Miami	1.987	3.496	4.461	7.579
Minneapolis	2.182	3.956	4.265	8.798
Oakland	2.079	3.817	6.155	9.574
Cleveland	2.079	3.817	6.155	9.574
Seattle	2.155	3.513	4.590	8.452
San Juan	2.393	4.316	5.282	9.635
Atlanta	2.109	3.744	5.298	8.676
Juneau	1.917	3.486	4.710	7.777
Cold Bay	2.170	3.857	6.543	7.952
Fairbanks	1.771	3.951	4.209	8.538
Bethel	1.914	3.821	5.099	7.309
Kotzebue	1.701	3.997	4.087	9.613

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-two WAAS sites from 1 July to 30 September 2007.

Figure 5-1 Global Vertical Error Histogram

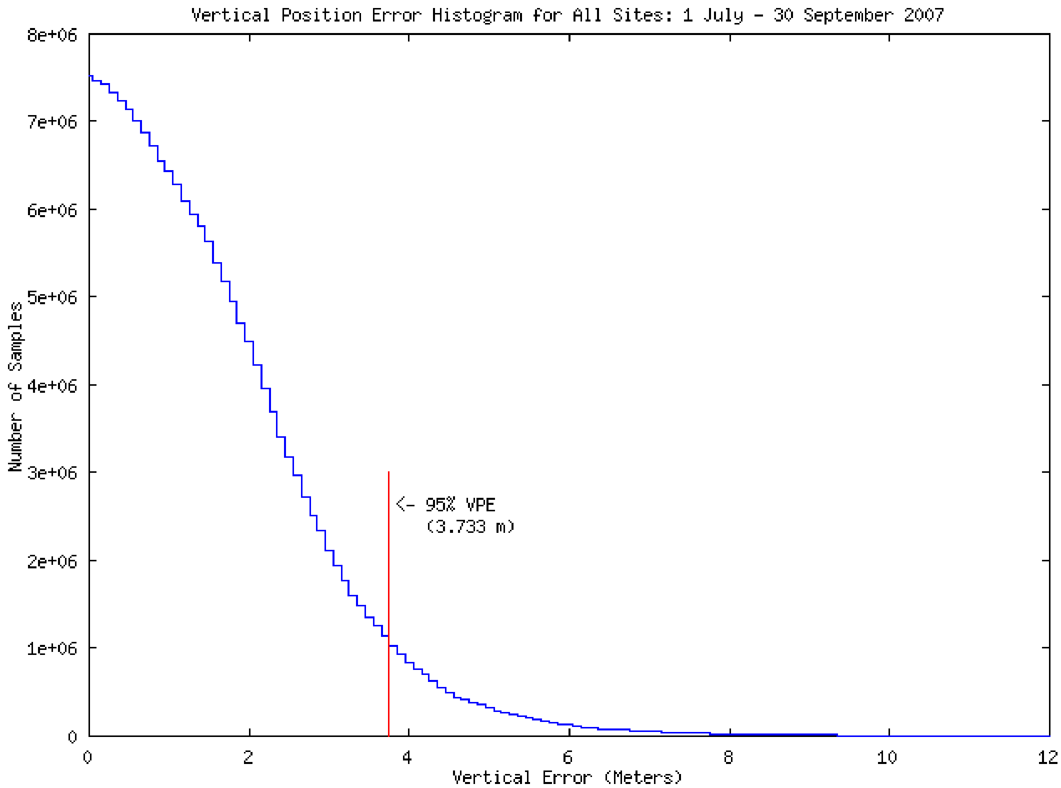
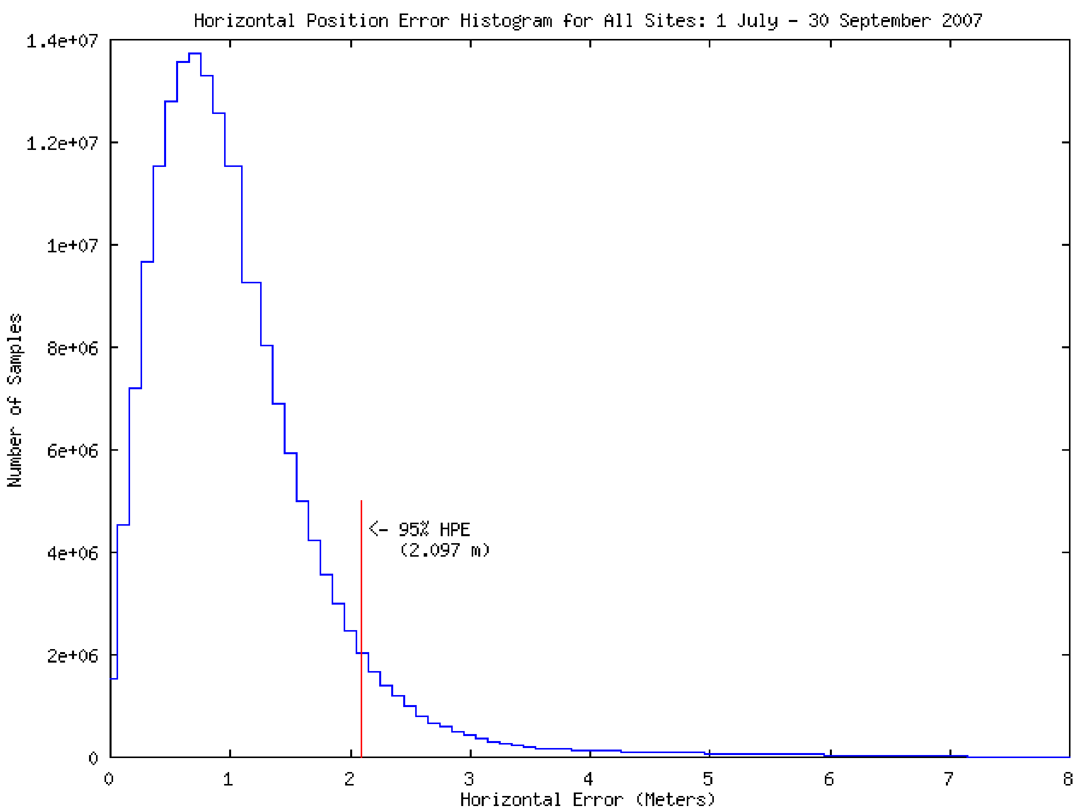


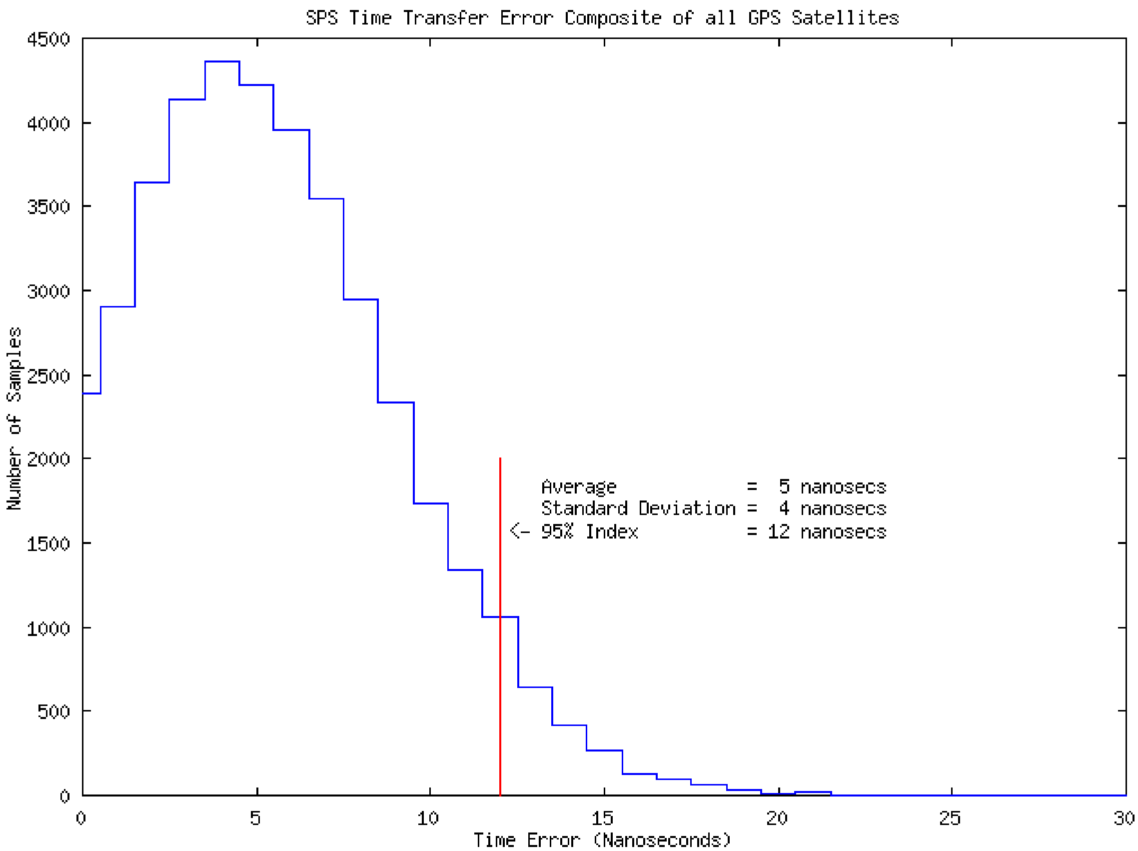
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 July and 30 September 2007 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 July and 30 September 2007. 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	1s	95% Range Error	Max Range Error (SPS Spec. ≤ 30 m)	Samples
1	2.294	0.633	1.929	4.084	9.561	3895747
2	1.528	0.806	1.196	2.800	7.430	4592772
3	1.958	1.021	1.369	3.380	8.372	3878139
4	1.462	0.435	1.200	2.806	7.257	4584445
5	1.761	1.212	1.170	3.135	7.326	4438713
6	1.581	0.582	1.313	3.003	8.737	4476067
7	2.285	1.543	1.522	4.423	11.194	1825782
8	1.905	0.543	1.416	3.445	8.064	4022336
9	1.972	1.088	1.471	3.629	13.154	4233856
10	2.353	1.507	1.548	4.132	9.751	1749952
11	1.625	0.816	1.233	2.878	6.476	3935529
12	1.343	0.432	1.163	2.567	6.825	4649722
13	1.286	0.311	1.126	2.460	8.424	4348298
14	1.641	1.050	1.187	3.064	7.994	4547789
16	1.408	0.862	1.016	2.541	5.582	4118017
17	1.517	-0.062	1.315	2.979	9.333	4568341
18	1.778	1.244	1.173	3.074	6.730	4212394
19	2.137	1.603	1.293	3.620	7.407	3939207
20	1.532	1.026	1.049	2.815	6.827	4577578
21	1.909	1.376	1.202	3.244	9.171	3820605
22	1.798	0.994	1.219	3.221	9.071	4003188
23	1.493	0.845	1.128	2.693	6.767	4069628
24	2.053	1.101	1.340	3.535	9.423	4050416
25	1.531	0.420	1.191	2.758	8.301	3792448
26	1.512	0.659	1.218	2.878	9.894	3877228
27	1.735	0.103	1.352	3.165	9.053	3920199
28	1.848	0.712	1.361	3.464	9.601	4019427
29	1.902	0.810	1.453	3.483	9.400	4006198
30	1.789	0.075	1.529	3.433	8.706	4272401
31	1.300	0.086	1.149	2.542	7.294	4513508

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

PRN	Range Rate Error RMS	Range Rate Error Mean	Range Rate Error 1s	95% Range Rate Error	Max Range Rate Error	Samples
1	0.003054	0.00003	0.00305	0.00293	0.24891	3895747
2	0.001403	-0.00003	0.00140	0.00271	0.03985	4592772
3	0.001900	-0.00007	0.00189	0.00309	0.14918	3878139
4	0.001376	-0.00005	0.00137	0.00264	0.05354	4584445
5	0.001376	0.00000	0.00137	0.00267	0.05048	4438713
6	0.001461	-0.00003	0.00146	0.00266	0.08931	4476067
7	0.001916	-0.00009	0.00191	0.00267	0.17118	1825782
8	0.001808	-0.00002	0.00180	0.00300	0.15075	4022336
9	0.001874	0.00004	0.00187	0.00308	0.15209	4233856
10	0.001883	0.00001	0.00188	0.00273	0.23810	1749952
11	0.001506	-0.00002	0.00150	0.00278	0.06239	3935529
12	0.001454	-0.00001	0.00145	0.00285	0.02982	4649722
13	0.001424	0.00002	0.00142	0.00276	0.06021	4348298
14	0.001459	0.00001	0.00146	0.00277	0.06498	4547789
16	0.001395	0.00001	0.00139	0.00272	0.03463	4118017
17	0.001667	-0.00003	0.00166	0.00285	0.14810	4568341
18	0.001482	-0.00004	0.00148	0.00284	0.07291	4212394
19	0.001466	-0.00001	0.00146	0.00282	0.07606	3939207
20	0.001387	-0.00001	0.00138	0.00270	0.04287	4577578
21	0.001473	-0.00002	0.00147	0.00287	0.02815	3820605
22	0.001879	-0.00005	0.00187	0.00282	0.16976	4003188
23	0.001380	0.00000	0.00138	0.00268	0.03552	4069628
24	0.001841	-0.00004	0.00184	0.00288	0.15242	4050416
25	0.001377	0.00001	0.00137	0.00258	0.11342	3792448
26	0.001566	-0.00003	0.00156	0.00267	0.17744	3877228
27	0.001767	0.00002	0.00176	0.00295	0.14451	3920199
28	0.001830	0.00002	0.00182	0.00283	0.13032	4019427
29	0.002099	0.00000	0.00210	0.00315	0.14865	4006198
30	0.001984	-0.00003	0.00198	0.00315	0.18017	4272401
31	0.001431	0.00003	0.00143	0.00271	0.07473	4513508

Table 5-4 Range Acceleration Error Statistics (meters/second^2)

PRN	Range Acceleration Error RMS	Range Acceleration Error Mean	Range Acceleration 1s	Max Range Acceleration Error	Samples
1	0.00003	0	0.00003	0.000021513	3895747
2	0.00001	0	0.00001	0.000021598	4592772
3	0.00002	0	0.00002	0.000024446	3878139
4	0.00001	0	0.00001	0.000021319	4584445
5	0.00001	0	0.00001	0.000020783	4438713
6	0.00001	0	0.00001	0.000021738	4476067
7	0.00002	0	0.00002	0.000021626	1825782
8	0.00001	0	0.00001	0.000022161	4022336
9	0.00002	0	0.00002	0.000023334	4233856
10	0.00002	0	0.00002	0.000021400	1749952
11	0.00001	0	0.00001	0.000021436	3935529
12	0.00001	0	0.00001	0.000021928	4649722
13	0.00001	0	0.00001	0.000021840	4348298
14	0.00001	0	0.00001	0.000021687	4547789
16	0.00001	0	0.00001	0.000021526	4118017
17	0.00001	0	0.00001	0.000021779	4568341
18	0.00001	0	0.00001	0.000022380	4212394
19	0.00001	0	0.00001	0.000021517	3939207
20	0.00001	0	0.00001	0.000021781	4577578
21	0.00001	0	0.00001	0.000021935	3820605
22	0.00002	0	0.00002	0.000021856	4003188
23	0.00001	0	0.00001	0.000021805	4069628
24	0.00001	0	0.00001	0.000021679	4050416
25	0.00001	0	0.00001	0.000020984	3792448
26	0.00001	0	0.00001	0.000020959	3877228
27	0.00001	0	0.00001	0.000021859	3920199
28	0.00002	0	0.00002	0.000021945	4019427
29	0.00002	0	0.00002	0.000024353	4006198
30	0.00002	0	0.00002	0.000022662	4272401
31	0.00001	0	0.00001	0.000021529	4513508

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 9 with an error of 13.154 meters. Satellite 16 had the lowest maximum range error of 5.582 meters.

Figure 5-4 Distribution of Daily Max Range Errors

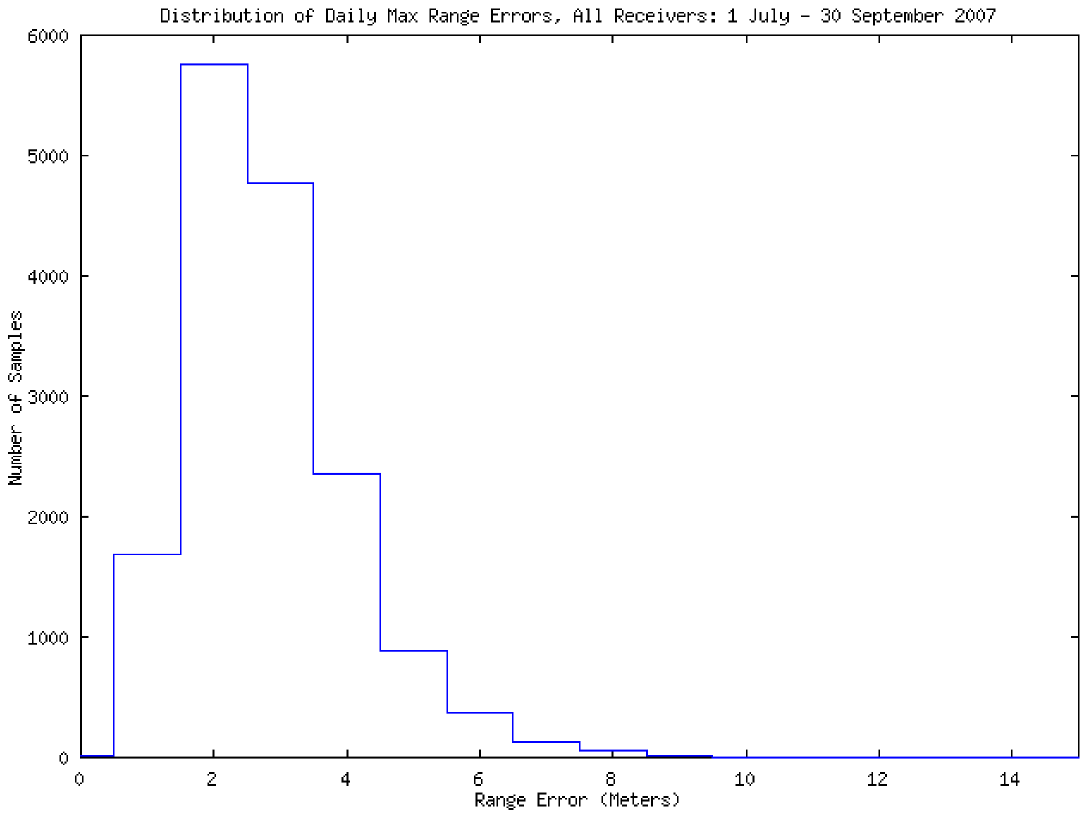


Figure 5-5: Distribution of Daily Max Range Rate Errors

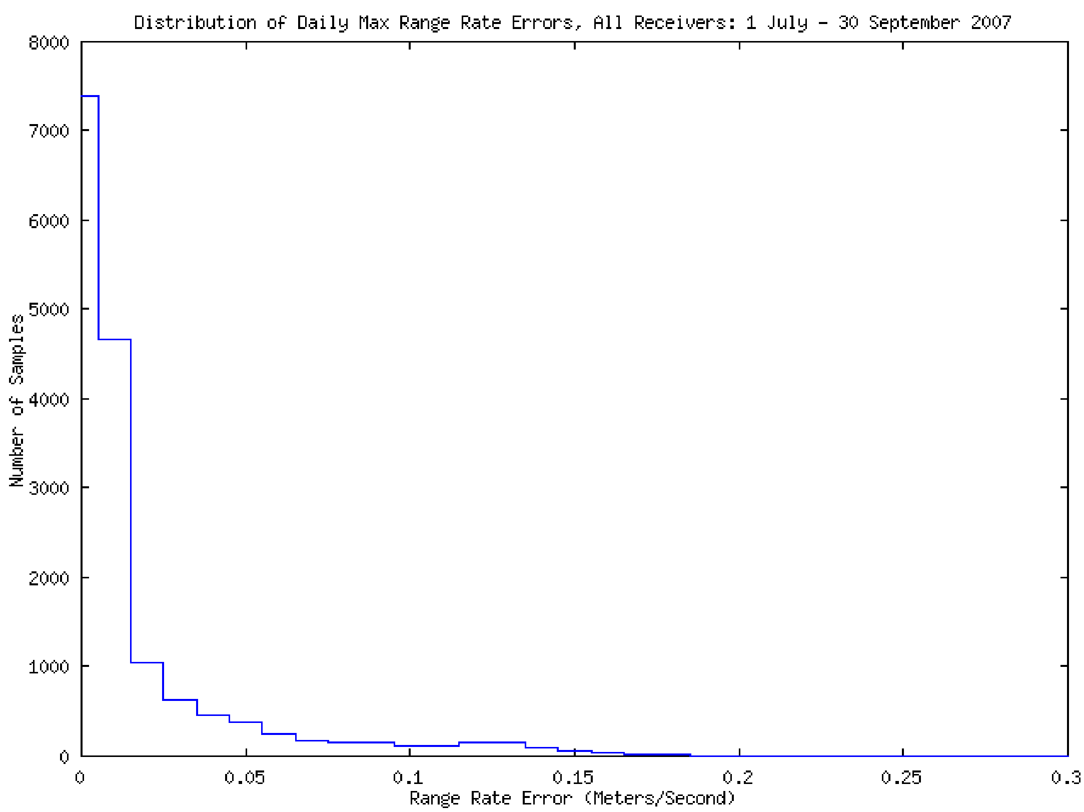


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

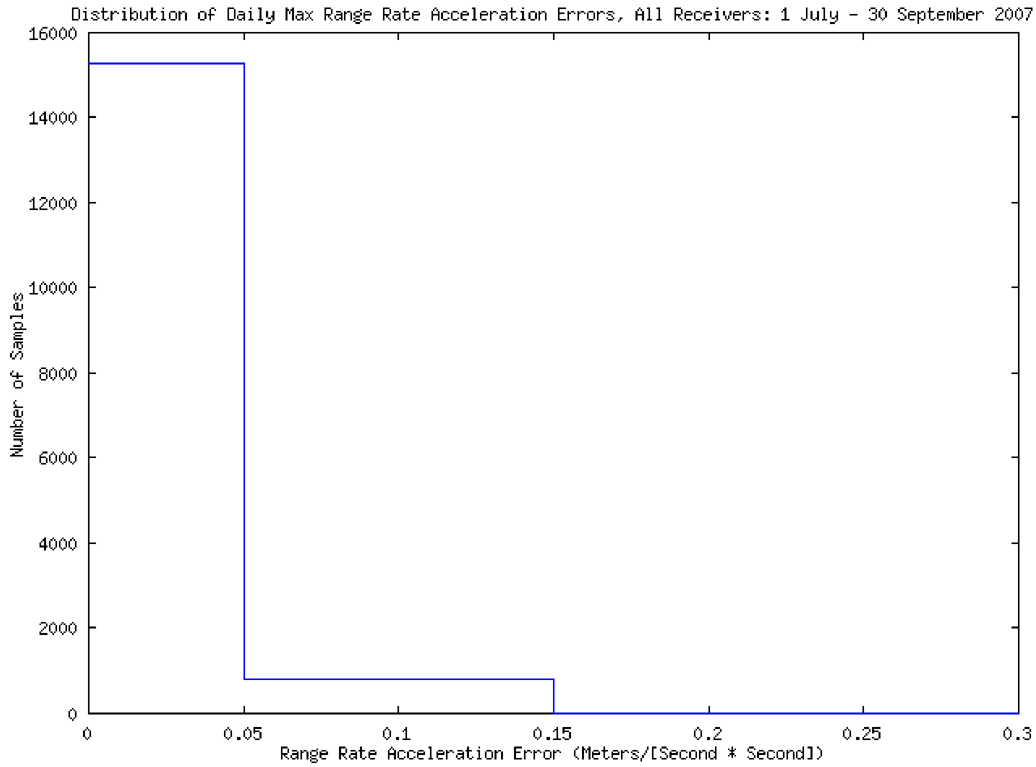


Figure 5-7: Range Error Histogram

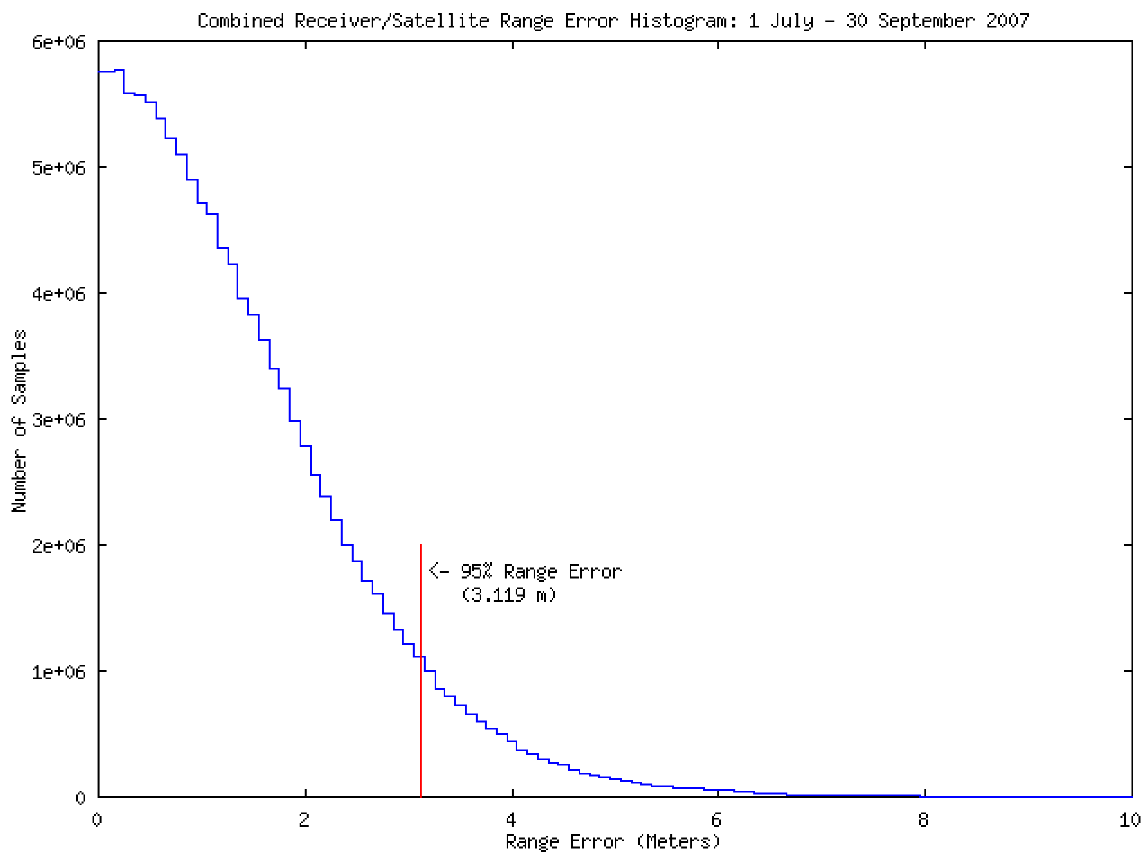


Figure 5-8: Maximum Range Error Per Satellite

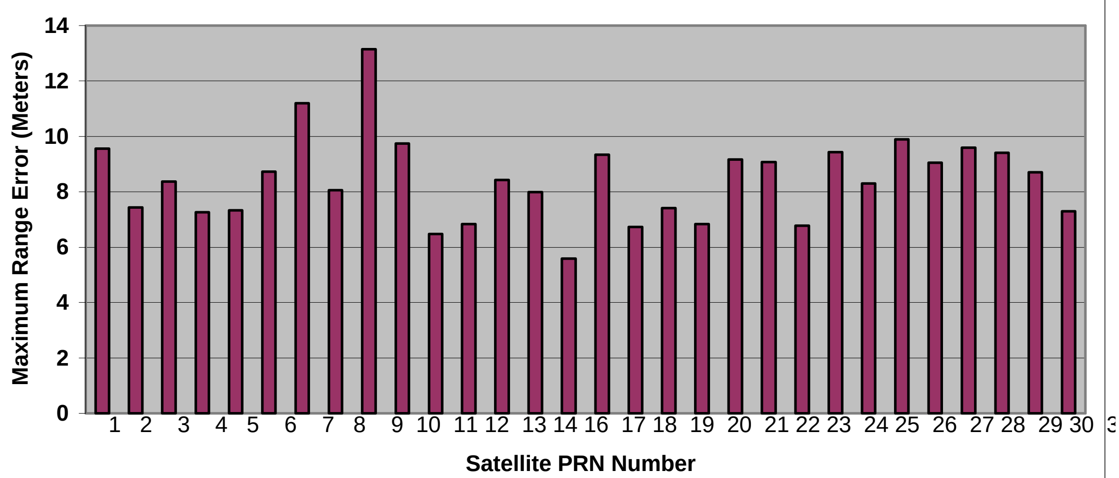


Figure 5-9: Maximum Range Rate Error Per Satellite

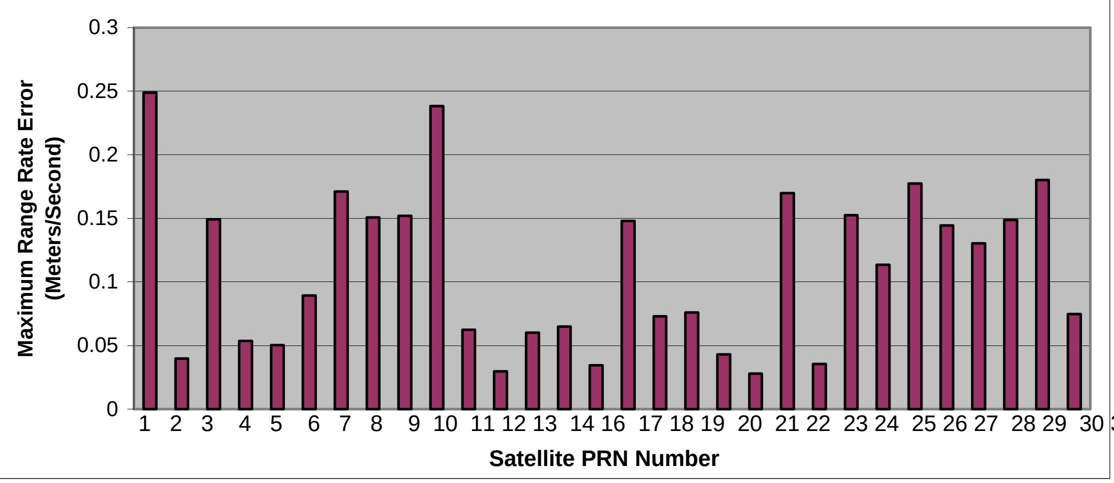
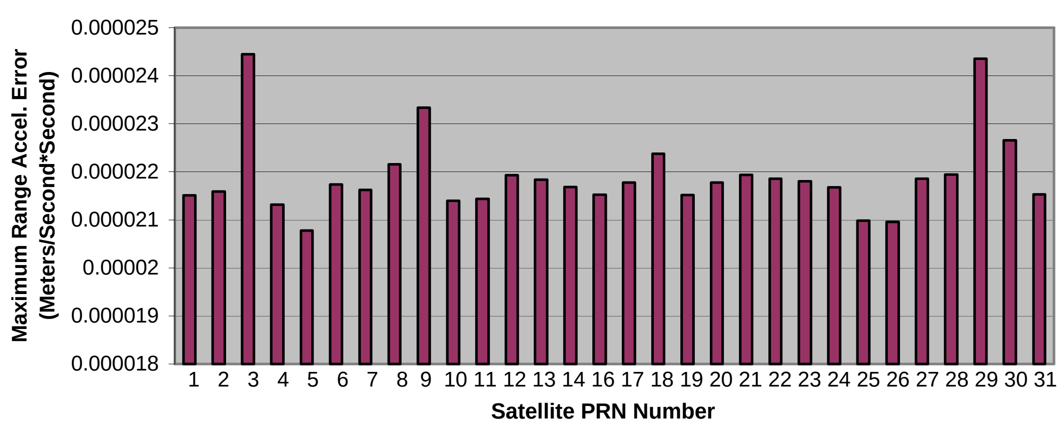


Figure 5-10: Maximum Range Acceleration Per Satellite



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 6-8 August 2007

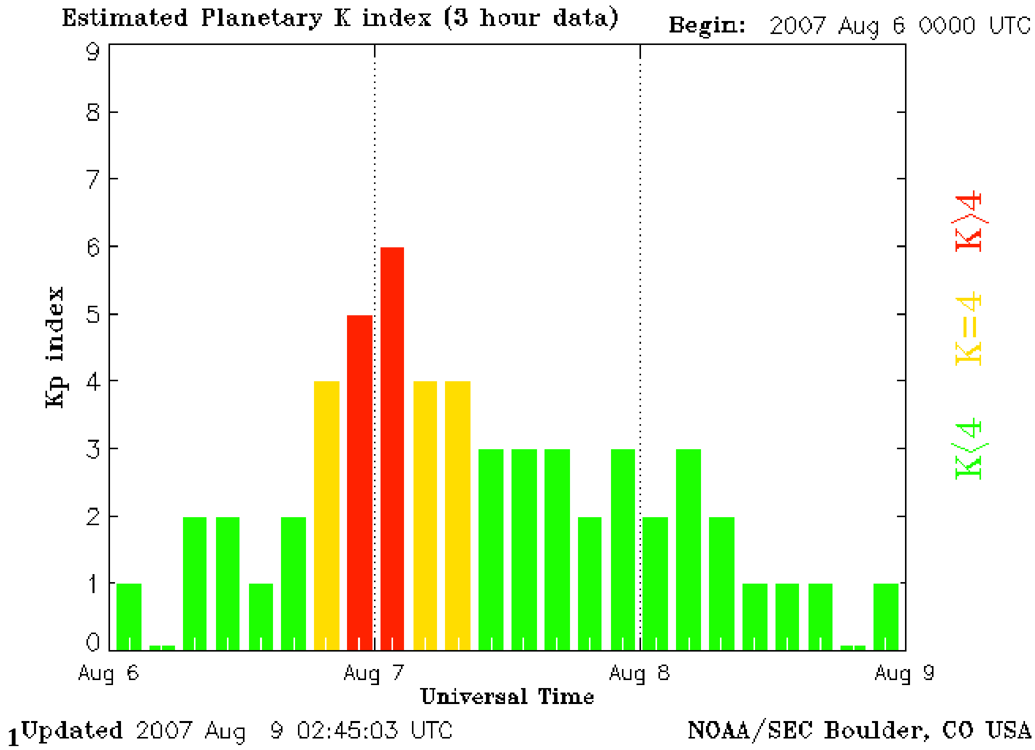


Figure 6-2 K-Index for 10-12 July 2007

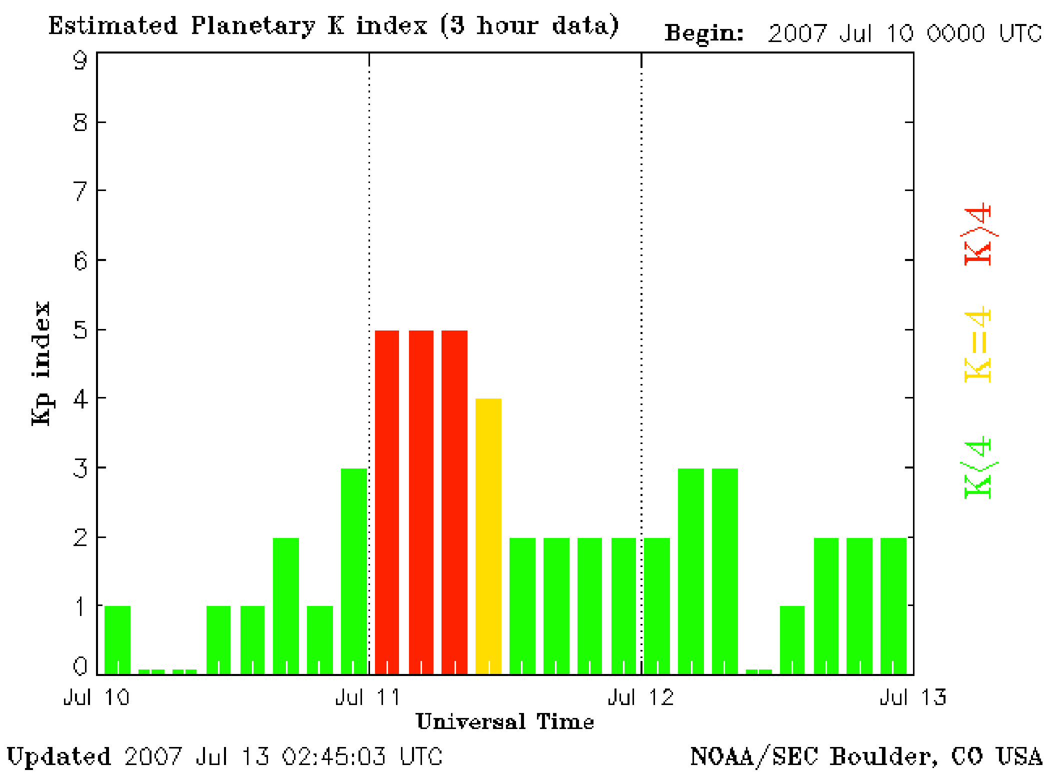
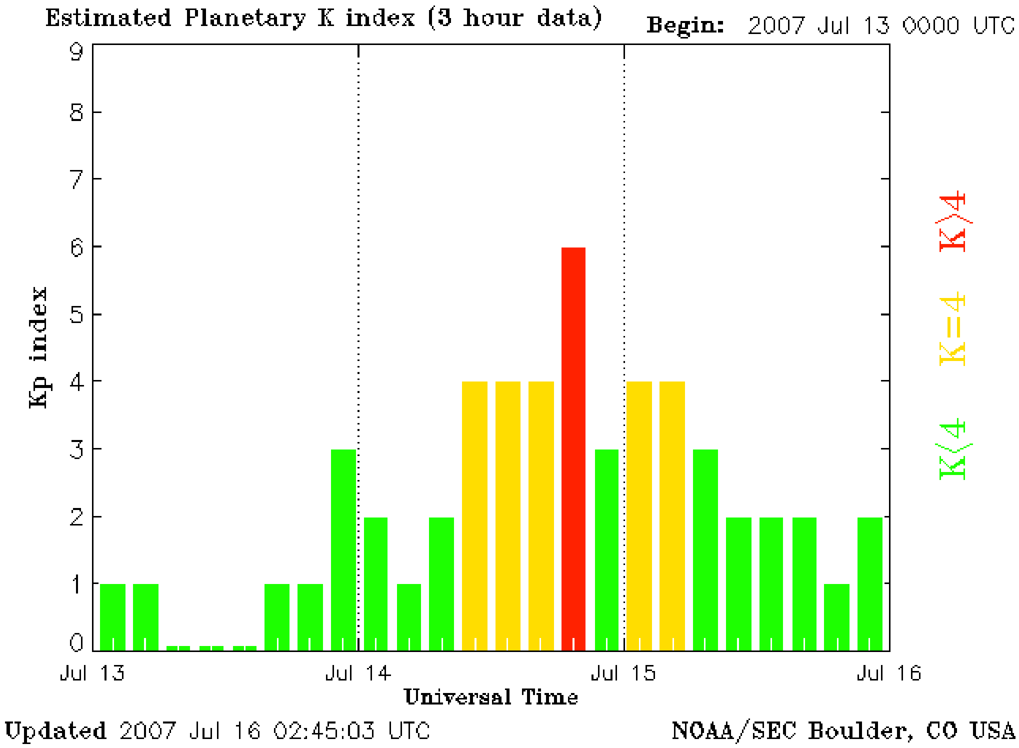


Figure 6-3 K-Index for 13-15 July 2007



Tables 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 29 January 2007

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Billings	2.282	2.963	2.821	4.191
Albuquerque	2.669	3.979	2.946	5.355
Anchorage	1.485	3.256	1.935	4.197
Boston	2.461	3.084	3.228	4.016
Washington, DC	2.296	3.244	3.930	4.894
Honolulu	2.363	4.722	2.870	6.377
Houston	2.648	3.336	3.785	5.394
Kansas City	2.255	3.148	2.615	4.799
Los Angeles	2.996	3.863	3.869	5.493
Salt Lake City	2.489	3.291	2.925	4.558
Miami	2.471	3.932	3.078	5.761
Minneapolis	2.396	2.598	3.078	3.774
Oakland	2.885	4.242	3.359	5.889
Cleveland	2.414	2.892	4.225	3.495
Seattle	2.066	2.933	2.575	4.878
San Juan	2.189	4.105	2.647	7.611
Atlanta	2.278	3.189	2.782	5.010
Juneau	1.810	3.024	2.254	4.522
Cold Bay	2.437	3.121	3.280	3.449
Fairbanks	1.588	3.659	2.121	5.047
Bethel	1.892	3.076	2.290	3.651
Kotzebue	1.551	3.582	1.941	5.034

APPENDICES A – D

Conditions and Constraints	***PDOP Availability Standard***	***Measured Performance***
• 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).	≥ 98% global Position Dilution of Precision (PDOP) of 6 or less ≥ 88% worst site PDOP of 6 or less	≥ 99.987% ≥ 99.028%
Conditions and Constraints	***Service Availability Standard***	***Measured Performance***
• 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.	≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	100%
• Based on using only satellites transmitting standard code and indicating “healthy” in the broadcast navigation message (sub-frame 1).	≥ 95.87% global average on worst-case day	100%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• 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.	≥ 99.94% global average	100%
• 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.	≥ 99.79% single point average	≥ 100%

Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• 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 • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only)	2.097 m 3.733 m
• 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 • ≤ 36 meters 95% All-in-View Horiz Error (SIS only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS only)	3.375 m 6.578 m
• 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 • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	12 nanoseconds 95%
• 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	1.709 meters

\# 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
\#

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2007 07 01	4	1 1 1 1 1 2 1 2	3	0 1 2 2 1 0 0 1	5	2 2 1 1 1 1 1 2
2007 07 02	2	0 0 1 1 1 1 0 1	1	1 0 1 1 0 0 0 0	3	1 0 1 1 1 0 1 1
2007 07 03	6	0 1 1 1 2 2 2 3	8	0 1 1 1 3 4 1 2	9	1 1 1 1 2 3 2 4
2007 07 04	13	3 3 2 4 3 2 2 2	25	4 4 3 6 4 3 1 1	16	4 4 3 4 3 2 3 2
2007 07 05	3	1 1 1 1 1 1 1 1	5	2 2 2 2 3 0 0 0	5	1 1 2 1 2 1 1 2
2007 07 06	4	1 1 1 1 1 1 1 2	6	1 1 1 2 3 2 1 1	5	1 1 1 1 2 2 1 2
2007 07 07	4	2 1 1 0 1 1 2 2	4	2 3 1 1 0 1 0 1	6	2 1 1 1 1 2 2 2
2007 07 08	3	1 2 1 0 1 0 1 1	3	2 2 2 1 0 0 0 0	4	1 2 1 1 1 1 1 1
2007 07 09	2	1 1 0 0 1 1 1 0	1	1 1 0 0 0 0 0 0	3	1 1 0 0 1 1 1 1
2007 07 10	5	0 0 1 0 1 1 2 3	3	0 0 1 1 2 0 0 2	6	1 0 0 1 1 2 1 3
2007 07 11	14	3 3 4 4 2 2 2 2	32	2 4 6 6 3 4 2 2	23	5 5 5 4 2 2 2 2
2007 07 12	6	2 2 3 0 1 1 1 2	10	2 3 4 0 3 1 1 1	8	2 3 3 0 1 2 2 2
2007 07 13	5	1 1 0 0 1 3 3 3	2	1 1 0 0 0 0 0 1	4	1 1 0 0 0 1 1 3
2007 07 14	12	2 1 2 3 3 3 3 3	39	1 1 1 6 6 6 5 3	23	2 1 2 4 4 4 6 3
2007 07 15	11	4 4 3 2 1 1 1 1	19	4 4 3 5 4 1 1 1	13	4 4 3 2 2 2 1 2
2007 07 16	4	1 1 1 1 1 2 2 0	7	1 2 2 3 1 1 3 1	6	1 2 2 1 2 1 1 2
2007 07 17	2	1 0 1 1 0 1 1 0	2	1 1 1 2 0 0 0 0	5	1 1 1 1 1 2 2 2
2007 07 18	3	1 1 1 0 1 1 1 1	2	1 1 1 0 0 0 1 0	3	1 1 0 0 1 0 1 1
2007 07 19	3	0 0 0 1 2 2 0 1	0	0 0 1 0 0 0 0 0	3	1 0 0 0 2 1 1 1
2007 07 20	9	0 2 2 3 4 1 2 2	17	0 2 2 5 5 3 2 2	12	0 1 3 3 4 3 2 2
2007 07 21	10	2 4 2 2 3 1 2 1	17	4 4 3 4 4 2 1 1	12	2 5 2 2 2 2 3 2
2007 07 22	3	1 1 1 1 1 1 1 0	3	1 2 2 2 0 0 0 0	4	1 2 1 0 1 1 1 1
2007 07 23	4	1 1 1 1 1 1 1 2	3	1 1 0 2 1 0 1 1	3	1 1 1 1 0 0 1 2
2007 07 24	2	0 0 0 0 2 1 1 0	1	0 1 0 0 0 0 1 1	2	0 0 0 0 1 1 0 1
2007 07 25	2	1 0 0 1 1 1 1 0	0	0 0 0 0 0 0 0 0	2	0 0 0 1 1 1 1 0
2007 07 26	6	0 0 0 1 1 2 3 3	5	0 0 0 0 1 2 2 3	9	0 0 0 1 1 4 3 3
2007 07 27	6	2 3 1 2 2 1 0 1	13	2 3 2 4 5 1 0 0	8	3 3 2 2 2 1 0 1
2007 07 28	3	1 1 1 0 1 1 1 2	2	1 1 1 2 1 0 0 0	4	2 1 1 1 0 1 0 2
2007 07 29	11	3 3 2 2 2 2 3 3	21	3 4 2 5 5 2 2 2	14	3 4 2 3 3 2 3 3
2007 07 30	10	4 3 2 2 2 2 2 1	18	3 4 5 2 2 2 1 4	10	3 4 3 1 1 2 2 2
2007 07 31	4	0 1 2 1 1 1 1 2	7	1 1 2 3 3 1 1 1	6	1 1 2 2 1 1 1 2
2007 08 01	15	3 4 4 2 3 2 2 3	24	3 3 4 6 4 3 1 2	17	3 4 4 3 2 2 3 3
2007 08 02	5	2 1 2 1 1 2 2 1	8	2 1 2 1 3 4 1 0	5	1 2 2 0 2 2 1 2
2007 08 03	4	1 2 2 0 2 1 1 1	4	1 2 2 0 2 0 1 1	4	1 2 2 0 1 1 1 2
2007 08 04	0	0 0 0 0 0 0 0 1	1	0 1 0 0 0 0 0 1	2	1 0 1 0 0 0 0 1
2007 08 05	2	0 0 0 0 1 0 2 1	0	0 0 0 0 0 0 1 0	2	1 0 0 0 0 1 1 1
2007 08 06	8	0 0 2 2 1 2 3 4	12	0 0 3 2 3 3 3 4	12	1 0 2 2 1 2 4 5
2007 08 07	23	6 3 4 3 2 2 3 3	34	4 3 6 6 4 4 2 2	23	6 4 4 3 3 3 2 3
2007 08 08	5	2 2 3 0 1 1 1 1	7	2 2 4 2 1 1 1 0	6	2 3 2 1 1 1 0 1
2007 08 09	2	1 0 1 1 0 1 1 1	4	1 1 2 3 1 0 1 1	4	1 0 2 2 1 0 1 1
2007 08 10	10	1 0 2 2 4 3 3 2	20	0 1 3 4 5 5 3 2	13	1 1 2 2 4 4 4 3
2007 08 11	7	3 2 2 1 1 2 2 2	21	3 3 5 4 4 4 2 1	12	3 3 3 2 2 3 3 2
2007 08 12	5	2 1 1 3 1 1 1 0	13	2 2 2 5 4 1 1 0	6	2 1 1 3 2 1 1 1
2007 08 13	2	1 1 0 0 0 1 0 1	2	1 1 0 0 0 0 0 2	3	1 1 0 0 1 1 0 2
2007 08 14	3	1 0 1 0 1 0 1 3	2	1 0 1 0 1 1 1 1	6	1 1 1 1 1 2 1 3
2007 08 15	6	2 2 1 1 2 2 2 2	9	2 2 1 4 3 2 1 1	8	3 3 1 1 2 2 2 2
2007 08 16	6	2 1 2 3 1 1 2 1	6	2 2 3 3 0 0 1 0	7	2 2 2 3 1 1 1 2
2007 08 17	2	1 1 0 0 1 1 1 1	2	2 1 0 0 0 0 1 1	5	2 1 0 0 1 1 2 2
2007 08 18	1	2 0 0 0 0 0 0 0	0	1 0 0 0 0 0 0 0	4	2 0 0 0 1 1 1 2
2007 08 19	2	0 0 0 1 2 1 0 0	2	0 0 0 0 2 1 0 1	3	0 0 0 1 2 2 0 1
2007 08 20	2	1 0 1 1 1 1 1 0	1	1 1 0 1 0 0 0 0	2	1 0 0 0 1 0 1 1
2007 08 21	3	2 1 0 0 2 1 1 1	2	1 1 0 1 1 0 1 1	4	2 1 0 1 2 1 0 1
2007 08 22	2	0 1 0 1 2 1 1 0	6	0 0 0 3 3 3 1 0	4	0 1 0 1 2 1 1 1
2007 08 23	1	0 0 0 1 1 0 1 0	1	0 0 0 1 1 0 0 0	2	0 0 0 1 1 0 0 1
2007 08 24	1	0 1 0 0 1 0 0 0	0	0 0 0 0 0 0 1 0	2	0 1 0 0 0 0 1 1
2007 08 25	6	1 0 1 2 2 1 3 2	18	1 1 1 5 6 1 1 1	8	2 1 1 2 3 2 3 2
2007 08 26	10	1 1 1 1 3 2 4 3	8	1 1 1 2 3 3 2 2	10	1 1 1 1 2 2 4 3
2007 08 27	10	3 2 3 1 2 2 3 2	13	3 1 4 4 2 1 3 2	12	3 2 4 2 2 2 3 3

2007 08 28	9	2	2	3	4	2	1	1	1	18	2	2	3	6	4	1	1	1	11	3	2	3	4	2	2	2	2
2007 08 29	4	1	0	2	1	1	1	2	1	3	1	1	1	0	1	1	1	1	4	2	0	1	1	1	1	1	2
2007 08 30	4	2	1	1	1	1	1	1	2	2	1	1	2	0	0	0	1	1	6	2	2	1	1	2	2	1	2
2007 08 31	7	1	2	1	1	1	1	3	3	6	1	1	1	3	2	1	2	2	7	1	1	1	2	2	2	3	3
2007 09 01	9	1	2	3	3	2	1	2	3	18	2	1	5	5	4	1	1	2	11	2	2	3	3	2	2	2	3
2007 09 02	17	3	5	3	2	3	2	3	2	38	4	5	5	6	5	4	3	2	23	4	5	3	4	4	2	4	3
2007 09 03	8	2	3	2	2	2	2	1	2	15	2	3	3	4	4	3	1	2	12	3	3	2	3	3	2	2	3
2007 09 04	4	1	1	2	2	0	1	1	2	6	2	1	2	3	2	0	1	2	6	2	2	2	1	1	2	2	1
2007 09 05	10	2	3	4	2	2	1	2	2	22	2	3	5	5	5	2	1	1	12	2	4	4	2	3	1	2	2
2007 09 06	8	3	2	1	2	1	1	2	3	19	2	1	1	5	2	5	4	2	13	3	2	1	2	2	2	3	4
2007 09 07	10	4	4	1	1	1	2	1	2	16	4	4	2	4	4	2	1	1	12	4	4	1	1	2	2	1	2
2007 09 08	3	1	1	2	1	1	1	1	0	8	1	2	3	4	1	2	1	0	6	2	2	2	2	1	2	2	1
2007 09 09	2	0	0	0	1	1	1	0	1	2	0	0	0	2	1	0	0	1	2	0	0	0	0	1	0	1	1
2007 09 10	2	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0	0	2	1	0	1	0	0	0	0	1
2007 09 11	2	0	0	1	1	1	0	1	0	1	0	0	1	1	1	0	0	0	2	0	0	1	1	1	0	0	1
2007 09 12	2	1	0	1	0	1	1	0	0	1	0	1	1	1	0	0	0	0	2	1	1	0	1	0	0	0	1
2007 09 13	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	1	1	1
2007 09 14	3	0	0	0	1	1	2	2	2	1	0	0	0	0	0	1	1	1	4	1	0	0	0	0	2	3	2
2007 09 15	3	2	0	0	0	1	1	2	1	2	2	0	0	0	0	0	1	1	4	2	1	0	1	1	1	1	2
2007 09 16	2	1	1	0	0	2	0	1	0	0	1	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	1
2007 09 17	1	0	0	0	0	0	0	1	2	1	0	0	0	0	1	0	1	1	2	0	0	0	0	1	1	1	2
2007 09 18	2	2	1	0	0	1	0	0	0	2	2	1	0	0	1	0	0	0	3	2	1	0	0	1	2	1	1
2007 09 19	2	0	2	0	0	1	0	1	0	1	0	1	0	1	1	0	0	0	4	0	2	0	1	1	1	1	1
2007 09 20	6	0	1	0	1	3	2	3	2	8	0	0	0	2	2	4	3	2	10	0	1	0	2	3	3	4	3
2007 09 21	7	2	1	1	2	2	1	2	3	6	2	2	2	2	2	1	1	2	9	2	2	1	2	2	2	2	4
2007 09 22	10	3	2	3	1	2	2	3	2	15	3	2	4	3	3	4	2	2	11	3	2	3	1	2	2	4	3
2007 09 23	11	3	3	3	2	2	1	2	3	20	3	4	4	5	4	2	1	2	15	3	4	4	2	2	1	2	3
2007 09 24	7	2	3	2	1	2	1	2	2	12	3	3	2	3	4	2	1	1	10	3	4	2	1	2	1	1	2
2007 09 25	5	3	1	1	1	0	1	2	2	4	2	1	2	0	1	1	1	2	6	3	0	1	1	1	1	3	2
2007 09 26	2	2	1	1	0	0	0	1	0	1	1	1	0	1	0	0	0	0	3	2	1	0	0	1	0	1	1
2007 09 27	10	0	0	0	2	1	4	3	4	10	0	0	0	1	0	5	3	3	19	0	0	0	2	1	6	5	4
2007 09 28	15	3	3	4	2	1	2	3	4	27	3	4	6	5	3	2	2	3	21	4	4	4	3	2	2	4	5
2007 09 29	24	5	5	4	3	3	2	3	3	45	5	5	6	6	5	4	3	3	26	5	5	5	4	3	2	4	3
2007 09 30	11	3	4	3	2	2	1	2	2	17	2	3	5	5	2	2	1	0	12	3	4	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.

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 (Ok) 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, ?, 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 Ok when the argument of latitude (?) 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, ?, 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 Ok when the argument of latitude (?) 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 (1ó) 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.