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

Submitted To

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

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Submitted by

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EXECUTIVE SUMMARY

The GPS Product Team (AND 730) has tasked the Navigation Branch (ACB 430) at the William J. Hughes Technical Center to document Global Positioning System (GPS) Standard Positioning Service (SPS) performance in quarterly GPS Performance Analysis (PAN) Reports. The report contains the analysis performed on data collected at twenty-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 #44, includes data collected from 1 October through 31 December 2003. The next quarterly report will be issued 30 April 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 98.819% or better.

Availability was verified by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 October and 31 December 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 42.680 meters on Satellite PRN 7. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 1.16303 Meters/second on Satellite PRN 29. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 11.62 Millimeters/second^{2} on Satellite PRN 29. The SPS specification states that the range acceleration error should never exceed 19 Millimeters/second^{2}.

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

From the analysis performed on data collected between 1 October and 31 December 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
- 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 214-227 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 3.82718 or better 99.9% of the time for each of the 24-hour intervals.

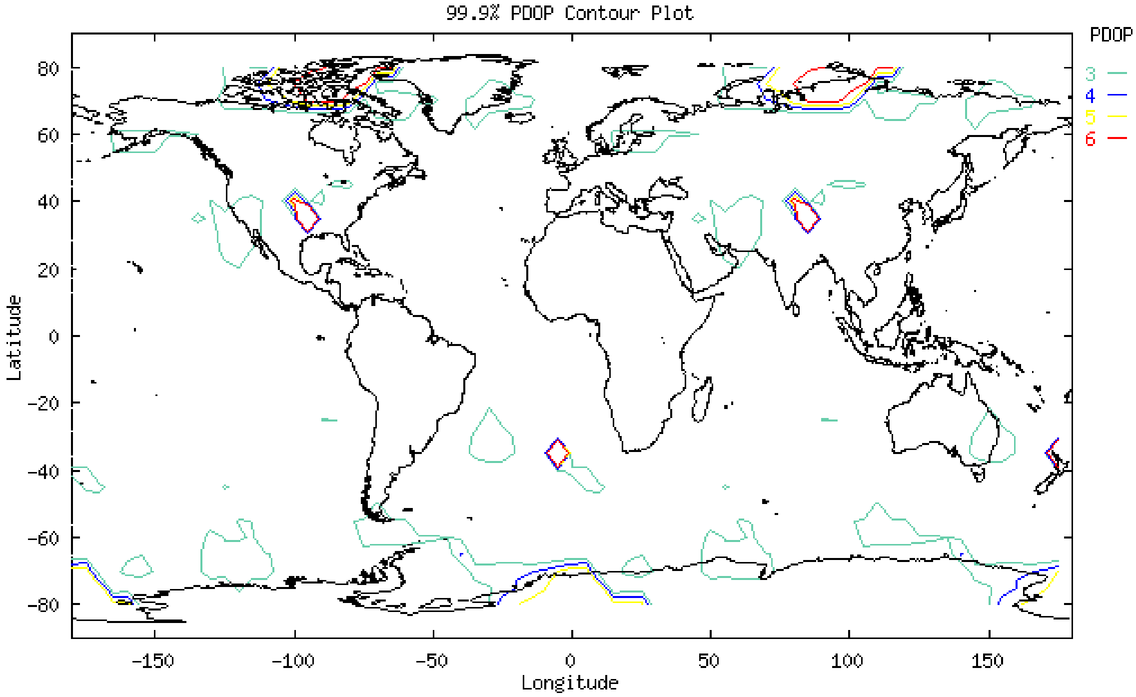
The GPS coverage performance evaluated met the specifications stated in the SPS.

Table 2-1 Coverage Statistics

GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
214	3.72634	99.966	98.889
215	3.72660	99.965	98.889
216	3.08687	99.996	99.167
217	3.08666	99.996	99.167
218	3.08518	99.995	99.167
219	3.07650	99.995	99.236
220	3.07658	99.995	99.236
221	3.80237	99.982	98.819
222	3.82718	99.982	98.889
223	3.07639	99.996	99.375
224	3.07323	99.995	99.375
225	3.06766	99.995	99.444
226	3.05245	99.995	99.514
227	3.05131	99.996	99.514

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

99.9% PDOP Contour Plot



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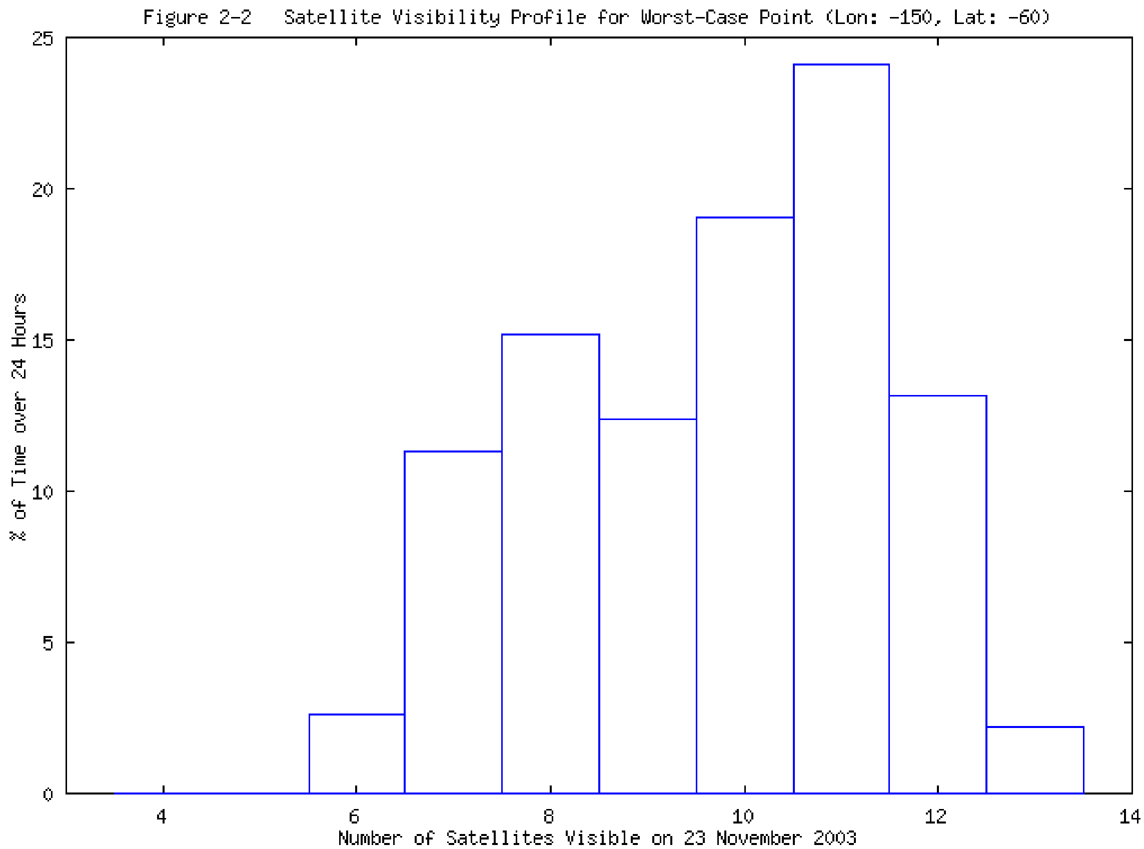


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -150, Lat: -60)
% of Time over 24 Hours
Number of Satellites Visible on 23 November 2003
0
5
10
15
20
25
4
6
8
10
12
14

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 October through 31 December 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
2003095	2	S	6-Nov	15:12	6-Nov	16:16		1.07	1.07
98	25	S	13-Nov	14:46	13-Nov	22:10		7.40	7.40
100	9	S	17-Nov	22:41	18-Nov	7:59		9.30	9.30
106	23	S	13-Nov	1:21	25-Nov	21:04		307.72	307.72
107	17	S	25-Nov	18:46	25-Nov	22:24		3.63	3.63
108	24	S	2-Dec	16:50	3-Dec	2:27		7.62	7.62
109	31	S	4-Dec	16:58	5-Dec	0:39		7.68	7.68
113	26	S	12-Dec	4:15	12-Dec	6:48		2.55	2.55
114	17	S	16-Dec	17:00	17-Dec	1:28		8.47	8.47
115	31	S	18-Dec	15:00	18-Dec	21:06		6.10	6.10
117	31	S	21-Dec	11:21	21-Dec	21:56	2.47	8.11	10.58
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**2.47**	**369.65**	**372.12**
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
2003094	2	F	6-Nov	14:15	7-Nov	2:15	12	See NANU 95
96	25	F	13-Nov	14:30	14-Nov	2:30	12	See NANU 98
97	23	F	13-Nov	1:21	N/A	N/A	N/A	See NANU 106
99	9	F	17-Nov	22:30	18-Nov	10:30	12	See NANU 100
101	17	F	25-Nov	18:00	26-Nov	6:00	12	See NANU 107
102	2	F	21-Nov	12:00	21-Nov	13:00	1	See NANU 103
104	24	F	2-Dec	16:30	3-Dec	4:30	12	See NANU 108
105	31	F	4-Dec	16:45	5-Dec	4:45	12	See NANU109
110	17	F	16-Dec	16:45	17-Dec	4:45	12	See NANU 114
111	31	F	18-Dec	14:15	19-Dec	2:15	12	See NANU 115
112	26	F	12-Dec	4:15	N/A	N/A	N/A	See NANU 113
116	31	F	21-Dec	13:49	N/A	N/A	N/A	See NANU 117
					Total Forecast Downtime		97	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
2003103	2	C	21-Nov	12:00	See NANU 102

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

Table 3-4 GPS Block II/IIA Satellite RMA Data		
Satellite Reliability/Maintainability/Availability (RMA) Parameter	**1 October - 31 Dec. 2003**	**1 October, 1999- 31 Dec. 2003**
Total Forecast Downtime (hrs):	97	4065.25
Total Actual Downtime (hrs):	372.12	7298.38
Total Actual Scheduled Downtime (hrs):	369.65	4371.72
Total Actual Unscheduled Downtime (hrs):	2.47	2926.66
Total Satellite Observed MTTR (hrs):	31.01	25.34
Scheduled Satellite Observed MTTR (hrs):	33.60	18.29
Unscheduled Satellite Observed MTTR (hrs):	2.47	59.73
# Total Satellite Outages:	12	288
# Scheduled Satellite Outages:	11	239
# Unscheduled Satellite Outages:	1	49
Percent Operational -- Scheduled Downtime:	99.40	99.58
Percent Operational -- All Downtime:	99.96	99.30

3.2 Service Availability

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

To verify availability, the data collected from receivers at the nine NSTB/WAAS sites was reduced to calculate DOP information and reported in Tables 3-5 to 3-7. The data was collected at one-second intervals between 1 October and 31 December 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	1.207	6.000	4.925	2.166	5.984	5.677	6691213
Elko	1.247	5.998	5.121	1.908	5.442	4.726	7513350
Billings	1.206	4.091	3.380	1.766	3.878	3.220	7422225
Cold Bay	1.105	5.504	5.154	1.732	4.102	3.794	7398648
Juneau	1.220	5.956	5.077	1.787	5.356	4.530	7404068
Albuquerque	1.257	5.922	5.263	1.784	5.796	5.146	7424226
Anchorage	1.183	5.743	5.322	1.771	4.493	4.273	7429428
Boston	1.227	5.095	3.888	1.727	4.206	3.683	7421813
Washington, D.C.	1.225	4.045	3.535	1.734	3.812	3.443	6824060

Honolulu	1.215	5.193	4.710	1.710	3.548	3.243	7318844
Houston	1.163	5.093	4.335	1.767	4.025	3.834	7409894
Kansas City	1.156	5.526	5.036	1.776	3.886	3.309	7422128
Los Angeles	1.203	5.873	5.415	1.792	4.346	3.965	7417394
Salt Lake City	1.230	5.153	4.718	1.762	4.374	4.080	7422008
Miami	1.159	5.384	5.193	1.797	5.172	4.999	7418563
Minneapolis	1.135	4.338	2.883	1.786	3.906	3.445	7420515
Oakland	1.165	5.987	5.581	1.775	4.961	4.474	7403677
Cleveland	1.148	4.276	3.648	1.787	3.989	3.504	7419383
Seattle	1.138	5.153	3.560	1.773	4.185	3.719	7432494
San Juan	1.197	5.999	5.357	1.780	5.380	4.533	6923032
Atlanta	1.227	6.000	5.647	1.779	4.904	4.553	7145819

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	6691213	0	100%
Elko	7513350	0	100%
Billings	7422225	0	100%
Cold Bay	7398648	0	100%
Juneau	7404068	0	100%
Albuquerque	7424226	0	100%
Anchorage	7429428	0	100%

Boston	7421813	0	100%
Washington, D.C.	6824060	0	100%
Honolulu	7318844	0	100%
Houston	7409894	0	100%
Kansas City	7422128	0	100%
Los Angeles	7417394	0	100%
Salt Lake City	7422008	0	100%
Miami	7418563	0	100%
Minneapolis	7420515	0	100%
Oakland	7403677	0	100%
Cleveland	7419383	0	100%
Seattle	7432494	0	100%
San Juan	6923032	0	100%
Atlanta	7145819	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	6691213	35.0
Elko	7513350	45.5
Billings	7422225	42.1

Cold Bay	7398648	17.3
Juneau	7404068	23.3
Albuquerque	7424226	42.4
Anchorage	7429428	12.3
Boston	7421813	15.1
Washington, D.C.	6824060	22.6
Honolulu	7318844	42.2
Houston	7409894	45.4
Kansas City	7422128	27.6
Los Angeles	7417394	38.5
Salt Lake City	7422008	45.4
Miami	7418563	49.3
Minneapolis	7420515	13.2
Oakland	7403677	25.0
Cleveland	7419383	19.7
Seattle	7432494	31.9
San Juan	6923032	46.3
Atlanta	7145819	36.3

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 October through 31 December 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	4.704	8.755	13.127	23.850
Elko	4.816	8.945	31.151	33.581
Billings	4.328	8.357	29.242	35.638
Cold Bay	4.026	9.737	13.082	27.347
Juneau	3.872	8.576	16.224	30.520
Albuquerque	4.469	9.347	40.119	57.258
Anchorage	3.783	9.587	8.106	31.533
Boston	4.307	8.119	15.499	23.803
Washington, D.C.	4.265	8.618	20.217	29.129
Honolulu	12.004	16.531	21.923	41.347
Houston	4.574	9.947	36.448	58.768
Kansas City	4.311	8.579	30.001	31.180
Los Angeles	4.557	9.625	35.506	28.884
Salt Lake City	4.403	8.819	38.892	36.346
Miami	4.661	10.286	26.969	34.086
Minneapolis	4.318	8.312	20.322	35.979
Oakland	4.610	9.400	36.356	24.636
Cleveland	4.392	8.233	16.341	38.577
Seattle	4.303	8.698	31.285	48.431
San Juan	6.560	13.104	21.489	38.210
Atlanta	4.492	9.182	26.494	29.440

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 October to 31 December 2003.

Figure 5-1 Combined Vertical Error Histogram

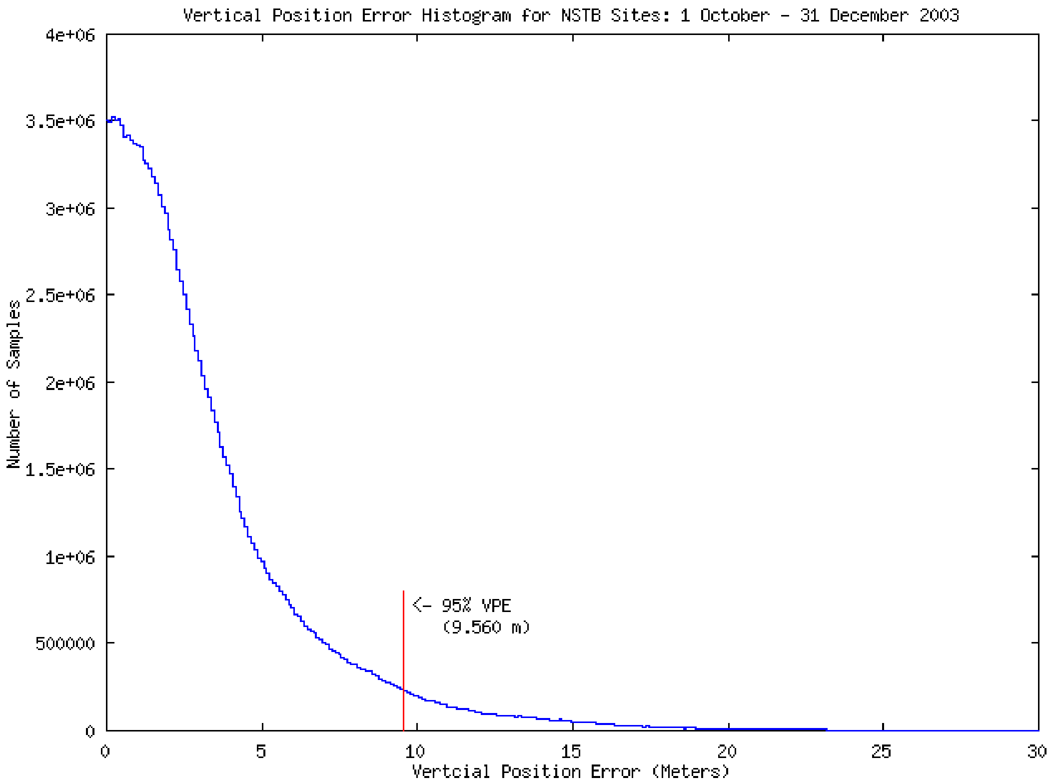
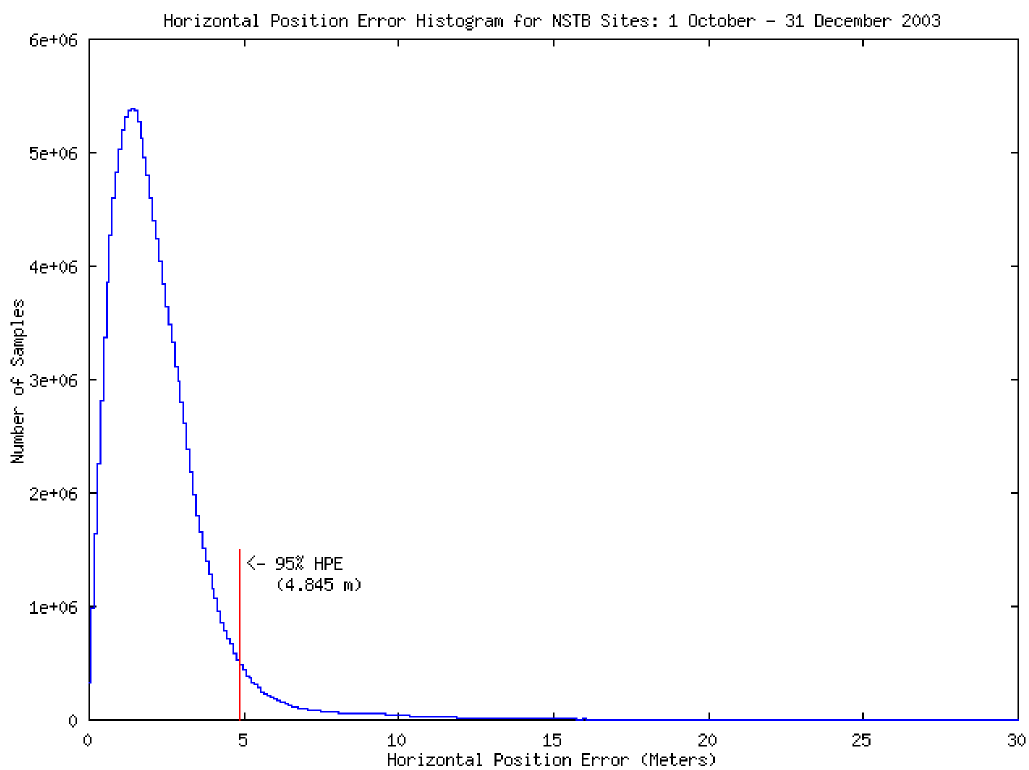


Figure 5-2 Combined Horizontal Error Histogram



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	1.047	3.423
Elko	1.493	4.028
Billings	1.423	3.329
Cold Bay	1.402	3.663
Juneau	1.039	2.947
Albuquerque	1.398	3.754
Anchorage	0.997	3.204
Boston	1.068	3.204
Washington, D.C.	1.043	3.039
Honolulu	2.391	6.878
Houston	1.132	3.164
Kansas City	1.394	3.182
Los Angeles	1.262	2.939
Salt Lake City	1.320	3.829
Miami	1.056	3.553
Minneapolis	1.234	2.772
Oakland	1.244	2.856
Cleveland	1.360	3.574
Seattle	1.555	3.641
San Juan	1.338	5.178
Atlanta	1.163	3.676

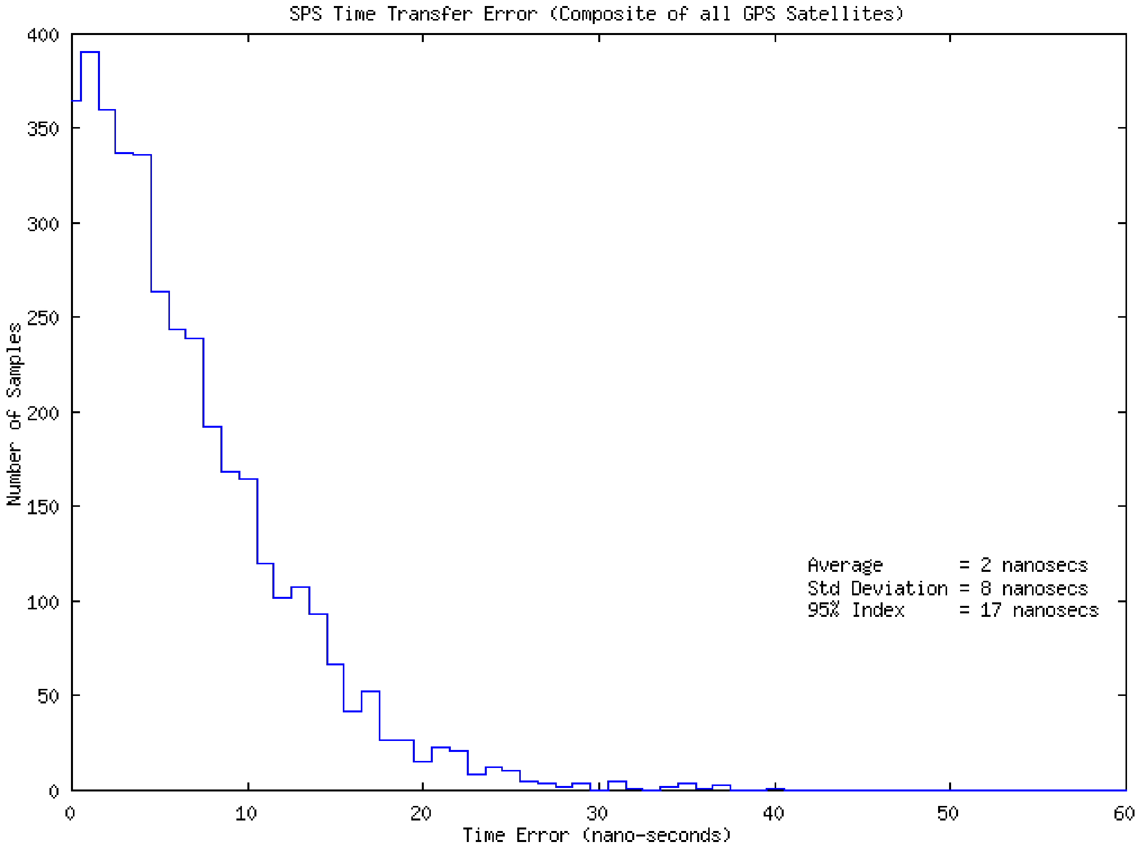
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 October and 31 December 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 October and 31 December 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	0.275	4.168	4.159	8.684	40.512	1874648
2	0.812	4.010	3.927	8.254	29.602	1995708
3	0.607	3.066	3.006	6.475	24.065	2325941
4	0.458	3.499	3.468	7.204	37.198	2017740
5	2.197	3.714	2.994	7.937	19.308	1800040
6	2.221	3.241	2.360	6.242	10.097	1749016
7	1.434	4.462	4.225	9.857	42.680	1922088
8	-0.053	4.939	4.939	9.877	35.151	1820023
9	0.948	3.161	3.015	7.031	26.267	2254368
10	0.814	3.104	2.995	5.796	30.710	2183501
11	0.224	3.141	3.133	5.399	41.167	2335783
13	-0.347	4.207	4.193	8.183	42.192	1731915
14	1.156	2.096	1.748	4.039	11.200	1862382
15	0.792	2.302	2.161	4.550	7.895	1769174
16	0.506	2.926	2.882	6.196	18.309	2241896
17	1.883	3.146	2.521	6.379	18.471	1926378
18	1.212	1.918	1.486	3.608	6.157	1925133
20	0.545	2.872	2.820	5.676	22.468	2083219
21	1.450	2.415	1.932	4.613	8.125	1926694
23	1.464	2.845	2.439	5.523	11.429	1624492
24	1.970	3.637	3.058	7.628	37.212	1800342
25	1.295	2.794	2.475	5.796	13.611	1741362
26	-0.093	2.757	2.755	5.279	30.086	2317705
27	-0.446	4.643	4.621	8.961	34.396	1964475
28	0.141	4.667	4.665	9.275	36.228	1992466
29	0.283	3.259	3.246	5.768	41.987	2385530
30	1.215	2.570	2.265	5.521	19.418	2240769
31	0.374	4.141	4.124	7.438	39.189	2181754

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	0.00017	0.00731	0.00731	0.00557	1.06811	1874648
2	-0.00016	0.00874	0.00873	0.00708	1.05305	1995708
3	-0.00023	0.00639	0.00638	0.00550	0.72292	2325941
4	-0.00023	0.00704	0.00703	0.00663	0.70838	2017740
5	-0.00007	0.00432	0.00432	0.00569	0.39125	1800040
6	-0.00008	0.00409	0.00409	0.00525	0.28571	1749016
7	-0.00025	0.00685	0.00685	0.00585	0.70345	1922088
8	0.00017	0.00832	0.00832	0.00631	0.92633	1820023
9	0.00009	0.00487	0.00487	0.00535	0.56790	2254368
10	0.00001	0.00734	0.00734	0.00570	0.97584	2183501
11	-0.00016	0.00718	0.00718	0.00558	0.76564	2335783
13	0.00014	0.00655	0.00655	0.00587	0.60062	1731915
14	0.00005	0.00260	0.00259	0.00457	0.28169	1862382
15	0.00001	0.00284	0.00284	0.00467	0.20536	1769174
16	-0.00014	0.00420	0.00420	0.00518	0.53146	2241896
17	-0.00011	0.00298	0.00298	0.00504	0.35692	1926378
18	-0.00008	0.00233	0.00233	0.00458	0.03926	1925133
20	0.00008	0.00625	0.00625	0.00555	0.86180	2083219
21	-0.00011	0.00256	0.00256	0.00478	0.15336	1926694
23	0.00002	0.00322	0.00322	0.00463	0.19273	1624492
24	-0.00020	0.00407	0.00407	0.00547	0.33278	1800342
25	-0.00002	0.00373	0.00373	0.00502	0.37004	1741362
26	0.00019	0.00749	0.00748	0.00538	0.75188	2317705
27	0.00004	0.00706	0.00706	0.00596	0.61273	1964475
28	-0.00010	0.00844	0.00844	0.00631	0.86656	1992466
29	0.00015	0.00739	0.00738	0.00552	1.16303	2385530
30	0.00004	0.00373	0.00373	0.00513	0.71662	2240769
31	-0.00026	0.00790	0.00790	0.00577	0.95267	2181754

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1s	% ≤ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. ≤ 0.019 m/s2)	Samples
1	0	0.00007	0.00007	99.99	0.01073	1874648
2	0	0.00008	0.00008	99.99	0.01056	1995708
3	0	0.00006	0.00006	100	0.00725	2325941
4	0	0.00006	0.00006	100	0.00706	2017740
5	0	0.00004	0.00004	100	0.00392	1800040
6	0	0.00004	0.00004	100	0.00285	1749016
7	0	0.00006	0.00006	100	0.00702	1922088
8	0	0.00007	0.00007	99.99	0.00926	1820023
9	0	0.00004	0.00004	100	0.00567	2254368
10	0	0.00007	0.00007	99.99	0.00978	2183501
11	0	0.00006	0.00006	100	0.00775	2335783
13	0	0.00006	0.00006	100	0.00602	1731915
14	0	0.00002	0.00002	100	0.00282	1862382
15	0	0.00002	0.00002	100	0.00202	1769174
16	0	0.00004	0.00004	100	0.00532	2241896
17	0	0.00002	0.00002	100	0.00355	1926378
18	0	0.00002	0.00002	100	0.00038	1925133
20	0	0.00006	0.00006	99.99	0.00863	2083219
21	0	0.00002	0.00002	100	0.00154	1926694
23	0	0.00003	0.00003	100	0.00191	1624492
24	0	0.00003	0.00003	100	0.00335	1800342
25	0	0.00003	0.00003	100	0.00370	1741362
26	0	0.00007	0.00007	100	0.00763	2317705
27	0	0.00006	0.00006	100	0.00615	1964475
28	0	0.00007	0.00007	99.99	0.00866	1992466
29	0	0.00007	0.00007	99.99	0.01162	2385530
30	0	0.00003	0.00003	100	0.00716	2240769
31	0	0.00007	0.00007	99.99	0.00956	2181754

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the maximum range error, range rate error and range acceleration error for all satellites. None of the range errors for any of the satellites exceeded the 150-meter SPS requirement. The highest maximum range error occurred on satellite 7 with an error of 42.680 meters. Satellite 18 had the lowest maximum range error of 6.157 meters.

Figure 5-4 Distribution of Daily Max Range Errors

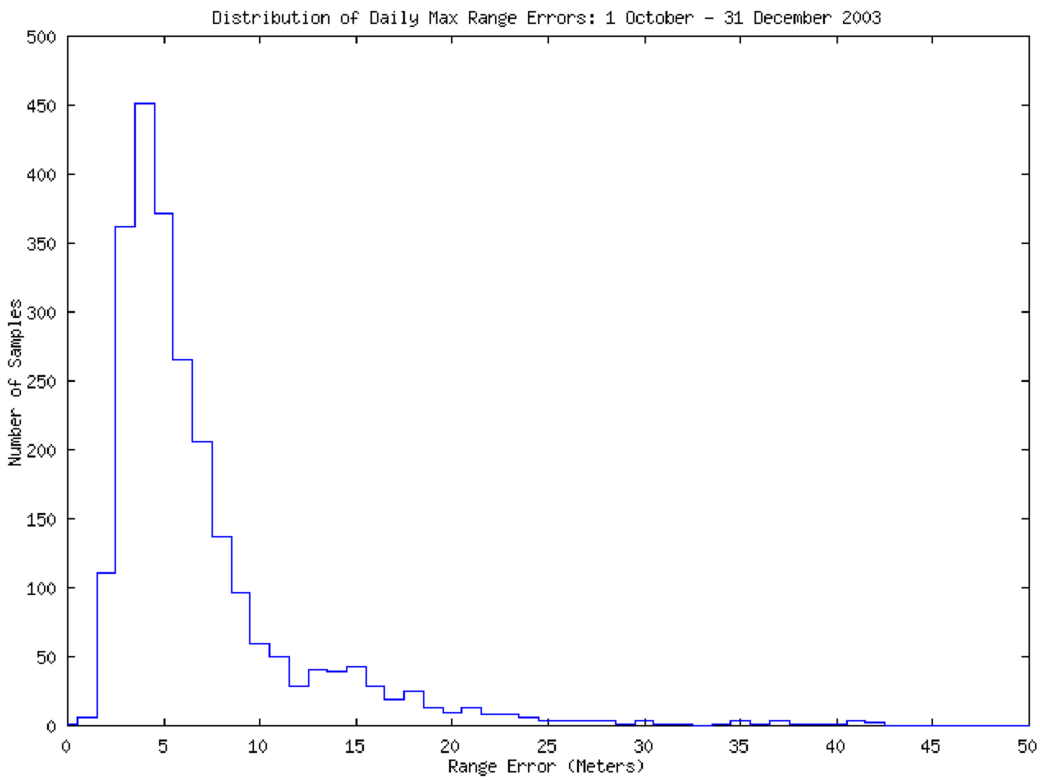


Figure 5-5: Distribution of Daily Max Range Rate Errors

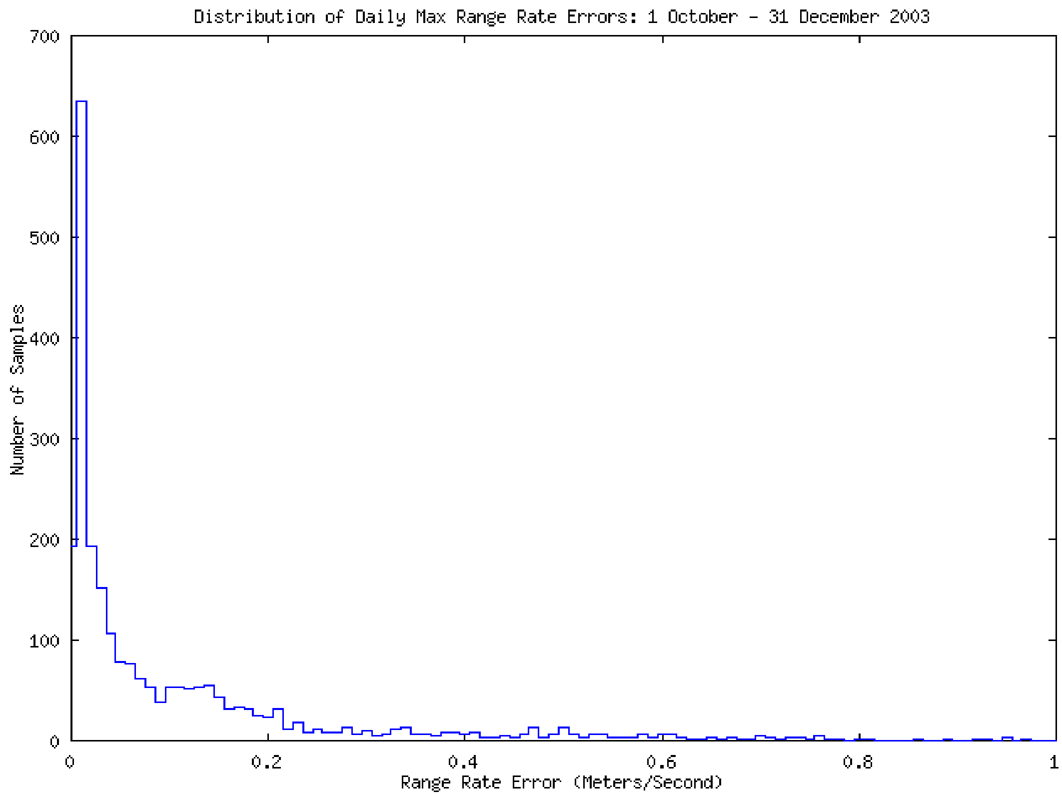


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

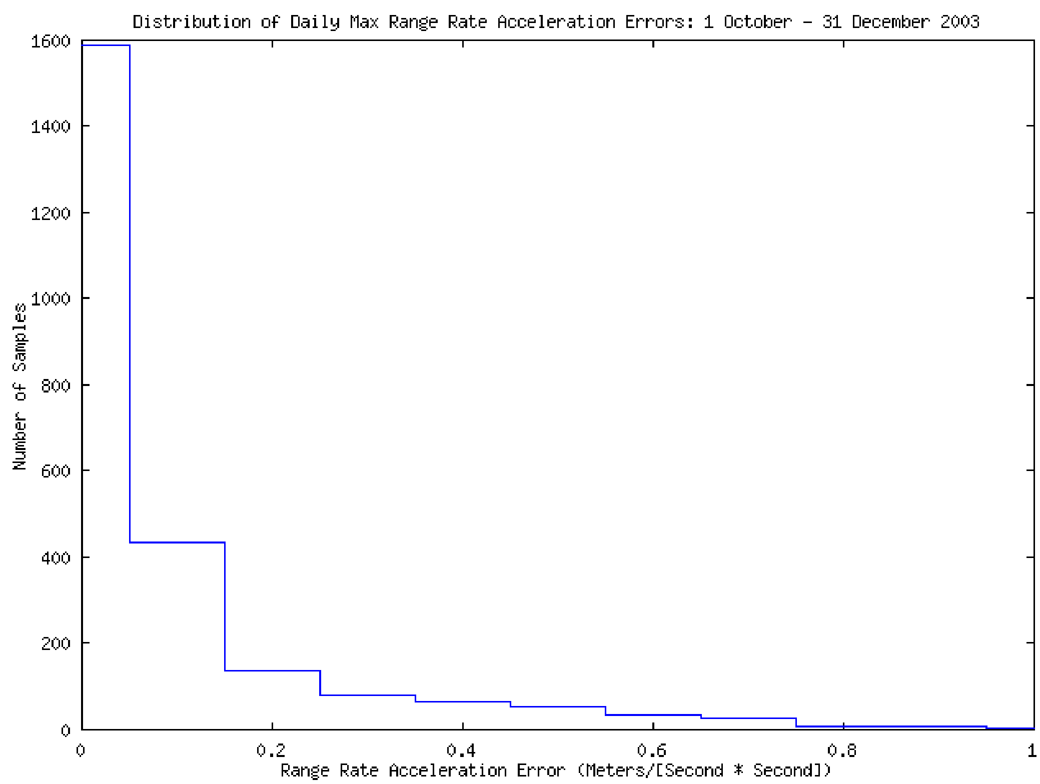


Figure 5-7: Range Error Histogram

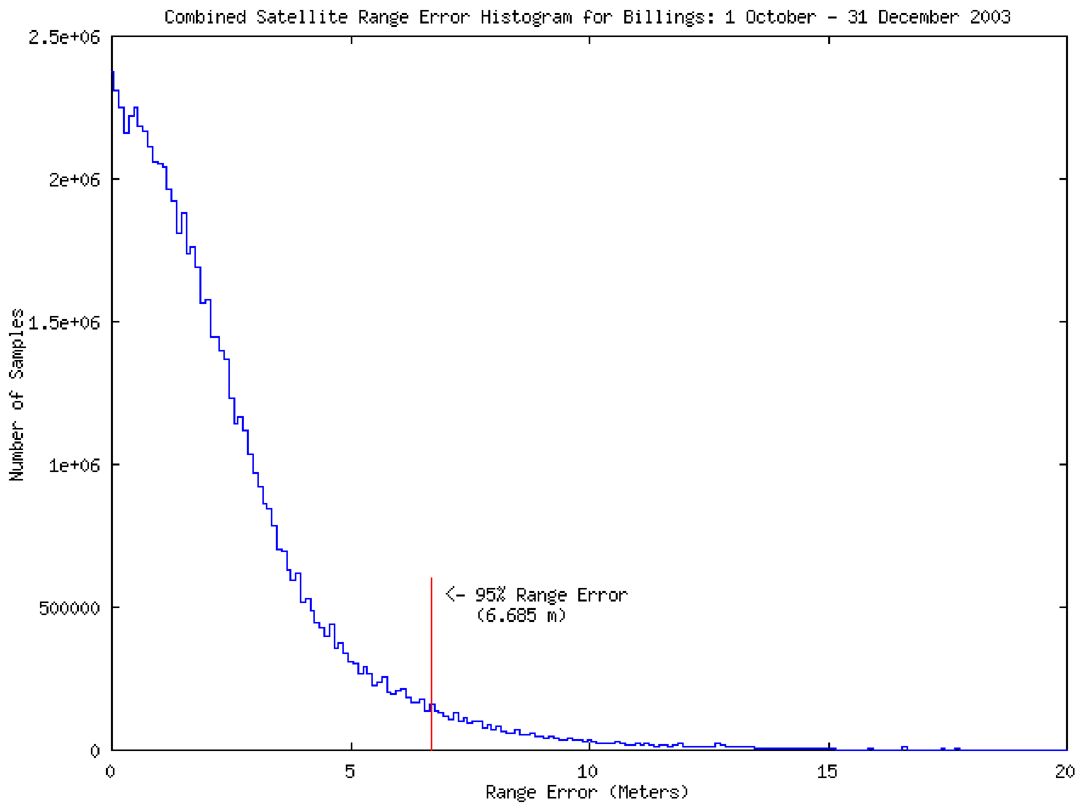
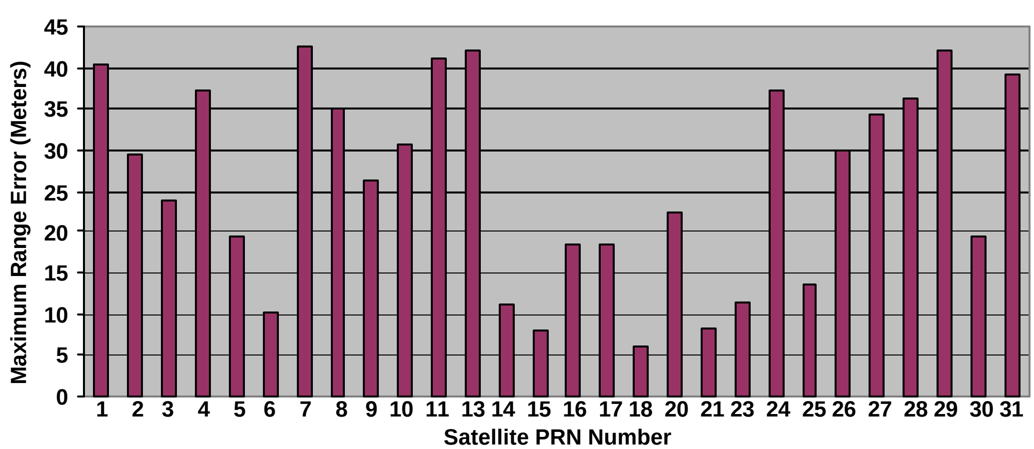
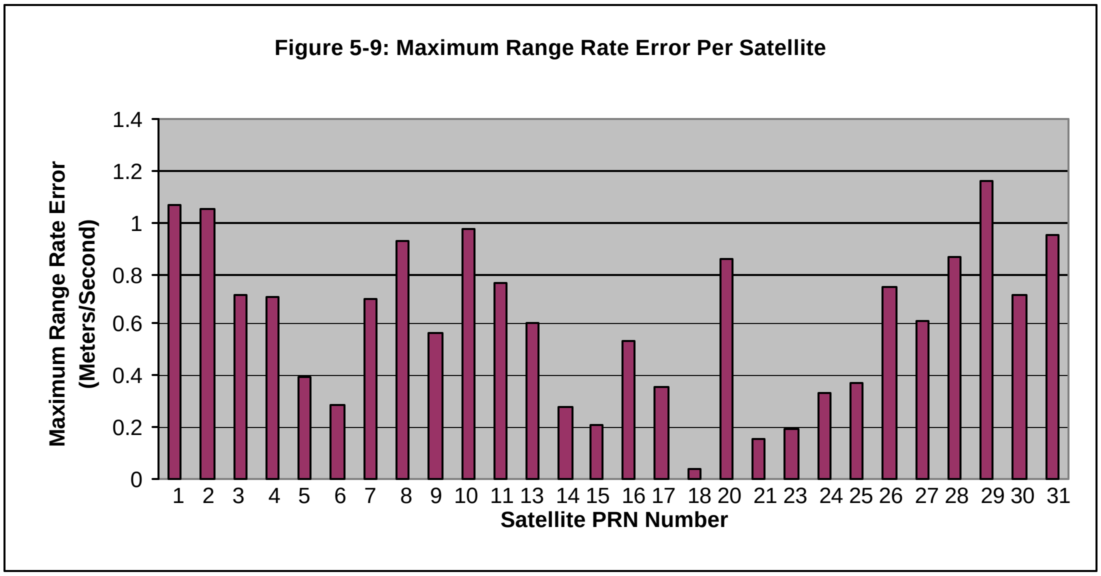
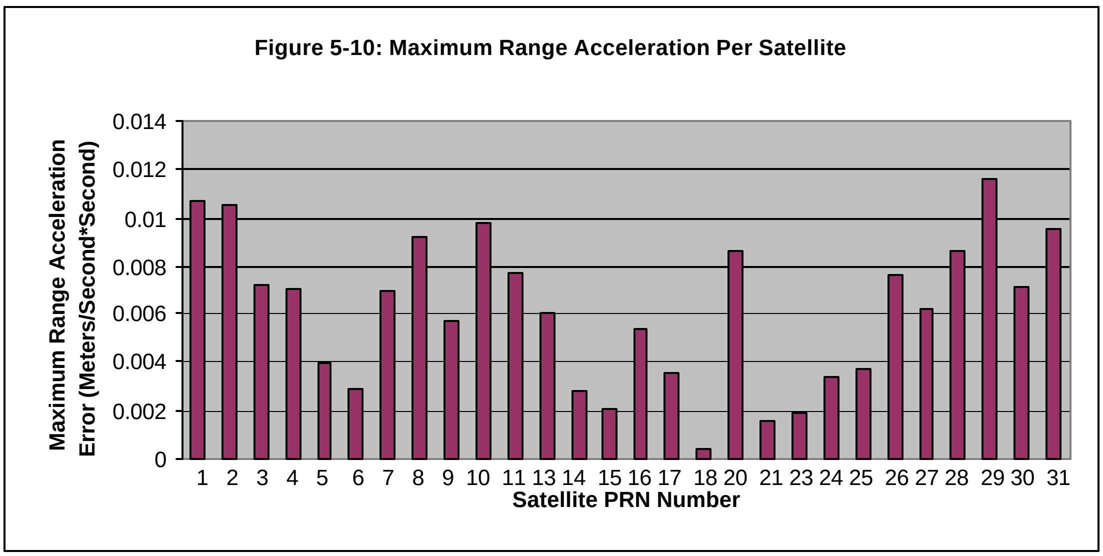


Figure 5-8: Maximum Range Error Per Satellite







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

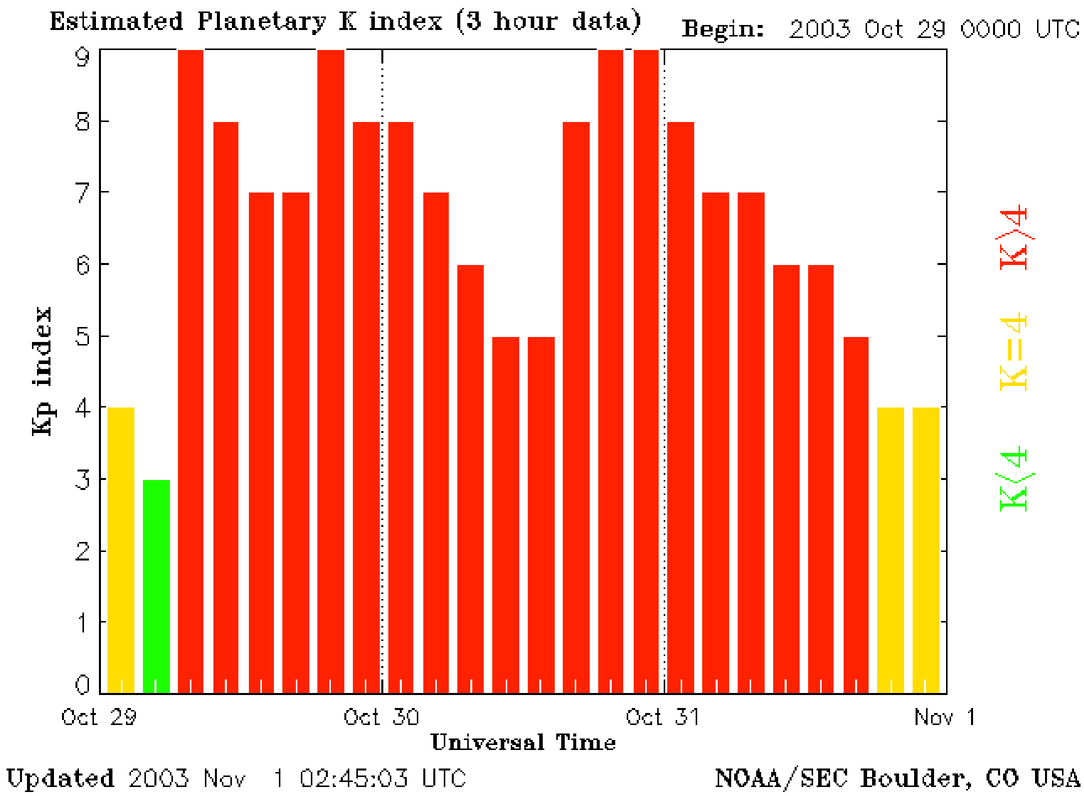


Figure 6-2 K-Index for 16-18 June 2003

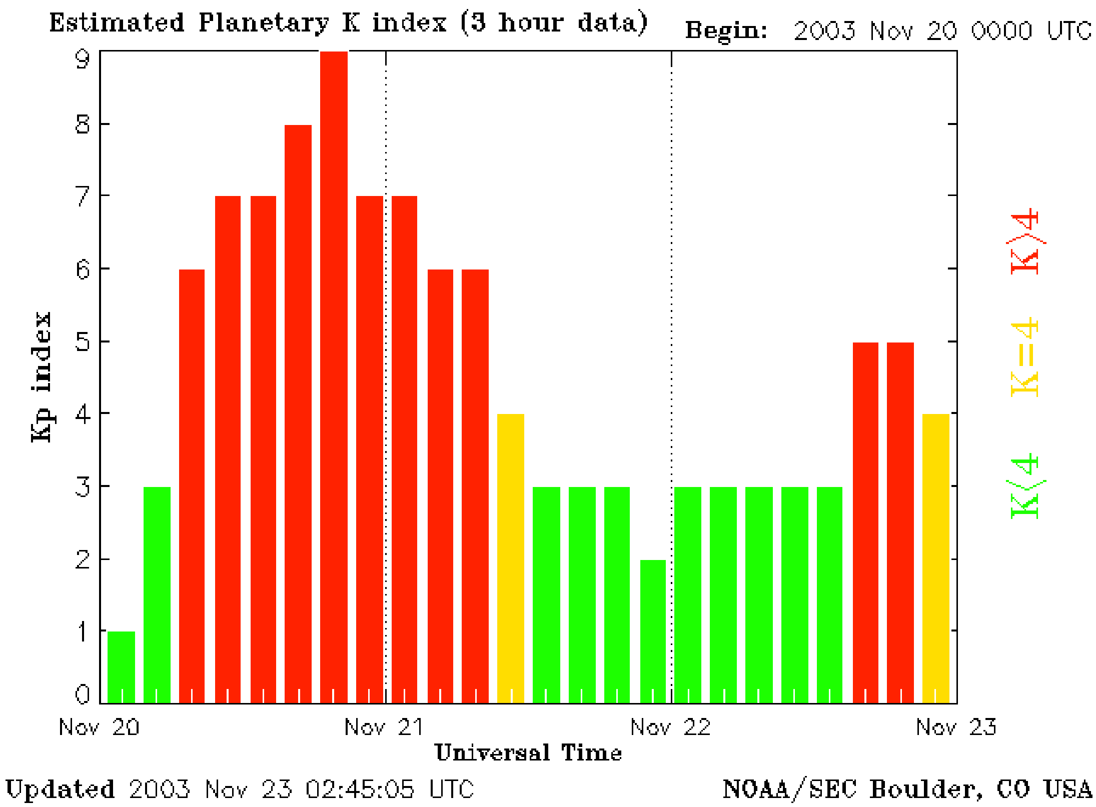
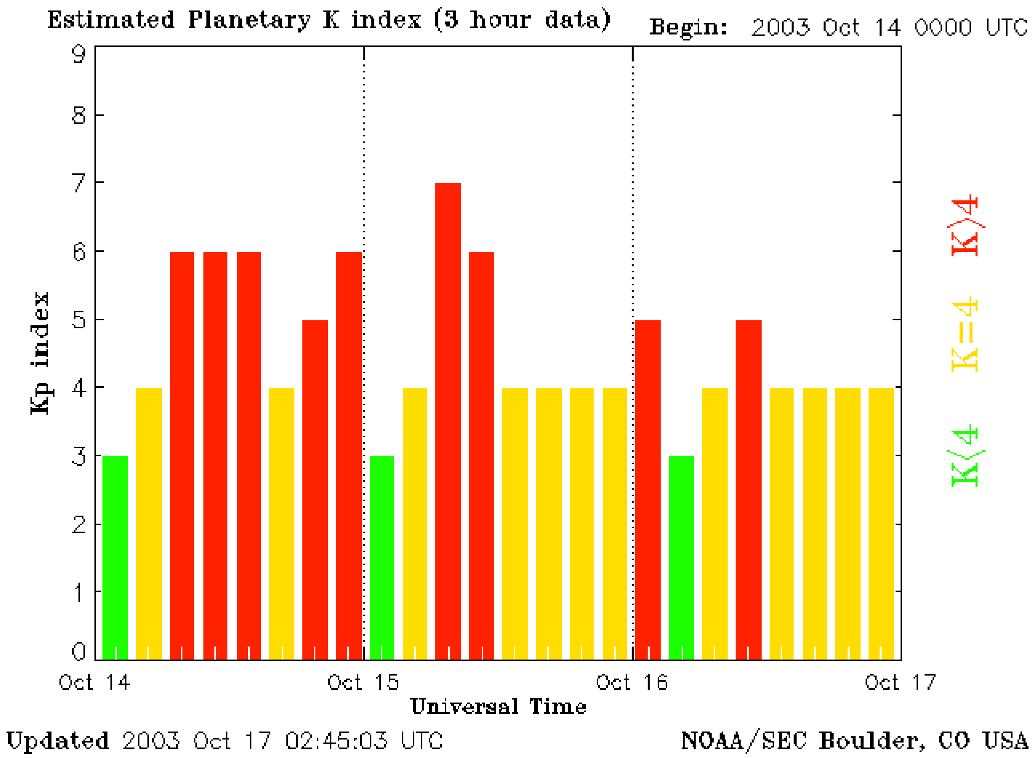


Figure 6-3 K-Index for 29 April - 1 May 2003



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 30 October 2003

Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Bangor	1.258	5.873	1.855	5.613	4.900
Elko	1.300	4.934	1.896	4.932	4.665
Billings	1.229	2.946	1.752	2.946	2.560
Cold Bay	1.105	3.813	1.710	3.811	3.443
Juneau	1.228	5.480	1.758	5.459	5.067
Albuquerque	1.270	3.684	1.748	3.677	3.171
Anchorage	1.192	5.743	1.752	5.713	5.293
Boston	1.238	3.370	1.686	2.851	2.344
Washington, D.C.	1.250	3.506	1.700	3.506	3.011
Honolulu	1.215	3.298	1.671	3.297	3.059
Houston	1.170	2.748	1.721	2.748	2.408
Kansas City	1.157	3.029	1.744	3.029	2.492
Los Angeles	1.203	3.368	1.761	3.368	3.095
Salt Lake City	1.232	4.304	1.754	4.298	4.036
Miami	1.167	3.974	1.776	3.963	3.442
Minneapolis	1.140	2.876	1.740	2.876	2.484
Oakland	1.167	4.513	1.740	4.469	4.099
Cleveland	1.152	3.471	1.738	3.469	2.983
Seattle	1.157	3.250	1.734	2.889	2.401
San Juan	1.275	5.746	1.759	5.667	4.348

Atlanta	1.239	3.462	1.747	3.462	3.033

Table 6-2 Horizontal & Vertical Accuracy Statistics for 30 October 2003

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Bangor	6.456	17.788	10.329	24.456
Elko	26.929	23.023	40.283	39.916
Billings	20.907	22.815	30.085	38.691
Cold Bay	10.285	22.340	16.554	31.457
Juneau	9.526	23.055	22.446	48.665
Albuquerque	33.561	20.828	44.292	42.362
Anchorage	5.221	24.827	11.550	42.651
Boston	6.690	17.204	8.328	20.802
Washington, D.C.	7.051	15.828	9.198	18.427
Honolulu	14.072	18.444	19.335	39.467
Houston	28.480	27.573	34.905	40.355
Kansas City	17.800	13.529	25.679	21.381
Los Angeles	28.819	21.994	35.684	38.323
Salt Lake City	35.199	19.489	39.788	29.566
Miami	18.896	18.633	24.110	26.764
Minneapolis	11.214	13.003	15.283	16.045
Oakland	30.306	14.116	39.462	26.148
Cleveland	7.319	14.326	10.063	17.715
Seattle	22.096	23.815	34.449	46.196
San Juan	16.981	21.648	24.553	46.550
Atlanta	14.543	13.964	20.263	17.565

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	99.982%
• 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	98.819% Availability 99.9% PDOP was 3.827
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	<u>Predictable Accuracy</u> ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	≤12.004m HE 95% ≤40.119m HE 99.99% ≤16.531m VE 95% ≤57.258m VE 99.99%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	<u>Repeatable Accuracy</u> ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	≤2.391m HE 95% ≤6.878m VE 95%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	<u>Relative Accuracy</u> ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	Future Reports
• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	<u>Time Transfer Accuracy</u> ≤ 340 nanoseconds time transfer error 95% of time	≤17 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each	<u>Range Domain Accuracy</u> ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range	42.680m NTE Range Error 1.16303m/s NTE Rate Error 11.62mm/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 99.999% of the time

Appendix B Geomagnetic Data

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

                  Middle Latitude        High Latitude           Estimated
                - Fredericksburg -     ---- College ----      --- Planetary ---
   Date         A     K-indices        A     K-indices        A     K-indices
2003 10 01      7  3 2 2 1 1 1 1 3    11  1 1 4 4 2 1 1 3    10  3 2 2 3 2 2 3 3
2003 10 02      4  2 1 1 0 1 1 2 2     6  2 2 1 1 2 1 2 2     9  2 3 2 2 2 3 3 3
2003 10 03     11  2 4 2 2 3 2 2 2    14  3 4 3 2 3 3 3 1    16  3 5 3 3 3 3 3 2
2003 10 04      5  1 1 3 2 2 1 0 0     8  1 1 3 3 4 0 0 0     9  1 2 4 2 3 2 2 2
2003 10 05      4  0 1 0 0 0 1 2 3     2  0 0 0 0 0 1 2 2     9  2 2 1 2 2 3 3 4
2003 10 06      7  1 1 1 1 2 2 3 3     7  1 1 0 1 2 2 3 3    10  2 2 2 2 3 3 3 3
2003 10 07     11  4 2 2 3 2 2 2 2    18  4 2 3 5 4 2 2 1    13  4 2 2 3 3 3 3 3
2003 10 08      6  1 1 2 1 2 1 2 3     7  2 1 2 3 1 1 2 2     9  2 2 2 2 3 3 3 3
2003 10 09      4  3 1 1 1 1 1 1 0     4  3 2 1 1 1 0 1 0     8  4 2 2 2 2 2 2 2
2003 10 10      4  0 0 0 0 1 2 3 1     0  0 0 0 0 0 0 0 1     5  2 1 1 2 2 2 1 2
2003 10 11      2  1 0 1 1 1 1 0 1     0  0 0 0 0 0 0 0 0     5  2 1 2 1 2 2 1 2
2003 10 12      3  0 0 0 1 2 2 1 2     2  0 0 1 1 1 1 0 0     6  1 2 1 3 2 2 2 2
2003 10 13     12  3 2 1 2 3 3 2 4    21  0 1 1 5 5 5 2 2    13  3 2 2 2 3 3 3 4
2003 10 14     33  2 4 5 3 3 4 5 6    65  3 4 6 7 5 6 6 5    48  3 4 6 6 6 4 5 6
2003 10 15     22  3 3 4 4 3 3 3 5    71  4 4 7 7 6 6 5 4    42  3 4 7 6 4 4 4 4
2003 10 16     16  4 3 3 3 2 3 2 4    36  4 2 5 6 5 5 3 3    26  5 3 4 5 4 4 4 4
2003 10 17     20  4 5 4 3 3 2 2 3    54  4 6 7 6 5 4 3 3    31  4 5 5 5 4 3 3 3
2003 10 18     15  4 4 3 2 3 2 2 3    30  3 4 5 5 5 4 3 3    27  4 5 4 4 4 3 4 4
2003 10 19     22  3 3 5 3 3 3 4 4    62  3 4 7 6 6 6 5 4    32  3 4 5 5 5 4 4 4
2003 10 20     20  3 2 3 3 4 3 3 5    51  3 3 6 6 6 6 4 4    30  3 4 5 5 4 4 4 5
2003 10 21     28  4 3 4 5 4 3 3 5    69  5 4 5 6 7 7 4 5    39  5 5 5 5 5 4 4 5
2003 10 22     20  5 4 4 2 3 3 3 1    50  4 4 7 6 4 6 3 1    33  4 5 6 5 4 4 3 2
2003 10 23      5  3 2 1 1 2 1 1 0    -1 -1-1-1-1-1-1-1-1     7  3 2 2 2 2 2 2 2
2003 10 24     28  0 1 3 2 3 6 4 6    70  0 0 2 6 7 8 5 5    34  2 2 2 4 5 7 4 5
2003 10 25     10  3 2 2 1 4 3 2 1    22  3 2 2 3 6 5 1 2    14  3 3 2 2 4 4 3 3
2003 10 26      5  1 2 1 2 1 1 2 2     5  1 1 1 1 0 1 2 3    10  2 2 2 3 2 3 3 3
2003 10 27     13  3 5 3 2 2 2 1 0    24  4 4 5 5 2 3 2 3    15  3 3 4 3 2 3 3 1
2003 10 28     15  2 4 3 3 2 3 3 3    28  2 3 5 5 3 5 4 3    20  3 4 4 4 3 4 3 4
2003 10 29    199  3 3 9 6 7 7 9 9   197  5 4 9 8 7 8 9 6   189  4 3 9 8 7 7 9 8
2003 10 30    144  7 5 4 4 4 6 9 9   124  6 5 4 6 7 8 7 8   162  8 7 6 5 5 8 9 9
2003 10 31     73  8 7 6 4 5 3 3 3    69  6 6 6 6 6 5 6 4    93  8 7 7 6 6 5 4 4
2003 11 01     16  5 4 3 1 2 2 1 3    32  4 4 5 5 5 4 3 3    21  4 5 4 3 3 3 3 3
2003 11 02     11  3 3 2 2 2 3 3 2    27  4 3 3 4 5 5 4 2    18  3 4 3 3 3 4 4 3
2003 11 03     15  4 2 1 1 5 2 2 3    12  3 3 1 3 2 3 2 3    10  3 3 2 3 2 3 2 3
2003 11 04     20  2 2 5 5 2 2 4 2    34  3 3 5 7 3 2 4 2    31  3 2 5 7 3 3 4 3
2003 11 05      4  1 0 1 2 1 1 2 2     6  2 1 2 1 1 1 2 3     9  2 1 2 2 2 3 3 3
2003 11 06     11  2 2 1 0 2 1 5 3    11  1 2 1 0 3 3 4 3    14  2 2 2 2 3 3 5 4
```

2003 11 07	6	3 2 1 2 1 1 3 1	11	3 3 3 4 2 1 1 1	8	3 2 1 2 3 3 2 2
2003 11 08	7	0 0 0 3 3 2 2 3	17	0 0 1 4 5 5 2 1	10	1 1 1 3 3 3 3 3
2003 11 09	20	5 2 3 3 4 3 3 3	42	1 1 5 5 7 4 5 3	25	2 3 4 4 6 4 4 3
2003 11 10	15	3 3 3 3 3 3 3 3	52	3 4 4 6 6 6 6 4	30	4 4 4 5 5 4 4 4
2003 11 11	39	5 4 5 4 4 4 4 6	104	4 6 7 7 7 7 7 4	51	5 6 5 6 5 5 5 4
2003 11 12	20	4 3 3 3 3 5 3 2	54	3 3 6 7 5 6 5 2	26	4 4 4 5 4 4 4 3
2003 11 13	28	3 4 4 4 5 4 4 4	108	3 4 6 8 8 7 6 5	42	3 5 4 5 6 5 5 4
2003 11 14	21	5 4 3 3 3 3 3 3	75	4 5 7 7 7 4 5 4	37	5 5 5 5 5 3 4 3
2003 11 15	21	2 4 5 3 3 4 3 3	66	3 3 7 7 6 6 4 4	40	3 4 6 5 5 5 4 4
2003 11 16	32	3 4 4 3 5 5 4 5	63	4 4 6 6 6 6 6 5	35	4 5 5 5 4 5 4 4
2003 11 17	21	4 3 3 3 4 4 3 4	60	4 5 4 7 6 6 5 4	34	5 4 4 5 5 5 4 4
2003 11 18	18	5 3 3 2 3 3 3 3	36	4 4 4 6 5 4 5 2	20	4 4 4 4 4 4 3 2
2003 11 19	12	2 2 3 2 2 2 4 3	20	3 2 4 5 4 3 3 1	14	2 3 4 4 3 3 3 2
2003 11 20	67	1 3 5 6 5 7 7 6	161	0 3 9 7 9 8 7 7	117	1 3 6 7 7 8 9 7
2003 11 21	18	4 4 5 3 2 2 2 1	38	4 6 6 4 4 4 4 2	39	7 6 6 4 3 3 3 2
2003 11 22	14	3 2 1 2 3 2 4 4	44	4 3 3 3 5 7 6 3	22	3 3 3 3 3 5 5 4
2003 11 23	13	2 4 3 2 3 2 3 3	37	4 6 4 5 5 4 4 3	21	3 5 4 3 3 3 4 4
2003 11 24	7	2 1 2 2 3 2 1 2	24	3 2 2 2 6 5 3 3	12	2 2 3 2 4 3 3 3
2003 11 25	9	3 2 3 2 3 2 1 1	29	3 3 3 5 6 5 2 1	13	3 3 3 3 3 3 3 2
2003 11 26	4	1 1 1 1 2 2 1 1	9	2 2 2 1 4 2 1 2	9	2 2 2 2 3 3 3 2
2003 11 27	3	1 2 0 1 1 1 1 0	5	2 1 1 3 2 0 1 1	10	2 2 2 2 3 3 3 3
2003 11 28	5	3 1 0 2 2 2 1 0	9	0 0 0 3 5 2 1 0	10	2 2 2 3 3 3 2 2
2003 11 29	4	2 1 1 1 1 2 1 1	7	0 1 2 3 4 0 0 1	9	2 2 2 3 3 3 2 2
2003 11 30	7	2 2 1 1 2 2 3 2	14	1 2 0 2 4 4 4 3	10	2 2 2 2 3 3 3 2
2003 12 01	9	2 2 2 2 2 1 4 2	11	3 2 4 3 2 2 2 1	10	2 3 3 3 3 3 2 2
2003 12 02	6	2 1 2 2 1 1 3 0	3	2 1 2 2 0 0 0 1	9	3 2 3 2 3 2 3 1
2003 12 03	4	0 0 1 0 1 2 3 1	1	0 0 1 1 0 1 0 0	7	1 2 2 2 2 3 2 2
2003 12 04	3	1 0 0 1 1 1 1 2	4	0 0 1 3 0 1 1 2	9	2 1 2 3 3 3 3 3
2003 12 05	21	1 4 5 3 4 3 3 3	68	3 5 7 6 7 6 4 3	43	2 5 6 5 5 5 4 4
2003 12 06	14	5 3 3 2 2 2 2 2	34	3 3 5 6 5 4 4 3	22	4 4 4 4 3 4 4 3
2003 12 07	7	1 2 3 1 2 2 2 2	41	2 1 3 5 6 6 6 3	15	2 2 3 3 3 4 4 3
2003 12 08	20	2 5 3 4 3 2 3 4	59	3 3 7 6 6 6 5 3	39	2 5 5 6 6 5 4 4
2003 12 09	17	3 3 3 3 3 3 3 4	78	3 3 7 7 7 6 5 5	31	3 4 5 5 5 5 4 4
2003 12 10	24	5 2 3 4 4 4 3 4	91	4 3 7 7 7 7 6 5	42	5 4 5 6 5 5 5 4
2003 12 11	27	5 4 4 4 4 3 2 4	81	5 4 6 7 7 7 5 4	40	5 5 6 5 4 5 3 4
2003 12 12	17	3 3 3 2 3 2 3 5	42	3 3 5 6 6 5 4 4	23	4 4 4 3 4 3 4 5
2003 12 13	20	5 4 2 3 3 3 3 3	59	4 3 6 7 6 6 4 4	28	5 4 4 4 5 5 4 3
2003 12 14	16	4 3 2 2 3 3 3 4	43	3 2 3 5 6 6 6 3	24	4 3 3 4 4 5 4 4
2003 12 15	18	4 3 4 3 4 3 2 2	43	4 4 6 6 5 5 3 3	25	4 4 4 5 4 4 3 3
2003 12 16	9	3 2 2 2 2 2 3 2	15	2 2 3 5 3 3 2 2	11	3 3 3 3 3 3 3 2
2003 12 17	4	1 2 2 1 2 1 0 0	8	2 3 3 2 2 3 0 0	10	2 3 3 3 3 3 3 1
2003 12 18	2	0 2 0 1 1 1 0 0	1	0 1 1 1 0 1 0 0	8	1 3 2 3 3 3 2 1
2003 12 19	1	0 0 1 0 1 0 0 0	0	0 0 0 1 0 0 0 0	7	2 1 1 2 3 3 2 2
2003 12 20	9	0 1 1 3 3 2 3 3	17	0 0 2 4 4 5 3 3	16	1 2 2 4 3 4 4 4
2003 12 21	18	4 3 3 4 3 3 3 3	34	3 3 4 5 5 6 4 3	21	4 3 4 4 3 4 4 3
2003 12 22	18	4 3 3 3 3 4 3 3	34	2 2 5 6 5 5 3 3	15	3 3 3 4 3 3 3 2
2003 12 23	6	1 1 1 2 2 3 2 1	14	2 1 2 4 4 4 2 2	9	2 2 1 3 3 3 3 2
2003 12 24	6	1 1 1 1 1 3 2 2	5	1 0 1 0 2 3 2 1	8	1 2 2 2 3 3 3 2
2003 12 25	8	2 1 1 2 3 3 2 2	6	1 0 0 3 3 3 0 1	6	2 1 1 2 2 3 2 2
2003 12 26	11	2 2 2 3 2 3 3 3	6	1 2 0 3 3 1 1 1	9	2 2 2 3 3 3 2 3
2003 12 27	12	2 3 2 3 2 3 3 3	8	1 2 0 3 2 3 1 3	12	3 3 2 3 3 3 3 4
2003 12 28	13	3 3 2 3 2 3 3 3	14	2 3 2 4 3 3 3 2	12	3 3 2 3 3 3 3 2
2003 12 29	4	1 0 1 2 2 3 0 0	7	1 0 1 2 2 4 2 0	6	1 1 2 3 2 2 2 1
2003 12 30	3	0 1 1 0 1 1 2 2	6	0 0 3 1 1 1 3 2	8	2 1 3 2 2 3 3 2
2003 12 31	9	2 1 1 2 2 3 3 3	32	3 1 2 5 5 6 4 4	17	3 2 2 3 4 5 4 3

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.

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.