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

Submitted To

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GPS Product Team
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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-one NSTB and 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 #52, includes data collected from 1 January through 31 March 2006. The next quarterly report will be issued 31 July 2006.

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 98.194% 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 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 twelve outages were reported in the NANU’s this quarter. Eight outages were scheduled while four were unscheduled.

The quarterly service availability standard was verified using 24-hour position accuracy values computed from data collected at one-second intervals. All 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 from the Billings, Montana WAAS site. 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 15.860 meters on Satellite PRN 4. The SPS specification states that the range error should never exceed 30 meters. The maximum 24-hour RMS range error value of 5.349 was recorded on satellite 19. 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 2006, the GPS performance met 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-one National Satellite Test Bed (NSTB) and WAAS reference station locations:

- Billings, MT
- Cold Bay, 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 3.88017 or better 99.9% of the time for each of the 24-hour intervals.

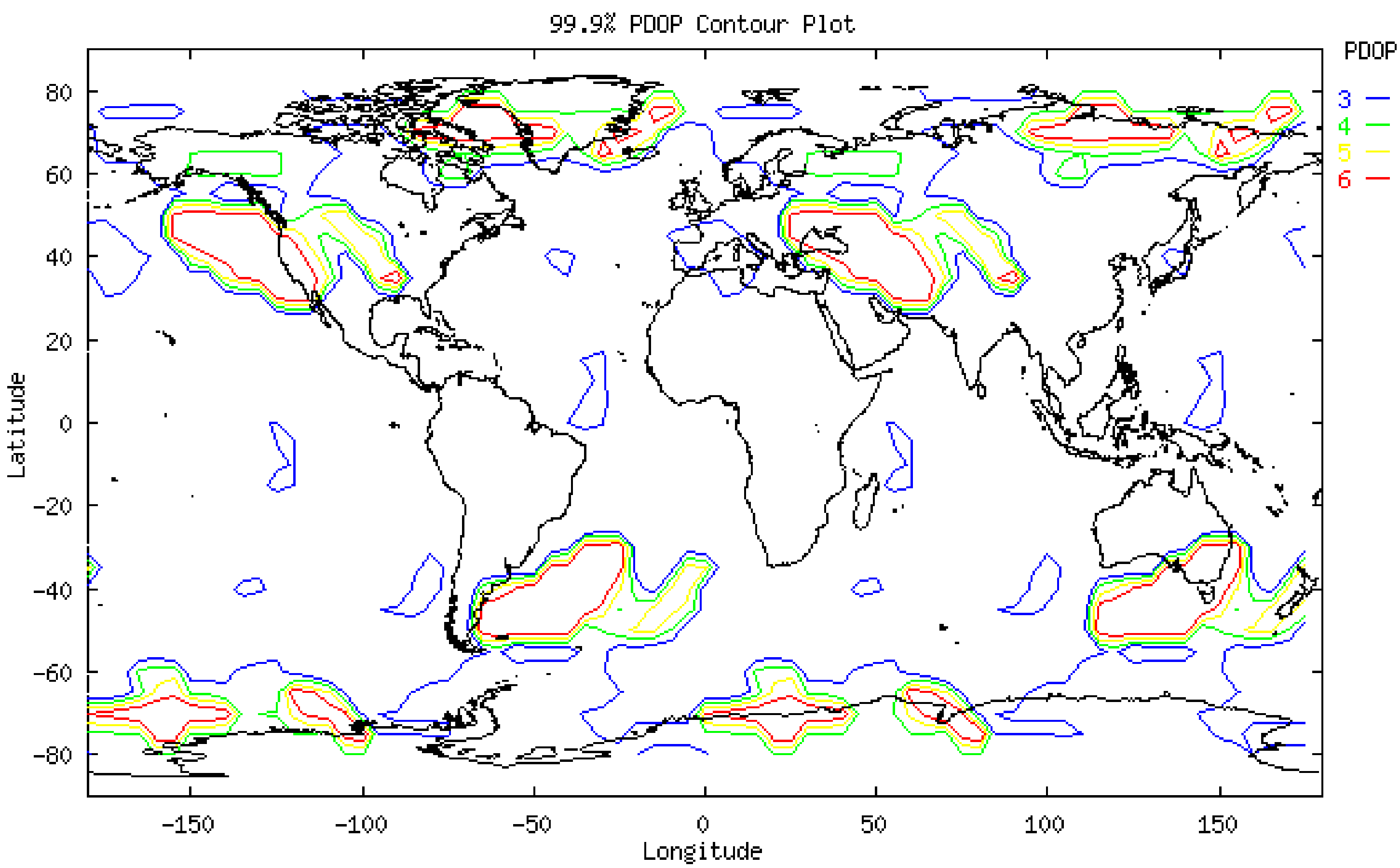
Figure 2-1 is a contour plot of PDOP values over the entire globe. Inside each contour area, the PDOP value is greater than or equal to the contour value shown in the legend for that color line. That areas' value is also less than the next higher contour value, unless another contour line lies within the current area. A single "DOP hole" where the PDOP value is greater than 6 was evaluated for satellite visibility for one 24-hour interval from the week shaded in Table 2-1. The histogram in figure 2-2 shows the satellite visibility at the DOP hole position for the 24 hour interval in question.

The GPS coverage performance evaluated met the specifications stated in the SPS.

Table 2-1 PDOP Availability Statistics

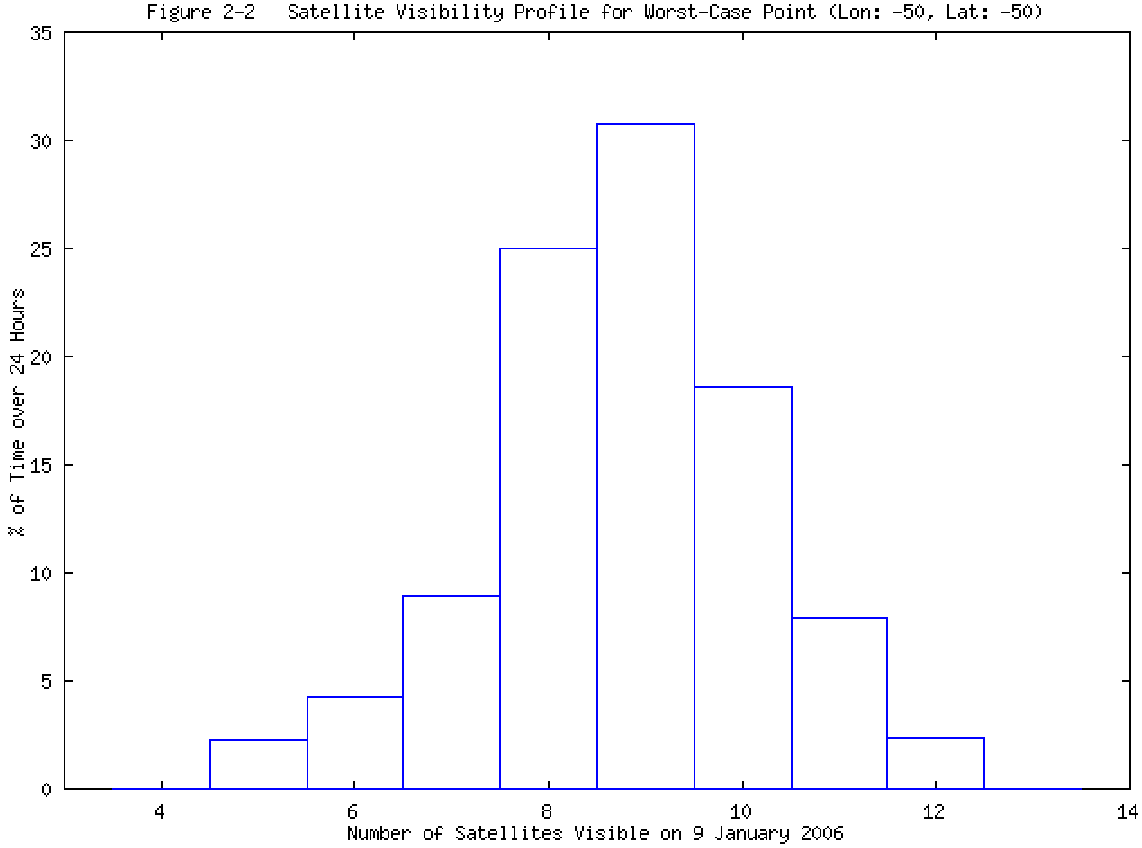
Date Range of Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
1 – 7 Jan 2006	3.22082	99.988	98.750
8 – 14 Jan 2006	3.88017	99.923	98.264
15 – 21 Jan 2006	3.21449	99.987	98.750
22 – 28 Jan 2006	3.17925	99.987	98.750
29 Jan – 4 Feb 2006	2.83707	100	100
5 – 11 Feb 2006	2.86868	100	100
12 – 18 Feb 2006	2.92780	100	100
19 – 25 Feb 2006	2.91858	100	100
26 Feb – 4 Mar 2006	2.88519	100	100
5 – 11 Mar 2006	2.91551	100	100
12 – 18 Mar 2006	3.19987	99.999	99.653
19 – 25 Mar 2006	3.19955	100	99.722
26 Mar – 1 Apr 2006	2.96291	100	100

Figure 2-1 PDOP Availability Plot (24-Hour Period: 9 January 2006)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -50, Lat: -50)



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 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
2	21	UNUSABLE	8-Jan	19:31	10-Jan	7:20	35.81		35.81
5	10	FCSTSUMM	17-Jan	2:16	17-Jan	8:30		6.23	6.23
7	7	FCSTSUMM	19-Jan	16:16	20-Jan	19:00		26.85	26.85
8	25	UNUSABLE	1-Jan	0:00	24-Jan	16:21	568.35		568.35
9	19	FCSTSUMM	24-Jan	9:40	24-Jan	17:40		8.00	8.00
13	5	FCSTSUMM	9-Feb	16:11	9-Feb	20:55		4.73	4.73
14	25	FCSTSUMM	10-Feb	16:42	10-Feb	19:13		2.51	2.51
17	30	FCSTSUMM	28-Feb	15:37	28-Feb	23:07		7.50	7.50
18	20	FCSTSUMM	2-Mar	22:39	3-Mar	5:09		6.50	6.50
22	4	FCSTSUMM	16-Mar	14:17	16-Mar	20:46		6.48	6.48
28	30	UNUSABLE	11-Mar	2:00	27-Mar	21:29	403.48		403.48
29	25	UNUSABLE	22-Mar	1:49	28-Mar	1:44	143.91		143.91
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**1151.55**	**68.80**	**1220.35**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
1	21	UNUSUFN	8-Jan	19:31	N/A	N/A	N/A	See NANU 2
3	10	FCSTDV	17-Jan	2:15	17-Jan	14:15	12	See NANU 5
4	7	FCSTDV	19-Jan	16:15	21-Jan	16:15	48	See NANU 7
6	19	FCSTDV	24-Jan	9:00	24-Jan	21:00	12	See NANU 9
11	5	FCSTMX	9-Feb	16:00	9-Feb	22:00	6	See NANU 13
12	25	FCSTMX	10-Feb	16:00	11-Feb	4:00	12	See NANU 14
15	30	FCSTDV	28-Feb	15:15	1-Mar	3:15	12	See NANU 17
16	20	FCSTDV	2-Mar	22:30	3-Mar	10:30	12	See NANU 18
19	4	FCSTDV	16-Mar	20:00	17-Mar	8:00	CANC	See NANU 21
20	30	UNUSUFN	11-Mar	2:00	N/A	N/A	N/A	See NANU 28
21	4	FCSTRESCD	16-Mar	14:00	17-Mar	2:00	12	See NANU 22
23	10	FCSTMX	22-Mar	23:00	23-Mar	11:00	CANC	See NANU 26
24	25	FCSTMX	24-Mar	15:30	25-Mar	3:30	CANC	See NANU 25
27	25	UNUSUFN	22-Mar	1:49	N/A	N/A	N/A	See NANU 29
					Total Forecast Downtime		**126**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
25	25	FCSTCANC	24-Mar	15:30	See NANU 24
26	10	FCSTCANC	22-Mar	23:00	See NANU 23

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 January - 31 Mar. 2005**	**1 October, 1999- 31 Mar. 2006**
Total Forecast Downtime (hrs):	126.00	5658.73
Total Actual Downtime (hrs):	1220.35	17197.75
Total Actual Scheduled Downtime (hrs):	68.80	3101.49
Total Actual Unscheduled Downtime (hrs):	1151.55	14096.26
Total Satellite Observed MTTR (hrs):	101.70	40.85
Scheduled Satellite Observed MTTR (hrs):	8.60	10.34
Unscheduled Satellite Observed MTTR (hrs):	287.89	16.50
# Total Satellite Outages:	12	421
# Scheduled Satellite Outages:	8	300
# Unscheduled Satellite Outages:	4	121
Percent Operational -- Scheduled Downtime:	99.89	99.80
Percent Operational -- All Downtime:	99.92	98.89

NANU 10 corrected the start time of NANU 8.

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-one NSTB/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 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 %
Bangor	7673603	0	100%
Mauna Loa	7545688	0	100%
Billings	7763746	0	100%
Cold Bay	7734457	0	100%
Juneau	7702778	0	100%
Albuquerque	7762384	0	100%
Anchorage	7757879	0	100%
Boston	7762710	0	100%
Washington, D.C.	7621748	0	100%
Honolulu	7714271	0	100%
Houston	7762306	0	100%
Kansas City	7031071	0	100%
Los Angeles	7758789	0	100%
Salt Lake City	7744277	0	100%
Miami	7762920	0	100%
Minneapolis	7753920	0	100%
Oakland	7755109	0	100%
Cleveland	7764537	0	100%
Seattle	7760121	0	100%
San Juan	7709447	0	100%
Atlanta	7617161	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 15.860 meters on satellite PRN 4.

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 2006	**Billings**	61,609,199	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 January through 31 March 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)
Bangor	3.524	5.979	11.051	16.425
Mauna Loa	6.800	8.065	11.867	22.128
Billings	2.524	4.542	5.566	8.924
Cold Bay	2.322	4.715	4.725	10.431
Juneau	2.143	4.359	4.615	10.280
Albuquerque	2.486	4.467	5.288	9.691
Anchorage	2.182	4.658	4.834	12.571
Boston	2.735	4.458	5.327	8.824
Washington, D.C.	2.738	4.716	6.014	9.575
Honolulu	4.268	5.196	7.571	11.875
Houston	2.490	4.831	5.829	12.055
Kansas City	2.694	4.815	5.482	9.845
Los Angeles	2.415	4.978	4.568	11.080
Salt Lake City	2.483	4.649	4.956	9.543
Miami	2.619	4.868	6.583	10.454
Minneapolis	2.703	4.727	4.941	9.367
Oakland	2.284	4.982	6.305	10.800
Cleveland	2.792	4.562	6.323	9.750
Seattle	2.418	4.682	4.966	9.642
San Juan	2.782	4.503	8.392	13.744
Atlanta	2.723	4.796	6.668	9.705

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-one NSTB and WAAS sites from 1 January to 31 March 2006.

Figure 5-1 Global Vertical Error Histogram

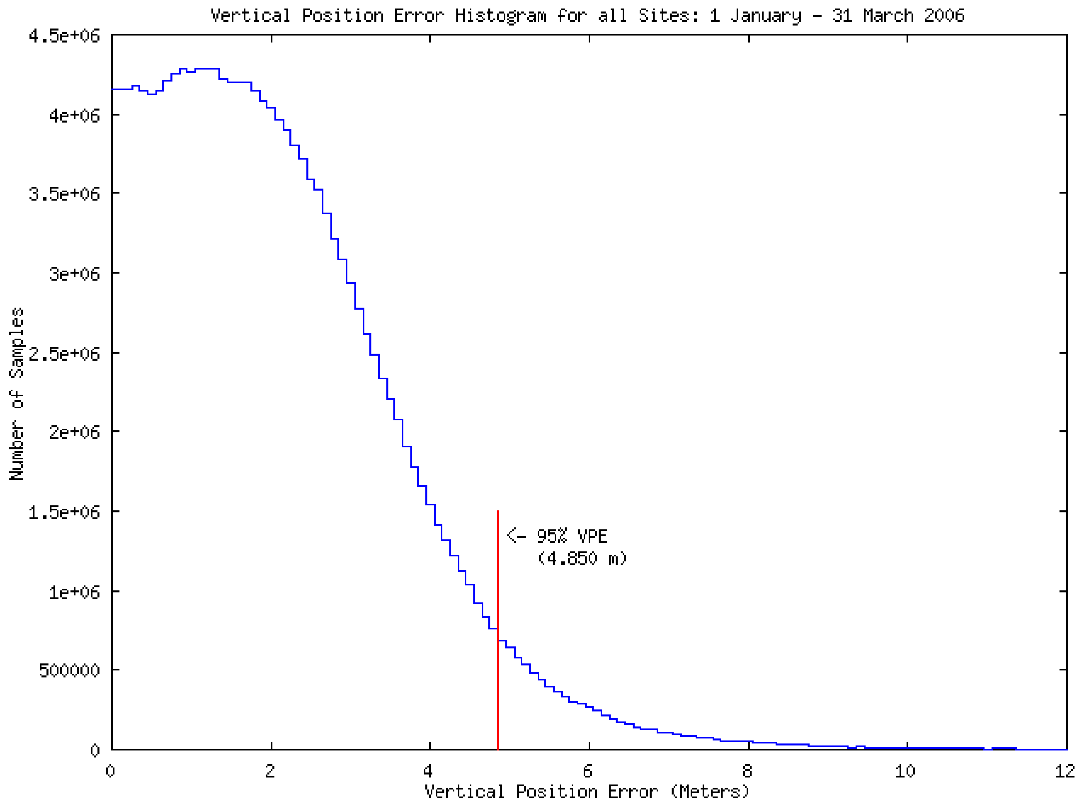
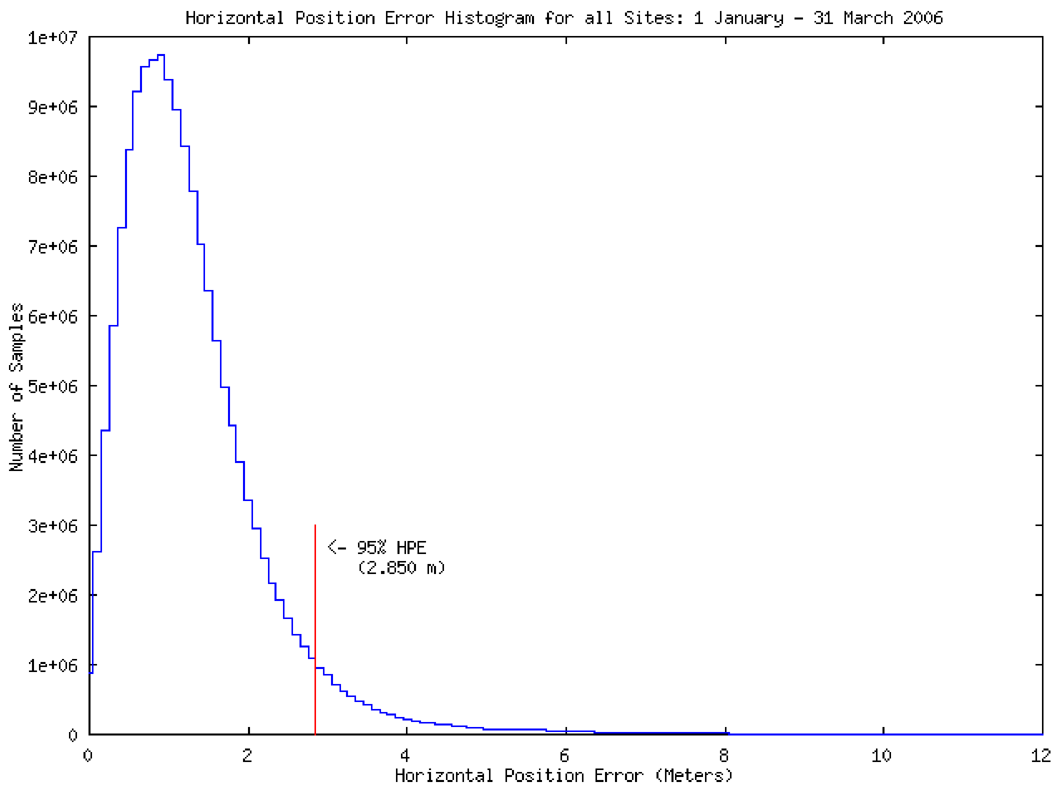


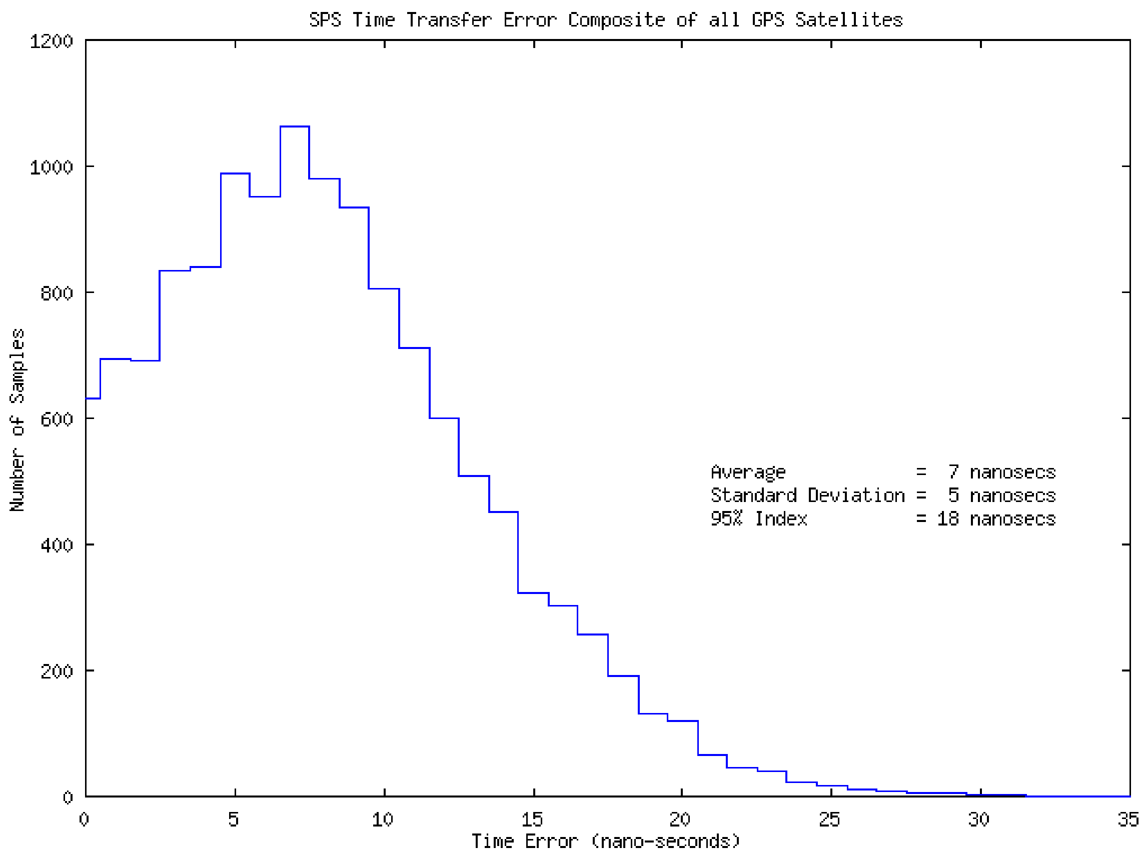
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 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 January and 31 March 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	3.987	4.646	2.384	7.720	13.372	2090599
2	2.684	3.387	2.065	5.982	9.390	1884336
3	2.736	3.485	2.158	5.973	10.625	2470077
4	1.317	2.453	2.069	5.106	15.860	2022436
5	2.169	3.066	2.167	5.883	9.822	2173679
6	1.647	2.590	1.999	5.156	7.442	1892660
7	2.037	2.633	1.669	4.736	7.980	1997628
8	2.848	3.533	2.091	6.412	9.416	1957494
9	1.836	2.647	1.907	5.026	8.417	2446099
10	3.357	4.243	2.594	7.459	12.563	2323824
11	3.405	4.033	2.163	6.475	9.381	2485289
13	2.821	3.343	1.794	5.761	8.607	1838909
14	4.166	4.728	2.235	7.133	12.549	1971655
15	3.381	4.265	2.601	7.522	15.487	1982162
16	3.270	3.964	2.240	6.609	10.185	2429281
17	1.929	2.700	1.889	5.062	8.579	1969919
18	3.551	4.084	2.018	6.450	9.091	2069057
19	4.636	5.349	2.668	8.014	10.758	2462505
20	3.747	4.395	2.297	6.966	13.099	2160571
21	3.651	4.289	2.251	7.060	9.342	2024203
22	3.863	4.453	2.2147	6.914	10.362	2114339
23	4.726	5.318	2.438	8.057	10.508	1973574
24	2.005	2.914	2.114	5.416	9.414	2445715
25	3.350	4.099	2.362	7.143	10.850	1213869
26	2.146	2.802	1.802	4.882	7.991	2498589
27	2.732	3.475	2.147	6.165	8.731	2099739
28	3.407	4.005	2.105	6.755	9.461	2130860
29	2.540	3.215	1.971	5.594	10.033	2559356
30	1.984	2.817	2.001	5.159	10.163	1905086

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	-0.00004	0.00292	0.00292	0.00362	0.19876	2090599
2	-0.00003	0.00186	0.00186	0.00360	0.05977	1884336
3	0	0.00245	0.00245	0.00366	0.17093	2470077
4	-0.00004	0.00406	0.00406	0.00448	0.35972	2022436
5	0.00009	0.00228	0.00228	0.00377	0.20718	2173679
6	0.00008	0.00254	0.00254	0.00375	0.18773	1892660
7	-0.00002	0.00186	0.00186	0.00348	0.08002	1997628
8	0.00002	0.00207	0.00207	0.00374	0.15342	1957494
9	-0.00004	0.00254	0.00254	0.00394	0.19273	2446099
10	0.00009	0.00287	0.00287	0.00405	0.23384	2323824
11	-0.00001	0.00208	0.00208	0.00368	0.20157	2485289
13	0.00002	0.00285	0.00285	0.00374	0.17673	1838909
14	0.00001	0.00234	0.00234	0.00345	0.25957	1971655
15	0.00004	0.00288	0.00287	0.00376	0.66329	1982162
16	-0.00002	0.00308	0.00308	0.00391	0.25763	2429281
17	-0.00010	0.00173	0.00172	0.00338	0.01999	1969919
18	0.00003	0.00189	0.00189	0.00351	0.15338	2069057
19	0.00002	0.00209	0.00209	0.00357	0.19494	2462505
20	-0.00001	0.00349	0.00349	0.00407	0.61048	2160571
21	0.00003	0.00207	0.00207	0.00367	0.22873	2024203
22	0.00007	0.00177	0.00177	0.00339	0.18631	2114339
23	-0.00006	0.00187	0.00187	0.00347	0.03826	1973574
24	-0.00005	0.00271	0.00271	0.00387	0.22331	2445715
25	-0.00001	0.00228	0.00228	0.00333	0.16952	1213869
26	0.00001	0.00233	0.00233	0.00351	0.25797	2498589
27	-0.00004	0.00214	0.00214	0.00363	0.16557	2099739
28	-0.00003	0.00187	0.00187	0.00341	0.16474	2130860
29	0.00005	0.00231	0.00231	0.00356	0.23081	2559356
30	0	0.00238	0.00238	0.00371	0.17487	1905086

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1σ	Max Range Acceleration Error	Samples
1	0	0.00003	0.00003	0.00200	2090599
2	0	0.00002	0.00002	0.00061	1884336
3	0	0.00002	0.00002	0.00171	2470077
4	0	0.00004	0.00004	0.00356	2022436
5	0	0.00002	0.00002	0.00201	2173679
6	0	0.00002	0.00002	0.00185	1892660
7	0	0.00002	0.00002	0.00078	1997628
8	0	0.00002	0.00002	0.00153	1957494
9	0	0.00002	0.00002	0.00193	2446099
10	0	0.00002	0.00002	0.00232	2323824
11	0	0.00002	0.00002	0.00201	2485289
13	0	0.00003	0.00003	0.00176	1838909
14	0	0.00002	0.00002	0.00259	1971655
15	0	0.00003	0.00003	0.00663	1982162
16	0	0.00003	0.00003	0.00257	2429281
17	0	0.00001	0.00001	0.00022	1969919
18	0	0.00002	0.00002	0.00154	2069057
19	0	0.00002	0.00002	0.00192	2462505
20	0	0.00003	0.00003	0.00599	2160571
21	0	0.00002	0.00002	0.002119	2024203
22	0	0.00002	0.00002	0.00186	2114339
23	0	0.00002	0.00002	0.00037	1973574
24	0	0.00002	0.00002	0.00217	2445715
25	0	0.00002	0.00002	0.00170	1213869
26	0	0.00002	0.00002	0.00252	2498589
27	0	0.00002	0.00002	0.00165	2099739
28	0	0.00002	0.00002	0.00167	2130860
29	0	0.00002	0.00002	0.00231	2559356
30	0	0.00002	0.00002	0.00174	1905086

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. None of the range errors for any of the satellites exceeded the 30-meter SPS requirement. The highest maximum range error occurred on satellite 4 with an error of 15.860 meters. Satellite 6 had the lowest maximum range error of 7.442 meters.

Figure 5-4 Distribution of Daily Max Range Errors

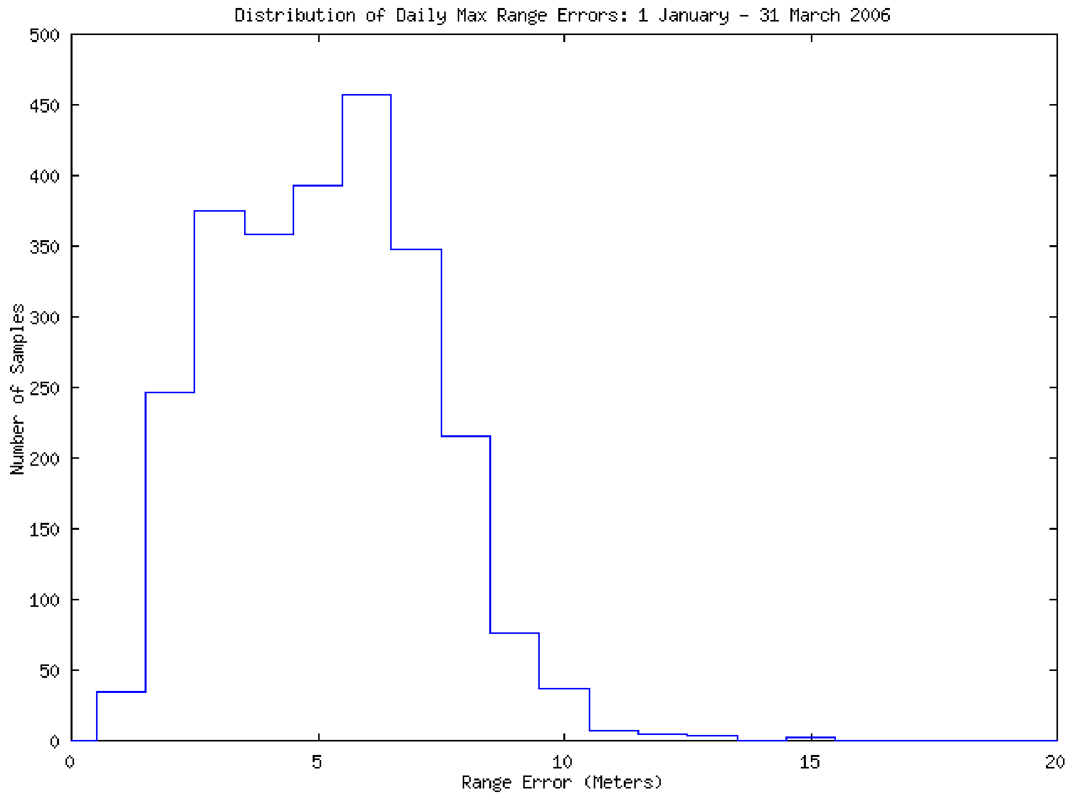


Figure 5-5: Distribution of Daily Max Range Rate Errors

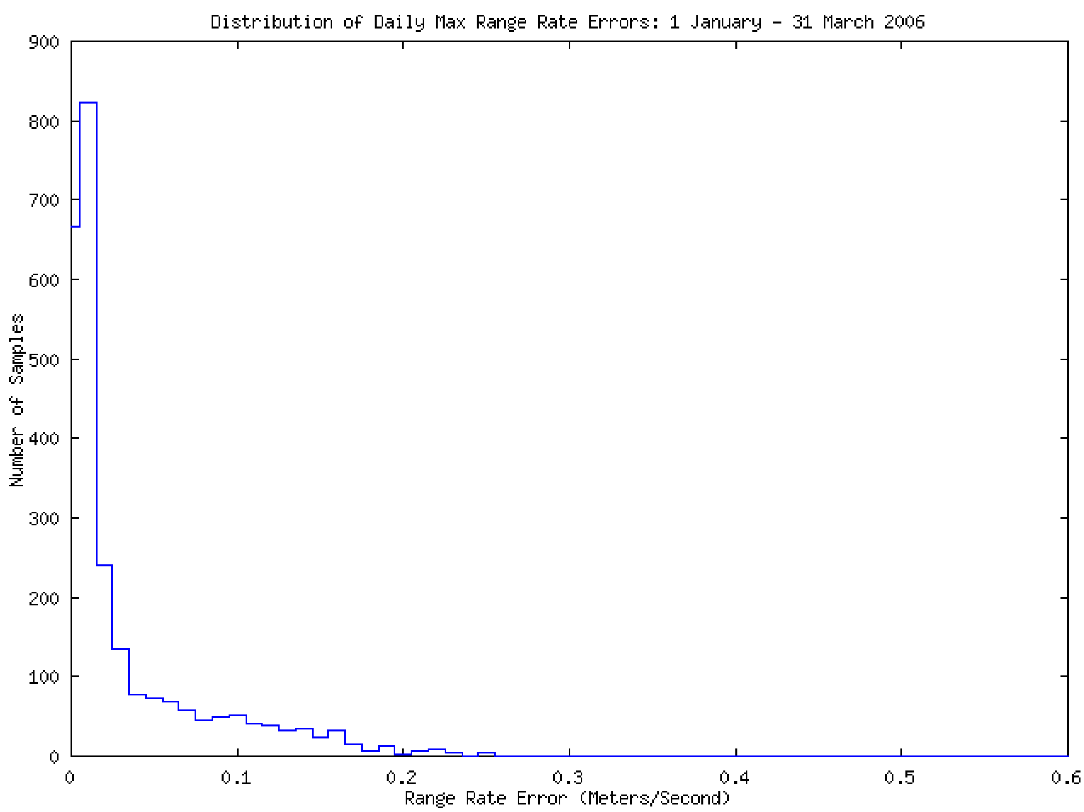


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

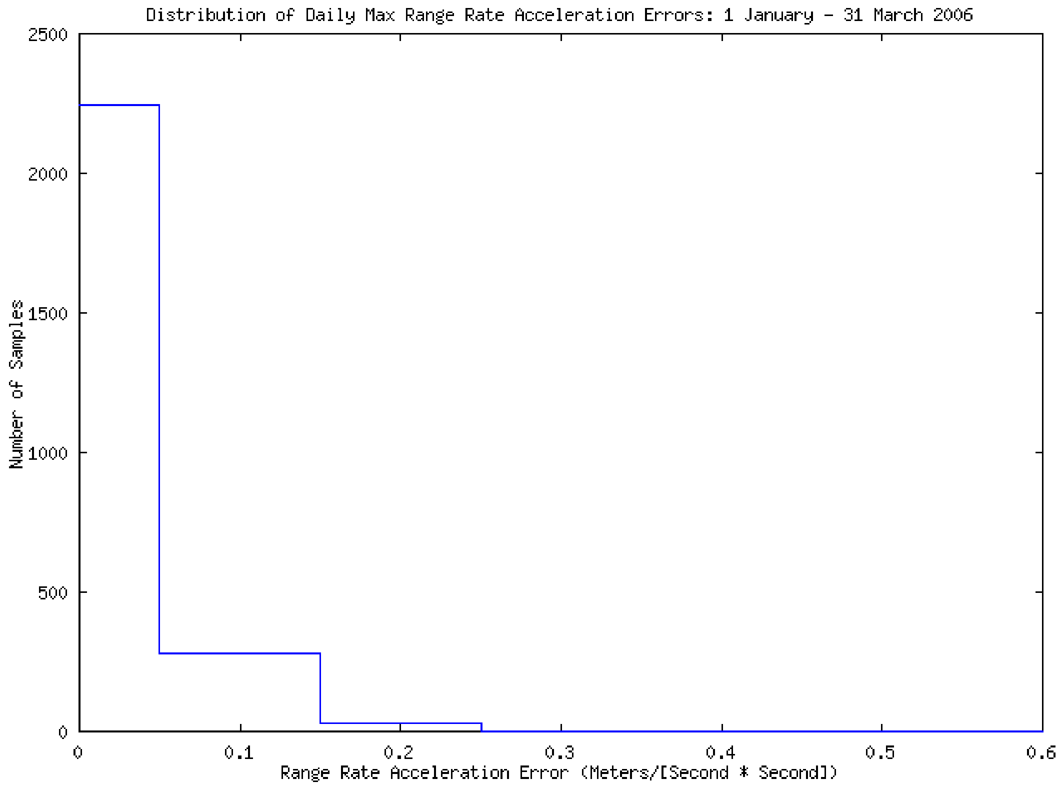


Figure 5-7: Range Error Histogram

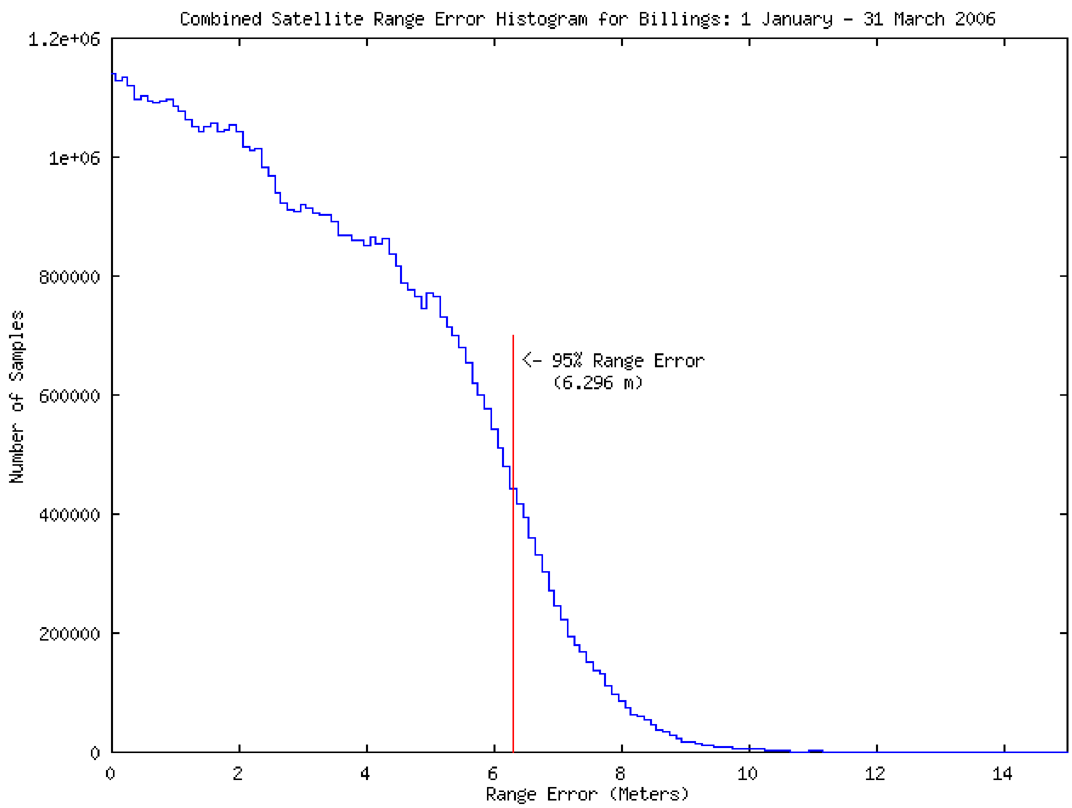


Figure 5-8: Maximum Range Error Per Satellite

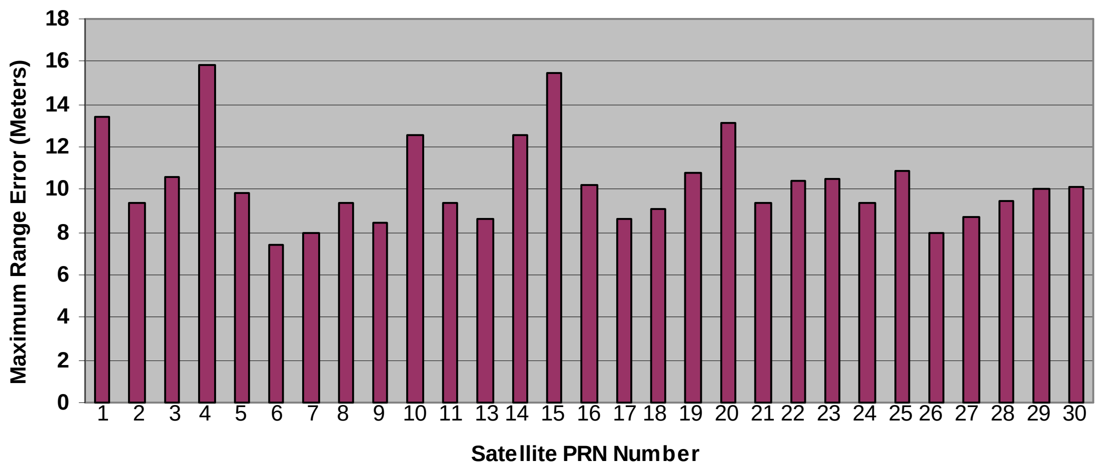


Figure 5-9: Maximum Range Rate Error Per Satellite

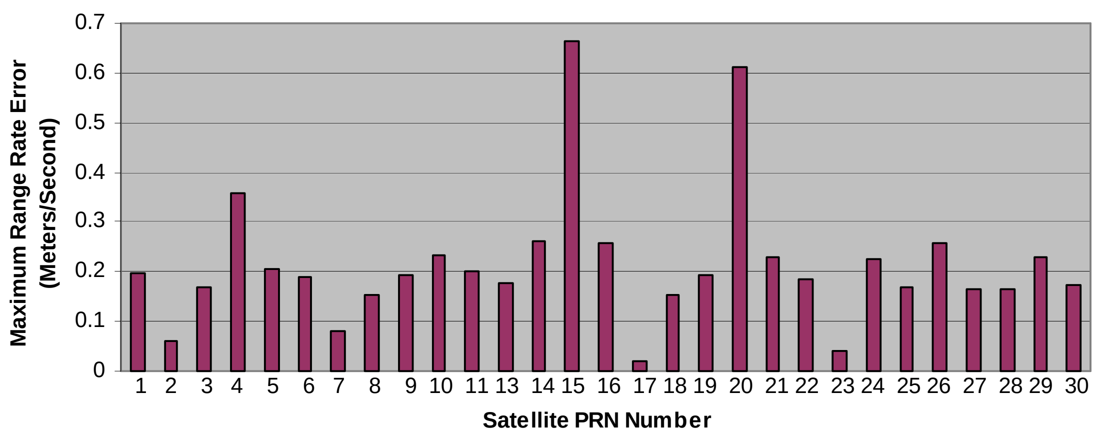
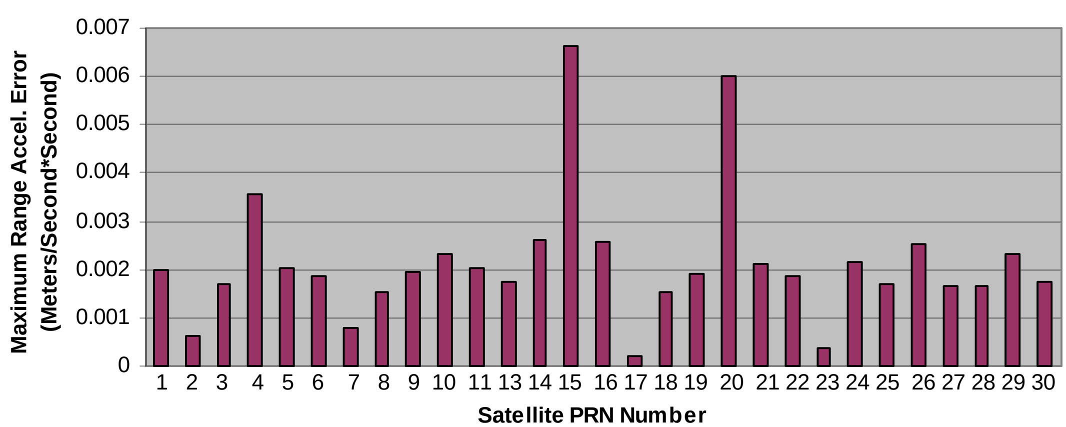


Figure 5-10: Maximum Range Acceleration Per Satellite



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 18-20 March 2006

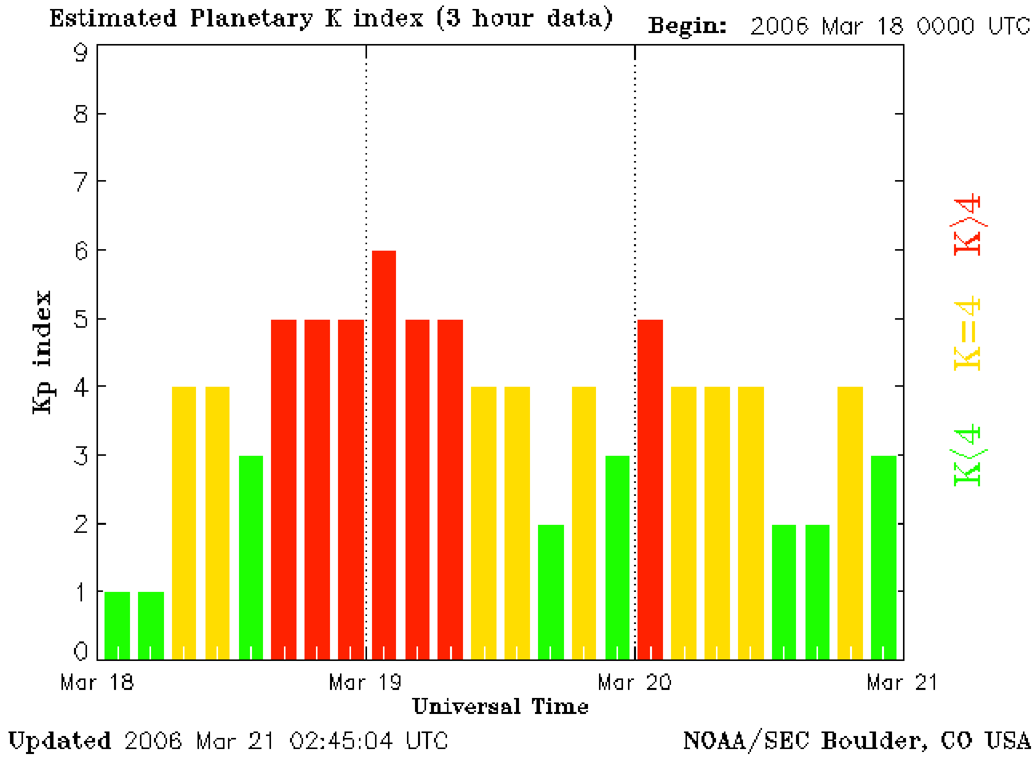


Figure 6-2 K-Index for 25-27 January 2006

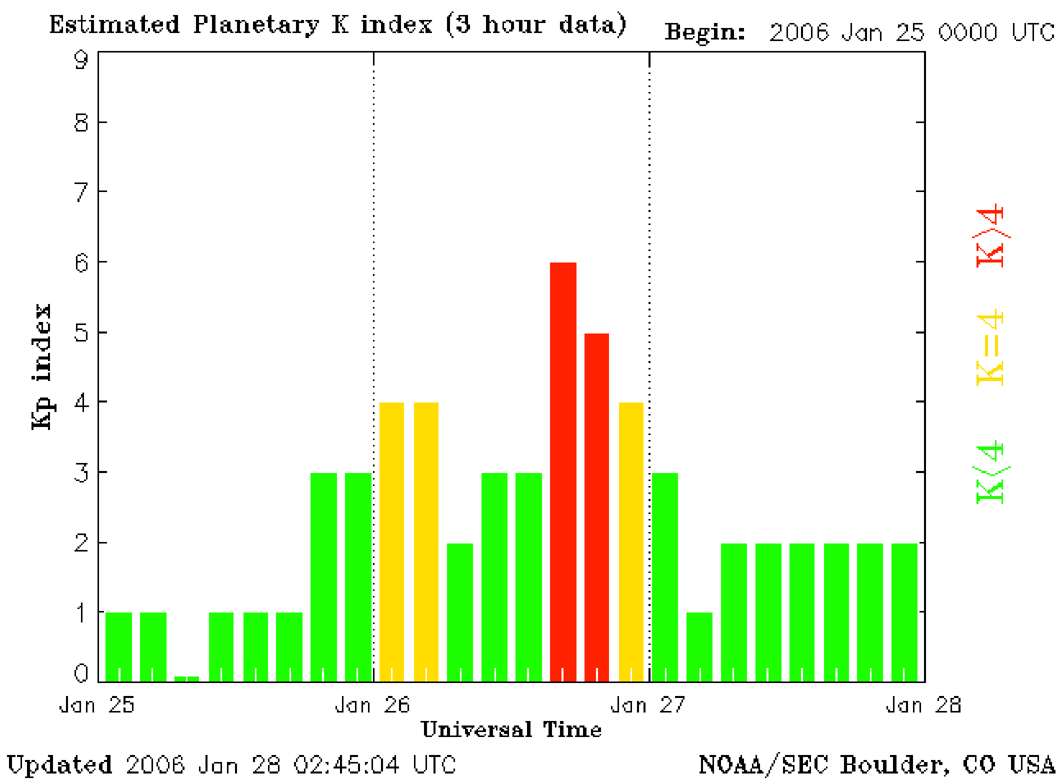
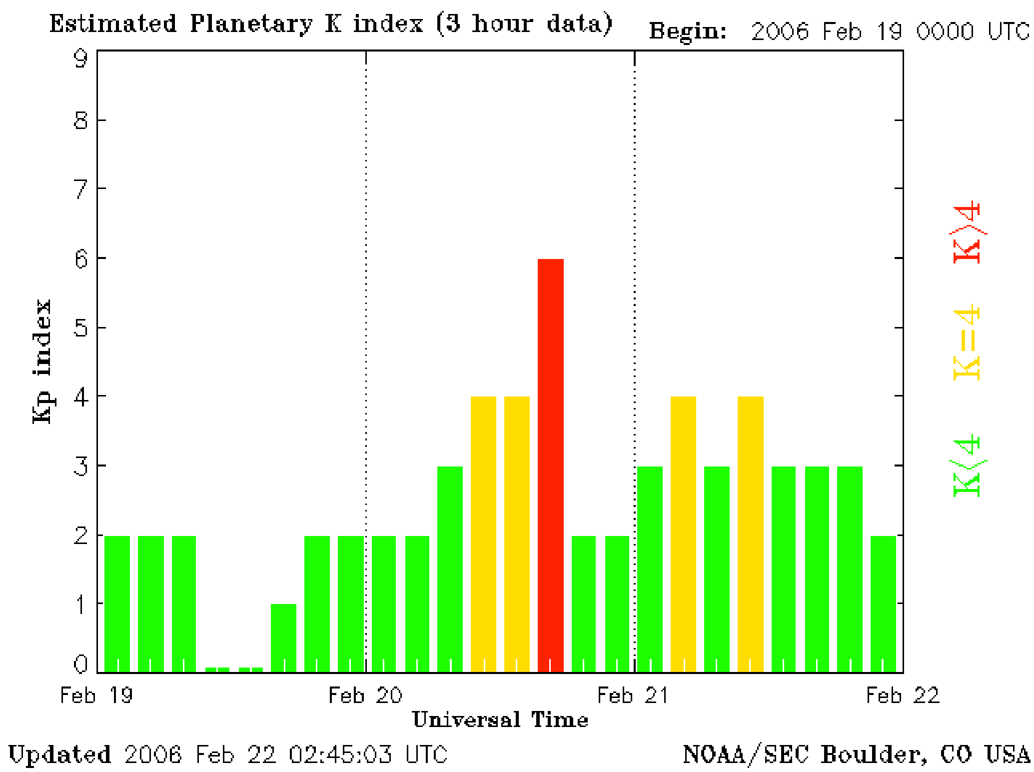


Figure 6-3 K-Index for 19-21 February 2006



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 March 2006

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Bangor	3.051	5.577	5.817	8.057
Mauna Loa	4.264	9.923	6.014	11.447
Billings	2.305	3.395	3.119	4.526
Cold Bay	2.380	4.592	3.793	6.902
Juneau	1.716	3.862	2.799	5.429
Albuquerque	2.149	3.447	3.874	4.304
Anchorage	1.695	4.814	2.899	6.718
Boston	2.666	3.630	4.097	4.537
Washington, D.C.	2.778	3.786	3.308	5.293
Honolulu	3.838	9.985	5.409	11.794
Houston	2.756	5.798	4.047	6.904
Kansas City	Site	down	this	day
Los Angeles	2.365	4.253	4.308	7.330
Salt Lake City	2.457	3.515	3.085	5.169
Miami	2.922	5.697	4.062	8.286
Minneapolis	3.045	3.592	4.082	4.322
Oakland	2.402	4.699	2.987	6.625
Cleveland	2.768	3.733	3.173	5.970
Seattle	2.511	3.973	4.181	6.018
San Juan	4.361	6.264	5.231	7.978
Atlanta	2.693	3.880	3.622	6.757

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	≥ 99.923% ≥ 98.264%
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)	2.863 m 4.930 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)	6.800 m 8.065 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)	18 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	≤ 3.687 meters

\# Prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center.
\#
\# Current Quarter Daily Geomagnetic Data
\#

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2006 01 01	5	2 1 1 1 2 2 1 1	3	2 1 1 0 1 1 1 1	4	2 1 0 0 2 1 1 1
2006 01 02	5	2 2 1 2 1 1 1 2	3	0 1 0 2 0 0 1 2	5	1 2 1 2 1 1 1 2
2006 01 03	3	2 1 0 0 1 2 1 0	2	0 0 0 1 2 2 0 0	3	2 0 0 0 1 1 1 1
2006 01 04	1	0 1 0 0 1 1 0 0	0	0 0 0 0 0 0 0 0	2	0 1 0 0 0 0 0 0
2006 01 05	3	0 0 2 2 1 1 0 1	2	0 0 1 2 1 0 0 0	3	0 0 1 2 2 0 0 1
2006 01 06	6	1 3 1 1 2 2 1 1	15	0 1 4 4 5 3 1 0	6	1 2 2 2 3 2 1 1
2006 01 07	6	1 1 3 2 2 2 1 0	7	1 0 2 2 3 4 0 0	5	1 1 2 2 1 2 1 0
2006 01 08	5	0 0 3 2 2 2 0 0	6	0 0 2 3 3 2 1 0	4	0 1 2 2 2 0 0 1
2006 01 09	1	0 1 0 0 1 0 0 0	0	0 0 0 0 0 0 0 0	2	0 1 0 0 0 0 1 0
2006 01 10	2	0 0 0 0 2 2 0 0	1	1 0 0 1 0 1 0 0	1	0 0 0 0 0 1 0 0
2006 01 11	1	0 0 0 0 2 1 0 0	2	0 0 0 0 3 1 0 0	2	0 0 0 0 1 1 1 1
2006 01 12	2	1 1 1 1 0 2 0 0	1	0 0 1 2 0 0 0 0	3	1 1 1 1 0 0 0 1
2006 01 13	4	1 0 0 0 2 2 3 1	2	0 0 0 0 2 2 1 0	2	1 0 0 0 1 1 0 1
2006 01 14	2	0 0 0 1 2 2 1 0	1	0 0 0 1 0 0 0 1	3	0 1 0 1 1 1 1 1
2006 01 15	4	1 1 0 0 1 2 2 2	1	0 0 0 0 0 1 2 0	4	2 1 0 0 0 2 2 2
2006 01 16	8	0 3 3 2 2 2 2 2	19	0 1 3 5 5 4 2 0	14	0 3 2 2 4 3 4 3
2006 01 17	10	2 4 3 3 2 1 1 1	10	2 1 3 3 4 2 1 0	8	2 3 2 2 2 2 1 1
2006 01 18	9	1 2 3 4 1 2 1 1	-1	0-1-1-1-1 3 1 1	5	2 1 1 2 1 2 1 1
2006 01 19	5	1 1 2 1 2 2 1 2	10	2 3 1 4 3 2 1 1	7	2 1 2 2 3 2 1 2
2006 01 20	4	1 1 1 1 2 1 1 1	7	1 0 1 3 3 2 2 1	6	1 1 0 1 2 3 3 2
2006 01 21	4	1 3 1 1 1 1 0 0	6	1 1 1 4 3 0 0 0	4	1 2 1 1 1 0 0 1
2006 01 22	4	0 1 1 2 2 2 1 1	12	0 0 1 4 4 3 4 0	6	1 1 1 2 3 3 0 2
2006 01 23	13	1 3 3 4 3 2 2 3	27	4 3 3 6 5 3 2 2	15	1 4 3 4 3 2 2 3
2006 01 24	6	2 3 2 1 0 0 3 1	19	5 3 5 3 1 2 3 1	7	3 4 2 0 1 0 1 1
2006 01 25	8	2 0 0 2 1 1 4 3	5	0 0 0 3 0 1 2 3	7	1 1 0 1 1 1 3 3
2006 01 26	15	3 2 1 2 2 4 4 4	36	3 3 4 5 5 6 4 4	29	4 4 2 3 3 6 5 4
2006 01 27	7	3 1 2 2 2 2 2 2	13	3 2 2 4 3 3 2 2	8	3 1 2 2 2 2 2 2
2006 01 28	4	2 1 2 1 1 0 2 1	7	1 1 2 3 3 0 1 1	6	2 1 2 2 1 1 2 2
2006 01 29	1	0 1 0 0 0 0 0 0	2	1 1 1 1 0 0 0 1	3	1 1 1 0 1 1 0 0
2006 01 30	0	0 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 0	1	1 0 0 0 0 1 0 0
2006 01 31	1	0 0 0 0 1 1 1 0	1	0 0 0 0 1 1 0 0	2	0 0 0 0 1 1 0 1
2006 02 01	3	0 1 2 1 1 1 0 1	3	0 1 2 2 2 0 0 1	4	0 0 2 1 2 1 0 2
2006 02 02	1	1 0 0 1 0 0 1 1	3	0 0 0 3 2 0 1 0	3	1 0 0 1 1 0 1 2
2006 02 03	3	0 0 1 2 0 1 2 1	4	0 0 0 3 2 0 2 1	4	0 0 0 1 0 1 2 1
2006 02 04	3	1 3 1 1 1 0 0 0	6	1 1 2 3 3 1 0 0	4	1 2 2 1 1 0 0 1
2006 02 05	3	1 0 2 0 0 0 2 1	1	0 0 1 0 0 0 1 0	3	1 0 2 0 0 0 1 1
2006 02 06	11	1 3 2 2 3 2 3 3	32	0 2 4 5 7 3 2 3	12	1 4 2 2 3 2 3 3
2006 02 07	4	2 1 1 0 0 2 1 2	3	2 1 2 0 1 1 0 0	4	1 1 1 0 1 1 1 2
2006 02 08	2	2 1 2 0 0 0 0 0	2	0 0 2 2 1 0 0 0	3	2 0 2 1 1 0 0 0
2006 02 09	2	0 0 0 0 1 3 1 0	1	0 0 0 1 1 0 1 0	2	0 0 0 0 1 0 1 1
2006 02 10	2	1 0 0 0 0 0 1 2	1	0 0 0 1 0 0 0 1	2	1 0 0 0 0 0 1 2
2006 02 11	4	2 1 2 0 2 2 1 0	6	1 0 2 1 4 2 1 0	6	2 1 2 0 2 3 1 1
2006 02 12	2	1 1 1 0 1 1 0 0	2	0 2 0 0 2 1 0 0	3	2 2 1 0 1 0 0 0
2006 02 13	2	0 0 0 0 1 2 1 0	1	0 0 0 0 1 1 0 0	2	0 0 0 0 1 1 0 1
2006 02 14	1	0 0 0 0 1 0 0 1	0	0 0 0 0 0 0 0 1	1	0 0 0 0 0 0 0 1
2006 02 15	7	0 1 1 3 2 1 3 3	11	1 0 1 5 3 2 2 2	12	0 1 1 3 2 2 4 4
2006 02 16	7	2 2 2 2 2 2 2 1	17	3 2 5 5 3 0 1 1	8	3 2 3 3 1 0 1 2
2006 02 17	2	0 2 1 1 1 1 0 0	5	0 2 2 1 3 2 0 0	4	1 3 2 0 1 0 0 1
2006 02 18	2	0 0 0 1 2 0 1 1	2	0 1 0 1 2 0 0 0	2	0 0 0 0 1 0 0 1
2006 02 19	5	2 2 2 1 1 1 1 1	6	1 1 3 2 2 1 1 1	6	2 2 2 0 0 1 2 2
2006 02 20	9	1 2 2 3 3 3 2 2	45	2 2 3 6 6 7 3 3	20	2 2 3 4 4 6 2 2
2006 02 21	15	3 3 4 3 3 3 2 2	36	2 2 4 7 5 4 4 2	17	3 4 3 4 3 3 3 2
2006 02 22	11	4 3 3 2 2 2 1 1	25	3 2 3 6 5 4 2 0	12	4 3 3 3 3 2 1 2
2006 02 23	4	1 2 2 1 1 1 1 0	5	1 0 3 3 1 0 0 0	3	1 2 2 1 0 0 0 0
2006 02 24	4	2 1 0 2 2 1 2 0	13	1 0 1 5 5 1 0 0	6	2 2 0 3 3 0 0 0
2006 02 25	1	2 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 0	1	1 0 0 0 0 0 0 1
2006 02 26	3	0 2 0 0 1 1 1 2	4	0 1 0 0 2 3 1 1	5	0 2 1 0 1 2 1 2
2006 02 27	2	1 0 2 0 1 0 0 1	3	1 1 2 1 2 0 0 0	3	1 1 2 0 1 0 0 2

2006 02 28	2	0 0 0 2 0 1 1 1	7	0 0 0 5 2 0 1 0	5	0 0 0 3 2 1 1 2
2006 03 01	5	2 2 2 2 2 2 0 0	11	1 1 1 3 5 3 0 0	7	2 2 1 2 3 2 1 1
2006 03 02	4	0 1 1 0 3 2 0 1	2	0 0 1 2 2 0 0 0	4	0 1 1 1 1 1 2 1
2006 03 03	2	1 0 0 0 1 1 2 0	1	0 0 0 1 1 0 1 0	4	1 0 0 1 1 2 2 1
2006 03 04	1	0 1 2 0 0 0 0 0	1	1 0 2 0 0 0 0 0	3	0 0 1 0 0 1 0 1
2006 03 05	1	1 0 0 0 0 1 0 0	0	0 0 0 0 0 0 0 0	2	1 0 0 0 1 1 2 1
2006 03 06	8	0 0 1 1 3 3 3 3	8	0 0 0 2 4 3 2 2	8	0 0 1 1 3 3 3 3
2006 03 07	6	3 2 2 1 1 1 1 1	16	3 3 4 5 3 2 0 0	12	4 4 3 3 2 1 0 1
2006 03 08	3	2 1 0 0 2 1 1 0	2	0 0 0 2 2 0 0 1	4	2 1 0 0 1 1 1 2
2006 03 09	3	0 1 0 0 1 2 2 1	1	0 0 0 0 0 1 1 1	4	0 1 0 0 0 2 3 2
2006 03 10	9	1 2 2 2 3 2 2 3	25	1 1 5 5 5 3 2 4	12	1 3 2 3 3 2 2 4
2006 03 11	9	3 2 3 2 1 3 1 1	26	3 2 6 6 2 3 1 1	12	4 3 3 3 1 3 2 1
2006 03 12	3	0 2 1 1 1 1 2 0	4	0 0 2 3 1 1 0 0	6	0 1 2 1 1 2 2 1
2006 03 13	2	0 1 0 1 1 1 1 0	1	1 0 0 2 0 0 0 0	3	0 0 0 1 0 1 2 2
2006 03 14	2	0 0 0 1 1 1 0 1	1	0 0 0 0 2 0 0 1	4	0 0 0 1 2 2 2 2
2006 03 15	6	2 3 1 2 2 1 2 0	7	2 1 1 3 1 1 3 1	7	1 2 1 2 2 2 3 1
2006 03 16	4	0 1 2 2 2 1 1 1	12	1 2 3 5 2 3 1 0	6	1 2 2 2 1 2 1 2
2006 03 17	2	0 1 0 0 1 0 1 1	2	0 0 0 2 1 0 1 1	3	0 0 0 0 1 1 1 1
2006 03 18	15	0 1 3 3 3 3 4 4	39	0 1 4 6 5 6 5 4	26	1 1 4 4 3 5 5 5
2006 03 19	24	6 5 3 2 3 2 3 2	51	4 4 7 6 6 4 3 3	37	6 5 5 4 4 2 4 3
2006 03 20	14	4 3 3 3 1 2 3 3	40	6 5 5 6 3 4 3 2	22	5 4 4 4 2 2 4 3
2006 03 21	8	2 3 1 1 2 3 2 2	28	2 2 2 5 5 6 3 3	13	3 4 1 1 3 3 3 3
2006 03 22	9	2 3 3 1 1 1 2 2	10	2 3 3 4 1 1 1 1	10	3 4 3 1 1 1 2 3
2006 03 23	2	2 1 0 1 0 0 0 1	3	2 2 1 0 0 1 0 1	5	2 2 2 0 0 1 1 1
2006 03 24	2	1 0 0 0 1 1 1 2	2	1 0 0 1 0 1 1 1	4	1 0 0 0 1 1 2 2
2006 03 25	4	1 3 2 0 1 0 2 0	7	2 1 2 3 3 1 1 0	7	2 3 1 1 2 1 2 1
2006 03 26	5	1 2 0 1 2 1 2 2	6	0 0 0 3 3 2 2 1	7	1 1 0 1 2 2 3 3
2006 03 27	8	3 3 0 0 1 3 1 3	5	2 2 0 0 1 3 1 2	9	3 3 0 0 1 2 2 3
2006 03 28	4	0 3 1 0 1 1 1 1	4	1 2 1 0 2 1 1 1	6	1 3 1 0 1 1 2 1
2006 03 29	4	1 1 0 1 2 2 1 1	2	0 1 0 2 0 0 0 1	6	1 2 0 1 2 3 2 2
2006 03 30	2	1 1 0 0 0 1 1 1	2	2 0 0 0 0 0 2 1	4	1 1 0 0 1 2 2 2
2006 03 31	2	0 0 1 1 1 1 2 0	9	2 0 3 3 4 2 0 0	4	1 0 1 2 2 1 2 1

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 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.