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

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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 Reference Station locations: Anderson, Atlantic City, Dayton, Elko, Gander, Great Falls, Oklahoma City, Seattle and Sitka. This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification Annex A.

This report, Report #27, includes data collected from 1 July through 30 September 1999. The next quarterly report will be issued at the end of January 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 for the CONUS was 99.963% or better.

Availability was verified by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 April and 30 June 1999 and by calculating the satellite availability from the data obtained from the nine NSTB sites. A total of twenty-six satellite outages were reported in the NANUs. Twenty of the outages were scheduled and six were unscheduled. Between 1 April and 30 June 1999, the availability for Anderson, Atlantic City, Dayton, Elko, Gander, Great Falls, Oklahoma City, Seattle and Sitka was ***(INSERT PERCENTAGES HERE)***, 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.

Satellite outages caused the PDOP to exceed six. To aid in determining the cause of these increases ACT-360 monitors satellite and receiver activity. There are times when a satellite stops transmitting a signal for a few seconds. Although this does not cause any position or range problems, the PDOP may exceed 6 during this time. Even though this reporting period had more satellites outages than previous reporting periods, all GPS SPS requirements were met.

For the time period of this report, ***(NEW #)*** days showed significant solar activity. The data for these days met all GPS Standard Positioning Service (SPS) specifications. However, the PDOP did go above six at three different sites (Elko, Honolulu and Winnipeg) due to a satellite outage during the same time of the storm (16 April 1999). The Millenium receivers at Elko and Winnipeg and the WAAS receiver in Honolulu had problems tracking other satellites during the time of the satellite outage. Although the PDOP went above six at these three sites, all GPS SPS requirements were met.

Position accuracies were verified by calculating the 95% and 99.99% values of horizontal and vertical errors. All of these values were within the SPS limits. The average 95% horizontal error, 95% vertical error, 99.99% horizontal error and 99.99% vertical error for all nine sites was 44.30 meters, 73.96 meters, 104.66 meters and 178.22 meters, respectively.

Range performance was verified for each satellite using the data collected from the NSTB Dayton site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 149.09 meters on Satellite PRN 5. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 1.81 meters/second on Satellite PRN 13. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 16.5 millimeters/second^2. 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 and GPS-only with WAAS corrections added performances (from an Ashtech Z-12 receiver). The 95% horizontal error and vertical error for the GPS/GLONASS solution with four or more GLONASS satellites were 28 meters and 65 meters. The 95% horizontal error and vertical error for the GPS solution were 50 meters and 84 meters. The GPS/WAAS user solution although providing good navigation error performance, the PDOP is not as good as the GPS/GLONASS user solution. The reason for the higher PDOP's is due to the removal of some GPS satellite measurements from the WAAS Precision Approach (PA) user solution (in accordance with the MOPS) which do not have WAAS ionospheric corrections available. The WAAS Ionospheric Grid Points (IGP's) around Atlantic City are not always considered monitored because of the restrictive monitoring rules imposed by the WAAS master station. This reduces the number of WAAS usable satellites for PA operation and hence increases the PDOP that a WAAS user will observe over an extended period of time.

From the analysis performed on data collected between 1 July and 30 September 1999, the GPS performance met all SPS requirements that were evaluated.

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1.0 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. Knowledge gained from ground-based radionavigational aides to space-based radionavigation aids. 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 Analysis report. This report contains data collected at the following National Satellite Testbed (NSTB) reference station locations:

- Atlantic City, NJ
- Anderson, ***(INSERT STATE HERE)***
- Dayton, OH
- Elko, NV
- Gander, NFLD (Canada)
- Great Falls, ***(INSERT STATE HERE)***
- Oklahoma City, OK
- Seattle, WA
- Sitka, AK

During this quarter, the Millenium receivers in Dayton and Winnipeg, the WAAS receiver in Honolulu and the GSV receiver in Seattle malfunctioned. The rubidium clock in the Millenium receiver in Dayton had to be replaced. No data was collected between 19 April and 28 June from the Dayton receiver. The receivers in Honolulu and Winnipeg were taken out of the PAN data collection on 20 June 1999. These two receivers still need to be fixed. The Ashtech receiver in Atlantic City was added to the PAN data collection on 27 May 1999.

Since there have been an increasing number of problems with receivers, the next report will have another section that will document all the problems experienced with receivers and or TRS software. Receiver monitoring software is being developed by ACT-360. This software will output flags any time a receiver in the NSTB network does not track a satellite that it should be tracking using YUMA almanac as a basis. This software will also output times when a receiver has a false lock and times when an ephemeris is sent late.

(Future reports will include all 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 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 is new to the PAN report. This section will provide 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 of this report provides an example of how future WAAS data analysis will be presented. The data in this report is data collected during the WAAS stability testing. All data collected for this section was stored in a newly developed Oracle database. This database is still under development and will eventually be used to store data from all NSTB and WAAS sites. The requirements were taken from the WAAS specification (FAA-E-2892B).

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

Table 1-1 SPS Performance Requirements

Coverage Standard	**Conditions and Constraints**	**Evaluated in this Report**
≥ 99.9% global average	• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	✓
≥ 96.9% at worst-case point	• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	✓
Satellite Availability Standard	**Conditions and Constraints**	
≥ 99.85% global average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	✓
≥ 99.16% single point average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	✓
≥ 95.87% global average on worst-case day	• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	✓
≥ 83.92% at worst-case point on worst-case day	• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	✓
Service Availability Standard	**Conditions and Constraints**	
≥ 99.97% global average	• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	✓
≥ 99.79% single point average	• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	✓

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

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	4×10^{-8} probability of Hazardously Misleading Information 6.2 seconds to alarm
Availability	0.95 Navigation and fault detection functions are operational Signal-in-Space meets accuracy and continuity requirements
Service Volume	50% in CONUS

2.0 Coverage Performance

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

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

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

Almanacs for GPS weeks 1017 - 1030 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^{o} point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Eight out of the fourteen days had Availabilities of 100%. The six days that gave less than 100% availability were in Weeks 1017, 1018, 1022, and 1024 through 1030. Table 2-1 also gives the global 99.9% PDOP value for each of the fourteen GPS Weeks. The PDOP was 5.02 or better 99.9% for each of the 24-hour intervals.

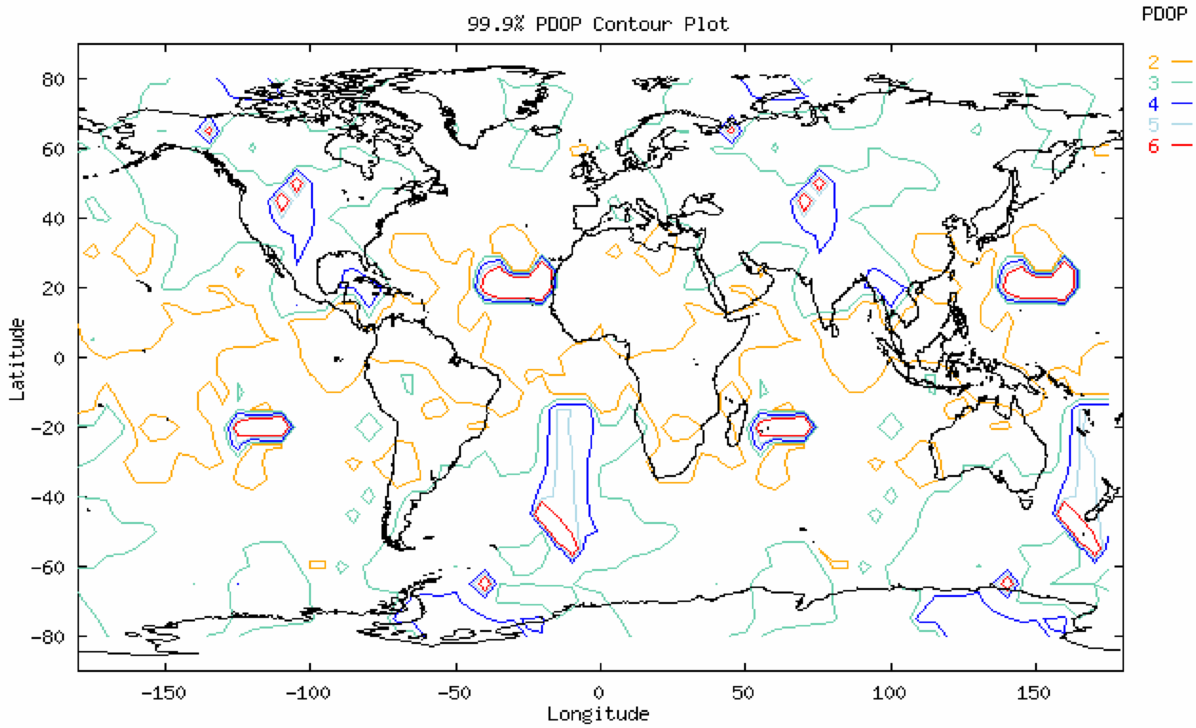
All GPS SPS requirements were met for the coverage portion of the analysis.

Table 2-1 Coverage Statistics

GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
1017	4.03	99.978%	98.889%
1018	4.06	99.977%	98.819%
1019	3.30	100%	100%
1020	3.31	100%	100%
1021	3.30	100%	100%
1022	3.59	99.992%	98.819%
1023	3.29	100%	100%
1024	3.32	100%	99.931%
1025	3.81	99.983%	97.847%
1026	3.74	99.988%	97.917%
1027	3.24	100%	99.792%
1028	3.23	99.999%	99.792%
1029	3.64	99.992%	98.264%
1030	3.21	99.999%	99.722%

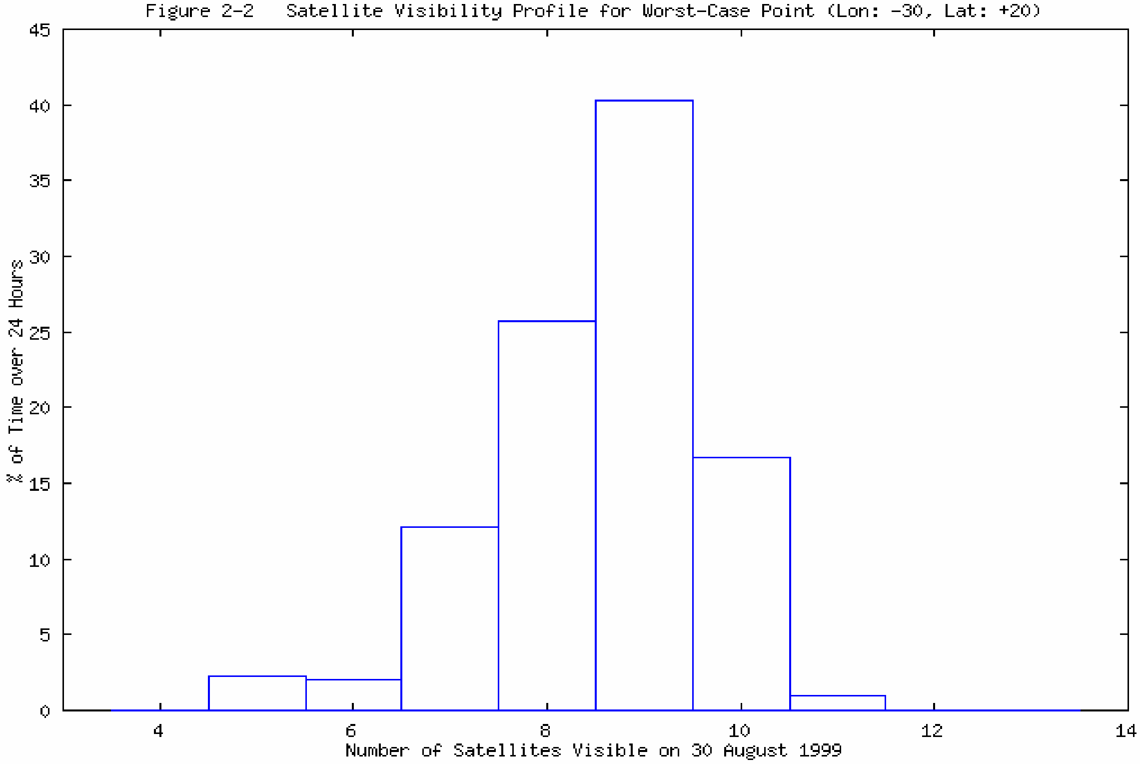
The GPS coverage performance evaluated met the specifications stated in the SPS 1999.

Figure 2-1 SPS Coverage (24-Hour Period: 30 August 1999)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -30, Lat: +20)



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 from 1 April through 30 June 1999, there were a total of 26 reported outages. Twenty of these outages were maintenance activities and were reported in advance. Six 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.

*__Note__: For NANU 77, Satellite PRN 15 does not get set healthy until 15 July. So the outage was calculated from 2 June until the end of the reporting period, 30 June 1999.

Table 3-1 NANUs Affecting Satellite Availability

NANU#	SVN/PRN	Type	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
36	36/6	S	1-Apr	21:00	2-Apr	3:47		6.78	6.78
39	43/13	S	6-Apr	7:27	6-Apr	11:02		3.58	3.58
40	14/14	S	9-Apr	4:45	9-Apr	10:59		6.23	6.23
41	19/19	S	9-Apr	11:12	9-Apr	15:24		4.20	4.20
42	19/19	S	16-Apr	5:15	16-Apr	11:03		5.80	5.80
48	27/27	S	23-Apr	7:30	23-Apr	19:40		12.17	12.17
49	27/27	S	25-Apr	7:22	25-Apr	20:58		13.60	13.60
55	27/27	S	27-Apr	8:24	27-Apr	18:59		10.58	10.58
57	27/27	S	1-May	9:02	1-May	20:04		11.03	11.03
58	33/3	S	3-May	21:19	4-May	1:23		4.07	4.07
59	15/15	S	5-May	3:24	5-May	8:00		4.60	4.60
61	17/17	S	10-May	17:04	10-May	18:22		1.30	1.30
67	23/23	S	17-May	16:50	17-May	21:56		5.10	5.10
73	27/27	S	27-May	5:23	27-May	10:56		5.55	5.55
76	43/13	S	1-Jun	5:11	1-Jun	11:02		5.85	5.85
78	34/4	S	3-Jun	7:42	3-Jun	15:43		8.02	8.02
95	18/18	S	15-Jun	3:31	15-Jun	9:21		5.83	5.83
98	16/16	S	17-Jun	3:15	17-Jun	11:38		8.38	8.38
107	39/9	S	29-Jun	8:39	29-Jun	12:54		4.25	4.25
108	39/9	S	1-Jul	11:04	1-Jul	16:11		5.12	5.12
44	37/7	UFN	20-Apr	4:37	N/A	N/A	N/A		N/A
50	37/7	U	20-Apr	4:37	26-Apr	15:33	154.93		154.93
77*	15/15	U	2-Jun	1:10	15 July		694.83		694.83
88	25/25	U	11-Jun	13:17	11-Jun	13:39	0.37		0.37
89	29/29	U	11-Jun	14:59	11-Jun	15:20	0.35		0.35

NANU#	SVN/PRN	Type	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
87	32/1	U	11-Jun	13:33	11-Jun	13:54	0.35		0.35
96	24/24	U	15-Jun	13:32	15-Jun	14:44	1.20		1.20
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**852.03**	**132.04**	**984.07**

Type: S = Schedule U = Unschedule UFN – Until Further Notice

Table 3-2 NANUs Forecasted To Affect Satellite Availability

NANU#	SVN/PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
28	36/6	F	1-Apr	20:00	2-Apr	4:00	8.00	See Nanu 36
34	19/19	F	3-Apr	11:30	3-Apr	23:30	12.00	See Nanu 37
29	19/19	F	5-Apr	6:00	5-Apr	18:00		See Nanu 35, 42
35	19/19	F/Rescheduled	16-Apr	5:00	16-Apr	17:00	12.00	See Nanu 29
30	43/13	F	6-Apr	7:00	6-Apr	14:00	7.00	See Nanu 39
31	14/14	F	9-Apr	4:00	9-Apr	12:00	8.00	See Nanu 40
38	19/19	F	9-Apr	11:00	9-Apr	22:00	11.00	See Nanu 41
43	27/27	F	23-Apr	8:00	23-Apr	22:00	14.00	See Nanu 48
45	27/27	F	25-Apr	7:00	25-Apr	21:00	14.00	See Nanu 49
46	27/27	F	27-Apr	7:00	27-Apr	21:00	14.00	See Nanu 55
47	27/27	F	28-Apr	7:00	28-Apr	21:00	14.00	See Nanu 51, 56
51	27/27	F	29-Apr	7:00	29-Apr	22:00	15.00	See Nanu 47
52	27/27	F	1-May	6:00	1-May	22:00	16.00	See Nanu 57
53	33/3	F	3-May	21:00	4-May	9:00	12.00	See Nanu 58
54	15/15	F	5-May	3:00	5-May	15:00	12.00	See Nanu 59
60	17/17	F	10-May	16:30	11-May	4:30	12.00	See Nanu 61
62	23/23	F	17-May	16:30	18-May	4:30	12.00	See Nanu 67, 73
63	43/13	F	18-May	10:30	18-May	20:30	10.00	See Nanu 66
64	27/27	F	19-May	12:30	19-May	21:30		See Nanu 65, 68
65	27/27	F/Rescheduled	19-May	10:30	19-May	21:30	11.00	See Nanu 64
69	34/4	F	25-May	6:00	25-May	18:00		See Nanu 71, 78
71	34/4	F/Rescheduled	3-Jun	5:45	3-Jun	17:45	12.00	See Nanu 069
70	27/27	F	27-May	4:30	27-May	11:00	6.50	See Nanu 72
72	27/27	F/Entended	27-May	4:30	N/A	N/A		See Nanu 70
74	43/13	F	1-Jun	4:00	1-Jun	13:00	9.00	See Nanu 76
79	16/16	F	11-Jun	21:30	12-Jun	9:30	12.00	See Nanu 83
80	36/6	F	14-Jun	12:30	15-Jun	00:30	12.00	See Nanu 81
84	16/16	F	15-Jun	21:30	16-Jun	9:30		See Nanu 94, 98
94	16/16	F/Rescheduled	17-Jun	3:15	17-Jun	15:15	12.00	See Nanu 084
85	18/18	F	15-Jun	2:45	15-Jun	12:00	9.25	See Nanu 95
103	39/9	F	29-Jun	8:00	29-Jun	20:00	12.00	See Nanu 107
104	39/9	F	30-Jun	4:45	30-Jun	16:45		See Nanu 105, 106, 108

105	39/9	F/Rescheduled	30-Jun	10:45	30-Jun	22:45		See Nanu 104
106	39/9	F/Rescheduled	1-Jul	10:45	1-Jul	22:45	12.00	See Nanu 105
						Total Forecasted Downtime	**310.75**	

Type: F = Forecasted

Table 3-3 *NANUs Canceled*

NANU#	SVN/PRN	Type	Start Date	Start Time	Comments
37	19/19	C	3-Apr	11:30	See Nanu 034
56	27/27	C	29-Apr	7:00	See Nanu 051
66	43/13	C	18-May	10:30	See Nanu 063
68	27/27	C	19-May	10:30	See Nanu 065
83	16/16	C	11-Jun	21:30	See Nanu 079
81	36/6	C	14-Jun	12:30	See Nanu 080

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 April – 30 June 1999	12 December 1998– 30 June 1999
Total Forecast Downtime (hrs):	310.75	594.75
Total Actual Downtime (hrs):	984.07	1103.59
Total Actual Scheduled Downtime (hrs):	132.04	250.10
Total Actual Unscheduled Downtime (hrs):	852.03	853.49
Total Satellite Observed MTTR (hrs):	37.85	23.99
Scheduled Satellite Observed MTTR (hrs):	6.60	6.58
UnScheduled Satellite Observed MTTR (hrs):	142.01	106.68
# Total Satellite Outages:	26	46
# Scheduled Satellite Outages:	20	38
# Unscheduled Satellite Outages:	6	8
Percent Operational -- Scheduled Downtime:	99.78%	99.81%
Percent Operational -- All Downtime:	98.33%	99.15%

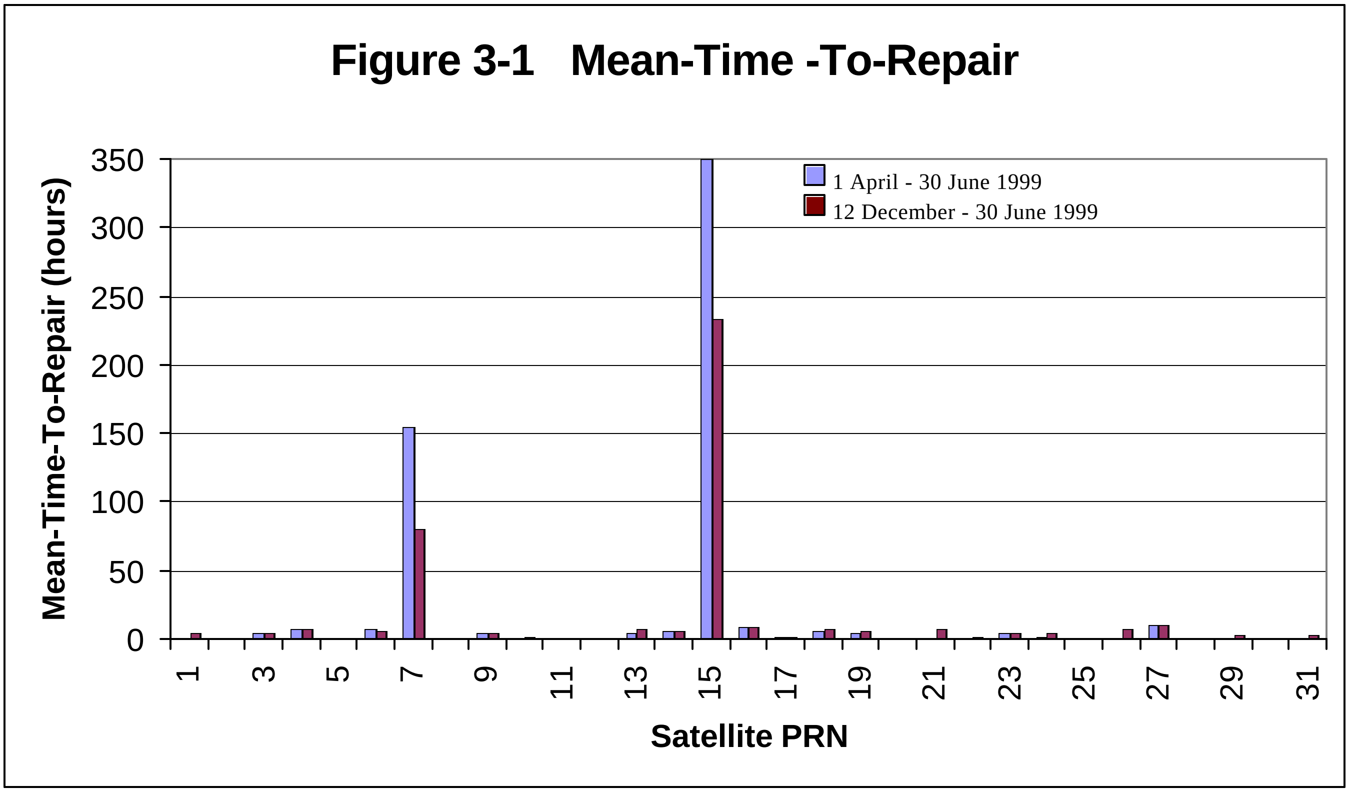


Figure 3-1 Mean-Time -To-Repair
Mean-Time-To-Repair (hours)
350
300
250
200
150
100
50
0
1 April - 30 June 1999
12 December - 30 June 1999
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Satellite PRN

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 sites was reduced to calculate DOP information and reported in Tables 3-5 to 3-7. The data was collected at one-second intervals between 1 April – 30 June 1999.

The sample size of the data for each of the nine receivers vary. The following list provides some reasons for the varying sample sizes:

- The Millenium receiver at Dayton began to malfunction on 19 April 1999 and was fixed on 21 June 1999. No PAN data was recorded from the Dayton Millenium between 20 April and 30 June 1999.
- The Ashtech in Atlantic City was added onto the list of PAN NSTB sites 27 May 1999.
- The WAAS receiver in Honolulu and the Millenium receiver in Winnipeg began to malfunction on 21 June 1999. No PAN data was recorded for these two sites between 21 and 30 June 1999.
- Millenium receivers need to be reset every so often. Some data may be lost until the receiver is reset. If a reset is needed during the weekend, a few days data may be lost.
- The T1 line may go down. This usually does not occur often but it did happen this quarter for about two hours.
- If it is determined that bad performance data is not attributed to GPS SPS (e.g. the receiver has problems tracking), this data is removed from the cumulated PAN data.

Table 3-5 PDOP Statistics

NSTB Site	Min PDOP	Max PDOP	HDOP at Max PDOP	VDOP at Max PDOP	Mean PDOP	95% PDOP	Number of Samples
Atlantic City	1.24	12.70	6.48	10.92	1.59	2.23	2844577
Bangor	1.21	19.67	11.60	15.89	1.41	2.36	7539521
Dayton	1.30	5.83	2.18	5.41	1.65	2.04	1794914
Elko	1.28	19.57	8.36	17.69	1.36	1.92	7310215
Gander	1.25	5.95	2.70	5.30	1.28	1.84	6681297
Honolulu	1.17	16.28	5.04	15.49	1.24	1.62	6331383
Seattle	1.23	6.63	4.27	5.07	1.38	2.30	7462171
Sitka	1.24	7.24	2.21	6.89	1.31	2.48	5829312
Winnipeg	1.24	11.23	4.61	10.24	1.40	2.22	6707627

Tables 3-6 and 3-7 show the statistics related to maximum PDOP and PDOP greater than six, respectively. 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.

Even though the data collected for this quarter showed more PDOP going above six due to more maintenance on the GPS satellites, **all of the performance met the requirements in the GPS SPS specification**.

Whenever the PDOP goes above six, regardless of whether or not the SPS performance was 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 cause of these high PDOP's were all due to satellite outages. 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
Atlantic City	1013/5 (11 June 1999)	12.69	181	NANU 77, 15 NANU 86, 7	86033	99.7896%
Bangor	1007/0 (25 April 1999)	6.76	9	NANU 50, 7 SOD, 2	85530	99.9895%
Bangor	1013/5	19.67	198	NANU 77, 15 NANU 86, 7	86019	99.7698%
Elko	1005/5 (16 April 1999)	19.56	8	NANU 42, 19	85646	99.9907%
Elko	1016/2 (29 June 1999)	6.13	579	NANU 107, 9	79106	99.2681%
Site	**GPS Week/ Day**	**Max PDOP**	**Number of Seconds of Whole Day**	**NANU/SOD, Satellite PRN**	**Number of Samples**	**Availability on days when**

			PDOP > 6	Number		PDOP > 6
Honolulu	1005/5 (16 April 1999)	13.45	26	*, 27	64869	99.9599%
Honolulu	1006/4 (22 April 1999)	7.42	151	NANU 50, 7	86107	99.8246%
Honolulu	1006/5 (23 April 1999)	6.56	159	NANU 50, 7	86246	99.8156%
Honolulu	1006/6 (24 April 1999)	6.59	169	NANU 50, 7	86261	99.8041%
Honolulu	1007/0 (25 April 1999)	7.56	181	NANU 50, 7	86174	99.7899%
Honolulu	1007/1 (26 April 1999)	7.64	191	NANU 50, 7	84844	99.7749%
Honolulu	1014/2 (15 June 1999)	16.29	310	NANU 95, 18	86004	99.6396%
Seattle	1016/2 (29 June 1999)	6.63	314	NANU 107, 9	79384	99.6044%
Sitka	1011/5 (28 May 1999)	7.24	24	SOD, 17	85621	99.9720%
Winnipeg	1005/5 (16 April 1999)	11.23	12	NANU 42, 19	85646	99.9860%
Winnipeg	1012/1 (31 May 1999)	7.60	19	SOD, 18	85592	99.9778%
Winnipeg	1014/0 (13 June 1999)	8.16	12	SOD, 17	86154	99.9861%
Winnipeg	1014/2 (15 June 1999)	8.04	635	NANU 95, 18	86276	99.2640%
Worst-Case Point on Worst-Case Day = 99.2640 % (SPS Spec. ≥ 83.92%)						

*Both the Trimble and WAAS receivers lost track of Satellite PRN 27 at the same time. This outage was not recorded by the Satellite Outage Detection program because less than six NSTB receivers were tracking Satellite 27 prior to the outage.

Global Average on Worst-Case Day (Week_1014Day_2, 15 June 1999) = 99.86%
(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
Atlantic City	2844577	181	99.9936%
Bangor	7539521	207	99.9973%
Dayton	1794914	0	100%
Elko	7310215	587	99.9919%
Gander	6681297	0	100%
Honolulu	6331383	1187	99.9813%
Seattle	7462171	314	99.9958%
Sitka	5829312	24	99.9996%
Winnipeg	6707627	678	99.9899%
Worst Single Point Average = 99.9813% (SPS Spec. ≥ 99.16%)			

Global Average over Reporting Period = 99.99% (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 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 Site	Number of Samples	Maximum Horizontal Error (meters)
Atlantic City	2844577	272
Bangor	7539521	444
Dayton	1794914	127
Elko	7310215	187
Gander	6681297	213
Honolulu	6331383	158
Seattle	7462171	246
Sitka	5829312	215
Winnipeg	6707627	192

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

5.0 Accuracy Characteristics

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

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

5.1 Position Accuracies

The data used for this section was collected for every second between 1 April through 30 June 1999 at the nine NSTB selected locations.

Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies which were all within the specified limits.

Table 5-1 Horizontal & Vertical Accuracy Statistics

NSTB Site	95% Horizontal (meters)	95% Vertical (meters)	99.99% Horizontal (meters)	99.99% Vertical (meters)
Atlantic City	49.4	81.5	108.0	195.0
Bangor	45.9	74.3	110.0	184.0
Dayton	41.3	68.8	87.4	148.0
Elko	44.4	71.2	96.8	170.0
Gander	45.1	73.4	102.0	168.0
Honolulu	40.4	77.1	93.7	211.0
Seattle	45.0	72.3	116.0	156.0
Sitka	42.9	71.8	114.0	165.0
Winnipeg	44.5	75.2	114.0	207.0
All 9 Sites	44.3	73.96	104.66	178.22

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all nine NSTB sites from 1 April through 30 June 1999.

Figure 5-1 Combined Vertical Error Histogram

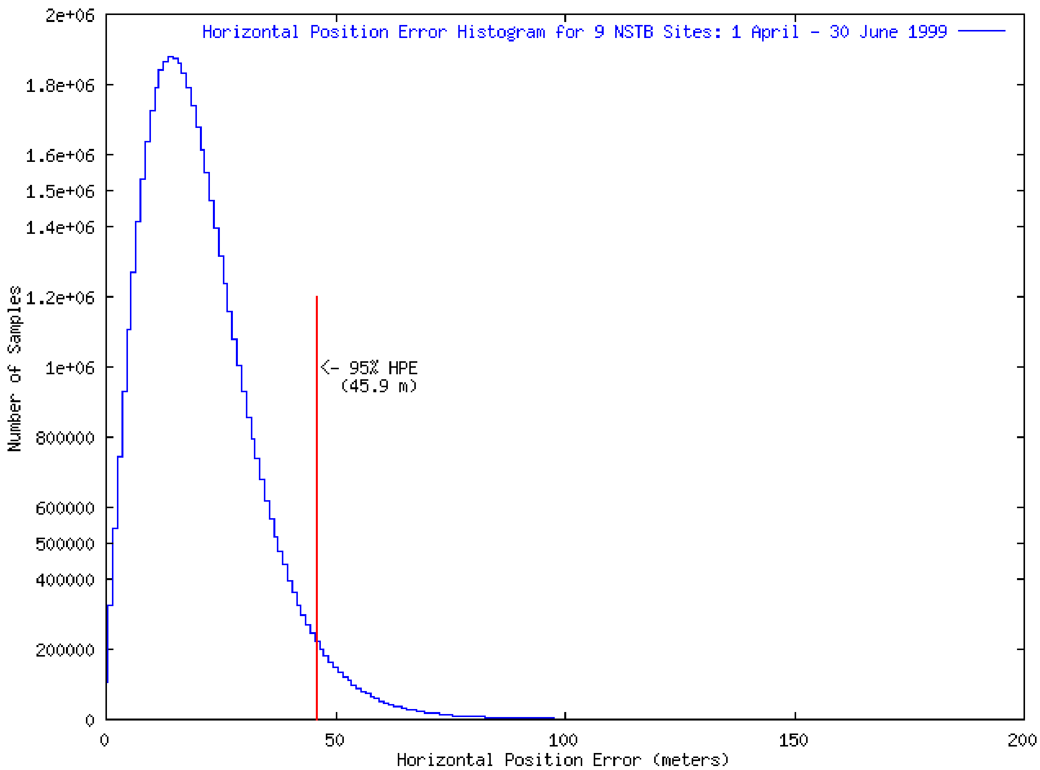
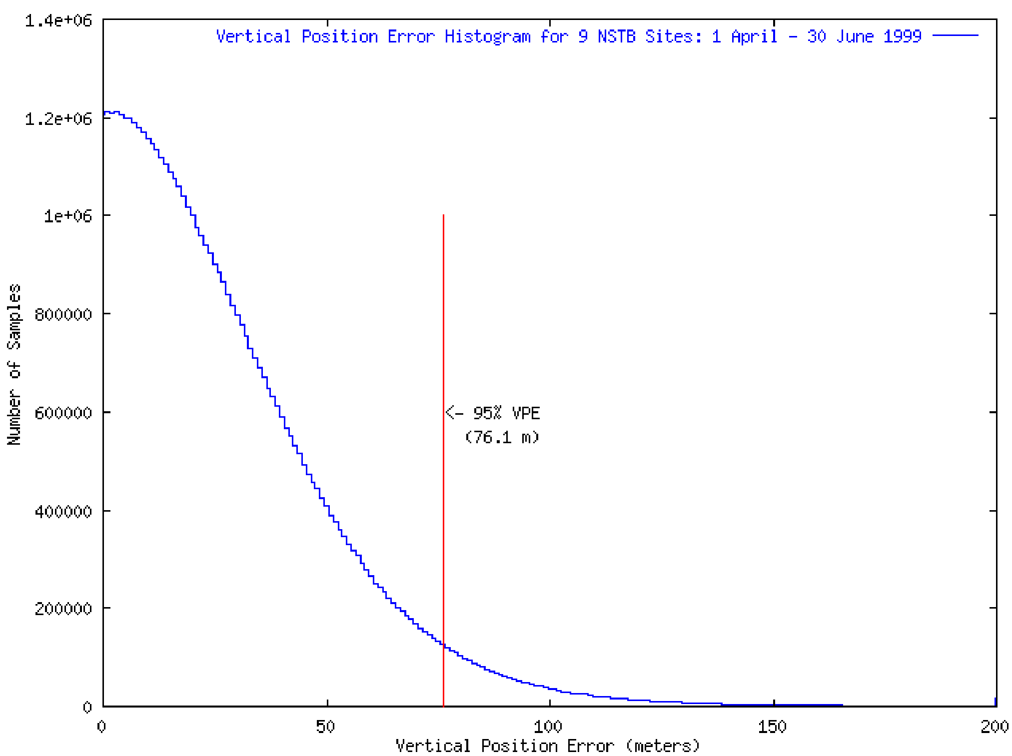


Figure 5-2 Combined Horizontal Error Histogram



5.2 Repeatable Accuracy

Table 5-2 provides the repeatability statistics which met all of the evaluated requirements stated in the SPS.

Table 5-2 Repeatability Statistics

NSTB Site	95% Horizontal (m)	95% Vertical (m)
Atlantic City	41.7	117.0
Bangor	35.8	107.0
Dayton	33.8	96.4
Elko	34.4	99.6
Gander	35.7	103.0
Honolulu	30.7	107.0
Seattle	35.2	99.0
Sitka	34.4	99.9
Winnipeg	35.6	110.0
Average	35.3	104.3

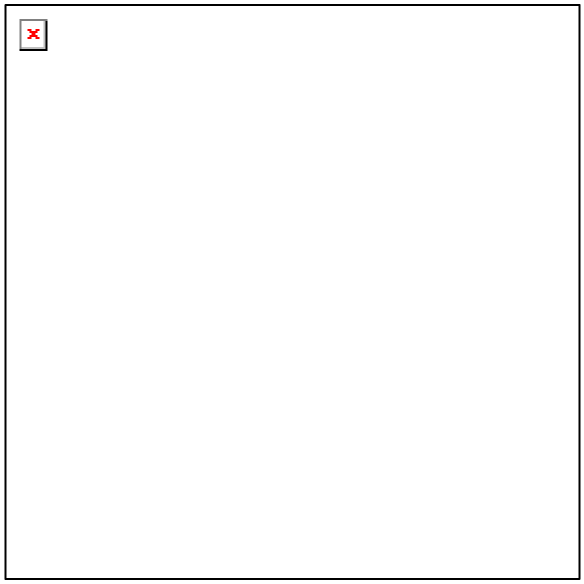
5.3 Relative Accuracy

To be included in next report.

5.4 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 1999 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 5-15) 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 5-15. 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 April and 30 June1999. The data was collected from the Dayton and Elko NSTB site. Since the Millenium receiver in Dayton malfunctioned on 19 April 1999, the Millenium at Elko was used to collect range measurements from 19 April through 30 June 1999. Future PAN reports will contain statistics from all NSTB sites.

A weighted average filter was used for the calculation of the range rate error range acceleration error. **All Range Domain SPS specifications were met.**

Table 5-3 Range Error Statistics (meters)

PRN	Mean	RMS	1 s	95% (SPS Spec. ≤ 150 m)	Max	Samples
1	1.61	17.57	15.34	61.08	111.85	2118162
2	2.77	17.59	15.45	48.91	124.11	2054015
3	0.97	17.11	15.52	48.72	132.57	2277915
4	1.18	17.16	15.38	51.08	144.51	1987462
5	1.66	16.68	14.65	53.12	149.09	1933593
6	1.86	16.97	15.16	43.44	134.75	1960449
7	1.93	17.09	14.87	56.16	144.45	1985364
8	1.53	17.15	15.66	56.52	130.23	2264399
9	1.19	17.19	15.44	61.05	124.57	2263260
10	2.18	17.55	15.68	56.08	136.88	2102368
13	0.43	16.71	15.03	53.42	135.25	2162476
14	1.27	16.93	14.94	54.78	135.93	1950306
15	2.18	9.90	6.16	54.78	107.41	2124248
16	1.36	17.22	15.67	50.56	127.37	2183448
17	2.05	17.01	15.38	47.45	123.17	1983264
18	0.98	17.21	15.33	53.75	149.03	1930496
19	0.68	17.64	15.67	41.25	125.84	1975343
21	1.94	17.24	15.36	51.57	124.36	2056435
22	1.80	17.33	15.75	48.60	121.21	2081158

23	2.48	16.80	15.07	51.76	131.31	2069517
24	2.07	16.59	14.67	53.90	136.33	1932101
25	0.80	17.07	14.72	53.56	128.53	1801396
26	1.67	17.41	15.52	45.91	119.10	2147384
27	1.57	18.01	15.98	54.41	121.01	1829784
29	1.10	16.82	14.73	52.07	110.77	2033161
30	0.58	17.26	15.57	56.22	135.45	2067612
31	0.52	18.13	15.99	51.69	126.46	2105590

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

PRN	Mean	RMS	1 s	95% (SPS Spec. ≤ 2 m/s)	Max	Samples
1	0.00000	0.13327	0.13327	0.26301	0.94429	2118162
2	0.00001	0.13207	0.13207	0.25757	0.90075	2054015
3	0.00004	0.13215	0.13215	0.25801	1.13366	2277915
4	0.00030	0.13138	0.13138	0.25691	1.37340	1987462
5	0.00014	0.12666	0.12667	0.24761	0.89036	1933593
6	0.00012	0.12903	0.12902	0.25349	0.93316	1960449
7	0.00047	0.12813	0.12811	0.25057	0.90314	1985364
8	0.00038	0.13209	0.13209	0.25914	1.19510	2264399
9	0.00011	0.13104	0.13104	0.25628	1.02300	2263260
10	0.00038	0.13230	0.13229	0.25961	1.47625	2102368
13	0.00049	0.12512	0.12512	0.24646	1.80549	2162476
14	0.00003	0.12859	0.12858	0.25106	0.89977	1950306
15	0.00028	0.03860	0.03858	0.07358	1.15262	2124248
16	0.00008	0.13061	0.13061	0.25735	0.88304	2183448
17	0.00022	0.13062	0.13062	0.25593	0.86573	1983264
18	0.00005	0.12858	0.12858	0.25321	1.31627	1930496
19	0.00011	0.13283	0.13283	0.25850	0.86050	1975343
21	0.00020	0.13187	0.13186	0.25747	0.88925	2056435
22	0.00035	0.13551	0.13550	0.36439	1.58780	2081158
23	0.00002	0.12966	0.12966	0.25285	0.90045	2069517
24	0.00009	0.12723	0.12723	0.24937	1.38732	1932101
25	0.00005	0.12970	0.12969	0.25424	1.08180	1801396
26	0.00015	0.13115	0.13114	0.25685	1.02691	2147384
27	0.00035	0.13403	0.13402	0.26301	0.79549	1829784
29	0.00018	0.12820	0.128419	0.25095	1.01755	2033161
30	0.00024	0.13105	0.13104	0.25717	0.88874	2067612
31	0.00020	0.13570	0.13569	0.26621	1.35226	2105590

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

PRN	Mean	RMS	1 s	% < .008 (SPS Spec. 95% of Time)	Max (SPS Spec. ≤ 19 mm/s^2)	Samples
1	0.00000	0.00104	0.00104	1.00000	0.00736	2118162
2	0.00001	0.00103	0.00103	1.00000	0.00765	2054015
3	0.00000	0.00103	0.00103	0.99999	0.01098	2277915

4	0.00001	0.00103	0.00103	1.00000	0.01081	1987462
5	0.00000	0.00100	0.00100	1.00000	0.00735	1933593
6	0.00001	0.00100	0.00100	1.00000	0.00740	1960449
7	0.00001	0.000097	0.00097	1.00000	0.00755	1985364
8	0.00000	0.00102	0.00102	1.00000	0.01101	2264399
9	0.00001	0.00101	0.00101	1.00000	0.00876	2263260
10	0.00001	0.00103	0.00103	1.00000	0.01300	2102368
13	0.00000	0.00097	0.00097	0.99999	0.01455	2162476
14	0.00000	0.00101	0.00101	1.00000	0.00694	1950306
15	0.00000	0.00033	0.00033	1.00000	0.01149	2124248
16	0.00000	0.00103	0.00103	1.00000	0.00747	2183448
17	0.00000	0.00101	0.00101	1.00000	0.00766	1983264
18	0.00000	0.00101	0.00101	0.99999	0.01160	1930496
19	0.00000	0.00101	0.00101	1.00000	0.00739	1975343
21	0.00000	0.00104	0.00104	1.00000	0.00714	2056435
22	0.00001	0.00103	0.00103	1.00000	0.01654	2081158
23	0.00000	0.00102	0.00102	1.00000	0.00718	2069517
24	0.00001	0.00098	0.00098	1.00000	0.01241	1932101
25	0.00000	0.00102	0.00102	0.99999	0.01241	1801396
26	0.00000	0.00100	0.00100	1.00000	0.00761	2147384
27	0.00000	0.00104	0.00104	1.00000	0.00699	1829784
29	0.00000	0.00098	0.00098	1.00000	0.00802	2033161
30	0.00000	0.00102	0.00102	1.00000	0.00778	2067612
31	0.00000	0.00105	0.00105	1.00000	0.01215	2105590

Figures 5-16, 5-17 and 5-18 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 14 with an error of 148.32 meters. Satellite 15 had the lowest maximum range error of 69.28 meters.

Figure 5-4 Distribution of Daily Max Range Errors: 1 April – 30 June 1999

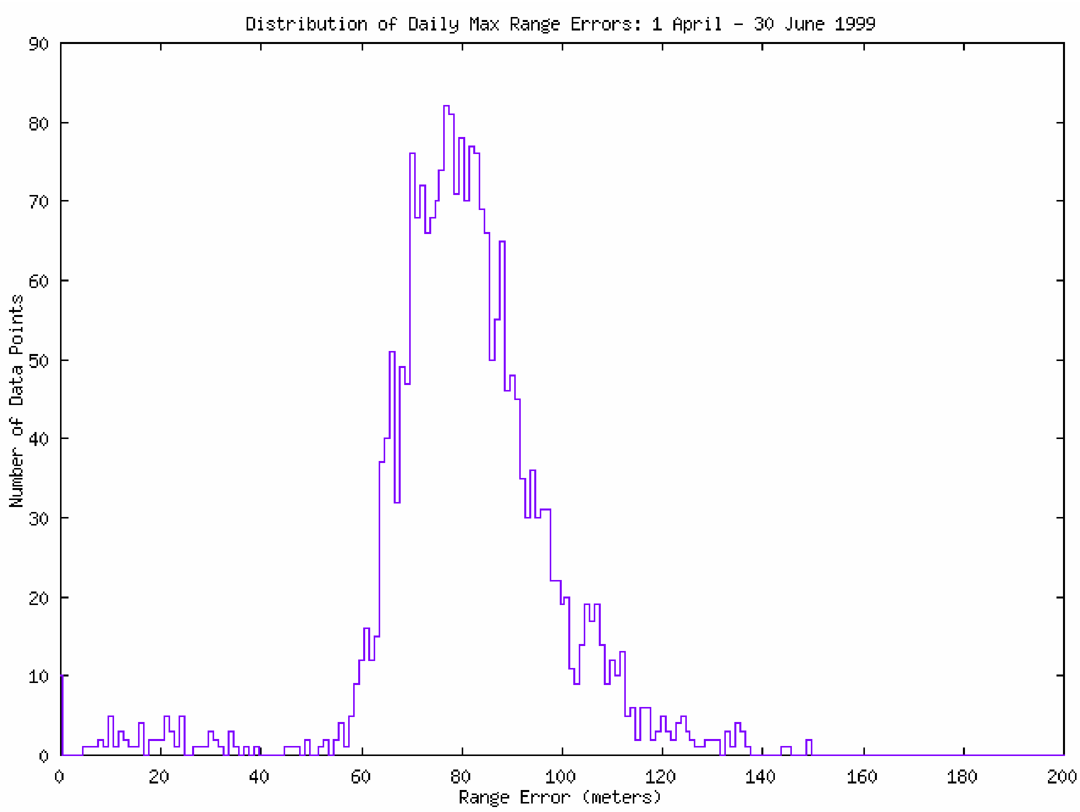

Distribution of Daily Max Range Errors: 1 April - 30 June 1999
Number of Data Points
Range Error (meters)
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100
120
140
160
180
200

Figure 5-5 Distribution of Daily Max Range Rate Errors: 1 April – 30 June 1999

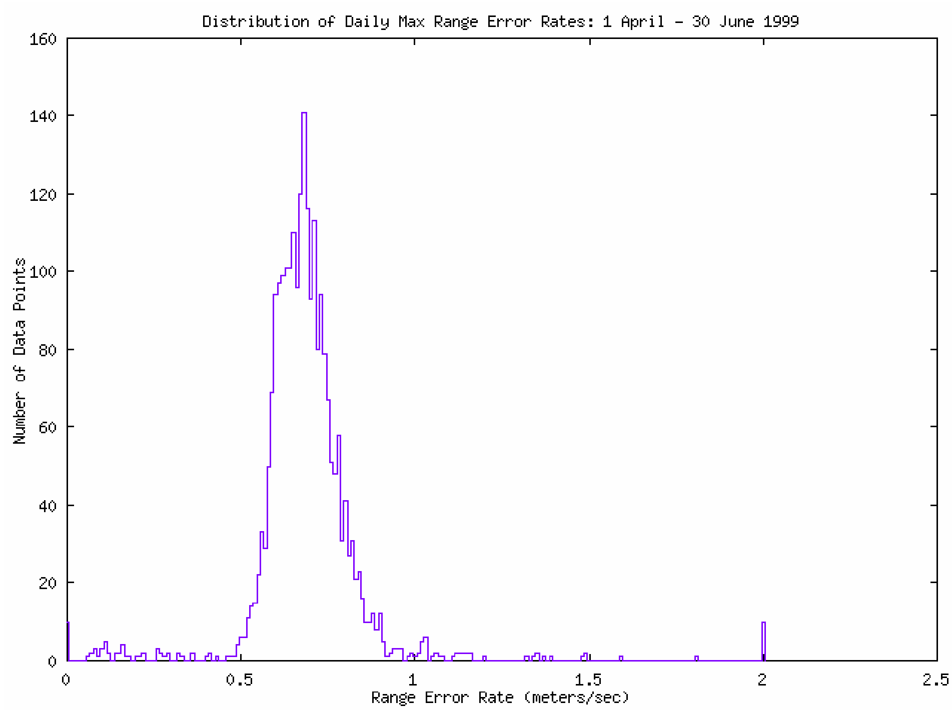


Figure 5-6 Distribution of Daily Max Acceleration Rate Errors: 1 April – 30 June 1999

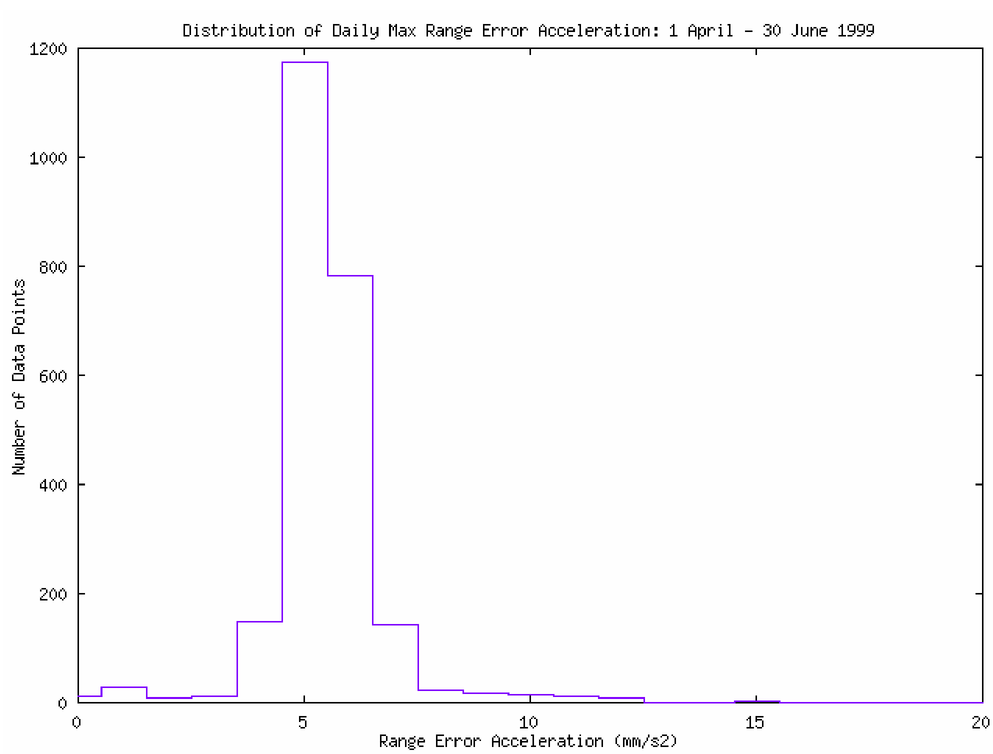


Figure 5-7 Maximum Range Error Per Satellite

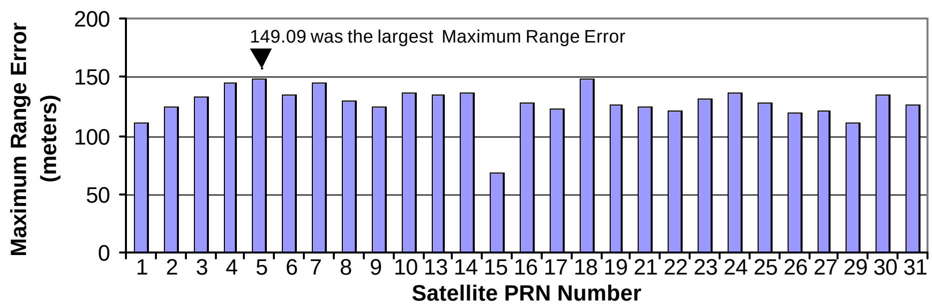


Figure 5-8 Maximum Range Rate Error Per Satellite

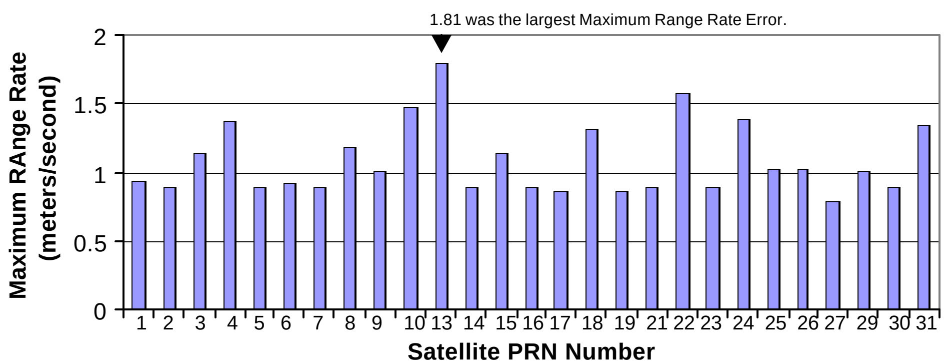
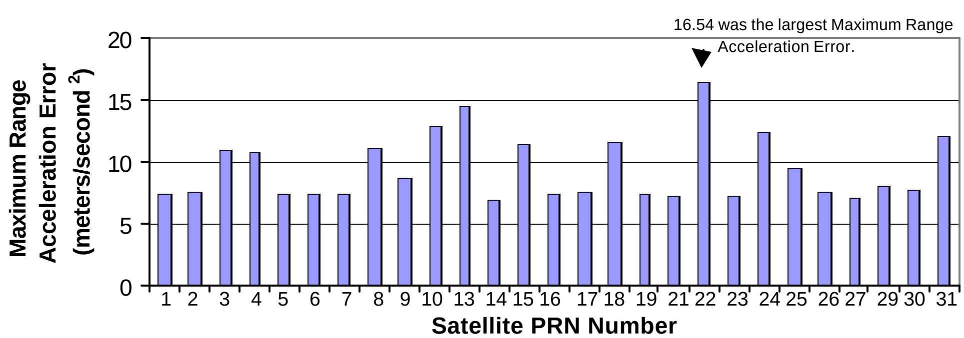


Figure 5-9 Maximum Range Acceleration Error Per Satellite



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. For this reporting period, storm activity was reported in January, February and March.

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 6-4 show the K-index for four different time periods. (See Appendix B for the actual geomagnetic data for this reporting period.)

Figure 6-? K-Index for 1-4 July 1999

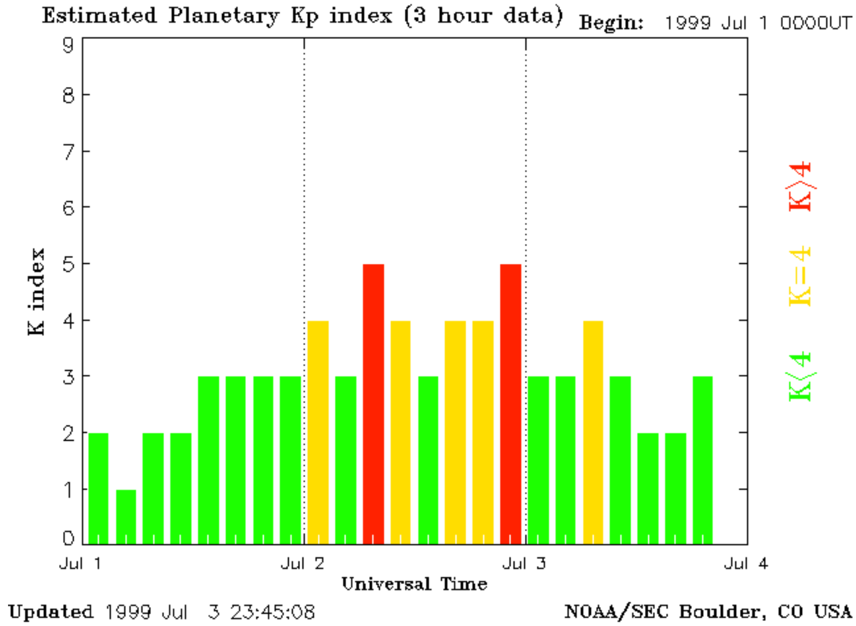


Figure 6-1 K-Index for 21-24 July 1999

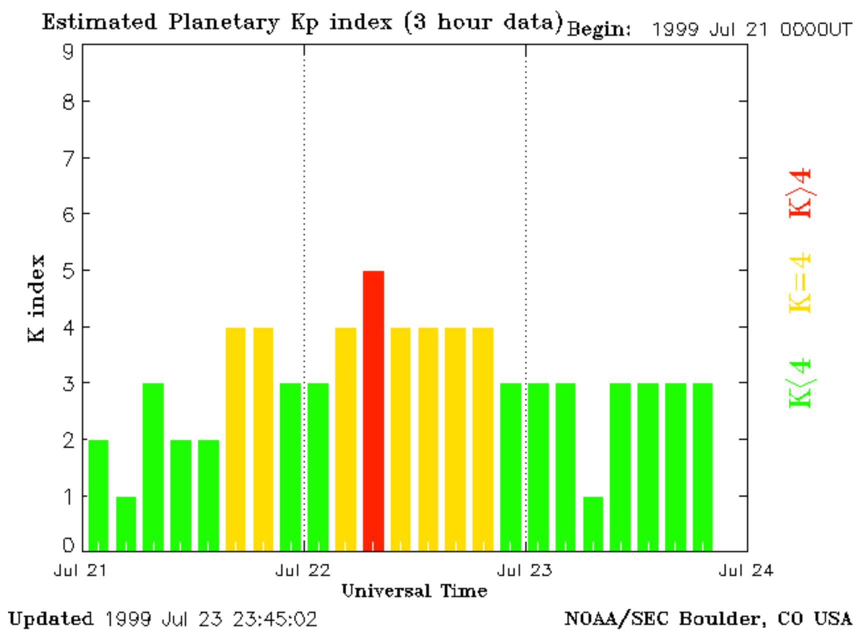


Figure 6-? K-Index for 29 July – 1 August 1999

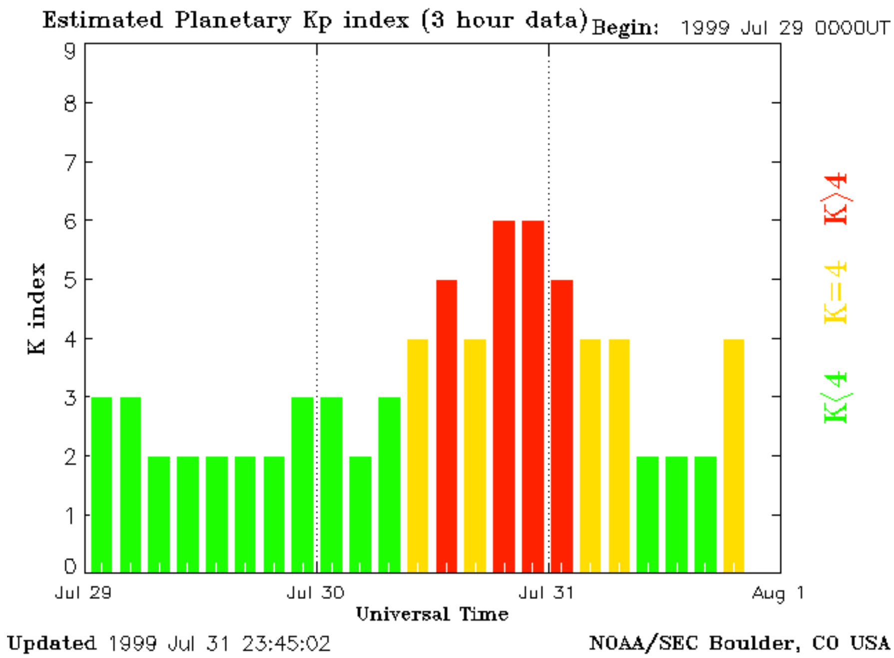


Figure 6-? K-Index for 15-18 August 1999

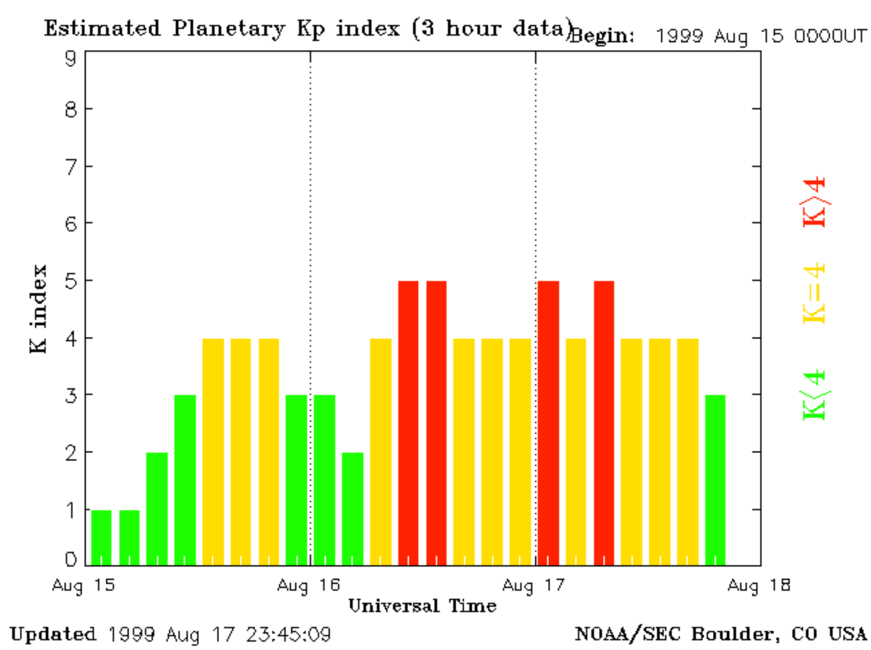


Figure 6-? K-Index for 18-21 August 1999

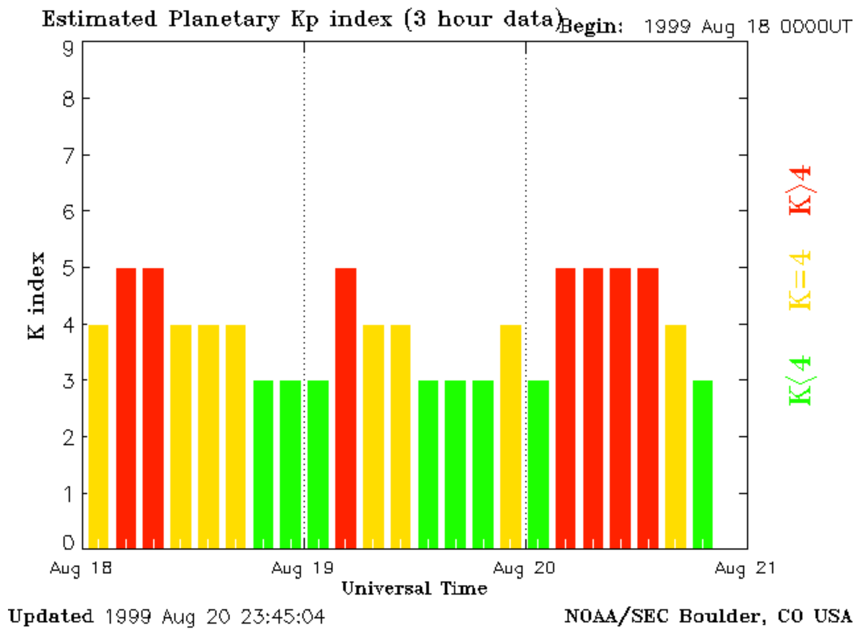


Figure 6-? K-Index for 22-25 August 1999

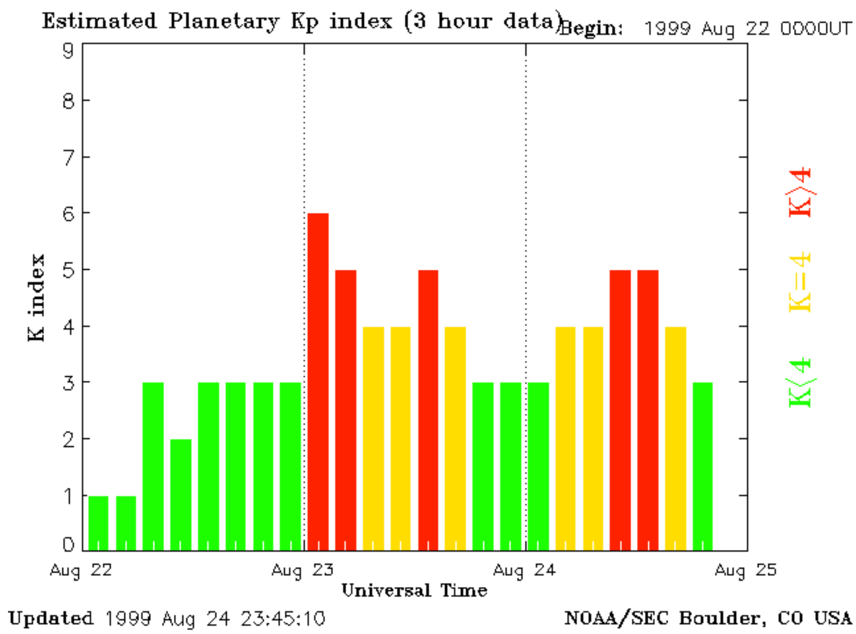


Figure 6-? K-Index for 1-4 July 1999

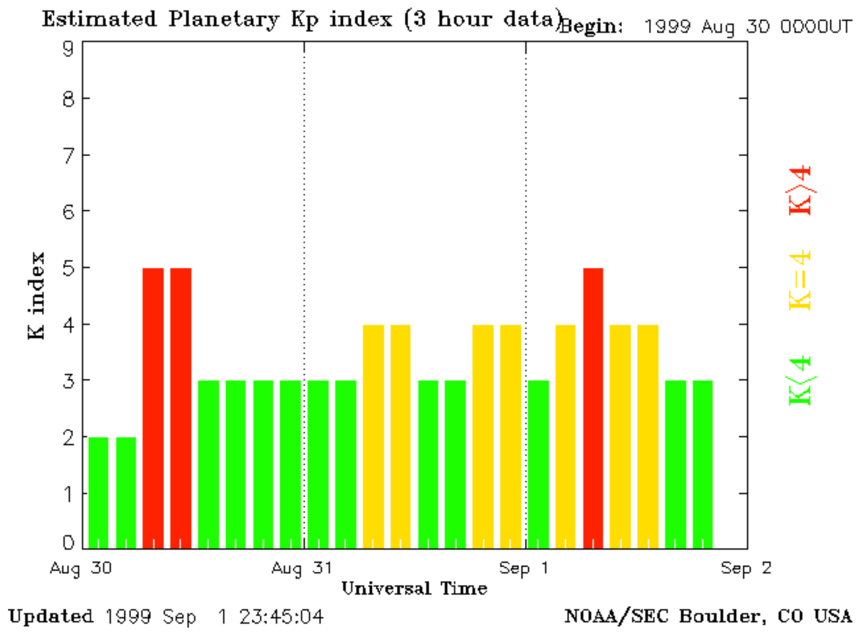


Figure 6-? K-Index for 2-5 September 1999

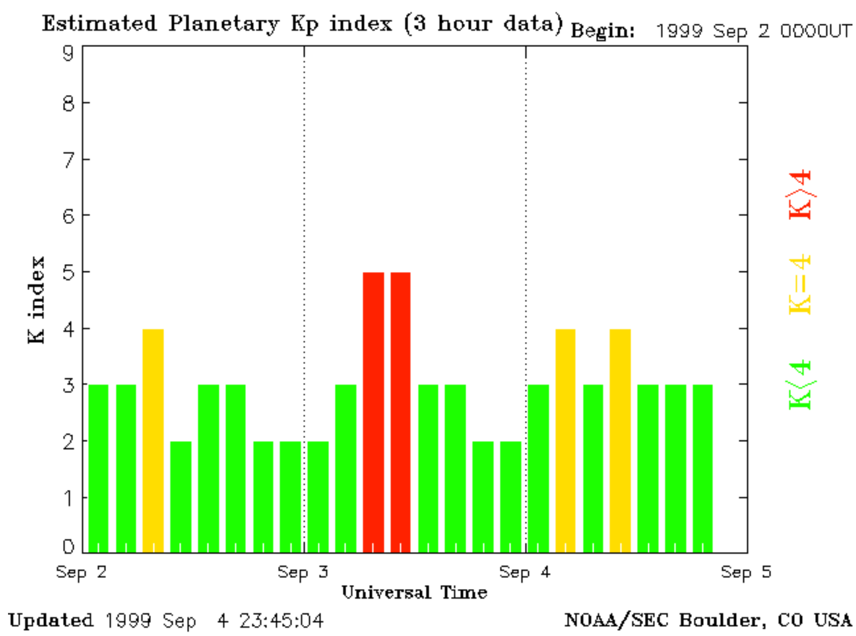


Figure 6-? K-Index for 12-15 September 1999

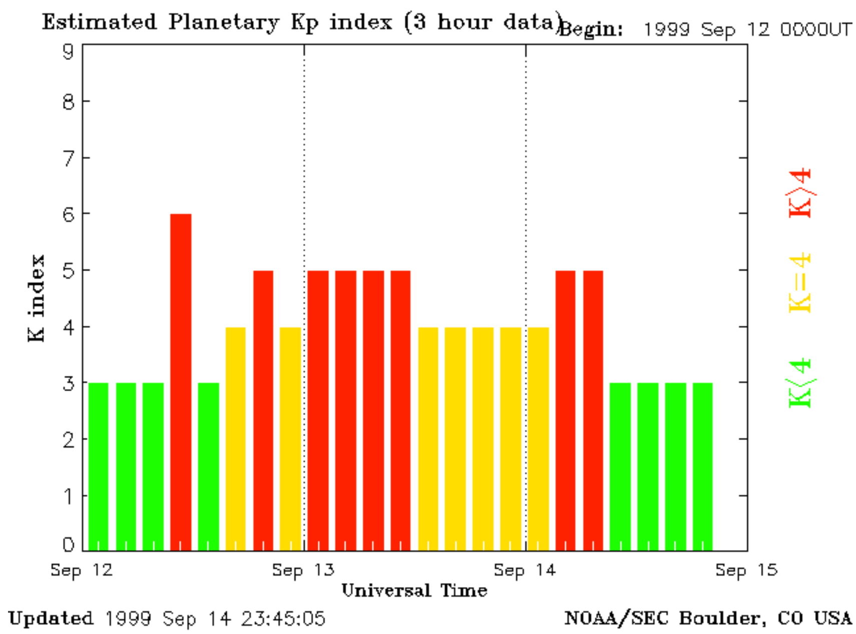


Figure 6-? K-Index for 15-18 September 1999

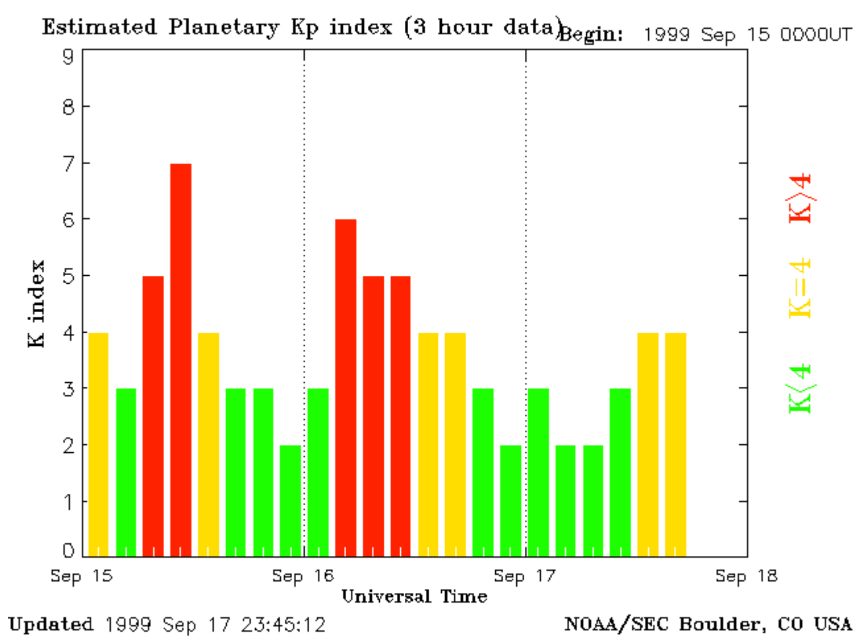


Figure 6-? K-Index for 21-24 September 1999

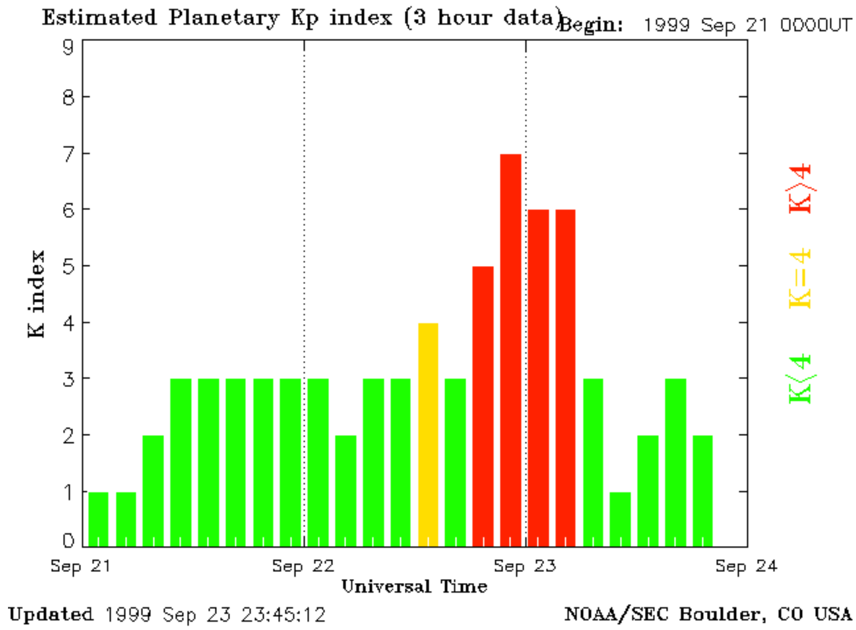


Figure 6-? K-Index for 26-29 September 1999

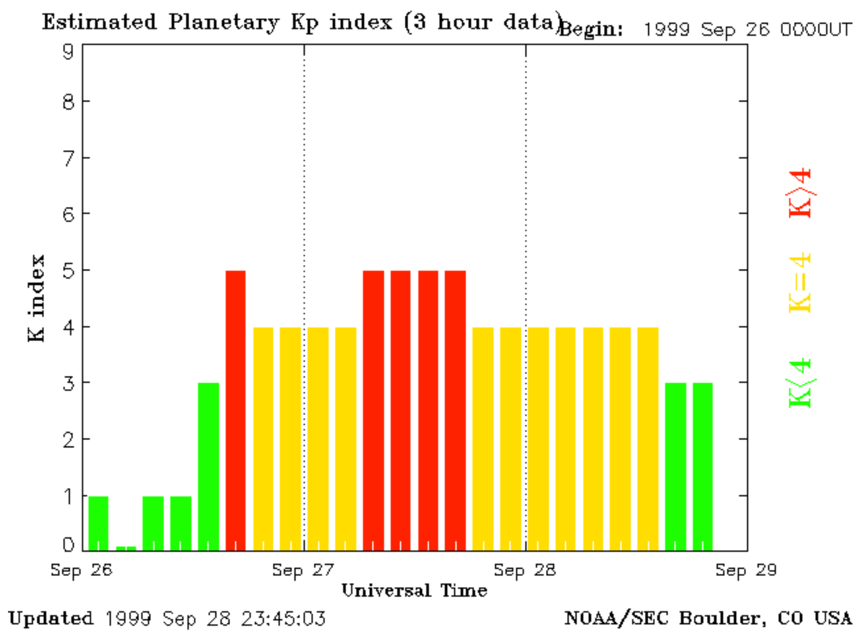
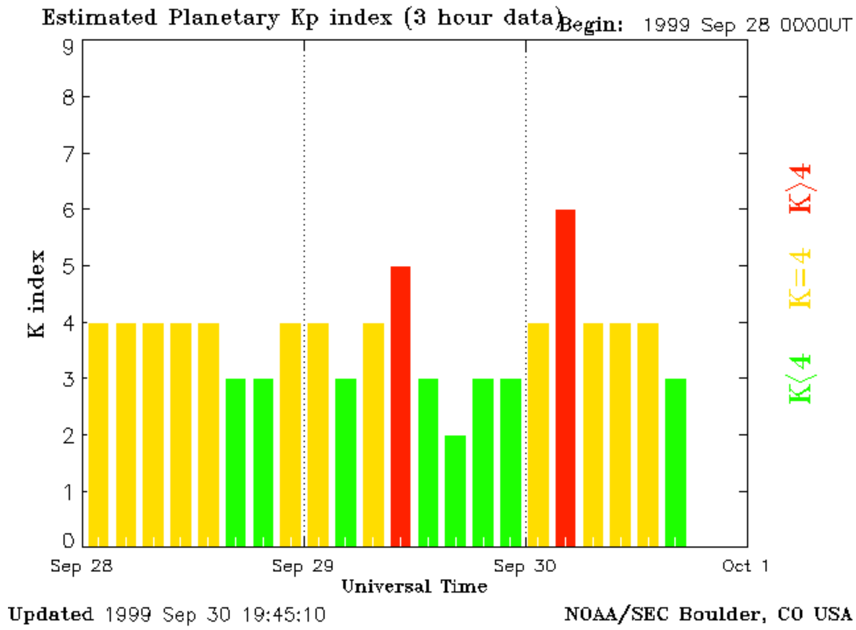


Figure 6-? K-Index for 1-4 July 1999


Estimated Planetary Kp index (3 hour data)
Begin: 1999 Sep 28 0000UT
K index
0
1
2
3
4
5
6
7
8
9
K>4
K=4
K<4
Sep 28
Sep 29
Sep 30
Oct 1
Universal Time
Updated 1999 Sep 30 19:45:10
NOAA/SEC Boulder, CO USA

Tables 6-1 and 6-2 show the PDOP and position accuracy information, respectively, for the days corresponding to Figures 6-1 through 6-4. The PDOPs and position accuracies show no significant differences between the days with storms and the days with no storms with the exception of 16 April at Elko, Honolulu and Winnipeg. Satellite PRN 19 was also set unhealthy (NANU 1999042) during the times of high PDOP. Using a PDOP calculation program (produced by Intermetrics), the PDOP's were calculated for these sites at the times of the high PDOP's. For Winnipeg, the PDOP calculation program gave a PDOP above six without Satellite 19. The Millenium at Winnipeg also had problems tracking Satellite PRN 25, but the co-located GSV receiver did not. The WAAS receiver and the Trimble receiver in Honolulu had problems tracking Satellite PRN 27 at the time of high PDOP. The Millenium at Elko also had problems tracking Satellite PRN 4 at the time of the high PDOP. The data for the Trimble receiver at Elko also showed that the Trimble receiver did not track Satellite 4. The satellite outage in conjunction with the ionospheric activity may have contributed to the increases in PDOP. However, tracking performance varies from receiver to receiver. The data may be a reflection of the different receiver capabilities to track the GPS signals during solar activities rather than GPS performance. The purple-shaded cells are when the PDOP exceed six. (**Even when the PDOP did go above six, the GPS SPS performance still met the availability requirements**.)

Table 6-1 PDOP Statistics*

NSTB Site	Min	Max	Mean	95%
Bangor				
4-16-99	1.21	4.87	1.84	1.88
4-17-99	1.21	4.88	1.83	1.87
4-29-99	1.21	4.87	1.84	1.87
4-30-99	1.21	4.88	1.85	1.88
5-13-99	1.21	4.95	1.83	1.87
5-18-99	1.27	4.97	1.84	1.88
Dayton				
4-16-99	1.33	4.42	1.84	1.87
4-17-99	1.33	4.24	1.83	1.86
4-29-99	1.31	4.12	1.82	1.85
4-30-99	1.31	3.48	1.82	1.85
Elko				
4-16-99	1.27	19.56	1.72	1.82
4-17-99	1.27	4.42	1.75	1.77
4-29-99	1.28	4.55	1.75	1.77
4-30-99	1.28	4.95	1.75	1.77
5-13-99	1.28	4.80	1.75	1.77
5-18-99	1.28	4.45	1.75	1.78
Gander				
4-16-99	1.26	4.01	1.82	1.87
4-17-99	1.25	3.22	1.79	1.82
4-29-99	1.26	3.22	1.77	1.80
4-30-99	1.26	3.23	1.77	1.80
5-13-99	1.26	4.45	1.76	1.79
5-18-99	1.26	4.96	1.76	1.79
Honolulu				
4-16-99	1.20	13.45	1.86	1.92
4-17-99	1.19	4.08	1.79	1.83
4-29-99	1.26	4.09	1.79	1.83
NSTB Site	**Min**	**Max**	**Mean**	**95%**

4-30-99	1.26	4.09	1.79	1.83
5-13-99	1.26	4.14	1.79	1.83
5-18-99	1.26	4.15	1.81	1.85
Seattle				
4-16-99	1.24	5.20	1.82	1.88
4-17-99	1.24	3.59	1.76	1.79
4-29-99	1.23	3.92	1.76	1.79
4-30-99	1.25	2.94	1.76	1.79
5-13-99	1.24	2.93	1.77	1.80
5-18-99	1.24	3.65	1.78	1.80
Sitka				
4-16-99	1.25	4.97	1.83	1.91
4-17-99	1.25	4.18	1.74	1.78
4-29-99	1.25	4.18	1.73	1.76
4-30-99	1.25	4.18	1.73	1.76
5-13-99	1.25	4.16	1.73	1.76
5-18-99	1.24	4.16	1.74	1.77
Winnipeg				
4-16-99	1.31	11.23	1.83	1.88
4-17-99	1.31	5.25	1.83	1.87
4-29-99	1.31	5.23	1.83	1.87
4-30-99	1.31	5.23	1.82	1.86
5-13-99	1.30	5.20	1.83	1.87
5-18-99	1.30	4.54	1.83	1.88

***Note**: Not all receivers were available on the dates of solar activity. So some sites do not have data for all the dates listed.

Table 6-2 Horizontal & Vertical Accuracy Statistics*

NSTB Site	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)
Bangor				
4-16-99	44.3	69.3	90.2	150.0
4-17-99	44.0	74.9	85.4	166.0
4-29-99	41.5	74.5	94.7	172.0
4-30-99	46.9	75.8	87.9	181.0
5-13-99	42.4	69.9	82.4	167.0
5-18-99	42.5	71.8	74.5	163.0
Dayton				
4-16-99	44.2	73.5	76.0	164.0
4-17-99	48.5	78.2	93.0	183.0
4-29-99	42.2	73.1	73.2	144.0
4-30-99	44.8	75.4	91.8	154.0
Elko				
4-16-99	44.4	72.1	111.0	163.0
4-17-99	42.5	70.1	79.2	132.0
4-29-99	44.9	73.5	80.9	191.0
4-30-99	40.7	66.9	80.3	189.0
NSTB Site	**95%**	**95%**	**99.99%**	**99.99%**

	Horizontal (m)	Vertical (m)	Horizontal (m)	Vertical (m)
5-13-99	39.4	70.4	95.4	141.0
5-18-99	40.0	69.8	88.8	172.0
Gander				
4-16-99	44.6	73.0	97.8	213.0
4-17-99	43.8	73.2	78.7	152.0
4-29-99	42.5	70.1	91.7	159.0
4-30-99	45.6	71.4	86.0	191.0
5-13-99	42.5	71.6	79.7	162.0
5-18-99	41.6	73.7	95.3	135.0
Honolulu				
4-16-99	42.8	73.1	96.9	178.0
4-17-99	37.7	75.0	98.7	186.0
4-29-99	42.7	77.7	93.9	215.0
4-30-99	37.1	72.4	71.3	149.0
5-13-99	40.7	76.1	64.3	189.0
5-18-99	40.0	76.2	84.0	232.0
Seattle				
4-16-99	46.6	74.6	110.0	159.0
4-17-99	43.1	69.9	75.2	107.0
4-29-99	42.0	74.8	85.4	127.0
4-30-99	42.0	72.6	91.6	159.0
5-13-99	40.8	69.7	69.0	125.0
5-18-99	40.0	68.9	83.2	146.0
Sitka				
4-16-99	44.5	74.2	107.0	177.0
4-17-99	42.2	69.1	75.4	193.0
4-29-99	40.2	80.9	77.6	165.0
4-30-99	38.0	71.0	105.0	133.0
5-13-99	42.5	68.8	74.9	127.0
5-18-99	37.4	68.5	62.5	111.0
Winnipeg				
4-16-99	45.0	77.4	128.0	219.0
4-17-99	43.2	75.3	147.0	345.0
4-29-99	45.0	80.6	111.0	139.0
4-30-99	45.7	73.8	95.9	211.0
5-13-99	44.0	76.2	93.9	219.0
5-18-99	40.4	74.0	71.7	138.0

***Note**: Not all receivers were available on the dates of solar activity. So some sites do not have data for all the dates listed.

7.0 GLONASS/GPS Performance

7.1 Introduction

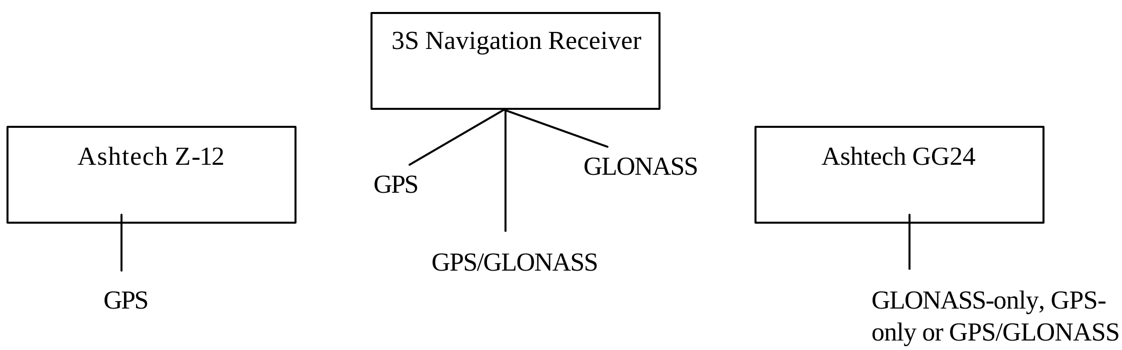
This section is new to the PAN report. In April 1999, ACT-360 was tasked to monitor, analyze and characterize GLONASS and GPS/GLONASS system performance. The objective of this task is to evaluate the ability of GLONASS to provide navigation by itself and with SPS GPS and to assess the incremental benefit 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 that is 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 R-100/30T receiver GPS and GLONASS solutions will be compared to the Z-12 GPS and GG24 GLONASS solutions, respectively, for consistency. In addition, GLONASS may provide an additional benefit to WAAS in the area of ionospheric data collection. WAAS requires multiple measurements of the ionosphere to determine the delay in the ionosphere, and provide a bound of error on the delay. Current WAAS algorithms are very dependent on the concept of surrounding Ionospheric Grid Points (IGPs) with measurement data from pierce points; the current methodology limits availability of WAAS near the edge of coverage areas. (Note: These algorithms are being analyzed to determine the amount of "relaxation" that can happen and still maintain safety.) One way to increase the availability of WAAS would be to increase the number of pierce points available; if GLONASS dual frequency measurements can accurately measure the delay in the ionosphere, then an additional pierce point would be added for each available GLONASS satellite in view. This part of the effort will compare the ionospheric measurements of the local NSTB receivers to those measured by GLONASS, and the differences will be reported quarterly. At the end of the first year, the value of continuing this effort will be determined by considering:

(1) approved relaxation of WAAS ionospheric algorithms,

(2) WAAS needs for additional pierce point data to improve availability;
(3) accuracy and availability of dual frequency GLONASS measurements, and
(4) cost and benefit of implementing GLONASS receivers at some WAAS WRS sites.

The 3S Navigation receiver will be used for this effort because the Ashtech GG24 is a single frequency receiver.

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.

These receivers will also be placed on FAA aircraft for flight-testing. This can be accomplished during the ACT-360 flight-testing (e.g. LAAS) whenever possible and during NSTB international demonstrations.

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 between 13 June and 3 July 1999.

Table 7-1 PDOP Statistics for Two Solutions (13 June – 3 July 1999)

Receiver	Solution	Maximum PDOP	Minimum PDOP	Mean PDOP	95% PDOP	Number of Samples
Ashtech GG24	GPS/GLONASS	4.40	1.00	1.18	1.67	1736870
Ashtech Z12	GPS-only	7.61	1.24	1.64	2.32	1527585

Table 7-2 Position Accuracy Statistics for Two Solutions (13 June – 3 July 1999)

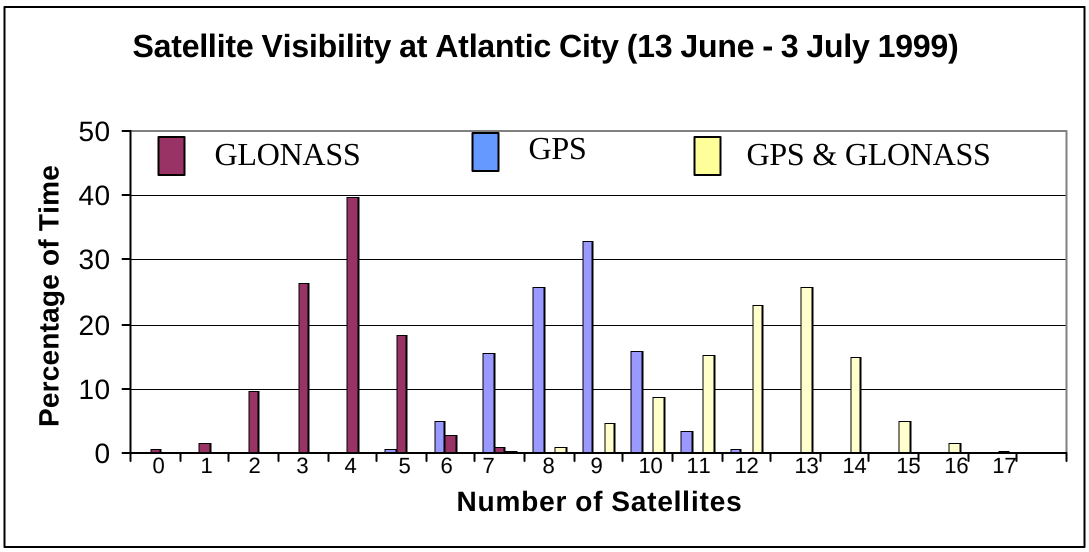
Receiver	Solution	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)	Number of Samples
Ashtech GG24	GPS/GLONASS	32.0	71.3	76.8	138.0	1736870
Ashtech Z12	GPS-only	50.4	84.1	106.0	206.0	1527585

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 during 13 June and 3 July 1999. There were 4 or more GLONASS satellites available about 60% of the time.

Table 7-3 PDOP and Position Accuracies Versus Number of GLONASS Satellites

Number of GLONASS Satellites	Maximum PDOP	Mean PDOP	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)	Number of Samples
4 or more	4.40	1.42	28.0	65.6	126.0	139.0	1450159
5 or more	4.40	1.37	20.0	62.7	61.1	127.0	520572
6 or more	2.51	1.29	14.6	57.5	40.7	86.2	93336
7 or more	1.79	1.25	13.1	55.1	20.2	70.0	25040

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 Z-12 GPS-only solution, respectively.

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

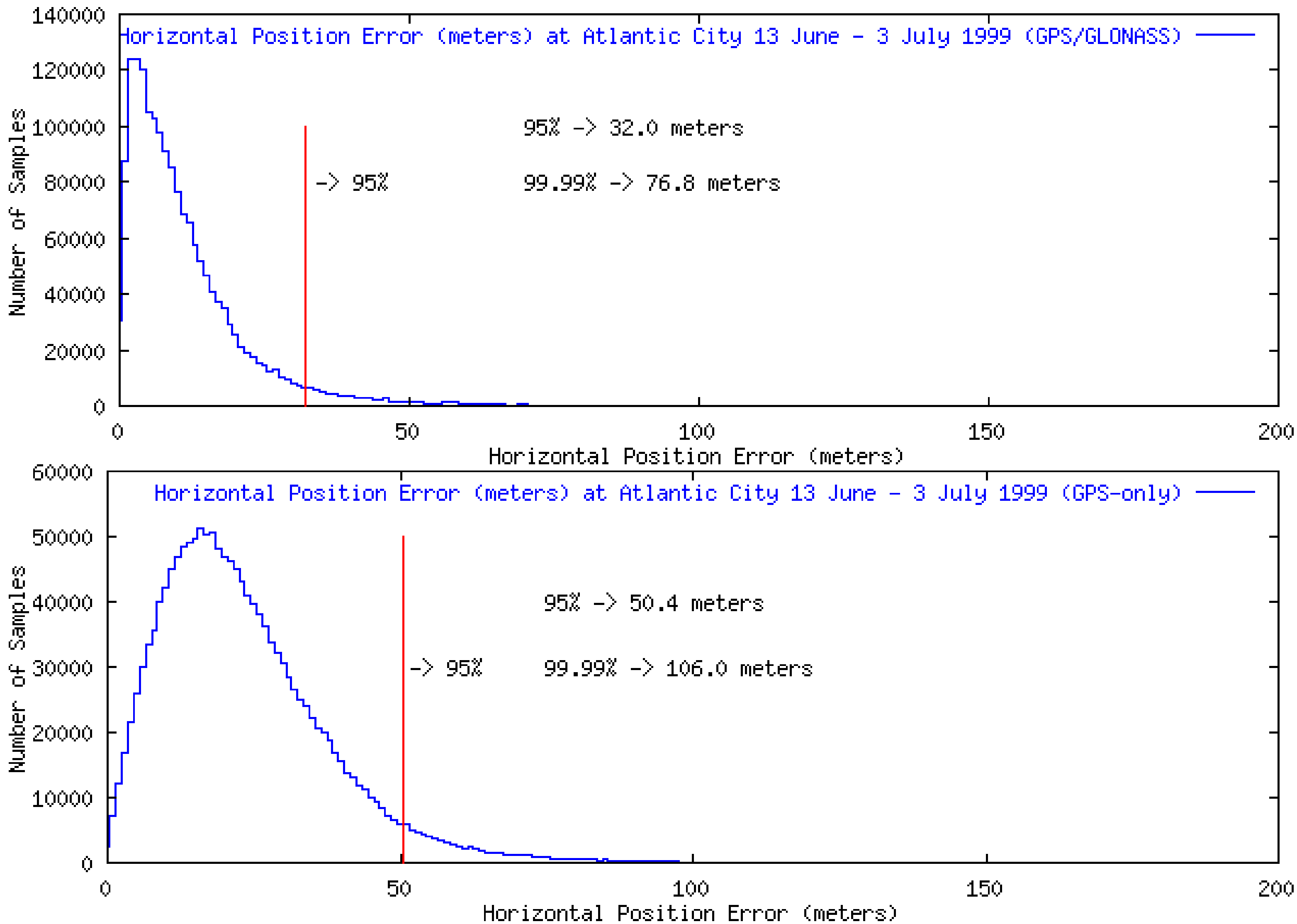
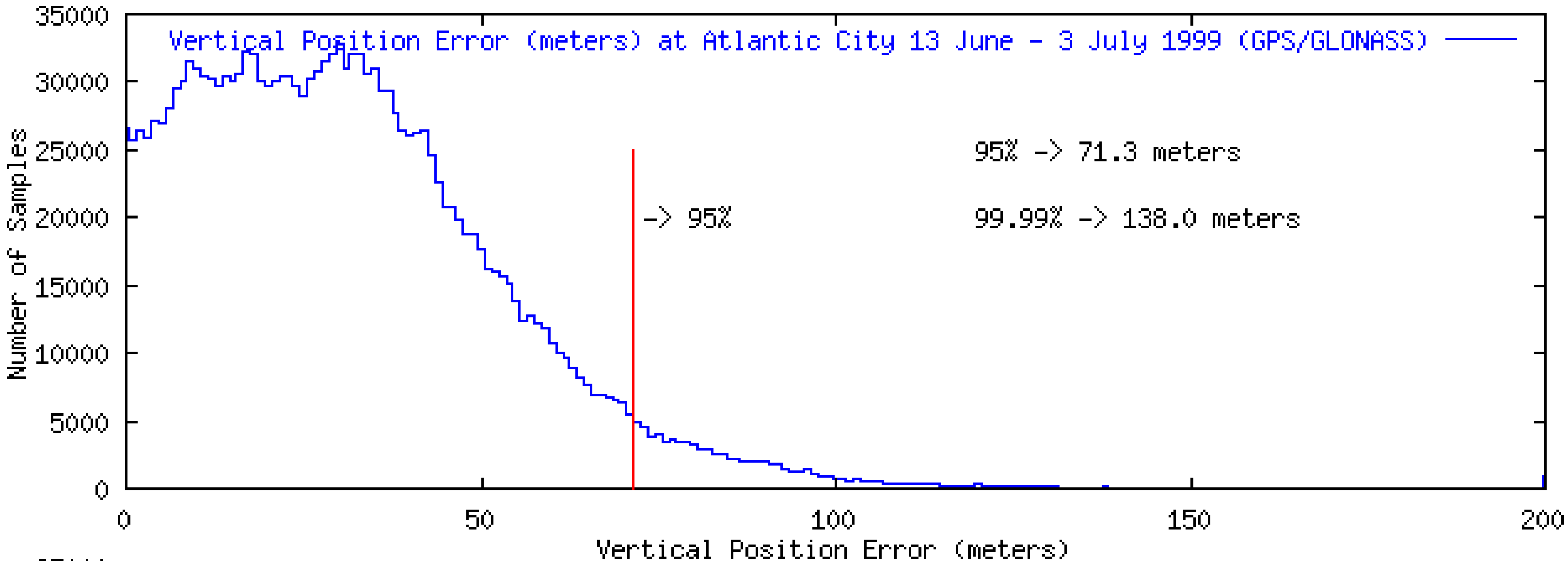
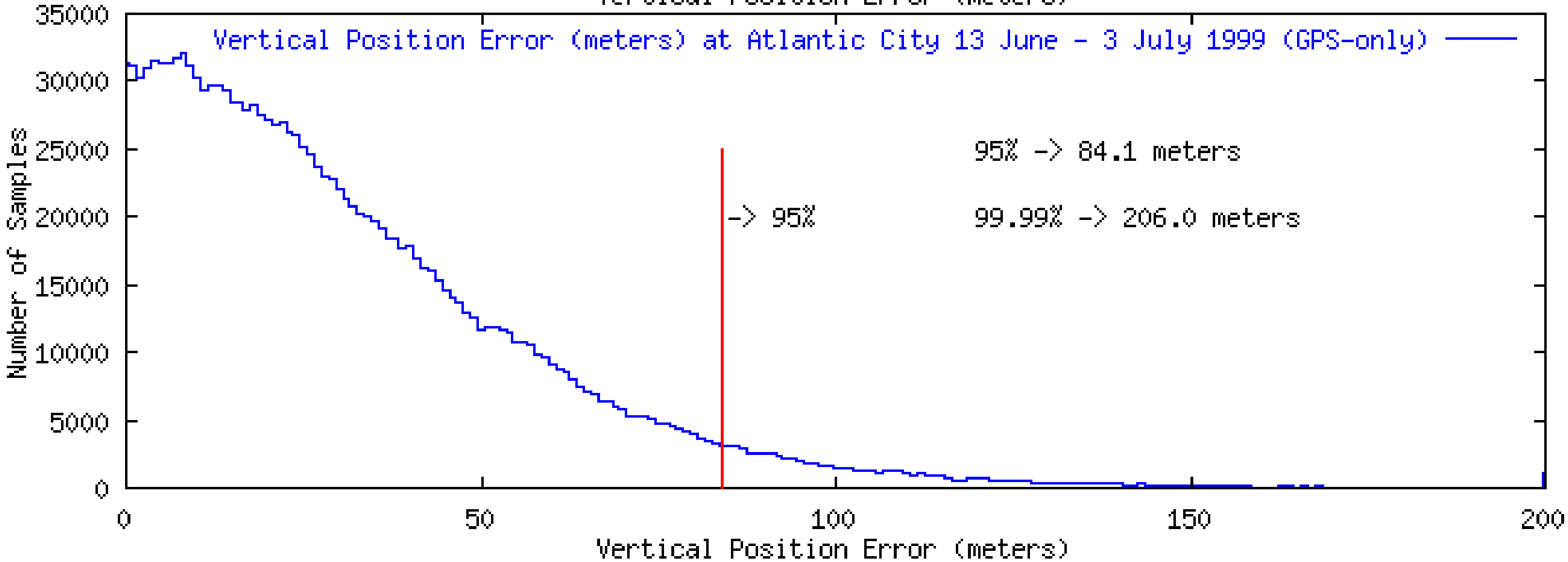


Figure 7-4 Vertical Position Error Histograms for GPS/GLONASS and GPS-Only Solutions





Tables 7-4 amd 7-5 provide the statistics for the GG24 GPS/GLONASS solution, the Z-12 GPS-only solution and the Z-12 GPS-only with WAAS corrections added solution. It should be noted that the GPS/WAAS user solution although providing good navigation error performance, the PDOP is not as good as the GPS-only user solution. The reason for the higher PDOP's is due to the removal of some GPS satellite measurements from the WAAS Precision Approach (PA) user solution (in accordance with the MOPS) which do not have WAAS ionospheric corrections available. The WAAS Ionospheric Grid Points (IGP's) around Atlantic City are not always considered monitored because of the restrictive monitoring rules imposed by the WAAS master station. This reduces the number of WAAS usable satellites for PA operation and hence increases the PDOP that a WAAS user will observe over an extended period of time.

Table 7-4 PDOP Statistics for Three Solutions on 19 June 1999 (1313 – 1846 hrs UTC)

Receiver	Solution	Maximum PDOP	Minimum PDOP	Mean PDOP	95% PDOP	Number of Samples
Ashtech GG24	GPS/GLONASS	2.25	1.00	1.36	1.53	20001
Ashtech Z12	GPS-only	2.58	1.25	1.84	2.34	20001
Ashtech Z12	GPS with WAAS Corrections	23.48	1.57	3.79	6.56	20001

Table 7-5 Position Accuracy Statistics for Three Solutions on 19 June 1999 (1313 – 1846 hrs UTC)

Receiver	Solution	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)	Number of Samples
Ashtech GG24	GPS/GLONASS	13.3	62.7	42.1	98.1	20001
Ashtech Z12	GPS-only	46.6	82.1	62.9	121.0	20001
Ashtech Z12	GPS with WAAS Corrections	5.47	8.12	21.3	28.3	20001

Figures 7-5 through 7-7 show the East, North and Up Error for all three solutions, respectively. The last graph in each of the aforementioned figures provides the number of GLONASS satellites available at each second.

Figure 7-5 East Position Error for Three Solutions

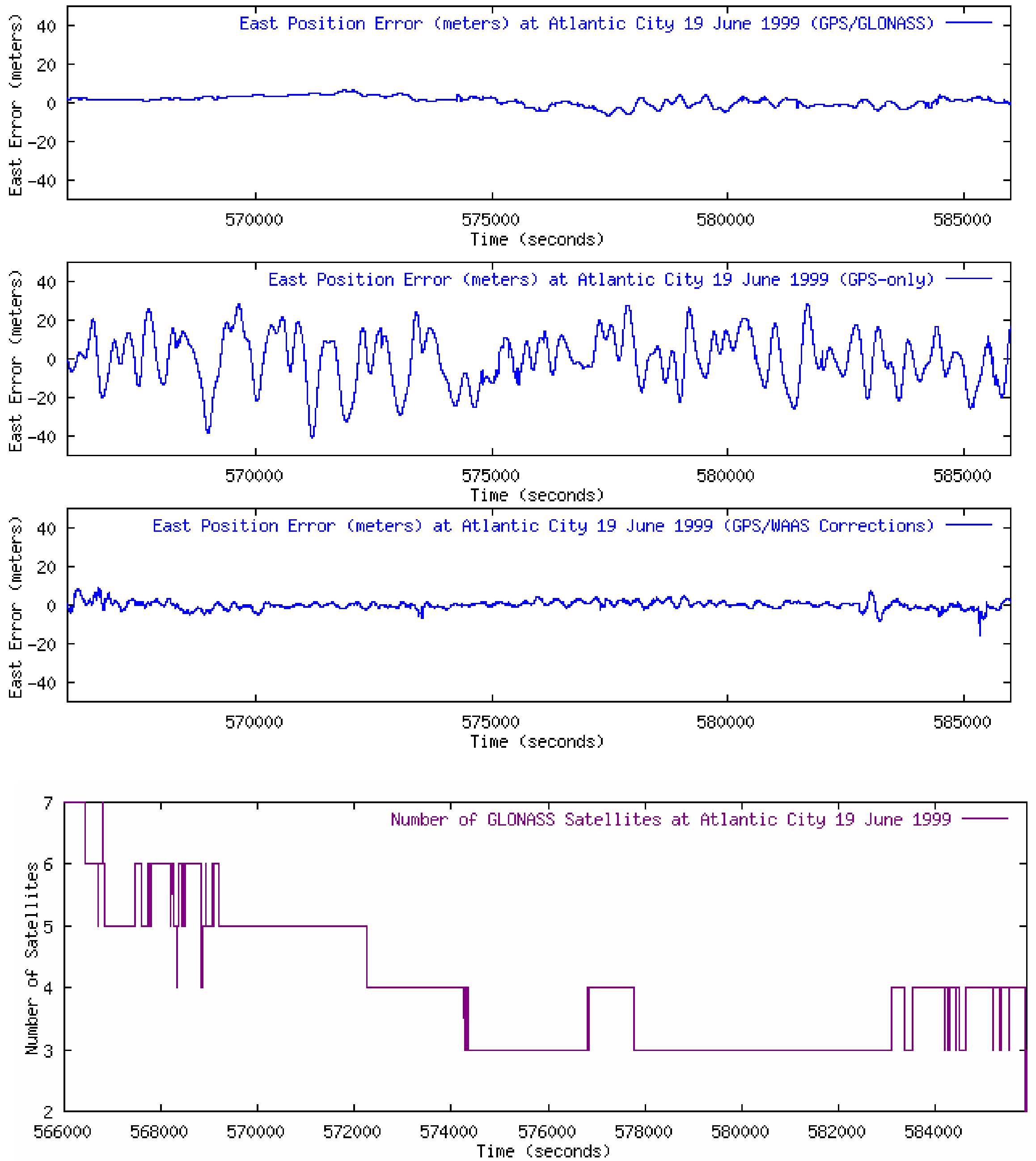


Figure 7-6 North Position Error for Three Solutions

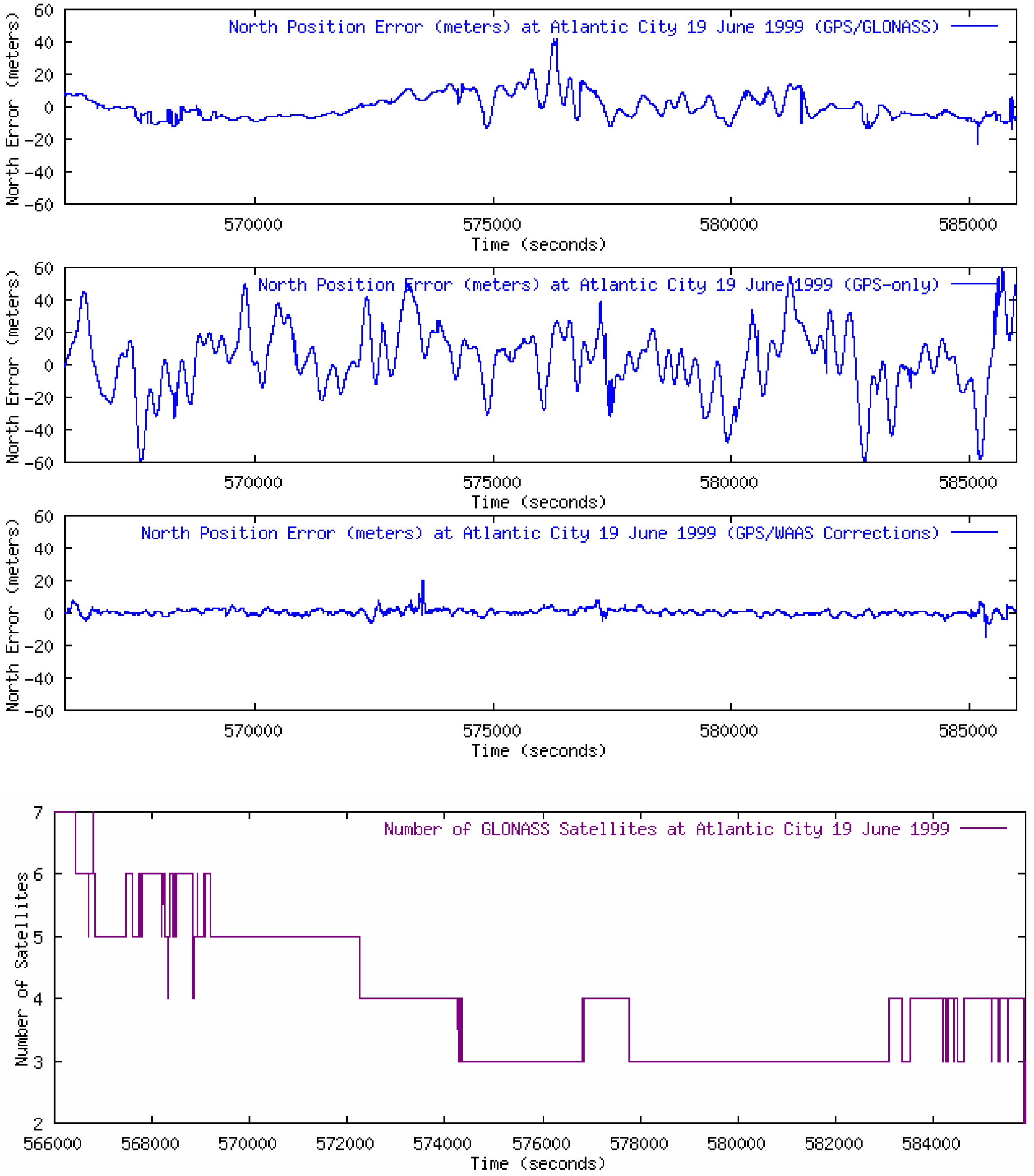
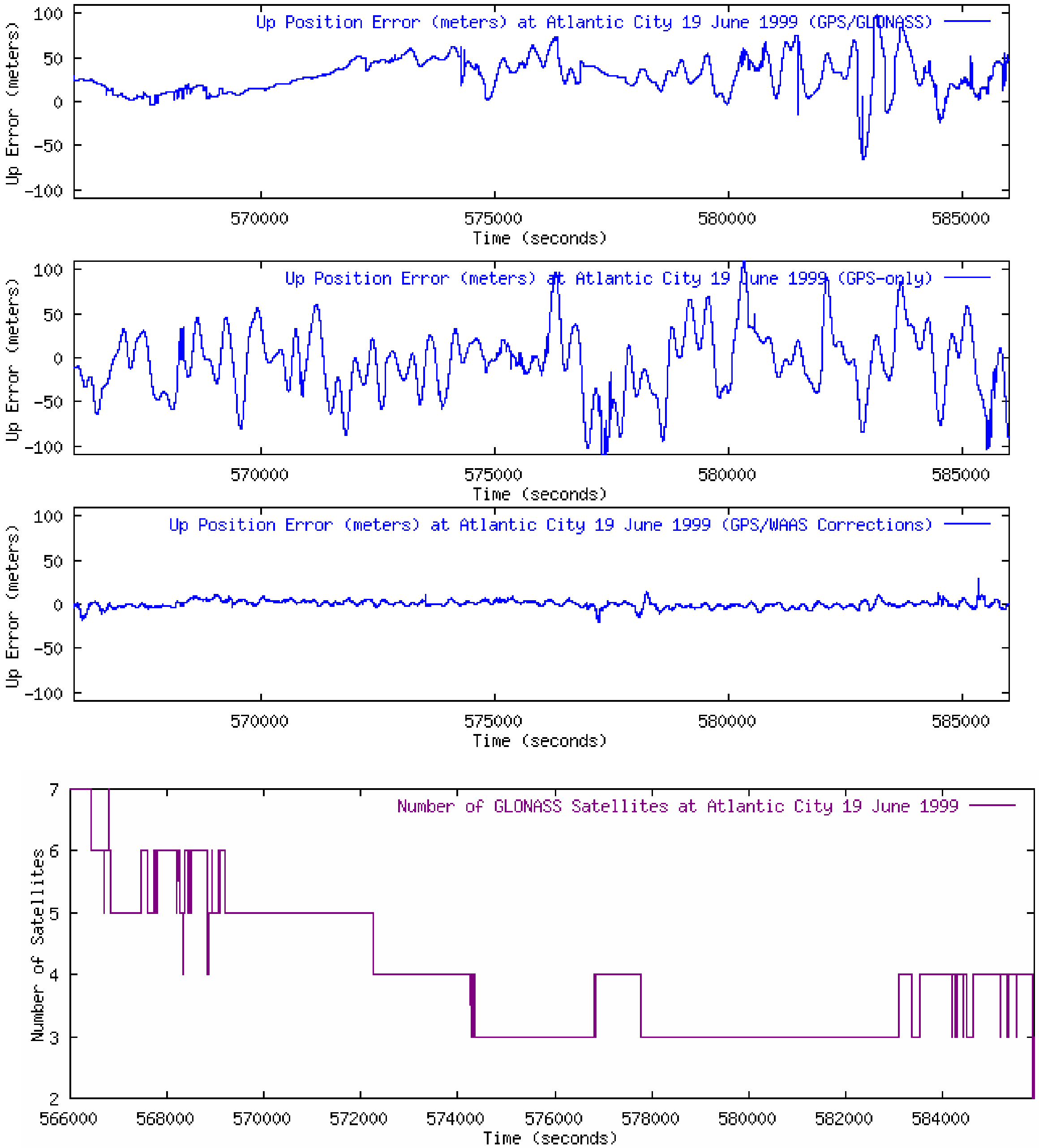


Figure 7-7 Up Position Error for Three Solutions



APPENDICES A – D

Appendix A Performance Summary

Coverage Standard	***Conditions and Constraints***	***Measured Performance***
≥ 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	99.963%
≥ 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	98.264% availability 99.9% PDOP was 5.02
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	99.99%
≥ 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	99.98%
≥ 95.87% global average on worst-case day	• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	99.86%
≥ 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	99.26%
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	Future Reports (100% for this quarter)

≥ 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	Future Reports (100% for this quarter)
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	44.3 m horz. error 95% of time 73.96 m vert. error 95% of time 104.66 m horz. error 99.99% of time 178.22 m vert. error 99.99% of time
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	35.30 m horz. error 95% of time 104.30 m vert. error 95% of time
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	89 ns 95% of the time
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	149.09 m NTE range error 1.81 m/s NTE range rate error less than 8 mm/sec2 at least 95% of the time 16.54 mm NTE range acceleration error

:Product: Daily Geomagnetic Data quar_DGD.txt
:Issued: 0225 UT 07 Jul 1999
#
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
1999 07 01	6	1 0 2 2 1 1 2 3	5	1 2 2 1 0 1 1 3	9	2 1 2 2 3 3 3 3
1999 07 02	23	4 3 4 3 2 3 4 5	39	4 4 6 6 4 4 3 4	26	4 3 5 4 3 4 4 5
1999 07 03	10	4 2 3 3 1 1 0 2	19	3 3 5 5 3 2 0 1	13	3 3 4 3 2 2 3 2
1999 07 04	0	0 0 0 0 1 0 0 0	-1	0 0 0 0-1 0 1 0	4	1 0 0 1 1 2 2 1
1999 07 05	3	0 0 0 0 1 2 2 2	1	0 0 0 0 0 1 2 1	4	0 0 0 0 1 2 2 2
1999 07 06	7	2 2 2 1 0 1 3 3	20	2 2 2 2 4 5 5 2	9	2 2 3 2 2 3 3 3
1999 07 07	3	1 1 1 0 0 1 2 2	12	1 2 1 4 5 1 1 1	5	2 1 1 0 1 2 2 3
1999 07 08	6	2 1 1 2 2 2 1 2	-1	-1 1 1 3 3 4 2 1	8	2 2 1 3 3 2 3 2
1999 07 09	5	2 1 0 0 1 2 1 2	3	3 1 0 0 0 0 0 0	6	3 2 1 1 1 2 1 2
1999 07 10	4	0 1 1 1 2 1 2 1	3	0 1 0 1 0 0 1 1	5	1 1 1 1 2 2 3 2
1999 07 11	2	0 0 1 0 1 1 1 2	3	0 1 0 2 2 1 0 1	6	1 1 2 1 2 2 2 3
1999 07 12	12	3 4 2 3 2 2 2 2	20	3 3 5 5 3 2 2 1	14	3 4 4 3 3 2 3 2
1999 07 13	3	1 2 1 0 0 1 1 1	3	2 2 0 0 1 1 1 0	6	1 2 0 1 1 3 3 2
1999 07 14	5	0 0 0 1 1 0 3 3	5	0 0 0 3 3 0 2 1	6	2 0 1 2 2 1 3 3
1999 07 15	8	3 2 3 1 2 1 1 2	24	4 4 3 5 5 3 2 2	10	3 2 3 2 2 2 3 2
1999 07 16	5	1 1 1 1 2 2 1 2	3	1 1 0 1 2 1 1 1	5	2 1 1 2 2 2 2 2
1999 07 17	3	1 0 1 1 2 1 1 0	2	1 0 1 0 1 2 0 0	5	1 0 1 1 2 2 2 2
1999 07 18	5	1 1 2 2 2 1 1 2	3	0 1 2 1 1 2 0 1	4	1 1 1 1 2 2 1 2
1999 07 19	3	1 1 1 1 1 0 1 1	3	1 1 0 0 2 2 0 0	4	2 1 1 1 1 1 1 1
1999 07 20	5	1 1 0 0 3 2 1 2	5	1 1 0 0 3 3 1 1	6	1 1 1 1 3 3 2 2
1999 07 21	9	1 1 2 2 2 2 4 2	11	1 1 2 2 2 4 4 2	13	2 1 3 2 2 4 4 3
1999 07 22	23	2 4 4 4 4 4 4 3	30	3 3 4 4 5 6 3 3	24	3 4 5 4 4 4 4 3

1999 07 23	10	3 3 1 2 3 2 3 1	17	3 2 1 5 3 4 3 2	12	3 3 1 3 3 3 3 2
1999 07 24	8	2 2 1 3 2 1 2 3	16	3 3 2 5 4 1 2 2	11	3 3 2 3 3 2 3 3
1999 07 25	8	3 2 2 1 2 1 3 2	13	2 2 2 2 4 4 2 3	8	2 3 2 1 2 2 2 3
1999 07 26	4	1 0 1 2 2 1 1 1	10	2 1 2 3 4 3 1 1	7	3 1 3 2 2 2 2 1
1999 07 27	6	2 2 2 1 2 2 1 1	4	2 1 2 1 1 2 0 0	6	2 2 2 1 2 2 2 1
1999 07 28	7	0 1 1 2 2 2 3 3	17	1 1 1 5 2 5 3 2	9	1 1 2 2 2 3 3 3
1999 07 29	6	2 2 1 1 2 1 2 2	8	3 3 1 3 1 1 0 2	10	3 3 2 2 2 2 2 3
1999 07 30	41	2 2 2 3 4 5 7 6	44	2 3 4 5 6 5 6 5	36	3 2 3 4 5 4 6 6
1999 07 31	21	4 4 3 2 2 2 4 5	21	4 4 4 2 2 4 4 3	21	5 4 4 2 2 2 4 4
1999 08 01	10	5 3 2 1 1 0 0 1	-1	4 4 2 0 0-1 0 0	9	4 3 1 1 1 1 1 1
1999 08 02	7	0 3 3 2 2 1 2 1	9	0 2 3 2 3 4 2 0	9	2 2 3 2 2 3 3 2
1999 08 03	5	2 1 1 0 1 1 2 3	6	3 2 1 3 0 0 1 2	8	3 1 1 2 1 2 3 3
1999 08 04	9	3 3 3 2 1 1 2 2	11	3 4 4 1 1 2 1 1	11	3 4 3 2 2 3 2 2
1999 08 05	6	2 2 1 1 2 2 1 2	6	3 2 1 1 3 0 0 1	11	3 2 2 1 2 2 2 2
1999 08 06	12	2 2 2 3 3 3 3 3	22	2 2 2 3 4 5 5 3	13	2 2 2 3 3 4 4 3
1999 08 07	11	3 3 2 2 2 1 3 3	-1	3 3 2-1-1 2 2 2	11	3 3 3 2 2 2 3 3
1999 08 08	7	2 1 1 2 1 1 3 3	-1	-1-1-1-1-1-1-1-1	7	2 1 1 2 2 2 3 3
1999 08 09	10	3 3 3 3 2 2 1 1	60	4 5 6 7 7 5 1 0	19	4 4 3 4 3 4 3 2
1999 08 10	5	1 0 0 1 2 2 2 3	5	0 0 0 3 2 2 2 2	7	2 1 0 1 2 3 3 3
1999 08 11	6	2 2 1 1 1 1 3 2	-1	2 3 4 2-1-1 2 1	8	3 2 1 2 2 2 3 2
1999 08 12	8	2 2 2 2 2 1 2 3	-1	2 2-1 4 3 0-1-1	10	2 2 3 3 3 3 2 3
1999 08 13	6	2 3 2 1 1 1 1 1	-1	-1-1-1-1-1-1-1-1	11	2 4 3 3 3 1 2 2
1999 08 14	4	1 1 1 2 1 1 1 2	-1	-1-1-1-1-1-1-1-1	5	2 1 1 2 1 2 2 2
1999 08 15	15	1 2 2 3 3 3 4 4	-1	-1-1-1-1-1-1-1-1	15	1 1 2 3 4 4 4 3
1999 08 16	22	2 2 4 5 4 3 4 3	-1	-1-1-1-1-1-1-1-1	29	3 2 4 5 5 4 4 4
1999 08 17	25	5 4 5 3 4 3 3 2	-1	-1-1-1-1-1-1-1-1	27	5 4 5 4 4 4 3 3
1999 08 18	28	4 5 5 3 4 4 3 3	-1	-1-1-1-1-1-1-1-1	26	4 5 5 4 4 4 3 3
1999 08 19	19	3 3 4 3 4 2 3 4	41	3 5 6 5 6 4 3 3	22	3 5 4 4 3 3 3 4
1999 08 20	22	3 5 4 4 4 2 2 3	65	4 4 6 7 6 7 2 3	33	3 5 5 5 5 4 3 3
1999 08 21	4	1 1 2 1 2 2 1 0	10	2 2 2 3 2 4 1 1	6	1 2 2 2 2 2 2 2
1999 08 22	7	0 1 3 1 1 2 2 3	18	0 1 3 3 5 4 4 2	11	1 1 3 2 3 3 3 3
1999 08 23	22	5 5 3 2 3 3 3 3	67	4 5 5 6 7 7 5 2	33	6 5 4 4 5 4 3 3
1999 08 24	18	3 4 3 3 4 3 3 3	45	2 4 4 5 7 5 5 3	29	3 4 4 5 5 4 3 3
1999 08 25	8	2 1 1 1 2 1 2 4	-1	3 1 1 1-1 1 1 3	8	2 2 1 1 2 2 2 4
1999 08 26	10	2 3 0 2 3 2 3 3	48	2 5 5 5 5 7 4 3	13	2 3 1 2 4 4 3 3
1999 08 27	9	2 2 3 1 2 2 3 2	15	4 2 4 1 4 3 2 2	13	3 3 4 2 3 3 3 2
1999 08 28	11	2 2 2 3 3 3 3 2	26	3 2 5 4 6 3 2 2	14	3 2 3 3 3 3 3 3
1999 08 29	6	2 2 2 2 1 2 2 1	27	2 3 5 6 5 2 2 2	10	2 2 2 3 2 3 3 3
1999 08 30	13	1 2 4 3 3 3 2 3	35	2 2 6 6 4 5 4 2	20	2 2 5 5 3 3 3 3
1999 08 31	12	3 2 2 3 3 2 3 3	34	3 5 4 6 5 4 3 3	18	3 3 4 4 3 3 4 4
1999 09 01	14	2 5 3 2 3 2 2 2	37	2 5 6 4 6 4 3 3	22	3 4 5 4 4 3 3 2
1999 09 02	11	3 2 4 2 2 3 1 1	28	3 5 5 4 5 4 2 1	11	3 3 4 2 3 3 2 2
1999 09 03	14	1 3 4 4 3 3 1 2	-1	-1-1-1-1-1-1-1-1	18	2 3 5 5 3 3 2 2

1999 09 04	11 1 4 3 2 2 1 2 3	-1 -1-1-1-1-1-1-1-1	15 3 4 3 4 3 3 3 3
1999 09 05	4 2 2 0 1 1 1 1 2	7 2 2 1 3 3 1 0 1	8 2 3 1 2 3 2 2 2
1999 09 06	4 1 1 2 1 1 1 1 2	11 0 5 4 1 0 1 1 1	6 1 2 2 1 1 2 2 2
1999 09 07	12 1 2 3 3 2 2 4 3	24 1 1 5 5 5 2 2 4	17 2 1 4 4 3 3 4 4
1999 09 08	5 2 0 1 1 2 2 2 2	11 2 1 1 3 4 4 1 1	9 3 1 1 2 3 3 2 3
1999 09 09	7 2 1 2 1 3 2 2 1	-1 2 1 2 3 1 1-1-1	8 3 1 2 2 3 3 2 2
1999 09 10	12 2 3 3 2 3 2 3 3	19 3 3 4 4 4 4 2 2	15 2 3 4 3 4 3 3 3
1999 09 11	8 4 2 1 1 2 0 2 2	15 4 4 1 4 4 1 1 1	10 4 3 2 2 2 2 2 2
1999 09 12	17 2 3 1 5 3 2 4 3	-1 2 3 3 7 5 5 6-1	26 3 3 3 6 3 4 5 4
1999 09 13	23 4 5 4 3 3 3 4 2	-1 6 6 6 6 5 5-1-1	38 5 5 5 5 4 4 4 4
1999 09 14	22 4 5 5 3 2 3 3 2	34 3 5 6 5 3 5 2 2	23 4 5 5 3 3 3 3 3
1999 09 15	21 4 3 5 5 3 1 2 2	-1 3 5 7 7 5 4-1 5	32 4 3 5 7 4 3 3 2
1999 09 16	18 3 4 4 4 2 3 3 2	63 3 6 7 6 6 5 3 5	32 3 6 5 5 4 4 3 2
1999 09 17	9 2 1 1 2 3 3 3 2	32 3 2 3 4 6 6 4 2	15 3 2 2 3 4 4-1 2
1999 09 18	13 1 3 2 4 4 3 1 1	-1 -1-1-1-1-1-1-1-1	16 2 3 3 4 4 4 3 2
1999 09 19	9 2 3 1 3 3 1 2 2	18 3 3 2 5 5 2 1 1	10 2 3 2 3 3 3 2 2
1999 09 20	6 2 1 2 1 2 1 2 2	14 1 2 4 4 3 3 2 2	10 2 2 2 3 3 2 3 3
1999 09 21	10 2 1 2 3 2 2 3 3	-1 5 1 3 3 5-1-1 3	10 1 1 2 3 3 3 3 3
1999 09 22	29 2 2 2 2 4 3 6 6	36 3 2 2 4 6 4 5 6	37 3 2 3 3 4 3 5 7
1999 09 23	22 6 5 2 1 1 1 2 4	-1 5 5 2 1 1 2-1 3	24 6 6 3 1 2 3 2 2
1999 09 24	-1 -1-1-1-1-1-1-1-1	-1 -1-1-1-1-1-1-1-1	6 2 2 2 2 2 1 2 2
1999 09 25	2 1 1 0 1 1 0 1 1	-1 -1-1-1-1-1-1-1-1	4 1 0 1 1 2 2 2 1
1999 09 26	12 0 0 1 1 2 4 4 4	26 0 0 1 3 3 6 5 5	15 1 0 1 1 3 5 4 4
1999 09 27	31 5 4 4 3 5 4 4 4	66 6 5 4 6 6 7 5 4	37 4 4 5 5 5 5 4 4
1999 09 28	20 4 4 4 4 3 3 2 3	34 4 3 5 5 6 4 3 3	20 4 4 4 4 4 3 3 4
1999 09 29	15 4 3 4 3 2 2 1 3	29 3 4 6 5 3 3 3 3	19 4 3 4 5 3 2 3 3
1999 09 30	14 4 4 3 2 3 2 2 2	44 5 5 4 7 5 4 2 1	29 4 6 4 4 4 3 3 2

Appendix C WAAS DATA from Stability Testing

Background:

The Stability Build is one of the test milestones which requires the WAAS system to operate continuously for 72 hours broadcasting WAAS corrections which include fast, long term and iono corrections. For this test, Independent Data Verification (IDV) and Integrity Data Monitoring (IDM) functions are not required and were stubbed out and bypassed. On Tuesday, April 6 at approximately 9:00 am PDT the Stability Test began and it ran continuously and provided WAAS corrections for 100 hours.

Using NSTB reference station data at Oklahoma City and the WAAS broadcast corrections transmitted from AOR-W satellite collected at Dayton, position errors were computed. Plots of vertical and horizontal position errors for Wednesday, April 7, through Saturday, April 10, show the performance and continuous operation of the WAAS system. Presentation of the plots includes the vertical 3d-histogram and position errors for vertical and horizontal. The vertical 3d-histogram shows the density of the vertical position error (VPE) versus vertical protection level (VPL) in five zones: HMI, Non-precision approach with vertical guidance (NPV), Instrument approach with vertical guidance (IPV), Precision approach (PA) and Unavailable. These five zones are defined as follow:

HMI – VPE is greater than VPL
NPV – VPL is less than or equal to 50 meters (No HMI included).
IPV – VPL is less than or equal to 20 meters (No HMI included).
PA – VPL is less than or equal to 15 meters (No HMI included).
Unavailable – VPL is greater than 50 meters.

Statistical values of mean, standard deviation, and 95% for the overall and the five zones are shown on the plots. The position error plot shows the two graphs of the vertical errors and horizontal errors bounded by the VPL and HPL. Occurrences of HMI and NotAvailable events are marked with diamonds and crosses respectively on both horizontal and vertical graphs.

Figure C-1 Position Accuracy Versus WAAS Specification: 7 April 1999

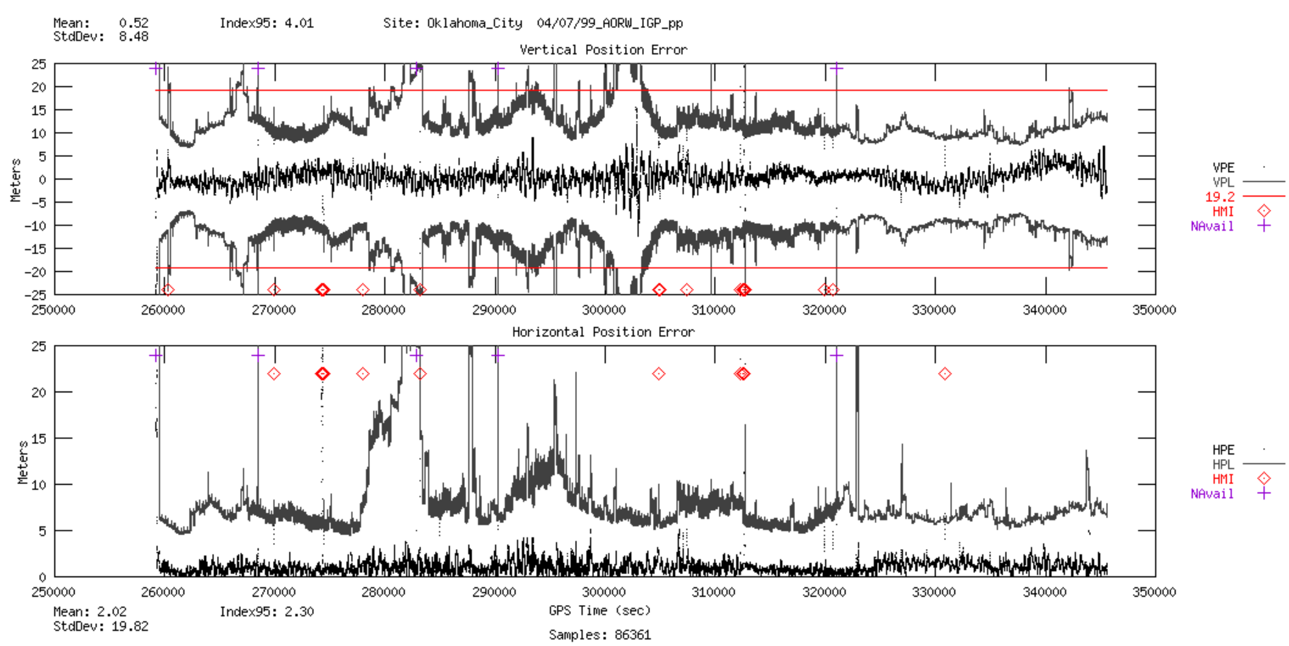


Figure C-2 Position Accuracy Versus WAAS Specification: 8 April 1999

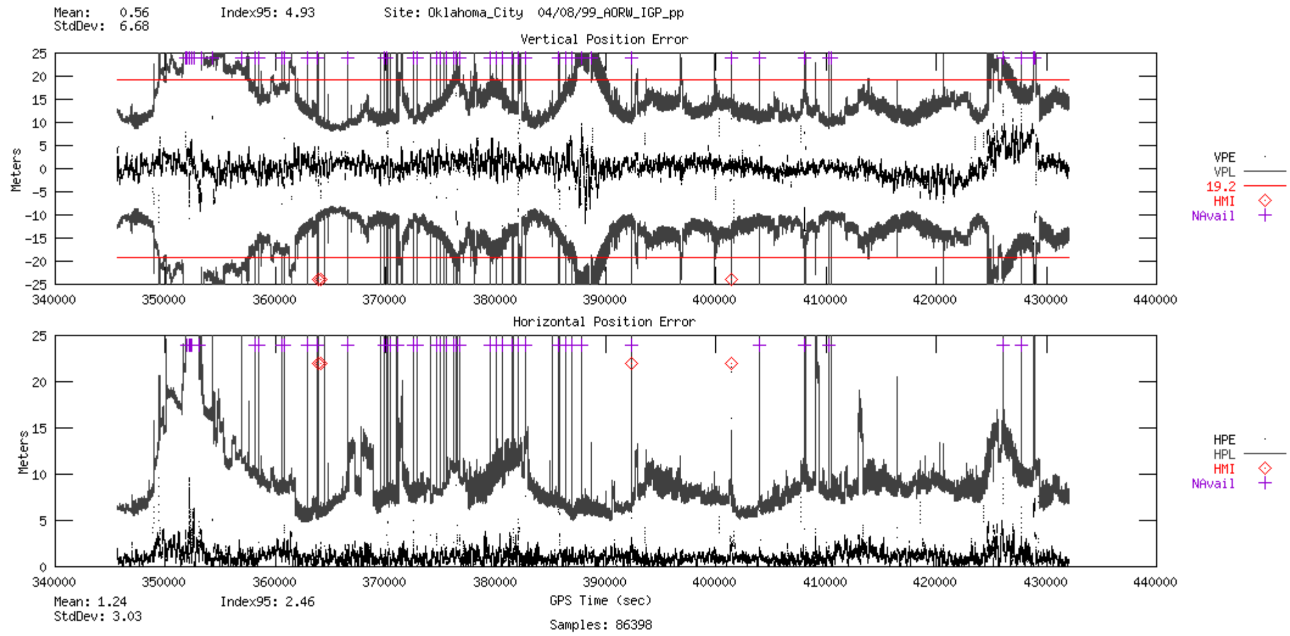


Figure C-3 Position Accuracy Versus WAAS Specification: 9 April 1999

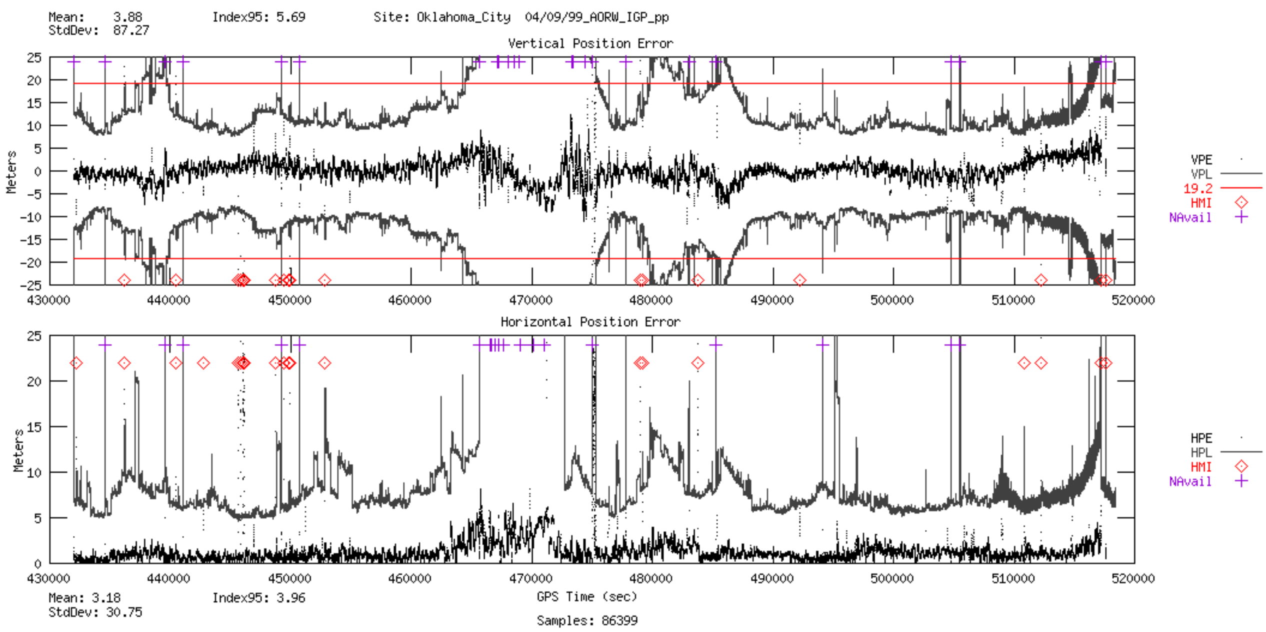


Figure C-4 Position Accuracy Versus WAAS Specification: 10 April 1999

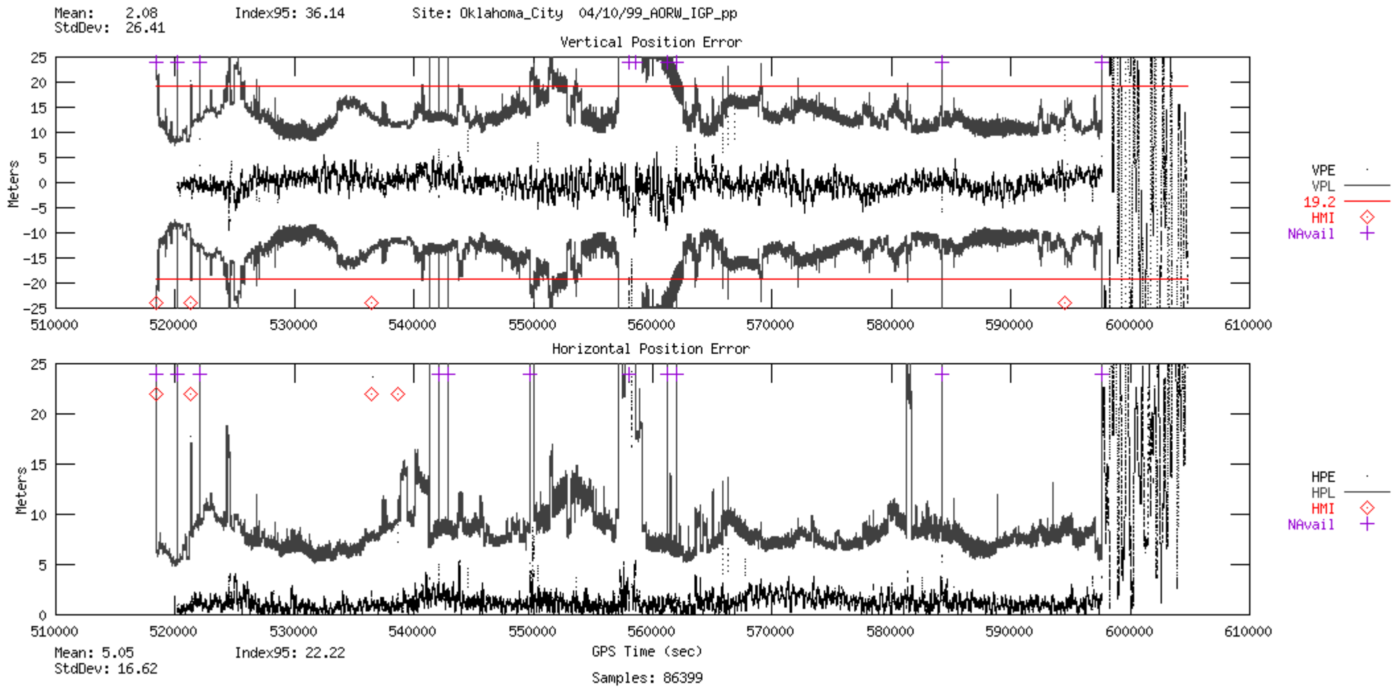


Figure C-5 VPE vs VPL 3D Histogram – Oklahoma: 7 April 1999

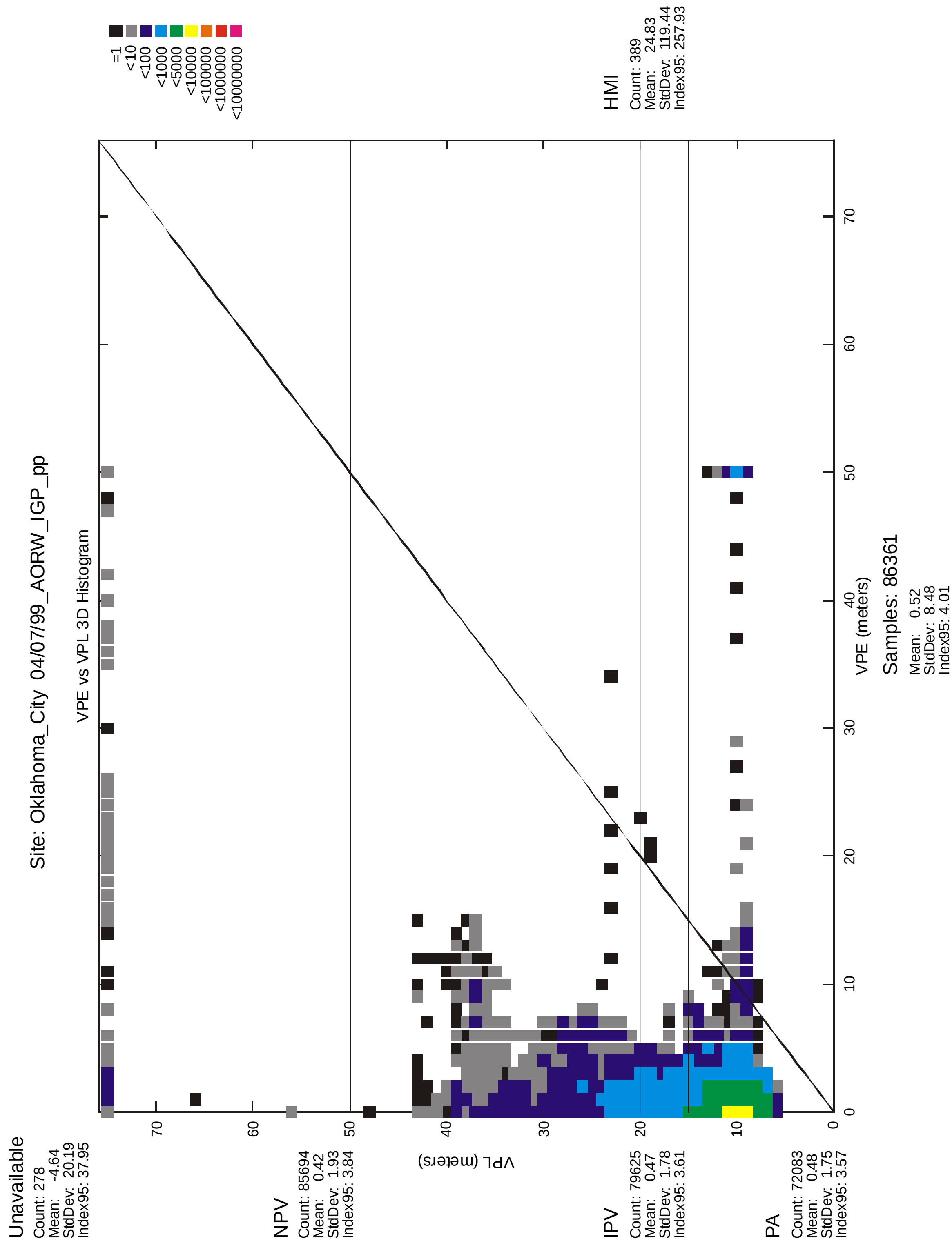


Figure C-6 VPE vs VPL 3D Histogram – Oklahoma: 8 April 1999

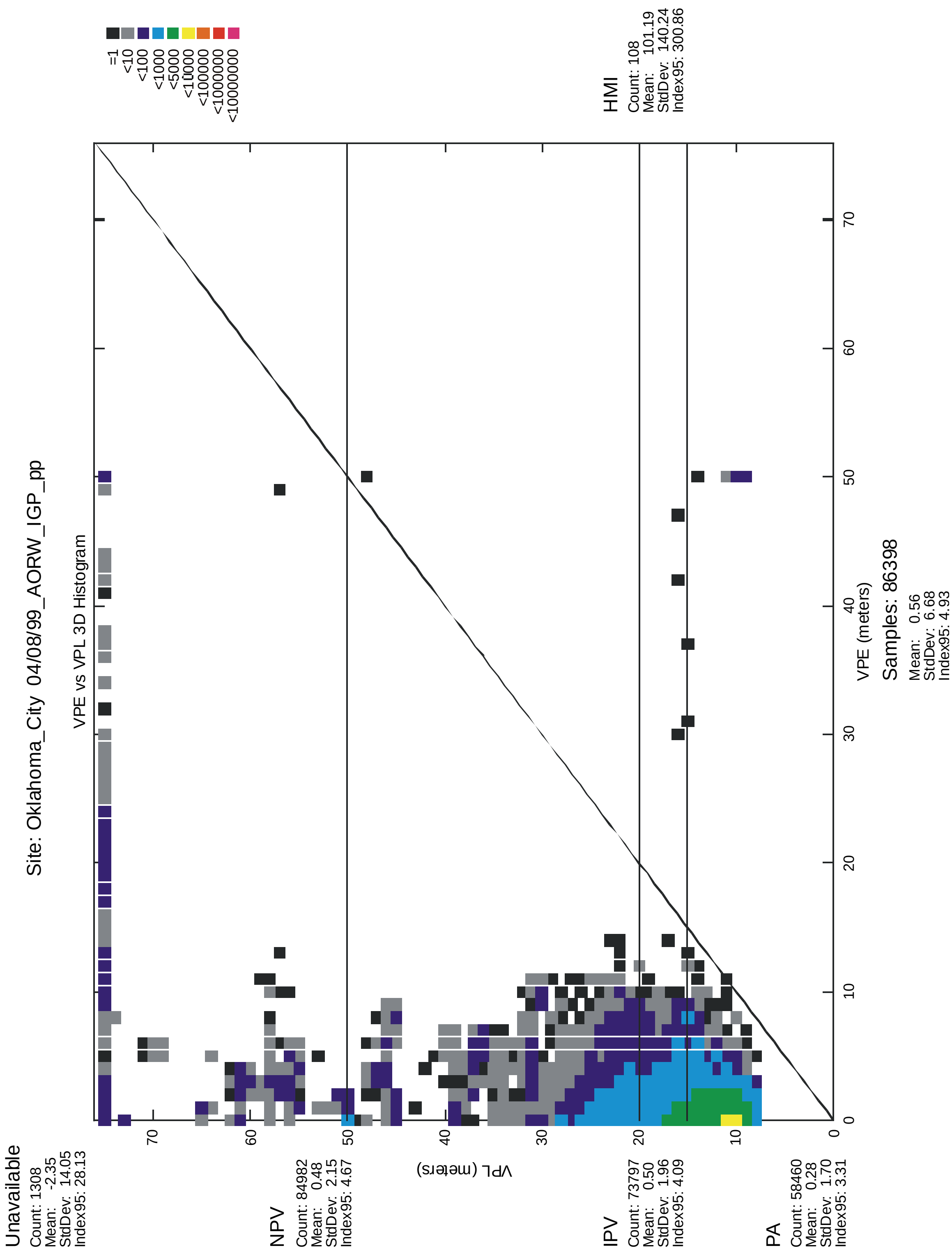


Figure C-7 VPE vs VPL 3D Histogram – Oklahoma: 9 April 1999

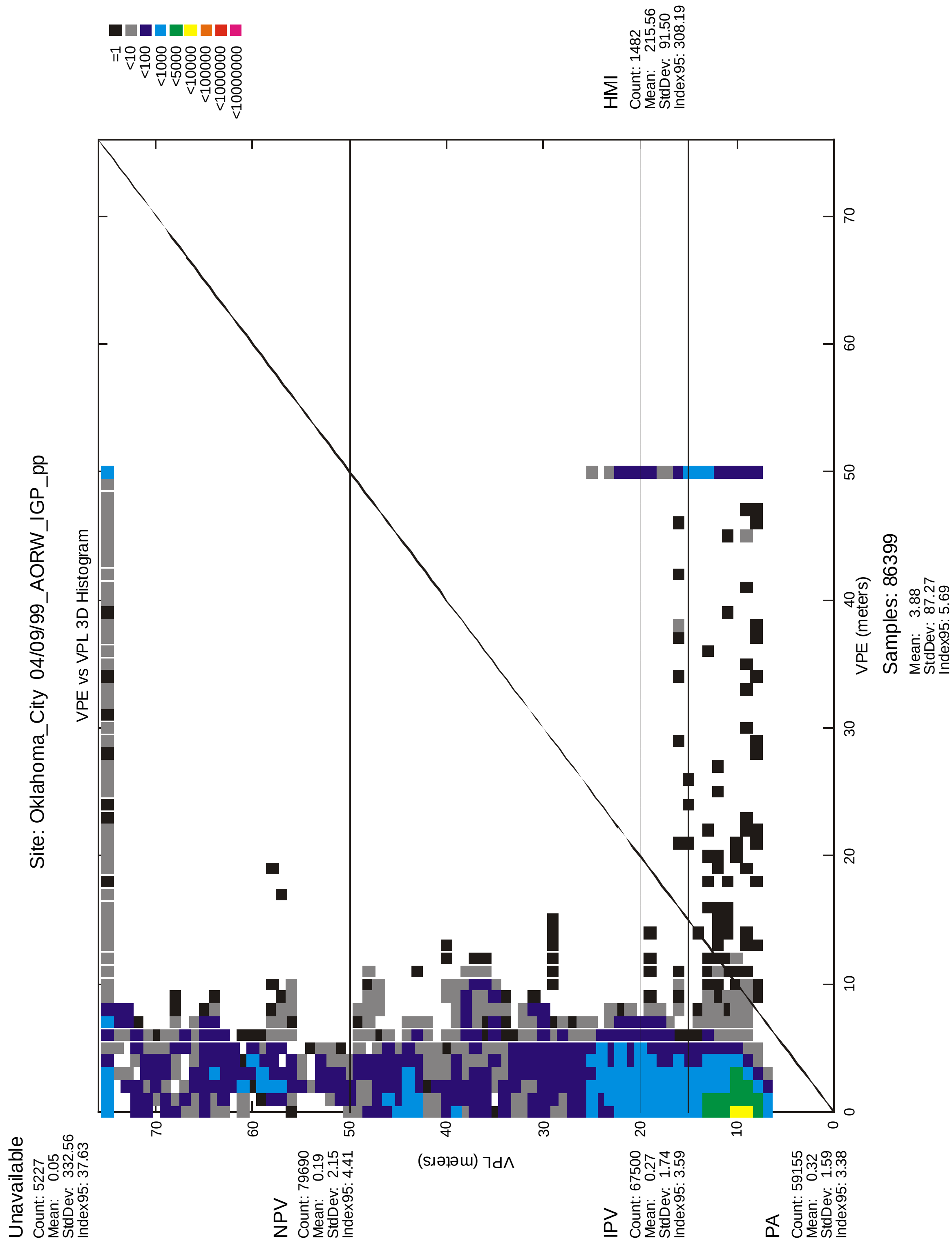
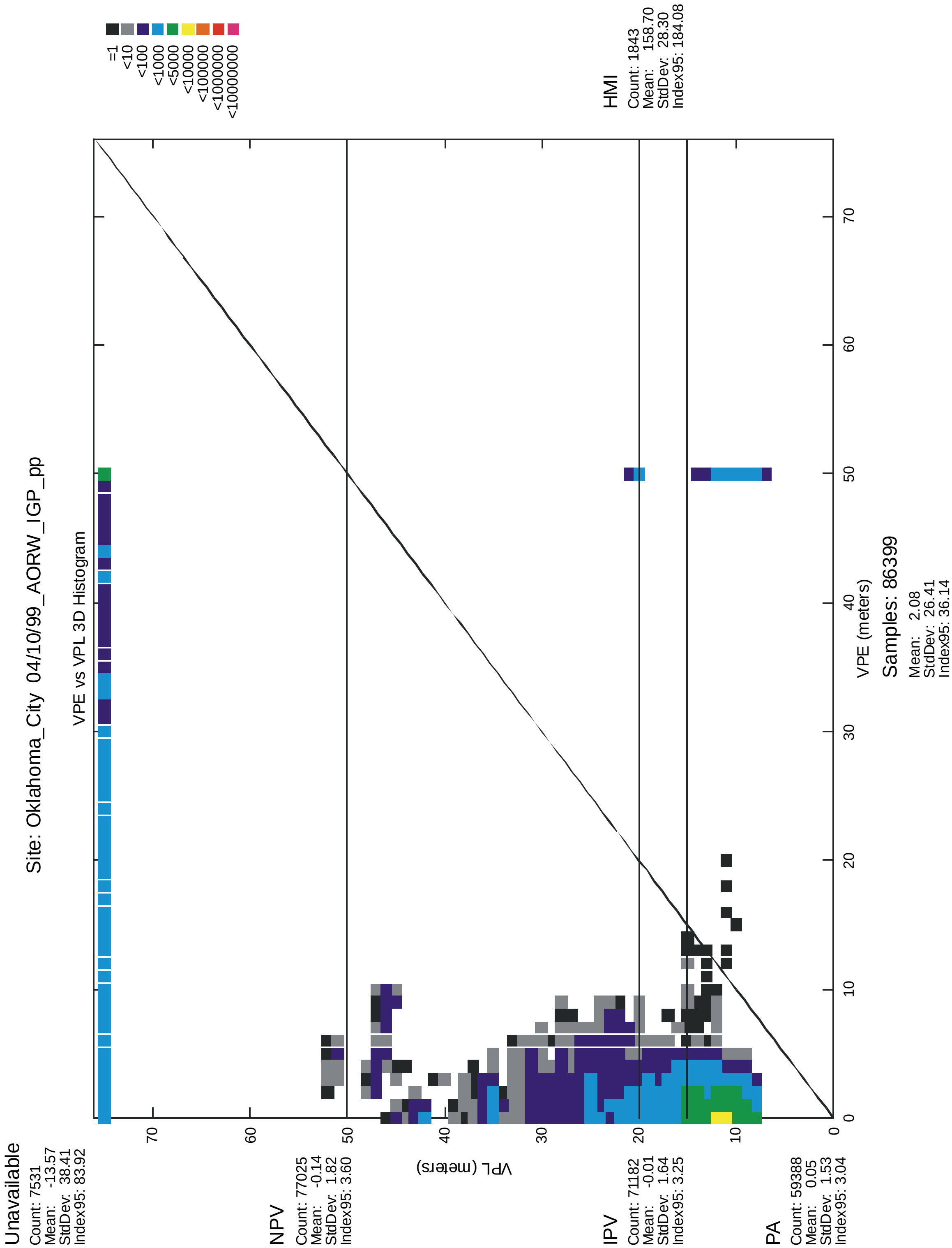


Figure C-8 VPE vs VPL 3D Histogram – Oklahoma: 10 April 1999



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: 7 April 1999

WAAS Requirement	Count	% of Total	Mean	Std_dev	95 index	99 index	99.9 index	99.99 index
Vertical_Total	86361	0.9967809	0.517	8.476	4.01	7.09	145.09	313.37
Vertical_Not_Available	278	0.0032191	-4.639	20.186	37.95	120.55	161.6	161.6
Vertical_HMI	389	0.0045044	24.827	119.436	257.93	323.84	324.17	324.17
Vertical_PA	72083	0.8346707	0.479	1.751	3.57	5.34	8.7	10.17
Vertical_IPV	79625	0.9220018	0.475	1.78	3.61	5.35	8.82	10.17
Vertical_NPV	85694	0.9922766	0.424	1.931	3.84	5.96	10.31	15.09
Horizontal_Total	86361	0.9967809	2.021	19.822	2.296	3.771	481.936	538.378
Horizontal_Not_Available	120	0.0013895	13.07	11.176	34.242	39.465	68.687	68.687
Horizontal_HMI	479	0.0055465	171.645	204.633	489.185	539.928	1562.022	1562.022
Horizontal_PA	80801	0.9356191	1.042	0.631	2.197	2.967	4.609	5.562
Horizontal_IPV	83178	0.9631431	1.047	0.634	2.214	2.993	4.591	5.705
Horizontal_NPV	85762	0.993064	1.058	0.643	2.246	3.025	4.591	5.705

Table C-2 Position Accuracy Statistics for WAAS Stability Test: 8 April 1999

WAAS Requirement	Count	% of Total	Mean	Std_dev	95 index	99 index	99.9 index	99.99 index
Vertical_Total	86398	0.9848608	0.559	6.684	4.93	8.65	138.03	259.83
Vertical_Not_Available	1308	0.0151392	-2.351	14.049	28.13	50.88	107.44	107.44
Vertical_HMI	108	0.00125	101.194	140.239	300.86	362.91	573.74	573.74
Vertical_PA	58460	0.676636	0.281	1.697	3.31	5.53	8.03	10.57
Vertical_IPV	73797	0.8541517	0.5	1.96	4.09	6.89	9.09	11.22
Vertical_NPV	84982	0.9836108	0.476	2.149	4.67	7.64	10.27	12.03
Horizontal_Total	86398	0.9848608	1.236	3.026	2.461	4.072	57.431	107.43
Horizontal_Not_Available	980	0.0113429	5.855	6.75	19.063	33.507	44.46	44.46
Horizontal_HMI	114	0.0013195	63.754	45.625	120.875	141.061	473.737	473.737
Horizontal_PA	79909	0.9248941	1.051	0.627	2.18	3.222	4.449	7.027
Horizontal_IPV	83520	0.9666891	1.077	0.655	2.284	3.359	4.507	7.617
Horizontal_NPV	85304	0.9873377	1.099	0.711	2.355	3.576	6.5	8.554

Table C-3 Position Accuracy Statistics for WAAS Stability Test: 9 April 1999

WAAS Requirement	Count	% of Total	Mean	Std_dev	95 index	99 index	99.9 index	99.99 index
Vertical_Total	86399	0.9395016	3.881	87.267	5.69	227.48	308.08	395.95
Vertical_Not_Available	5227	0.0604984	0.055	332.558	37.63	93.97	436.71	23691.84
Vertical_HMI	1482	0.017153	215.556	91.504	308.19	317.4	430.94	469.87
Vertical_PA	59155	0.6846723	0.322	1.586	3.38	4.49	6.58	11.35
Vertical_IPV	67500	0.7812591	0.266	1.742	3.59	5.05	7.62	11.67
Vertical_NPV	79690	0.9223486	0.195	2.147	4.41	6.54	10.46	12.54
Horizontal_Total	86399	0.9395016	3.184	30.75	3.958	113.854	143.839	149.878
Horizontal_Not_Available	3759	0.0435075	7.663	130.119	18.456	45.838	212.852	7871.472
Horizontal_HMI	1478	0.0171067	104.542	40.429	147.593	149.69	155.072	155.084

Horizontal_PA	76465	0.8850218	1.055	0.686	2.318	3.536	4.829	7.662
Horizontal_IPV	77111	0.8924987	1.056	0.687	2.32	3.55	4.829	7.662
Horizontal_NPV	81162	0.9393859	1.13	0.805	2.64	4.382	5.115	8.707

Table C-4 Position Accuracy Statistics for WAAS Stability Test: 10 April 1999

WAAS Requirement	Count	% of Total	Mean	Std_dev	95 index	99 index	99.9 index	99.99 index
Vertical_Total	86399	0.9128346	2.077	26.411	36.14	162.56	184.17	195.12
Vertical_Not_Available	7531	0.0871654	-13.573	38.413	83.92	123.07	126.24	126.34
Vertical_HMI	1843	0.0213313	158.7	28.3	184.08	189.87	307.26	332.65
Vertical_PA	59388	0.6873691	0.046	1.533	3.04	4.11	5.62	9.78
Vertical_IPV	71182	0.8238753	-0.009	1.643	3.25	4.47	5.76	10.99
Vertical_NPV	77025	0.8915034	-0.14	1.819	3.6	5.45	9.26	10.99
Horizontal_Total	86399	0.9128346	5.045	16.618	22.215	112.414	121.317	122.76
Horizontal_Not_Available	7776	0.090001	17.943	10.37	35.881	48.895	57.443	60.865
Horizontal_HMI	1845	0.0213544	110.042	11.105	121.255	122.623	146.906	159.102
Horizontal_PA	74169	0.8584474	1.2	0.662	2.419	3.047	4.51	5.91
Horizontal_IPV	75250	0.8709592	1.199	0.661	2.415	3.049	4.51	5.91
Horizontal_NPV	76778	0.8886445	1.216	0.688	2.47	3.311	4.821	5.91

Appendix D Glossary

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

General Terms and Definitions

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

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

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

Major Service Failure. A condition over a time interval during which one or mo re 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.