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

Submitted To

Federal Aviation Administration
GPS Product Team

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Submitted by

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 January through 31 March 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 January and 31 March 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. Eleven outages were scheduled while one was 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 sites achieved 100% reliability; meeting the SPS specification. The maximum range error recorded was 29.668 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 4.093 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 January and 31 March 2008, the GPS performance met all SPS requirements that were evaluated. There were no significant problems to report for the duration of the quarter.

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

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

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

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

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

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

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

Appendix D provides a glossary of terms used in this PAN report. This glossary was obtained directly from the GPS SPS specification document (October 2001).

Table 1-1 SPS Performance Requirements

PDOP Availability Standard	Conditions and Constraints	Evaluated in This Report
≥ 98% global Position Dilution of Precision (PDOP) of 6 or less ≥ 88% worst site PDOP of 6 or less	• Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. • Based on using only satellites transmitting standard code and indicating "health" in the broadcast navigation message (sub-frame 1).	✓
Service Availability Standard	**Conditions and Constraints**	
≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	• 36 meter horizontal (SIS only) 95% threshold. • 77 meter vertical (SIS only) 95% threshold. • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	✓
≥ 95.87% global average on worst-case day	• Based on using only satellites transmitting standard code and indicating "healthy" in the broadcast navigation message (sub-frame 1).	✓
Service Reliability Standard	**Conditions and Constraints**	
≥ 99.94% global average	• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	✓
≥ 99.79% single point average	• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values from the worst-case point within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	✓

Accuracy Standard	**Conditions and Constraints**	
Global Average Positioning Domain Accuracy • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only)	• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	✓
Worst Site Positioning Domain Accuracy • ≤ 36 meters 95% All-in-View Horizontal Error (SIS only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS only)	• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours for any point within the service volume.	✓
Time Transfer Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for time transfer solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	✓
SPS SIS URE STANDARD	**Conditions and Constraints**	
≤ 6 meters RMS SIS SPS URE across the entire constellation	• Average of the constellation's individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point thing the service volume.	✓

2.0 PDOP Availability Standard

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

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

PDOP Availability Standard	Conditions and Constraints
≥ 98% global Position Dilution of Precision (PDOP) of 6 or less ≥ 88% worst site PDOP of 6 or less	• Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. • Based on using only satellites transmitting standard code and indicating "health" in the broadcast navigation message (sub-frame 1).

Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by the GPS test team was used to calculate the PDOP at every 5^o point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.08085 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 January	3.03796	0.99994	0.99306
6-12 January	2.98863	0.99993	0.99306
13-19 January	3.06671	0.99992	0.99306
20-26 January	3.07792	0.99992	0.99306
27 Jan – 2 Feb	3.07748	0.99992	0.99236
3-9 February	3.08037	0.99992	0.99306
10-16 February	3.07570	0.99991	0.99306
17-23 February	3.07897	0.99992	0.99306
24 Feb – 1 Mar	3.08085	0.99991	0.99306
2-8 Mar	3.08405	0.99991	0.99236
9-15 Mar	3.07671	0.99991	0.99236
16-22 Mar	3.07046	0.99991	0.99236
23-31 Mar	3.08055	0.99984	0.98889

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

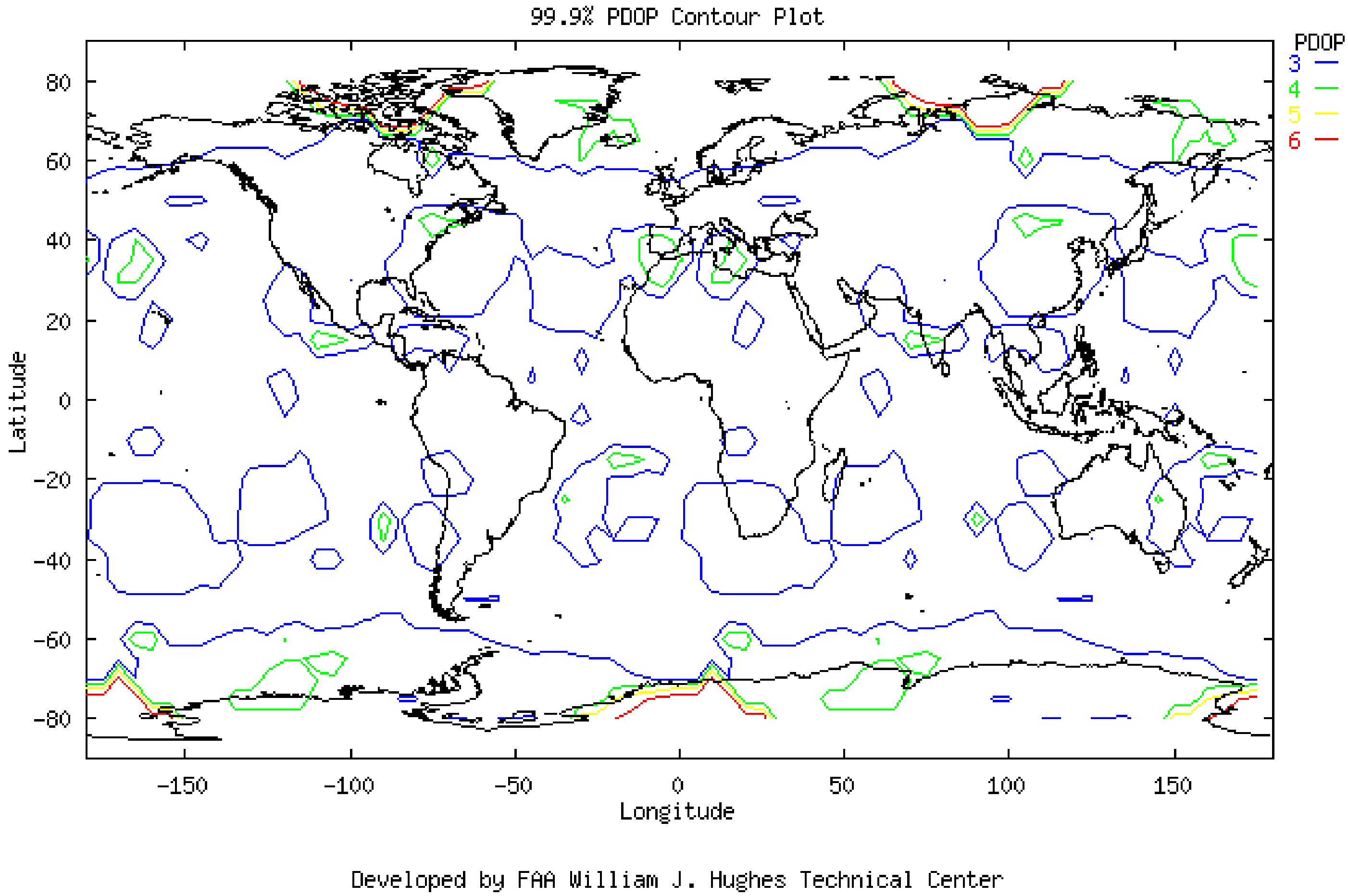
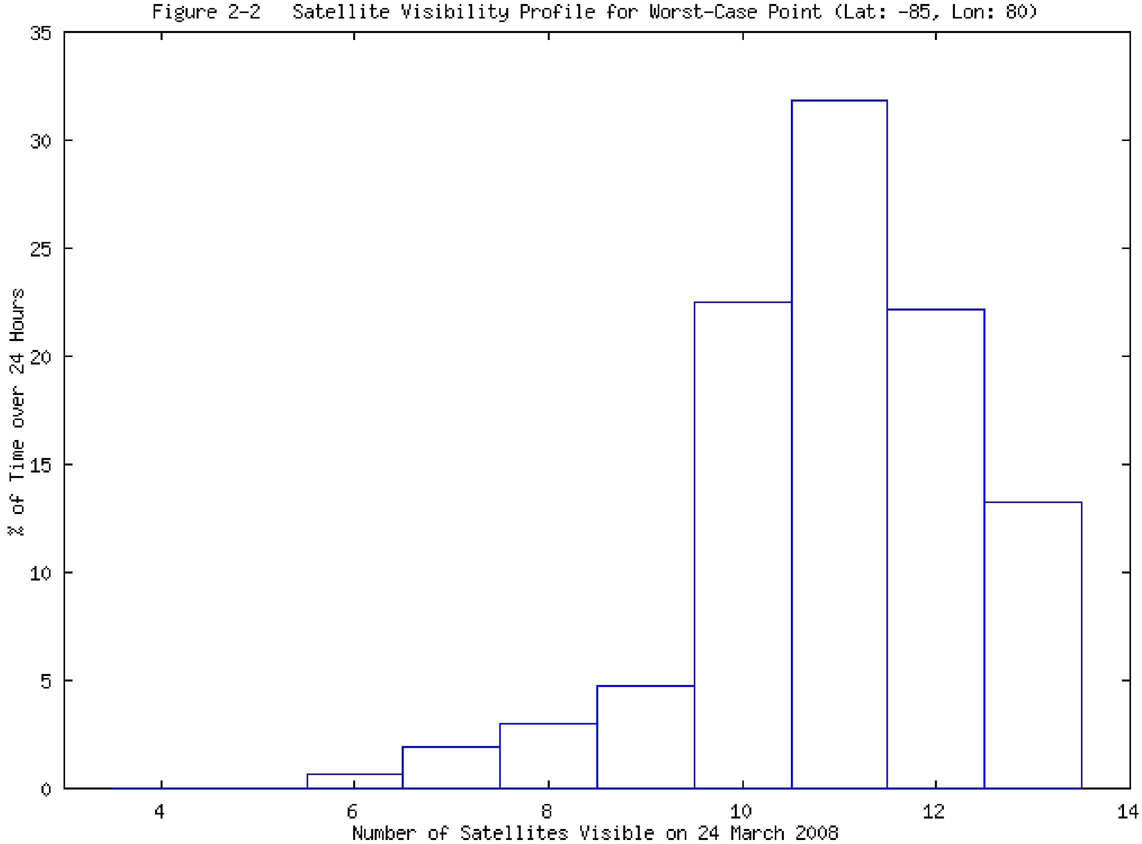


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lat: -85, Lon: 80)



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 January through 31 March 2008, there were a total of twelve reported outages. Eleven of these outages were maintenance activities and were reported in advance. One was an unscheduled outage. 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
2008003	6	FCSTSUMM	8-Jan	20:58	9-Jan	6:15		9.28	9.28
2008006	29	FCSTSUMM	16-Jan	19:00	17-Jan	11:05		16.08	16.08
2008007	25	FCSTSUMM	18-Jan	10:01	18-Jan	16:04		6.05	6.05
2008011	4	FCSTSUMM	29-Jan	7:49	29-Jan	15:49		8.00	8.00
2008012	10	FCSTSUMM	29-Jan	18:34	30-Jan	0:19		5.75	5.75
2008013	6	FCSTSUMM	30-Jan	15:37	30-Jan	20:57		5.33	5.33
2008017	16	FCSTSUMM	5-Feb	21:30	6-Feb	3:32		6.03	6.03
2008018	15	FCSTSUMM	7-Feb	18:49	7-Feb	23:55		5.10	5.10
2008021	23	FCSTSUMM	15-Feb	1:41	15-Feb	8:02		6.35	6.35
2008026	10	FCSTSUMM	5-Mar	15:17	5-Mar	18:12		2.92	2.92
2008031	25	FCSTSUMM	17-Mar	22:26	18-Mar	2:19		3.88	3.88
2008036	10	UNUSABLE	25-Mar	2:30	27-Mar	23:49	69.32		69.32
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**69.32**	**74.78**	**144.10**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2008002	6	FCSTDV	8-Jan	20:30	9-Jan	22:30	26.00	See Nanu 2008003
2008004	29	FCSTDV	16-Jan	19:00	17-Jan	22:00	27.00	See Nanu 2008006
2008005	25	FCSTDV	18-Jan	9:30	19-Jan	12:00	26.50	See Nanu 2008007
2008008	4	FCSTMX	29-Jan	7:15	29-Jan	19:15	12.00	See Nanu 2008011
2008009	6	FCSTMX	30-Jan	15:00	31-Jan	3:00	12.00	See Nanu 2008013
2008010	10	FCSTDV	29-Jan	18:00	30-Jan	8:00	14.00	See Nanu 2008012
2008014	16	FCSTDV	5-Feb	21:20	6-Feb	11:00	13.67	See Nanu 2008017
2008015	15	FCSTMX	7-Feb	18:00	8-Feb	6:00	12.00	See Nanu 2008018
2008019	23	FCSTDV	15-Feb	1:00	15-Feb	16:00	15.00	See Nanu 2008021
2008025	10	FCSTMX	5-Mar	13:00	6-Mar	1:00	12.00	See Nanu 2008026
2008027	25	FCSTMX	17-Mar	22:00	18-Mar	10:00	12.00	See Nanu 2008031
2008032	10	FCSTMX	26-Mar	6:00	26-Mar	18:00	CANC	See Nanu 2008035
2008034	10	UNUSUFN	25-Mar	2:30	N/A	N/A	N/A	See Nanu 2008036
						Total Forecast Downtime	**182.17**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
2008035	10	FCSTCANC	26-Mar	6:00	See Nanu 2008032

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 Jan - 31 Mar. 2008**	**1 October, 1999- 31 Mar. 2008**
Total Forecast Downtime (hrs):	182.17	6890.65
Total Actual Downtime (hrs):	144.10	25069.02
Total Actual Scheduled Downtime (hrs):	74.78	3648.30
Total Actual Unscheduled Downtime (hrs):	69.32	21420.72
Total Satellite Observed MTTR (hrs):	12.01	45.83
Scheduled Satellite Observed MTTR (hrs):	6.80	9.31
Unscheduled Satellite Observed MTTR (hrs):	69.32	138.20
# Total Satellite Outages:	12	547
# Scheduled Satellite Outages:	11	392
# Unscheduled Satellite Outages:	1	155
Percent Operational -- Scheduled Downtime:	99.89	99.82
Percent Operational -- All Downtime:	99.99	98.79

3.2 Service Availability Standard

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

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

Service Availability Standard	Conditions and Constraints
≥ 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 January and 31 March 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	7756614	0	100%
Anchorage	7816760	0	100%
Atlanta	7804765	0	100%
Barrow	7187556	0	100%
Bethel	6853161	0	100%
Billings	7712930	0	100%
Boston	7752557	0	100%
Cleveland	7810740	0	100%
Cold Bay	7741398	0	100%
Fairbanks	7718201	0	100%
Gander	6711654	0	100%
Honolulu	7803270	0	100%
Houston	7653240	0	100%
Iqaluit	7686308	0	100%
Juneau	7716076	0	100%
Kansas City	7776735	0	100%
Kotzebue	7753452	0	100%
Los Angeles	7799091	0	100%
Merida	7257762	0	100%
Miami	7814725	0	100%
Minneapolis	7798482	0	100%
Oakland	7813675	0	100%
Salt Lake City	7785003	0	100%
San Jose Del Cabo	7235180	0	100%
San Juan	7764021	0	100%
Seattle	7800413	0	100%
Tapachula	6273398	0	100%
Washington, DC	7773011	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 16.871 meters at Boston on satellite PRN 2.

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**	55,987,779	0	100%
1 Jan. – 31 Mar 2008	**Honolulu**	59,393,811	0	100%
1 Jan. – 31 Mar 2008	**Los Angeles**	58,654,115	0	100%
1 Jan. – 31 Mar 2008	**Miami**	59,300,386	0	100%
1 Jan. – 31 Mar 2008	**San Juan**	59,852,070	0	100%
1 Jan. – 31 Mar 2008	**Juneau**	57,114,034	0	100%
1 Jan. – 31 Mar 2008	**Global**	350,302,195	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 January through 31 March 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	2.233	4.038	4.664	11.583
Anchorage	1.960	4.822	4.638	9.913
Atlanta	2.439	4.552	6.661	14.186
Barrow	1.726	5.800	3.628	11.810
Bethel	1.960	4.897	3.771	11.077
Billings	2.277	4.205	4.035	10.204
Boston	2.470	4.253	6.272	14.349
Cleveland	2.502	4.334	7.276	13.369
Cold Bay	2.238	4.915	4.247	9.273
Fairbanks	1.823	4.893	4.416	10.975
Gander	2.431	3.818	4.800	13.803
Honolulu	3.963	4.879	9.372	12.592
Houston	2.256	4.264	5.154	13.330
Iqaluit	11.706	4.423	13.428	14.344
Juneau	2.005	4.591	4.374	9.895
Kansas City	2.407	4.414	5.609	12.304
Kotzebue	1.856	4.946	3.485	10.460
Los Angeles	2.218	4.651	4.542	11.871
Merida	2.397	4.199	5.854	14.235
Miami	2.302	4.558	4.916	14.732
Minneapolis	2.360	4.272	6.667	12.389
Oakland	2.207	4.813	4.443	10.561
Salt Lake City	2.301	4.296	4.239	10.547
San Jose Del Cabo	2.437	4.609	10.287	12.792
San Juan	2.359	4.834	4.887	15.506
Seattle	2.342	4.636	4.222	8.589
Tapachula	3.337	4.625	7.702	14.031
Washington, DC	2.520	4.515	7.955	14.083

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-eight WAAS sites from 1 January to 31 March 2008.

Figure 5-1 Global Vertical Error Histogram

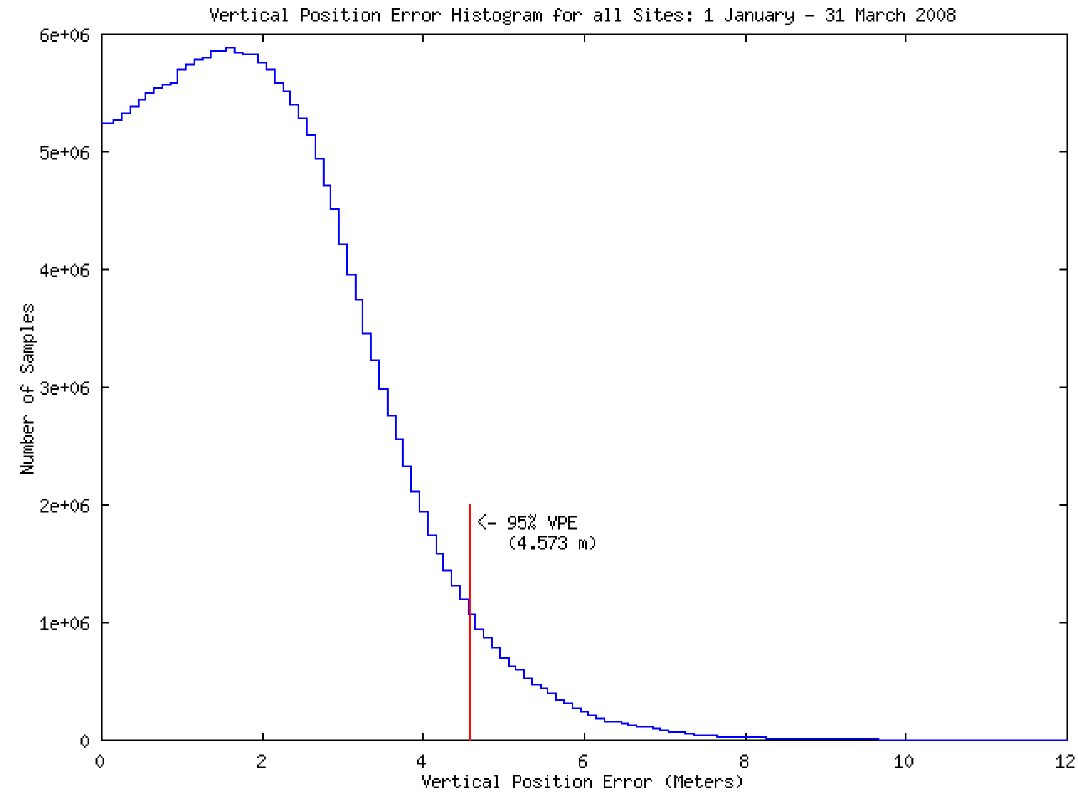
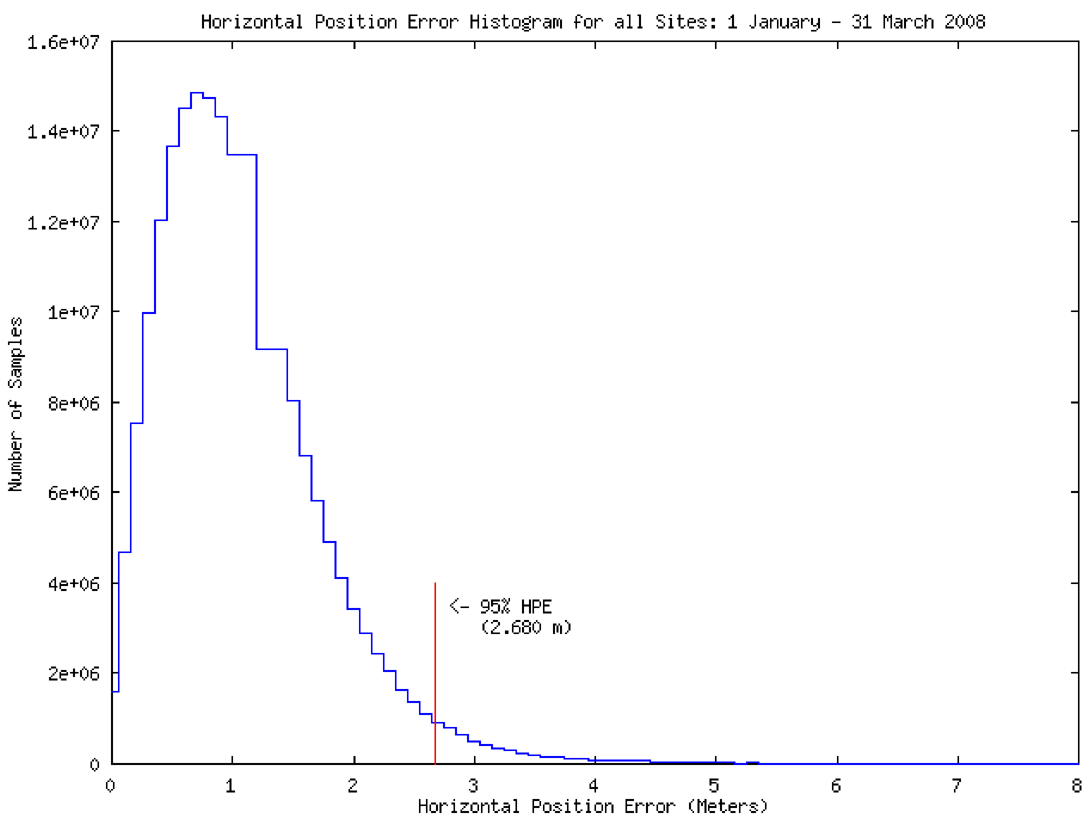


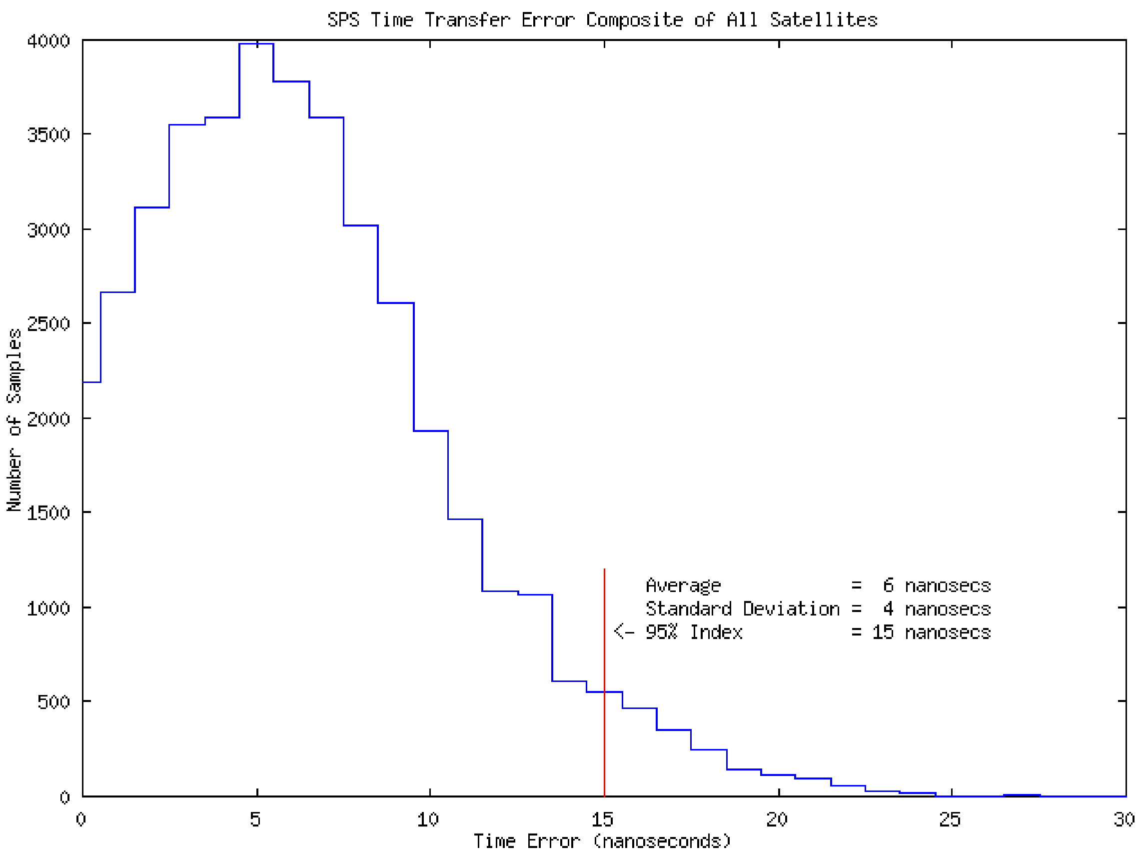
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 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 January and 31 March 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	1s	95% Range Error	Max Range Error (SPS Spec. ≤ 30 m)	Samples
1	2.759	1.944	1.753	4.936	10.633	10270930
2	1.562	0.974	1.123	2.824	18.636	12558535
3	1.860	0.748	1.409	3.311	26.141	10880344
4	1.483	0.530	1.202	2.854	17.249	12389124
5	1.945	1.506	1.136	3.319	19.577	12239870
6	1.531	0.730	1.159	2.811	17.129	12419776
7	4.093	-3.734	1.558	6.153	10.696	390818
8	1.993	1.143	1.328	3.616	15.238	11364480
9	1.928	0.945	1.378	3.388	12.190	11614854
10	1.937	0.948	1.358	3.428	19.494	11650524
11	1.855	1.094	1.344	3.375	9.099	11016643
12	1.365	0.625	1.103	2.520	18.644	12820179
13	1.361	0.700	1.062	2.534	14.222	12290548
14	1.901	1.171	1.264	3.451	10.440	12649997
15	1.360	0.664	1.063	2.546	19.349	11217498
16	1.785	1.216	1.150	3.100	11.377	11565925
17	1.474	0.501	1.220	2.856	11.813	12591784
18	1.847	1.186	1.208	3.169	15.168	11676432
19	2.175	1.579	1.318	3.683	11.852	11133353
20	2.022	1.496	1.257	3.681	10.775	12617605
21	1.889	1.203	1.261	3.179	15.346	10507744
22	1.958	1.083	1.211	3.396	10.185	11053237
23	1.808	1.220	1.235	3.210	13.832	11109319
24	2.218	1.544	1.271	3.689	19.534	11169229
25	1.338	0.379	1.126	2.553	9.745	10772118
26	1.650	1.036	1.123	2.948	19.471	10764636
27	2.093	1.154	1.285	3.680	19.539	11207852
28	2.051	1.371	1.255	3.667	12.202	11212937
29	1.550	0.456	1.138	2.829	18.971	11527074
30	1.739	0.292	1.400	3.264	29.668	11819724
31	1.561	0.705	1.205	2.918	10.533	12457579
32	2.207	1.360	1.333	3.894	6.654	10341527

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
1	0.00241	-0.00006	0.00241	0.00285	0.19518	10270930
2	0.00134	0.00000	0.00133	0.00254	0.34076	12558535
3	0.00181	-0.00003	0.00181	0.00297	0.27882	10880344
4	0.00140	-0.00001	0.00140	0.00254	0.61655	12389124
5	0.00136	0.00003	0.00136	0.00243	0.50631	12239870
6	0.00132	0.00001	0.00132	0.00242	0.54013	12419776
7	0.00151	-0.00005	0.00151	0.00305	0.01769	390818
8	0.00162	-0.00003	0.00161	0.00286	0.60382	11364480
9	0.00194	0.00000	0.00193	0.00281	0.32415	11614854
10	0.00226	-0.00001	0.00226	0.00258	0.34876	11650524
11	0.00145	0.00000	0.00145	0.00273	0.09587	11016643
12	0.00145	-0.00002	0.00145	0.00266	0.56652	12820179
13	0.00140	0.00000	0.00140	0.00258	0.48220	12290548
14	0.00148	-0.00006	0.00147	0.00261	0.18177	12649997
15	0.00138	-0.00004	0.00138	0.00256	0.41126	11217498
16	0.00139	0.00001	0.00138	0.00266	0.21270	11565925
17	0.00160	0.00003	0.00160	0.00271	0.48220	12591784
18	0.00134	-0.00004	0.00134	0.00257	0.33219	11676432
19	0.00136	0.00001	0.00136	0.00264	0.06017	11133353
20	0.00139	-0.00002	0.00139	0.00271	0.10608	12617605
21	0.00140	-0.00003	0.00140	0.00268	0.22509	10507744
22	0.00152	-0.00002	0.00151	0.00272	0.36858	11053237
23	0.00135	-0.00001	0.00135	0.00256	0.55759	11109319
24	0.00166	-0.00002	0.00166	0.00267	0.47371	11169229
25	0.00164	0.00002	0.00164	0.00241	0.14049	10772118
26	0.00145	-0.00003	0.00144	0.00245	0.42742	10764636
27	0.00162	-0.00001	0.00162	0.00276	0.62933	11207852
28	0.00154	0.00001	0.00154	0.00266	0.14182	11212937
29	0.00148	0.00001	0.00148	0.00255	0.40202	11527074
30	0.00196	-0.00001	0.00196	0.00296	0.46826	11819724
31	0.00147	0.00000	0.00146	0.00261	0.16861	12457579
32	0.00124	-0.00001	0.00124	0.00244	0.01674	10341527

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
1	0.000020	0	0.000020	0.00197	10270930
2	0.000011	0	0.000011	0.00339	12558535
3	0.000013	0	0.000013	0.00278	10880344
4	0.000011	0	0.000011	0.00619	12389124
5	0.000011	0	0.000011	0.00505	12239870
6	0.000011	0	0.000011	0.00538	12419776
7	0.000010	0	0.000010	0.00017	390818
8	0.000012	0	0.000012	0.00607	11364480
9	0.000016	0	0.000016	0.00325	11614854
10	0.000019	0	0.000019	0.00348	11650524
11	0.000011	0	0.000011	0.00096	11016643
12	0.000011	0	0.000011	0.00568	12820179
13	0.000011	0	0.000011	0.00482	12290548
14	0.000011	0	0.000011	0.00182	12649997
15	0.000011	0	0.000011	0.00410	11217498
16	0.000010	0	0.000010	0.00213	11565925
17	0.000012	0	0.000012	0.00482	12591784
18	0.000010	0	0.000010	0.00332	11676432
19	0.000010	0	0.000010	0.00060	11133353
20	0.000010	0	0.000010	0.00106	12617605
21	0.000010	0	0.000010	0.00226	10507744
22	0.000011	0	0.000011	0.00368	11053237
23	0.000010	0	0.000010	0.00558	11109319
24	0.000013	0	0.000013	0.00473	11169229
25	0.000014	0	0.000014	0.00141	10772118
26	0.000012	0	0.000012	0.00427	10764636
27	0.000012	0	0.000012	0.00628	11207852
28	0.000012	0	0.000012	0.00142	11212937
29	0.000012	0	0.000012	0.00402	11527074
30	0.000015	0	0.000015	0.00468	11819724
31	0.000011	0	0.000011	0.00169	12457579
32	0.000010	0	0.000010	0.00017	10341527

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 29.668 meters. Satellite 32 had the lowest maximum range error of 6.654 meters.

Figure 5-4 Distribution of Daily Max Range Errors

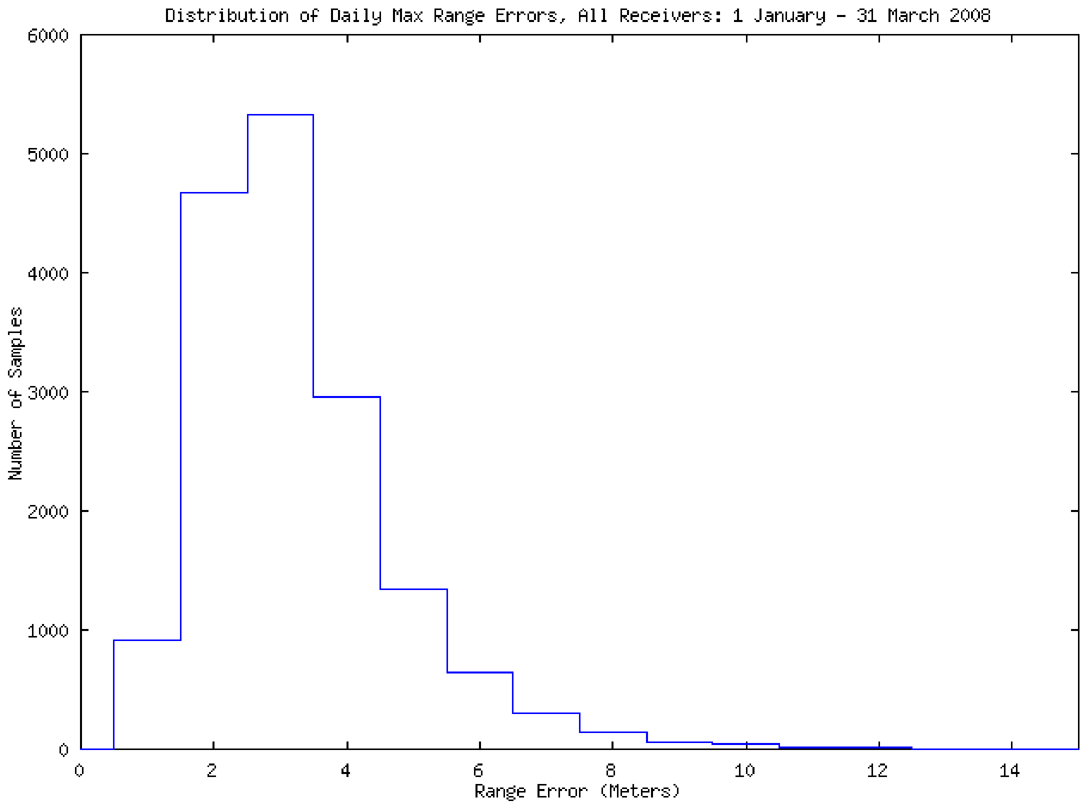


Figure 5-5: Distribution of Daily Max Range Rate Errors

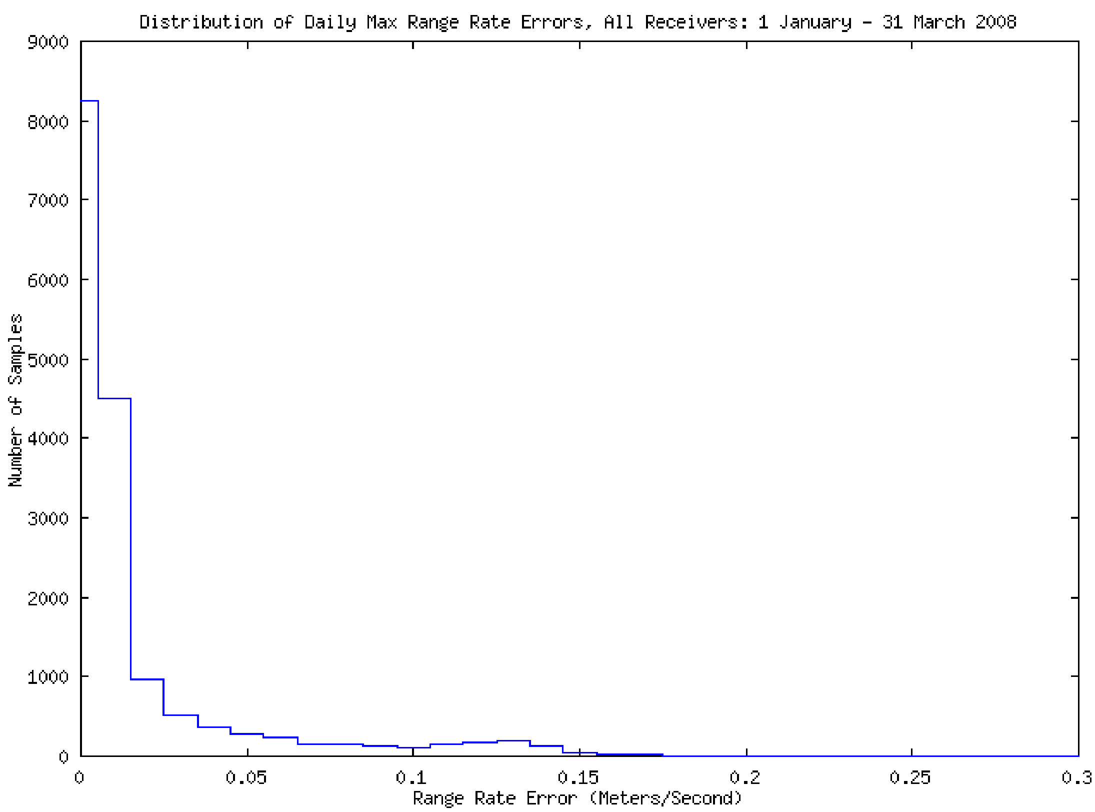


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

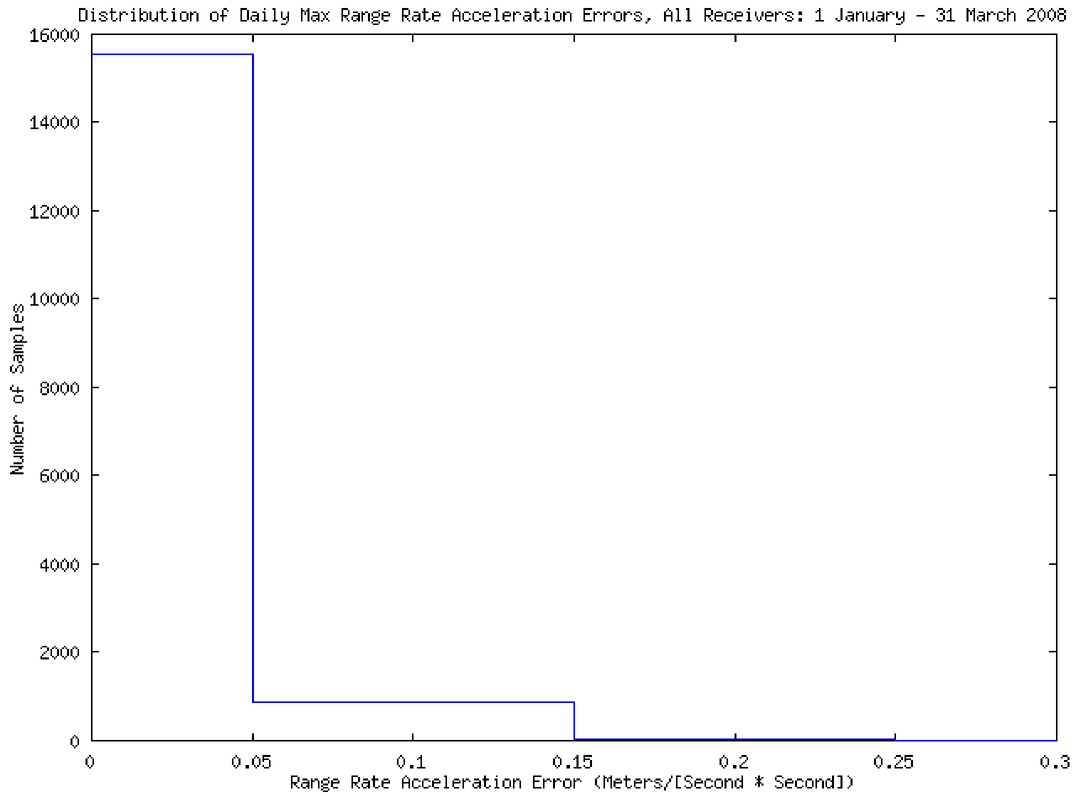
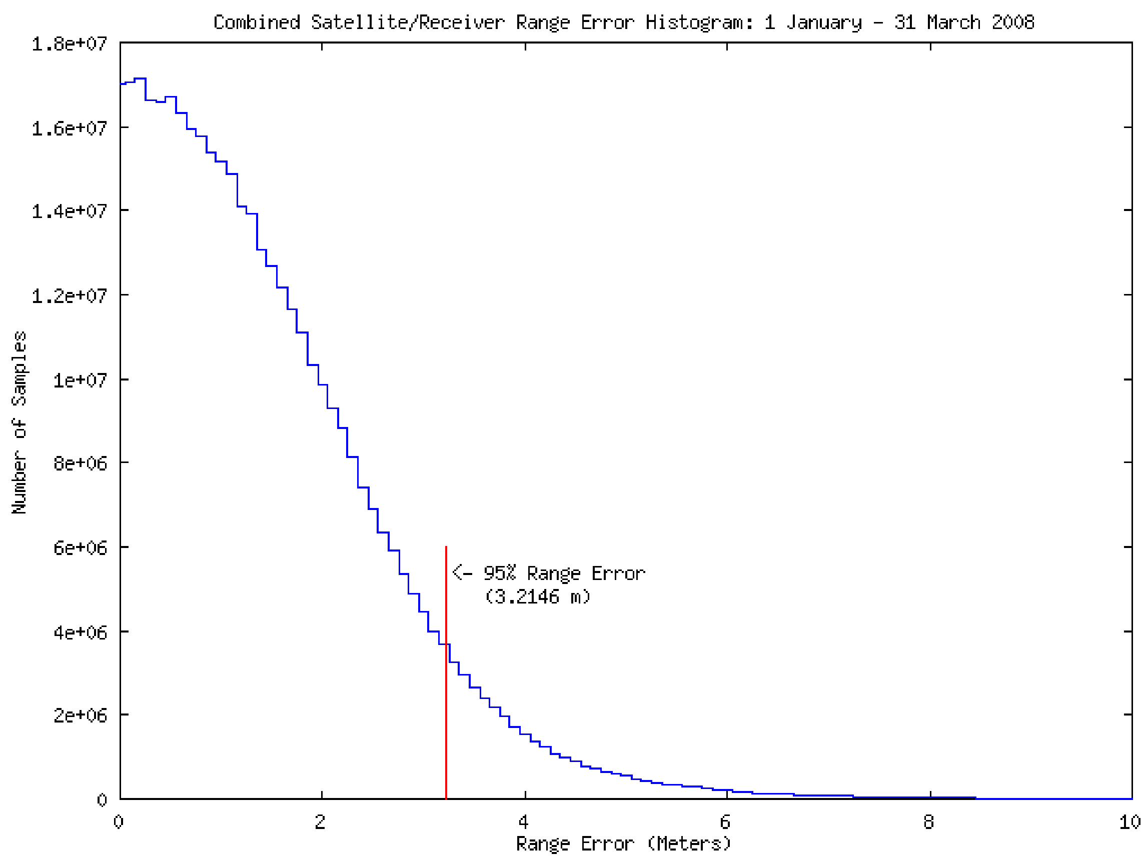


Figure 5-7: Range Error Histogram



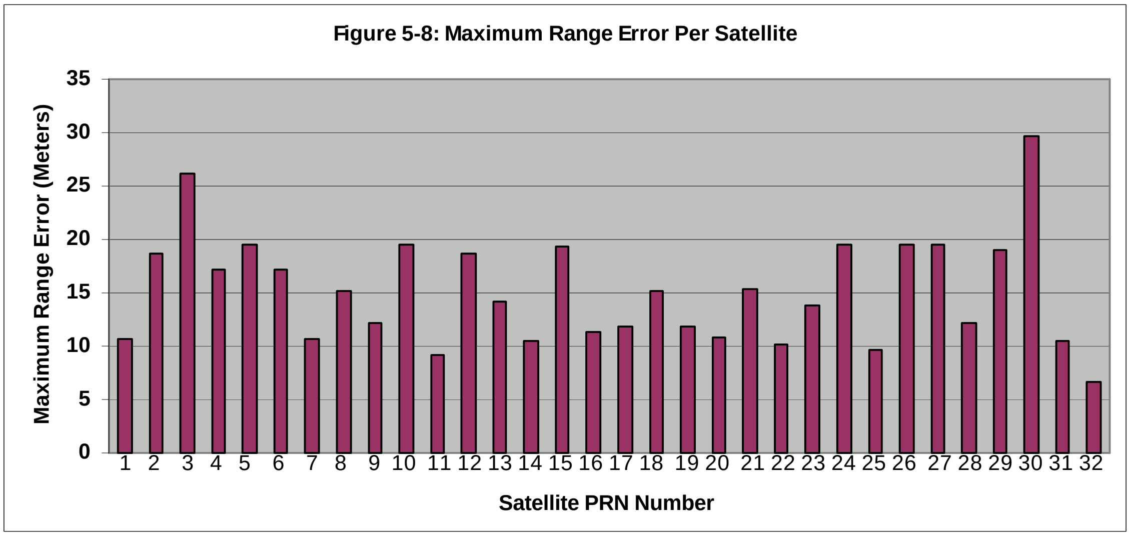


Figure 5-8: Maximum Range Error Per Satellite
Maximum Range Error (Meters)
0
5
10
15
20
25
30
35
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

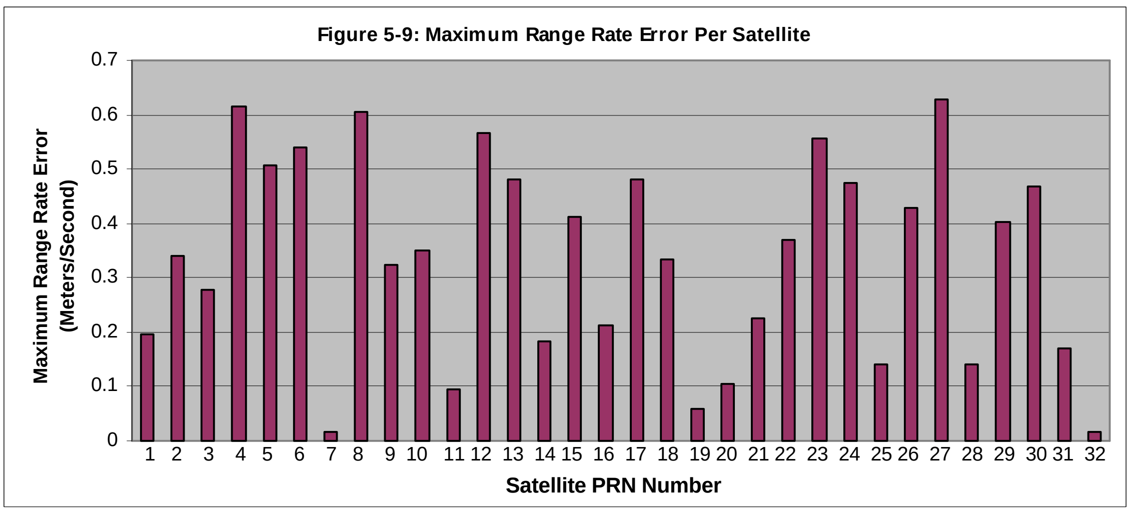


Figure 5-9: Maximum Range Rate Error Per Satellite
Maximum Range Rate Error (Meters/Second)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

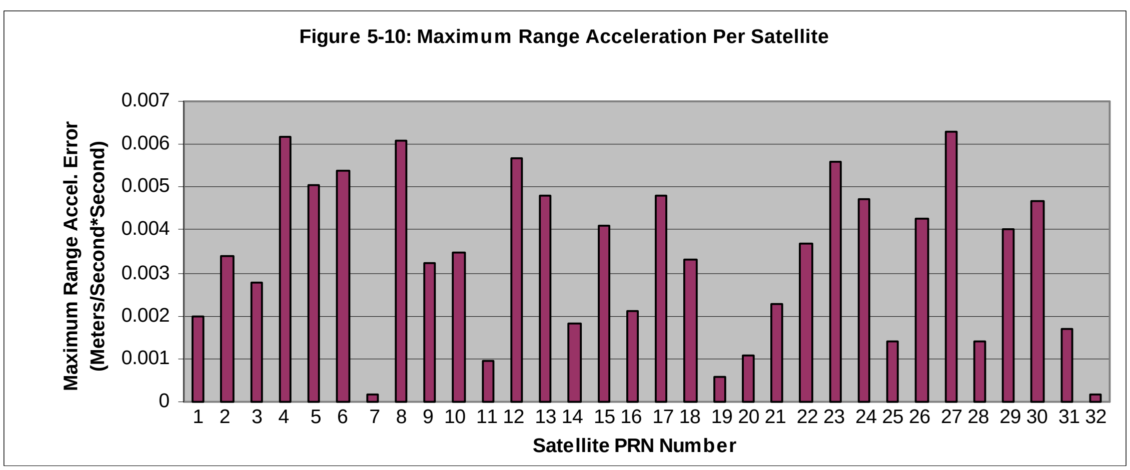


Figure 5-10: Maximum Range Acceleration Per Satellite
Maximum Range Accel. Error (Meters/Second*Second)
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

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 26-28 March 2008

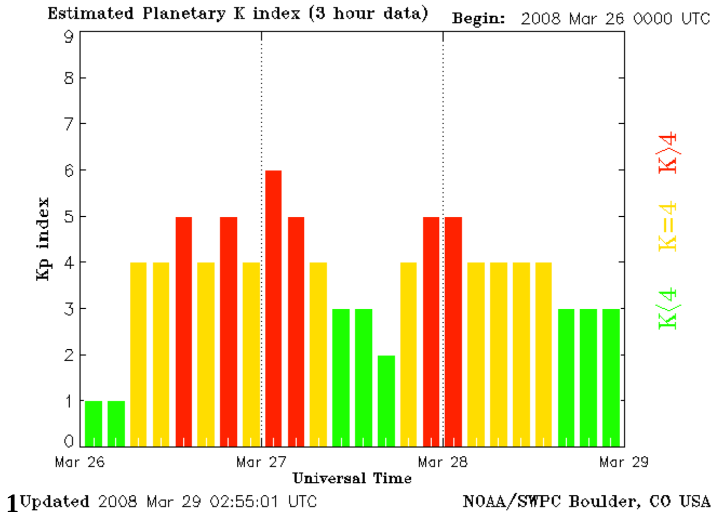


Figure 6-2 K-Index for 28 February-1 March 2008

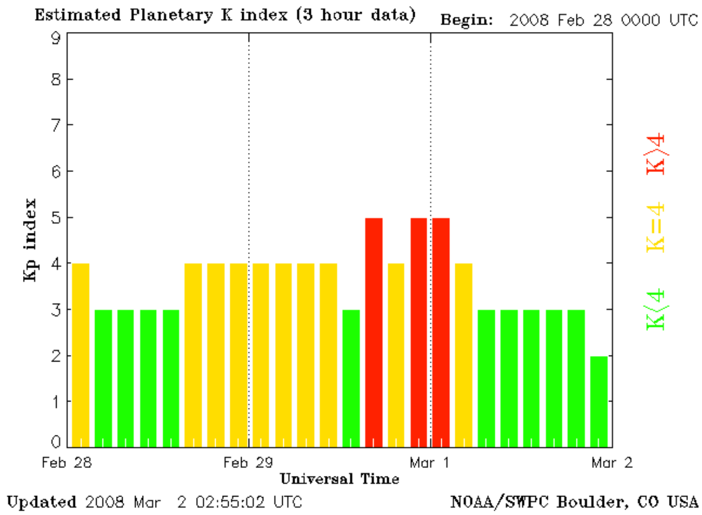
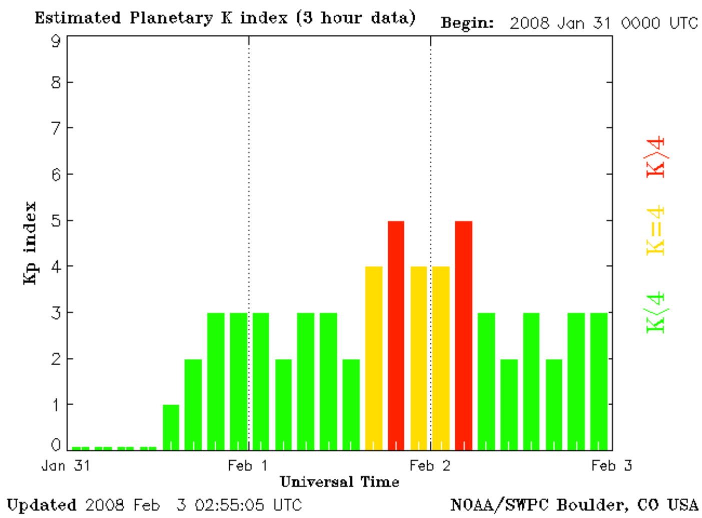


Figure 6-3 K-Index for 31January-2 February 2008



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 27 March 2008

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Albuquerque	2.770	4.090	3.820	5.470
Anchorage	1.930	5.600	3.080	7.120
Atlanta	2.650	4.210	3.530	5.190
Barrow	1.700	5.450	2.010	6.680
Bethel	2.150	5.930	2.910	7.290
Billings	2.840	4.110	3.270	5.980
Boston	3.110	4.330	3.530	5.440
Cleveland	2.940	3.730	3.350	5.010
Cold Bay	2.400	5.960	4.050	6.900
Fairbanks	1.980	5.600	3.170	7.930
Gander	2.990	5.110	3.490	8.320
Honolulu	3.980	4.780	4.780	7.380
Houston	2.450	4.140	3.140	5.330
Iqaluit	1.850	4.800	2.730	5.820
Juneau	1.990	4.890	2.180	7.080
Kansas City	2.920	3.490	5.580	5.080
Kotzebue	1.900	5.470	2.730	6.290
Los Angeles	2.390	5.930	3.320	8.470
Merida	2.740	4.620	4.300	6.310
Miami	2.180	4.820	2.660	5.660
Minneapolis	2.910	3.360	4.590	3.880
Oakland	2.340	5.920	2.910	9.200
Salt Lake City	2.700	4.480	3.390	5.740
San Jose Del Cabo	2.740	4.550	3.670	5.500
San Juan	2.580	5.400	3.130	7.380
Seattle	5.540	5.320	6.260	9.020
Tapachula	2.900	4.380	3.370	5.460
Washington, DC	2.770	4.090	3.820	5.470

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	≥ 99.984% ≥ 98.889%
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)	11.706 m 5.800 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)	13.428 m 15.506 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	4.093 meters

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

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2008 01 01	2	1 1 0 0 0 1 1 0	2	1 0 1 1 1 0 0 0	3	1 1 0 0 1 1 0 1
2008 01 02	1	0 0 0 0 0 1 1 0	0	0 0 0 1 0 0 0 0	1	0 0 0 0 0 0 0 0
2008 01 03	1	0 0 0 0 0 1 1 0	1	0 0 1 1 0 0 0 0	1	0 0 0 0 0 0 0 0
2008 01 04	2	0 0 0 1 1 1 1 2	1	0 0 0 2 0 0 0 1	2	0 0 0 0 0 1 0 2
2008 01 05	13	2 2 3 3 3 2 2 4	29	1 2 3 5 6 5 3 3	18	2 2 4 4 4 4 3 4
2008 01 06	12	2 4 2 2 2 3 3 2	21	3 2 3 4 5 4 3 3	13	2 4 2 2 3 3 3 3
2008 01 07	10	4 3 2 2 2 1 1 2	23	3 3 3 6 5 1 0 2	12	4 4 2 3 3 0 1 2
2008 01 08	11	3 2 2 3 1 3 3 2	16	1 2 3 4 3 4 4 2	13	2 3 2 2 1 4 4 2
2008 01 09	6	3 1 2 1 1 1 2 1	9	3 2 3 3 3 1 1 1	6	3 2 2 1 1 0 1 1
2008 01 10	2	2 0 1 0 1 1 1 0	2	0 0 0 2 2 0 1 0	3	2 0 0 1 1 1 0 1
2008 01 11	2	1 1 1 2 0 0 1 0	1	0 0 0 2 0 0 1 0	2	1 0 1 1 0 0 1 1
2008 01 12	4	0 0 1 1 1 3 2 1	11	0 0 1 3 2 5 3 1	9	0 0 1 1 2 4 3 2
2008 01 13	9	3 2 1 1 3 3 2 1	24	1 1 1 3 6 5 4 3	11	3 2 2 1 3 3 3 2
2008 01 14	14	3 2 2 4 3 2 3 3	30	2 2 4 6 4 5 4 3	16	3 3 3 4 3 3 3 3
2008 01 15	7	3 2 2 1 2 2 1 1	19	3 2 3 5 5 3 0 1	8	3 2 2 2 3 2 0 2
2008 01 16	9	3 2 2 2 2 2 1 3	22	2 2 4 5 5 3 2 3	11	3 3 3 3 2 2 2 3
2008 01 17	7	2 1 1 1 2 2 2 3	16	3 1 2 4 5 3 2 1	10	3 1 1 2 2 2 2 3
2008 01 18	10	3 3 3 2 2 2 2 1	20	3 2 3 3 5 5 2 1	10	3 3 3 1 2 3 2 2
2008 01 19	6	1 1 2 2 2 3 1 1	28	1 1 5 6 5 4 2 2	9	1 1 3 3 3 3 1 2
2008 01 20	4	0 2 2 1 2 1 1 1	5	0 2 2 2 2 0 1 2	6	1 3 2 1 2 1 2 2
2008 01 21	3	0 1 1 1 1 1 2 1	6	0 1 2 3 3 1 2 0	4	1 1 1 1 1 1 1 1
2008 01 22	2	0 1 0 0 0 1 1 1	0	0 0 0 0 0 1 0 0	2	0 1 0 0 0 1 0 1
2008 01 23	3	0 0 1 1 2 2 1 1	1	0 0 0 0 0 0 1 1	3	0 0 1 0 0 1 1 2
2008 01 24	3	2 1 1 1 1 1 1 0	4	0 0 2 2 3 1 1 0	5	1 1 2 1 2 1 2 2
2008 01 25	8	2 3 3 2 1 1 2 1	8	1 3 3 3 1 1 1 2	11	2 4 3 2 1 1 3 2
2008 01 26	6	3 2 1 2 1 2 0 1	8	2 1 1 4 3 1 2 0	5	2 2 1 2 2 1 1 1
2008 01 27	2	1 0 0 0 0 1 1 1	1	0 0 0 0 1 1 1 1	2	1 0 0 0 0 1 1 2
2008 01 28	2	0 1 0 1 1 1 1 1	4	0 0 0 3 2 0 1 1	2	1 1 0 1 0 0 0 2
2008 01 29	3	1 2 2 1 1 0 0 0	3	1 2 2 2 1 0 0 0	4	1 2 1 2 1 0 0 0
2008 01 30	1	0 1 0 0 0 1 0 0	1	1 2 0 0 0 0 0 0	2	1 2 0 0 0 0 0 1
2008 01 31	3	0 0 0 0 1 2 2 2	2	0 0 0 0 0 1 2 2	5	0 0 0 0 1 2 3 3
2008 02 01	10	2 2 3 2 2 2 3 3	25	3 2 2 5 3 5 5 3	18	3 2 3 3 2 4 5 4
2008 02 02	19	5 5 2 2 3 2 3 2	28	4 4 4 4 6 2 3 3	19	4 5 3 2 3 2 3 3
2008 02 03	10	3 2 2 3 2 2 3 2	35	3 2 5 6 5 5 3 3	12	3 2 3 3 2 3 3 2
2008 02 04	6	3 2 1 2 2 1 1 1	10	3 2 2 4 2 2 1 1	6	3 2 1 2 1 1 1 1
2008 02 05	2	2 1 0 0 1 0 1 0	3	1 1 0 0 2 2 0 1	3	2 1 0 0 1 1 1 1
2008 02 06	2	0 0 1 0 1 1 1 1	3	0 0 0 0 1 2 2 1	4	0 0 0 0 1 1 3 2
2008 02 07	6	3 2 0 0 1 2 1 3	5	2 2 0 0 0 3 1 2	5	2 2 0 0 0 2 0 2
2008 02 08	3	1 1 1 0 1 0 1 2	2	2 0 1 1 0 0 1 1	4	2 0 1 1 1 0 1 2
2008 02 09	2	0 0 0 0 1 1 1 1	5	0 0 0 1 4 2 1 1	2	1 0 0 0 2 0 1 1
2008 02 10	13	1 2 3 3 3 3 3 3	42	0 2 3 5 7 6 4 3	18	0 2 3 2 4 5 3 3
2008 02 11	16	3 4 3 4 4 2 1 2	31	2 3 4 6 6 4 2 2	17	4 3 2 4 4 3 2 2
2008 02 12	6	2 2 2 2 2 2 1 1	22	1 2 3 6 5 3 2 1	11	2 3 3 3 3 3 2 2
2008 02 13	10	3 3 3 2 3 2 1 1	26	1 1 4 5 6 4 3 1	12	2 2 3 2 4 3 2 2
2008 02 14	10	2 2 1 2 2 1 4 3	16	2 1 3 3 5 2 3 3	15	2 1 2 1 3 1 5 4
2008 02 15	8	2 3 3 2 2 1 1 1	26	1 2 3 6 6 3 2 1	10	2 3 3 3 3 2 1 1
2008 02 16	8	3 3 2 2 2 1 2 0	12	1 2 3 4 4 2 2 1	9	3 3 2 2 3 2 2 1
2008 02 17	3	0 2 1 1 1 1 1 0	6	0 2 2 3 3 0 0 0	5	1 1 2 2 2 1 1 1
2008 02 18	9	1 1 1 3 3 2 2 3	27	0 0 2 5 6 5 3 3	12	1 1 2 4 3 3 3 3
2008 02 19	10	3 3 3 2 2 2 2 1	29	2 3 5 5 6 4 2 1	12	3 3 3 2 3 2 2 2
2008 02 20	5	2 3 2 1 1 1 0 0	9	1 1 4 4 2 2 0 0	7	2 3 3 1 1 1 1 1
2008 02 21	3	0 0 1 1 2 2 1 0	8	0 0 2 3 4 3 1 0	6	0 0 1 2 3 2 1 1
2008 02 22	3	0 1 3 1 1 1 0 0	5	0 0 2 3 3 1 0 0	4	0 2 2 1 1 1 0 1
2008 02 23	3	0 0 1 0 1 2 2 1	4	0 0 1 1 2 3 1 1	4	0 0 1 0 1 1 2 1
2008 02 24	2	1 1 0 0 1 1 1 0	0	0 0 0 1 0 0 0 0	3	1 0 0 1 1 1 2 1
2008 02 25	1	1 0 1 1 0 0 0 0	2	0 1 2 2 0 0 0 0	3	1 1 1 2 0 1 0 0
2008 02 26	2	0 2 0 0 1 0 1 1	2	0 0 0 1 2 2 0 0	3	0 1 1 0 2 1 0 1
2008 02 27	6	2 2 1 0 1 2 3 2	8	1 1 0 1 3 3 3 2	12	2 2 0 1 2 3 5 3

2008 02 28	17	4	3	2	3	3	3	3	4	27	2	3	3	6	4	4	4	3	22	4	3	3	3	3	4	4	4
2008 02 29	18	3	3	3	3	2	3	3	5	44	3	4	5	6	5	6	4	4	27	4	4	4	4	3	5	4	5
2008 03 01	13	5	2	2	2	3	2	2	2	44	5	5	5	6	6	4	3	2	19	5	4	3	3	3	3	3	2
2008 03 02	8	2	2	3	2	2	2	1	2	12	2	2	3	4	3	3	1	1	8	2	2	3	2	2	2	1	2
2008 03 03	4	2	2	1	1	1	1	1	0	7	2	2	1	4	1	2	1	0	5	3	2	1	2	1	1	1	0
2008 03 04	3	1	2	2	0	1	0	0	0	4	0	1	3	2	2	0	0	0	4	1	2	2	1	1	1	0	1
2008 03 05	7	1	2	2	2	3	2	1	1	19	1	1	3	5	5	4	1	1	8	1	1	2	3	3	2	1	2
2008 03 06	2	0	0	0	0	1	2	0	1	1	1	0	0	0	1	1	0	0	2	0	0	0	0	1	2	0	1
2008 03 07	1	1	0	1	0	1	0	0	0	1	0	0	1	1	0	0	0	0	3	1	1	1	0	1	1	1	1
2008 03 08	6	0	0	1	1	3	2	3	1	22	0	0	0	3	6	4	5	1	11	0	0	1	1	4	4	3	1
2008 03 09	14	3	4	3	3	2	2	2	3	41	3	5	6	6	5	4	3	3	25	4	5	5	3	3	2	2	4
2008 03 10	12	3	3	2	3	2	2	3	3	25	4	4	3	5	4	4	3	3	18	4	4	2	3	4	2	3	4
2008 03 11	7	2	2	3	2	3	2	2	1	25	3	2	4	5	6	3	2	1	12	3	1	4	2	4	3	1	2
2008 03 12	9	2	3	3	2	1	1	3	2	15	2	2	4	4	3	2	3	3	14	2	4	4	2	1	1	4	2
2008 03 13	11	3	3	2	2	3	2	3	1	33	2	2	2	7	6	3	2	1	14	2	3	2	4	4	3	3	2
2008 03 14	12	3	3	3	1	2	3	2	3	22	2	2	4	4	4	5	3	3	13	2	3	3	2	2	4	3	3
2008 03 15	7	2	2	2	3	2	1	2	1	33	4	2	4	7	5	2	1	1	11	3	3	1	4	3	2	1	1
2008 03 16	4	2	2	1	0	1	1	1	1	7	2	2	2	1	3	2	1	1	5	2	2	1	0	1	1	1	2
2008 03 17	3	2	0	0	0	1	2	2	1	4	2	0	1	2	0	2	2	1	4	2	0	0	0	1	2	2	1
2008 03 18	7	3	3	2	1	1	1	1	1	8	2	2	3	2	3	2	1	1	8	3	4	1	1	1	1	0	1
2008 03 19	5	0	0	2	0	3	2	2	2	10	0	0	1	0	5	3	2	2	6	0	1	1	1	3	3	1	2
2008 03 20	7	2	1	1	2	3	2	2	1	16	2	1	1	4	6	2	1	0	8	2	1	1	1	4	2	2	2
2008 03 21	4	2	1	0	0	1	1	2	2	5	1	1	2	3	1	1	1	1	5	2	1	0	1	1	2	2	2
2008 03 22	4	2	0	1	1	1	1	1	2	3	1	1	1	2	0	0	1	2	5	1	0	1	1	1	1	1	3
2008 03 23	7	3	1	3	2	2	1	1	1	11	2	2	2	5	3	1	1	0	8	3	3	3	2	1	1	1	1
2008 03 24	2	0	1	1	1	1	1	0	1	1	1	1	0	1	0	0	0	0	4	1	1	1	0	1	1	1	1
2008 03 25	3	0	0	0	0	2	1	2	1	1	0	0	0	0	1	0	1	1	4	0	0	0	1	1	2	2	2
2008 03 26	16	1	2	3	3	3	3	4	4	45	1	2	5	6	6	6	5	3	27	1	1	4	4	5	4	5	4
2008 03 27	19	5	4	2	3	2	2	3	4	36	5	4	5	5	3	5	4	4	31	6	5	4	3	3	2	4	5
2008 03 28	13	4	3	3	3	3	1	2	2	53	5	4	6	7	6	4	3	2	21	5	4	4	4	4	3	3	3
2008 03 29	6	2	2	2	1	2	1	2	2	20	3	2	4	5	5	2	1	2	8	2	3	2	2	2	1	2	3
2008 03 30	6	3	2	2	1	1	1	1	2	12	3	2	4	2	4	2	1	1	8	4	2	2	2	2	1	1	2
2008 03 31	2	1	0	0	1	1	0	1	1	5	1	1	0	3	3	0	0	1	4	2	0	0	2	1	1	1	2

Appendix C Performance Analysis (PAN) Problem Report

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

Problem Description:

There were no problems to report for the quarter.

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

General Terms and Definitions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SPS SIS User Range Error (URE) Statistic:

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

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

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

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

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

User Range Accuracy (URA): A conservative representation of each satellite's expected (1ó) SIS URE performance (excluding residual group delay) based on historical data. A URA value is provided that is representative over the curve fit interval of the navigation data from which the URA is read. The URA is a coarse representation of the URE statistic in that it is quantized to levels represented in ICDGPS200C.