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

Submitted To

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GPS Product Team
AND 730
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Submitted by

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EXECUTIVE SUMMARY

The GPS Product Team (AND 730) has tasked the Navigation Branch (ACB 430) 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-four 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 #54, includes data collected from 1 July through 30 September 2006. 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 availability based on PDOP less than six for the CONUS was 99.963% 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 2006. 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 fifteen outages were reported in the NANU's this quarter. Eight outages were scheduled while seven 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. All of the satellites met the URE and service reliability specifications. The maximum range error recorded was 18.972 meters on Satellite PRN 3. The SPS specification states that the range error should never exceed 30 meters. The maximum 24-hour RMS range error value of 2.1099 was recorded on satellite 28. 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 2006, the GPS performance meet all SPS requirements that were evaluated.

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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-four 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
- Mauna Loa, HI
- Bangor, ME
- 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 ACB 430. 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 ACB 430 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 3.65933 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%)
2 – 8 July	3.64961	99.963	99.167
9 – 15 July	3.65933	99.963	99.167
16 – 22 July	3.01357	99.996	99.236
23 – 29 July	3.00537	99.996	99.236
30 July – 5 Aug	3.01388	99.996	99.306
6 – 12 Aug	3.02358	99.995	99.306
13 – 19 Aug	3.01927	99.995	99.375
20 – 26 Aug	3.11934	99.994	99.306
27 Aug – 2 Sep	3.47483	99.988	99.236
3 – 9 Sep	3.47259	99.989	99.306
10 – 16 Sep	3.47182	99.993	99.306
17 – 23 Sep	3.11833	99.995	99.444
24 – 30 Sep	3.13516	99.996	99.583

Figure 2-1 PDOP Availability Plot (24-Hour Period: 10 July 2006)

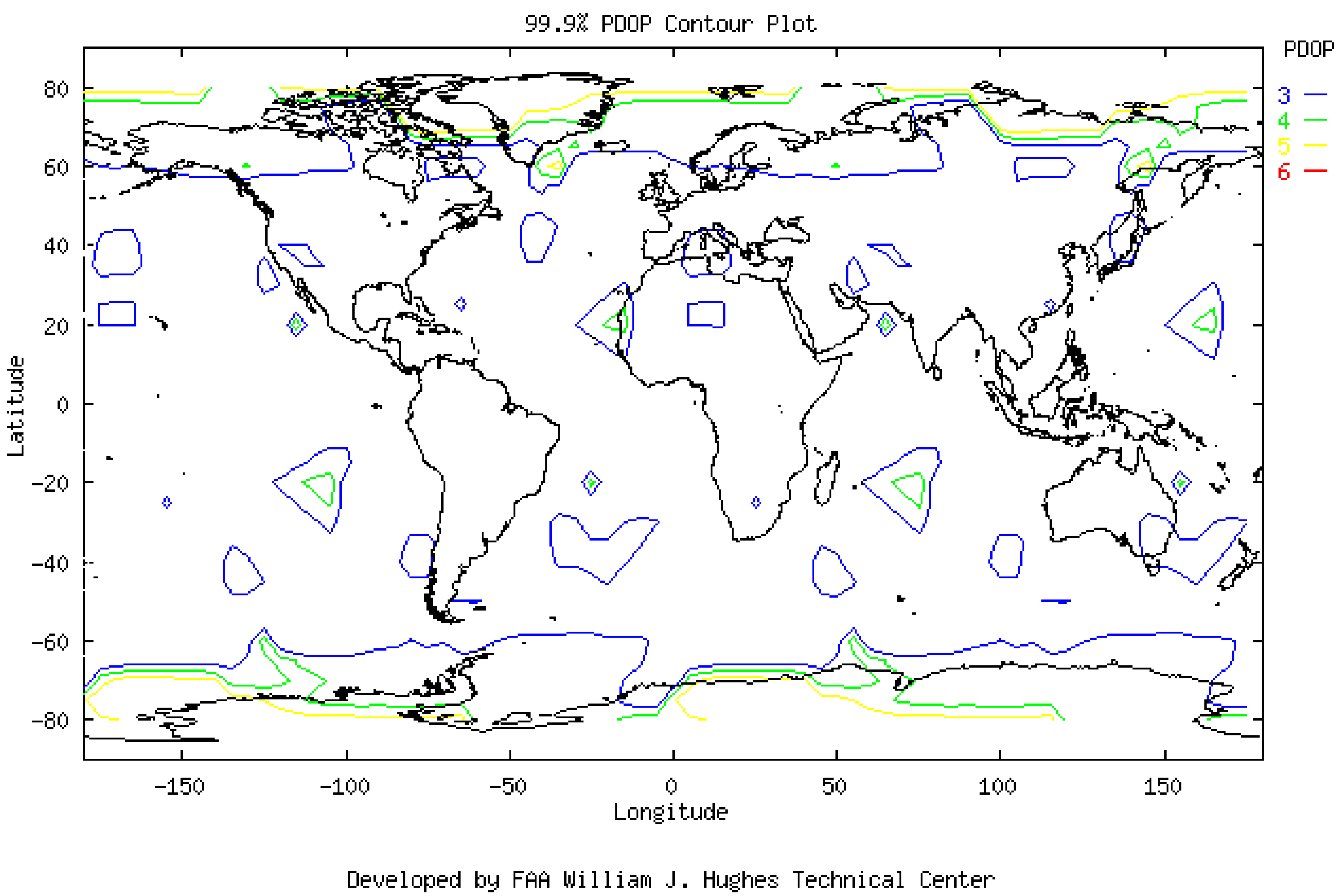
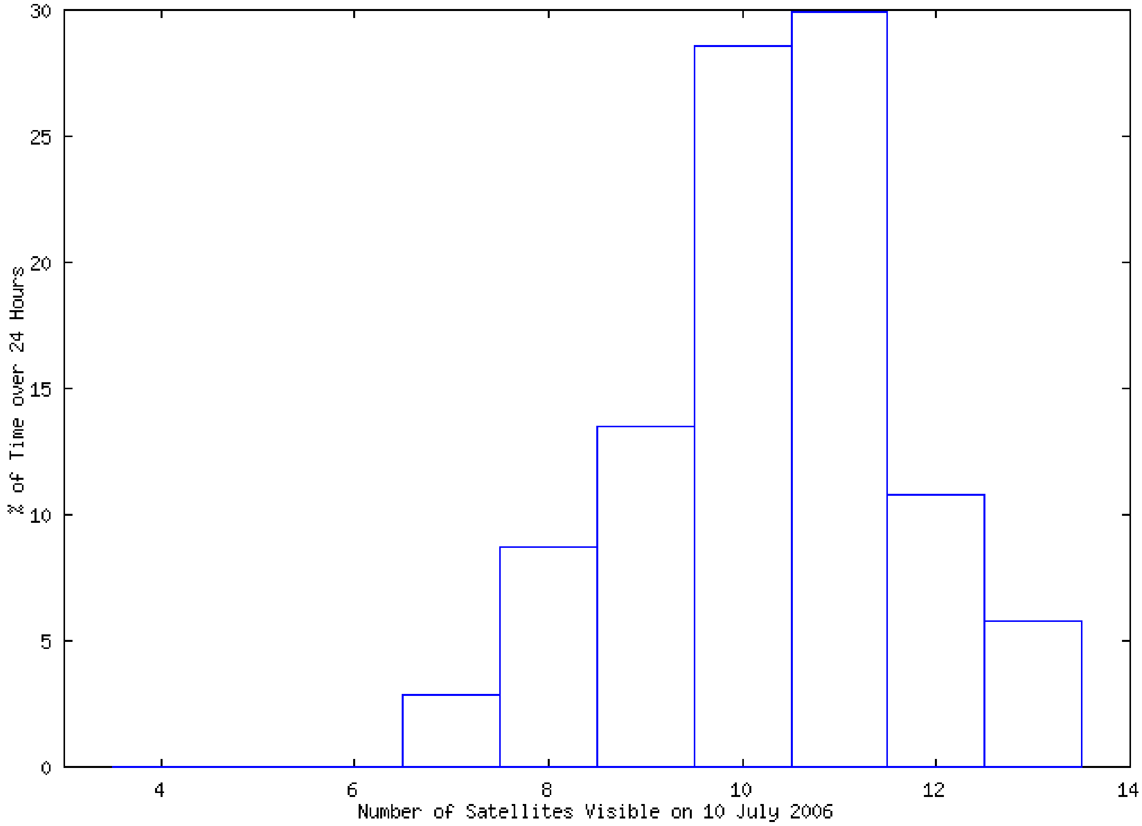


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lat: 75, Lon: -75)



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 2006, there were a total of twelve reported outages. Eight 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
62	6	UNUSABLE	1-Jul	0:00	17-Jul	16:48	400.8		400.80
63	3	FCSTSUMM	17-Jul	16:15	17-Jul	19:57		3.70	3.70
67	25	FCSTSUMM	4-Aug	14:34	4-Aug	16:55		2.35	2.35
70	8	FCSTSUMM	5-Aug	19:08	5-Aug	19:57		0.81	0.81
71	3	UNUSABLE	1-Aug	20:34	7-Aug	19:44	143.16		143.16
77	5	FCSTSUMM	15-Aug	3:12	15-Aug	8:36		5.40	5.40
78	29	FCSTSUMM	18-Aug	0:51	18-Aug	4:07		3.26	3.26
85	18	UNUSABLE	5-Sep	0:52	5-Sep	5:35	4.71		4.71
86	3	UNUSABLE	24-Aug	15:02	8-Sep	19:04	340.03		340.03
90	17	FCSTSUMM	12-Sep	16:33	12-Sep	17:59		1.43	1.43
91	25	FCSTSUMM	14-Sep	11:15	14-Sep	21:44		10.48	10.48
92	29	UNUSABLE	26-Aug	1:47	14-Sep	22:31	476.73		476.73
94	24	FCSTSUMM	21-Sep	23:38	22-Sep	18:30		18.86	18.86
96	24	UNUSABLE	22-Sep	20:15	24-Sep	0:56	25.68		25.68
??	15	UNUSABLE	21-Aug	13:58	1-Oct	0:00	970.03		970.03
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**2361.14**	**46.29**	**2407.43**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
59	6	UNUSUFN	29-Jun	11:05	N/A	N/A	N/A	See NANU 62
61	3	FCSTMX	17-Jul	16:00	17-Jul	22:30	6.5	See NANU 63
64	8	FCSTMX	5-Aug	17:30	6-Aug	4:30	11	See NANU 70
65	25	FCSTMX	4-Aug	14:00	4-Aug	19:00	5	See NANU 67
66	3	UNUSUFN	1-Aug	20:34	N/A	N/A	N/A	See NANU 71
68	15	DCSTDV	10-Aug	1:00	10-Aug	21:00	CANC	See NANU 73
72	5	FCSTDV	15-Aug	2:45	15-Aug	13:00	10.25	See NANU 77
74	29	FCSTMX	18-Aug	0:30	18-Aug	9:00	8.5	See NANU 78
75	15	FCSTDV	16-Aug	21:45	17-Aug	21:45	CANC	See NANU 76
79	15	UNUSUFN	21-Aug	13:58	N/A	N/A	N/A	See NANU ??
80	27	FCSTMX	29-Aug	14:30	30-Aug	2:30	12	See NANU 83
81	3	UNUSUFN	24-Aug	15:02	N/A	N/A	N/A	See NANU 86
82	29	UNUSUFN	26-Aug	1:47	N/A	N/A	N/A	See NANU 92
84	18	UNUSUFN	5-Sep	0:52	N/A	N/A	N/A	See NANU 85
87	25	FCSTDV	14-Sep	11:15	14-Sep	23:15	12	See NANU 91
88	17	FCSTMX	12-Sep	16:15	13-Sep	0:15	8	See NANU 90
93	24	FCSTDV	21-Sep	22:00	22-Sep	22:00	24	See NANU 94
95	24	UNUSUFN	22-Sep	20:15	N/A	N/A	N/A	See NANU 96
					Total Forecast Downtime		**97.25**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
73	15	FCSTCANC	10-Aug	1:00	See NANU 68
76	15	FCSTCANC	16-Aug	21:45	See NANU 75
83	27	FCSTCANC	29-Aug	14:30	See NANU 80

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 July - 30 Sep. 2006**	**1 October, 1999- 30 Sep. 2006**
Total Forecast Downtime (hrs):	97.25	5899.98
Total Actual Downtime (hrs):	2407.43	21078.16
Total Actual Scheduled Downtime (hrs):	46.29	3198.41
Total Actual Unscheduled Downtime (hrs):	2361.14	17879.75
Total Satellite Observed MTTR (hrs):	160.50	47.05
Scheduled Satellite Observed MTTR (hrs):	5.79	10.12
Unscheduled Satellite Observed MTTR (hrs):	337.31	135.45
# Total Satellite Outages:	15	448
# Scheduled Satellite Outages:	8	316
# Unscheduled Satellite Outages:	7	132
Percent Operational -- Scheduled Downtime:	99.93	99.81
Percent Operational -- All Downtime:	99.86	98.74

NANU 69 corrected the "Type" of NANU 68
NANU 89 announced turning on of dataless M-code.
NANU 97 announced the launch of PRN 31.

3.2 Service Availability Standard

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

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

Service Availability Standard	Conditions and Constraints
≥ 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-four 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 2006.

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	6423264	0	100%
Albuquerque	7877989	0	100%
Anchorage	7904100	0	100%
Boston	7821362	0	100%
Washington, DC	7331102	0	100%
Honolulu	7820165	0	100%
Houston	6332240	0	100%
Kansas City	7357020	0	100%
Los Angeles	7837742	0	100%
Salt Lake City	7908695	0	100%
Miami	7845075	0	100%
Minneapolis	7892382	0	100%
Oakland	7912441	0	100%
Cleveland	7879105	0	100%
Seattle	7845900	0	100%
San Juan	7912763	0	100%
Atlanta	7909553	0	100%
Juneau	7837595	0	100%
Cold Bay	7880296	0	100%
Fairbanks	7820737	0	100%
Bethel	7672565	0	100%
Kotzebue	7491558	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 18.972 meters on satellite PRN 3.

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 Sep 2006	**Boston**	57864077	0	100%
1 July – 30 Sep 2006	**Honolulu**	59392621	0	100%
1 July – 30 Sep 2006	**Los Angeles**	61147359	0	100%
1 July – 30 Sep 2006	**Miami**	60632903	0	100%
1 July – 30 Sep 2006	**San Juan**	62824963	0	100%
1 July – 30 Sep 2006	**Juneau**	59761144	0	100%
1 July – 30 Sep 2006	**Global**	361,623,067	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 2006 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	2.341	4.045	7.095	8.067
Albuquerque	2.461	4.005	5.287	8.945
Anchorage	2.263	4.268	10.753	10.426
Boston	2.466	4.237	6.14	12.486
Washington, DC	2.54	4.577	12.697	12.877
Honolulu	3.854	4.764	7.494	10.641
Houston	2.582	4.471	5.498	9.48
Kansas City	2.518	4.527	21.809	11.218
Los Angeles	2.53	4.31	4.973	9.784
Salt Lake City	2.466	4.266	5.687	10.556
Miami	2.74	4.602	5.475	11.094
Minneapolis	2.443	4.245	18.433	12.594
Oakland	2.521	4.491	5.801	9.272
Cleveland	2.549	4.435	14.527	12.598
Seattle	2.525	4.237	6.727	10.563
San Juan	2.905	4.47	9.763	12.603
Atlanta	2.489	4.284	16.583	11.676
Juneau	2.265	3.946	4.971	8.471
Cold Bay	2.414	4.315	8.165	10.956
Fairbanks	2.113	4.135	9.575	10.472
Bethel	2.199	4.078	7.682	10.019
Kotzebue	2.105	4.272	6.556q	11.405

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-four WAAS sites from 1 July to 30 September 2006.

Figure 5-1 Global Vertical Error Histogram

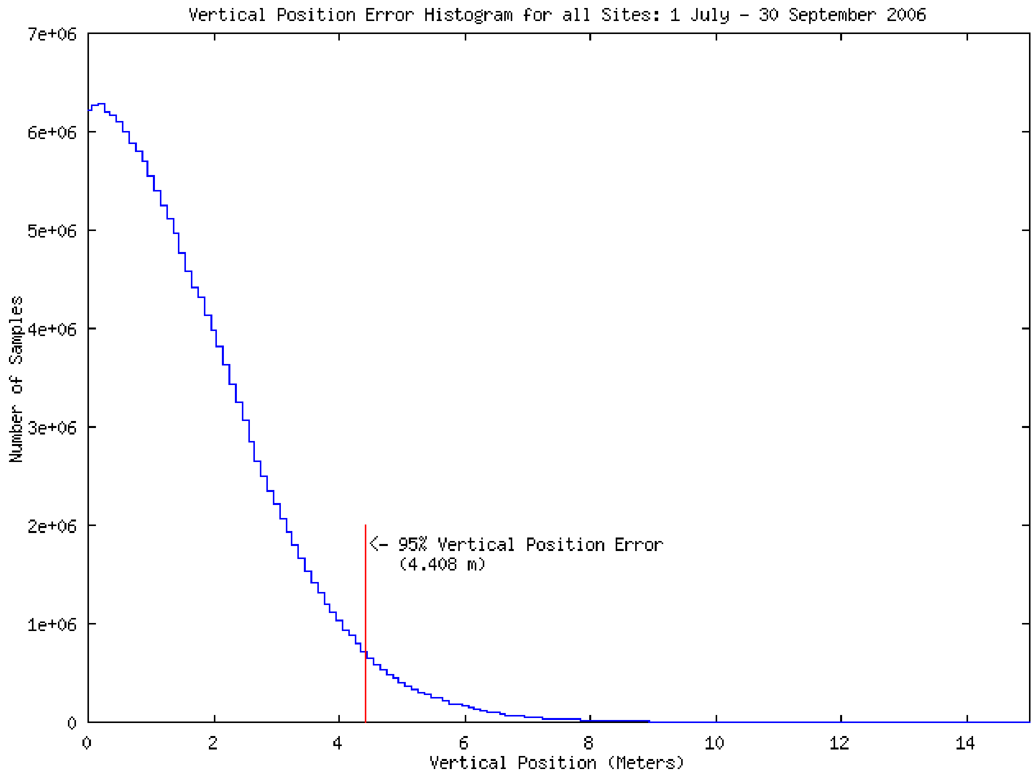
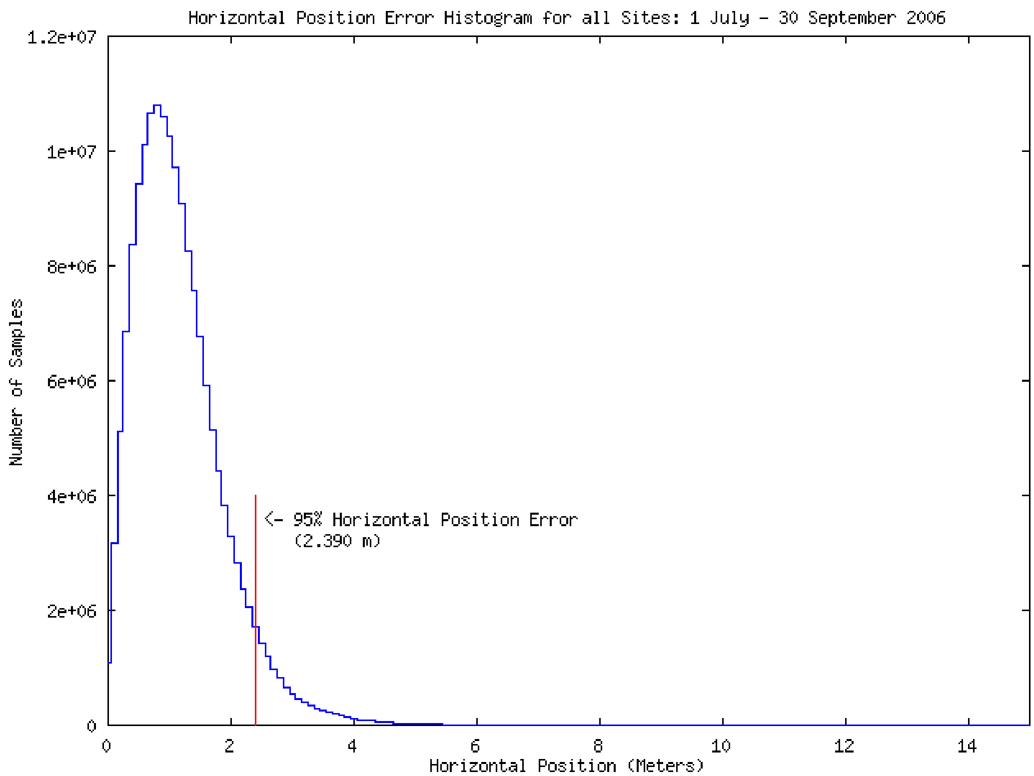


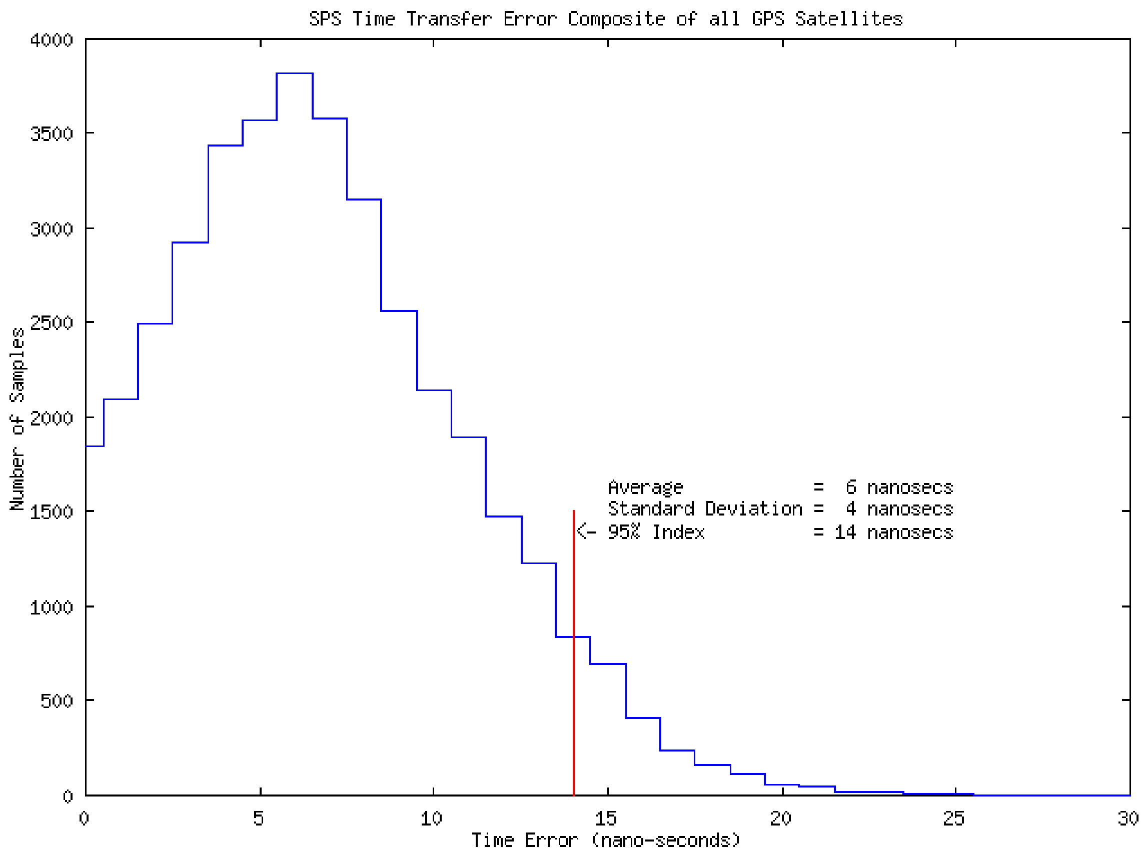
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 July and 30 September 2006 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 2006. 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	Range Error Mean	RMS Range Error (≤ 6 m)	1s	95% Range Error	Max Range Error (SPS Spec. ≤ 30 m)	Samples
1	0.1253	1.9762	1.4568	3.5846	14.342	12439438
2	0.6714	1.5943	1.2567	2.9962	11.234	14003189
3	0.2781	1.9298	1.4595	3.5183	18.972	9303513
4	0.1718	1.5978	1.2653	3.0187	9.359	13801041
5	0.5590	1.6220	1.3131	3.0351	10.233	13947260
6	0.5464	1.6451	1.3102	3.0342	11.329	11086846
7	0.7700	1.7282	1.3341	3.1726	12.987	12894984
8	0.3284	2.0202	1.5660	3.8341	10.964	12685240
9	-0.0187	1.7713	1.3298	3.2141	9.753	12723461
10	0.9282	2.0539	1.4618	3.6100	10.292	13535575
11	0.3717	1.6056	1.3444	2.9909	8.192	12068153
13	-0.3647	1.5188	1.2735	2.9353	11.100	13390144
14	0.4727	1.5054	1.2052	2.8215	14.647	13688985
15	0.1030	1.8641	1.4524	3.4034	8.392	6991667
16	0.3093	1.5708	1.3329	2.9421	11.776	12817666
17	-0.1030	1.7638	1.4946	3.4012	12.291	14018102
18	0.6869	1.5435	1.1138	2.8042	6.917	12883765
19	0.7691	1.7145	1.2957	3.1247	13.608	12580456
20	0.6311	1.5120	1.2488	2.9169	8.786	13585765
21	0.6893	1.5088	1.1049	2.7361	7.765	11815916
22	0.7682	1.7004	1.2100	3.0957	12.147	12358287
23	0.1875	1.5053	1.2736	2.8368	11.331	12582657
24	0.4886	1.8614	1.4154	3.5253	11.850	12996288
25	0.1363	1.9547	1.4572	3.5773	14.004	13894372
26	0.2320	1.5573	1.3077	2.9214	9.395	12174660
27	0.0775	1.9862	1.5926	3.6668	12.199	12310087
28	0.5270	2.1099	1.6223	3.9055	11.496	12326985
29	0.2174	1.6641	1.3904	3.1037	14.992	9680087
30	-0.2407	1.7499	1.4545	3.3130	10.087	13038478

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

PRN	Range Rate Error Mean	Range Rate Error RMS	Range Rate Error 1s	95% Range Rate Error	Max Range Rate Error	Samples
1	0.00005	0.0026	0.0025	0.0038	0.2199	12439438
2	-0.00005	0.0018	0.0018	0.0036	0.1480	14003189
3	-0.00004	0.0024	0.0024	0.0036	0.4795	9303513
4	-0.00003	0.0019	0.0019	0.0035	0.1322	13801041
5	0.00001	0.0019	0.0019	0.0035	0.1398	13947260
6	0.00000	0.0019	0.0019	0.0036	0.1440	11086846
7	-0.00001	0.0019	0.0019	0.0036	0.1043	12894984
8	-0.00003	0.0023	0.0023	0.0040	0.1501	12685240
9	0.00003	0.0023	0.0023	0.0041	0.1706	12723461
10	0.00001	0.0022	0.0022	0.0037	0.1747	13535575
11	-0.00002	0.0020	0.0020	0.0038	0.0877	12068153
13	0.00005	0.0019	0.0018	0.0036	0.0676	13390144
14	0.00002	0.0019	0.0019	0.0036	0.1531	13688985
15	0.00006	0.0026	0.0026	0.0037	0.1917	6991667
16	-0.00002	0.0020	0.0020	0.0038	0.0567	12817666
17	-0.00003	0.0021	0.0021	0.0036	0.1721	14018102
18	-0.00003	0.0019	0.0019	0.0036	0.1034	12883765
19	-0.00001	0.0020	0.0020	0.0038	0.0999	12580456
20	0.00003	0.0018	0.0018	0.0035	0.0431	13585765
21	0.00001	0.0019	0.0019	0.0038	0.0414	11815916
22	0.00000	0.0021	0.0020	0.0037	0.1412	12358287
23	0.00003	0.0019	0.0019	0.0036	0.0503	12582657
24	-0.00002	0.0022	0.0022	0.0039	0.1562	12996288
25	0.00001	0.0025	0.0025	0.0034	0.2264	13894372
26	-0.00003	0.0019	0.0019	0.0036	0.1327	12174660
27	0.00005	0.0022	0.0022	0.0040	0.1805	12310087
28	-0.00002	0.0024	0.0024	0.0038	0.1407	12326985
29	0.00003	0.0022	0.0022	0.0037	0.2350	9680087
30	-0.00004	0.0024	0.0024	0.0041	0.1811	13038478

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1s	Max Range Acceleration Error	Samples
1	0	0.00002	0.00002	0.0022	12439438
2	0	0.00001	0.00001	0.0015	14003189
3	0	0.00002	0.00002	0.0048	9303513
4	0	0.00001	0.00001	0.0013	13801041
5	0	0.00001	0.00001	0.0014	13947260
6	0	0.00002	0.00002	0.0014	11086846
7	0	0.00001	0.00001	0.0011	12894984
8	0	0.00002	0.00002	0.0015	12685240
9	0	0.00002	0.00002	0.0017	12723461
10	0	0.00002	0.00002	0.0018	13535575
11	0	0.00002	0.00002	0.0009	12068153
13	0	0.00001	0.00001	0.0007	13390144
14	0	0.00001	0.00001	0.0015	13688985
15	0	0.00002	0.00002	0.0019	6991667
16	0	0.00001	0.00001	0.0006	12817666
17	0	0.00002	0.00002	0.0017	14018102
18	0	0.00001	0.00001	0.0010	12883765
19	0	0.00002	0.00002	0.0010	12580456
20	0	0.00001	0.00001	0.0004	13585765
21	0	0.00002	0.00002	0.0004	11815916
22	0	0.00002	0.00002	0.0014	12358287
23	0	0.00001	0.00001	0.0005	12582657
24	0	0.00002	0.00002	0.0016	12996288
25	0	0.00002	0.00002	0.0023	13894372
26	0	0.00001	0.00001	0.0013	12174660
27	0	0.00002	0.00002	0.0018	12310087
28	0	0.00002	0.00002	0.0014	12326985
29	0	0.00002	0.00002	0.0024	9680087
30	0	0.00002	0.00002	0.0018	13038478

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 3 with an error of 18.972 meters. Satellite 18 had the lowest maximum range error of 6.917 meters.

Figure 5-4 Distribution of Daily Max Range Errors

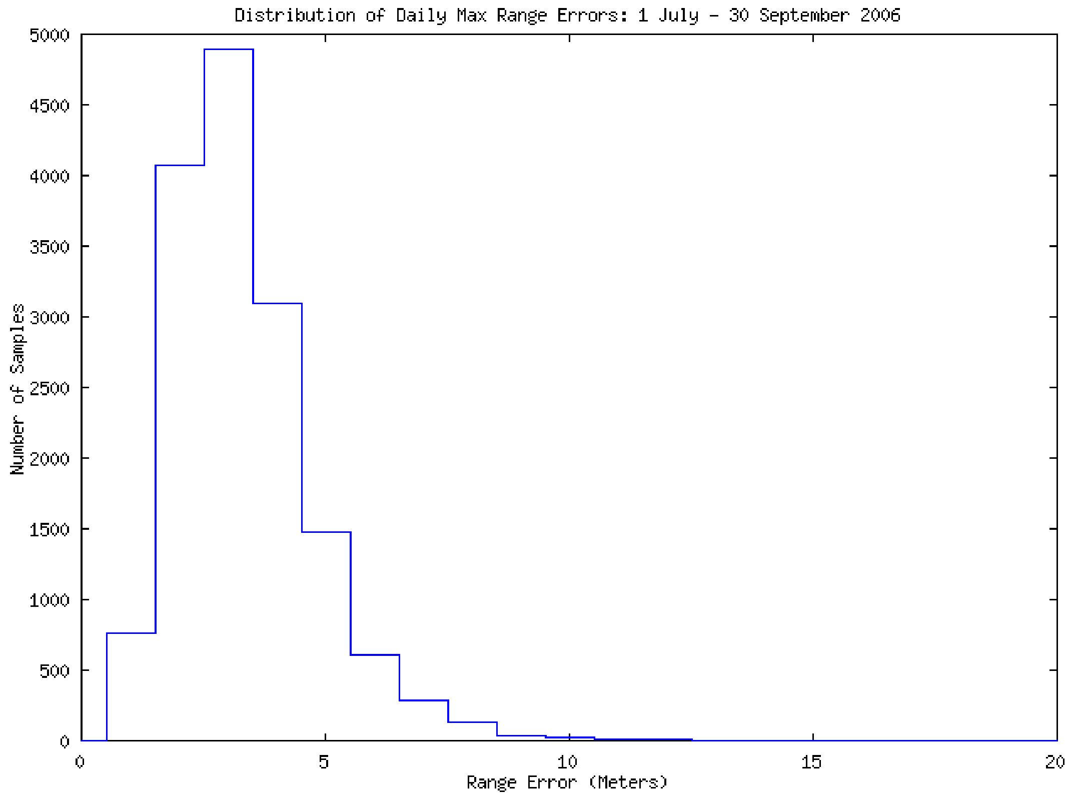


Figure 5-5: Distribution of Daily Max Range Rate Errors

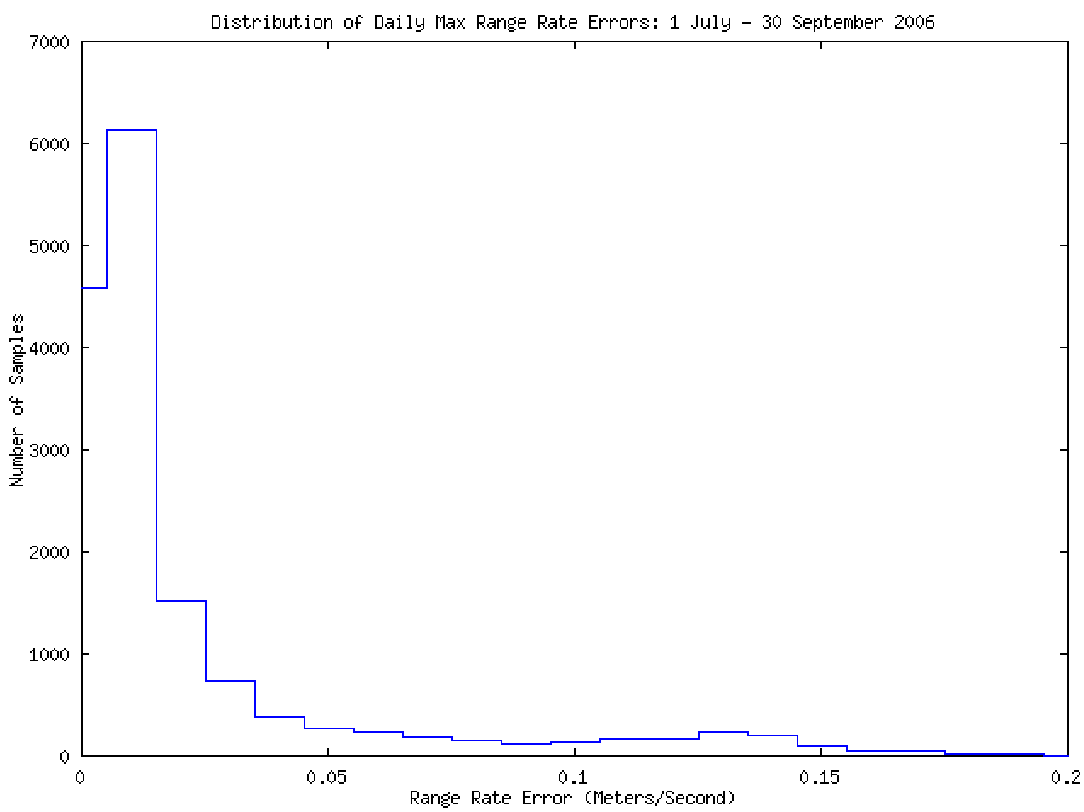


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

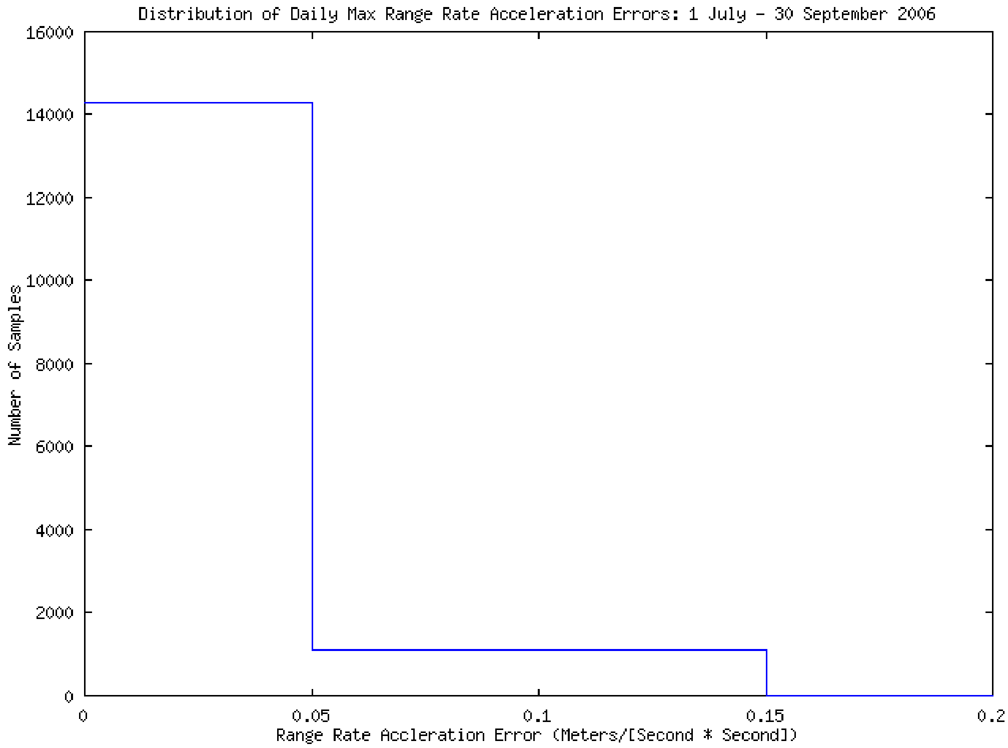


Figure 5-7: Range Error Histogram

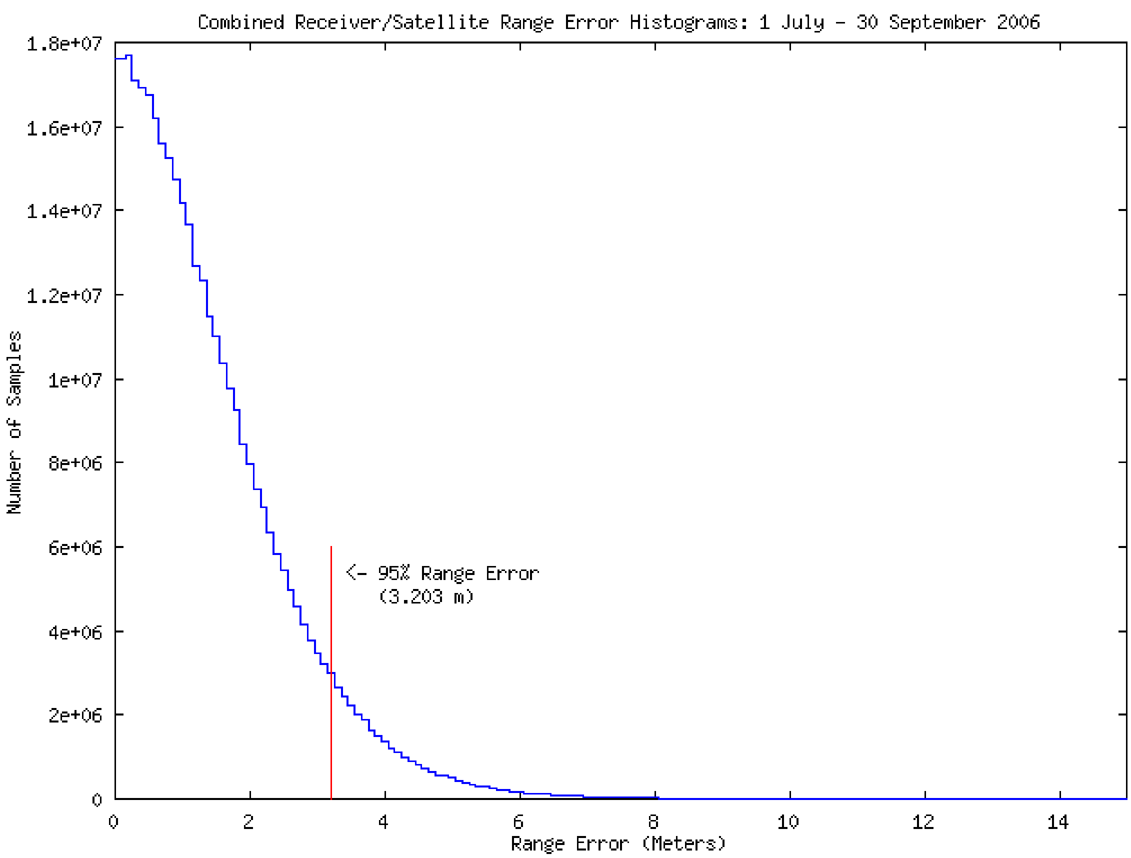


Figure 5-8: Maximum Range Error Per Satellite

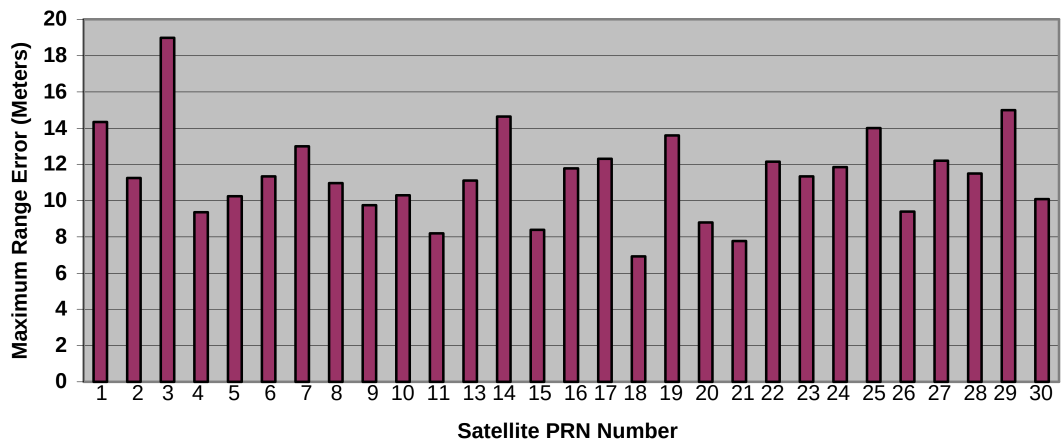


Figure 5-9: Maximum Range Rate Error Per Satellite

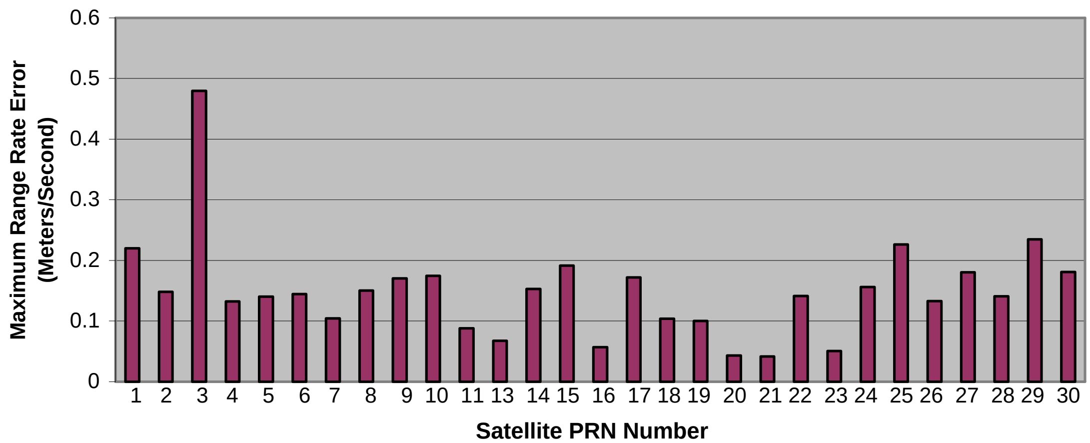
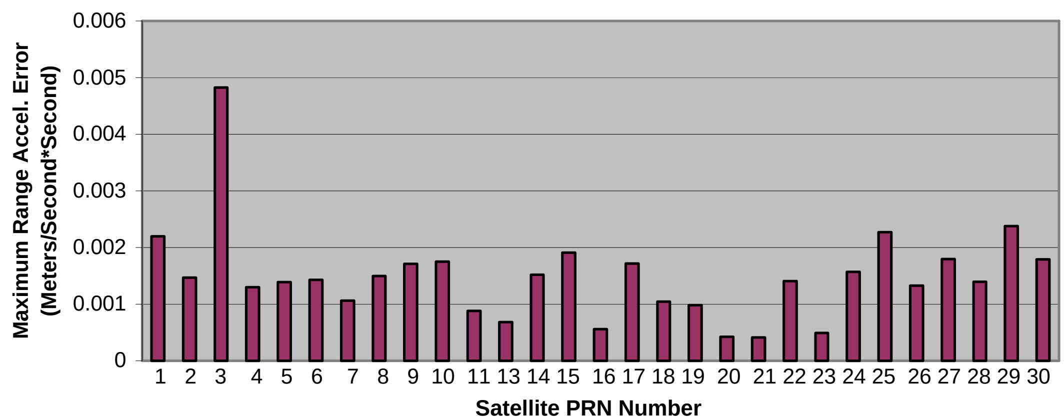


Figure 5-10: Maximum Range Acceleration Per Satellite



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 19-21 August 2006

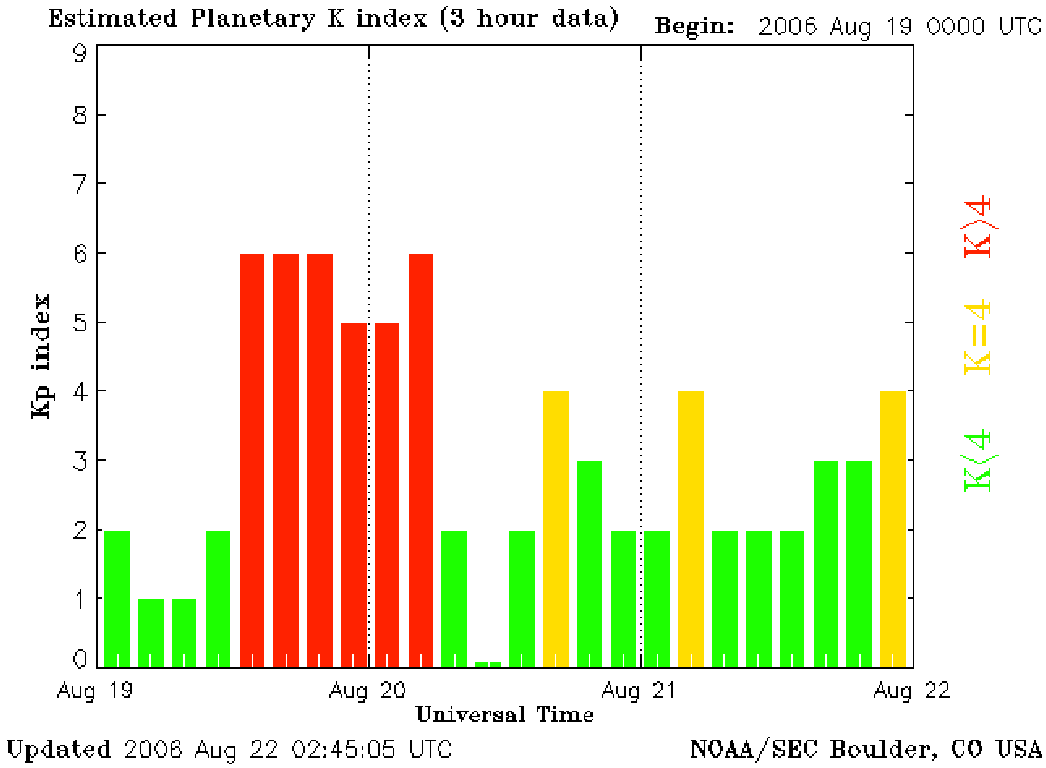


Figure 6-2 K-Index for 7-9 August 2006

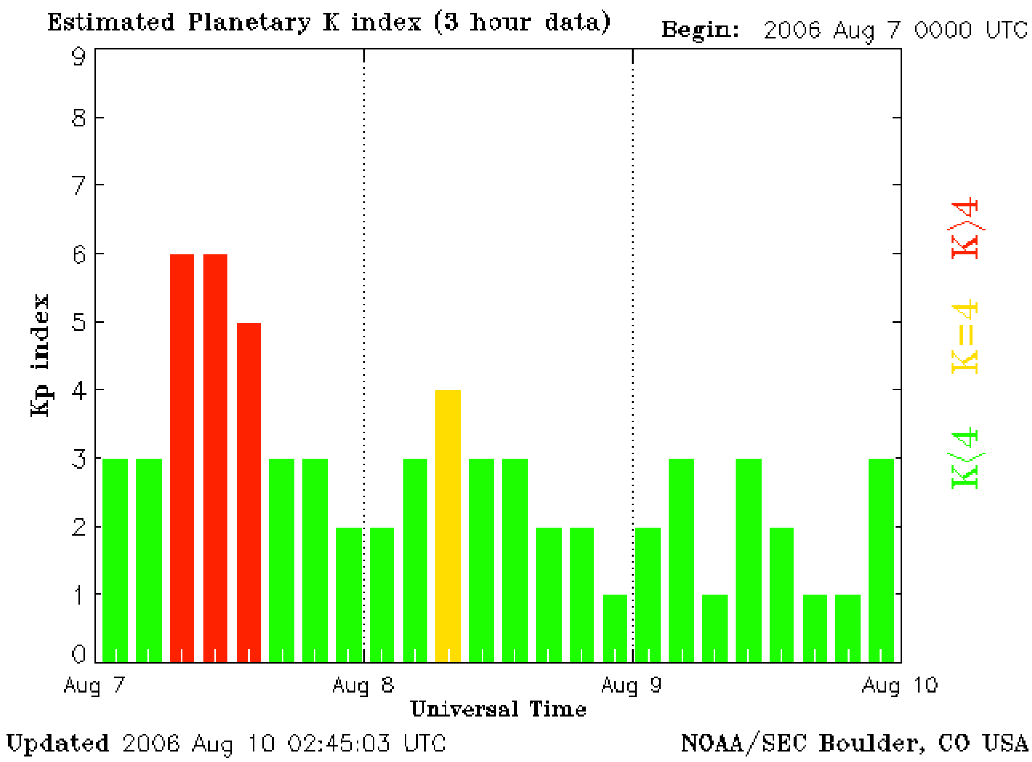
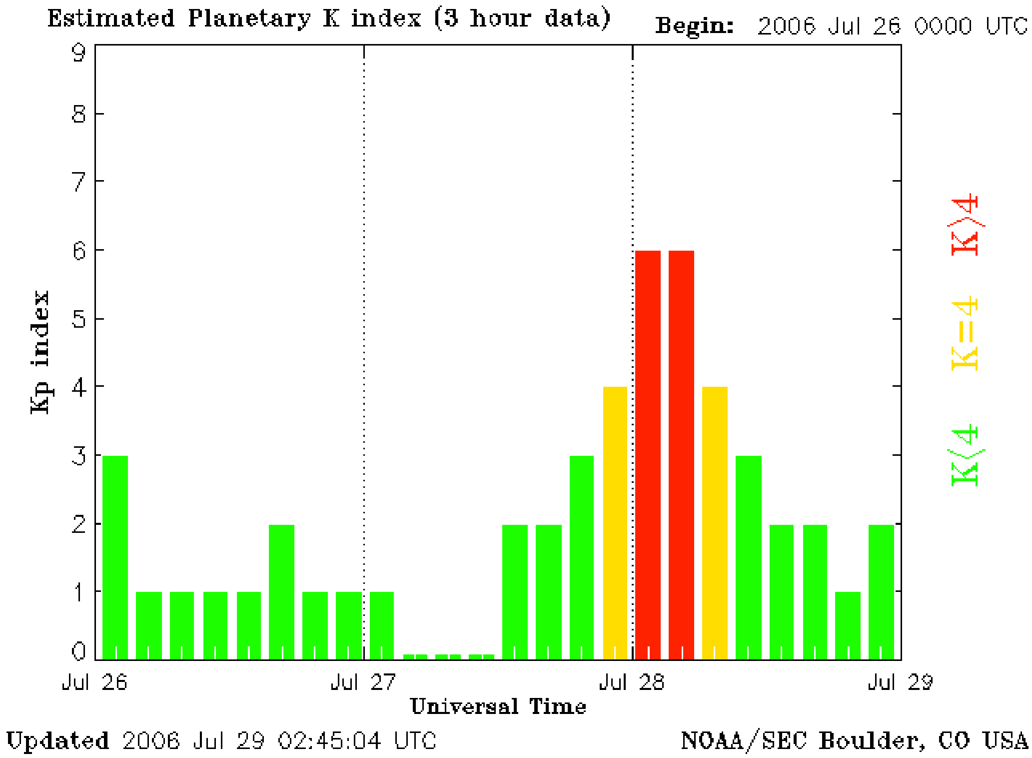


Figure 6-3 K-Index for 26-28 July 2006



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 19 August 2006

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Albuquerque	4.068	5.132	5.65	8.68
Anchorage	3.019	5.083	4.19	7.54
Boston	2.438	5.818	4.94	6.50
Washington, DC	2.424	6.001	3.91	7.90
Honolulu	3.919	5.584	7.98	13.50
Houston	3.572	5.427	7.39	12.90
Kansas City	3.647	5.425	5.05	7.29
Los Angeles	3.800	4.571	4.53	6.26
Salt Lake City	4.027	4.638	9.77	12.70
Miami	4.159	6.430	5.24	10.30
Minneapolis	3.027	4.050	5.20	7.00
Oakland	3.866	4.704	5.28	11.20
Cleveland	2.551	5.911	3.87	6.50
Seattle	3.567	4.815	5.37	9.23
San Juan	2.433	7.464	8.41	11.30
Atlanta	3.112	5.859	5.44	8.22
Juneau	2.963	4.894	2.92	12.90
Cold Bay	3.28	4.395	6.83	11.70
Fairbanks	2.212	5.301	3.02	6.84
Bethel	2.818	4.999	3.63	6.09
Kotzebue	2.246	5.045	2.95	7.36

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	≥ 99.963% ≥ 99.167%
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)	2.390 m 4.408 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)	4.854 m 5.354 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)	14 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	1.724 meters

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#  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
2006 07 01	3	1 2 1 1 1 1 1 0	2	1 2 1 1 1 0 0 0	5	1 2 1 0 1 2 1 1
2006 07 02	1	0 0 0 0 1 2 0 0	0	1 0 0 0 0 0 0 0	2	1 0 0 0 1 2 0 1
2006 07 03	2	0 0 1 1 0 1 1 1	2	0 1 0 2 0 2 0 0	4	1 0 1 1 0 2 1 2
2006 07 04	11	0 1 1 2 4 2 3 4	11	1 2 1 3 4 2 2 3	13	1 1 1 2 4 3 3 4
2006 07 05	18	4 4 5 1 2 2 2 3	28	4 5 6 4 3 3 2 2	19	4 5 5 2 2 2 2 4
2006 07 06	7	3 2 3 1 1 1 1 2	17	3 2 5 5 1 2 1 1	11	4 3 3 3 1 1 2 2
2006 07 07	5	1 1 1 2 2 2 1 1	8	1 2 2 3 3 3 1 0	6	2 2 1 1 2 2 3 1
2006 07 08	2	0 0 1 0 0 1 1 1	1	0 1 1 0 0 0 0 0	3	1 0 2 0 1 1 1 2
2006 07 09	5	0 0 0 1 0 1 1 4	1	1 0 0 0 0 0 0 2	5	1 0 0 0 0 1 1 4
2006 07 10	12	4 2 1 2 3 3 3 2	18	3 2 1 4 5 4 3 1	11	3 2 1 2 3 3 3 3
2006 07 11	5	0 1 1 1 2 2 2 2	4	0 1 1 0 1 2 2 2	7	1 1 1 2 2 2 3 3
2006 07 12	9	2 1 3 3 3 2 1 2	18	2 2 3 5 5 2 2 2	12	3 2 3 4 4 2 1 2
2006 07 13	3	1 2 1 1 0 1 1 1	5	2 3 2 2 1 0 0 0	5	2 2 2 1 1 1 0 2
2006 07 14	10	1 2 1 1 4 3 3 2	17	1 2 1 1 5 5 3 2	14	1 1 0 2 3 4 4 3
2006 07 15	5	1 2 2 2 2 1 1 1	10	1 2 2 4 4 1 1 0	6	2 2 2 2 2 2 1 2
2006 07 16	2	0 2 1 1 0 1 1 0	2	0 1 1 1 0 1 0 0	4	1 2 1 0 1 1 0 1
2006 07 17	2	0 0 1 0 2 1 1 1	2	1 1 0 1 2 0 1 0	4	1 1 0 1 1 1 1 1
2006 07 18	2	1 1 0 1 0 1 1 0	1	0 1 0 1 0 0 1 0	3	1 1 0 0 1 1 1 1
2006 07 19	2	1 1 0 0 1 0 1 1	2	1 1 0 0 0 0 1 1	2	1 1 0 0 0 0 1 1
2006 07 20	2	0 1 0 0 1 0 1 1	1	1 1 0 0 0 0 1 0	3	1 1 0 0 1 1 1 1
2006 07 21	1	1 0 0 0 0 0 1 0	1	0 1 0 0 0 0 1 1	2	1 0 0 0 1 0 1 1
2006 07 22	3	0 2 1 1 1 1 0 2	1	0 1 1 0 0 0 0 1	4	1 2 1 1 1 1 1 2
2006 07 23	4	2 1 2 1 1 0 1 1	2	1 1 2 1 1 0 0 0	4	2 1 2 1 1 1 1 1
2006 07 24	7	1 0 2 2 3 3 1 2	10	0 0 3 2 4 4 1 1	4	1 0 1 1 2 2 1 2
2006 07 25	5	2 2 1 0 1 2 1 2	9	2 2 3 1 3 2 1 3	6	3 2 1 0 2 1 1 2
2006 07 26	5	3 1 1 1 1 1 1 2	-1	-1-1-1-1-1-1-1-1	6	3 1 1 1 1 2 1 1
2006 07 27	5	0 0 0 1 1 1 2 4	-1	-1-1-1-1-1-1-1-1	9	1 0 0 0 2 2 3 4
2006 07 28	26	6 5 5 2 1 3 1 2	-1	-1-1-1-1-1-1-1-1	29	6 6 4 3 2 2 1 2
2006 07 29	3	2 0 1 1 0 0 2 1	-1	-1-1-1-1-1-1-1-1	5	3 1 2 1 0 1 1 1
2006 07 30	3	1 1 1 0 0 0 2 2	-1	-1-1-1-1-1-1-1-1	5	2 2 1 0 0 1 1 2
2006 07 31	11	2 3 3 3 3 1 2 2	16	3 2 2 4 5 3 1 2	12	2 3 3 3 3 2 2 3
2006 08 01	9	2 3 3 3 2 2 1 1	25	3 4 4 5 5 4 2 1	12	2 4 4 3 2 2 1 2
2006 08 02	7	3 2 2 2 2 1 1 2	12	2 2 3 4 4 1 1 1	10	3 2 3 3 2 1 1 3
2006 08 03	5	3 2 1 1 1 0 1 2	5	3 2 1 1 2 0 1 1	6	3 2 0 1 0 1 2 2
2006 08 04	2	0 2 0 0 0 0 1 1	1	0 1 0 0 0 0 0 1	3	1 1 0 0 0 0 1 1
2006 08 05	2	1 1 1 0 1 0 1 1	1	1 1 1 0 0 0 0 0	4	2 1 1 0 1 1 1 1
2006 08 06	2	1 0 1 0 1 0 0 1	2	1 1 0 0 1 0 0 1	4	1 1 1 0 1 2 2 1
2006 08 07	19	3 3 5 4 3 2 3 2	52	3 4 6 7 6 5 3 2	32	3 3 6 6 5 3 3 2
2006 08 08	10	2 3 4 2 2 1 2 1	35	4 3 6 6 5 4 2 1	12	2 3 4 3 3 2 2 1
2006 08 09	9	2 3 1 3 3 1 1 2	14	2 2 1 5 4 2 1 2	9	2 3 1 3 2 1 1 3
2006 08 10	4	1 1 0 0 1 1 1 2	2	1 1 0 0 1 0 1 2	5	1 1 0 0 1 2 0 3
2006 08 11	3	1 1 1 1 1 2 0 1	8	2 2 1 3 3 2 1 1	6	2 1 2 1 2 2 2 2
2006 08 12	4	2 2 1 1 1 1 1 1	10	2 2 3 3 3 3 0 1	8	2 3 2 2 1 2 1 1
2006 08 13	2	2 0 0 0 1 1 1 0	0	0 0 0 1 0 0 0 0	2	0 0 0 0 1 1 1 1
2006 08 14	2	0 0 1 0 2 1 1 0	1	0 0 0 0 2 0 0 1	4	1 0 1 1 1 1 1 1
2006 08 15	2	1 1 1 0 0 1 1 1	1	0 0 1 1 0 0 0 0	3	1 0 0 0 0 1 1 1
2006 08 16	2	1 0 0 1 1 0 1 1	0	1 0 0 0 0 0 0 0	3	1 1 0 1 1 0 1 1
2006 08 17	4	0 0 2 1 2 1 2 1	2	0 0 2 0 0 1 1 1	5	1 0 2 1 1 1 2 2
2006 08 18	9	2 3 2 2 2 1 2 3	13	2 4 3 4 3 1 1 1	12	2 4 2 2 2 3 2 3
2006 08 19	21	2 1 1 2 5 4 4 5	61	2 2 0 4 7 8 5 3	38	2 1 1 2 6 6 6 5
2006 08 20	14	4 5 2 1 2 2 2 1	12	4 4 2 1 2 3 2 1	24	5 6 2 0 2 4 3 2
2006 08 21	10	1 3 2 2 2 2 3 3	24	2 2 4 4 5 3 3 5	13	2 4 2 2 2 3 3 4
2006 08 22	17	3 1 5 4 3 3 2 2	42	3 2 6 7 5 4 3 1	17	3 3 3 4 4 4 4 2
2006 08 23	4	2 2 3 0 1 0 1 0	5	2 2 3 0 0 0 2 0	7	2 3 3 0 1 1 1 2
2006 08 24	4	3 1 0 0 1 1 1 1	3	1 1 1 0 2 2 1 1	5	3 1 0 1 1 1 1 2
2006 08 25	0	0 0 0 1 0 0 0 0	1	0 1 0 1 0 0 0 0	2	1 1 0 1 1 1 0 1
2006 08 26	2	0 1 1 0 0 0 2 1	1	0 0 1 0 0 0 1 1	3	1 1 1 0 0 0 2 2
2006 08 27	12	1 1 2 2 3 3 4 3	27	2 1 2 5 5 6 3 2	18	2 1 1 3 4 5 4 3

2006 08 28	9	4	2	2	1	2	1	2	2	13	3	3	3	3	3	2	3	2	11	4	3	2	2	2	2	3	2
2006 08 29	9	3	2	2	3	2	2	2	2	21	2	2	5	6	3	2	1	0	9	2	2	3	4	1	2	2	2
2006 08 30	5	1	1	2	2	1	1	2	1	14	1	1	5	5	2	1	0	0	6	1	1	3	2	1	1	1	2
2006 08 31	6	1	1	3	0	2	2	2	2	9	1	1	2	2	2	4	3	1	8	1	1	2	1	1	3	3	3
2006 09 01	8	2	0	1	2	2	2	2	4	26	3	2	3	3	5	6	3	3	13	3	1	2	2	3	3	4	3
2006 09 02	6	3	1	1	1	1	1	2	2	10	3	2	0	3	4	2	2	1	7	3	1	1	1	1	1	3	3
2006 09 03	6	2	3	2	1	1	1	1	1	5	2	2	2	2	1	1	0	1	6	2	3	1	1	1	1	1	2
2006 09 04	15	3	5	4	2	2	2	2	1	30	3	5	5	5	5	3	3	1	23	4	6	4	3	3	3	3	2
2006 09 05	7	3	2	2	2	2	2	1	1	24	3	2	5	6	3	3	2	1	8	3	2	3	2	1	2	2	2
2006 09 06	6	2	2	2	2	2	1	2	1	16	2	1	2	5	4	4	1	2	7	2	2	1	2	2	2	2	2
2006 09 07	5	1	2	3	1	1	2	1	0	17	2	2	5	2	5	3	0	0	8	1	1	1	1	2	2	2	1
2006 09 08	4	2	2	2	1	1	1	0	1	4	1	3	3	0	0	0	0	0	4	1	2	1	0	1	1	0	2
2006 09 09	1	1	1	0	0	0	0	1	0	1	1	1	0	1	0	0	0	0	2	1	1	0	0	0	0	0	1
2006 09 10	5	1	2	1	1	2	1	2	2	5	1	1	2	3	0	2	1	1	6	1	2	1	1	1	2	1	2
2006 09 11	7	2	2	3	3	2	1	0	1	11	2	2	3	4	4	1	0	1	8	3	3	3	2	2	1	0	1
2006 09 12	2	1	0	1	1	1	0	1	1	3	1	0	2	2	0	1	1	0	4	1	0	2	1	1	1	1	1
2006 09 13	3	1	2	1	2	1	1	0	0	8	0	3	4	2	3	0	0	0	6	1	3	2	1	1	1	0	1
2006 09 14	4	1	3	2	1	1	1	0	0	5	1	2	2	3	2	0	0	0	6	1	3	2	2	1	1	1	1
2006 09 15	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	1	0	0	0	1	0	2	2
2006 09 16	1	0	0	0	0	1	1	1	0	1	1	1	0	0	0	1	0	0	3	0	0	0	0	1	1	2	2
2006 09 17	9	0	1	3	3	3	1	3	2	27	1	1	3	6	6	1	3	3	16	1	1	2	4	4	1	4	3
2006 09 18	16	4	4	3	3	2	2	3	3	34	3	4	6	6	4	3	3	3	24	5	5	3	3	3	2	5	3
2006 09 19	8	3	3	3	1	1	1	1	1	19	3	3	5	5	3	2	1	1	12	4	3	4	2	2	2	2	2
2006 09 20	3	2	2	1	0	0	1	0	0	1	1	0	2	0	0	0	0	0	5	2	2	1	1	1	1	1	1
2006 09 21	2	0	1	0	1	1	1	1	0	2	0	0	1	2	1	0	0	0	4	0	1	1	1	0	1	2	2
2006 09 22	1	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	3	0	1	0	0	1	2	2	1
2006 09 23	7	0	1	1	1	1	1	3	4	8	0	0	2	3	3	1	2	3	9	0	1	2	1	1	1	3	4
2006 09 24	15	4	4	3	3	3	2	2	2	29	4	5	4	6	4	3	1	1	23	5	5	4	5	3	2	2	2
2006 09 25	6	1	2	1	3	2	1	1	2	19	2	1	2	6	5	1	1	1	6	1	2	1	3	2	0	1	2
2006 09 26	5	2	2	1	1	1	1	1	2	6	1	3	2	1	2	1	1	2	6	2	3	2	0	1	1	1	2
2006 09 27	2	2	1	0	0	1	1	0	0	2	2	1	0	2	0	0	0	0	4	3	2	0	1	1	0	0	1
2006 09 28	2	0	0	1	1	1	1	1	1	1	0	0	0	2	1	0	0	0	2	0	0	1	1	1	0	0	1
2006 09 29	3	0	1	0	0	1	2	2	1	2	0	0	2	1	0	0	1	0	3	1	1	1	0	0	1	2	1
2006 09 30	9	1	3	2	3	2	2	2	2	18	0	3	4	6	3	1	1	1	12	0	3	3	4	2	2	1	3

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 issued with SPS performance this quarter.

Appendix D Glossary

The terms and definitions discussed below are taken from the Standard Positioning Service Performance Specification (October 2001). An understanding of these terms and definitions is a necessary prerequisite to full understanding of the Signal Specification.

General Terms and Definitions

Almanac Longitude of the Ascending Node (.o): Equatorial angle from the Prime Meridian (Greenwich) at the weekly epoch to the ascending node at the ephemeris reference epoch.

Coarse/Acquisition (C/A) Code: A PRN code sequence used to modulate the GPS L1 carrier.

Corrected Longitude of Ascending Node (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.