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 #45, includes data collected from 1 January through 31 March 2004. The next quarterly report will be issued 31 July 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 98.472% or better.

Availability was verified by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 January and 31 March 2004 and by calculating the satellite availability from the data obtained from the twenty-one sites. A total of fourteen 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 24.881 meters on Satellite PRN 30. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 0.94728 Meters/second on Satellite PRN 20. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 9.41 Millimeters/second^2 on Satellite PRN 20. 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 2004, the GPS performance did not meet all SPS requirements that were evaluated. Please see the problem report section for further details.

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1.0 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS and WAAS for IFR operations and is developing Local Area Augmentation (LAAS), which is an additional GPS augmentation system. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Analysis report. This report contains data collected at the following twenty-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
- Houston, TX
- Kansas City, KS
- Los Angeles, CA
- Salt Lake City, UT
- Miami, FL
- Minneapolis, MI
- Oakland, CA
- Cleveland, OH
- Seattle, WA
- San Juan, PR
- Atlanta, GA

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

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

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

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

1.2 Summary of Performance Requirements and Metrics

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

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

1.3 Report Overview

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

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

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

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

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

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

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

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

Table 1-1 SPS Performance Requirements

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

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

2.0 Coverage Performance

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

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

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

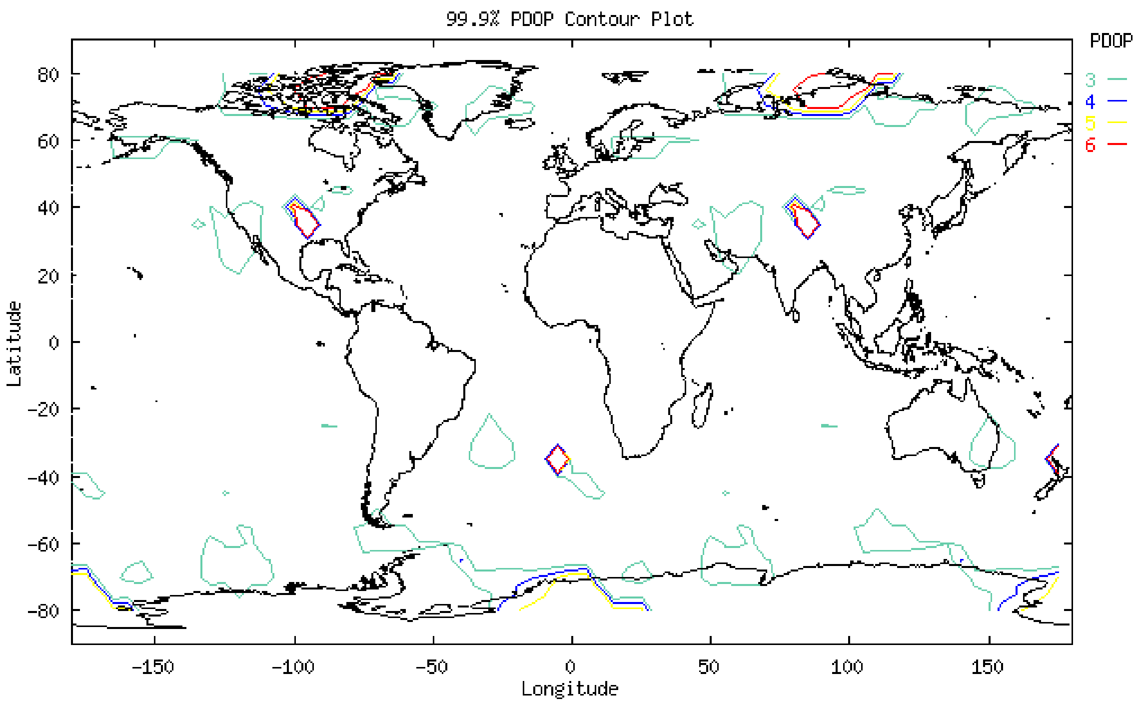
Almanacs for GPS weeks 228-240 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACB 430 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.91277 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

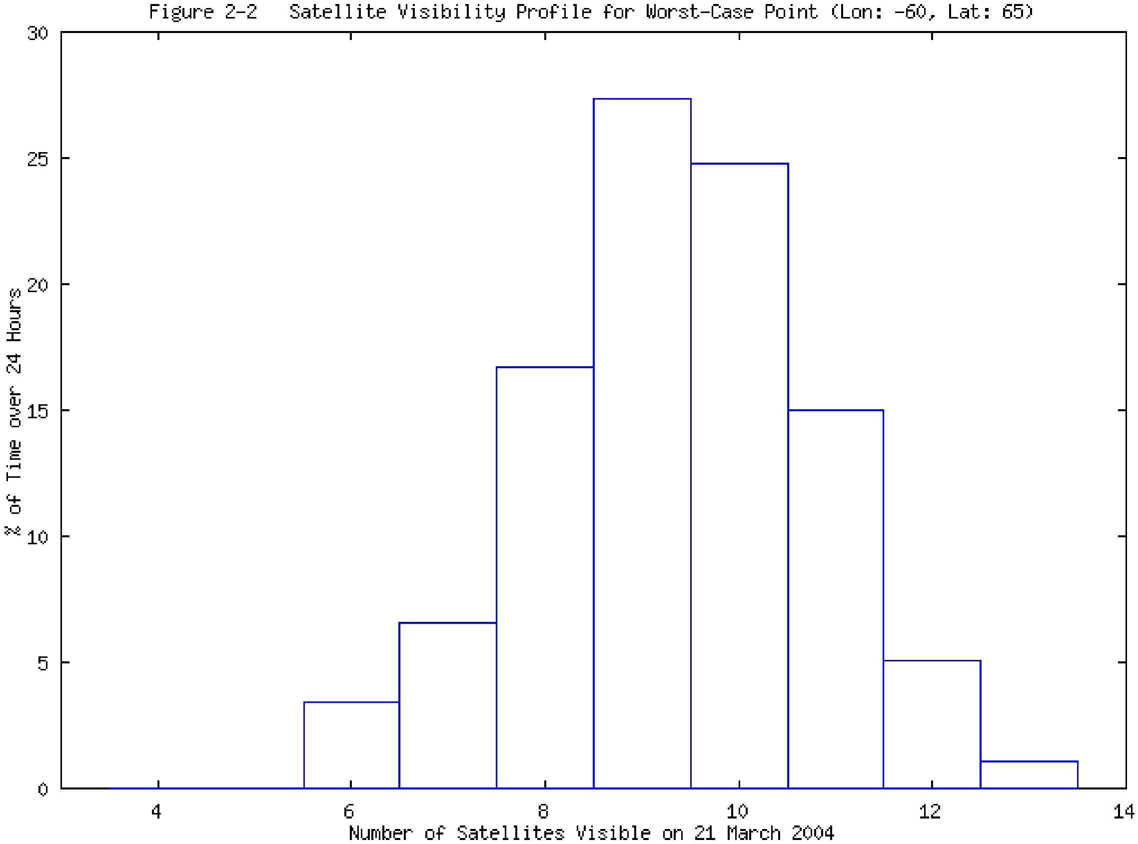
GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
228	3.87375	99.971	98.958
229	3.86895	99.970	98.889
230	3.07390	99.994	99.097
231	2.91628	99.999	99.722
232	3.20706	100	99.792
233	3.11346	99.994	99.028
234	3.64648	99.967	98.819
235	3.21725	99.994	99.097
236	3.21274	99.993	99.097
237	3.91277	99.980	99.167
238	3.20162	99.993	99.236
239	3.84623	99.961	98.472
240	3.18538	99.995	99.375

Figure 2-1 SPS Coverage (24-Hour Period: 21 March 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 January through 31 March 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
2004002	2	S	6-Jan	2:30	6-Jan	12:18		9.63	9.63
6	14	S	16-Jan	1:45	16-Jan	6:43		4.46	4.46
8	23	S	1-Jan	21:18	20-Jan	22:53		457.58	457.58
11	4	S	21-Jan	19:39	22-Jan	2:07		6.46	6.46
14	24	S	28-Jan	18:38	28-Jan	23:28		4.83	4.83
15	27	S	3-Feb	12:09	3-Feb	18:16		6.11	6.11
20	10	S	10-Feb	20:04	10-Feb	21:15		1.18	1.18
23	31	S	15-Feb	4:52	15-Feb	14:17		9.41	9.41
24	6	S	12-Feb	18:28	20-Feb	20:52		194.40	194.40
31	31	S	4-Mar	0:14	5-Mar	18:18		42.06	42.06
32	27	S	9-Mar	5:14	9-Mar	11:11		5.95	5.95
35	5	S	17-Mar	14:52	18-Mar	0:23		9.51	9.51
39	6	S	17-Mar	15:31	29-Mar	15:58		288.45	288.45
40	26	S	29-Mar	19:27	30-Mar	0:05		4.63	4.63
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**0.00**	**1044.66**	**1044.66**
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
2003119	2	F	6-Jan	2:15	6-Jan	14:15	12	See NANU 120
121	2	F	6-Jan	2:15	6-Jan	14:15	12	See NANU 2
2004001	23	F	1-Jan	21:18	N/A	N/A	N/A	See NANU 8
3	14	F	13-Jan	1:15	13-Jan	13:15	12	See NANU 4
4	14	FR	16-Jan	1:15	16-Jan	13:15	12	See NANU 6
7	4	F	21-Jan	19:00	22-Jan	7:00	12	See NANU 11
9	27	F	26-Jan	12:15	27-Jan	0:15	12	See NANU 12
10	24	F	28-Jan	18:15	29-Jan	6:15	12	See NANU 14
13	27	F	3-Feb	11:45	3-Feb	23:45	12	See NANU 15
16	23	F	5-Feb	20:30	N/A	N/A	N/A	
17	10	F	10-Feb	19:15	11-Feb	7:15	12	See NANU 20
18	6	F	12-Feb	18:00	13-Feb	6:00	12	See NANU 19
19	6	FR	12-Feb	18:00	27-Feb	23:59	365.98	See NANU 24
22	31	F	15-Feb	4:52	N/A	N/A	N/A	See NANU 23
25	2	F	22-Feb	10:37	N/A	N/A	N/A	
26	27	F	4-Mar	5:00	4-Mar	17:00	12	See NANU 29
27	30	F	9-Mar	14:30	10-Mar	2:30	12	See NANU 30
28	31	F	4-Mar	0:14	N/A	N/A	N/A	See NANU 31
29	27	FR	9-Mar	4:45	9-Mar	16:45	12	See NANU 32
33	5	F	17-Mar	14:30	18-Mar	2:30	12	See NANU 35
34	6	F	17-Mar	15:31	N/A	N/A	N/A	See NANU 39
37	26	F	29-Mar	18:45	30-Mar	6:45	12	See NANU 40
					Total Forecast Downtime		**545.98**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
2003120	2	C	6-Jan	2:15	See NANU 119
2004012	27	C	26-Jan	12:15	See NANU 9
30	30	C	9-Mar	14:30	See NANU 27

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

Table 3-4 GPS Block II/IIA Satellite RMA Data		
Satellite Reliability/Maintainability/Availability (RMA) Parameter	**1 October - 31 Mar. 2004**	**1 October, 1999- 31 Mar. 2004**
Total Forecast Downtime (hrs):	545.98	4611.23
Total Actual Downtime (hrs):	1044.66	8343.04
Total Actual Scheduled Downtime (hrs):	1044.66	5416.38
Total Actual Unscheduled Downtime (hrs):	0	2926.66
Total Satellite Observed MTTR (hrs):	74.62	27.63
Scheduled Satellite Observed MTTR (hrs):	74.62	21.41
Unscheduled Satellite Observed MTTR (hrs):	N/A	59.73
# Total Satellite Outages:	14	302
# Scheduled Satellite Outages:	14	253
# Unscheduled Satellite Outages:	0	49
Percent Operational -- Scheduled Downtime:	98.29	99.51
Percent Operational -- All Downtime:	99.90	99.24

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

2004005: Announced the usability of PRN 22.
2004021: Announced the decommissioning of PRN 23.
2004036: Announced the launch of PRN 19.

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 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	1.551	6.000	5.387	2.761	5.995	5.669	2689901
Elko	1.258	5.973	5.510	1.899	5.451	4.469	7721439
Billings	1.201	4.038	3.361	1.774	3.668	2.998	6623543
Cold Bay	1.107	5.833	5.729	1.753	4.568	4.277	7113359
Juneau	1.219	4.140	3.948	1.804	3.989	3.795	6984038
Albuquerque	1.228	5.965	5.822	1.793	4.197	3.813	7165210
Anchorage	1.191	4.907	4.679	1.784	4.152	3.913	7165963
Boston	1.222	5.281	5.089	1.757	3.793	2.908	7160136
Washington, D.C.	1.184	5.064	3.599	1.772	3.885	3.397	7173014
Honolulu	1.233	5.880	4.545	1.757	4.085	3.799	7023550
Houston	1.195	4.336	3.715	1.773	3.714	3.459	6979647
Kansas City	1.158	3.904	3.482	1.779	3.736	2.883	7166208
Los Angeles	1.206	6.000	5.665	1.811	4.388	3.833	7167639
Salt Lake City	1.222	6.000	5.339	1.795	4.457	4.023	7167164
Miami	1.224	5.084	4.925	1.804	4.966	4.803	7167147
Minneapolis	1.144	5.590	5.138	1.761	3.948	3.539	7164897
Oakland	1.157	5.977	5.700	1.777	5.225	4.629	7164013
Cleveland	1.160	4.807	4.246	1.790	4.287	3.724	7167356
Seattle	1.131	4.053	3.456	1.799	3.836	3.260	6789327
San Juan	1.210	5.844	5.536	1.785	4.880	4.590	7168460
Atlanta	1.252	5.497	5.243	1.813	4.624	4.047	7165634

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	2689901	0	100%
Elko	7721439	0	100%
Billings	6623543	0	100%
Cold Bay	7113359	0	100%
Juneau	6984038	0	100%
Albuquerque	7165210	0	100%
Anchorage	7165963	0	100%
Boston	7160136	0	100%
Washington, D.C.	7173014	0	100%
Honolulu	7023550	0	100%
Houston	6979647	0	100%
Kansas City	7166208	0	100%
Los Angeles	7167639	0	100%
Salt Lake City	7167164	0	100%
Miami	7167147	0	100%
Minneapolis	7164897	0	100%
Oakland	7164013	0	100%
Cleveland	7167356	0	100%
Seattle	6789327	0	100%
San Juan	7168460	0	100%
Atlanta	7165634	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	2689901	29.4
Elko	7721439	20.6
Billings	6623543	12.8
Cold Bay	7113359	10,800*
Juneau	6984038	7,770*
Albuquerque	7165210	17.9
Anchorage	7165963	8,900*
Boston	7160136	122*
Washington, D.C.	7173014	16.9
Honolulu	7023550	16.4
Houston	6979647	15.8
Kansas City	7166208	24.1
Los Angeles	7167639	15.1
Salt Lake City	7167164	12.9
Miami	7167147	29.8
Minneapolis	7164897	17.9
Oakland	7164013	12.4
Cleveland	7167356	17.1
Seattle	6789327	11.3
San Juan	7168460	15.4
Atlanta	7165634	14.9

*See Problem Report Section

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 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	5.106	7.281	20.410	26.015
Elko	4.597	5.615	12.251	18.697
Billings	4.175	5.448	10.807	11.671
Cold Bay	3.895	6.261	8.160	13.546
Juneau	3.737	5.596	7.302	11.370
Albuquerque	4.215	5.418	12.251	17.104
Anchorage	3.623	6.107	8.396	12.359
Boston	4.096	5.331	11.761	10.967
Washington, D.C.	4.111	5.246	12.869	11.199
Honolulu	8.605	9.926	15.454	22.776
Houston	4.433	5.974	12.540	15.270
Kansas City	4.279	5.438	12.884	12.694
Los Angeles	4.407	5.733	11.381	13.785
Salt Lake City	4.284	5.373	11.393	11.816
Miami	4.572	6.445	11.204	17.592
Minneapolis	4.283	5.367	11.788	11.114
Oakland	4.368	5.604	10.460	12.516
Cleveland	4.258	5.307	13.026	10.939
Seattle	4.366	5.392	9.551	12.312
San Juan	5.268	8.102	14.667	27.173
Atlanta	4.340	5.730	10.927	12.788

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 January to 31 March 2004.

Figure 5-1 Combined Vertical Error Histogram

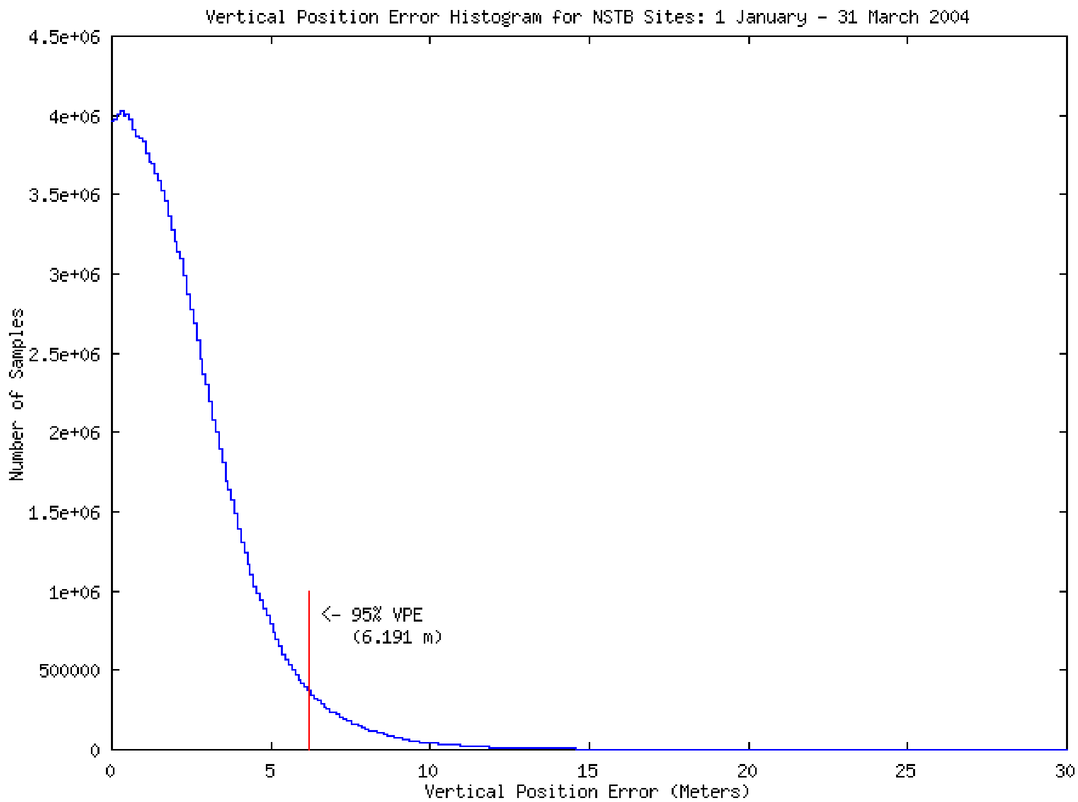
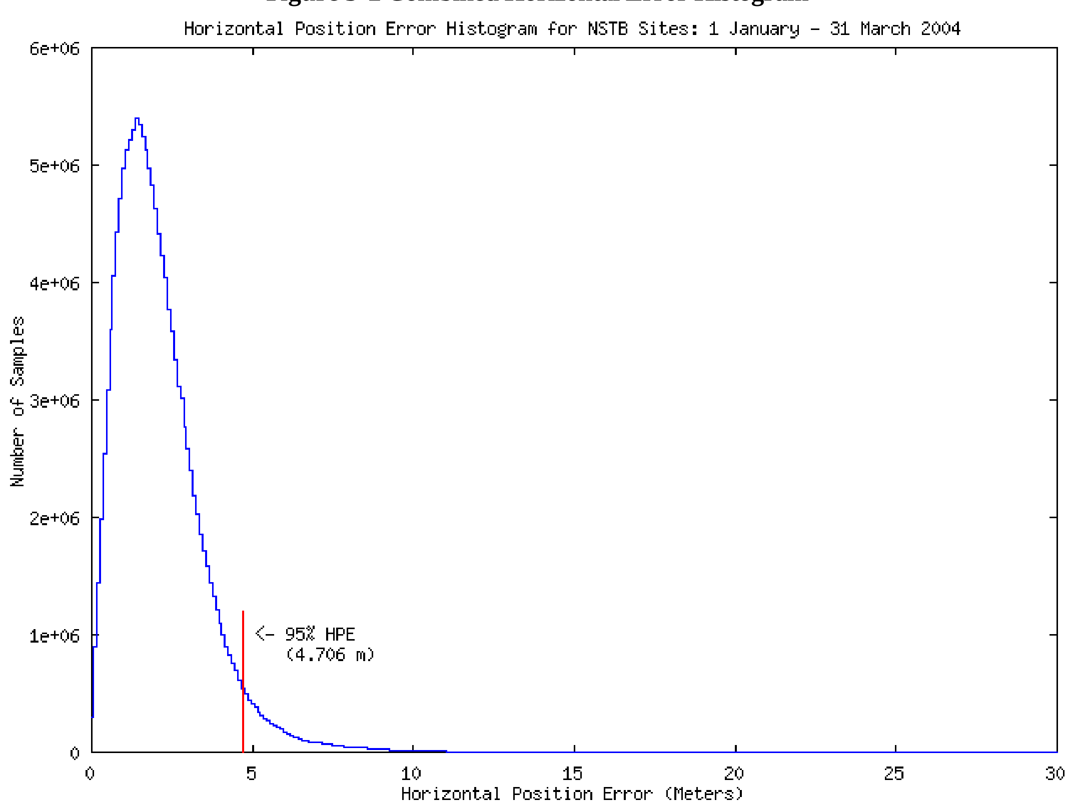


Figure 5-2 Combined Horizontal Error Histogram



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	2.171	6.306
Elko	1.710	3.716
Billings	1.091	2.460
Cold Bay	1.055	2.192
Juneau	0.937	2.522
Albuquerque	1.001	2.192
Anchorage	0.908	2.272
Boston	1.144	2.177
Washington, D.C.	1.043	1.922
Honolulu	2.136	5.151
Houston	0.986	2.209
Kansas City	0.926	2.242
Los Angeles	0.962	2.303
Salt Lake City	0.979	2.345
Miami	0.863	2.099
Minneapolis	1.247	2.670
Oakland	1.208	2.621
Cleveland	1.345	2.646
Seattle	1.107	2.602
San Juan	0.993	2.780
Atlanta	0.958	1.964

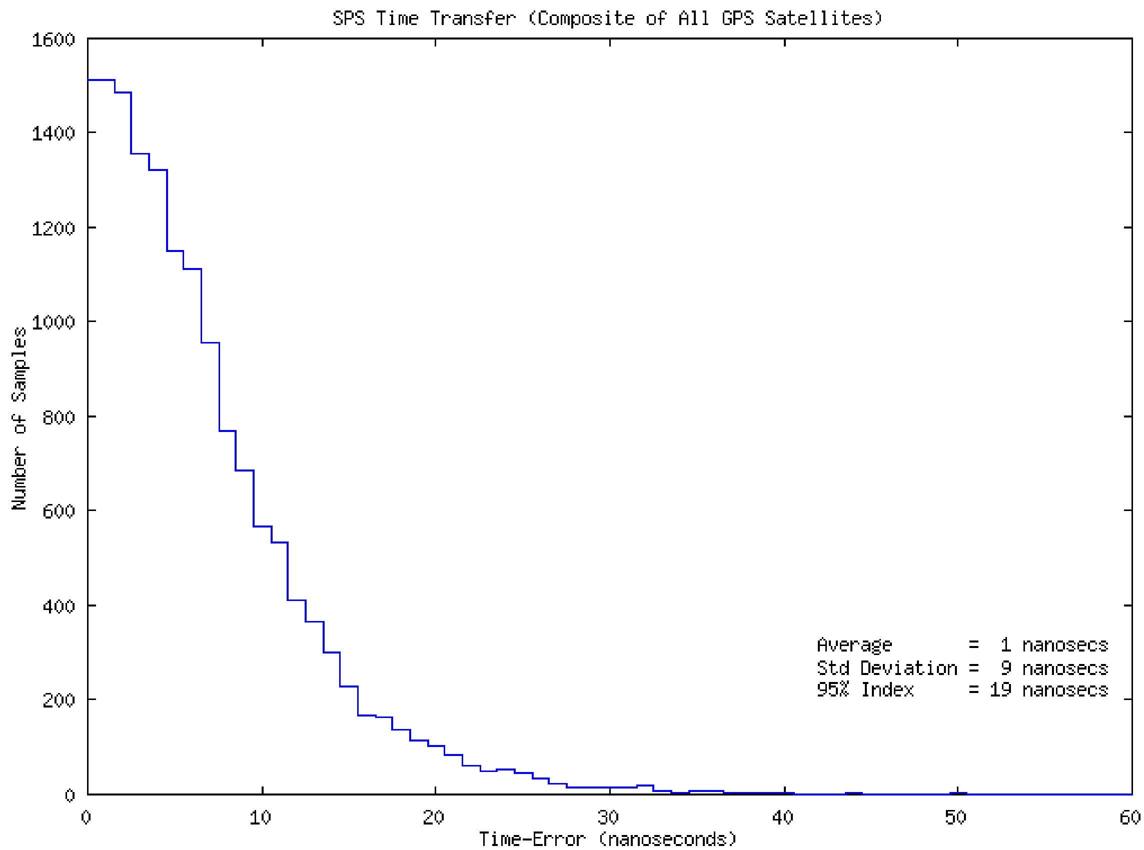
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 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 January and 31 March 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	1.921	3.198	2.557	6.181	20.137	1684581
2	2.459	3.373	2.308	6.086	16.466	1144267
3	1.299	2.582	2.232	4.818	11.765	2111981
4	-0.341	3.328	3.310	6.682	24.683	1775439
5	1.193	3.563	3.357	6.848	22.448	1762064
6	1.961	3.551	2.960	6.899	10.752	1172047
7	0.673	2.401	2.305	4.816	14.384	1715481
8	1.496	2.747	2.304	5.275	13.112	1619496
9	-0.353	2.461	2.435	4.810	11.525	2081220
10	1.614	3.708	3.338	6.860	12.540	1939186
11	1.625	2.562	1.981	4.783	10.737	2092168
13	1.672	2.450	1.790	4.479	17.412	1539386
14	2.060	2.860	1.984	5.030	13.395	1691354
15	1.444	2.968	2.594	5.596	11.893	1591455
16	1.780	2.956	2.360	5.414	19.733	2043033
17	0.868	3.882	3.783	7.407	11.120	1704910
18	1.691	2.933	2.396	5.708	10.447	1759484
20	1.898	3.249	2.637	6.002	21.154	1898464
21	1.985	3.402	2.763	6.399	11.314	1750277
22	0.898	2.958	2.818	5.286	8.260	1515372
23	1.855	2.551	1.751	4.699	11.206	362635
24	-0.459	4.034	4.008	7.808	14.175	1580415
25	1.838	2.885	2.223	5.550	10.435	1578670
26	0.310	2.451	2.432	4.825	8.686	2078205
27	1.704	2.406	1.699	4.461	17.796	1744091
28	0.953	2.304	2.098	4.401	10.304	1756321
29	0.560	2.614	2.553	5.323	9.276	2137786
30	0.053	3.417	3.416	6.775	24.881	2010471
31	1.896	2.999	2.324	5.659	23.446	1993939

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

PRN	Range Rate Error Mean	Range Rate Error RMS	Range Rate Error 1s	95% Range Rate Error	Max Range Rate Error (SPS Spec. ≤ 2 m)	Samples
1	-0.00004	0.00567	0.00567	0.00532	0.84053	1684581
2	0.00005	0.00565	0.00565	0.00594	0.37776	1144267
3	-0.00007	0.00287	0.00287	0.00513	0.15842	2111981
4	-0.00015	0.00574	0.00574	0.00590	0.91337	1775439
5	0.00018	0.00559	0.00558	0.00585	0.69675	1762064
6	0.00004	0.00321	0.00321	0.00554	0.18129	1172047
7	-0.00017	0.00251	0.00250	0.00490	0.08702	1715481
8	0.00002	0.00284	0.00283	0.00488	0.16869	1619496
9	0.00006	0.00319	0.00318	0.00517	0.18109	2081220
10	-0.00012	0.00349	0.00349	0.00557	0.22347	1939186
11	-0.00008	0.00273	0.00273	0.00512	0.15643	2092168
13	0.00006	0.00361	0.00361	0.00534	0.29459	1539386
14	0.0000	0.00263	0.00263	0.00489	0.55318	1691354
15	0.00001	0.00354	0.00354	0.00518	0.29792	1591455
16	-0.0005	0.00350	0.00350	0.00540	0.31077	2043033
17	-0.00003	0.00291	0.0091	0.00534	0.18554	1704910
18	-0.00004	0.00260	0.00259	0.00512	0.04600	1759484
20	-0.00010	0.00458	0.00458	0.00537	0.94728	1898464
21	-0.0008	0.00278	0.00278	0.00523	0.17320	1750277
22	-0.00001	0.00282	0.00282	0.00492	0.15665	1515372
23	-0.0009	0.00268	0.00268	0.00488	0.05470	362635
24	-0.00018	0.00332	0.00331	0.00549	0.28513	1580415
25	0.00001	0.00310	0.00310	0.00518	0.22036	1578670
26	-0.0005	0.00263	0.00263	0.00504	0.32928	2078205
27	0.00001	0.00284	0.00284	0.00497	0.63202	1744091
28	-0.00012	0.00280	0.00280	0.00492	0.19522	1756321
29	-0.00003	0.00288	0.00288	0.00513	0.16241	2137786
30	0.00018	0.00311	0.00310	0.00543	0.18328	2010471
31	-0.00009	0.00365	0.00365	0.00495	0.65377	1993939

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1s	% ≤ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. ≤ 0.019 m/s2)	Samples
1	0	0.00005	0.00005	99.999	0.00881	1684581
2	0	0.00005	0.00005	100	0.00388	1144267
3	0	0.00002	0.00002	100	0.00159	2111981
4	0	0.00005	0.00005	99.999	0.00916	1775439
5	0	0.00005	0.00005	100	0.00743	1762064
6	0	0.00003	0.00003	100	0.00184	1172047
7	0	0.00002	0.00002	100	0.00086	1715481
8	0	0.00002	0.00002	100	0.00167	1619496
9	0	0.00003	0.00003	100	0.00182	2081220
10	0	0.00003	0.00003	100	0.00222	1939186
11	0	0.00002	0.00002	100	0.00155	2092168
13	0	0.00003	0.00003	100	0.00322	1539386
14	0	0.00002	0.00002	100	0.00550	1691354
15	0	0.00003	0.00003	100	0.00272	1591455
16	0	0.00003	0.00003	100	0.00302	2043033
17	0	0.00002	0.00002	100	0.00185	1704910
18	0	0.00002	0.0002	100	0.00048	1759484
20	0	0.00004	0.00004	99.999	0.00941	1898464
21	0	0.00002	0.00002	100	0.00173	1750277
22	0	0.00002	0.00002	100	0.00157	1515372
23	0	0.00002	0.00002	100	0.00046	362635
24	0	0.00003	0.00003	100	0.00280	1580415
25	0	0.00003	0.00003	100	0.00221	1578670
26	0	0.00002	0.00002	100	0.00330	2078205
27	0	0.00002	0.00002	100	0.00631	1744091
28	0	0.00002	0.00002	100	0.00192	1756321
29	0	0.00002	0.00002	100	0.00161	2137786
30	0	0.00003	0.00003	100	0.00183	2010471
31	0	0.00003	0.00003	100	0.00653	1993939

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 30 with an error of 24.881 meters. Satellite 22 had the lowest maximum range error of 8.260 meters.

Figure 5-4 Distribution of Daily Max Range Errors

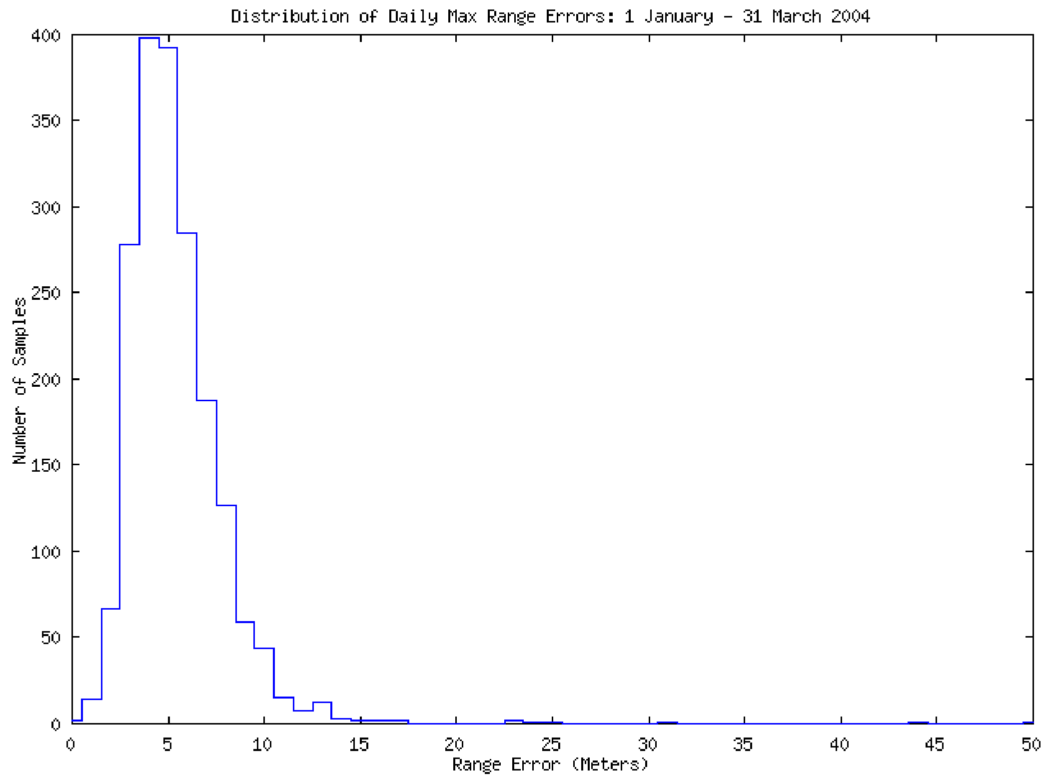


Figure 5-5: Distribution of Daily Max Range Rate Errors

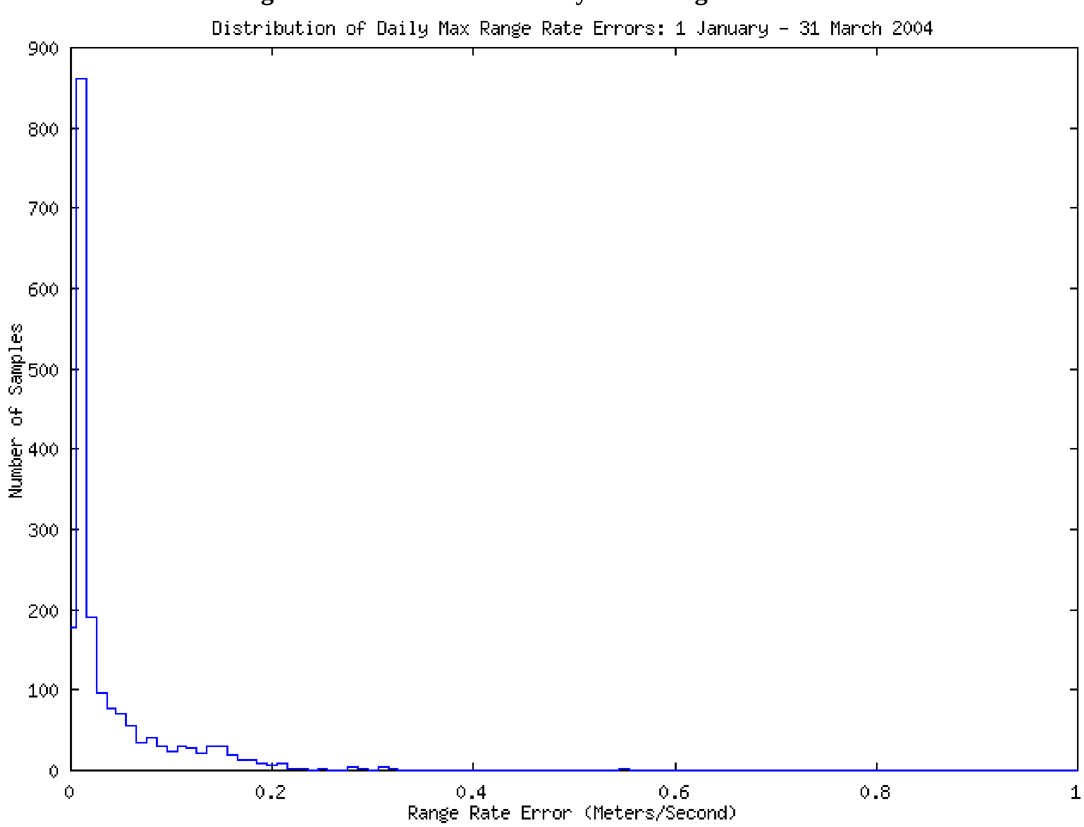


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

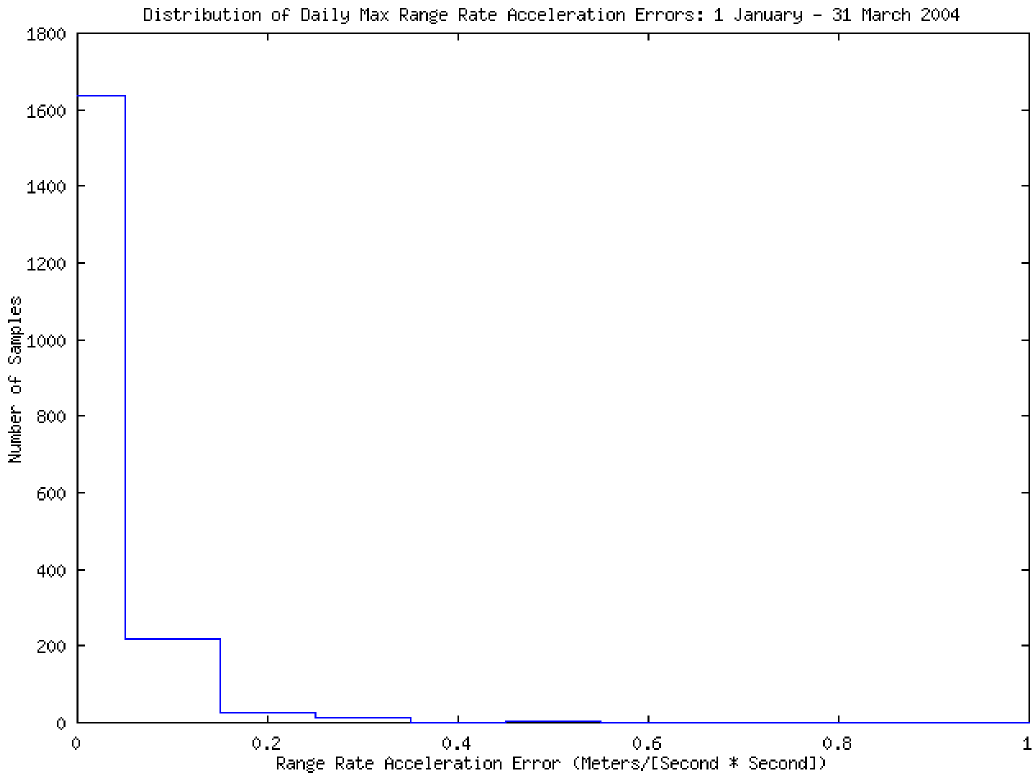


Figure 5-7: Range Error Histogram

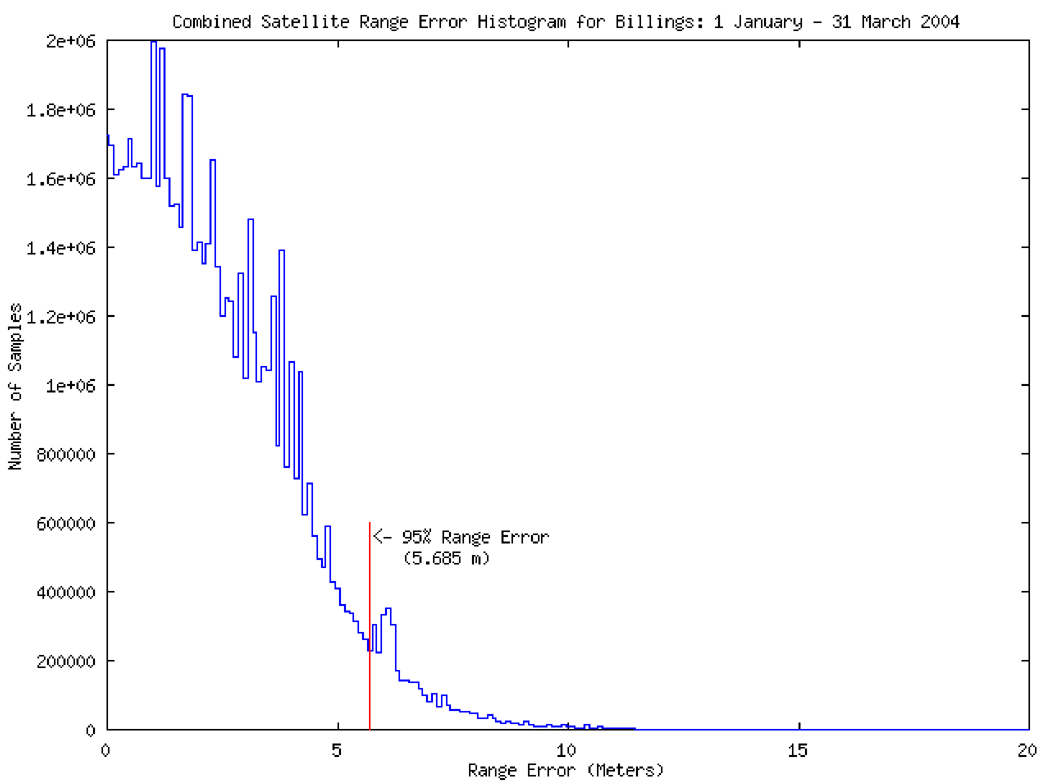


Figure 5-8: Maximum Range Error Per Satellite

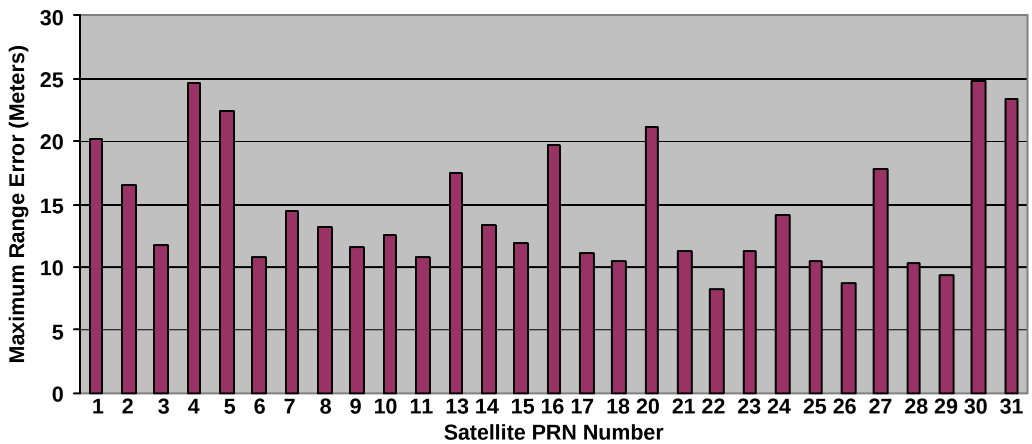


Figure 5-9: Maximum Range Rate Error Per Satellite

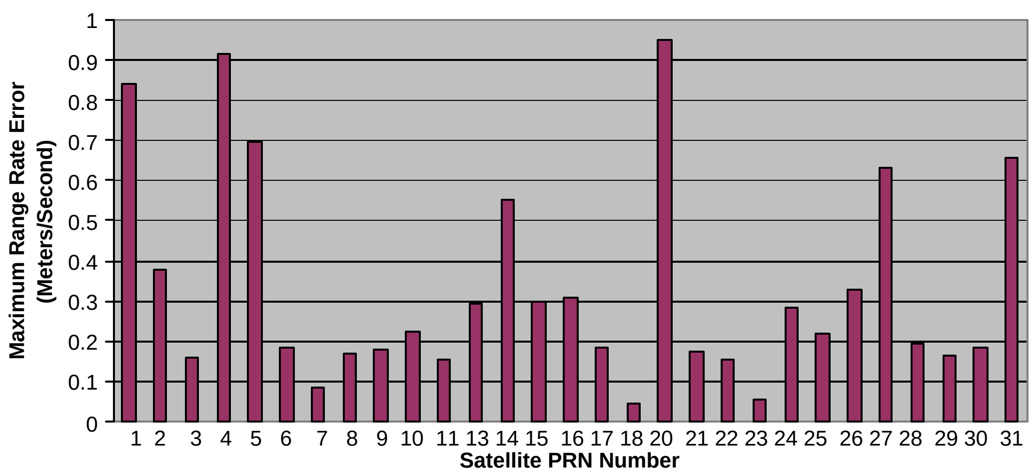
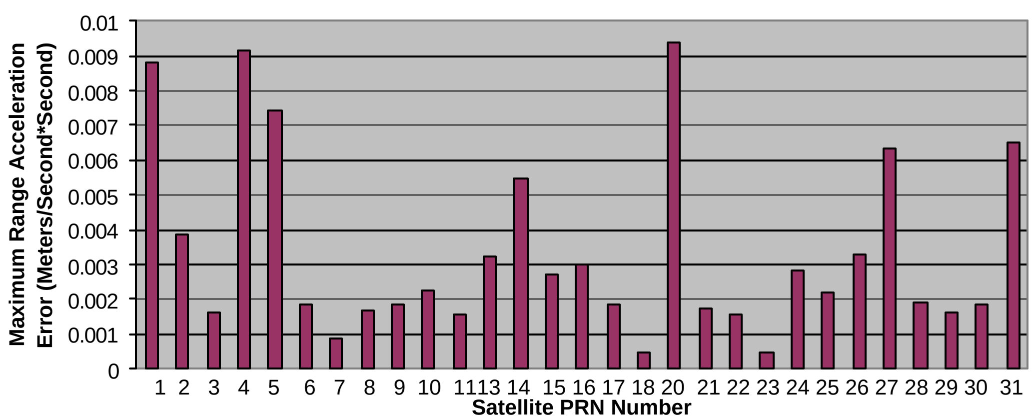


Figure 5-10: Maximum Range Acceleration Per Satellite



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 22-24 January 2004

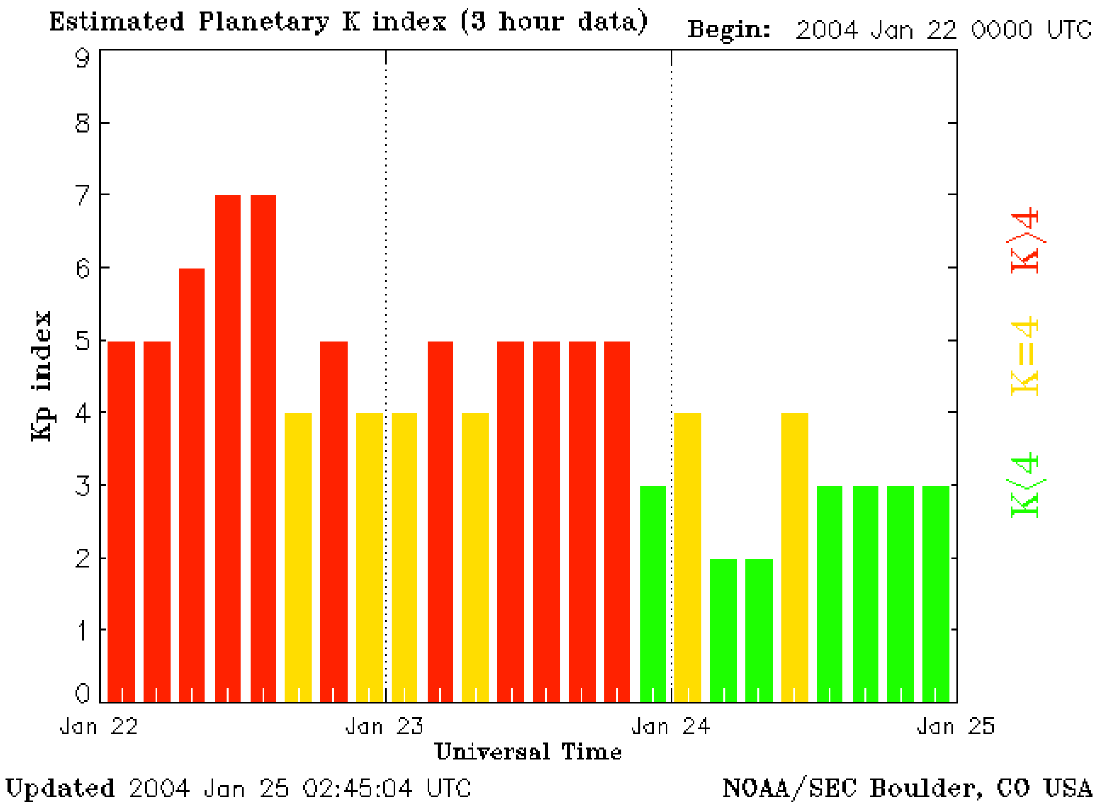


Figure 6-2 K-Index for 11-13 February 2004

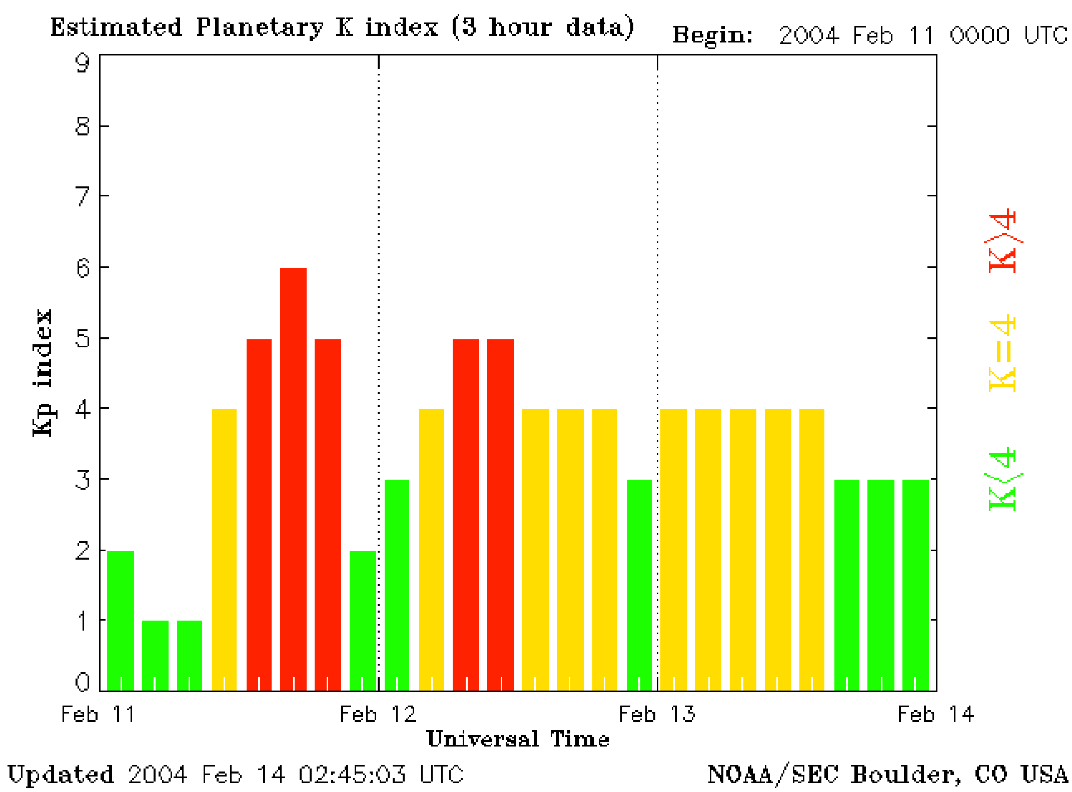
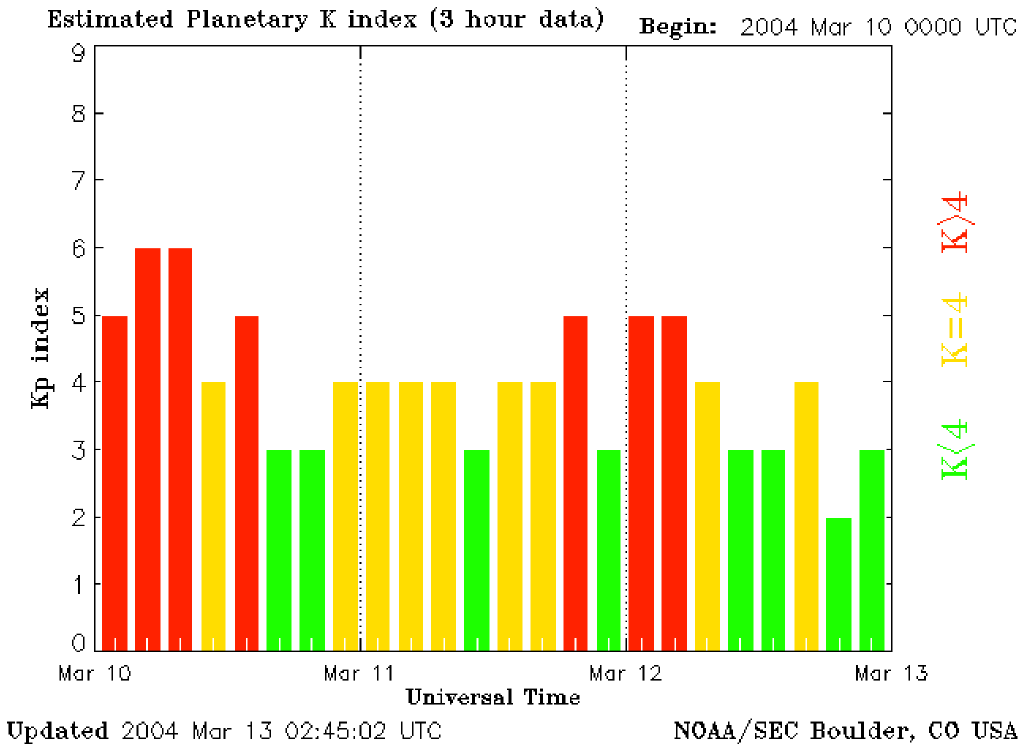


Figure 6-3 K-Index for 10-12 March 2004



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 22 January 2004

Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Bangor	1.580	6.000	2.760	5.998	5.600
Elko	1.304	5.291	1.836	5.287	4.631
Billings	1.240	2.696	1.710	2.695	2.298
Cold Bay	1.137	3.525	1.690	3.097	2.569
Juneau	1.254	3.045	1.723	3.033	2.784
Albuquerque	1.228	3.218	1.710	3.217	2.786
Anchorage	1.210	3.269	1.725	3.265	2.814
Boston	1.226	3.638	1.678	3.630	3.162
Washington, D.C.	1.255	3.817	1.721	3.817	3.312
Honolulu	1.235	3.148	1.643	3.146	2.857
Houston	1.195	3.060	1.708	3.059	2.607
Kansas City	1.225	2.526	1.709	2.523	2.216
Los Angeles	1.244	3.275	1.756	3.273	2.989
Salt Lake City	1.237	2.766	1.719	2.765	2.277
Miami	1.239	3.851	1.762	3.851	3.604
Minneapolis	1.144	2.781	1.697	2.781	2.451
Oakland	1.231	4.142	1.748	4.139	3.886
Cleveland	1.169	3.833	1.715	3.833	3.331
Seattle	1.213	2.843	1.757	2.842	2.367
San Juan	1.251	2.716	1.711	2.716	2.499
Atlanta	1.255	3.766	1.725	3.762	3.474

Table 6-2 Horizontal & Vertical Accuracy Statistics for 22 January 2004

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Bangor	7.782	7.895	10.461	14.677
Elko	5.605	5.025	7.465	7.994
Billings	3.806	6.974	5.683	10.442
Cold Bay	4.191	6.666	6.702	9.503
Juneau	3.819	7.654	5.259	9.891
Albuquerque	6.733	5.250	8.273	10.473
Anchorage	3.420	7.849	5.050	9.919
Boston	7.132	6.133	8.694	7.782
Washington, D.C.	5.588	5.048	6.769	10.744
Honolulu	8.099	12.013	10.281	16.776
Houston	5.922	6.784	7.128	10.976
Kansas City	5.478	5.650	7.166	9.997
Los Angeles	7.376	7.602	9.978	9.934
Salt Lake City	5.276	5.443	6.710	8.710
Miami	4.920	6.780	5.909	13.788
Minneapolis	4.418	6.529	6.979	10.212
Oakland	7.096	6.641	9.077	8.616
Cleveland	5.740	5.391	7.692	12.253
Seattle	6.471	6.591	9.073	10.091
San Juan	5.198	5.957	5.532	8.523
Atlanta	5.454	5.173	7.137	11.860

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	99.961%
• 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	98.472% Availability 99.9% PDOP was 3.912
Conditions and Constraints	***Satellite Availability Standard***	***Measured Performance***
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.85% global average	100%
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.16% single point average	100%
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	100%
• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	≥ 83.92% at worst-case point on worst-case day	100%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• Conditioned on coverage and service avail. standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.97% global average	100%
• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.79% single point average	100%

Conditions and Constraints	*Accuracy Standard*	*Measured Performance*
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	Predictable Accuracy ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	≤8.605m HE 95% ≤20.410m HE 99.99% ≤9.926m VE 95% ≤27.173m 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	≤2.171m HE 95% ≤6.306m 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	≤19 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	Range Domain Accuracy ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range acceleration error ≤ 8 mm/s^2 range acceleration error 95% of time	24.881m NTE Range Error 0.94728m/s NTE Rate Error 9.41mm/s^2 NTE Accl. Error ≤8mm/s^2 99.999% of the time

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

	Middle Latitude		High Latitude		Estimated	
	- Fredericksburg -		---- College ----		--- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2004 01 01	12	2 3 2 3 4 2 2 2	55	3 4 7 5 7 4 4 3	27	3 4 5 5 5 4 3 3
2004 01 02	9	4 2 1 1 2 2 2 2	24	2 2 3 3 6 5 3 2	13	3 2 2 2 3 4 3 3
2004 01 03	11	2 2 3 3 3 2 3 2	41	2 3 6 6 6 4 3 4	26	2 3 5 5 4 4 4 3
2004 01 04	13	2 2 3 3 3 4 2 2	42	2 3 4 4 6 7 4 3	24	3 3 4 4 4 4 4 3
2004 01 05	15	3 3 2 2 3 4 3 3	42	2 5 3 5 6 6 4 4	22	4 3 3 3 4 4 4 4
2004 01 06	17	3 3 4 2 2 2 2 5	22	3 3 3 5 2 3 3 5	20	3 3 4 3 3 3 3 5
2004 01 07	16	3 3 4 3 4 3 2 2	70	4 3 6 7 7 6 5 4	32	3 4 5 5 5 5 4 3
2004 01 08	4	1 0 0 1 1 1 1 3	9	3 2 0 3 3 1 2 2	9	2 1 1 3 3 3 2 3
2004 01 09	16	2 2 5 3 2 4 2 2	39	2 3 6 4 5 6 5 2	21	2 3 5 4 3 4 3 3
2004 01 10	20	2 5 5 3 4 2 2 1	34	2 4 5 6 4 4 5 2	24	3 5 5 4 3 3 4 2
2004 01 11	12	1 2 3 3 3 4 2 1	36	1 1 4 6 6 6 3 1	17	2 2 3 4 4 4 4 2
2004 01 12	5	1 1 0 0 1 2 2 3	12	1 1 0 2 4 4 3 3	10	2 2 1 2 3 3 3 3
2004 01 13	14	3 3 2 1 3 3 4 3	29	3 2 3 2 6 5 5 3	18	3 3 3 2 4 4 4 3
2004 01 14	7	3 3 1 1 2 1 1 1	18	4 2 1 4 4 4 3 2	12	3 3 2 3 3 3 2 2
2004 01 15	9	1 3 1 1 3 3 2 3	29	2 2 1 1 6 6 4 4	16	2 3 2 2 4 4 4 3
2004 01 16	21	5 3 2 4 3 3 4 3	44	4 3 2 6 5 6 5 5	26	4 4 3 5 4 4 5 4
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2004 01 18	15	1 4 3 2 2 1 4 4	19	2 4 4 3 4 2 3 4	18	2 4 4 3 3 3 4 4
2004 01 19	10	3 2 2 2 3 3 2 2	37	3 2 2 6 6 6 3 3	17	3 2 3 4 4 4 3 3
2004 01 20	11	3 2 2 2 3 3 2 2	37	3 2 2 6 6 6 3 3	16	3 3 3 2 4 4 3 3
2004 01 21	8	2 2 3 2 2 1 2 2	26	2 2 4 5 5 5 3 2	12	2 2 4 3 4 3 3 2
2004 01 22	35	4 4 3 5 5 2 4 6	80	5 5 7 7 7 4 6 3	62	5 5 6 7 7 4 5 4
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2004 01 25	17	4 3 3 3 3 3 2 3	48	4 5 5 6 5 6 4 4	33	5 5 5 4 4 4 3 3
2004 01 26	9	2 2 3 3 2 2 2 2	29	3 2 4 5 5 5 4 3	17	3 1 4 3 4 4 4 3
2004 01 27	13	3 3 2 2 3 3 3 3	20	3 4 3 4 4 4 3 2	16	3 4 2 3 3 3 3 3
2004 01 28	24	5 4 5 3 3 3 3 2	29	3 3 5 4 5 5 3 3	19	5 4 4 3 3 3 3 2
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2004 02 01	10	2 2 2 2 3 3 2 3	11	1 2 1 3 4 3 2 2	11	2 3 2 2 3 3 3 3
2004 02 02	28	2 2 6 5 4 4 3 3	34	1 1 4 6 6 5 3 3	21	2 1 5 4 4 4 3 3
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2004 02 08	2	0 0 0 0 1 1 1 2	1	0 0 0 0 0 0 1 1	8	1 1 1 2 3 3 2 3
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2004 02 18	4	1 1 1 0 1 2 2 2	10	2 2 1 1 1 4 3 3	8	2 2 1 2 2 3 3 2
2004 02 19	5	2 1 1 3 0 1 1 2	8	3 3 2 2 0 1 2 2	5	2 1 1 1 2 3 2 1
2004 02 20	2	1 1 0 0 1 1 1 1	3	1 1 0 0 1 2 2 0	4	1 1 1 1 2 1 2 1
2004 02 21	4	2 1 0 1 2 1 1 1	9	1 1 0 2 5 2 1 1	7	2 1 1 2 3 3 2 2
2004 02 22	7	1 1 0 4 2 1 1 2	16	1 1 1 3 6 3 1 2	8	2 1 1 2 3 3 2 2
2004 02 23	9	3 2 2 2 3 2 2 2	7	2 1 2 3 2 2 2 1	8	2 1 2 2 3 3 3 2
2004 02 24	9	4 2 3 2 1 1 1 1	16	2 2 4 4 4 3 3 1	11	3 3 3 3 3 3 2 2
2004 02 25	3	1 1 1 1 2 0 1 1	11	2 1 3 5 3 0 1 0	8	2 1 2 3 3 3 2 2
2004 02 26	2	1 1 0 0 2 0 0 0	2	0 0 1 1 2 1 0 0	5	1 1 1 2 2 3 2 1
2004 02 27	8	1 3 1 2 2 1 3 2	6	0 2 1 3 1 0 3 2	11	2 3 1 3 2 3 4 3
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2004 02 29	17	2 2 2 5 4 2 3 3	39	1 2 2 7 6 5 3 3	21	2 3 3 5 5 4 3 3
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2004 03 04	4	1 1 1 2 1 1 2 1	6	1 1 1 4 2 1 1 0	7	2 2 1 3 2 3 2 2
2004 03 05	4	2 1 2 1 1 0 1 2	4	1 1 2 3 0 0 0 1	8	2 1 2 2 0 2 3 2
2004 03 06	3	1 2 1 0 1 1 1 0	1	0 1 0 1 0 0 0 0	5	2 2 1 2 2 2 2 1
2004 03 07	3	0 0 2 1 1 1 1 1	2	0 0 2 1 0 1 1 1	6	1 1 2 2 2 3 1 2
2004 03 08	2	1 1 2 1 0 1 0 0	3	1 0 3 2 0 0 0 0	6	1 1 2 2 2 3 2 1
2004 03 09	11	0 1 2 2 3 3 3 4	42	0 0 1 3 6 6 6 6	21	1 2 3 3 4 4 4 5
2004 03 10	36	5 6 5 3 4 2 3 5	47	4 5 7 4 6 4 3 3	40	5 6 6 4 5 3 3 4
2004 03 11	17	4 3 3 2 3 3 4 3	61	5 3 6 6 6 6 6 4	26	4 4 4 3 4 4 5 3
2004 03 12	19	5 4 4 2 2 3 2 3	36	3 4 6 5 5 5 3 2	23	5 5 4 3 3 4 2 3
2004 03 13	10	2 2 4 2 3 2 2 1	40	3 2 5 4 6 5 3 2	15	3 1 4 3 4 4 2 2
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2004 03 15	11	4 3 1 2 3 1 2 2	19	3 2 2 4 5 4 3 2	13	4 3 2 3 3 3 3 2
2004 03 16	6	2 1 0 2 2 2 2 2	11	3 2 1 4 2 3 1 2	8	3 2 1 3 2 3 2 2
2004 03 17	5	2 2 0 0 1 3 1 1	5	1 2 1 3 1 1 1 0	6	1 2 1 2 2 3 2 1
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2004 03 19	5	2 3 1 1 1 0 1 2	5	2 2 0 3 2 1 1 1	6	2 3 0 2 2 2 2 2
2004 03 20	7	2 3 1 1 2 2 2 2	11	2 3 2 2 3 4 1 1	9	3 3 1 2 2 3 2 2
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2004 03 23	5	3 1 2 1 1 1 1 1	4	3 1 1 2 0 0 1 0	8	3 3 2 2 2 2 3 1
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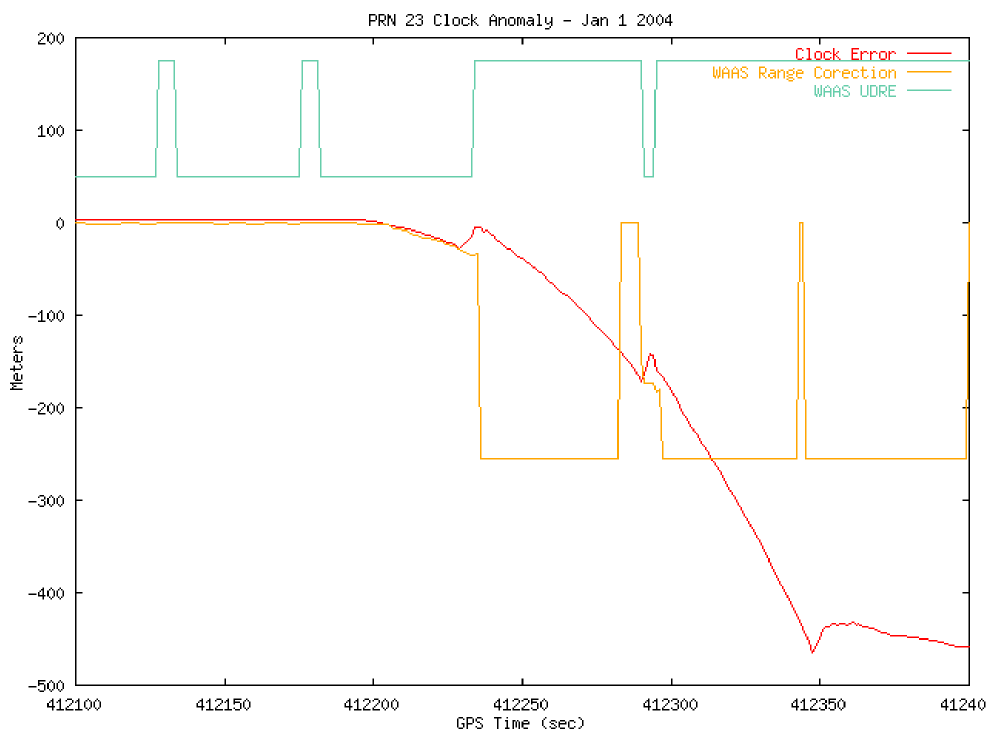
2004 03 30	11	2 2 3 3 3 3 2 1	28	2 2 4 6 6 3 1 1	12	1 2 4 4 4 3 2 1
2004 03 31	7	1 2 3 1 2 2 2 2	14	1 1 4 3 4 3 3 1	7	1 2 3 1 3 2 3 2

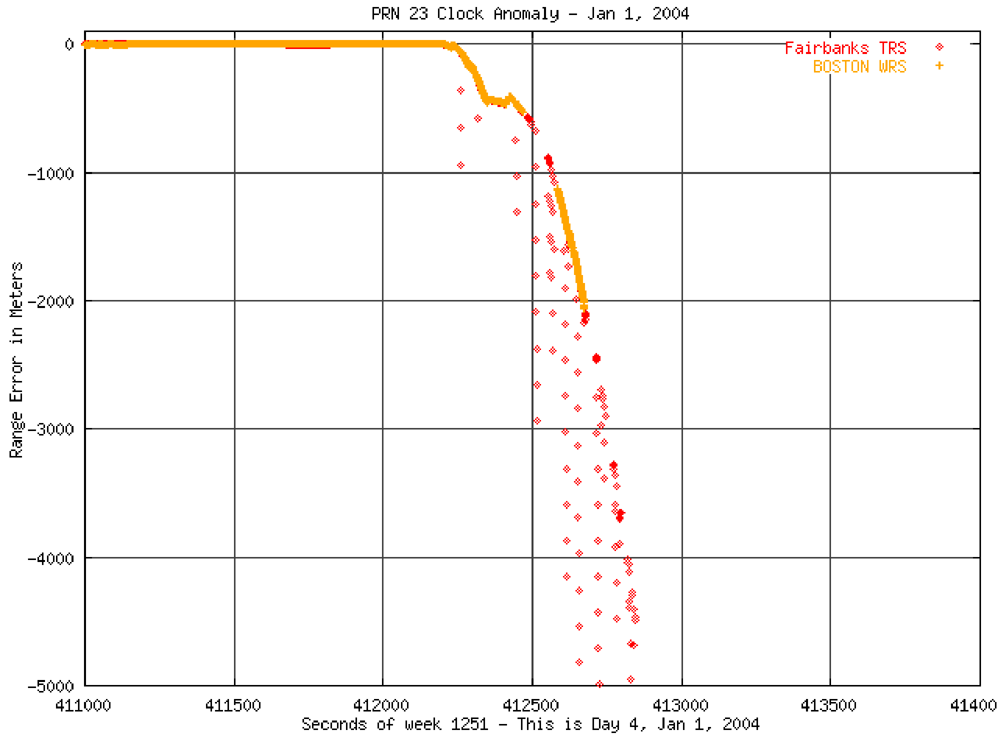
Background:

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.

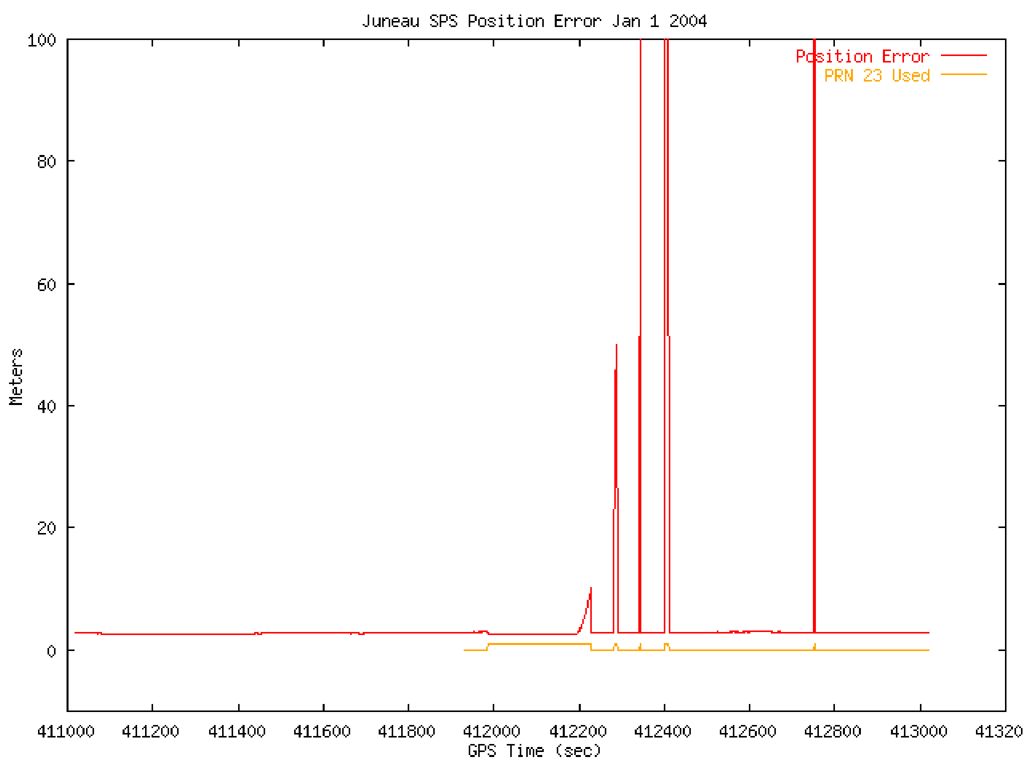
Problem Description:

GPS satellite PRN 23 clock anomaly occurred on Jan 1 2004 at approximately 18:30 GMT (412200 GPS time of week). PRN 23 was visible during the time of the anomaly at the northern latitudes over North America and was tracked by several WAAS and NSTB reference receivers. The range errors grew from 1 meter to 500 meters in 150 seconds as seen in figure 1 with the GPS satellite status set too healthy. The range errors continued to grow with time as shown in figure 2 exceeding 5000 meters within 700 seconds. The GPS satellite health was not set to unhealthy even after 2 hours of operation from the unset of the anomaly.





GPS SPS user 3D position errors (No FDE) at Juneau Alaska are plotted in figure 3. The large position errors resulted when PRN 23 was used in the SPS navigation solution. The errors dropped to nominal SPS accuracy when PRN 23 was excluded form the navigation solution due to lost of tracking or poor measurement quality. The table on the next page shows the 24-hour accuracy statistics (No FDE) for Jan 1 2004 at several reference receivers in North America. Position accuracy in Alaska (Cold Bay, Juneau, Anchorage) was extremely high for 99.99 percentile.

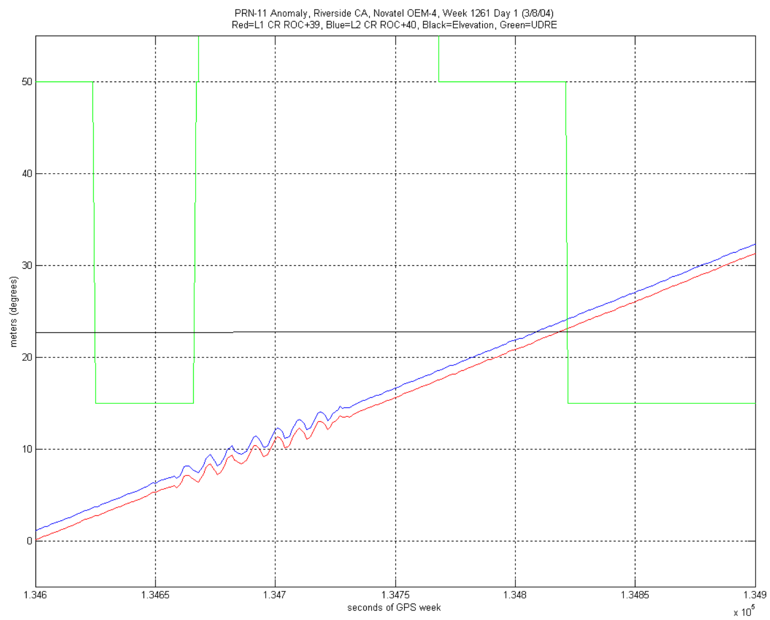


Location	Availability		Vert 95% (<= 77m)		Vert 99.99%		Horiz 95% (<= 36m)		Horiz 99.99%		Vert_repeat		Horz_repeat		Max Horiz	
Bangor	100.00	pass	6.15	pass	21.1	pass	3.88	pass	6.51	pass	5.65	pass	1.43	pass	6.59	pass
Elko	100.00	pass	4.84	pass	18.3	pass	4.78	pass	8.96	pass	3.81	pass	1.31	pass	9.00	pass
Billings	100.00	pass	5.23	pass	7.13	pass	3.66	pass	5.01	pass	2.60	pass	1.16	pass	5.02	pass
Cold Bay	100.00	pass	6.18	pass	1.30e+04	FAIL*	3.83	pass	1.08e+04	FAIL*	2.66	pass	1.01	pass	1.08e+04	FAIL
Juneau	100.00	pass	5.60	pass	9.11e+03	FAIL*	3.66	pass	7.77e+03	FAIL*	4.59	pass	1.31	pass	7.77e+03	FAIL*
Albuquerque	100.00	pass	4.49	pass	6.12	pass	3.52	pass	5.43	pass	2.77	pass	0.874	pass	5.45	pass
Anchorage	100.00	pass	6.51	pass	6.79e+03	FAIL*	3.43	pass	8.88e+03	FAIL*	2.47	pass	1.11	pass	8.90e+03	FAIL*
Boston	100.00	pass	3.68	pass	210.	pass	3.82	pass	104.	pass	2.28	pass	0.973	pass	122.	pass
Washington, DC	100.00	pass	3.52	pass	6.48	pass	3.67	pass	4.48	pass	2.41	pass	1.03	pass	4.64	pass
Honolulu	100.00	pass	8.70	pass	17.9	pass	9.98	pass	12.6	pass	4.39	pass	2.48	pass	12.7	pass
Houston	100.00	pass	4.95	pass	8.21	pass	3.55	pass	4.75	pass	2.40	pass	1.13	pass	4.76	pass
Kansas City	100.00	pass	4.28	pass	7.31	pass	3.67	pass	4.60	pass	2.32	pass	0.770	pass	4.60	pass
Los Angeles	100.00	pass	4.80	pass	10.8	pass	3.57	pass	4.26	pass	4.05	pass	0.718	pass	4.27	pass
Salt Lake City	100.00	pass	4.70	pass	8.81	pass	3.40	pass	5.22	pass	3.04	pass	0.921	pass	5.23	pass
Miami	100.00	pass	4.83	pass	7.39	pass	3.54	pass	4.71	pass	2.12	pass	0.945	pass	4.73	pass
Minneapolis	100.00	pass	5.08	pass	7.73	pass	3.93	pass	5.48	pass	2.87	pass	1.40	pass	5.49	pass
Oakland	100.00	pass	4.17	pass	10.4	pass	3.61	pass	4.31	pass	2.62	pass	1.17	pass	4.32	pass
Cleveland	100.00	pass	4.18	pass	7.45	pass	3.92	pass	4.97	pass	2.65	pass	1.35	pass	5.03	pass
Seattle	100.00	pass	5.24	pass	7.38	pass	3.63	pass	5.12	pass	3.38	pass	1.20	pass	5.13	pass
San Juan	100.00	pass	3.35	pass	7.25	pass	4.62	pass	5.39	pass	2.52	pass	0.841	pass	5.41	pass
Atlanta	100.00	pass	4.08	pass	7.31	pass	3.92	pass	4.47	pass	1.96	pass	0.914	pass	4.53	pass

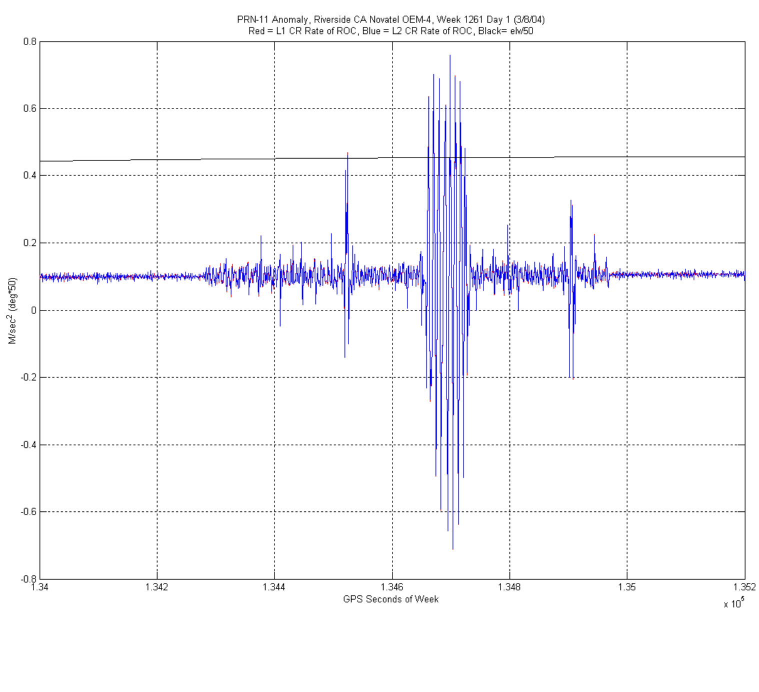
- ***All failures based on old SPS spec numbers.***

GPS satellite PRN 11 clock anomaly occurred on March 8, 2004 at GPS second 134647, and lasted for about 90 seconds. It consisted of a series of "stair step" variations in the observed (apparent) Doppler frequency of the satellite signal. Each "stair step" lasted 1.4 to 1.6 seconds, with a relatively constant observed Doppler during that interval. The stair steps followed an approximation to a sine wave or triangle wave with a period of about 6 seconds. The amplitude of this wave increased and then decreased until it was invisible. The total duration of the anomaly was about 90 seconds.

PRN-11 Carrier Pseudorange Rate of Change from 1 Hz Measurements



Carrier Rate of Rate of Change



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.

<u>Performance Parameter Definitions</u>

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.