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

Submitted To

Federal Aviation Administration
GPS Product Team
AND 730
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Submitted by

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The GPS Product Team (AND 730) has tasked the Navigation Branch (ACT 360) at the William J. Hughes Technical Center to document Global Positioning System (GPS) Standard Positioning Service (SPS) performance in quarterly GPS Performance Analysis (PAN) Reports. The report contains the analysis performed on data collected at the following NSTB and Wide Area Augmentation System (WAAS) Reference Station locations: Anderson, Atlantic City, Columbus, Denver, Elko, Great Falls, Atlantic City (FVS), Bangor (FVS), Kansas City (WAAS), Salt Lake City (WAAS), Miami (WAAS) and Atlanta (WAAS). This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification Annex A.

This report, Report #35, includes data collected from 1 July through 30 September 2001. The next quarterly report will be issued 31 January 2002.

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

Coverage performance was based on Position Dilution of Precision (PDOP). Utilizing the weekly almanac posted on the US Coast Guard navigation web site, the coverage for every 5^{o} grid point between 180W to 180E and 80S and 80N was calculated for every minute over a 24-hour period for each of the weeks covered in the reporting period. For this reporting period, the coverage based on PDOP less than six for the CONUS was 99.9% or better.

Availability was verified by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 July and 30 September 2001 and by calculating the satellite availability from the data obtained from the nine sites. A total of sixteen outages were reported in the NANU’s. Eleven of the outages were scheduled and five were unscheduled. The quarterly availabilities for Anderson, Atlantic City, Columbus, Denver, Elko, Grand Forks, Great Falls, Atlantic City (FVS), Bangor (FVS), Atlanta, Kansas City, Salt Lake City and Miami were 100%, 99.989%, 99.997%, 99.994%, 100%, 99.999%, 100%, 100%, 99.999%, 99.999%, 99.993%, 99.997% and 99.974% respectively. Each of these availabilities is within the SPS value of 99.85%. In this quarter, SPS specifications were exceeded. These availability percentages were calculated using DOP data collected at one-second intervals.

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

Position accuracies were verified by calculating the 95% and 99.99% values of horizontal and vertical errors. Due to the failure of PRN22 on 28 July 2001, the 99.99% values for all sites tracking the satellite at the time of failure have been severely affected. Both the vertical and horizontal 95% values failed for the day of the PRN22 failure (28 July 2001). This problem is addressed further in the problem section of this report.

Range performance was verified for each satellite using the data collected from the NSTB Anderson site. The data was collected in one-second samples. All of the satellites met the range error specifications except for PRN22 on 28 July 2001. This is addressed separately in the problem section of this report. The maximum range error recorded was 22.377 meters on Satellite PRN 9. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 0.74953 Meters/second on Satellite PRN 9. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 7.50 Millimeters/second^2 on Satellite PRN 9. The SPS specification states that the range acceleration error should never exceed 19 Millimeters/second^2.

A GLONASS/GPS performance section was added to the PAN report. In April 1999, ACT-360 was tasked to monitor, analyze and characterize GLONASS and GPS/GLONASS system performance. The objective of this task is to evaluate the ability of GLONASS to provide navigation by itself and with SPS GPS and to assess the incremental benefit to WAAS obtained from using GLONASS. A GPS/GLONASS receiver was used in the NSTB laboratory at the FAA Technical Center. The GPS/GLONASS performance (from an Ashtech GG24) was compared against GPS-only performance (collected from a Novatel receiver). The 95% horizontal error and vertical error for the GPS/GLONASS solution were 4.785 Meters and 8.893 Meters, respectively.

From the analysis performed on data collected between 1 July and 30 September 2001, the GPS performance did not meet all SPS requirements that were evaluated. Please view the problem section of this report for a further explanation of the problems that occurred this quarter.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

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

- Anderson, SC
- Atlantic City, NJ
- Columbus, NE
- Denver, CO
- Elko, NV
- Grand Forks, ND
- Great Falls, MT
- Atlantic City, NJ (FVS)
- Bangor, ME (FVS)
- Kansas City, KS
- Salt Lake City, UT
- Miami, FL
- Atlanta, GA

(Future reports will include all WAAS sites but a database that can handle all that data needs to be developed. ACT-360 is in the process of setting up an Oracle database for this purpose.)

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

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

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

1.2 Summary of Performance Requirements and Metrics

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

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

1.3 Report Overview

Section 2 of this report summarizes the results obtained from the coverage calculation program called SPS_CoverageArea developed by ACT-360. The SPS_CoverageArea program uses the GPS satellite almanacs to compute each satellite position as a function of time for a selected day of the week. This program establishes a 5-degree grid between 180 degrees east and 180 degrees west, and from 80 degrees north and 80 degrees south. The program then computes the PDOP at each grid point (1485 total grid points) every minute for the entire day and stores the results. After the PDOP's have been saved the 99.99% index of 1-minute PDOP at each grid point is determined and plotted as contour lines (Figure 2-1). The program also saves the number of satellites used in PDOP calculation at each grid point for analysis.

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

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

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

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

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

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

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report. The SPS specification was not met in several instances during the entire quarter due to the failure of PRN22 on 28 July 2001.

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

Appendix E provides the WAAS performance analysis report.

Table 1-1 SPS Performance Requirements

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

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

2.0 Coverage Performance

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

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

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

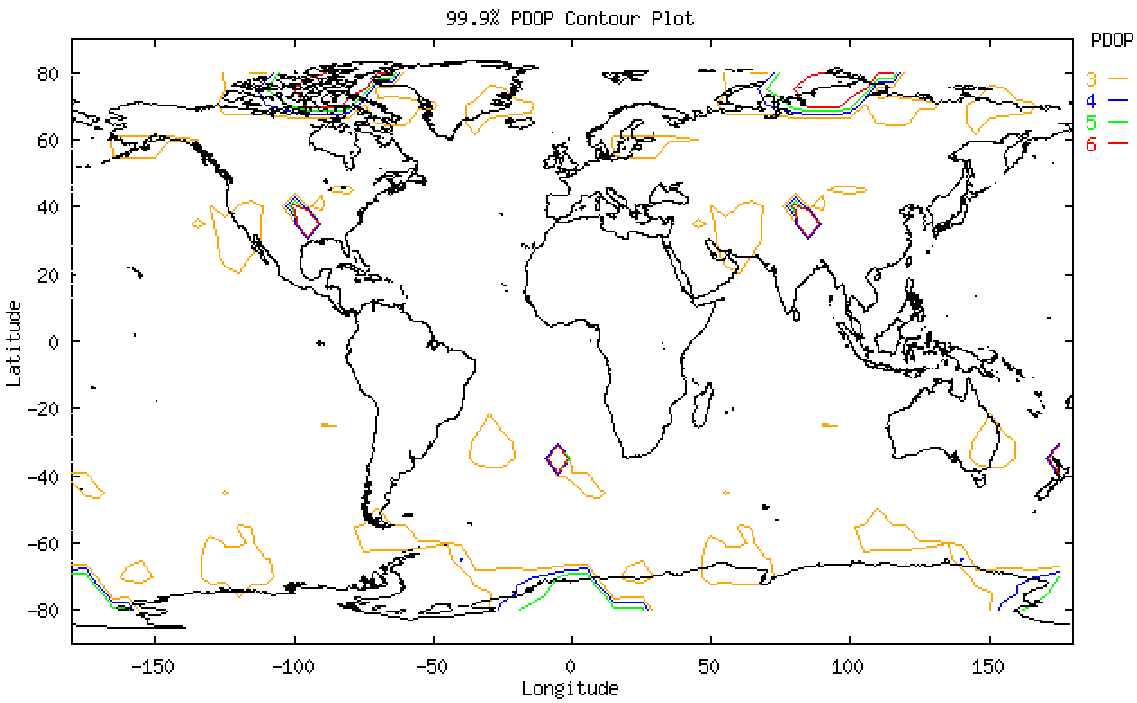
Almanacs for GPS weeks 97-109 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACT-360 was used to calculate the PDOP at every 5^o point between longitudes of 180W to 180E and 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. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.866 or better 99.9% for each of the 24-hour intervals.

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

Table 2-1 Coverage Statistics

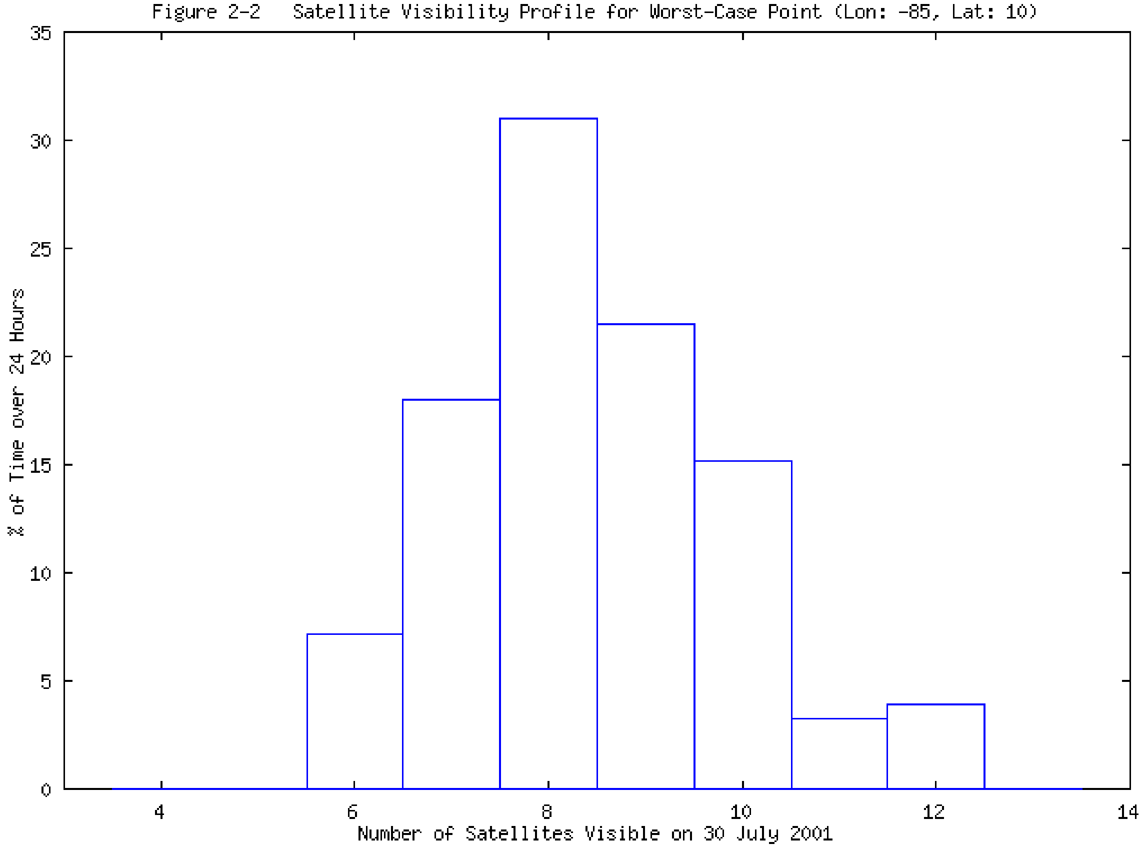
GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
97	3.100	100%	99.792%
98	3.100	100%	99.792%
99	3.080	100%	99.722%
100	3.056	100%	99.722%
101	3.866	99.972%	98.194%
102	3.866	99.972%	98.194%
103	3.858	99.972%	98.194%
104	2.957	100%	99.722%
105	2.959	100%	99.722%
106	3.313	99.992%	99.167%
107	2.969	100%	99.722%
108	2.991	100%	99.722%
109	3.003	100%	99.722%

Figure 2-1 SPS Coverage (24-Hour Period: 30 July 2001)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -85, Lat: 10)



3.0 Service Availability Performance

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

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANU's). During this reporting period, 1 July through 30 September 2001, there were a total of seventeen reported outages. Twelve of these outages were maintenance activities and were reported in advance. Five were unscheduled outages. A complete listing of outage NANU's for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-2. Canceled outage NANU's are provided in Table 3-3.

Table 3-1 NANUs Affecting Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
1086	24	S	10-Jul	4:37	10-Jul	16:17		11.67	11.67
1089	20	S	12-Jul	17:59	13-Jul	0:51		6.70	6.70
1092	15	S	13-Jul	17:53	13-Jul	23:39		5.77	5.77
1093	7	U	15-Jul	14:37	N/A	N/A	N/A	N/A	N/A
1094	7	U	15-Jul	14:37	15-Jul	15:49	1.20		1.20
1095	24	S	20-Jul	4:00	20-Jul	12:18		8.30	8.30
1100	9	S	27-Jul	4:29	27-Jul	8:28		3.98	3.98
1101	22	U	28-Jul	23:58	N/A	N/A	N/A	N/A	N/A
1104	1	U	6-Aug	15:35	6-Aug	16:16	0.68		0.68
1106	22	U	28-Jul	23:58	11-Aug	4:13	316.25		316.25
1107	17	S	21-Aug	14:36	21-Aug	18:32		3.93	3.93
1111	7	S	28-Aug	18:48	28-Aug	22:01		3.21	3.21
1112	30	U	29-Aug	21:02	N/A	N/A	N/A	N/A	N/A
1113	6	S	31-Aug	6:00	31-Aug	9:02		3.03	3.03
1114	30	U	29-Aug	21:02	4-Sep	20:55		23.88	23.88
1116	26	S	5-Sep	1:22	5-Sep	6:55		5.55	5.55
1117	15	S	11-Sep	14:45	11-Sep	15:57		1.20	1.20
1119	11	U	13-Sep	0:30	N/A	N/A	N/A	N/A	N/A
11120	11	U	13-Sep	0:30	13-Sep	5:30	5.00		5.00
1122	4	S	20-Sep	6:42	20-Sep	17:23		10.68	10.68
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**323.13**	**87.90**	**411.03**
Type:	S = Scheduled		U = Unscheduled						

	Table 3-2 NANUs Forecasted to Affect Satellite Availability							
NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
1083	24	F	10-Jul	4:30	7/10/2001	16:30	12	See NANU 1086
1084	20	F	12-Jul	17:45	13-Jul	5:45	12	See NANU 1089
1085	15	F	13-Jul	16:30	14-Jul	4:30	12	See NANU 1092
1087	18	F	20-Jul	19:00	21-Jul	7:00	12	See NANU 1096
1088	9	F	20-Jul	4:15	20-Jul	16:15	12	See NANU 1091
1090	24	F	20-Jul	4:00	20-Jul	16:00	12	See NANU 1095
1097	9	F	27-Jul	4:15	27-Jul	16:15	12	See NANU 1100
1098	6	F	2-Aug	7:30	2-Aug	19:30	12	See NANU 1102
1099	18	F	3-Aug	16:00	4-Aug	4:00	12	See NANU 1103
1105	17	F	21-Aug	14:00	22-Aug	2:00	12	See NANU 1107
1108	7	F	28-Aug	18:30	29-Aug	6:30	12	See NANU 1111
1109	6	F	31-Aug	6:00	31-Aug	18:00	12	See NANU 1113
1110	26	F	5-Sep	1:00	5-Sep	13:00	12	See NANU 1116
1115	15	F	11-Sep	14:00	12-Sep	2:00	12	See NANU 1117
1121	4	F	20-Sep	6:30	20-Sep	18:30	12	See NANU 1122
					Total Forecast Downtime		**168**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
1091	9	C	20-Jul	4:15	See NANU 1088
1096	18	C	20-Jul	19:00	See NANU 1087
1102	6	C	2-Aug	7:30	See NANU 1098
1103	18	C	3-Aug	16:00	See NANU 1099

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

Table 3-4 GPS Block II/IIA Satellite RMA Data		
Satellite Reliability/Maintainability/Availability (RMA) Parameter	**1 Jul - 30 Sep, 2001**	**12 December, 1998- 31 March, 2001 (qtrs = 9.21)**
Total Forecast Downtime (hrs):	168	3116.47
Total Actual Downtime (hrs):	411.03	5407.86
Total Actual Scheduled Downtime (hrs):	87.9	1628.57
Total Actual Unscheduled Downtime (hrs):	323.13	3755.31
Total Satellite Observed MTTR (hrs):	25.69	44.48
Scheduled Satellite Observed MTTR (hrs):	7.99	16.85
Unscheduled Satellite Observed MTTR (hrs):	64.63	112.93
# Total Satellite Outages:	16	219
# Scheduled Satellite Outages:	11	172
# Unscheduled Satellite Outages:	5	47
Percent Operational -- Scheduled Downtime:	99.86%	99.79%
Percent Operational -- All Downtime:	99.37%	98.92%

3.2 Service Availability

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

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

Table 3-5 PDOP Statistics

NSTB/WAAS Site	Min PDOP	Max PDOP	VDOP at Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP	Number of Samples
Anderson	1.315	5.711	5.472	2.191	5.500	5.187	758519
Atlantic City	1.256	6.844	6.110	1.837	6.327	5.651	7944430
Columbus	1.236	7.636	7.117	1.852	5.640	4.993	6493572
Denver	1.200	6.713	3.558	1.827	5.727	4.816	7788160
Elko	1.178	5.668	4.963	1.867	5.041	4.424	757013
Grand Forks	1.240	7.622	7.238	1.804	5.546	5.172	7941857
Great Falls	1.321	3.530	2.645	2.062	3.519	2.741	751721
Atlantic City (FVS)	1.274	4.401	4.030	1.870	4.352	4.064	758504
Bangor (FVS)	1.192	20.871	17.113	1.822	5.656	5.182	2606166
Atlanta	1.284	6.273	5.860	1.845	5.213	4.588	4872316
Kansas City	1.265	7.755	7.072	1.823	5.904	5.206	4535897
Salt Lake City	1.154	6.448	5.761	1.775	4.928	4.486	4821025
Miami	1.205	6.964	6.572	1.785	6.794	6.285	4677306

Tables 3-6 and 3-7 show the statistics related to maximum PDOP and PDOP greater than six, respectively. Table 3-6 shows the PDOP statistics for the worst-case point on the worst-case day. NOTE: Global in this report refers to the nine sites used. Although future reports will have all WAAS sites, a true global availability cannot be determined since there aren't reference stations around the world.

Whenever the PDOP goes above six and an SPS requirement is not met, an investigation is performed to determine what caused the PDOP to go above six. The following is a list of programs/procedures used during times of high PDOP:

- Notice of Advisory to Navstar Users (NANU's) messages are used to verify that satellite outages did occur. (See Section 3.1 for more details about NANU's for this quarter.)

- A satellite outage detection program developed by ACT-360 verifies satellite outages that are not verified through a NANU. For example, a satellite outage can occur for just a few seconds during an upload. This satellite detection program monitors all the receivers and keeps track of what satellites the receiver should be tracking versus what satellites the receiver is actually tracking. At least six receivers need to be tracking the satellite prior to the outage and no receiver can be tracking the satellite for the program to detect an outage. This program is also being enhanced so that false locks and late ephemeris problems can also be detected. This program will also output flags from the receivers so that problems with the receiver or TRS software, if any, can be tracked more easily.

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

The instance of worst performance where the PDOP went above six is reported in Table 3-6. The column labeled "NANU/SOD" reports whether the outage was detected via a NANU or the Satellite Outage Detection (SOD) program along with the Satellite PRN number that had the outage.

Table 3-6 Maximum PDOP Statistics

Site	GPS Week/ Day	Max PDOP	Number of Seconds of Whole Day PDOP > 6	NANU/SOD, Satellite PRN Number	Number of Samples	Availability on days when PDOP > 6
Miami	103_1	6.964	1213		86395	98.595
Worst-Case Point on Worst-Case Day = 98.595% (SPS Spec. ≥ 83.92%)						

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

Table 3-7 PDOP > 6 Statistics

NSTB/WAAS Site	Total Number of Seconds of PDOP Monitoring	Total Seconds with PDOP > 6	Overall % Availability
Anderson	758519	0	100%
Atlantic City	7944430	834	99.989%
Columbus	6493572	191	99.997%
Denver	7788160	406	99.994%
Elko	757013	0	100%
Grand Forks	7941857	52	99.999%
Great Falls	751721	0	100%
Atlantic City (FVS)	758504	0	100%
Bangor (FVS)	2606166	10	99.999%
Atlanta	4872316	29	99.999%
Kansas City	4535897	293	99.993%
Salt Lake City	4821025	105	99.997%
Miami	4677306	1213	99.974%
Worst Single Point Average = 99.974% (SPS Spec. ≥ 99.16%)			

Global Average over Reporting Period = 99.995% (SPS Spec. > 99.85%)

4.0 Service Reliability Standard

Service Reliability: *Given coverage and service availability, the percentage of time over a specified time interval that the instantaneous predictable horizontal error is maintained within a specified threshold at any point on or near the Earth.*

Service Reliability Standard	Conditions and Constraints
≥ 99.97% global average	• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval
≥ 99.79% single point average	• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval

Table 4-1 has the 99.99% horizontal errors reported by a receiver at each of the nine NSTB/WAAS sites. This will be evaluated against the SPS specification at the end of the year.

Table 4-1 Service Reliability Based on Horizontal Error

NSTB/WAAS Site	Number of Samples This Quarter	Maximum Horizontal Error (Meters)
Anderson	758519	17.9
Atlantic City	7944430	222000*
Columbus	6493572	278000*
Denver	7788160	264000*
Elko	757013	9.73
Grand Forks	7941857	220000*
Great Falls	751721	8.14
Atlantic City (FVS)	758504	8.66
Bangor (FVS)	2606166	180000*
Atlanta	4872316	167000*
Kansas City	4535897	181000*
Salt Lake City	4821025	200000*
Miami	4677306	136000

* Note: Numbers rounded to nearest thousands due to memory restrictions of statistical process.

All sites that tracked the PRN22 event on 28 July 2001 exceeded the 500-meter Horizontal Error 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 July through 30 September 2001 at the NSTB and WAAS selected locations.

Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter.

Table 5-1 Horizontal & Vertical Accuracy Statistics for the Quarter

NSTB Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal* (Meters)	99.99% Vertical* (Meters)
Anderson	1.403	9.171	11.778	21.032
Atlantic City	4.499	7.902	208491.297	366464.500
Columbus	4.905	7.534	181428.047	114620.000
Denver	4.798	7.496	187235.672	89303.898
Elko	4.404	8.020	8.683	16.177
Grand Forks	4.809	7.266	153539.125	120874.008
Great Falls	3.584	7.642	7.827	12.654
Atlantic City (FVS)	4.952	7.474	8.182	13.683
Bangor (FVS)	6.138	7.780	160931.750	273606.438
Atlanta	5.192	8.537	165911.906	394625.188
Kansas City	5.126	7.649	92148.531	63184.152
Salt Lake City	5.051	7.876	10.350	20.522
Miami	5.924	10.583	135032.594	431648.281

* Note: For those sites that were tracking the failure of PRN22 on 28 July 2001, the 99.99% values will be affected. This is due to the fact that the PRN22 event lasted long enough to fail the 99.99% requirement.

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all seven NSTB and two WAAS sites from 1 July to 30 September 2001. Any value greater than 30 meters was placed into the 30+ meter histogram bin. Due to the PRN22 event on 28 July 2001, you will notice a spike at the far right of the histogram.

Figure 5-1 Combined Vertical Error Histogram

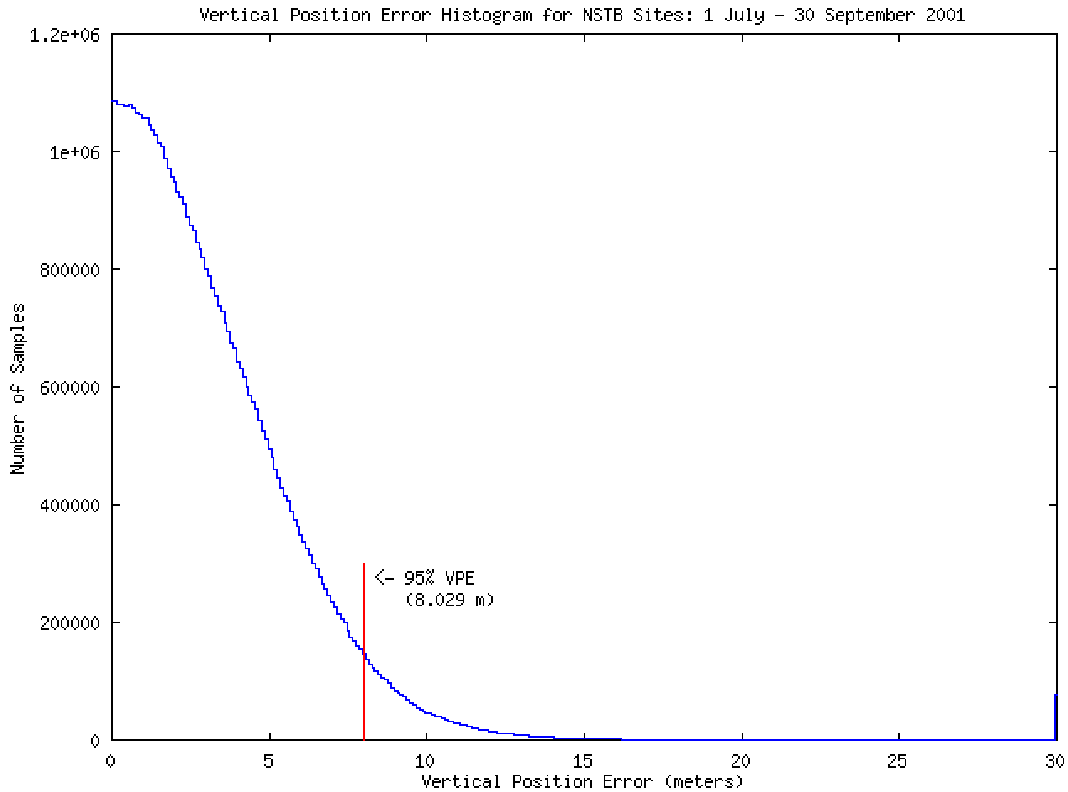
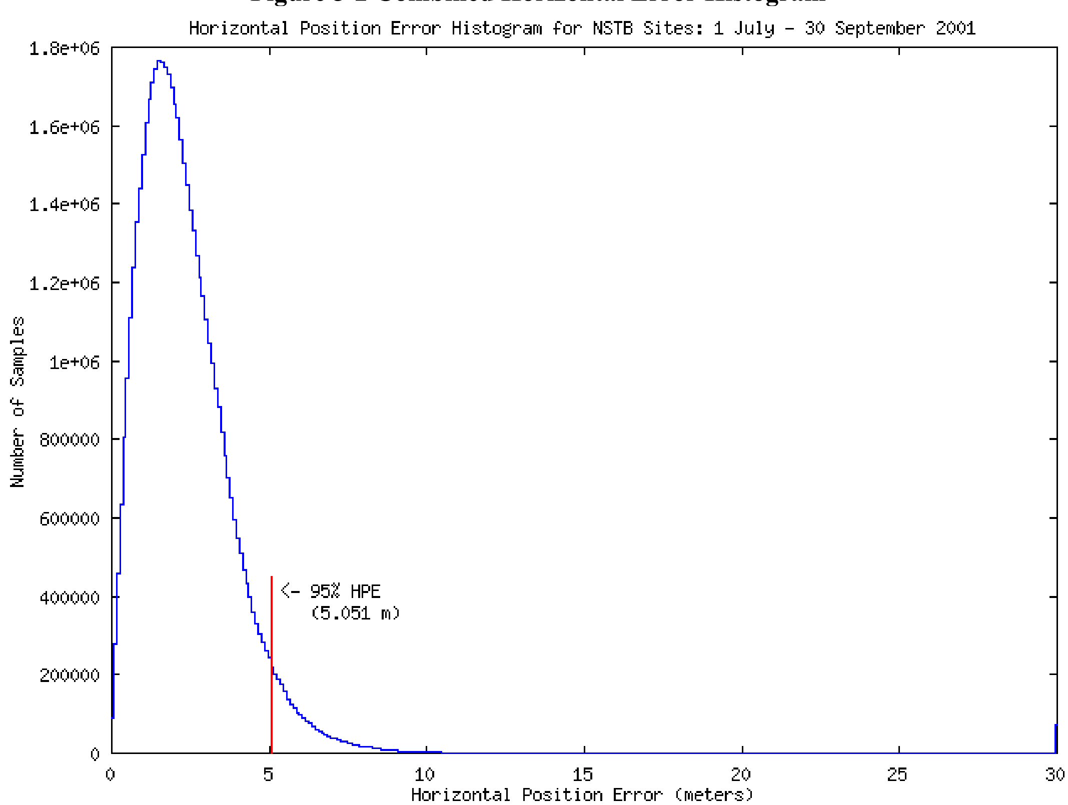


Figure 5-2 Combined Horizontal Error Histogram



5.2 Repeatable Accuracy

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

Table 5-2 Repeatability Statistics

NSTB Site	95% Horizontal (m)	95% Vertical (m)
Anderson	2.213	7.122
Atlantic City	1.705	3.966
Columbus	1.356	3.066
Denver	1.405	3.455
Elko	1.778	4.871
Grand Forks	1.440	3.130
Great Falls	1.415	3.521
Atlantic City (FVS)	2.044	4.960
Bangor (FVS)	1.964	4.507
Atlanta	1.632	4.321
Kansas City	1.489	3.801
Salt Lake City	1.360	3.327
Miami	1.717	4.944

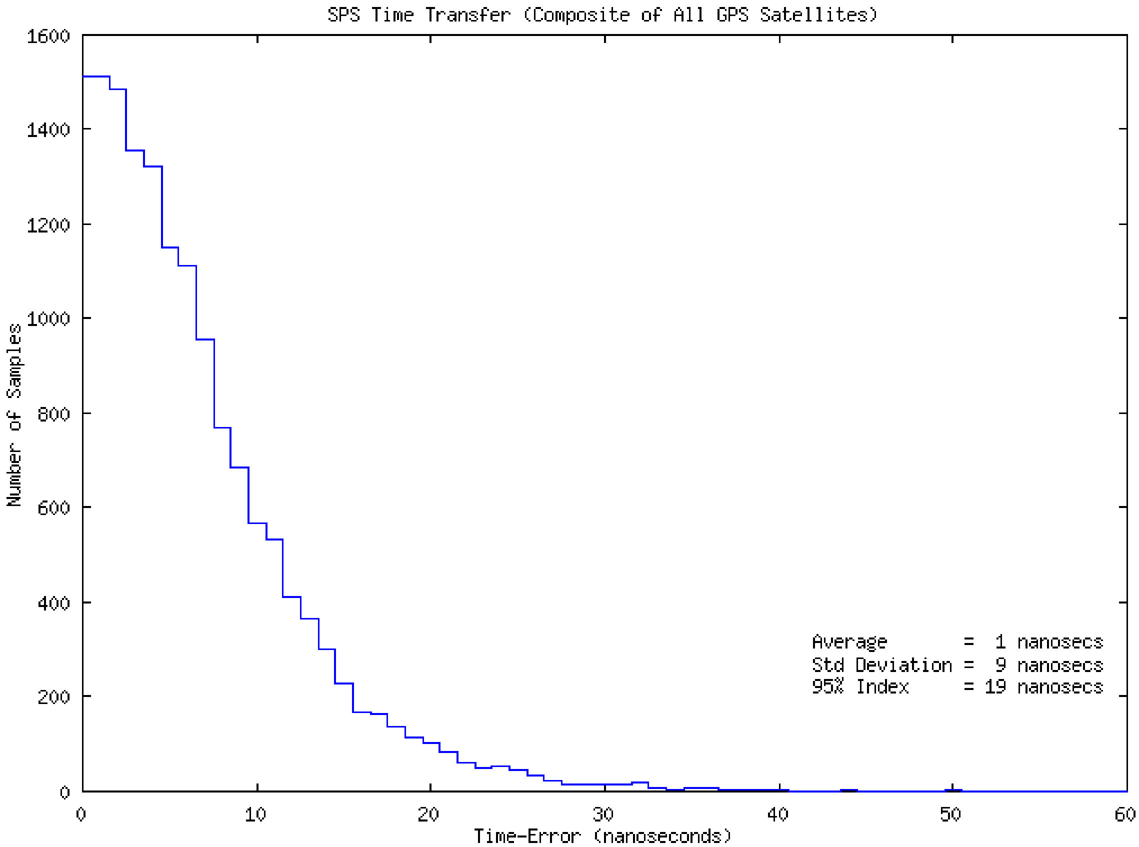
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 July and 30 September 2001 was down loaded from USNO Internet site. The USNO data file contains the time difference between the USNO master clock and GPS system time for each GPS satellites during the time period. Over 10,000 samples of GPS time error are contained in the USNO data file. In order to evaluate the GPS time transfer error, the data file was used to create a histogram (Fig 5-3) to represent the distribution of GPS time error. The histogram was created by taking the absolute value of time difference between the USNO master clock and GPS system time, then creating data bins with one nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Fig 5-3. The mean, standard deviation, and 95% index are within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Errors



5.5 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 July and 30 September 2001. The Millennium at Anderson was used to collect range measurement. Future PAN reports will contain statistics from all WAAS sites.

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

Table 5-3 Range Error Statistics (meters)

PRN	Range Error Mean	Range Error RMS	1σ	95% Range Error	Max Range Error (SPS Spec. ≤ 150 m)	Samples
1	-1.416	3.046	2.697	6.275	11.386	2210489
2	-0.374	2.577	2.550	5.210	12.003	1992492
3	-1.852	3.539	3.016	7.274	16.832	2016271
4	-0.432	2.168	2.124	4.301	8.276	2186973
5	0.168	2.722	2.717	5.285	19.383	2551839
6	-1.012	3.366	3.210	6.428	13.216	2462647
7	0.070	2.195	2.193	4.323	10.918	2273255
8	-0.885	2.971	2.836	5.673	15.609	2164066
9	0.460	3.478	3.447	6.712	22.377	2281456
10	-0.098	2.861	2.860	5.882	11.008	2077887
11	-0.994	2.622	2.426	5.232	18.907	2185788
13	-0.809	2.407	2.267	4.886	18.992	2509241
14	0.753	3.263	3.175	6.234	10.813	2251001
15	0.844	4.300	4.216	8.397	13.299	2009223
17	0.561	4.655	4.621	8.698	16.047	1826098
18	1.135	3.890	3.720	7.519	12.521	2163128
20	-0.233	2.159	2.147	4.250	17.248	2538469
21	1.078	3.970	3.821	7.705	15.805	1983521
22	-1.191	3.515	3.307	6.840	14.339	1759159
23	0.130	4.038	4.036	7.654	14.065	2277183
24	0.124	2.629	2.626	5.312	10.275	2260537
25	-0.787	3.759	3.676	7.085	18.314	2289913
26	0.152	3.597	3.594	6.850	16.085	1822143
27	-1.690	3.441	2.997	6.673	13.617	1829819
28	-0.968	3.097	2.942	5.928	13.250	2190464
29	-0.237	3.147	3.138	6.088	11.640	2229672
30	-0.688	3.036	2.957	5.850	19.444	2329380
31	-1.550	3.463	3.097	6.965	13.785	1912486

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

PRN	Range Rate Error Mean	Range Rate Error RMS	Range Rate Error 1σ	95% Range Rate Error	Max Range Rate Error (SPS Spec. ≤ 2 m)	Samples
1	0.00000	0.00739	0.00739	0.01474	0.23881	2210489
2	-0.00006	0.00772	0.00772	0.01495	0.20948	1992492
3	-0.00012	0.00799	0.00798	0.01401	0.55200	2016271
4	0.00001	0.00589	0.00589	0.01210	0.15011	2186973
5	-0.00014	0.00927	0.00926	0.01669	0.58077	2551839
6	0.00001	0.00783	0.00783	0.01521	0.25999	2462647
7	0.00007	0.00698	0.00698	0.01448	0.17950	2273255
8	-0.00009	0.00759	0.00759	0.01517	0.19150	2164066
9	-0.00032	0.01069	0.01068	0.01788	0.74953	2281456
10	0.00001	0.00679	0.00679	0.01190	0.42546	2077887
11	0.00008	0.01068	0.01068	0.01736	0.74109	2185788
13	0.00003	0.00823	0.00823	0.01391	0.69738	2509241
14	-0.00013	0.00758	0.00758	0.01629	0.09274	2251001
15	0.00027	0.00826	0.00826	0.01663	0.25031	2009223
17	0.00011	0.00709	0.00709	0.01445	0.31504	1826098
18	-0.00004	0.00717	0.00717	0.01470	0.08502	2163128
20	-0.00007	0.00933	0.00933	0.01616	0.61157	2538469
21	0.00011	0.00750	0.00750	0.01534	0.26132	1983521
22	-0.00029	0.00643	0.00642	0.01191	0.28556	1759159
23	0.00008	0.00706	0.00706	0.01430	0.18500	2277183
24	-0.00001	0.00721	0.00721	0.01401	0.29441	2260537
25	-0.00022	0.00753	0.00752	0.01493	0.20282	2289913
26	-0.0023	0.00708	0.00708	0.01328	0.43242	1822143
27	0.00000	0.00727	0.00727	0.01436	0.26463	1829819
28	0.00006	0.00727	0.00727	0.01450	0.19279	2190464
29	-0.00005	0.00714	0.00714	0.01441	0.41893	2229672
30	-0.00017	0.01009	0.01009	0.01828	0.70992	2329380
31	-0.00014	0.00693	0.00693	0.01265	0.32857	1912486

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1σ	% ≤ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. ≤ 0.019 m/s2)	Samples
1	0.00000	0.00007	0.00007	100	0.00232	2210489
2	0.00000	0.00007	0.00007	100	0.00230	1992492
3	0.00000	0.00007	0.00007	100	0.00553	2016271
4	0.00000	0.00005	0.00005	100	0.00148	2186973
5	0.00000	0.00008	0.00008	100	0.00575	2551839
6	0.00000	0.00007	0.00007	100	0.00264	2462647
7	0.00000	0.00006	0.00006	100	0.00177	2273255
8	0.00000	0.00007	0.00007	100	0.00190	2164066
9	0.00000	0.00010	0.00010	100	0.00750	2281456
10	0.00000	0.00006	0.00006	100	0.00431	2077887
11	0.00000	0.00010	0.00010	100	0.00737	2185788
13	0.00000	0.00008	0.00008	100	0.00700	2509241
14	0.00000	0.00007	0.00007	100	0.00083	2251001
15	0.00000	0.00007	0.00007	100	0.00250	2009223
17	0.00000	0.00006	0.00006	100	0.00319	1826098
18	0.00000	0.00006	0.00006	100	0.00088	2163128
20	0.00000	0.00009	0.00009	100	0.00605	2538469
21	0.00000	0.00007	0.00007	100	0.00262	1983521
22	0.00000	0.00006	0.00006	100	0.00286	1759159
23	0.00000	0.00006	0.00006	100	0.00185	2277183
24	0.00000	0.00006	0.00006	100	0.00296	2260537
25	0.00000	0.00007	0.00007	100	0.00199	2289913
26	0.00000	0.00006	0.00006	100	0.00432	1822143
27	0.00000	0.00006	0.00006	100	0.00262	1829819
28	0.00000	0.00006	0.00006	100	0.00198	2190464
29	0.00000	0.00006	0.00006	100	0.00418	2229672
30	0.00000	0.00009	0.00009	100	0.00713	2329380
31	0.00000	0.00006	0.00006	100	0.00335	1912486

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the maximum range error, range rate error and range acceleration error for all satellites. None of the range errors for any of the satellites exceeded the 150-meter SPS requirement. The highest maximum range error occurred on satellite 9 with an error of 22.377 meters. Satellite 4 had the lowest maximum range error of 8.276.

Figure 5-4 Distribution of Daily Max Range Errors

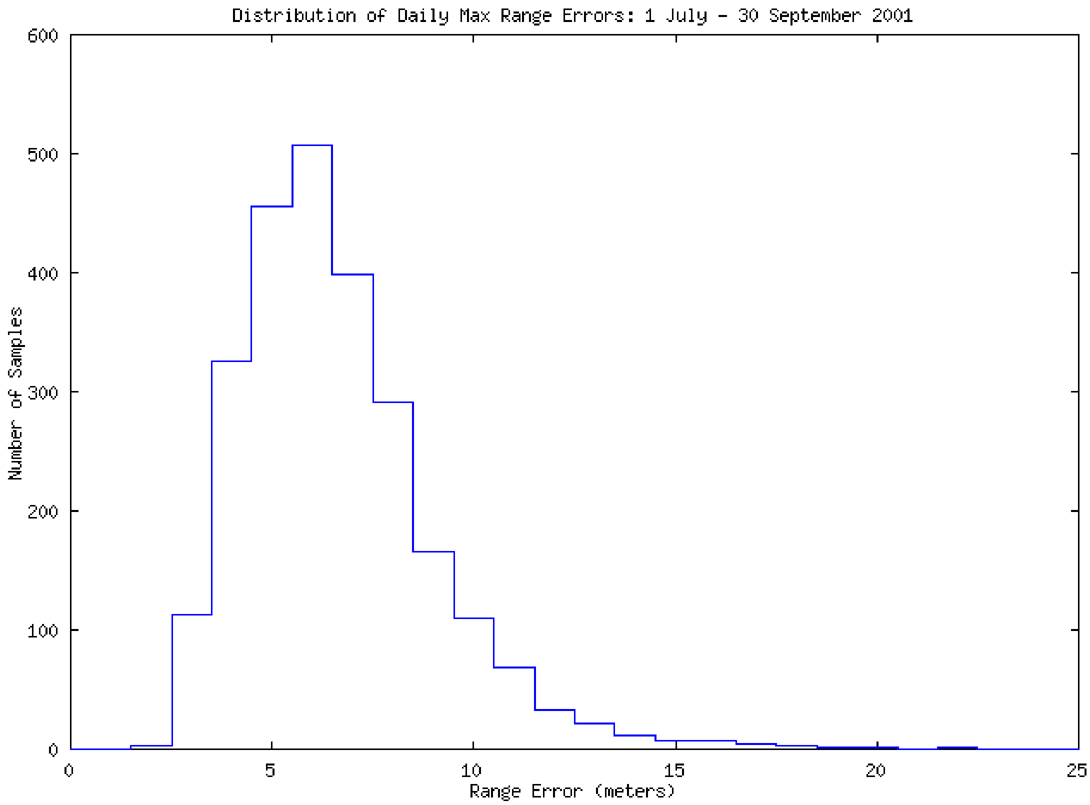


Figure 5-5: Distribution of Daily Max Range Rate Errors

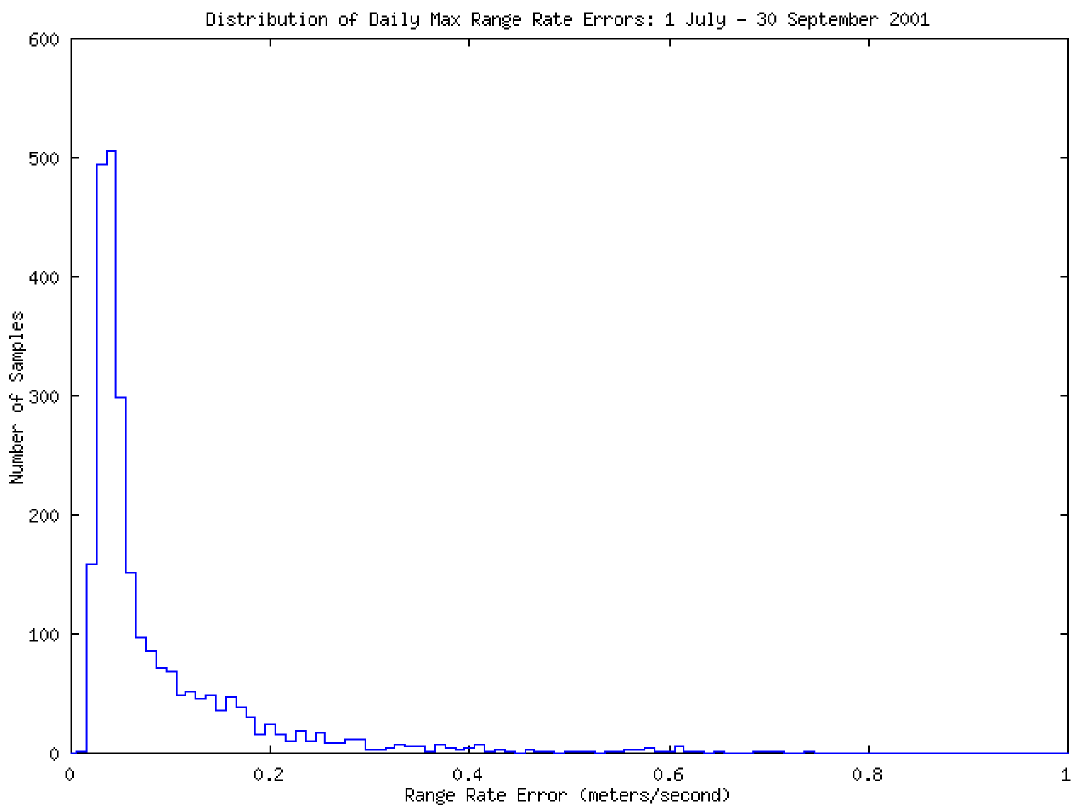


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

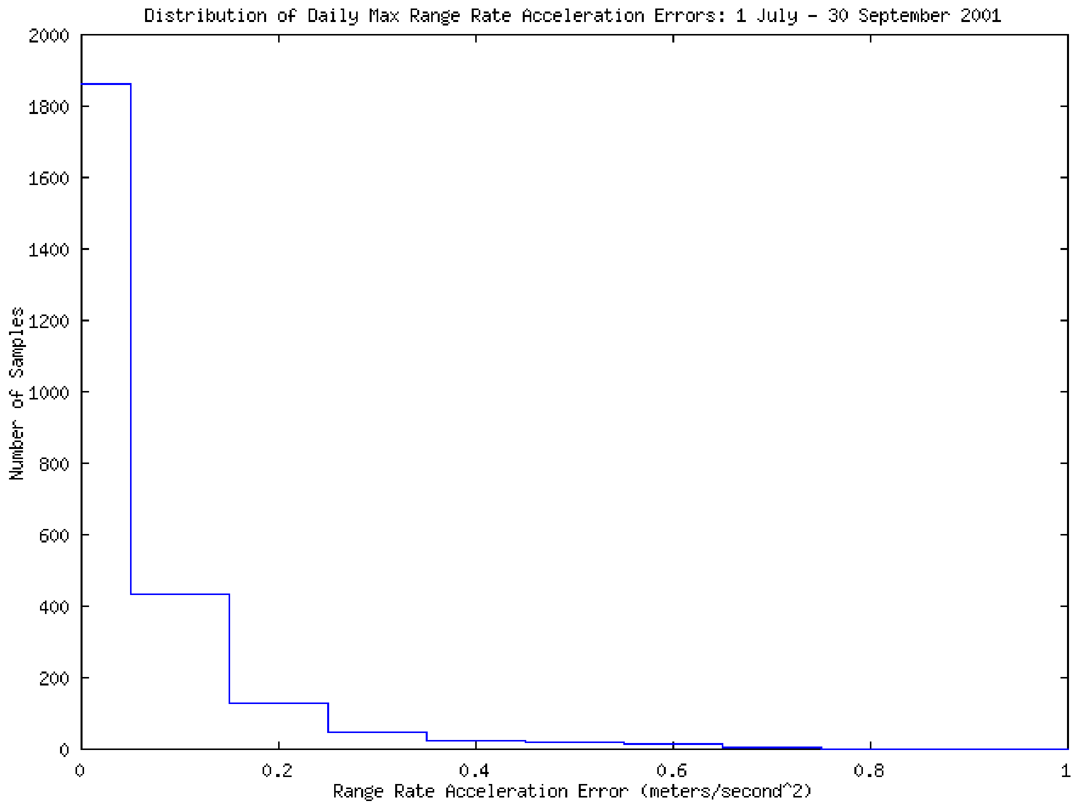


Figure 5-7: Maximum Range Error Per Satellite

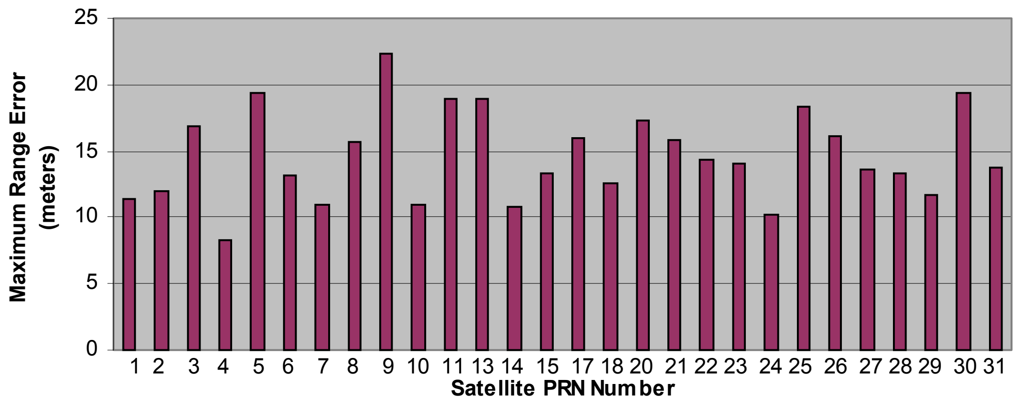


Figure 5-8: Maximum Range Rate Error Per Satellite

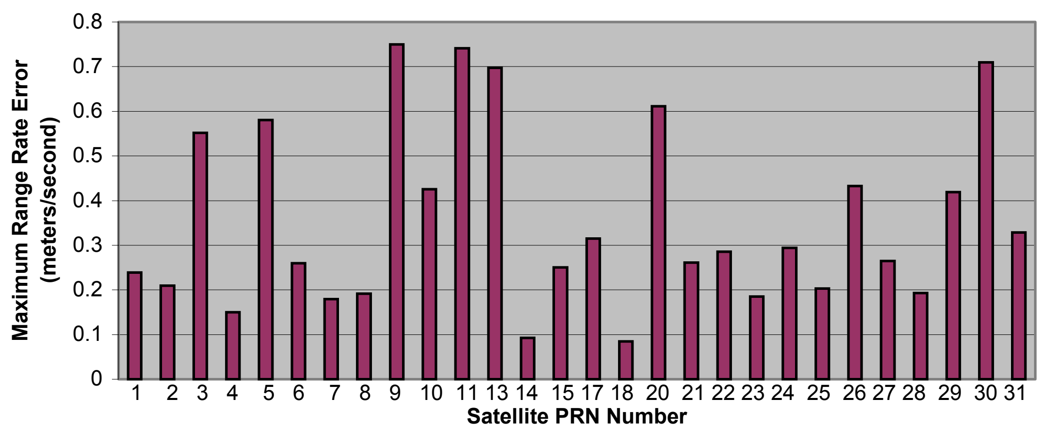
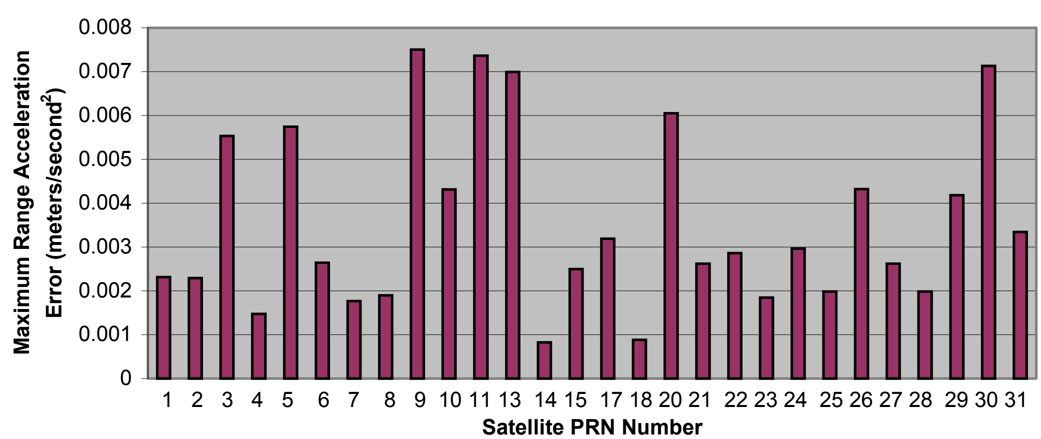


Figure 5-9: Maximum Range Acceleration Per Satellite



6.0 Solar Storms

Solar storm activity is being monitored in order to assess the possible impact on GPS SPS performance. Solar activity is reported by the Space Environment Center (SEC) , a division of the National Oceanic and Atmospheric Administration (NOAA). When storm activity is indicated, ionospheric delays of the GPS signal, satellite outages, position accuracy and availability will be analyzed.

The following article was taken from the SEC web site http://sec.noaa.gov. It briefly explains some of the ideas behind the association of the aurora with geomagnetic activity and a bit about how the 'K-index' or 'K-factor' works.

> *The aurora is caused by the interaction of high-energy particles (usually electrons) with neutral atoms in the earth's upper atmosphere. These high-energy particles can 'excite' (by collisions) valence electrons that are bound to the neutral atom. The 'excited' electron can then 'de-excite' and return back to its initial, lower energy state, but in the process it releases a photon (a light particle). The combined effect of many photons being released from many atoms results in the aurora display that you see.*
>
> *The details of how high energy particles are generated during geomagnetic storms constitute an entire discipline of space science in its own right. The basic idea, however, is that the Earth's magnetic field (let us say the 'geomagnetic field') is responding to an outwardly propagating disturbance from the Sun. As the geomagnetic field adjusts to this disturbance, various components of the Earth's field change form, releasing magnetic energy and thereby accelerating charged particles to high energies. These particles, being charged, are forced to stream along the geomagnetic field lines. Some end up in the upper part of the earth's neutral atmosphere and the auroral mechanism begins.*
>
> *An instrument called a magnetometer may also measure the disturbance of the geomagnetic field. At NOAA's operations center magnetometer data is received from dozens of observatories in one-minute intervals. The data is received at or near to 'real-time' and allows NOAA to keep track of the current state of the geomagnetic conditions. In order to reduce the amount of data NOAA converts the magnetometer data into three-hourly indices, which give a quantitative, but less detailed measure of the level of geomagnetic activity. The K-index scale has a range from 0 to 9 and is directly related to the maximum amount of fluctuation (relative to a quiet day) in the geomagnetic field over a three-hour interval.*
>
> *The K-index is therefore updated every three hours. The K-index is also necessarily tied to a specific geomagnetic observatory. For locations where there are no observatories, one can only estimate what the local K-index would be by looking at data from the nearest observatory, but this would be subject to some errors from time to time because geomagnetic activity is not always spatially homogenous.*
>
> *Another item of interest is that the location of the aurora usually changes geomagnetic latitude as the intensity of the geomagnetic storm changes. The location of the aurora often takes on an 'oval-like' shape and is appropriately called the auroral oval.*

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

Figure 6-1 K-Index for 15 - 17 August 2001

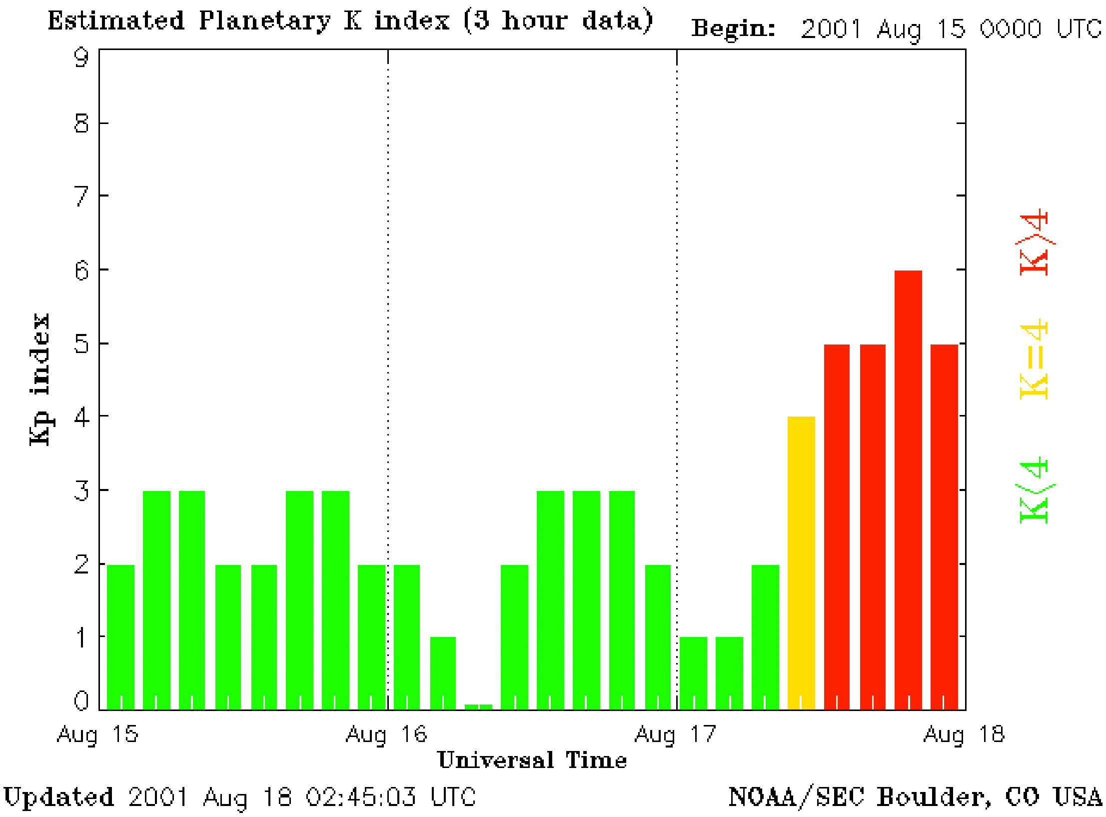


Figure 6-2 K-Index for 23-25 September 2001

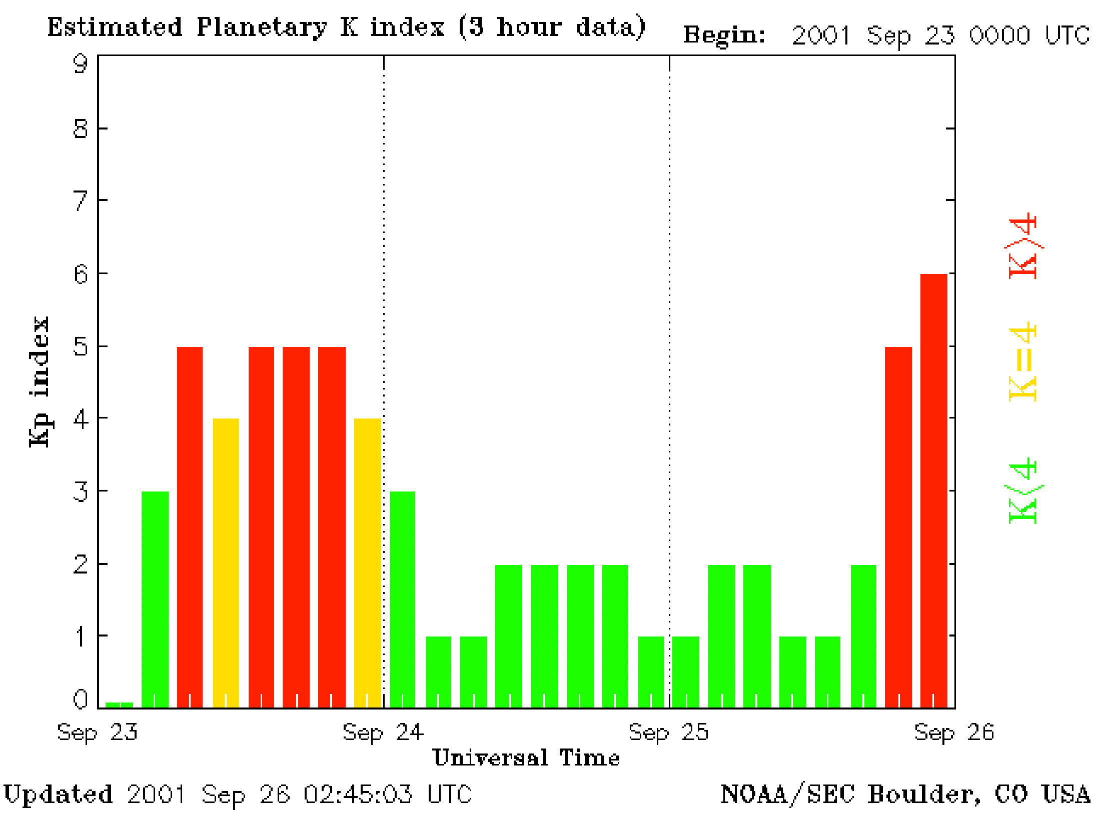
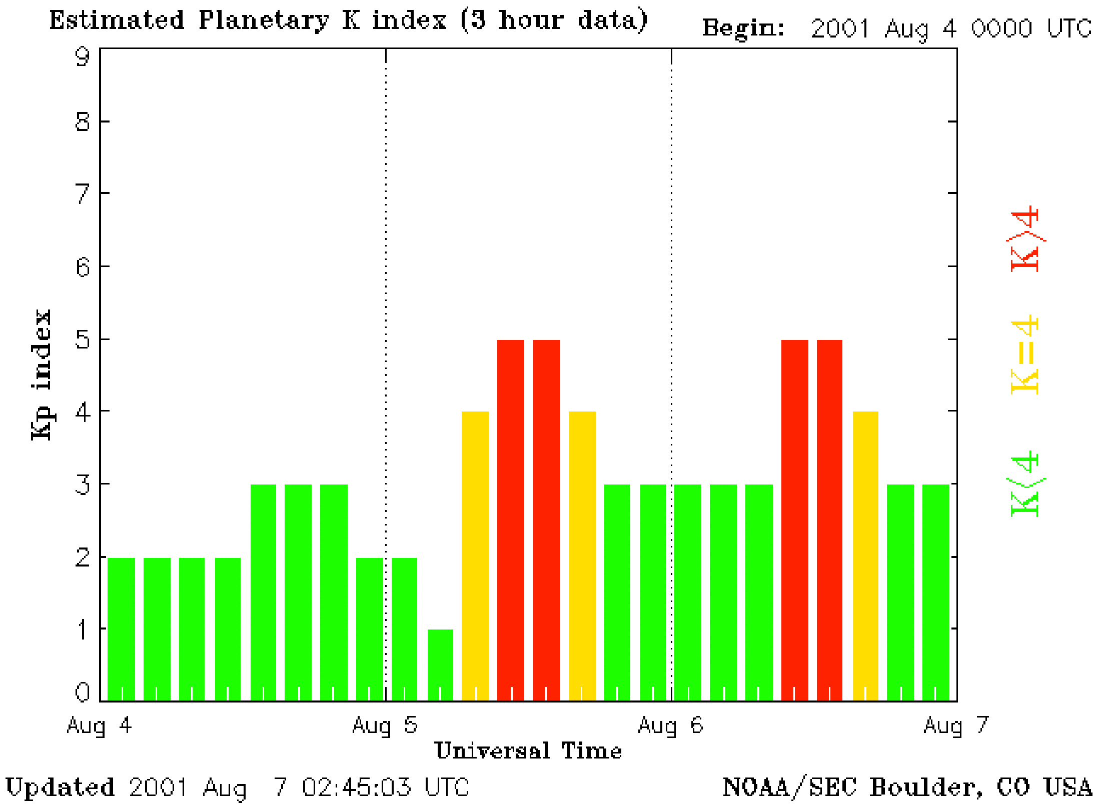


Figure 6-3 K-Index for 4-6 August 2001



Tables 6-1 and 6-2 below show the PDOP and position accuracy information, respectively, for the days corresponding to Figure 6-1. The GPS SPS performance met the availability requirements during all storms that occurred during this quarter.

Table 6-1 PDOP Statistics

NSTB Site	Min	Max	Mean	99.99%	99.99% VDOP
Anderson					
8/17/01	1.349	5.826	2.062	5.358	5.019
Arcata					
8/17/01	1.224	3.224	1.811	3.222	2.910
Atlantic City					
8/17/01	1.263	5.595	1.753	4.388	3.751
Columbus					
8/17/01	1.240	3.038	1.800	3.037	2.694
Grand Forks					
8/17/01	1.252	2.845	1.766	2.844	2.385
Greenwood					
8/17/01	1.298	3.050	1.813	3.050	2.686
Prescott					
8/17/01	1.358	4.970	2.111	4.965	4.480

Table 6-2 Horizontal & Vertical Accuracy Statistics*

NSTB Site	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)
Anderson				
8/17/01	5.030	8.592	8.643	20.871
Arcata				
8/17/01	7.615	6.941	9.828	9.623
Atlantic City				
8/17/01	6.510	5.763	8.758	11.996
Columbus				
8/17/01	6.647	6.406	9.359	12.019
Grand Forks				
8/17/01	5.051	8.717	9.631	11.576
Greenwood				
8/17/01	7.312	7.432	10.636	12.084
Prescott				
8/17/01	7.287	6.613	10.188	11.416

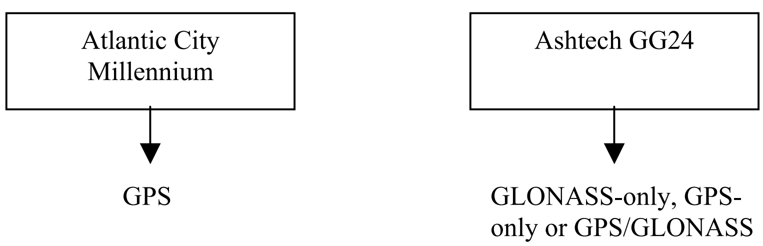
7.1 Introduction

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

7.2 Approach

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

Figure 7-1 Receivers with Corresponding Solutions



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

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

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

7.3 Quarter Results

For this quarter, data collected from the Atlantic City Ashtech GG24 Glonass/GPS receiver and the Millennium GPS receiver will be analyzed and compared.

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

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

Receiver	Solution	Maximum PDOP	Minimum PDOP	Mean PDOP	95% PDOP	Number of Samples
Ashtech GG24	GPS/GLONASS	4.519	1.131	1.737	2.326	7543713
Millenium	GPS Only Atlantic City	6.844	1.256	1.837	2.418	7944430

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

Receiver	Solution	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)	Number of Samples
Ashtech GG24	GPS/GLONASS	4.785	8.893	89.426	171.936	7543713
Millenium	GPS Only Atlantic City	4.499	7.902	208491.297	366464.500	7944430

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

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

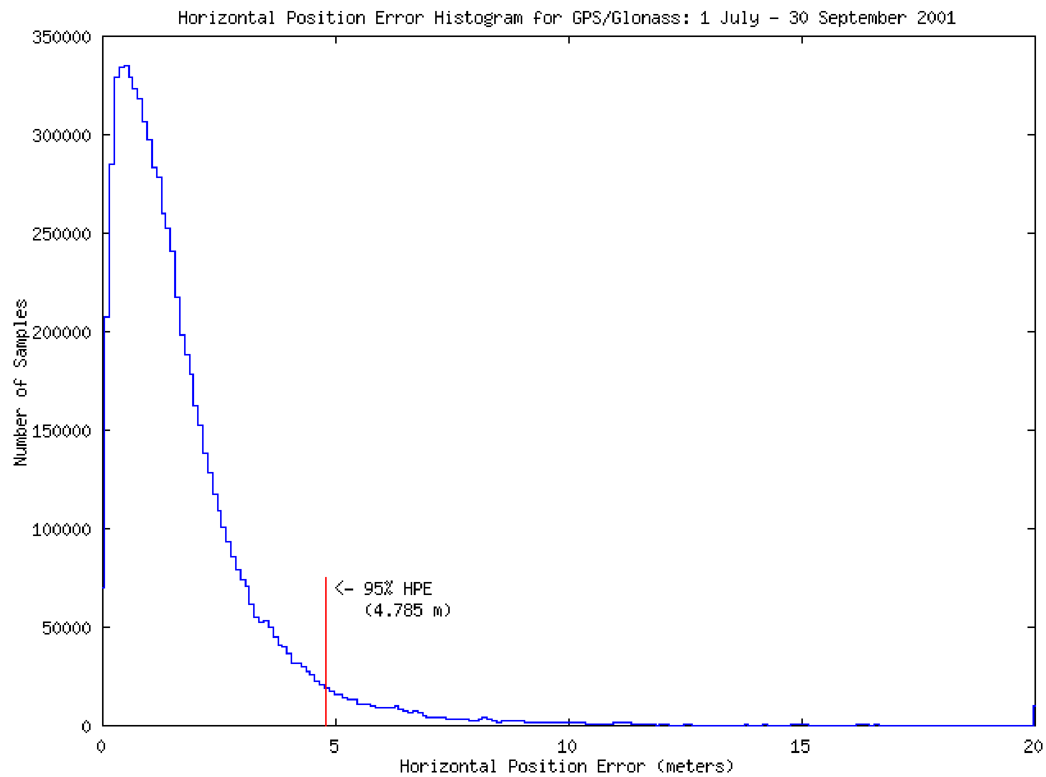


Figure 7-3 Vertical Position Error Histogram for GPS/GLONASS

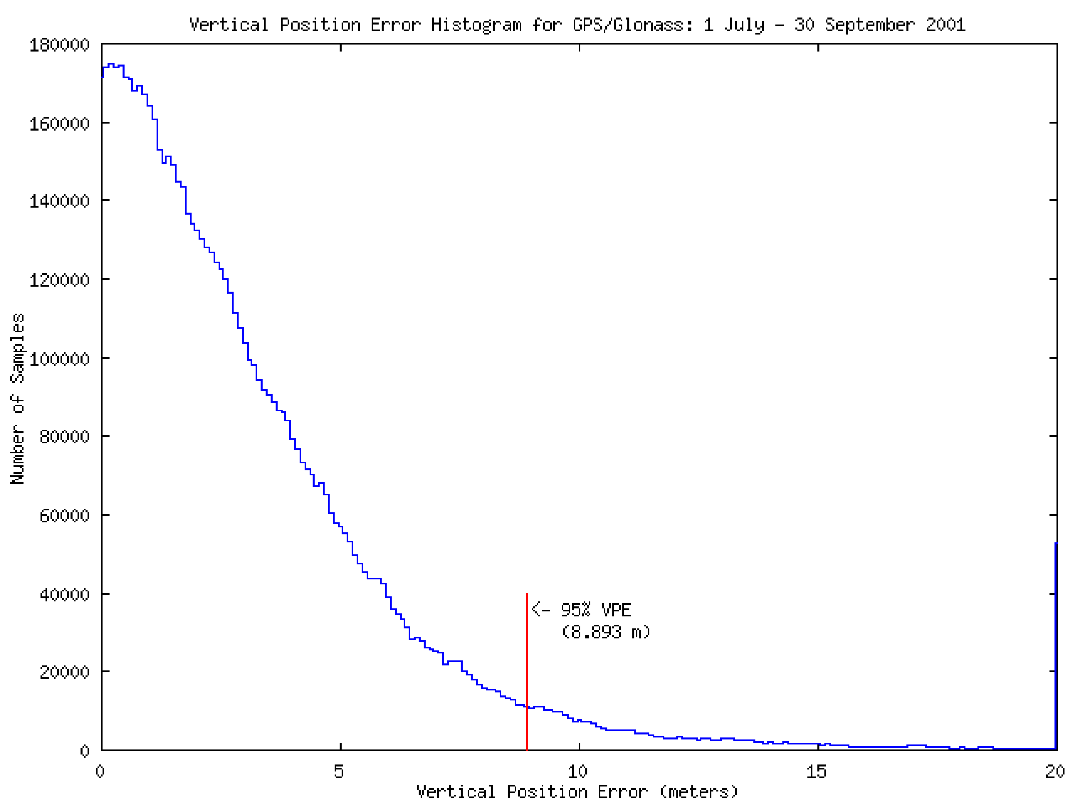
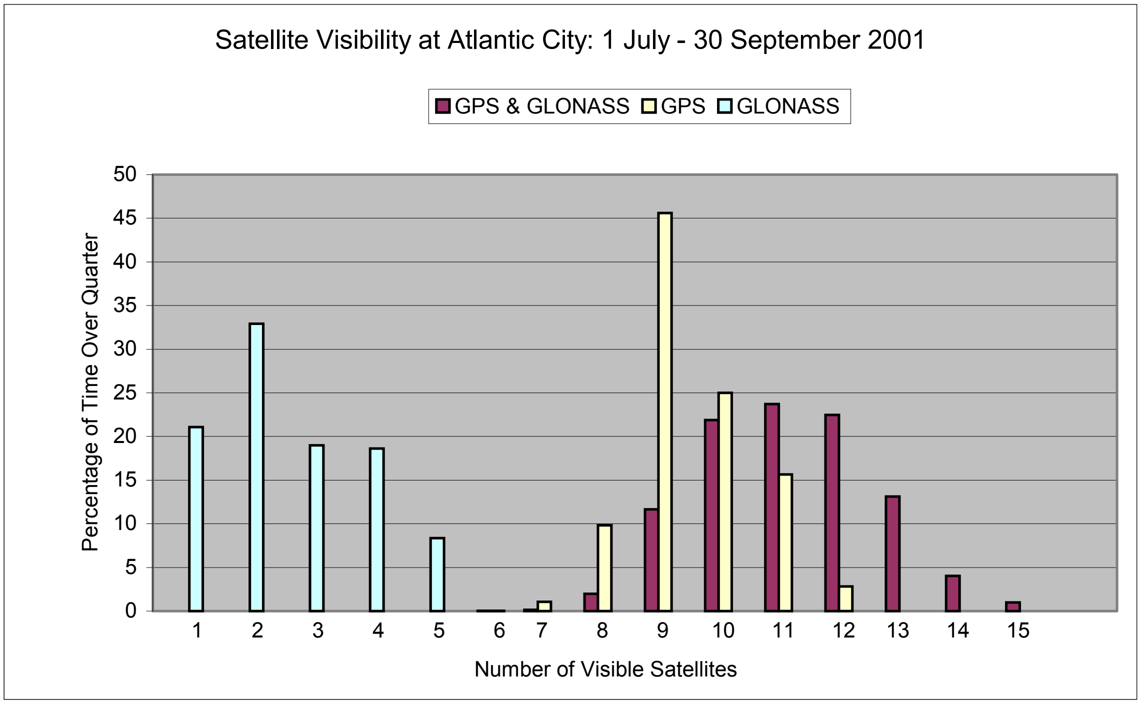


Figure 7-4 Glonass and GPS Satellite Visibility



APPENDICES A – E

Conditions and Constraints	*Coverage Standard*	*Measured Performance*
• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 99.9% global average	99.972%
• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 96.9% at worst-case point	98.194% Availability 99.991% PDOP was 3.866
Conditions and Constraints	***Satellite Availability Standard***	***Measured Performance***
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.85% global average	99.995%
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.16% single point average	99.974%
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	99.815%
• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	≥ 83.92% at worst-case point on worst-case day	98.595%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.97% global average	100%

• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.79% single point average	100%
Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	Predictable Accuracy ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	≤6.138m H Er. 95% ≤208491.297m H Er. 99.99% ≤10.583m V Er. 95% ≤431648.281m V Er. 99.99%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	Repeatable Accuracy ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	≤2.213m H Er. 95% ≤7.122m V Er. 95%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	Relative Accuracy ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	Future Reports
• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	≤19 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards	Range Domain Accuracy ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range	22.377m NTE Range Error 0.74953m/s NTE Rate Error 7.50mm/s^2 NTE Accl. Error

satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	acceleration error ≤ 8 mm/s^2 range acceleration error 95% of time	$\leq$8mm/s^2 100% of the time

Appendix B Geomagnetic Data

```
Product: Daily Geomagnetic Data     quar_DGD.txt
Issued: 2120 UT 07 Oct 2001
#
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center.
#  Please send comment and suggestions to sec@sec.noaa.gov
#
#             Current Quarter Daily Geomagnetic Data
#

                Middle Latitude        High Latitude            Estimated
              - Fredericksburg -     ---- College ----      --- Planetary ---
   Date         A     K-indices      A     K-indices        A     K-indices
2001 07 01      8   2 2 1 1 1 2 3 3    7   3 3 1 1 0 1 2 2    12   3 3 1 2 3 3 3 3
2001 07 02      4   2 1 0 1 1 0 3 1   -1   2 1 1-1 1 1 2 1     8   3 2 1 2 2 3 3 2
2001 07 03      5   0 1 2 2 2 1 2 2   10   0 1 2 3 5 2 1 0     9   1 2 2 3 3 3 3 3
2001 07 04      6   2 1 1 1 2 2 2 2   -1   2 1 0 2-1-1 1 1     8   2 2 1 2 3 3 2 3
2001 07 05     10   2 2 2 2 3 2 3 3   12   2 2 3 2 5 2 1 1    13   2 3 3 3 3 3 3 3
2001 07 06      7   2 2 1 2 2 2 2 2   -1   2 1 1 3-1 2 1 1    10   2 2 1 3 3 3 3 3
2001 07 07      6   1 2 1 2 2 1 2 2   -1   2 1 1 1-1-1 1 2     7   2 2 1 2 2 3 2 2
2001 07 08     11   2 3 2 1 1 2 3 4   13   2 2 3 3 4 2 2 3    16   2 3 3 3 3 3 4 4
2001 07 09      7   4 2 1 1 1 1 1 1   10   5 3 1 0 0 1 2 1    11   4 3 1 2 2 3 2 2
2001 07 10      7   1 2 2 2 2 2 2 2   18   0 2 4 4 4 5 2 1    11   1 2 3 3 3 3 3 3
2001 07 11      5   3 2 0 0 2 1 2 1   15   5 5 2 0 2 1 1 1     9   3 3 1 1 2 3 3 2
2001 07 12      8   2 2 3 1 2 1 1 3   10   4 3 2 2 2 1 2 1     9   2 2 3 2 3 3 2 3
2001 07 13      7   3 2 1 2 1 1 1 3   -1  -1-1-1-1-1-1-1-1     9   2 2 1 2 2 3 3 3
2001 07 14     13   4 5 1 2 2 1 1 2   16   3 4 1 4 4 4 0 1    13   4 4 2 2 3 3 2 2
2001 07 15      6   1 1 1 1 2 2 3 2   13   1 1 2 2 3 5 3 1    11   2 0 3 2 3 4 4 2
2001 07 16     11   2 3 1 2 3 2 2 4   17   2 4 2 4 3 4 2 3    17   3 4 3 3 3 4 3 4
2001 07 17     11   4 3 2 2 3 2 1 2   31   5 5 2 4 5 5 3 2    17   4 4 3 3 3 3 3 3
2001 07 18      8   2 3 3 1 2 2 1 1   18   2 5 5 2 2 3 1 2    11   2 3 3 2 2 3 3 3
2001 07 19      6   1 2 2 2 2 2 2 1    7   1 2 1 3 3 2 1 1     9   1 2 2 2 2 4 3 2
2001 07 20      8   2 2 2 2 3 2 2 1    9   2 2 2 3 2 4 1 0     8   2 2 2 3 3 3 2 2
2001 07 21      3   1 2 0 1 1 0 1 2    6   3 2 0 0 3 2 1 1     8   1 2 0 2 3 3 3 3
2001 07 22      6   1 2 1 2 2 2 2 2   14   2 4 3 4 3 2 2 2    11   2 3 2 3 3 3 3 3
2001 07 23      8   2 3 2 1 2 1 3 2   15   3 3 1 2 5 3 2 2    12   3 3 2 3 3 3 3 2
2001 07 24     11   3 2 2 2 3 2 3 3   25   3 2 3 3 6 3 5 2    15   3 3 3 2 4 3 3 3
2001 07 25     21   3 4 4 4 3 3 4 3   -1   3 4 7 6 3-1 4 2    22   3 4 5 4 3 4 4 3
2001 07 26     11   4 4 2 2 2 0 2 2   16   3 4 2 4 5 0 1 1    14   4 4 2 3 3 3 2 3
2001 07 27      8   1 2 3 1 2 2 2 3   13   2 1 3 5 3 2 1-1     9   2 2 3 3 2 3 2 3
2001 07 28      2   2 1 0 0 1 0 1 1   -1   1 0 0 0-1 0 0 0     5   2 0 0 2 2 2 2 2
2001 07 29      5   1 2 3 1 1 1 1 1    8   1 2 3 2 4 1 1 0     8   1 2 3 2 3 3 2 2
2001 07 30      8   2 1 1 1 2 1 2 4    9   2 1 4 3 1 1 2 2     9   2 1 2 2 2 3 3 4
2001 07 31     20   3 4 3 3 4 4 3 3   23   2 4 4 2 4 5 4 3    23   3 4 4 3 4 4 3 3
2001 08 01     10   3 2 2 3 2 3 2 2   23   3 2 2 6 5 2 3 1    12   3 2 3 3 3 3 2 2
2001 08 02      7   2 1 3 1 2 3 1 2    9   1 2 3 3 3 2 1 1     8   1 1 3 2 2 3 3 2
2001 08 03     11   3 2 4 2 2 2 2 2   13   1 2 4 4 4 2 1 1    14   2 2 4 3 3 3 3 3
2001 08 04      7   1 2 2 2 2 2 2 2   19   1 1 3 5 5 4 1 1     9   2 2 2 2 3 3 3 2
2001 08 05     13   2 1 3 2 4 3 3 3   37   2 2 4 6 6 6 2 2    23   2 1 4 5 5 4 3 3
2001 08 06     14   3 3 3 2 3 3 3 3   29   3 3 3 6 5 5 2 2    21   3 3 3 5 5 4 3 3
2001 08 07      8   3 3 1 2 2 1 2 1   15   2 2 2 5 4 1 3 1    13   3 3 2 3 3 3 3 3
2001 08 08      7   2 1 1 2 2 1 3 2   10   2 0 2 4 4 1 2 1     9   2 2 3 2 3 3 3 2
2001 08 09      8   1 3 1 2 2 2 2 3   15   1 3 1 4 5 1 2 3    10   1 3 2 2 3 3 3 3
2001 08 10      6   3 2 2 1 1 0 2 2   -1   3-1 2-1-1 0 1 1    11   3 2 2 2 3 3 4 3
2001 08 11      2   2 1 0 0 0 1 0 1   -1   2 0 0-1 0 0 0 1     6   3 0 1 2 2 2 2 2
2001 08 12     11   1 2 1 3 2 2 3 4   10   1 1 1 2 1 2 2 5    14   2 2 2 3 3 4 3 4
```

2001 08 13	15	3 5 3 2 3 2 2 2	31	5 5 3 5 5 3 3 2	19	4 5 3 3 3 3 3 3
2001 08 14	10	2 2 1 3 3 2 3 2	24	3 2 2 6 5 4 2 1	12	3 2 2 3 3 3 3 3
2001 08 15	4	1 2 1 0 1 2 1 2	6	2 3 2 1 1 1 2 1	9	2 3 3 2 2 3 3 2
2001 08 16	3	1 1 0 1 1 0 1 2	2	1 0 0 2 1 1 0 1	8	2 1 0 2 3 3 3 2
2001 08 17	27	1 0 3 3 4 4 5 6	60	0 1 1 4 7 7 7 4	29	1 1 2 4 5 5 6 5
2001 08 18	13	2 3 3 1 3 2 3 4	30	7 3 3 1 3 3 2 4	14	3 3 3 2 3 4 3 3
2001 08 19	8	0 3 3 3 1 1 3 0	7	0 3 3 2 2 1 2 1	12	1 3 3 3 3 3 3 3
2001 08 20	6	1 0 1 3 2 1 1 3	4	1 1 0 2 2 1 2 1	10	2 1 1 3 3 3 3 2
2001 08 21	12	2 2 1 3 2 3 4 3	11	1 2 1 4 2 4 2 1	14	2 1 2 3 3 4 4 2
2001 08 22	14	1 2 3 3 3 3 3 4	22	2 2 3 5 5 4 3 3	17	2 2 3 4 4 4 4 4
2001 08 23	7	3 2 2 0 2 2 2 2	14	3 2 4 0 4 1 1 4	12	3 2 4 2 3 3 3 2
2001 08 24	5	1 1 0 1 3 3 0 0	1	1 2 0 0 0 0 0 0	4	1 1 1 1 2 2 2 1
2001 08 25	10	0 1 1 1 3 3 4 3	10	0 1 3 4 1 2 3 2	10	1 1 1 2 3 4 4 3
2001 08 26	9	2 2 2 2 2 2 3 3	20	3 2 5 4 5 1 2 1	12	3 1 3 3 3 3 3 3
2001 08 27	14	2 4 1 1 2 3 4 4	-1	2 5 1 3 4-1-1-1	12	2 3 1 1 3 3 4 4
2001 08 28	6	3 2 2 1 1 1 2 1	16	4 3 3 3 5 1 1 0	15	4 3 3 3 3 4 3 2
2001 08 29	5	1 2 3 2 1 1 1 0	16	2 2 2 5 5 1 1 1	9	2 2 3 3 2 3 2 2
2001 08 30	8	1 2 2 2 2 3 2 2	-1	1 1 4-1-1-1-1 1	13	2 2 3 3 3 4 3 2
2001 08 31	11	3 3 2 3 2 3 1 2	22	1 2 4 6 5 2 1 1	16	3 3 4 4 3 4 3 3
2001 09 01	4	2 2 2 1 1 1 0 0	5	2 2 1 3 1 1 0 0	8	2 1 2 2 3 3 3 2
2001 09 02	2	0 0 0 1 2 1 1 1	5	0 0 0 2 2 3 1 2	7	1 0 0 2 3 3 3 3
2001 09 03	12	2 2 3 2 3 3 3 3	21	2 2 4 4 5 4 3 2	17	3 2 3 4 4 4 3 4
2001 09 04	11	3 4 3 2 2 2 1 1	29	2 4 6 5 5 3 2 1	20	3 4 4 3 4 4 3 3
2001 09 05	6	3 1 2 1 2 2 2 0	13	3 1 1 0 4 5 2 1	10	3 1 2 2 3 3 3 2
2001 09 06	3	1 0 2 1 1 1 0 1	8	2 1 2 4 2 1 1 1	8	2 0 2 2 3 3 3 3
2001 09 07	4	0 1 0 2 0 1 2 3	2	0 0 0 0 0 1 1 2	6	1 0 1 1 3 3 1 3
2001 09 08	5	2 1 1 1 3 1 1 0	6	1 2 2 2 3 2 0 0	7	3 2 2 2 2 3 2 2
2001 09 09	7	2 1 1 2 3 3 2 1	3	1 0 1 3 1 0 0 0	7	2 1 1 2 2 3 3 2
2001 09 10	5	2 1 1 1 1 3 1 1	-1	1-1-1-1-1 0 0 0	5	2 1 1 1 2 3 2 2
2001 09 11	12	1 2 1 1 4 4 3 3	14	0 4 5 0 3 2 2 2	9	1 0 0 1 3 4 3 3
2001 09 12	9	2 2 4 2 2 1 2 2	31	2 6 6 3 5 2 2 2	13	2 3 4 3 3 3 3 2
2001 09 13	11	2 4 4 2 2 1 2 1	25	2 5 5 5 3 4 2 0	18	3 4 5 4 3 3 3 1
2001 09 14	8	3 2 1 1 3 1 1 3	6	3 2 1 0 2 1 0 3	10	3 1 1 2 3 3 2 4
2001 09 15	10	2 2 1 3 2 3 3 2	-1	-1-1-1-1-1-1-1-1	15	3 2 2 3 4 4 3 3
2001 09 16	7	2 1 1 1 3 3 2 2	-1	-1-1-1-1-1-1-1-1	8	2 1 1 1 3 3 3 2
2001 09 17	6	1 2 3 1 1 2 1 1	16	2 2 3 5 4 1 3 1	10	1 2 3 3 3 3 3 3
2001 09 18	7	2 1 0 0 1 2 4 2	7	2 2 0 0 1 2 4 1	8	2 2 1 1 2 2 4 2
2001 09 19	8	3 3 2 1 2 1 3 1	7	3 3 2 2 1 1 2 0	8	3 3 2 2 2 2 3 1
2001 09 20	7	1 1 2 2 1 2 3 3	3	1 0 0 3 1 0 0 1	5	1 1 1 2 2 2 2 2
2001 09 21	3	2 0 0 1 1 1 1 2	1	1 0 0 0 0 0 0 1	5	1 0 0 2 2 2 2 2
2001 09 22	6	2 1 2 2 3 2 0 0	17	2 0 3 5 5 3 0 0	10	2 1 3 4 4 3 2 1
2001 09 23	18	0 3 4 3 4 4 3 3	51	0 3 7 4 6 6 5 3	27	0 3 5 4 5 5 5 4
2001 09 24	5	3 2 1 1 1 1 1 1	4	3 1 1 0 1 1 1 1	6	3 1 1 2 2 2 2 1
2001 09 25	17	1 2 2 0 3 0 4 6	23	1 2 2 2 0 0 6 6	18	1 2 2 1 1 2 5 6
2001 09 26	13	5 2 3 2 2 2 2 2	35	5 5 6 5 4 2 3 2	24	5 4 5 4 3 3 2 2
2001 09 27	9	1 1 1 2 2 3 4 2	19	2 2 2 5 3 5 3 2	10	1 1 1 3 3 3 3 3
2001 09 28	10	2 2 3 1 2 3 2 3	28	2 2 5 3 5 5 4 4	13	2 2 3 3 3 3 3 3
2001 09 29	19	3 2 2 4 2 3 4 5	46	4 4 4 6 6 4 5 5	21	3 3 3 4 3 4 3 5
2001 09 30	15	3 2 1 2 3 3 4 4	25	5 3 2 3 4 5 4 3	17	4 3 2 2 3 4 4 4

Background:

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

Problem Description:

GPS suffered a satellite failure of PRN22 in July of this quarter. The range residual for PRN22 was less than 5 meters until approximately 22:07 GMT (598060 GPS TOW) on 28 July 2001. At that time the range residual began to drift very rapidly making the satellite unusable for accurate navigation after 7 minutes. Within this time PRN22 range residual grew from less than 5 meters to over 250 meters. The satellite health contained in the navigation data message (IODE = 69, TOC = TOE = 0sec) reported the status as healthy for the remainder of the GPS day. Any GPS SPS users tracking and using PRN22 at this time would experience degraded navigation accuracy. The range residual continued to drift, reaching to over 300,000 meters by the end of the GPS day, while the satellite health remained "Healthy". SPS users not implementing autonomous integrity monitoring would have been unable to produce a valid navigation solution using PRN22. The satellite was dropped from track at 23:58 GMT (604701 GPS TOW). PRN22 remained off of the receiver track list until approximately 0:44 GMT (2692 GPS TOW) on 29 July 2001. At this time receivers began tracking PRN22 intermittently, but not long enough to collect a complete navigation data message. A full navigation data message from PRN22 was eventually collected at 1:07 GMT (4075 GPS TOW), which changed the health status to "Unhealthy" preventing its use for navigation. The effect on GPS can be seen in section 5.1. The event lasted long enough to affect the 99.99% horizontal and vertical error values for all those sites that were tracking PRN22 at the time of the failure.

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

Alert. An alert is an indication provided by the GPS/WAAS equipment to inform the user when the positioning performance achieved by the equipment does not meet the integrity requirements.

APV-I (LNAV/VNAV). APV-I is a WAAS operational service level with an HAL equal to 556 meters and a VAL equal to 50 meters.

Availability. The availability of a navigation system is the ability of the system to provide the required function and performance at the initiation of the intended operation. Availability is an indication of the ability of the system to provide usable service within the specified coverage area.

AVP-II. APV-I is a WAAS operational service level with an HAL equal to 40 meters and a VAL equal to 20 meters.

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.

CONUS. Continental United States.

Continuity. The continuity of a system is the ability of the total system (comprising all elements necessary to maintain aircraft position within the defined airspace) to perform its function without interruption during the intended operation. More specifically, continuity is the probability that the specified system performance will be maintained for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation.

Coverage. The coverage provided by a radio navigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors that affect signal availability.

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.

Fault Detection and Exclusion (FDE). Fault detection and exclusion is a receiver processing scheme that autonomously provides integrity monitoring for the position solution, using redundant range measurements. The FDE consists of two distinct parts: fault detection and fault exclusion. The fault detection part detects the presence of an unacceptably large position error for a given mode of flight. Upon the detection, fault exclusion follows and excludes the source of the unacceptably large position error, thereby allowing navigation to return to normal performance without an interruption in service.

GEO. Geostationary Satellite.

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

Global Positioning System (GPS). A space-based positioning, velocity, and time system composed of space, control, and user segments. The space segment, when fully operational, will be composed of 24 satellites in six orbital planes. The control segment consists of five monitor stations, three ground antennas, and a master control station. The user segment consists of antennas and receiver-processors that provide positioning, velocity, and precise timing to the user.

GLS. GLS is a WAAS operational service level with HAL equal to 40 meters and VAL equal to 12 meters.

Grid Ionospheric Vertical Error (GIVE). GIVEs indicate the accuracy of ionospheric vertical delay correction at a geographically defined ionoshperic grid point (IGP). WAAS transmits one GIVE for each IGP in the mask.

Hazardous Misleading Information (HMI). Hazardous misleading information is any position data, that is output, that has an error larger than the current protection level (HPL/VPL), without any indication of the error (e.g., alert message sequence).

Horizontal Alert Limit (HAL). The Horizontal Alert Limit (HAL) is the radius of a circle in the horizontal plane (the local plane tangent to the WGS-84 ellipsoid), with its center being at the true position, which describes the region that is required to contain the indicated horizontal position with a probability of $1\text{-}10^{-7}$ per flight hour, for a particular navigation mode, assuming the probability of a GPS satellite integrity failure being included in the position solution is less than or equal to 10^{-4} per hour.

Horizontal Protection Level (HPL). The Horizontal Protection Level is the radius of a circle in the horizontal plane (the plane tangent to the WGS-84 ellipsoid), with its center being at the true position, which describes the region that is assured to contain the indicated horizontal position. It is based upon the error estimates provided by WAAS.

Ionospheric Grid Point (IGP). IGP is a geographically defined point for which the WAAS provides the vertical ionospheric delay.

LNAV. Lateral Navigation.

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

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

MOPS. Minimum Operational 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.

Non-Precision Approach (NPA) Navigation Mode. The Non-Precision Approach navigation mode refers to the navigation solution operating with a minimum of four satellites with fast and long term WAAS corrections (no WAAS ionospheric corrections) available.

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

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

Precision Approach (PA) Navigation Mode. The Precision Approach navigation mode refers to the navigation solution operating with a minimum of four satellites with all WAAS corrections (fast, long term, and ionospheric) available.

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.

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.

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.

SV. Satellite Vehicle.

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

User Differential Range Error (UDRE). UDRE’s indicate the accuracy of combined fast and slow error corrections. WAAS transmits one UDRE for each satellite in the mask.

Vertical Alert Limit (VAL). The Vertical Alert Limit is half the length of a segment on the vertical axis (perpendicular to the horizontal plane of WGS-84 ellipsoid), with its center being at the true position, which describes the region that is required to contain the indicated vertical position with a probability of $1\text{-}10^{-7}$ per flight hour, for a particular navigation mode, assuming the probability of a GPS satellite integrity failure being included in the position solution is less than or equal to 10^{-4} per hour.

Vertical Protection Level (VPL). The Vertical Protection Level is half the length of a segment on the vertical axis (perpendicular to the horizontal plane of WGS-84 ellipsoid), with its center being at the true position, which describes the region that is assured to contain the indicated vertical position. It is based upon the error estimates provided by WAAS.

VNAV. Vertical Navigation.

Wide Area Augmentation System (WAAS). The WAAS is made up of an integrity reference monitoring network, processing facilities, geostationary satellites, and control facilities.Wide area reference stations and integrity monitors are widely dispersed data collection sites that contain GPS/WAAS ranging receivers that monitor all signals from the GPS, as well as the WAAS geostationary satellites. The reference stations collect measurements from the GPS and WAAS satellites so that differential corrections, ionospheric delay information, GPS/WAAS accuracy, WAAS network time, GPS time, and UTC can be determined. The wide area reference station and integrity monitor data are forwarded to the central data processing sites. These sites process the data in order to determine differential corrections, ionospheric delay information, and GPS/WAAS accuracy, as well as verify residual error bounds for each monitored satellite. The central data processing sites also generate navigation messages for the geostationary satellites and WAAS messages. This information is modulated on the GPS-like signal and broadcast to the users from geostationary satellites.

Performance Parameter Definitions

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix E

Wide Area Augmentation System (WAAS) Performance Analysis Report

October 31, 2001

FAA/William J. Hughes Technical Center
NSTB/WAAS T&E Team
ACT 360
Atlantic City International Airport, NJ 08405

Executive Summary

Since 1999, the Navigation Branch (ACT-360) at the William J. Hughes Technical Center has reported GPS performance as measured against the GPS Standard Positioning Service (SPS) Signal Specification. These quarterly reports are known as the PAN (Performance Analysis Network) Report. Beginning with the 3rd quarter 2001, the PAN report will include a section on Wide Area Augmentation System (WAAS) performance and a report on observed WAAS anomalies. The following observations were made during the reporting period:

1. For all the sites evaluated, the 95% horizontal and vertical accuracy was less than 7 meters. While the LNAV/VNAV service was available, the maximum vertical error was 6.435 meters at Bangor, and the minimum vertical error was 1.751 meters at Kansas City. While the LNAV/VNAV service was available, the maximum horizontal error was 7.392 meters at Bangor, and the minimum horizontal error was 0.984 meters at Kansas City.

2. For all sites evaluated, the instantaneous availability was calculated. The instantaneous availability is the percentage of time the calculated protection level is less than a particular service level's alarm limit. The instantaneous availability is calculated once per second. When the LNAV/VNAV service was available, all sites except Anchorage had 100% horizontal instantaneous availability. Anchorage had 99.99% instantaneous availability. When the LNAV/VNAV service was available, the minimum vertical instantaneous availability was 9.57% at Anchorage, and the maximum vertical instantaneous availability was 99.58% at Salt Lake City.

3. Vertical and horizontal protection limits were calculated once per second for each site evaluated. While the LNAV/VNAV service was available, the maximum 95% HPL was 152.66 meters at Bangor, and the minimum 95% HPL was 8.89 meters at Atlanta. While the LNAV/VNAV service was available, the maximum 95% VPL was 131.43 meters in Bangor, and the minimum 95% VPL was 14.7 meters in Denver.

4. LNAV/VNAV service coverage was calculated for CONUS over the entire quarter. The 95% LNAV/VNAV coverage ranged from 50% to 65% of CONUS.

5. The system continuity of WAAS was calculated for the quarter. The continuity performance parameters include continuity of navigation and continuity of fault detection for en route/NPA operations and continuity of function for PA operations. For all the sites evaluated, the NPA continuity of navigation was 100%. The maximum NPA continuity of fault detection was 96.3% for Arcata, and the minimum was 94.3% at Bangor. The maximum PA continuity of function was 99.8 % at Kansas City and the minimum was 46.6% at Bangor.

6. During the reporting period, there were no unboundings or HMI events recorded. In addition to looking for these events, a safety index was calculated for the quarter. The safety index provides the degree of safety provided by WAAS based on the calculated protection levels and positioning errors. The maximum safety index in the vertical dimension was 2.96 in Prescott and the minimum was 1.4 in Atlantic City. The maximum in the horizontal dimension was 4.29 in Prescott and the minimum was 1.71 in Atlantic City. For the safety margin metric, as the value increases, so does the safety. Also, any value above 1 means a safe bounding for the largest observed error.

7. In addition to position domain analysis, this report includes range domain analysis. ACT-360 collected and analyzed range domain data for each GPS satellite and the AOR-W GEO based on data from the Atlanta WAAS reference station. An analysis of how well the WAAS UDRE for each satellite bounded the actual range error was performed. For all GPS satellites the residual error was less than 2 meters 95% of the time. For the AOR-W GEO satellite, the residual error was approximately 3.1 meters 95% of the time. Also, the WAAS UDRE bounded all satellites at least 99.9% of the time except for SV 10 (99.8%) and SV 25 (99.6%).

TABLE OF CONTENTS

1.0 Introduction

The FAA began monitoring GPS SPS performance in order to ensure the safe and effective use of the satellite navigation system in the NAS. The Wide Area Augmentation System (WAAS) that is being developed by the FAA adds integrity monitoring of GPS and improves position accuracy of GPS within the WAAS coverage area.

Objectives of this report are:

a. To evaluate and monitor the ability of WAAS to augment GPS by characterizing important performance parameters.
b. To analyze the effects of GPS satellite operation and maintenance, and ionospheric activity on the WAAS performance.
c. To investigate any GPS and WAAS navigation anomalies and determine their impact on potential users.

The WAAS data transmitted from GEO satellite PRN#122 was used in the evaluation. This report presents results from three months of data, collected between 7/1/2001 and 9/30/2001, from NSTB and WAAS reference station receivers at locations listed in the table below.

Table E-1.1 NSTB and WAAS Reference Station Receivers

NSTB:	Number of Days Evaluated	Number of Samples
• Arcata, CA	61	5251049
• Atlantic City, NJ	83	7151106
• Columbus, OH	83	7152616
• Denver, CO	89	7685605
• Grand Forks, ND	83	7146728
• Greenwood, MS	80	6912717
• Prescott, AZ	79	6864179
• San Angelo, CA	22	1939861
WAAS:		
• Bangor, ME	43	3685103
• Billings, MT	69	5926908
• Anchorage, AK	78	6773491
• Chicago, IL	68	5865091
• Kansas City, KS	72	6224526
• Salt Lake City, UT	80	6906251
• Miami, FL	74	6361324
• Atlanta, GA	76	6538141

The report is divided to six performance categories listed below.

1. WAAS Position Accuracy
2. WAAS Operational Service Availability
3. LNAV/VNAV (APV-I) Coverage
4. Continuity
5. Integrity
6. WAAS Range Domain Accuracy

Table E-1.2 lists the performance parameters evaluated for the WAAS in this report.

Table E-1.2 WAAS Performance Parameters

Performance Parameter	Expected WAAS Performance
Accuracy Horizontal	≤7.6m error 95% of the time
Accuracy Vertical	≤7.6m error 95% of the time
Availability GLS	Not Defined for Current WAAS phase
Availability APV-II	Not Defined for Current WAAS phase
Availability LNAV/VNAV	95% of the time within service area
Coverage GLS	Not Defined for Current WAAS phase
Coverage APV-II	Not Defined for Current WAAS phase
Coverage LNAV/VNAV	≥50% of CONUS
NPA Continuity of NAV	≥99.999% of the time
NPA Continuity of Fault Detection	≥99.999% of the time
LNAV/VNAV Continuity of Function	≥99.9945% of the time
Integrity	≤4 X 10e-8 HMI's per approach
Accuracy Range Domain	≥99.9% of range error bounded by UDRE

1.1 Event Summary

Table E-1.3 lists test events that occurred during the reporting period that affected WAAS performance or the ability to access the WAAS performance. These events include GPS or WAAS anomalies, relevant receiver malfunctions, and receiver maintenance conducted.

Table E-1.3 Test Events

Date	Description
7/10/2001	GUS anomaly caused loss of GEO PRN#122 broadcast
7/28 to 9/30/2001	NSTB receiver failure at San Angelo
7/28 to 7/29/2001	GPS satellite PRN#22 clock failure
8/9 to 8/16/2001	WAAS WRS software upgrade caused loss of WAAS receiver data
9/14/2001	GUS hardware failure caused loss of GEO PRN#122 broadcast
9/10 to 9/30/2001	NSTB receiver failure at Arcata

1.2 Report Overview

Section 2.0 provides the vertical and horizontal position accuracies from data collected, on a daily basis, at one second intervals. The 95% accuracy index for the reporting period is tabulated. The daily 95% accuracy index is plotted graphically for each receiver. Histograms of the vertical and horizontal error distribution are provided for two receivers within the WAAS service area.

Section 3.0 summarizes the WAAS availability performance, at each receiver, for three operational service levels during the reporting period. Daily availability is also plotted for each receiver evaluated.

Section 4.0 provides the percent of CONUS covered by WAAS at LNAV/VNAV operational service level on a daily basis. Monthly roll-up graphs presented indicate the portions of CONUS covered, and the percentage of time that WAAS was available.

Section 5.0 provides the percentage of time continuity requirements were met during the reporting period for each receiver.

Section 6.0 summarizes the number of HMI's detected during the reporting period and presents a safety margin index for each receiver. The safety index reflects the amount of over bounding of position error by WAAS protection levels.

Section 7.0 provides the UDRE bounding percentage and the 95% index of the range domain accuracy for each satellite tracked by the WAAS receiver in Atlanta.

2.0 WAAS Position Accuracy

Navigation error data, collected from WAAS and NSTB reference stations, was processed to determine position accuracy at each location. This was accomplished by utilizing the GPS/WAAS position solution tool to compute a MOPS-weighted least squares user navigation solution, and WAAS horizontal and vertical protection levels (HPL & VPL), once every second. The user position calculated for each receiver was compared to the surveyed position of the antenna to assess position error associated with the WAAS SIS over time. The position errors were analyzed and statistics were generated for three operational service levels: WAAS GLS, WAAS APV II, and WAAS APV I, as shown in Table E-2.1. For this evaluation, the WAAS operational service level is considered available at a given time and location, if the computed WAAS HPL and VPL are within the horizontal and vertical alarm limits (HAL & VAL) specified in Table E-2.1.

Table E-2.1 Operational Service Levels

WAAS Operational Service Levels	Horizontal Alert Limit HAL (meters)	Vertical Alert Limit VAL (meters)
GLS	40	12
APV-II	40	20
APV-I (LNAV/VNAV)	556	50

Table E-2.2 shows the horizontal and vertical position accuracy maintained for 95% of the time at WAAS GLS, APV II, and APV I operational service levels for the quarter. Note that WAAS accuracy statistics presented are compiled only when all WAAS corrections (fast, long term, and ionospheric) for at least 4 satellites are available. This is referred to as PA navigation mode. The percentage of time that PA navigation mode was supported by WAAS at each receiver is also shown in Table E-2.2. A user is considered to be in NPA navigation mode if only WAAS fast and long term corrections are available to a user (no ionospheric corrections). Figures E-2.1 and E-2.2 show the daily vertical and horizontal 95% accuracy for APV-I (LNAV/VNAV) operational service level.

Table E-2.2 95% Horizontal and Vertical Accuracy

Location	Horizontal GLS/APV-II (HAL=40m) (meters)	Horizontal LNAV/VNAV (HAL=556m) (meters)	Vertical GLS (VAL=12m) (meters)	Vertical APV-II (VAL=20m) (meters)	Vertical LNAV/VNAV (VAL=50m) (meters)	Percentage in PA mode (%)
Kansas City	0.966	0.984	1.619	1.746	1.751	99.531
Salt Lake City	1.216	1.236	2.119	2.498	2.555	99.576
Columbus	1.115	1.134	1.968	2.169	2.196	99.564
Denver	1.098	1.113	1.816	2.046	2.053	99.512
Atlanta	1.241	1.261	1.843	2.069	2.086	99.552
Greenwood	1.404	1.428	2.271	2.512	2.525	99.502
Chicago	1.507	1.606	1.776	2.098	2.272	99.113
San Angelo	1.776	2.098	1.375	1.865	2.193	89.407
Atlantic City	2.303	2.887	1.965	2.636	3.407	96.326
Prescott	1.723	3.063	1.233	1.676	1.930	83.048
Miami	3.024	4.795	2.245	2.951	4.480	78.891
Arcata	2.649	4.063	1.516	2.123	3.619	78.973
Billings	2.452	4.34	2.072	2.602	3.161	91.714
Grand Forks	2.858	4.399	2.253	2.973	4.639	39.703
Bangor	4.071	7.392	1.414	3.352	6.435	25.49
Anchorage	4.289	4.351	n/a	3.645	5.641	13.238

Figure E-2.1 95% Horizontal Accuracy at LNAV/VNAV

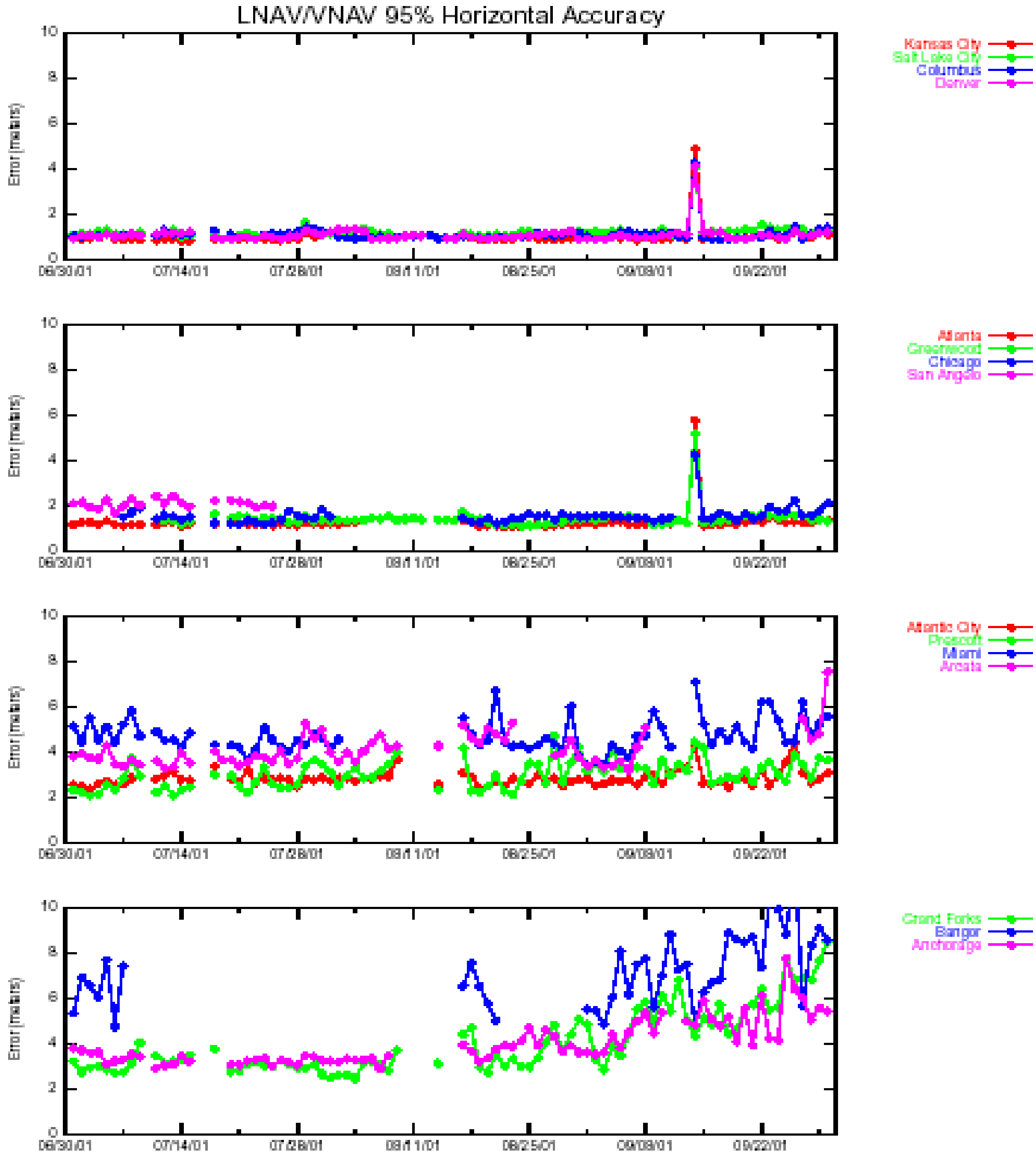
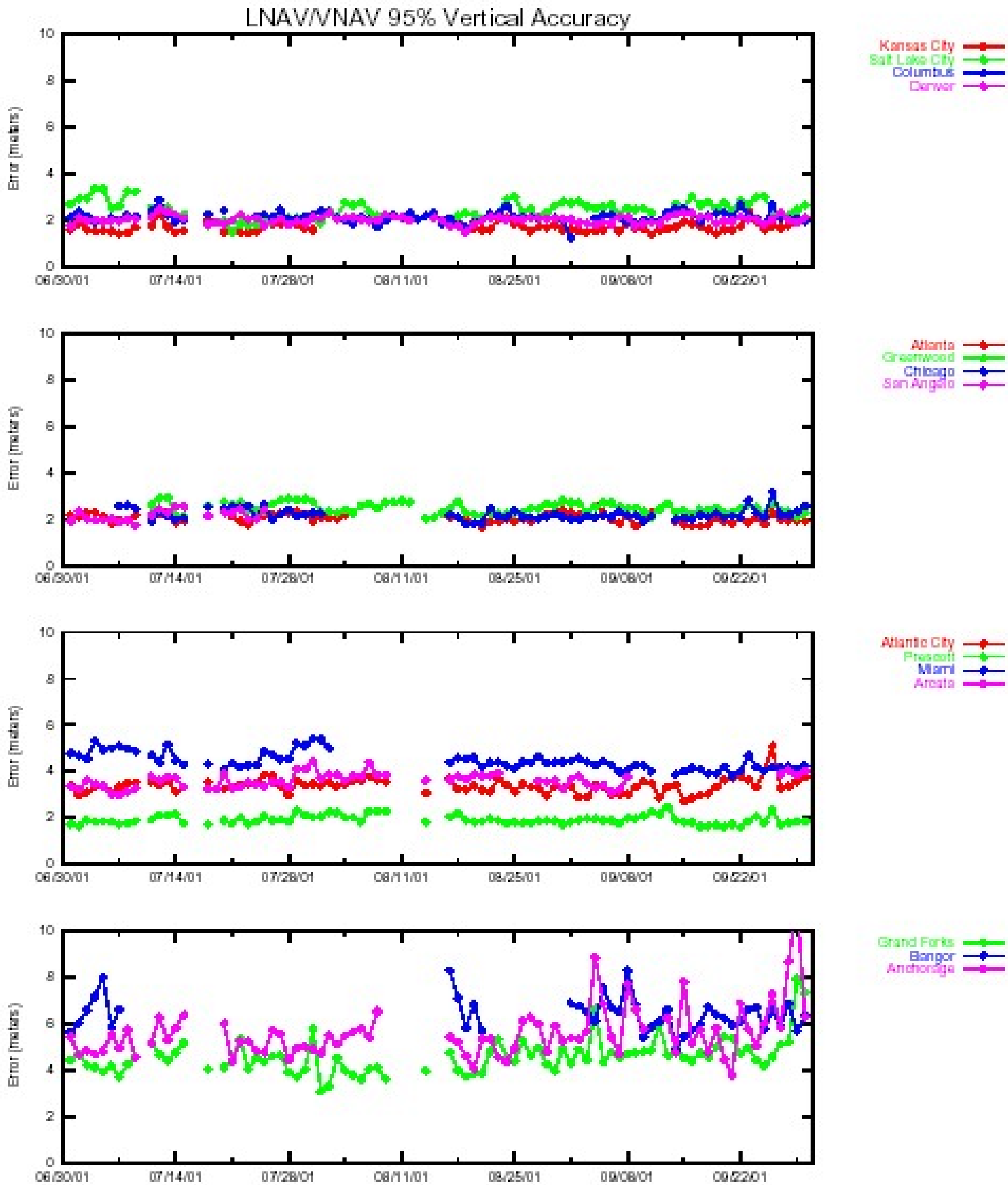


Figure E-2.2 95% Vertical Accuracy at LNAV/VNAV



At all evaluated sites, the 95% horizontal and vertical accuracy are less than 7.4 meters for all WAAS operational service levels. The maximum error for vertical LNAV/VNAV is 6.4 meters at Bangor and the minimum error for vertical LNAV/VNAV is 1.751 meters at Kansas City. With the current ionospheric monitoring rules of the WAAS, receivers toward the center of CONUS have better accuracy performance and PA mode availability, than those located on the edge of CONUS or Alaska. This is due to the fact that more satellites with WAAS corrections can be used to calculate the position solution in the center of the service area.

Figures E-2.3 to E-2.8 show the distributions of the vertical and horizontal errors in triangle charts and 2-D histogram plots for the quarter at two locations, Denver and Kansas City. The triangle charts show the distributions of vertical position errors (VPE) versus vertical protection levels (VPL) and horizontal position errors (HPE) versus horizontal protection levels (HPL). The horizontal axis is the position error and the vertical axis is the WAAS protection levels. Lower protection levels equate to better availability and the diagonal line shows the point where error equals protection level. Above and to the left in the chart, errors are bounded; below and to the right, errors are not bounded. The horizontal lines at various protection levels represent the various operational service levels as defined in Table E-2.1. The 2-D histogram plots contain four histograms showing the distributions of vertical and horizontal error and normalized position errors. The left top and bottom histograms show the distributions of the actual vertical and horizontal errors. The horizontal axis is the position errors and the vertical axis is the total count of data samples in each 0.1-meter bin. The right top and bottom histograms show the distributions of the actual vertical and horizontal errors normalized by one-sigma value of the protection level, vertical - (VPL/5.33) and horizontal - (HPL/6.0). The horizontal axis is the standard units and vertical axis is the total count of data samples in each 0.1-sigma bin. Narrowness of the normalized error distributions shows very good observed safety performance.

Figure E-2.3 Horizontal Triangle Chart for Denver

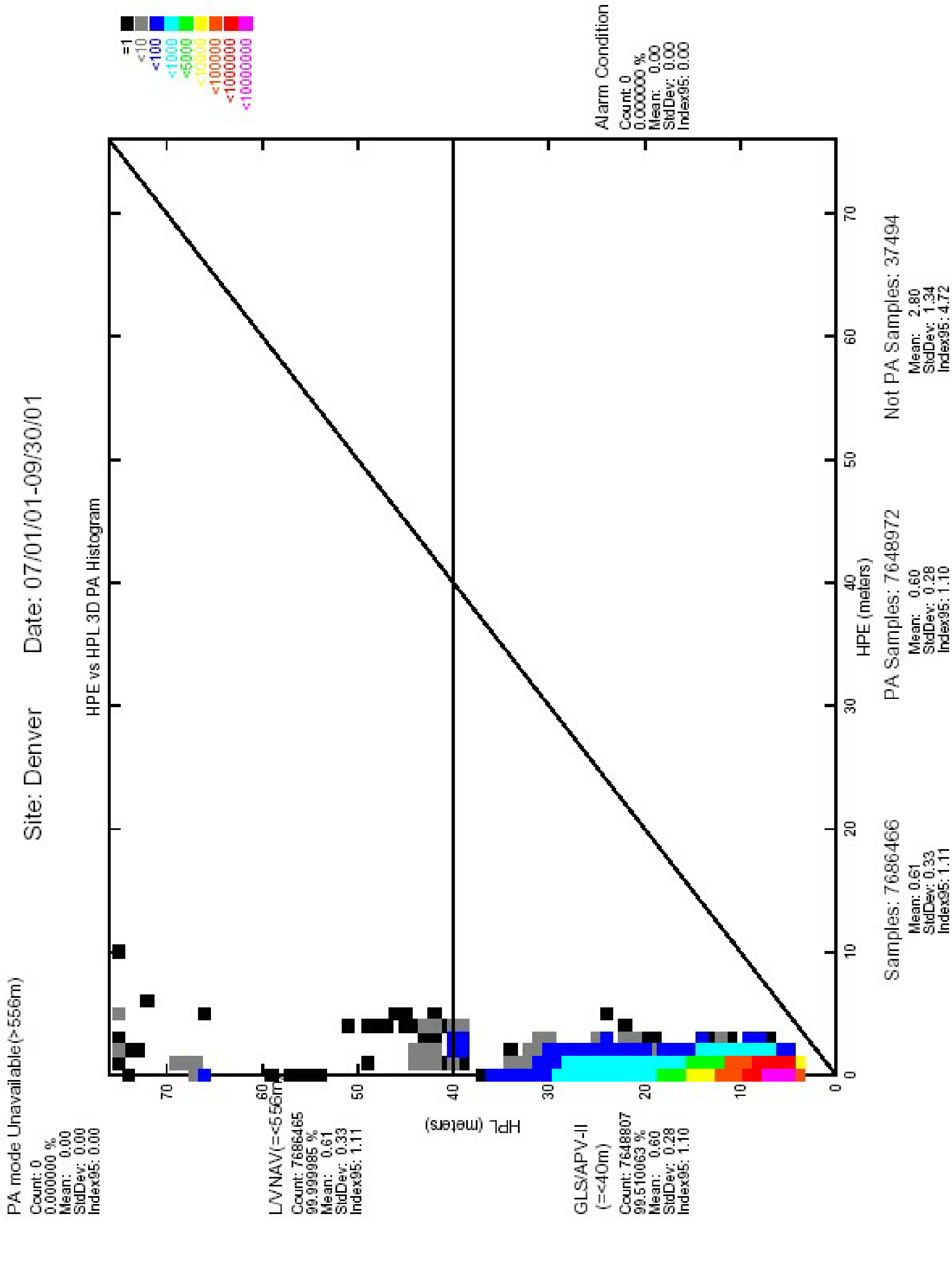


Figure E-2.4 Vertical Triangle Chart for Denver

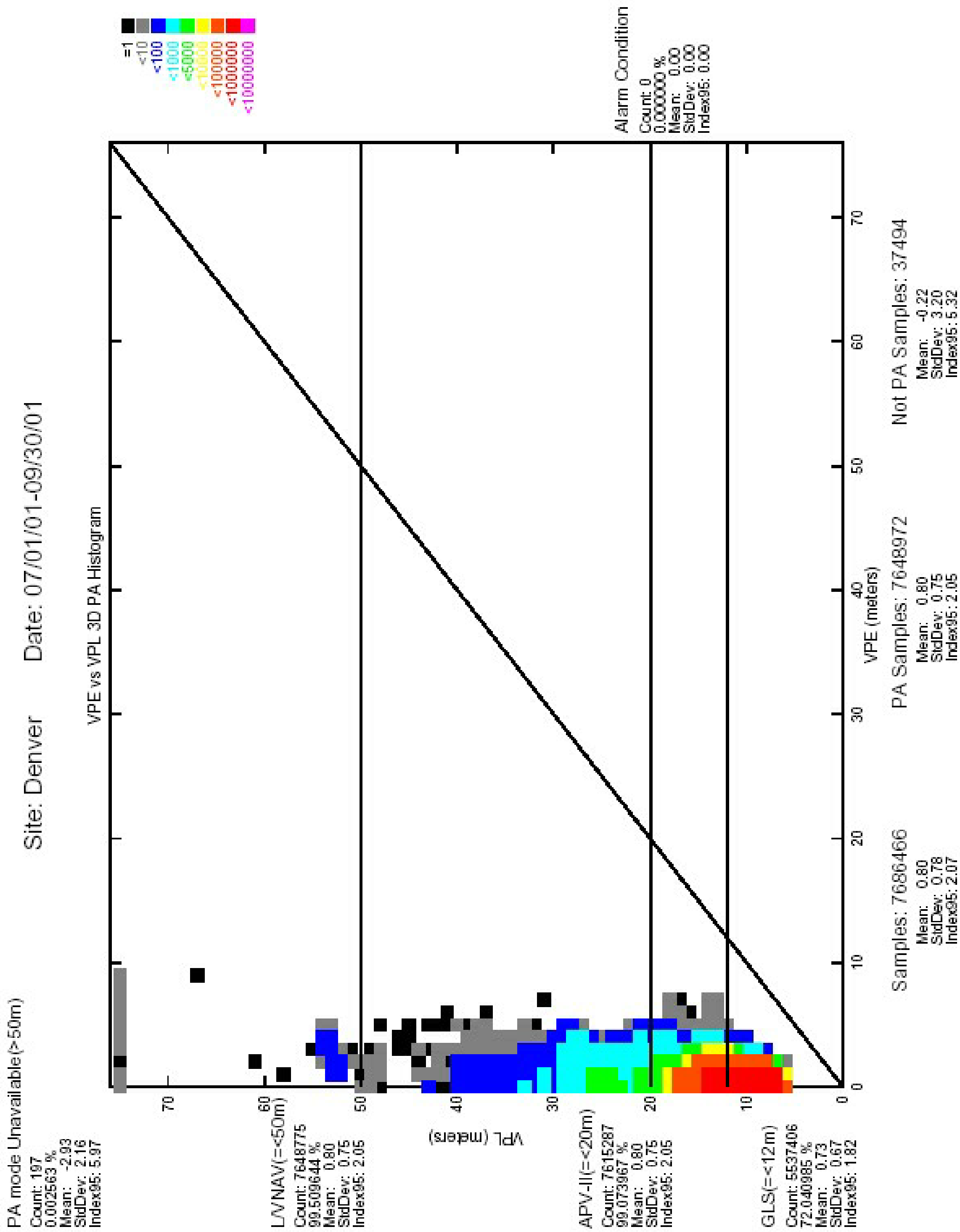


Figure E-2.5 2-D Histogram for Denver

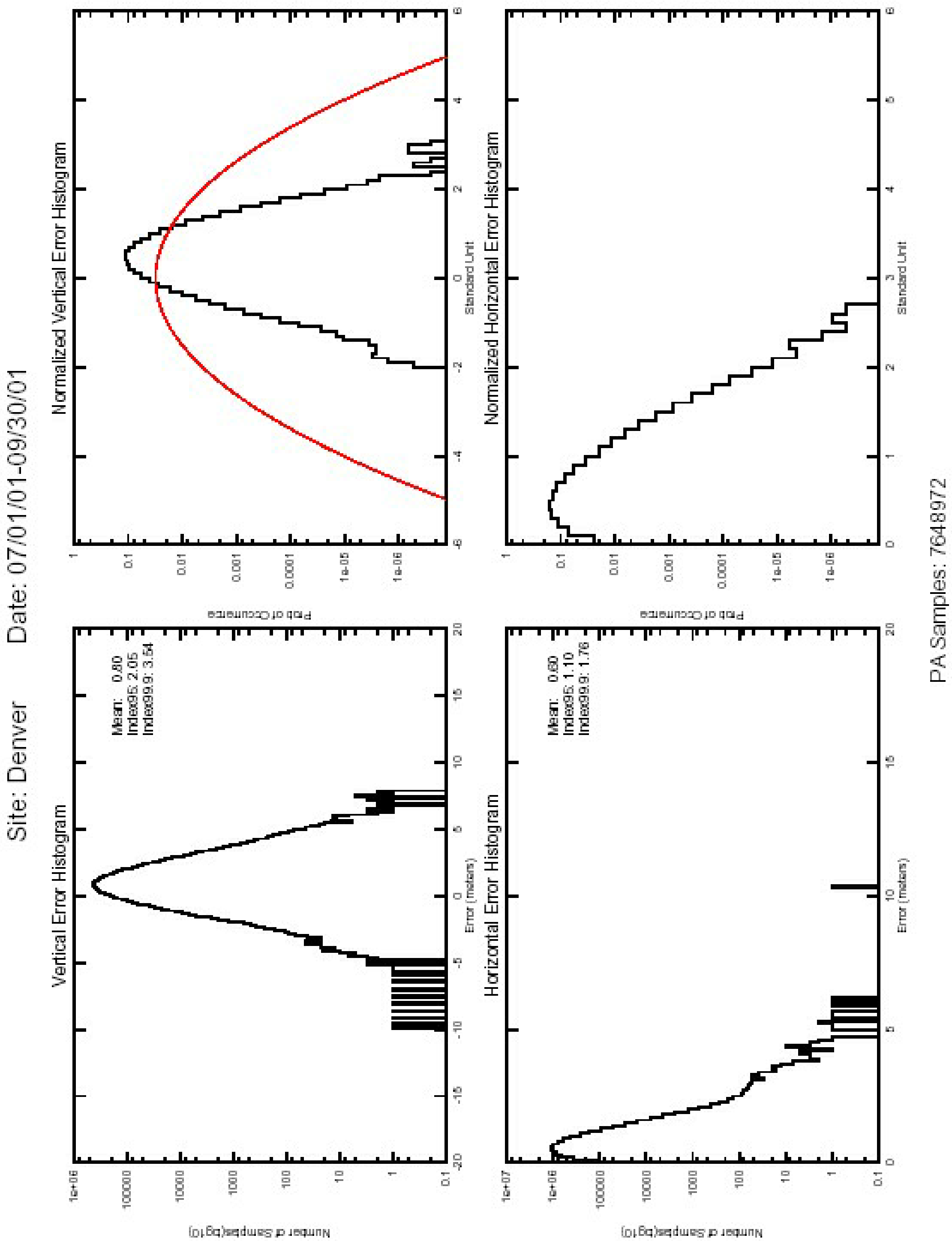


Figure E-2.6 Horizontal Triangle Chart for Kansas City

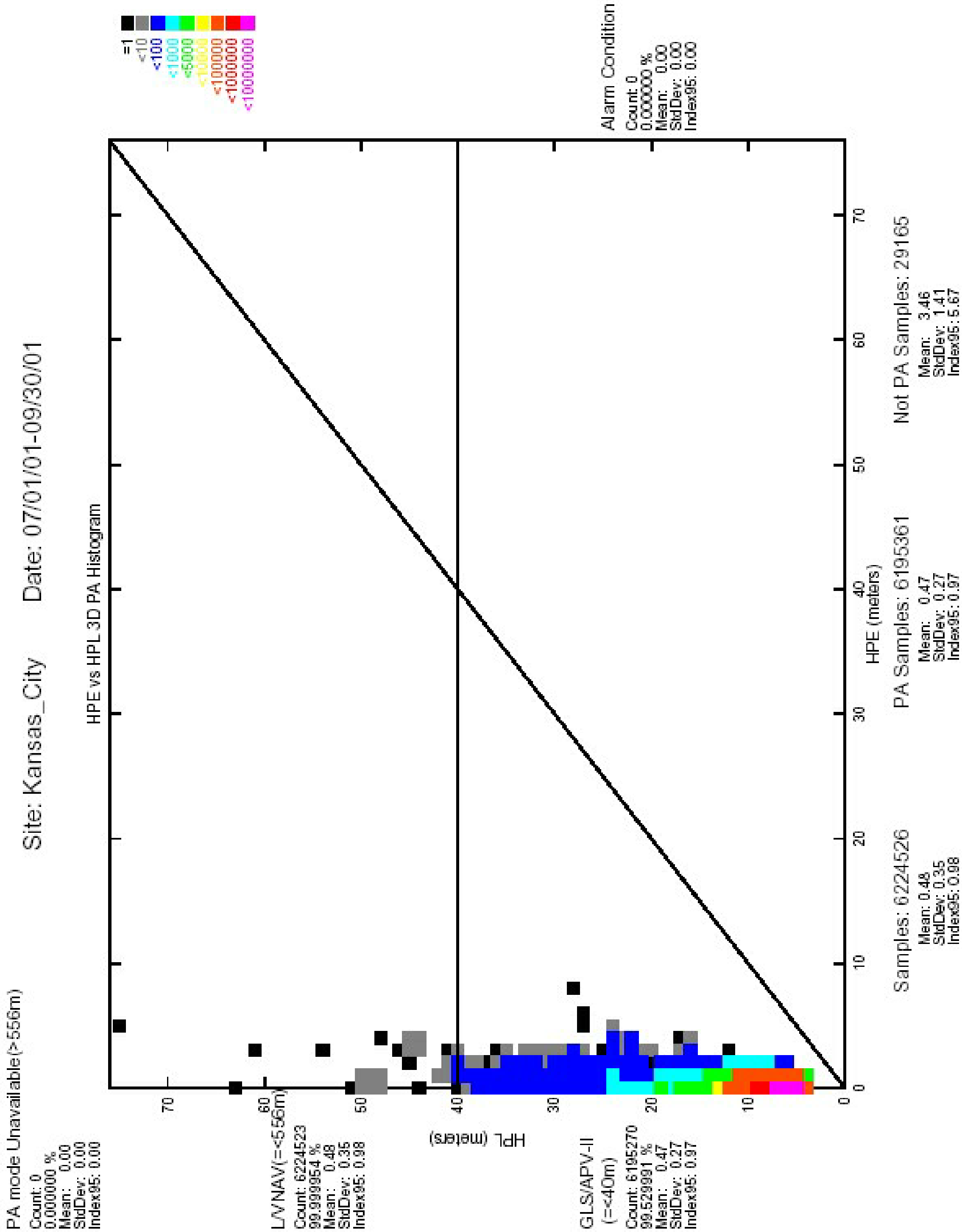


Figure E-2.7 Vertical Triangle Chart for Kansas City

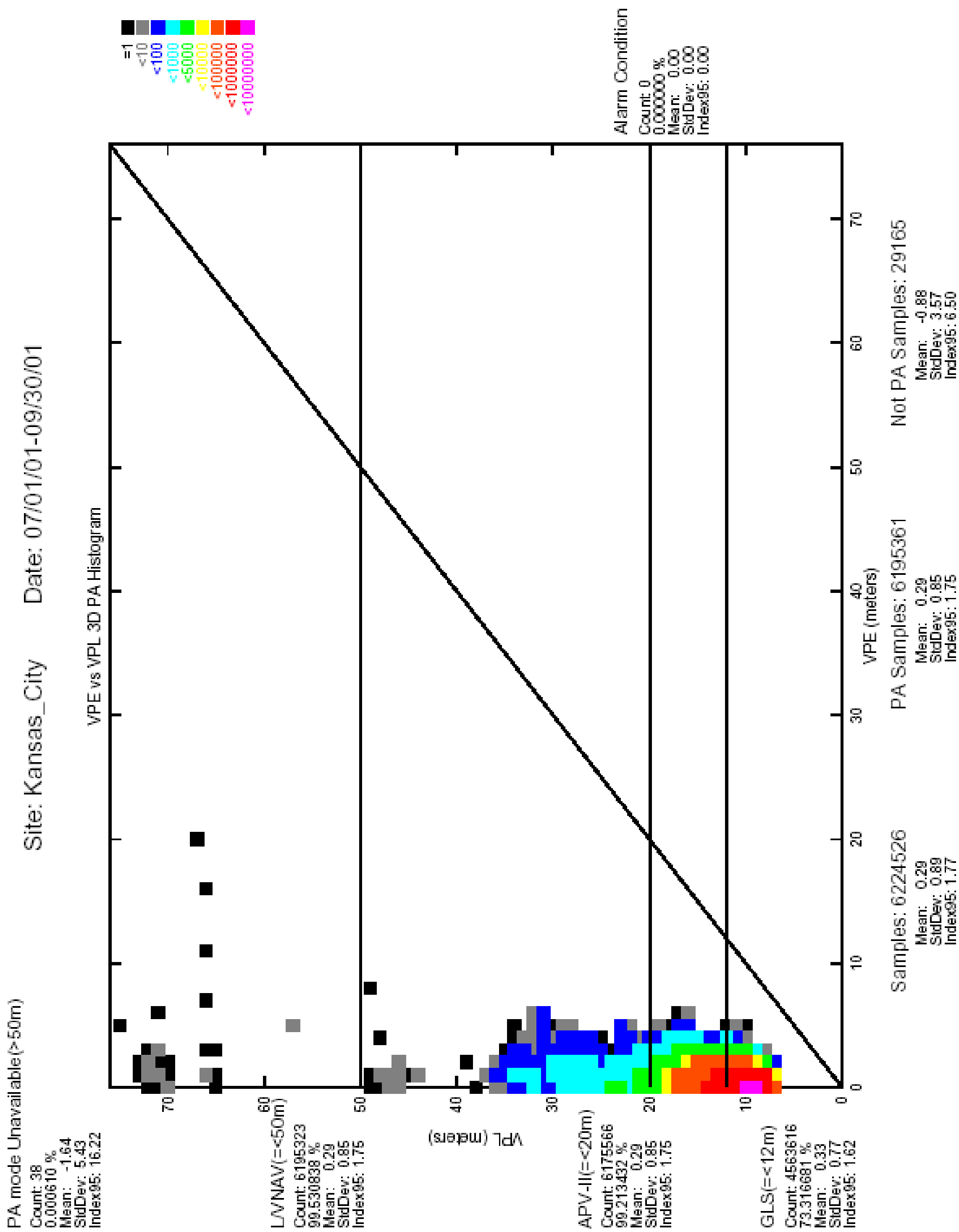
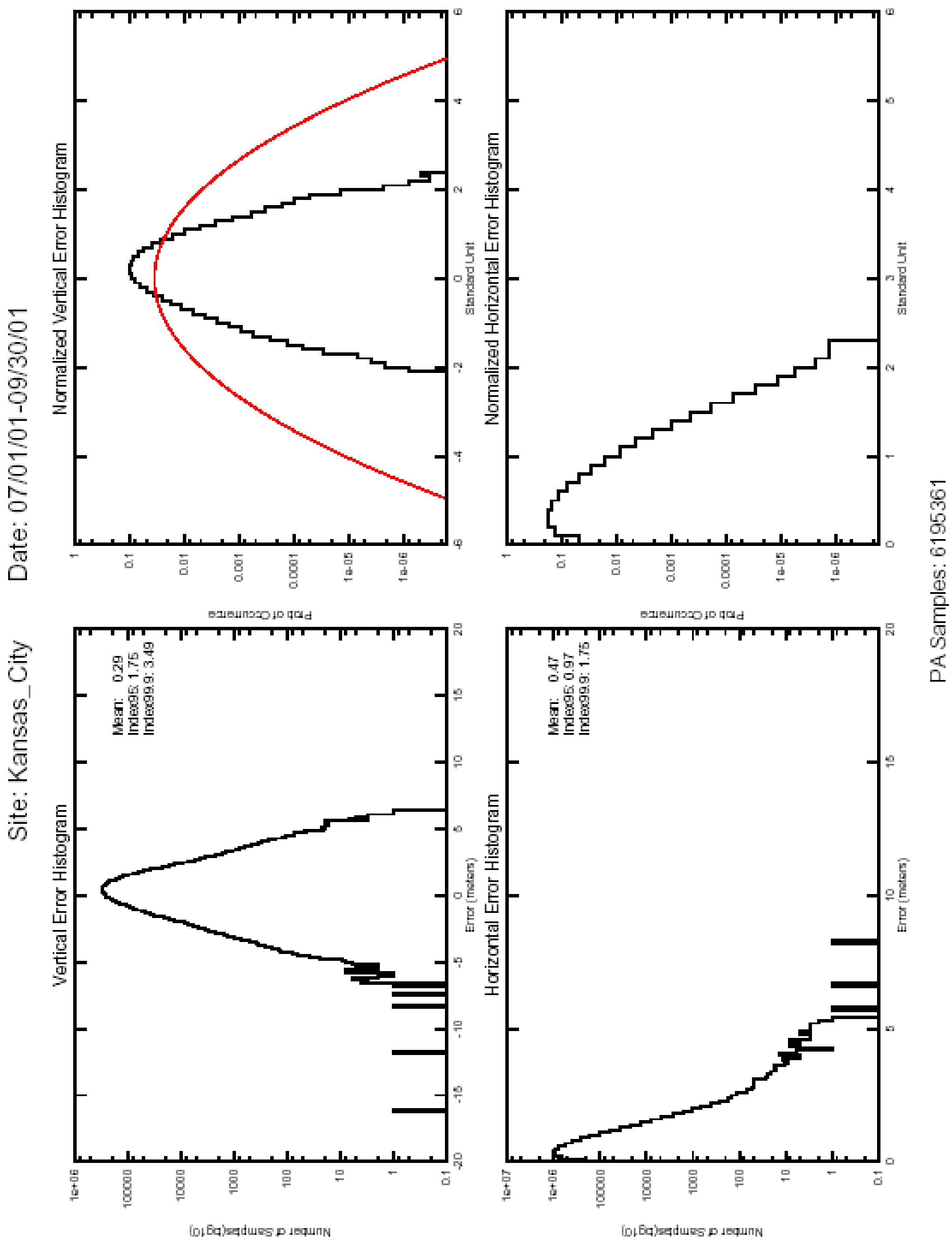


Figure E-2.8 2-D Histogram for Kansas City



3.0 Availability

WAAS availability evaluation estimates the probability that the WAAS can provide Operational Service Levels (GLS, APV-II, and LNAV/VNAV) defined in Table E-2.1. At each receiver the WAAS message along with the GPS/GEO satellites tracked were used to produce WAAS protection levels in accordance with MOPS. Table E-3.1 shows the protection levels that were maintained for 95% of the time for each receiver location. Table E-3.2 presents the percentage of time that vertical and horizontal operational service levels were available at each receiver location.

The geographic location of each receiver evaluated is depicted in Figure E-3.1 along with the 95% VPL value and the WAAS LNAV/VNAV availability at each location. The daily WAAS availability, at each receiver location, for the three operational service levels is shown in Figures E-3.2 to E-3.6

Table E-3.1 95% Protection Level

Location	95% HPL (meters)	95% VPL (meters)	% in PA mode
Kansas City	9.25	15.00	99.531
Salt Lake City	10.69	16.34	99.576
Columbus	11.61	17.09	99.564
Denver	9.33	14.70	99.512
Atlanta	8.89	16.43	99.552
Greenwood	10.57	16.86	99.502
Chicago	14.73	22.00	99.113
San Angelo	36.48	36.57	89.407
Atlantic City	34.69	36.41	96.326
Prescott	67.01	30.40	83.048
Miami	61.68	49.11	78.891
Arcata	72.99	61.44	78.973
Billings	70.29	73.93	91.714
Grand Forks	67.38	83.51	39.703
Bangor	152.66	131.43	25.490
Anchorage	115.64	88.83	13.238

Table E-3.2 Availability Statistics

Location	Horizontal APV-II % of time (HAL = 40 m)	Horizontal LNAV/VNAV % of time (HAL = 556 m)	Vertical GLS % of time (VAL = 12 m)	Vertical APV-II % of time (VAL = 20 m)	Vertical LNAV/VNAV % of time (VAL = 50 m)
Kansas City	99.53	100	73.32	99.21	99.53
Salt Lake City	99.56	100	64.70	98.08	99.58
Columbus	99.51	100	56.36	98.07	99.44
Denver	99.51	100	72.04	99.07	99.51
Atlanta	99.55	100	59.98	98.54	99.55
Greenwood	99.50	100	55.89	98.41	99.50
Chicago	98.55	100	37.51	91.96	98.45
San Angelo	86.35	100	29.09	72.46	87.28
Atlantic City	92.81	100	12.15	68.76	93.81
Prescott	73.65	100	6.54	60.65	82.66
Miami	69.8	100	4.27	46.19	75.23
Arcata	68.43	100	5.50	34.55	72.82
Billings	81.74	100	18.20	61.3	83.95
Grand Forks	34.4	100	0.53	18.47	35.48
Bangor	17.74	100	0.01	5.00	18.56
Anchorage	6.36	99.99	0.00	0.31	9.57

Several events occurred during the reporting period that adversely affected WAAS availability at all operational service levels. The following is a list of the events that reduced WAAS availability: GPS satellite PRN#24 was not available for navigation, due to operational maintenance, between 7/11/2001 and 7/12/2001; a GPS satellite PRN#22 clock failure, which occurred between 7/29/2001 and 7/30/2001, caused the WAAS to be restarted; WAAS GEO satellite PRN#122 stopped broadcasting the signal in space for several hours on 9/14/2001, due to a GUS hardware failure.

As evidenced by these statistics, WAAS performed well throughout this quarter with respect to LNAV/VNAV operational service levels. Every site, except Anchorage, met the horizontal LNAV/VNAV operational service level 100% of the time for the entire quarter. It should be noted that central CONUS sites exhibit better performance with regards to availability. It should, therefore, be expected that results will vary for sites with different locations in CONUS. More centrally located sites exhibit much higher availability for all of the operational service levels.

Figure E-3.1 95% VPL, and LNAV/VNAV Availability

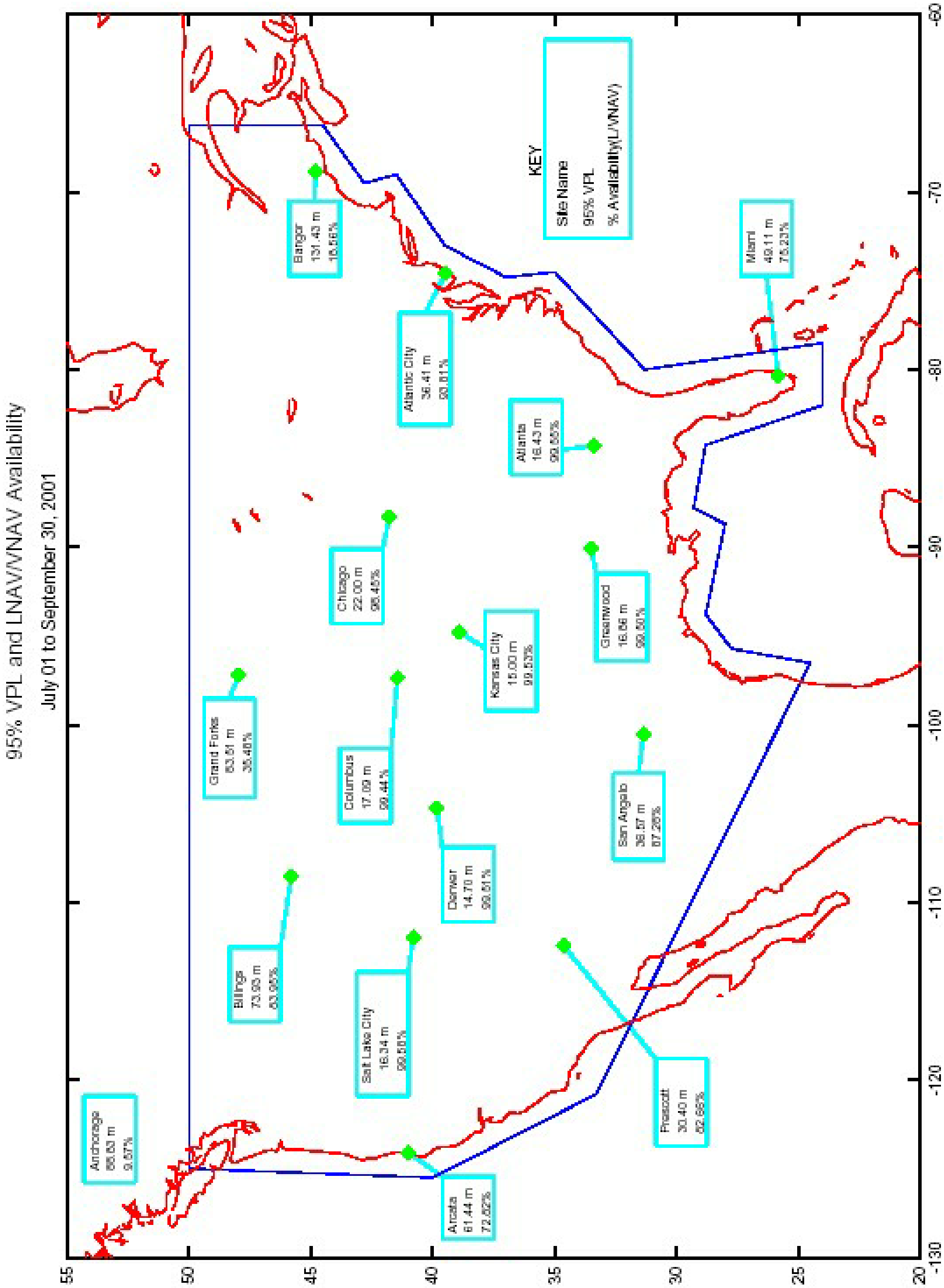


Figure E-3.2 APV-I Horizontal Availability Trends

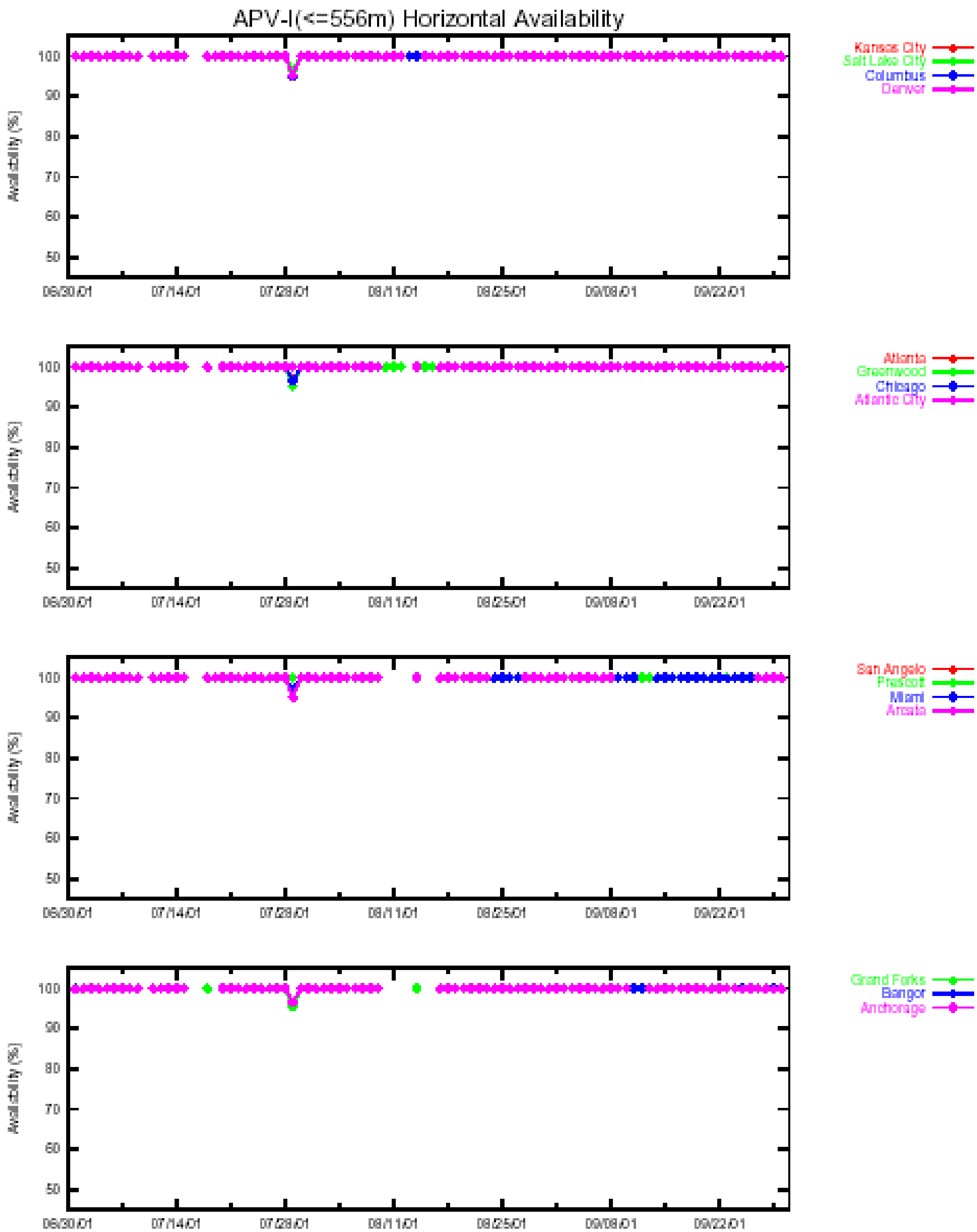


Figure E-3.3 GLS/APV-II Horizontal Availability Trends

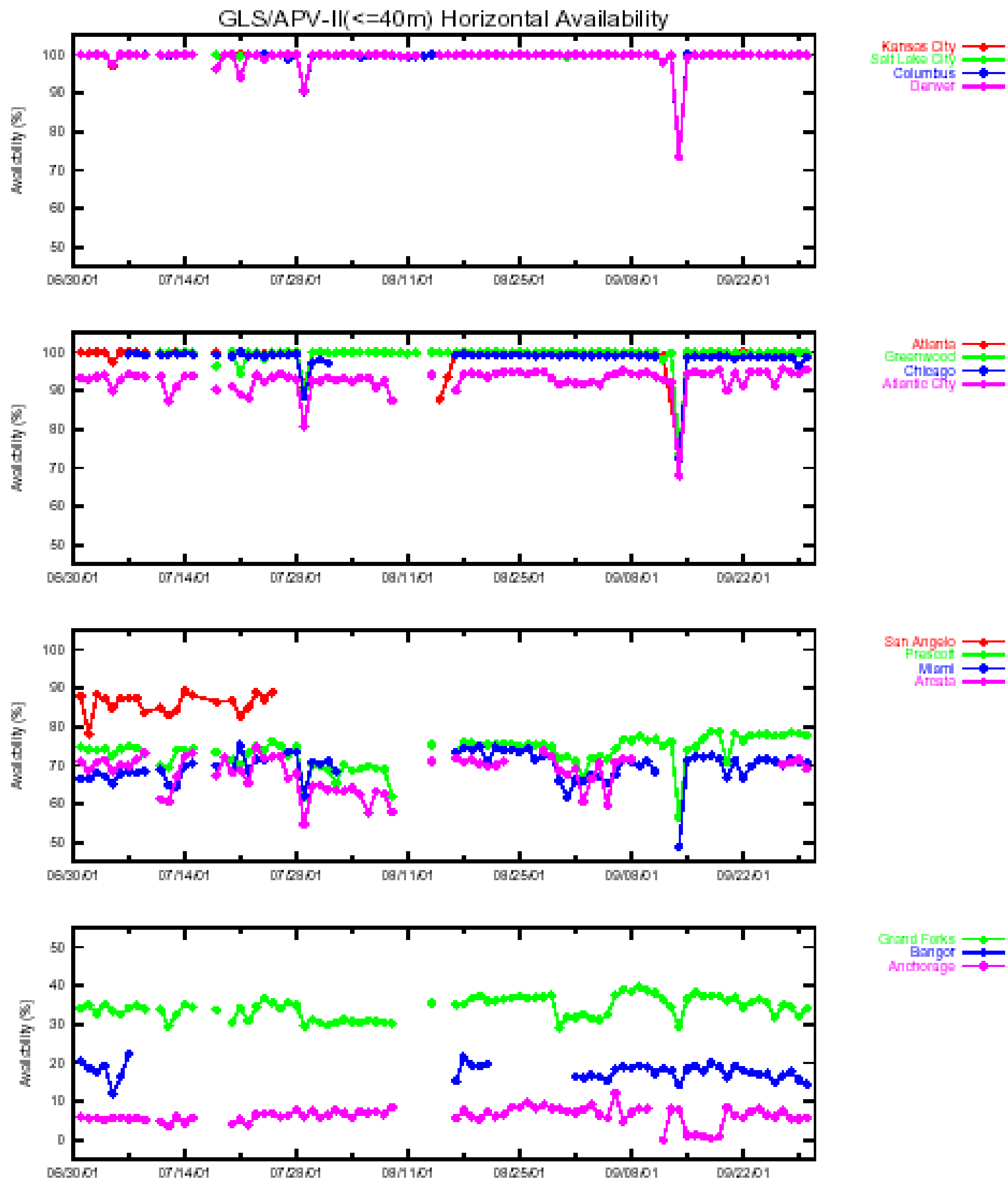


Figure E-3.4 APV-I Vertical Availability Trends

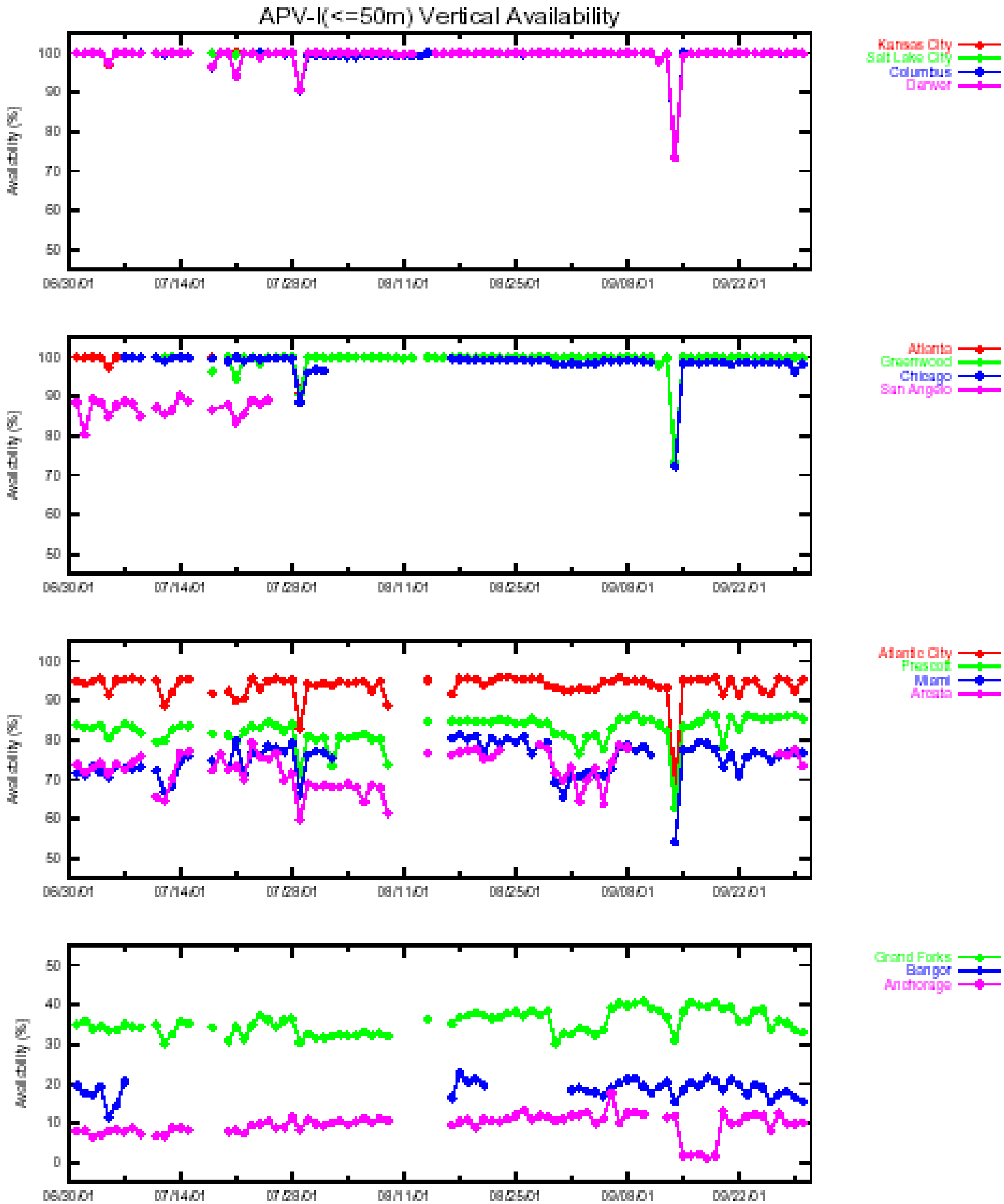


Figure E-3.5 APV-II Vertical Availability Trends

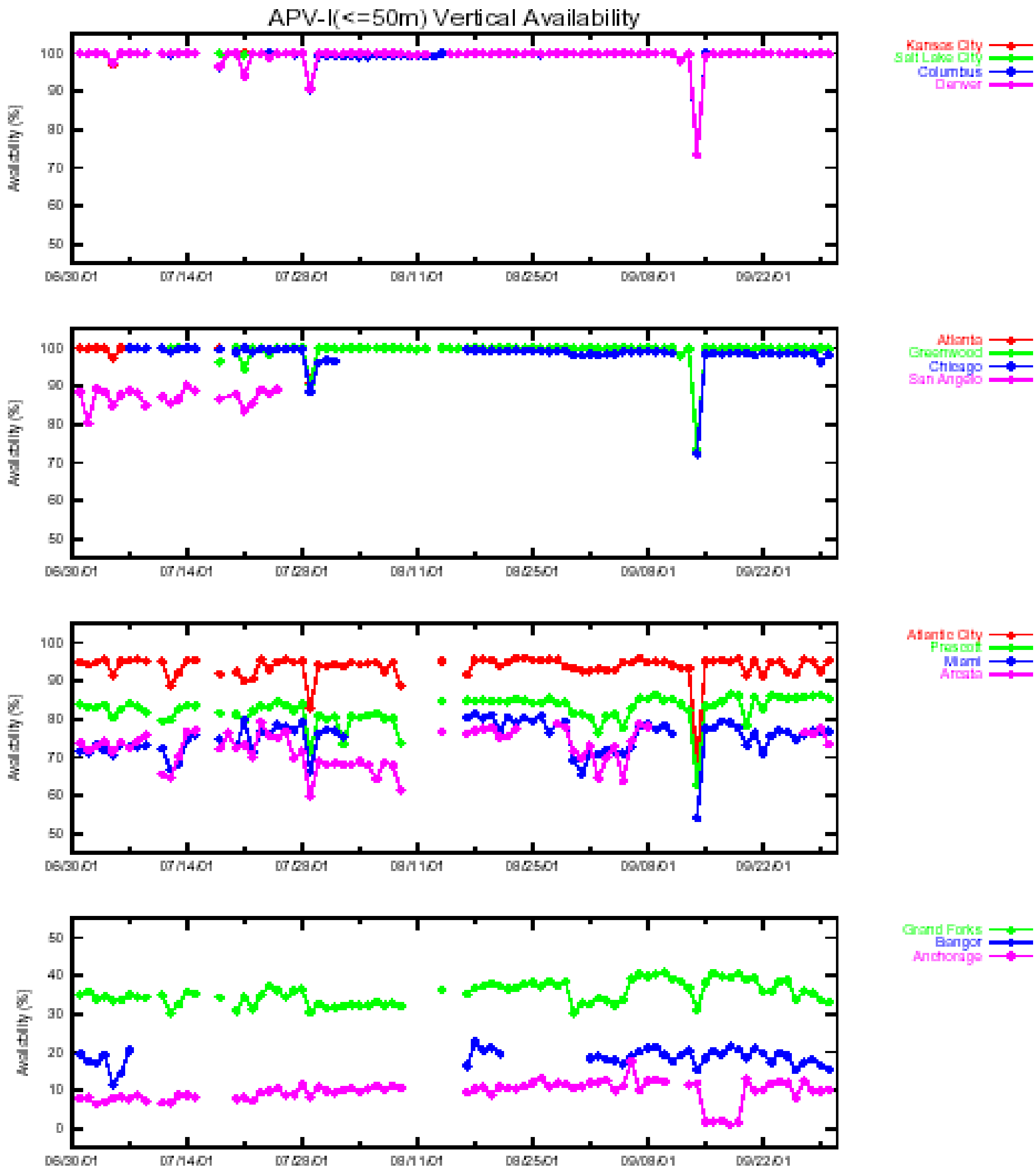
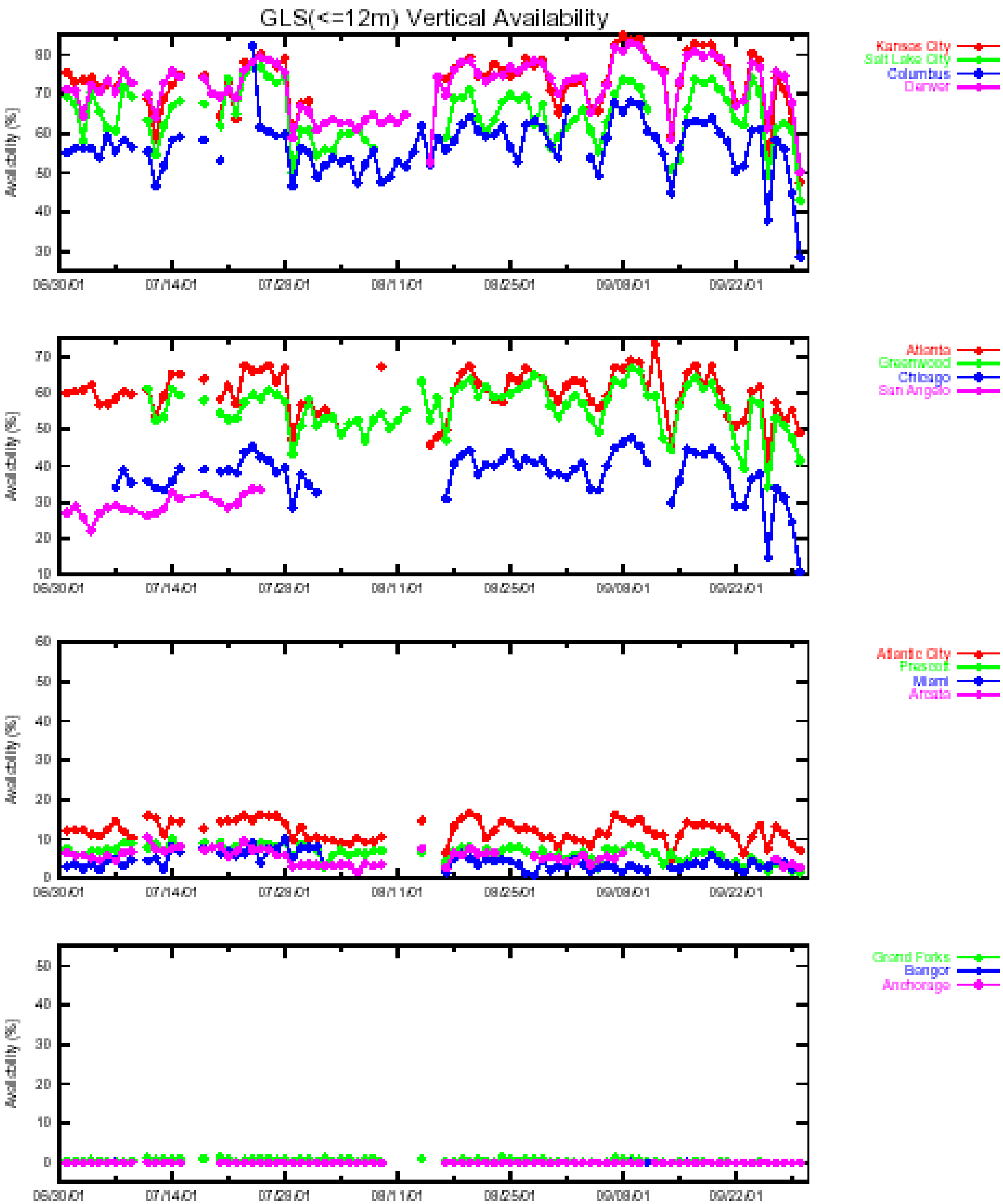


Figure E-3.6 GLS Vertical Availability Trends



4.0 Coverage

WAAS Coverage area evaluation estimates the percent of CONUS where WAAS is providing LNAV/VNAV service. The WAAS message, along with GPS/GEO satellite status, is used to determine WAAS availability across North America at an array of locations that are spaced two degrees apart. If the protection levels at a given location meet LNAV/VNAV alert limits (VAL = 50 and HAL = 556) 95% of the time, then the location is considered to be available.

Figures E-4.1 to E-4.3 shows the WAAS coverage area for each of the three months of the 3rd quarter. The portion of CONUS, where WAAS provides LNAV/VNAV service, is included in the 95% availability area colored in blue and 99% availability area colored in purple. The month of September does not contain 99% availability due to a WAAS GUS hardware problem on 9/14/2001, which prevented the system from broadcasting the WAAS signal in space for several hours.

The daily WAAS LNAV/VNAV CONUS coverage percentage is plotted in Figure E-4.4. The daily coverage percentage typically varied between 50% and 60% of CONUS, except on 9/14/2001 when the WAAS hardware problem occurred. Factors such as GPS satellite operational maintenance and ionospheric activity contributed to the daily fluctuations in WAAS coverage area.

Figure E-4.1 WAAS Coverage: July, 2001

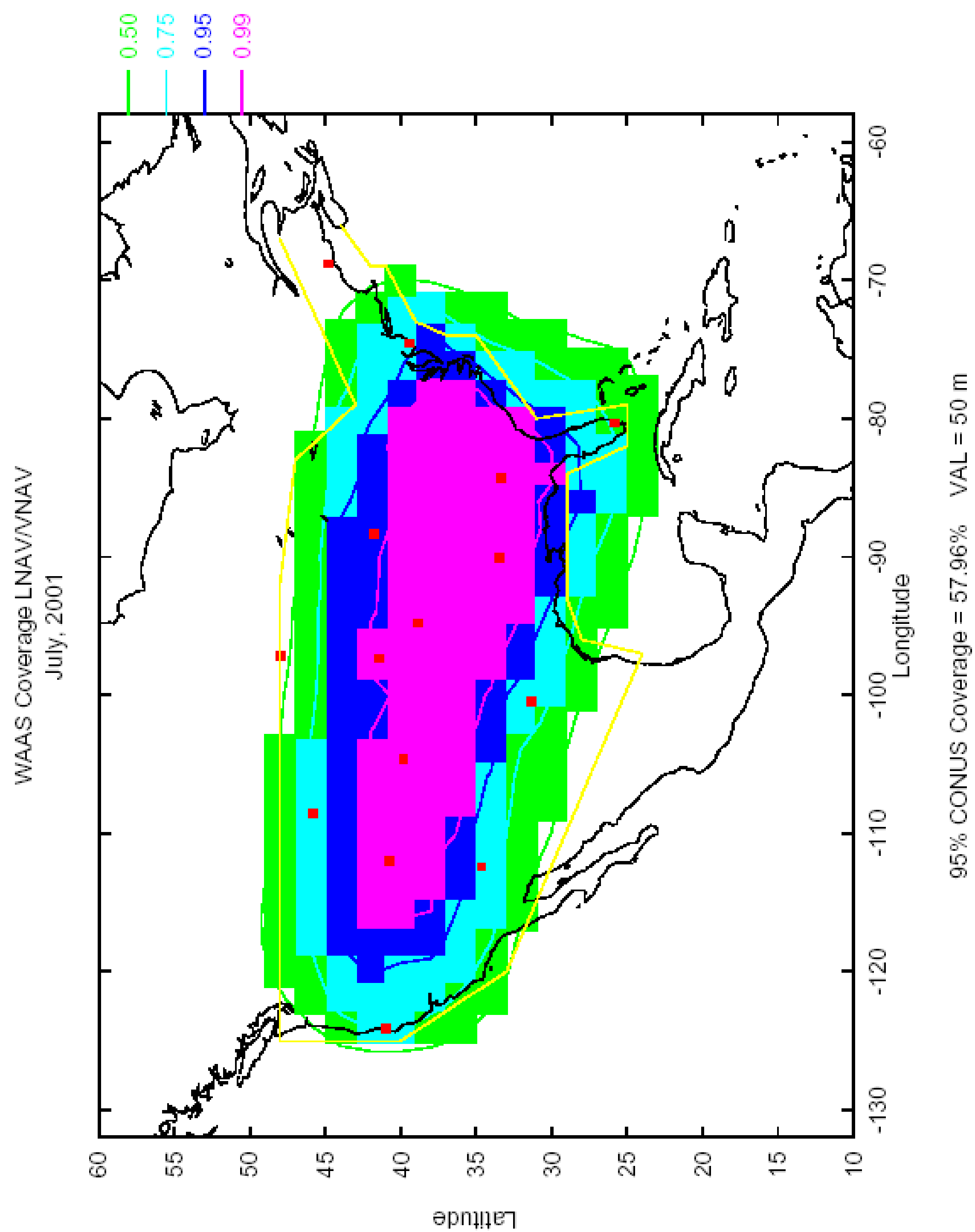


Figure E-4.2 WAAS Coverage: August, 2001

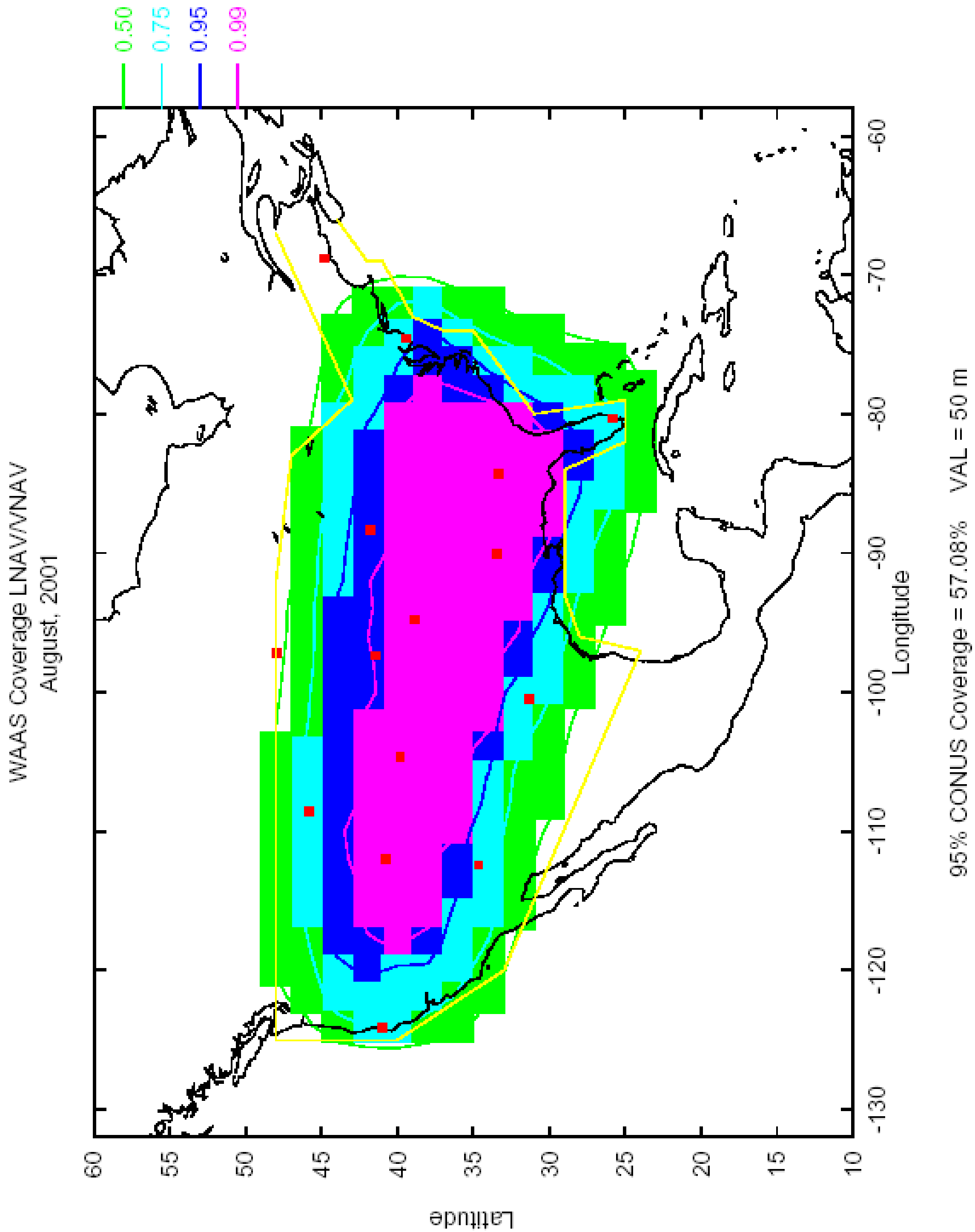


Figure E-4.3 WAAS Coverage: September, 2001

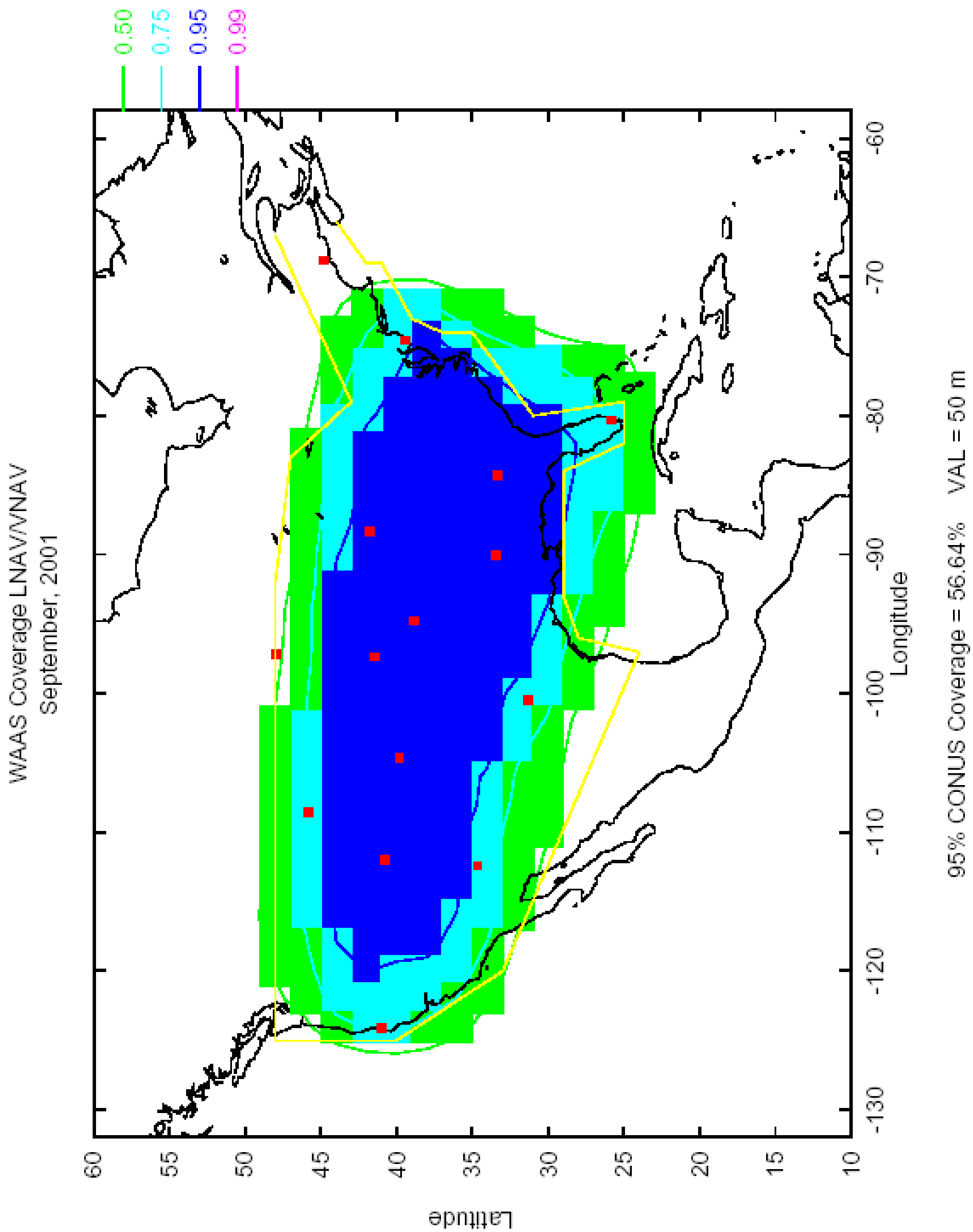
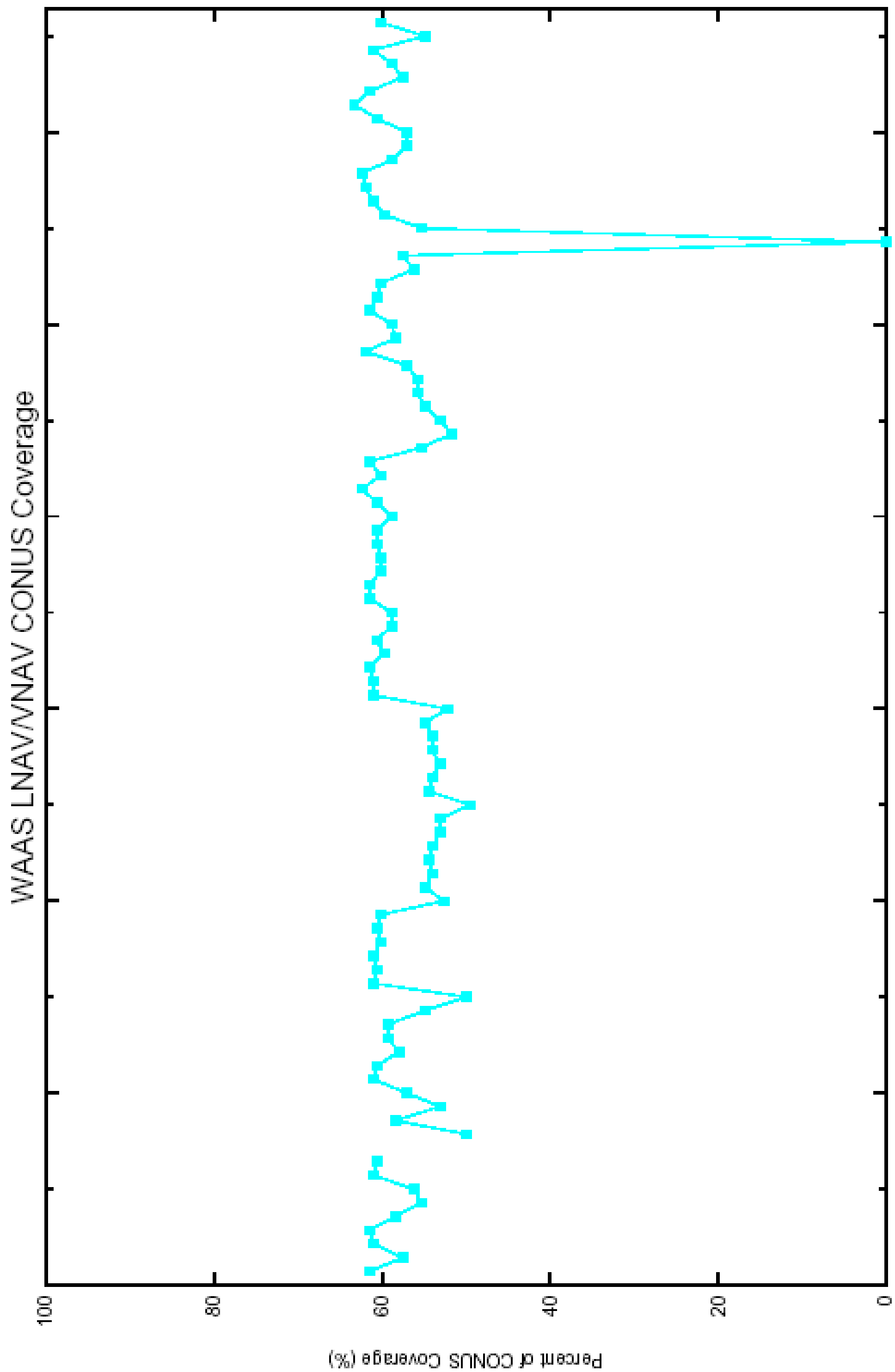


Figure E-4.4 Daily WAAS LNAV/VNAV CONUS Coverage



5.0 Continuity

5.1 NPA Continuity of Navigation.

NPA continuity of navigation was evaluated by monitoring the accuracy performance throughout each flight hour. Navigation error data for each site was divided into multiple bins consisting of 3600 data samples. The position accuracy data for each bin was analyzed and statistics were generated to evaluate the data. If the horizontal position error is less than 100 meters 95% of the time, then the continuity of navigation flag is set to "1" to indicate the continuity of navigation is met for that particular flight hour. The continuity of navigation percentile statistic was computed for each reference site by summing the continuity of navigation flags of "1" together and dividing by the total number of test hours (bins) accumulated. The NPA Continuity of Navigation column of Table E-5.1 shows all evaluated sites have the maximum probability of 1.

Table E-5.1 Continuity

Location	NPA Continuity of Navigation	NPA Continuity of Fault Detection	LNVA/VNAV Continuity of Function
Kansas City	1	0.959373	0.998087
Salt Lake City	1	0.962343	0.997754
Columbus	1	0.958586	0.995683
Denver	1	0.954374	0.997195
Atlanta	1	0.960752	0.997972
Greenwood	1	0.954545	0.997208
Chicago	1	0.960591	0.986348
San Angelo	1	0.962825	0.939865
Atlantic City	1	0.954914	0.941380
Prescott	1	0.951451	0.935214
Miami	1	0.957411	0.852781
Arcata	1	0.962938	0.837240
Billings	1	0.958511	0.858952
Grand Forks	1	0.955443	0.748665
Bangor	1	0.942970	0.466092
Anchorage	1	0.959979	0.476551

5.2 NPA Continuity of Fault Detection.

NPA continuity of fault detection was evaluated by monitoring the integrity performance throughout each flight hour. Navigation error data for each reference site was divided into multiple bins consist of 3600 data samples. The horizontal and vertical position error data for each bin was analyzed and statistics were generated to evaluate the data as follows:

- No HMIs have occurred in the horizontal or vertical dimensions.
- User maintains either PA or NPA navigation mode of operation.

If the above conditions are met, then the continuity of fault detection flag is set to "1" to indicate the continuity of fault detection is met for that particular flight hour. The continuity of fault detection percentile statistic was computed for each reference site by summing the continuity of fault detection flags of "1" together and dividing by the total number of test hours (bins) accumulated. The NPA Continuity of Fault Detection column of Table E-5.1 shows the probability for NPA continuity of fault detection. The probability ranges from 0.942970 to 0.962938. This probability is much lower than expected for two reasons: first, a large number of SV and IGP alerts were sent by the WAAS, and second, interruptions of the WAAS SIS that occurred. Both of these factors can cause the SV fast corrections to time out reducing the navigation mode to GPS only operation.

5.3 LNAV/VNAV Continuity of Function.

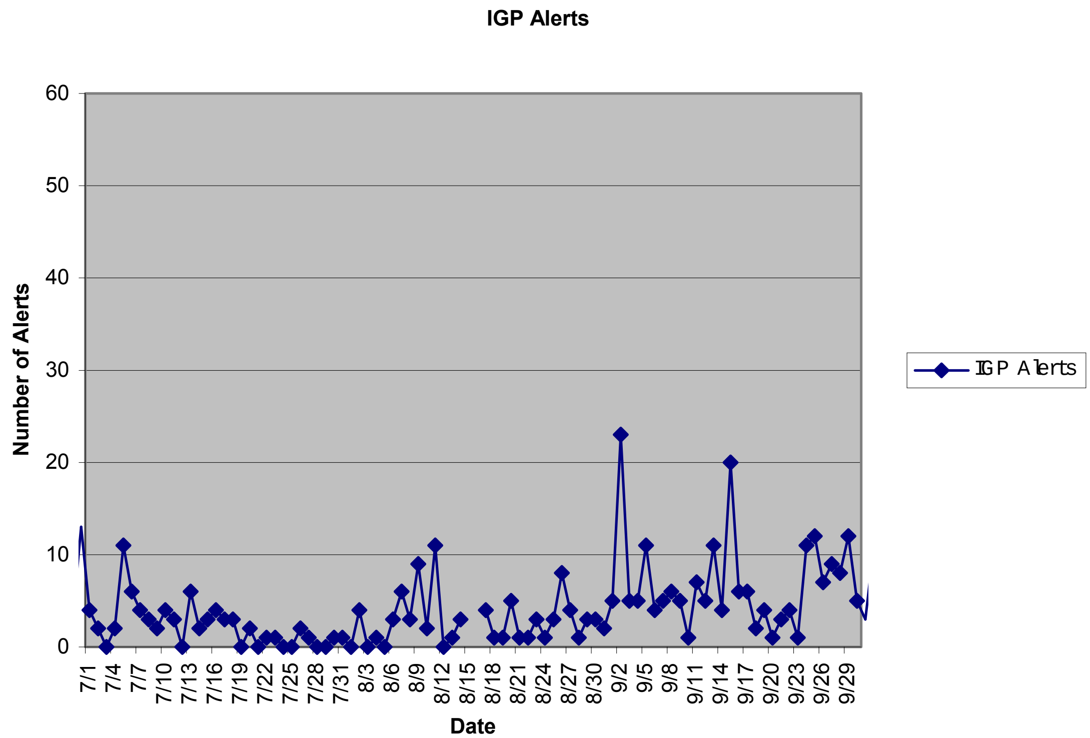
LNAV/VNAV continuity of function was evaluated by monitoring the accuracy and integrity performance throughout each flight segment. Navigation error data for each reference site was divided into multiple bins consist of 150 data samples. The position accuracy and integrity performance data for each bin was analyzed and statistics were generated to evaluate the data as follows:

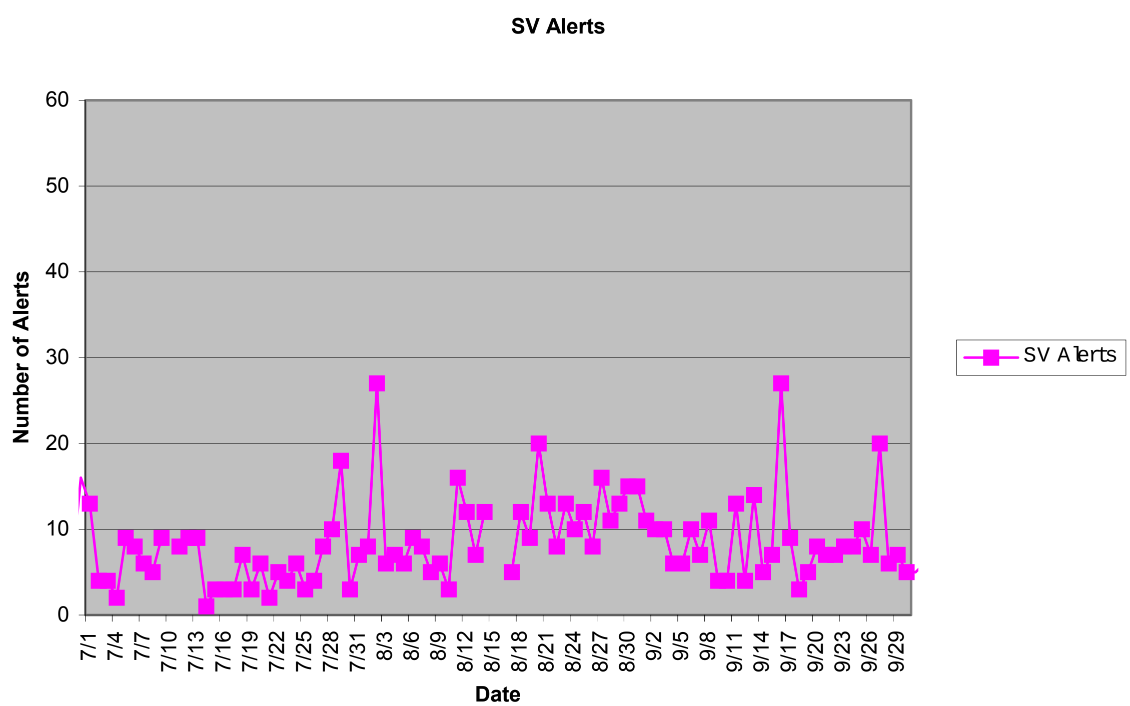
- The horizontal and vertical position errors are less than 7.6 meter 95% of the time for each bin.
- No HMIs have occurred in the horizontal or vertical dimensions.
- User maintains PA mode of operation.
- VPL is less than or equal to 50m.

If the above conditions are met, then the continuity of function flag is set to "1" to indicate the continuity of function is met for that particular flight segment. The continuity of function percentile statistic was computed for each reference site by summing the continuity of function flags of "1" together and dividing by the total number of test segments (bins) accumulated. LNAV/VNAV Continuity of Function column of Table E-5.1 shows the probability for LNAV/VNAV continuity of function range from 0.466092 to 0.998087. With the current ionospheric monitoring rules of the WAAS, sites toward the center of CONUS have better accuracy and availability performance than sites located on the edge of CONUS or in Alaska thus resulted in better continuity performance.

The WAAS produces alert messages to protect the users from satellite degradation or severe ionospheric activity, both of which can cause unsafe conditions for a user. Space Vehicle (SV) alerts increase the User Differential Range Error (UDRE) of satellites, which can reduce the weighting of the satellite in the navigation solution or completely exclude it from the navigation solution. Ionospheric Grid Point (IGP) alerts increase the Grid Ionospheric Vertical Error (GIVE) of IGP's, which can affect the usage of satellites whose pierce points are in the vicinity of the IGP. An increase in either UDRE's or GIVE's after an alert effectively increases the user protection levels (HPL and VPL). If the protection levels are raised above LNAV/VNAV alarm limits (VAL = 50, HAL = 556) continuity of function is not met for that flight segment. Additionally, if an alert message sequence lasts for more than 12 seconds, WAAS fast corrections can time out, causing continuity of fault detection to not be met for that flight segment. Figure E-5.1 shows the number of SV alerts and IGP alerts that occurred daily during the reporting period.

Figure E-5.1 IGP and SV Quarterly Alert Trends





6.0 Integrity

Analysis of integrity includes the identification and evaluation of HMIs (hazardously misleading information), as well as the generation of a safety index to illustrate the margin of safety that WAAS protection levels are maintaining. The safety margin index (shown in Table E-6.1) is a metric that shows how well the protection levels are bounding the maximum observed error. The process for determining this index involves normalizing the largest error observed at a site. This is accomplished by dividing this maximum observed error by the WAAS estimated standard deviation of the error. The safety margin requirement, 5.33 standard units for vertical and 6 standard units for horizontal, is then divided by this maximum normalized error.

Table E-6.1 Safety Margin Index and HMI Statistics

Location	Safety Margin Index		Number of HMIs
	Horizontal	Vertical	0
Kansas City	2.73	2.05	0
Salt Lake City	3.00	1.97	0
Columbus	2.73	1.97	0
Denver	2.31	1.78	0
Atlanta	2.07	2.22	0
Greenwood	2.31	1.90	0
Chicago	2.07	2.22	0
San Angelo	3.00	2.32	0
Atlantic City	1.71	1.40	0
Prescott	4.29	2.96	0
Miami	2.14	1.84	0
Arcata	2.31	1.90	0
Billings	2.07	2.05	0
Grand Forks	2.07	1.78	0
Bangor	1.94	1.62	0
Anchorage	3.00	2.42	0

An observed safety margin index of greater than one indicates safe bounding of the greatest observed error, less than one indicates that the maximum error was not bounded, and a result equal to one means that the error was equal to the protection level. As evidenced by the statistics in the above table (see Table E-6.1), the safety margin index never drops below 1.4 at any site. Also, Table E-6.1 shows the number of HMIs that occurred during the quarter. An HMI occurs if the error exceeds the protection level in the vertical or horizontal dimensions at any time and 6.2 or more seconds pass before this event is reported.

7.0 SV Range Accuracy

Range accuracy evaluation computes the probability that the WAAS User Differential Range Error (UDRE) and Grid Ionospheric Vertical Error (GIVE) statistically bound 99.9% of the range residuals for each satellite tracked by the receiver. For this report only the UDRE performance is evaluated. Future reports will also present GIVE performance evaluation. A UDRE is broadcast by the WAAS for each satellite that is monitored by the system and is required to bound 99.9% of the residual error on a pseudorange after application of fast and long-term corrections. The pseudorange residual error is determined by taking the difference between the raw pseudorange and a calculated reference range. The reference range is equal to the true range between the corrected satellite position and surveyed user antenna plus all corrections (WAAS Fast Clock, WAAS Long-Term Clock, WAAS Ionospheric delay, Tropospheric delay, Receiver Clock Bias, and Multipath).

Since the true ionospheric delay and multipath error are not precisely known the estimated variance in these error sources are added to the UDRE before the comparing it to the residual error.

GPS and WAAS GEO satellite range residual errors were calculated for the WAAS receiver in Atlanta during the quarter and the 95% index is reported in Table E-7.1. All GPS satellite residual errors were less than 2.0 meters 95% of the time. The WAAS GEO satellite residual error was approximately 3.1 meters 95% of the time. The probability that the UDRE bounds the residual error is also presented in Table E-7.1. All satellites were bounded at least 99.9% of the time except GPS satellites PRN 10 and 25, which were bounded 99.8% and 99.6% respectively. The lower bounding probability for PRN 10 and 25 is primarily due to higher than expected code noise and multipath errors present on the psuedorange measurements.

Table E-7.1 Range Error and 3.29 Sigma Bounding

SV	95% Range Error	3.29 Sigma Bounding
1	1.43	99.999
2	1.44	100
3	1.57	99.996
4	1.56	99.982
5	1.63	100
6	1.58	99.996
7	1.33	100
8	1.5	99.999
9	1.52	100
10	1.97	99.886
11	1.47	100
13	1.55	100
14	1.63	99.998
15	1.48	100
17	1.57	99.994
18	1.45	100
20	1.65	99.998
21	1.46	100
22	1.88	99.988
23	1.61	99.976
24	1.97	99.923
25	1.93	99.623
26	1.86	99.974
27	1.44	100
28	1.54	99.999
29	1.5	100
30	1.76	100
31	1.57	99.999
122	3.09	99.999