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

Submitted To

Federal Aviation Administration
GPS Product Team
AND 730
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Submitted by

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EXECUTIVE SUMMARY

The GPS Product Team (AND 730) has tasked the Navigation Branch (ACB 430) at the William J. Hughes Technical Center to document 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-two 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 #43, includes data collected from 1 July through 30 September 2003. 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 2003 and by calculating the satellite availability from the data obtained from the twenty-two sites. A total of twelve outages were reported in the NANU's. All but one of the outages was scheduled. 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 22.058 meters on Satellite PRN 3. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 0.61030 Meters/second on Satellite PRN 3. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 6.23 Millimeters/second^2 on Satellite PRN 3. 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 2003, 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-two National Satellite Test Bed (NSTB) and WAAS reference station locations:

- Bangor, ME
- Elko, NV
- Mauna Loa
- Billings, MT
- Cold Bay, AK
- Juneau, AK
- Albuquerque, NM
- Anchorage, AK
- Boston, MA
- Washington, D.C.
- Honolulu
- Houston, TX
- Kansas City, KS
- Los Angeles, CA
- Salt Lake City, UT
- Miami, FL
- Minneapolis, MI
- Oakland, CA
- Cleveland, OH
- Seattle, WA
- San Juan, PR
- Atlanta, GA

(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	✓
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

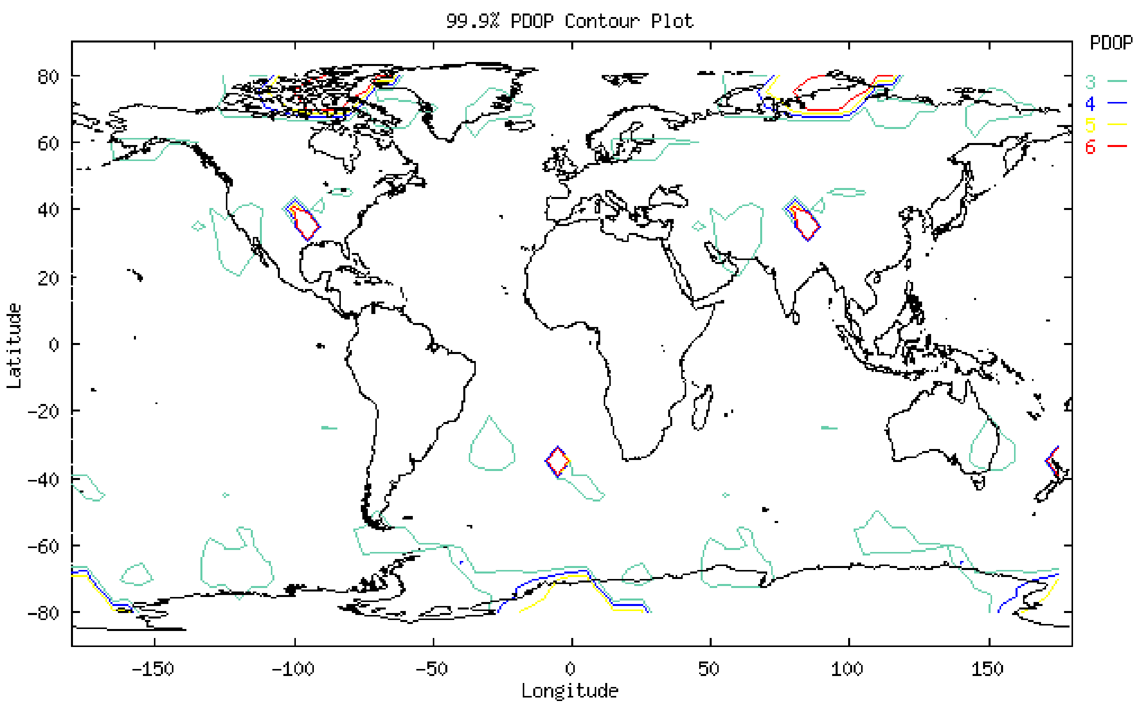
Almanacs for GPS weeks 149-162 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACB 430 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 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 3.677 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%)
201	3.677	99.977	98.542
202	3.184	99.995	99.375
203	3.184	99.995	99.306
204	3.133	99.994	99.306
205	3.219	99.994	99.306
206	3.211	99.994	99.236
207	3.113	99.994	99.236
208	3.111	99.994	99.236
209	3.123	99.994	99.167
210	3.110	99.994	99.167
211	3.120	99.994	99.167
212	3.119	99.994	99.167
213	3.121	99.994	99.167

Figure 2-1 SPS Coverage (24-Hour Period: 1 July 2003)



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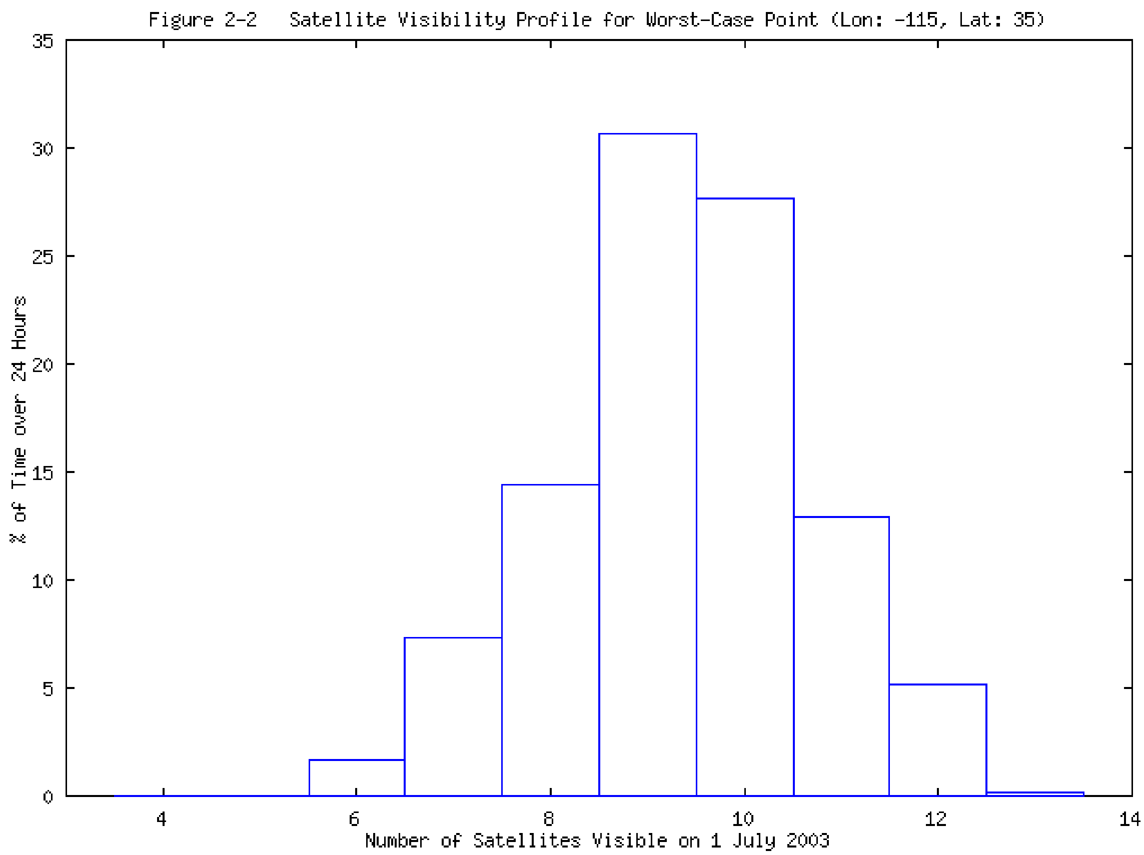


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -115, Lat: 35)
% of Time over 24 Hours
Number of Satellites Visible on 1 July 2003
35
30
25
20
15
10
5
0
4
6
8
10
12
14

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 2003, 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
2003064	21	S	3-Jul	12:36	3-Jul	20:09		7.55	7.55
67	26	S	15-Jul	4:32	15-Jul	15:11		10.65	10.65
68	30	S	17-Jul	4:29	17-Jul	10:14		5.75	5.75
73	9	S	29-Jul	2:10	29-Jul	5:37		3.45	3.45
74	10	S	1-Aug	3:15	1-Aug	12:34		9.32	9.32
75	29	S	25-Jul	2:06	4-Aug	19:05		256.98	256.98
78	24	U	23-Aug	21:44	23-Aug	21:55	0.18		0.18
79	17	S	28-Aug	16:21	28-Aug	18:24		2.05	2.05
82	13	S	23-Sep	13:04	23-Sep	21:27		8.38	8.38
83	6	S	25-Sep	2:59	25-Sep	6:12		3.21	3.21
87	16	S	29-Sep	14:12	1-Oct	0:00		33.80	33.80
89	5	S	26-Sep	7:45	1-Oct	0:00		112.25	112.25
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**0.18**	**453.39**	**453.57**
Type:	S = Scheduled		U = Unscheduled						

There were multiple NANU's that were not listed in any of the charts. They are as follows:

NANU 70: Pertained to data from the previous quarter. Included in last quarter's analysis.

NANU 76: Announced the decommissioning of PRN 22 on August 6, 2003, at 22:00 Zulu.

NANU's 86 & 88: These NANU's pertain to next quarter's data.

	Table 3-2 NANUs Forecasted to Affect Satellite Availability							
NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2003062	21	F	3-Jul	12:00	4-Jul	0:00	12	See NANU 64
65	26	F	15-Jul	4:15	15-Jul	16:15	12	See NANU 67
66	30	F	17-Jul	4:15	17-Jul	16:15	12	See NANU 68
69	9	F	29-Jul	1:45	29-Jul	13:45	12	See NANU 73
71	29	F	25-Jul	1:30	N/A	N/A		See NANU 75
72	10	F	1-Aug	3:15	1-Aug	15:15	12	See NANU 74
77	17	F	28-Aug	16:00	29-Aug	4:00	12	See NANU 79
80	13	F	23-Sep	12:45	24-Sep	0:45	12	See NANU 82
81	6	F	25-Sep	2:30	25-Sep	14:30	12	See NANU 83
84	5	F	26-Sep	7:45	N/A	N/A		See NANU 89
85	16	F	29-Sep	14:12	N/A	N/A		See NANU 87
					Total Forecast Downtime		**96**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments

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 Sept. 2003**	**1 October, 1999- 30 Sept. 2003**
Total Forecast Downtime (hrs):	96	3968.25
Total Actual Downtime (hrs):	453.57	6926.26
Total Actual Scheduled Downtime (hrs):	453.39	4002.07
Total Actual Unscheduled Downtime (hrs):	0.18	2924.19
Total Satellite Observed MTTR (hrs):	37.80	25.10
Scheduled Satellite Observed MTTR (hrs):	41.22	17.55
Unscheduled Satellite Observed MTTR (hrs):	0.18	60.92
# Total Satellite Outages:	12	276
# Scheduled Satellite Outages:	11	228
# Unscheduled Satellite Outages:	1	48
Percent Operational -- Scheduled Downtime:	99.27	99.59
Percent Operational -- All Downtime:	99.95	99.29

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 2003.

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	1.225	5.795	3.601	1.916	4.485	4.018	4932639
Elko	1.243	5.999	5.537	1.947	5.908	5.432	7226311
Mauna Loa	1.224	4.717	4.498	1.776	3.676	3.450	7221028
Billings	1.185	4.735	4.521	1.780	3.488	2.950	7030172
Cold Bay	1.106	5.805	5.236	1.751	4.317	3.904	7031340
Juneau	1.178	5.784	4.918	1.791	3.901	3.713	7008309
Albuquerque	1.245	5.205	4.841	1.794	3.441	3.039	7029238
Anchorage	1.146	5.922	5.381	1.766	3.995	3.823	7035389
Boston	1.210	5.862	4.553	1.727	3.391	2.955	7031575
Washington, D.C.	1.196	3.521	3.034	1.727	3.518	3.034	7044847
Honolulu	1.208	5.983	5.701	1.753	4.161	3.727	6943655
Houston	1.160	4.532	3.892	1.741	3.708	3.179	7030185
Kansas City	1.160	5.999	5.083	1.779	3.439	3.085	7031266
Los Angeles	1.201	5.998	5.535	1.820	4.076	3.758	7018410
Salt Lake City	1.220	5.999	5.766	1.812	5.011	4.779	7024133
Miami	1.221	5.156	4.925	1.793	5.035	4.798	7032731
Minneapolis	1.171	5.997	4.684	1.776	5.320	4.642	6498752
Oakland	1.171	5.642	3.421	1.799	4.813	4.447	7029042
Cleveland	1.179	5.512	5.273	1.779	3.712	3.382	7025890
Seattle	1.126	5.623	2.696	1.793	4.132	3.647	7043252
San Juan	1.196	4.402	4.083	1.765	3.498	3.345	7032928
Atlanta	1.238	5.999	5.645	1.848	5.337	4.900	6978187

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-two 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
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	4932639	0	100%
Elko	7226311	0	100%
Mauna Loa	7221028	0	100%
Billings	7030172	0	100%
Cold Bay	7031340	0	100%
Juneau	7008309	0	100%
Albuquerque	7029238	0	100%
Anchorage	7035389	0	100%
Boston	7031575	0	100%
Washington, D.C.	7044847	0	100%
Honolulu	6943655	0	100%
Houston	7030185	0	100%
Kansas City	7031266	0	100%
Los Angeles	7018410	0	100%
Salt Lake City	7024133	0	100%
Miami	7032731	0	100%
Minneapolis	6498752	0	100%
Oakland	7029042	0	100%
Cleveland	7025890	0	100%
Seattle	7043252	0	100%
San Juan	7032928	0	100%
Atlanta	6978187	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-two 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	4932639	15.2
Elko	7226311	19.2
Mauna Loa	7221028	45.1
Billings	7030172	15.7
Cold Bay	7031340	43.4
Juneau	7008309	44.5
Albuquerque	7029238	16.3
Anchorage	7035389	18.7
Boston	7031575	13.5
Washington, D.C.	7044847	14.7
Honolulu	6943655	42.8
Houston	7030185	20.2
Kansas City	7031266	16.5
Los Angeles	7018410	43.8
Salt Lake City	7024133	44.4
Miami	7032731	20.2
Minneapolis	6498752	43.3
Oakland	7029042	15.8
Cleveland	7025890	14.7

Seattle	7043252	14.5
San Juan	7032928	44.7
Atlanta	6978187	16.5

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 2003 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	3.575	5.803	7.772	13.107
Elko	3.761	6.259	10.709	14.372
Mauna Loa	7.541	13.546	14.822	28.013
Billings	3.442	5.506	8.395	14.062
Cold Bay	3.141	5.679	5.732	11.780
Juneau	3.049	5.229	6.599	11.265
Albuquerque	4.001	7.208	9.636	15.996
Anchorage	3.024	5.307	6.093	11.493
Boston	3.446	5.665	7.082	12.057
Washington, D.C.	3.495	6.291	7.382	14.384
Honolulu	7.709	12.173	18.227	25.949
Houston	4.465	8.447	9.219	17.864
Kansas City	3.692	6.219	8.674	14.379
Los Angeles	4.099	7.027	8.517	15.174
Salt Lake City	3.637	6.026	9.947	16.431
Miami	4.682	9.506	9.691	18.353
Minneapolis	3.605	5.653	8.646	14.582
Oakland	3.825	6.369	7.912	13.728
Cleveland	3.524	5.963	7.408	14.426
Seattle	3.400	5.433	8.628	12.793
San Juan	4.699	10.816	13.034	26.292
Atlanta	3.825	7.324	8.008	15.867

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-two NSTB and WAAS sites from 1 July to 30 September 2003.

Figure 5-1 Combined Vertical Error Histogram

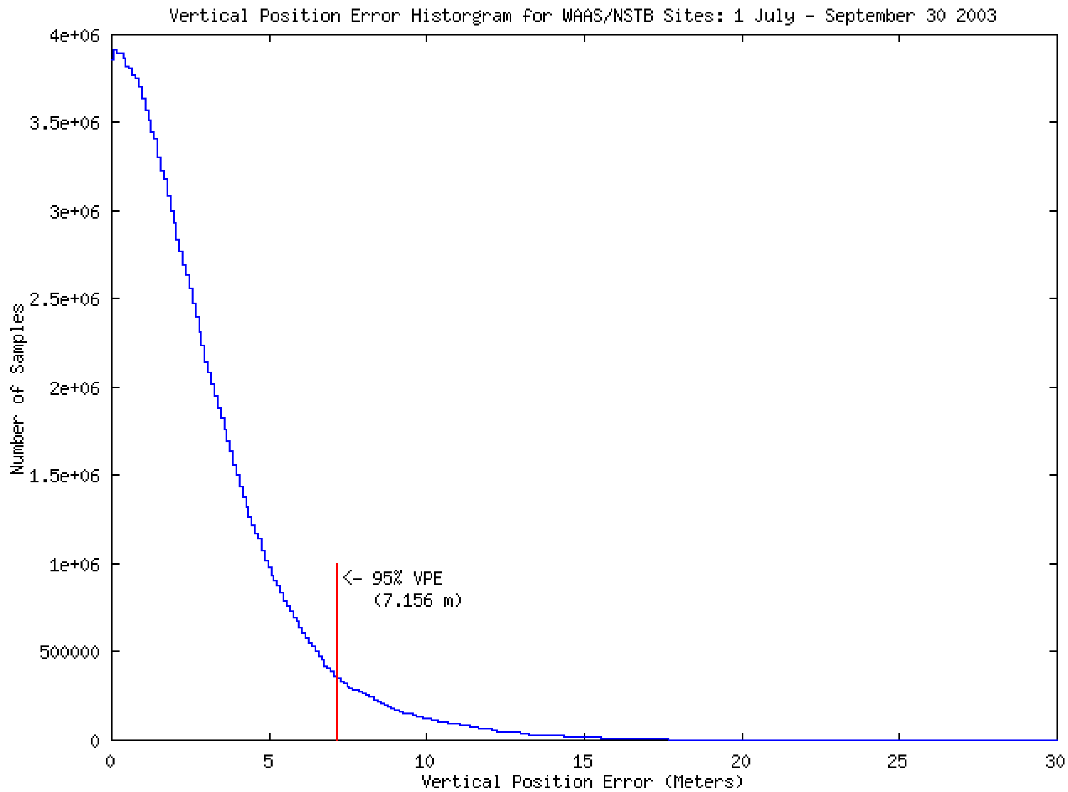
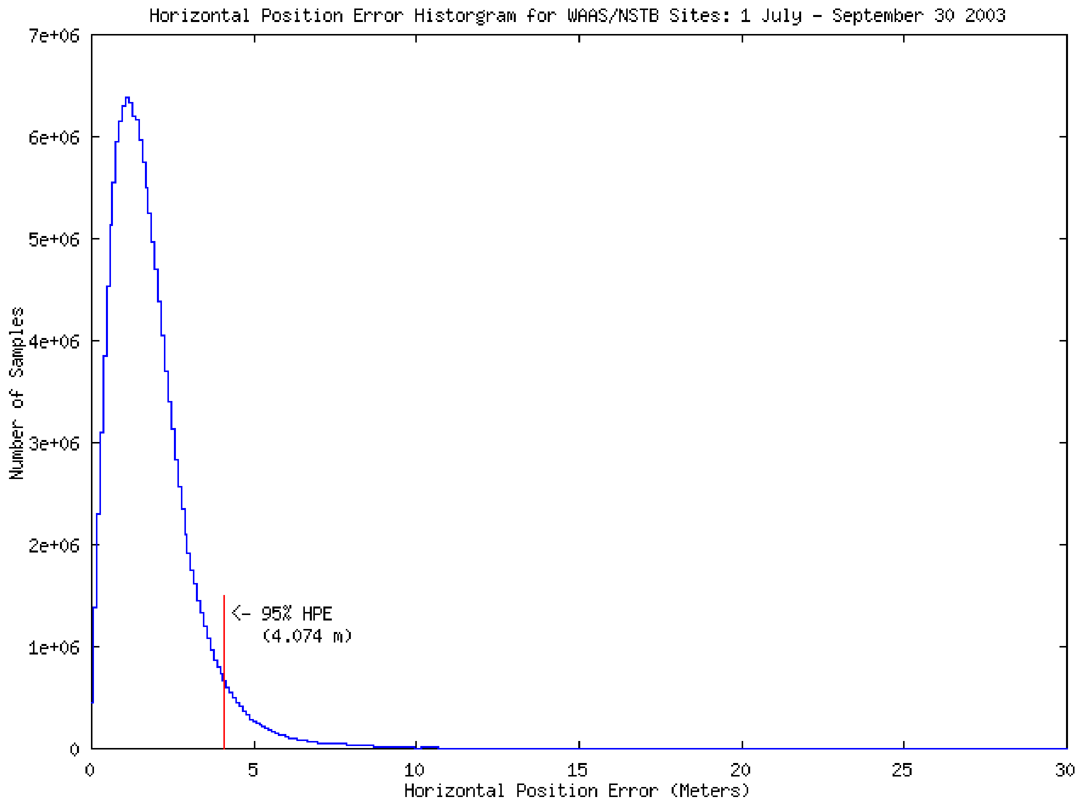


Figure 5-2 Combined Horizontal Error Histogram



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	1.944	3.598
Elko	1.414	3.517
Mauna Loa	1.163	4.116
Billings	1.165	2.841
Cold Bay	1.125	2.557
Juneau	1.137	2.781
Albuquerque	1.456	3.336
Anchorage	1.080	3.212
Boston	1.171	2.545
Washington, D.C.	1.132	2.476
Honolulu	1.344	3.689
Houston	1.346	3.265
Kansas City	1.270	2.965
Los Angeles	1.568	3.021
Salt Lake City	1.140	2.954
Miami	1.079	3.211
Minneapolis	1.193	2.881
Oakland	1.269	2.821

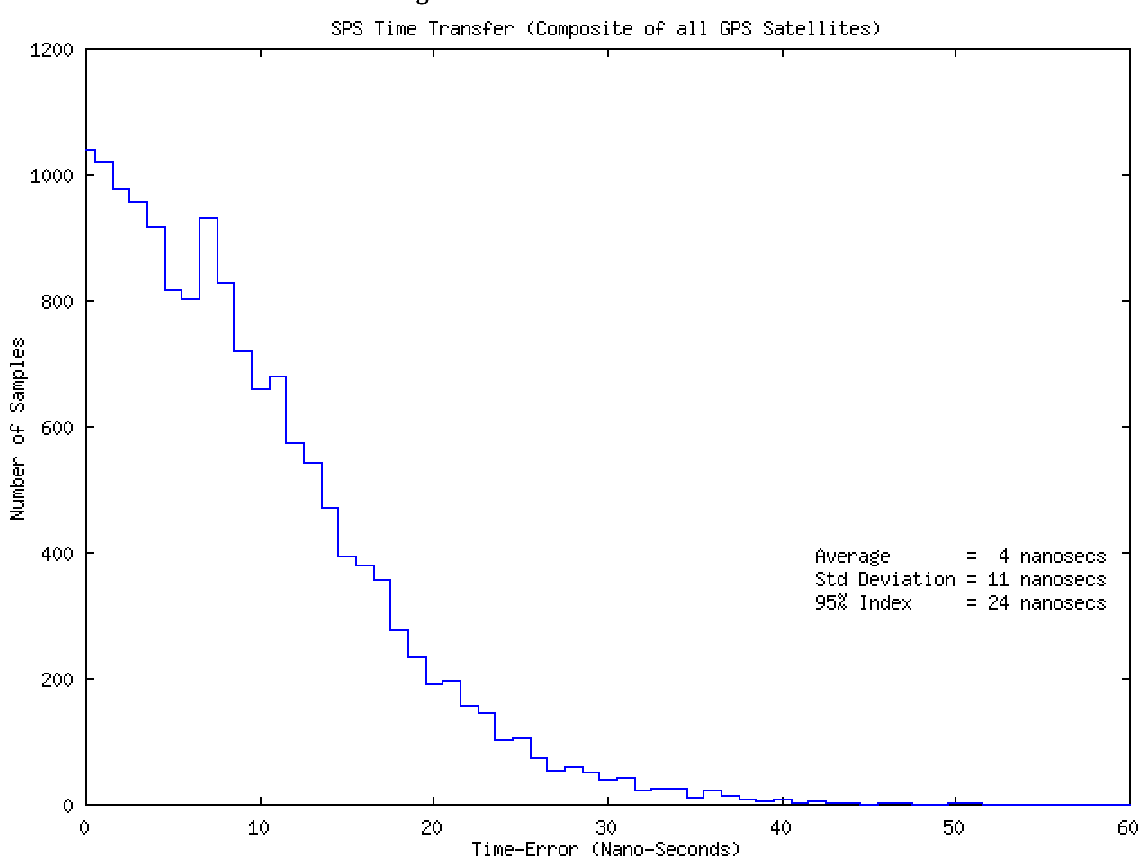
Cleveland	1.216	2.583
Seattle	1.204	2.532
San Juan	0.938	2.725
Atlanta	1.160	2.965

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 2003 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 2003. 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	-2.905	4.772	3.786	9.467	16.374	1774411
2	-2.235	4.929	4.393	9.358	18.312	1839684
3	-1.554	3.422	3.049	7.008	22.058	2066717
4	-0.081	1.937	1.935	3.954	8.744	1710375
5	-0.084	2.439	2.438	4.855	11.351	1899028
6	-0.734	2.824	2.727	5.673	11.668	1601894
7	0.637	2.110	2.012	4.366	10.413	2104214
8	-0.646	2.771	2.695	5.562	16.024	1727688
9	-0.326	2.363	2.341	4.806	11.960	2176559
10	0.854	2.738	2.602	5.515	12.932	1634942
11	-1.008	2.582	2.378	5.169	16.022	2272839

13	-2.903	4.263	3.122	8.344	17.101	1579805
14	-2.712	4.071	3.036	7.705	14.956	2121476
15	-0.531	3.174	3.129	6.100	13.426	1667153
16	-2.863	4.645	3.658	8.939	16.627	1567720
17	0.842	2.391	2.238	4.768	15.784	1563017
18	-1.279	2.830	2.524	5.913	12.032	2132645
20	-1.664	3.819	3.437	7.757	16.046	2018095
21	-0.560	2.549	2.487	5.089	10.746	1761912
23	-2.183	3.981	3.329	7.969	14.816	2126670
24	0.094	2.374	2.372	4.946	9.428	1970243
25	-3.154	4.953	3.819	9.348	17.213	1965948
26	-0.665	2.339	2.242	4.979	10.012	1871043
27	-1.510	3.110	2.719	6.599	14.525	1898209
28	0.027	2.080	2.079	4.312	14.273	2086263
29	-0.474	2.319	2.269	4.771	10.189	1912962
30	-1.160	2.892	2.649	5.997	11.931	2190870
31	-1.157	3.834	3.655	7.934	17.676	1500255

Table 5-4 Range Rate Error Statistics (meters/second)

PRN	Range Rate Error Mean	Range Rate Error RMS	Range Rate Error 1σ	95% Range Rate Error	Max Range Rate Error (SPS Spec. ≤ 2 m)	Samples
1	0.00007	0.00497	0.00497	0.00491	0.35491	1774411
2	-0.00029	0.00528	0.00527	0.00538	0.45948	1839684
3	-0.00018	0.00626	0.00626	0.00545	0.61030	2066717
4	0.00000	0.00207	0.00207	0.00334	0.14205	1710375
5	-0.00020	0.00334	0.00334	0.00392	0.26737	1899028
6	0.00006	0.00259	0.00259	0.00368	0.23583	1601894
7	-0.00005	0.00211	0.00211	0.00334	0.21103	2104214
8	0.00012	0.00375	0.00375	0.00371	0.41672	1727688
9	-0.00013	0.00309	0.00309	0.00361	0.29444	2176559
10	0.00002	0.00246	0.00246	0.00377	0.15699	1634942
11	0.00012	0.00486	0.00485	0.00464	0.54048	2272839
13	0.00027	0.00450	0.00449	0.00478	0.31498	1579805
14	-0.00009	0.00386	0.00386	0.00400	0.43980	2121476
15	0.00024	0.00298	0.00297	0.00395	0.22907	1667153
16	-0.00036	0.00481	0.00479	0.00525	0.38846	1567720
17	0.00010	0.00263	0.00263	0.00352	0.20430	1563017
18	-0.00001	0.00320	0.00320	0.00379	0.31405	2132645
20	0.00018	0.00503	0.00502	0.00511	0.40831	2018095

21	-0.00005	0.00382	0.00382	0.00441	0.27834	1761912
23	0.00021	0.00372	0.00372	0.00414	0.33143	2126670
24	-0.00005	0.00237	0.00237	0.00365	0.17737	1970243
25	-0.00018	0.00485	0.00484	0.00491	0.55897	1965948
26	-0.00002	0.00252	0.00252	0.00366	0.25509	1871043
27	0.00002	0.00433	0.00433	0.00402	0.51213	1898209
28	-0.00003	0.00345	0.00345	0.00373	0.47020	2086263
29	0.00005	0.00388	0.00388	0.00442	0.24332	1912962
30	-0.00011	0.00342	0.00341	0.00369	0.31886	2190870
31	-0.00032	0.00453	0.00452	0.00486	0.39079	1500255

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1 s	% $\leq$ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. $\leq$ 0.019 m/s2)	Samples
1	0	0.00004	0.00004	100	0.00354	1774411
2	0	0.00005	0.00005	100	0.00461	1839684
3	0	0.00006	0.00006	100	0.00623	2066717
4	0	0.00002	0.00002	100	0.00142	1710375
5	0	0.00003	0.00003	100	0.00267	1899028
6	0	0.00002	0.00002	100	0.00236	1601894
7	0	0.00002	0.00002	100	0.00205	2104214
8	0	0.00003	0.00003	100	0.00418	1727688
9	0	0.00003	0.00003	100	0.00296	2176559
10	0	0.00002	0.00002	100	0.00157	1634942
11	0	0.00004	0.00004	100	0.00537	2272839
13	0	0.00004	0.00004	100	0.00312	1579805
14	0	0.00003	0.00003	100	0.00443	2121476
15	0	0.00002	0.00002	100	0.00227	1667153

16	0	0.00004	0.00004	100	0.00387	1567720
17	0	0.00002	0.00002	100	0.00213	1563017
18	0	0.00003	0.00003	100	0.00296	2132645
20	0	0.00004	0.00004	100	0.00407	2018095
21	0	0.00003	0.00003	100	0.00277	1761912
23	0	0.00003	0.00003	100	0.00332	2126670
24	0	0.00002	0.00002	100	0.00177	1970243
25	0	0.00004	0.00004	100	0.00561	1965948
26	0	0.00002	0.00002	100	0.00255	1871043
27	0	0.00004	0.00004	100	0.00511	1898209
28	0	0.00003	0.00003	100	0.00471	2086263
29	0	0.00003	0.00003	100	0.00244	1912962
30	0	0.00003	0.00003	100	0.00318	2190870
31	0	0.00004	0.00004	100	0.00390	1500255

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 3 with an error of 22.058 meters. Satellite 4 had the lowest maximum range error of 8.744 meters.

Figure 5-4 Distribution of Daily Max Range Errors

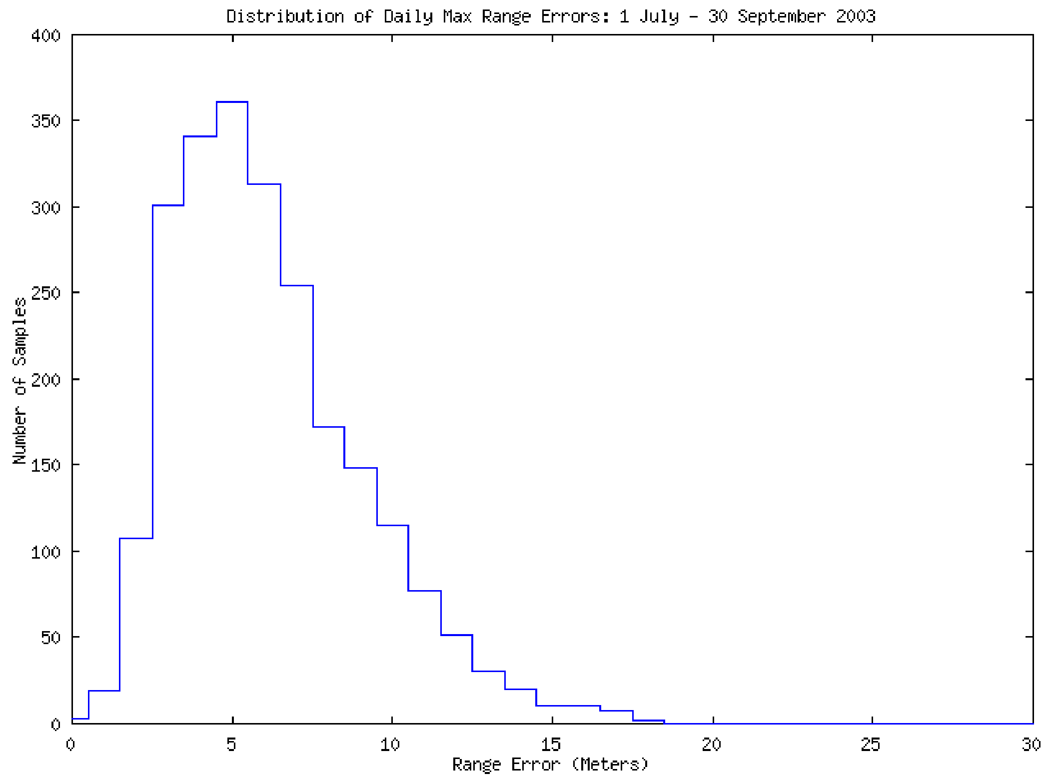


Figure 5-5: Distribution of Daily Max Range Rate Errors

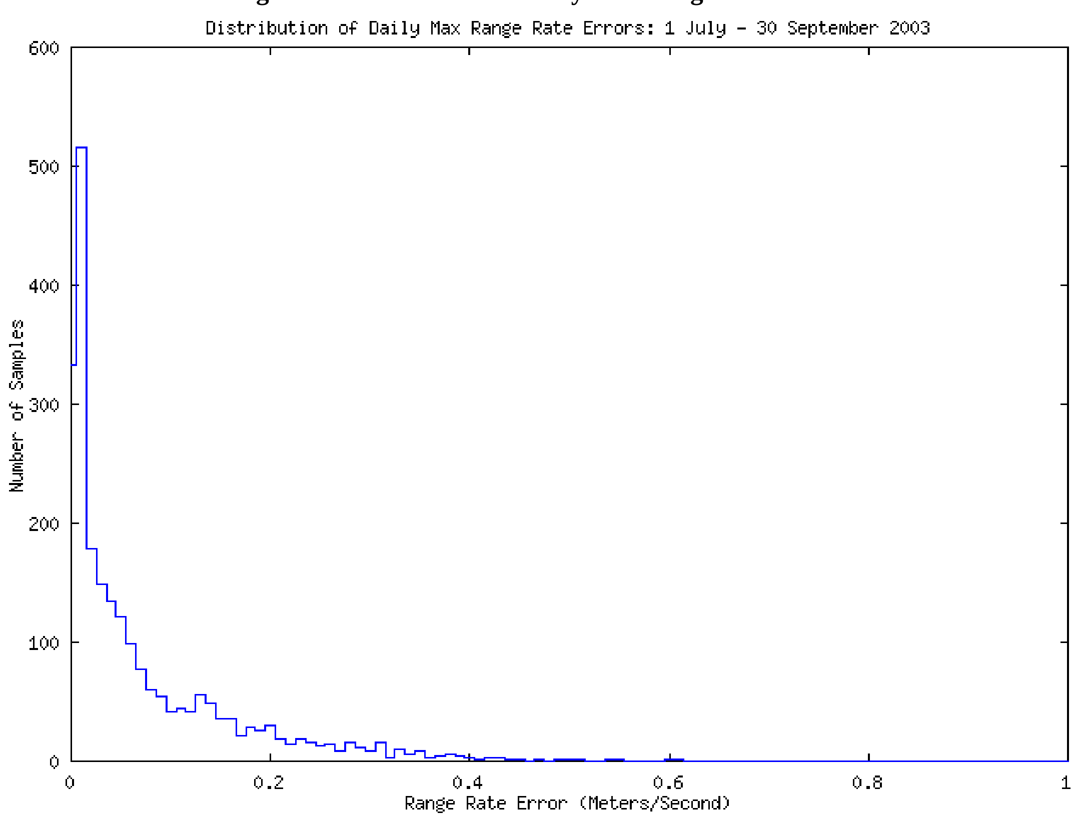


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

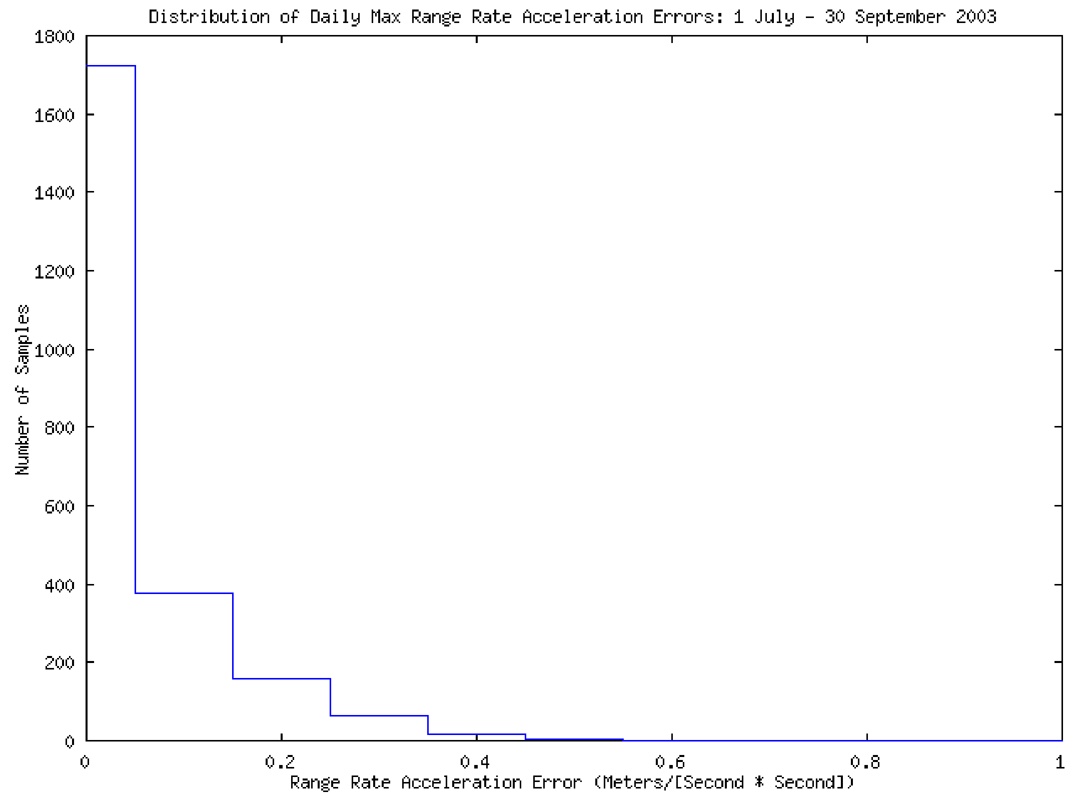


Figure 5-7: Range Error Histogram

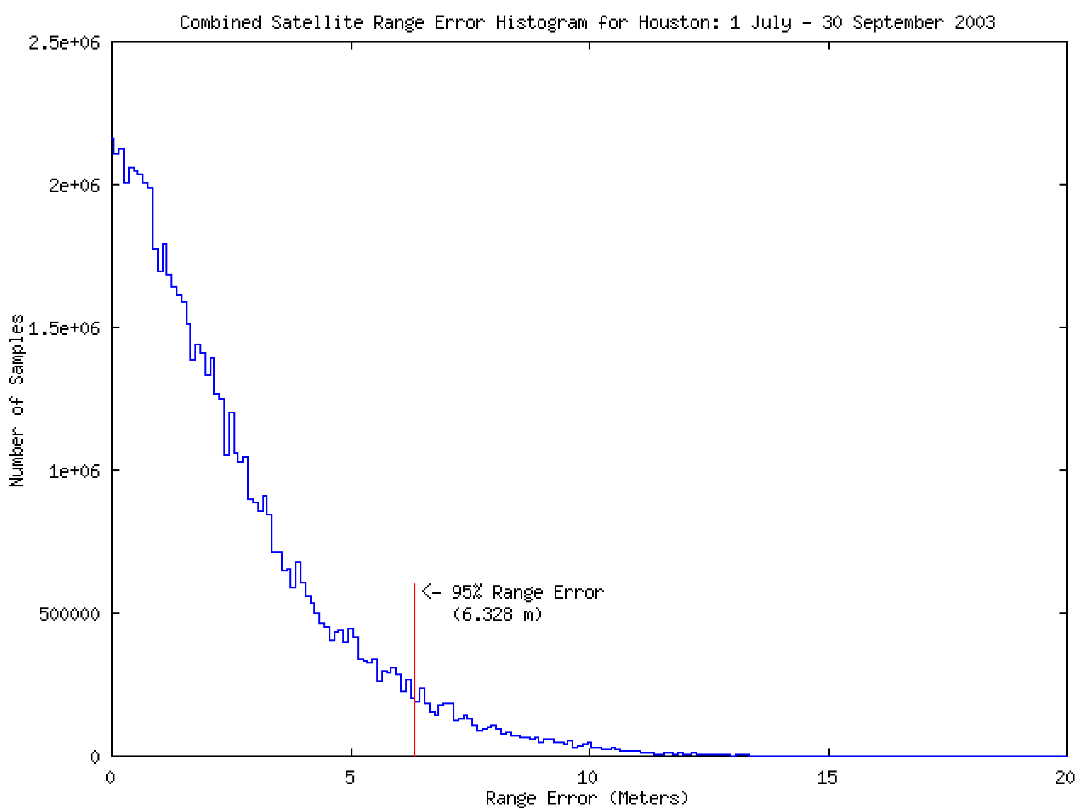


Figure 5-8: Maximum Range Error Per Satellite

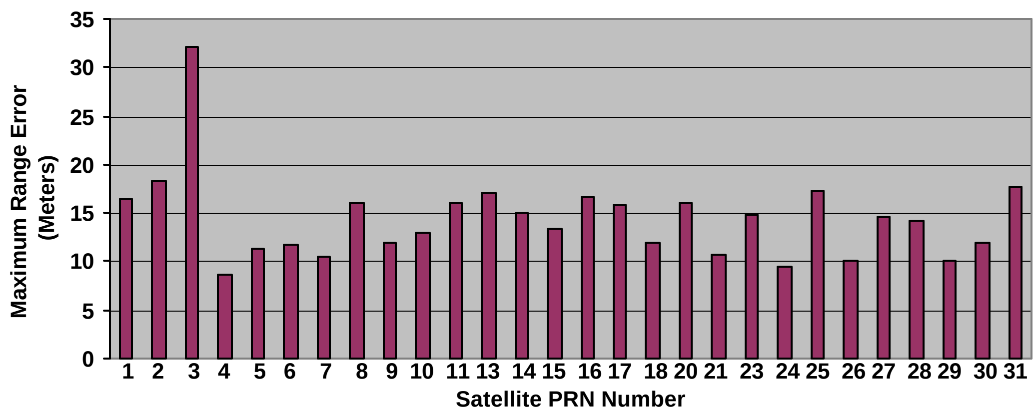


Figure 5-9: Maximum Range Rate Error Per Satellite

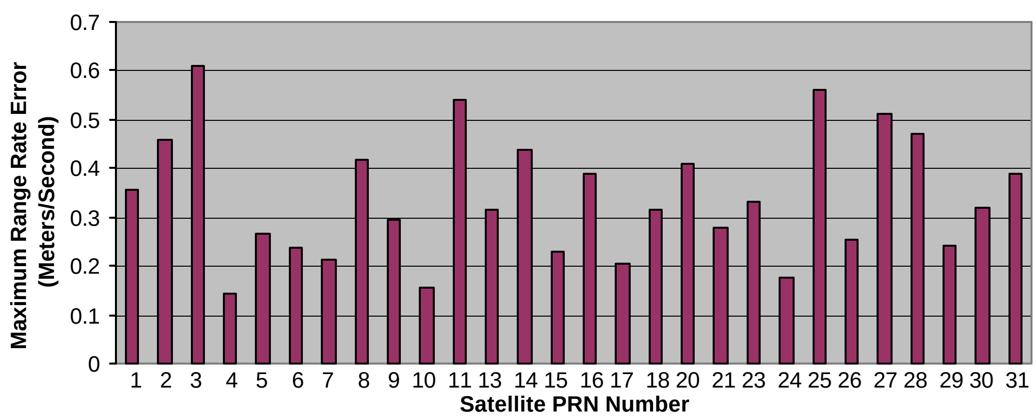
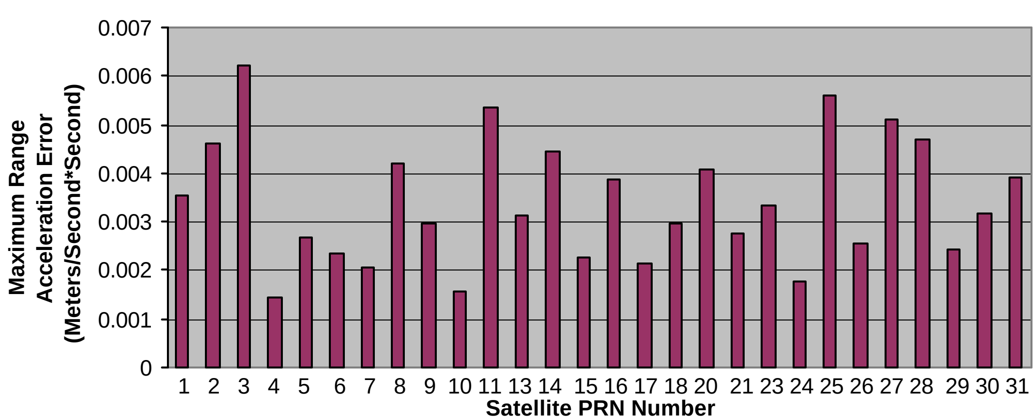


Figure 5-10: Maximum Range Acceleration Per Satellite



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 28-30 May 2003

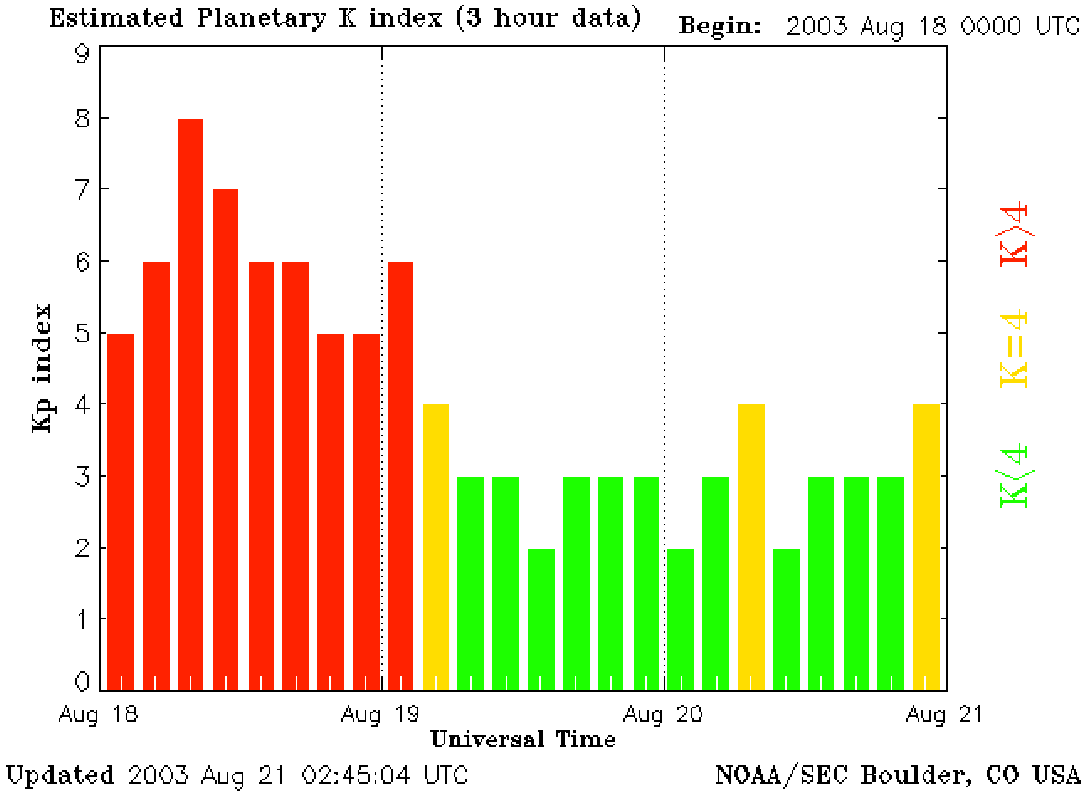


Figure 6-2 K-Index for 16-18 June 2003

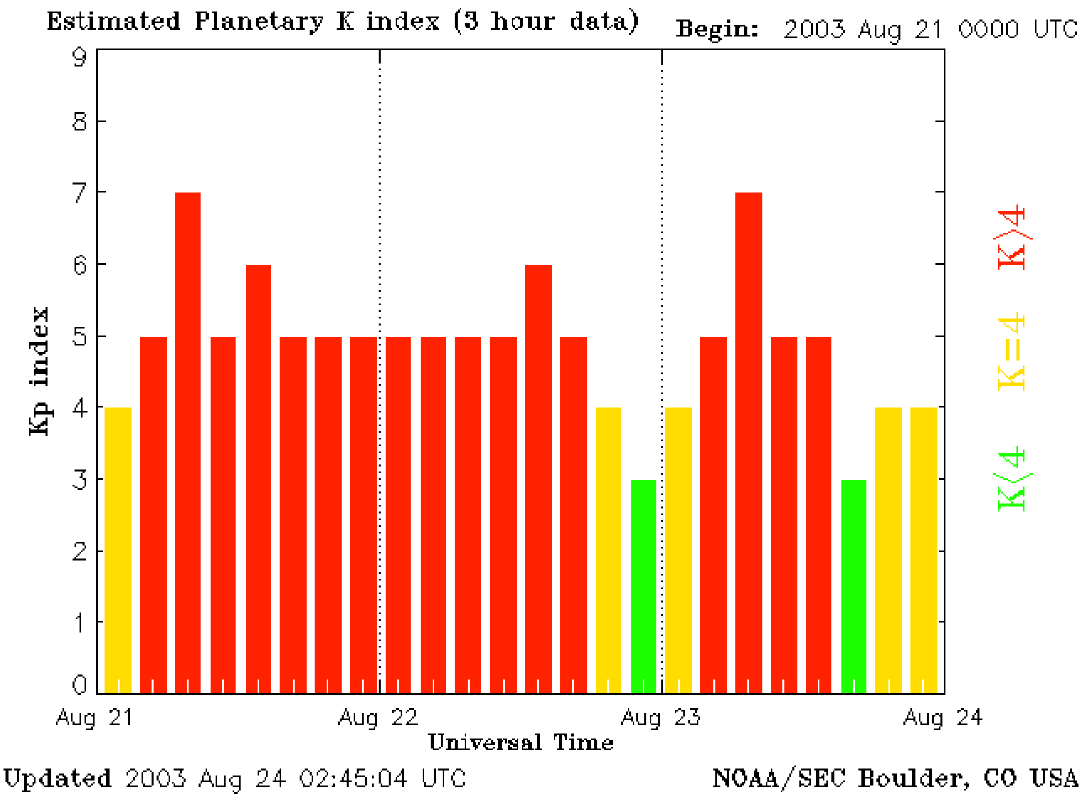
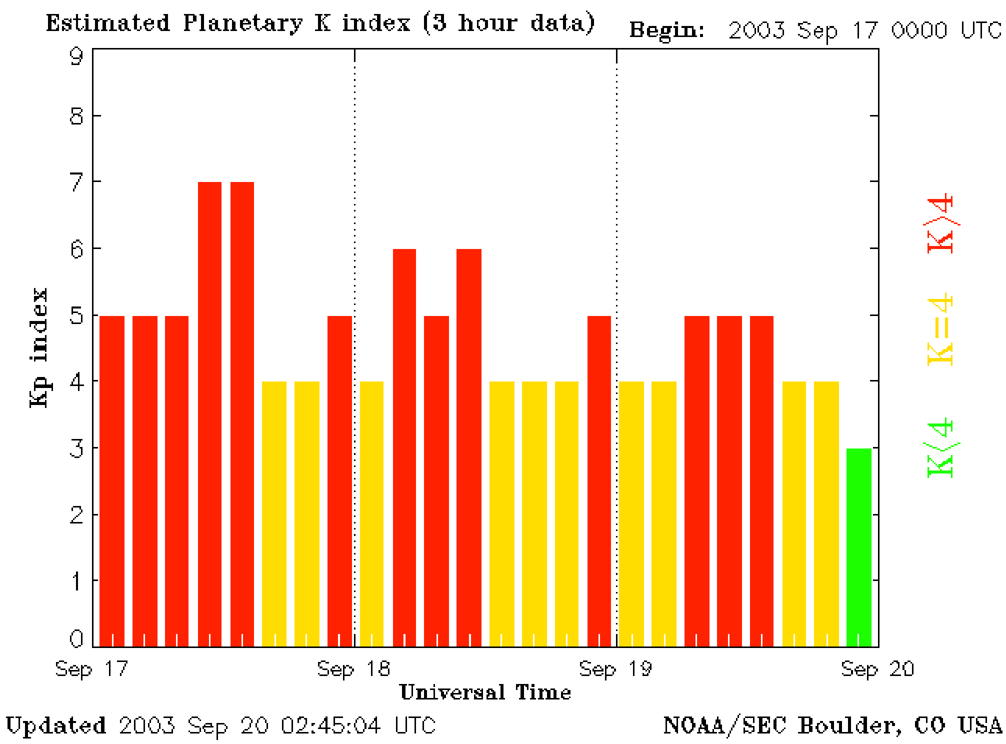


Figure 6-3 K-Index for 29 April - 1 May 2003



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 18 August 2003

Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Bangor	1.302	3.725	1.875	3.723	3.526
Elko	1.277	5.817	1.891	5.817	5.311
Mauna Loa	1.303	2.847	1.761	2.847	2.657
Billings	1.233	2.894	1.773	2.894	2.489
Cold Bay	1.108	2.890	1.759	2.889	2.283
Juneau	1.270	2.617	1.772	2.617	2.301
Albuquerque	1.316	3.903	1.735	3.901	3.303
Anchorage	1.191	5.322	1.769	5.316	4.749
Boston	1.213	3.058	1.663	3.057	2.602
Washington, D.C.	1.217	2.822	1.695	2.822	2.433
Honolulu	1.305	2.844	1.741	2.843	2.639
Houston	1.180	3.970	1.632	3.968	3.125
Kansas City	1.164	2.991	1.670	2.990	2.411
Los Angeles	1.252	2.637	1.745	2.629	2.348
Salt Lake City	1.267	2.930	1.779	2.930	2.420
Miami	1.250	3.273	1.711	3.271	3.022
Minneapolis	1.208	2.983	1.736	2.983	2.541
Oakland	1.240	2.875	1.744	2.874	2.523
Cleveland	1.286	3.033	1.721	3.033	2.757
Seattle	1.148	2.824	1.772	2.822	2.428
San Juan	1.220	2.427	1.691	2.308	2.066
Atlanta	1.275	3.550	1.779	3.550	3.137

Table 6-2 Horizontal & Vertical Accuracy Statistics for 18 August 2003

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Bangor	2.961	3.544	3.516	6.215
Elko	3.743	3.421	4.787	5.456
Mauna Loa	3.048	6.546	3.542	9.473
Billings	2.921	2.776	3.241	4.026
Cold Bay	2.696	3.382	3.734	7.735
Juneau	2.110	3.705	2.927	6.681
Albuquerque	2.654	2.935	4.086	6.958
Anchorage	2.276	4.487	4.474	9.057
Boston	2.696	2.868	4.345	5.454
Washington, D.C.	2.707	2.832	3.153	3.590
Honolulu	2.316	5.267	3.244	7.581
Houston	2.450	2.949	3.335	4.966
Kansas City	2.658	2.551	3.490	3.384
Los Angeles	2.805	2.676	3.865	3.979
Salt Lake City	2.811	2.655	3.636	4.295
Miami	3.004	6.071	3.335	6.902
Minneapolis	2.336	2.634	2.912	4.885
Oakland	2.724	2.594	3.548	4.232
Cleveland	2.466	2.693	3.097	4.518
Seattle	2.838	3.390	4.742	6.730
San Juan	3.288	11.483	7.256	17.410
Atlanta	2.666	4.293	3.726	7.378

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	99.978%
• 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 3.677
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 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	≥ 99.97% 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	≤7.709m HE 95% ≤18.227m HE 99.99% ≤13.546m VE 95% ≤28.013m 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	≤1.944m HE 95% ≤4.116m 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	≤24 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	Range Domain Accuracy ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range	22.058m NTE Range Error 0.61030m/s NTE Rate Error 6.23mm/s^2 NTE Accl. Error

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	acceleration error ≤ 8 mm/s^2 range acceleration error 95% of time	≤8mm/s^2 100% of the time

Appendix B Geomagnetic Data

```
#  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
2003 07 01	14	5 3 3 2 2 2 1 2	15	3 3 4 3 4 2 2 2	13	3 4 3 2 3 3 3 3
2003 07 02	11	1 2 3 3 2 2 4 2	21	1 2 3 5 5 3 3 3	15	1 3 3 4 3 3 4 3
2003 07 03	14	2 3 1 2 3 3 4 4	18	3 3 3 3 4 4 3 3	17	3 3 2 3 3 4 4 4
2003 07 04	15	3 3 2 4 3 3 3 3	40	4 4 4 7 4 5 3 3	25	4 5 3 5 4 4 3 4
2003 07 05	14	3 3 3 2 3 3 3 3	33	4 4 5 5 5 5 3 2	17	4 3 4 3 3 3 3 3
2003 07 06	10	3 2 1 2 3 3 2 2	17	2 2 2 5 4 4 2 1	12	3 3 2 3 3 3 3 3
2003 07 07	9	3 2 3 2 2 2 2 1	17	3 3 5 3 4 2 1 2	14	3 3 4 3 3 2 2 2
2003 07 08	3	1 0 0 1 1 2 1 1	2	0 0 1 1 2 0 1 0	5	1 1 1 1 2 2 3 2
2003 07 09	3	0 1 0 1 1 0 2 2	4	0 2 2 0 1 1 2 1	6	2 2 1 2 2 2 2 2
2003 07 10	6	1 1 2 2 2 1 1 3	18	2 1 4 5 5 1 1 2	8	2 2 2 2 3 2 3 3
2003 07 11	36	3 4 5 5 4 4 5 5	61	2 4 7 6 6 6 5 4	46	3 5 6 5 5 4 5 5
2003 07 12	25	4 6 4 3 3 2 3 3	33	5 6 5 4 4 3 2 3	46	6 7 6 4 3 3 4 3
2003 07 13	9	3 2 3 2 2 2 2 2	21	4 3 4 4 4 4 2 2	14	3 3 4 3 3 3 2 3
2003 07 14	13	2 3 3 1 3 3 3 3	18	3 4 4 4 3 3 2 2	15	3 3 4 2 3 3 3 4
2003 07 15	15	3 4 2 4 2 2 3 3	31	5 5 4 6 3 2 2 3	27	5 5 3 5 3 3 4 4
2003 07 16	23	4 3 4 5 3 2 3 4	63	4 4 6 7 7 5 3 4	48	4 5 6 6 6 4 4 5
2003 07 17	14	4 3 2 2 3 2 3 3	28	4 3 3 5 5 5 3 3	22	5 4 3 3 3 3 4 4
2003 07 18	11	2 3 2 1 2 2 3 4	15	3 4 3 3 3 3 2 2	14	3 3 2 2 2 3 3 4
2003 07 19	20	4 2 2 3 3 3 4 5	33	3 3 3 5 6 5 3 4	26	4 3 3 4 4 4 4 5
2003 07 20	16	4 3 3 3 3 2 3 3	22	5 3 3 5 3 3 2 3	19	5 4 4 3 3 3 3 3
2003 07 21	8	4 3 2 1 1 0 1 1	10	4 4 1 1 3 0 0 2	12	4 4 2 1 2 2 3 2
2003 07 22	5	2 0 2 2 2 2 1 1	-1	-1-1-1-1-1-1-1-1	9	3 1 2 3 2 2 3 2
2003 07 23	10	2 2 2 3 2 3 2 3	-1	-1-1-1-1-1-1-1-1	11	2 2 2 3 2 3 3 4
2003 07 24	6	2 1 1 1 2 1 2 3	-1	-1-1-1-1-1-1 2 2	10	3 2 1 0 2 3 3 4
2003 07 25	8	1 2 4 2 2 1 1 2	10	2 2 3 4 3 1 1 1	11	2 2 4 3 2 3 3 2
2003 07 26	20	2 3 2 3 4 3 4 5	37	2 3 4 3 5 6 6 4	26	3 3 3 3 4 5 5 5
2003 07 27	16	4 4 3 3 3 1 3 2	31	5 4 4 5 5 4 3 2	24	5 4 5 4 3 3 3 2
2003 07 28	15	2 2 3 3 4 4 2 3	-1	2-1-1-1-1-1 4 3	17	2 2 3 4 5 4 3 3
2003 07 29	24	4 5 4 2 3 3 4 4	57	3 4 6 6 6 6 6 4	36	4 5 4 4 5 5 5 5
2003 07 30	24	3 4 4 5 3 3 4 3	43	4 4 5 6 5 6 3 3	29	4 4 5 5 4 4 4 4
2003 07 31	22	3 3 4 5 3 3 3 4	59	3 5 6 7 6 6 3 3	32	4 5 4 5 4 4 3 4
2003 08 01	28	5 5 4 3 3 3 3 5	74	5 5 7 7 7 5 3 3	37	5 5 5 5 5 3 3 5
2003 08 02	15	4 3 3 2 2 2 4 3	37	4 4 6 6 4 4 3 3	21	4 4 4 3 3 3 4 4
2003 08 03	10	3 3 2 2 2 2 2 3	24	3 4 5 5 4 3 2 2	15	3 4 3 3 3 3 3 3
2003 08 04	12	3 2 3 3 1 2 3 3	14	2 2 4 5 0 2 2 2	14	2 2 4 4 1 2 4 4
2003 08 05	6	3 1 2 1 1 1 2 2	3	2 1 1 0 0 1 1 2	9	3 2 1 1 2 3 3 3
2003 08 06	34	5 6 6 4 3 2 2 2	37	4 5 6 6 5 2 2 1	43	6 6 7 5 4 3 3 2

2003 08 07	15	1 2 2 1 4 3 3 4	23	2 2 2 2 5 5 5 3	15	2 2 1 2 3 4 5 4
2003 08 08	22	5 4 4 3 3 3 3 3	41	5 5 6 6 3 4 3 3	32	5 5 5 4 3 4 3 3
2003 08 09	10	2 2 2 2 3 2 3 3	30	2 3 6 6 4 3 2 2	15	3 3 4 4 3 3 3 3
2003 08 10	9	3 2 2 2 3 2 2 2	14	3 3 2 5 2 2 2 1	12	4 3 2 3 2 2 3 2
2003 08 11	9	1 2 2 2 2 2 3 3	9	2 2 2 2 2 2 3 3	11	2 2 2 2 2 2 3 4
2003 08 12	17	3 4 4 3 3 3 2 3	47	4 5 5 6 6 6 2 2	25	4 5 5 4 3 4 3 3
2003 08 13	15	4 4 3 1 3 2 3 2	17	3 3 4 4 4 3 2 2	17	3 5 3 2 3 2 4 3
2003 08 14	12	3 4 3 1 2 2 2 3	-1	2 5 5 3 2 2 2 3	18	3 4 4 2 3 3 4 4
2003 08 15	9	2 2 2 2 2 3 2 3	12	3 3 3 1 2 4 2 2	14	3 2 3 2 3 4 4 3
2003 08 16	7	3 3 1 1 2 2 1 1	17	3 2 2 5 4 4 1 1	11	3 3 2 3 3 3 3 2
2003 08 17	10	1 0 1 0 4 3 3 3	9	0 0 0 0 3 3 3 4	15	2 1 0 1 4 4 4 5
2003 08 18	46	5 5 7 5 4 3 3 4	132	4 6 7 8 7 8 7 5	86	5 6 8 7 6 6 5 5
2003 08 19	18	5 4 3 3 2 2 3 2	12	4 3 2 2 2 3 2 2	21	6 4 3 3 2 3 3 3
2003 08 20	12	1 2 3 1 2 3 3 4	23	1 3 4 5 5 3 3 3	15	2 3 4 2 3 3 3 4
2003 08 21	29	3 5 5 3 4 4 4 4	76	3 4 7 6 7 6 6 5	53	4 5 7 5 6 5 5 5
2003 08 22	25	5 4 3 4 4 3 4 3	70	4 5 7 6 7 6 4 3	43	5 5 5 5 6 5 4 3
2003 08 23	26	5 5 4 3 3 3 3 4	73	4 4 8 6 7 5 3 2	44	4 5 7 5 5 3 4 4
2003 08 24	14	3 3 3 3 3 2 3 3	46	3 3 6 7 6 3 3 2	24	3 4 5 5 4 3 4 3
2003 08 25	16	3 3 4 2 3 2 4 3	39	4 5 6 5 5 5 2 2	21	4 4 5 3 3 3 3 3
2003 08 26	8	3 1 1 2 1 2 3 2	22	3 2 1 6 4 4 3 2	14	3 2 1 4 3 4 3 3
2003 08 27	9	1 2 3 3 2 1 3 2	26	2 2 4 6 5 4 2 2	13	2 2 3 4 3 3 3 3
2003 08 28	11	2 3 3 3 2 3 2 2	42	2 4 5 6 4 7 2 2	18	3 4 4 4 3 3 3 3
2003 08 29	12	0 2 1 3 3 3 4 3	24	1 1 1 5 5 5 4 3	15	1 2 2 4 3 4 4 3
2003 08 30	12	4 4 2 2 2 1 2 2	23	3 4 5 5 3 4 2 1	17	4 5 3 3 3 3 3 2
2003 08 31	5	1 2 1 1 2 1 2 1	14	1 2 3 3 5 3 2 1	7	2 2 2 2 3 2 2 2
2003 09 01	11	2 4 4 1 1 2 2 2	12	2 4 3 2 1 2 3 3	14	2 4 4 1 2 3 3 3
2003 09 02	12	3 1 2 3 4 2 2 3	18	2 2 1 3 6 3 2 2	12	3 2 1 2 4 3 3 3
2003 09 03	14	3 3 2 2 3 2 3 4	16	3 3 3 5 3 2 2 2	17	3 3 3 4 3 3 3 4
2003 09 04	15	4 3 3 3 3 2 3 3	32	3 3 5 6 4 4 3 4	19	3 3 4 4 3 3 3 4
2003 09 05	9	3 3 2 2 2 2 2 1	22	3 3 3 5 5 4 2 1	16	3 4 3 4 4 3 3 2
2003 09 06	7	2 2 1 2 2 1 3 1	10	2 2 2 4 3 1 2 2	12	3 2 3 3 3 3 3 2
2003 09 07	3	2 2 0 0 1 1 1 1	2	2 1 0 1 0 1 0 0	10	3 3 1 2 3 3 3 3
2003 09 08	4	0 0 0 1 2 1 1 3	4	0 0 0 0 1 2 1 3	9	2 1 2 2 3 3 3 3
2003 09 09	17	2 2 2 3 4 3 4 4	17	2 2 3 4 4 2 3 4	19	2 2 3 4 4 3 4 4
2003 09 10	12	4 1 2 3 3 2 3 2	30	5 3 3 6 4 4 3 3	19	4 2 3 4 3 3 4 3
2003 09 11	10	3 4 1 2 2 2 2 1	15	3 4 1 4 4 2 1 2	15	4 5 2 3 3 3 3 3
2003 09 12	8	3 3 2 2 2 1 2 1	10	2 3 2 3 3 2 2 1	11	3 3 3 3 3 3 2 2
2003 09 13	6	3 3 2 1 0 0 1 2	9	3 2 4 3 0 1 1 1	11	3 3 3 3 2 2 2 2
2003 09 14	3	1 1 1 0 1 1 1 1	3	1 0 0 1 1 2 1 1	7	2 1 2 2 2 3 2 2
2003 09 15	3	0 1 0 0 1 1 2 2	2	1 0 0 0 0 1 1 2	6	2 1 1 2 2 2 2 3
2003 09 16	15	4 2 2 3 4 3 3 2	69	4 4 6 7 7 6 5 2	37	4 3 5 5 6 5 4 2
2003 09 17	35	5 4 4 4 5 4 4 5	80	4 4 6 7 8 5 5 4	61	5 5 5 7 7 4 4 5
2003 09 18	29	5 6 2 4 3 3 3 4	75	4 5 7 8 5 5 4 4	40	4 6 5 6 4 4 4 5
2003 09 19	26	4 4 5 4 4 4 3 3	68	7 3 7 6 6 5 4 3	32	4 4 5 5 5 4 4 3
2003 09 20	34	5 6 5 4 4 4 3 2	-1	3 4-1-1 6 5 2 2	25	4 4 5 4 4 4 3 2
2003 09 21	19	4 3 4 3 4 4 2 2	57	3 2 6 5 7 7 3 2	21	4 3 4 4 5 4 3 3
2003 09 22	17	2 4 3 4 3 3 4 2	30	2 3 5 6 5 4 3 1	18	3 4 4 4 4 3 4 2
2003 09 23	10	2 3 3 2 2 2 2 3	21	2 4 3 5 5 3 3 2	17	3 4 3 3 3 3 4 3
2003 09 24	27	5 5 3 3 3 3 3 5	44	4 5 6 5 4 6 4 3	33	5 5 5 4 4 4 4 4
2003 09 25	16	3 3 4 3 3 3 3 3	40	3 4 6 6 5 5 3 2	28	4 4 5 5 4 4 4 3
2003 09 26	11	3 2 3 3 2 2 2 3	27	3 2 5 6 4 4 2 2	17	3 3 4 4 3 3 3 3
2003 09 27	13	3 2 4 5 0 0 1 2	5	3 1 1 2 0 0 2 1	9	3 2 2 3 2 2 2 2
2003 09 28	2	0 1 0 1 1 1 1 0	4	0 0 1 3 2 1 1 0	6	2 1 2 3 2 2 2 1
2003 09 29	4	2 2 0 1 1 1 1 2	4	0 0 1 3 2 1 0 0	7	2 2 1 3 3 2 2 1
2003 09 30	3	0 1 2 1 1 1 1 1	8	0 0 2 3 4 3 0 1	7	2 2 2 3 3 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:

GPS did not fail SPS specification in any instances during 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.

<u>General Terms and Definitions</u>

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.