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 #46, includes data collected from 1 April through 30 June 2004. The next quarterly report will be issued 31 October 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 April and 30 June 2004 and by calculating the satellite availability from the data obtained from the twenty-one sites. A total of sixteen outages were reported in the NANU's. None of the outages was unscheduled. The quarterly availabilities for all sites were 100%. Each of these availabilities is within the SPS value of 99.85%. These availability percentages were calculated using DOP data collected at one-second intervals.

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

Position accuracies were verified by calculating the 95% and 99.99% values of horizontal and vertical errors. Range performance was verified for each satellite using the data collected from the NSTB Atlantic City site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 25.262 meters on Satellite PRN 15. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 0.91389 Meters/second on Satellite PRN 4. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 9.15 Millimeters/second^2 on Satellite PRN 4. 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 April and 30 June 2004, the GPS performance met all SPS requirements that were evaluated.

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1.0 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS and WAAS for IFR operations and is developing Local Area Augmentation (LAAS), which is an additional GPS augmentation system. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Analysis report. This report contains data collected at the following twenty-one National Satellite Test Bed (NSTB) and WAAS reference station locations:

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

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

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

- Coverage Performance
- Satellite Availability Performance
- Service Reliability Standard
- Positioning, Ranging and Timing Accuracy Standard.

The results were then compared to the performance parameters stated in the SPS.

1.2 Summary of Performance Requirements and Metrics

Table 1-1 lists the performance parameters from the SPS and identifies those parameters verified in this report.

Appendix E Table 1.2 contains the performance parameters evaluated for the WAAS in this report.

1.3 Report Overview

Section 2 of this report summarizes the results obtained from the coverage calculation program called SPS_CoverageArea developed by ACB 430. The SPS_CoverageArea program uses the GPS satellite almanacs to compute each satellite position as a function of time for a selected day of the week. This program establishes a 5-degree grid between 180 degrees east and 180 degrees west, and from 80 degrees north and 80 degrees south. The program then computes the PDOP at each grid point (1485 total grid points) every minute for the entire day and stores the results. After the PDOP's have been saved the 99.99% index of 1-minute PDOP at each grid point is determined and plotted as contour lines (Figure 2-1). The program also saves the number of satellites used in PDOP calculation at each grid point for analysis.

Section 3 summarizes the GPS availability performance by providing the “Notice: Advisory to Navstar Users” (NANU) messages to calculate the total time of forecasted and actual satellite outages. This section also includes the maximum and minimum of the PDOP, HDOP and VDOP for each of the thirteen NSTB/WAAS sites.

Section 4 summarizes service reliability performance. It will be reported at the end of the first year of this analysis because the SPS standard is based a measurement interval of one year. Data for the quarter is provided for completeness.

Section 5 provides the position and repeatable accuracies based on data collected on a daily basis at one-second intervals. This section also provides the statistics on the range error, range error rate and range acceleration error for each satellite. The overall average, maximum, minimum and standard deviations of the range rates and accelerations are tabulated for each satellite.

In Section 6, the data collected during solar storms is analyzed to determine the effects, if any, of GPS SPS performance.

Appendix A provides a summary of all the results as compared to the SPS specification.

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

Appendix D provides a glossary of terms used in this PAN report. This glossary was obtained directly from the GPS SPS specification document.

Table 1-1 SPS Performance Requirements

Coverage Standard	Conditions and Constraints	Evaluated in This Report
≥ 99.9% global average	• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	✓
≥ 96.9% at worst-case point	• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	✓
Satellite Availability Standard	**Conditions and Constraints**	
≥ 99.85% global average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	✓
≥ 99.16% single point average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	✓
≥ 95.87% global average on worst-case day	• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	✓
≥ 83.92% at worst-case point on worst-case day	• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	✓
Service Availability Standard	**Conditions and Constraints**	
≥ 99.97% global average	• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	✓

≥ 99.79% single point average	• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	✓
Accuracy Standard	Conditions and Constraints	
Predictable Accuracy ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	✓
Repeatable Accuracy ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	✓
Relative Accuracy ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	Future Reports
Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	✓
Range Domain Accuracy ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 8 mm/s^2 range acceleration error 95% of time ≤ 19 mm/s^2 NTE range acceleration error	• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	✓

2.0 Coverage Performance

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

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

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

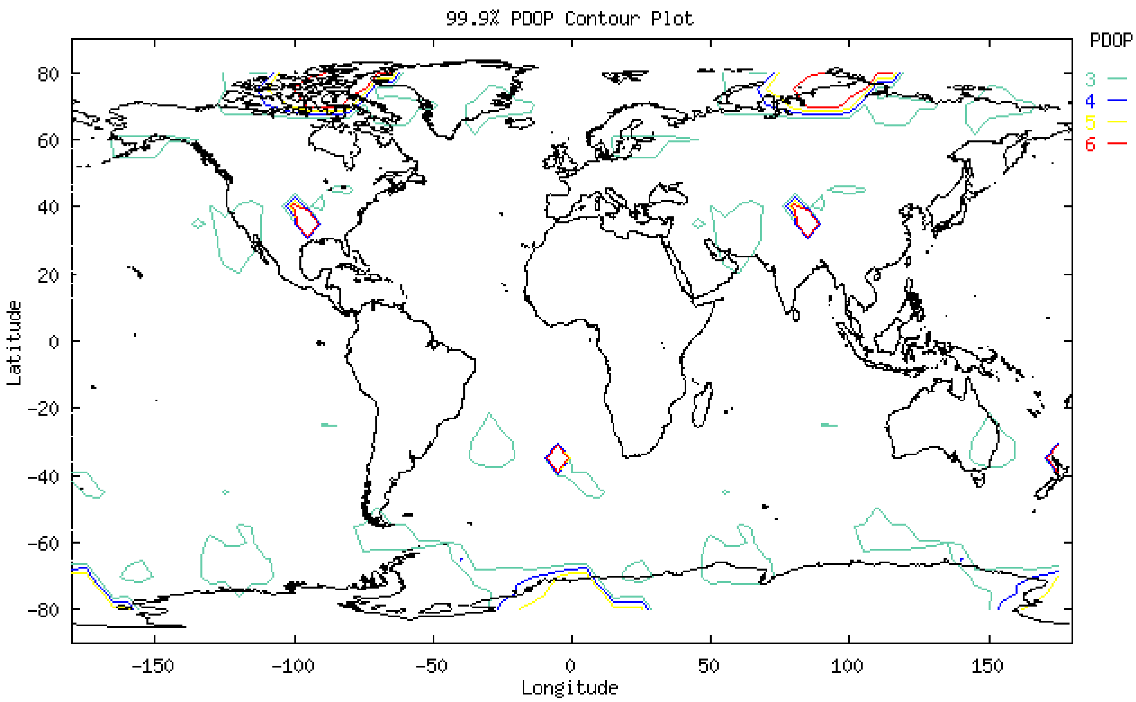
Almanacs for GPS weeks 228-240 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACB 430 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.96964 or better 99.9% of the time for each of the 24-hour intervals.

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

Table 2-1 Coverage Statistics

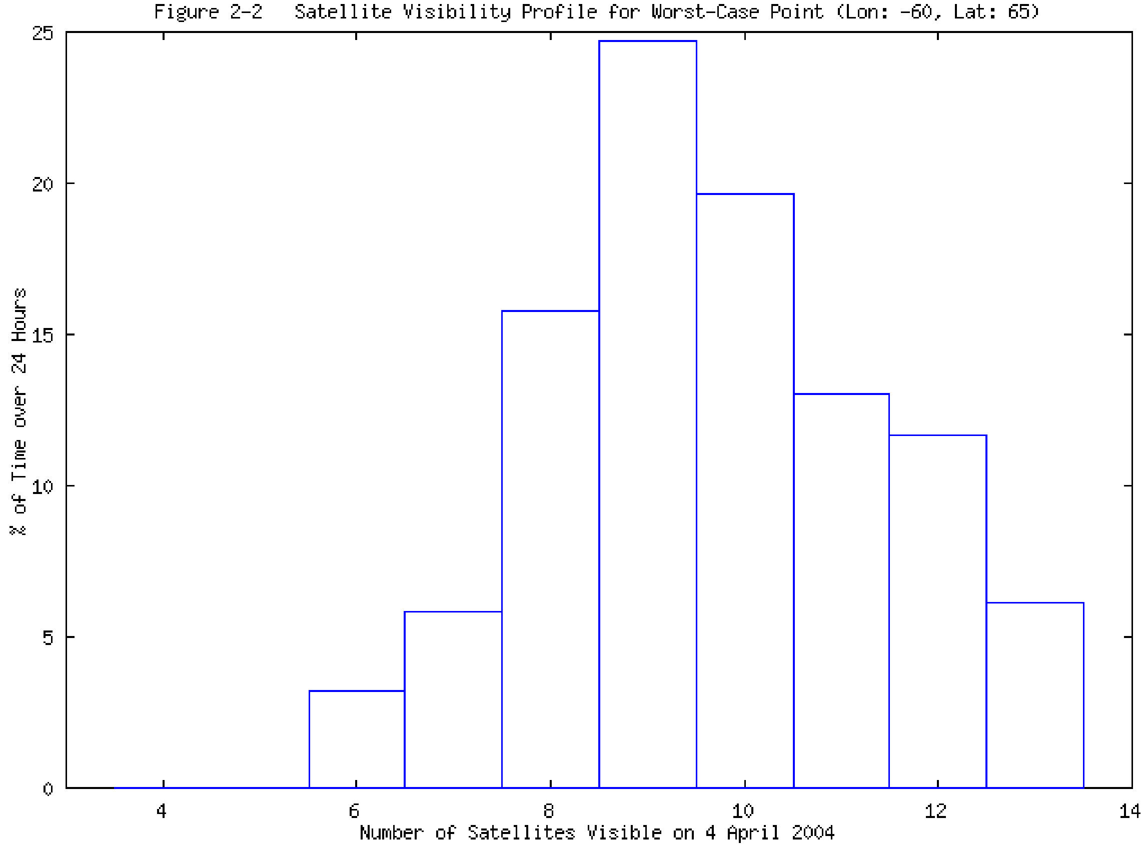
GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
241	3.18251	99.996	99.236
242	3.86064	99.968	98.542
243	3.12189	99.997	99.097
244	3.12284	99.996	99.028
245	3.14885	99.996	98.958
246	3.29409	99.995	98.889
247	3.12636	99.995	98.819
248	3.96964	99.976	98.750
249	3.16357	99.995	98.681
250	3.19042	99.995	98.542
251	3.23809	99.995	98.681
252	3.23944	99.995	98.542
253	3.21339	99.995	98.542

Figure 2-1 SPS Coverage (24-Hour Period: 4 April 2004)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -60, Lat: 65)



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 April through 30 June 2004, there were a total of twelve reported outages. Eleven of these outages were maintenance activities and were reported in advance. One was an unscheduled outage. A complete listing of outage NANU's for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-2. Canceled outage NANU's are provided in Table 3-3.

Table 3-1 NANUs Affecting Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2004041	30	S	1-Apr	13:41	1-Apr	17:03		3.36	3.36
45	3	S	7-Apr	18:10	7-Apr	21:37		3.45	3.45
47	4	S	11-Apr	15:11	11-Apr	16:29		1.30	1.30
48	6	S	13-Apr	9:07	13-Apr	18:18		9.18	9.18
50	8	S	22-Apr	13:38	22-Apr	16:50		3.20	3.20
53	8	S	3-May	11:17	5-May	5:03		41.76	41.76
55	31	S	4-May	18:28	5-May	10:58		16.50	16.50
56	2	S	1-Apr	12:00	12-May	17:01		977.02	977.02
64	8	S	5-May	9:06	18-May	1:42		304.60	304.60
65	17	S	19-May	17:03	19-May	22:05		5.03	5.03
68	16	S	21-May	0:28	21-May	6:57		6.48	6.48
69	6	S	25-May	11:49	25-May	14:13		2.40	2.40
70	22	S	27-May	17:22	28-May	0:59		7.62	7.62
72	29	S	17-Jun	12:41	17-Jun	16:39		3.97	3.97
77	7	S	25-Jun	4:03	25-Jun	12:38		8.58	8.58
79	1	S	28-Jun	23:42	29-Jun	9:58		10.27	10.27
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**0.00**	**1404.72**	**1404.72**
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
2004038	30	F	1-Apr	13:15	2-Apr	1:15	12	See NANU 41
42	3	F	7-Apr	17:30	8-Apr	5:30	12	See NANU 45
44	6	F	13-Apr	8:45	13-Apr	20:45	12	See NANU 48
46	4	F	11-Apr	15:11	N/A	N/A	N/A	See NANU 47
49	8	F	22-Apr	13:38	N/A	N/A	N/A	See NANU 50
51	31	F	4-May	18:15	6-May	18:15	48	See NANU 55
52	8	F	3-May	11:17	N/A	N/A	N/A	See NANU 53
54	8	F	5-May	8:56	N/A	N/A	N/A	See NANU 64
58	17	F	19-May	14:00	20-May	2:00	12	See NANU 60
59	17	F	19-May	14:00	20-May	2:00	12	See NANU 61
62	17	F	19-May	14:00	20-May	2:00	12	See NANU 65
63	16	F	20-May	23:45	21-May	11:45	12	See NANU 68
66	6	F	25-May	11:30	25-May	23:30	12	See NANU 69
67	22	F	27-May	17:00	28-May	5:00	12	See NANU 70
71	29	F	17-Jun	12:00	18-Jun	0:00	12	See NANU 72
73	7	F	25-Jun	3:45	25-Jun	15:45	12	See NANU 77
74	1	F	25-Jun	23:15	26-Jun	11:15	12	See NANU 75
76	1	F	28-Jun	23:15	29-Jun	23:15	12	See NANU 79
					Total Forecast Downtime		**204**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
2004060	17	C	19-May	14:00	See NANU 58
61	17	C	19-May	14:00	See NANU 59
75	1	C	25-Jun	23:15	See NANU 74

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 April -**	**1 October,**
	30 Jun. 2004	**1999- 31 Mar. 2004**
Total Forecast Downtime (hrs):	204.00	4815.23
Total Actual Downtime (hrs):	1404.72	9747.76
Total Actual Scheduled Downtime (hrs):	1404.72	6821.10
Total Actual Unscheduled Downtime (hrs):	0	2926.66
Total Satellite Observed MTTR (hrs):	87.80	30.65
Scheduled Satellite Observed MTTR (hrs):	87.80	25.36
Unscheduled Satellite Observed MTTR (hrs):	N/A	59.73
# Total Satellite Outages:	16	318
# Scheduled Satellite Outages:	16	269
# Unscheduled Satellite Outages:	0	49
Percent Operational -- Scheduled Downtime:	97.70	99.41
Percent Operational -- All Downtime:	99.88	99.16

Several NANU's were omitted in the summary charts above for the following reasons:

2004043: Announced the usability of PRN 19.
2004057: Announced the decommissioning of PRN 2.
2004078: Announced the launch of PRN 23.

3.2 Service Availability

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

To verify availability, the data collected from receivers at the nine NSTB/WAAS sites was reduced to calculate DOP information and reported in Tables 3-5 to 3-7. The data was collected at one-second intervals between 1 April and 30 June 2004.

Table 3-5 PDOP Statistics

NSTB/WAAS Site	Min PDOP	Max PDOP	VDOP at Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP	Number of Samples
Bangor	1.540	5.998	5.711	2.350	5.710	4.920	3536566
Elko	1.290	5.706	5.000	1.867	4.163	3.613	7046951
Mauna Loa	1.192	5.620	4.779	1.754	3.616	3.216	6867850
Billings	1.166	6.000	5.049	1.759	5.456	4.917	7200331
Cold Bay	1.095	4.168	3.711	1.727	3.795	3.382	7421840
Juneau	1.178	5.441	5.111	1.786	3.866	3.343	7412383
Albuquerque	1.225	4.499	4.279	1.753	4.264	3.916	7472288
Anchorage	1.174	5.316	4.657	1.750	3.603	3.269	7426851
Boston	1.214	5.406	4.819	1.755	4.185	3.153	7460632
Washington, D.C.	1.211	5.262	4.610	1.750	4.998	4.297	7478682
Honolulu	1.192	3.738	3.547	1.730	3.577	3.320	7476136
Houston	1.175	5.664	5.195	1.746	4.614	4.228	7461634
Kansas City	1.141	5.608	4.204	1.759	4.357	3.982	7476742
Los Angeles	1.144	4.338	3.873	1.794	3.667	3.128	7472181
Salt Lake City	1.157	5.012	4.707	1.765	4.263	3.865	7476167
Miami	1.223	5.237	4.998	1.796	5.211	4.972	7466068
Minneapolis	1.139	5.997	4.895	1.743	4.097	3.261	7476336
Oakland	1.159	5.030	4.553	1.773	3.855	3.429	7476632
Cleveland	1.145	5.683	5.293	1.790	5.049	4.268	7474362
Seattle	1.129	5.763	4.967	1.772	3.844	3.273	7476068
San Juan	1.194	5.342	5.197	1.784	4.629	4.490	7473860
Atlanta	1.200	5.057	4.556	1.762	4.859	4.365	7478347

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

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

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

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

Table 3-6 Maximum PDOP Statistics

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

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

Table 3-7 PDOP > 6 Statistics

Site	Total Number of Seconds of PDOP Monitoring	Total Seconds with PDOP > 6	Overall % Availability
Bangor	3536566	0	100%
Elko	7046951	0	100%
Mauna Loa	6867850	0	100%
Billings	7200331	0	100%
Cold Bay	7421840	0	100%
Juneau	7412383	0	100%
Albuquerque	7472288	0	100%
Anchorage	7426851	0	100%
Boston	7460632	0	100%
Washington, D.C.	7478682	0	100%
Honolulu	7476136	0	100%
Houston	7461634	0	100%
Kansas City	7476742	0	100%
Los Angeles	7472181	0	100%
Salt Lake City	7476167	0	100%
Miami	7466068	0	100%
Minneapolis	7476336	0	100%
Oakland	7476632	0	100%
Cleveland	7474362	0	100%
Seattle	7476068	0	100%
San Juan	7473860	0	100%
Atlanta	7478347	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	3536566	16.4
Elko	7046951	13.9
Mauna Loa	6867850	26.5
Billings	7200331	11.5
Cold Bay	7421840	13.8
Juneau	7412383	13.3
Albuquerque	7472288	10.6
Anchorage	7426851	12.1
Boston	7460632	12.6
Washington, D.C.	7478682	12.2
Honolulu	7476136	24.3
Houston	7461634	12.8
Kansas City	7476742	10.6
Los Angeles	7472181	11.9
Salt Lake City	7476167	10.6
Miami	7466068	15.3
Minneapolis	7476336	13.6
Oakland	7476632	10.0
Cleveland	7474362	13.6
Seattle	7476068	9.91
San Juan	7473860	25.2
Atlanta	7478347	12.7

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 April through 30 June 2004 at the NSTB and WAAS selected locations.

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

Table 5-1 Horizontal & Vertical Accuracy Statistics for the Quarter

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Bangor	3.752	5.954	10.208	14.819
Elko	4.709	6.504	10.996	32.266
Mauna Loa	5.881	7.683	11.187	23.903
Billings	3.623	5.044	9.398	10.869
Cold Bay	3.439	5.048	8.708	10.191
Juneau	3.074	4.511	9.586	22.220
Albuquerque	4.121	5.649	11.371	27.215
Anchorage	3.068	4.718	12.190	11.961
Boston	3.505	4.971	13.847	24.528
Washington, D.C.	3.573	5.397	10.440	11.951
Honolulu	5.964	7.177	11.274	22.014
Houston	4.394	5.751	10.808	13.165
Kansas City	3.804	5.596	11.614	11.366
Los Angeles	4.474	6.021	11.234	23.208
Salt Lake City	3.892	5.520	11.502	29.755
Miami	4.488	5.622	14.860	28.728
Minneapolis	3.679	5.315	10.971	11.749
Oakland	4.129	5.748	11.864	12.203
Cleveland	3.628	5.445	11.419	11.070
Seattle	3.657	4.832	8.997	25.982
San Juan	4.449	6.853	12.999	24.624
Atlanta	3.863	5.612	15.416	18.699

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 April to 30 June 2004.

Figure 5-1 Combined Vertical Error Histogram

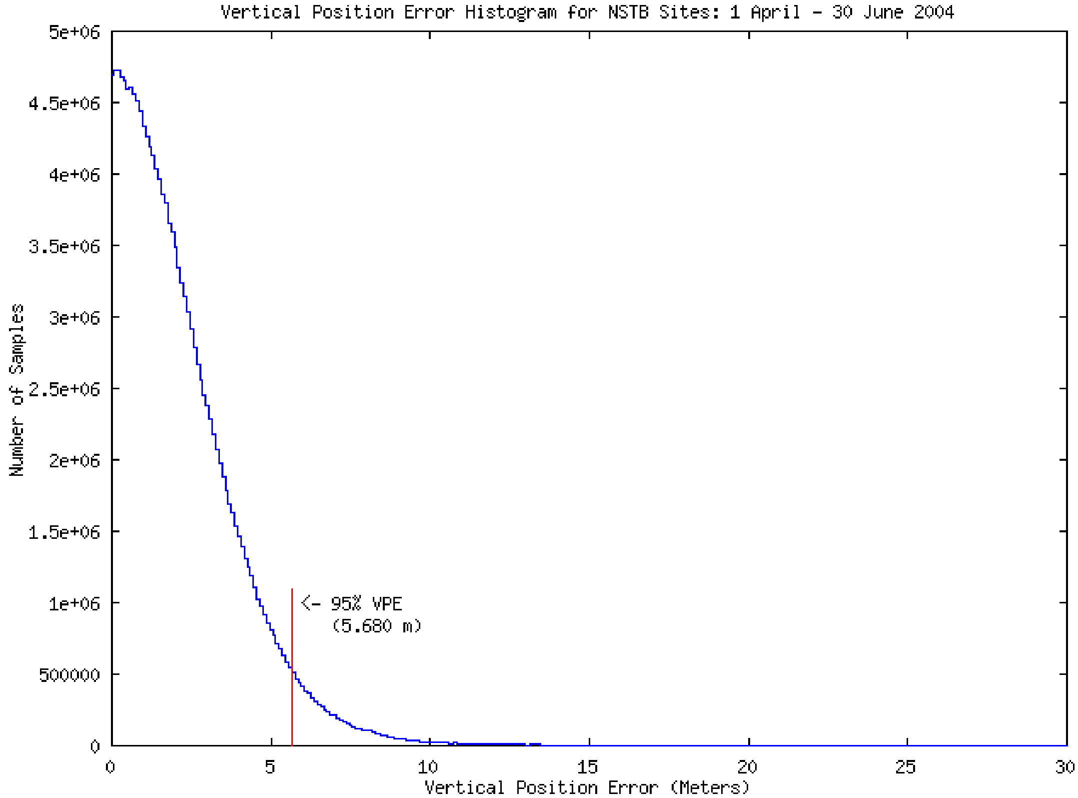
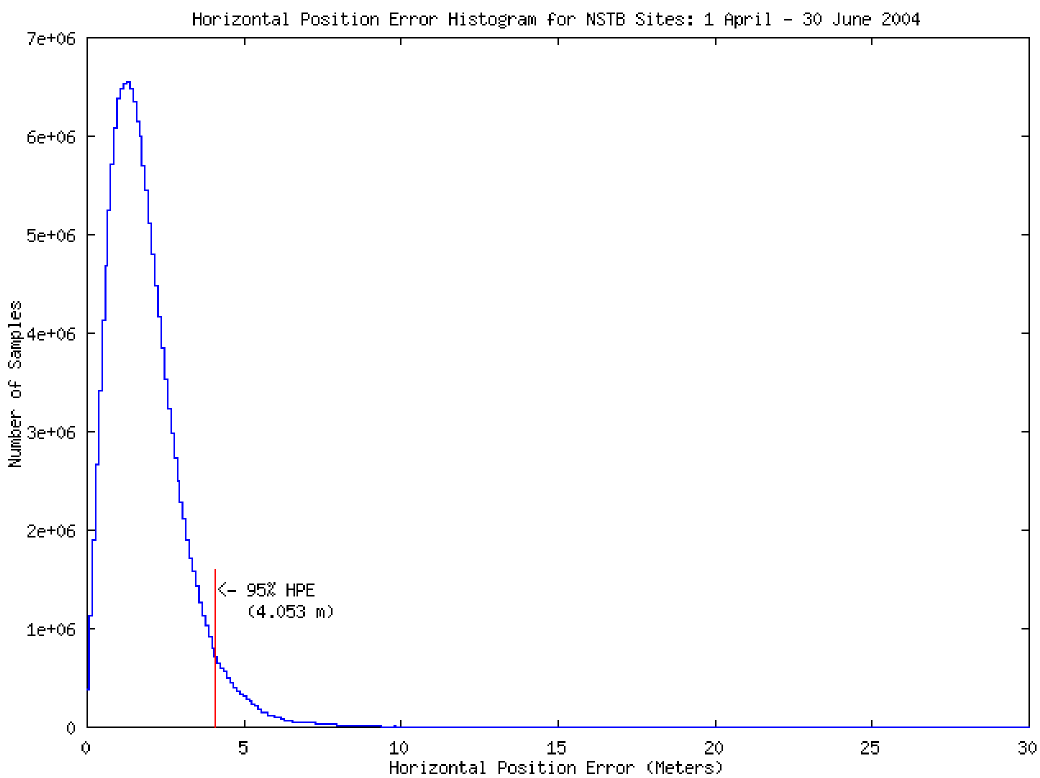


Figure 5-2 Combined Horizontal Error Histogram



5.2 Repeatable Accuracy

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

Table 5-2 Repeatability Statistics

Site	95% Horizontal (m)	95% Vertical (m)
Bangor	1.382	4.127
Elko	1.497	3.220
Mauna Loa	1.620	4.856
Billings	1.062	2.471
Cold Bay	0.955	2.597
Juneau	0.940	2.540
Albuquerque	1.176	2.677
Anchorage	0.858	2.125
Boston	1.064	2.229
Washington, D.C.	1.066	2.630
Honolulu	1.395	5.054
Houston	1.203	2.794
Kansas City	1.170	2.562
Los Angeles	1.558	3.113
Salt Lake City	1.223	2.685
Miami	1.250	3.344
Minneapolis	1.269	2.247
Oakland	1.152	2.604
Cleveland	1.069	2.803
Seattle	0.949	1.923
San Juan	1.273	3.617
Atlanta	1.167	2.904

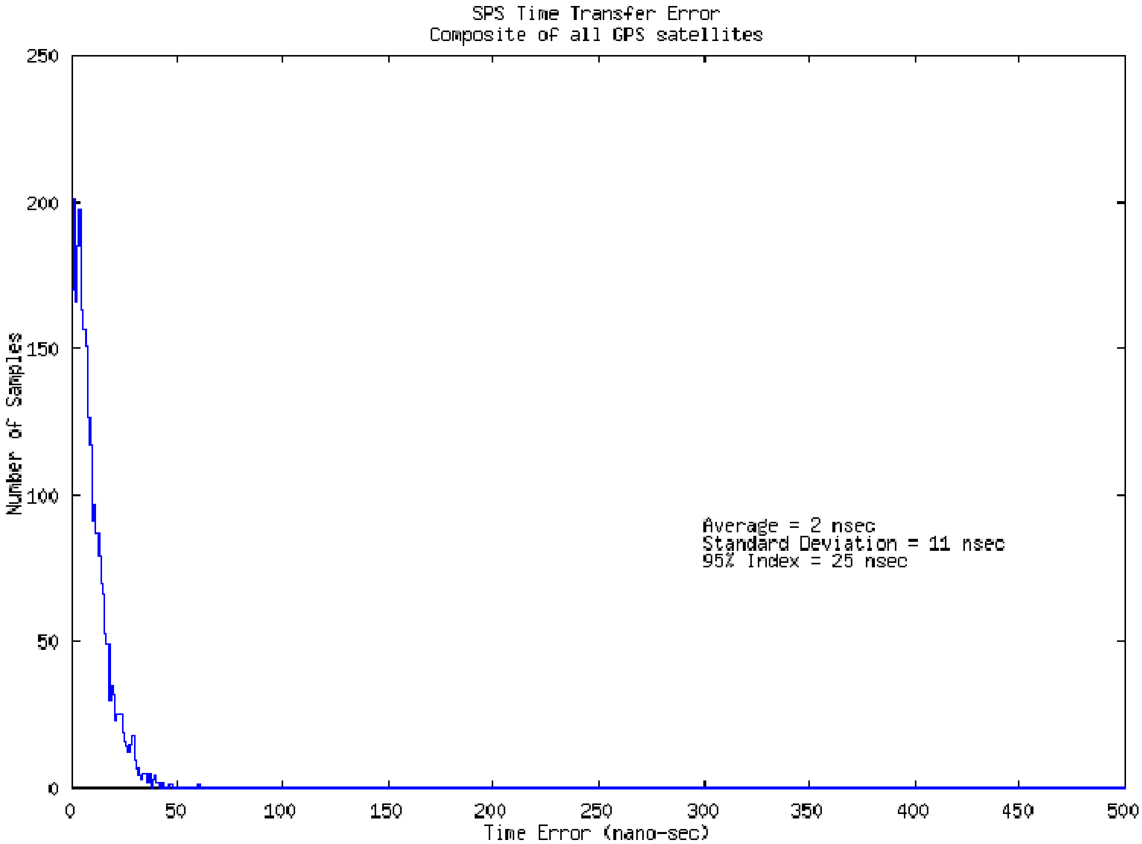
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 2004 was down loaded from USNO Internet site. The USNO data file contains the time difference between the USNO master clock and GPS system time for each GPS satellites during the time period. Over 10,000 samples of GPS time error are contained in the USNO data file. In order to evaluate the GPS time transfer error, the data file was used to create a histogram (Fig 5-3) to represent the distribution of GPS time error. The histogram was created by taking the absolute value of time difference between the USNO master clock and GPS system time, then creating data bins with one nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Fig 5-3. The mean, standard deviation, and 95% index are within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Errors



5.5 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 April and 30 June 2004. The WAAS receiver at Houston was used to collect range measurement. Future PAN reports will contain statistics from all WAAS sites.

A weighted average filter was used for the calculation of the range rate error and the range acceleration error. All Range Domain SPS specifications were met.

Table 5-3 Range Error Statistics (meters)

PRN	Range Error Mean	Range Error RMS	1s	95% Range Error	Max Range Error (SPS Spec. ≤ 150 m)	Samples
1	2.218	3.932	3.247	7.538	13.469	1842576
3	2.500	3.631	2.633	6.836	11.597	2312339
4	1.449	2.531	2.075	4.923	24.033	1963075
5	2.442	3.426	2.403	6.394	15.389	1943335
6	1.859	3.005	2.362	5.936	9.159	1743937
7	2.875	3.245	1.505	5.170	10.124	1810883
8	2.552	3.522	2.428	6.296	23.695	1525145
9	2.222	3.248	2.369	6.379	11.504	2276448
10	2.680	3.400	2.093	6.091	10.963	2159347
11	3.666	4.168	1.983	6.979	15.930	2317903
13	1.518	2.595	2.105	4.994	13.602	1661503
14	4.210	4.894	2.495	8.366	12.434	1856588
15	4.359	5.286	2.990	9.002	25.362	1757376
16	2.505	3.484	2.421	6.338	14.921	2197334
17	1.656	2.618	2.028	5.297	9.123	1862793
18	3.577	4.347	2.470	7.514	11.791	1924985
19	4.646	5.145	2.211	8.233	16.772	2280428
20	3.376	4.073	2.278	6.884	10.605	2082830
21	3.725	4.604	2.705	7.853	16.940	1920628
22	3.786	4.688	2.764	8.065	11.349	1958971
24	0.679	2.297	2.195	4.637	11.440	1746396
25	2.853	4.020	2.831	7.486	11.440	1735932
26	1.758	2.781	2.155	5.320	13.269	2308761
27	1.958	2.850	2.071	5.057	11.303	1925571
28	3.283	3.816	1.945	6.151	11.785	1956604
29	2.114	2.993	2.118	5.522	10.622	2350166
30	1.095	2.602	2.360	5.236	9.980	2185560
31	3.732	4.556	2.613	8.140	24.588	2032816

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	-0.00009	0.00423	0.00423	0.00640	0.34095	1842576
3	0.00010	0.00364	0.00364	0.00617	0.35559	2312339
4	0.00000	0.00619	0.00619	0.00719	0.91389	1963075
5	-0.00001	0.00519	0.00519	0.00669	0.77694	1943335
6	0.00006	0.00342	0.00342	0.00597	0.21287	1743937
7	0.00002	0.00361	0.00361	0.00585	0.25836	1810883
8	0.00009	0.00429	0.00429	0.00608	0.25898	1525145
9	-0.00004	0.00326	0.00326	0.00592	0.18991	2276448
10	0.00004	0.00391	0.00391	0.00632	0.41004	2159347
11	0.00003	0.00338	0.00338	0.00605	0.58335	2317903
13	-0.00002	0.00566	0.00566	0.00677	0.53225	1661503
14	0.00001	0.00323	0.00323	0.00585	0.25073	1856588
15	0.00015	0.00384	0.00384	0.00616	0.84399	1757376
16	-0.00001	0.00468	0.00468	0.00672	0.60657	2197334
17	0.00002	0.00317	0.00317	0.00591	0.12189	1862793
18	0.00005	0.00301	0.00301	0.00587	0.05711	1924985
19	0.00013	0.00331	0.00331	0.00599	0.22511	2280428
20	-0.00016	0.00377	0.00376	0.00641	0.32225	2082830
21	0.00002	0.00359	0.00359	0.00612	0.64255	1920628
22	0.00004	0.00301	0.00301	0.00576	0.18388	1958971
24	0.00000	0.00342	0.00342	0.00604	0.19290	1746396
25	-0.00012	0.00372	0.00372	0.00624	0.21436	1735932
26	0.00005	0.00350	0.00350	0.00599	0.22572	2308761
27	0.00006	0.00341	0.00341	0.00604	0.19925	1925571
28	0.00004	0.00394	0.00394	0.00594	0.27733	1956604
29	0.00006	0.00401	0.00401	0.00605	0.39544	2350166
30	0.00009	0.00316	0.00316	0.00599	0.12253	2185560
31	0.00010	0.00625	0.00625	0.00650	0.90293	2032816

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1 s	% ≤ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. ≤ 0.019 m/s2)	Samples
1	0	0.00004	0.0004	100	0.00335	1842576
3	0	0.00003	0.00003	100	0.00356	2312339
4	0	0.00006	0.00006	99.999	0.00915	1963075
5	0	0.00005	0.00005	100	0.00774	1943335
6	0	0.00003	0.00003	100	0.00211	1743937
7	0	0.00003	0.00003	100	0.00247	1810883
8	0	0.00004	0.00004	100	0.00227	1525145
9	0	0.00003	0.00003	100	0.00185	2276448
10	0	0.00003	0.00003	100	0.00409	2159347
11	0	0.00003	0.00003	100	0.00582	2317903
13	0	0.00005	0.00005	100	0.00530	1661503
14	0	0.00003	0.00003	100	0.00249	1856588
15	0	0.00003	0.00003	99.999	0.00846	1757376
16	0	0.00004	0.00004	100	0.00606	2197334
17	0	0.00003	0.00003	100	0.00121	1862793
18	0	0.00003	0.00003	100	0.00057	1924985
19	0	0.00003	0.00003	100	0.00225	2280428
20	0	0.00003	0.00003	100	0.00319	2082830
21	0	0.00003	0.00003	100	0.00638	1920628
22	0	0.00003	0.00003	100	0.00183	1958971
24	0	0.00003	0.00003	100	0.00186	1746396
25	0	0.00003	0.00003	100	0.00212	1735932
26	0	0.00003	0.00003	100	0.00215	2308761
27	0	0.00003	0.00003	100	0.00202	1925571
28	0	0.00004	0.00004	100	0.00296	1956604
29	0	0.00004	0.00004	100	0.00378	2350166
30	0	0.00003	0.00003	100	0.00123	2185560
31	0	0.00006	0.00006	99.999	0.00877	2032816

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 15 with an error of 25.362 meters. Satellite 17 had the lowest maximum range error of 9.123 meters.

Figure 5-4 Distribution of Daily Max Range Errors

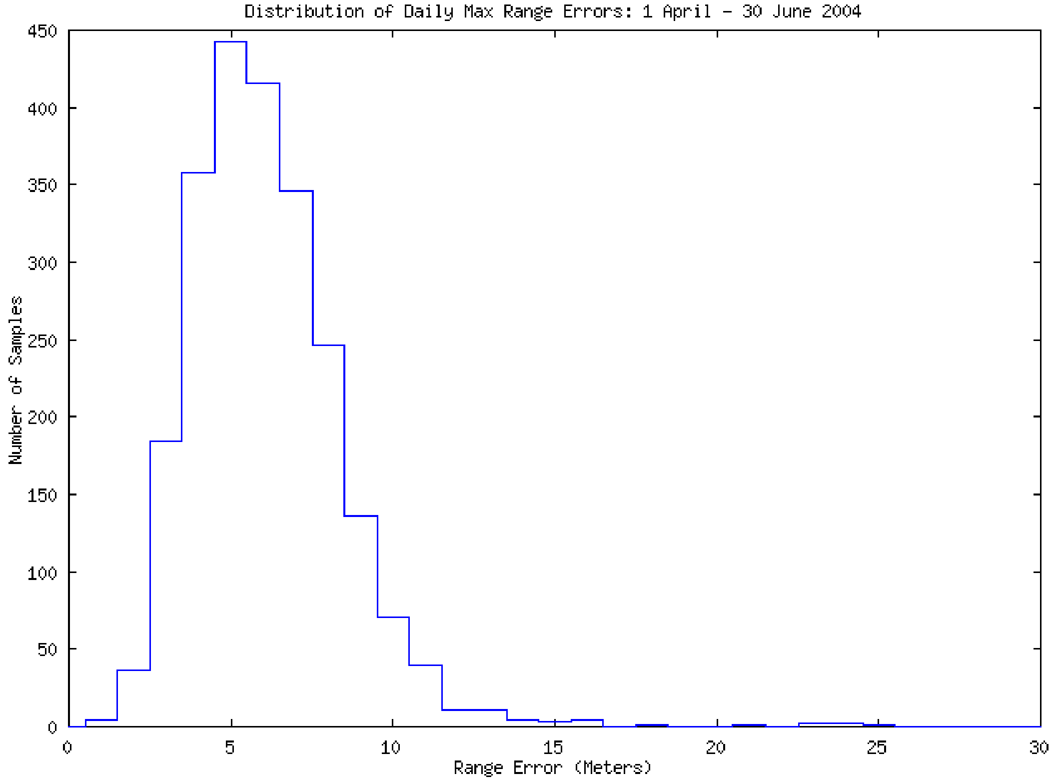


Figure 5-5: Distribution of Daily Max Range Rate Errors

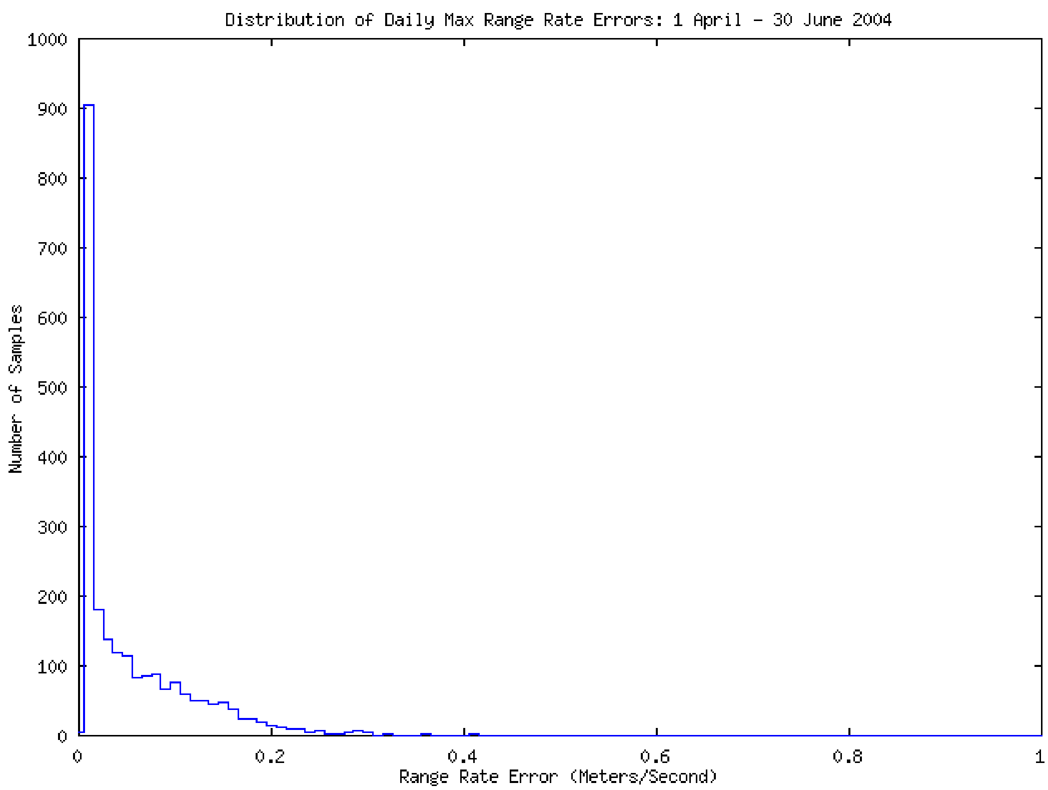


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

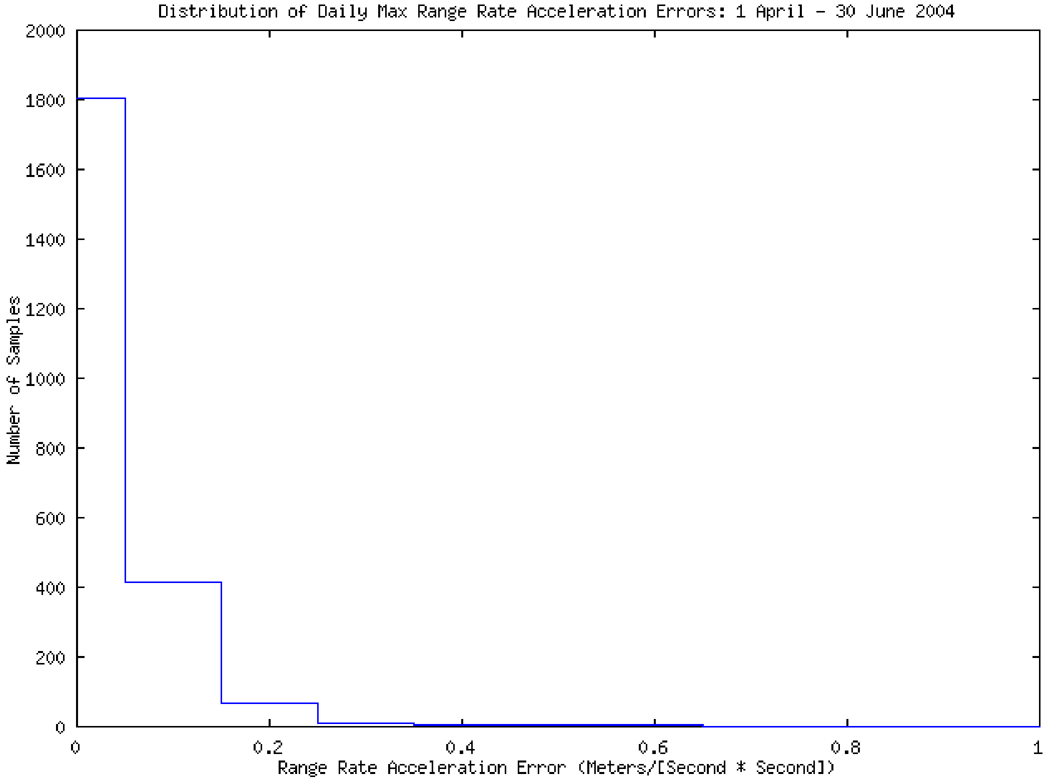


Figure 5-7: Range Error Histogram

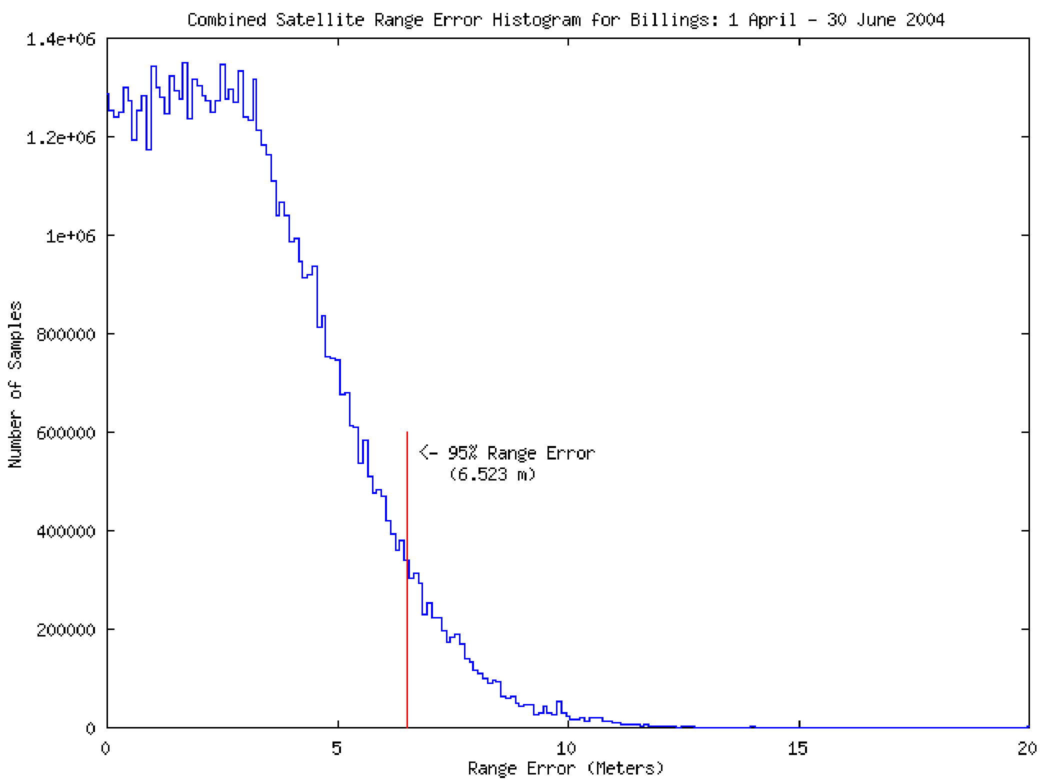


Figure 5-8: Maximum Range Error Per Satellite

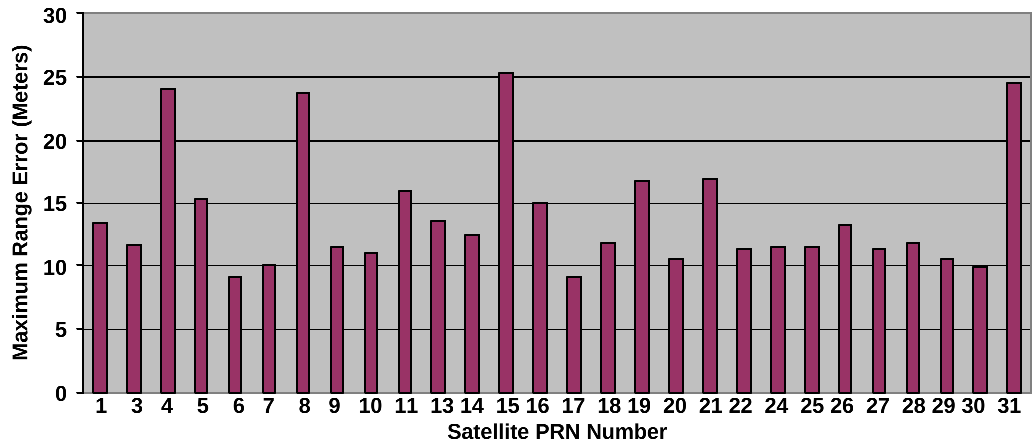


Figure 5-9: Maximum Range Rate Error Per Satellite

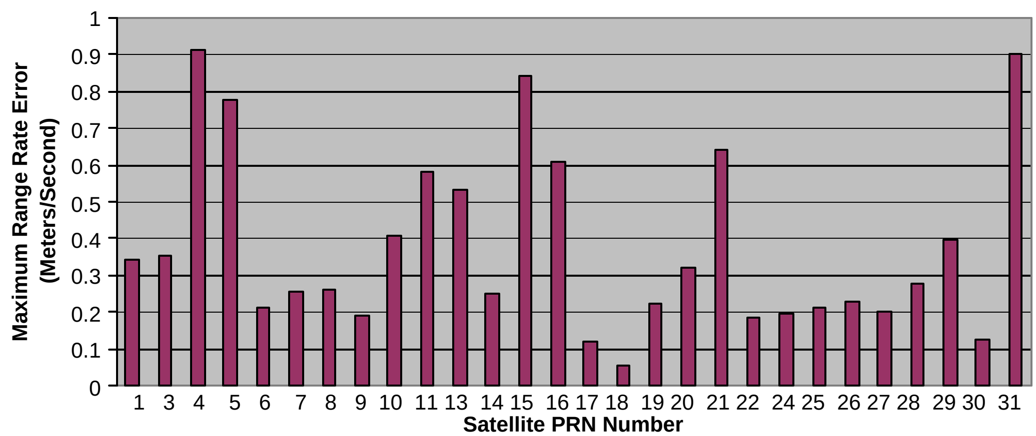
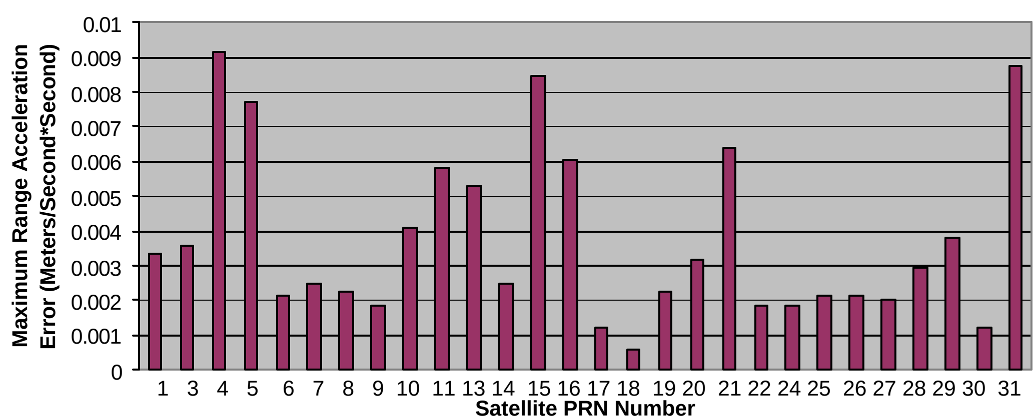


Figure 5-10: Maximum Range Acceleration Per Satellite



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 1-3 April 2004

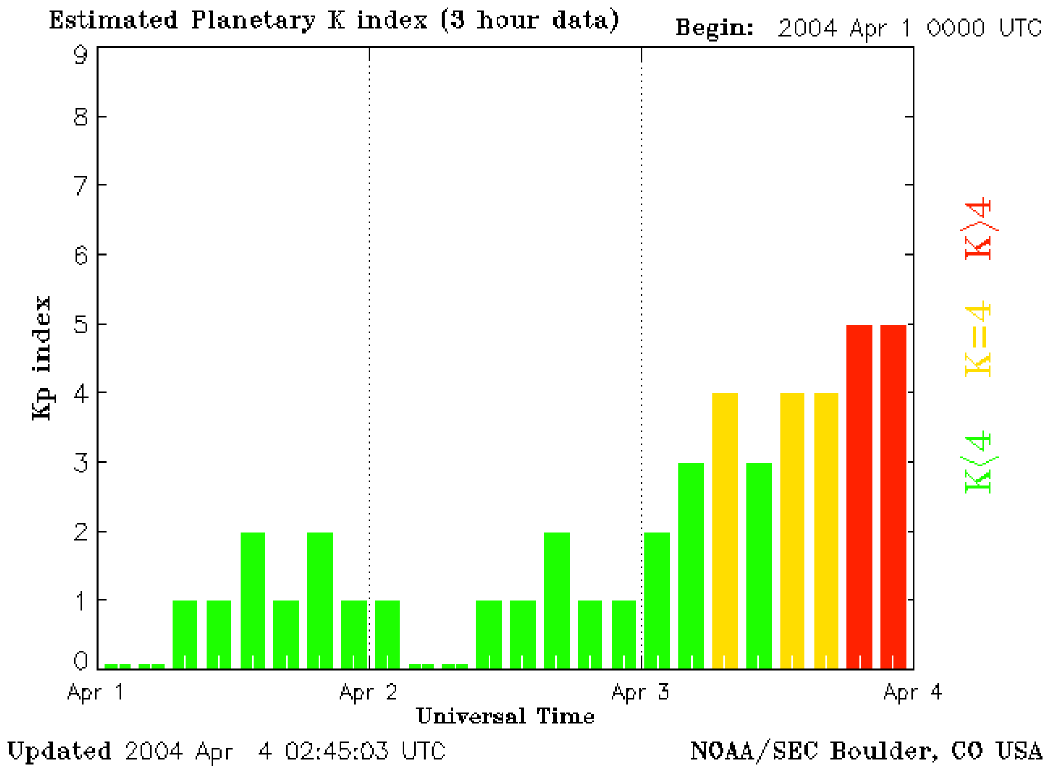


Figure 6-2 K-Index for 4-6 April 2004

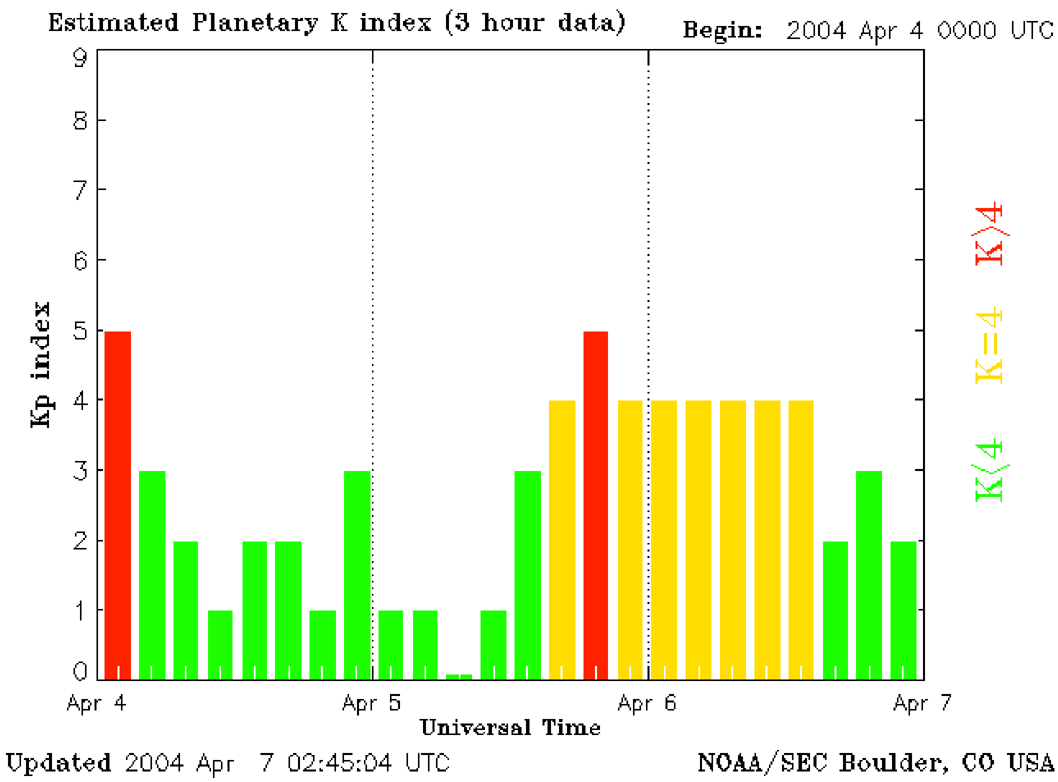
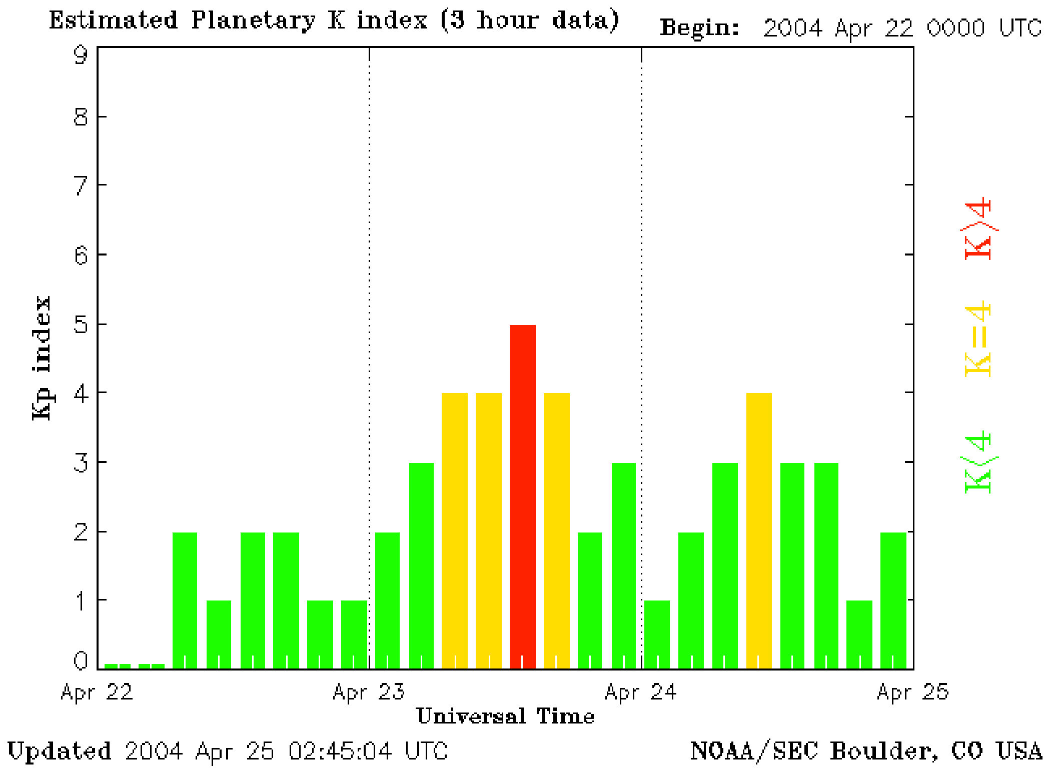


Figure 6-3 K-Index for 22-24 April 2004



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

Table 6-1 PDOP Statistics for 3 April 2004

Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Elko	1.310	3.752	1.840	3.748	3.408
Cold Bay	1.147	3.810	1.733	3.810	3.216
Juneau	1.269	3.250	1.777	3.246	2.898
Albuquerque	1.304	3.553	1.763	3.549	2.744
Anchorage	1.210	3.137	1.755	3.133	2.784
Boston	1.222	2.787	1.756	2.787	2.323
Washington, D.C.	1.251	3.420	1.766	3.418	2.943
Honolulu	1.234	3.176	1.732	3.175	2.854
Houston	1.230	2.847	1.753	2.847	2.512
Kansas City	1.160	2.777	1.752	2.773	2.344
Los Angeles	1.206	3.094	1.793	2.992	2.707
Salt Lake City	1.222	3.920	1.773	3.915	3.659
Miami	1.224	3.389	1.788	3.389	3.131
Minneapolis	1.196	3.089	1.751	3.089	2.724
Oakland	1.217	3.349	1.775	3.347	3.075
Cleveland	1.161	3.591	1.803	3.583	3.344
Seattle	1.193	3.694	1.765	3.694	3.265
San Juan	1.239	3.370	1.777	3.367	3.100
Atlanta	1.281	4.031	1.786	4.025	3.674

**** Bangor, Billings and Mauna Loa receivers were down this day!***

Table 6-2 Horizontal & Vertical Accuracy Statistics for 3 April 2004

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Elko	4.348	4.877	6.859	9.710
Cold Bay	3.082	4.746	4.375	7.395
Juneau	2.393	3.110	2.894	6.224
Albuquerque	4.702	5.978	5.439	8.041
Anchorage	2.509	3.645	2.832	5.242
Boston	9.106	4.301	10.835	5.158
Washington, D.C.	5.180	4.948	6.116	6.522
Honolulu	6.001	7.836	7.055	10.038
Houston	5.141	6.317	6.103	9.051
Kansas City	4.565	3.867	5.823	6.291
Los Angeles	5.279	5.066	6.425	8.112
Salt Lake City	4.386	3.913	5.488	6.234
Miami	5.858	7.858	8.482	10.445
Minneapolis	6.130	4.079	9.739	5.775
Oakland	4.942	3.737	6.261	5.541
Cleveland	6.213	4.860	8.168	8.772
Seattle	3.746	2.981	4.819	4.755
San Juan	4.811	9.901	7.093	12.615
Atlanta	4.888	6.095	5.948	9.798

**** Bangor, Billings and Mauna Loa receivers were down this day!***

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	99.968%
• 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 3.96964
Conditions and Constraints	***Satellite Availability Standard***	***Measured Performance***
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.85% global average	100%
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.16% single point average	100%
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	100%
• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	≥ 83.92% at worst-case point on worst-case day	100%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• Conditioned on coverage and service avail. standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.97% global average	100%
• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.79% single point average	100%

Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	<u>Predictable Accuracy</u> ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	≤5.964m HE 95% ≤15.416m HE 99.99% ≤7.683m VE 95% ≤32.266m 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	≤1.620m HE 95% ≤5.054m 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	≤25 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	<u>Range Domain Accuracy</u> ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range acceleration error ≤ 8 mm/s^2 range acceleration error 95% of time	25.362m NTE Range Error 0.91389m/s NTE Rate Error 9.15mm/s^2 NTE Accl. Error ≤8mm/s^2 99.999% of the time

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#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center.
#  Please send comment and suggestions to SEC.Webmaster@noaa.gov
#
#             Current Quarter Daily Geomagnetic Data
#
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	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2004 04 01	2	0 0 1 0 1 0 2 1	3	1 0 0 1 2 1 1 1	3	0 0 1 1 2 1 2 1
2004 04 02	3	1 0 1 0 0 0 1 3	1	1 0 1 1 0 0 0 0	3	1 0 0 1 1 2 1 1
2004 04 03	21	2 3 2 2 4 4 4 5	56	2 3 4 4 6 7 7 3	23	2 3 4 3 4 4 5 5
2004 04 04	12	5 1 2 1 2 2 2 3	8	4 2 1 1 2 2 1 2	12	5 3 2 1 2 2 1 3
2004 04 05	9	1 1 0 1 3 2 4 3	38	0 0 0 2 5 6 7 4	14	1 1 0 1 3 4 5 4
2004 04 06	17	5 3 3 4 3 1 2 2	39	4 4 6 6 6 2 2 2	21	4 4 4 4 4 2 3 2
2004 04 07	7	2 3 2 1 1 2 2 2	14	2 3 4 4 3 2 2 2	10	3 3 3 2 2 2 2 3
2004 04 08	16	5 3 3 3 3 2 2 1	30	3 3 5 6 5 4 2 1	16	2 4 4 4 3 3 2 2
2004 04 09	11	3 3 4 2 2 1 2 2	25	3 5 5 5 3 3 2 1	16	3 5 4 3 2 2 2 2
2004 04 10	10	3 2 3 1 1 1 3 3	17	1 2 5 4 3 1 3 3	10	3 3 3 2 2 2 3 3
2004 04 11	6	3 2 2 1 1 1 2 1	10	2 1 3 4 2 2 1 2	8	3 2 3 2 2 2 2 2
2004 04 12	7	3 2 2 1 1 1 3 1	19	4 3 5 4 2 2 3 1	11	3 2 4 3 2 2 3 1
2004 04 13	5	2 1 1 1 2 1 2 1	7	1 1 2 3 3 1 1 1	6	2 2 2 2 2 2 2 2
2004 04 14	2	1 1 0 0 1 0 0 2	2	1 0 0 0 2 0 0 1	5	2 1 1 0 3 2 2 1
2004 04 15	3	1 1 0 1 1 0 2 2	4	0 0 0 1 2 2 1 3	6	1 1 1 1 2 2 2 3
2004 04 16	10	2 3 2 2 2 3 3 2	27	2 3 5 5 4 4 2 2	12	2 3 4 3 2 3 3 2
2004 04 17	6	1 3 1 1 1 1 2 2	8	2 2 2 2 3 3 1 1	9	2 3 2 1 2 3 3 2
2004 04 18	6	1 2 3 2 1 0 2 2	18	1 3 4 4 5 3 1 1	11	1 2 4 2 3 3 3 2
2004 04 19	4	2 2 1 1 1 1 1 1	8	1 2 3 4 2 1 0 0	6	2 2 2 2 2 2 2 1
2004 04 20	4	1 1 1 1 2 0 1 2	2	1 0 2 1 0 0 0 1	4	1 1 1 2 2 2 1 2
2004 04 21	6	1 3 1 1 2 1 2 1	4	0 2 1 1 1 2 1 1	5	1 3 1 2 2 2 2 1
2004 04 22	2	0 0 1 1 1 1 1 1	5	1 1 1 1 3 1 2 1	4	0 0 2 1 2 2 1 1
2004 04 23	16	2 2 4 4 3 3 3 3	34	2 3 4 5 6 6 2 2	20	2 3 4 4 5 4 2 3
2004 04 24	7	1 2 2 3 2 2 2 1	17	1 2 3 4 5 4 1 1	11	1 2 3 4 3 3 1 2
2004 04 25	7	1 2 3 2 2 1 1 2	17	2 3 5 4 4 2 1 1	12	1 3 4 3 3 3 2 2
2004 04 26	4	2 1 1 0 1 1 2 1	5	2 2 2 0 1 1 2 2	7	2 1 3 1 2 2 2 2
2004 04 27	5	1 2 1 1 1 2 2 1	2	1 2 0 0 0 1 1 1	5	1 1 1 1 2 2 2 2
2004 04 28	8	1 0 2 2 2 3 3 2	7	1 0 1 0 2 3 3 3	8	1 0 2 1 2 3 4 2
2004 04 29	3	1 2 1 0 1 0 1 2	3	1 1 2 1 0 0 1 1	4	1 2 1 1 2 2 1 2
2004 04 30	9	2 3 2 1 1 2 3 3	10	1 3 3 2 0 2 3 3	12	2 3 3 1 2 3 3 4
2004 05 01	8	3 2 2 2 2 1 1 3	10	3 3 3 3 2 2 1 0	13	3 3 3 3 3 3 3 3
2004 05 02	4	2 1 1 2 1 0 2 1	3	3 1 0 1 0 1 1 0	6	3 1 0 2 2 2 2 2
2004 05 03	6	1 2 2 1 2 2 1 2	6	0 2 3 2 2 1 1 2	7	2 1 2 2 2 2 2 2
2004 05 04	6	2 2 2 1 2 1 1 2	10	3 2 4 2 3 1 1 2	10	2 3 3 2 3 2 2 3
2004 05 05	12	2 2 3 3 2 3 3 3	23	2 3 4 5 3 5 3 2	13	2 3 3 3 3 3 3 3
2004 05 06	10	2 2 3 1 2 2 2 4	12	3 2 3 2 4 2 2 2	8	2 2 3 2 2 2 3 2
2004 05 07	13	3 3 3 2 2 2 2 4	31	3 5 5 4 5 5 1 2	17	3 4 4 2 3 4 3 2
2004 05 08	7	2 2 1 2 2 2 2 2	9	3 3 2 2 3 2 1 1	10	3 3 2 2 3 3 3 2
2004 05 09	3	1 2 1 0 1 1 1 1	8	2 3 1 3 3 1 0 1	6	2 3 2 1 2 3 2 1
2004 05 10	5	2 2 1 1 1 1 1 2	4	1 1 1 1 2 1 1 2	7	1 2 2 1 2 2 3 3
2004 05 11	8	3 2 2 0 1 1 3 3	6	3 2 2 0 1 1 2 2	10	3 3 1 1 2 2 3 4
2004 05 12	9	3 4 1 1 1 1 2 2	16	3 4 5 3 1 2 2 1	11	3 4 2 2 2 2 3 2
2004 05 13	17	2 2 5 5 1 1 3 2	21	1 3 6 4 3 3 2 2	13	2 3 4 3 3 3 3 3
2004 05 14	4	2 2 1 0 1 0 2 2	9	3 3 2 1 3 1 1 2	8	2 3 1 1 3 2 2 2
2004 05 15	7	3 2 2 2 1 1 1 2	10	2 3 3 4 1 2 1 1	9	4 2 2 2 2 2 2 2
2004 05 16	4	2 1 1 1 0 1 1 2	4	1 2 2 2 1 1 0 1	4	2 2 1 1 2 1 1 2
2004 05 17	3	1 1 0 1 1 0 1 2	2	1 1 0 0 0 1 2 1	5	2 1 0 1 2 3 2 2
2004 05 18	4	2 1 1 1 2 2 1 0	4	2 1 2 2 1 1 0 1	4	1 1 1 2 2 1 1 1

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

Background:

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

Problem Description:

There were no problems with GPS performance 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.