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

Submitted To

Federal Aviation Administration
GPS Product Team
AND 730
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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: Atlantic City, Columbus, Denver, Grand Forks, Green Bay, Greenwood, Prescott, Anchorage (WAAS), Billings (WAAS), Chicago (WAAS), Kansas City (WAAS), Salt Lake City (WAAS), Miami (WAAS) and Atlanta (WAAS). This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification Annex A.

This report, Report #36, includes data collected from 1 October through 31 December 2001. The next quarterly report will be issued 30 April 2002.

Analysis of this data includes the following categories: Coverage performance, Service Availability Performance, Position Performance, Range Performance, Solar Storm Effects on GPS SPS performance, GPS/GLONASS performance and WAAS 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 99.792% or better.

Availability was verified by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 October and 31 December 2001 and by calculating the satellite availability from the data obtained from the fourteen sites. A total of nineteen outages were reported in the NANU's. Thirteen of the outages were scheduled and six were unscheduled. The quarterly availabilities for Atlantic City was 99.985%; while Columbus, Denver, Grand Forks, Green Bay, Greenwood, Prescott, Anchorage, Billings, Chicago, Atlanta, Kansas City, Miami and Salt Lake City were all 100%. Each of these availabilities is within the SPS value of 99.85%. These availability percentages were calculated using DOP data collected at one-second intervals.

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

Position accuracies were verified by calculating the 95% and 99.99% values of horizontal and vertical errors. Range performance was verified for each satellite using the data collected from the NSTB Atlantic City site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 25.290 meters on Satellite PRN 15. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 0.85850 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 8.59 Millimeters/second^2 on Satellite PRN 20. 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. The 95% horizontal error and vertical error for the GPS/GLONASS solution were 5.450 Meters and 10.080 Meters, respectively.

From the analysis performed on data collected between 1 October and 31 December 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:

- Atlantic City, NJ
- Columbus, NE
- Denver, CO
- Grand Forks, ND
- Elko, NV
- Green Bay, WI
- Greenwood, MS
- Prescott, AZ
- Billings, MT
- Anchorage, AK
- Chicago, IL
- Kansas City, KS
- Salt Lake City, UT
- Miami, FL
- Atlanta, GA

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

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 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 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.

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 met in all instances this quarter.

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

Table 1-1 SPS Performance Requirements

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

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

2.0 Coverage Performance

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

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

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

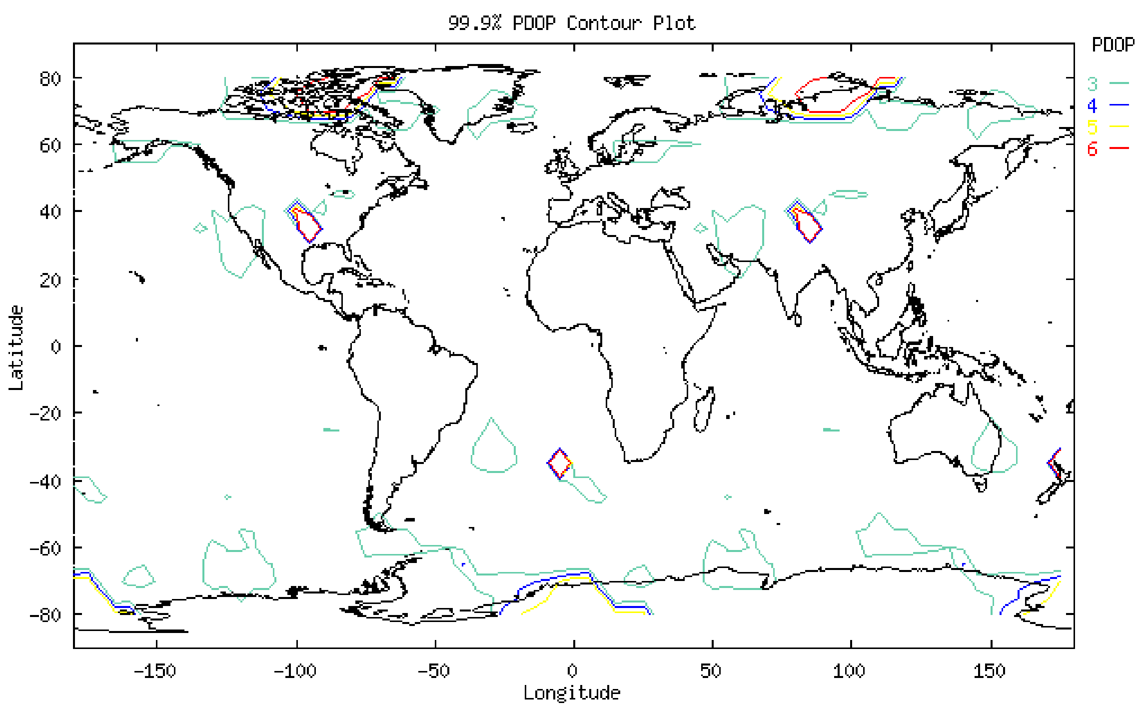
Almanacs for GPS weeks 97-109 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACT-360 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 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 3.061 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

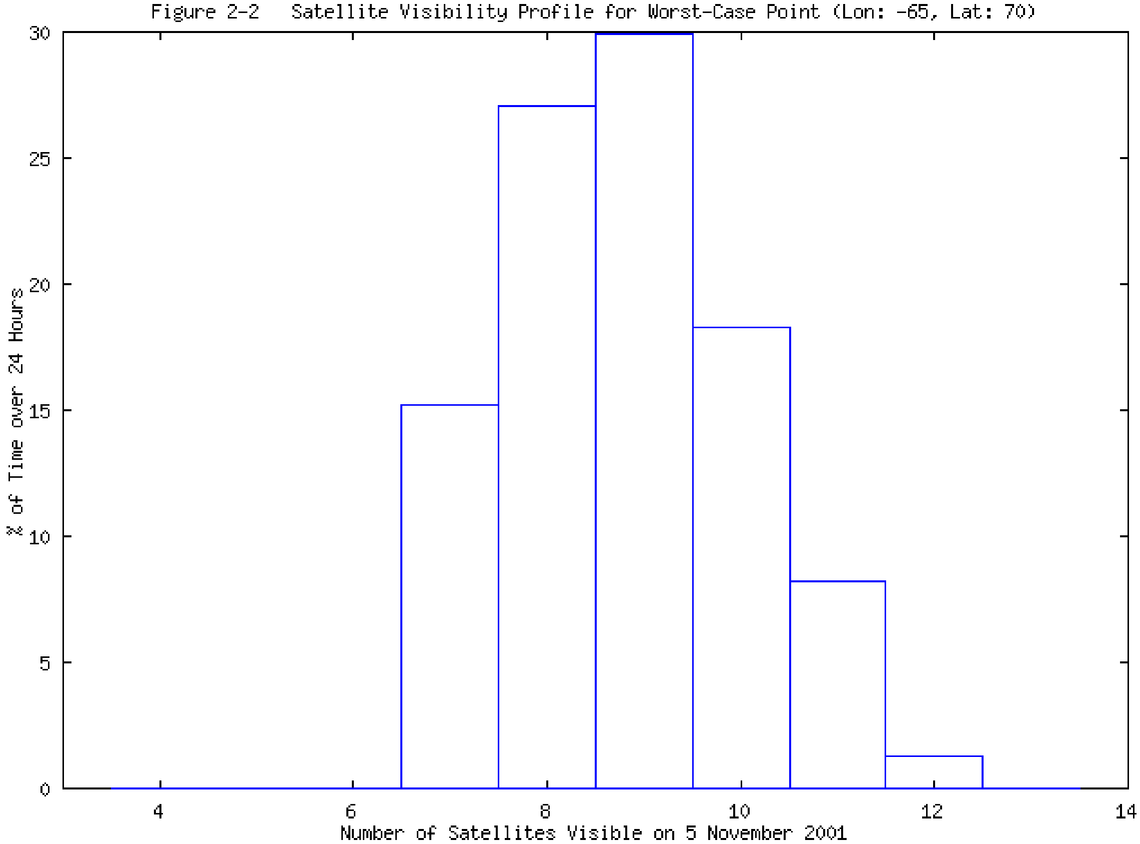
GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
110	3.018	100%	99.792%
111	3.042	100%	99.792%
112	3.046	100%	99.792%
113	3.049	100%	99.792%
114	3.056	100%	99.861%
115	3.061	100%	99.861%
116	3.046	100%	99.861%
117	3.039	100%	99.931%
118	3.004	100%	100%
119	2.982	100%	100%
120	2.966	100%	100%
121	2.954	100%	100%
122	3.030	100%	99.931%
123	3.030	100%	99.931%

Figure 2-1 SPS Coverage (24-Hour Period: 5 November 2001)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -65, Lat: 70)



> ***Service Availability:*** *Given coverage, the percentage of time over a specified time interval that a sufficient number of satellites are transmitting a usable ranging signal within view of any point on or near the Earth.*

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANU's). During this reporting period, 1 October through 31 December 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 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
1126	28	S	12-Oct	7:45	12-Oct	22:34		4.82	4.82
1127	24	S	18-Oct	3:17	18-Oct	7:26		4.15	4.15
1131	27	S	25-Oct	17:16	25-Oct	21:25		4.15	4.15
1132	2	S	29-Oct	22:41	30-Oct	8:03		14.63	14.63
1134	23	S	1-Nov	7:13	1-Nov	10:34		3.35	3.35
1136	7	S	8-Nov	3:12	9-Nov	2:35		23.38	23.38
1138	25	S	13-Nov	14:14	13-Nov	23:22		9.13	9.13
1139	14	S	20-Nov	5:45	20-Nov	13:14		7.48	7.48
1141	7	U	23-Nov	5:34	N/A	N/A	N/A	N/A	N/A
1143	7	U	23-Nov	5:34	24-Nov	23:48	18.23		18.23
1144	23	U	24-Nov	18:54	24-Nov	23:39	4.75		4.75
1146	29	U	4-Dec	10:00	N/A	N/A	N/A	N/A	N/A
1147	13	S	28-Nov	12:55	28-Nov	15:31		2.60	2.60
1149	29	U	4-Dec	10:26	4-Dec	14:17	3.85		3.85
1152	28	S	6-Dec	17:27	6-Dec	20:09		2.70	2.70
1153	30	S	10-Dec	21:52	11-Dec	0:14		2.37	2.37
1155	13	U	11-Dec	15:38	N/A	N/A	N/A	N/A	N/A
1156	13	U	11-Dec	15:38	11-Dec	23:02	7.40		7.40
1157	5	U	12-Dec	20:51	13-Dec	7:31	10.67		10.67
1160	17	S	18-Dec	0:37	18-Dec	4:58		4.35	4.35
1161	29	S	20-Dec	5:11	20-Dec	12:13		7.03	7.03
1162	28	U	22-Dec	19:21	N/A	N/A	N/A	N/A	N/A
1163	28	U	22-Dec	19:21	23-Dec	0:40	5.32		5.32
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**50.22**	**90.14**	**140.36**
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
1123	28	F	12-Oct	7:45	12-Oct	19:45	12	See NANU 1126
1124	24	F	18-Oct	3:00	18-Oct	15:00	12	See NANU 1127
1128	27	F	25-Oct	17:00	26-Oct	5:00	12	See NANU 1131
1129	2	F	29-Oct	22:30	30-Oct	22:30	24	See NANU 1132
1130	23	F	1-Nov	7:00	1-Nov	19:00	12	See NANU 1134
1133	7	F	8-Nov	16:45	9-Nov	4:45	12	See NANU 1136
1135	25	F	13-Nov	14:00	14-Nov	2:00	12	See NANU 1138
1137	14	F	20-Nov	5:00	20-Nov	17:00	12	See NANU 1139
1140	13	F	28-Nov	12:00	29-Nov	0:00	12	See NANU 1147
1148	28	F	6-Dec	17:00	7-Dec	5:00	12	See NANU 1152
1150	30	F	10-Dec	21:30	11-Dec	9:30	12	See NANU 1153
1154	17	F	18-Dec	0:30	18-Dec	12:30	12	See NANU 1160
1158	29	F	20-Dec	5:00	20-Dec	17:00		See NANU 1159
1159	29	Rescheduled	20-Dec	5:00	21-Dec	5:00	24	See NANU 1161
					Total Forecast Downtime		**168**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
NONE					

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 Oct - 31 Dec, 2001**	**12 December, 1998- 31 Dec, 2001**
Total Forecast Downtime (hrs):	168	3284.47
Total Actual Downtime (hrs):	140.36	5548.22
Total Actual Scheduled Downtime (hrs):	90.14	1718.71
Total Actual Unscheduled Downtime (hrs):	50.22	3805.53
Total Satellite Observed MTTR (hrs):	7.39	51.87
Scheduled Satellite Observed MTTR (hrs):	6.93	23.78
Unscheduled Satellite Observed MTTR (hrs):	8.37	121.3
# Total Satellite Outages:	19	238
# Scheduled Satellite Outages:	13	185
# Unscheduled Satellite Outages:	6	53
Percent Operational -- Scheduled Downtime:	99.99%	99.80%
Percent Operational -- All Downtime:	99.99%	98.96%

3.2 Service Availability

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

To verify availability, the data collected from receivers at the nine NSTB/WAAS sites was reduced to calculate DOP information and reported in Tables 3-5 to 3-7. The data was collected at one-second intervals between 1 October and 31 December 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
Atlantic City	1.239	6.470	6.129	1.816	6.275	5.940	7251132
Columbus	1.250	5.125	4.569	1.806	4.790	4.261	7233111
Denver	1.200	5.963	4.333	1.794	4.846	4.195	6580445
Grand Forks	1.214	5.368	3.403	1.766	4.705	4.366	6771380
Green Bay	1.186	5.991	5.537	1.800	5.344	5.009	6406279
Greenwood	1.264	5.960	5.410	1.849	5.286	4.715	7251436
Prescott	1.363	5.998	5.097	2.103	5.928	5.681	7253534
Billings	1.142	4.104	3.396	1.750	4.045	3.349	2392875
Anchorage	1.200	4.880	4.571	1.740	4.159	3.986	2388049
Chicago	1.247	3.893	3.366	1.765	3.837	3.313	2392838
Kansas City	1.253	3.898	3.442	1.759	3.887	3.433	2385532
Salt Lake City	1.142	4.649	3.866	1.749	4.435	3.687	2393124
Miami	1.208	2.925	2.701	1.758	2.807	2.550	2392956
Atlanta	1.240	4.558	4.099	1.796	4.555	4.095	2393057

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
Atlantic City	117_5	6.470	571	1143, 7	86232	99.338%
Atlantic City	117_6	6.350	523	1144, 23	86381	99.395%
Worst-Case Point on Worst-Case Day = 99.338% (SPS Spec. ≥ 83.92%)						

Global Average on Worst-Case Day = 99.815 % (SPS Spec. ≥ 95.87%)

Table 3-7 PDOP > 6 Statistics

NSTB/WAAS Site	Total Number of Seconds of PDOP Monitoring	Total Seconds with PDOP > 6	Overall % Availability
Atlantic City	7251132	1094	99.985%
Columbus	7233111	0	100%
Denver	6580445	0	100%
Grand Forks	6771380	0	100%
Green Bay	6406279	0	100%
Greenwood	7251436	0	100%
Prescott	7253534	0	100%
Billings	2392875	0	100%
Anchorage	2388049	0	100%
Chicago	2392838	0	100%
Kansas City	2385532	0	100%
Salt Lake City	2393124	0	100%
Miami	2392956	0	100%
Atlanta	2393057	0	100%
Worst Single Point Average = 99.985% (SPS Spec. ≥ 99.16%)			

Global Average over Reporting Period = 99.998% (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)
Atlantic City	7251132	17.6
Columbus	7233111	17.6
Denver	6580445	19.0
Grand Forks	6771380	18.6
Green Bay	6406279	22.5
Greenwood	7251436	19.4
Prescott	7253534	16.9
Billings	2392875	12.0
Anchorage	2388049	16.0
Chicago	2392838	11.5
Kansas City	2385532	12.3
Salt Lake City	2393124	12.5
Miami	2392956	14.3
Atlanta	2393057	14.4

5.0 Accuracy Characteristics

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

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

5.1 Position Accuracies

The data used for this section was collected for every second between 1 October through 31 December 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)
Atlantic City	5.669	9.930	14.891	21.419
Columbus	5.903	9.662	16.223	22.115
Denver	5.875	10.151	14.622	18.993
Grand Forks	6.313	8.432	16.403	19.019
Green Bay	5.987	9.678	17.718	21.046
Greenwood	5.209	10.453	17.618	19.930
Prescott	5.437	11.029	14.665	23.172
Billings	6.459	7.886	11.429	12.966
Anchorage	6.787	7.262	15.736	20.939
Chicago	6.304	9.512	11.025	17.976
Kansas City	6.198	8.837	11.951	16.568
Salt Lake City	6.014	8.646	12.087	15.954
Miami	5.509	11.375	13.376	18.681
Atlanta	5.502	9.833	14.098	19.482

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 October to 31 December 2001.

Figure 5-1 Combined Vertical Error Histogram

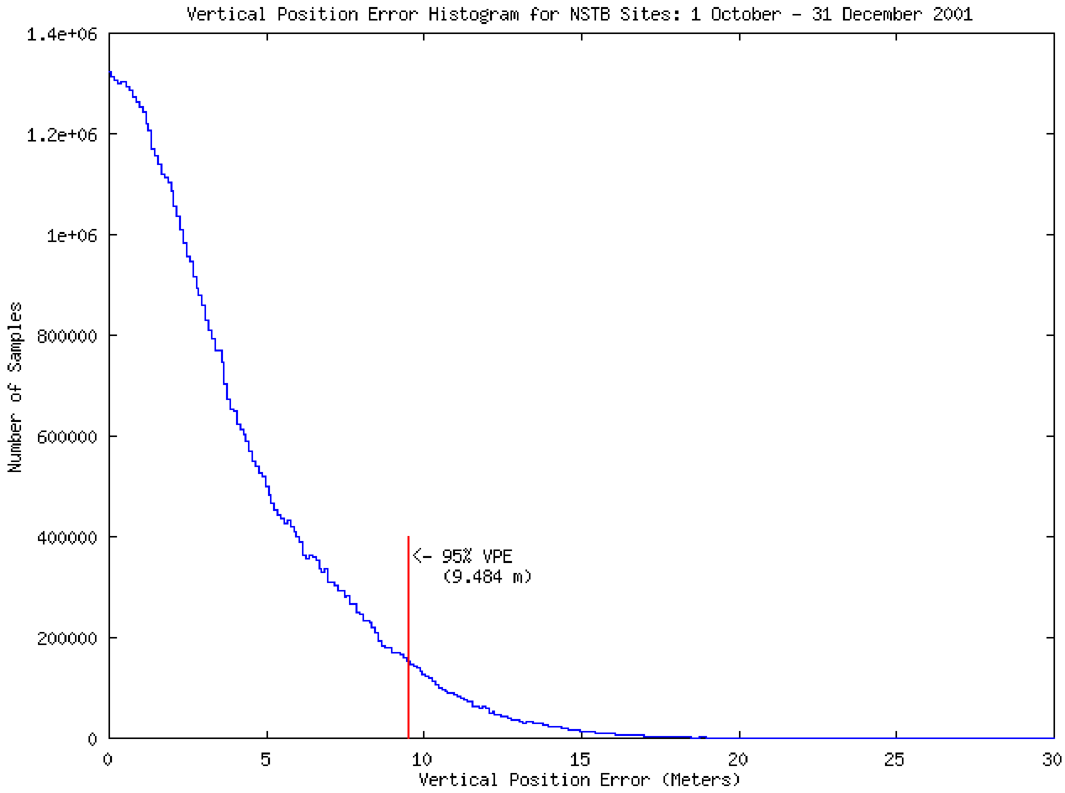
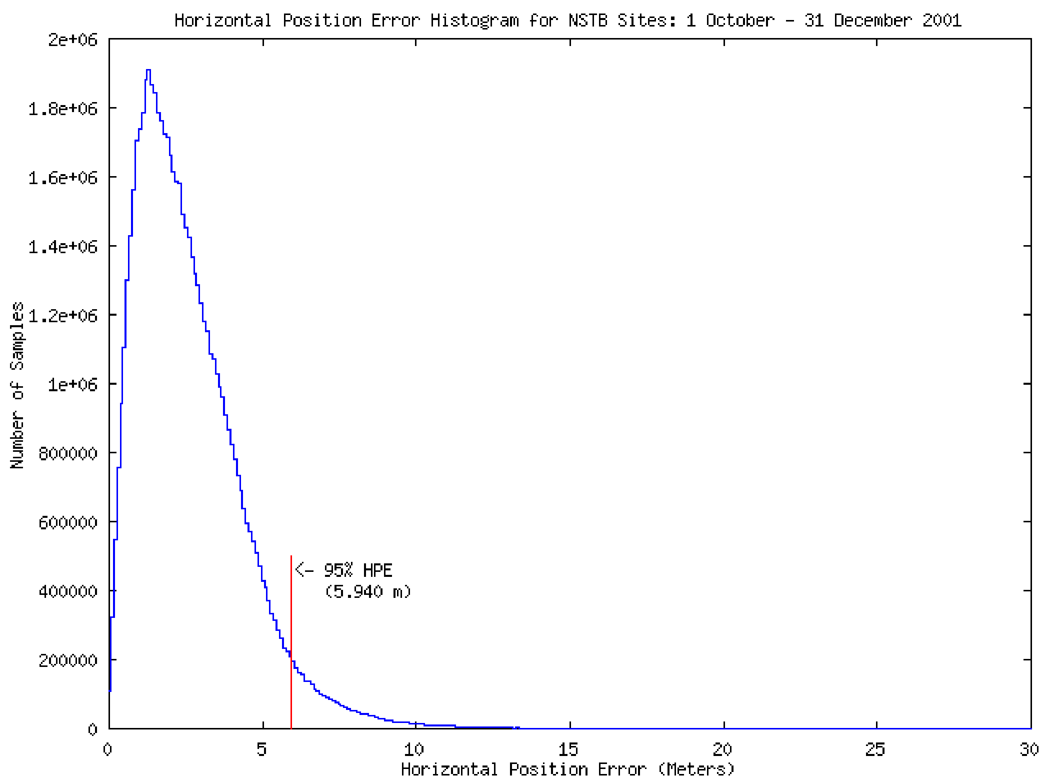


Figure 5-2 Combined Horizontal Error Histogram



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)
Atlantic City	2.067	4.875
Columbus	2.189	4.295
Denver	2.097	3.995
Grand Forks	2.033	4.462
Green Bay	2.102	4.658
Greenwood	2.269	5.493
Prescott	1.978	3.737
Billings	1.921	3.851
Anchorage	1.525	4.229
Chicago	2.079	4.336
Kansas City	2.367	4.642
Salt Lake City	2.100	3.780
Miami	2.377	5.501
Atlanta	2.468	4.529

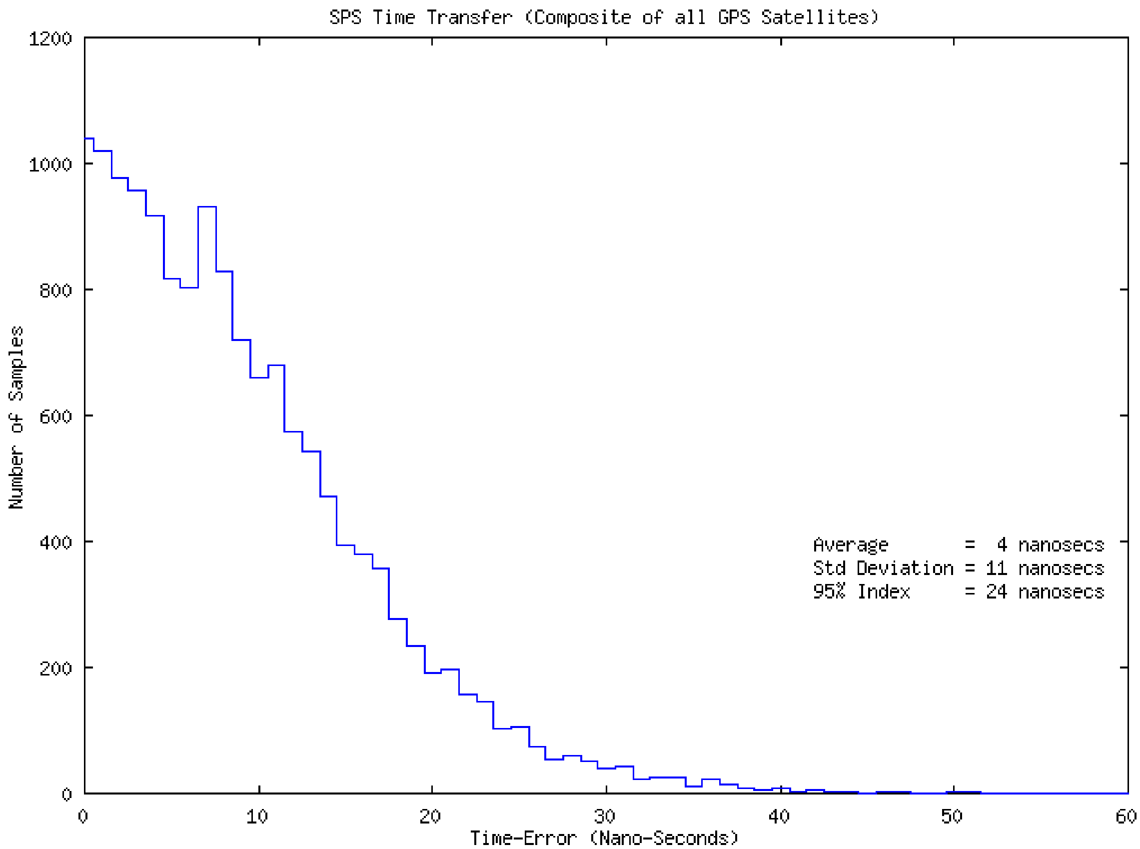
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 October and 31 December 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 Errors



5.5 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 October and 31 December 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	-3.369	5.373	4.186	11.200	20.540	2188844
2	-1.758	4.378	4.010	8.701	20.589	1935836
3	-4.411	6.423	4.669	12.480	24.896	1956759
4	-0.840	2.738	2.606	5.378	16.371	2218587
5	-0.509	2.611	2.560	4.991	18.804	2552712
6	-0.811	2.813	2.694	5.572	22.309	2466409
7	-1.203	3.368	3.146	6.824	14.342	2206334
8	-0.977	3.791	3.663	8.162	16.483	2145344
9	-0.788	3.195	3.096	6.929	14.748	2290326
10	0.267	2.233	2.217	4.496	11.141	2112148
11	-4.016	5.320	3.489	10.138	21.456	2130761
13	-2.362	4.376	3.684	9.510	18.199	2458645
14	-2.842	4.852	3.933	9.825	20.250	2238729
15	-1.417	3.856	3.586	7.714	25.290	2033690
17	-1.174	3.207	2.984	6.820	17.464	1865357
18	-1.468	3.930	3.645	8.227	20.101	2184056
20	-2.780	4.136	3.062	7.945	22.927	2540399
21	-2.341	4.493	3.835	9.239	15.416	1999749
22	-3.517	5.715	4.505	12.006	23.707	2029156
23	-0.926	3.669	3.550	7.547	15.643	2309149
24	-0.263	2.411	2.396	5.054	12.325	2294276
25	-3.783	5.454	3.929	10.968	21.759	2256879
26	-0.563	2.267	2.196	4.611	9.837	1858078
27	-2.979	5.320	4.408	10.974	17.851	1785139
28	-1.270	3.863	3.648	8.097	18.266	1970455
29	-4.400	5.647	3.541	10.592	16.440	1974209
30	-1.518	3.480	3.131	7.223	14.407	2494745
31	-3.655	5.755	4.446	11.592	22.232	1843648

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	0.00031	0.00352	0.00350	0.00624	0.19884	2188844
2	-0.00008	0.00409	0.00409	0.00668	0.24994	1935836
3	-0.00043	0.00647	0.00646	0.00666	0.54099	1956759
4	-0.00019	0.00304	0.00303	0.00514	0.16503	2218587
5	-0.00013	0.00698	0.00698	0.00663	0.67469	2552712
6	-0.00018	0.00466	0.00466	0.00652	0.28468	2466409
7	-0.00013	0.00403	0.00402	0.00605	0.26584	2206334
8	-0.00004	0.00363	0.00363	0.00698	0.17813	2145344
9	0.00008	0.00643	0.00643	0.00648	0.59625	2290326
10	0.00004	0.00324	0.00324	0.00481	0.22854	2112148
11	-0.00022	0.00597	0.00597	0.00736	0.72313	2130761
13	-0.00001	0.00607	0.00607	0.00701	0.47629	2458645
14	-0.00005	0.00342	0.00342	0.00575	0.16880	2238729
15	0.00006	0.00426	0.00426	0.00678	0.25274	2033690
17	0.00012	0.00339	0.00339	0.00578	0.22050	1865357
18	0.00010	0.00354	0.00354	0.00586	0.22450	2184056
20	0.00001	0.00909	0.00909	0.00691	0.85850	2540399
21	0.00019	0.00380	0.00380	0.00624	0.30264	1999749
22	-0.00039	0.00388	0.00386	0.00600	0.23659	2029156
23	0.00005	0.00401	0.00401	0.00561	0.23449	2309149
24	-0.00008	0.00325	0.00325	0.00481	0.26969	2294276
25	-0.00017	0.00383	0.00383	0.00603	0.18172	2256879
26	-0.00009	0.00372	0.00372	0.00537	0.31822	1858078
27	0.00008	0.00395	0.00395	0.00687	0.23786	1785139
28	-0.00014	0.00348	0.00348	0.00634	0.15448	1970455
29	0.00023	0.00326	0.00325	0.00591	0.12583	1974209
30	-0.00006	0.00553	0.00553	0.00670	0.49703	2494745
31	-0.00032	0.00600	0.00600	0.00686	0.81106	1843648

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	0.00000	0.00003	0.00003	100	0.00201	2188844
2	0.00000	0.00003	0.00003	100	0.00248	1935836
3	0.00000	0.00006	0.00006	100	0.00549	1956759
4	0.00000	0.00002	0.00002	100	0.00165	2218587
5	0.00000	0.00007	0.00007	100	0.00675	2552712
6	0.00000	0.00004	0.00004	100	0.00307	2466409
7	0.00000	0.00003	0.00003	100	0.00265	2206334
8	0.00000	0.00003	0.00003	100	0.00179	2145344
9	0.00000	0.00006	0.00006	100	0.00596	2290326
10	0.00000	0.00003	0.00003	100	0.00229	2112148
11	0.00000	0.00005	0.00005	100	0.00722	2130761
13	0.00000	0.00006	0.00006	100	0.00479	2458645
14	0.00000	0.00003	0.00003	100	0.00168	2238729
15	0.00000	0.00003	0.00003	100	0.00252	2033690
17	0.00000	0.00003	0.00003	100	0.00183	1865357
18	0.00000	0.00003	0.00003	100	0.00178	2184056
20	0.00000	0.00009	0.00009	99.9999	0.00859	2540399
21	0.00000	0.00003	0.00003	100	0.00303	1999749
22	0.00000	0.00003	0.00003	100	0.00236	2029156
23	0.00000	0.00003	0.00003	100	0.00237	2309149
24	0.00000	0.00003	0.00003	100	0.00267	2294276
25	0.00000	0.00003	0.00003	100	0.00184	2256879
26	0.00000	0.00003	0.00003	100	0.00316	1858078
27	0.00000	0.00003	0.00003	100	0.00237	1785139
28	0.00000	0.00003	0.00003	100	0.00154	1970455
29	0.00000	0.00002	0.00002	100	0.00113	1974209
30	0.00000	0.00005	0.00005	100	0.00498	2494745
31	0.00000	0.00005	0.00005	99.9999	0.00808	1843648

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the maximum range error, range rate error and range acceleration error for all satellites. None of the range errors for any of the satellites exceeded the 150-meter SPS requirement. The highest maximum range error occurred on satellite 15 with an error of 25.290 meters. Satellite 26 had the lowest maximum range error of 9.837 meters.

Figure 5-4 Distribution of Daily Max Range Errors

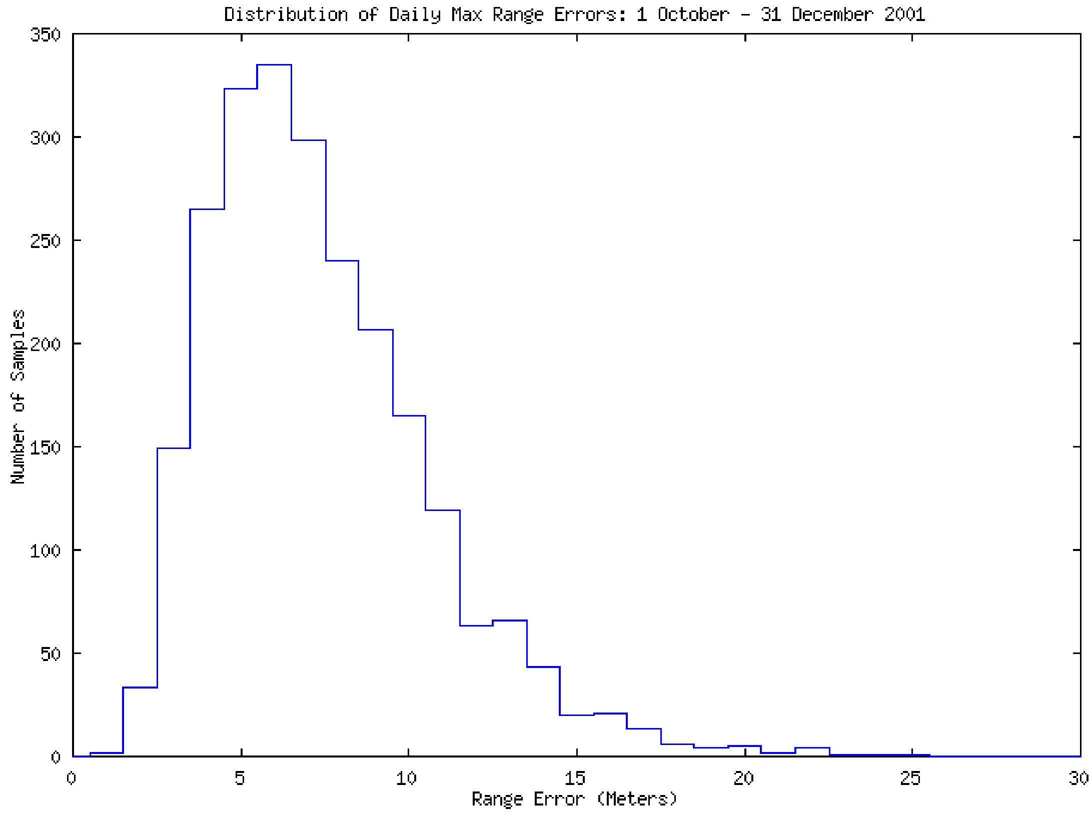


Figure 5-5: Distribution of Daily Max Range Rate Errors

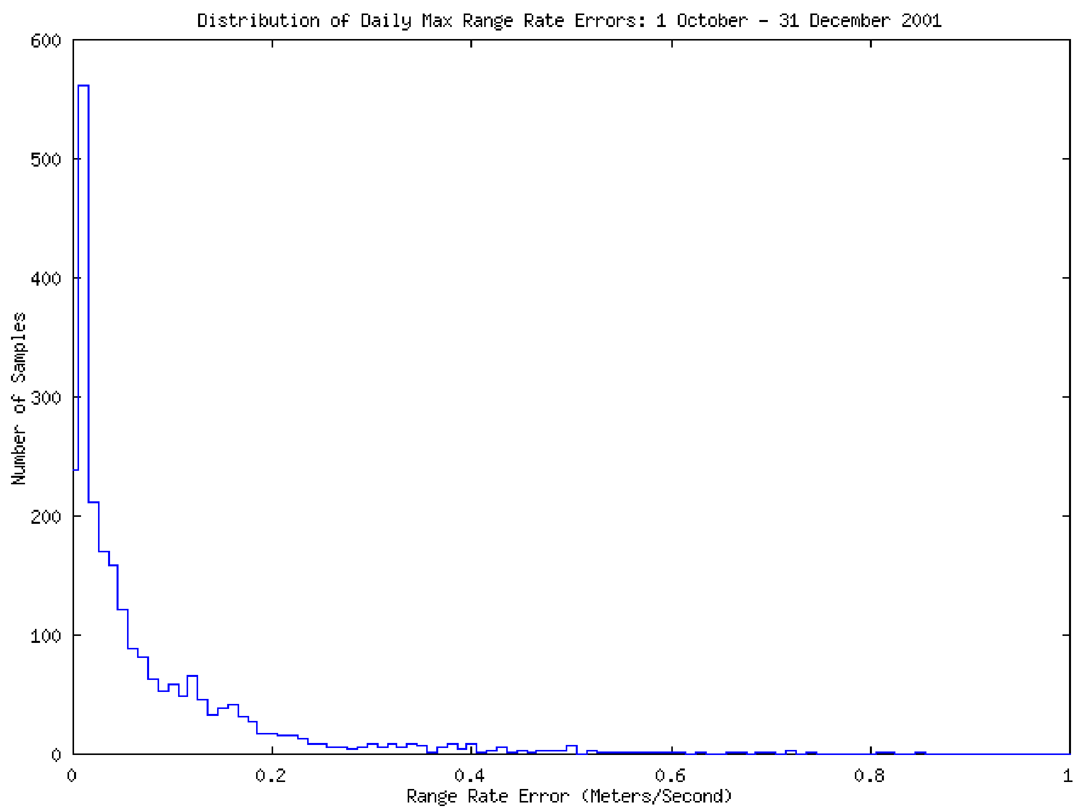


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

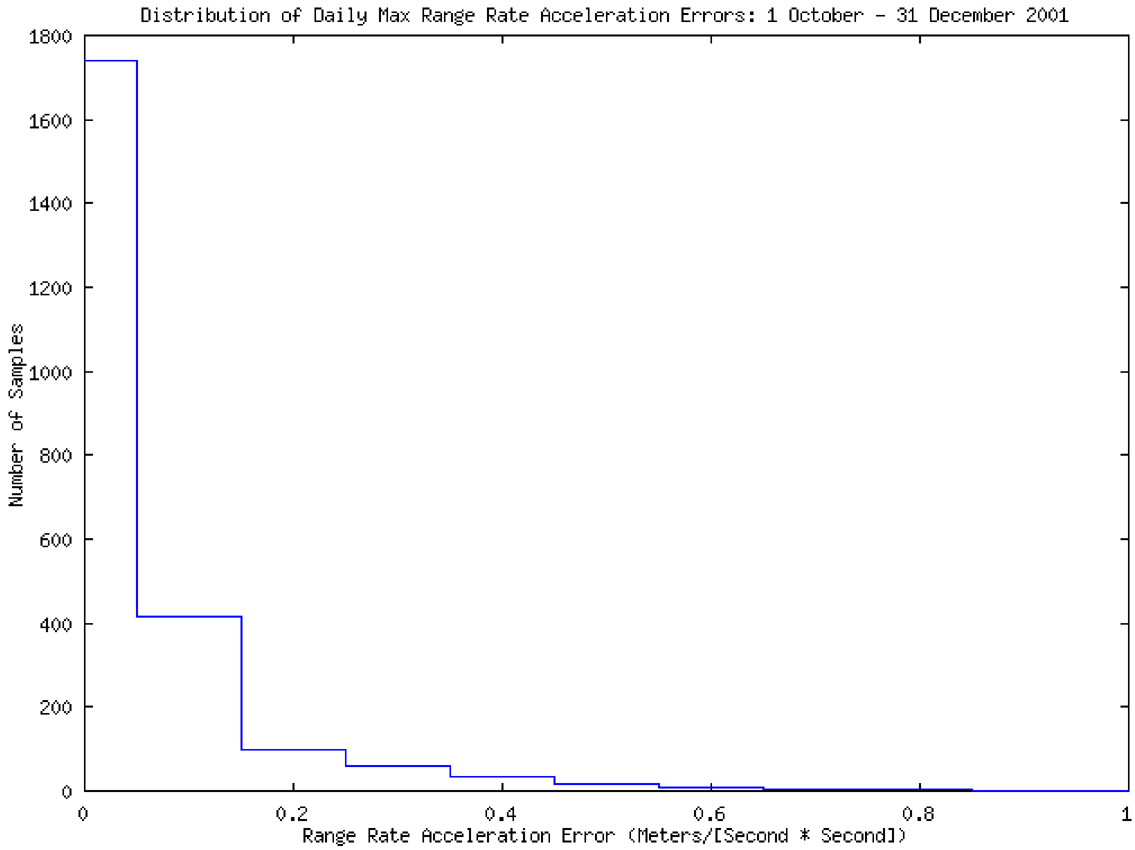


Figure 5-7: Maximum Range Error Per Satellite

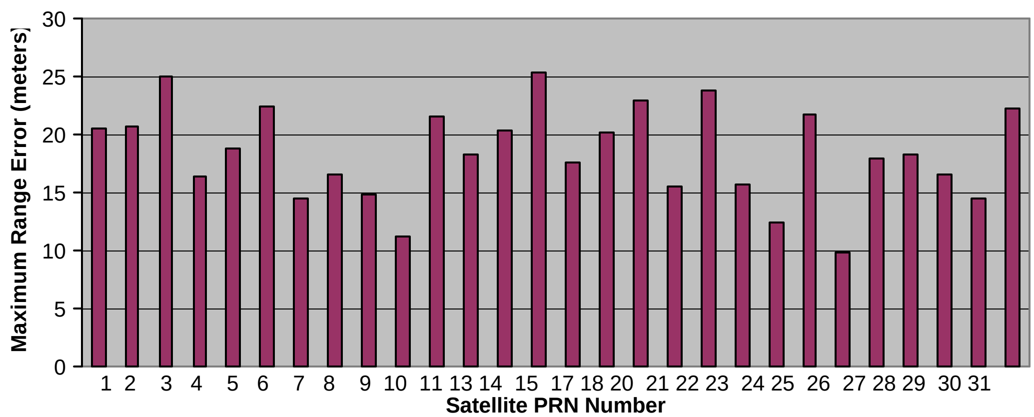


Figure 5-8: Maximum Range Rate Error Per Satellite

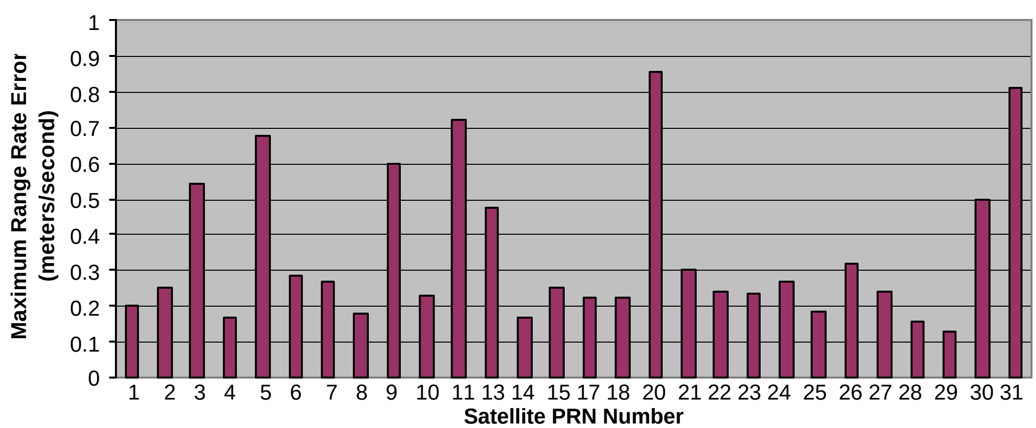
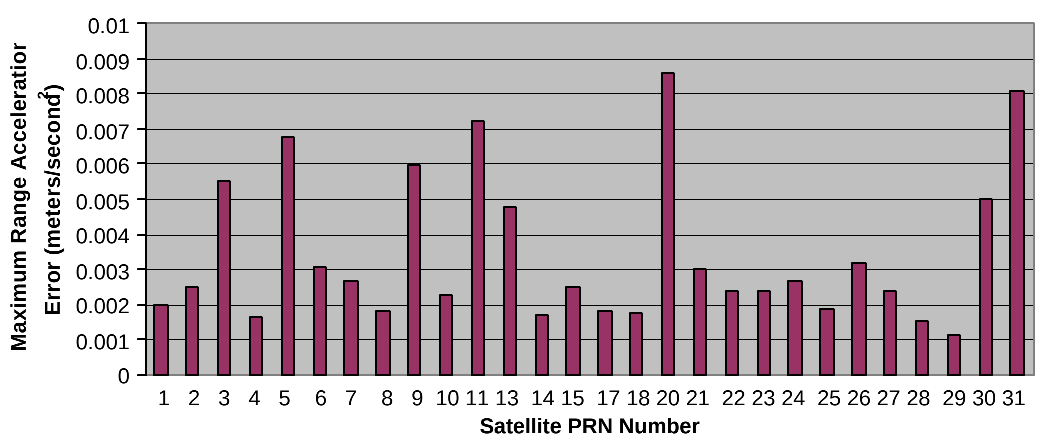


Figure 5-9: Maximum Range Acceleration Per Satellite



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 23-25 November 2001

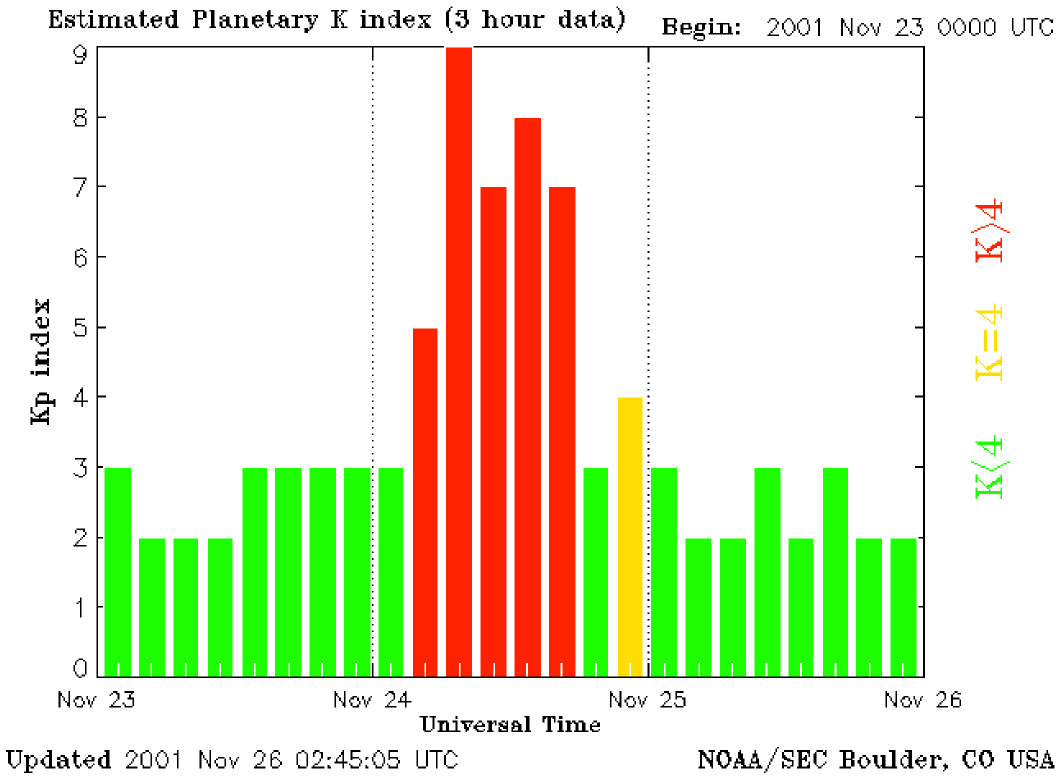


Figure 6-2 K-Index for 5-7 November 2001

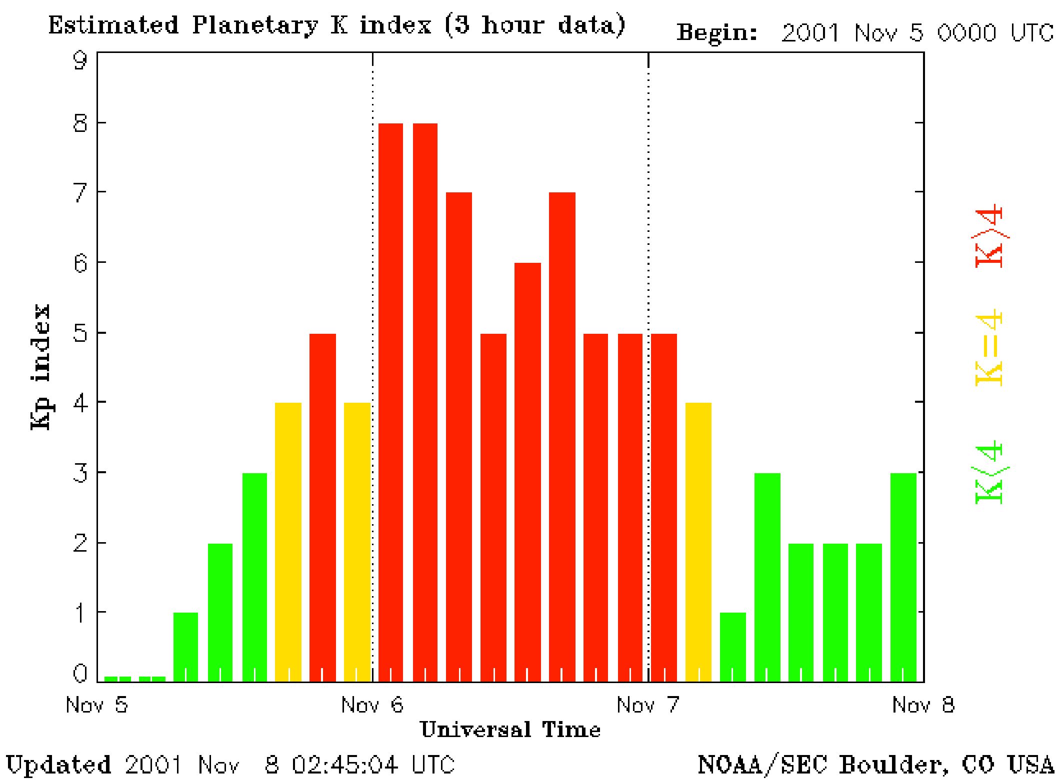
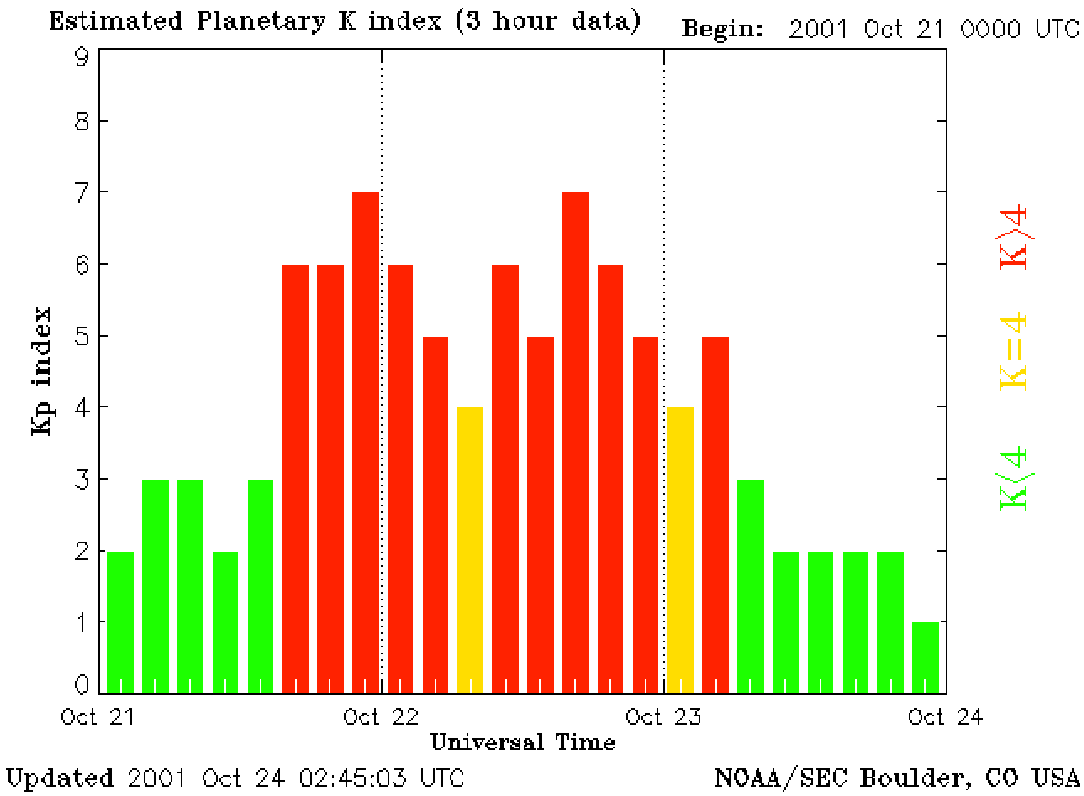


Figure 6-3 K-Index for 21-23 October 2001



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/WAAS Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Atlantic City	1.252	6.350	1.997	6.350	6.012
Columbus	1.284	4.074	1.865	4.072	3.538
Denver	1.246	4.373	1.858	4.373	3.470
Grand Forks	1.237	5.029	1.896	4.893	4.649
Green Bay	1.187	4.234	1.890	3.826	3.579
Greenwood	1.270	5.252	1.867	5.236	4.454
Prescott	1.377	5.906	2.169	5.895	5.145
Billings*					
Anchorage*					
Chicago*					
Kansas City*					
Salt Lake City*					
Miami*					
Atlanta*					

***NOTE: No data for WAAS sites on this day due to shutdown of O&M station here in Atlantic City. We now have a WEI interface that provides us with all WAAS data.**

Table 6-2 Horizontal & Vertical Accuracy Statistics

NSTB Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Atlantic City	9.879	8.787	15.954	22.239
Columbus	7.325	8.186	9.883	12.269
Denver	8.146	7.357	12.900	11.144
Grand Forks	6.349	10.273	7.588	16.085
Green Bay	5.931	9.455	7.631	13.043
Greenwood	11.540	9.016	19.342	18.003
Prescott	10.046	8.756	16.830	14.474
Billings*				
Anchorage*				
Chicago*				
Kansas City*				
Salt Lake City*				
Miami*				
Atlanta*				

***NOTE: No data for WAAS sites on this day due to shutdown of O&M station here in Atlantic City. We now have a WEI interface that provides us with all WAAS data.**

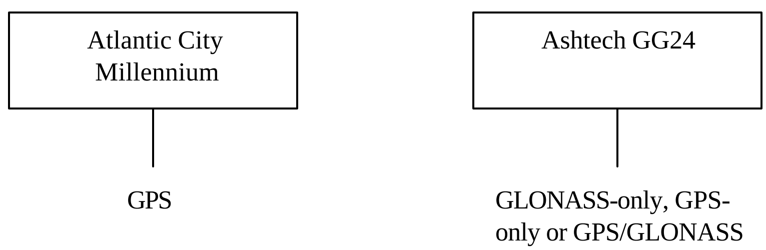
7.1 Introduction

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.

Tables 7-1 and 7-2 provide PDOP and Position Accuracy statistics for the two receivers from 1 October through 31 December 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	5.940	1.063	1.721	2.247	7816761
Millenium	GPS Only Atlantic City	6.470	1.239	1.816	2.338	7251132

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	5.450	10.080	22.555	32.053	7816761
Millenium	GPS Only Atlantic City	5.669	9.930	14.891	21.419	7251132

Figures 7-2 and 7-3 show the Horizontal and Vertical Error histograms for the GG24 GLONASS/GPS solution.

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

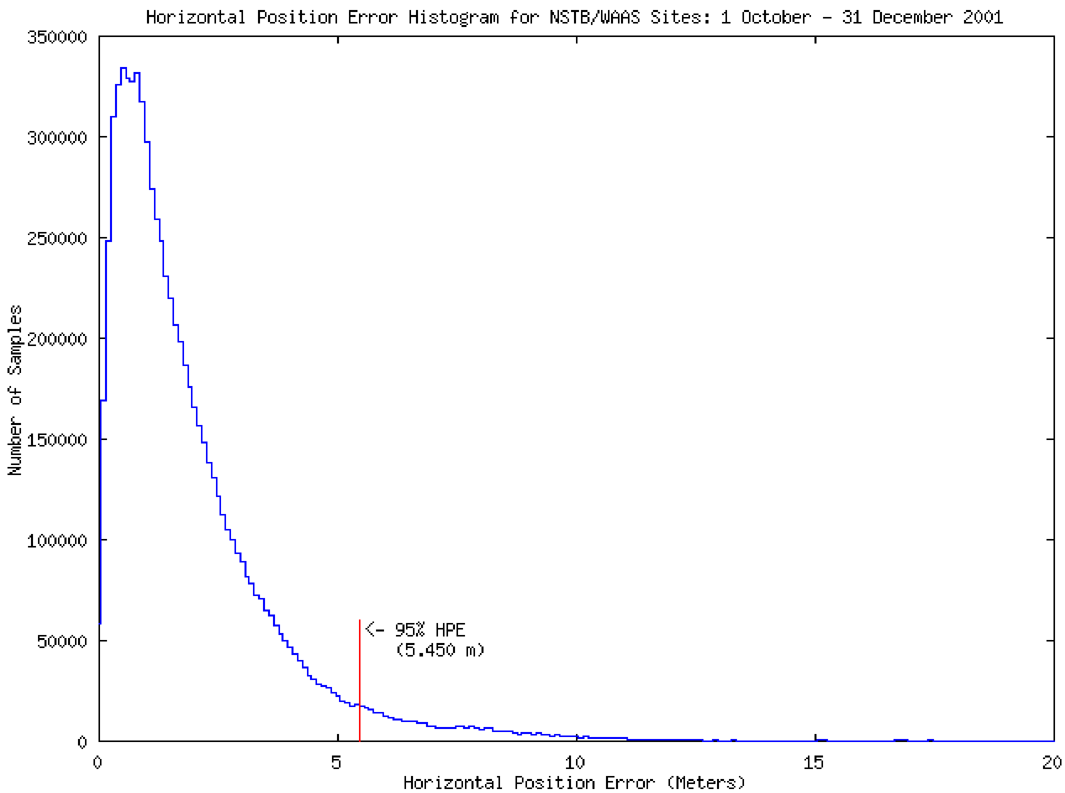


Figure 7-3 Vertical Position Error Histogram for GPS/GLONASS

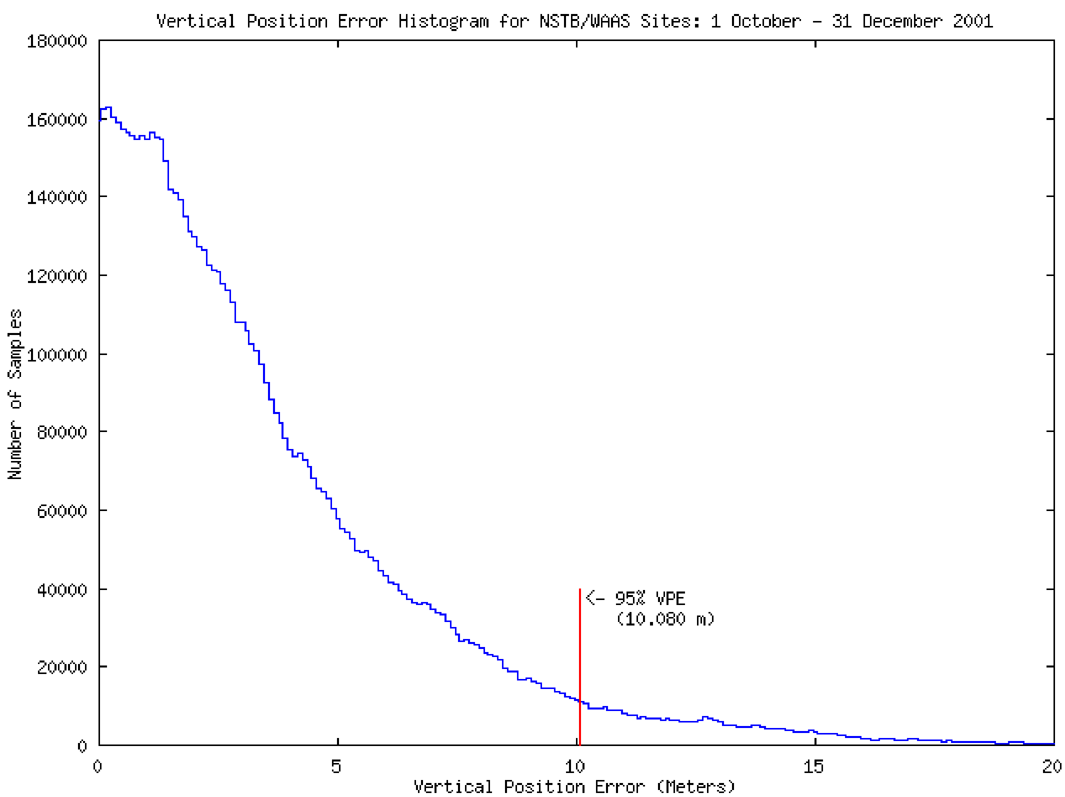
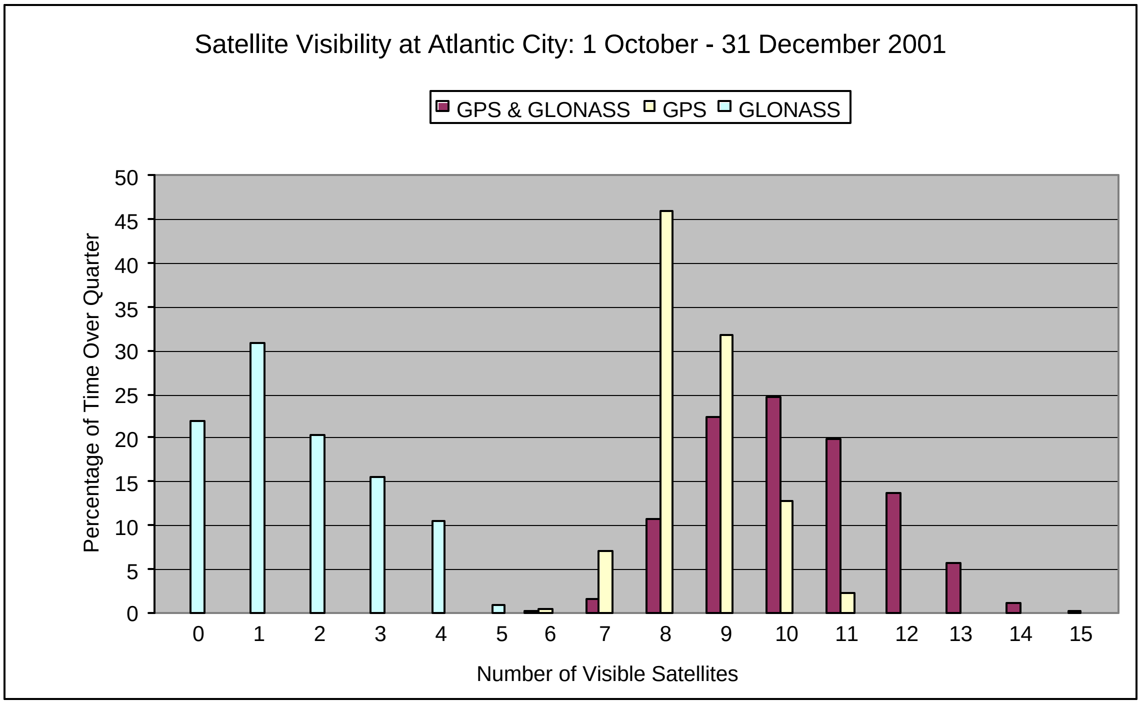


Figure 7-4 Glonass and GPS Satellite Visibility



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	100%
• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 96.9% at worst-case point	99.792% Availability 99.991% PDOP was 3.061
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	99.998%
• 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	99.985%
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	99.815%
• 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	99.338%
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%

Conditions and Constraints	Accuracy Standard	Measured Performance
• 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	≤6.787m H Er. 95% ≤17.718m H Er. 99.99% ≤11.375m V Er. 95% ≤23.172m V Er. 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	≤2.468m H Er. 95% ≤5.501m V Er. 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	≤24 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	25.290m NTE Range Error 0.85850m/s NTE Rate Error 8.59mm/s^2 NTE Accl. Error

satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	acceleration error ≤ 8 mm/s^2 range acceleration error 95% of time	≤8mm/s^2 99.9999% of the time

Appendix B Geomagnetic Data

```
Product: Daily Geomagnetic Data     quar_DGD.txt
Issued: 2120 UT 07 Jan 2002
#
#  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 10 01    25  4 4 4 4 4 2 2 5    50  4 5 6 6 6 5 3 4    50  4 5 6 6 5 4 3 5
2001 10 02    24  3 4 4 4 3 3 3 5    82  3 4 8 6 4 7 6 5    43  4 5 5 5 4 4 5 5
2001 10 03    26  3 2 4 4 5 4 4 4    58  5 3 5 7 6 6 4 4    53  4 3 5 7 6 6 4 4
2001 10 04     9  3 1 3 3 2 2 2 1    36  4 1 6 5 5 3 3 5    19  4 1 5 4 3 4 3 2
2001 10 05    10  1 1 1 3 3 3 3 2    -1  1 0 1 4-1 2 3 1     9  1 1 1 3 2 3 3 2
2001 10 06     6  2 3 2 2 1 1 1 1    11  1 1 3 5 3 0 0 0     8  2 2 2 2 3 2 2 2
2001 10 07     1  0 0 0 0 2 0 0 1     1  1 0 0 1 0 0 0 1     4  0 0 0 1 2 2 2 2
2001 10 08    11  2 2 3 2 3 3 2 3    -1  2 1 3 3 5 4 2-1    15  2 3 3 3 4 4 2 4
2001 10 09    16  4 3 2 3 4 4 2 2    -1  3 2-1-1-1 5 3 2    15  3 2 3 4 4 4 2 2
2001 10 10     6  1 2 2 2 2 2 1 1    20  1 1 3 3 6 4 3 1     8  1 3 2 2 3 2 2 1
2001 10 11    13  2 3 1 1 1 4 4 3    55  4 4 4 3 5 7 7 3    17  2 3 2 1 3 5 5 4
2001 10 12    18  4 5 3 3 3 2 2 2    39  4 5 3 6 6 4 4 2    27  5 6 3 4 4 3 3 3
2001 10 13     9  3 3 2 2 2 2 2 1    19  3 3 5 5 3 2 1 1    10  3 3 3 3 2 2 2 1
2001 10 14     6  1 1 2 2 2 2 2 2    12  1 1 4 4 3 2 2 2     9  1 2 3 2 2 2 3 3
2001 10 15     9  3 4 2 1 2 2 1 1    11  3 4 4 2 1 1 1 1    11  3 4 3 2 2 3 2 2
2001 10 16     6  3 1 1 1 2 2 2 1    13  2 1 2 4 5 2 1 1     8  3 2 2 2 3 3 2 1
2001 10 17     2  2 1 1 0 1 0 0 1     3  0 1 1 3 0 0 0 0     4  2 1 1 1 2 2 2 1
2001 10 18     2  1 0 0 0 1 2 1 1     1  0 0 0 0 1 1 1 0     4  0 0 0 1 2 3 2 1
2001 10 19     6  0 1 1 1 2 3 2 2    14  0 0 2 2 4 5 3 2     8  0 1 2 2 3 3 2 3
2001 10 20     8  0 3 1 3 2 2 2 2    21  1 2 2 6 4 4 3 1    10  1 3 2 4 3 3 2 2
2001 10 21    29  1 2 2 1 2 5 6 6    67  2 3 3 3 4 7 8 6    40  2 3 3 2 3 6 6 7
2001 10 22    33  5 4 3 4 4 5 5 4    93  5 4 6 7 6 8 6 5    66  6 5 4 6 5 7 6 5
2001 10 23    10  4 4 2 1 2 1 1 0    26  7 4 3 1 3 2 1 0    15  4 5 3 2 2 2 2 1
2001 10 24     4  2 1 1 1 2 2 1 1     0  0 0 0 1 0 0 0 0     3  1 0 0 1 1 2 1 1
2001 10 25     5  0 0 3 1 2 2 1 1     2  0 0 1 1 0 1 2 1     7  0 0 2 2 2 3 3 2
2001 10 26     6  0 0 1 1 1 4 2 2     4  1 0 2 3 0 0 1 1     5  1 0 2 2 1 2 2 2
2001 10 27     6  1 2 1 1 3 2 1 2    -1  1 3 1 3 4-1-1-1     6  1 2 1 2 3 2 2 2
2001 10 28    34  1 6 5 5 4 3 3 3    -1 -1-1-1-1-1-1-1-1    41  2 6 6 6 5 4 4 3
2001 10 29    18  3 3 4 3 4 3 3 3    -1 -1-1-1-1-1 2 3 3    16  3 3 4 3 4 3 3 3
2001 10 30     6  2 3 3 1 1 0 0 1    10  2 2 4 3 2 2 1 1     8  2 3 3 2 2 2 2 2
2001 10 31     8  2 1 1 0 3 2 3 3     9  0 0 1 1 4 3 3 2     9  1 1 2 0 3 3 3 3
2001 11 01    15  4 4 4 2 3 2 2 1    32  3 5 5 4 6 4 2 1    25  4 4 5 4 5 4 3 2
2001 11 02     6  1 1 2 0 4 1 0 1     8  1 1 1 0 5 1 0 0     6  1 1 1 0 3 2 2 2
2001 11 03     1  1 1 0 0 1 0 0 0     0  0 0 0 0 0 0 0 0     3  0 0 0 0 1 2 2 1
```

2001 11 04	4	0 0 2 3 1 2 1 0	17	0 0 3 5 5 3 2 0	7	0 0 2 3 3 3 2 1
2001 11 05	12	0 0 1 2 4 3 4 3	11	0 0 0 2 3 4 4 3	13	0 0 1 2 3 4 5 4
2001 11 06	60	7 7 5 3 4 5 4 4	101	8 7 6 6 6 6 6 4	112	8 8 7 5 6 7 5 5
2001 11 07	11	4 3 1 2 2 1 2 3	26	5 5 1 5 4 3 3 1	15	5 4 1 3 2 2 2 3
2001 11 08	3	2 1 2 1 0 1 1 0	10	2 2 4 4 1 1 1 1	5	2 1 2 2 1 2 2 1
2001 11 09	2	1 1 0 1 1 1 1 0	2	1 0 0 1 0 1 1 2	4	1 0 0 0 1 2 2 2
2001 11 10	5	1 1 0 2 2 2 2 2	-1	1 0 0-1-1-1-1-1	6	1 1 0 0 2 2 3 3
2001 11 11	5	2 2 1 2 2 1 1 1	-1	-1-1-1-1-1-1-1-1	4	2 1 0 2 1 2 2 1
2001 11 12	1	1 0 0 0 2 0 0 0	-1	-1-1-1-1-1-1-1-1	2	1 0 0 0 1 2 1 1
2001 11 13	4	1 2 1 1 2 2 1 1	-1	-1-1-1-1-1 0 1 0	3	1 0 0 0 1 2 2 2
2001 11 14	3	1 1 1 0 2 1 1 0	0	0 0 1 0 0 0 0 0	3	0 0 1 0 1 1 2 1
2001 11 15	5	0 0 0 0 1 3 3 2	12	0 0 0 3 1 4 5 1	7	0 0 0 1 1 4 4 2
2001 11 16	4	1 2 2 2 2 1 0 0	11	1 1 2 3 4 4 1 0	8	2 2 3 2 3 3 1 1
2001 11 17	9	1 1 1 2 2 2 4 3	-1	0 1 3 4 5 3 3-1	11	2 3 3 3 4 3 3 3
2001 11 18	7	1 2 1 2 2 2 1 3	12	1 1 2 3 4 4 2 1	7	2 2 2 2 2 3 2 2
2001 11 19	10	2 2 1 3 3 2 3 2	32	3 2 3 5 6 5 4 3	16	3 2 2 3 3 3 4 4
2001 11 20	8	3 3 4 1 0 0 0 0	11	2 4 5 2 0 0 0 0	8	3 3 4 1 1 1 1 0
2001 11 21	2	0 0 2 1 1 0 0 1	10	0 0 2 4 5 1 0 0	6	1 1 3 1 1 2 2 1
2001 11 22	8	1 2 2 2 2 2 3 2	-1	0 2 2-1 2 2 2 1	8	1 2 2 3 2 2 3 2
2001 11 23	11	2 1 2 2 3 4 1 3	23	3 2 3 4 5 5 2 3	12	3 2 2 2 3 3 3 3
2001 11 24	76	3 5 8 6 7 5 2 4	-1	3 5 7 7-1-1-1-1	108	3 5 9 7 8 7 3 4
2001 11 25	6	1 2 2 2 2 2 1 1	-1	-1-1-1-1-1-1-1-1	8	3 2 2 3 2 3 2 2
2001 11 26	4	1 0 3 1 1 1 0 1	-1	-1-1-1-1-1 1 1 2	5	2 1 3 1 1 2 1 1
2001 11 27	1	1 0 0 0 0 1 0 1	2	0 0 0 0 0 2 1 1	2	1 0 0 0 0 2 1 1
2001 11 28	3	1 0 0 0 1 3 0 1	0	0 0 0 0 0 1 0 0	3	1 0 0 0 0 2 2 1
2001 11 29	1	1 0 1 0 1 0 0 0	1	0 0 1 0 0 0 1 0	3	2 1 1 1 1 1 1 0
2001 11 30	2	1 0 0 0 1 1 1 1	-1	-1 0 0 0 0 0 0 0	3	1 0 0 1 1 1 2 2
2001 12 01	6	1 0 2 1 2 3 2 2	3	0 0 3 1 1 0 0 0	7	1 1 3 2 3 2 1 3
2001 12 02	6	1 0 1 1 3 3 1 1	1	0 0 0 0 0 1 2 0	4	1 0 0 1 2 3 2 1
2001 12 03	6	0 1 0 1 2 1 3 3	4	0 0 0 0 1 2 3 2	7	1 1 0 1 2 2 3 3
2001 12 04	6	3 1 1 1 2 1 2 2	10	2 1 1 4 4 2 1 1	6	3 2 1 2 2 2 2 2
2001 12 05	7	3 2 1 2 1 2 2 2	11	2 2 3 4 1 3 2 1	8	3 2 2 3 2 2 3 2
2001 12 06	10	2 1 1 3 3 2 3 3	-1	-1-1-1-1-1-1-1-1	8	2 1 1 3 2 3 3 3
2001 12 07	7	2 1 1 1 3 2 3 2	-1	-1-1-1-1-1-1-1-1	5	2 1 0 1 2 2 2 2
2001 12 08	7	2 1 2 2 2 2 2 2	7	1 0 2 3 4 1 0 0	5	2 0 2 2 2 2 2 1
2001 12 09	1	0 0 0 1 0 0 0 1	-1	0 0 0 2-1-1 0 0	3	2 0 0 1 1 1 2 1
2001 12 10	3	0 0 2 1 2 2 1 1	3	0 0 2 1 3 0 0 0	4	1 1 2 1 2 2 1 1
2001 12 11	3	1 2 0 1 1 1 1 1	-1	0 0 1 2 0 1-1-1	4	1 1 0 1 1 2 2 2
2001 12 12	8	1 2 2 4 1 1 1 2	-1	1 1 3 6 4 3 2-1	12	2 2 2 5 3 2 3 3
2001 12 13	4	2 1 0 0 3 2 0 0	-1	1 2 2 0 0 0-1 0	4	2 1 1 0 2 1 1 1
2001 12 14	4	0 1 0 1 2 2 1 2	7	0 1 0 3 3 2 3 1	4	1 1 0 1 2 2 2 2
2001 12 15	10	2 3 3 3 3 2 1 2	13	2 1 3 5 4 1 0 1	11	3 3 3 3 3 2 2 2
2001 12 16	8	2 3 3 3 2 1 1 0	13	1 2 4 4 4 2 2 0	10	2 3 3 3 3 2 2 2
2001 12 17	9	1 2 2 3 3 2 2 2	-1	1 2 5 6 5 6 4-1	15	2 3 3 4 4 4 3 2
2001 12 18	7	3 1 2 2 2 2 2 1	24	2 2 2 6 4 2 5 2	8	3 1 2 3 3 2 2 2
2001 12 19	5	2 1 2 2 1 1 2 1	12	2 1 3 5 2 3 1 0	9	3 1 3 3 2 3 2 2
2001 12 20	2	0 0 1 1 2 1 1 0	7	1 0 1 4 3 1 1 0	5	1 0 1 2 2 3 2 1
2001 12 21	9	1 2 1 2 3 3 3 2	22	1 1 2 4 3 6 4 3	11	1 2 2 2 3 4 4 3
2001 12 22	6	2 2 2 2 0 0 2 3	13	2 1 4 5 2 1 2 0	8	2 2 3 3 2 2 2 1
2001 12 23	5	0 0 2 2 2 2 1 2	16	0 1 3 5 4 4 1 1	7	2 1 2 3 2 2 2 3
2001 12 24	13	1 3 4 3 3 3 2 2	36	0 3 6 4 6 5 4 2	19	3 3 5 4 4 4 3 2
2001 12 25	11	2 2 2 3 3 3 2 3	-1	-1-1-1-1-1-1-1-1	8	3 2 1 3 2 2 1 3
2001 12 26	10	2 1 1 1 3 4 3 2	-1	-1-1-1-1-1-1-1-1	7	2 0 0 1 2 3 3 2
2001 12 27	10	2 1 2 2 3 3 3 2	-1	-1-1-1-1-1-1-1-1	6	2 1 1 2 2 3 3 1
2001 12 28	9	1 0 2 2 3 3 3 3	-1	-1-1-1-1-1-1-1-1	5	1 0 1 2 2 2 2 2
2001 12 29	13	2 4 2 2 2 4 2 3	-1	-1-1-1-1-1-1-1-1	10	2 4 2 2 2 3 3 2
2001 12 30	15	3 3 3 2 2 2 4 4	-1	-1-1-1-1-1-1-1-1	17	3 4 4 2 3 2 4 4
2001 12 31	12	4 3 1 2 2 3 2 3	-1	-1-1-1-1-1-1-1-1	11	3 3 2 2 2 3 3 4

Background:

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

Problem Description:

GPS did not fail SPS specification in any instances during this quarter.

The terms and definitions discussed below are taken from the Standard Positioning Service Performance Specification (SPS) (June 2, 1995). An understanding of these terms and definitions is a necessary prerequisite to full understanding of the Signal Specification.

General Terms and Definitions

Block I and Block II Satellites. The Block I is a GPS concept validation satellite; it does not have all of the design features and capabilities of the production model GPS satellite, the Block II. The FOC 24 satellite constellation is defined to consist entirely of Block II/IIA satellites. For the purposes of this Signal Specification, the Block II satellite and a slightly modified version of the Block II known as the Block IIA provide an identical service.

Dilution of Precision (DOP). The magnifying effect on GPS position error induced by mapping GPS ranging errors into position through the position solution. The DOP may be represented in any user local coordinate desired. Examples are HDOP for local horizontal, VDOP for local vertical, PDOP for all three coordinates, and TDOP for time.

Geometric Range. The difference between the estimated locations of a GPS satellite and an SPS receiver.

Major Service Failure. A condition over a time interval during which one or more SPS performance standards are not met and the civil community was not warned in advance.

Minimum SPS Receiver Capabilities. Minimum standards for signal reception and processing capabilities that are incorporated into the design of an SPS receiver. This ensures consistent performance with the SPS performance standards.

Navigation Data. Data provided to the SPS receiver via each satellite's ranging signal, containing the ranging signal time of transmission, the transmitting satellite's orbital elements, an almanac containing abbreviated orbital element information to support satellite selection, ranging measurement correction information, and status flags.

Navigation Message. Message structure designed to carry navigation data.

Operational Satellite. A GPS satellite that is capable of, but may or may not be, transmitting a usable ranging signal. For the purposes of the SPS, any satellite contained within the transmitted navigation message almanac is considered to be an operational satellite.

Position Solution. The use of ranging signal measurements and navigation data from at least four satellites to solve for three position coordinates and a time offset.

Selective Availability. Protection technique employed by the DOD to deny full system accuracy to unauthorized users.

Service Disruption. A condition over a time interval during which one or more SPS performance standards are not supported, but the civil community was warned in advance.

SPS Performance Envelope. The range of variation in specified aspects of SPS performance.

SPS Performance Standard. A quantifiable minimum level for a specified aspect of GPS SPS performance.

Standard Positioning Service (SPS). Three-dimensional position and time determination capability provided to a user equipped with a minimum capability GPS SPS receiver in accordance with GPS national policy and the performance specifications.

SPS Ranging Signal Measurement. The difference between the ranging signal time of reception (as defined by the receiver's clock) and the time of transmission contained within the satellite's navigation data (as defined by the satellite's clock) multiplied by the speed of light. Also known as the *pseudo range*.

SPS Signal, or SPS Ranging Signal. An electromagnetic signal originating from an operational satellite. The SPS ranging signal consists of a Pseudo Random Noise (PRN) Coarse/Acquisition (C/A) code, a timing reference and sufficient data to support the position solution generation process.

Usable SPS Ranging Signal. An SPS ranging signal that can be received, processed and used in a position solution by a receiver with minimum SPS receiver capabilities.

Performance Parameter Definitions

The definitions provided below establish the basis for correct interpretation of the GPS SPS performance standards. The GPS performance parameters contained in the SPS are defined differently than other radio navigation systems in the Federal Radio Navigation Plan. For a more comprehensive treatment of these definitions and their implications on system use, refer to Annex B of the SPS.

Coverage. The percentage of time over a specified time interval that a sufficient number of satellites are above a specified mask angle and provide an acceptable position solution geometry at any point on or near the Earth. The term "near the Earth" means on or within approximately 200 kilometers of the Earth's surface.

Positioning Accuracy. Given reliable service, the percentage of time over a specified time interval that the difference between the measured and expected user position or time is within a specified tolerance at any point on or near the Earth. This general accuracy definition is further refined through the more specific definitions of four different aspects of positioning accuracy:

- **Predictable Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a position measurement and a surveyed benchmark is within a specified tolerance at any point on or near the Earth.

- **Repeatable Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a position measurement taken at one time and a position measurement taken at another time at the same location is within a specified tolerance at any point on or near the Earth.

- **Relative Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between two receivers' position estimates taken at the same time is within a specified tolerance at any point on or near the Earth.

- **Time Transfer Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a Universal Coordinated Time (commonly referred to as UTC) time estimate from the position solution and UTC as it is managed by the United States Naval Observatory (USNO) is within a specified tolerance.

Range Domain Accuracy. Range domain accuracy deals with the performance of each satellite's SPS ranging signal. Range domain accuracy is defined in terms of three different aspects:

- **Range Error.** Given reliable service, the percentage of time over a specified time interval that the difference between an SPS ranging signal measurement and the "true" range between the satellite and an SPS user is within a specified tolerance at any point on or near the Earth.

- **Range Rate Error.** Given reliable service, the percentage of time over a specified time interval that the instantaneous rate-of-change of range error is within a specified tolerance at any point on or near the Earth.

- **Range Acceleration Error.** Given reliable service, the percentage of time over a specified time interval that the instantaneous rate-of-change of range rate error is within a specified tolerance at any point on or near the Earth.

Service Availability. Given coverage, the percentage of time over a specified time interval that a sufficient number of satellites are transmitting a usable ranging signal within view of any point on or near the Earth.

Service Reliability. Given service availability, the percentage of time over a specified time interval that the instantaneous predictable horizontal error is maintained within a specified reliability threshold at any point on or near the Earth. Note that service reliability does not take into consideration the reliability characteristics of the SPS receiver or possible signal interference. Service reliability may be used to measure the total number of major failure hours experienced by the satellite constellation over a specified time interval.