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

Report #34
July 31, 2001
Reporting Period: 1 April – 30 June 2001

Submitted by

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EXECUTIVE SUMMARY

The GPS Product Team (AND 730) has tasked the Navigation Branch (ACT 360) 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: Anderson, Atlantic City, Dayton, Elko, Great Falls and Oklahoma City, Kansas City (WAAS) and Salt Lake City (WAAS). This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification Annex A.

This report, Report #34, includes data collected from 1 April through 30 June 2001. The next quarterly report will be issued 31 October 2001.

Analysis of this data includes the following categories: Coverage Performance, Service Availability Performance, Position Performance, Range Performance, Solar Storm Effects on GPS SPS performance and GPS/GLONASS 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 99.9% or better.

Availability was verified by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 April and 30 June 2001 and by calculating the satellite availability from the data obtained from the nine sites. A total of seventeen outages were reported in the NANU’s. Twelve of the outages were scheduled and five were unscheduled. The quarterly availabilities for Anderson, Atlantic City, Dayton, Elko, Great Falls, Oklahoma City, Kansas City, and Salt Lake City were 100%, 100%, 100%, 100%, 100%, 100%, 100%, 99.966%, respectively. Each of these availabilities is within the SPS value of 99.85%. In this quarter, SPS specifications were not exceeded. Both the 95% and 99.99% horizontal and vertical accuracy requirement passed. 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 Anderson site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 30.141 meters on Satellite PRN 6. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 0.87478 Meters/second on Satellite PRN 3. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 8.70 Millimeters/second^2 on Satellite PRN 3. The SPS specification states that the range acceleration error should never exceed 19 Millimeters/second^2.

A GLONASS/GPS performance section was added to the PAN report. In April 1999, ACT-360 was tasked to monitor, analyze and characterize GLONASS and GPS/GLONASS system performance. The objective of this task is to evaluate the ability of GLONASS to provide navigation by itself and with SPS GPS and to assess the incremental benefit to WAAS obtained from using GLONASS. A GPS/GLONASS receiver was used in the NSTB laboratory at the FAA Technical Center. The GPS/GLONASS performance (from an Ashtech GG24) was compared against GPS-only performance (collected from a Novatel receiver). The 95% horizontal error and vertical error for the GPS/GLONASS solution were 5.939 Meters and 10.126 Meters, respectively. From the analysis performed on data collected between 1 April and 30 June 2001, 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:

- Anderson, SC
- Atlantic City, NJ
- Dayton, OH
- Elko, NV
- Gander, NFLD (Canada)
- Great Falls, ND
- Oklahoma City, OK
- Kansas City, KS
- Salt Lake City, UT

(Future reports will include all WAAS sites but a database that can handle all that data needs to be developed. ACT-360 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.

Table 1-2 and 1-3 lists the non-precision and precision, respectively, performance parameters that will be evaluated for the Wide Area Augmentation System (WAAS) in future versions of 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 ACT-360. 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 nine 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.

Section 7 provides the analysis on GPS/GLONASS performance. A GPS/GLONASS receiver was used in the NSTB laboratory at the FAA Technical Center.

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 not met in one instance during the entire 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	✓

Table 1-2 Future WAAS Performance Summary
En Route through Non-Precision Approach (from FAA-Spec-2892B)

Performance Parameter	*Requirements from WAAS Specification*
Accuracy	100 m (95% Horizontal Position) 500 m (99.999% Horizontal Position)
Integrity	10^{-7} probability of Hazardously Misleading Information 8 seconds to alarm Alarm Limit: 556 m - Total System HPL bound error - WAAS
Availability	0.999 Navigation and fault detection functions are operational Signal-in-Space meets accuracy and continuity requirements
Service Volume	50% in CONUS 35% of Total Service Volume

Table 1-3 Future WAAS Performance Summary
Precision Approach (from FAA-Spec-2892B)

Performance Parameter	*Requirements from WAAS Specification*
Accuracy	7.6 m (95% Horizontal Position) 7.6 m (95% Vertical Position)
Integrity	4×10^{-8} probability of Hazardously Misleading Information 6.2 seconds to alarm
Availability	0.95 Navigation and fault detection functions are operational Signal-in-Space meets accuracy and continuity requirements
Service Volume	50% in CONUS

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

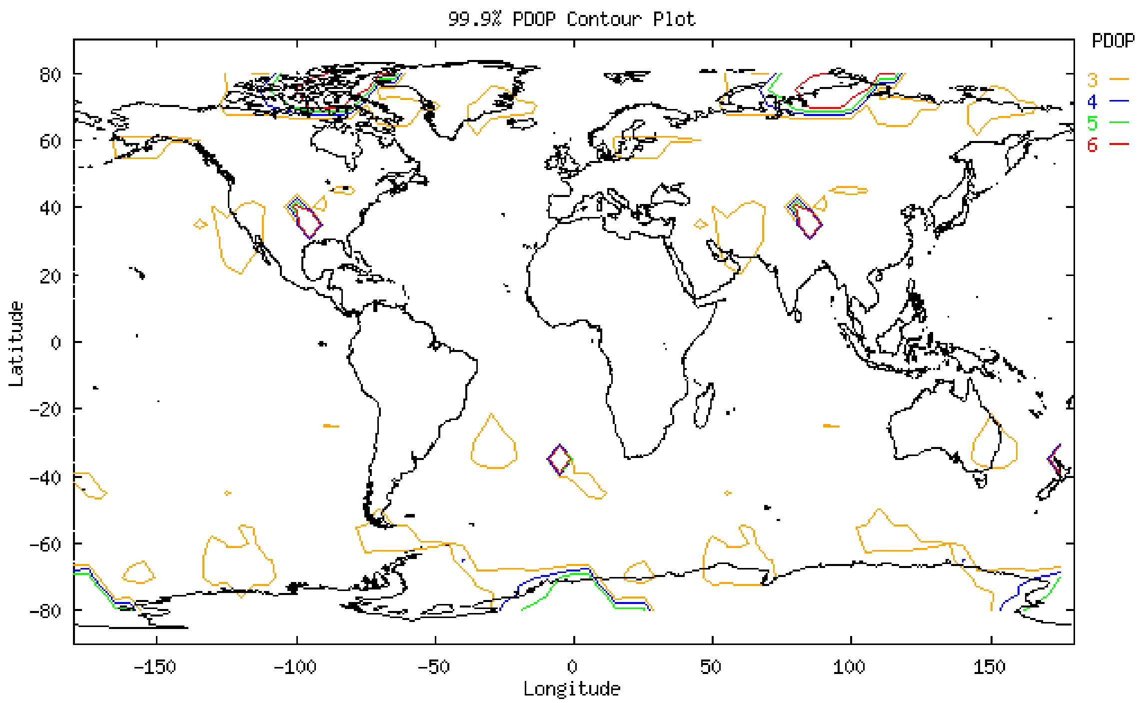
Almanacs for GPS weeks 84-96 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACT-360 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 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 3.811 or better 99.9% 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%)
84	3.251	100%	99.861%
85	3.443	99.991%	98.611%
86	3.204	100%	100%
87	3.201	100%	100%
88	3.195	100%	100%
89	3.186	100%	100%
90	3.184	100%	99.931%
91	3.171	100%	99.931%
92	3.166	100%	99.931%
93	3.155	100%	99.931%
94	3.155	100%	99.861%
95	3.144	100%	99.792%
96	3.130	100%	99.792%

Figure 2-1 SPS Coverage (24-Hour Period: 8 January 2001)



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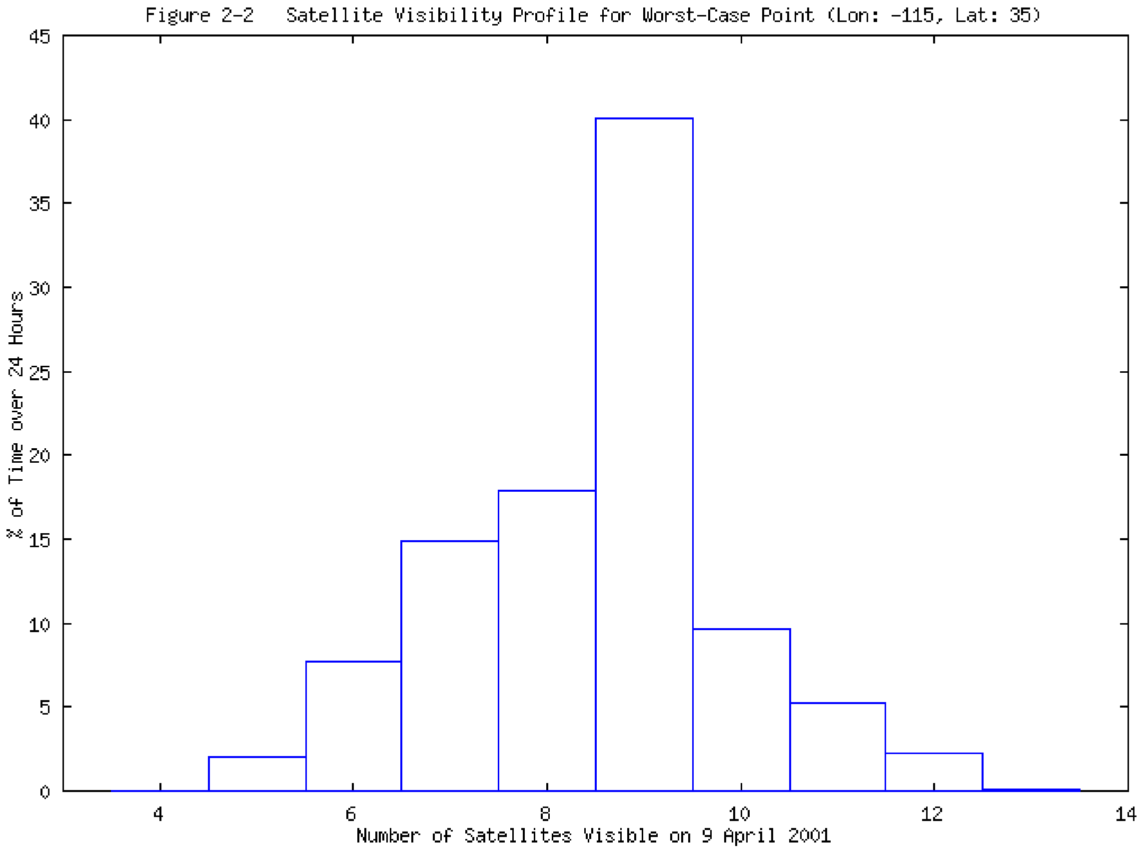


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -115, Lat: 35)
% of Time over 24 Hours
Number of Satellites Visible on 9 April 2001
45
40
35
30
25
20
15
10
5
0
4
6
8
10
12
14

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 (NANUs). During this reporting period, 1 April through 30 June 2001, there were a total of seventeen reported outages. Twelve of these outages were maintenance activities and were reported in advance. Five were unscheduled outages. A complete listing of outage NANUs for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANUs for the reporting period can be found in Table 3-2. Canceled outage NANUs 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
1053	10	S	3-Apr	3:00	3-Apr	10:43		7.72	7.72
1058	17	S	6-Apr	6:48	16-Apr	22:53		256.08	256.08
1059	14	S	17-Apr	21:28	18-Apr	5:47		8.32	8.32
1063	23	S	11-May	4:23	11-May	10:37		6.23	6.23
1068	22	S	17-May	18:31	17-May	23:13		4.70	4.70
1071	8	S	22-May	7:24	22-May	12:50		5.27	5.27
1072	31	S	24-May	20:14	24-May	20:58		0.73	0.73
1074	17	S	4-Jun	20:21	4-Jun	22:56		2.58	2.58
1078	29	S	12-Jun	20:25	13-Jun	0:02		3.62	3.62
1079	23	S	19-Jun	16:30	19-Jun	21:38		5.13	5.13
1080	1	S	20-Jun	20:09	21-Jun	2:38		6.48	6.48
1082	18	S	29-Jun	18:27	30-Jun	0:22		5.92	5.92
1054	15	U	30-Jan	2:11	5-Apr	7:06	103.10		103.10
1056	2	U	14-Apr	15:30	N/A	N/A	N/A	N/A	N/A
1057	2	U	14-Apr	15:30	16-Apr	0:20	8.83		8.83
1060	18	U	22-Apr	17:05	N/A	N/A	N/A	N/A	N/A
1061	18	U	22-Apr	17:05	24-Apr	1:58	32.88		32.88
1065	17	U	13-May	1:52	N/A	N/A	N/A	N/A	N/A
1066	17	U	13-May	1:52	13-May	2:53	1.02		1.02
1070	3	U	20-May	9:02	20-May	9:27	0.42		0.42
Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**146.25**	**312.78**	**459.03**
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
1050	10	F	3-Apr	2:45	4/3/2001	14:45	12	See NANU 1053
1052	17	F	6-Apr	18:00	20-Apr	18:00	24	See NANU 1058
1055	14	F	17-Apr	21:00	18-Apr	9:00	12	see NANU 1059
1062	23	F	11-May	4:00	11-Apr	16:00	12	see NANU 1063
1064	22	F	17-May	18:00	18-May	6:00	12	see NANU 1068
1067	8	F	22-May	6:15	22-May	18:15	12	see NANU 1071
1069	31	F	24-May	20:00	25-May	8:00	12	see NANU 1072
1073	17	F	4-Jun	20:00	5-Jun	8:00	12	see NANU 1074
1075	29	F	12-Jun	20:00	13-Jun	8:00	12	see NANU 1078
1076	1	F	20-Jun	19:45	21-Jun	7:45	12	see NANU 1080
1077	23	F	19-Jun	16:30	20-Jun	4:30	12	see NANU 1079
1081	18	F	29-Jun	18:00	30-Jun	6:00	12	see NANU 1082
					Total Forecast Downtime		144	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
There were no NANUS cancelled in this quarter					

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published "Notice: Advisory to Navstar Users" messages (NANUs). 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 NANUs. 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 Apr - 30 June, 2001**	**12 December, 1998- 31 March, 2001 (qtrs = 9.21)**
Total Forecast Downtime (hrs):	144	2948.47
Total Actual Downtime (hrs):	459.03	4996.83
Total Actual Scheduled Downtime (hrs):	312.78	1540.67
Total Actual Unscheduled Downtime (hrs):	146.25	3432.18
Total Satellite Observed MTTR (hrs):	27	18.79
Scheduled Satellite Observed MTTR (hrs):	26.07	8.86
Unscheduled Satellite Observed MTTR (hrs):	29.25	48.3
# Total Satellite Outages:	17	203
# Scheduled Satellite Outages:	12	161
# Unscheduled Satellite Outages:	5	42
Percent Operational -- Scheduled Downtime:	99.83%	99.78%
Percent Operational -- All Downtime:	99.80%	98.91%

3.2 Service Availability

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

To verify availability, the data collected from receivers at the nine NSTB/WAAS sites was reduced to calculate DOP information and reported in Tables 3-5 to 3-7. The data was collected at one-second intervals between 1 April and 30 June 2001.

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
Anderson	1.312	5.999	5.639	2.148	5.839	5.406	7698038
Atlantic City	1.265	5.670	5.282	1.859	4.998	4.513	7775262
Dayton	1.256	5.997	4.980	1.902	5.523	4.664	7673368
Elko	1.190	5.999	5.785	1.943	5.912	5.506	7738505
Great Falls	1.324	5.999	5.485	2.071	5.848	5.590	7677697
Oklahoma City	1.257	5.798	5.107	1.869	4.283	3.637	7452289
Kansas City	1.269	5.999	4.873	1.852	5.378	4.512	7681170
Salt Lake City	1.170	6.949	6.767	1.821	6.644	6.458	7682026

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 nine sites used. Although future reports will have all WAAS 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 ACT-360 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
Salt Lake City	85_3	6.949	238		85883	
Worst-Case Point on Worst-Case Day = 98.611% (SPS Spec. ≥ 83.92%)						

Global Average on Worst-Case Day = 99.768 % (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
Anderson	7698038	0	100%
Atlantic City	7775262	0	100%
Dayton	7673368	0	100%
Elko	7738505	0	100%
Great Falls	7677697	0	100%
Oklahoma City	7452289	0	100%
Kansas City	7681170	0	100%
Salt Lake City	7682026	2611	99.966%
Worst Single Point Average = 99.712% (SPS Spec. ≥ 99.16%)			

Global Average over Reporting Period = 99.999% (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 nine 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)
Anderson	7698038	29.9
Atlantic City	7775262	30.5
Dayton	7673368	72.5
Elko	7738505	28.5
Great Falls	7677697	48.9
Oklahoma City	7452289	19.8
Kansas City	7681170	23.2
Salt Lake City	7682026	26.5

None of the horizontal error exceeded the 500-meter threshold for this quarter.

5.0 Accuracy Characteristics

Accuracy: *Given coverage, service availability and service reliability, the percentage of time over a specified time interval that the difference between the measured and expected user position or time is within a specified threshold at any point on or near the Earth.*

Accuracy Standard	Conditions and Constraints
Predictable Accuracy ≤ 100 meters horizontal error 95% of time ≤ 156 meters vertical error 95% of time ≤ 300 meters horizontal error 99.99% of time ≤ 500 meters vertical error 99.99% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe
Repeatable Accuracy ≤ 141 meters horizontal error 95% of time ≤ 221 meters vertical error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe
Relative Accuracy ≤ 1.0 meters horizontal error 95% of time ≤ 1.5 meters vertical error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time
Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory
Range Domain Accuracy ≤ 150 meters NTE range error ≤ 2 meters/second NTE range rate error ≤ 8 millimeters/second^2 range acceleration error 95% of time ≤ 19 millimeters/second^2 NTE range acceleration error	• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard

5.1 Position Accuracies

The data used for this section was collected for every second between 1 April through 30 June 2001 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)
Anderson	6.260	9.364	21.473	26.393
Atlantic City	5.445	8.246	25.947	21.703
Dayton	9.524	12.107	27.794	37.264
Elko	6.154	8.540	22.897	32.311
Great Falls	4.957	7.762	25.891	28.970
Oklahoma City	6.046	8.258	18.904	22.681
Kansas City	5.791	8.036	19.328	21.311
Salt Lake City	5.922	7.874	21.686	26.827

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all seven NSTB and two WAAS sites from 1 April to 30 June 2001.

Figure 5-1 Combined Vertical Error Histogram

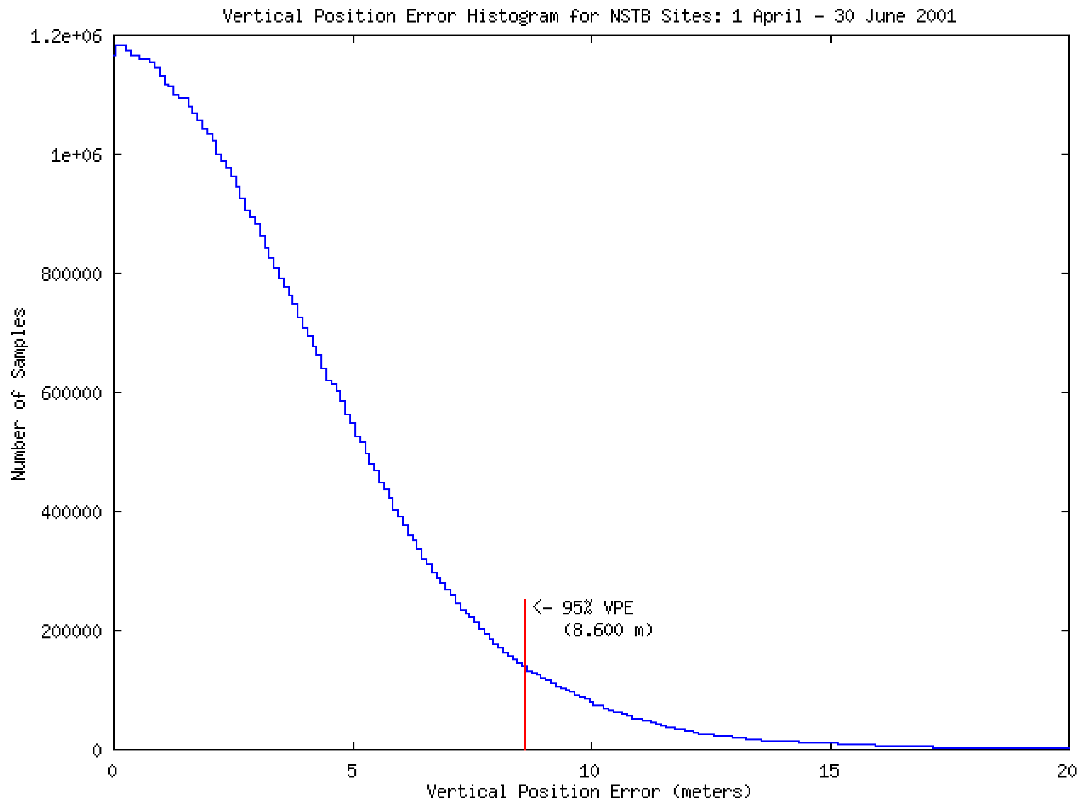
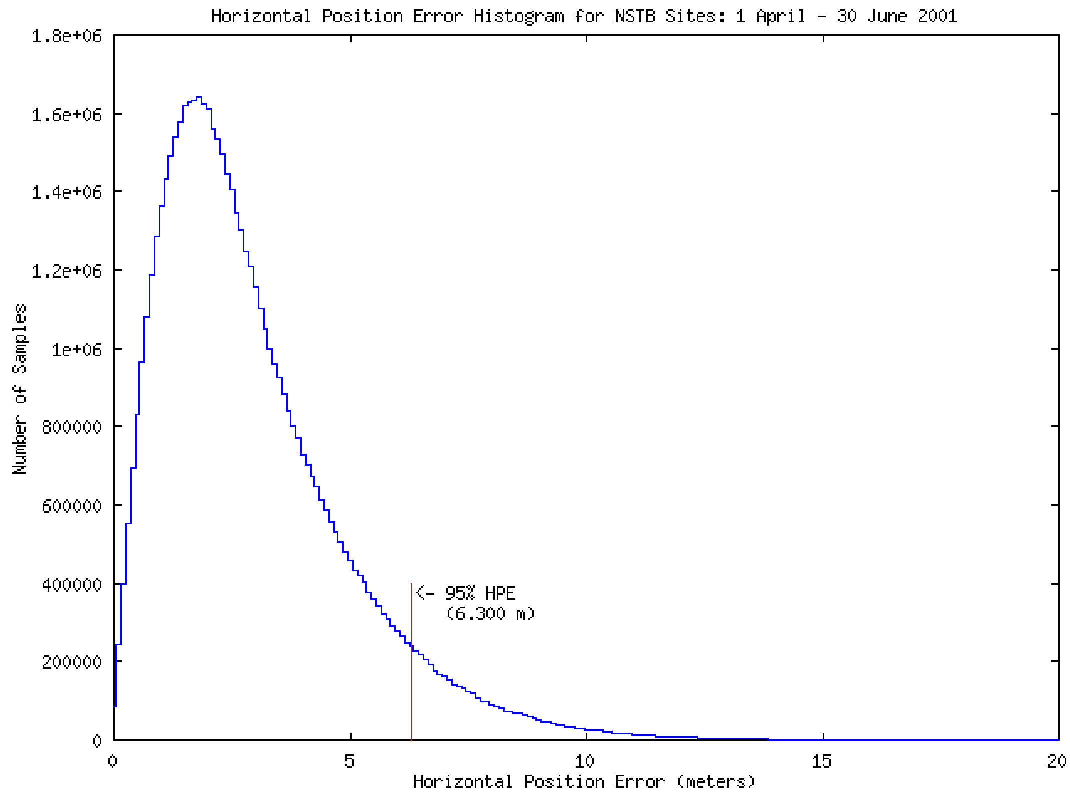


Figure 5-2 Combined Horizontal Error Histogram



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)
Anderson	2.641	7.727
Atlantic City	2.351	4.698
Dayton	3.146	8.998
Elko	2.758	7.840
Great Falls	2.101	4.836
Oklahoma City	2.101	4.751
Kansas City	2.163	5.030
Salt Lake City	2.403	6.400

5.3 Relative Accuracy

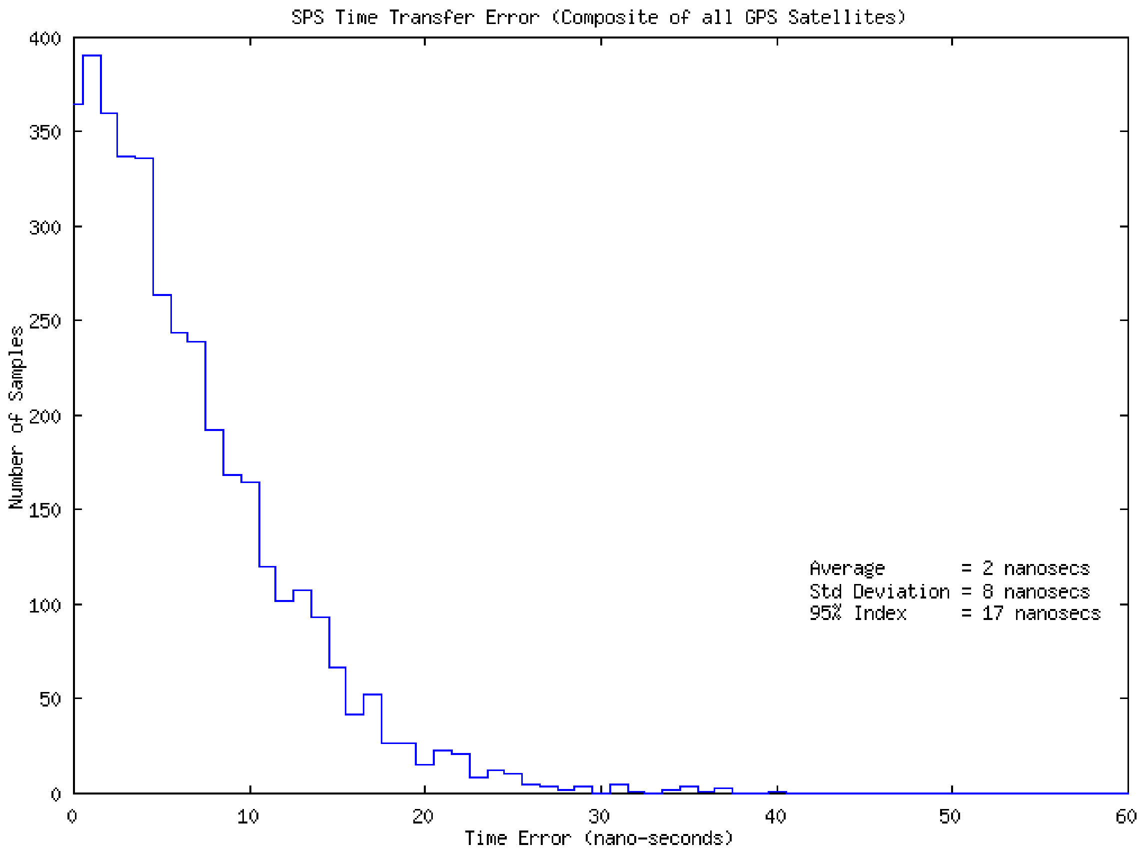
To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 2001 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 Error


SPS Time Transfer Error (Composite of all GPS Satellites)
Number of Samples
400
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
Time Error (nano-seconds)
Average = 2 nanosecs
Std Deviation = 8 nanosecs
95% Index = 17 nanosecs

5.5 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 April and 30 June 2001. 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. ≤ 150 m)	Samples
1	-1.383	3.079	2.751	6.227	19.362	2135733
2	-0.596	3.847	3.801	7.442	15.117	1935194
3	-1.015	2.988	2.811	6.233	19.918	1987201
4	-0.185	3.248	3.242	6.290	12.884	2153866
5	-0.266	3.516	3.506	6.560	23.319	2523226
6	0.466	3.802	3.774	7.208	30.141	2411868
7	-0.260	3.510	3.501	6.833	13.133	2248157
8	-1.659	3.976	3.613	7.718	23.680	2087505
9	-1.177	3.498	3.294	6.712	23.515	2290842
10	1.725	4.113	3.734	7.796	21.271	2082113
11	-1.413	3.133	2.796	6.376	14.885	2208105
13	-1.217	2.929	2.664	5.787	22.456	2437652
14	-1.293	3.036	2.747	5.774	22.189	2110055
15	0.171	3.135	3.131	6.061	13.064	1760813
17	0.545	3.709	3.669	7.587	12.679	1630262
18	-1.305	3.403	3.143	6.822	13.778	2099459
20	-0.630	2.628	2.551	5.264	16.942	2513512
21	-1.763	3.693	3.245	7.323	12.075	1963225
22	-0.085	2.809	2.807	5.496	20.129	1989515
23	-0.220	3.533	3.526	6.589	18.055	2162843
24	0.892	3.471	3.355	6.906	13.316	2256354
25	-1.720	3.351	2.876	6.810	11.246	2239050
26	-0.033	3.798	3.798	7.228	20.349	1815098
27	-2.451	3.907	3.042	7.461	14.688	1795371
28	-0.781	3.000	2.897	5.955	13.425	2173041
29	-2.070	3.449	2.759	6.540	15.675	2212383
30	-1.511	3.403	3.049	6.507	17.332	2448795
31	-0.845	3.244	3.132	6.438	16.882	1868849

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	0.00006	0.00805	0.00805	0.01598	0.36842	2135733
2	0.00013	0.00832	0.00832	0.01587	0.21760	1935194
3	0.00001	0.00824	0.00824	0.01471	0.87478	1987201
4	-0.00003	0.00642	0.00642	0.01292	0.48304	2153866
5	0.00011	0.00958	0.00958	0.01669	0.65118	2523226
6	0.00025	0.00766	0.00765	0.01523	0.28479	2411868
7	0.00018	0.00770	0.00769	0.01658	0.10853	2248157
8	0.00017	0.00825	0.00824	0.01668	0.20667	2087505
9	-0.00009	0.00921	0.00921	0.01866	0.37590	2290842
10	-0.00028	0.00649	0.00648	0.01233	0.60817	2082113
11	-0.00009	0.00927	0.00926	0.01797	0.57801	2208105
13	-0.00019	0.00744	0.00744	0.01442	0.40197	2437652
14	-0.00008	0.00725	0.00725	0.01469	0.09741	2110055
15	0.00005	0.00794	0.00794	0.01646	0.25017	1760813
17	0.00000	0.00686	0.00686	0.01410	0.32018	1630262
18	-0.00008	0.00712	0.00712	0.01447	0.11979	2099459
20	-0.00014	0.00858	0.00858	0.01626	0.72214	2513512
21	0.00002	0.00785	0.00785	0.01523	0.33784	1963225
22	-0.00001	0.00733	0.00733	0.01185	0.81776	1989515
23	0.00001	0.00714	0.00714	0.01402	0.26352	2162843
24	-0.00012	0.00697	0.00697	0.01391	0.17425	2256354
25	-0.00002	0.00706	0.00706	0.01396	0.23988	2239050
26	-0.00046	0.00726	0.00725	0.01380	0.39691	1815098
27	0.00015	0.00763	0.00763	0.01539	0.39424	1795371
28	-0.00004	0.00723	0.00723	0.01442	0.21380	2173041
29	0.00010	0.00706	0.00706	0.01439	0.11878	2212383
30	-0.00002	0.00889	0.00889	0.01771	0.50871	2448795
31	-0.00019	0.00684	0.00684	0.01252	0.52599	1868849

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1σ	% $\leq$ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. $\leq$ 0.019 m/s2)	Samples
1	0.00000	0.00007	0.00007	100%	0.00370	2135733
2	0.00000	0.00007	0.00007	100%	0.00225	1935194
3	0.00000	0.00008	0.00008	99.999%	0.00870	1987201
4	0.00000	0.00006	0.00006	100%	0.00489	2153866
5	0.00000	0.00009	0.00009	100%	0.00649	2523226
6	0.00000	0.00007	0.00007	100%	0.00288	2411868
7	0.00000	0.00007	0.00007	100%	0.00108	2248157
8	0.00000	0.00007	0.00007	100%	0.00206	2087505
9	0.00000	0.00008	0.00008	100%	0.00382	2290842
10	0.00000	0.00006	0.00006	100%	0.00612	2082113
11	0.00000	0.00008	0.00008	100%	0.00579	2208105
13	0.00000	0.00007	0.00007	100%	0.00403	2437652
14	0.00000	0.00006	0.00006	100%	0.00084	2110055
15	0.00000	0.00007	0.00007	100%	0.00246	1760813
17	0.00000	0.00006	0.00006	100%	0.00301	1630262
18	0.00000	0.00006	0.00006	100%	0.00113	2099459
20	0.00000	0.00008	0.00008	100%	0.00727	2513512
21	0.00000	0.00007	0.00007	100%	0.00338	1963225
22	0.00000	0.00007	0.00007	99.999%	0.00817	1989515
23	0.00000	0.00006	0.00006	100%	0.00260	2162843
24	0.00000	0.00006	0.00006	100%	0.00171	2256354
25	0.00000	0.00006	0.00006	100%	0.00239	2239050
26	0.00000	0.00007	0.00007	100%	0.00399	1815098
27	0.00000	0.00007	0.00007	100%	0.00398	1795371
28	0.00000	0.00006	0.00006	100%	0.00217	2173041
29	0.00000	0.00006	0.00006	100%	0.00099	2212383
30	0.00000	0.00008	0.00008	100%	0.00508	2448795
31	0.00000	0.00006	0.00006	100%	0.00527	1868849

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 6 with an error of 30.141 meters. Satellite 25 had the lowest maximum range error of 11.246.

Figure 5-4 Distribution of Daily Max Range Errors

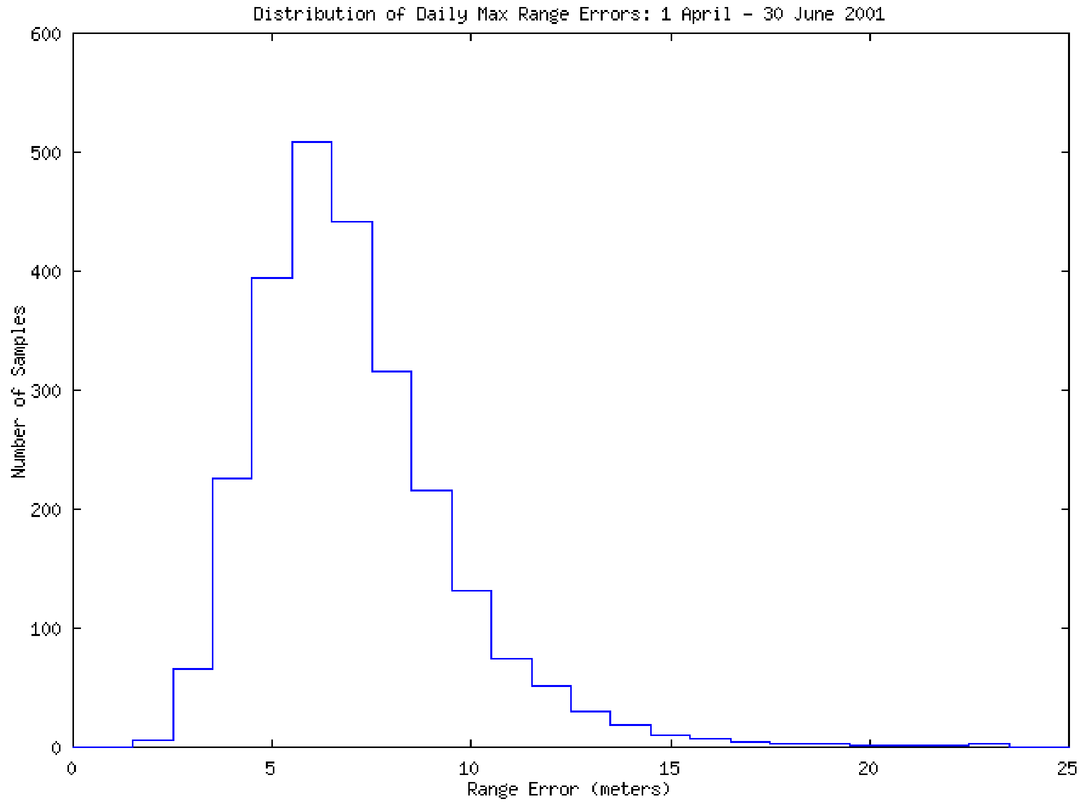


Figure 5-5: Distribution of Daily Max Range Rate Errors

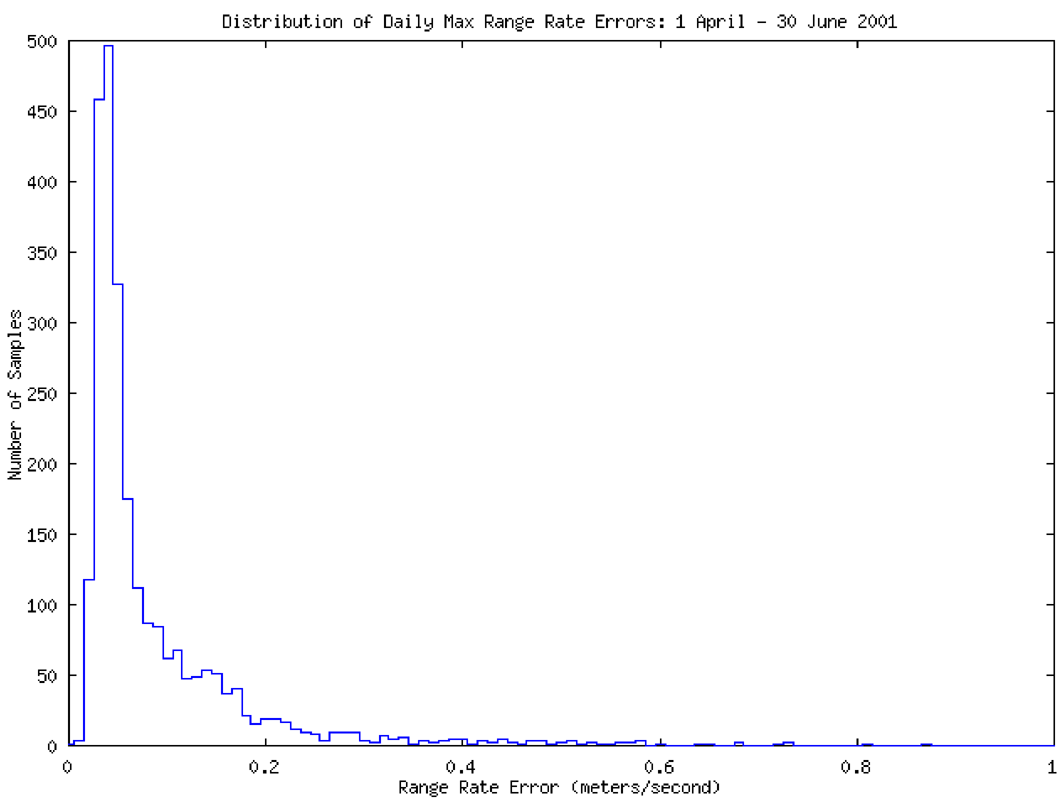


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

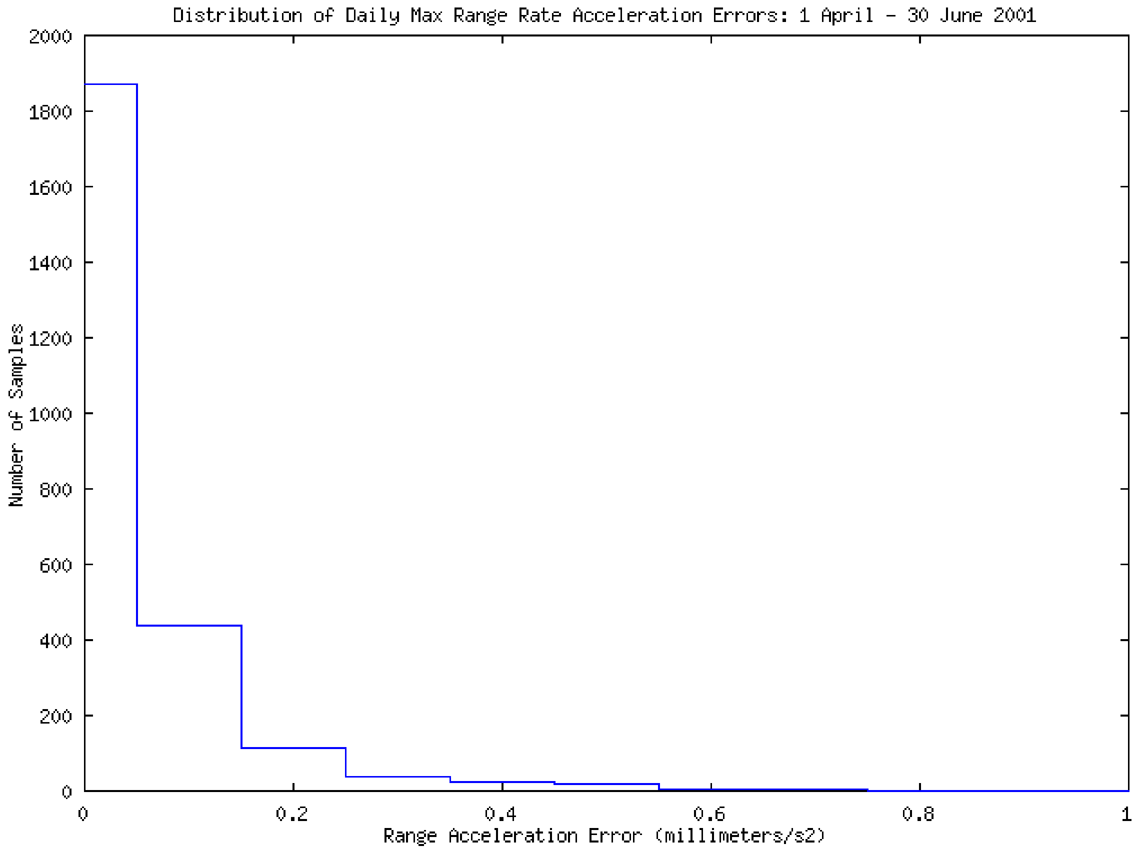


Figure 5-7: Maximum Range Error Per Satellite

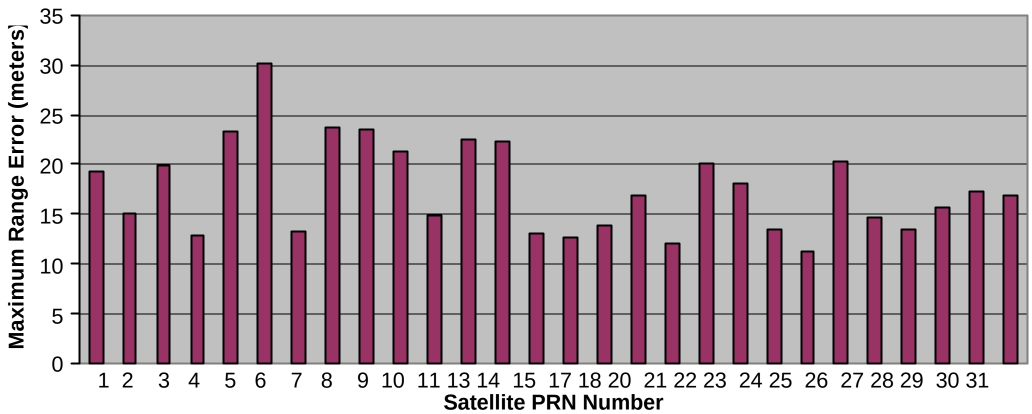


Figure 5-8: Maximum Range Rate Error Per Satellite

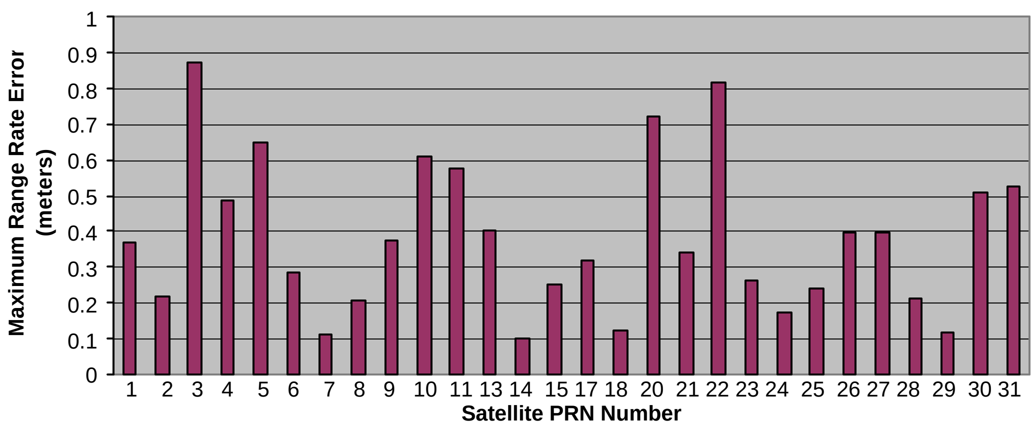
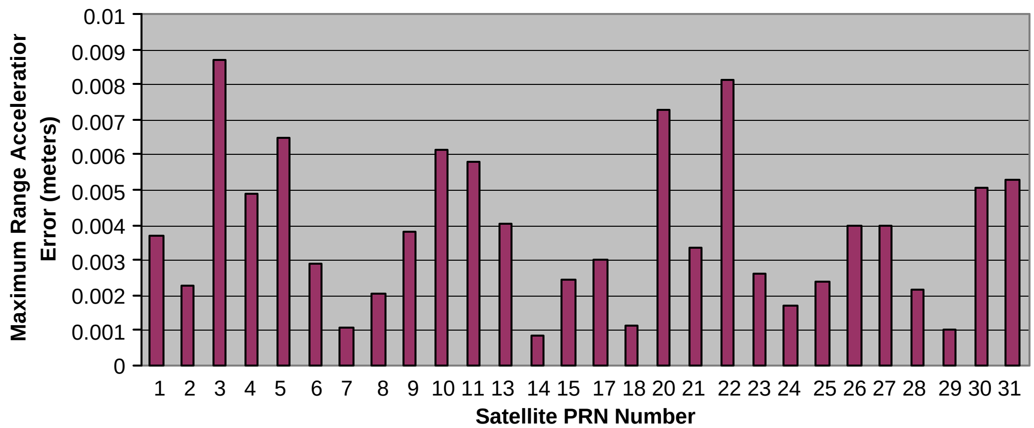


Figure 5-9: Maximum Range Acceleration Per Satellite



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 11-13 April 2001

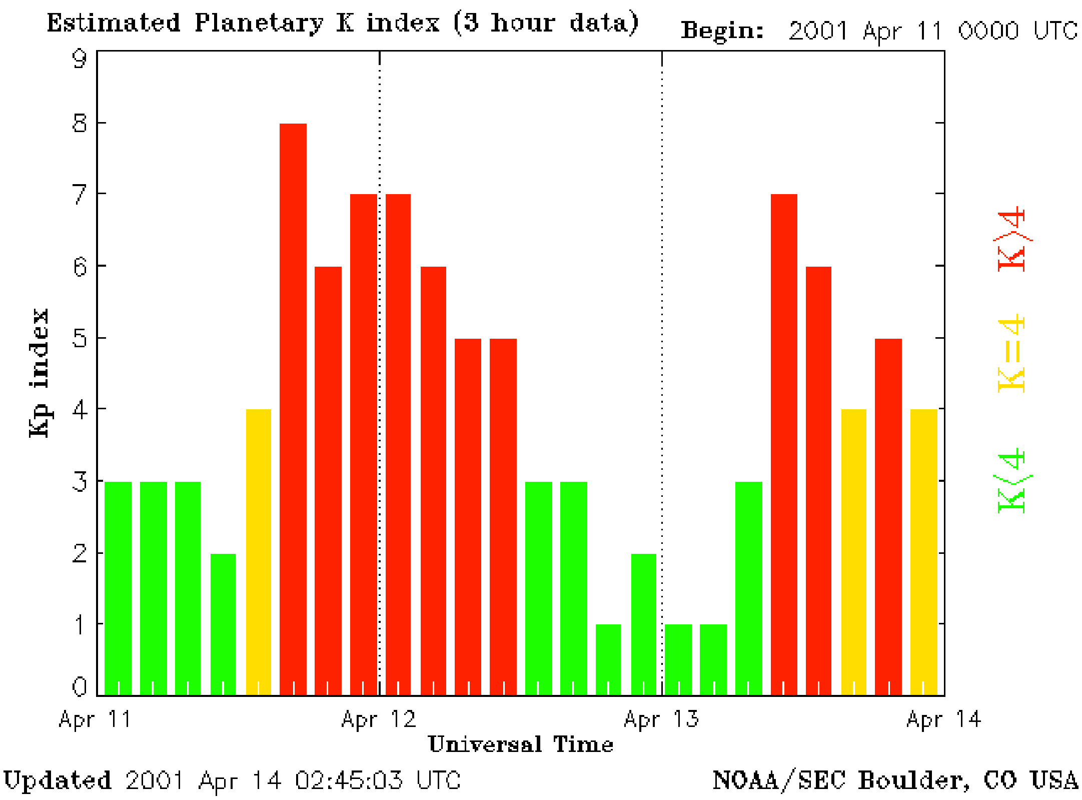


Figure 6-2 K-Index for 8-10 April 2001

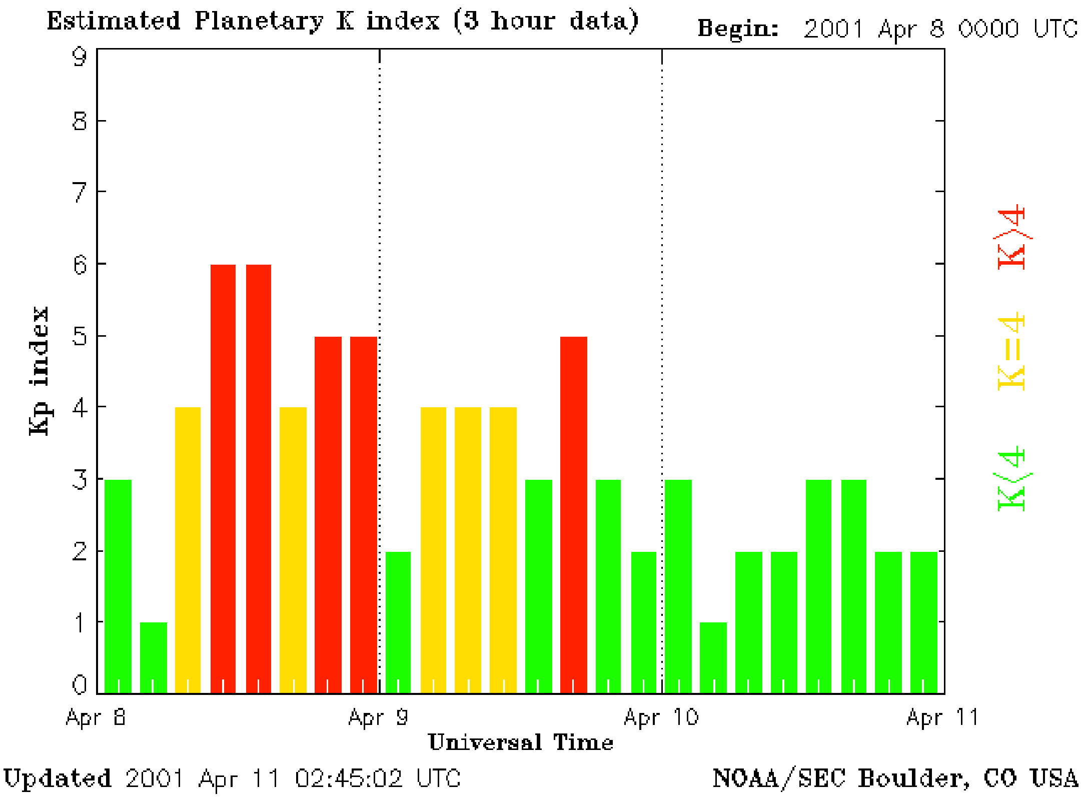
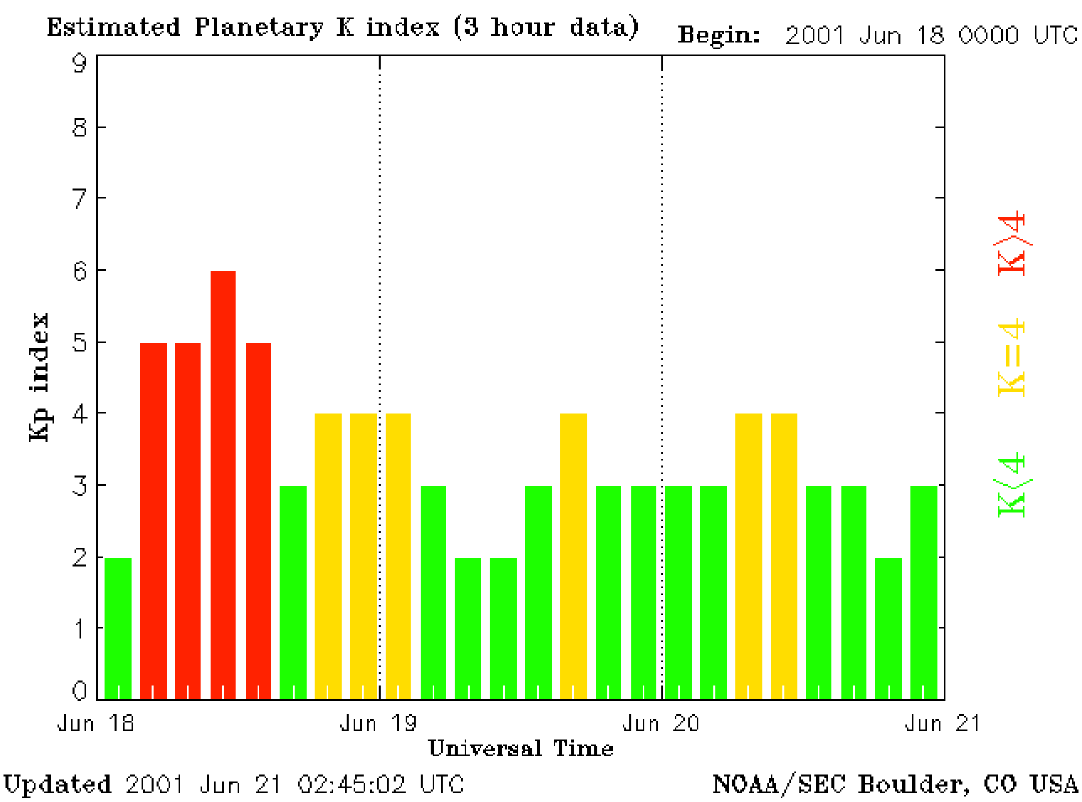


Figure 6-3 K-Index for 18-20 June 2001



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

NSTB Site	Min	Max	Mean	99.99%	99.99% VDOP
Anderson					
04/11/01	1.321	5.626	2.098	5.586	5.370
Atlantic City					
04/11/01	1.296	4.961	1.870	4.944	4.334
Dayton					
04/11/01	1.270	5.507	1.922	5.128	4.456
Elko					
04/11/01	1.199	5.846	1.941	5.756	5.511
Great Falls					
04/11/01	1.332	5.998	2.142	5.986	5.772
Oklahoma City					
04/11/01	1.390	5.798	2.252	5.795	5.104
Kansas City					
04/11/01	1.296	5.999	1.902	5.948	4.834
Salt Lake City					
04/11/01	1.198	6.949	1.913	6.913	6.731

Table 6-2 Horizontal & Vertical Accuracy Statistics*

NSTB Site	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)
Anderson				
	11.671	15.925	29.757	33.421
Atlantic City				
	17.268	13.461	30.309	25.452
Dayton				
	19.902	16.518	29.937	53.393
Elko				
	15.060	12.397	28.312	53.486
Great Falls				
	11.244	7.151	48.756	39.162
Oklahoma City				
	18.474	22.363	18.474	47.411
Kansas City				
	15.279	10.507	23.123	28.076
Salt Lake City				
	15.704	7.953	26.350	31.662

7.0 GLONASS/GPS Performance

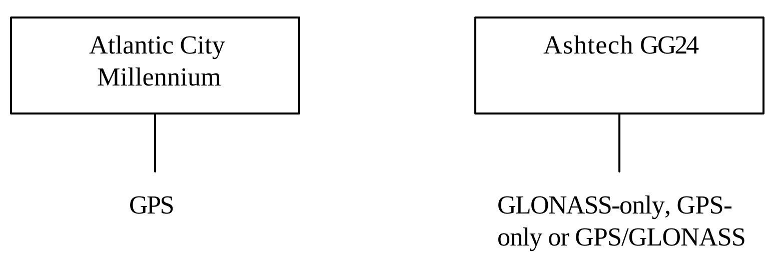
7.1 Introduction

In April 1999, ACT-360 was tasked to monitor, analyze and characterize GLONASS and GPS/GLONASS system performance. The objective of this task is to evaluate the ability of GLONASS to provide navigation by itself and with SPS GPS and to assess the incremental benefit to WAAS obtained from using GLONASS.

7.2 Approach

The GPS, GLONASS and blended data will be collected daily at one-second intervals. Since ACT-360 already collects the GPS data from the NSTB reference station sites, existing techniques and software programs will be used for the GLONASS and blended data collection and analysis. Initially, GPS/GLONASS receivers will be placed only at one site, Atlantic City. The Ashtech GG24 provides the three solutions but only one at a time. Therefore we have the Ashtech permanently outputting a blended solution.

Figure 7-1 Receivers with Corresponding Solutions



Analysis will include the comparison of the different solutions obtained from the Ashtech GG24 and the NSTB Millennium receiver. The GPS/GLONASS receiver solutions will be compared to the Millennium GPS-only and GPS/WAAS-corrected solutions.

The following table summarizes the performance data that will be reported on a quarterly basis.

Performance	GPS	GLONASS	GPS+GLONASS
Coverage	X	X	X
Service Availability	X	X	X
Position Accuracy	X	X	X
Range Accuracy	X	X	X
Time Accuracy	X	X	X
Satellite Visibility	X	X	X
Ionospheric Effects	X	X	X

7.3 Quarter Results

For this quarter, data collected from the Atlantic City Ashtech GG24 Glonass/GPS receiver and the Millennium GPS receiver will be analyzed and compared. Earlier test results using the GG24 were subject to an error that had not been resolved at the time of the last PAN report. The problem has now been identified as an error in the receiver configuration. The solution reported previously did not include any ionospheric correction. On October 31 new firmware was loaded in the receiver and it was reconfigured to apply corrections using a standard ionospheric model. All data included in this report now is acquired using the correct ionospheric model.

Tables 7-1 and 7-2 provide PDOP and Position Accuracy statistics for the two receivers from 1 April through 30 June 2001. The statistics are cumulative.

Table 7-1 PDOP Statistics for Ashtech GG24 & Atlantic City

Receiver	Solution	Maximum PDOP	Minimum PDOP	Mean PDOP	95% PDOP	Number of Samples
Ashtech GG24	GPS/GLONASS	5.061	1.063	1.719	2.360	7754987
Millenium	GPS Only Atlantic City	5.670	1.265	1.859	2.550	7775262

Table 7-2 Position Accuracy Statistics for Ashtech GG24 & Atlantic City

Receiver	Solution	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)	Number of Samples
Ashtech GG24	GPS/GLONASS	5.939	10.126	18.477	37.798	7754987
Millenium	GPS Only Atlantic City	5.445	8.246	25.947	21.703	7775262

Figures 7-3 and 7-4 show the Horizontal and Vertical Error histograms for the GG24 GLONASS/GPS solution and the GPS-only solution, respectively.

Figure 7-2 Horizontal Position Error Histogram for GPS/GLONASS

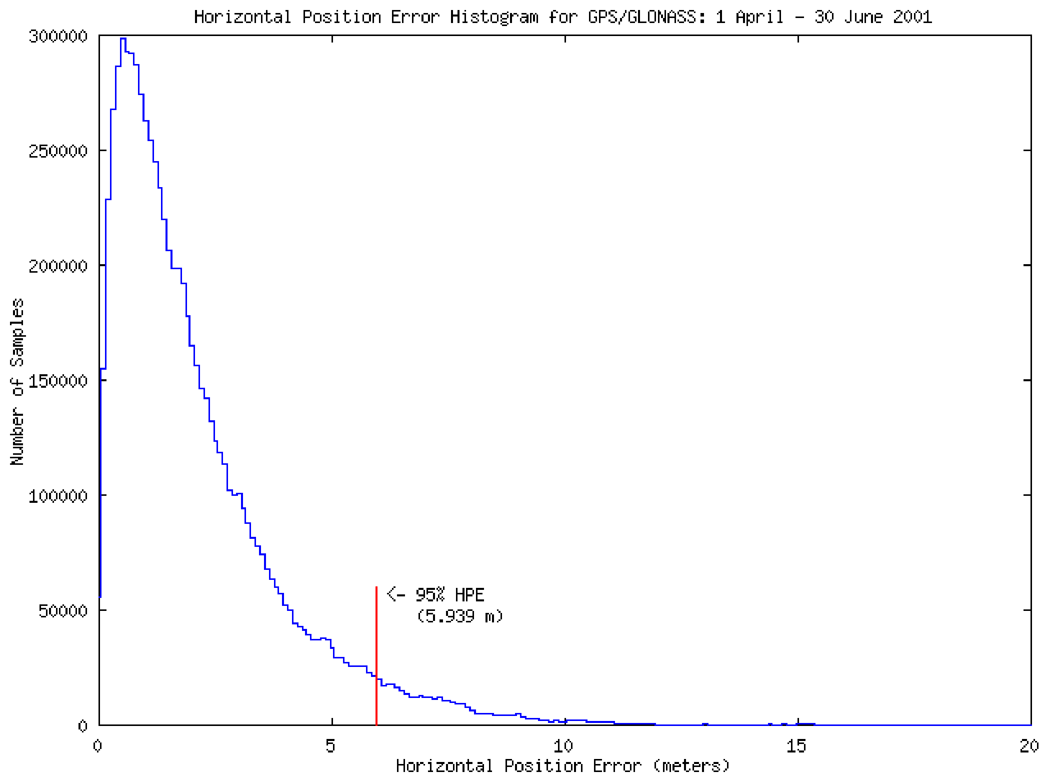


Figure 7-3 Vertical Position Error Histogram for GPS/GLONASS

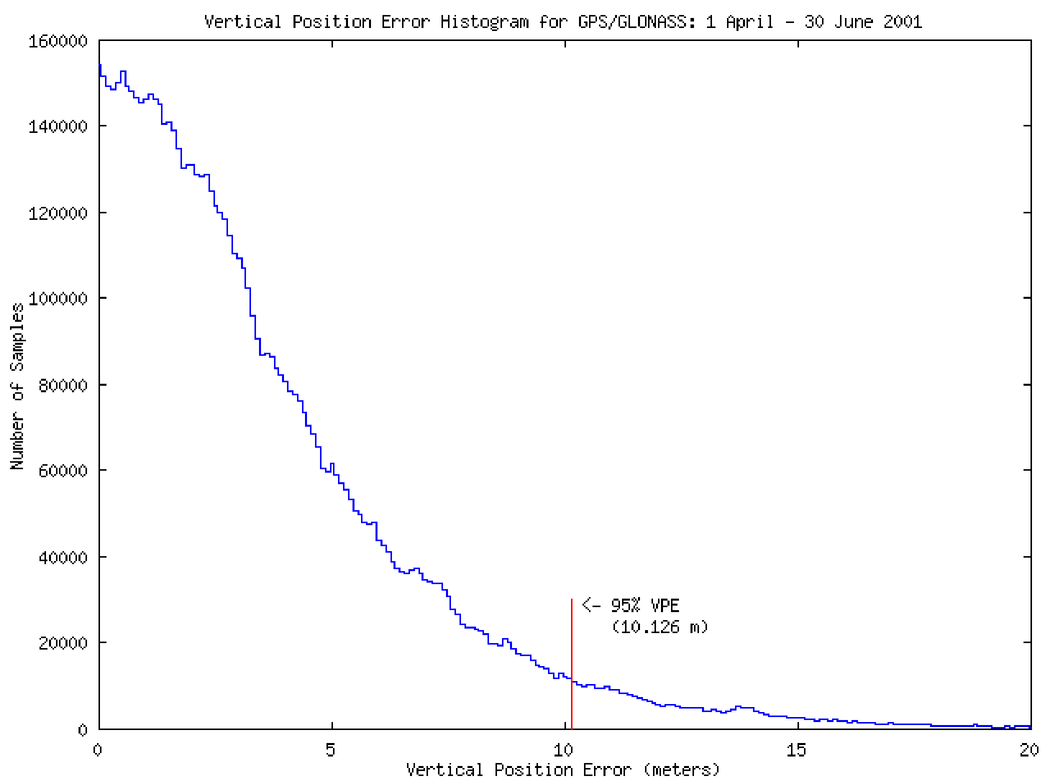
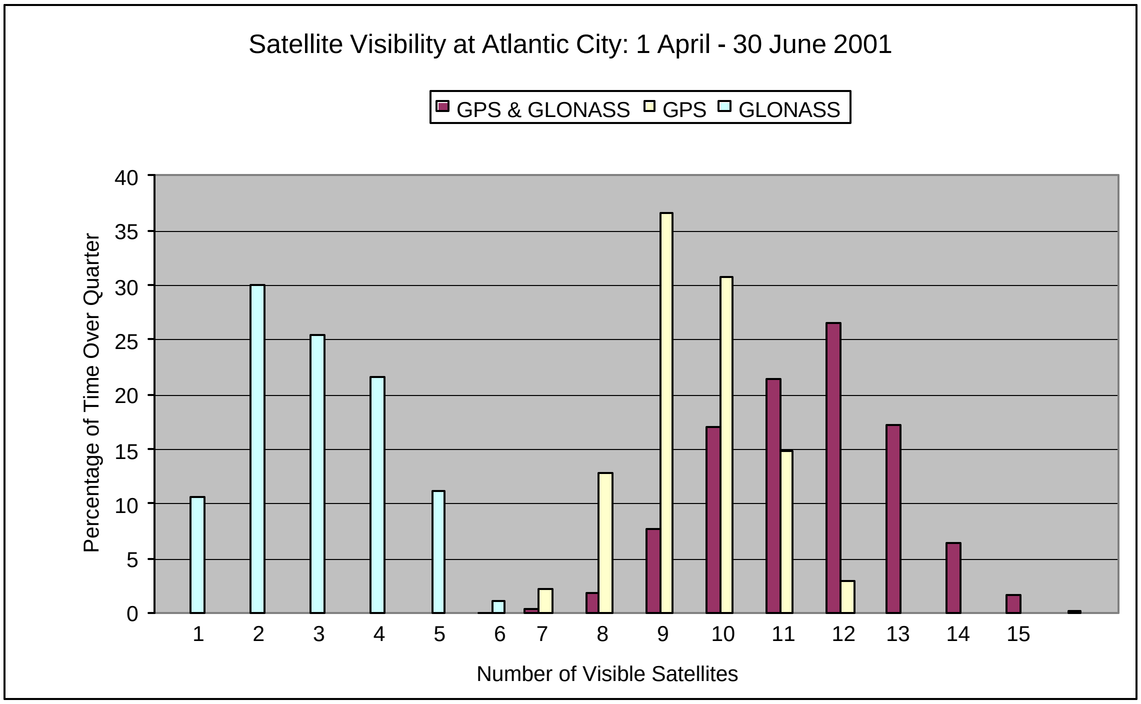


Figure 7-4 Glonass and GPS Satellite Visibility



APPENDICES A – D

Appendix A Performance Summary

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	99.818%
• 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	98.611% Availability 99.991% PDOP was 3.443
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	99.999%
• 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	99.712%
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	99.768%
• 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	98.611%
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	≤9.524m horz error 95% ≤27.794m horz error 99.99% ≤12.107m vert error 95% ≤37.264m vert error 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	≤3.146m horz error 95% ≤8.998m vert error 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	≤17 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each	Range Domain Accuracy ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range	30.141m NTE Range Error 0.8748m/s NTE Rate Error 8.70mm/s^2 NTE Accel 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 $\leq 8\ mm/s^2$ range acceleration error 95% of time	$\leq 8 mm/s^2$ 100% of the time

Appendix B Geomagnetic Data

```
Product: Daily Geomagnetic Data     quar_DGD.txt
Issued: 2120 UT 07 Jul 2001
#
#  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
2001 04 01     26  5 5 5 1 3 2 3 4    28  3 4 6 4 3 3 3 4    30  4 5 6 3 3 3 4 4
2001 04 02     12  4 2 3 1 2 2 3 3    23  4 4 5 3 3 4 3 2    20  4 4 4 3 3 3 3 4
2001 04 03      5  2 1 1 1 1 3 1 1     7  2 2 1 1 1 3 2 2     5  2 1 1 1 2 3 2 2
2001 04 04     12  2 1 1 1 4 3 4 2    19  2 2 1 4 5 4 4 1    15  2 2 2 2 3 4 5 2
2001 04 05     11  1 1 3 3 2 3 3 3    27  2 1 5 6 3 4 4 2    19  2 2 4 5 3 4 4 4
2001 04 06     11  2 1 3 2 1 2 4 3    18  2 1 3 4 5 3 3 3    12  1 1 3 3 3 3 3 3
2001 04 07     17  3 4 2 2 2 2 5 3    36  3 5 6 4 3 5 5 2    16  3 4 3 2 2 4 4 3
2001 04 08     33  3 2 4 5 5 4 5 5    -1  3 1 3-1-1-1-1-1    41  3 1 4 6 6 4 5 5
2001 04 09     17  2 4 4 3 3 4 3 2    -1 -1-1-1-1-1 5 3 2    19  2 4 4 4 3 5 3 2
2001 04 10      7  3 0 1 2 3 1 1 2    -1  2 2-1 3 4 3 2 4     9  3 1 2 2 3 3 2 2
2001 04 11     50  2 2 2 1 3 7 6 7   100  2 3 4 5 6 8 7 8    60  3 3 3 2 4 8 6 7
2001 04 12     29  6 6 4 3 3 2 1 2    34  6 4 5 6 4 2 1 1    38  7 6 5 5 3 3 1 2
2001 04 13     31  1 1 3 6 5 4 5 4    -1 -1-1-1-1-1 6 5 3    36  1 1 3 7 6 4 5 4
2001 04 14     13  4 3 3 2 3 2 2 2    29  3 4 4 5 5 5 3 1    15  3 3 4 3 3 3 3 2
2001 04 15      9  3 3 2 1 3 2 1 2    21  2 3 5 4 5 3 1 2    13  3 4 3 2 4 3 2 3
2001 04 16      7  3 1 1 1 2 1 1 3    10  4 3 1 3 2 2 1 1     7  3 2 1 1 2 3 2 2
2001 04 17      4  1 2 1 1 1 1 1 2     9  2 1 3 4 2 2 1 1     7  2 3 2 2 2 3 2 2
2001 04 18     22  5 5 5 2 2 2 2 2    -1  5 6 6 5 2 3 2-1    50  5 7 7 4 3 4 1 2
2001 04 19      5  2 1 2 1 2 1 1 1     8  2 2 3 4 2 1 0 0     7  3 2 3 1 2 2 1 2
2001 04 20      5  2 2 1 1 1 1 2 1     6  2 1 1 2 4 1 0 0     8  3 3 1 2 2 3 2 2
2001 04 21      7  1 2 0 1 1 2 2 4     5  1 1 0 2 2 2 1 2     7  1 2 1 2 2 3 2 3
2001 04 22     17  4 3 4 3 3 3 3 2    52  3 3 4 4 7 7 5 2    28  4 3 5 4 5 5 3 4
2001 04 23     18  4 5 5 2 2 1 1 1    14  3 3 4 4 3 2 1 0    21  4 4 5 4 3 3 3 2
2001 04 24     11  1 2 2 2 1 5 1 2    19  1 4 4 6 1 1 1 2     8  1 2 3 2 2 3 2 2
2001 04 25      7  1 1 1 2 3 2 2 2    10  4 3 0 3 2 2 2 1     7  1 1 1 2 3 3 2 2
2001 04 26      8  0 1 2 1 2 4 2 2    14  0 2 5 5 1 0 1 1     7  1 2 3 2 2 3 2 1
2001 04 27      3  1 1 1 0 1 1 1 1     4  2 0 0 0 1 1 2 3     6  2 1 0 2 3 3 2 1
2001 04 28     34  1 5 3 4 6 5 4 4    46  1 5 4 5 7 6 3 2    28  2 5 3 4 5 5 3 3
2001 04 29     11  4 3 2 2 3 2 2 1     9  4 3 2 1 2 1 2 1    15  4 4 2 2 3 2 2 1
2001 04 30      1  1 0 0 0 0 0 2 0    -1 -1 0 0 0 0 0 1 0     5  1 0 0 0 1 3 3 1
2001 05 01      3  1 0 1 0 2 1 2 1     3  2 0 0 0 0 1 2 1     4  1 0 1 1 2 2 2 2
2001 05 02      4  1 1 2 2 1 1 1 1     8  1 1 2 3 4 1 1 0     6  2 1 3 2 2 2 2 1
2001 05 03      6  2 1 1 2 2 2 2 2    10  2 1 1 4 1 3 1 3     7  1 1 2 3 2 2 3 2
2001 05 04      5  1 2 2 2 1 1 2 2    -1  2 2 3 3-1-1 1 3     9  1 3 3 3 2 2 2 2
```

2001 05 05	2	1 0 1 0 0 1 1 1	-1	1 0 1 1 -1 0 1 1	5	1 0 1 2 2 2 2 2
2001 05 06	5	1 0 2 2 2 1 2 2	-1	0 0 1 -1 1 1 1 1	7	1 0 2 2 3 3 2 2
2001 05 07	11	2 4 4 2 2 1 2 1	25	2 3 5 3 5 3 2 5	17	4 5 4 3 3 3 3 2
2001 05 08	16	2 3 3 3 3 3 3 4	23	1 0 3 4 4 6 3 3	14	2 1 3 3 3 4 4 4
2001 05 09	19	4 4 3 2 3 3 3 4	-1	5 5 5 5 7 -1 4 3	32	5 5 4 4 4 4 4 4
2001 05 10	23	5 5 4 3 3 1 3 3	22	4 5 4 4 4 2 2 2	28	5 5 5 4 3 3 3 3
2001 05 11	5	2 1 1 1 1 1 1 3	13	2 1 3 3 1 2 1 5	9	3 1 2 2 2 3 3 3
2001 05 12	20	3 2 2 5 4 3 3 4	36	4 2 4 6 5 5 4 4	34	4 2 4 6 6 4 3 4
2001 05 13	17	5 3 2 2 3 3 3 3	33	4 4 2 5 5 6 3 3	23	5 4 2 3 3 4 4 4
2001 05 14	10	4 3 3 0 1 2 1 2	-1	4 3 5 0 0 2 2 -1	12	4 3 4 1 2 3 3 2
2001 05 15	10	2 1 4 3 2 1 2 2	27	2 2 5 6 5 3 2 1	16	2 2 4 4 2 4 4 3
2001 05 16	7	3 2 2 1 1 2 1 2	-1	3 2 6 5 -1 1 1 -1	12	3 3 3 3 2 3 2 2
2001 05 17	7	1 3 1 1 1 2 2 3	7	2 3 1 3 0 1 1 2	9	2 3 1 3 2 3 2 3
2001 05 18	11	3 2 1 2 2 2 3 4	12	3 2 1 4 4 1 2 2	11	3 3 2 2 3 3 3 3
2001 05 19	10	4 4 2 1 1 0 2 1	9	3 4 2 3 2 0 1 0	12	4 4 2 2 3 3 3 2
2001 05 20	6	1 2 2 2 2 1 1 2	2	1 2 1 1 1 0 0 0	10	2 3 3 2 3 3 2 2
2001 05 21	3	1 0 1 2 2 0 0 1	9	1 1 1 5 3 0 0 0	8	2 1 1 2 3 3 3 2
2001 05 22	8	2 2 2 1 2 2 3 2	5	1 1 1 3 1 1 2 1	9	2 1 2 3 3 3 3 2
2001 05 23	8	2 2 2 1 2 3 2 2	16	4 2 3 5 2 2 2 2	11	3 2 2 2 3 4 3 3
2001 05 24	7	2 3 2 1 1 1 2 2	9	3 2 1 2 3 0 1 4	9	3 2 1 2 3 3 3 3
2001 05 25	6	2 1 1 2 2 2 2 2	13	0 1 1 3 4 5 2 1	8	2 1 2 2 3 3 3 2
2001 05 26	6	2 2 1 2 2 1 1 2	9	2 3 2 2 4 0 2 1	8	2 2 2 2 2 3 3 2
2001 05 27	8	0 0 0 0 2 4 3 3	6	0 0 0 1 0 4 2 2	9	1 0 0 2 3 4 3 3
2001 05 28	14	2 2 2 2 4 3 3 4	31	2 3 2 4 6 6 3 3	18	2 3 2 4 4 4 3 4
2001 05 29	9	4 2 1 1 3 2 2 1	12	3 2 1 1 5 3 1 0	10	4 2 2 1 3 3 2 2
2001 05 30	2	0 0 0 0 1 1 1 1	1	0 0 0 0 1 0 1 1	5	1 0 0 1 2 2 2 2
2001 05 31	4	0 0 0 0 2 3 1 1	4	0 0 0 0 2 3 1 1	7	1 0 0 1 3 3 2 2
2001 06 01	9	0 0 0 2 3 2 3 4	12	0 1 0 3 5 3 1 3	11	1 1 1 3 3 3 3 4
2001 06 02	18	5 3 2 3 4 2 2 3	19	4 4 2 4 4 3 2 3	21	5 4 3 3 4 3 3 3
2001 06 03	7	2 2 1 1 1 2 2 3	9	3 1 4 1 1 2 2 2	11	2 2 3 2 3 4 3 3
2001 06 04	4	2 1 1 0 1 2 1 2	9	3 2 4 1 2 2 1 1	11	4 1 2 2 3 3 3 3
2001 06 05	5	2 2 1 1 1 1 1 2	5	2 3 1 2 0 1 1 2	9	3 3 1 2 2 3 2 3
2001 06 06	6	2 1 1 1 2 2 2 2	7	2 1 2 1 4 1 1 1	10	2 2 2 2 3 3 3 3
2001 06 07	9	2 3 1 2 3 2 2 2	11	2 3 2 4 4 0 1 1	12	2 3 2 3 3 3 3 3
2001 06 08	7	1 2 2 2 1 2 2 3	7	1 2 1 1 3 2 2 2	8	2 2 2 2 2 2 3 3
2001 06 09	19	2 3 3 2 3 3 4 5	28	2 3 5 4 4 5 4 4	20	3 4 3 3 3 3 4 5
2001 06 10	13	5 2 3 2 2 2 2 2	31	5 5 5 5 4 3 2 2	20	5 3 4 4 3 4 3 3
2001 06 11	7	3 2 0 1 2 2 2 2	9	3 2 1 2 4 1 1 2	10	3 3 1 2 3 3 3 3
2001 06 12	5	2 2 2 1 1 0 2 2	4	2 2 2 1 0 1 1 1	7	2 2 2 2 2 2 3 2
2001 06 13	10	3 4 3 2 1 1 1 2	11	2 3 4 3 2 3 0 1	14	3 4 4 3 2 3 3 2
2001 06 14	6	1 1 1 0 1 1 1 4	5	2 1 3 0 0 1 1 2	9	2 1 1 2 2 3 3 4
2001 06 15	6	3 3 1 2 0 0 2 0	10	3 4 3 3 1 0 1 0	12	3 3 3 3 3 3 2 3
2001 06 16	4	2 2 2 0 0 1 2 0	3	2 1 2 0 0 0 1 0	7	2 2 2 2 2 3 3 2
2001 06 17	5	0 0 2 1 3 1 2 2	10	0 0 2 5 3 2 1 0	9	1 1 2 2 4 3 3 3
2001 06 18	25	1 5 4 3 4 2 4 5	46	2 5 4 7 6 4 3 4	34	2 5 5 6 5 3 4 4
2001 06 19	12	4 2 1 1 1 2 4 3	13	4 2 1 2 1 3 3 4	14	4 3 2 2 3 4 3 3
2001 06 20	10	2 3 3 2 3 2 1 2	26	3 4 5 6 4 2 1 1	15	3 3 4 4 3 3 2 3
2001 06 21	11	1 2 3 3 2 3 3 2	24	2 3 4 5 5 4 3 2	13	2 3 3 3 3 3 3 3
2001 06 22	3	1 1 0 1 1 1 1 2	5	2 1 1 1 2 2 1 2	7	2 2 1 2 3 2 2 3
2001 06 23	5	2 1 1 1 1 2 1 2	9	4 1 1 0 4 1 1 1	8	2 1 1 2 3 3 3 2
2001 06 24	11	2 2 2 3 3 3 3 2	-1	-1 -1 -1 -1 -1 -1 -1 -1	10	3 2 2 3 3 3 3 3
2001 06 25	7	2 3 2 2 1 2 2 2	-1	-1 -1 -1 -1 -1 1 1 2	8	2 2 2 2 2 3 2 2
2001 06 26	11	1 1 2 2 2 3 3 4	13	3 2 2 2 3 3 4 2	13	1 2 2 3 3 4 3 3
2001 06 27	5	3 3 1 0 1 1 1 0	11	4 4 2 1 3 1 1 1	10	4 4 2 1 2 2 2 2
2001 06 28	2	0 0 0 1 1 1 2 1	-1	0 0 0 0 1 -1 2 1	5	0 0 1 2 2 3 2 2
2001 06 29	2	0 0 1 1 1 0 1 2	1	0 0 0 1 0 1 1 0	7	1 1 1 2 2 3 2 3
2001 06 30	9	0 2 1 3 4 0 2 3	10	1 1 1 4 4 1 1 2	10	1 2 2 3 3 3 3 3

Background:

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

Problem Description:

There were no problems that failed any requirements as stated by the spec.

Appendix D Glossary

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.