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: Anderson, Atlantic City, Dayton, Elko, Gander, 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 #29, includes data collected from 1 January through 31 March 2000. The next quarterly report will be issued 31 July 2000.

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 January and 31 March 2000 and by calculating the satellite availability from the data obtained from the nine sites. A total of sixteen satellite outages were reported in the NANUs. Twelve of the outages were scheduled and four were unscheduled. The availabilities for Anderson, Atlantic City, Dayton, Elko, Gander, Great Falls, Oklahoma City, Kansas City, and Salt Lake City were 100%, 100%, 100%, 99.99%, 100%, 100%, 99.70%, 100%, and 99.97, respectively. 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. In this quarter, satellite outages on Satellite PRN 14 (NANU #37) and Satellite PRN 16 (NANU #31) caused vertical and horizontal errors to exceed the GPS SPS specifications. The 95% horizontal accuracy requirement did not meet SPS specification for one day for Oklahoma City. The 99.99% horizontal accuracy requirement did not meet SPS specification for nine days for Oklahoma City. The 99.99% vertical accuracy requirement did not meet SPS specification for fourteen days for Oklahoma City and for three days in Elko.

Range performance was verified for each satellite using the data collected from the NSTB Elko site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 143 meters on Satellite PRN 29. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 1.79 meters/second on Satellite PRN 31. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 17 millimeters/second^2 on Satellite PRN 9. 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. Two GPS/GLONASS receivers have been added into 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 Millenium receiver). The 95% horizontal error and vertical error for the GPS/GLONASS solution were 36 meters and 76 meters, respectively. The 95% horizontal error and vertical error for the GPS-only solution were 45 meters and 76 meters, respectively.

From the analysis performed on data collected between 1 January and 31 March 2000, the GPS performance met all SPS requirements that were evaluated except for the 95% horizontal accuracy and the 99.99% horizontal and vertical accuracies.

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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 Testbed (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. Two GPS/GLONASS receivers have been added to the NSYB 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 an example of how future WAAS data analysis will be presented. The data in this report is data collected during WAAS Flight Testing. The requirements were taken from the WAAS specification (FAA-E-2892B).

Appendix D provides a PAN Problem Report. This is the first quarter that the GPS SPS specification for position accuracy was not met.

Appendix E 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	✓

Table 1-2 Future WAAS Performance Summary
En Route through Nonprecision 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	$4x10^{-8}$ 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

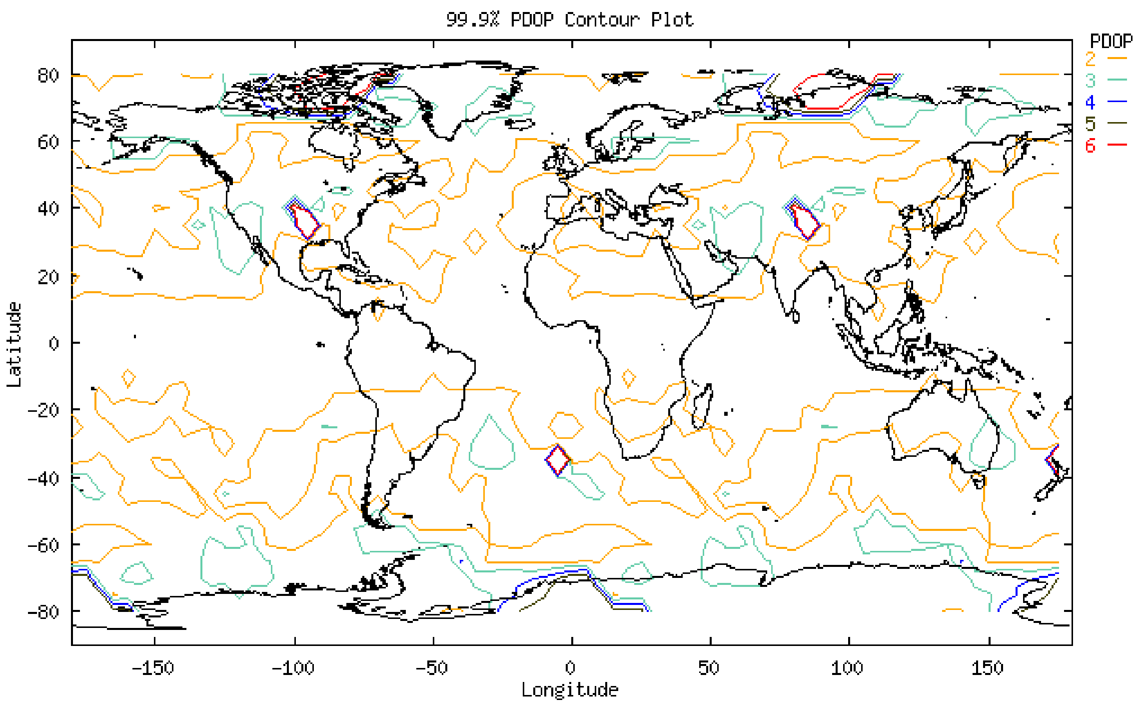
Almanacs for GPS weeks 6-18 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACT-360 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 80S 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 3.28 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%)
19	3.03	100%	99.44%
20	3.02	100%	99.44%
21	3.02	100%	99.44%
22	3.01	100%	99.51%
23	3.65	100%	99.38%
24	3.02	100%	99.38%
25	3.05	99.99%	99.31%
26	3.08	99.99%	99.24%
27	3.11	99.99%	99.17%
28	3.28	99.99%	99.17%
29	3.28	99.99%	99.17%
30	3.27	99.99%	99.03%
31	3.26	99.99%	99.17%

Figure 2-1 SPS Coverage (24-Hour Period: 19 March 2000)



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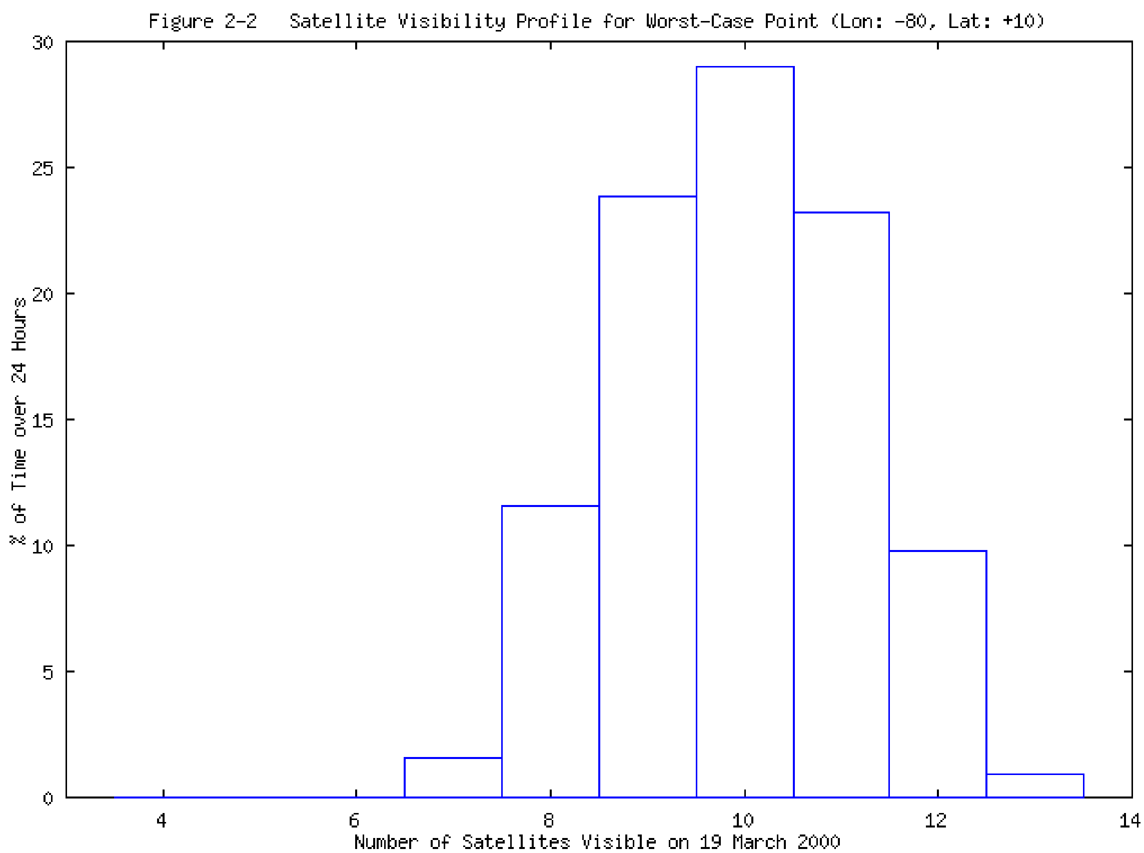


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -80, Lat: +10)
30
25
20
15
10
5
0
% of Time over 24 Hours
4
6
8
10
12
14
Number of Satellites Visible on 19 March 2000

3.0 Service Availability Performance

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

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANUs). During this reporting period, 1 January through 31 March 2000, there were a total of sixteen reported outages. Twelve of these outages were maintenance activities and were reported in advance. Four 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
7	13	S	6-Jan	17:29	6-Jan	22:12		4.72	4.72
8	6	S	11-Jan	1:22	11-Jan	7:46		6.40	6.40
9	21	S	12-Jan	2:08	12-Jan	7:11		5.05	5.05
10	10	S	13-Jan	12:35	13-Jan	13:50		1.25	1.25
11	5	S	14-Jan	14:22	14-Jan	15:30		1.13	1.13
16	11	S	21-Jan	17:50	22-Jan	4:47		10.95	10.95
19	18	S	25-Jan	8:36	25-Jan	21:44		13.13	13.13
22	1	S	28-Jan	13:13	28-Jan	23:37		10.40	10.40
29	7	S	28-Feb	17:08	29-Feb	5:56		12.80	12.80
30	23	S	3-Mar	4:15	3-Mar	12:42		8.45	8.45
33	8	S	7-Mar	7:41	7-Mar	16:40		8.98	8.98
38	9	S	26-Mar	15:42	27-Mar	6:34		14.87	14.87
1*	11	U	3-Jan	15:02	N/A	N/A	N/A	0.00	0.00
20/23	14	U	26-Jan	1:30	3-Feb	18:16	208.77	0.00	208.77
24/25	16	U	19-Feb	9:42	21-Feb	20:07	58.42	0.00	58.42
31**	16	U	4-Mar	9:55	1-Apr	0:00	662.08	0.00	662.08
37**	14	U	26-Mar	23:48	1-Apr	0:00	120.20	0.00	120.20
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**1049.47**	**98.13**	**1147.60**
Type:	S = Scheduled		U = Unscheduled						

* **Note**: NANU 1 is a USABINIT type NANU. This means that a new satellite was launched and is ready for operations. There is only a start time, which corresponds to the first time the satellite was set healthy following its launch.

** **Note**: NANU 31 and NANU 37 continued past the end of the quarter. Times are calculated for only this quarter.

Table 3-2 NANUs Forecasted To Affect Satellite Availability

NANU#	SVN/PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2	13	F	6-Jan	16:30	7-Jan	4:30	12.00	See NANU 0007
3	6	F	11-Jan	1:00	11-Jan	13:00	12.00	See NANU 0008
4	21	F	12-Jan	0:30	12-Jan	12:30	12.00	See NANU 0009
5	10	F	13-Jan	12:00	14-Jan	0:00	12.00	See NANU 0010
6	5	F	14-Jan	14:00	15-Jan	2:00	12.00	See NANU 0011
12	1	F	21-Jan	7:15	21-Jan	19:15	12.00	See NANU 0014
13	11	F	21-Jan	17:00	22-Jan	7:00	14.00	See NANU 0016
15	18	F	25-Jan	8:00	25-Jan	20:00	12.00	See NANU 0018
17	1	F	28-Jan	6:30	28-Jan	18:30	12.00	See NANU 0021
26	7	F	28-Feb	16:00	29-Feb	6:00	14.00	See NANU 0026
27	23	F	3-Mar	4:00	3-Mar	16:00	12.00	See NANU 0027
28	8	F	6-Mar	7:30	6-Mar	19:30	12.00	See NANU 0028
34	9	F	26-Mar	15:00	27-Mar	8:00	17.00	See NANU 0038
35	11	F	29-Mar	12:00	30-Mar	0:00	12.00	See NANU 0039
36	11	F	30-Mar	12:00	31-Mar	0:00	12.00	See NANU 0040
41	19	F	31-Mar	11:15	1-Apr	0:00	12.75	*
18	18	F/Extended	25-Jan	8:00	N/A	N/A	0.00	See Nanu 0019
21	1	F/Rescheduled	28-Jan	12:30	29-Jan	1:00	12.50	See Nanu 0022
32	8	F/Rescheduled	7-Mar	7:30	7-Mar	19:30	12.00	See Nanu 0033
						Total Forecast Downtime	**226.25**	

* **Note**: This outage went beyond the end of the quarter. Outage time is calculated for this quarter only.

Table 3-3 *NANUs Canceled*

NANU#	PRN	Type	Start Date	Start Time	Comments
14	1	C	19-Jan	20:55	See Nanu 0012
39	11	C	28-Mar	19:48	See Nanu 0035
40	11	C	28-Mar	19:51	See Nanu 0036

Type: C = Cancelled

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. A plot of satellite Mean Time To Repair (MTTR) has been included in Figures 3-1.

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 January– 31 March 2000	12 December 1998– 31 March 2000
Total Forecast Downtime (hrs):	226.25	1562.47
Total Actual Downtime (hrs):	1147.60	3215.56
Total Actual Scheduled Downtime (hrs):	98.13	696.20
Total Actual Unscheduled Downtime (hrs):	1049.47	2519.36
Total Satellite Observed MTTR (hrs):	71.75	31.84
Scheduled Satellite Observed MTTR (hrs):	8.18	8.49
UnScheduled Satellite Observed MTTR (hrs):	262.37	132.60
# Total Satellite Outages:	16	101
# Scheduled Satellite Outages:	12	82
# Unscheduled Satellite Outages:	4	19
Percent Operational -- Scheduled Downtime:	99.84%	99.78%
Percent Operational -- All Downtime:	98.12%	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 January – 31 March 2000.

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	1.29	5.66	5.35	1.87	4.12	3.74	7370930
Atlantic City	1.24	5.99	5.61	1.84	3.65	3.21	7083819
Dayton	1.26	5.92	4.62	1.82	4.13	3.43	7377539
Elko	1.21	39.37	38.18	1.81	6.40	5.90	5614331
Gander	1.22	5.99	5.69	1.90	4.99	3.23	7370188
Great Falls	1.26	6.00	4.57	2.07	5.41	4.65	7351351
Oklahoma	1.19	43.37	40.04	1.77	16.6	6.72	7114893
Kansas (WAAS)	1.22	4.05	3.71	1.81	4.15	3.39	3659737
Salt Lake City (WAAS)	1.17	12.95	12.45	1.77	4.89	4.34	3628642

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 (NANUs) messages are used to verify that satellite outages did occur. (See Section 3.1 for more details about NANUs 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.

- A PDOP calculation program developed by Intermetrics was used to verify that certain satellite outage do cause the PDOP to go above six.

- Data from co-located receivers is also analyzed for times that the PDOP goes above six. This helps in determining whether the problem is due to the environment.

All of the times that the PDOP went above six are 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.

All of the Satellite Availability data evaluated met the requirements stated in the SPS.

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
Oklahoma	22_2	14.2	761	-	7114893	99.99%
Worst-Case Point on Worst-Case Day = 99.99% (SPS Spec. ≥ 83.92%)						

Global Average on Worst-Case Day = 99.999 %
(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	7370930	0	100
Atlantic City	7083819	0	100
Dayton	7377539	0	100
Elko	5614331	457	99.99
Gander	7370188	0	100
Great Falls	7351351	2	100
Oklahoma	7114893	21008	99.70
Kansas (WAAS)	3659737	0	100
Salt Lake City (WAAS)	3628642	1118	99.97
Worst Single Point Average = 99.70% (SPS Spec. ≥ 99.16%)			

Global Average over Reporting Period = 99.96% (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 99.9% 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	7370930	134
Atlantic City	7083819	182
Dayton	7377539	203
Elko	5614331	239
Gander	7370188	226
Great Falls	7351351	195
Oklahoma	7114893	847
Kansas (WAAS)	3659737	151
Salt Lake City (WAAS)	3628642	186

None of the horizontal error exceeded the 500 meter threshold for this quarter. Also, since it has been a year of monitoring the maximum horizontal error, the performance can be compared against the SPS specification. Although the maximum horizontal error for Oklahoma was 847 meters, the 99.79% SPS specification was still met.

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 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 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 • Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard

5.1 Position Accuracies

The data used for this section was collected for every second between 1 January through 31 March 2000 at the NSTB and WAAS selected locations.

Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter. In this quarter, satellite outages on Satellite PRN 14 (NANU #37) and Satellite PRN 16 (NANU #31) caused vertical and horizontal errors to exceed the GPS SPS specifications. Table 5-1a shows the sites and the days that the SPS specification was exceeded during the aforementioned satellite outages. The shaded areas are the position accuracies that did not meet specifications. (See Appendix D for a description of the problems. Although the description is just for Oklahoma, the performance data is similar for all sites.

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	45.3	78.0	102.0	198.0
Atlantic City	45.2	76.0	97.5	177.0
Dayton	45.0	75.2	105.0	188.0
Elko	60.2	81.8	135.0	269.0
Gander	51.4	81.0	142.0	194.0
Great Falls	61.8	90.4	144.0	235.0
Oklahoma	45.7	75.0	191.0	420.0
Kansas (WAAS)	53.5	77.0	135.0	228.0
Salt Lake City (WAAS)	66.2	84.6	147.0	234.0

Table 5-1a Horizontal & Vertical Accuracy Statistics for Satellite Outage Days

Week_Day	Site	95% Vert. Error	99.9% Vert. Error	95% Horz. Error	99.9% Horz. Error	Exceeded Spec.
27_6	Oklahoma	71.2	420	48.5	140	
28_0	Oklahoma	78.3	939	44.3	338	X
28_1	Oklahoma	77.2	426	47.0	176	
28_2	Oklahoma	79.6	647	45.5	266	X
28_3	Oklahoma	74.9	1.64e3	47.1	679	X
28_4	Oklahoma	74.6	413	47.3	112	
28_5	Oklahoma	75.7	340	44.5	113	
28_6	Oklahoma	78.1	742	46.5	368	X
29_0	Oklahoma	75.5	328	48.4	145	
29_1	Oklahoma	75.2	1.38e3	44.5	561	X
29_2	Oklahoma	76.8	877	46.4	424	X
29_3	Oklahoma	72.1	1.25e3	46.1	544	X
29_4	Oklahoma	78.4	351	44.1	119	
29_5	Oklahoma	75.7	373	44.9	134	
29_6	Oklahoma	90.5	1.35e3	50.0	647	X
30_0	Oklahoma	74.6	712	46.5	274	X

30_1	Oklahoma	107.0	1.57e3	148	846	X
30_2	Oklahoma	75.7	497	45.0	174	
Week_Day	**Site**	**95% Vert. Error**	**99.9% Vert. Error**	**95% Horz. Error**	**99.9% Horz. Error**	**Exceeded Spec.**
30_3	Oklahoma	75.8	578	46.1	275	X
30_4	Oklahoma	78.5	690	45.8	249	X
30_5	Oklahoma	73.3	627	42.9	282	X
30_6	Oklahoma	77.6	415	45.1	170	
31_0	Oklahoma	73.7	1.81e3	49.8	740	X
31_1	Oklahoma	84.8	189	52.8	101	
31_2	Elko	81.2	526	51.1	145	X
	Salt Lake City	81.0	396	50.6	151	
	Oklahoma	80.7	189	45.9	97	
31_3	Elko	76.8	1.01e3	53.0	239	X
	Salt Lake City	78.2	274	55.2	186	
	Oklahoma	76.1	167	49.8	93	
31_4	Elko	78.5	645	50.6	214	X
	Salt Lake City	78.6	444	48.9	134	
	Oklahoma	76.4	187	45.9	108	
31_5	Elko	83.0	284	51.8	119	
	Salt Lake City	82.4	247	51.4	164	
	Oklahoma	85.1	308	49.6	121	

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 January to 31 March 2000.

Figure 5-1 Combined Vertical Error Histogram

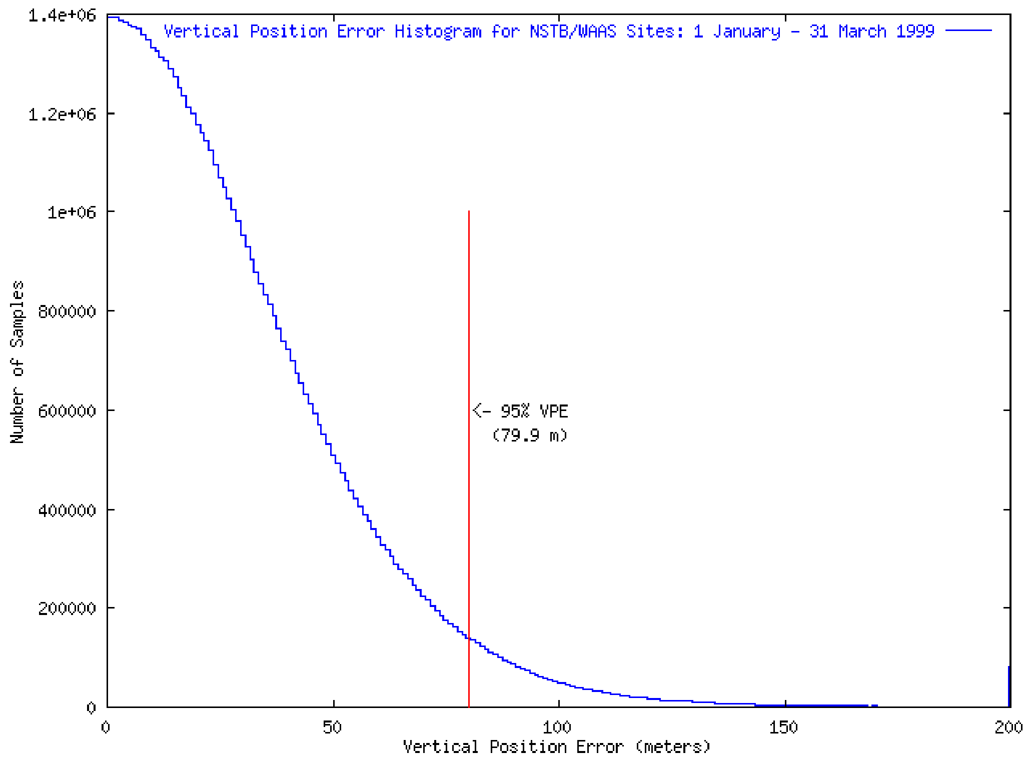
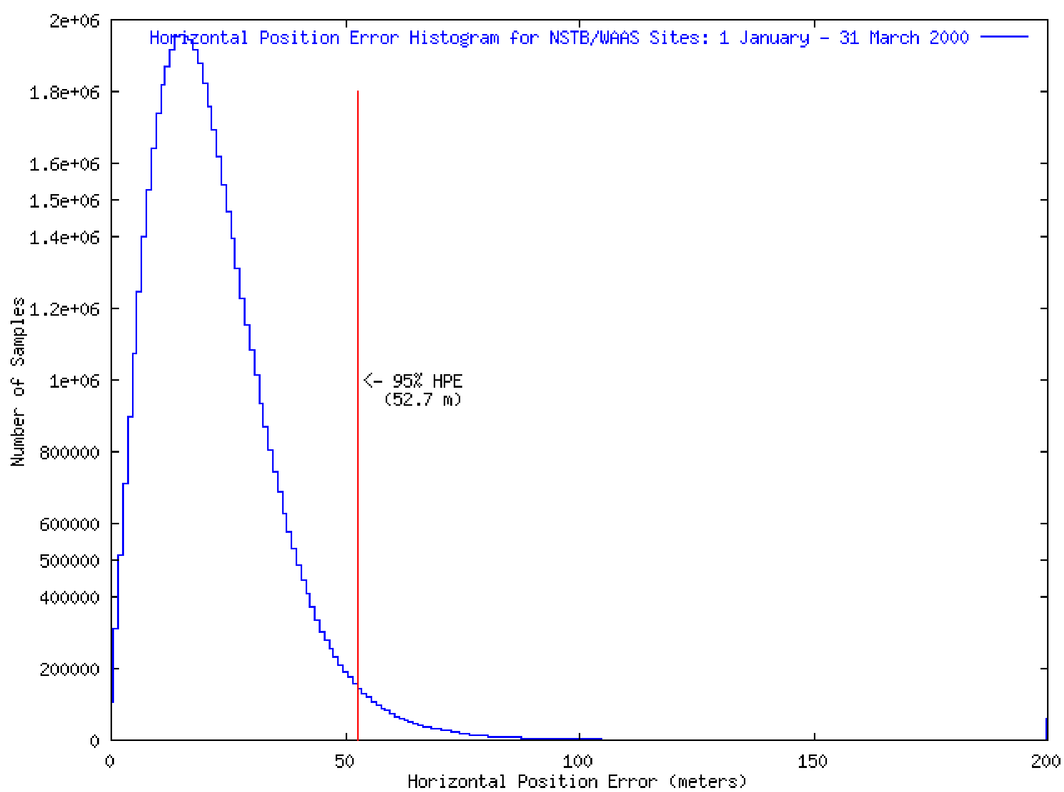


Figure 5-2 Combined Horizonatal Error Histogram



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	37.0	113.0
Atlantic City	36.5	110.0
Dayton	35.9	107.0
Elko	41.2	111.0
Gander	42.5	116.0
Great Falls	43.8	124.0
Oklahoma	36.3	115.0
Kansas (WAAS)	36.9	108.0
Salt Lake City (WAAS)	40.9	104.0

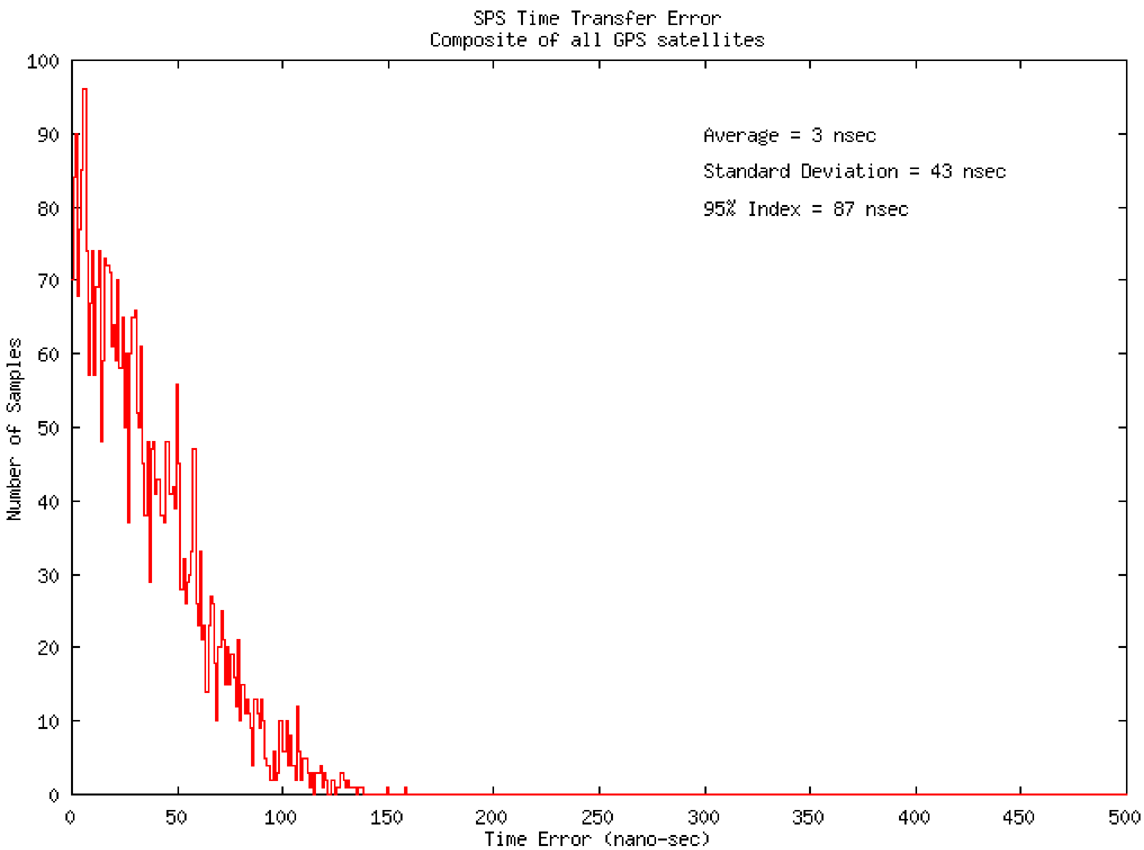
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 2000 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



5.5 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 January through 31 March 2000. The Millenium at Elko 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	0.868	17.252	16.982	47.49	122.59	1675982
2	0.401	17.325	17.039	46.49	115.53	1921401
3	0.228	16.958	16.762	47.084	134.35	2166949
4	0.313	17.618	17.34	49.985	126.72	1919953

PRN	Range Error Mean	Range Error RMS	1s	95% Range Error	Max Range Error (SPS Spec. ≤ 150 m)	Samples
5	1.156	16.231	16.039	45.075	110.71	2284133
6	0.611	17.064	16.857	53.717	136.01	2031062
7	0.565	17.107	16.862	48.371	115.23	2054000
8	0.799	16.956	16.642	54.905	114.03	1861840
9	0.31	16.253	16.121	50.401	115.4	2259258
10	0.82	17.468	17.184	48.5	111.33	1816249
11	-0.346	16.599	16.374	49.025	125.56	1920720
13	0.047	16.776	16.639	51.44	117.45	2292760
14	0.815	16.677	16.521	51.44	104.58	2171002
15	0.745	6.889	6.62	19.562	101.38	1969533
16	0.643	13.597	13.406	19.562	119.54	2048132
17	0.393	17.022	16.841	52.658	111.16	1849242
18	0.535	17.31	17.132	53.767	121.98	2140805
19	0.205	17.459	17.187	48.985	126.74	1782364
21	0.834	17.417	17.188	48.569	125.29	1888213
22	1.599	17.435	17.172	64.419	118.18	1743650
23	0.192	16.841	16.686	47.243	115.16	2013506
24	1.01	17.542	17.293	50.47	105.73	2091449
25	1.592	17.66	17.38	53.034	127.75	1948996
26	-0.006	17.348	17.135	52.44	115.45	1919271
27	0.743	17.346	17.105	54.173	128.94	1664851
29	0.98	17.187	17.004	52.599	143.46	2069201
30	0.587	16.605	16.482	54.678	110.82	2015904
31	0.562	17.33	17.065	56.272	105.22	1620051

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	0.00009	0.13684	0.13683	0.26585	1.01024	1675982
2	-0.00035	0.1374	0.1374	0.26834	0.91886	1921401
3	-0.00015	0.13761	0.1376	0.26866	1.44849	2166949
4	-0.00006	0.13596	0.13596	0.26777	1.85418	1919953
5	0.00004	0.13554	0.13551	0.26555	0.97304	2284133
6	0.00018	0.1376	0.13758	0.2708	1.28744	2031062
7	-0.00042	0.13632	0.1363	0.26718	0.89118	2054000
8	0.00006	0.13317	0.13317	0.26015	0.93877	1861840
9	0.0001	0.13523	0.13523	0.26473	1.77789	2259258
10	-0.00026	0.13545	0.13545	0.26464	1.21607	1816249
11	-0.00022	0.13923	0.13923	0.27269	1.33769	1920720
13	-0.00023	0.13672	0.13672	0.26713	1.11656	2292760
14	-0.00041	0.13659	0.13659	0.26624	1.12083	2171002
15	0.00006	0.02253	0.02251	0.04425	1.26473	1969533
16	-0.00024	0.10027	0.10027	0.19647	1.37329	2048132
17	-0.0001	0.13531	0.13531	0.26598	0.97386	1849242

PRN	Range Rate Error Mean	Range Rate Error RMS	Range Rate Error 1σ	95% Range Rate Error	Max Range Rate Error (SPS Spec. ≤ 2 m)	Samples
18	-0.00016	0.13773	0.13773	0.26936	1.12451	2140805
19	0.00013	0.13672	0.13672	0.26773	0.92003	1782364
21	-0.00017	0.13752	0.13752	0.26959	0.94052	1888213
22	-0.00001	0.13803	0.13803	0.27356	1.57694	1743650
23	-0.0002	0.13564	0.13564	0.26561	0.93509	2013506
24	0.00002	0.13776	0.13774	0.27152	0.98863	2091449
25	-0.00002	0.13838	0.13838	0.2706	0.9881	1948996
26	-0.00031	0.13825	0.13824	0.26948	1.22435	1919271
27	0.00011	0.13813	0.13813	0.27123	0.89214	1664851
29	0.00016	0.13695	0.13695	0.2687	0.91759	2069201
30	0.00008	0.13773	0.13774	0.27008	1.14701	2015904
31	-0.00003	0.13702	0.13702	0.26812	1.78864	1620051

Table 5-5 Range Acceleration Error Statistics (m/s^2)

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1σ	% ≤ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. ≤ 0.019 m/s2)	Samples
1	0	0.00103	0.00103	100	0.00706	1675982
2	0	0.00107	0.00107	100	0.00919	1921401
3	0	0.00105	0.00105	100	0.01364	2166949
4	0	0.00105	0.00105	100	0.01651	1919953
5	0	0.00104	0.00104	100	0.01016	2284133
6	0	0.00106	0.00106	99.999	0.01165	2031062
7	-0.00001	0.00104	0.00104	100	0.0073	2054000
8	0	0.00103	0.00103	100	0.00795	1861840
9	0	0.00103	0.00103	99.120	0.01656	2259258
10	0	0.00104	0.00104	100	0.01189	1816249
11	0	0.00108	0.00108	100	0.01072	1920720
13	0	0.00105	0.00105	100	0.01025	2292760
14	0	0.00105	0.00105	100	0.01092	2171002
15	0	0.00022	0.00022	99.999	0.01273	1969533
16	0	0.00076	0.00076	99.999	0.01326	2048132
17	0	0.00103	0.00103	100	0.00744	1849242
18	0	0.00106	0.00106	99.998	0.01204	2140805
19	0	0.00105	0.00105	100	0.00684	1782364
21	0.00001	0.00106	0.00106	100	0.00715	1888213
22	0	0.00108	0.00108	100	0.01661	1743650
23	0	0.00105	0.00105	100	0.00677	2013506
24	-0.00001	0.00103	0.00103	100	0.00797	2091449
25	0	0.00107	0.00107	100	0.00757	1948996
26	0	0.00106	0.00106	100	0.01095	1919271
27	0.00001	0.00105	0.00105	100	0.00707	1664851
29	0	0.00106	0.00106	100	0.00769	2069201
30	0	0.00107	0.00107	100	0.00799	2015904

31	0	0.00103	0.00103	100	0.01652	1620051

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the minimum and 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 29 with an error of 143.46 meters. Satellite 15 had the lowest maximum range error of 101.38 meters.

Figure 5-4 Distribution of Daily Max Range Errors

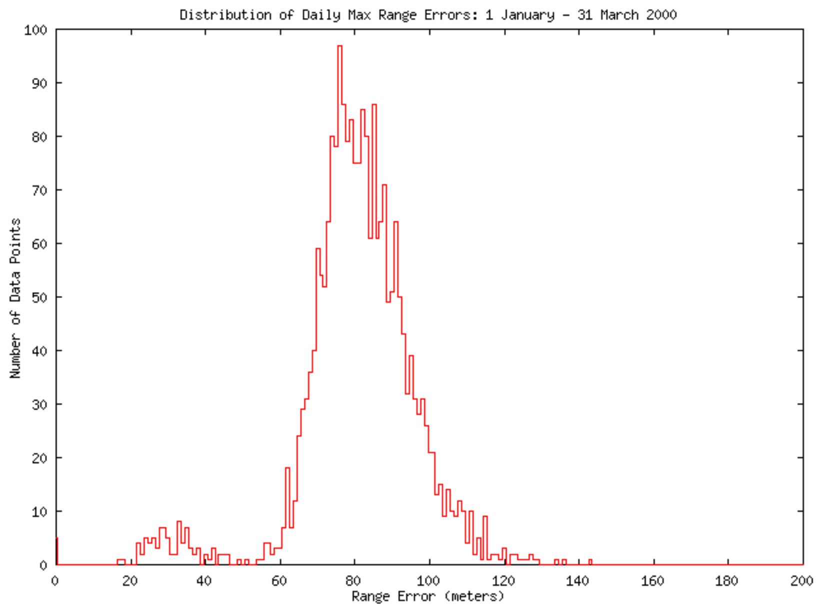


Figure 5-5 Distribution of Daily Max Range Rate Errors

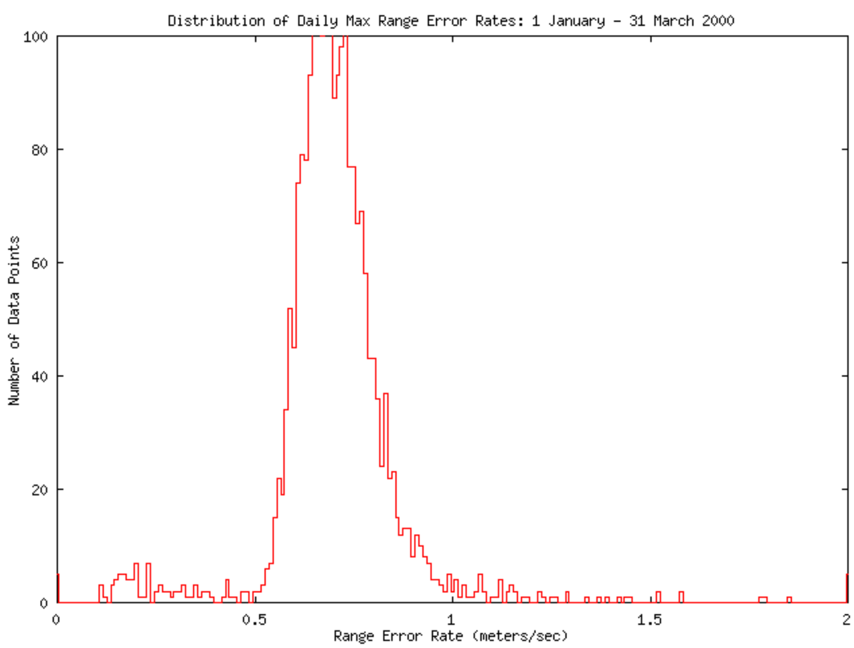


Figure 5-6 Distribution of Daily Max Acceleration Rate Errors

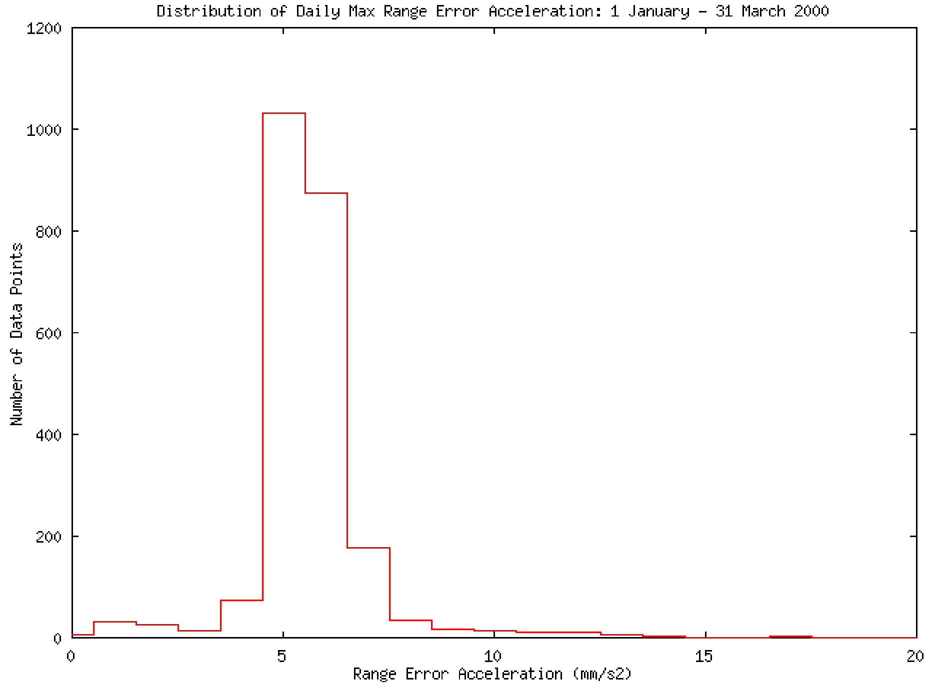


Figure 5-7 Maximum Range Error Per Satellite

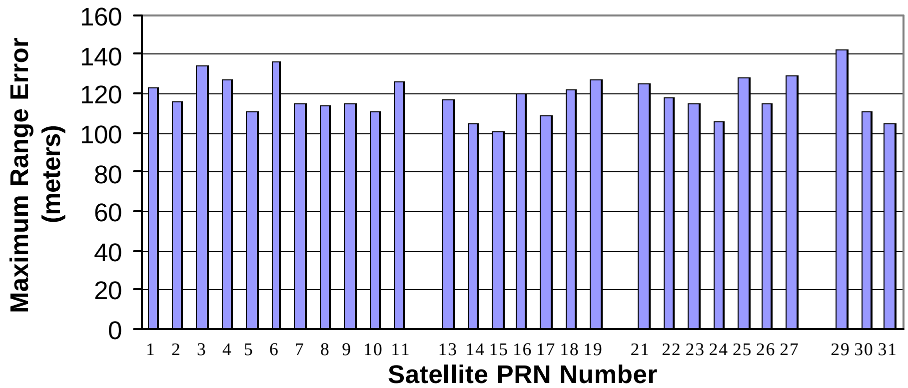


Figure 5-8 Maximum Range Error Rate Error Per Satellite

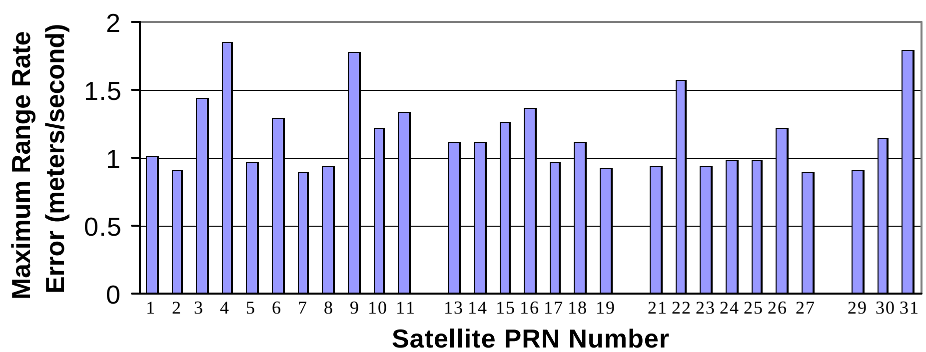
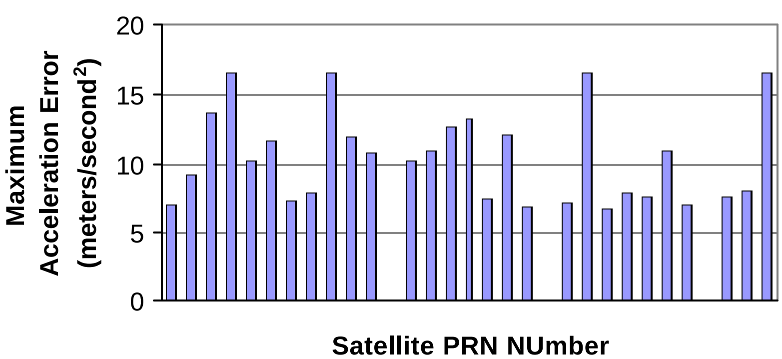


Figure 5-9 Maximum Range Acceleration Error Per Satellite



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 understood to be 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 a 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.

The disturbance of the geomagnetic field may also be measured by an instrument called a magnetometer. At NOAA's operations center magnetometer data is received from dozens of observatories in one minute intervals. The data is received at or near to 'real-time' and allows NOAA to keep track of the current state of the geomagnetic conditions. In order to reduce the amount of data NOAA converts the magnetometer data into three-hourly indices which give a quantitative, but less detailed measure of the level of geomagnetic activity. The K-index scale has a range from 0 to 9 and is directly related to the maximum amount of fluctuation (relative to a quiet day) in the geomagnetic field over a three-hour interval.

The K-index is therefore updated every three hours. The K-index is also necessarily tied to a specific geomagnetic observatory. For locations where there are no observatories, one can only estimate what the local K-index would be by looking at data from the nearest observatory, but this would be subject to some errors from time to time because geomagnetic activity is not always spatially homogenous.

Another item of interest is that the location of the aurora usually changes geomagnetic latitude as the intensity of the geomagnetic storm changes. The location of the aurora often takes on an 'oval-like' shape and is appropriately called the auroral oval.

Figures 6-1 through 6-3 show the K-index for three time periods with significant solar activity. Although there were other days with increased solar activity, these time periods were selected as examples. (See Appendix B for the actual geomagnetic data for this reporting period.)

Figure 6-1 K-Index for 31 December 1999 – 3 January 2000

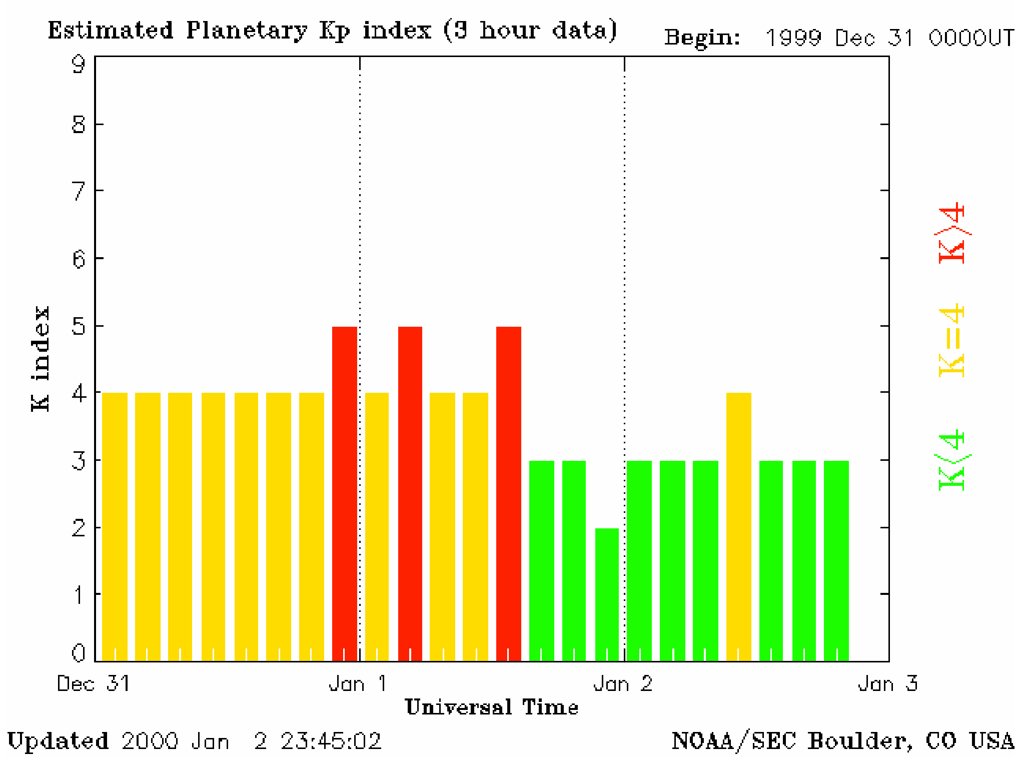


Figure 6-2 K-Index for 22-25 January 2000

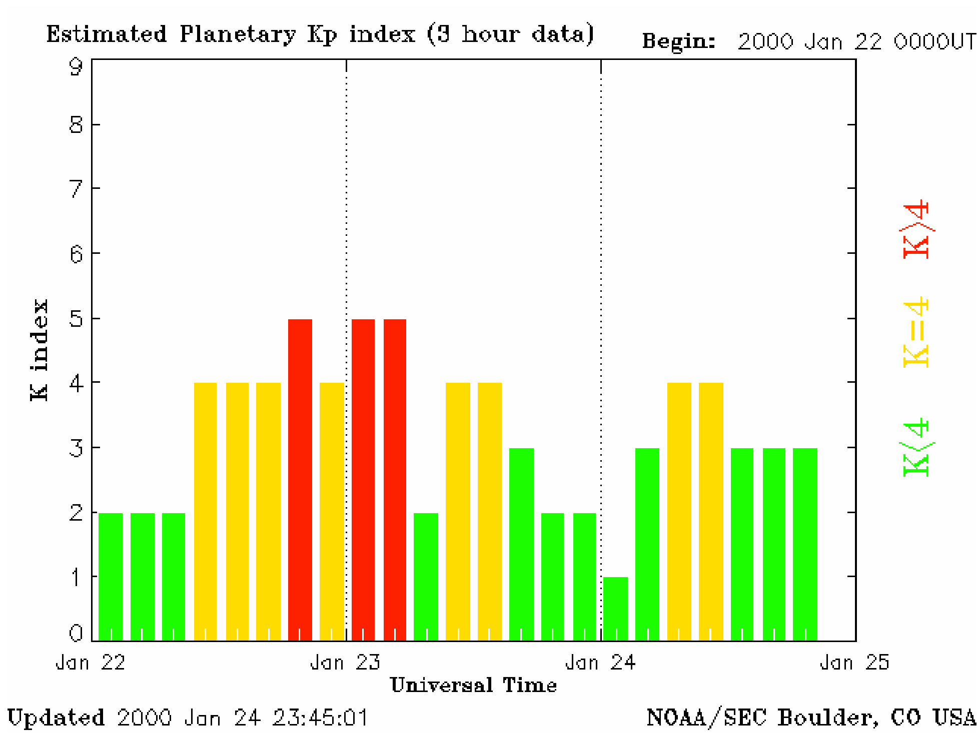
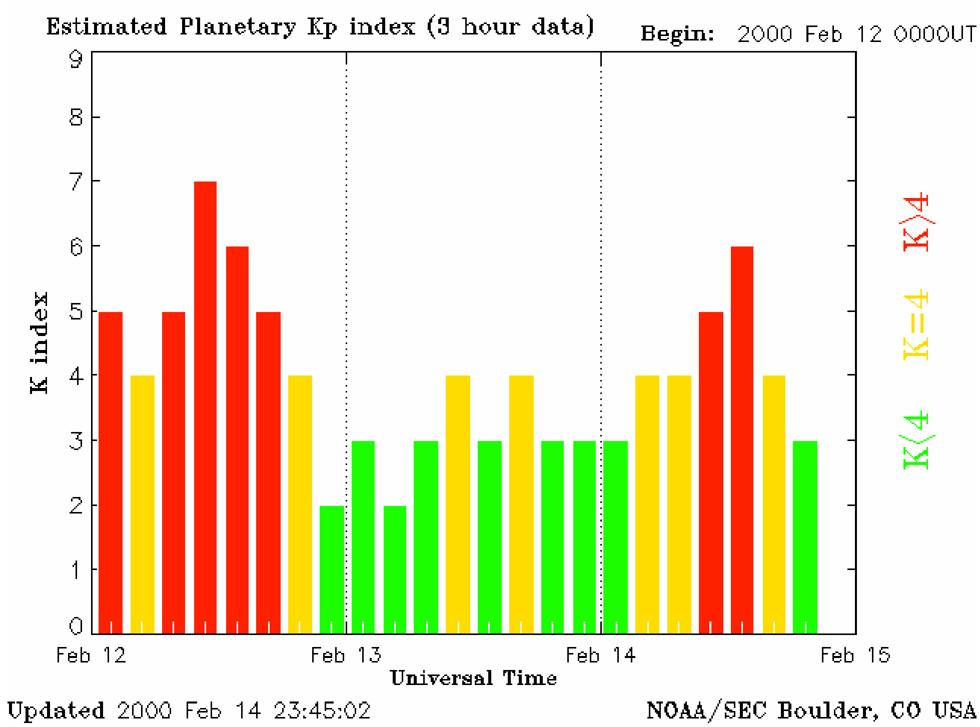


Figure 6-3 K-Index for 12-15 February 2000



Tables 6-1 and 6-2 show the PDOP and position accuracy information, respectively, for the days corresponding to Figures 6-3. The PDOPs and position accuracies show no significant differences between the days with storms and the days with no storms. 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	95%	95% VDOP
Anderson					
2-12-00	1.30	3.34	1.85	2.38	2.02
Atlantic City					
2-12-00	1.25	3.08	1.80	2.36	1.97
Dayton					
2-12-00	1.29	4.07	1.84	2.31	2.02
Gander					
2-12-00	1.35	3.81	2.00	2.74	2.31
Great Falls					
2-12-00	1.39	3.81	2.07	2.89	2.47
Oklahoma					
2-12-00	1.22	11.68	1.83	2.30	2.01

Table 6-2 Horizontal & Vertical Accuracy Statistics*

NSTB Site	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)
Anderson				
2-12-00	45.2	72.3	80.4	164.0
Atlantic City				
2-12-00	45.4	71.1	73.6	162.0
Dayton				
2-12-00	46.6	80.4	85.2	164.0
Gander				
2-12-00	50.1	90.0	104.0	157.0
Great Falls				
2-12-00	49.3	86.8	107.0	164.0
Oklahoma				
2-12-00	45.3	73.6	86.3	152.0

7.0 GLONASS/GPS Performance

7.1 Introduction

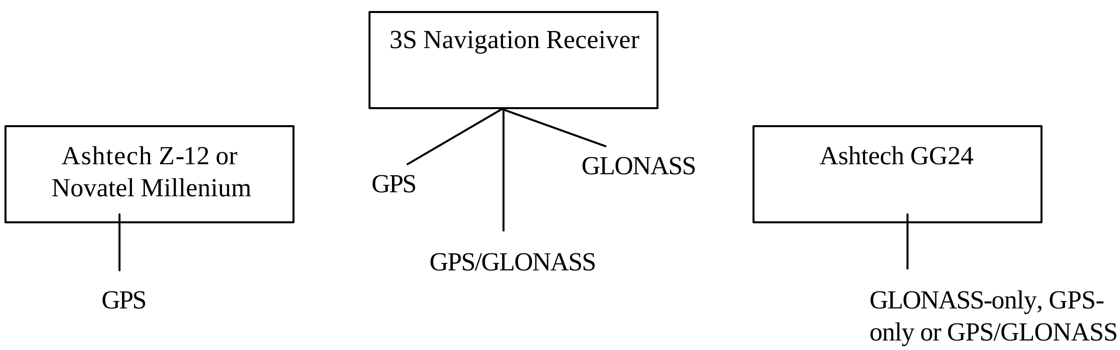
This section is new to the PAN report. In April 1999, ACT-360 was tasked to monitor, analyze and characterize GLONASS and GPS/GLONASS system performance. The objective of this task is to evaluate the ability of GLONASS to provide navigation by itself and with SPS GPS and to assess the incremental benefit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

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.

Two GPS/GLONASS receivers were purchased and placed in the ACT-360 NSTB laboratory. The 3S Navigation R-100/30T receiver provides the three solutions (GPS, GLONASS and blended) simultaneously. The Ashtech GG24 provides the three solutions but only one at a time. With these two receivers in addition to the Ashtech Z-12 and the Novatel Millenium that are already in the NSTB laboratory, any performance due to a receiver problem can be eliminated.

Figure 7-1 Receiver with Corresponding Solutions



Analysis will include the comparison of the different solutions obtained from all three. The GPS/GLONASS receiver solutions will be compared to the Z-12 or Millenium 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

Data will also be provided at an NSTB website. Graphical representation of the previous day's performance data (e.g. position accuracies, availabilities, satellite visibility) will be made available at the website.

7.3 Quarter Results

For this quarter, data collected from the Ashtech GG24 receiver and the Ashtech Z-12 will be analyzed and compared. Tables 7-1 and 7-2 provide PDOP and Position Accuracy statistics for the two Ashtech receivers from 1 January through 31 March 2000. The statistics are cumulative.

Table 7-1 PDOP Statistics for Two Solutions

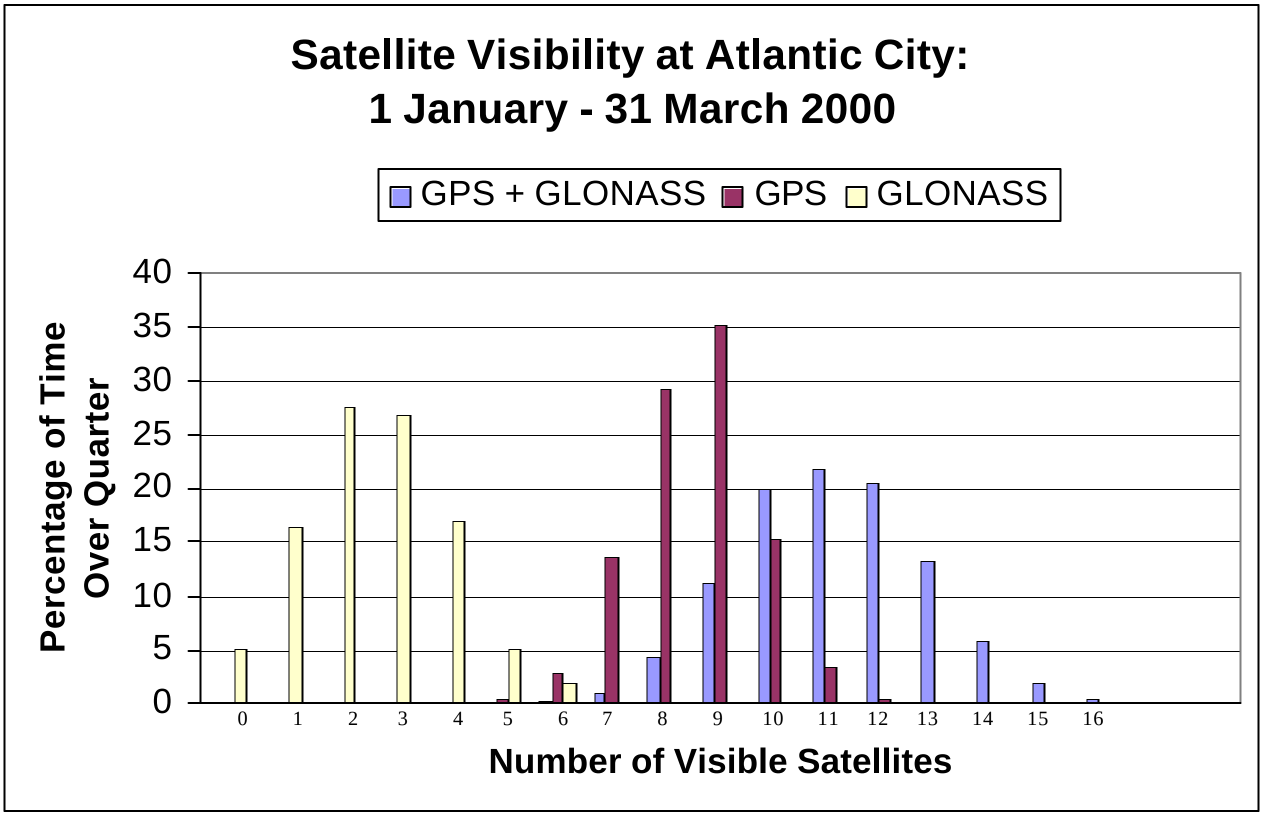
Receiver	Solution	Maximum PDOP	Minimum PDOP	Mean PDOP	95% PDOP	Number of Samples
Ashtech GG24	GPS/GLONASS	5.38	1.08	1.63	2.21	6932202
Novatel Millenium	GPS-only	5.99	1.24	1.84	2.52	7083819

Table 7-2 Position Accuracy Statistics for Two Solutions

Receiver	Solution	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)	Number of Samples
Ashtech GG24	GPS/GLONASS	34.5	75.8	76.6	160.0	6932202
Novatel Millenium	GPS-only	45.2	76.0	97.5	177.0	7083819

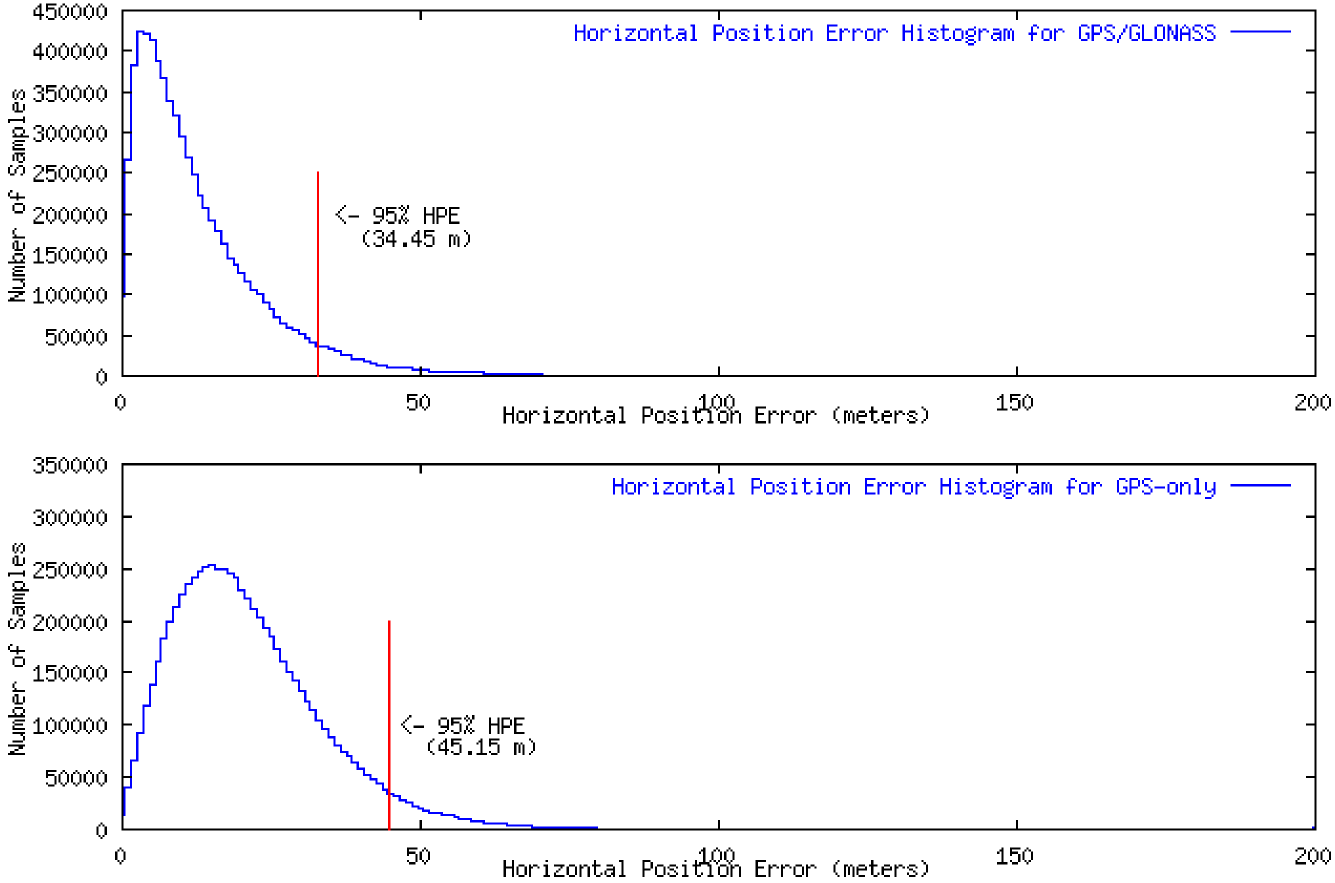
Table 7-3 shows the PDOP and Position Accuracy statistics broken down by the number of GLONASS satellites tracked. Figure 7-2 provides the satellite visibility from 1 January through 31 March 2000.

Figure 7-2 Satellite Visibility Based on GG24 Data



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

Figure 7-3 Horizontal Position Error Histograms for GPS/GLONASS and GPS-Only Solutions



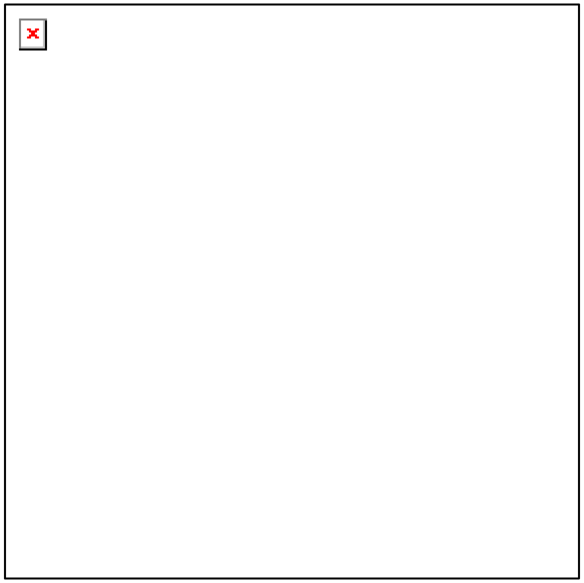
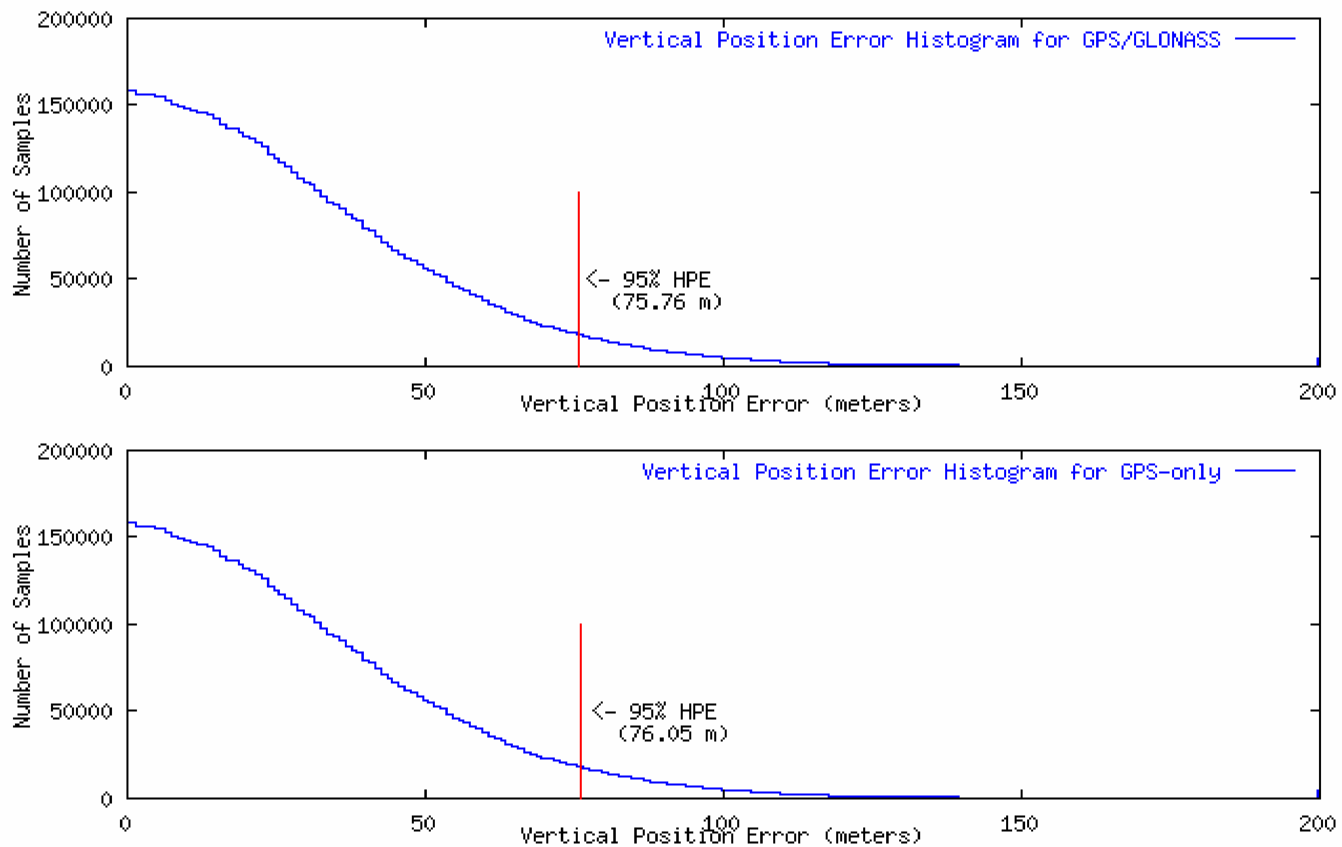


Figure 7-4 Vertical Position Error Histograms for GPS/GLONASS and GPS-Only Solutions



Vertical Position Error Histogram for GPS/GLONASS
<- 95% HPE
(75.76 m)
Number of Samples
Vertical Position Error (meters)
200000
150000
100000
50000
0
0
50
100
150
200
Vertical Position Error Histogram for GPS-only
<- 95% HPE
(76.05 m)
Number of Samples
Vertical Position Error (meters)

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	99.995%
• 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	99.03% availability 99.9% PDOP was 3.27
Conditions and Constraints	***Satellite Availability Standard***	
• 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	99.96%
• 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	99.70%
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	99.99%
• 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	99.99%
Conditions and Constraints	***Service Availability Standard***	
• 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***	
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	<u>Predictable Accuracy</u> ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	Failed See Section 5.1.
• 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	39 m horz. error 95% of time 112 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	<u>Relative Accuracy</u> ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	Future Reports
• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	<u>Time Transfer Accuracy</u> ≤ 340 nanoseconds time transfer error 95% of time	87 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	<u>Range Domain Accuracy</u> ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 8 mm/s^2 range acceleration error 95% of time ≤ 19 mm/s^2 NTE range acceleration error	144 m NTE range error 1.78 m/s NTE range rate error less than 8 mm/sec2 100% of the time 17 mm NTE range acceleration error

Appendix B Geomagnetic Data

:Product: Daily Geomagnetic Data quar_DGD.txt
#
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
#

NOTE: A value of –1 for either the A or K terms means that there is no data for that time period.

Table B-1 Current Quarter Daily Geomagnetic Data

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	**A**	**K-indices**	**A**	**K-indices**	**A**	**K-indices**
2000 01 01	21	5 5 3 3 3 2 3 2	44	4 3 6 6 6 4 4 3	27	4 5 4 4 5 3 3 2
2000 01 02	13	3 3 3 3 2 3 3 2	25	3 3 4 5 4 4 3 4	14	3 3 3 4 3 3 3 3
2000 01 03	10	3 3 3 2 2 1 3 1	19	3 2 4 5 4 3 2 2	13	4 3 3 3 2 2 3 2
2000 01 04	9	2 2 2 3 2 2 2 3	28	0 1 3 6 6 4 2 3	12	1 2 3 3 4 3 2 3
2000 01 05	13	3 3 3 3 2 2 3 3	29	2 3 3 5 4 6 4 3	15	3 3 3 3 3 3 3 4
2000 01 06	15	2 3 1 4 4 4 2 1	39	2 2 1 5 7 6 3 3	17	2 3 1 3 5 4 3 3
2000 01 07	7	3 2 1 2 1 2 2 2	12	2 3 1 4 3 3 2 2	8	3 2 1 3 2 2 2 2
2000 01 08	3	2 0 1 2 1 2 0 0	6	1 0 0 3 3 3 0 0	6	1 1 2 3 2 2 2 1
2000 01 09	1	2 0 0 0 0 1 0 0	0	0 0 0 1 0 0 0 0	3	1 0 0 0 1 1 1 2
2000 01 10	4	1 1 1 0 1 1 1 3	3	0 0 0 1 1 0 1 3	6	1 1 1 1 1 2 2 3
2000 01 11	15	2 1 1 2 2 3 4 5	25	2 1 1 2 4 5 6 4	16	2 1 1 2 3 4 5 4
2000 01 12	8	2 3 2 2 3 2 2 1	-1	3 2 3 2-1 2 2-1	9	3 3 2 2 1 2 3 2
2000 01 13	9	1 3 2 2 4 1 1 1	-1	1 1 5 4 4 3-1-1	10	2 2 3 3 2 3 2 2
2000 01 14	4	2 2 1 0 1 1 2 1	15	2 2 1 3 4 2 5 2	7	2 2 0 1 2 3 3 2
2000 01 15	5	1 1 1 0 2 3 1 1	8	0 2 1 0 5 0 1 0	5	2 1 1 1 2 2 2 2
2000 01 16	4	1 1 1 2 1 2 1 1	3	1 1 0 3 2 1 0 0	6	2 1 0 1 2 2 2 3
2000 01 17	4	1 2 1 0 1 3 0 0	2	1 0 2 1 0 0 0 0	3	1 0 1 1 1 2 2 1
2000 01 18	3	0 1 0 1 2 1 2 0	1	0 0 1 1 1 0 0 0	4	0 0 0 1 1 3 2 2
2000 01 19	3	0 0 0 0 0 2 2 2	1	0 0 0 0 0 0 1 1	4	0 0 0 0 0 2 2 3
2000 01 20	13	2 1 3 4 3 3 3 2	-1	2 1 2 6-1-1-1 4	12	2 1 3 3 3 3 3 2
2000 01 21	0	0 0 0 0 0 0 0 0	6	0 0 0 1 5 0 0 0	3	1 0 0 0 1 1 1 1
2000 01 22	11	1 2 2 2 2 3 3 4	28	0 2 3 4 5 5 5 4	19	2 2 2 4 4 4 5 4
2000 01 23	12	5 3 1 2 3 2 1 0	27	4 4 2 5 6 4 0 0	25	5 5 2 4 4 3 2 2
2000 01 24	12	1 2 4 4 2 2 2 2	26	1 2 4 6 5 4 3 2	17	1 3 4 4 3 3 3 2
2000 01 25	4	1 2 1 1 1 1 2 1	12	2 3 3 3 4 2 2 1	7	2 3 2 2 1 2 2 2
2000 01 26	7	1 3 3 2 1 1 1 2	-1	1 4 2 0-1 1 1 2	7	2 4 2 0 1 2 2 2
2000 01 27	10	2 1 2 2 1 2 4 3	22	2 1 2 4 6 2 4 3	12	2 2 2 3 3 3 4 4
2000 01 28	22	4 4 4 3 4 3 3 4	62	6 5 5 6 7 5 4 4	29	4 5 4 4 5 3 3 4
2000 01 29	22	3 3 4 3 4 4 4 4	-1	4 5-1-1-1-1-1-1	25	3 4 4 4 5 4 4 3
2000 01 30	12	2 3 4 2 3 2 3 1	-1	-1-1-1-1-1-1-1-1	11	2 2 3 2 3 2 4 1

2000 01 31	7 2 2 2 2 3 2 2 1	-1 -1-1-1-1-1 3 2 2	6 3 2 2 2 3 3 2 2
2000 02 01	5 1 1 2 0 2 2 2 2	-1 1 1 2 1-1 3-1 1	8 3 1 2 1 3 3 2 2
2000 02 02	9 3 1 0 2 2 4 2 1	15 1 2 0 2 4 4 5 1	7 3 1 0 2 3 3 2 1
2000 02 03	7 1 1 3 1 3 1 2 2	16 1 1 3 4 5 4 1 1	8 1 1 3 2 2 2 3 3
2000 02 04	4 2 1 2 0 2 1 1 1	7 1 2 4 0 3 1 0 0	4 2 0 2 0 2 1 2 1
2000 02 05	10 1 0 0 1 1 2 5 3	16 0 0 0 2 0 3 6 4	9 0 0 0 1 1 3 4 4
2000 02 06	21 3 4 3 3 4 3 4 4	43 3 3 4 7 5 5 4 4	24 4 4 4 5 4 4 3 4
2000 02 07	19 4 3 3 3 3 2 4 4	38 3 3 4 6 6 5 4 3	25 4 3 3 4 5 4 4 3
2000 02 08	10 3 3 1 3 2 3 2 2	-1 3 2-1-1-1-1-1-1	12 3 3 1 3 2 3 3 3
2000 02 09	6 1 2 2 1 2 3 1 1	21 1 2 3 1 6 5 2 1	11 1 3 2 1 4 4 3 2
2000 02 10	10 2 2 3 1 1 4 2 2	7 2 1 3 2 2 2 1 2	7 2 2 2 1 2 2 2 3
2000 02 11	10 2 4 2 2 2 1 1 3	20 2 4 1 4 4 4 3 4	13 3 4 2 3 3 3 3 3
2000 02 12	35 5 4 5 6 5 3 2 2	71 4 4 5 8 7 5 4 2	52 5 4 5 7 6 5 4 2
2000 02 13	13 3 2 2 3 3 4 2 2	22 3 1 3 4 5 5 3 2	14 3 2 3 4 3 4 3 3
2000 02 14	20 3 4 4 3 5 3 2 2	38 3 3 4 6 6 5 4 3	29 3 4 4 5 6 4 3 3
2000 02 15	11 3 3 2 1 2 1 2 4	15 4 4 3 3 2 2 2 3	11 3 4 2 1 2 2 3 2
2000 02 16	6 2 3 1 0 2 1 2 2	20 6 3 1 2 4 3 2 1	5 2 2 0 1 2 2 2 0
2000 02 17	6 0 1 1 3 3 2 2 1	-1 0 0-1-1-1-1 2 0	6 0 0 1 3 3 2 2 2
2000 02 18	2 0 2 1 0 1 1 0 1	0 0 0 0 0 0 0 0 0	2 0 0 1 0 1 1 1 1
2000 02 19	3 0 0 1 2 1 1 1 1	6 0 0 1 5 0 0 0 0	4 0 0 2 3 0 1 1 1
2000 02 20	5 0 0 2 0 0 0 1 4	4 0 0 1 3 0 0 0 3	5 1 0 3 1 0 0 2 3
2000 02 21	15 3 4 2 2 3 4 3 2	25 2 3 3 4 5 6 1 1	15 3 4 3 2 3 4 3 2
2000 02 22	5 2 3 0 0 2 1 1 1	5 4 1 0 1 1 1 0 0	5 1 2 0 1 2 2 2 1
2000 02 23	8 2 0 1 2 4 3 1 1	20 1 0 1 4 6 5 1 1	9 3 0 1 2 4 4 2 2
2000 02 24	20 2 4 3 3 4 3 4 4	31 2 3 4 5 5 4 5 4	26 2 4 4 5 4 4 4 4
2000 02 25	14 3 4 4 2 3 2 2 2	27 2 3 5 4 6 3 3 2	18 3 4 4 3 4 3 2 3
2000 02 26	10 2 2 3 2 2 2 3 3	19 2 1 4 5 4 2 3 3	12 3 2 4 3 2 3 3 3
2000 02 27	6 2 1 2 2 2 1 2 2	19 3 2 2 5 5 3 2 2	10 3 1 2 3 2 3 3 2
2000 02 28	12 2 3 2 2 4 3 2 2	26 2 4 3 5 6 3 2 2	12 3 3 3 2 4 3 2 2
2000 02 29	5 0 1 2 3 2 1 1 1	12 1 1 5 4 3 1 0 0	6 0 1 3 3 2 2 2 1
2000 03 01	16 2 3 3 4 3 3 2 4	38 1 3 5 6 6 5 3 3	19 2 3 4 4 4 4 3 3
2000 03 02	7 3 3 1 1 2 0 1 2	8 3 3 1 2 3 1 1 1	8 4 3 2 1 2 2 2 2
2000 03 03	5 1 0 0 0 4 0 2 1	4 0 0 0 1 3 2 1 1	5 1 0 0 1 2 3 2 2
2000 03 04	5 1 0 0 0 4 2 1 1	3 0 0 0 0 2 3 1 0	5 1 0 0 0 2 3 2 2
2000 03 05	4 1 2 1 1 1 1 2 1	3 0 0 0 2 1 1 2 2	7 2 2 1 2 2 2 2 3
2000 03 06	8 1 2 2 2 3 2 2 2	13 0 1 4 3 4 2 2 3	11 2 2 3 3 3 3 3 3
2000 03 07	10 3 2 3 2 2 2 2 3	28 3 3 5 6 4 4 2 2	16 3 3 4 4 3 3 3 3
2000 03 08	9 2 3 2 2 3 2 2 2	17 2 2 2 4 4 4 4 2	13 3 3 2 3 3 3 3 3
2000 03 09	3 2 0 0 0 2 2 0 1	5 1 0 0 2 3 0 1 3	5 2 0 0 2 3 2 2 2
2000 03 10	8 1 1 1 1 3 2 3 3	15 1 1 1 4 5 4 2 2	10 1 0 1 3 3 3 2 4
2000 03 11	7 3 1 2 2 2 1 1 2	14 2 2 3 3 5 3 1 1	12 3 3 4 2 4 2 2 2
2000 03 12	15 2 1 4 4 4 3 1 2	27 3 2 5 5 6 3 1 1	19 3 3 5 4 4 3 3 3
2000 03 13	2 2 1 0 0 0 1 1 1	2 2 1 0 1 0 0 1 1	4 2 1 1 0 1 2 2 2
2000 03 14	5 2 2 1 2 1 1 1 1	10 1 1 2 5 3 2 0 0	6 2 2 1 3 1 2 2 2
2000 03 15	0 0 0 1 0 0 0 0 0	5 4 2 1 1 0 0 0 0	3 1 0 0 0 1 2 1 2
2000 03 16	2 0 0 0 0 0 1 1 2	0 0 0 0 0 0 0 0 0	4 0 0 0 0 1 1 2 1
2000 03 17	3 2 0 2 2 1 0 0 0	4 1 0 0 4 0 0 0 0	6 2 1 2 2 2 2 2 2
2000 03 18	6 1 0 1 1 2 2 3 2	4 0 0 0 3 2 1 2 1	7 1 0 1 2 2 3 3 2
2000 03 19	6 2 2 2 2 2 1 2 1	8 1 2 3 3 2 2 1 0	8 2 2 2 2 2 3 3 2
2000 03 20	5 1 1 1 2 3 1 1 1	7 0 0 0 4 3 0 3 0	8 1 0 1 3 3 2 2 2
2000 03 21	2 0 0 1 0 1 1 1 1	7 0 0 0 0 5 1 2 0	6 1 0 1 1 3 2 2 2
2000 03 22	8 1 1 1 2 2 2 2 4	15 1 3 2 2 5 3 3 2	11 2 2 2 3 3 3 3 3
2000 03 23	8 2 2 2 2 3 2 2 2	13 2 2 2 3 4 4 2 1	11 2 2 2 3 3 3 3 2
2000 03 24	9 2 2 1 2 4 3 1 2	-1 1 1 0 4 6 3-1 2	10 2 2 1 2 4 3 2 2

2000 03 25 5 2 2 1 1 2 2 2 0 9 2 1 4 2 0 3 3 0 8 2 2 2 2 1 3 3 1
2000 03 26 3 1 0 1 1 1 2 1 1 3 1 0 0 0 0 3 1 1 5 1 0 2 2 2 3 2 1
2000 03 27 3 1 2 0 1 1 1 0 1 -1 -1 1 0 0 0 0-1 0 5 2 1 0 1 2 2 2 1
2000 03 28 3 2 1 1 1 1 1 1 0 1 1 1 0 1 0 0 0 0 5 2 1 2 2 1 2 2 1
2000 03 29 9 0 0 1 1 2 1 4 4 -1 0 0 3 5 0 0 3-1 9 1 0 1 2 2 2 4 4
2000 03 30 8 2 1 1 0 3 2 3 3 16 5 1 3 4 2 1 3 2 10 2 2 2 2 3 3 3 3
2000 03 31 18 3 4 4 3 3 3 3 3 -1 -1-1-1-1-1-1-1-1 19 3 4 4 4 4 3 3 3

Appendix C WAAS DATA from Performance Build Testing

Background: WAAS Stability Test

During January WAAS precision approaches were flown to three airports during the 60-day Stability Test. Roughly forty approaches each were flown at Anderson, SC; Columbus, NE, and Prescott, AZ. Two FAA aircraft were deployed to the sites to conduct simultaneous approach operations, using actual WAAS precision approach procedures developed by the FAA Flight Standards Service.

Data were collected using the Enhanced Miniature Aviation GPS Receiver (EMAGR) manufactured for the FAA by Rockwell-Collins, collecting data once per second. Position reference data were provided using two Ashtech Z-12 receivers. One of these was on the aircraft and another was at a surveyed location on the ground. Using post-flight data processing software, accuracy of 2 meters or better was obtained.

The 2-d histogram plot includes four histogram graphs of horizontal error histogram, normalized horizontal error histogram, vertical error histogram, and normalized vertical error histogram.
Statistical values of mean, standard deviation, and 95% for the overall and the individual operational zones are shown on the 3d-histogram plots. In addition, Tables C-1 through C-3 shows the statistical values of mean, standard deviation, 95%, 99%, 99.9%, and 99.99% for the overall and the individual operation area both for vertical and horizontal. Graphical results for system accuracy are presented in Figures C-1 through C-9.

Figure C-1 Vertical and Horizontal Histograms: Anderson

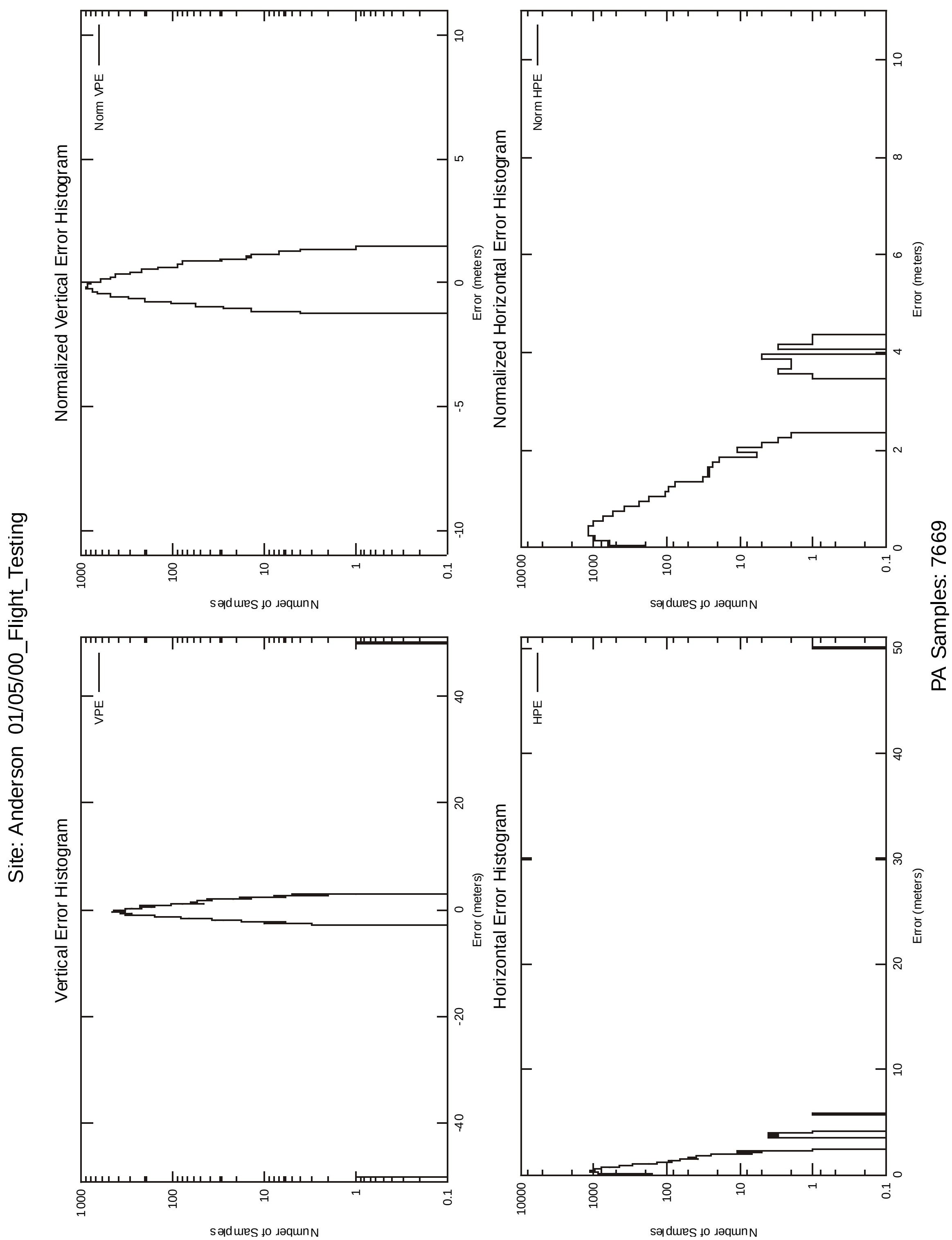


Figure C-2 Vertical and Horizontal Histograms: Columbus

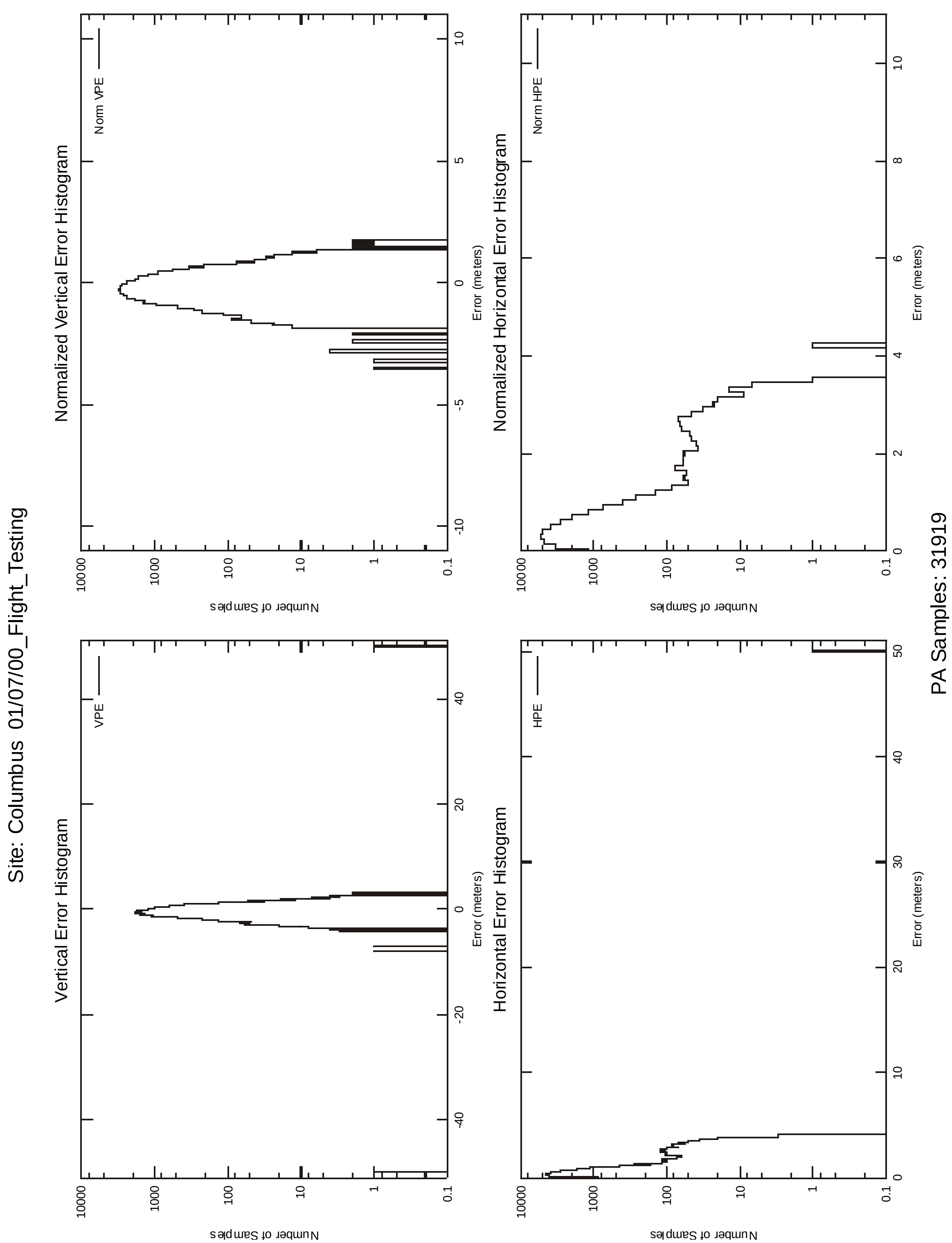


Figure C-3 Vertical and Horizontal Histograms: Prescott

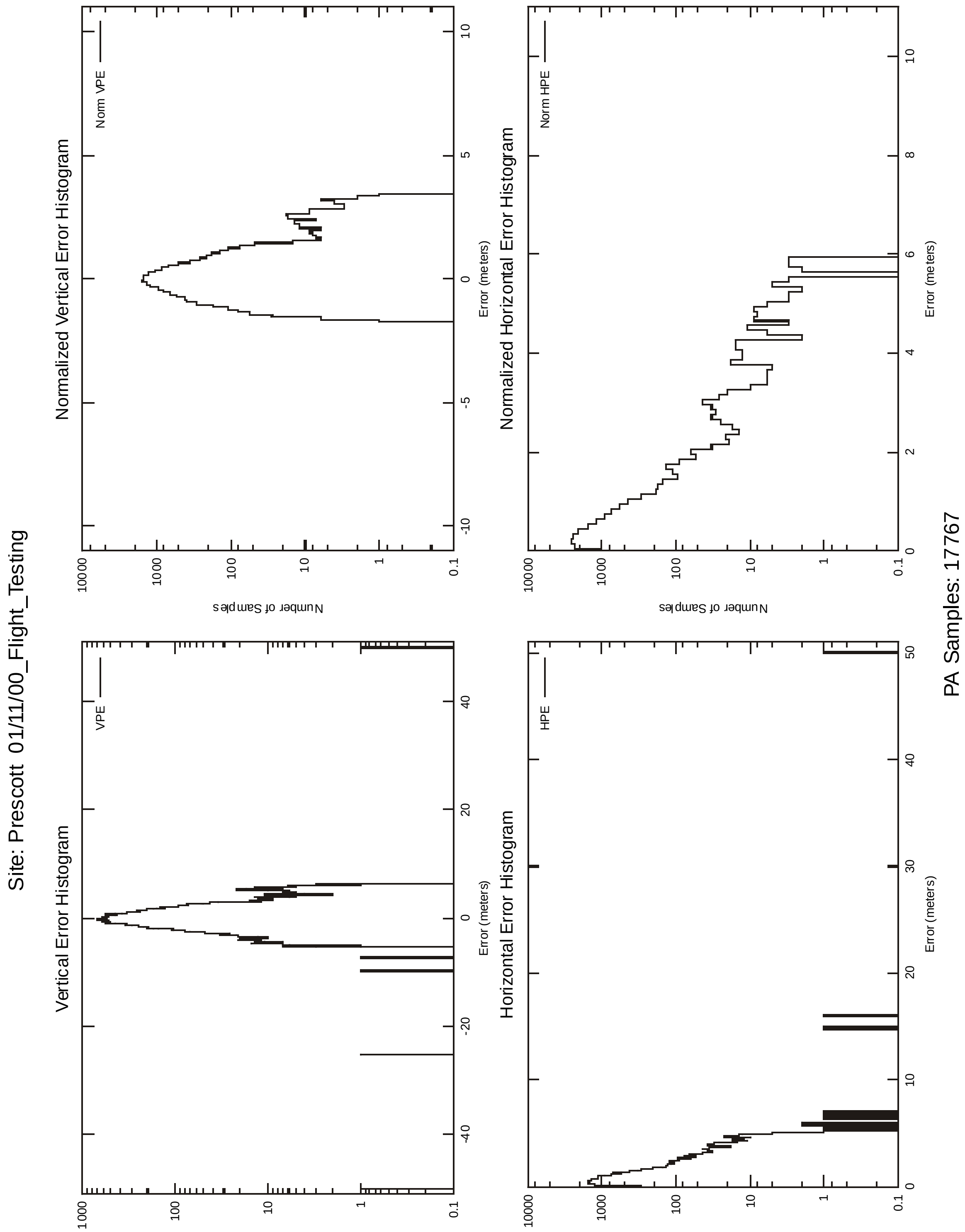


Figure C-4 HPE vs HPL 3D Histogram: Anderson

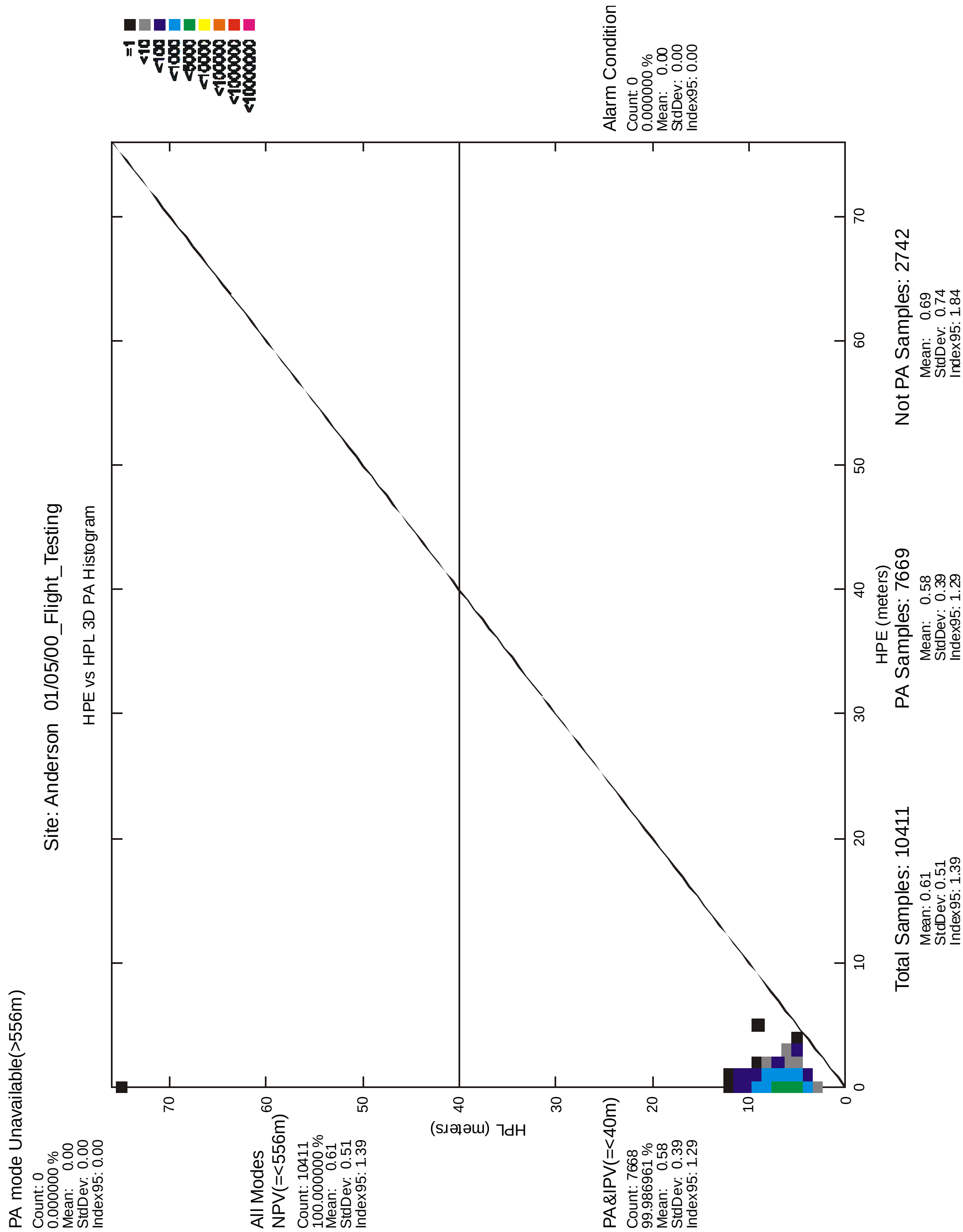


Figure C-5 HPE vs HPL 3D Histogram: Columbus

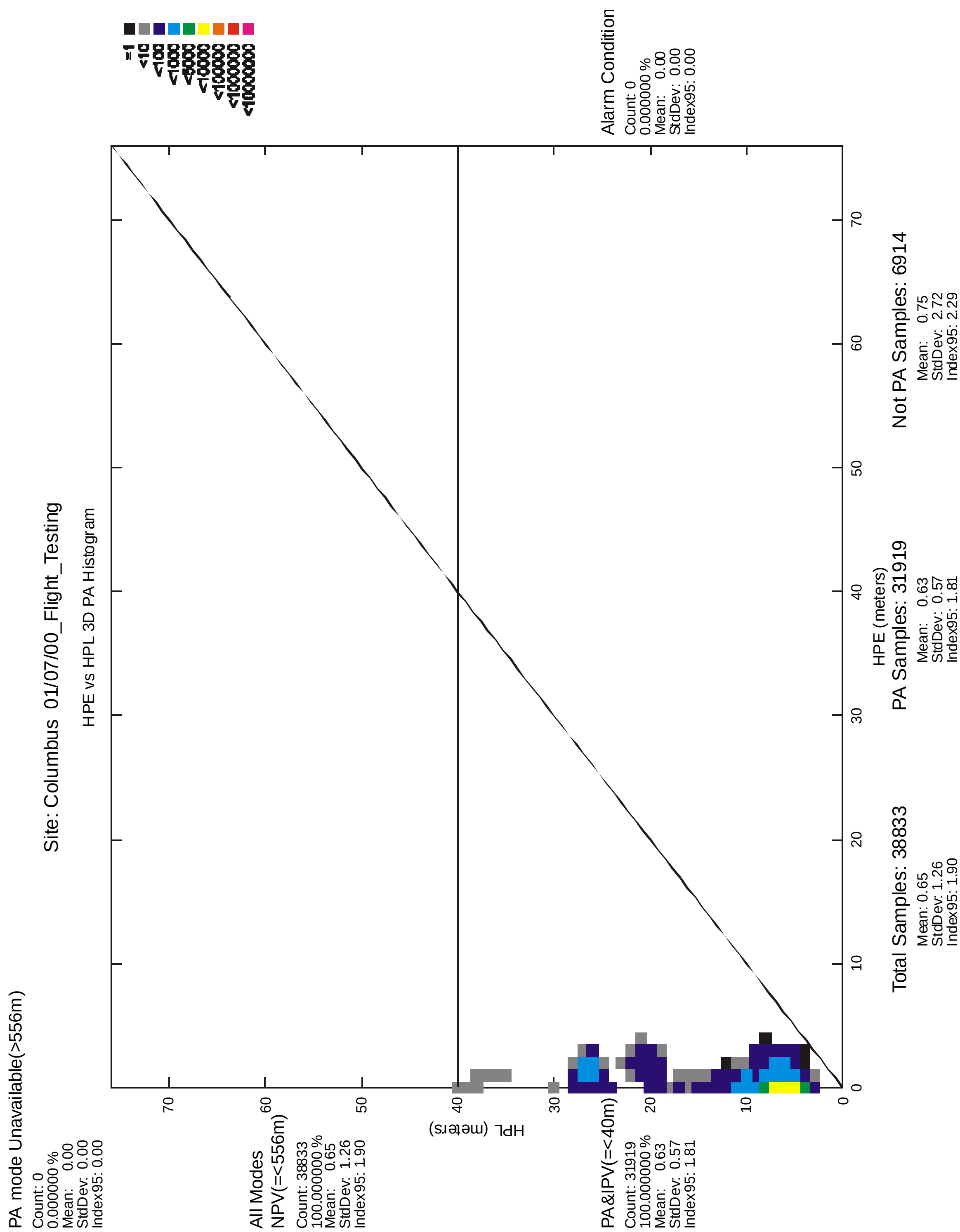


Figure C-5 HPE vs HPL 3D Histogram: Prescott

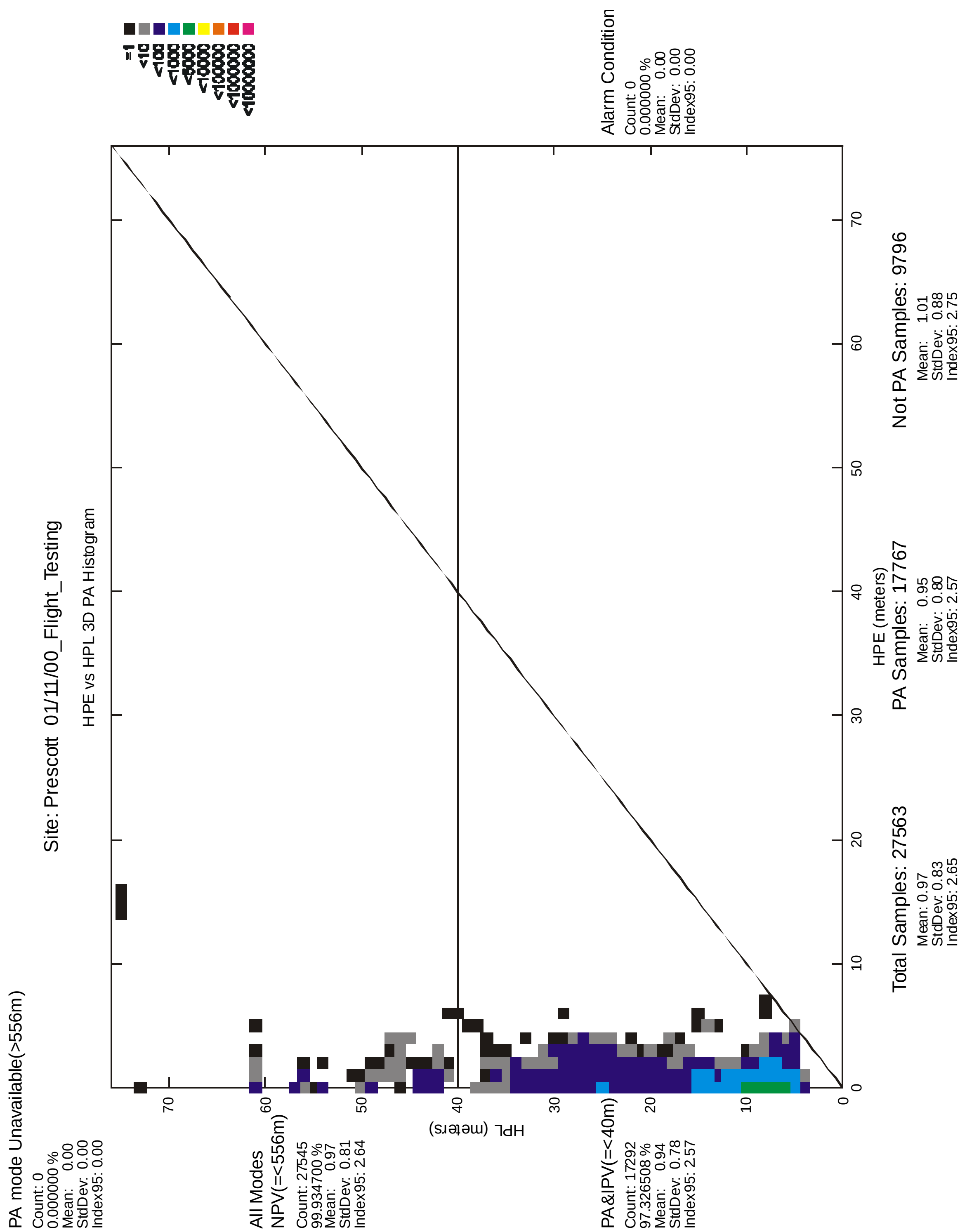


Figure C-7 VPE vs VPL 3D Histogram: Anderson

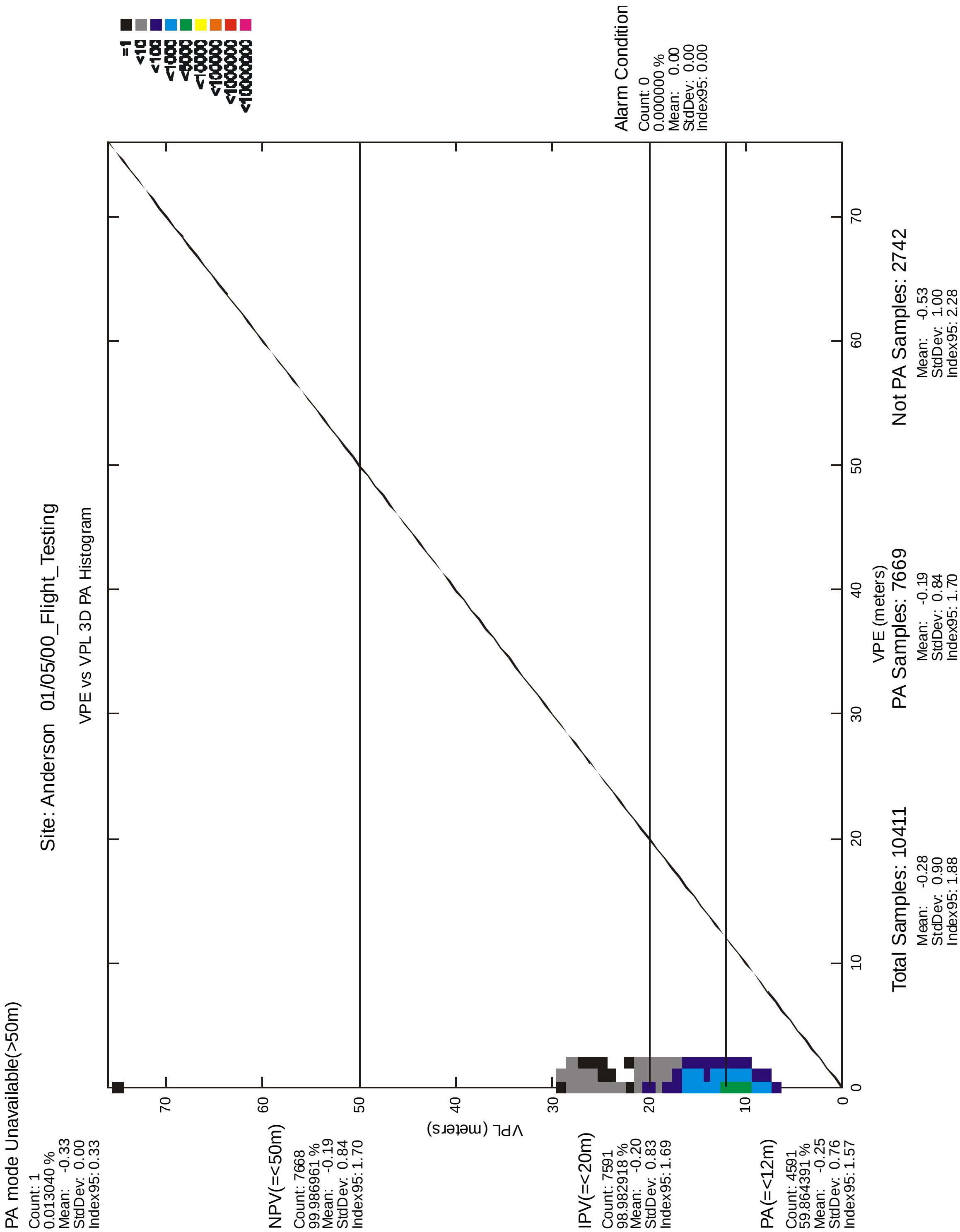


Figure C-8 VPE vs VPL 3D Histogram: Columbus

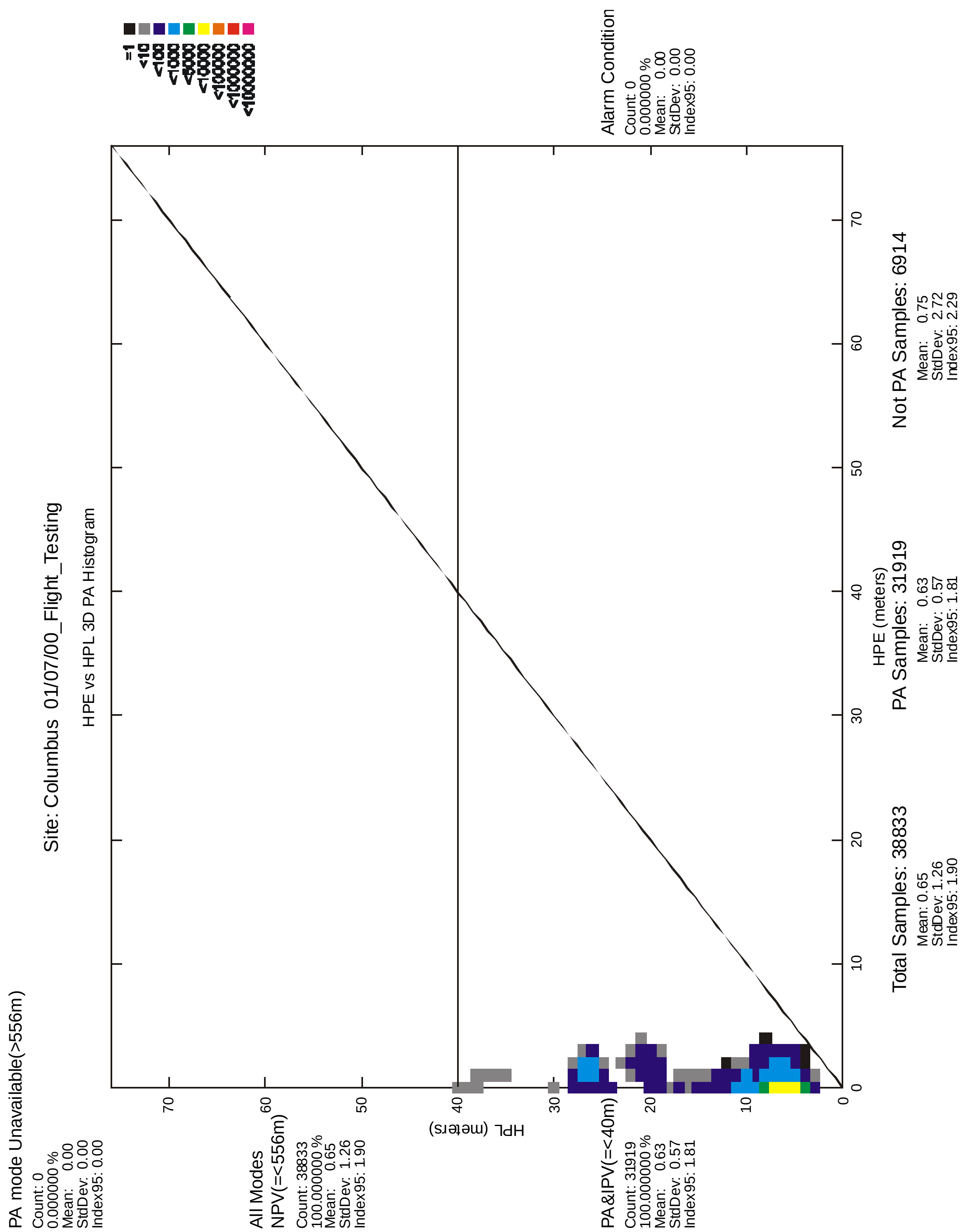
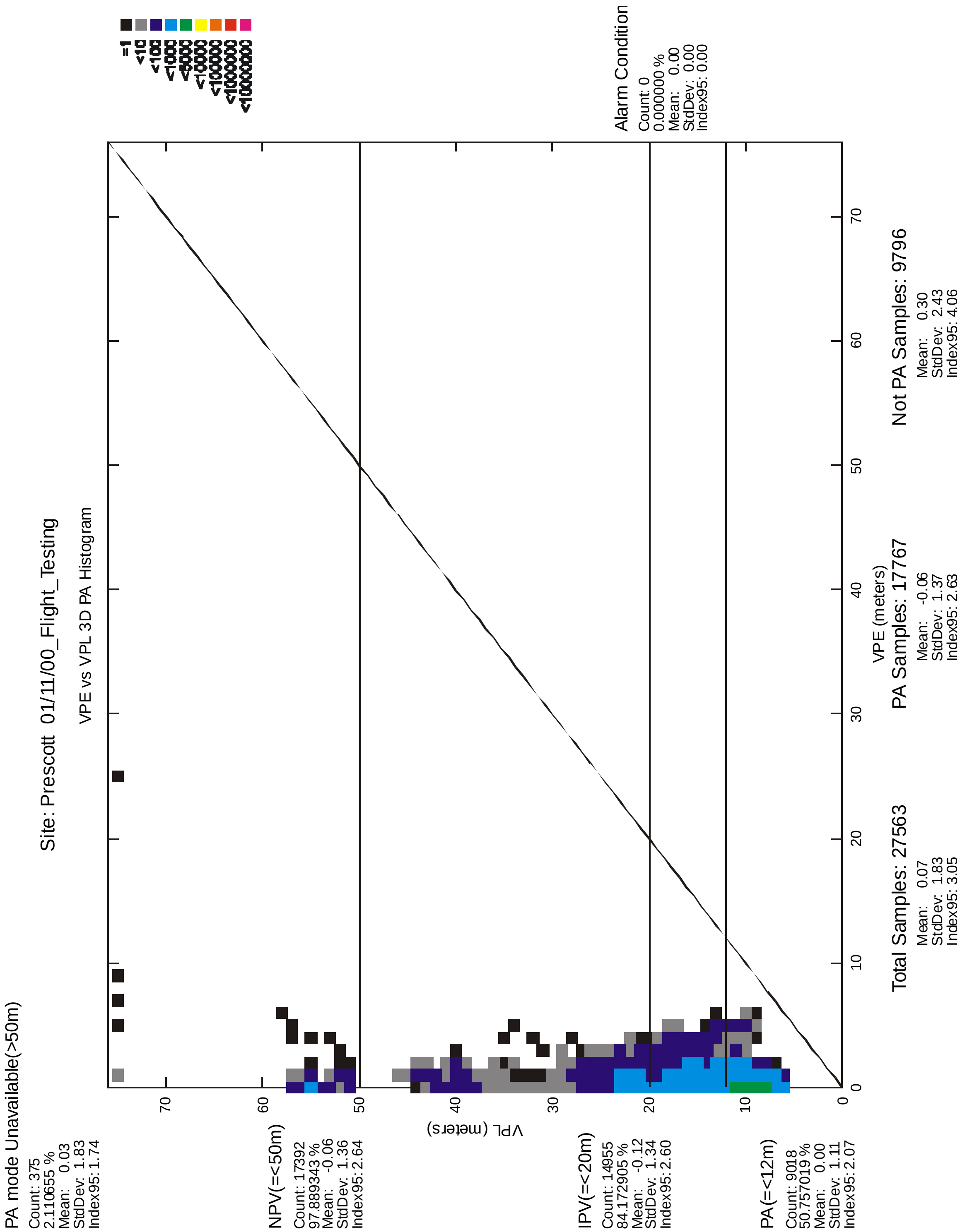


Figure C-9 VPE vs VPL 3D Histogram: Presoctt



The statistic table for each day shows mean, standard deviation, 95%, 99%, 99.9%, and 99.99% for the overall and the individual operation area both for vertical and horizontal.

Table C-1 Position Accuracy Statistics for WAAS Stability Test At Anderson

	Count	% of Total	Mean	Std_dev	95 index	99 index	99.9 index	99.99 index
Vertical_Total	10411	1	-0.283	0.896	1.88	2.55	3.7	6.67
Vertical_Alarm_Condition	0	0	0	0	0	0	0	0
Horizontal_Total	10411	1	0.611	0.508	1.39	3.475	4.112	5.912
Horizontal_Alarm_Condition	0	0	0	0	0	0	0	0
Horizontal_NPA	10411	1	0.611	0.508	1.39	3.475	4.112	5.912
Not_PA_Vertical_Total	2742	0.263375	-0.534	0.998	2.28	3.02	6.36	6.82
Not_PA_Horizontal_Total	2742	0.263375	0.694	0.744	1.838	3.924	4.814	7.889
PA_Vertical_Total	7669	0.736625	-0.193	0.839	1.7	2.23	2.76	2.87
Vertical_Not_Available	1	0.00013	-0.33	0	0.33	0.33	0.33	0.33
Vertical_PA	4591	0.598644	-0.253	0.764	1.57	2.14	2.6	2.87
Vertical_SPEC	7579	0.988264	-0.196	0.83	1.69	2.21	2.76	2.87
Vertical_IPV	7591	0.989829	-0.197	0.831	1.69	2.21	2.76	2.87
Vertical_NPV	7668	0.99987	-0.193	0.839	1.7	2.23	2.76	2.87
PA_Horizontal_Total	7669	0.736625	0.581	0.386	1.292	1.855	3.893	5.866
Horizontal_Not_Available	0	0	0	0	0	0	0	0
Horizontal_PA_IPV	7668	0.99987	0.581	0.386	1.292	1.855	3.893	5.866

Table C-2 Position Accuracy Statistics for WAAS Stability Test At Columbus

	Count	% of Total	Mean	Std_dev	95 index	99 index	99.9 index	99.99 index
Vertical_Total	38833	1	-0.426	2.727	1.82	2.79	6.71	167.22
Vertical_Alarm_Condition	0	0	0	0	0	0	0	0
Horizontal_Total	38833	1	0.649	1.258	1.9	3.252	4.026	72.214
Horizontal_Alarm_Condition	0	0	0	0	0	0	0	0
Horizontal_NPA	38833	1	0.649	1.258	1.9	3.252	4.026	72.214
Not_PA_Vertical_Total	6914	0.178044	-0.11	6.23	2.28	4.85	125.41	188.75
Not_PA_Horizontal_Total	6914	0.178044	0.752	2.719	2.286	3.618	49.787	96.657
PA_Vertical_Total	31919	0.821956	-0.495	0.784	1.74	2.57	3.24	4.28
Vertical_Not_Available	0	0	0	0	0	0	0	0
Vertical_PA	27857	0.87274	-0.531	0.761	1.73	2.57	3.28	4.28
Vertical_SPEC	31740	0.994392	-0.495	0.781	1.74	2.56	3.24	4.28
Vertical_IPV	31788	0.995896	-0.495	0.782	1.74	2.56	3.24	4.28
Vertical_NPV	31919	1	-0.495	0.784	1.74	2.57	3.24	4.28
PA_Horizontal_Total	31919	0.821956	0.626	0.567	1.811	3.164	3.689	3.939
Horizontal_Not_Available	0	0	0	0	0	0	0	0
Horizontal_PA_IPV	31919	1	0.626	0.567	1.811	3.164	3.689	3.939

Table C-3 Position Accuracy Statistics for WAAS Stability Test At Prescott

	Count	% of Total	Mean	Std_dev	95 index	99 index	99.9 index	99.99 index
Vertical_Total	27563	1	0.068	1.826	3.05	5.75	15.48	47.55
Vertical_Alarm_Condition	0	0	0	0	0	0	0	0
Horizontal_Total	27563	1	0.97	0.828	2.646	4.009	6.581	15.079
Horizontal_Alarm_Condition	0	0	0	0	0	0	0	0
Horizontal_NPA	27545	0.999347	0.966	0.815	2.638	3.985	5.416	15.079
Not_PA_Vertical_Total	9796	0.355404	0.299	2.43	4.06	7.22	36.1	49.88
Not_PA_Horizontal_Total	9796	0.355404	1.014	0.875	2.748	3.99	7.889	18.508
PA_Vertical_Total	17767	0.644596	-0.06	1.367	2.63	4.65	5.86	9.73
Vertical_Not_Available	375	0.021107	0.027	1.832	1.74	6.24	25.18	25.18
Vertical_PA	9018	0.50757	0.002	1.112	2.07	3	5.87	6.23
Vertical_SPEC	14734	0.82929	-0.12	1.337	2.58	4.75	5.84	6.18
Vertical_IPV	14955	0.841729	-0.117	1.342	2.6	4.75	5.84	6.18
Vertical_NPV	17392	0.978893	-0.062	1.356	2.64	4.63	5.83	6.18
PA_Horizontal_Total	17767	0.644596	0.946	0.8	2.565	4.053	5.077	15.079
Horizontal_Not_Available	0	0	0	0	0	0	0	0
Horizontal_PA_IPV	17292	0.973265	0.938	0.778	2.565	4.009	4.972	6.781

Appendix D Performance Analysis (PAN) Problem Report

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 Testbed (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:
The data collected from the NSTB Ashtech receiver in Oklahoma City showed a 99.99% horizontal position error of 679 meters (SPS Specification is $\leq$ 300 meters) and a 99.99% vertical position error of 1639 meters (SPS Specification is $\leq$ 500 meters) on 8 March 2000 between 11:00:11 and 11:07:48 AM (298812 and 299268 GPS TOW).

The data collected from the NSTB Ashtech receiver in Oklahoma City showed a 99.99% horizontal position error of 561 meters (SPS Specification is $\leq$ 300 meters) and a 99.99% vertical position error of 1389 meters (SPS Specification is $\leq$ 500 meters) on 13 March 2000 between 10:39:44 and 10:48:03 AM (124784 and 125283 GPS TOW).

The data collected from the NSTB Ashtech receiver in Oklahoma City showed a 99.99% horizontal position error of 544 meters (SPS Specification is $\leq$ 300 meters) and a 99.99% vertical position error of 1250 meters (SPS Specification is $\leq$ 500 meters) on 15 March 2000 between 10:31:32 and 10:40:10 AM (297092 and 297610 GPS TOW).

Problem Analysis:

1. Conditions During Failure

8 March 2000
At 11:00:11, Satellite PRN 11 set (i.e. below 5^o elevation). Satellite PRN 18 did not rise (i.e. above 5^o elevation) until 11:07:48. Satellite PRN 16 was down for maintenance (NANU 2000031).

10 March 2000
At 10:39:44, Satellite PRN 11 set (i.e. below 5^o elevation). Satellite PRN 18 did not rise (i.e. above 5^o elevation) until 10:48:04. Satellite PRN 16 was down for maintenance (NANU 2000031).

15 March 2000
At 10:31:32, Satellite PRN 11 set (i.e. below 5^o elevation). Satellite PRN 18 did not rise (i.e. above 5^o elevation) until 10:40:10. Satellite PRN 16 was down for maintenance (NANU 2000031).

Table 1-1 shows the satellites tracked by receivers located at Oklahoma City and the closest NSTB or WAAS reference stations.

Table 1-1 Satellites Tracked

Location	Receiver Type	Satellites Tracked (PRN) 3 March	Satellites Tracked (PRN) 10 March	Satellites Tracked (PRN) 15 March
Oklahoma City	ASHTECH (NSTB)	1, 14, 22, 25	1, 14, 22, 25	1, 14, 22, 25
Oklahoma City	WAAS	1, 14, 22, 25	1, 14, 22, 25	1, 14, 22, 25
San Angelo	ASHTECH (NSTB)	1, 11, 14, 22, 25	1, 11, 14, 22, 25	1, 11, 14, 22, 25
Kansas City	WAAS	1, 6, 14, 22, 25	1, 6, 14, 22, 25	1, 6, 14, 22, 25

The Positioning Accuracy Standard requirements in the GPS SPS specification can only be evaluated given that the Coverage, Service Availability and Service Reliability Standards are met. Tables 2-1, 3-1, 4-1 and 5-1 were taken from Section 2 of Appendix A of the GPS SPS Specification (dated June 2,1995).

Since the performance data was similar for all three days, only the data for 8 March will be presented.

2. Coverage

Table 2-1 Coverage Standard

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

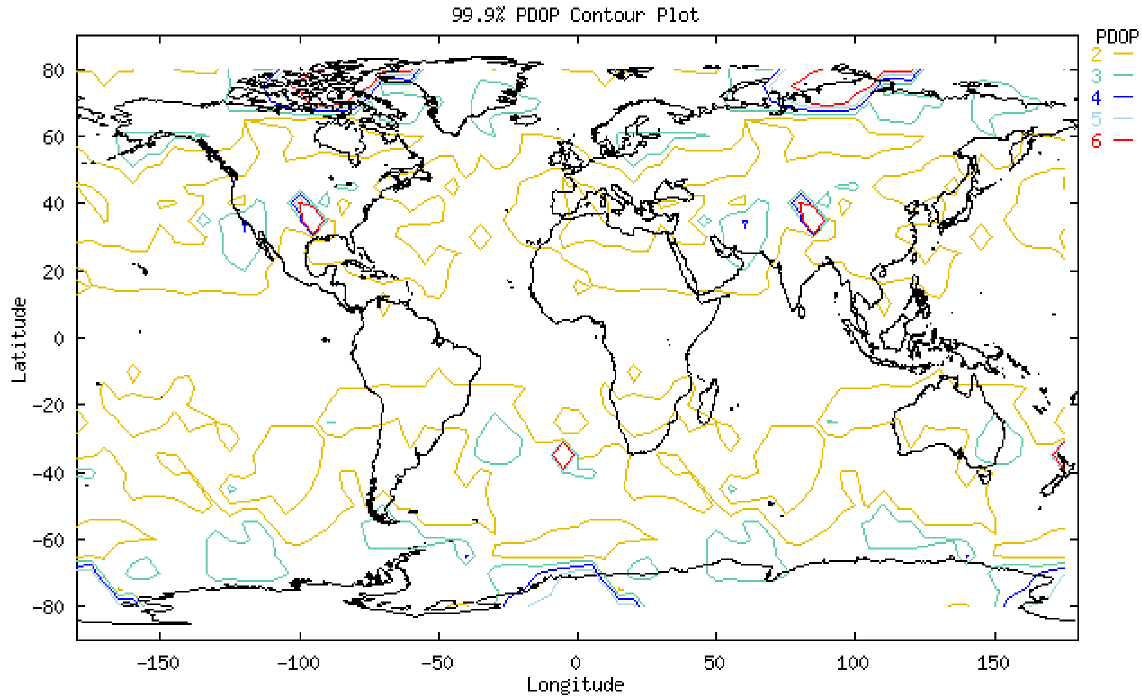
Figure 2-1 is a contour coverage plot of 8 March 2000. The PDOP was calculated at every 5^{o} point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. This contour plot is representative of plots for 13 and 15 March 2000. The PDOP calculations were based on YUMA almanacs obtained at the following US Coast Guard website: http://www.navcen.uscg.mil/gps/.

On Figure 2-1, a red band is seen around Oklahoma City indicating that the 99.9% PDOP within that red band is 6 or above. The coordinates for Oklahoma City are: Latitude of 35.4a and Longitude of -97.6. The 99.9% PDOP and the mean availability of the grid points surrounding Oklahoma City are as follows:

Latitude	Longitude	99.9% PDOP	Mean Availabilty
40	-100	7.31	99.72%
35	-100	3.59	100%
40	-95	3.91	100%
35	-95	21.26	99.44%

The global average coverage for the 24-hour period was 99.987% and the worst case-point was 99.167%. Both of the coverage standard requirements were met.

Figure 2-1 SPS Coverage (24-Hour Period: 8 March 2000)



Developed by FAA William J. Hughes Technical Center

3. Service Availability

Table 3-1 Service Availability Standard

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

NOTE: Global in this report refers to the nine sites used. Although future reports will have all NSTB sites, a true global availability cannot be determined since there aren't reference stations around the world.

Table 3-2 Maximum PDOP Statistics

Location	GPS Week/Day	Max PDOP	Number of Seconds of 24-Hour Period PDOP > 6	Number of Samples	Availability
Oklahoma City	28/3	30.69	457	86156	99.47%
Worst-Case Point on Worst-Case Day = 99.47% (SPS Spec. ≥ 83.92%)					

Global Average on Worst-Case Day = 99.94% (SPS Spec. > 95.87%)

Table 3-7 PDOP > 6 Statistics

NSTB Site	Total Number of Seconds of PDOP Monitoring	Total Seconds with PDOP > 6	Overall % Availability
Anderson	85611	0	100
Atlantic City	86156	0	100
Dayton	86156	0	100
Elko	86156	0	100
Gander	85211	0	100
Great Falls	85732	0	100
Oklahoma City	86156	457	99.47
Kansas City	83797	0	100
Salt Lake City	83957	0	100
Worst Single Point Average = 99.47% (SPS Spec. ≥ 99.16%)			

Global Average over 24-Hour Period = 99.94% (SPS Spec. > 99.85%)

The requirements for Service Availability were met.

4. Service Reliability

Table 4-1 Service Reliability Standard

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

The horizontal position error for Oklahoma City was below 500 meters 99.96% of the day and the average for all nine sites was 99.99%. Since the GPS Standard Positioning Service Signal Specification states that the horizontal position error will not exceed 500 meters 99.79% over a 24-hour period for any single point average or 99.97% over a 24-hour period for a global average, the SPS requirements were met.

NSTB Site	Number of Samples This Quarter	Maximum Horizontal Error (meters)	Service Reliability
Anderson	85611	115	100%
Atlantic City	86156	95	100%
Dayton	86156	114	100%
Elko	86156	96	100%
Gander	85211	147	100%
Great Falls	85732	104	100%
Oklahoma City	86156	726	99.96%
Kansas City	83797	108	100%
Salt Lake City	83957	110	100%

5. Positioning Accuracy

Table 5-1 Positioning Accuracy Standard

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

Table 5-2 Horizontal & Vertical Accuracy Statistics

Reference Station	95% Horizontal (meters)	95% Vertical (meters)	99.99% Horizontal (meters)	99.99% Vertical (meters)
Anderson	47.7	77.9	115	156
Atlantic City	47.8	70.4	93	155
Dayton	46.9	73.2	112	148
Elko	48.2	74.2	96	179
Gander	56.2	90.4	143	194
Great Falls	53.6	87.3	104	156
Oklahoma City	47.1	74.9	679	1639
Kansas City	47.5	72.2	102	156
Salt Lake City	49.8	73.7	110	141

Conclusion:

Given that Coverage, Service Availability and Service Reliability were met, the Position Accuracy Standard should have been met. However, the Position Accuracy requirements for the 99.99% horizontal and vertical errors were not met. Satellite PRN 16 is still out for maintenance, so the conditions that created this problem is still present.

Appendix E 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. The minimum signal reception and processing capabilities which must be designed into an SPS receiver in order to experience performance consistent 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 which 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 which 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 Radionavigation 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.