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 the following NSTB and Wide Area Augmentation System (WAAS) Reference Station locations: Atlantic City, Columbus, Denver, Grand Forks, Greenwood, Prescott, Anchorage (WAAS), Billings (WAAS), Chicago (WAAS), Kansas City (WAAS), Salt Lake City (WAAS), Miami (WAAS) and Atlanta (WAAS). This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification Annex A.

This report, Report #41, includes data collected from 1 January through 31 March 2003. The next quarterly report will be issued 31 July 2003.

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 98.750% or better.

Availability was verified by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 January and 31 March 2003 and by calculating the satellite availability from the data obtained from the fourteen sites. A total of thirteen outages were reported in the NANU’s. All thirteen of the outages were scheduled. The quarterly availabilities for all thirteen sites was 100%. Each of these availabilities is within the SPS value of 99.85%. These availability percentages were calculated using DOP data collected at one-second intervals.

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

Position accuracies were verified by calculating the 95% and 99.99% values of horizontal and vertical errors. Range performance was verified for each satellite using the data collected from the NSTB Atlantic City site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 26.067 meters on Satellite PRN 20. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 0.87556 Meters/second on Satellite PRN 11. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 8.77 Millimeters/second^2 on Satellite PRN 11. 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 January and 31 March 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 for IFR and is developing Wide Area Augmentation System (WAAS) and Local Area Augmentation (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 Analysis report. This report contains data collected at the following National Satellite Test Bed (NSTB) and WAAS reference station locations:

- Atlantic City, NJ
- Columbus, NE
- Denver, CO
- Grand Forks, ND
- Greenwood, MS
- Prescott, AZ
- Billings, MT
- Anchorage, AK
- Chicago, IL
- Kansas City, KS
- Salt Lake City, UT
- Miami, FL
- 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. The SPS specification was met in all instances this quarter.

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

Table 1-1 SPS Performance Requirements

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

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

2.0 Coverage Performance

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

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

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

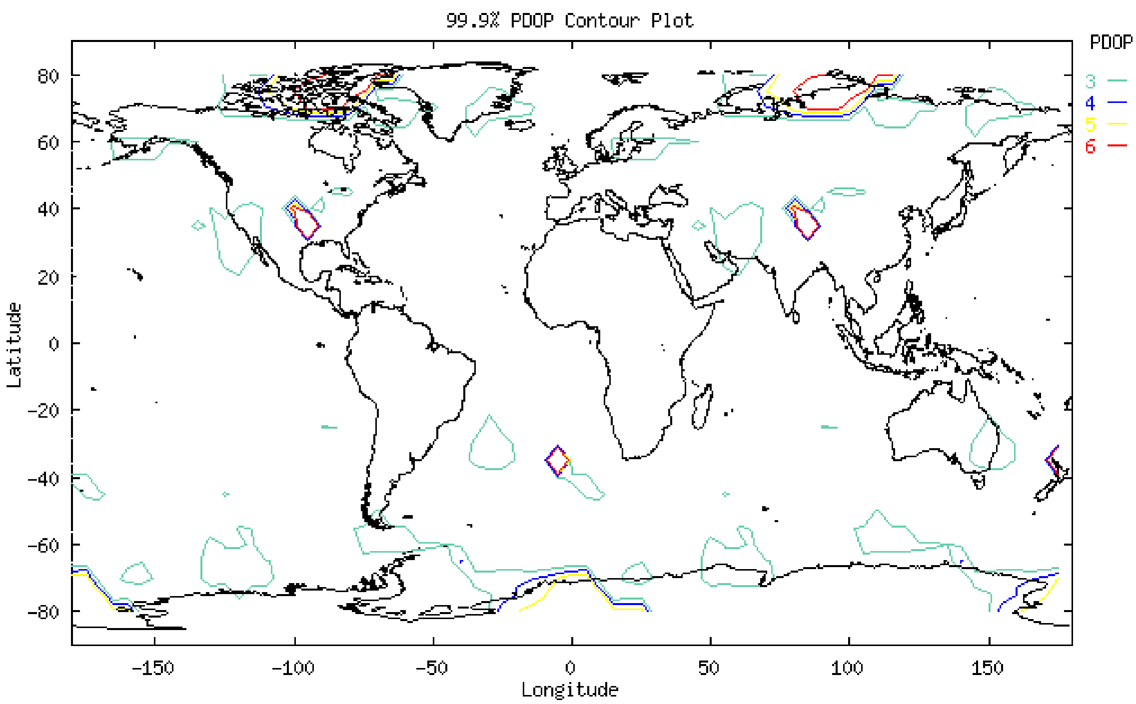
Almanacs for GPS weeks 149-162 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACB 430 was used to calculate the PDOP at every 5^{o} point between longitudes of 180W to 180E 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 4.12829 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

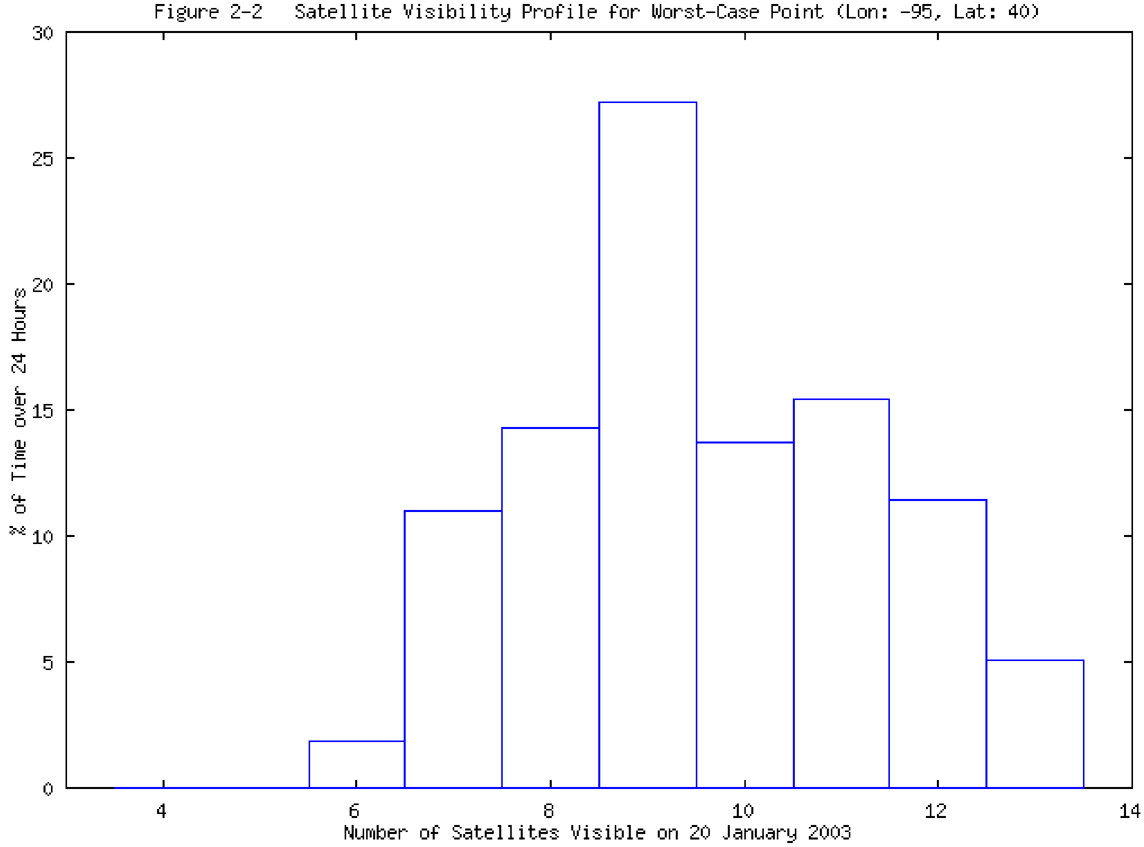
GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
176	3.99347	99.976	98.750
177	4.03108	99.977	99.028
178	4.12829	99.977	98.819
179	4.04369	99.979	99.028
180	3.99258	99.979	99.028
181	3.95466	99.979	99.097
182	3.61756	99.986	99.097
183	3.61746	99.986	99.097
184	3.59224	99.986	99.167
185	3.59657	99.985	99.097
186	3.61415	99.985	99.097
187	3.72324	99.983	99.097
188	3.78170	99.982	99.167

Figure 2-1 SPS Coverage (24-Hour Period: 20 January 2003)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -95, Lat: 40)



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 January through 31 March 2003, there were a total of twenty-one reported outages. Seventeen of these outages were maintenance activities and were reported in advance. Four were unscheduled outages. 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
2003002	24	S	9-Jan	1:45	9-Jan	5:20		3.58	3.58
5	5	S	23-Jan	21:30	24-Jan	4:53		7.38	7.38
6	17	S	25-Jan	0:16	27-Jan	19:22		52.36	52.36
10	5	S	3-Feb	16:26	3-Feb	19:18		2.87	2.87
12	10	S	4-Feb	12:50	4-Feb	15:32		1.03	1.03
15	17	S	4-Feb	14:01	4-Feb	18:34		4.55	4.55
16	8	S	10-Feb	13:00	10-Feb	21:43		8.72	8.72
20	17	S	24-Feb	12:14	24-Feb	15:17		3.05	3.05
22	7	S	27-Feb	5:22	27-Feb	11:03		5.68	5.68
24	31	S	4-Mar	15:18	4-Mar	20:52		5.57	5.57
27	6	S	7-Mar	14:04	7-Mar	21:27		7.38	7.38
29	18	S	12-Mar	14:01	12-Mar	23:22		9.35	9.35
31	16	S	14-Mar	19:56	15-Mar	2:14		6.30	6.30
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**0.00**	**117.82**	**117.82**
Type:	S = Scheduled		U = Unscheduled						

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

NANU 7: Announced the decommission of PRN21 on 27 January at 22:00 Zulu.

NANU 14: Announced the launch of PRN16 on 29 January. Another NANU will be issued when the satellite is set to active service.

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2003001	24	F	9-Jan	1:30	9-Jan	13:30	12	See NANU 2
3	5	F	23-Jan	21:15	24-Jan	9:15	12	See NANU 5
4	17	F	25-Jan	0:00	N/A	N/A	N/A	See NANU 6
8	5	F	3-Feb	16:00	4-Feb	4:00	12	See NANU 10
9	10	F	4-Feb	12:00	5-Feb	0:00	12	See NANU 12
11	8	F	10-Feb	12:45	11-Feb	0:45	12	See NANU 16
13	17	F	4-Feb	14:01	N/A	N/A	N/A	See NANU 15
18	17	F	24-Feb	12:00	25-Feb	0:00	12	See NANU 20
19	7	F	27-Feb	3:45	27-Feb	15:45	12	See NANU 22
21	31	F	4-Mar	15:00	5-Mar	3:00	12	See NANU 24
23	6	F	7-Mar	13:45	8-Mar	1:45	12	See NANU 27
25	18	F	12-Mar	13:45	13-Mar	1:45	12	See NANU 29
26	16	F	14-Mar	19:15	15-Mar	7:15	12	See NANU 31
28	17	F	17-Mar	22:00	18-Mar	10:00	12	See NANU 30
					Total Forecast Downtime		**144**	

Table 3-3 NANUs Canceled

NANU#	PRN	Type	Start Date	Start Time	Comments
30	17	C	17-Mar	22:00	See NANU 28

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 January - 31 Mar. 2003	1 October, 1999- 31 Mar. 2003
Total Forecast Downtime (hrs):	144	3752.25
Total Actual Downtime (hrs):	117.82	6115.63
Total Actual Scheduled Downtime (hrs):	117.82	3191.62
Total Actual Unscheduled Downtime (hrs):	0	2924.01
Total Satellite Observed MTTR (hrs):	9.06	24.46
Scheduled Satellite Observed MTTR (hrs):	9.06	15.72
Unscheduled Satellite Observed MTTR (hrs):	N/A	62.21
# Total Satellite Outages:	13	250
# Scheduled Satellite Outages:	13	203
# Unscheduled Satellite Outages:	0	47
Percent Operational -- Scheduled Downtime:	99.80	99.63
Percent Operational -- All Downtime:	99.99	99.28

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 January and 31 March 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
Atlantic City	1.245	5.600	4.791	1.855	3.888	3.396	7755295
Columbus	1.210	4.657	3.603	1.907	4.654	3.603	7052500
Denver	1.202	5.906	5.581	1.925	4.705	3.757	7650974
Grand Forks	1.147	5.856	4.578	1.903	4.589	3.858	7291762
Greenwood	1.228	5.722	5.426	1.890	5.226	4.941	7625200
Prescott	1.309	6.000	4.107	2.288	5.971	5.687	7714113
Billings	1.160	5.999	5.272	1.888	5.180	4.860	7552131
Anchorage	1.158	5.594	5.014	1.858	4.587	4.211	7681230
Chicago	1.181	5.977	4.633	1.836	4.625	3.538	7557673
Kansas City	1.230	5.669	5.467	1.869	4.805	3.681	7657504
Salt Lake City	1.193	5.959	5.397	1.894	4.283	3.860	7675623
Miami	1.188	4.340	4.056	1.843	3.854	3.605	7665111
Atlanta	1.247	5.893	5.557	1.853	5.459	5.101	6305276

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 fourteen 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

NSTB/WAAS Site	Total Number of Seconds of PDOP Monitoring	Total Seconds with PDOP > 6	Overall % Availability
Atlantic City	7755295	0	100%
Columbus	7052500	0	100%
Denver	7650974	0	100%
Grand Forks	7291762	0	100%
Greenwood	7625200	0	100%
Prescott	7714113	0	100%
Billings	7552131	0	100%
Anchorage	7681230	0	100%
Chicago	7557673	0	100%
Kansas City	7657504	0	100%
Salt Lake City	7675623	0	100%
Miami	7665111	0	100%
Atlanta	6305276	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 fourteen 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

NSTB/WAAS Site	Number of Samples This Quarter	Maximum Horizontal Error (Meters)
Atlantic City	7755295	26.4
Columbus	7052500	17.2
Denver	7650974	15.5
Grand Forks	7291762	14.2
Greenwood	7625200	18.0
Prescott	7714113	12.3
Billings	7552131	18.2
Anchorage	7681230	9.53
Chicago	7557673	22.0
Kansas City	7657504	17.1
Salt Lake City	7675623	13.3
Miami	7665111	24.1
Atlanta	6305276	20.1

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 January through 31 March 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

NSTB Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Atlantic City	4.735	8.661	19.840	17.248
Columbus	4.738	8.327	11.920	16.326
Denver	4.576	8.997	13.293	20.121
Grand Forks	5.080	7.354	12.210	14.992
Greenwood	4.667	9.748	16.269	19.127
Prescott	4.712	9.844	11.403	22.949
Billings	5.118	7.648	12.441	15.971
Anchorage	4.448	7.191	8.724	16.516
Chicago	4.879	8.001	14.620	16.950
Kansas City	4.824	8.469	12.828	17.765
Salt Lake City	4.656	8.926	11.922	18.303
Miami	4.982	12.254	18.160	23.577
Atlanta	4.976	9.960	15.917	18.677

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all fourteen NSTB and WAAS sites from 1 January to 31 March 2003.

Figure 5-1 Combined Vertical Error Histogram

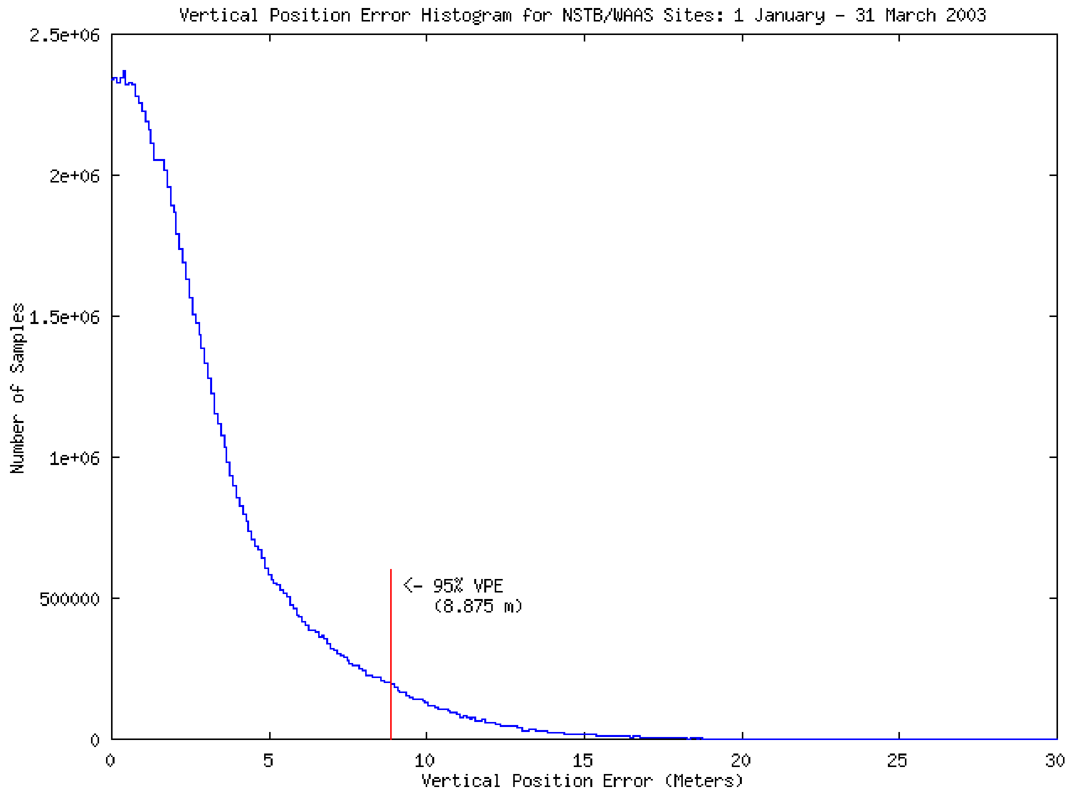
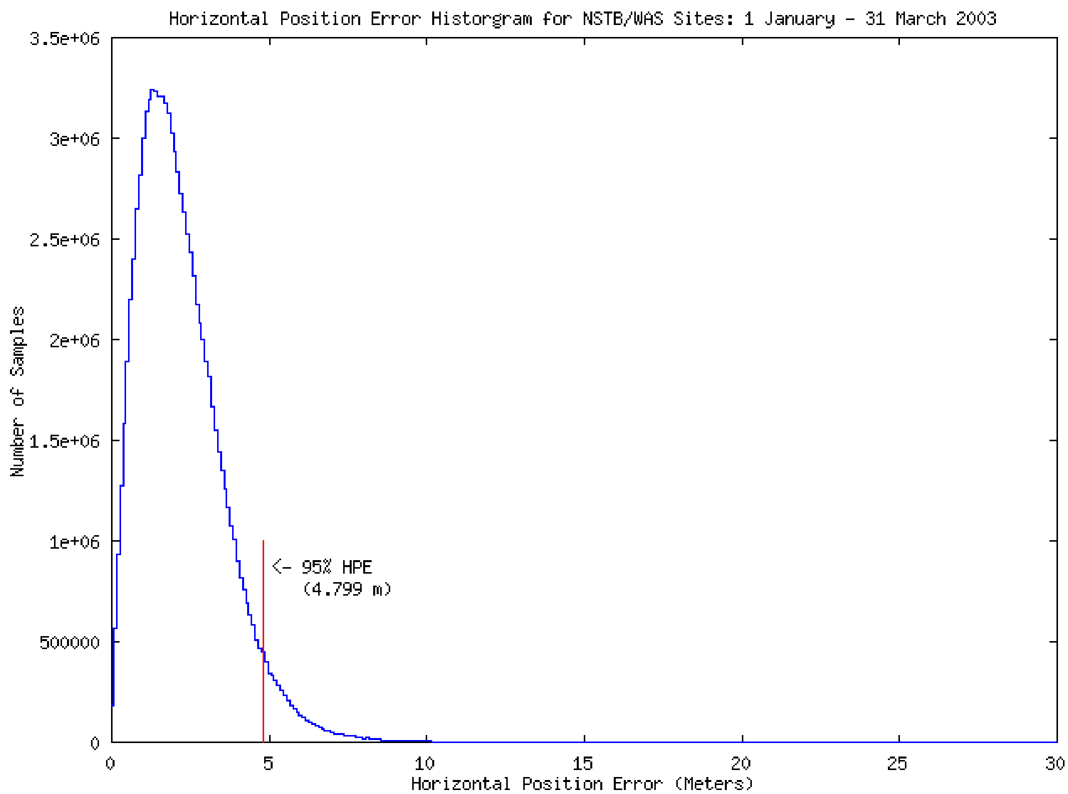


Figure 5-2 Combined Horizontal Error Histogram



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

NSTB Site	95% Horizontal (m)	95% Vertical (m)
Atlantic City	1.127	2.996
Columbus	1.389	3.773
Denver	1.346	4.424
Grand Forks	1.538	3.795
Greenwood	1.072	3.342
Prescott	1.387	4.431
Billings	1.364	3.305
Anchorage	1.568	3.297
Chicago	1.356	3.641
Kansas City	1.244	3.334
Salt Lake City	1.308	3.300
Miami	1.131	3.660
Atlanta	1.008	3.192

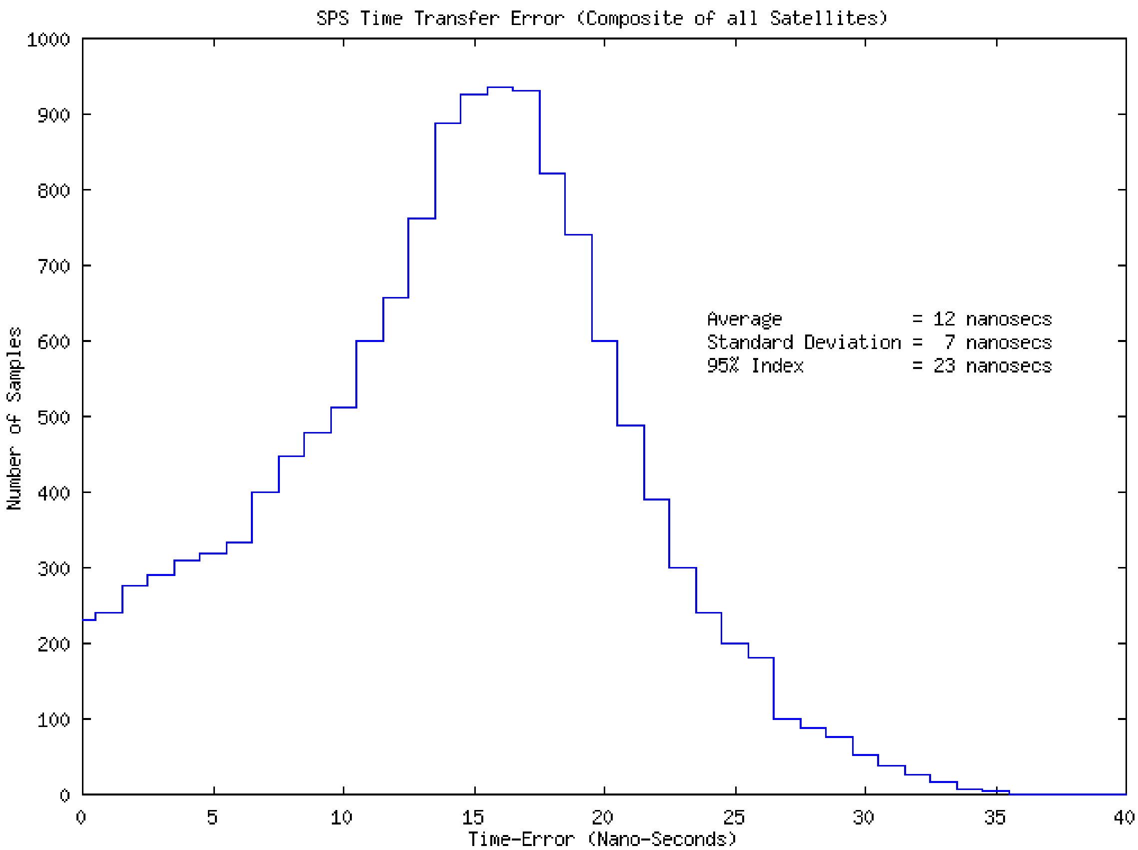
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 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 January and 31 March 2003. The Millennium at Anderson 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. $\leq$ 150 m)	Samples
1	-0.996	3.197	3.038	6.392	20.597	2137679
2	0.405	3.012	2.984	5.974	14.504	2171708
3	-0.505	3.331	3.293	6.818	20.799	1705835
4	-2.315	4.733	4.128	9.353	18.995	2139796
5	0.183	3.178	3.173	6.317	20.413	2474551
6	0.013	2.757	2.757	5.432	15.468	2396228
7	-2.145	4.752	4.241	9.618	22.906	2206488
8	-1.401	3.947	3.691	7.675	19.027	2019093
9	-0.043	2.716	2.716	5.274	23.704	2212854
10	-0.205	3.548	3.542	7.418	24.347	2039759
11	-1.542	3.942	3.628	8.303	24.182	2060361
13	-2.160	3.480	2.728	6.766	22.952	2390617
14	1.270	2.289	1.904	4.234	14.235	2187148
15	0.734	2.599	2.493	4.878	17.717	2134204
17	1.106	3.198	3.001	6.383	20.017	1768478
18	1.156	2.348	2.044	4.318	21.770	2093752
20	-1.410	3.699	3.420	7.876	26.067	2465275
23	2.080	3.469	2.776	6.701	19.799	2234290
24	-1.345	4.289	4.073	9.075	18.580	2228812
25	0.808	2.401	2.261	4.623	9.710	2208931
26	-0.261	2.774	2.762	5.640	15.052	1777304
27	-1.885	3.953	3.474	7.643	17.114	1737643
28	-2.161	4.716	4.192	9.916	21.573	1953302
29	-0.681	2.992	2.914	5.883	18.858	1771123
30	0.545	2.843	2.790	5.192	20.702	2419145
31	-0.748	3.576	3.497	7.095	16.760	1818212

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	0.00671	0.00671	0.00411	0.82052	2137679
2	0.00004	0.00426	0.00426	0.00361	0.37350	2171708
3	-0.00016	0.00453	0.00453	0.00396	0.54994	1705835
4	-0.00019	0.00817	0.00817	0.00756	0.57139	2139796
5	-0.00003	0.00758	0.00758	0.00501	0.64349	2474551
6	-0.00005	0.00462	0.00462	0.00392	0.61740	2396228
7	-0.00002	0.00830	0.00830	0.00811	0.63967	2206488
8	0.00017	0.00739	0.00739	0.00635	0.53177	2019093
9	0.00002	0.00809	0.00809	0.00532	0.76939	2212854
10	-0.00017	0.00551	0.00550	0.00518	0.66146	2039759
11	-0.00018	0.00723	0.00723	0.00650	0.87556	2060361
13	-0.00010	0.00676	0.00676	0.00545	0.71461	2390617
14	-0.00007	0.00211	0.00211	0.00323	0.16114	2187148
15	-0.00009	0.00414	0.00414	0.00419	0.50225	2134204
17	-0.00003	0.00495	0.00495	0.00449	0.49876	1768478
18	-0.00001	0.00220	0.00220	0.00371	0.05514	2093752
20	-0.00032	0.00759	0.00758	0.00577	0.65440	2465275
23	-0.00010	0.00315	0.00314	0.00397	0.42233	2234290
24	-0.00020	0.00679	0.00678	0.00638	0.72737	2228812
25	0.00006	0.00253	0.00253	0.00333	0.17126	2208931
26	-0.00025	0.00379	0.00378	0.00429	0.38677	1777304
27	0.00027	0.00578	0.00578	0.00540	0.55032	1737643
28	0.00011	0.00774	0.00774	0.00749	0.50836	1953302
29	-0.00020	0.00436	0.00435	0.00437	0.56268	1771123
30	0.00009	0.00617	0.00617	0.00424	0.60091	2419145
31	-0.00020	0.00558	0.00558	0.00470	0.67806	1818212

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	0.00006	0.00006	99.999	0.00822	2137679
2	0	0.00004	0.00004	100	0.00373	2171708
3	0	0.00004	0.00004	100	0.00551	1705835
4	0	0.00007	0.00007	100	0.00573	2139796
5	0	0.00007	0.00007	100	0.00643	2474551
6	0	0.00004	0.00004	100	0.00617	2396228
7	0	0.00007	0.00007	100	0.00639	2206488
8	0	0.00006	0.00006	100	0.00537	2019093
9	0	0.00007	0.00007	100	0.00771	2212854
10	0	0.00005	0.00005	100	0.00659	2039759
11	0	0.00006	0.00006	99.999	0.00877	2060361
13	0	0.00006	0.00006	100	0.00715	2390617
14	0	0.00001	0.00001	100	0.00162	2187148
15	0	0.00003	0.00003	100	0.00502	2134204
17	0	0.00004	0.00004	100	0.00497	1768478
18	0	0.00001	0.00001	100	0.00059	2093752
20	0	0.00007	0.00007	100	0.00654	2465275
23	0	0.00002	0.00002	100	0.00426	2234290
24	0	0.00006	0.00006	100	0.00728	2228812
25	0	0.00002	0.00002	100	0.00173	2208931
26	0	0.00003	0.00003	100	0.00388	1777304
27	0	0.00005	0.00005	100	0.00553	1737643
28	0	0.00007	0.00007	100	0.00507	1953302
29	0	0.00004	0.00004	100	0.00561	1771123
30	0	0.00005	0.00005	100	0.00599	2419145
31	0	0.00005	0.00005	100	0.00681	1818212

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 25 with an error of 30.122 meters. Satellite 17 had the lowest maximum range error of 12.090 meters.

Figure 5-4 Distribution of Daily Max Range Errors

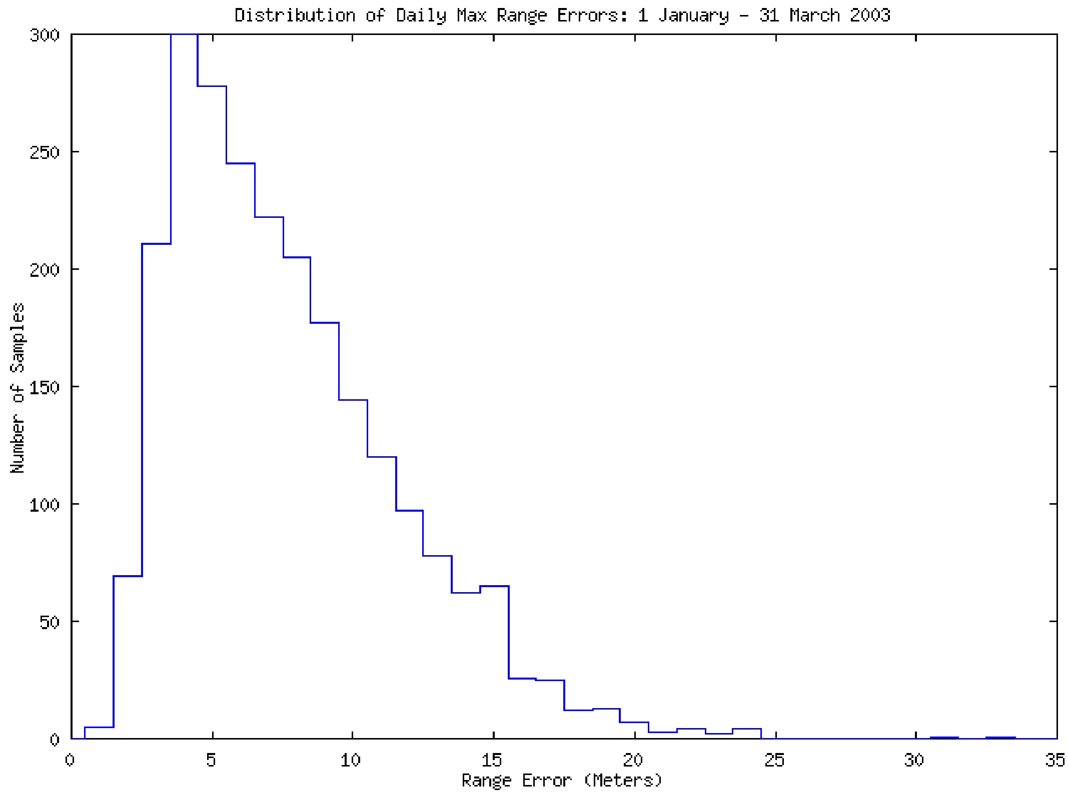


Figure 5-5: Distribution of Daily Max Range Rate Errors

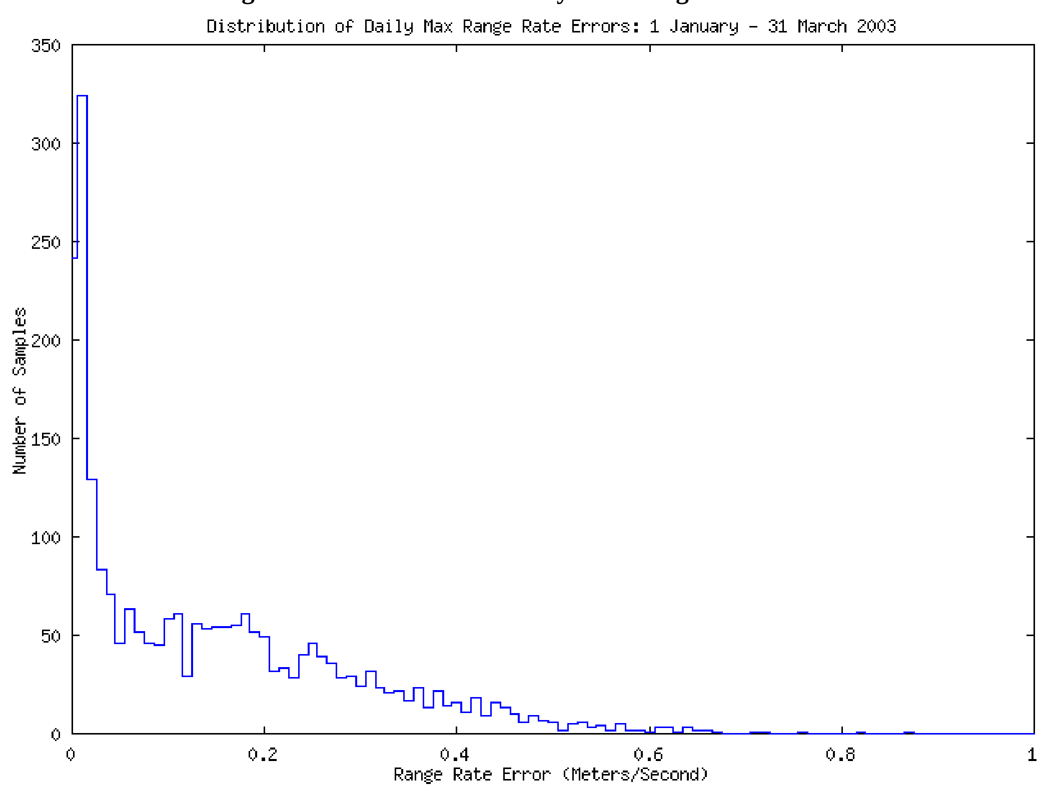


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

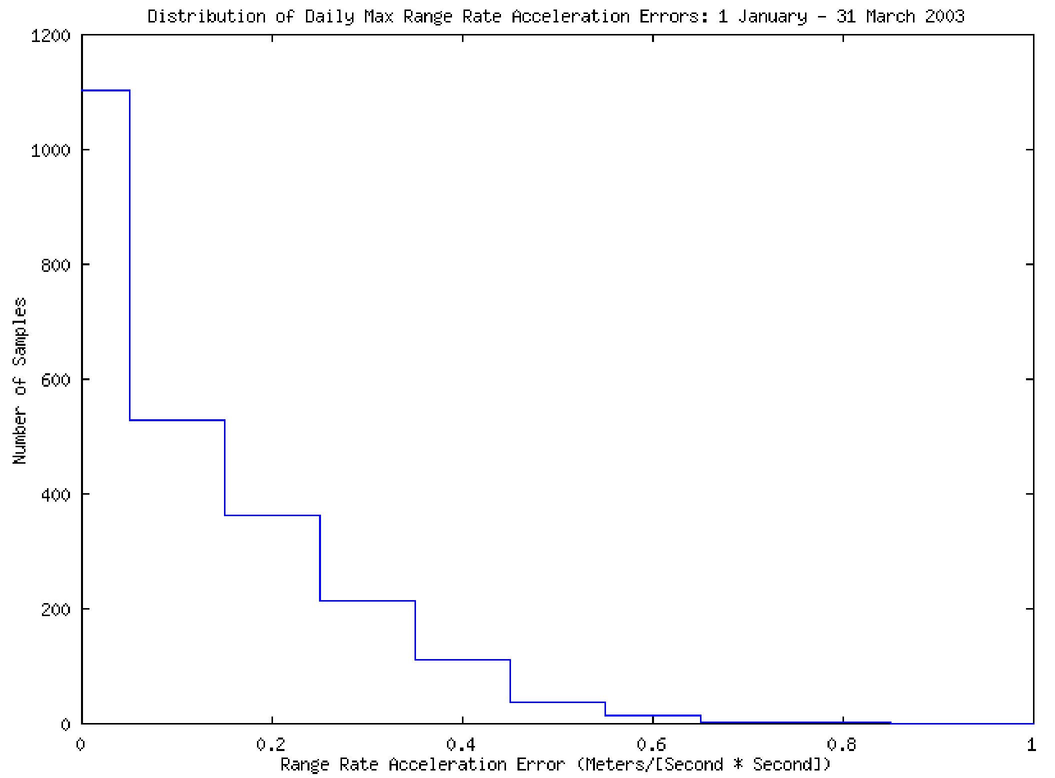


Figure 5-7: Range Error Histogram

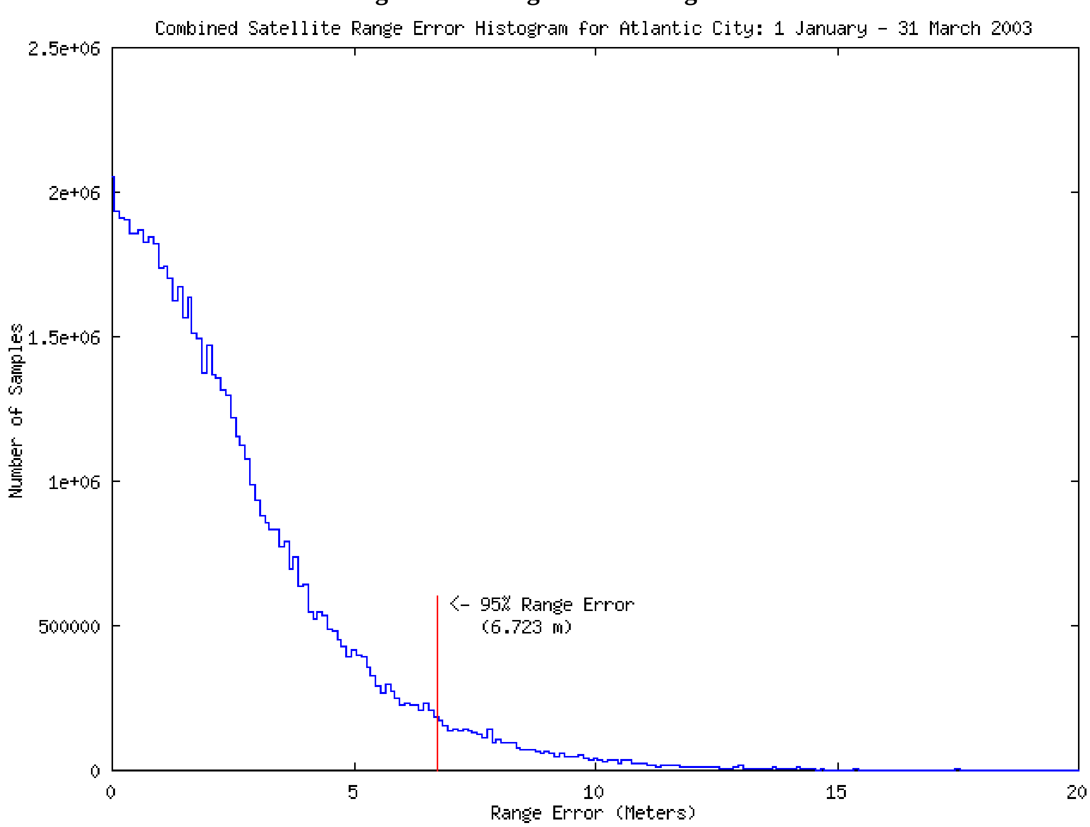


Figure 5-8: Maximum Range Error Per Satellite

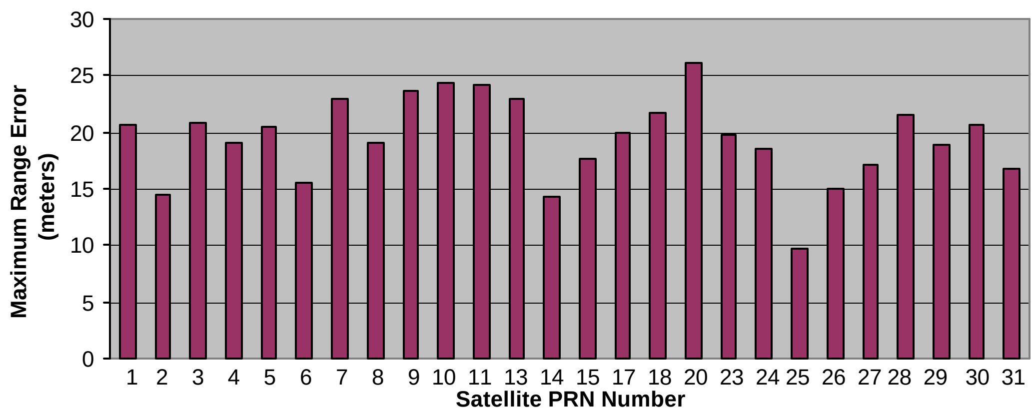


Figure 5-9: Maximum Range Rate Error Per Satellite

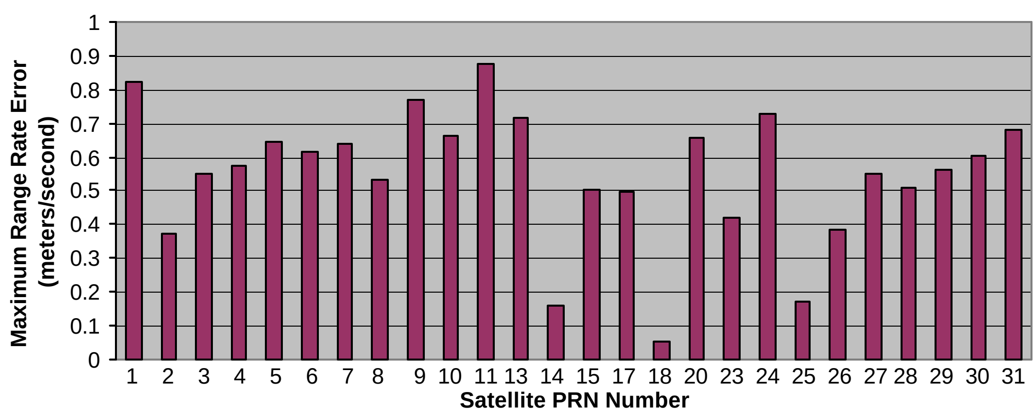
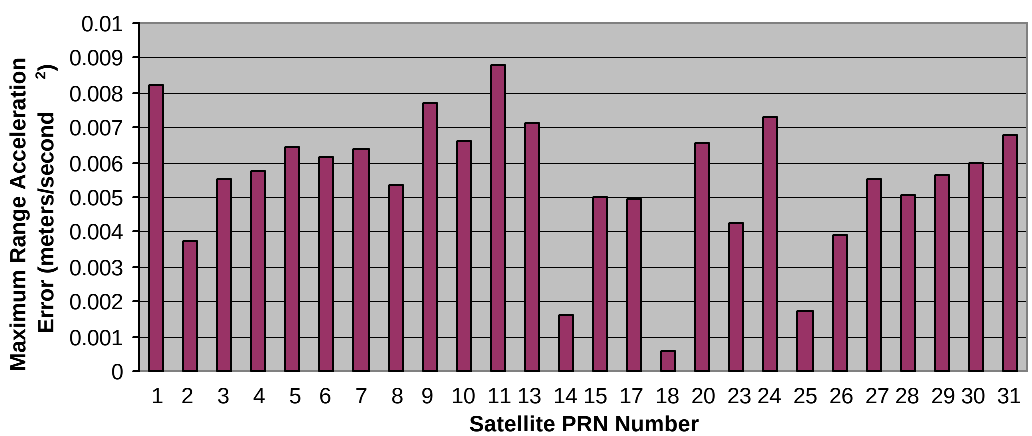


Figure 5-10: Maximum Range Acceleration Per Satellite



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 31 January – 2 February 2003

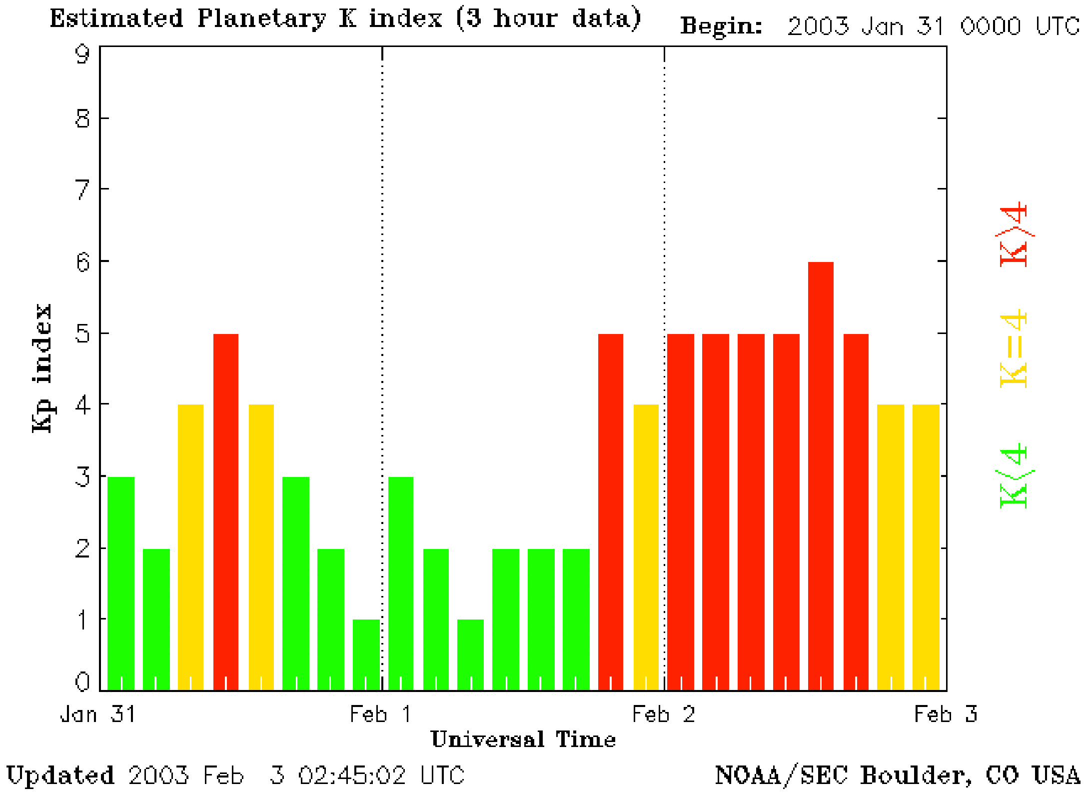


Figure 6-2 K-Index for 17-19 March 2003

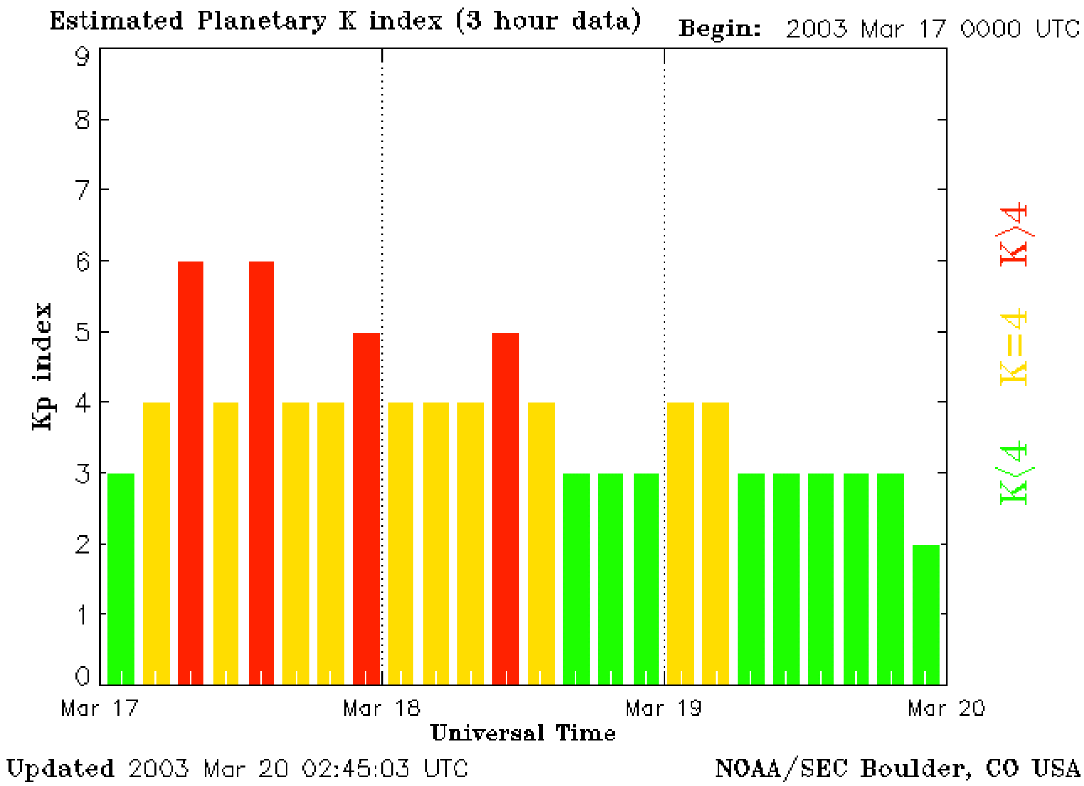
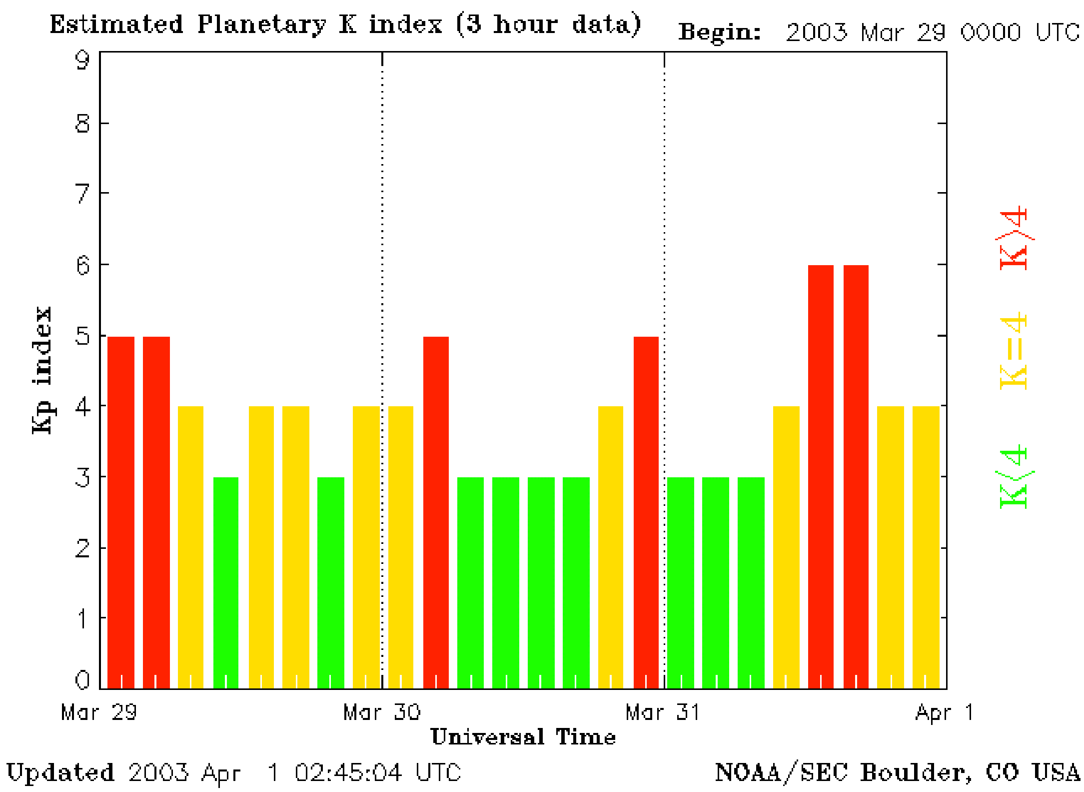


Figure 6-3 K-Index for 29-31 March 2003



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 2 February 2003

NSTB/WAAS Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Atlantic City	1.248	4.255	1.856	4.254	3.750
Columbus	1.292	4.636	1.941	4.636	3.599
Denver	1.206	4.676	1.928	4.674	3.601
Grand Forks	1.214	4.569	1.932	4.569	3.851
Greenwood	1.293	4.592	1.889	4.166	2.967
Prescott	1.422	5.998	1.938	5.972	5.675
Billings	1.219	4.210	1.890	4.199	3.503
Anchorage	1.159	4.076	1.859	4.071	3.376
Chicago	1.182	4.616	1.846	4.616	3.535
Kansas City	1.230	4.662	1.895	4.662	3.465
Salt Lake City	1.200	3.422	1.905	3.421	3.055
Miami	1.188	3.077	1.833	3.077	2.832
Atlanta	1.264	4.222	1.863	4.210	3.838

Table 6-2 Horizontal & Vertical Accuracy Statistics for 2 February 2003

NSTB Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Atlantic City	5.039	6.164	19.737	25.507
Columbus	4.829	7.270	7.886	11.768
Denver	5.485	8.257	7.181	11.327
Grand Forks	3.975	7.843	11.834	15.053
Greenwood	6.730	8.085	9.068	10.788
Prescott	6.526	9.201	7.860	11.039
Billings	5.153	6.401	9.818	10.726
Anchorage	4.881	5.359	6.430	7.861
Chicago	6.076	6.357	10.134	10.749
Kansas City	5.669	7.130	7.343	12.855
Salt Lake City	6.589	8.140	9.445	9.917
Miami	5.521	8.462	14.774	11.158
Atlanta	6.046	8.009	10.399	9.208

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	99.976%
• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 96.9% at worst-case point	99.028% Availability 99.9% PDOP was 4.128
Conditions and Constraints	***Satellite Availability Standard***	***Measured Performance***
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.85% global average	100%
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.16% single point average	100%
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	100%
• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	≥ 83.92% at worst-case point on worst-case day	100%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.97% global average	100%

• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.79% single point average	100%
Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	Predictable Accuracy ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	≤5.118m HE 95% ≤19.840m HE 99.99% ≤12.254m VE 95% ≤23.577m VE 99.99%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	Repeatable Accuracy ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	≤1.568m HE 95% ≤4.431m VE 95%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	Relative Accuracy ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	Future Reports
• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	≤23 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each	Range Domain Accuracy ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range	26.067m NTE Range Error 0.87556m/s NTE Rate Error 8.77mm/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	$\leq$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@sec.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 01 01     9  4 1 3 1 3 1 1 1    8  0 0 3 3 4 1 1 1   10  2 2 3 3 3 3 2 2
2003 01 02     5  1 1 1 2 2 2 2 1    9  1 1 1 3 3 3 1 1    8  2 2 2 2 3 3 3 1
2003 01 03    12  2 2 2 2 3 4 2 3   23  1 1 2 2 4 6 4 4   13  2 2 2 2 3 4 3 4
2003 01 04     9  3 2 2 2 3 2 2 2   20  4 3 1 4 5 3 3 2   13  4 4 2 2 3 3 3 2
2003 01 05     5  1 1 1 1 2 2 2 2    7  1 1 1 1 3 3 2 2    9  2 2 2 2 3 3 3 2
2003 01 06     2  0 0 0 0 1 2 1 1    1  1 0 0 1 0 0 0 1    7  0 2 1 1 2 3 2 2
2003 01 07     5  1 2 2 1 1 2 1 1    7  2 1 1 4 2 1 1 1    9  2 3 2 3 2 2 3 2
2003 01 08     4  2 0 3 1 1 1 0 0    2  1 0 2 2 0 0 0 0    7  2 2 3 2 2 2 2 2
2003 01 09     2  0 0 0 0 1 1 2 1    1  0 0 0 0 0 1 1 0    7  2 2 1 1 2 3 3 3
2003 01 10     7  1 2 1 2 2 2 2 3   15  1 1 2 3 5 3 3 3   10  2 2 2 2 3 3 3 3
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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.