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

Submitted To

Federal Aviation Administration
GPS Product Team
AND 730
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Submitted by

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EXECUTIVE SUMMARY

The GPS Product Team (AND 730) has tasked the Navigation Branch (ACB 430) at the William J. Hughes Technical Center to document the Global Positioning System (GPS) Standard Positioning Service (SPS) performance in quarterly GPS Performance Analysis (PAN) Reports. The report contains the analysis performed on data collected at twenty-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 October through 31 December 2005. The next quarterly report will be issued 30 April 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 October and 31 December 2005. 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. Seven outages were scheduled while five 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 24.908 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 4.663 was recorded on satellite 2. 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 October and 31 December 2005, 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 3.51682 or better 99.9% of the time for each of the 24-hour intervals.

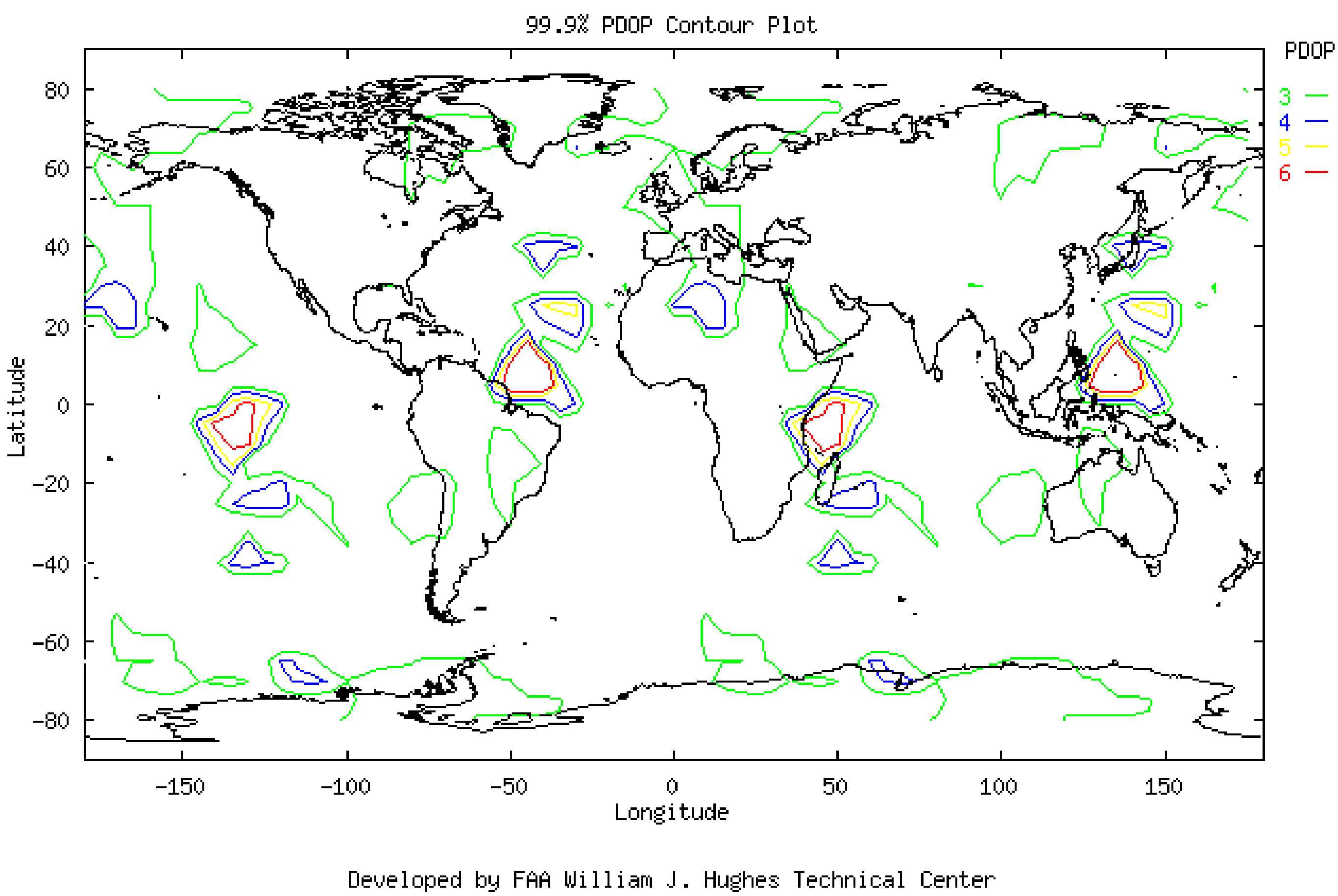
Figure 2-1 is a contour plot of PDOP values over the entire globe. Inside each contour area, the PDOP value is greater than or equal to the contour value shown in the legend for that color line. That areas’ value is also less than the next higher contour value, unless another contour line lies within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

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

Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
2 – 8 Oct 2005	2.89794	100	100
9 – 15 Oct 2005	2.89488	100	100
16 – 22 Oct 2005	2.91019	100	100
23 – 29 Oct 2005	2.90966	100	100
30 Oct – 5 Nov 2005	3.51166	99.987	98.194
6 – 12 Nov 2005	3.51682	99.987	98.264
13 – 19 Nov 2005	2.92542	100	100
20 – 26 Nov 2005	2.93363	100	100
27 Nov – 3 Dec 2005	2.94274	100	100
4 – 10 Dec 2005	2.94575	100	100
11 – 17 Dec 2005	2.94528	100	100
18 – 24 Dec 2005	2.88605	100	100
25 – 31 Dec 2005	3.22071	99.989	98.750

Figure 2-1 PDOP Availability Plot (24-Hour Period: 30 November 2005)



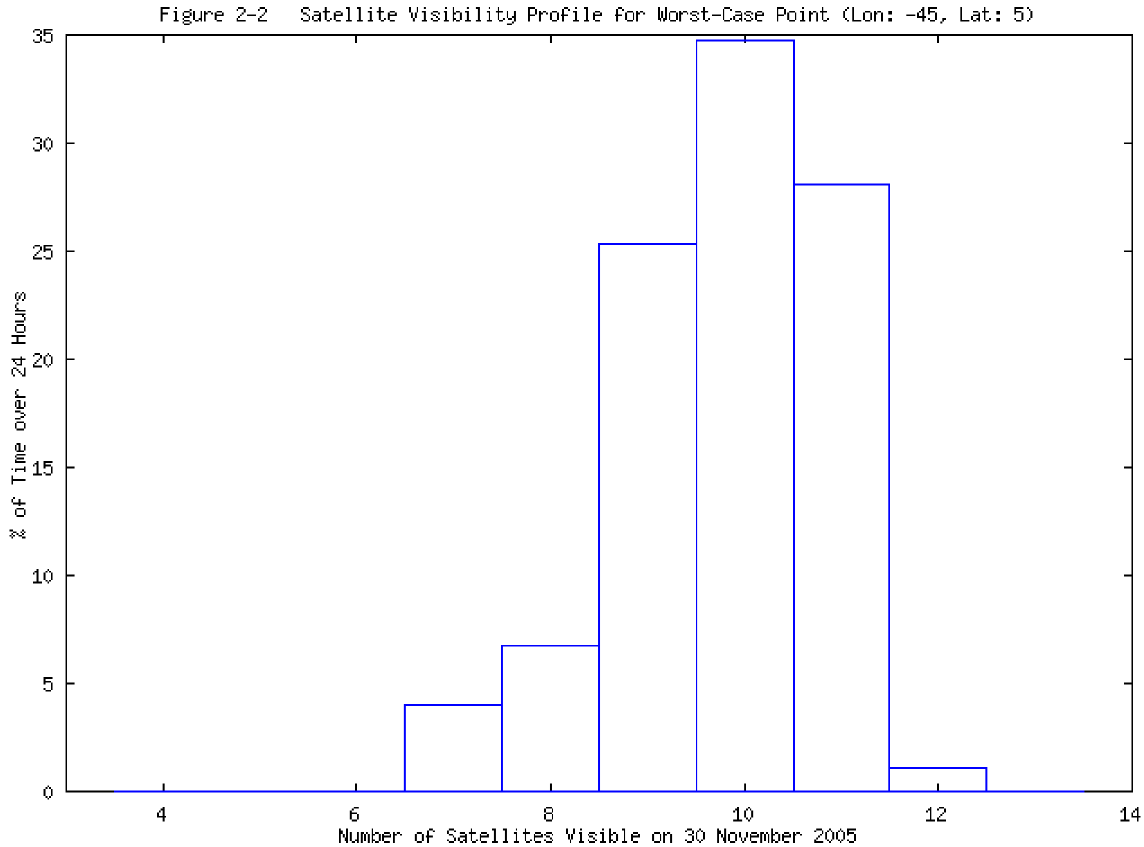


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -45, Lat: 5)
% of Time over 24 Hours
Number of Satellites Visible on 30 November 2005
0
5
10
15
20
25
30
35
4
6
8
10
12
14

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 October through 31 December 2005, there were a total of twelve reported outages. Seven of these outages were maintenance activities and were reported in advance. Five 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
128	4	FCSTSUMM	4-Oct	14:47	4-Oct	19:39		4.86	4.86
130	21	FCSTSUMM	13-Oct	2:17	13-Oct	9:05		6.80	6.80
132	25	FCSTSUMM	20-Oct	2:12	20-Oct	10:16		8.06	8.06
134	31	UNUSABLE	1-Oct	0:00	24-Oct	22:42	558.13		558.13
140	9	UNUSABLE	31-Oct	15:06	15-Nov	0:26	345.33		345.33
145	6	FCSTSUMM	21-Nov	14:12	21-Nov	21:53		7.68	7.68
148	15	FCSTSUMM	1-Dec	19:24	2-Dec	2:09		6.75	6.75
153	30	FCSTSUMM	15-Dec	13:48	15-Dec	20:09		6.35	6.35
157	26	FCSTSUMM	20-Dec	14:37	20-Dec	19:27		4.83	4.83
159	25	UNUSABLE	23-Dec	22:20	24-Dec	6:52	8.53		8.53
160	9	UNUSABLE	19-Dec	14:49	24-Dec	7:38	112.81		112.81
??	25	UNUSABLE	25-Dec	21:06	1-Jan	0:00	146.90		146.90
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**1171.70**	**45.33**	**1217.03**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
127	4	FCSTMX	4-Oct	14:15	5-Oct	2:15	12	See NANU 128
129	21	FCSTDV	13-Oct	2:00	13-Oct	14:00	12	See NANU 130
131	25	FCSTDV	20-Oct	1:30	20-Oct	13:30	12	See NANU 132
137	9	UNUSUFN	31-Oct	15:06	N/A	N/A	N/A	See NANU 140
139	6	FCSTMX	18-Nov	14:05	19-Nov	2:05	RESCD	See NANU 143
143	6	FCSTRESCD	21-Nov	13:55	22-Nov	1:55	12	See NANU 145
146	15	FCSTDV	1-Dec	19:00	2-Dec	7:00	12	See NANU 148
149	29	FCSTMX	13-Dec	4:00	14-Dec	4:00	CANC	See NANU 152
150	30	FCSTMX	15-Dec	13:30	16-Dec	1:30	12	See NANU 153
151	26	FCSTMX	20-Dec	14:00	21-Dec	2:00	12	See NANU 157
156	9	UNUSUFN	19-Dec	14:49	N/A	N/A	N/A	See NANU 160
158	25	UNUSUFN	23-Dec	22:20	N/A	N/A	N/A	See NANU 159
161	25	UNUSUFN	25-Dec	21:06	N/A	N/A	N/A	See NANU ??
					Total Forecast Downtime		**84**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
152	29	FCSTCANC	13-Dec	4:00	See NANU 149

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 October - 31 Dec. 2005**	**1 October, 1999- 31 Dec. 2005**
Total Forecast Downtime (hrs):	84.00	5532.73
Total Actual Downtime (hrs):	1217.03	15977.40
Total Actual Scheduled Downtime (hrs):	45.33	3032.69
Total Actual Unscheduled Downtime (hrs):	1171.70	12944.71
Total Satellite Observed MTTR (hrs):	101.42	39.06
Scheduled Satellite Observed MTTR (hrs):	6.48	10.39
Unscheduled Satellite Observed MTTR (hrs):	234.34	110.64
# Total Satellite Outages:	12	409
# Scheduled Satellite Outages:	7	292
# Unscheduled Satellite Outages:	5	117
Percent Operational -- Scheduled Downtime:	99.93	99.80
Percent Operational -- All Downtime:	99.92	98.92

NANU 133 announced decommissioning of satellite PRN 31.
NANU's 135 & 136 announced testing of PRN's 1 & 25 October 26-28.
NANU 138 announced PRN 17 would be set healthy at 2100z on 11 Nov.
NANU 144 declared a technical error, NANU's 141 and 142 do not exist
NANU 147 gave details regarding the application of the GPS leap second.
NANU 154 announced L2C being turned on.
NANU 155 announced usability of PRN 17.

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 October and 31 December 2005.

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	7868856	0	100%
Mauna Loa	7805369	0	100%
Billings	7942387	0	100%
Cold Bay	7879544	0	100%
Juneau	7884469	0	100%
Albuquerque	7933364	0	100%
Anchorage	7936181	0	100%
Boston	7938165	0	100%
Washington, D.C.	7943063	0	100%
Honolulu	6942126	0	100%
Houston	7919381	0	100%
Kansas City	7816516	0	100%
Los Angeles	7939511	0	100%
Salt Lake City	7941444	0	100%
Miami	7933976	0	100%
Minneapolis	7809493	0	100%
Oakland	7940930	0	100%
Cleveland	7939544	0	100%
Seattle	7940768	0	100%
San Juan	7866766	0	100%
Atlanta	7917018	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 spec calls for yearly evaluations, we will be evaluating this SPS specification 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 24.908 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 Oct – 31 Dec 2005	**Billings**	79,033,153	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 October through 31 December 2005 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	3.287	5.702	9.740	16.597
Mauna Loa	7.109	9.816	11.413	24.755
Billings	2.639	4.408	5.056	9.585
Cold Bay	2.525	5.449	5.048	9.601
Juneau	2.287	4.739	5.051	10.007
Albuquerque	2.437	4.508	4.760	9.367
Anchorage	2.288	5.334	4.205	10.407
Boston	2.746	4.390	5.687	9.848
Washington, D.C.	2.775	4.342	4.942	9.856
Honolulu	5.455	6.066	9.110	12.230
Houston	2.376	5.014	4.381	10.690
Kansas City	2.684	4.537	4.819	10.694
Los Angeles	2.395	4.988	4.638	9.921
Salt Lake City	2.607	4.516	4.745	9.703
Miami	2.516	4.864	4.686	10.512
Minneapolis	2.693	4.401	5.167	10.825
Oakland	2.444	5.086	4.495	10.280
Cleveland	2.802	4.280	5.138	9.779
Seattle	2.599	4.502	5.203	9.653
San Juan	2.622	4.879	6.887	11.299
Atlanta	2.706	4.700	5.862	9.787

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 October to 31 December 2005.

Figure 5-1 Global Vertical Error Histogram

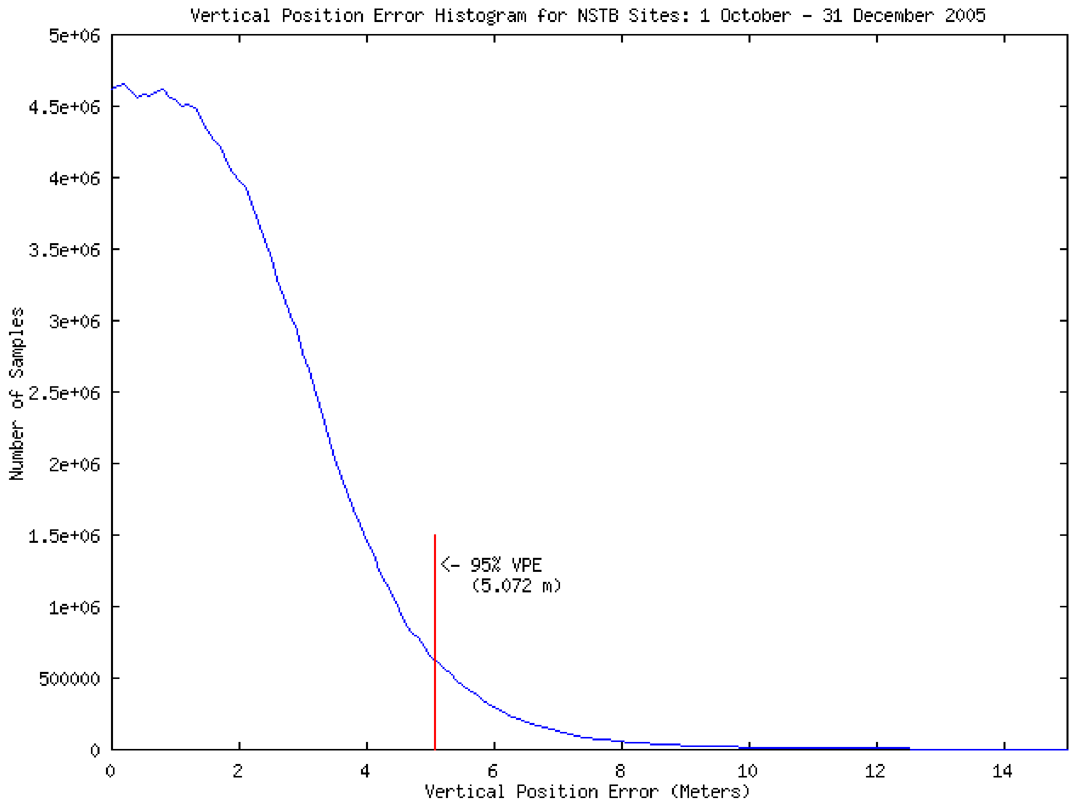
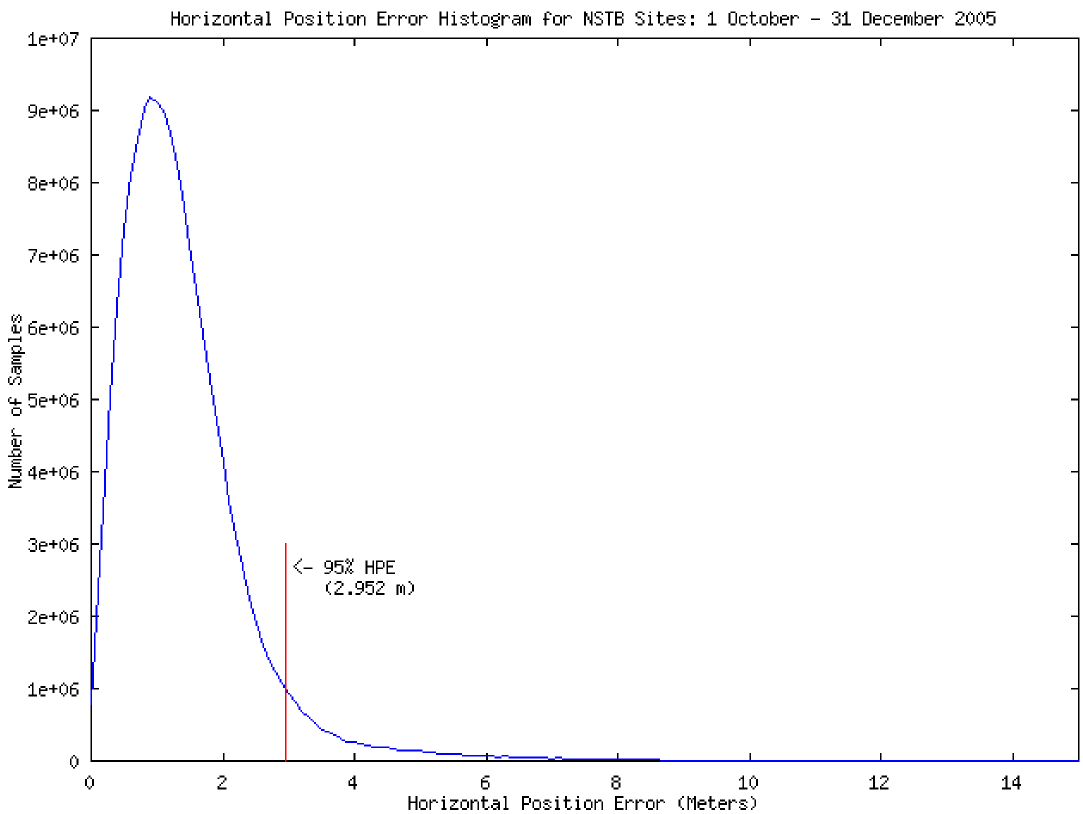


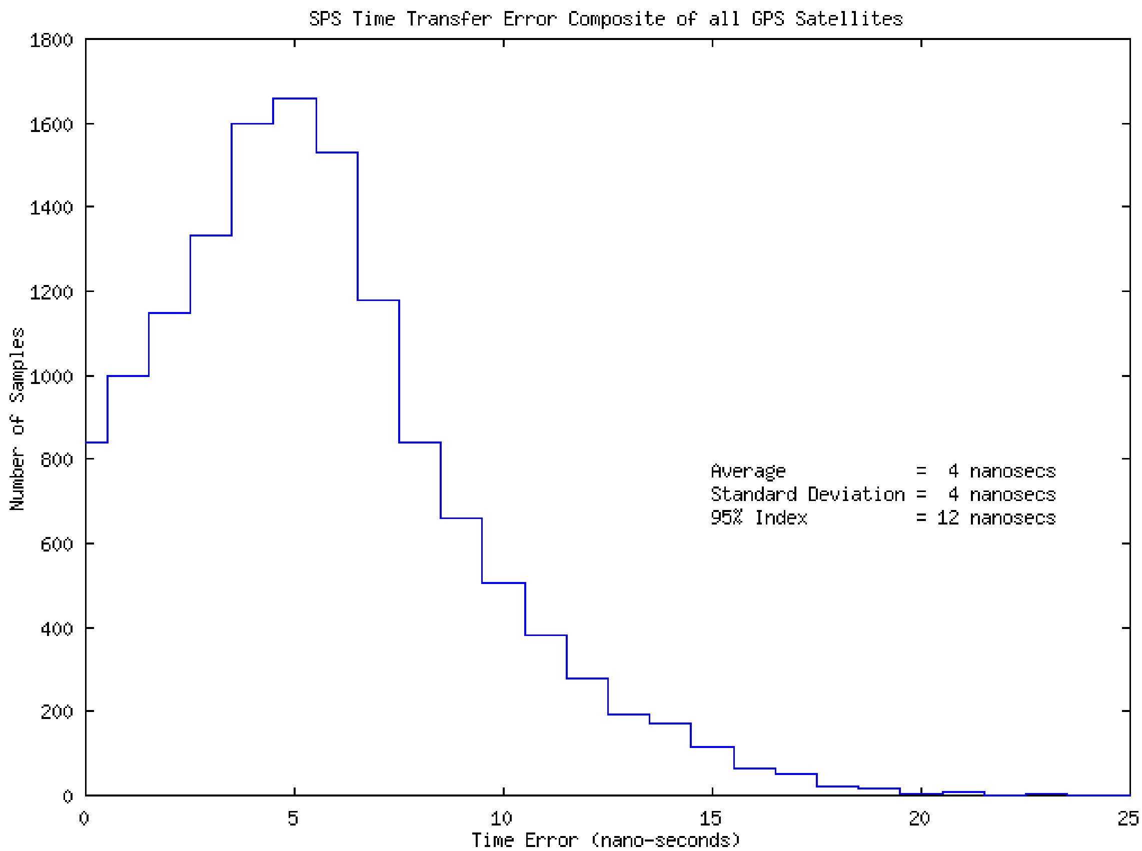
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 October and 31 December 2005 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 October and 31 December 2005. 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	1.606	2.690	2.158	5.103	9.461	2151957
2	4.174	4.663	2.079	7.961	11.268	1953446
3	1.814	2.765	2.087	5.141	14.476	2542461
4	1.906	2.959	2.263	5.479	24.908	2121967
5	3.157	3.836	2.179	6.771	10.434	2239231
6	2.568	3.158	1.839	5.819	10.467	1920157
7	2.230	3.276	2.400	6.270	9.299	2124587
8	0.831	2.827	2.702	5.844	9.129	1995793
9	2.157	2.959	2.025	5.403	12.260	1984964
10	3.588	4.402	2.551	7.747	16.477	2389595
11	2.278	2.980	1.921	5.159	8.268	2552351
13	0.991	2.205	1.969	4.281	17.138	1867811
14	3.466	3.771	1.487	5.800	9.443	2041926
15	3.186	3.667	1.815	6.275	21.955	2011944
16	2.799	3.311	1.768	5.457	9.412	2458952
17	0.096	2.398	2.396	5.041	7.360	362237
18	3.652	3.865	1.267	5.671	8.338	2106820
19	3.937	4.407	1.981	6.848	10.170	2549880
20	2.813	3.333	1.788	5.697	10.067	2263971
21	4.062	4.303	1.422	6.496	10.968	2089595
22	3.697	3.911	1.278	5.716	8.049	2161186
23	3.582	4.040	1.870	6.548	9.049	2011936
24	1.332	2.580	2.210	5.004	11.459	2532065
25	1.937	2.801	2.023	5.365	12.806	1802287
26	1.155	2.360	2.059	4.342	8.503	2492989
27	0.537	2.325	2.262	4.712	9.206	2145535
28	1.875	3.088	2.453	6.023	9.530	2172380
29	1.602	2.492	1.909	4.718	10.512	2580964
30	2.193	2.939	1.957	5.547	10.626	2442607

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	-0.00006	0.00327	0.00327	0.00354	0.20033	2151957
2	0.00003	0.00191	0.00191	0.00359	0.16144	1953446
3	-0.00003	0.00227	0.00227	0.00358	0.38549	2542461
4	0.00009	0.00681	0.00681	0.00529	1.10200	2121967
5	0.00008	0.00242	0.00242	0.00378	0.19227	2239231
6	-0.00003	0.00282	0.00282	0.00372	0.31792	1920157
7	0.00008	0.00172	0.00172	0.00325	0.16144	2124587
8	0.00012	0.00232	0.00232	0.00381	0.22735	1995793
9	0.00004	0.00275	0.00275	0.00366	0.20549	1984964
10	0.00006	0.00367	0.00367	0.00410	0.65976	2389595
11	0.00007	0.00212	0.00212	0.00366	0.19044	2552351
13	0.00002	0.00399	0.00399	0.00383	0.79480	1867811
14	-0.00004	0.00257	0.00257	0.00345	0.19233	2041926
15	0	0.00309	0.00309	0.00367	1.01682	2011944
16	-0.00011	0.00276	0.00276	0.00372	0.26483	2458952
17	-0.00001	0.00211	0.00211	0.00357	0.16254	362237
18	-0.00003	0.00178	0.00178	0.00342	0.13695	2106820
19	0	0.00184	0.00184	0.00342	0.16250	2549880
20	0.00001	0.00282	0.00282	0.00374	0.21720	2263971
21	-0.00005	0.00192	0.00191	0.00358	0.15848	2089595
22	-0.00004	0.00184	0.00184	0.00323	0.14753	2161186
23	-0.00004	0.00180	0.00180	0.00340	0.03835	2011936
24	0.00006	0.00312	0.00312	0.00394	0.26997	2532065
25	-0.00008	0.00219	0.00219	0.00357	0.57270	1802287
26	0.00008	0.00240	0.00240	0.00353	0.16334	2492989
27	-0.00001	0.00247	0.00247	0.00363	0.16898	2145535
28	0.00007	0.00200	0.00200	0.00336	0.16139	2172380
29	0.00006	0.00259	0.00259	0.00352	0.21853	2580964
30	0.00004	0.00230	0.00230	0.00370	0.15872	2442607

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	0.00201	2151957
2	0	0.00002	0.00002	0.00152	1953446
3	0	0.00002	0.00002	0.00386	2542461
4	0	0.00006	0.00006	0.01105	2121967
5	0	0.00002	0.00002	0.00191	2239231
6	0	0.00002	0.00002	0.00316	1920157
7	0	0.00001	0.00001	0.00152	2124587
8	0	0.00002	0.00002	0.00228	1995793
9	0	0.00002	0.00002	0.00205	1984964
10	0	0.00003	0.00003	0.00662	2389595
11	0	0.00002	0.00002	0.00191	2552351
13	0	0.00004	0.00004	0.00793	1867811
14	0	0.00002	0.00002	0.00183	2041926
15	0	0.00003	0.00003	0.00560	2011944
16	0	0.00002	0.00002	0.00258	2458952
17	0	0.00002	0.00002	0.00152	362237
18	0	0.00002	0.00002	0.00137	2106820
19	0	0.00002	0.00002	0.00163	2549880
20	0	0.00002	0.00002	0.00216	2263971
21	0	0.00002	0.00002	0.00159	2089595
22	0	0.00002	0.00002	0.00146	2161186
23	0	0.00002	0.00002	0.00034	2011936
24	0	0.00003	0.00003	0.00268	2532065
25	0	0.00002	0.00002	0.00572	1802287
26	0	0.00002	0.00002	0.00172	2492989
27	0	0.00002	0.00002	0.00169	2145535
28	0	0.00002	0.00002	0.00151	2172380
29	0	0.00002	0.00002	0.00210	2580964
30	0	0.00002	0.00002	0.00159	2442607

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 24.908 meters. Satellite 17 had the lowest maximum range error of 7.360 meters.

Figure 5-4 Distribution of Daily Max Range Errors

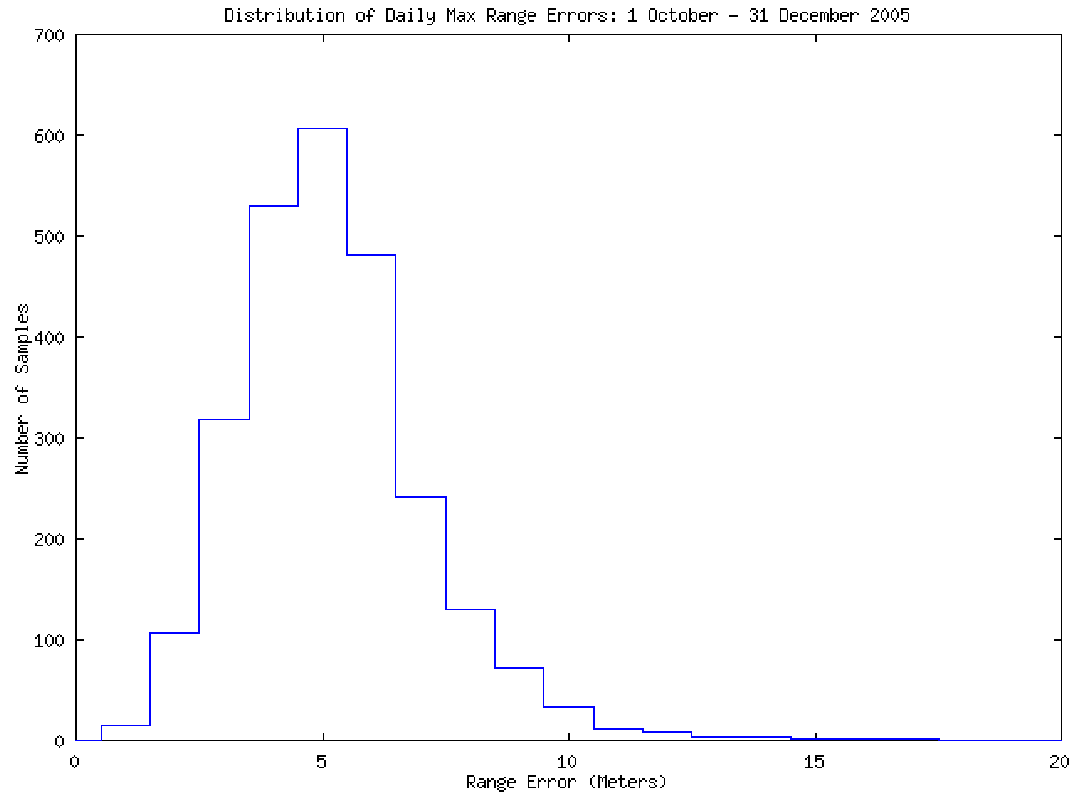


Figure 5-5: Distribution of Daily Max Range Rate Errors

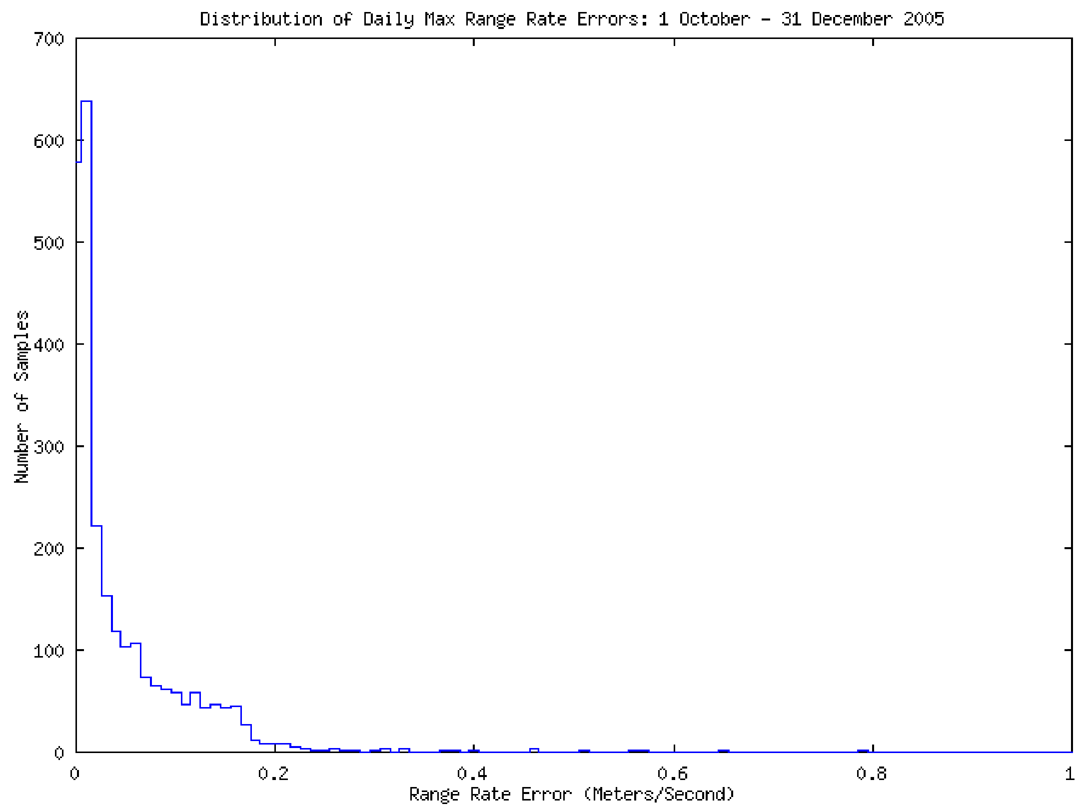


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

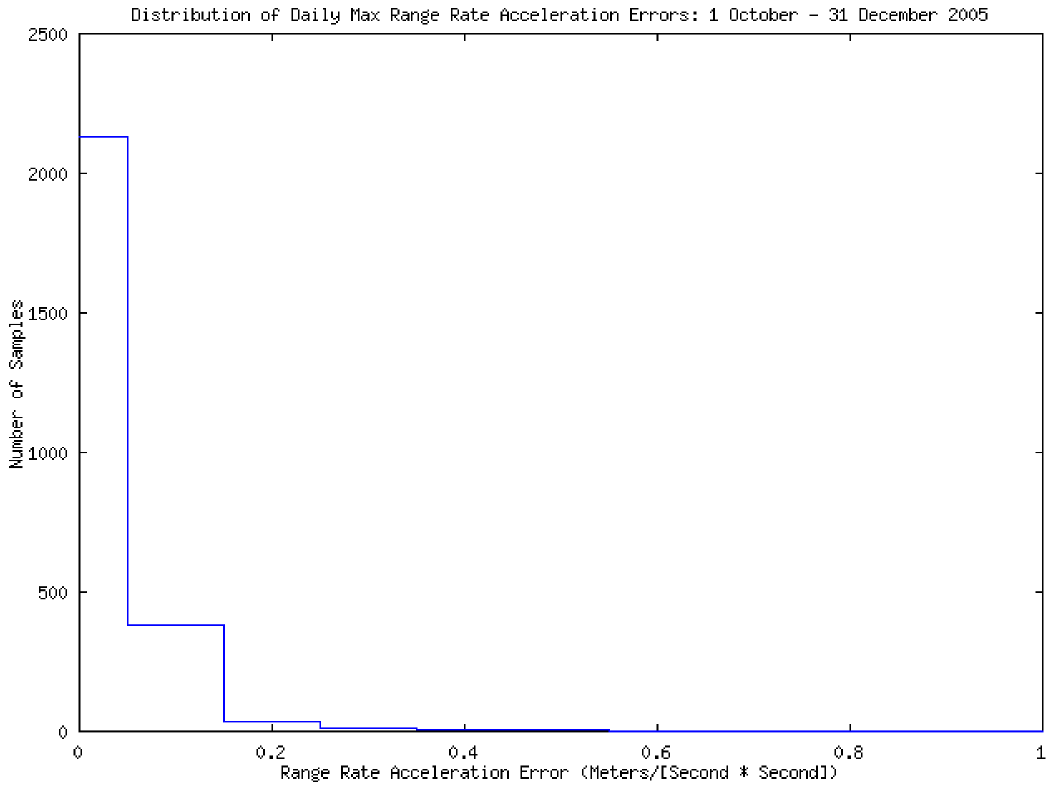


Figure 5-7: Range Error Histogram

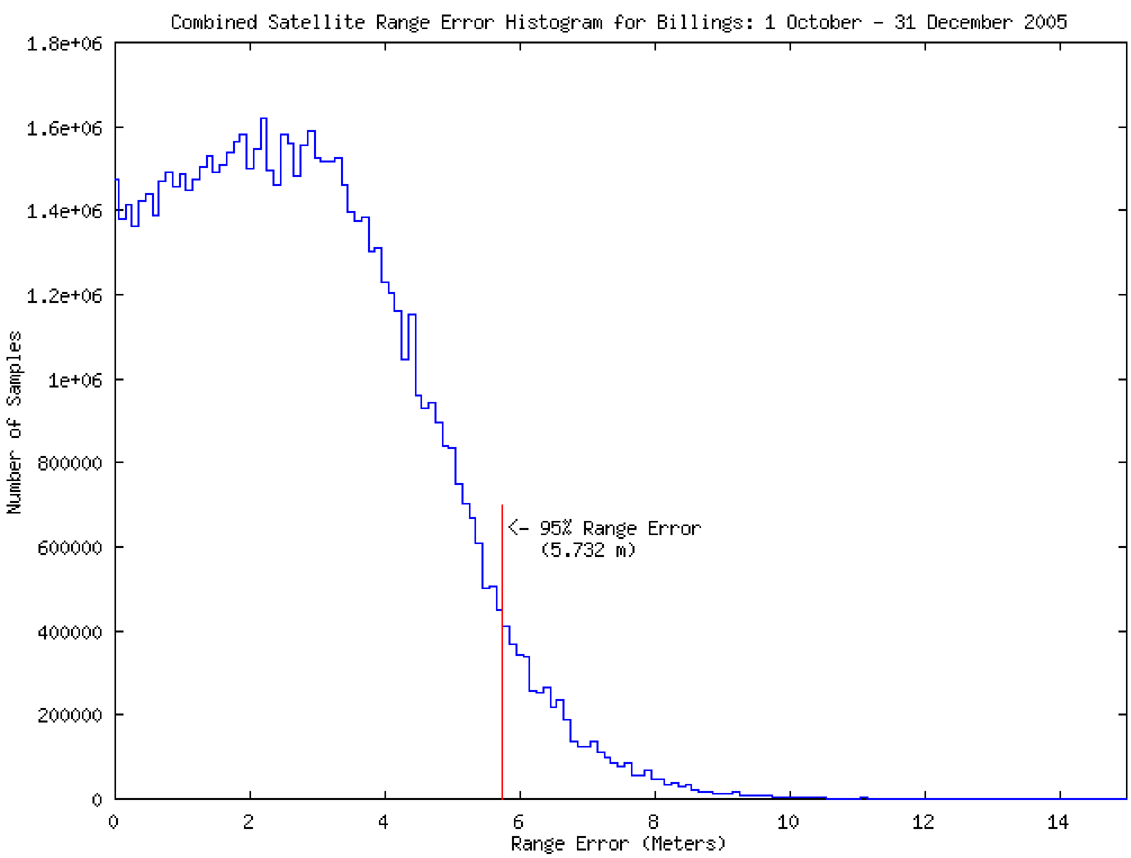


Figure 5-8: Maximum Range Error Per Satellite

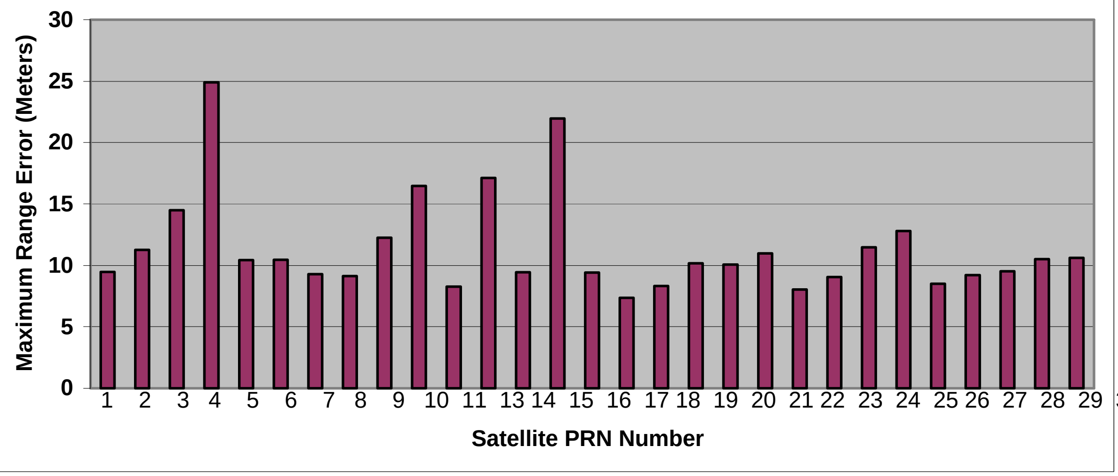


Figure 5-9: Maximum Range Rate Error Per Satellite

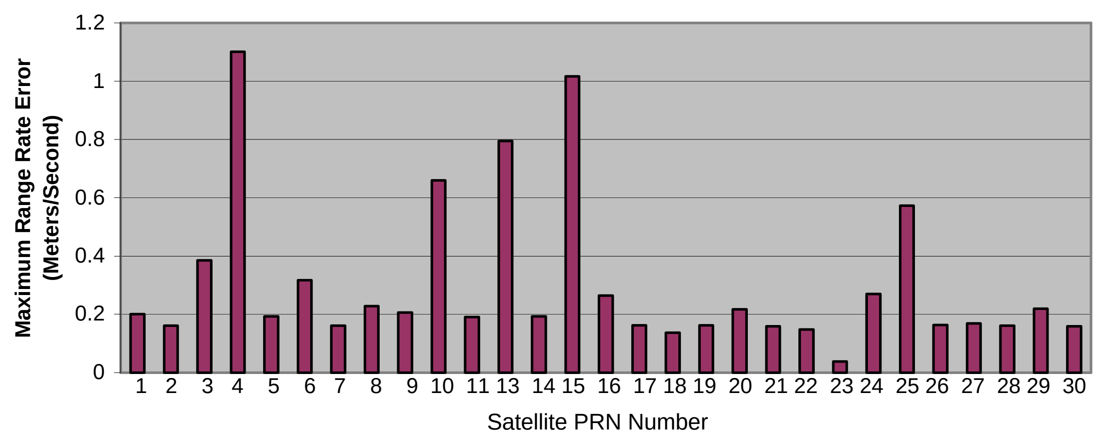
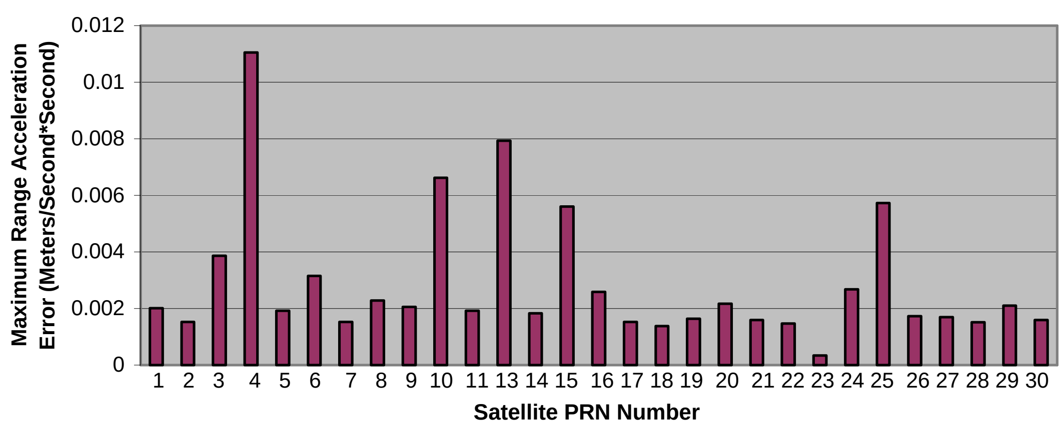


Figure 5-10: Maximum Range Acceleration Per Satellite



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 27-29 December 2005

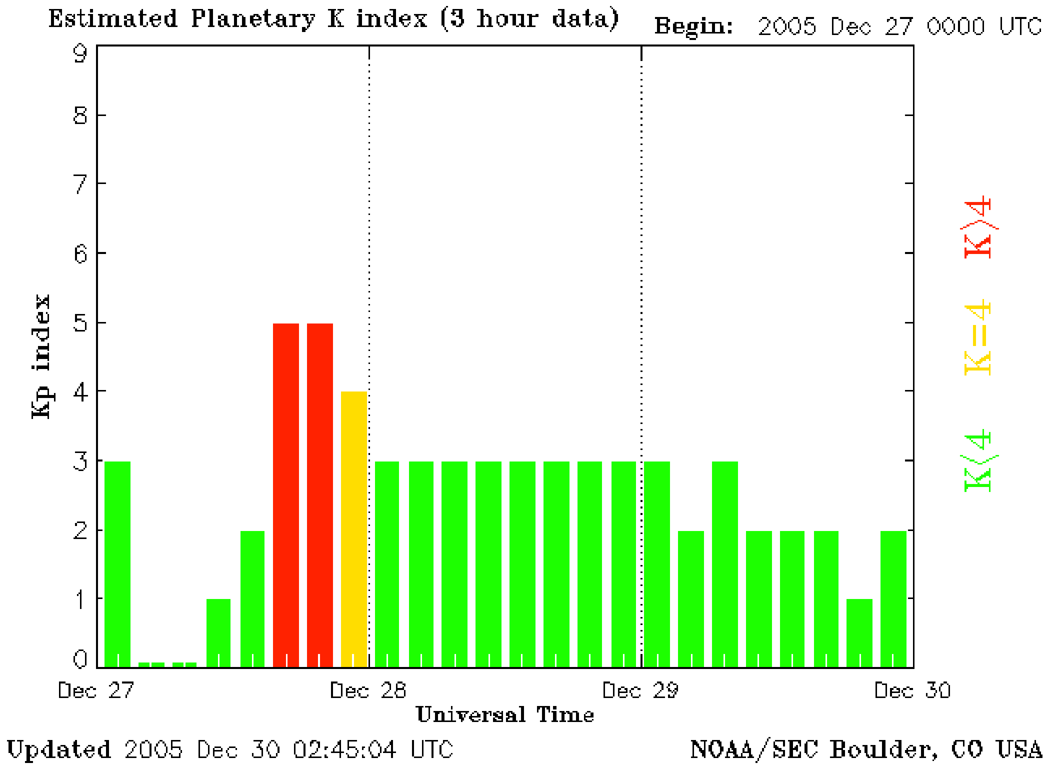


Figure 6-2 K-Index for 9-11 December 2005

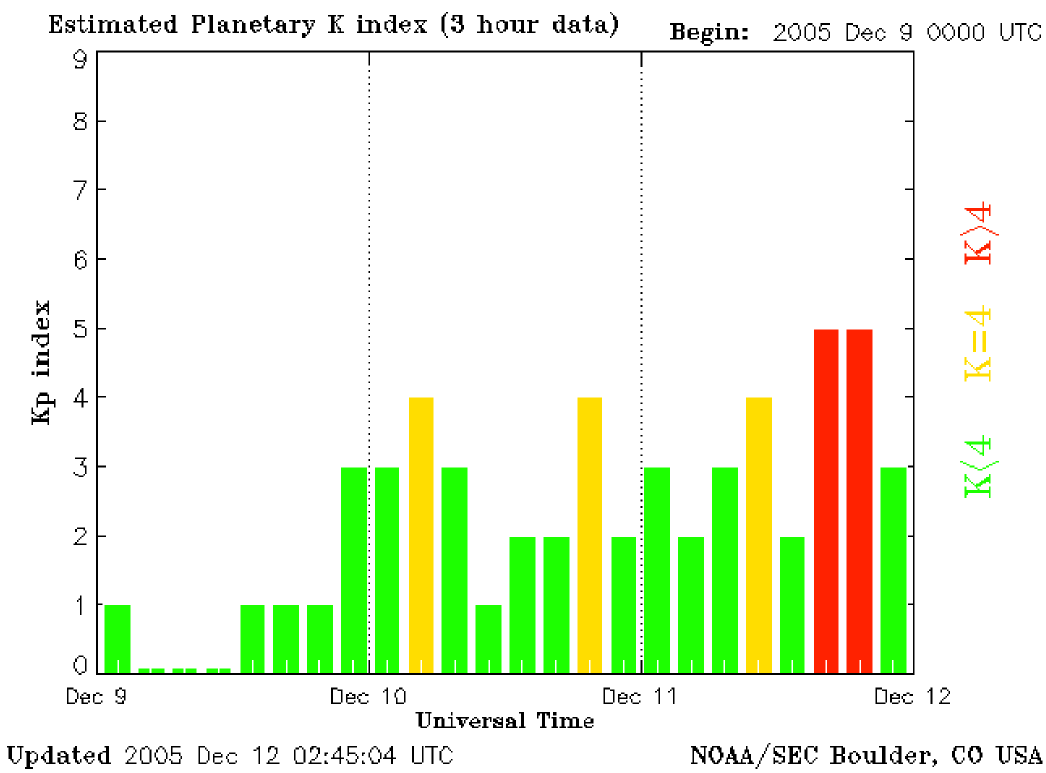
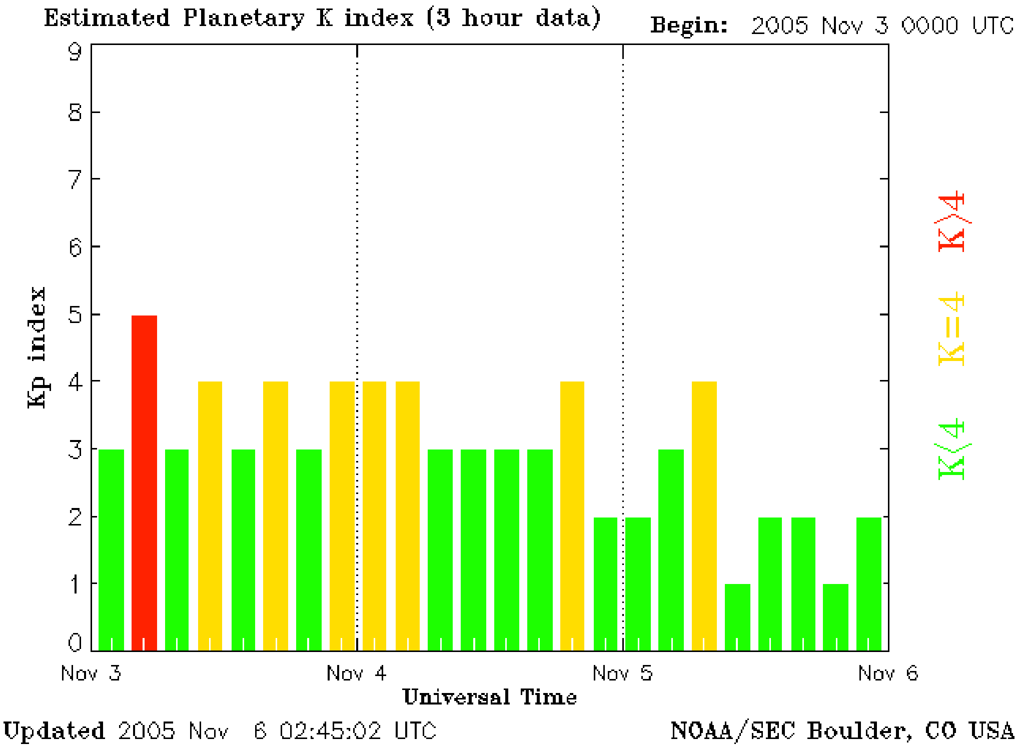


Figure 6-3 K-Index for 3-5 November 2005



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 December 2005

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Bangor	3.335	5.873	5.816	11.590
Mauna Loa	8.971	9.472	10.836	13.594
Billings	2.292	5.090	2.865	6.456
Cold Bay	2.938	7.217	3.942	8.861
Juneau	2.844	4.868	3.710	7.425
Albuquerque	1.764	5.231	2.279	6.361
Anchorage	2.696	6.396	3.650	9.240
Boston	2.466	3.985	3.431	5.415
Washington, D.C.	2.197	3.832	4.532	4.910
Honolulu	7.380	6.552	8.563	7.438
Houston	1.744	5.258	2.207	7.012
Kansas City	2.036	5.033	2.785	6.619
Los Angeles	2.027	5.414	2.412	8.051
Salt Lake City	2.065	5.115	4.031	7.548
Miami	2.235	4.383	3.093	5.441
Minneapolis	2.074	4.570	2.497	7.697
Oakland	2.042	5.229	2.357	7.123
Cleveland	2.346	3.455	4.560	5.103
Seattle	2.797	4.986	3.447	6.270
San Juan	3.131	4.249	4.807	6.582
Atlanta	1.977	3.908	4.201	5.070

APPENDICES A – D

Conditions and Constraints	*PDOP Availability Standard*	*Measured Performance*
• Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. • Based on using only satellites transmitting standard code and indicating "health" in the broadcast navigation message (sub-frame 1).	≥ 98% global Position Dilution of Precision (PDOP) of 6 or less ≥ 88% worst site PDOP of 6 or less	≥ 99.987% ≥ 98.194%
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)	2.952 m 5.072 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)	7.109 m 9.816 m
• Defined for time transfer solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	Time Transfer Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	12 nanoseconds 95%
• Average of the constellation's individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point thing the service volume.	≤ 6 meters RMS SIS SPS URE across the entire constellation	≤ 4.663 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**
2005 10 01	10	3 3 3 2 1 1 2 3	24	4 3 5 5 4 3 2 2	13	3 4 3 3 3 2 3 3
2005 10 02	8	2 2 3 2 1 2 2 2	29	3 3 5 5 5 5 1 2	13	4 3 4 2 2 3 2 2
2005 10 03	5	2 3 2 1 1 1 1 0	8	2 2 3 4 2 0 0 0	7	2 3 2 2 1 1 2 1
2005 10 04	2	1 1 0 0 1 1 0 0	4	0 0 1 1 3 0 0 0	4	1 1 0 0 1 1 1 1
2005 10 05	2	0 1 1 0 1 1 1 0	3	0 0 2 1 2 1 1 0	4	0 1 1 0 1 1 2 1
2005 10 06	2	0 1 1 0 1 1 2 0	3	0 1 1 1 3 0 1 0	4	1 1 1 1 1 1 1 1
2005 10 07	11	2 2 1 2 2 4 3 3	12	0 0 3 4 3 2 3 3	11	1 2 2 2 2 2 3 4
2005 10 08	16	4 3 3 3 3 2 3 3	36	4 5 5 6 4 4 3 3	22	4 4 4 4 3 2 4 3
2005 10 09	7	3 1 1 1 2 1 2 3	11	2 2 2 4 3 2 2 2	9	3 2 1 2 2 1 3 3
2005 10 10	7	2 2 3 2 1 1 1 3	8	2 1 3 4 3 0 0 1	10	2 3 3 3 2 0 1 3
2005 10 11	5	3 2 0 0 1 2 1 1	8	2 1 0 0 3 2 1 4	6	3 2 0 0 1 1 1 2
2005 10 12	1	0 1 0 0 1 0 0 1	-1	-1-1-1-1-1-1-1-1	1	0 0 0 0 0 0 0 1
2005 10 13	2	0 0 2 0 0 1 1 0	-1	-1-1-1-1-1-1-1-1	4	1 0 2 1 1 0 2 1
2005 10 14	1	0 2 0 0 0 0 0 0	-1	-1-1-1-1-1-1-1-1	2	1 2 0 0 0 1 1 0
2005 10 15	2	0 1 0 0 1 0 1 1	4	4 0 0 1 0 0 0 0	2	0 1 0 0 1 0 0 1
2005 10 16	5	0 1 2 1 1 1 2 3	14	0 1 4 4 4 3 2 1	8	1 1 2 2 2 2 2 3
2005 10 17	7	2 3 3 2 1 2 1 0	26	3 4 5 5 5 3 1 0	13	3 4 3 2 3 3 1 1
2005 10 18	5	1 2 1 1 2 2 1 1	16	4 1 4 4 4 3 1 0	5	1 3 1 1 2 1 1 1
2005 10 19	3	1 2 1 1 2 1 0 0	13	1 1 4 3 4 4 0 0	7	2 2 2 2 2 3 0 1
2005 10 20	2	1 0 2 1 0 0 0 0	2	0 0 1 3 0 0 0 0	3	1 0 2 1 0 0 0 1
2005 10 21	1	0 0 0 0 0 0 0 2	0	0 0 0 0 0 0 0 1	2	0 0 0 0 0 1 1 3
2005 10 22	7	4 3 1 0 1 0 1 1	4	3 1 1 0 2 0 1 1	6	4 2 1 0 1 0 1 1
2005 10 23	2	1 0 0 0 1 1 1 0	1	0 0 0 0 1 1 0 0	2	0 0 0 0 1 1 1 1
2005 10 24	3	1 0 0 0 2 1 2 2	4	0 0 0 1 3 2 1 1	4	1 0 0 0 2 2 2 2
2005 10 25	17	4 3 5 3 2 2 1 3	27	2 3 4 6 4 4 2 4	19	4 3 4 4 2 3 3 3
2005 10 26	8	2 2 3 2 2 2 2 1	16	2 2 5 3 3 3 3 1	8	1 2 3 2 1 2 1 1
2005 10 27	5	3 1 0 1 2 2 1 0	12	1 1 1 2 5 4 2 0	6	3 0 0 1 3 2 1 1
2005 10 28	4	0 0 1 2 2 1 2 1	17	0 0 4 5 5 2 1 0	5	1 0 2 2 2 1 1 1
2005 10 29	1	0 0 1 0 0 1 1 0	2	1 0 2 0 0 1 1 0	2	1 0 1 0 0 1 0 1
2005 10 30	3	1 1 0 1 1 1 1 1	4	0 2 0 1 3 1 1 1	5	2 2 0 0 1 0 1 2
2005 10 31	6	0 2 1 1 2 2 2 3	35	1 1 1 5 6 6 5 3	13	1 1 1 2 3 4 3 4
2005 11 01	7	3 1 0 2 1 2 1 3	12	3 1 0 4 4 3 2 1	8	3 2 0 2 2 3 1 2
2005 11 02	5	1 1 0 0 1 1 3 3	5	2 1 0 0 1 1 3 2	6	1 1 0 0 0 1 3 3
2005 11 03	19	4 4 3 3 3 2 3 4	43	2 5 3 6 6 5 5 3	24	3 5 3 4 3 4 3 4
2005 11 04	16	4 4 4 2 2 3 3 1	22	3 4 3 4 4 4 4 2	20	4 4 3 3 3 3 4 2
2005 11 05	10	3 2 4 1 2 2 1 2	14	3 3 4 2 3 3 2 2	10	2 3 4 1 2 2 1 2
2005 11 06	12	4 2 2 2 2 3 3 2	15	2 2 2 5 3 3 3 2	10	3 3 2 2 2 2 3 2
2005 11 07	6	3 1 3 2 1 1 1 0	7	3 1 3 2 2 1 2 0	6	3 1 2 1 1 1 1 1
2005 11 08	2	1 0 1 0 1 1 0 1	3	2 0 2 1 0 1 0 1	3	1 0 1 1 1 1 0 1
2005 11 09	1	2 0 0 0 0 0 1 0	1	1 0 1 1 0 0 0 0	3	2 0 0 0 0 1 0 1
2005 11 10	1	0 0 1 0 0 0 0 1	2	0 0 1 1 0 0 0 2	2	0 0 1 0 0 0 1 1
2005 11 11	3	1 2 0 1 1 1 1 1	4	0 1 0 3 2 2 1 0	5	1 2 1 1 2 2 1 1
2005 11 12	7	2 3 2 2 2 2 1 1	33	1 5 4 5 6 5 2 1	10	2 3 2 2 3 3 2 1
2005 11 13	12	3 4 3 2 2 2 1 3	37	1 2 3 6 6 6 4 2	14	3 4 3 3 3 3 2 3
2005 11 14	7	3 3 2 2 1 1 1 1	16	2 3 3 5 4 2 1 2	10	4 3 2 2 2 1 2 2
2005 11 15	5	1 0 3 3 1 0 1 0	10	1 1 4 4 3 1 0 0	4	1 1 2 2 2 0 0 1
2005 11 16	1	0 2 0 0 0 0 0 0	1	0 0 0 1 0 1 1 0	3	0 2 0 0 1 1 1 1
2005 11 17	1	0 0 2 0 0 0 0 0	3	0 0 0 0 0 0 4 0	3	1 0 2 1 0 0 0 0
2005 11 18	2	0 0 2 0 1 1 2 0	3	0 0 1 2 3 0 1 0	4	0 0 1 1 2 1 1 1
2005 11 19	6	1 1 1 0 2 3 2 2	5	0 0 0 0 1 4 2 2	10	1 0 0 0 1 4 4 3
2005 11 20	5	1 2 3 1 1 2 1 1	11	0 2 3 5 2 1 2 0	7	1 2 3 2 1 2 1 2
2005 11 21	2	1 2 0 0 1 1 1 0	2	2 1 0 1 1 1 0 0	3	2 2 0 0 1 1 0 1
2005 11 22	3	0 0 2 1 1 1 1 2	14	0 0 4 5 4 2 1 1	6	0 1 2 2 2 2 2 2
2005 11 23	12	2 3 3 3 3 3 2 2	-1	-1-1-1-1-1-1-1-1	8	1 3 3 2 2 2 1 2
2005 11 24	6	1 1 1 3 1 2 1 2	16	1 1 2 5 3 4 3 2	9	1 1 2 3 2 2 3 3
2005 11 25	8	3 3 3 1 1 1 1 1	17	3 3 4 4 4 3 1 1	10	3 4 3 2 1 2 2 1
2005 11 26	3	2 0 2 1 1 1 0 0	10	1 0 2 5 3 2 1 0	5	2 0 2 2 2 1 0 1
2005 11 27	2	0 0 2 0 0 1 0 1	1	0 0 1 1 0 0 0 0	2	0 0 1 1 0 1 0 1
2005 11 28	6	0 1 2 2 2 2 2 2	24	0 1 3 6 6 2 1 1	9	0 1 2 2 4 2 2 3
2005 11 29	6	1 0 1 1 0 2 2 4	3	1 0 0 2 0 1 1 2	5	2 0 0 1 0 2 1 3
2005 11 30	9	2 2 2 3 2 1 2 3	25	2 2 4 5 6 3 2 2	10	3 2 2 4 3 1 2 3
2005 12 01	12	4 1 1 3 2 2 2 4	17	3 2 1 5 3 3 2 4	13	4 2 1 2 2 2 2 4
2005 12 02	10	2 3 3 3 2 2 2 2	15	3 3 3 4 4 2 2 2	12	3 4 3 3 2 1 3 2
2005 12 03	9	3 2 1 2 2 3 2 2	17	2 3 1 4 4 4 3 3	11	4 2 1 2 2 3 3 3
2005 12 04	3	1 0 1 1 1 1 2 1	9	3 1 1 1 4 2 2 1	5	1 0 1 1 2 1 2 1
2005 12 05	2	1 1 1 0 0 2 1 0	2	1 1 1 0 0 0 0 1	2	1 1 0 0 0 0 0 1
2005 12 06	2	0 0 1 1 1 1 0 0	4	0 1 1 3 2 0 0 0	3	0 0 1 1 1 0 1 1

2005 12 07	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005 12 08	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1
2005 12 09	3	1	0	0	0	1	1	1	3	4	2	0	0	2	0	0	0	3	4	1	0	0	0	1	1	1	3
2005 12 10	17	3	4	3	1	3	3	4	3	-1	-1	-1	-1	-1	-1	-1	-1	-1	12	3	4	3	1	2	2	4	2
2005 12 11	10	3	2	2	3	2	3	2	1	40	3	3	5	5	5	6	5	3	22	3	2	3	4	2	5	5	3
2005 12 12	7	2	3	1	1	1	2	2	2	12	2	2	1	1	3	3	4	3	9	2	3	1	0	1	2	3	2
2005 12 13	4	0	2	1	1	2	1	1	1	4	1	1	2	1	2	1	1	1	5	0	2	1	0	3	1	1	2
2005 12 14	2	0	0	1	1	1	0	1	0	3	0	1	2	2	1	0	0	0	2	0	1	2	1	0	0	0	1
2005 12 15	2	1	1	1	1	0	1	0	0	1	0	0	1	1	0	0	0	0	2	0	0	1	1	0	0	0	0
2005 12 16	3	0	3	1	0	1	1	1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	5	1	3	1	1	1	1	1	1
2005 12 17	2	0	1	1	1	1	0	0	1	6	0	0	1	4	3	0	0	0	5	0	1	1	2	2	1	0	1
2005 12 18	2	1	0	0	1	1	1	0	1	1	0	0	0	2	0	0	0	0	3	1	0	0	1	1	0	0	1
2005 12 19	6	1	1	1	1	2	2	2	3	9	0	0	0	3	3	2	4	2	8	2	1	0	0	2	2	4	3
2005 12 20	11	3	2	2	2	3	2	3	3	28	2	4	3	5	6	3	3	3	16	4	3	3	2	3	2	4	3
2005 12 21	5	1	1	2	2	2	2	1	1	24	1	1	2	5	6	5	1	0	8	1	2	2	2	3	3	1	2
2005 12 22	4	2	1	1	2	1	1	1	0	2	2	0	1	2	0	0	0	0	4	2	1	1	1	1	1	1	1
2005 12 23	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
2005 12 24	2	0	0	0	1	2	1	1	0	6	0	0	0	3	4	1	0	0	3	0	0	0	1	2	1	1	1
2005 12 25	3	0	2	1	2	2	1	0	0	14	0	1	4	4	5	2	1	0	6	1	3	2	2	3	1	0	0
2005 12 26	3	0	0	1	0	2	1	2	2	6	0	0	1	0	4	2	2	1	6	1	0	1	0	2	2	3	3
2005 12 27	10	3	0	0	1	3	3	3	3	15	2	1	0	1	2	5	4	4	18	3	0	0	1	2	5	5	4
2005 12 28	13	3	3	2	2	2	2	3	4	26	3	3	3	5	5	4	3	4	14	3	3	3	3	3	3	3	3
2005 12 29	7	2	2	2	2	2	2	2	2	22	3	3	5	5	3	3	3	2	8	3	2	3	2	2	2	1	2
2005 12 30	6	3	2	1	1	1	2	1	1	6	2	1	1	3	1	2	1	1	7	2	3	1	2	1	2	1	2
2005 12 31	9	3	2	3	1	2	3	1	2	8	2	2	1	1	2	4	2	2	9	3	2	3	1	2	3	1	2

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

Problem Description:

There were no problems this 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.