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

Submitted To

Federal Aviation Administration
GPS Product Team

1284 Maryland Avenue SW
Washington, DC 20024

Report #62
July 31, 2008
Reporting Period: 1 April – 30 June 2008

Submitted by

William J. Hughes Technical Center
NSTB/WAAS T&E Team
Atlantic City International Airport, NJ 08405

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 #61, includes data collected from 1 April through 30 June 2008. The next quarterly report will be issued 31 July 2008.

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 99.984% or better.

NANU summary and evaluation was achieved by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 April and 30 June 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 twelve outages were reported in the NANU's this quarter. Nine outages were scheduled while three were unscheduled.

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

Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error 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 17.570 meters on Satellite PRN 30. 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 2.310 recorded on satellite 7. 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 April and 30 June 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

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-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.

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 3.26127 or better 99.9% of the time for each of the 24-hour intervals.

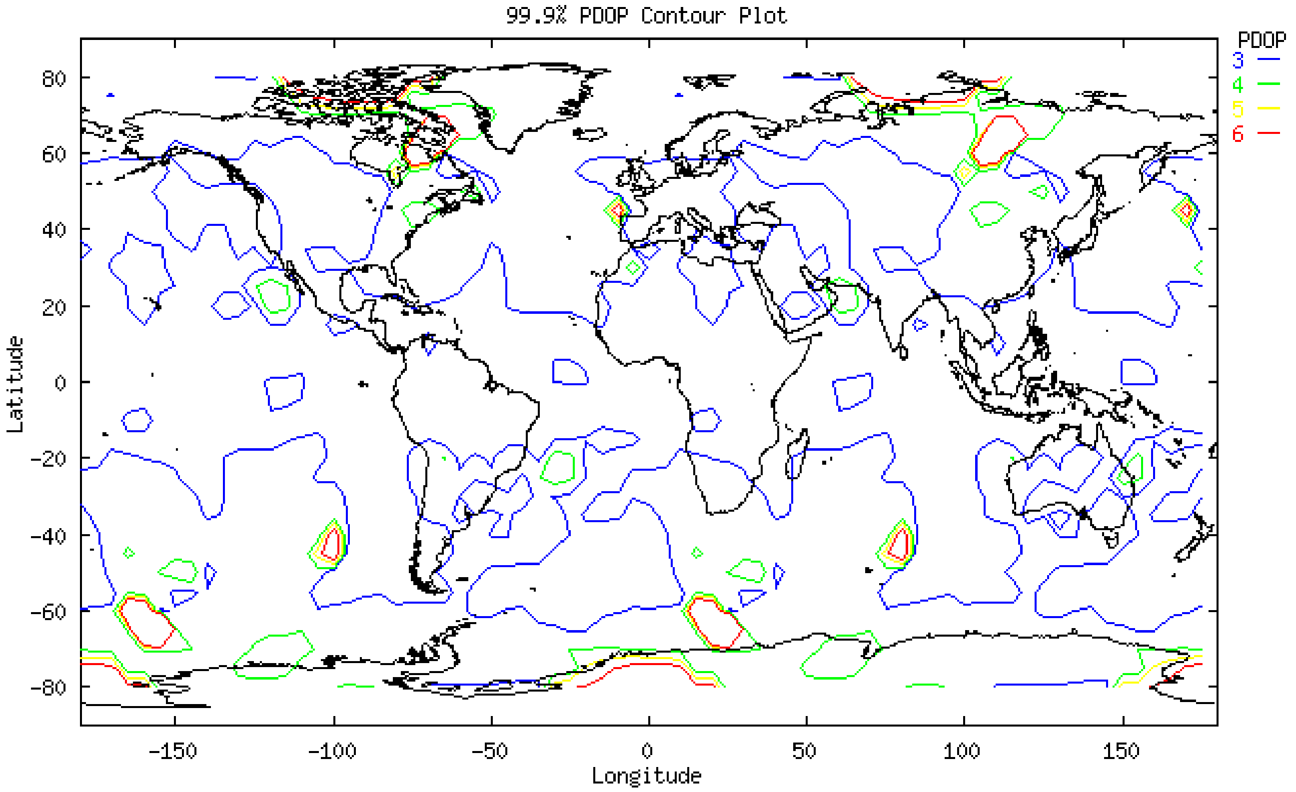
Figure 2-1 is a contour plot of PDOP values over the entire globe. Inside each contour area, the PDOP value is greater than or equal to the contour value shown in the legend for that color line. That areas' value is also less than the next higher contour value, unless another contour line lies within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

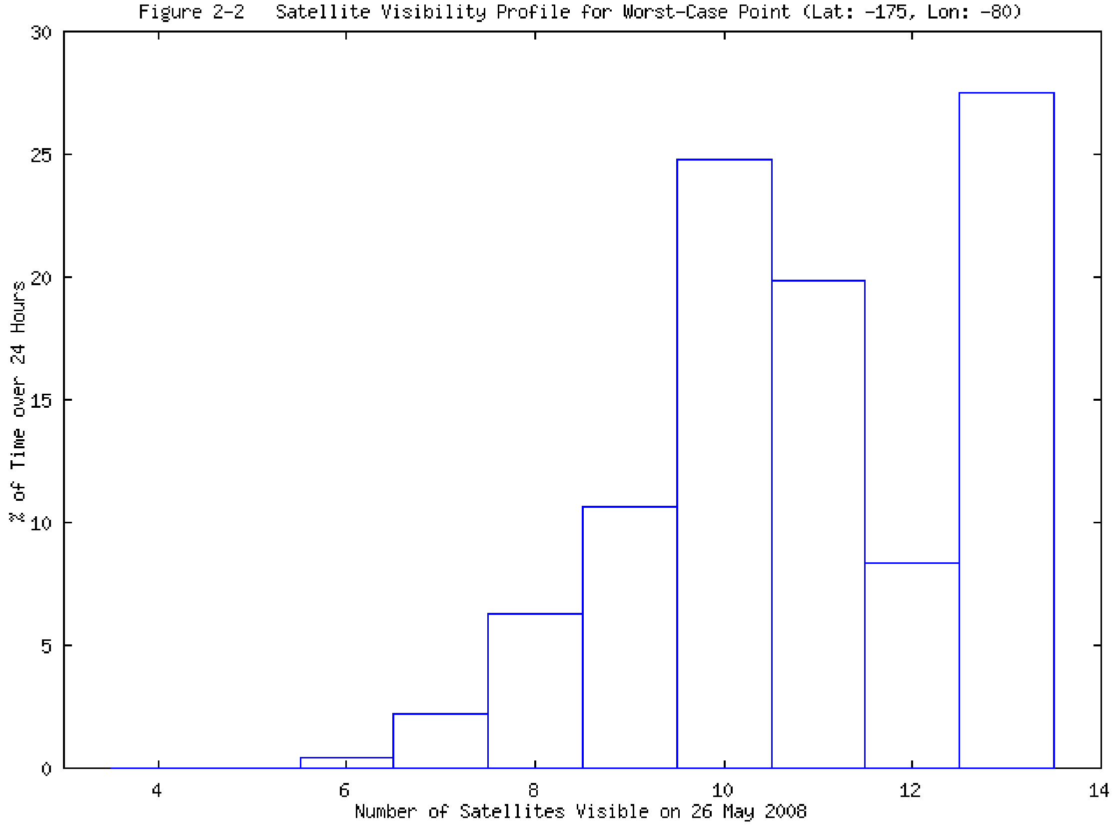
Date Range of Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
1-5 Apr	3.07132	99.984	98.889
6-12 Apr	3.09064	99.983	98.889
13-19 Apr	3.11171	99.983	98.889
20-26 Apr	3.22308	99.983	98.889
27 Apr - 3 May	3.22267	99.983	98.889
4-10 May	3.22170	99.983	98.958
11-17 May	3.23462	99.984	98.958
18-24 May	3.23445	99.983	98.819
25-31 May	3.23454	99.983	98.819
1-7 June	3.23163	99.985	99.097
8-14 June	3.26127	99.985	99.097
15-21 June	3.22127	99.986	99.097
22-30 June	3.22282	99.986	99.167

Figure 2-1 PDOP Availability Plot (24-Hour Period: 26 May 2008)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lat: -175, Lon: -80)



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 April through 30 June 2008, there were a total of twelve reported outages. Nine of these outages were maintenance activities and were reported in advance. Three 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
2008038	12.00	UNUSABLE	2-Apr	0.41	2-Apr	0.63	5.37		5.37
2008040	11.00	FCSTSUMM	15-Apr	0.86	16-Apr	0.17		7.58	7.58
2008042	25.00	FCSTSUMM	23-Apr	0.80	24-Apr	0.02		5.15	5.15
2008045	2.00	UNUSABLE	26-Apr	0.12	29-Apr	0.51	81.47		81.47
2008046	30.00	FCSTSUMM	29-Apr	0.43	29-Apr	0.72		7.08	7.08
2008048	27.00	FCSTSUMM	22-May	0.76	23-May	0.10		8.10	8.10
2008052	5.00	FCSTSUMM	3-Jun	0.60	3-Jun	0.64		0.98	0.98
2008053	6.00	FCSTSUMM	6-Jun	0.37	6-Jun	0.74		8.88	8.88
2008055	25.00	FCSTSUMM	7-Jun	0.73	7-Jun	0.84		2.65	2.65
2008057	9.00	UNUSABLE	7-Jun	0.74	9-Jun	0.85	50.43		50.43
2008058	25.00	FCSTSUMM	12-Jun	0.68	12-Jun	0.79		2.47	2.47
2008060	8.00	FCSTSUMM	25-Jun	0.98	26-Jun	0.22		5.75	5.75
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**137.27**	**48.65**	**185.92**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2008037	12	UNUSUFN	2-Apr	9:46	N/A	N/A	N/A	See Nanu 2008038
2008039	11	FCSTDV	15-Apr	20:30	16-Apr	11:00	14.5	See Nanu 2008040
2008041	25	FCSTDV	23-Apr	19:00	24-Apr	10:00	15	See Nanu 2008042
2008043	30	FCSTDV	29-Apr	10:00	30-Apr	0:00	14	See Nanu 2008046
2008044	2	UNUSUFN	26-Apr	2:46	N/A	N/A	N/A	See Nanu 2008045
2008047	27	FCSTDV	22-May	18:15	23-May	8:00	13.75	See Nanu 2008048
2008049	5	FCSTMX	3-Jun	13:30	4-Jun	1:30	12	See Nanu 2008052
2008050	6	FCSTDV	6-Jun	8:00	7-Jun	12:00	28	See Nanu 2008053
2008051	25	FCSTMX	7-Jun	17:00	8-Jun	5:00	12	See Nanu 2008055
2008054	9	UNUSUFN	7-Jun	17:51	N/A	N/A	N/A	See Nanu 2008057
2008056	25	FCSTMX	12-Jun	16:00	12-Jun	22:00	6	See Nanu 2008058
2008059	8	FCSTDV	25-Jun	23:30	26-Jun	13:30	14	See Nanu 2008060
2008061	32	FCSTDV	1-Jul	14:00	2-Jul	16:00	26	See Nanu 2008062
					Total Forecast Downtime		**155.25**	

Table 3-3 NANUs Canceled					
NANU#	PRN	Type	Start Date	Start Time	Comments

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published "Notice: Advisory to Navstar Users" messages (NANU's). This data has been summarized in Table 3-4. The "Total Satellite Observed MTTR" was calculated by taking the average downtime of all satellite outage occurrences. 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 Apr - 30-Jun**	**1 October, 1999- 30 June 2008**
Total Forecast Downtime (hrs):	155.25	7045.90
Total Actual Downtime (hrs):	185.92	25254.94
Total Actual Scheduled Downtime (hrs):	48.65	3696.95
Total Actual Unscheduled Downtime (hrs):	137.27	21557.99
Total Satellite Observed MTTR (hrs):	15.49	45.18
Scheduled Satellite Observed MTTR (hrs):	5.41	9.22
Unscheduled Satellite Observed MTTR (hrs):	45.76	136.44
# Total Satellite Outages:	12	559
# Scheduled Satellite Outages:	9	401
# Unscheduled Satellite Outages:	3	158
Percent Operational -- Scheduled Downtime:	99.93	99.83
Percent Operational -- All Downtime:	99.99	98.82

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-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 April and 30 June 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	7812893	0	100%
Anchorage	7810694	0	100%
Atlanta	7835859	0	100%
Barrow	7796869	0	100%
Bethel	7823065	0	100%
Billings	7771154	0	100%
Boston	7834036	0	100%
Cleveland	6827667	0	100%
Cold Bay	7649336	0	100%
Fairbanks	7800539	0	100%
Gander	7813611	0	100%
Honolulu	7735897	0	100%
Houston	7834858	0	100%
Iqaluit	7814625	0	100%
Juneau	7816960	0	100%
Kansas City	7792385	0	100%
Kotzebue	7822071	0	100%
Los Angeles	7833155	0	100%
Merida	7818025	0	100%
Miami	7835033	0	100%
Minneapolis	7835862	0	100%
Oakland	7824725	0	100%
Salt Lake City	7714874	0	100%
San Jose Del Cabo	7818009	0	100%
San Juan	7606436	0	100%
Seattle	6641468	0	100%
Tapachula	7810808	0	100%
Washington, DC	7833523	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 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 17.570 meters at Miami on satellite PRN 30.

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 Jan. – 31 Mar 2008	**Boston**	65,855,072	0	100%
1 Jan. – 31 Mar 2008	**Honolulu**	67,961,162	0	100%
1 Jan. – 31 Mar 2008	**Los Angeles**	67,266,098	0	100%
1 Jan. – 31 Mar 2008	**Miami**	67,118,048	0	100%
1 Jan. – 31 Mar 2008	**San Juan**	65,355,848	0	100%
1 Jan. – 31 Mar 2008	**Juneau**	67,822,181	0	100%
1 Jan. – 31 Mar 2008	**Global**	341,378,409	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 from 1 April through 30 June 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	2.143	4.528	5.083	9.729
Anchorage	1.986	3.886	3.614	9.569
Atlanta	2.346	5.426	5.484	13.289
Barrow	1.72	4.347	3.203	10.323
Bethel	1.99	4.023	3.522	9.819
Billings	2.149	4.212	6.03	9.467
Boston	2.163	4.615	4.846	8.985
Cleveland	2.296	5.095	4.943	12.327
Cold Bay	2.102	4.229	4.027	9.473
Fairbanks	1.939	4.075	3.587	9.592
Gander	2.077	4.11	4.56	8.959
Honolulu	3.449	4.357	8.114	10.542
Houston	2.203	4.581	5.531	9.925
Iqaluit	1.703	3.825	5.65	20.53
Juneau	1.94	3.806	4.484	8.783
Kansas City	2.332	4.984	4.812	9.172
Kotzebue	1.945	4.08	3.646	9.589
Los Angeles	2.336	5.658	9.3	14.775
Merida	2.682	4.568	5.272	10.518
Miami	2.294	5.063	4.975	13.356
Minneapolis	2.284	4.702	6.007	9.372
Oakland	2.283	5.831	4.777	11.14
Salt Lake City	2.144	4.636	4.533	8.438
San Jose Del Cabo	3.02	4.744	6.961	11.095
San Juan	2.313	5.152	4.357	12.048
Seattle	2.355	5.152	4.94	8.984
Tapachula	3.297	4.116	6.627	8.522
Washington, DC	2.287	5.171	4.788	11.936

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-eight WAAS sites from 1 April to 30 June 2008.

Figure 5-1 Global Vertical Error Histogram

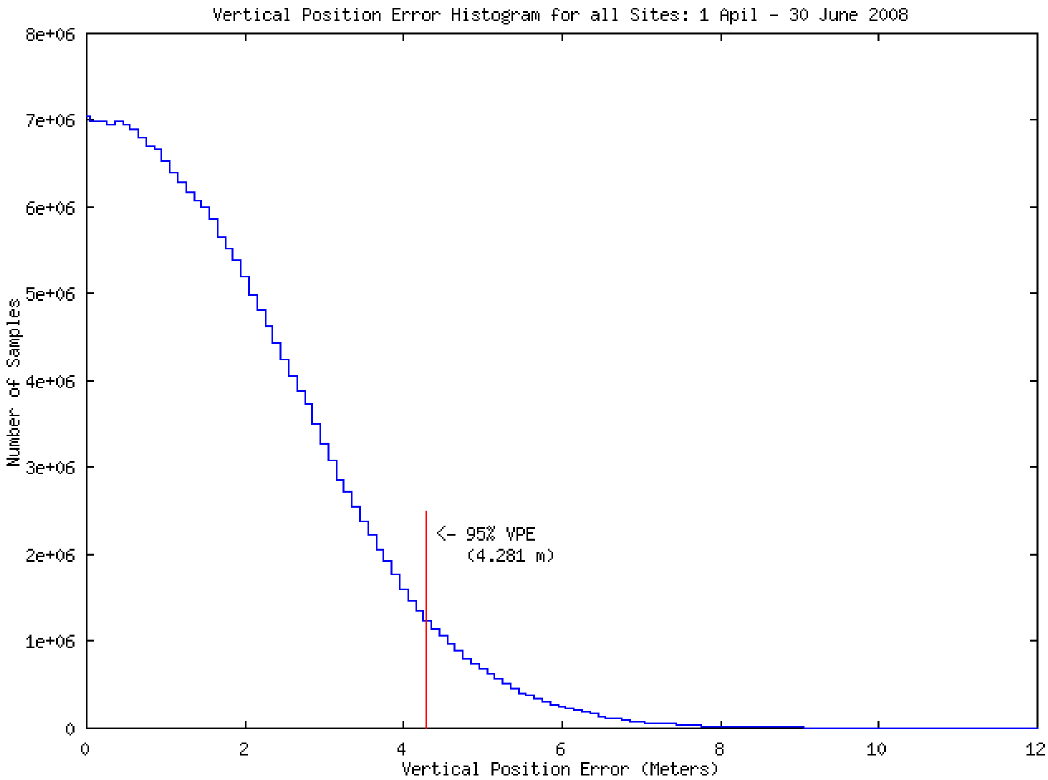
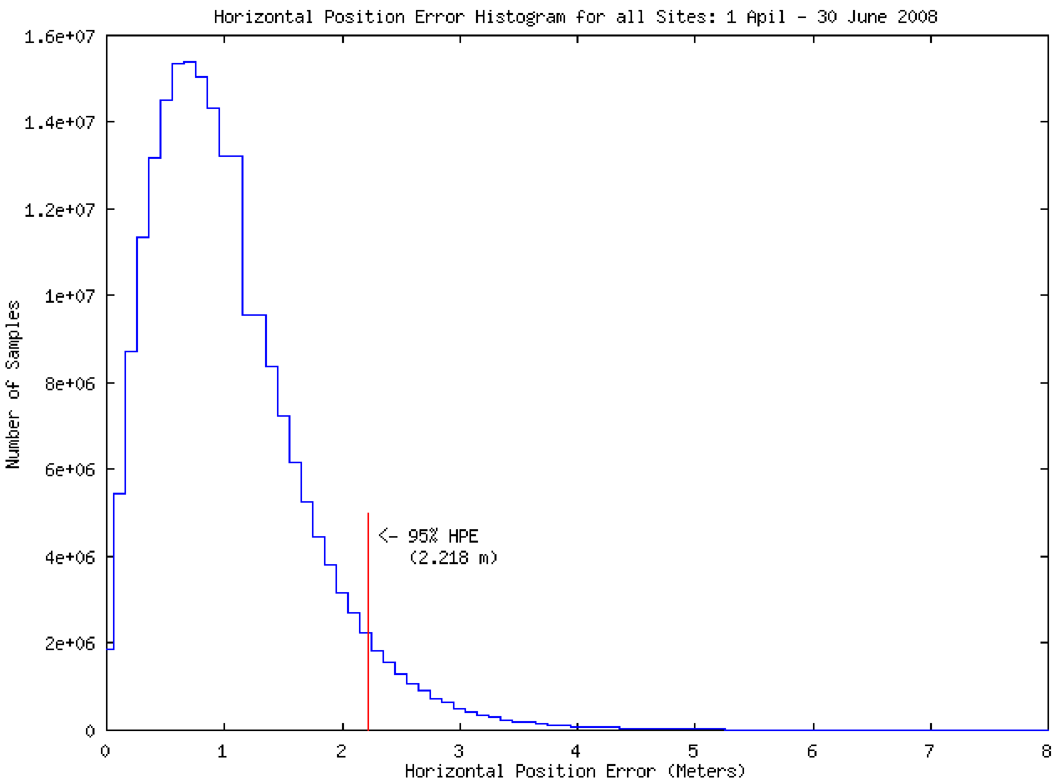


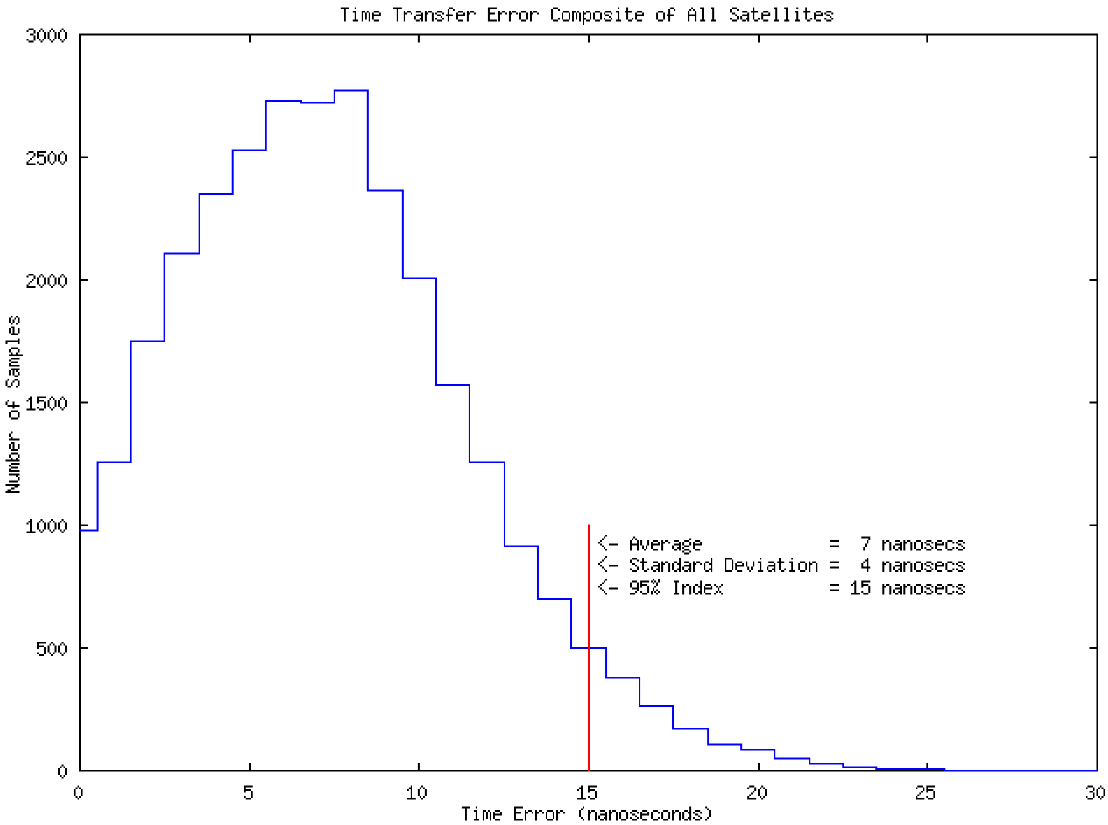
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 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 April and 30 June 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	1.6208	0.8062	1.2499	2.9976	11.272	13537367
3	1.7492	0.6328	1.3263	3.1058	8.552	12312634
4	1.6240	0.7214	1.2346	3.0890	9.762	13843995
5	1.6854	0.9458	1.1681	2.9942	7.060	13654284
6	1.4824	0.4861	1.1161	2.6737	7.504	13128745
7	2.3103	-1.5341	1.2434	3.7749	11.103	12015085
8	2.0483	1.1428	1.5213	3.8109	12.332	12601767
9	1.8924	0.9052	1.3326	3.3379	11.141	12522816
10	2.0823	1.3468	1.3651	3.6141	12.827	13527061
11	1.7148	1.0613	1.2064	3.1014	8.454	12188402
12	1.4395	0.7301	1.1288	2.6154	8.156	14120175
13	1.3902	0.3829	1.1491	2.6038	9.043	13906678
14	1.5579	0.9740	1.0439	2.7534	6.937	13976888
15	1.3543	0.3393	1.0963	2.5382	8.421	12556691
16	1.6006	0.9942	1.1318	2.8495	9.031	13088167
17	1.6251	0.7307	1.2497	3.0798	8.909	13944122
18	1.8019	1.2663	1.1137	3.0843	8.142	12960043
19	1.7304	1.2105	1.1263	3.0340	9.211	12475138
20	1.8684	1.2942	1.2378	3.4776	12.780	14125586
21	1.8250	1.3360	1.1263	3.0605	7.869	11990859
22	1.8511	1.1778	1.0986	3.1434	7.857	12262673
23	1.6179	0.7206	1.2689	2.9357	9.193	12783190
24	1.9335	1.1052	1.2255	3.2839	11.691	12463523
25	2.1479	1.1311	1.4169	3.6992	8.113	12416715
26	1.5150	0.6225	1.1651	2.7904	7.922	12177263
27	2.1545	1.3202	1.4149	3.8031	11.008	12537507
28	2.1753	1.3210	1.4355	3.8672	11.588	12477006
29	1.4270	0.6234	1.0795	2.6441	7.371	13648850
30	1.7450	0.6120	1.3488	3.1866	17.570	13043930
31	1.4671	0.4021	1.1579	2.6951	6.765	13951711
32	1.7833	1.2031	1.0997	3.1057	10.561	13265474

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	0.00137	-0.00002	0.00137	0.00254	0.15133	13537367
3	0.00188	-0.00006	0.00188	0.00285	0.15567	12312634
4	0.00130	-0.00003	0.00130	0.00246	0.07705	13843995
5	0.00157	0.00002	0.00156	0.00239	0.15378	13654284
6	0.00142	-0.00002	0.00142	0.00233	0.12672	13128745
7	0.00137	-0.00001	0.00136	0.00255	0.15872	12015085
8	0.00182	-0.00007	0.00181	0.00285	0.17393	12601767
9	0.00164	0.00000	0.00164	0.00279	0.25100	12522816
10	0.00181	0.00005	0.00180	0.00296	0.18355	13527061
11	0.00142	-0.00004	0.00141	0.00259	0.15048	12188402
12	0.00135	-0.00003	0.00135	0.00262	0.08564	14120175
13	0.00133	0.00003	0.00133	0.00252	0.06701	13906678
14	0.00131	-0.00004	0.00131	0.00249	0.05943	13976888
15	0.00132	-0.00001	0.00132	0.00254	0.03452	12556691
16	0.00131	-0.00004	0.00131	0.00251	0.05766	13088167
17	0.00140	-0.00003	0.00139	0.00259	0.11015	13944122
18	0.00136	-0.00003	0.00135	0.00255	0.08824	12960043
19	0.00129	-0.00002	0.00129	0.00250	0.04836	12475138
20	0.00135	0.00005	0.00134	0.00261	0.07834	14125586
21	0.00142	-0.00001	0.00141	0.00272	0.08337	11990859
22	0.00152	0.00000	0.00151	0.00258	0.15452	12262673
23	0.00129	0.00000	0.00128	0.00247	0.04299	12783190
24	0.00156	-0.00001	0.00155	0.00261	0.15095	12463523
25	0.00178	-0.00001	0.00178	0.00232	0.16737	12416715
26	0.00135	0.00000	0.00135	0.00243	0.09888	12177263
27	0.00180	0.00001	0.00179	0.00276	0.18679	12537507
28	0.00153	0.00000	0.00153	0.00262	0.12680	12477006
29	0.00139	-0.00002	0.00138	0.00247	0.14247	13648850
30	0.00203	-0.00003	0.00203	0.00289	0.22645	13043930
31	0.00142	-0.00002	0.00142	0.00252	0.11157	13951711
32	0.00125	0.00005	0.00124	0.00234	0.09403	13265474

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

PRN	Range Acceleration Error RMS	Range Acceleration Error Mean	Range Acceleration 1σ	Max Range Acceleration Error	Samples
2	0.000011	0	0.000011	0.000020	13537367
3	0.000015	0	0.000015	0.000022	12312634
4	0.000010	0	0.000010	0.000019	13843995
5	0.000013	0	0.000013	0.000019	13654284
6	0.000012	0	0.000012	0.000020	13128745
7	0.000010	0	0.000010	0.000020	12015085
8	0.000014	0	0.000014	0.000021	12601767
9	0.000012	0	0.000012	0.000020	12522816
10	0.000013	0	0.000013	0.000023	13527061
11	0.000011	0	0.000011	0.000020	12188402
12	0.000010	0	0.000010	0.000020	14120175
13	0.000010	0	0.000010	0.000020	13906678
14	0.000010	0	0.000010	0.000020	13976888
15	0.000010	0	0.000010	0.000020	12556691
16	0.000010	0	0.000010	0.000020	13088167
17	0.000011	0	0.000011	0.000020	13944122
18	0.000010	0	0.000010	0.000020	12960043
19	0.000010	0	0.000010	0.000020	12475138
20	0.000010	0	0.000010	0.000020	14125586
21	0.000010	0	0.000010	0.000021	11990859
22	0.000012	0	0.000012	0.000020	12262673
23	0.000010	0	0.000010	0.000020	12783190
24	0.000012	0	0.000012	0.000020	12463523
25	0.000016	0	0.000016	0.000018	12416715
26	0.000011	0	0.000011	0.000019	12177263
27	0.000014	0	0.000014	0.000020	12537507
28	0.000012	0	0.000012	0.000020	12477006
29	0.000011	0	0.000011	0.000020	13648850
30	0.000016	0	0.000016	0.000021	13043930
31	0.000011	0	0.000011	0.000020	13951711
32	0.000010	0	0.000010	0.000019	13265474

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 30 with an error of 17.570 meters. Satellite 31 had the lowest maximum range error of 6.765 meters.

Figure 5-4 Distribution of Daily Max Range Errors

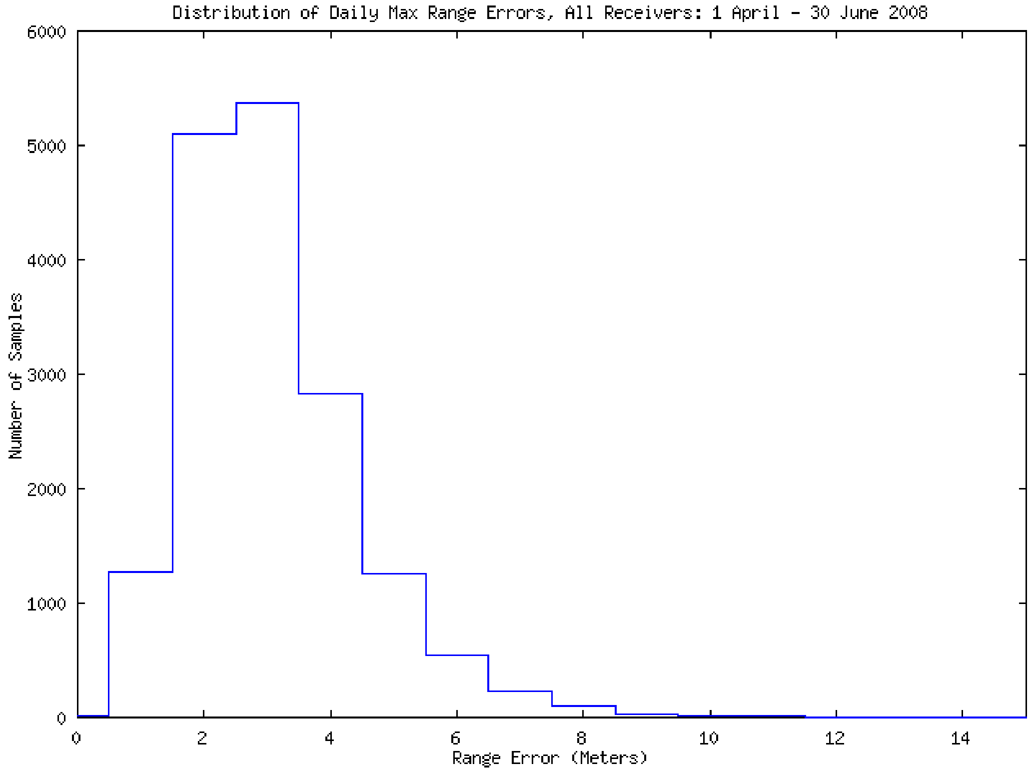


Figure 5-5: Distribution of Daily Max Range Rate Errors

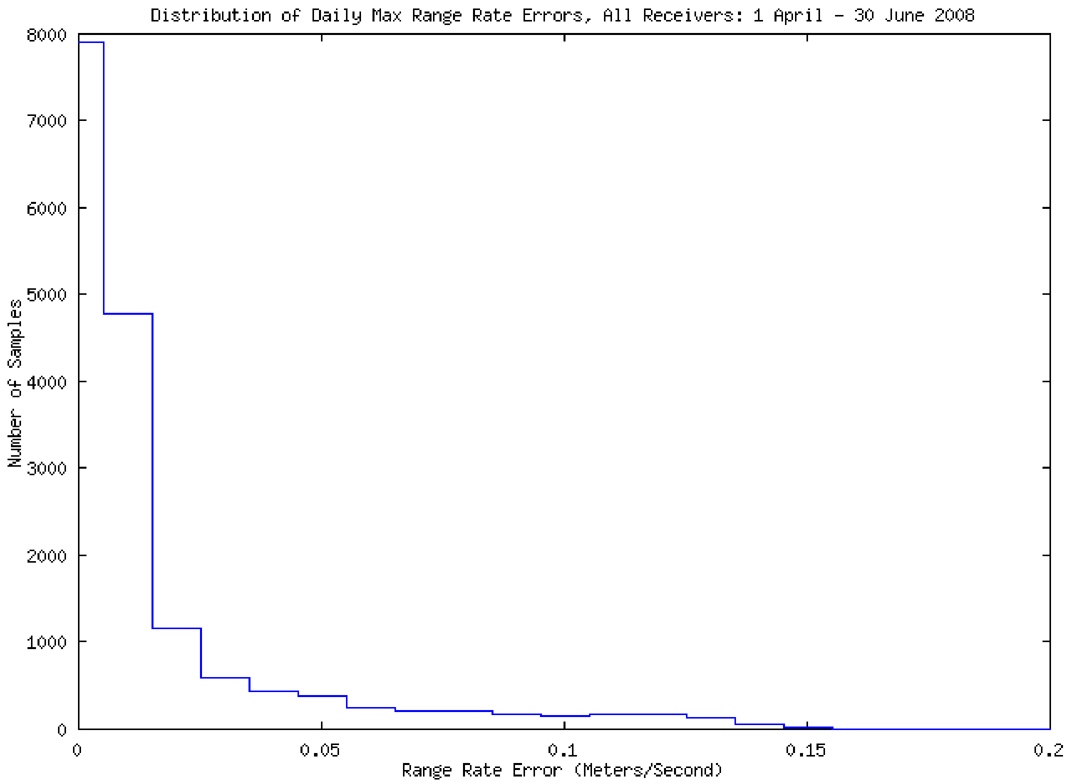


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

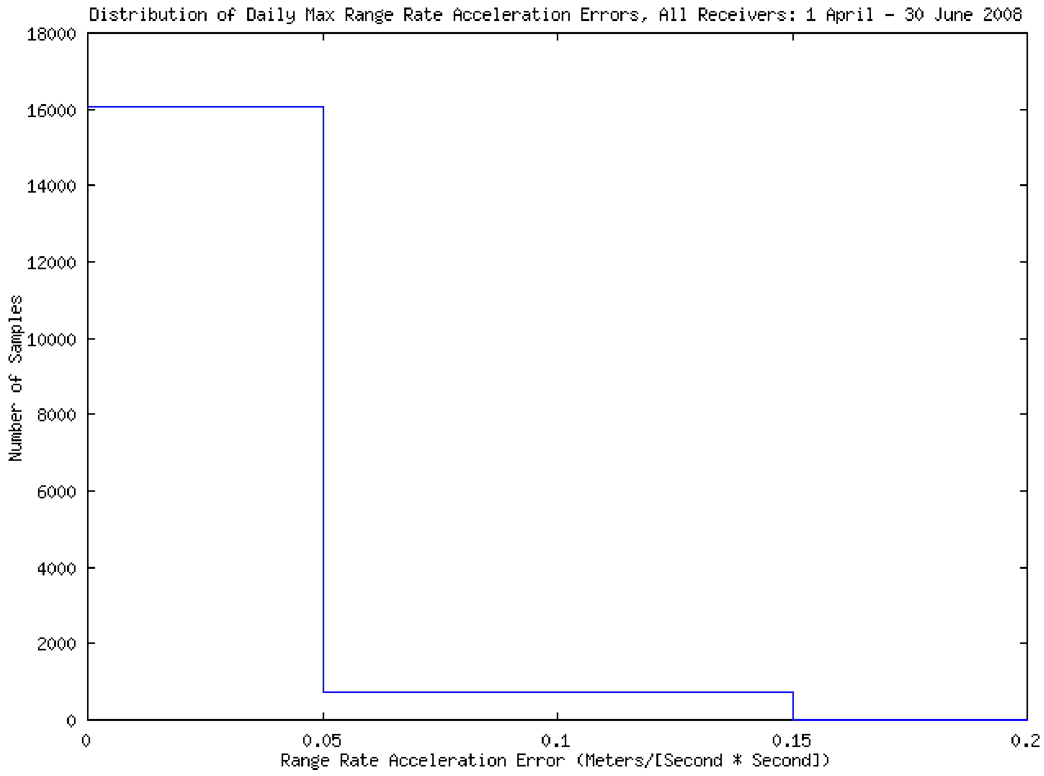
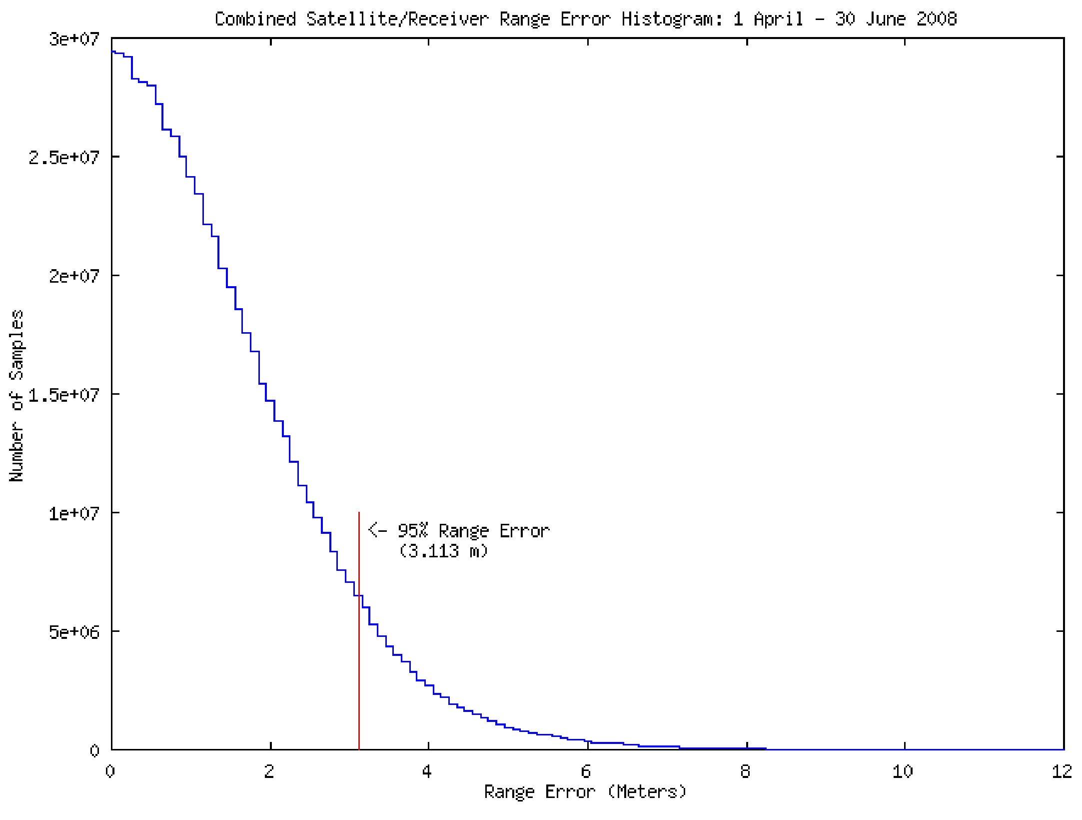


Figure 5-7: Range Error Histogram



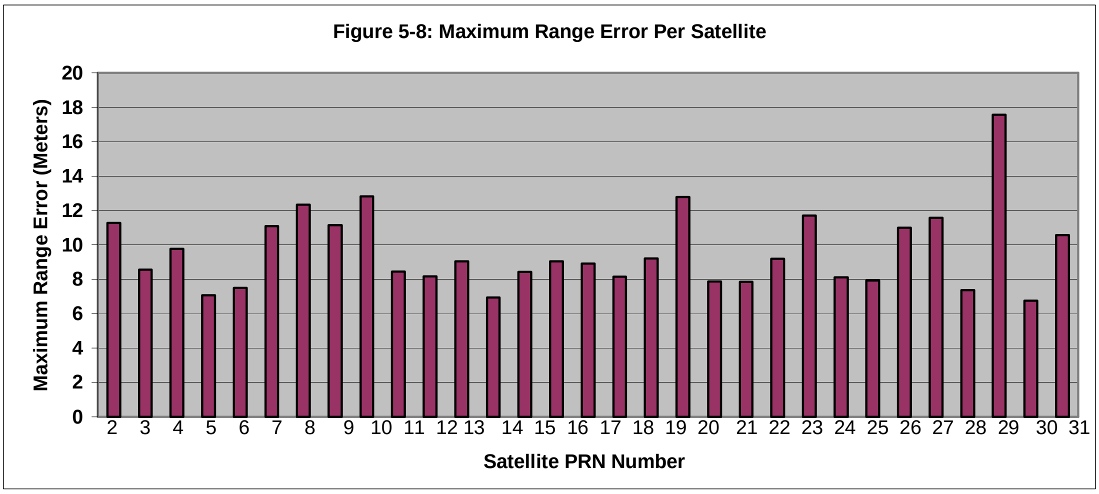


Figure 5-8: Maximum Range Error Per Satellite
Maximum Range Error (Meters)
0
2
4
6
8
10
12
14
16
18
20
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Satellite PRN Number

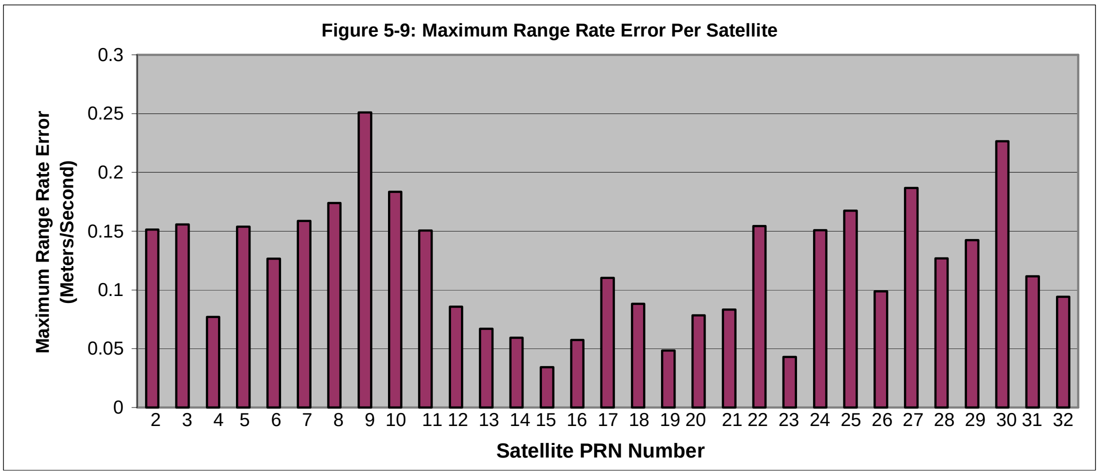


Figure 5-9: Maximum Range Rate Error Per Satellite
Maximum Range Rate Error (Meters/Second)
0
0.05
0.1
0.15
0.2
0.25
0.3
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

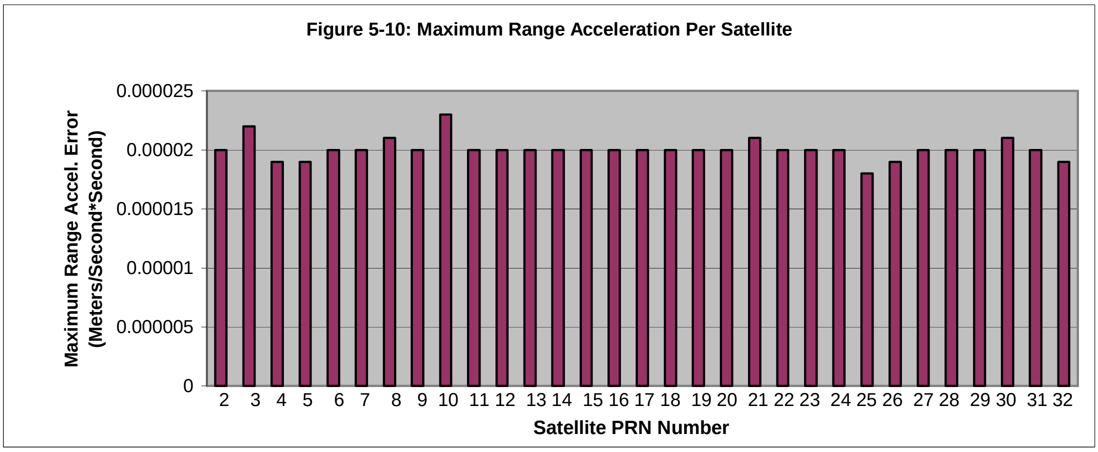


Figure 5-10: Maximum Range Acceleration Per Satellite
Maximum Range Accel. Error (Meters/Second*Second)
0
0.000005
0.00001
0.000015
0.00002
0.000025
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

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 4-6 April 2008

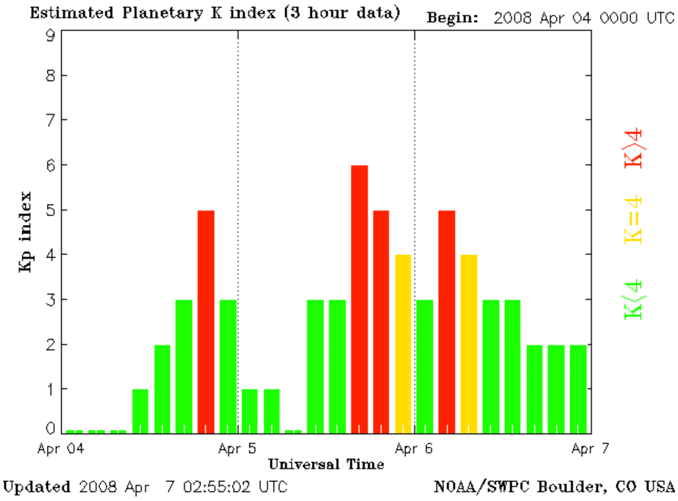


Figure 6-2 K-Index for 22-24 April 2008

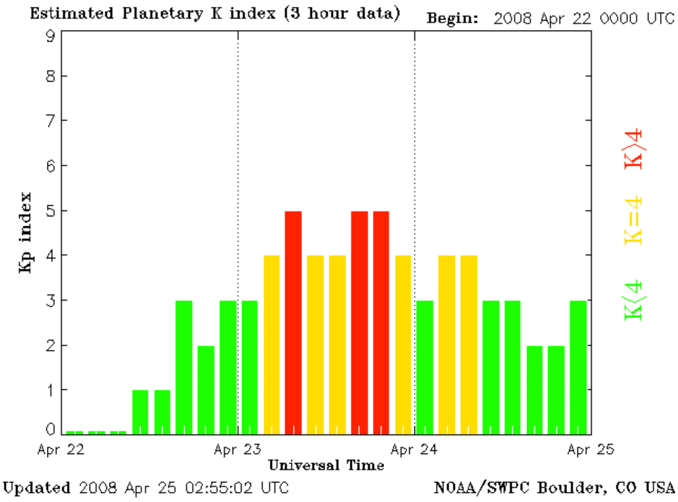
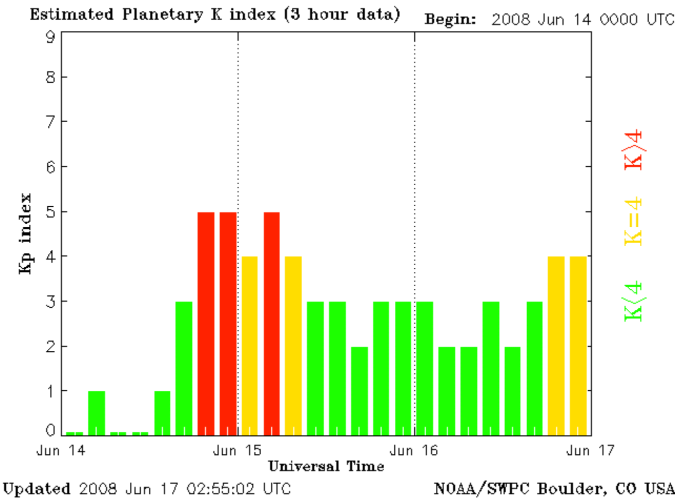


Figure 6-3 K-Index for 14-16 June 2008



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 5 April 2008

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Albuquerque	2.279	4.880	2.945	6.769
Anchorage	2.226	5.337	3.309	7.115
Atlanta	2.173	5.066	2.963	7.064
Barrow	1.982	5.396	2.638	7.006
Bethel	2.046	5.700	2.387	7.664
Billings	2.367	5.506	3.039	6.536
Boston	2.505	4.556	3.302	5.281
Cleveland	2.468	5.231	3.081	5.965
Cold Bay	2.603	5.424	2.943	7.431
Fairbanks	2.133	5.375	3.089	8.446
Gander	2.470	4.181	3.283	5.191
Honolulu	4.646	4.281	6.265	5.570
Houston	2.121	4.882	2.836	7.335
Iqaluit	1.829	4.475	2.415	5.220
Juneau	2.019	5.737	3.422	6.900
Kansas City	2.488	4.671	3.364	6.739
Kotzebue	1.855	5.161	2.786	6.716
Los Angeles	2.221	5.916	2.857	7.327
Merida	2.962	4.088	5.232	5.438
Miami	1.891	4.715	2.199	7.771
Minneapolis	2.310	4.560	3.251	6.146
Oakland	2.315	5.927	2.885	6.629
Salt Lake City	2.542	5.757	3.424	6.894
San Jose Del Cabo	3.252	4.598	3.886	6.208
San Juan	1.810	4.570	2.693	8.387
Seattle	2.492	6.173	3.431	6.658
Tapachula	3.811	3.801	5.892	6.303
Washington, DC	2.463	4.541	3.167	5.911

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	≥ 99.983% ≥ 98.819%
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)	2.278 m 4.606 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)	3.449 m 5.831 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)	15 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	2.310 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
\#

Date	Middle Latitude - Fredericksburg - A	K-indices								High Latitude ---- College ---- A	K-indices								Estimated --- Planetary --- A	K-indices							
2008 04 01	5	2	3	2	0	1	1	1	0	6	1	3	3	2	2	0	0	0	4	1	2	2	0	1	1	1	0
2008 04 02	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
2008 04 03	2	1	1	0	1	1	1	0	0	1	1	1	0	0	0	0	0	0	2	1	1	0	0	0	1	0	0
2008 04 04	8	0	0	0	1	2	3	4	3	10	0	0	0	2	4	4	3	2	11	0	0	0	1	2	3	5	3
2008 04 05	9	1	1	0	2	2	4	2	3	38	2	1	1	6	5	7	3	2	21	1	1	0	3	3	6	5	4
2008 04 06	11	2	4	3	2	2	2	2	2	28	3	3	5	6	5	2	3	1	18	3	5	4	3	3	2	2	2
2008 04 07	9	3	3	2	2	1	2	1	3	13	3	4	2	3	2	3	2	2	12	3	4	2	1	1	3	2	3
2008 04 08	6	1	2	2	2	2	2	1	2	21	2	1	2	6	5	2	2	2	9	1	1	2	3	3	2	2	3
2008 04 09	9	3	2	4	2	2	1	1	1	20	3	2	4	5	5	2	1	1	12	3	3	4	3	2	1	1	2
2008 04 10	-1	-1	-1	-1	-1	-1	-1	-1	-1	12	2	2	3	4	4	2	1	1	8	3	2	2	1	2	1	2	3
2008 04 11	3	1	1	0	1	2	1	1	1	8	1	2	0	4	3	2	0	1	4	2	1	0	2	1	1	0	2
2008 04 12	8	2	3	2	2	2	1	2	2	24	5	2	4	5	5	1	2	1	11	2	4	3	2	3	1	2	2
2008 04 13	6	1	2	1	1	2	2	2	2	11	1	1	3	4	3	3	2	1	7	1	2	1	2	2	3	2	2
2008 04 14	2	1	1	0	0	1	1	0	1	1	2	0	0	0	0	0	0	1	2	1	1	0	0	0	0	1	1
2008 04 15	3	0	0	0	0	2	1	2	2	2	0	0	0	0	1	1	1	2	5	0	0	0	0	2	1	2	3
2008 04 16	9	2	2	3	2	3	2	2	2	17	2	3	4	3	5	3	2	2	15	3	2	4	2	3	3	4	3
2008 04 17	7	3	3	1	1	1	1	2	1	5	2	2	1	2	0	2	2	1	8	3	3	1	1	1	2	2	1
2008 04 18	5	1	3	2	1	1	1	1	1	5	2	2	1	2	2	1	1	1	6	2	3	2	1	1	1	1	1
2008 04 19	6	3	2	1	1	1	1	1	2	4	2	1	2	2	0	1	1	1	5	2	2	1	1	1	1	1	2
2008 04 20	1	1	0	0	0	0	1	1	0	3	2	0	0	1	1	2	1	0	4	2	0	0	0	1	2	1	2
2008 04 21	3	1	2	1	1	1	1	0	0	3	2	2	1	2	0	1	0	0	4	1	2	1	1	0	1	1	1
2008 04 22	4	0	0	0	0	1	2	2	3	2	0	0	0	1	0	1	1	2	5	0	0	0	1	1	3	2	3
2008 04 23	17	2	3	4	3	3	4	3	3	51	3	4	6	6	6	6	4	3	32	3	4	5	4	4	5	5	4
2008 04 24	13	3	3	4	2	2	2	2	3	30	4	3	5	5	6	2	2	2	18	3	4	4	3	3	2	2	3
2008 04 25	7	3	2	2	2	2	1	2	1	10	2	3	3	3	3	1	1	1	8	3	3	2	2	1	2	2	2
2008 04 26	5	2	1	2	1	1	1	2	2	17	2	2	3	5	3	4	2	2	10	2	2	2	3	2	3	3	2
2008 04 27	7	2	2	3	2	1	1	1	2	12	1	2	3	5	2	3	1	0	10	2	3	3	2	1	3	2	2
2008 04 28	9	1	1	2	3	1	2	3	3	-1	2	0	4	4	-1	-1	2	1	11	2	1	2	3	3	3	3	3
2008 04 29	4	3	2	1	0	1	0	1	0	3	2	2	1	0	1	0	0	0	8	3	3	1	1	1	3	2	1
2008 04 30	4	0	1	0	1	1	2	3	1	5	0	0	0	2	1	3	3	1	8	1	0	0	1	1	3	4	2
2008 05 01	6	0	1	1	1	1	1	3	3	8	1	2	2	1	0	2	2	4	9	0	1	2	0	1	3	3	4
2008 05 02	7	4	3	2	1	1	0	0	1	13	3	3	3	2	5	1	0	1	12	4	4	3	0	3	2	0	2
2008 05 03	9	3	2	2	2	2	2	3	2	13	2	2	2	3	5	2	2	2	12	3	3	2	3	3	2	3	2
2008 05 04	6	0	2	2	2	2	2	2	2	9	1	2	3	4	2	1	1	2	8	1	2	3	3	1	2	2	2
2008 05 05	8	2	2	3	0	2	2	3	2	12	3	2	3	1	3	4	2	2	11	2	2	3	0	2	3	3	2
2008 05 06	9	4	2	3	2	1	1	1	1	8	2	2	3	4	2	0	0	1	10	4	3	3	2	1	1	1	1
2008 05 07	5	2	1	0	0	1	2	3	2	3	3	1	1	0	0	0	1	1	4	2	1	0	0	1	2	2	2
2008 05 08	3	1	1	2	1	1	0	1	0	4	2	1	2	2	1	0	1	0	4	2	1	2	2	1	0	1	1
2008 05 09	3	1	1	1	1	1	0	1	1	1	1	0	1	1	0	0	0	0	3	1	1	1	1	1	1	0	1
2008 05 10	4	1	2	1	1	1	0	1	2	4	1	1	2	2	0	0	1	2	5	1	2	1	1	1	1	1	2
2008 05 11	3	1	1	1	1	1	0	2	0	2	1	1	0	1	0	0	1	0	3	2	1	0	0	1	1	2	1
2008 05 12	3	1	0	1	1	0	1	1	2	2	1	1	0	1	0	0	1	1	4	1	0	1	0	1	1	1	2
2008 05 13	3	2	2	0	0	1	1	1	0	2	1	2	0	0	1	1	1	0	4	2	2	0	0	1	2	1	1
2008 05 14	1	0	1	0	0	1	1	0	0	1	0	1	0	0	0	0	1	0	3	1	1	0	0	1	0	1	1
2008 05 15	2	0	1	0	1	1	1	1	1	2	0	2	0	1	0	0	1	1	4	0	1	1	0	1	1	1	2
2008 05 16	3	1	0	0	1	1	2	1	1	4	2	1	0	1	3	1	1	1	4	2	1	1	1	2	1	1	1
2008 05 17	1	1	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	2	1	0	0	0	1	1	0	1
2008 05 18	2	0	1	0	1	2	0	1	0	2	1	1	0	1	1	0	0	0	3	1	1	0	1	2	1	0	1
2008 05 19	5	2	1	2	2	2	1	1	1	12	3	1	2	4	4	2	1	1	8	3	2	1	3	2	2	1	1
2008 05 20	7	1	2	3	0	2	2	2	2	11	2	4	2	2	4	2	1	1	10	2	2	3	1	2	3	2	3
2008 05 21	9	3	3	2	2	2	2	2	2	19	3	5	3	5	2	3	1	1	13	3	4	3	3	2	2	1	3
2008 05 22	7	2	1	1	1	2	2	3	2	8	3	3	1	1	2	2	2	2	9	3	2	1	1	2	3	3	3
2008 05 23	7	2	2	0	1	2	2	3	2	12	2	1	0	3	5	2	2	2	10	2	2	0	1	3	2	3	3
2008 05 24	4	2	0	1	1	2	1	1	2	15	3	1	3	4	5	2	0	1	7	3	1	1	2	2	2	1	2
2008 05 25	7	3	2	2	1	2	1	1	2	4	1	2	2	2	1	1	1	0	6	3	3	2	1	1	1	1	1
2008 05 26	3	1	1	1	1	1	0	1	1	3	1	1	2	2	0	0	0	0	4	1	1	1	2	1	0	1	1
2008 05 27	2	0	1	1	0	0	1	1	2	3	0	1	1	1	2	1	0	1	3	1	0	1	0	0	1	1	2
2008 05 28	10	3	2	3	2	3	2	1	2	21	3	2	3	3	6	4	1	1	12	3	2	3	2	3	3	2	3

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

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 (Ωk) and Geographic Longitude of the Ascending Node (GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the ascending node, both at arbitrary time T_k.

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

Equatorial Angle: An angle along the equator in the direction of Earth rotation.

Geometric Range: The difference between the estimated locations of a GPS satellite and an SPS receiver.

Ground track Equatorial Crossing (GEC, λ, 2 SOPS GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the location a ground track intersects the equator when crossing from the Southern to the Northern hemisphere. GEC is equal to Ωk when the argument of latitude (Φ) is zero.

Instantaneous User Range Error (URE): The difference between the pseudo range measured at a given location and the expected pseudo range, as derived from the navigation message and the true user position, neglecting the bias in receiver clock relative to GPS time. A signal-in-space (SIS) URE includes residual orbit, satellite clock, and group delay errors. A system URE (sometimes known as a User Equivalent Range Error, or UERE) contains all line-of-sight error sources, to include SIS, single-frequency ionosphere model error, troposphere model error, multipath and receiver noise.

Longitude of Ascending Node (LAN): A general term for the location of the ascending node – the point that an orbit intersects the equator when crossing from the Southern to the Northern hemisphere.

Longitude of the Ground track Equatorial Crossing (GEC, λ, 2 SOPS GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the location a ground track intersects the equator when crossing from the Southern to the Northern hemisphere. GEC is equal to Ωk when the argument of latitude (Φ) is zero.

Mean Down Time (MDT): A measure of time required to restore function after any downing event.

Mean Time Between Downing Events (MTBDE): A measure of time between any downing events.

Mean Time Between Failures (MTBF): A measure of time between unscheduled downing events.

Mean Time to Restore (MTTR): A measure of time required to restore function after an unscheduled downing event.

Navigation Message: Data contained in each satellite's ranging signal and consisting of the ranging signal time-of-transmission, the transmitting satellite's orbital elements, an almanac containing abbreviated orbital element information to support satellite selection, ranging measurement correction information, and status flags. The message structure is described in Section 2.1.2 of the SPS Performance Standard.

Operational Satellite: A GPS satellite which is capable of, but is not necessarily transmitting a usable ranging signal.

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

Positioning Accuracy: Defined to be the statistical difference, at a 95% probability, between position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

- **Horizontal Positioning Accuracy:** Defined to be the statistical difference, at a 95% probability, between horizontal position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.
- **Vertical Positioning Accuracy:** Defined to be the statistical difference, at a 95% probability, between vertical position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

Position Solution: An estimate of a user’s location derived from ranging signal measurements and navigation data from GPS.

Position Solution Geometry: The set of direction cosines that define the instantaneous relationship of each satellite's ranging signal vector to each of the position solution coordinate axes.

Pseudo Random Noise (PRN): A binary sequence that appears to be random over a specified time interval unless the shift register configuration and initial conditions for generating the sequence are known. Each satellite generates a unique PRN sequence that is effectively uncorrelated (orthogonal) to any other satellite’s code over the integration time constant of a receiver’s code tracking loop.

Representative SPS Receiver: The minimum signal reception and processing assumptions employed by the U.S. Government to characterize SPS performance in accordance with performance standards defined in Section 3 of the SPS Performance Standard. Representative SPS receiver capability assumptions are identified in Section 2.2 of the SPS Performance Standard.

Right Ascension of Ascending Node (RAAN): Equatorial angle from the celestial principal direction to the ascending node.

Root Mean Square (RMS) SIS URE: A statistic that represents instantaneous SIS URE performance in an RMS sense over some sample interval. The statistic can be for an individual satellite or for the entire constellation. The sample interval for URE assessment used in the SPS Performance Standard is 24 hours.

Selective Availability: Protection technique formerly employed to deny full system accuracy to unauthorized users. SA was discontinued effective midnight May 1, 2000.

Service Availability: Defined to be the percentage of time over any 24-hour interval that the predicted 95% positioning error is less than its threshold for any given point within the service volume.

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

Service Degradation: A condition over a time interval during which one or more SPS performance standards are not supported.

Service Failure: A condition over a time interval during which a healthy GPS satellite's ranging signal exceeds the Not-to-Exceed (NTE) SPS SIS URE tolerance.

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

Service Volume: The spatial volume supported by SPS performance standards. Specifically, the SPS Performance Standard supports the terrestrial service volume. The terrestrial service volume covers from the surface of the Earth up to an altitude of 3,000 kilometers.

SPS Performance Envelope: The range of nominal variation in specified aspects of SPS performance.

SPS Performance Standard: A quantifiable minimum level for a specified aspect of GPS SPS performance. SPS performance standards are defined in Section 3.0.

SPS Ranging Signal: An electromagnetic signal originating from an operational satellite. The SPS ranging signal consists of a Pseudo Random Noise (PRN) C/A code, a timing reference and sufficient data to support the position solution generation process. A description of the GPS SPS signal is provided in Section 2. The formal definition of the SPS ranging signal is provided in ICDGPS-200C.

SPS Ranging Signal Measurement: The difference between the ranging signal time of reception (as determined by the receiver's clock) and the time of transmission derived from the navigation signal (as defined by the satellite's clock) multiplied by the speed of light. Also known as the *pseudo range*.

SPS SIS User Range Error (URE) Statistic:

- A satellite SPS SIS URE statistic is defined to be the Root Mean Square (RMS) difference between SPS ranging signal measurements (neglecting user clock bias and errors due to propagation environment and receiver), and "true" ranges between the satellite and an SPS user at any point within the service volume over a specified time interval.
- A constellation SPS SIS URE statistic is defined to be the average of all satellite SPS SIS URE statistics over a specified time interval.

Time Transfer Accuracy Relative to UTC (USNO): The difference at a 95% probability between user UTC time estimates and UTC (USNO) at any point within the service volume over any 24-hour interval.

Transient Behavior: Short-term behavior not consistent with steady-state expectations.

Usable SPS Ranging Signal: An SPS ranging signal that can be received, processed, and used in a position solution by a receiver with representative SPS receiver capabilities.

User Navigation Error (UNE): Given a sufficiently stationary and ergodic satellite constellation ranging error behavior over a minimum sample interval, multiplication of the DOP and a constellation ranging error standard deviation value will yield an approximation of the RMS position error. This RMS approximation is known as the UNE (UHNE for horizontal, UVNE for vertical, and so on). The user is cautioned that any divergence away from the stationary and ergodic assumptions will cause the UNE to diverge from a RMS value based on actual measurements.

User Range Accuracy (URA): A conservative representation of each satellite's expected (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.