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

Submitted To

Federal Aviation Administration
GPS Product Team
AND 730
1284 Maryland Avenue SW
Washington, DC 20024

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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 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 Annex A.

This report, Report #48, includes data collected from 1 October through 31 December 2004. The next quarterly report will be issued 30 April 2005.

Analysis of this data includes the following categories: Coverage performance, Service Availability Performance, Position Performance, Range Performance and Solar Storm Effects on GPS SPS performance.

Coverage performance was 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 coverage based on PDOP less than six for the CONUS was 98.542% or better.

Availability was verified by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 October and 31 December 2004 and by calculating the satellite availability from the data obtained from the twenty-one sites. A total of sixteen outages were reported in the NANU’s. Eleven outages were scheduled while five were unscheduled. The quarterly availabilities for all sites was 100%. Each of these availabilities is within the SPS value of 99.85%. These availability percentages were calculated using DOP data collected at one-second intervals.

The statistics on the days of significant solar activity met all GPS Standard Positioning Service (SPS) specifications.

Position accuracies were verified by calculating the 95% and 99.99% values of horizontal and vertical errors. Range performance was verified for each satellite using the data collected from the NSTB Atlantic City site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 35.011 meters on Satellite PRN 7. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 1.33930 Meters/second on Satellite PRN 7. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 13.39 Millimeters/second^2 on Satellite PRN 7. The SPS specification states that the range acceleration error should never exceed 19 Millimeters/second^2.

The GLONASS/GPS performance section has been permanently removed from this report.

From the analysis performed on data collected between 1 October and 31 December 2004, 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

(Future reports will include all WAAS sites but a database that can handle all that data needs to be developed. ACB 430 is in the process of setting up an Oracle database for this purpose.)

The analysis of the data is divided into the four performance categories stated in the Standard Positioning Service Performance Specification (SPS) Annex A (June 2, 1995). These categories are:

- Coverage Performance
- Satellite Availability Performance
- 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.

Appendix E Table 1.2 contains the performance parameters evaluated for the WAAS 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 availability 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 includes the maximum and minimum of the PDOP, HDOP and VDOP for each of the twenty-one NSTB/WAAS sites.

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 a measurement interval of one year. Data for the quarter is provided for completeness.

Section 5 provides the position and repeatable 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.

Table 1-1 SPS Performance Requirements

Coverage Standard	Conditions and Constraints	Evaluated in This Report
≥ 99.9% global average	• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	✓
≥ 96.9% at worst-case point	• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	✓
Satellite Availability Standard	**Conditions and Constraints**	
≥ 99.85% global average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	✓
≥ 99.16% single point average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	✓
≥ 95.87% global average on worst-case day	• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	✓
≥ 83.92% at worst-case point on worst-case day	• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	✓
Service Availability Standard	**Conditions and Constraints**	
≥ 99.97% global average	• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	✓
≥ 99.79% single point average	• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	✓

Accuracy Standard	Conditions and Constraints	
Predictable Accuracy ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	✓
Repeatable Accuracy ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	✓
Relative Accuracy ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	Future Reports
Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	✓
Range Domain Accuracy ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 8 mm/s^2 range acceleration error 95% of time ≤ 19 mm/s^2 NTE range acceleration error	• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	✓

2.0 Coverage Performance

Coverage: *The percentage of time over a specified time interval that a sufficient number of satellites are above a specified mask angle and provide an acceptable position solution geometry at any point on or near the Earth.*

Dilution of Precision (DOP): *A Root Mean Square (RMS) measure of the effects that any given position solution geometry has on position errors. Geometry effects may be assessed in the local horizontal (HDOP), local vertical (VDOP), three-dimensional position (PDOP), or time (TDOP) for example.*

Coverage Standard	Conditions and Constraints
≥ 99.9% global average	• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac
≥ 96.9% at worst-case point	• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac

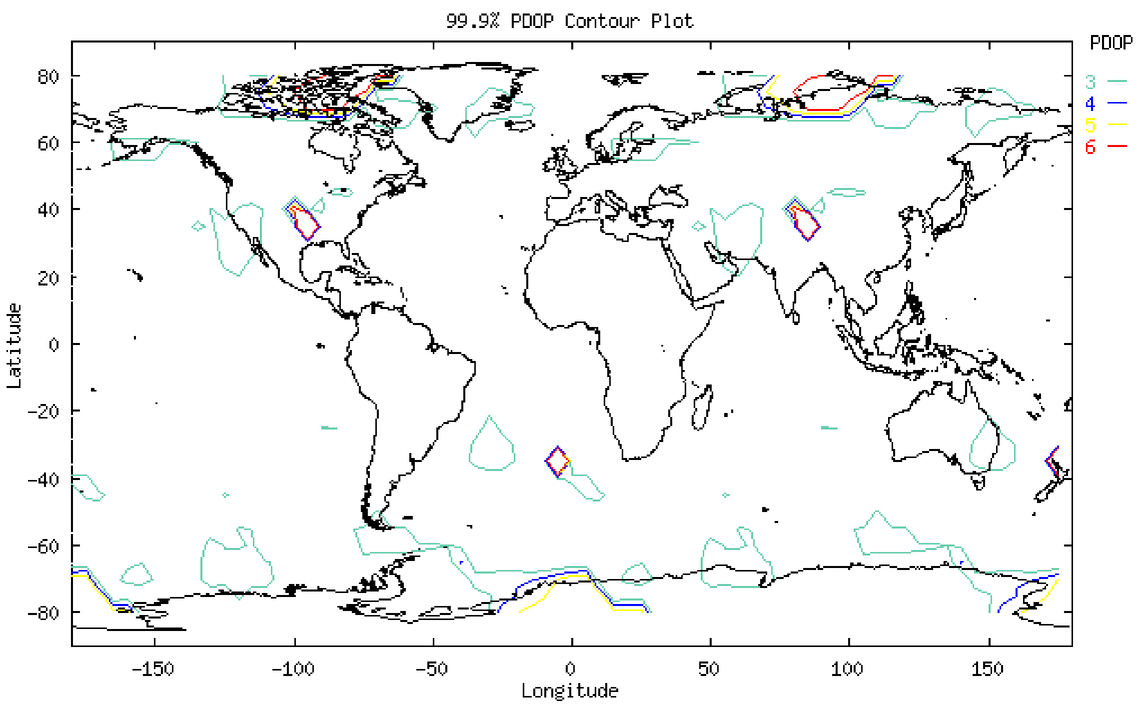
Almanacs for GPS weeks 228-240 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACB 430 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 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 3.23359 or better 99.9% of the time for each of the 24-hour intervals.

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

Table 2-1 Coverage Statistics

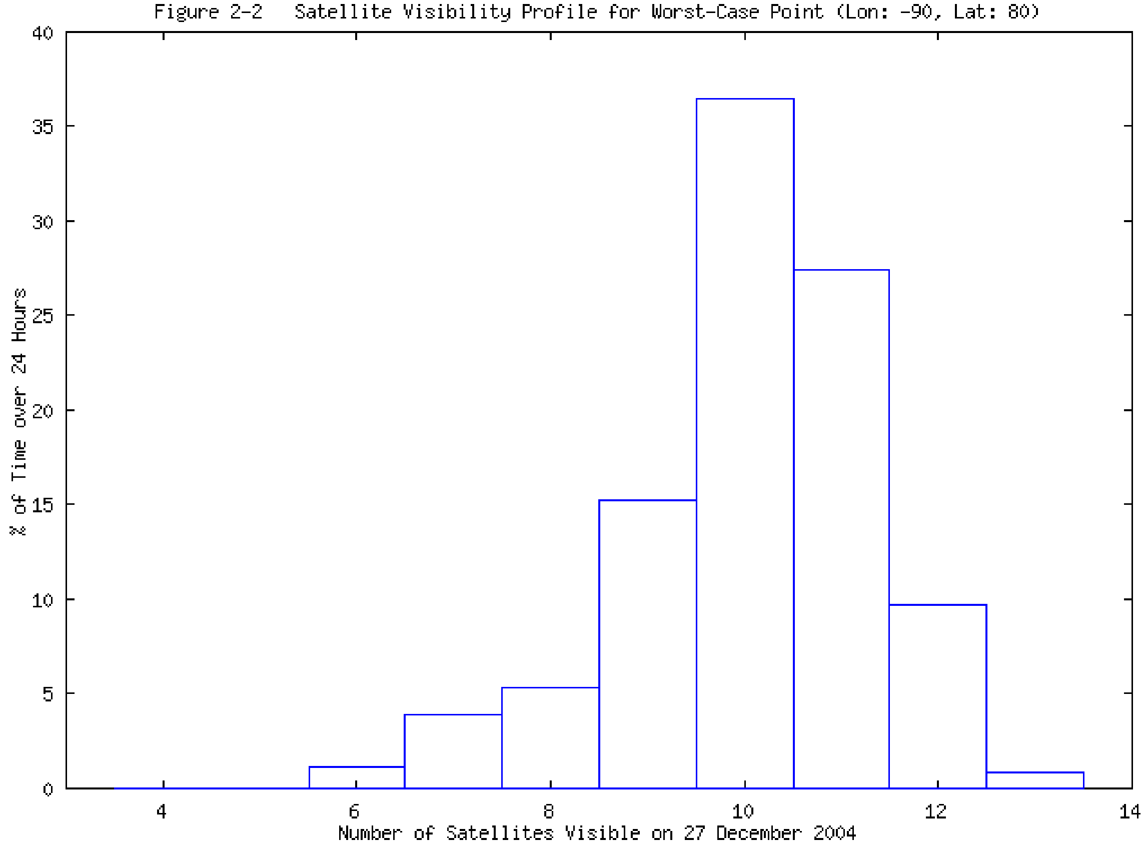
GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
267	3.10306	99.994	99.167
268	3.08471	99.992	99.097
269	3.06761	99.994	99.306
270	3.02675	99.997	99.444
271	3.00816	99.997	99.514
272	3.00896	99.997	99.514
273	2.99296	99.998	99.514
274	2.95677	99.998	99.514
275	2.92789	99.998	99.514
276	2.90733	99.998	99.514
277	2.88140	99.999	99.514
278	2.87157	99.999	99.583
279	3.23359	99.997	99.375

Figure 2-1 SPS Coverage (24-Hour Period: 27 December 2004)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -90, Lat: 80)



3.0 Service Availability Performance

Service Availability: *Given coverage, the percentage of time over a specified time interval that a sufficient number of satellites are transmitting a usable ranging signal within view of any point on or near the Earth.*

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 2004, there were a total of twelve reported outages. Eleven of these outages were maintenance activities and were reported in advance. One was an unscheduled outage. A complete listing of outage NANU's for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-2. Canceled outage NANU's are provided in Table 3-3.

Table 3-1 NANUs Affecting Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
109	10	S-FCSTSUMM	8-Oct	18:29	9-Oct	0:42		6.21	6.21
112	4	S-FCSTSUMM	15-Oct	14:48	15-Oct	18:58		4.16	4.16
113	25	S-FCSTSUMM	19-Oct	14:44	20-Oct	1:52		11.13	11.13
114	31	S-FCSTSUMM	21-Oct	15:15	22-Oct	0:22		9.11	9.11
117	31	U-UNUSABLE	26-Oct	3:54	26-Oct	11:51	7.95		7.95
122	1	S-FCSTSUMM	18-Nov	16:45	19-Nov	16:00		23.25	23.25
125	24	S-FCSTSUMM	23-Nov	16:20	24-Nov	8:08		15.80	15.80
131	31	U-UNUSABLE	1-Dec	17:39	2-Dec	1:11	7.53		7.53
134	2	S-FCSTSUMM	1-Dec	18:30	4-Dec	4:09		9.65	9.65
138	2	U-UNUSABLE	6-Dec	3:39	9-Dec	0:52	69.21		69.21
140	29	S-FCSTSUMM	10-Dec	5:00	10-Dec	10:09		5.15	5.15
142	31	U-UNUSABLE	10-Dec	23:23	13-Dec	21:20	69.95		69.95
144	30	S-FCSTSUMM	14-Dec	16:15	15-Dec	1:29		9.23	9.23
145	20	S-FCSTSUMM	16-Dec	5:09	16-Dec	11:43		6.56	6.56
146	6	S-FCSTSUMM	21-Dec	19:00	22-Dec	1:10		6.16	6.16
2005006	2	U-UNUSABLE	26-Dec	23:05	1-Jan	0:00	120.91		120.91
?	31	?	28-Dec	0:42	1-Jan	0:00	95.30		95.30
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							370.85	106.41	477.26
Type:	S = Scheduled		U = Unscheduled						

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
107	10	FCSTDV	8-Oct	18:00	9-Oct	6:00	12	See NANU 109
108	4	FCSTMX	15-Oct	14:30	16-Oct	2:30	12	See NANU 112
110	25	FCSTDV	19-Oct	14:15	20-Oct	2:15	12	See NANU 113
111	31	FCSTDV	21-Oct	15:15	22-Oct	3:15	12	See NANU 114
115	31	UNUSUFN	26-Oct	3:54	N/A	N/A	N/A	See NANU 117
120	1	FCSTDV	18-Nov	16:30	19-Nov	16:30	24	See NANU 122
121	24	FCSTDV	23-Nov	16:00	24-Nov	16:00	24	See NANU 125
124	29	FCSTDV	30-Nov	5:00	30-Nov	17:00	CANC	See NANU 127
126	2	FCSTDV	1-Dec	18:30	4-Dec	18:30	72	See NANU 134
128	31	UNUSUFN	1-Dec	17:41	N/A	N/A	N/A	See NANU 131
133	29	FCSTDV	10-Dec	4:30	10-Dec	16:30	12	See NANU 140
136	2	UNUSUFN	6-Dec	3:39	N/A	N/A	N/A	See NANU 138
137	30	FCSTDV	14-Dec	16:15	15-Dec	4:15	12	See NANU 144
139	20	FCSTDV	16-Dec	4:45	16-Dec	16:45	12	See NANU 145
141	31	UNUSUFN	10-Dec	23:23	N/A	N/A	N/A	See NANU 142
143	6	FCSTMX	21-Dec	19:00	22-Dec	7:00	12	See NANU 146
147	2	UNUSUFN	26-Dec	23:05	N/A	N/A	N/A	See NANU 2005006
148	31	UNUSUFN	28-Dec	0:42	N/A	N/A	N/A	
					Total Forecast Downtime		216	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
127	29	FCSTCANC	30-Nov	5:00	See NANU 124

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 Oct - 31 Dec. 2004**	**1 January, 2000 - 31 Dec. 2004**
Total Forecast Downtime (hrs):	216.00	4877.73
Total Actual Downtime (hrs):	381.96	11215.44
Total Actual Scheduled Downtime (hrs):	106.41	2755.43
Total Actual Unscheduled Downtime (hrs):	275.55	8460.01
Total Satellite Observed MTTR (hrs):	23.87	32.23
Scheduled Satellite Observed MTTR (hrs):	9.67	11.16
Unscheduled Satellite Observed MTTR (hrs):	55.11	83.76
# Total Satellite Outages:	16	348
# Scheduled Satellite Outages:	11	247
# Unscheduled Satellite Outages:	5	101
Percent Operational -- Scheduled Downtime:	99.84	99.78
Percent Operational -- All Downtime:	99.97	99.09

NANU 118 stated that NANU 116 was an erroneous NANU and was disregarded.
NANU 119 announced the launch of PRN 2 on 6 Nov 04.
NANU 123 announced usability of PRN 2 on 22 Nov 04 at 16:23.
NANU 130 disregarded NANU 129.
NANU 132 changed the reference NANU # of NANU 131.
NANU 135 changed the reference NANU # of NANU 134.
PRN 31 assumed as an unscheduled outage lasting until the end of the quarter until we hear of its decommissioning.

3.2 Service Availability

Service Availability Standard	Conditions and Constraints
≥ 99.85% global average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days
≥ 99.16% single point average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days
≥ 95.87% global average on worst-case day	• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe
≥ 83.92% at worst-case point on worst-case day	• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe

To verify availability, the data collected from receivers at the nine NSTB/WAAS sites was reduced to calculate DOP information and reported in Tables 3-5 to 3-7. The data was collected at one-second intervals between 1 October and 31 December 2004.

Table 3-5 PDOP Statistics

NSTB/WAAS Site	Min PDOP	Max PDOP	VDOP at Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP	Number of Samples
Bangor	1.541	6.000	5.057	2.465	5.983	5.679	7893891
Mauna Loa	1.221	5.090	4.552	1.731	3.849	3.452	7609486
Billings	1.189	5.992	3.695	1.730	3.393	2.950	7466514
Cold Bay	1.099	5.452	5.335	1.712	4.640	4.321	7836817
Juneau	1.225	5.692	5.207	1.756	4.660	4.261	7869239
Albuquerque	1.208	5.481	5.284	1.733	4.892	4.480	7926349
Anchorage	1.190	5.539	3.668	1.738	3.993	3.636	7923014
Boston	1.175	4.830	3.913	1.707	3.543	3.000	7923910
Washington, D.C.	1.122	5.834	5.311	1.723	5.267	4.803	7927541
Honolulu	1.182	5.865	5.695	1.699	4.063	3.787	7924902
Houston	1.183	5.301	3.068	1.722	3.426	3.178	7492252
Kansas City	1.183	4.279	3.573	1.729	3.449	3.042	7925098
Los Angeles	1.177	5.883	5.536	1.745	3.885	3.683	7924830
Salt Lake City	1.183	5.999	5.648	1.746	3.907	3.628	7924488
Miami	1.204	4.647	4.400	1.783	3.696	3.476	7926041
Minneapolis	1.175	4.162	3.500	1.707	3.470	2.931	7908754
Oakland	1.170	3.926	3.726	1.736	3.587	3.355	7923616
Cleveland	1.109	4.544	3.923	1.743	4.211	3.661	7730050
Seattle	1.174	3.510	3.060	1.719	3.392	2.749	7907215
San Juan	1.243	5.452	4.886	1.740	3.561	3.425	7853850
Atlanta	1.195	3.765	3.296	1.728	3.550	3.132	6674033

Tables 3-6 and 3-7 show the statistics related to maximum PDOP and PDOP greater than six, respectively. Table 3-6 shows the PDOP statistics for the worst-case point on the worst-case day.
NOTE: Global in this report refers to the twenty-one sites used. Although future reports will have all additional sites, a true global availability cannot be determined since there aren't reference stations around the world. Whenever the

PDOP goes above six and an SPS requirement is not met, an investigation is performed to determine what caused the PDOP to go above six. The following is a list of programs/procedures used during times of high PDOP:

- Notice of Advisory to Navstar Users (NANU's) messages are used to verify that satellite outages did occur. (See Section 3.1 for more details about NANU's for this quarter.)
- A satellite outage detection program developed by ACB 430 verifies satellite outages that are not verified through a NANU. For example, a satellite outage can occur for just a few seconds during an upload. This satellite detection program monitors all the receivers and keeps track of what satellites the receiver should be tracking versus what satellites the receiver is actually tracking. At least six receivers need to be tracking the satellite prior to the outage and no receiver can be tracking the satellite for the program to detect an outage. This program is also being enhanced so that false locks and late ephemeris problems can also be detected. This program will also output flags from the receivers so that problems with the receiver or TRS software, if any, can be tracked more easily.
- Data from co-located receivers is analyzed for times that the PDOP goes above six. This helps in determining whether the problem is due to the environment.

The instance of worst performance where the PDOP went above six is reported in Table 3-6. The column labeled "NANU/SOD" reports whether the outage was detected via a NANU or the Satellite Outage Detection (SOD) program along with the Satellite PRN number that had the outage.

Table 3-6 Maximum PDOP Statistics

Site	GPS Week/ Day	Max PDOP	Number of Seconds of Whole Day PDOP > 6	NANU/SOD, Satellite PRN Number	Number of Samples	Availability on days when PDOP > 6
None						
Worst-Case Point on Worst-Case Day = 100% (SPS Spec. ≥ 83.92%)						

Global Average on Worst-Case Day = 100% (SPS Spec. ≥ 95.87%)

Table 3-7 PDOP > 6 Statistics

Site	Total Number of Seconds of PDOP Monitoring	Total Seconds with PDOP > 6	Overall % Availability
Bangor	7893891	0	100%
Mauna Loa	7609486	0	100%
Billings	7466514	0	100%
Cold Bay	7836817	0	100%
Juneau	7869239	0	100%
Albuquerque	7926349	0	100%
Anchorage	7923014	0	100%
Boston	7923910	0	100%
Washington, D.C.	7927541	0	100%
Honolulu	7924902	0	100%
Houston	7492252	0	100%
Kansas City	7925098	0	100%
Los Angeles	7924830	0	100%
Salt Lake City	7924488	0	100%
Miami	7926041	0	100%
Minneapolis	7908754	0	100%
Oakland	7923616	0	100%
Cleveland	7730050	0	100%
Seattle	7907215	0	100%
San Juan	7853850	0	100%
Atlanta	6674033	0	100%
Worst Single Point Average = 100% (SPS Spec. ≥ 99.16%)			

Global Average over Reporting Period = 100% (SPS Spec. > 99.85%)

4.0 Service Reliability Standard

Service Reliability: *Given coverage and service availability, the percentage of time over a specified time interval that the instantaneous predictable horizontal error is maintained within a specified threshold at any point on or near the Earth.*

Service Reliability Standard	Conditions and Constraints
≥ 99.97% global average	• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval
≥ 99.79% single point average	• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval

Table 4-1 has the 99.99% horizontal errors reported by a receiver at each of the twenty-one NSTB/WAAS sites. This will be evaluated against the SPS specification at the end of the year.

Table 4-1 Service Reliability Based on Horizontal Error

Site	Number of Samples This Quarter	Maximum Horizontal Error (Meters)
Bangor	7893891	25.4
Mauna Loa	7609486	23.1
Billings	7466514	9.04
Cold Bay	7836817	11.5
Juneau	7869239	9.15
Albuquerque	7926349	8.64
Anchorage	7923014	12.8
Boston	7923910	13.2
Washington, D.C.	7927541	15.3
Honolulu	7924902	25.1
Houston	7492252	11.6
Kansas City	7925098	10.4
Los Angeles	7924830	8.58
Salt Lake City	7924488	8.4
Miami	7926041	12.7
Minneapolis	7908754	12.4
Oakland	7923616	8.77
Cleveland	7730050	15.0
Seattle	7907215	10.0
San Juan	7853850	20.1
Atlanta	6674033	15.3

5.0

5.1 Accuracy Characteristics

Accuracy: *Given coverage, service availability and service reliability, the percentage of time over a specified time interval that the difference between the measured and expected user position or time is within a specified threshold at any point on or near the Earth.*

Accuracy Standard	Conditions and Constraints
Predictable Accuracy ≤ 100 meters horizontal error 95% of time ≤ 156 meters vertical error 95% of time ≤ 300 meters horizontal error 99.99% of time ≤ 500 meters vertical error 99.99% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe
Repeatable Accuracy ≤ 141 meters horizontal error 95% of time ≤ 221 meters vertical error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe
Relative Accuracy ≤ 1.0 meters horizontal error 95% of time ≤ 1.5 meters vertical error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time
Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory
Range Domain Accuracy ≤ 150 meters NTE range error ≤ 2 meters/second NTE range rate error ≤ 8 millimeters/second^2 range acceleration error 95% of time ≤ 19 millimeters/second^2 NTE range acceleration error	• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard

5.1 Position Accuracies

The data used for this section was collected for every second between 1 October through 31 December 2004 at the NSTB and WAAS selected locations.

Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter.

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	3.821	6.589	16.153	18.076
Mauna Loa	8.153	7.186	22.517	23.414
Billings	2.937	5.281	7.357	10.121
Cold Bay	2.989	6.628	10.199	15.803
Juneau	2.726	6.010	8.767	13.116
Albuquerque	2.813	5.574	7.668	12.921
Anchorage	2.708	6.356	7.083	16.081
Boston	2.870	4.930	12.345	10.934
Washington, D.C.	2.910	5.200	13.365	11.567
Honolulu	7.936	7.074	24.287	20.810
Houston	2.857	6.095	9.847	14.340
Kansas City	2.970	5.504	9.201	11.732
Los Angeles	2.865	6.424	7.692	13.184
Salt Lake City	2.951	5.570	7.035	10.949
Miami	2.787	6.166	10.708	15.481
Minneapolis	2.927	5.171	11.631	11.198
Oakland	2.831	6.410	6.639	12.079
Cleveland	3.008	5.055	12.801	11.794
Seattle	2.948	5.763	8.088	10.678
San Juan	3.799	6.143	13.862	20.763
Atlanta	2.892	5.820	12.856	12.743

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 2004.

Figure 5-1 Combined Vertical Error Histogram

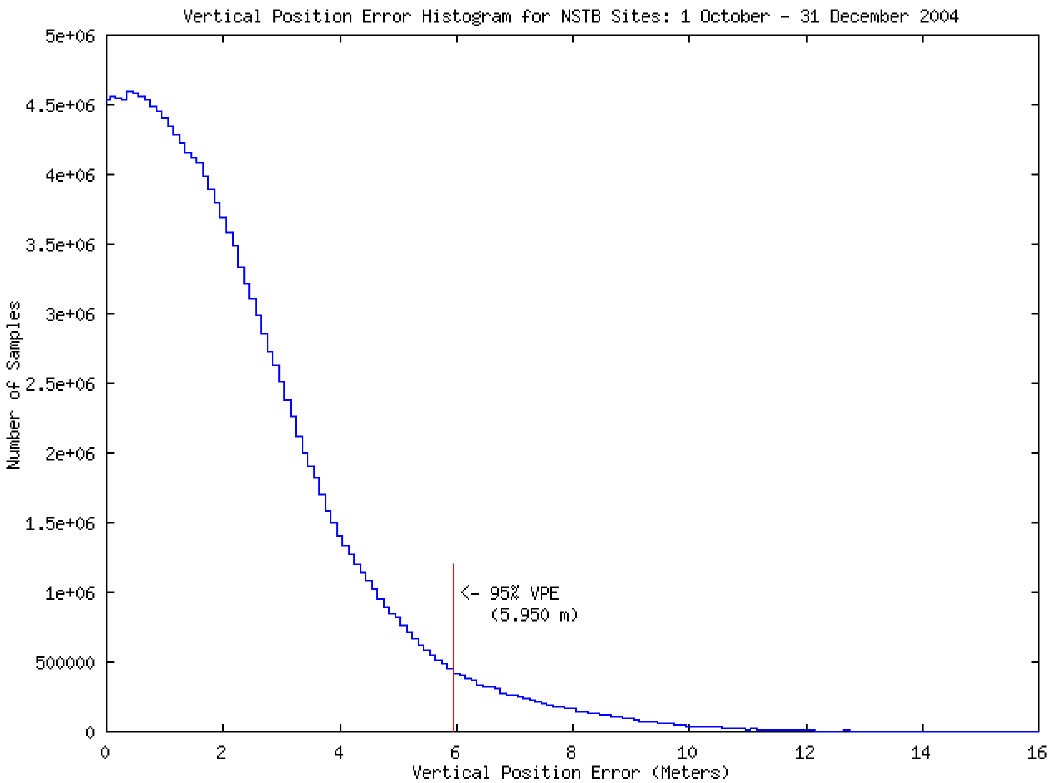
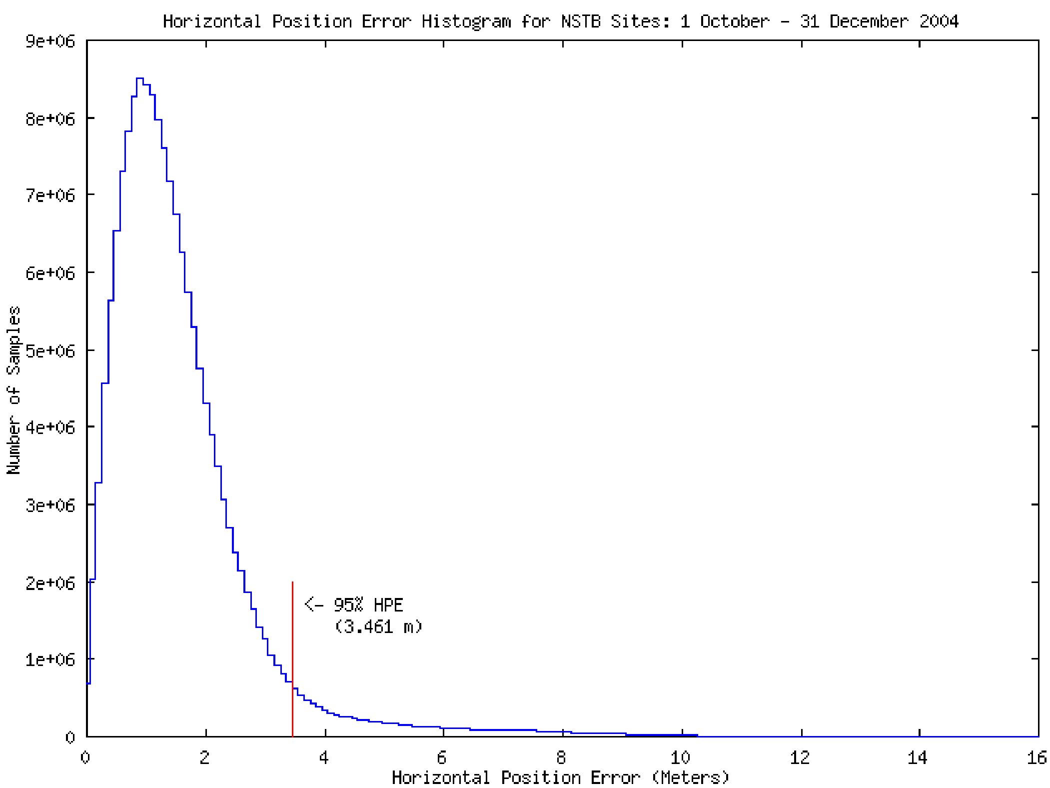


Figure 5-2 Combined Horizontal Error Histogram



5.2 Repeatable Accuracy

Table 5-2 provides the repeatability statistics, which met all of the evaluated requirements stated in the SPS.

Table 5-2 Repeatability Statistics

Site	95% Horizontal (m)	95% Vertical (m)
Bangor	2.133	3.842
Mauna Loa	1.239	3.381
Billings	0.887	2.250
Cold Bay	0.918	2.020
Juneau	0.768	2.199
Albuquerque	0.935	2.219
Anchorage	0.703	1.952
Boston	0.720	2.267
Washington, D.C.	0.734	2.027
Honolulu	1.081	3.072
Houston	0.777	2.005
Kansas City	0.876	2.583
Los Angeles	0.810	2.087
Salt Lake City	0.930	2.192
Miami	0.741	2.138
Minneapolis	0.992	3.109
Oakland	0.860	2.500
Cleveland	0.981	2.247
Seattle	1.241	2.458
San Juan	0.551	2.008
Atlanta	0.788	2.091

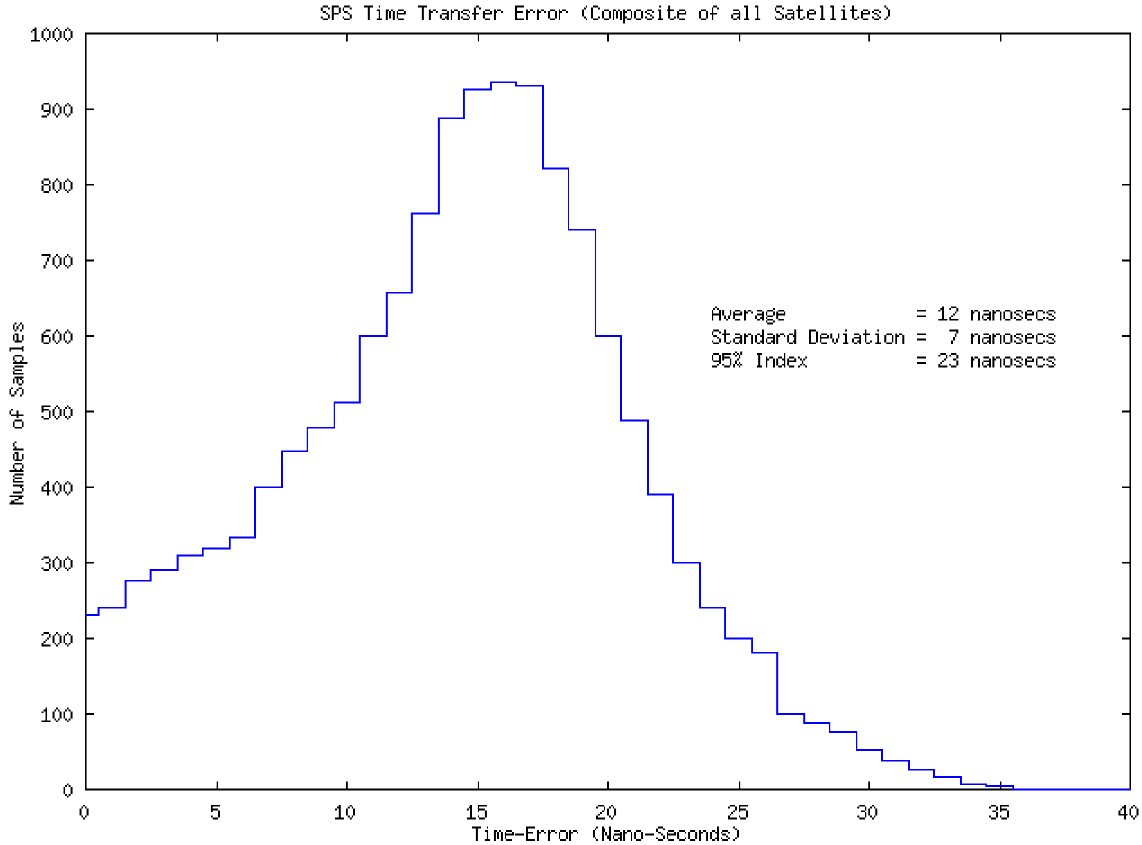
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 October and 31 December 2004 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



5.5 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 2004. The WAAS receiver at Houston was used to collect range measurement. Future PAN reports will contain statistics from all WAAS sites.

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 5-3 Range Error Statistics (meters)

PRN	Range Error Mean	Range Error RMS	1s	95% Range Error	Max Range Error (SPS Spec. ≤ 150 m)	Samples
1	3.021	3.969	2.575	7.067	9.936	2011520
2	4.978	5.554	2.463	8.681	14.683	577493
3	2.547	3.596	2.539	6.472	12.629	2361287
4	3.327	4.414	2.900	8.183	29.215	2026414
5	5.123	5.773	2.662	9.827	14.780	2093206
6	3.672	4.435	2.488	7.904	14.684	1764018
7	4.509	5.449	3.061	10.309	35.011	1888366
8	2.393	4.189	3.438	8.257	16.883	1854334
9	3.898	4.756	2.724	8.736	22.413	2366139
10	4.765	5.593	2.929	9.573	17.552	2211086
11	3.858	4.550	2.412	7.408	15.731	2388953
13	2.015	3.244	2.542	5.852	23.900	1725758
14	4.707	5.013	1.723	7.244	11.190	1906700
15	4.286	4.832	2.231	7.904	24.230	1798647
16	3.629	4.177	2.068	6.527	16.414	2306552
17	4.700	5.423	2.706	9.425	16.498	1934125
18	4.736	4.964	1.488	7.011	11.915	1972450
19	5.532	6.083	2.529	9.134	15.886	2368285
20	4.095	4.662	2.228	7.344	25.099	2081635
21	5.540	5.861	1.913	8.720	15.384	1968865
22	5.153	5.438	1.738	7.924	10.330	2023891
23	4.686	5.214	2.287	8.000	15.295	1883514
24	4.123	4.947	2.734	8.598	15.324	1811461
25	3.126	3.930	2.382	6.758	11.734	1795165
26	2.617	3.623	2.506	6.203	15.043	2358490
27	1.780	3.447	2.952	7.120	14.301	1967537
28	3.509	4.902	3.422	9.405	20.735	1989258
29	3.366	4.137	2.406	6.785	15.183	2404589
30	3.470	4.224	2.408	7.397	16.533	2288095
31	3.878	5.265	3.561	10.915	26.059	1627112

Table 5-4 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 (SPS Spec. ≤ 2 m)	Samples
1	0.00003	0.00344	0.00344	0.00589	0.19772	2011520
2	-0.0008	0.00409	0.00408	0.00260	0.44676	577493
3	-0.00006	0.00317	0.00317	0.00599	0.21157	2361287
4	0.00005	0.00732	0.00732	0.00746	1.16127	2026414
5	-0.00011	0.00352	0.00352	0.00628	0.20030	2093206
6	-0.00014	0.00349	0.00349	0.00611	0.33279	1764018
7	0.00007	0.00338	0.00338	0.00601	1.33930	1888366
8	0.00006	0.00403	0.00403	0.00629	0.33738	1854334
9	0.00010	0.00352	0.00352	0.00601	0.81395	2366139
10	0.00003	0.00452	0.00452	0.00658	0.66526	2211086
11	0.00006	0.00318	0.00318	0.00621	0.42826	2388953
13	-0.00004	0.00482	0.00482	0.00636	1.04298	1725758
14	-0.00009	0.00286	0.00286	0.00580	0.21886	1906700
15	0.00001	0.00345	0.00345	0.00596	0.87660	1798647
16	-0.00011	0.00372	0.00372	0.00622	0.71702	2306552
17	-0.00006	0.00296	0.00296	0.00593	0.16666	1934125
18	-0.00005	0.00264	0.00264	0.00579	0.10062	1972450
19	-0.00004	0.00260	0.00260	0.00583	0.29644	2368285
20	-0.00002	0.00451	0.00451	0.00659	1.08685	2081635
21	-0.00009	0.00289	0.00289	0.00595	0.17408	1968865
22	-0.00007	0.00268	0.00268	0.00574	0.14619	2023891
23	0.00005	0.00286	0.00286	0.00596	0.18749	1883514
24	-0.00006	0.00368	0.00368	0.00624	0.31065	1811461
25	-0.00005	0.00302	0.00302	0.00588	0.22715	1795165
26	0.00015	0.00328	0.00328	0.00618	0.49051	2358490
27	0.00012	0.00265	0.00264	0.00578	0.22890	1967537
28	0.00016	0.00378	0.00378	0.00606	0.23383	1989258
29	0.00007	0.00390	0.00390	0.00638	0.39139	2404589
30	-0.00002	0.00312	0.00312	0.00611	0.43799	2288095
31	0.00005	0.00347	0.00347	0.00614	1.11547	1627112

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1 s	% ≤ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. ≤ 0.019 m/s2)	Samples
1	0	0.00003	0.00003	100	0.00194	2011520
2	0	0.00004	0.00004	100	0.00446	577493
3	0	0.00003	0.00003	100	0.00204	2361287
4	0	0.00007	0.00007	99.999	0.01161	2026414
5	0	0.00003	0.00003	100	0.00186	2093206
6	0	0.00003	0.00003	100	0.00333	1764018
7	0	0.00003	0.00003	99.999	0.01339	1888366
8	0	0.00003	0.00003	100	0.00316	1854334
9	0	0.00003	0.00003	99.999	0.00814	2366139
10	0	0.00004	0.00004	100	0.00664	2211086
11	0	0.00003	0.00003	100	0.00429	2388953
13	0	0.00004	0.00004	99.999	0.01042	1725758
14	0	0.00003	0.00003	100	0.00219	1906700
15	0	0.00003	0.00003	99.999	0.00878	1798647
16	0	0.00003	0.00003	100	0.00708	2306552
17	0	0.00003	0.00003	100	0.00167	1934125
18	0	0.00002	0.00002	100	0.00101	1972450
19	0	0.00002	0.00002	100	0.00296	2368285
20	0	0.00004	0.00004	99.999	0.01085	2081635
21	0	0.00003	0.00003	100	0.00190	1968865
22	0	0.00002	0.00002	100	0.00147	2023891
23	0	0.00002	0.00002	100	0.00186	1883514
24	0	0.00003	0.00003	100	0.00310	1811461
25	0	0.00003	0.00003	100	0.00226	1795165
26	0	0.00003	0.00003	100	0.00490	2358490
27	0	0.00002	0.00002	100	0.00223	1967537
28	0	0.00003	0.00003	100	0.00234	1989258
29	0	0.00003	0.00003	100	0.00378	2404589
30	0	0.00003	0.00003	100	0.00460	2288095
31	0	0.00003	0.00003	99.999	0.01113	1627112

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 150-meter SPS requirement. The highest maximum range error occurred on satellite 7 with an error of 35.011 meters. Satellite 1 had the lowest maximum range error of 9.936 meters.

Figure 5-4 Distribution of Daily Max Range Errors

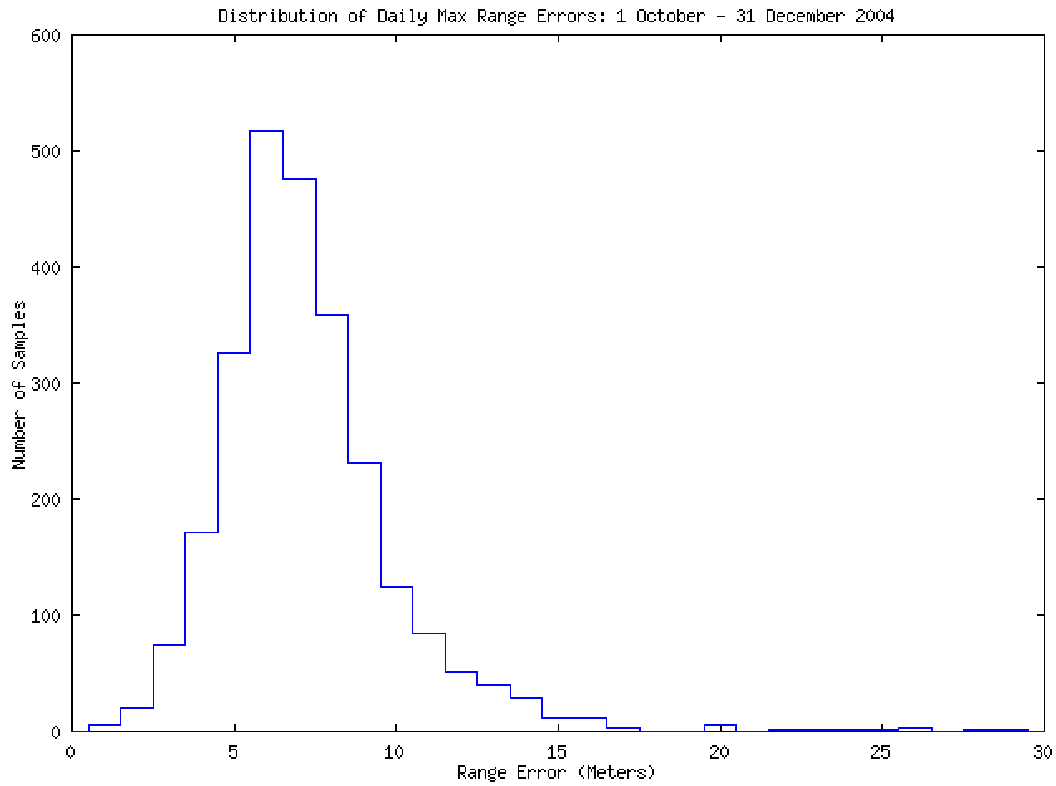


Figure 5-5: Distribution of Daily Max Range Rate Errors

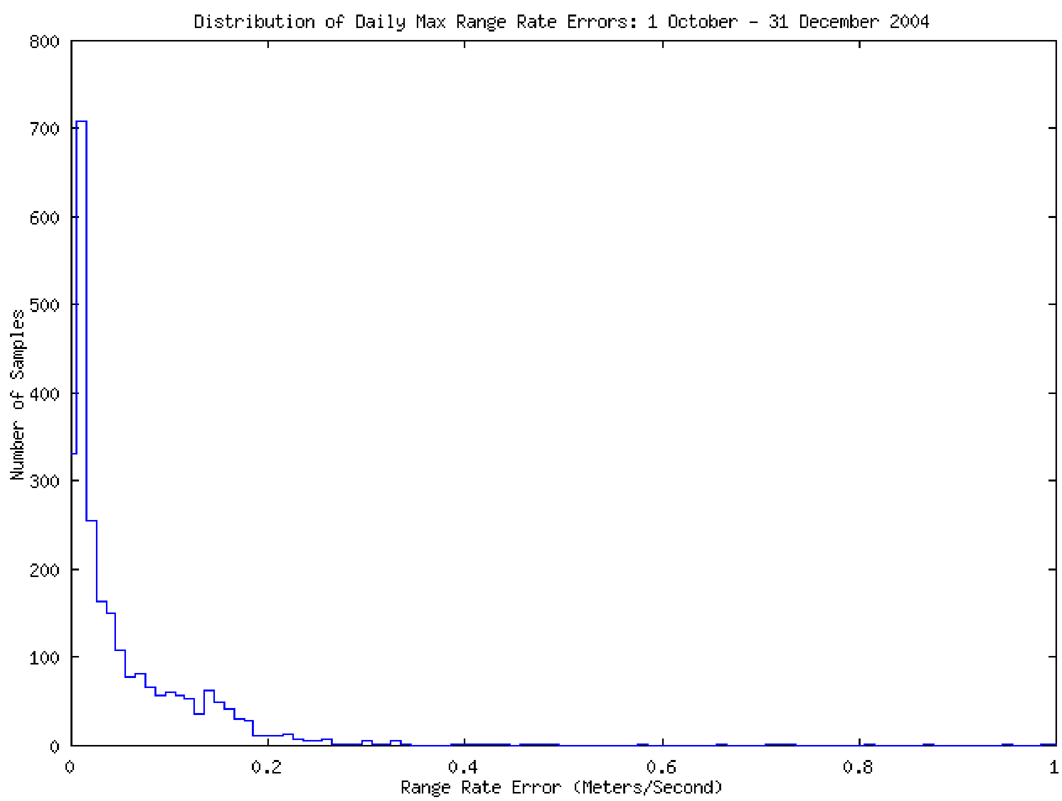


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

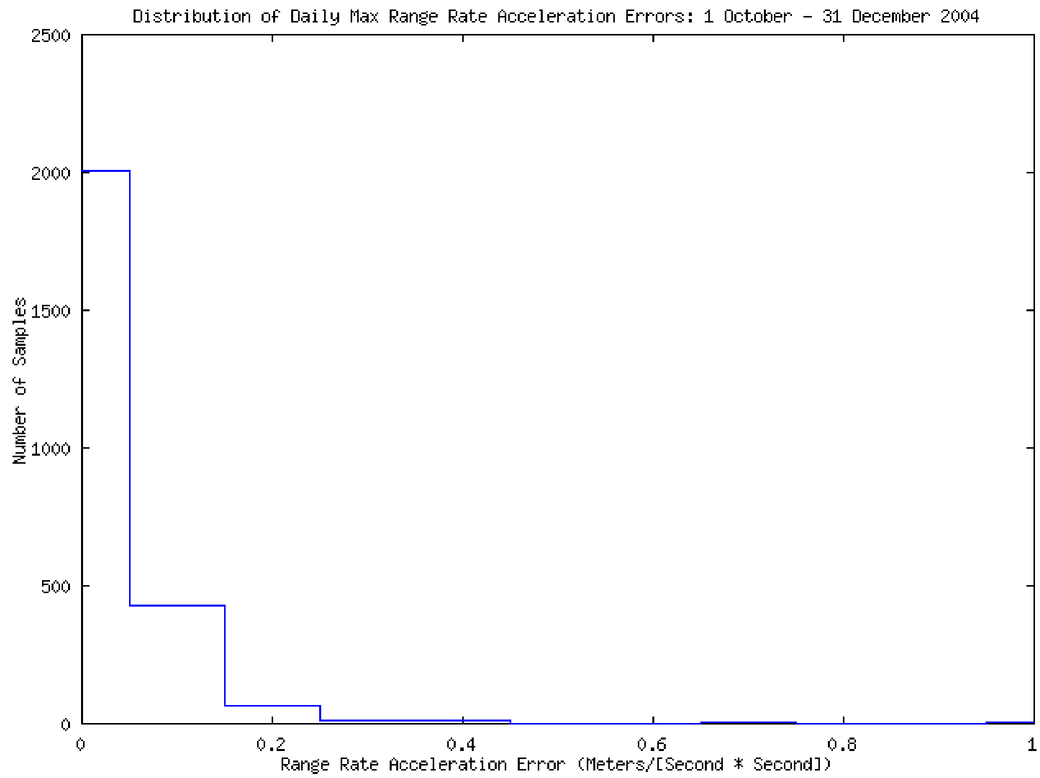


Figure 5-7: Range Error Histogram

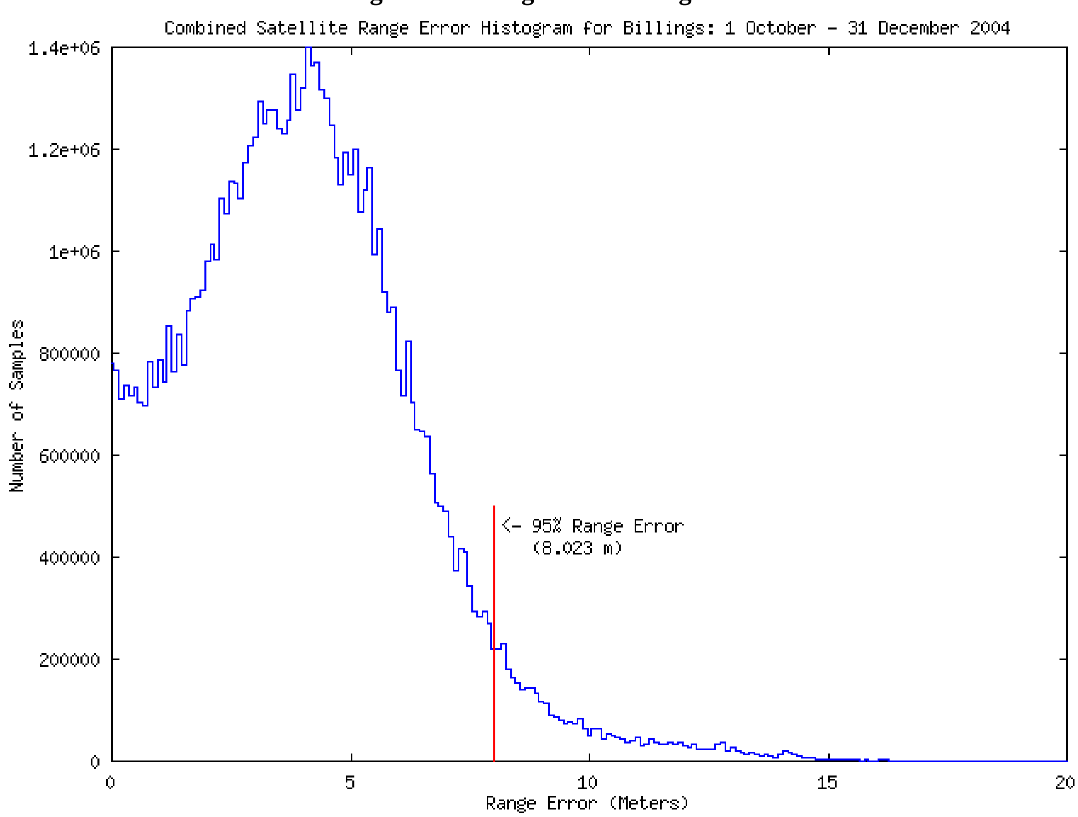


Figure 5-8: Maximum Range Error Per Satellite

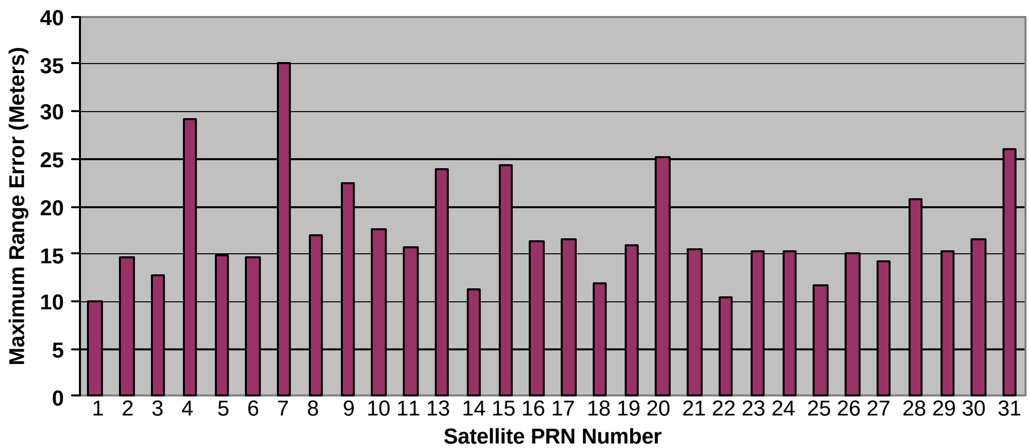


Figure 5-9: Maximum Range Rate Error Per Satellite

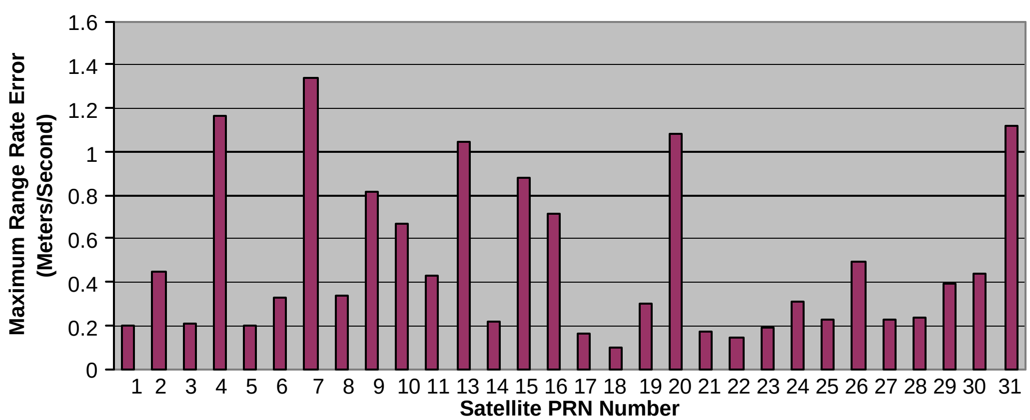
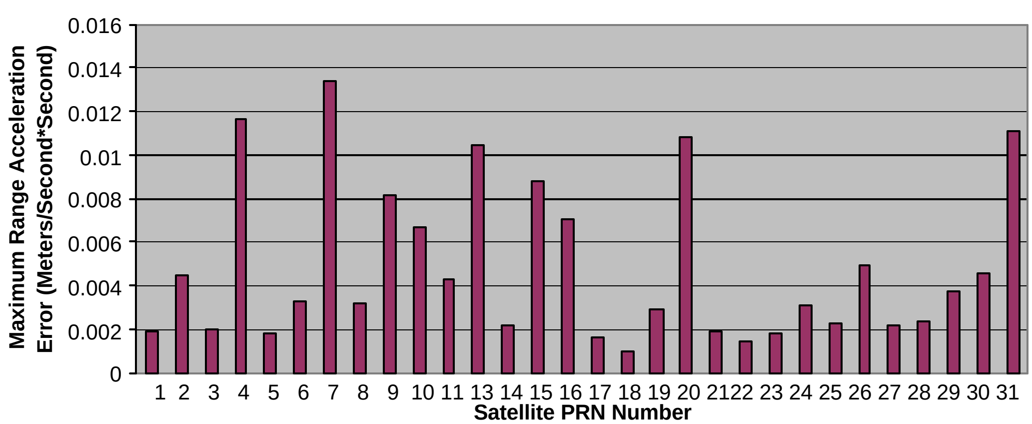


Figure 5-10: Maximum Range Acceleration Per Satellite



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 8-10 November 2004

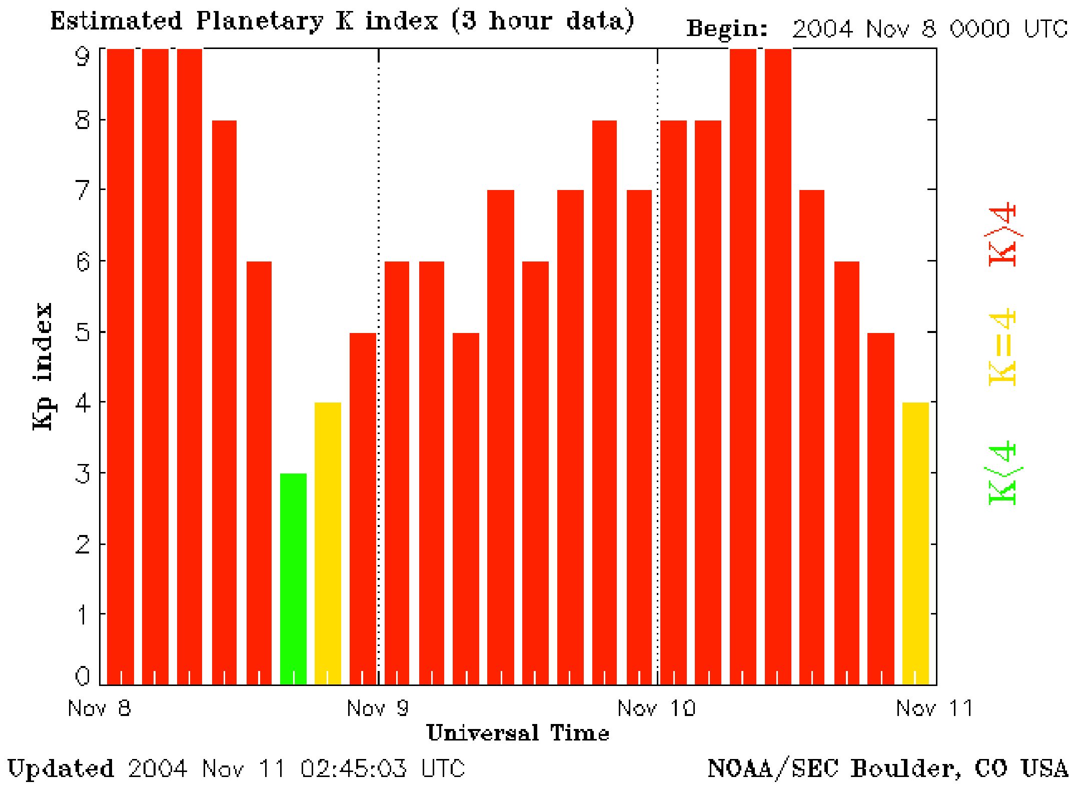


Figure 6-2 K-Index for 13-15 October 2004

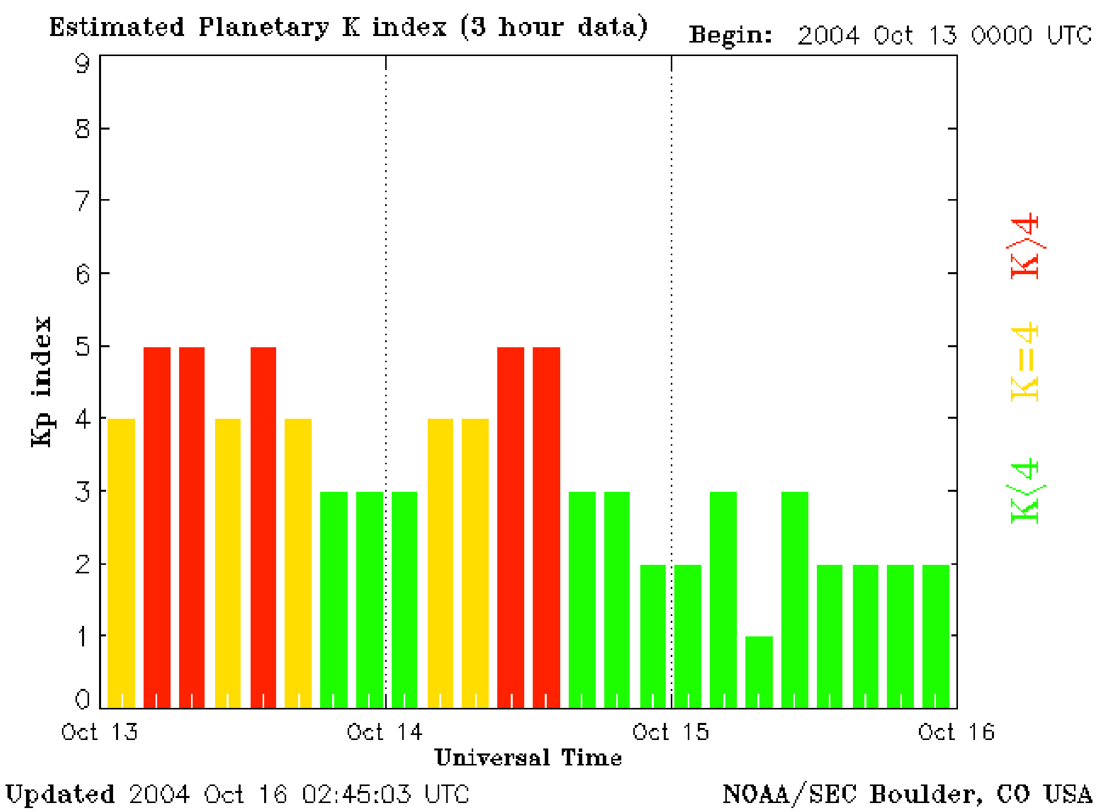
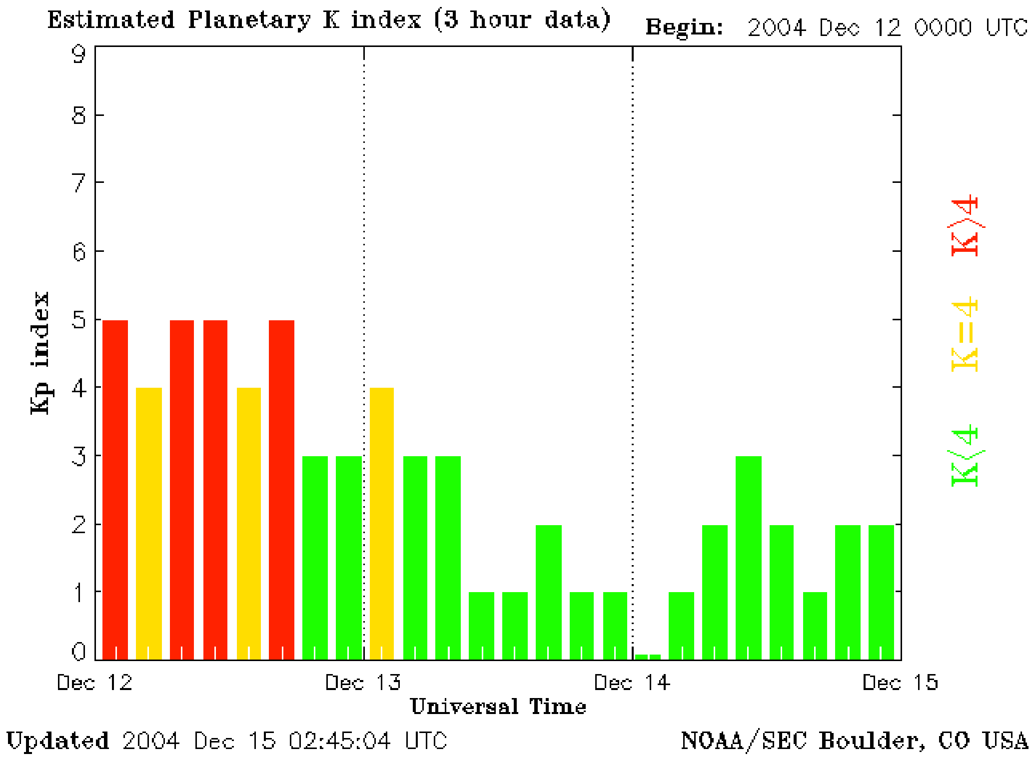


Figure 6-3 K-Index for 12-4 December 2004



Tables 6-1 and 6-2 below show the PDOP and position accuracy information, respectively, for the days corresponding to Figure 6-1. The GPS SPS performance met the availability requirements during all storms that occurred during this quarter.

Table 6-1 PDOP Statistics for 8 November 2004

Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Bangor	1.584	4.888	2.378	4.886	4.447
Mauna Loa	1.250	3.819	1.716	3.009	2.762
Billings	1.191	2.982	1.721	2.981	2.461
Cold Bay	1.151	4.608	1.703	4.605	4.320
Juneau	1.234	3.622	1.717	3.621	3.107
Albuquerque	1.211	3.591	1.716	3.591	2.914
Anchorage	1.212	3.994	1.722	3.994	3.671
Boston	1.209	3.548	1.692	3.546	2.999
Washington, D.C.	1.231	3.526	1.715	3.526	3.059
Honolulu	1.250	3.150	1.668	3.147	2.868
Houston	1.195	2.704	1.698	2.704	2.338
Kansas City	1.223	2.916	1.718	2.915	2.293
Los Angeles	1.179	2.720	1.739	2.720	2.475
Salt Lake City	1.190	3.847	1.729	3.843	3.586
Miami	1.212	3.467	1.750	3.467	3.218
Minneapolis	1.187	2.866	1.706	2.866	2.357
Oakland	1.172	2.720	1.716	2.718	2.440
Cleveland	1.204	3.541	1.731	3.541	2.960
Seattle	1.185	2.952	1.699	2.952	2.440
San Juan	1.256	3.515	1.722	3.515	3.380
Atlanta	1.203	3.492	1.721	3.491	3.076

Table 6-2 Horizontal & Vertical Accuracy Statistics for 8 November 2004

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Bangor	4.012	9.169	7.711	11.731
Mauna Loa	16.990	17.044	23.138	23.651
Billings	4.323	6.615	6.966	9.195
Cold Bay	7.515	7.404	11.510	16.977
Juneau	4.558	6.474	8.247	9.600
Albuquerque	5.148	7.573	6.202	11.948
Anchorage	5.255	6.935	7.642	15.311
Boston	3.176	8.570	4.612	9.949
Washington, D.C.	3.482	8.434	4.309	9.846
Honolulu	19.342	16.527	25.017	22.573
Houston	5.187	7.737	6.982	11.828
Kansas City	4.153	8.338	5.252	10.180
Los Angeles	5.330	7.877	8.279	11.725
Salt Lake City	5.298	7.079	8.377	9.777
Miami	3.254	8.989	4.680	11.131
Minneapolis	3.070	7.088	4.651	8.567
Oakland	4.882	7.464	5.941	9.257
Cleveland	3.728	7.877	5.952	9.696
Seattle	5.186	6.783	9.986	14.638
San Juan	3.768	8.250	6.201	11.431
Atlanta	3.674	7.862	4.726	9.469

APPENDICES A – D

Conditions and Constraints	Coverage Standard	Measured Performance
• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 99.9% global average	99.992%
• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 96.9% at worst-case point	99.097% Availability 99.9% PDOP was 3.23359
Conditions and Constraints	***Satellite Availability Standard***	***Measured Performance***
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.85% global average	100%
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.16% single point average	100%
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	100%
• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	≥ 83.92% at worst-case point on worst-case day	100%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• Conditioned on coverage and service avail. standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.97% global average	100%
• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.79% single point average	100%

Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	<u>Predictable Accuracy</u> ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	≤8.153m HE 95% ≤24.287m HE 99.99% ≤7.186m VE 95% ≤23.414m VE 99.99%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	<u>Repeatable Accuracy</u> ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	≤2.133m HE 95% ≤3.842m VE 95%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	<u>Relative Accuracy</u> ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	Future Reports
• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	<u>Time Transfer Accuracy</u> ≤ 340 nanoseconds time transfer error 95% of time	≤17 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	<u>Range Domain Accuracy</u> ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range acceleration error ≤ 8 mm/s^2 range acceleration error 95% of time	35.011m NTE Range Error 1.3393m/s NTE Rate Error 13.39mm/s^2 NTE Accl. Error ≤8mm/s^2 99.999% of the time

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#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center.
#  Please send comment and suggestions to SEC.Webmaster@noaa.gov
#
#            Current Quarter Daily Geomagnetic Data
#
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	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2004 10 01	2	0 0 0 0 1 0 2 2	1	0 0 0 0 0 0 1 1	4	1 1 1 0 1 2 2 2
2004 10 02	8	2 2 3 2 3 1 2 1	16	1 2 4 5 4 3 1 0	12	2 3 3 3 4 3 2 2
2004 10 03	7	0 1 2 2 3 2 2 2	33	0 1 4 6 6 5 3 2	15	1 2 3 4 4 3 3 3
2004 10 04	8	3 3 1 1 2 1 2 2	12	2 3 2 2 4 4 1 1	10	3 3 2 2 2 2 3 3
2004 10 05	3	2 2 1 0 1 0 0 1	4	2 2 3 1 0 0 0 1	5	2 2 2 0 1 2 2 2
2004 10 06	2	0 2 2 1 0 0 0 0	6	0 0 2 4 2 1 0 0	5	1 2 2 2 2 2 2 2
2004 10 07	4	0 1 0 0 0 3 3 0	2	0 0 1 1 2 0 0 0	4	1 2 1 1 2 2 2 2
2004 10 08	4	0 2 1 0 2 2 1 2	6	0 0 1 0 2 4 1 2	7	1 3 2 1 2 2 1 3
2004 10 09	3	2 1 1 0 1 1 1 1	4	3 1 0 2 0 1 1 1	6	3 1 0 1 1 2 2 2
2004 10 10	5	2 1 1 2 2 1 1 1	5	1 1 1 3 2 0 1 1	8	3 3 0 3 2 2 2 2
2004 10 11	9	2 4 2 1 1 1 2 3	14	1 3 3 2 5 3 1 1	11	3 3 2 1 3 3 2 3
2004 10 12	7	3 2 2 1 1 1 0 3	9	2 3 4 3 0 1 0 2	11	3 3 3 3 2 2 2 3
2004 10 13	17	3 4 4 3 3 2 3 3	52	4 5 6 5 7 5 3 2	35	4 5 5 4 5 4 3 3
2004 10 14	12	3 3 3 3 3 2 2 1	58	3 3 6 7 7 5 3 2	27	3 4 4 5 5 3 3 2
2004 10 15	6	2 2 1 2 2 1 2 1	19	2 2 3 6 4 3 0 1	9	2 3 1 3 2 2 2 2
2004 10 16	3	3 1 0 0 1 0 0 1	3	1 2 0 2 1 0 0 1	5	3 1 1 1 1 1 1 1
2004 10 17	0	0 1 0 0 0 0 0 0	0	0 0 0 1 0 0 0 0	3	0 1 1 1 1 0 1 1
2004 10 18	4	0 0 1 1 1 2 3 1	2	0 0 0 1 0 1 1 1	4	0 0 0 1 1 2 2 2
2004 10 19	3	0 1 0 1 2 1 1 1	3	0 0 0 1 2 2 1 1	4	0 1 0 1 2 2 1 1
2004 10 20	9	1 3 2 1 3 3 1 2	29	1 4 4 2 6 6 1 2	12	1 3 3 1 4 4 1 2
2004 10 21	5	2 2 2 1 1 1 1 1	6	2 3 3 2 0 0 0 0	8	2 3 3 1 2 2 2 1
2004 10 22	5	2 2 1 1 1 1 2 1	4	1 1 1 2 2 1 1 0	6	2 2 1 1 2 2 2 1
2004 10 23	1	0 0 0 0 0 1 1 1	1	0 0 0 1 0 0 1 0	4	0 0 1 1 1 2 1 1
2004 10 24	6	1 1 0 1 2 2 3 2	5	0 0 0 0 1 3 3 2	9	2 0 0 1 2 3 4 2
2004 10 25	9	2 2 3 3 3 2 1 1	15	1 2 3 5 4 2 2 1	13	2 3 3 4 3 2 2 1
2004 10 26	0	1 0 0 0 0 0 0 0	0	0 1 0 0 0 0 0 0	3	1 0 0 0 1 1 1 0
2004 10 27	2	0 0 0 0 2 1 1 1	2	0 0 0 1 1 1 1 0	3	0 0 0 1 1 2 1 2
2004 10 28	2	1 1 0 0 1 1 1 0	1	1 0 0 0 0 0 1 1	3	1 1 0 0 1 1 1 1
2004 10 29	6	0 0 0 2 3 2 3 1	16	0 0 1 5 5 2 3 1	7	0 0 1 3 3 2 3 1
2004 10 30	10	3 3 2 2 2 2 1 3	25	3 3 4 6 4 3 2 3	17	4 3 3 4 3 3 2 3
2004 10 31	7	2 2 0 2 3 2 2 2	18	2 1 1 5 5 4 1 2	10	3 2 1 2 3 2 2 3
2004 11 01	4	3 0 0 1 2 1 0 1	4	1 1 0 2 3 2 0 0	5	2 1 1 1 2 2 1 1
2004 11 02	2	1 0 0 1 1 1 1 1	5	0 0 0 3 2 2 2 1	4	1 0 0 2 1 2 2 1
2004 11 03	7	0 1 1 2 1 2 3 3	10	0 0 0 5 2 1 2 3	10	0 0 0 3 2 3 3 4
2004 11 04	5	1 2 1 1 1 1 1 3	9	2 2 4 3 1 2 0 1	7	1 2 2 1 1 3 2 2
2004 11 05	1	2 0 0 0 0 0 1 0	1	2 0 0 0 0 0 1 0	4	3 1 0 0 1 1 1 0
2004 11 06	4	0 2 1 0 1 1 3 1	0	0 0 0 0 0 0 0 0	3	0 0 0 0 1 1 1 1
2004 11 07	19	1 2 2 3 3 4 4 5	-1	-1-1-1-1-1-1-1-1	39	1 2 1 3 3 5 6 7
2004 11 08	116	9 8 7 6 3 2 3 4	114	6 7 7 9 6 3 4 4	189	9 9 9 8 6 3 4 5
2004 11 09	47	6 4 4 4 4 4 6 6	188	4 6 7 9 8 8 8 7	120	6 6 5 7 6 7 8 7
2004 11 10	101	7 7 8 7 6 4 4 3	122	6 6 8 8 7 7 5 2	181	8 8 9 9 7 6 5 4
2004 11 11	22	4 4 4 3 2 4 3 4	-1	3 5 5 5 4 4 4-1	23	4 5 4 4 2 3 2 4
2004 11 12	23	4 5 4 4 4 2 2 3	-1	-1-1-1-1-1 4 3 4	30	5 5 4 5 4 3 3 4
2004 11 13	7	2 2 3 1 2 2 1 1	12	2 2 3 4 3 3 2 1	8	2 2 4 2 2 2 1 1
2004 11 14	7	4 2 2 1 1 1 1 1	8	3 2 2 2 3 2 2 0	9	4 2 2 2 2 2 2 1
2004 11 15	2	0 0 1 0 1 1 2 0	0	0 0 0 0 0 0 0 0	3	0 0 1 0 1 1 1 0
2004 11 16	5	0 0 3 2 2 2 1 1	14	0 0 4 4 4 4 2 1	8	0 1 3 3 2 2 2 2
2004 11 17	7	1 1 3 2 1 0 2 3	9	1 1 4 4 2 0 1 0	6	1 1 3 2 1 1 1 1

2004 11 18	4	2 1 0 0 1 3 2 0	0	0 0 1 0 0 0 1 0	3	0 0 0 1 1 1 1 1
2004 11 19	3	0 2 1 0 0 1 2 1	1	0 0 0 0 0 1 1 1	4	0 2 0 0 1 2 2 2
2004 11 20	12	3 3 2 3 3 3 2 2	38	2 4 3 7 6 3 3 2	18	3 4 3 4 4 3 3 3
2004 11 21	9	2 1 2 2 3 2 3 2	32	2 1 3 6 6 5 2 3	16	2 1 3 5 4 3 2 2
2004 11 22	6	1 3 3 1 1 1 1 1	9	1 3 3 4 1 1 2 0	10	1 4 4 3 1 2 2 1
2004 11 23	4	2 1 0 1 1 2 1 2	5	1 1 2 0 0 3 1 2	5	2 1 1 1 1 2 1 2
2004 11 24	7	2 2 1 3 2 2 2 2	14	2 2 1 5 4 1 1 1	6	2 1 1 3 2 2 1 2
2004 11 25	19	4 4 3 3 3 4 2 3	33	5 5 4 5 5 4 2 2	20	4 5 3 4 4 3 2 2
2004 11 26	16	3 4 4 4 2 2 2 3	19	2 2 5 5 3 3 2 2	13	3 3 4 3 2 2 2 3
2004 11 27	10	2 2 3 2 3 3 2 2	28	2 1 5 5 5 5 3 1	10	1 2 3 2 3 3 3 2
2004 11 28	16	3 3 5 2 2 2 3 3	23	2 3 6 3 4 4 2 2	14	3 3 5 2 2 3 2 2
2004 11 29	20	3 3 3 4 3 4 3 4	16	2 2 3 3 4 4 3 3	15	3 3 3 3 3 3 3 4
2004 11 30	16	3 4 3 2 3 3 3 3	24	3 3 3 5 4 4 4 3	15	3 4 3 2 3 3 3 3
2004 12 01	11	1 3 4 2 2 2 2 3	13	2 2 4 4 3 2 2 2	13	1 3 5 2 1 2 1 2
2004 12 02	4	1 1 2 0 1 2 2 1	3	1 0 2 0 1 2 1 0	4	1 1 2 0 1 2 1 1
2004 12 03	1	0 0 0 0 1 0 1 0	1	0 0 0 0 0 0 1 1	3	0 1 1 0 1 1 1 1
2004 12 04	0	0 0 0 0 0 0 1 0	0	0 0 0 0 0 0 0 0	1	0 0 0 0 0 1 0 0
2004 12 05	7	0 1 4 2 1 2 1 1	2	0 0 2 1 0 1 1 0	8	0 1 4 2 1 2 2 1
2004 12 06	11	2 2 3 3 2 3 2 3	35	1 2 6 5 4 6 4 2	19	1 3 4 4 4 4 4 3
2004 12 07	9	2 3 2 2 2 2 3 1	25	3 3 3 5 5 4 4 2	15	2 5 2 3 3 3 3 2
2004 12 08	9	3 3 3 1 2 1 1 2	18	1 2 4 4 5 3 2 2	10	3 2 3 2 2 2 3 2
2004 12 09	7	3 0 1 3 2 1 2 1	13	2 1 1 5 4 2 2 1	8	2 1 1 4 2 2 2 1
2004 12 10	8	2 2 2 2 1 2 2 3	20	1 1 2 5 4 5 2 3	10	1 2 2 3 3 2 3 3
2004 12 11	11	1 0 3 2 3 3 2 4	23	1 0 3 3 6 4 4 3	15	1 1 3 2 4 3 4 4
2004 12 12	24	5 4 4 4 2 4 3 3	48	4 3 5 6 5 7 3 2	36	5 4 5 5 4 5 3 3
2004 12 13	8	3 3 3 1 2 1 1 1	7	3 3 3 2 1 1 0 0	11	4 3 3 1 1 2 1 1
2004 12 14	4	0 1 1 2 2 1 1 1	13	0 1 3 4 5 1 1 1	7	0 1 2 3 2 1 2 2
2004 12 15	3	1 1 2 0 1 1 1 1	6	1 1 3 1 1 3 1 1	6	1 1 2 1 1 2 2 2
2004 12 16	8	1 3 1 0 2 1 3 3	12	1 1 1 1 5 3 2 3	10	1 3 2 1 2 2 4 3
2004 12 17	9	3 2 2 2 2 2 2 3	29	3 5 5 4 4 5 2 3	15	3 4 4 3 2 3 2 3
2004 12 18	8	3 3 2 2 2 2 1 0	22	3 2 2 5 6 2 2 1	12	4 4 2 2 3 2 1 1
2004 12 19	1	1 0 0 0 0 0 1 1	2	1 0 1 2 0 0 0 0	4	1 0 1 1 1 2 1 1
2004 12 20	2	1 1 0 1 1 0 0 0	2	2 0 0 1 1 0 0 1	4	2 0 1 1 1 1 1 1
2004 12 21	6	1 0 2 3 2 1 1 2	18	2 0 1 6 3 4 2 2	12	2 1 3 5 2 3 2 2
2004 12 22	12	2 4 3 4 2 2 1 1	29	2 3 5 6 5 3 2 3	19	3 4 4 5 3 3 2 2
2004 12 23	5	1 2 1 1 1 2 2 1	8	3 1 0 3 2 3 1 1	6	1 2 1 1 1 2 2 2
2004 12 24	2	1 0 0 0 1 1 0 1	3	1 0 0 2 1 2 1 0	4	0 0 0 1 1 2 1 1
2004 12 25	6	2 3 2 1 1 1 1 1	8	2 3 3 3 1 1 1 1	12	3 4 4 2 1 1 2 2
2004 12 26	9	3 2 2 2 1 3 2 2	13	1 3 1 4 4 3 2 2	10	3 3 2 2 2 3 2 2
2004 12 27	6	1 2 2 1 1 1 3 2	7	1 1 3 0 0 1 3 3	7	1 1 3 1 1 1 3 2
2004 12 28	12	2 1 1 2 2 3 4 4	33	2 1 6 5 4 4 4 5	16	3 2 2 3 2 3 4 4
2004 12 29	16	3 3 2 2 4 5 1 2	29	3 4 4 6 5 4 2 1	18	4 4 3 4 4 2 2 2
2004 12 30	12	2 3 4 2 3 3 1 2	30	2 3 4 5 5 6 2 2	15	2 3 4 3 3 4 2 3
2004 12 31	5	2 1 2 2 2 1 1 1	6	1 1 2 3 3 1 1 0	8	3 1 3 2 3 2 1 1

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 (SPS) (June 2, 1995). An understanding of these terms and definitions is a necessary prerequisite to full understanding of the Signal Specification.

General Terms and Definitions

Block I and Block II Satellites. The Block I is a GPS concept validation satellite; it does not have all of the design features and capabilities of the production model GPS satellite, the Block II. The FOC 24 satellite constellation is defined to consist entirely of Block II/IIA satellites. For the purposes of this Signal Specification, the Block II satellite and a slightly modified version of the Block II known as the Block IIA provide an identical service.

Dilution of Precision (DOP). The magnifying effect on GPS position error induced by mapping GPS ranging errors into position through the position solution. 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.

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

Major Service Failure. A condition over a time interval during which one or more SPS performance standards are not met and the civil community was not warned in advance.

Minimum SPS Receiver Capabilities. Minimum standards for signal reception and processing capabilities that are incorporated into the design of an SPS receiver. This ensures consistent performance with the SPS performance standards.

Navigation Data. Data provided to the SPS receiver via each satellite's ranging signal, containing 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.

Navigation Message. Message structure designed to carry navigation data.

Operational Satellite. A GPS satellite that is capable of, but may or may not be, transmitting a usable ranging signal. For the purposes of the SPS, any satellite contained within the transmitted navigation message almanac is considered to be an operational satellite.

Position Solution. The use of ranging signal measurements and navigation data from at least four satellites to solve for three position coordinates and a time offset.

Selective Availability. Protection technique employed by the DOD to deny full system accuracy to unauthorized users.

Service Disruption. A condition over a time interval during which one or more SPS performance standards are not supported, but the civil community was warned in advance.

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

SPS Performance Standard. A quantifiable minimum level for a specified aspect of GPS SPS performance.

Standard Positioning Service (SPS). Three-dimensional position and time determination capability provided to a user equipped with a minimum capability GPS SPS receiver in accordance with GPS national policy and the performance specifications.

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

SPS Signal, or SPS Ranging Signal. An electromagnetic signal originating from an operational satellite. The SPS ranging signal consists of a Pseudo Random Noise (PRN) Coarse/Acquisition (C/A) code, a timing reference and sufficient data to support the position solution generation process.

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

Performance Parameter Definitions

The definitions provided below establish the basis for correct interpretation of the GPS SPS performance standards. The GPS performance parameters contained in the SPS are defined differently than other radio navigation systems in the Federal Radio Navigation Plan. For a more comprehensive treatment of these definitions and their implications on system use, refer to Annex B of the SPS.

Coverage. The percentage of time over a specified time interval that a sufficient number of satellites are above a specified mask angle and provide an acceptable position solution geometry at any point on or near the Earth. The term "near the Earth" means on or within approximately 200 kilometers of the Earth's surface.

Positioning Accuracy. Given reliable service, the percentage of time over a specified time interval that the difference between the measured and expected user position or time is within a specified tolerance at any point on or near the Earth. This general accuracy definition is further refined through the more specific definitions of four different aspects of positioning accuracy:

- **Predictable Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a position measurement and a surveyed benchmark is within a specified tolerance at any point on or near the Earth.

- **Repeatable Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a position measurement taken at one time and a position measurement taken at another time at the same location is within a specified tolerance at any point on or near the Earth.

- **Relative Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between two receivers' position estimates taken at the same time is within a specified tolerance at any point on or near the Earth.

- **Time Transfer Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a Universal Coordinated Time (commonly referred to as UTC) time estimate from the position solution and UTC as it is managed by the United States Naval Observatory (USNO) is within a specified tolerance.

Range Domain Accuracy. Range domain accuracy deals with the performance of each satellite’s SPS ranging signal. Range domain accuracy is defined in terms of three different aspects:

- **Range Error.** Given reliable service, the percentage of time over a specified time interval that the difference between an SPS ranging signal measurement and the “true” range between the satellite and an SPS user is within a specified tolerance at any point on or near the Earth.

- **Range Rate Error.** Given reliable service, the percentage of time over a specified time interval that the instantaneous rate-of-change of range error is within a specified tolerance at any point on or near the Earth.

- **Range Acceleration Error.** Given reliable service, the percentage of time over a specified time interval that the instantaneous rate-of-change of range rate error is within a specified tolerance at any point on or near the Earth.

Service Availability. Given coverage, the percentage of time over a specified time interval that a sufficient number of satellites are transmitting a usable ranging signal within view of any point on or near the Earth.

Service Reliability. Given service availability, the percentage of time over a specified time interval that the instantaneous predictable horizontal error is maintained within a specified reliability threshold at any point on or near the Earth. Note that service reliability does not take into consideration the reliability characteristics of the SPS receiver or possible signal interference. Service reliability may be used to measure the total number of major failure hours experienced by the satellite constellation over a specified time interval.