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

William J. Hughes Technical Center
NSTB/WAAS T&E Team
ACB 430
Atlantic City International Airport, NJ 08405

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 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 #47, includes data collected from 1 July through 30 September 2004. The next quarterly report will be issued 31 January 2004.

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 July and 30 September 2004 and by calculating the satellite availability from the data obtained from the twenty sites. A total of ten outages were reported in the NANU’s. None of the outages were unscheduled. The quarterly availabilities for all sites were 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 33.079 meters on Satellite PRN 28. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 1.87312 Meters/second on Satellite PRN 13. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 18.44 Millimeters/second^2 on Satellite PRN 13. 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 July and 30 September 2004, the GPS performance did not meet all SPS requirements that were evaluated. Please see the problem report section for further details.

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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 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
- 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 thirteen 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	✓
<u>Repeatable Accuracy</u> ≤ 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	✓
<u>Relative Accuracy</u> ≤ 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
<u>Time Transfer Accuracy</u> ≤ 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	✓
<u>Range Domain Accuracy</u> ≤ 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

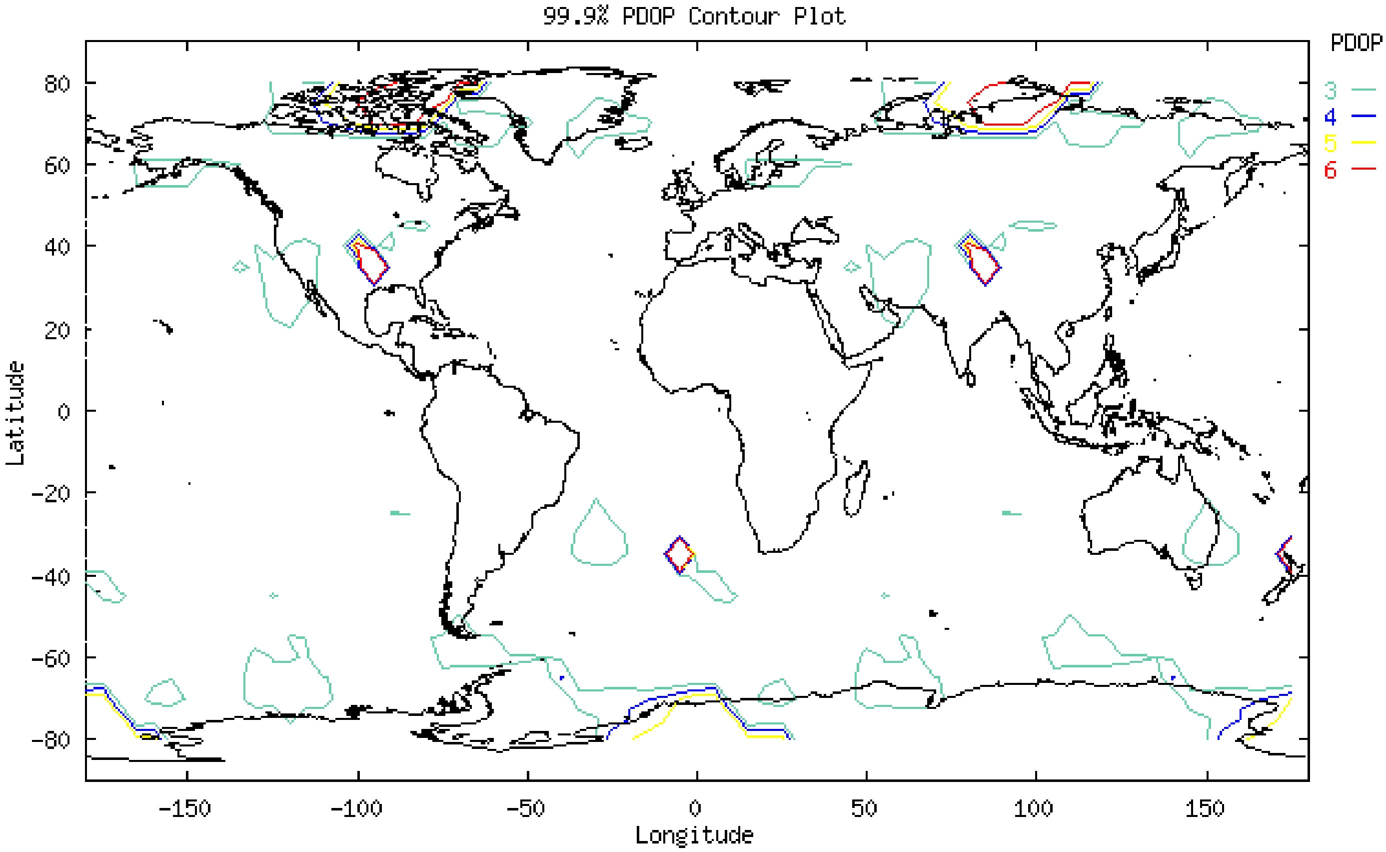
Almanacs for GPS weeks 228-240 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACB 430 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 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 3.96964 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

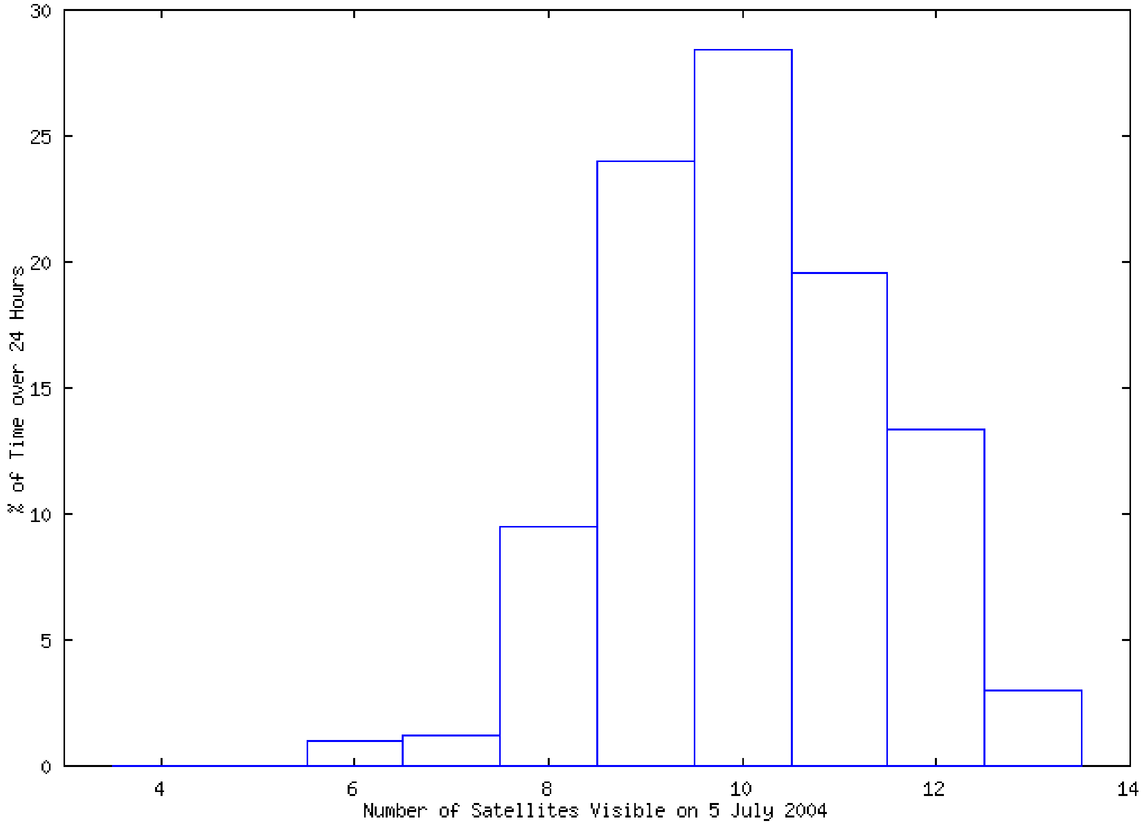
GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
254	3.21343	99.995	98.542
255	3.11662	99.996	98.542
256	3.02817	99.997	98.819
257	3.03947	99.997	98.819
258	3.07444	99.997	98.889
259	3.08515	99.995	98.958
260	3.10885	99.995	98.958
261	3.10903	99.995	98.958
262	3.33557	99.995	99.167
263	3.16231	99.995	99.236
264	3.17696	99.995	99.167
265	3.15432	99.995	99.236
266	3.10336	99.994	99.167

Figure 2-1 SPS Coverage (24-Hour Period: 5 July 2004)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -120, Lat: 20)



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 July through 30 September 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
83	19	S	16-Jul	0:20	16-Jul	6:31		6.18	6.18
84	23	S	19-Jul	19:20	20-Jul	3:47		8.45	8.45
86	23	S	20-Jul	7:48	20-Jul	20:32		12.73	12.73
91	31	S	3-Aug	3:00	3-Aug	19:55		16.91	16.91
93	23	S	5-Aug	19:23	6-Aug	2:42		7.31	7.31
96	25	S	10-Aug	12:47	10-Aug	12:58		0.18	0.18
97	28	S	13-Aug	2:08	13-Aug	7:14		5.10	5.10
98	9	S	16-Aug	12:42	16-Aug	16:50		4.13	4.13
100	27	S	29-Aug	1:32	30-Aug	19:12		41.66	41.66
102	31	S	13-Sep	5:12	13-Sep	15:18		10.10	10.10
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**0.00**	**112.75**	**112.75**
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
81	19	F	15-Jul	23:15	16-Jul	11:15	12	See NANU 83
82	23	F	19-Jul	19:00	20-Jul	19:00	24	See NANU 84
85	23	F	20-Jul	7:48	N/A	N/A	N/A	See NANU 86
87	9	F	29-Jul	12:00	30-Jul	0:00	12	See NANU 89
88	31	F	3-Aug	3:00	4-Aug	3:00	24	See NANU 91
90	23	F	5-Aug	18:30	6-Aug	6:30	12	See NANU 93
92	28	F	13-Aug	0:30	13-Aug	12:30	12	See NANU 97
94	9	F	16-Aug	12:00	17-Aug	0:00	12	See NANU 98
95	25	F	10-Aug	12:47	N/A	N/A	N/A	See NANU 96
99	27	F	29-Aug	1:32	N/A	N/A	N/A	See NANU 100
101	31	F	13-Sep	5:50	N/A	N/A	N/A	See NANU 102
103	10	F	29-Sep	6:15	29-Sep	18:15	12	See NANU 105
104	4	F	30-Sep	16:00	1-Oct	4:00	12	See NANU 106
					Total Forecast Downtime		**132**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
89	9	C	29-Jul	12:00	See NANU 87
105	10	C	29-Sep	6:15	See NANU 103
106	4	C	30-Sep	16:00	See NANU 104

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published "Notice: Advisory to Navstar Users" messages (NANU's). This data has been summarized in Table 3-4. The "Total Satellite Observed MTTR" was calculated by taking the average downtime of all satellite outage occurrences. Schedule downtime was forecasted in advance via NANU's. All other downtime reported via NANU was considered unscheduled. The "Percent Operational" was calculated based on the ratio of total actual operating hours to total available operating hours for every satellite.

Table 3-4 GPS Block II/IIA Satellite RMA Data		
Satellite Reliability/Maintainability/Availability (RMA) Parameter	**1 July - 30 Sep. 2004**	**1 October, 1999- 30 Sep. 2004**
Total Forecast Downtime (hrs):	132.00	4947.23
Total Actual Downtime (hrs):	112.75	9860.51
Total Actual Scheduled Downtime (hrs):	112.75	6933.85
Total Actual Unscheduled Downtime (hrs):	0	2926.66
Total Satellite Observed MTTR (hrs):	11.28	30.06
Scheduled Satellite Observed MTTR (hrs):	11.28	24.85
Unscheduled Satellite Observed MTTR (hrs):	N/A	59.73
# Total Satellite Outages:	10	328
# Scheduled Satellite Outages:	10	279
# Unscheduled Satellite Outages:	0	49
Percent Operational -- Scheduled Downtime:	99.82	99.43
Percent Operational -- All Downtime:	99.99	99.19

NANU 2004080 was omitted in the summary charts above because it announced the usability of PRN 23.

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 July and 30 September 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
Mauna Loa	1.193	4.160	3.982	1.744	3.944	3.755	7860267
Billings	1.193	4.172	3.797	1.731	3.296	3.003	7941828
Cold Bay	1.142	4.495	3.726	1.696	4.317	3.978	7910059
Juneau	1.188	4.569	4.064	1.755	4.087	3.756	7930752
Albuquerque	1.237	4.323	3.640	1.728	3.751	2.993	7944076
Anchorage	1.195	4.212	3.881	1.721	3.830	3.528	7943709
Boston	1.182	4.686	4.124	1.726	3.528	2.967	7942557
Washington, D.C.	1.211	4.727	4.255	1.744	4.531	4.064	7943839
Honolulu	1.151	4.049	3.859	1.699	3.955	3.761	7943132
Houston	1.194	5.996	1.846	1.720	3.240	2.567	7941926
Kansas City	1.156	3.472	2.915	1.709	3.150	2.740	7428292
Los Angeles	1.173	4.207	3.509	1.754	3.474	2.948	7944066
Salt Lake City	1.156	5.075	4.624	1.762	3.946	3.688	7942130
Miami	1.217	4.594	4.357	1.799	4.407	4.167	7944140
Minneapolis	1.159	4.357	3.853	1.707	3.970	3.534	7944185
Oakland	1.154	4.132	3.518	1.732	3.511	3.137	7941754
Cleveland	1.145	4.627	4.035	1.774	3.843	3.505	7943893
Seattle	1.166	4.042	3.667	1.730	3.409	2.942	7944421
San Juan	1.242	4.715	4.509	1.766	4.240	4.114	7938521
Atlanta	1.203	4.657	4.224	1.742	4.470	4.040	7937204

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 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. $\geq$ 83.92%)						

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

Table 3-7 PDOP > 6 Statistics

Site	Total Number of Seconds of PDOP Monitoring	Total Seconds with PDOP > 6	Overall % Availability
Mauna Loa	7860267	0	100%
Billings	7941828	0	100%
Cold Bay	7910059	0	100%
Juneau	7930752	0	100%
Albuquerque	7944076	0	100%
Anchorage	7943709	0	100%
Boston	7942557	0	100%
Washington, D.C.	7943839	0	100%
Honolulu	7943132	0	100%
Houston	7941926	0	100%
Kansas City	7428292	0	100%
Los Angeles	7944066	0	100%
Salt Lake City	7942130	0	100%
Miami	7944140	0	100%
Minneapolis	7944185	0	100%
Oakland	7941754	0	100%
Cleveland	7943893	0	100%
Seattle	7944421	0	100%
San Juan	7938521	0	100%
Atlanta	7937204	0	100%
Worst Single Point Average = 100% (SPS Spec. $\geq$ 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 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)
Mauna Loa	7860267	14.0
Billings	7941828	22.7
Cold Bay	7910059	12.9
Juneau	7930752	20.4
Albuquerque	7944076	32.8
Anchorage	7943709	14.9
Boston	7942557	46.3
Washington, D.C.	7943839	49.8
Honolulu	7943132	14.8
Houston	7941926	46.5
Kansas City	7428292	38.0
Los Angeles	7944066	25.0
Salt Lake City	7942130	24.4
Miami	7944140	34.7
Minneapolis	7944185	33.9
Oakland	7941754	24.5
Cleveland	7943893	43.8
Seattle	7944421	22.5
San Juan	7938521	28.2
Atlanta	7937204	51.8

5.0 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 July through 30 September 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)
Mauna Loa	5.868	7.264	12.889	67.967
Billings	3.249	5.406	22.217	22.871
Cold Bay	3.121	5.816	10.766	13.137
Juneau	2.778	4.938	17.185	17.862
Albuquerque	3.472	5.808	26.037	32.875
Anchorage	2.809	5.179	12.492	17.063
Boston	3.270	5.338	34.262	28.933
Washington, D.C.	3.313	5.782	33.564	41.998
Honolulu	5.884	6.842	14.264	39.210
Houston	3.813	6.051	21.832	53.443
Kansas City	3.371	6.054	29.023	43.247
Los Angeles	3.719	6.267	24.402	20.237
Salt Lake City	3.370	5.710	23.046	24.267
Miami	4.084	6.304	26.756	6.304
Minneapolis	3.292	5.735	27.716	30.555
Oakland	3.547	6.024	23.424	21.376
Cleveland	3.342	5.662	31.893	37.868
Seattle	3.243	5.125	20.750	18.405
San Juan	4.057	6.395	25.040	58.843
Atlanta	3.522	6.094	31.156	61.712

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty NSTB and WAAS sites from 1 July to 30 September 2004.

Figure 5-1 Combined Vertical Error Histogram

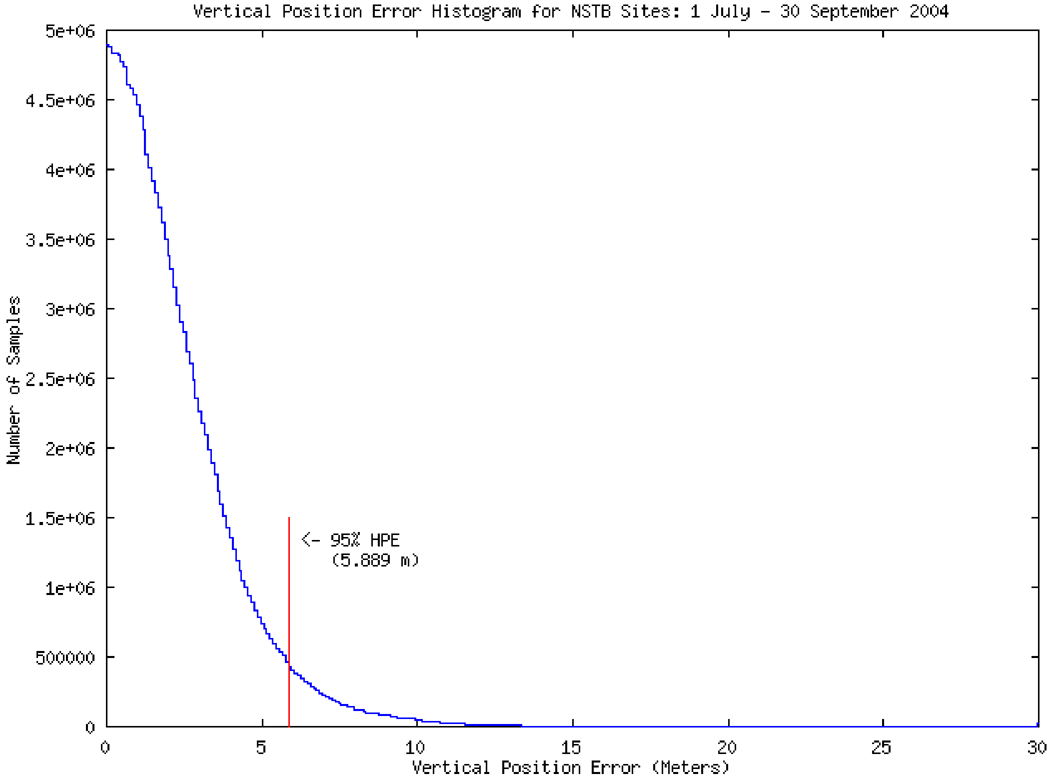
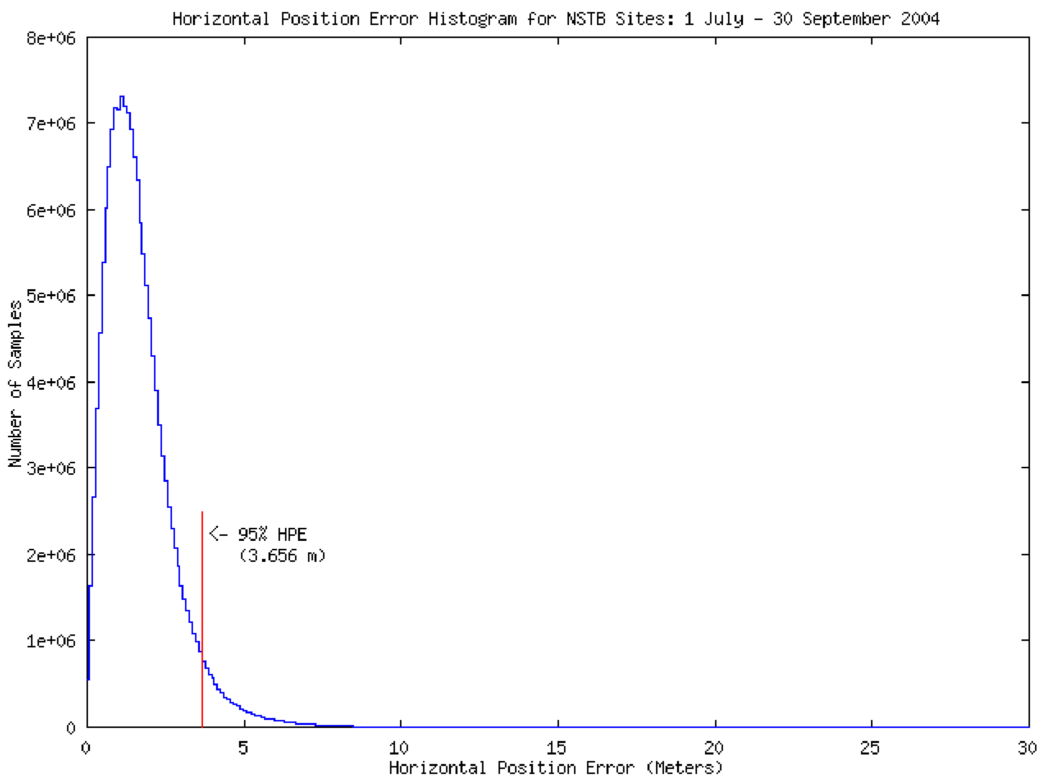


Figure 5-2 Combined Horizontal Error Histogram



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)
Mauna Loa	0.790	2.410
Billings	0.985	2.379
Cold Bay	0.976	2.065
Juneau	0.999	2.171
Albuquerque	1.145	2.188
Anchorage	0.959	2.162
Boston	0.893	2.138
Washington, D.C.	0.872	1.988
Honolulu	0.763	2.509
Houston	0.882	2.359
Kansas City	0.727	1.865
Los Angeles	1.125	2.316
Salt Lake City	0.978	2.393
Miami	0.728	2.910
Minneapolis	1.107	2.417
Oakland	1.114	2.529
Cleveland	0.818	2.167
Seattle	0.990	2.033
San Juan	0.619	2.331
Atlanta	0.847	2.409

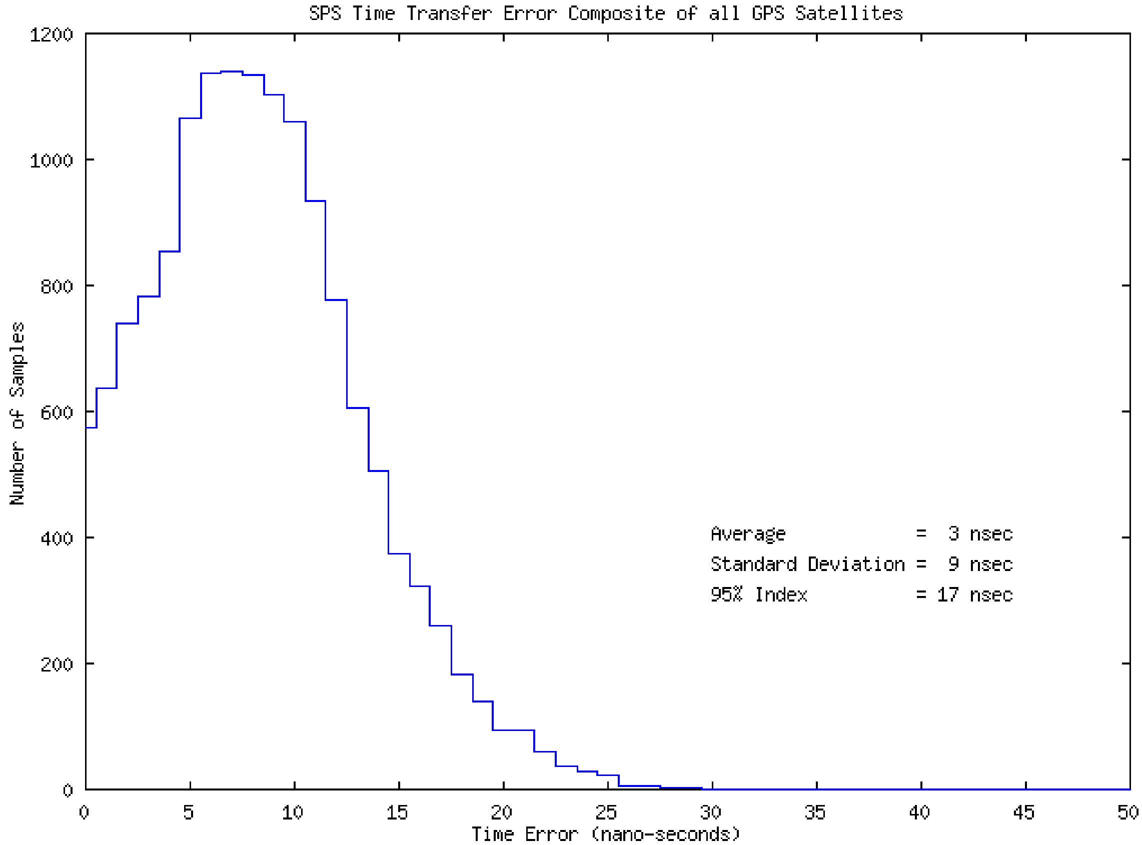
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 July and 30 September 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 July and 30 September 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	2.493	4.934	4.257	10.181	17.349	2123108
3	1.911	3.524	2.961	6.726	11.868	2545390
4	2.423	3.389	2.369	6.099	27.293	2184795
5	2.980	3.795	2.349	6.553	28.482	2231013
6	2.631	3.375	2.113	6.008	11.597	1920226
7	3.526	4.066	2.026	6.807	28.888	2027000
8	2.820	4.218	3.136	7.743	28.199	1993468
9	2.187	3.194	2.327	5.912	11.263	2495360
10	4.283	4.990	2.559	8.458	16.206	2359818
11	3.197	4.268	2.829	7.832	25.157	2552402
13	1.727	3.874	3.468	7.247	26.110	1867984
14	3.097	4.369	3.081	8.873	17.348	2024184
15	2.801	3.959	2.798	7.937	14.925	1927748
16	2.870	4.208	3.077	7.733	15.203	2453190
17	3.340	3.788	1.786	6.220	19.479	2069624
18	3.355	4.084	2.327	6.728	13.944	2110437
19	4.733	5.497	2.797	9.133	27.410	2545824
20	3.331	4.644	3.236	8.799	30.081	2272285
21	4.119	4.691	2.244	7.600	13.512	2106453
22	3.343	4.381	2.832	8.622	15.571	2164604
23	3.994	5.337	3.539	9.495	19.325	1767795
24	2.700	3.515	2.251	6.485	11.162	1950867
25	2.136	4.527	3.991	9.978	15.512	1904577
26	2.288	3.134	2.142	5.644	28.697	2546026
27	1.960	4.391	3.929	6.919	20.121	2092627
28	3.456	4.379	2.689	7.693	33.079	2155455
29	2.751	3.541	2.230	6.315	28.108	2610812
30	1.885	3.173	2.552	6.091	16.018	2445308
31	3.616	4.401	2.508	7.631	25.200	1880861

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	0.00005	0.00392	0.00392	0.00677	0.19861	2123108
3	-0.00002	0.00427	0.00427	0.00694	0.23565	2545390
4	0.00011	0.00972	0.00971	0.00882	1.59427	2184795
5	-0.00002	0.00504	0.00504	0.00718	0.98543	2231013
6	-0.00005	0.00403	0.00403	0.00680	0.22397	1920226
7	0.00004	0.00442	0.00442	0.00671	1.03356	2027000
8	0.00007	0.00456	0.00455	0.00705	0.28148	1993468
9	-0.00013	0.00364	0.00363	0.00662	0.18731	2495360
10	0.00013	0.00532	0.00531	0.00750	0.90461	2359818
11	0.00012	0.00385	0.00385	0.00686	0.22710	2552402
13	0.00007	0.00717	0.00716	0.00762	1.87312	1867984
14	0.00004	0.00374	0.00374	0.00650	0.23306	2024184
15	0.00007	0.00416	0.00416	0.00677	0.46250	1927748
16	-0.00012	0.00477	0.00477	0.00715	0.31022	2453190
17	0.00001	0.00394	0.00394	0.00663	0.82327	2069624
18	-0.00008	0.00332	0.00332	0.00649	0.08074	2110437
19	0.00006	0.00349	0.00349	0.00665	0.22810	2545824
20	-0.00006	0.00523	0.00523	0.00718	1.02155	2272285
21	-0.00009	0.00387	0.00387	0.00672	0.22640	2106453
22	-0.00001	0.00349	0.00349	0.00644	0.18596	2164604
23	0.00003	0.00418	0.00418	0.00690	0.90789	1767795
24	0.00002	0.00417	0.00417	0.00684	0.22189	1950867
25	-0.00001	0.00372	0.00372	0.00674	0.19823	1904577
26	0.00003	0.00490	0.00490	0.00690	1.22287	2546026
27	0	0.00505	0.00505	0.00669	0.93416	2092627
28	0.00003	0.00542	0.00542	0.00679	1.37673	2155455
29	-0.00001	0.00465	0.00465	0.00688	0.80897	2610812
30	0.00006	0.00364	0.00364	0.00666	0.15547	2445308
31	0.00001	0.00416	0.00416	0.00661	0.29899	1880861

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	0.0003	100%	0.00199	2123108
3	0	0.00004	0.00004	100%	0.00236	2545390
4	0	0.00009	0.00009	99.999%	0.01590	2184795
5	0	0.00005	0.00005	99.999%	0.00985	2231013
6	0	0.00004	0.00004	100%	0.00216	1920226
7	0	0.00004	0.00004	99.999%	0.01037	2027000
8	0	0.00004	0.0004	100%	0.00271	1993468
9	0	0.00003	0.00003	100%	0.00191	2495360
10	0	0.00005	0.00005	99.999%	0.00877	2359818
11	0	0.00003	0.00003	100%	0.00222	2552402
13	0	0.00007	0.00007	99.999%	0.01844	1867984
14	0	0.00003	0.00003	100%	0.00228	2024184
15	0	0.00004	0.00004	100%	0.00465	1927748
16	0	0.00004	0.00004	100%	0.00312	2453190
17	0	0.00004	0.00004	99.999%	0.00820	2069624
18	0	0.00003	0.00003	100%	0.00080	2110437
19	0	0.00003	0.00003	100%	0.00227	2545824
20	0	0.00005	0.00005	99.999%	0.01029	2272285
21	0	0.00003	0.00003	100%	0.00228	2106453
22	0	0.00003	0.00003	100%	0.00185	2164604
23	0	0.00004	0.00004	99.999%	0.00911	1767795
24	0	0.00004	0.00004	100%	0.00216	1950867
25	0	0.00003	0.00003	100%	0.00198	1904577
26	0	0.00004	0.00004	99.999%	0.01226	2546026
27	0	0.00004	0.00004	99.999%	0.00937	2092627
28	0	0.00005	0.00005	99.999%	0.01377	2155455
29	0	0.00004	0.00004	99.999%	0.00826	2610812
30	0	0.00003	0.00003	100%	0.00153	2445308
31	0	0.00004	0.00004	100%	0.00288	1880861

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 28 with an error of 33.079 meters. Satellite 24 had the lowest maximum range error of 11.162 meters.

Figure 5-4 Distribution of Daily Max Range Errors

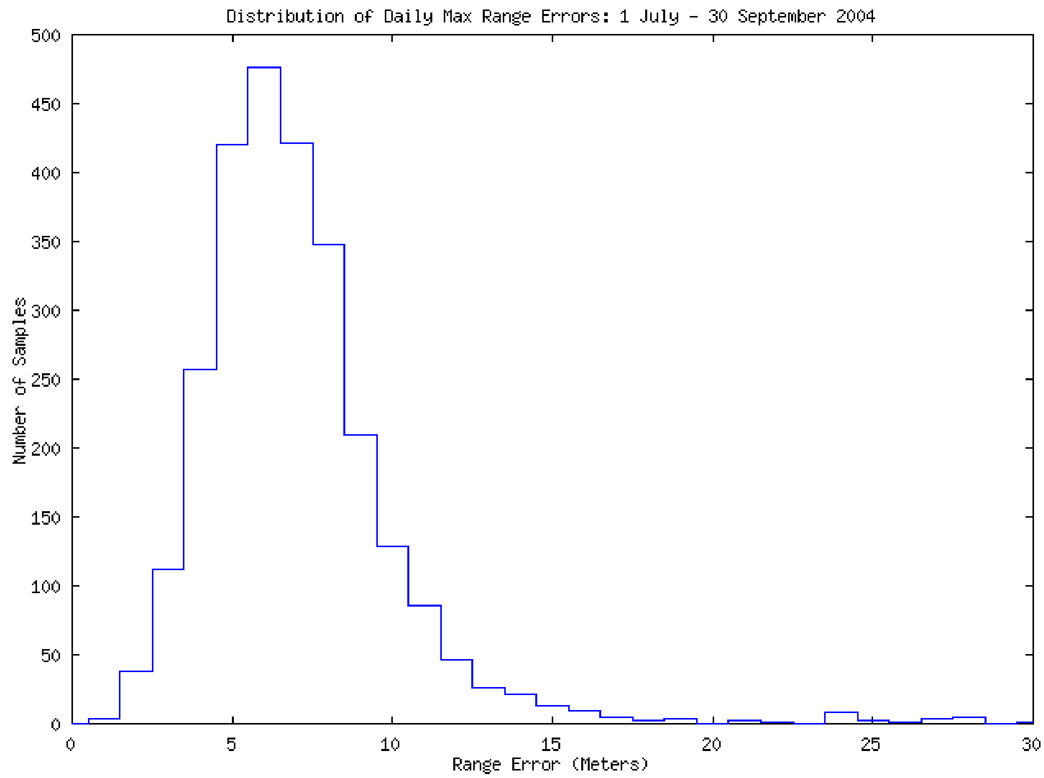


Figure 5-5: Distribution of Daily Max Range Rate Errors

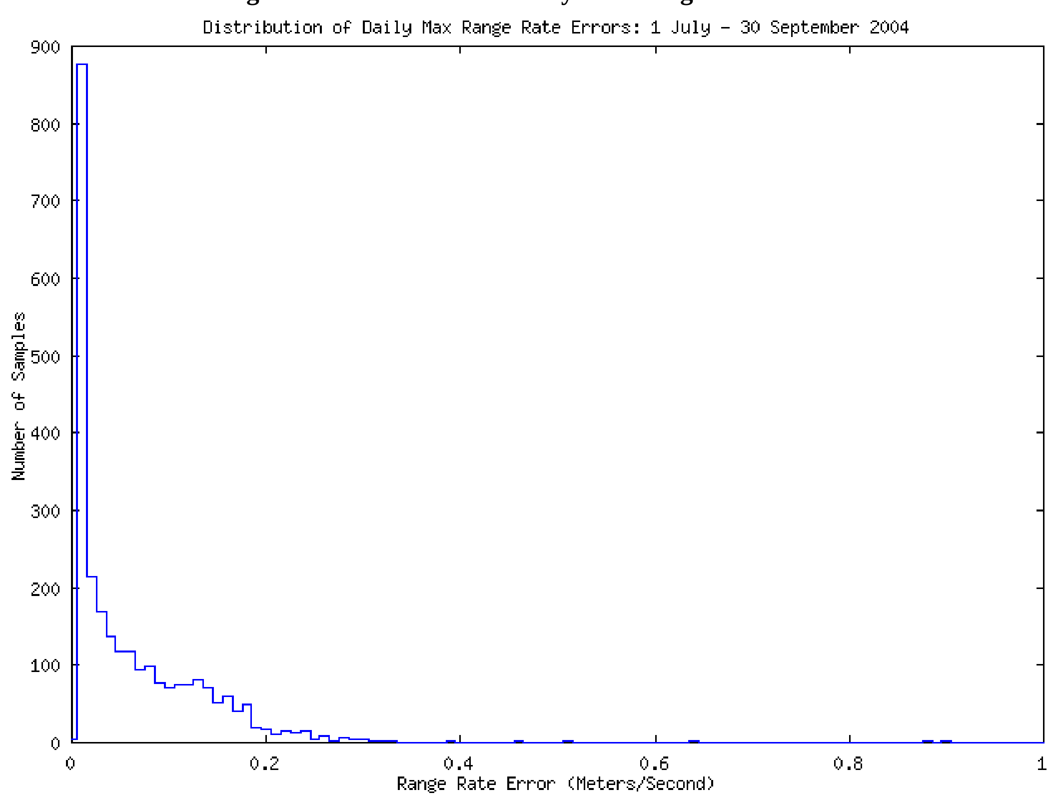


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

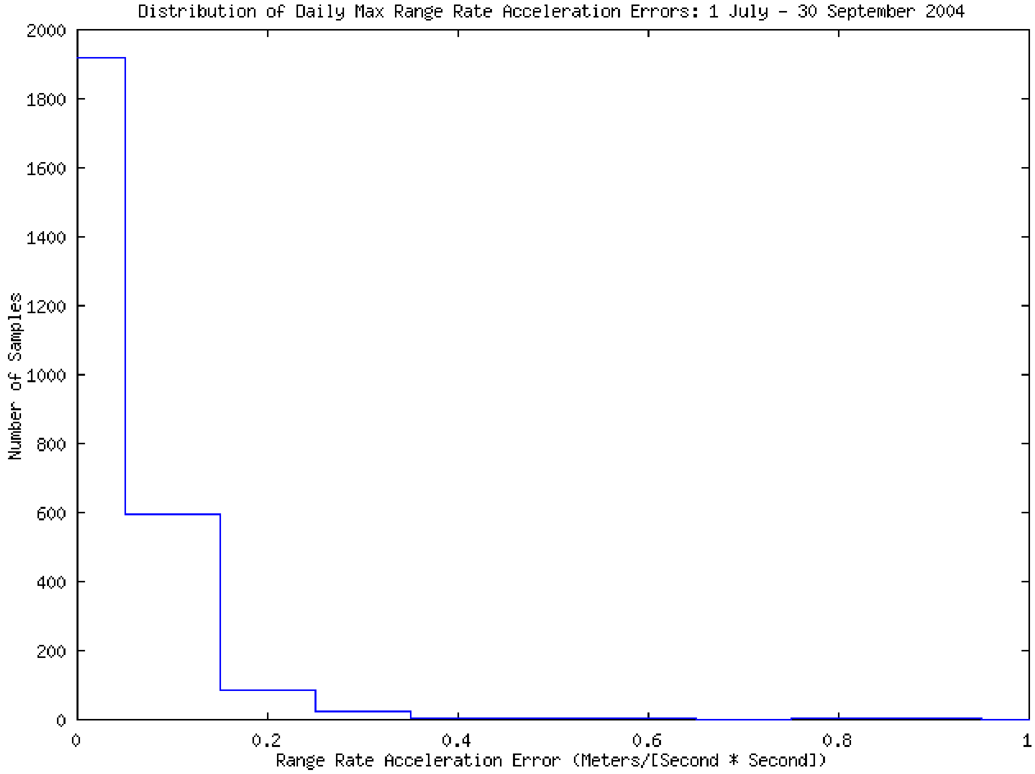


Figure 5-7: Range Error Histogram

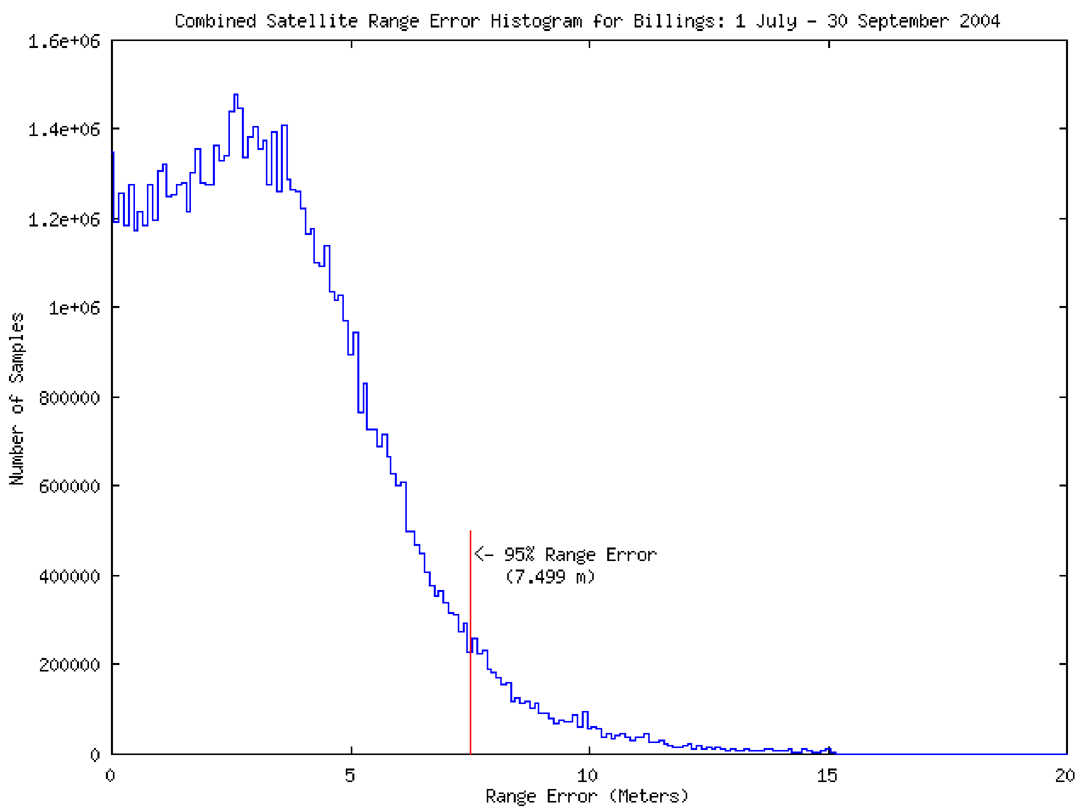


Figure 5-8: Maximum Range Error Per Satellite

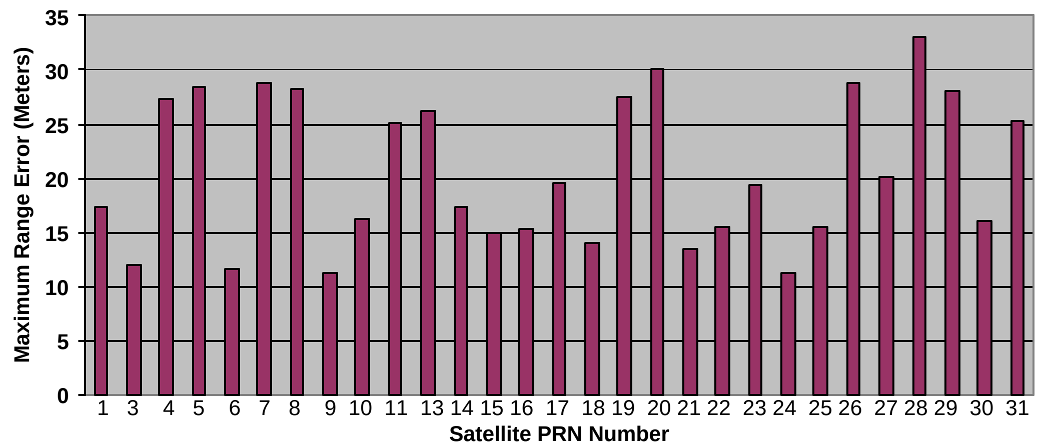


Figure 5-9: Maximum Range Rate Error Per Satellite

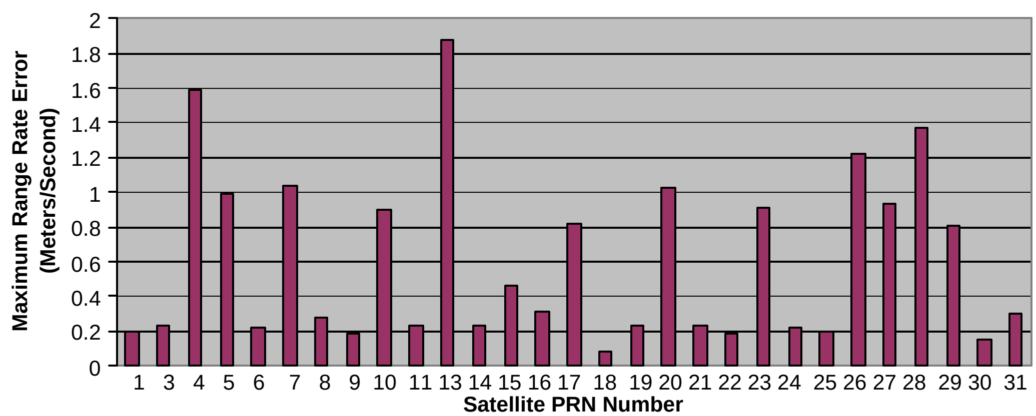
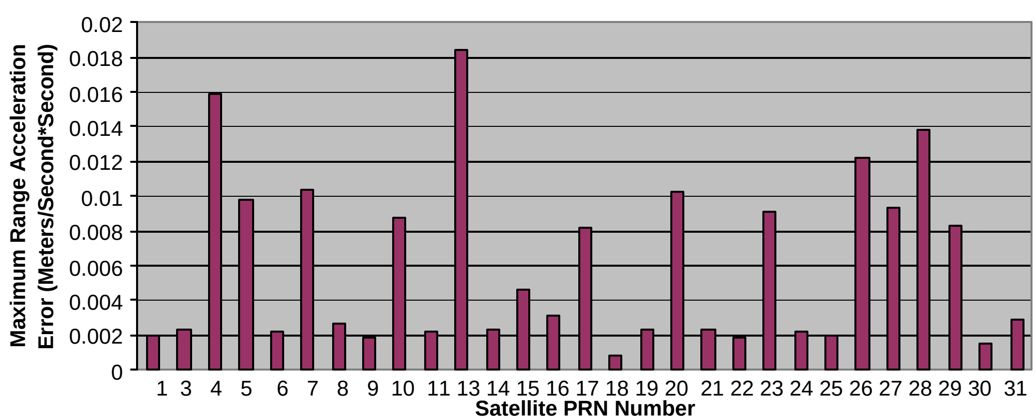


Figure 5-10: Maximum Range Acceleration Per Satellite



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 25-27 July 2004

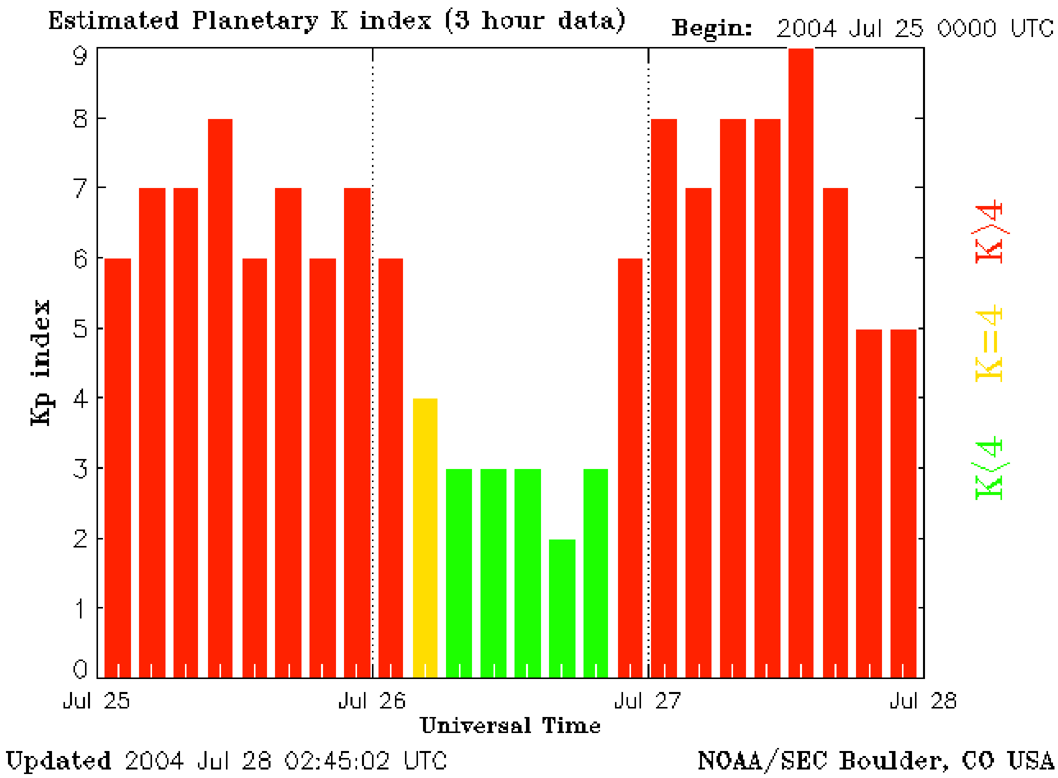


Figure 6-2 K-Index for 22-24 July 2004

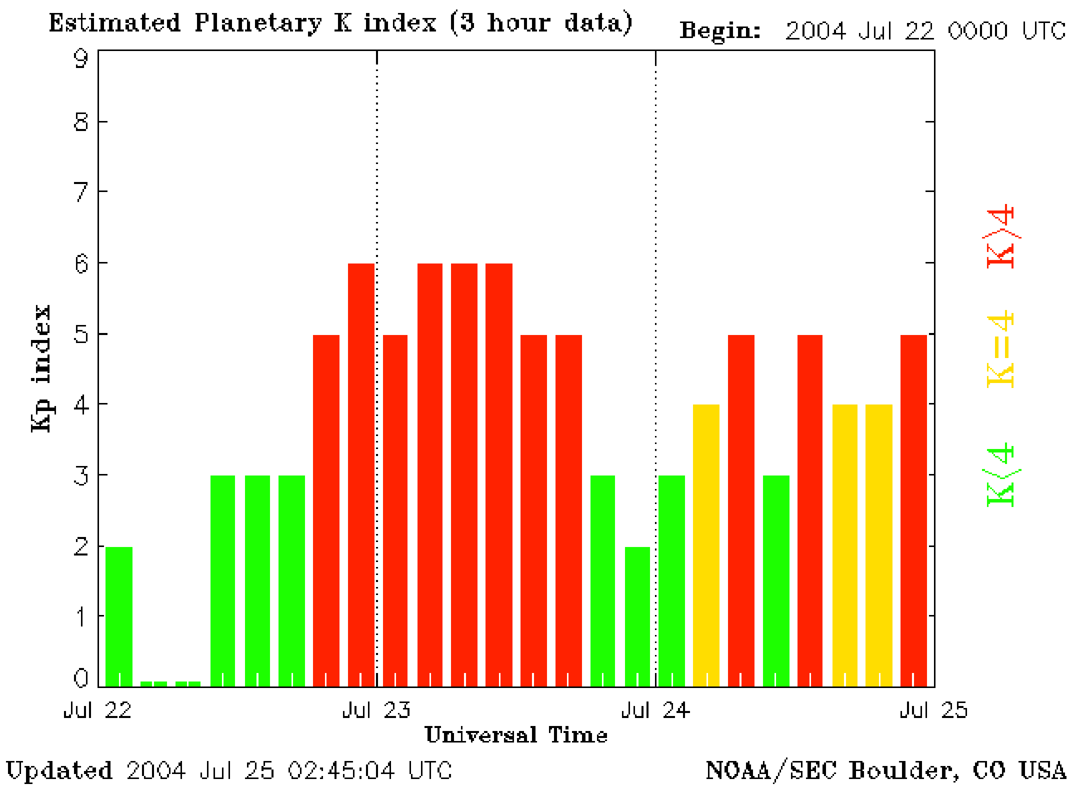
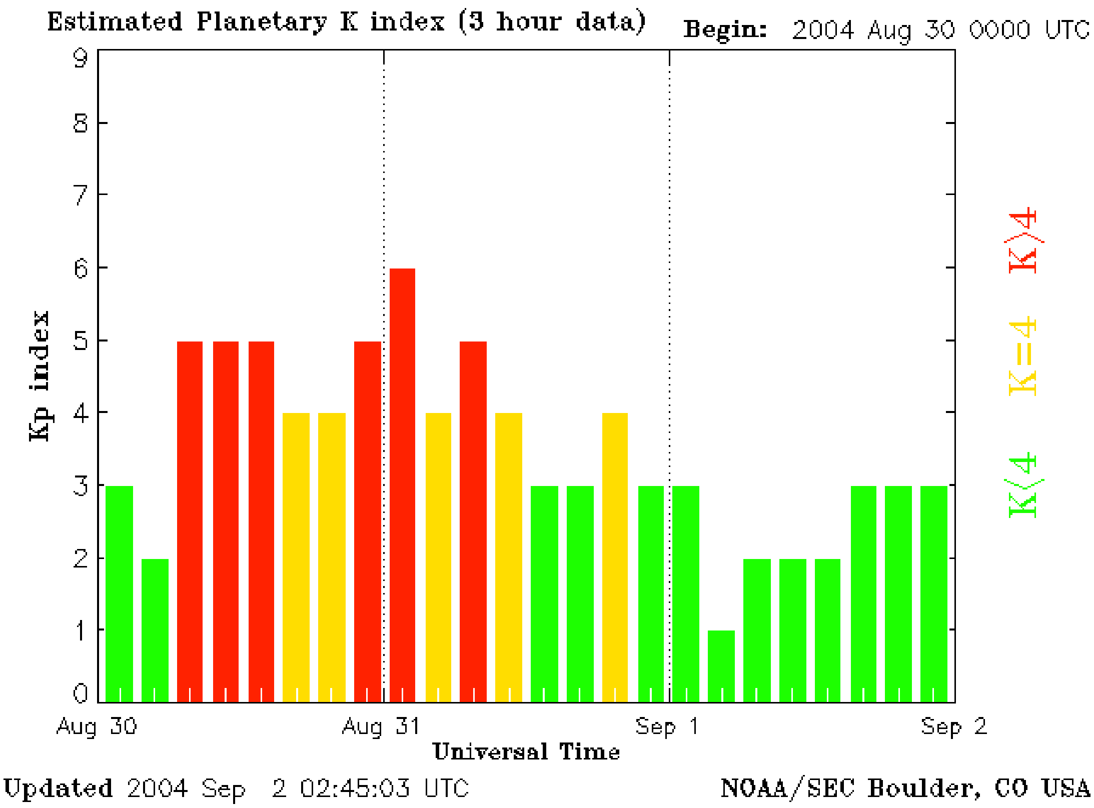


Figure 6-3 K-Index for 30 August-1 September 2004



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 27 July 2004

Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Mauna Loa	1.248	3.264	1.717	3.263	2.926
Billings	1.226	2.751	1.704	2.748	2.177
Cold Bay	1.154	3.429	1.697	3.425	2.926
Juneau	1.210	3.876	1.707	3.856	3.554
Albuquerque	1.258	2.812	1.699	2.809	2.180
Anchorage	1.200	3.307	1.703	3.306	2.956
Boston	1.231	2.976	1.693	2.975	2.475
Washington, D.C.	1.233	3.447	1.731	3.446	2.991
Honolulu	1.194	3.243	1.671	3.242	2.944
Houston	1.203	2.854	1.687	2.854	2.509
Kansas City	1.160	2.702	1.694	2.701	2.273
Los Angeles	1.211	3.148	1.744	3.148	2.856
Salt Lake City	1.204	3.949	1.741	3.946	3.686
Miami	1.221	3.394	1.754	3.394	3.153
Minneapolis	1.201	2.704	1.690	2.702	2.418
Oakland	1.158	3.156	1.733	3.155	2.765
Cleveland	1.237	3.454	1.744	3.454	3.023
Seattle	1.211	2.824	1.711	2.823	2.219
San Juan	1.245	3.464	1.752	3.464	3.324
Atlanta	1.214	3.409	1.739	3.408	3.009

Table 6-2 Horizontal & Vertical Accuracy Statistics for 27 July 2004

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Mauna Loa	3.209	6.894	4.092	9.686
Billings	3.028	7.771	4.205	9.776
Cold Bay	3.793	7.345	5.776	9.685
Juneau	2.533	6.010	3.327	8.558
Albuquerque	3.271	9.522	4.221	12.056
Anchorage	3.049	6.293	3.796	7.407
Boston	2.257	6.847	3.022	8.562
Washington, D.C.	2.495	7.202	3.296	8.467
Honolulu	2.770	7.193	3.178	10.330
Houston	3.343	9.480	3.744	11.266
Kansas City	4.037	10.095	5.807	14.004
Los Angeles	2.816	10.175	3.774	17.727
Salt Lake City	3.910	8.496	4.939	11.725
Miami	3.533	9.089	4.646	13.391
Minneapolis	2.298	8.537	3.234	13.611
Oakland	2.984	9.988	4.014	14.782
Cleveland	2.433	7.867	3.434	9.677
Seattle	4.467	8.346	5.565	10.604
San Juan	3.359	7.347	5.349	10.804
Atlanta	3.833	8.253	4.737	8.894

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	99.994%
• 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	98.542% Availability 99.9% PDOP was 3.21343
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	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	≤5.884m HE 95% ≤34.262m HE 99.99% ≤7.264m VE 95% ≤67.967m 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	Repeatable Accuracy ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	≤1.145m HE 95% ≤2.910m 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	Relative Accuracy ≤ 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	Time Transfer Accuracy ≤ 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	Range Domain Accuracy ≤ 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	33.079m NTE Range Error 1.87312m/s NTE Rate Error 18.44mm/s^2 NTE Accl. Error ≤8mm/s^2 99.999% of the time

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

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2004 07 01	9	2 2 3 2 2 1 3 2	24	2 3 5 6 3 3 2 2	13	3 3 3 3 3 3 3 2
2004 07 02	8	2 2 1 2 2 1 3 3	6	2 2 1 1 3 1 1 1	9	2 3 2 2 3 2 2 3
2004 07 03	5	2 1 1 1 1 2 2 1	10	2 2 3 3 4 1 1 1	9	2 1 2 3 3 3 3 1
2004 07 04	4	1 1 1 1 1 1 1 2	8	2 2 2 4 1 1 1 1	6	2 2 2 2 1 2 2 2
2004 07 05	5	1 2 1 1 1 2 2 2	4	2 1 0 1 2 1 1 2	7	2 2 0 1 2 2 3 3
2004 07 06	5	1 2 1 1 2 1 2 1	5	1 3 1 3 1 1 0 0	7	2 3 2 2 2 3 2 1
2004 07 07	2	0 2 1 0 1 0 0 0	3	0 2 1 1 2 0 0 1	5	1 2 1 1 2 2 1 1
2004 07 08	1	0 0 0 0 1 0 1 1	1	0 0 0 0 0 0 1 1	5	2 1 0 1 2 2 2 2
2004 07 09	4	1 1 1 0 2 2 1 1	3	2 2 2 0 0 0 1 0	5	1 2 2 0 2 3 2 1
2004 07 10	5	1 2 2 1 1 2 1 2	6	0 2 3 2 2 2 1 1	8	1 2 3 2 2 3 3 2
2004 07 11	13	2 1 1 3 4 2 3 4	12	3 1 0 3 4 1 3 3	14	3 2 1 3 3 2 3 4
2004 07 12	12	3 2 2 2 2 2 3 4	13	4 3 3 1 3 1 2 3	13	4 3 2 2 3 3 3 4
2004 07 13	11	4 3 3 2 2 1 2 2	14	3 3 4 1 3 3 3 1	16	4 3 4 2 2 3 3 3
2004 07 14	6	2 3 2 1 1 1 1 1	11	1 3 3 2 2 3 4 0	9	2 3 3 2 2 2 3 2
2004 07 15	7	1 0 0 1 1 2 3 4	3	1 1 0 0 0 1 2 2	9	2 1 1 1 2 3 3 4
2004 07 16	8	1 0 1 1 3 2 1 4	7	1 1 2 2 1 2 2 3	12	2 0 2 2 3 3 3 4
2004 07 17	13	5 3 3 2 2 1 1 2	28	5 4 4 6 4 2 1 1	24	6 4 5 3 3 3 3 2
2004 07 18	6	1 3 3 1 0 1 1 2	5	2 2 3 2 0 0 1 1	9	1 3 3 2 2 3 2 2
2004 07 19	8	1 3 1 2 1 2 2 3	16	2 1 4 5 3 3 1 2	9	1 3 2 3 2 3 3 3
2004 07 20	6	1 1 2 2 2 1 2 2	8	3 2 2 1 2 3 1 2	9	1 2 3 2 2 3 3 3
2004 07 21	5	3 2 1 0 1 1 0 2	4	2 2 3 0 0 0 0 0	6	2 1 2 1 1 3 2 2
2004 07 22	13	1 0 0 2 3 2 4 5	22	1 0 0 3 4 4 4 6	19	2 0 0 3 3 3 5 6
2004 07 23	21	4 4 4 4 3 4 2 2	79	4 5 8 6 6 7 3 1	47	5 6 6 6 5 5 3 2
2004 07 24	29	3 3 5 3 5 4 3 5	34	4 3 3 4 6 5 5 3	27	3 4 5 3 5 4 4 5
2004 07 25	64	6 6 5 5 5 6 5 6	138	6 8 7 7 8 7 6 5	122	6 7 7 8 6 7 6 7
2004 07 26	26	6 3 1 2 1 2 3 6	23	5 4 2 4 1 2 3 5	31	6 4 3 3 3 2 3 6
2004 07 27	119	7 7 6 7 8 7 4 5	212	6 6 9 9 9 8 5 5	162	8 7 8 8 9 7 5 5
2004 07 28	11	3 3 2 2 3 2 2 3	27	3 4 4 5 5 4 2 3	14	3 3 3 3 3 3 2 3
2004 07 29	6	2 2 2 1 1 2 2 1	9	3 3 2 3 1 2 1 1	9	2 3 3 2 2 3 2 2
2004 07 30	7	1 1 1 1 1 2 2 4	8	2 2 2 2 3 1 1 3	7	2 1 1 2 3 2 2 3
2004 07 31	7	2 2 2 2 2 2 2 2	20	4 2 2 3 5 5 2 1	9	2 2 2 2 3 3 3 3
2004 08 01	9	3 2 2 1 2 3 2 2	8	4 3 2 1 0 1 1 2	8	3 2 1 1 2 3 2 2
2004 08 02	5	1 1 2 2 1 0 1 3	9	1 2 4 4 0 0 1 2	8	2 1 3 3 2 2 2 3
2004 08 03	2	1 2 0 0 1 0 0 1	2	2 2 0 0 0 0 0 1	5	2 2 1 1 2 2 1 2
2004 08 04	2	0 0 1 1 2 1 1 0	2	0 0 0 0 2 2 0 0	4	1 0 0 1 2 2 2 1
2004 08 05	5	0 0 0 1 2 1 3 3	7	0 0 0 3 4 1 1 2	7	1 1 0 2 2 2 3 3
2004 08 06	3	2 0 0 0 1 1 2 2	4	2 1 1 0 1 0 2 2	7	3 1 1 1 2 2 3 3
2004 08 07	11	2 3 4 3 2 1 1 2	32	2 3 6 5 6 3 2 1	20	3 3 5 4 4 3 2 3
2004 08 08	2	2 1 1 0 1 1 0 0	2	1 2 1 0 1 0 1 0	5	2 2 1 0 2 2 2 2
2004 08 09	12	2 2 3 2 2 2 3 4	14	2 1 4 4 2 2 4 2	13	2 2 4 3 2 3 3 4
2004 08 10	12	4 1 2 2 3 2 3 3	28	4 2 1 4 6 5 3 3	14	4 1 2 2 3 4 3 3
2004 08 11	10	2 2 2 3 3 2 3 2	16	2 2 3 5 4 3 2 1	13	2 2 3 4 3 3 3 3
2004 08 12	6	2 2 2 1 2 1 2 2	-1	3 2 1-1 2 2 1 2	9	3 2 2 2 3 3 2 3
2004 08 13	5	2 1 1 0 1 1 3 2	6	2 2 0 1 3 1 1 2	9	2 2 2 1 3 2 3 3
2004 08 14	6	2 1 2 2 2 1 2 2	9	3 2 2 4 2 1 1 1	9	3 1 2 3 3 3 2 2
2004 08 15	3	1 1 0 0 3 0 1 0	1	1 0 0 0 1 0 0 0	7	2 1 1 2 3 3 2 2
2004 08 16	5	0 1 0 1 2 1 2 3	3	0 1 0 1 2 1 1 2	8	2 1 1 2 3 3 2 3
2004 08 17	9	3 1 1 1 3 2 2 3	7	2 1 1 1 2 3 2 2	11	3 1 1 2 3 3 4 3

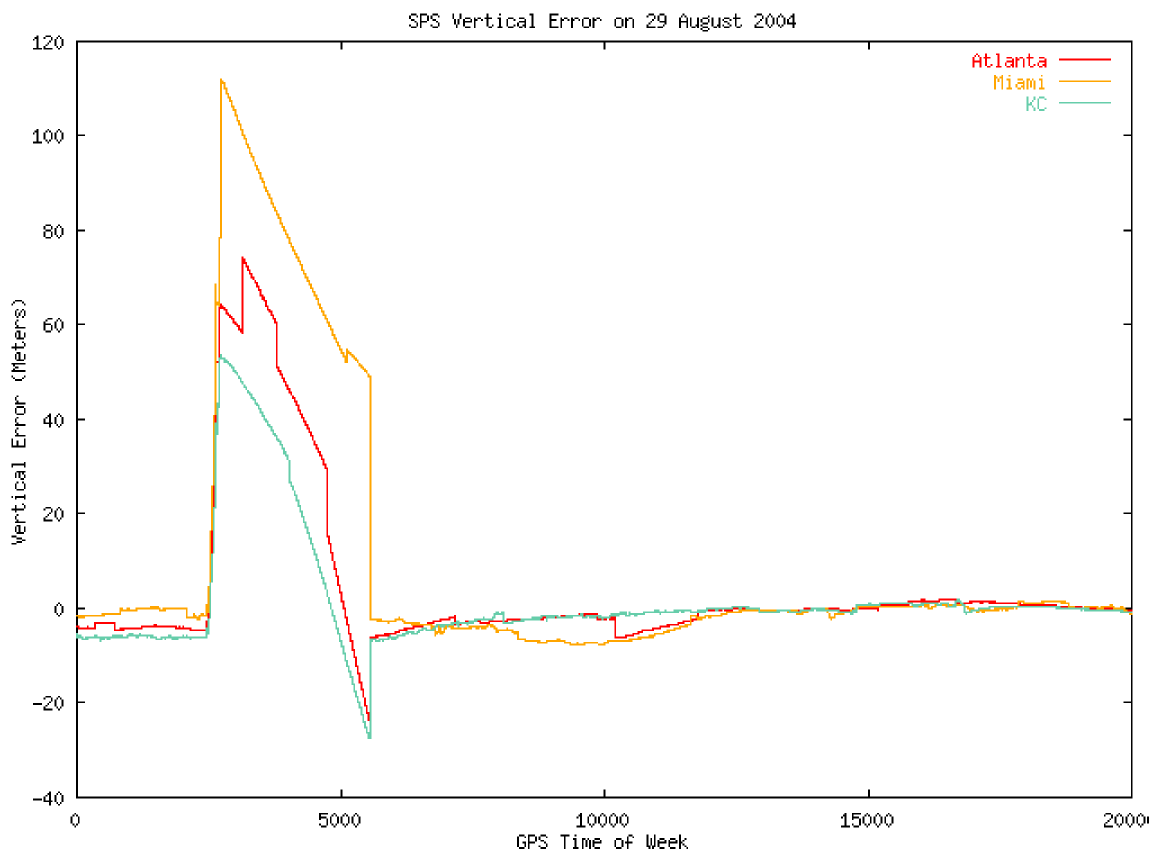
2004 08 18	10	2	2	3	2	2	3	2	3	-1	2	2	-1	-1	-1	-1	-1	0	13	3	2	4	3	3	3	3	3
2004 08 19	3	2	1	0	1	1	1	1	1	2	1	0	0	0	0	1	1	1	7	3	1	0	2	2	3	2	2
2004 08 20	9	2	2	2	3	3	2	2	1	26	2	2	4	5	5	5	3	2	14	3	3	3	4	3	3	3	3
2004 08 21	14	4	3	4	2	1	2	2	3	27	3	4	6	5	4	2	2	2	17	3	4	4	3	3	3	3	3
2004 08 22	8	2	2	3	2	2	2	2	2	28	3	3	6	5	4	4	1	2	13	3	3	4	4	3	3	2	2
2004 08 23	10	2	3	2	2	3	3	2	2	5	2	1	3	2	0	1	1	1	7	2	2	2	2	2	3	2	2
2004 08 24	3	2	0	1	1	1	1	1	0	4	1	0	2	2	3	1	1	0	5	2	1	1	1	2	2	2	2
2004 08 25	3	0	1	0	1	2	1	1	1	5	0	1	1	3	3	1	0	0	7	1	2	1	2	3	2	2	2
2004 08 26	4	1	0	1	1	2	1	2	2	3	1	1	0	1	1	2	1	1	7	2	1	1	1	2	3	3	3
2004 08 27	4	1	1	1	0	2	1	2	2	4	2	1	1	1	1	1	1	1	8	3	1	1	2	2	3	2	3
2004 08 28	6	1	3	2	2	1	1	1	1	7	2	1	4	3	0	1	1	0	12	2	3	4	3	3	3	3	2
2004 08 29	5	2	2	0	2	1	1	2	2	3	1	2	0	0	1	1	1	1	8	2	2	0	2	2	3	3	3
2004 08 30	27	3	2	4	4	3	3	4	6	63	3	2	5	7	6	7	5	4	34	3	2	5	5	5	4	4	5
2004 08 31	14	4	4	3	3	2	2	2	2	39	4	5	6	6	4	4	3	2	28	6	4	5	4	3	3	4	3
2004 09 01	5	3	1	1	1	1	1	1	1	8	2	2	2	3	3	2	1	1	9	3	1	2	2	2	3	3	3
2004 09 02	8	2	2	3	3	1	1	1	2	7	2	1	3	3	1	2	1	1	9	2	2	3	3	2	2	2	3
2004 09 03	1	2	1	0	0	0	0	0	0	2	2	1	1	0	0	0	1	0	3	2	1	1	0	1	2	1	1
2004 09 04	2	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	4	1	1	0	1	2	1	2	1
2004 09 05	5	1	0	2	1	1	2	3	1	14	0	1	3	4	4	4	2	1	7	1	1	2	2	2	3	3	2
2004 09 06	9	1	1	2	2	3	3	2	3	28	2	2	5	5	5	5	2	2	14	2	2	4	4	3	3	2	3
2004 09 07	11	3	3	3	3	2	1	2	2	27	2	3	6	5	5	3	1	1	16	3	4	4	4	3	3	2	2
2004 09 08	4	2	2	3	1	1	0	0	0	16	2	3	5	4	4	1	0	0	9	2	3	4	2	3	2	2	2
2004 09 09	3	0	2	0	1	1	0	1	2	2	0	1	0	2	0	0	1	1	4	1	1	0	1	2	1	2	2
2004 09 10	1	0	1	0	1	1	0	0	0	3	0	0	1	3	1	0	0	0	5	2	1	1	2	2	2	2	2
2004 09 11	1	0	0	0	0	1	0	1	1	1	0	0	0	0	2	1	0	0	6	2	0	0	1	3	2	3	2
2004 09 12	1	1	1	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	4	1	1	0	0	2	2	2	2
2004 09 13	5	0	0	0	0	0	0	3	4	3	0	0	0	0	0	0	2	3	8	2	1	0	1	2	2	3	4
2004 09 14	17	4	3	3	3	3	2	4	3	41	3	4	5	6	5	6	3	3	28	4	4	4	5	4	3	4	4
2004 09 15	9	4	2	1	1	2	2	2	2	23	4	3	3	5	5	3	2	2	14	4	3	2	3	3	3	3	2
2004 09 16	14	3	2	4	2	3	2	3	3	30	3	3	3	6	6	3	3	2	17	3	3	4	4	4	3	3	3
2004 09 17	15	4	4	3	2	2	1	3	3	26	4	4	4	4	5	4	2	3	20	5	4	4	3	3	3	3	4
2004 09 18	16	5	5	1	3	2	0	1	0	16	4	4	2	5	3	0	0	0	16	5	5	1	3	3	2	1	2
2004 09 19	4	1	0	1	1	1	1	1	3	3	1	0	1	2	1	1	1	1	5	1	1	1	1	2	2	2	3
2004 09 20	8	2	1	4	3	2	1	0	1	17	2	1	5	5	3	3	0	1	13	3	1	4	3	3	2	2	2
2004 09 21	6	1	3	1	1	2	1	2	1	12	2	4	4	3	2	2	1	1	9	2	3	3	2	2	2	2	2
2004 09 22	12	0	0	3	2	4	3	3	3	22	0	1	3	3	6	5	3	2	16	1	1	3	3	5	4	4	3
2004 09 23	10	4	4	1	1	1	1	1	2	15	4	5	1	3	2	2	2	1	12	4	4	2	2	2	2	2	2
2004 09 24	5	3	2	1	2	0	1	1	1	6	2	1	0	4	1	2	1	0	6	3	2	1	2	2	2	2	2
2004 09 25	2	0	0	0	1	2	1	1	0	7	0	0	0	4	4	1	0	0	5	0	1	0	2	2	3	2	2
2004 09 26	2	1	1	1	0	0	0	1	1	2	1	0	1	0	0	0	1	1	4	1	1	2	1	1	2	2	2
2004 09 27	2	0	0	0	0	2	1	1	0	5	1	0	0	2	3	2	1	1	5	1	1	0	1	2	2	3	1
2004 09 28	5	2	2	2	1	1	1	1	2	5	1	2	3	2	0	0	1	1	8	2	2	3	2	1	1	2	3
2004 09 29	3	1	0	1	0	2	1	1	2	-1	-1	-1	-1	-1	-1	-1	-1	-1	5	2	1	0	1	2	2	2	2
2004 09 30	2	1	0	0	0	1	1	1	0	1	2	0	0	0	0	0	0	0	4	2	1	0	0	1	2	2	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:

A satellite failure occurred on PRN 27 on 29 August 2004 (Week 1286 Day 0). There were two NANU's regarding the satellite on that day, they are listed below. The first NANU (forecast) quoted the start time as 1:32 Zulu (5402 GPS TOW). However, PRN 27 failed approximately 50 minutes before that time at approximately 2500 GPS TOW. The attached plot shows how three CONUS sites' vertical errors were affected by the satellite failure. The satellite was eventually not used in the SPS solution at time 5549 with a "Bad Measurements" error code given as the reason for the drop from the solution. At this time the solution returned to normal performance. Three seconds later at time 5552 it was dropped from the track list completely while the elevation of the satellite was over 50 degrees at Kansas City (middle of CONUS).



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.