WIDE-AREA AUGMENTATION SYSTEM PERFORMANCE ANALYSIS REPORT

Report #2

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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 included a section on Wide Area Augmentation System (WAAS) performance and a report on observed WAAS anomalies. Instead of including the WAAS reporting in the PAN report, the WAAS report is a separate document.

During the reporting period of October 1, 2001 and December 31, 2001 a major upgrade to the WAAS occurred. The WAAS prime contractor, Raytheon, installed the new Grid Ionospheric Vertical Error (GIVE) safety monitor on the system. Because of the significant differences in all evaluation parameters of this report, this report presents results for the pre-GIVE monitor and post-GIVE monitor time periods. Raytheon installed the new GIVE monitor on November 26, 2001.

There were no Hazardously Misleading Events (HMI) or under boundings (i.e. position error is greater than the calculated protection level) during this reporting period. Also, during the pre-GIVE monitor period the LNAV/VNAV coverage was 60% of CONUS. During the post-GIVE monitor period the LNAV/VNAV coverage was 96% of CONUS.

The following table shows observations for accuracy and availability made during the reporting period. See the body of the report for results in the continuity, safety index, and range analysis. Please note that the results in the below table are valid when the LNAV/VNAV service is available. See the body of the report for results when other service levels are available:

Parameter	Period	Site/Maximum	Site/Minimum
95% Horizontal Accuracy	Pre-GIVE Monitor	Grand Forks 7.551 meters	Kansas City 1.078 meters
95% Horizontal Accuracy	Post-GIVE Monitor	Anchorage* 6.569 meters	Kansas City 0.875 meters
95% Vertical Accuracy	Pre-GIVE Monitor	Anchorage 6.882 meters	Atlanta 1.435 meters
95% Vertical Accuracy	Post-GIVE Monitor	Anchorage 6.569 meters	Kansas City 1.448 meters
LNAV/VNAV Instantaneous Availability – Horizontal (556 m)	Pre-GIVE Monitor	All other sites 100%	Anchorage 99.93% Grand Forks 99.99%
LNAV/VNAV Instantaneous Availability – Horizontal (556 m)	Post-GIVE Monitor	All other sites 100%	Anchorage 95.96%
LNAV/VNAV Instantaneous Availability – Vertical (50 m)	Pre-GIVE Monitor	Salt Lake City 99.25%	Anchorage 0.15%
LNAV/VNAV Instantaneous Availability – Vertical (50 m)	Post-GIVE Monitor	Kansas City, Salt Lake City, Atlanta, Miami, and Billings 99.76%	Anchorage 86.65%
95% HPL	Pre-GIVE Monitor	Bangor 184.28 meters	Atlanta 9.38 meters
95% HPL	Post-GIVE Monitor	Anchorage** 511.2 meters	Kansas City 14.62 meters
95% VPL	Pre-GIVE Monitor	Bangor 168.46 meters	Kansas City 15.42 meters
95% VPL	Post-GIVE Monitor	Anchorage*** 374.42 meters	Kansas City 22.8 meters

* - The next lowest horizontal error was 1.459 meters at Grand Forks.
** - The next lowest 95% HPL was 28.86 meters at Miami
*** - The next lowest 95% VPL was 37.16 meters at Miami

TABLE OF CONTENTS

Appendix A: Glossary

LIST OF FIGURES

LIST OF TABLES

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) adds more timely integrity monitoring of GPS and improves position accuracy and availability 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 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 10/01/2001 and 12/31/2001, from NSTB and WAAS reference station receivers at locations listed in the table below. On 11/26/2001, the new Grid Ionosphere Vertical Error (GIVE) Monitor build was installed. For this quarter report, the results are divided into two periods, pre- and post-GIVE Monitor, 10/01 to 11/26/2001 and 11/27 to 12/31/ 2001, respectively.

The GIVE monitor is one of the WAAS components that ensures the WAAS is transmitting high integrity data to users. The GIVE monitor focuses on the ionospheric corrections provided by the WAAS. The GIVE value broadcast by WAAS is the bound on the actual ionospheric error experienced by a user. A user employs an interpolation scheme utilizing the broadcast GIVE's to determine the User Ionospheric Vertical Error (UIVE) for each satellite the user can see. The GIVE monitor ensures that the broadcast GIVE's have a sufficiently high level of integrity that UIVE's calculated by the user will bound their vertical ionospheric errors with a very high probability.

The GIVE monitor installed on November 26, 2001 replaces a previous version of GIVE monitor. This new version has several impacts on the performance of WAAS, as can be seen by comparing the results in this report before and after November 26. One noticeable difference includes the increased number of Ionospheric Grid Points (IGP) being monitored. This effect increases the LNAV/VNAV availability of the system. Another difference, while the availability increases, is the broadcast GIVE's also increased to ensure safety. These higher GIVE's also result in higher calculated VPL values.

Previously, the WAAS Test Team received WAAS reference station data via the Functional Verification System (FVS) network. At the beginning of this reporting period the FVS was reconfigured to support WAAS training requirements. Therefore, the WAAS reference station data is no longer available on the network. Replacing this data source is the WAAS External Interface (WEI). The WEI provides data for all WAAS reference receivers (currently 75) at a rate of once per second. Therefore, there are only 27 days of data available from WAAS reference stations in this report.

Table 1.1 NSTB and WAAS Reference Station Receivers

NSTB:	Number of Days Evaluated	Number of Samples
• Arcata, CA	-	-
• Atlantic City, NJ	91	7854237
• Columbus, OH	91	7835915
• Denver, CO	81	6995498
• Grand Forks, ND	85	7370575
• Greenwood, MS	91	7860028
• Prescott, AZ	88	7642175
• San Angelo, CA	-	-
WAAS:		
• Bangor, ME	11	933785
• Billings, MT	27	2307017
• Anchorage, AK	27	2295771
• Chicago, IL	27	2306870
• Kansas City, KS	27	2299086
• Salt Lake City, UT	27	2307108
• Miami, FL	27	2307119
• Atlanta, GA	27	2307131

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

Table 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	75% 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
Accuracy Iono	99.9% of iono error bounded by GIVE

1.1 Event Summary

Table 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 1.3 Test Events

Date	Description
10/01/01 to 12/31/01	NSTB receiver failure at San Angelo
10/01/01 to 12/31/01	NSTB receiver failure at Arcata
10/25/01 to 10/29/01	NSTB receiver failure at Grand Forks
10/11/01 to 10/17/01 11/11/01 to 11/13/01 11/25/01 to 11/17/01	NSTB receiver failure at Denver
11/26/01	GIVE Monitor was installed
10/9/01 to 12/12/01	Loss of data at all WAAS sites due to WEI installation
10/23/01 to 12/14/01	Intermittent GEO gaps
10/30/2001	GPS "Not Monitored" by WAAS

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 instantaneous 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 and GIVE bounding percentage and the 95% index of the range and ionospheric accuracy for each satellite tracked by the NSTB receiver in Columbus.

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 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 2.1.

Table 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 2.2 and 2.3 show 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 pre - and post-GIVE Monitor periods of 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 2.2 and 2.3. Note that the improvement of the percentage in PA mode (Table 2.3) in the post-GIVE monitor period for sites located in the edge of CONUS (i.e. Miami, Grand Forks, and Anchorage) is due to the increase of monitored IGPs making more satellites with WAAS Ionospheric correction available. Column Vertical GLS in Table 2.3 shows the 95% accuracy for most sites are 0.0. This is due to the fact that VPLs never fell below the 12m VAL therefore no samples were available at this operational service level. This is the expected result caused by the new GIVE monitoring rules which increases the user protection levels. 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 2.1 to 2.4 show the daily horizontal and vertical 95% accuracy for APV-I (LNAV/VNAV) operational service level for pre- and post-GIVE Monitor periods. Note the spikes occurred on various days are caused by ionospheric activity and satellites are not monitored by WAAS. These events effects both accuracy and availability.

Table 2.2 Pre-GIVE Monitor 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	1.076	1.078	1.322	1.535	1.561	99.973
Salt Lake City	1.215	1.218	1.461	1.897	1.904	99.973
Columbus	1.174	1.246	1.778	1.962	2.052	99.381
Denver	1.111	1.146	1.707	1.993	2.056	99.363
Atlanta	1.084	1.085	1.243	1.405	1.435	99.972
Greenwood	1.120	1.142	1.523	1.652	1.711	99.458
Chicago	1.248	1.348	1.415	1.806	1.942	99.063
San Angelo[1]	-	-	-	-	-	-
Atlantic City	2.124	2.797	1.712	2.147	2.825	96.457
Prescott	1.716	4.439	1.373	1.928	2.096	82.855
Miami	1.855	3.793	1.656	1.881	2.545	78.550
Arcata[2]	-	-	-	-	-	-
Billings	2.408	4.859	1.543	2.296	3.370	91.631
Grand Forks	2.438	7.551	2.022	2.455	3.798	42.323
Bangor	3.531	7.276	0.000	2.045	3.909	24.730
Anchorage	3.828	4.972	0.000	1.415	6.882	8.348

1-The receiver at San Angelo was down for maintenance this quarter due to a hardware failure
2-The receiver at Arcata was down for maintenance this quarter due to a hardware failure

Table 2.3 Post-GIVE Monitor 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	0.964	0.973	0.000[4]	1.349	1.448	99.760
Salt Lake City	1.121	1.143	0.000[4]	2.211	2.293	99.761
Columbus	0.856	0.875	0.719	1.325	1.463	99.452
Denver	0.919	0.934	0.000[4]	1.499	1.653	99.448
Atlanta	1.019	1.030	0.000[4]	1.478	1.628	99.760
Greenwood	0.926	0.943	0.781	1.661	1.740	99.472
Chicago	0.985	1.020	0.000[4]	1.371	1.491	99.760
San Angelo[1]	-	-	-	-	-	-
Atlantic City	0.910	0.968	0.000[4]	1.623	1.788	99.473
Prescott	1.007	1.023	0.918	1.149	1.565	99.402
Miami	1.128	1.176	0.000[4]	1.591	2.021	99.760
Arcata[2]	-	-	-	-	-	-
Billings	1.312	1.366	0.000[4]	1.774	2.111	99.761
Grand Forks	1.367	1.459	0.000[4]	1.854	2.104	99.449
Bangor[3]	-	-	-	-	-	-
Anchorage	2.723	6.569	0.000[4]	0.000	2.992	86.653

1-The receiver at San Angelo was down for maintenance this quarter due to a hardware failure
2-The receiver at Arcata was down for maintenance this quarter due to a hardware failure
3-Bangor receiver data was not available due to WEI installation.
4-GLS operational service level was not available after WAAS GIVE monitor update. (See table 3.4 for service availability)

Figure 2.1 Pre-GIVE Monitor 95% Horizontal Accuracy at LNAV/VNAV

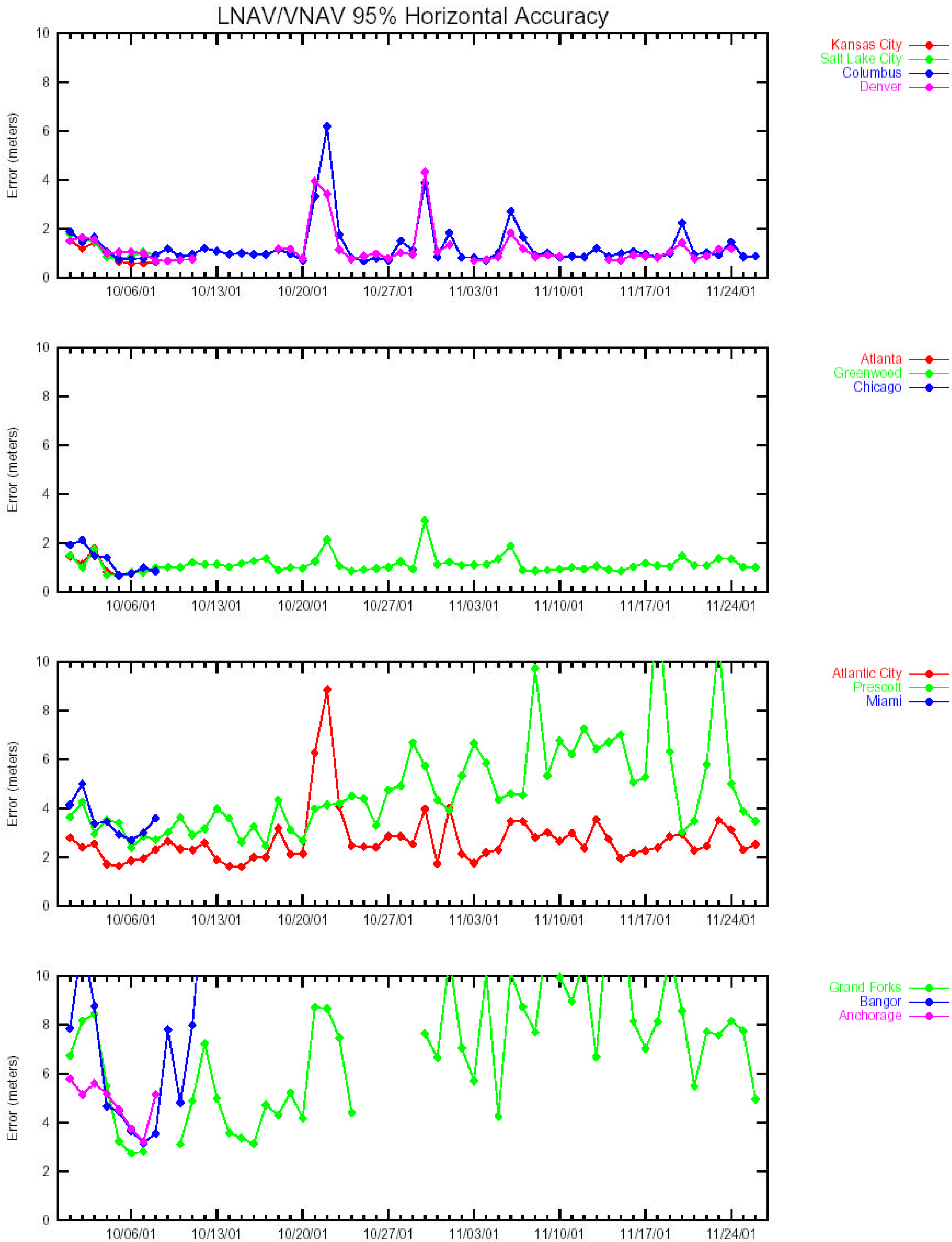


Figure 2.2 Pre-GIVE Monitor 95% Vertical Accuracy at LNAV/VNAV

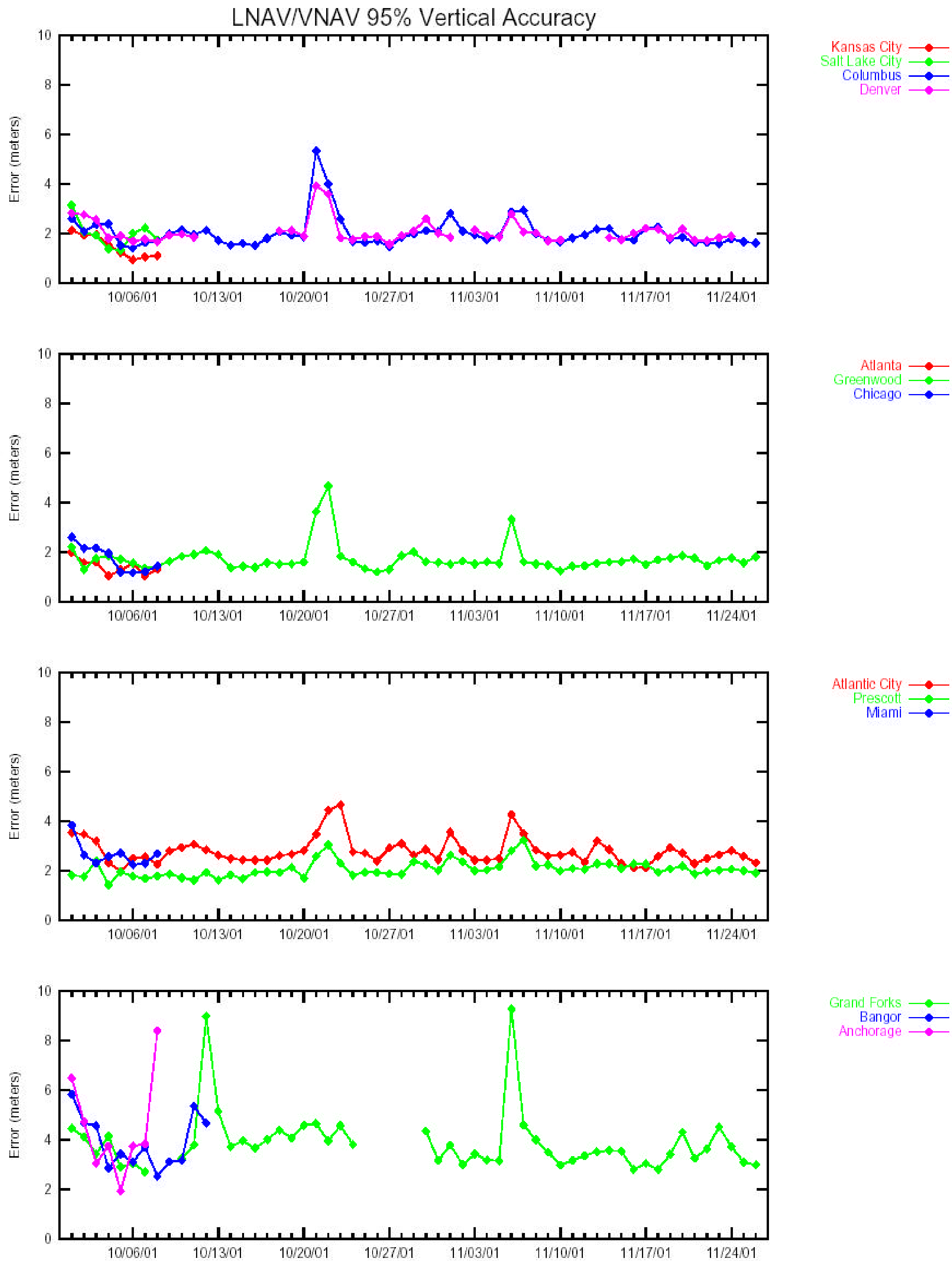


Figure 2.3 Post-GIVE Monitor 95% Horizontal Accuracy at LNAV/VNAV

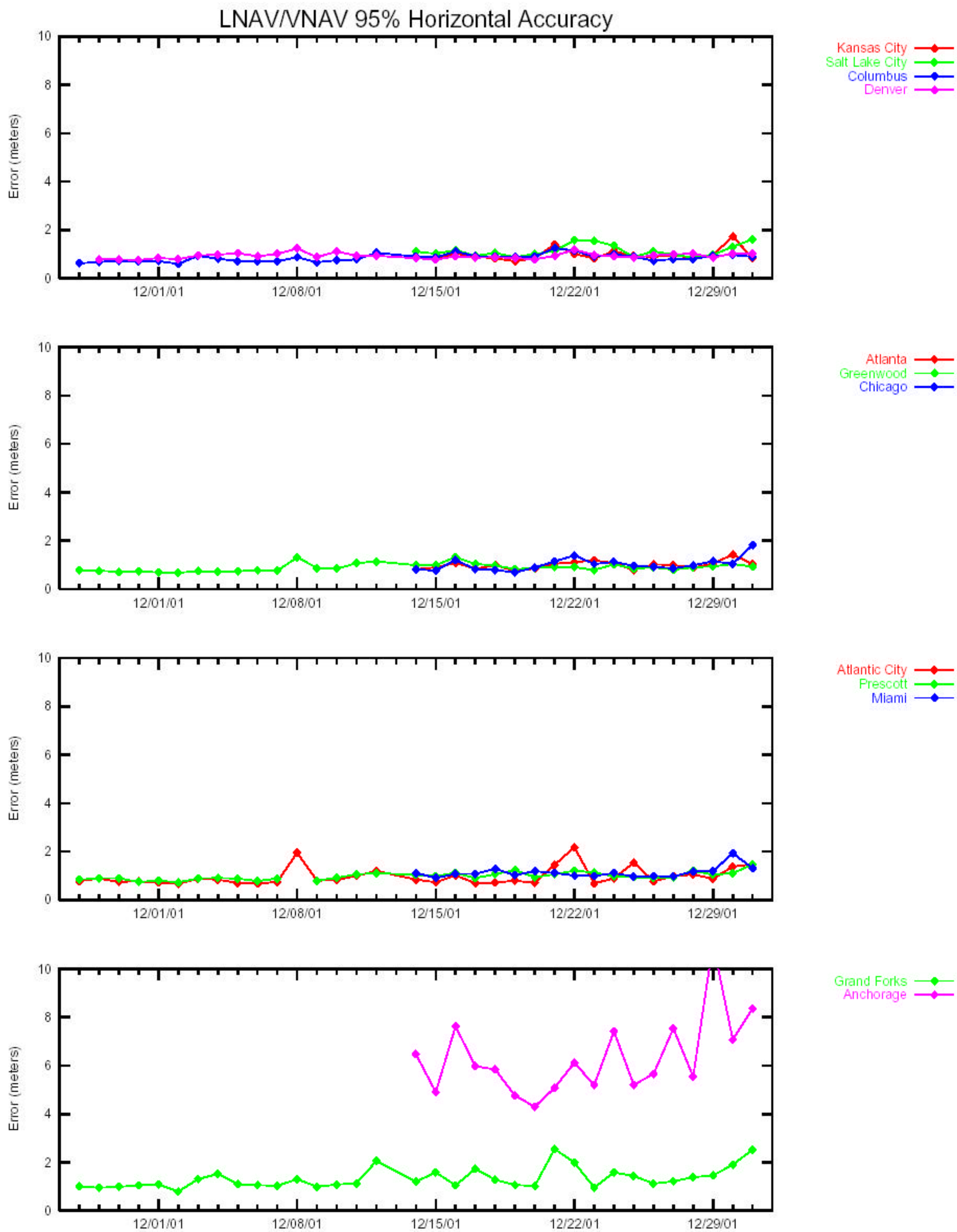
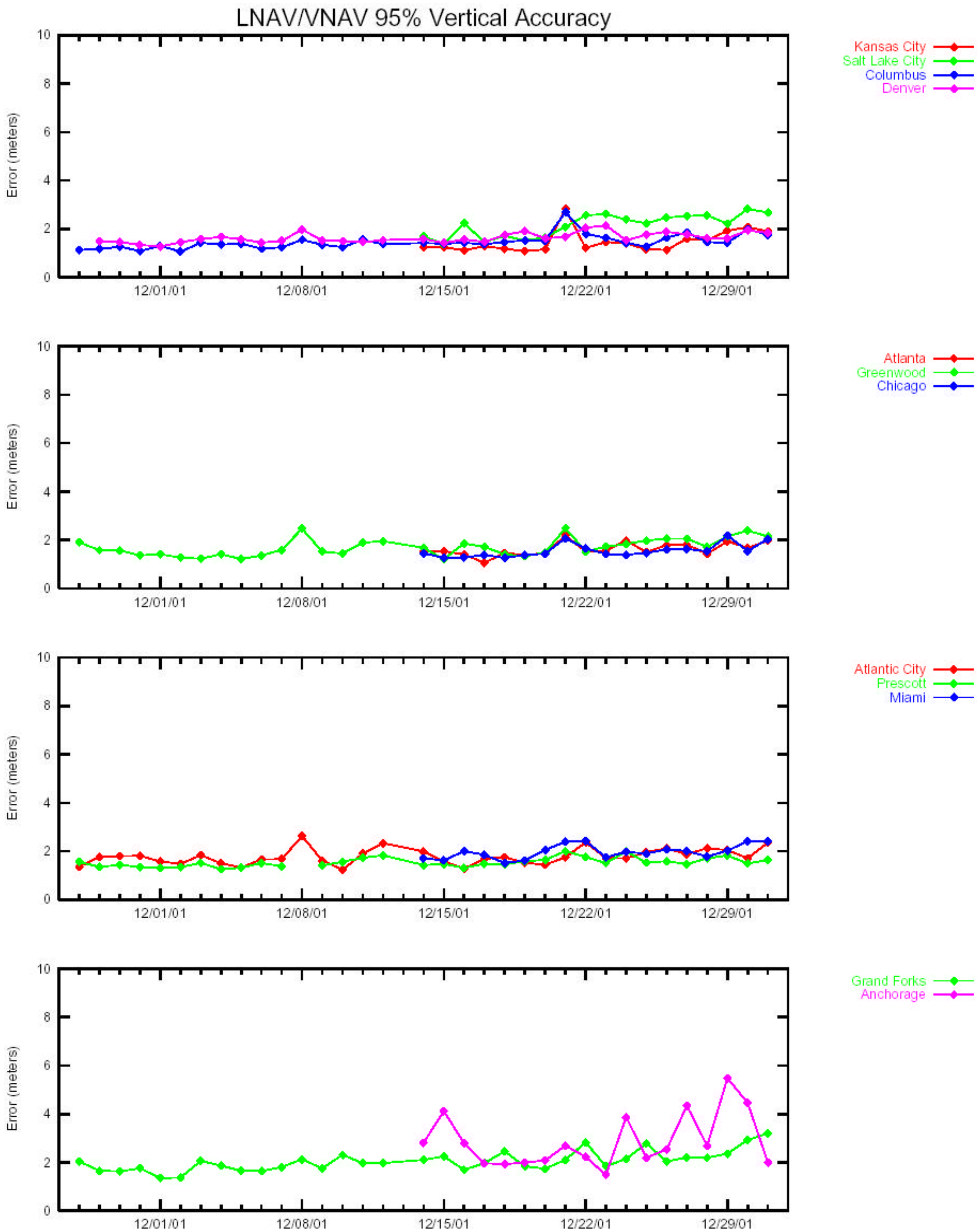


Figure 2.4 Post-GIVE Monitor 95% Vertical Accuracy at LNAV/VNAV



During pre-GIVE monitor period, the 95% horizontal and vertical accuracy at all evaluated sites are less than 7.6 meters for all WAAS operational service levels. The maximum horizontal and vertical LNAV/VNAV errors are 7.551 meters at Grand Forks and 6.882 meters at Anchorage, respectively. The minimum horizontal and vertical LNAV/VNAV errors are 1.078 meters at Kansas City and 1.435 meters at Atlanta, respectively. During post-GIVE Monitor period, the 95% horizontal and vertical accuracy at all evaluated sites are less than 7.6 meters for all WAAS operational service levels. The maximum horizontal and vertical LNAV/VNAV errors are 6.569 meters and 2.992 meters at Anchorage. The minimum horizontal and vertical LNAV/VNAV errors are 0.875 meters at Columbus and 1.448 meters at Kansas City, respectively.

Figures 2.5 to 2.16 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 Columbus. Figure 2.5 to 2.10 show the distributions of the pre-GIVE Monitor period and Figure 2.11 to 2.16 show the distributions of the post-GIVE Monitor period. 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 2.1. Note the amount of samples accumulated above the HPL 40m line and the VPL 50m line. This is caused by the GEO gaps encountered this quarter (see Table 1.3 Test Events). 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 (log scale) 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 observed distribution of normalized errors data samples in each 0.1-sigma bin. Narrowness of the normalized error distributions shows very good observed safety performance. Note the normalized error distributions in the post-GIVE monitor period (Figure 2.13 and 2.16) show an increase in safety performance.

Figure 2.5 Pre-GIVE Monitor Horizontal Triangle Chart for Denver

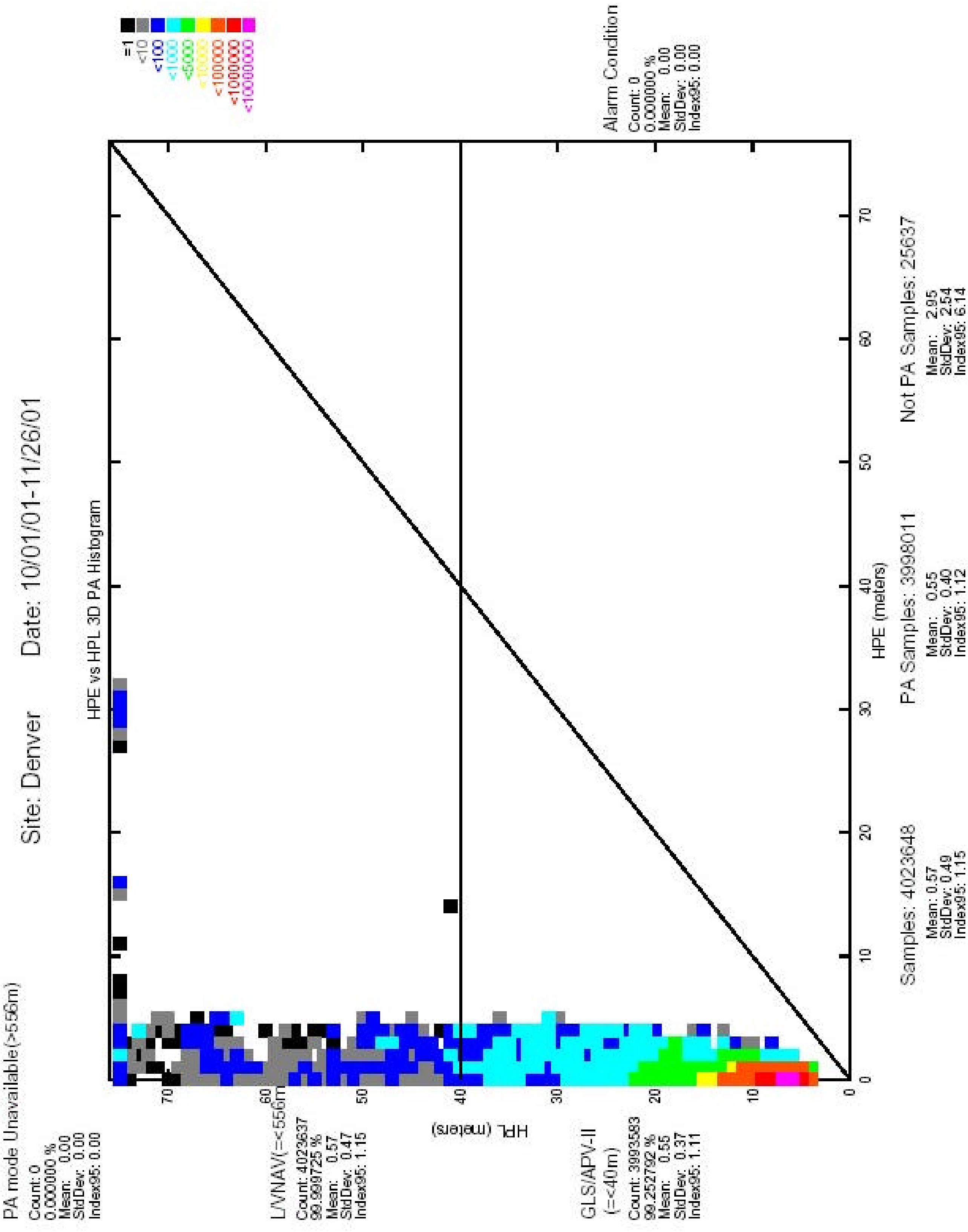


Figure 2.6 Pre-GIVE Monitor Vertical Triangle Chart for Denver

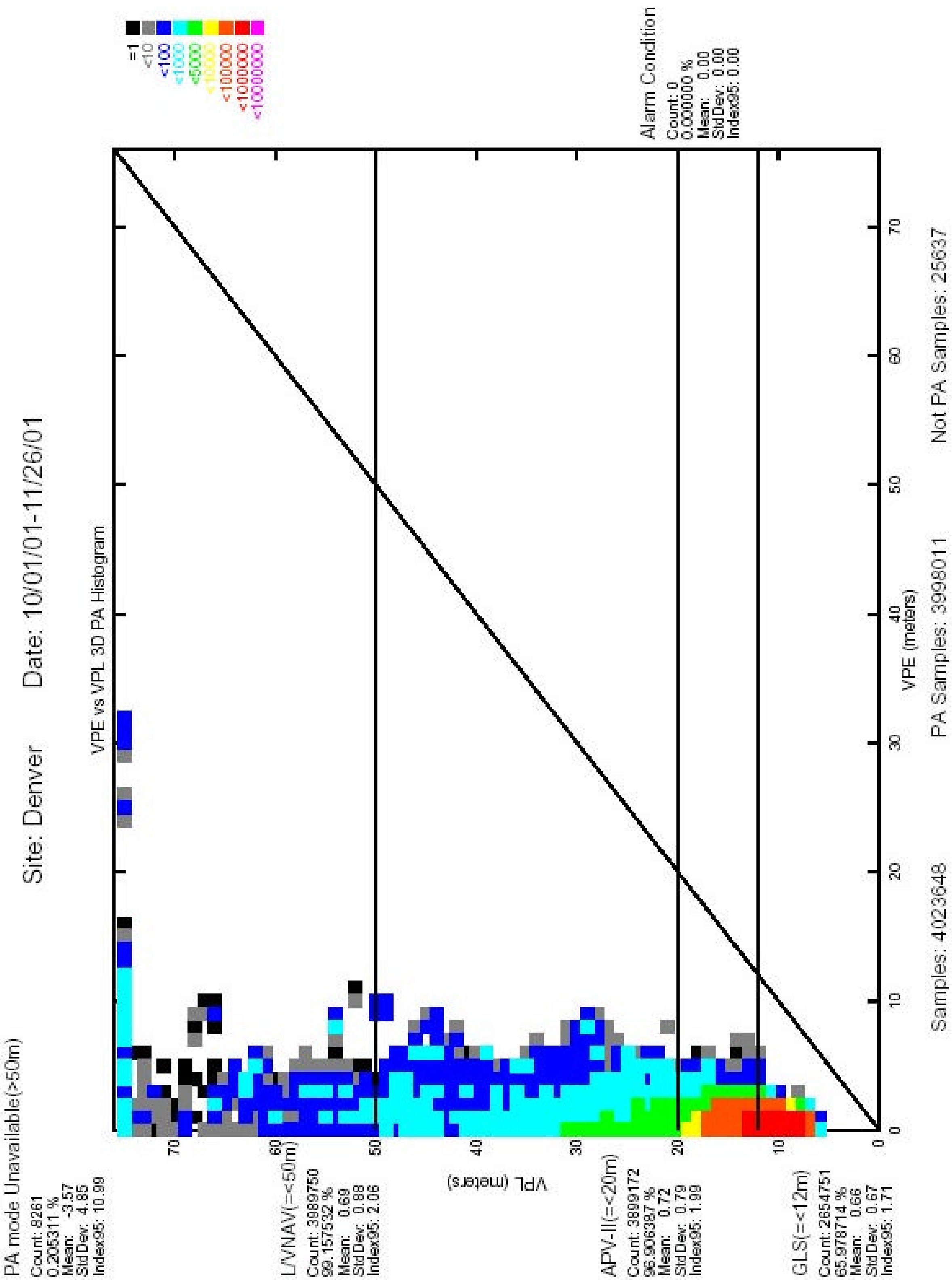


Figure 2.7 Pre-GIVE Monitor 2-D Histogram for Denver

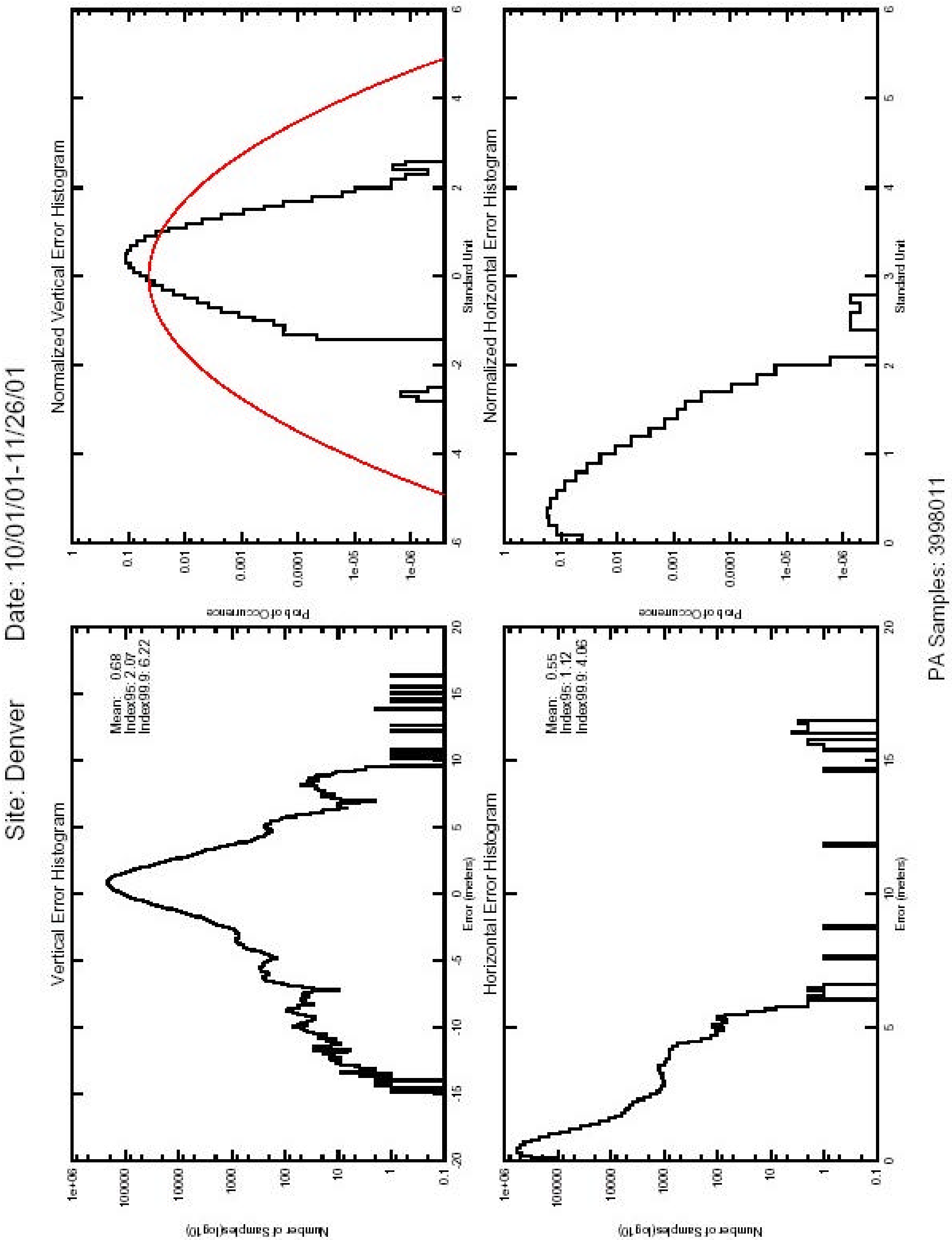


Figure 2.8 Pre-GIVE Monitor Horizontal Triangle Chart for Columbus

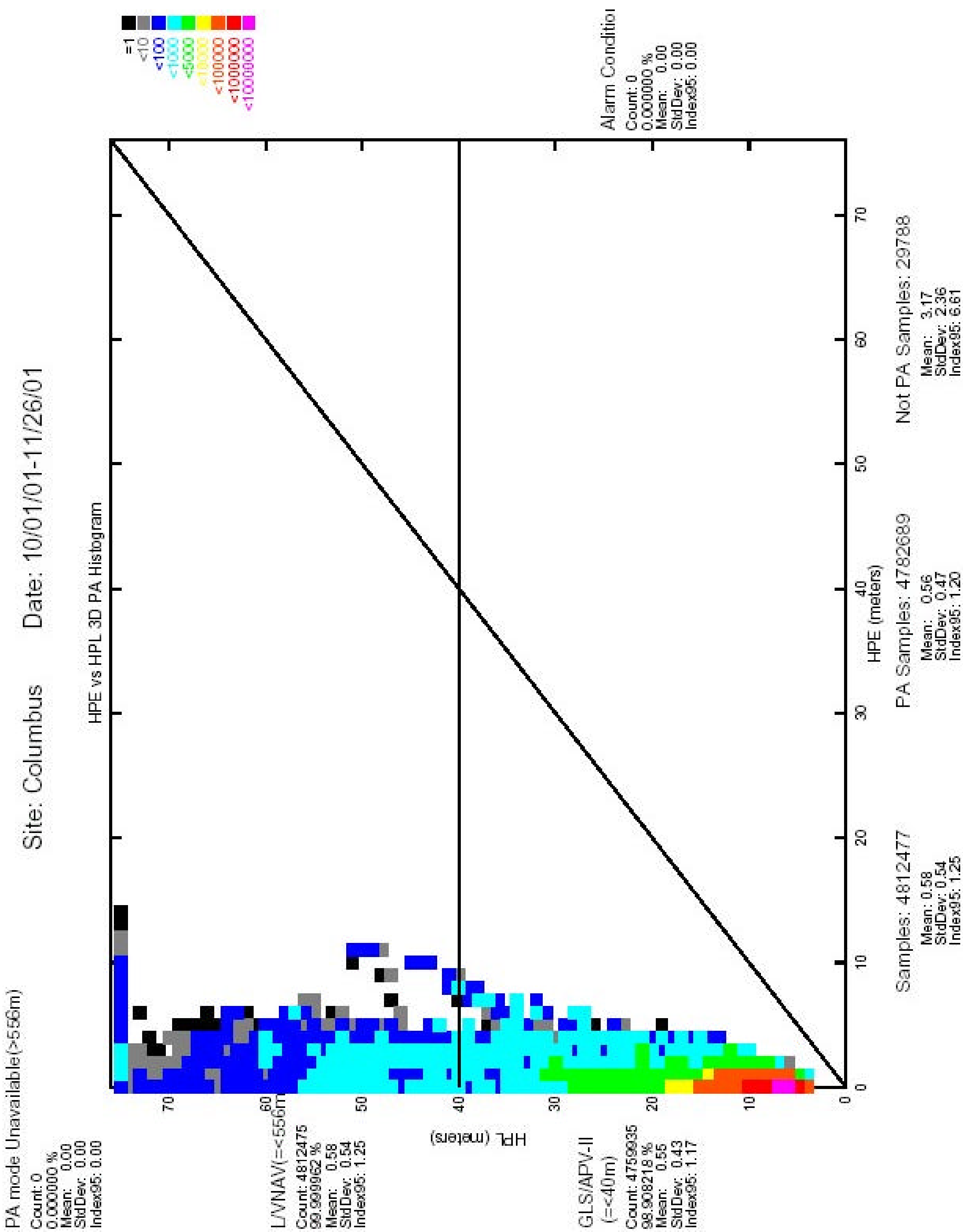


Figure 2.9 Pre-GIVE Monitor Vertical Triangle Chart for Columbus

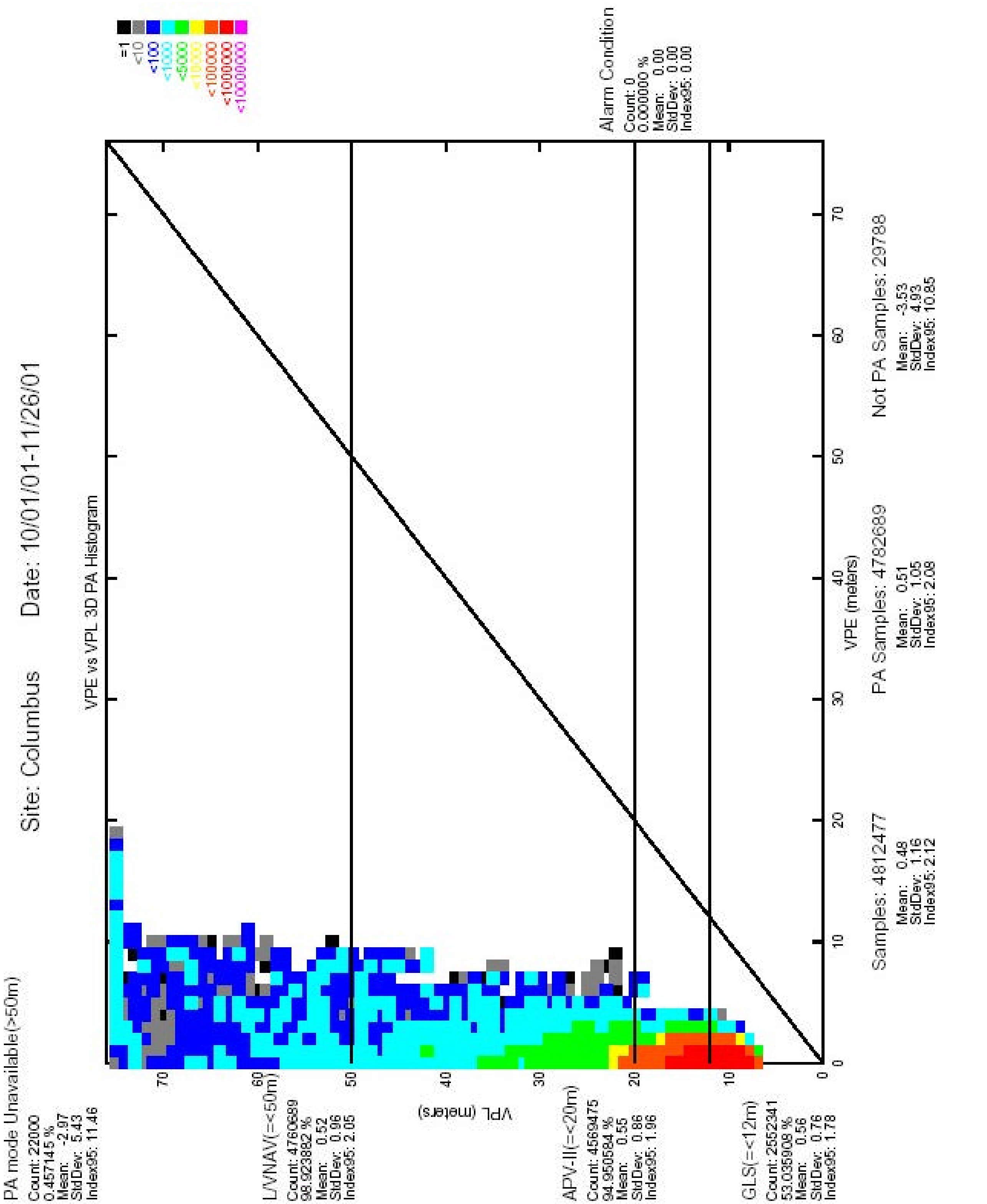


Figure 2.10 Pre-GIVE Monitor 2-D Histogram for Columbus

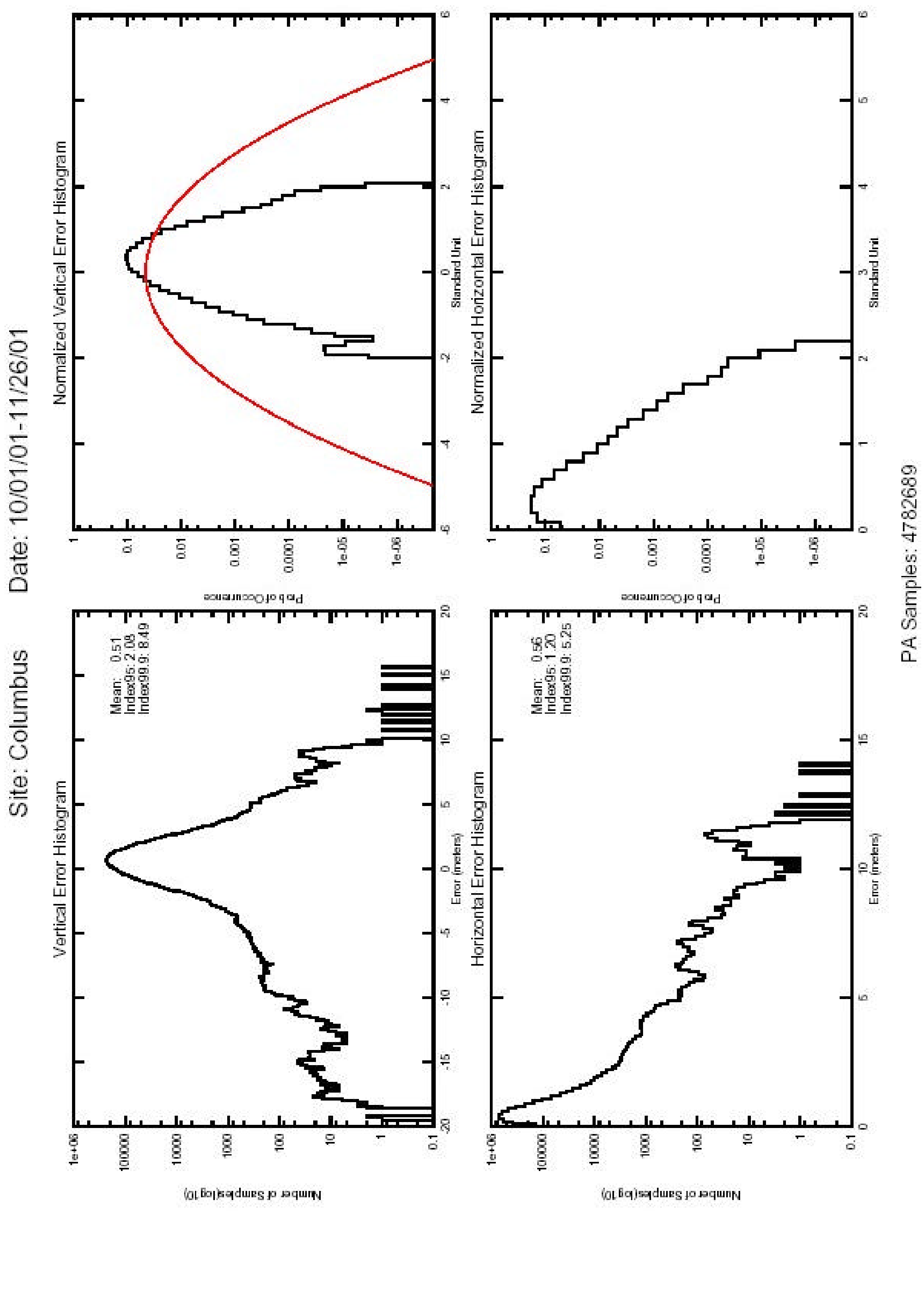


Figure 2.11 Post-GIVE Monitor Horizontal Triangle Chart for Denver

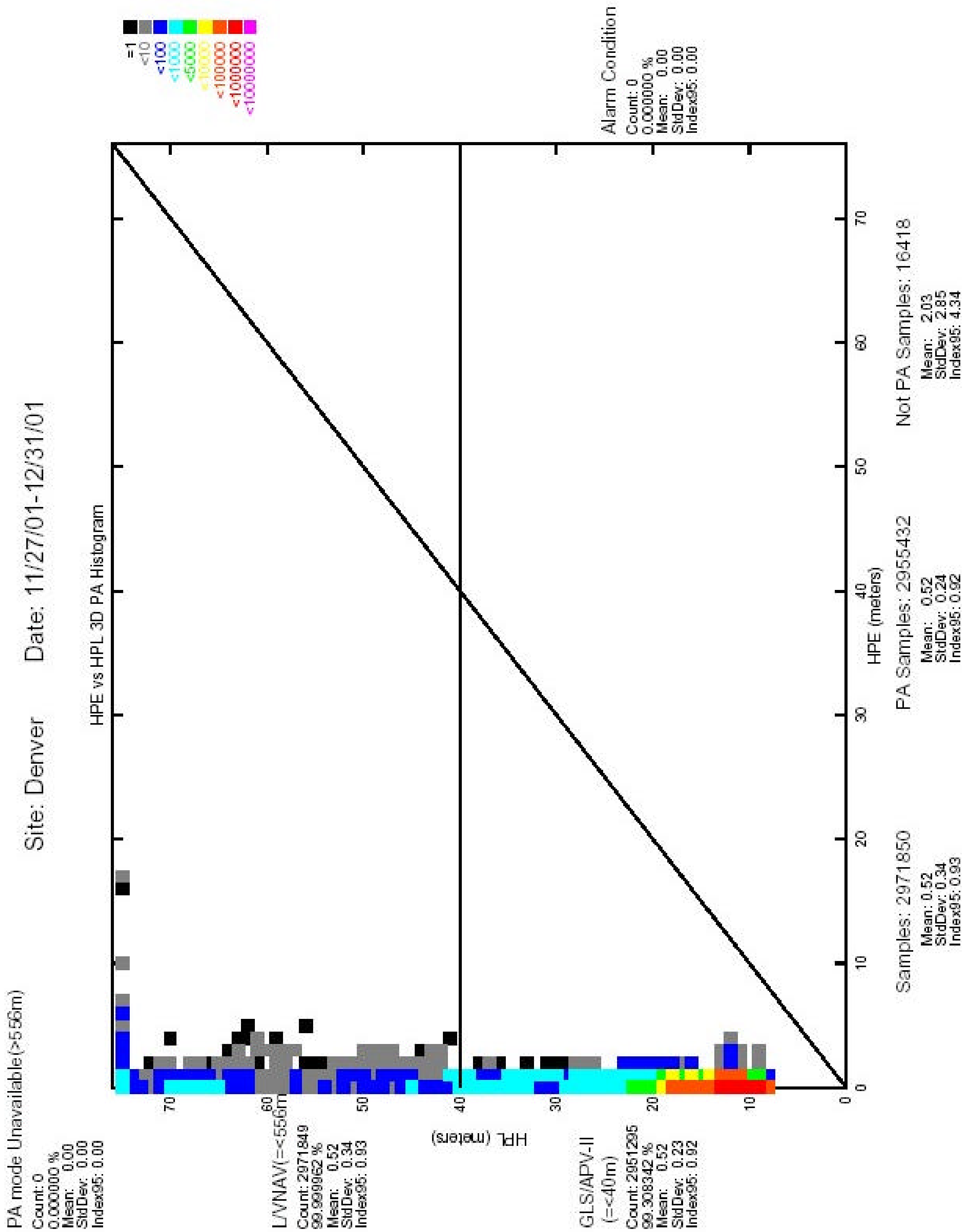


Figure 2.12 Post-GIVE Monitor Vertical Triangle Chart for Denver

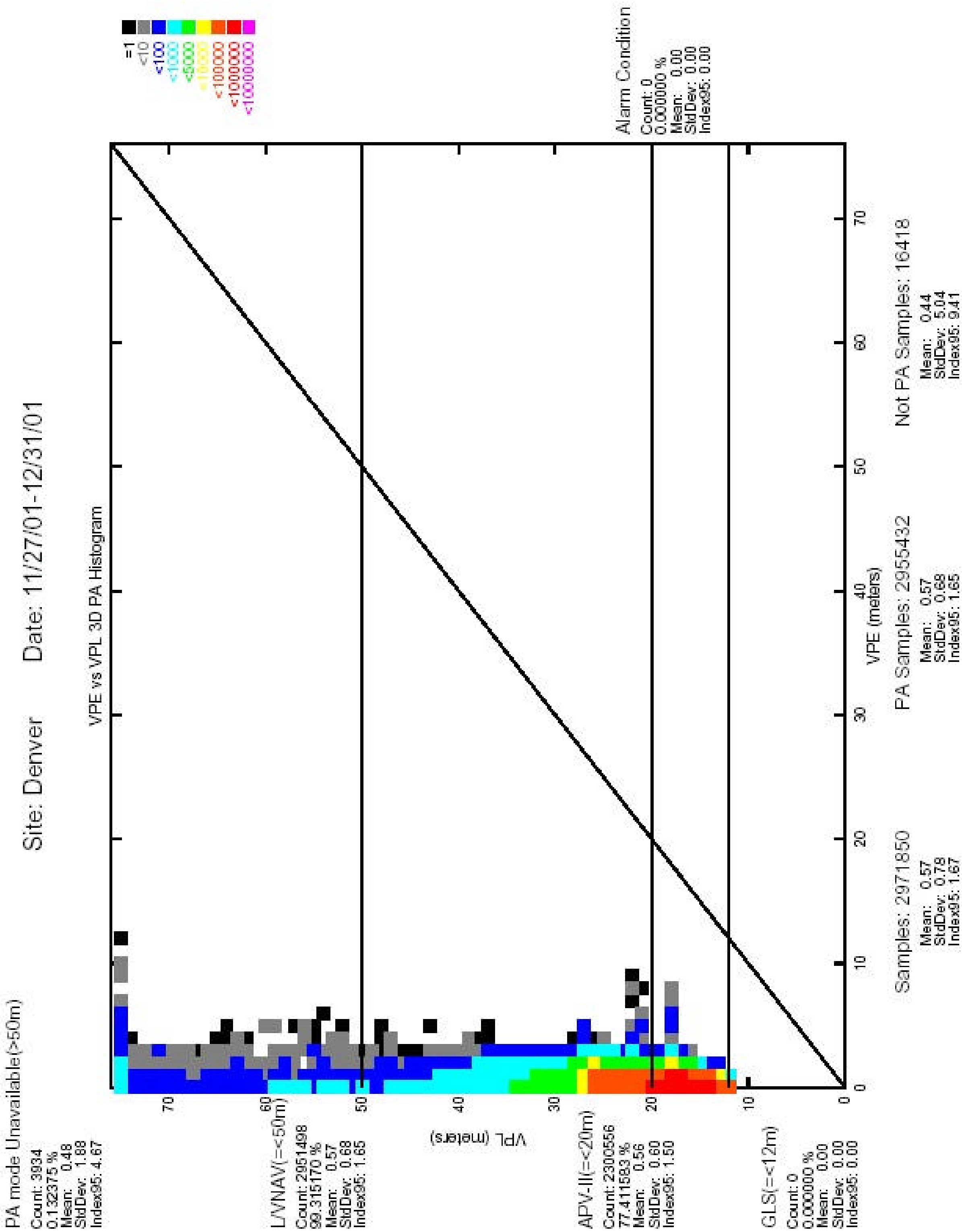


Figure 2.13 Post-GIVE Monitor 2-D Histogram for Denver

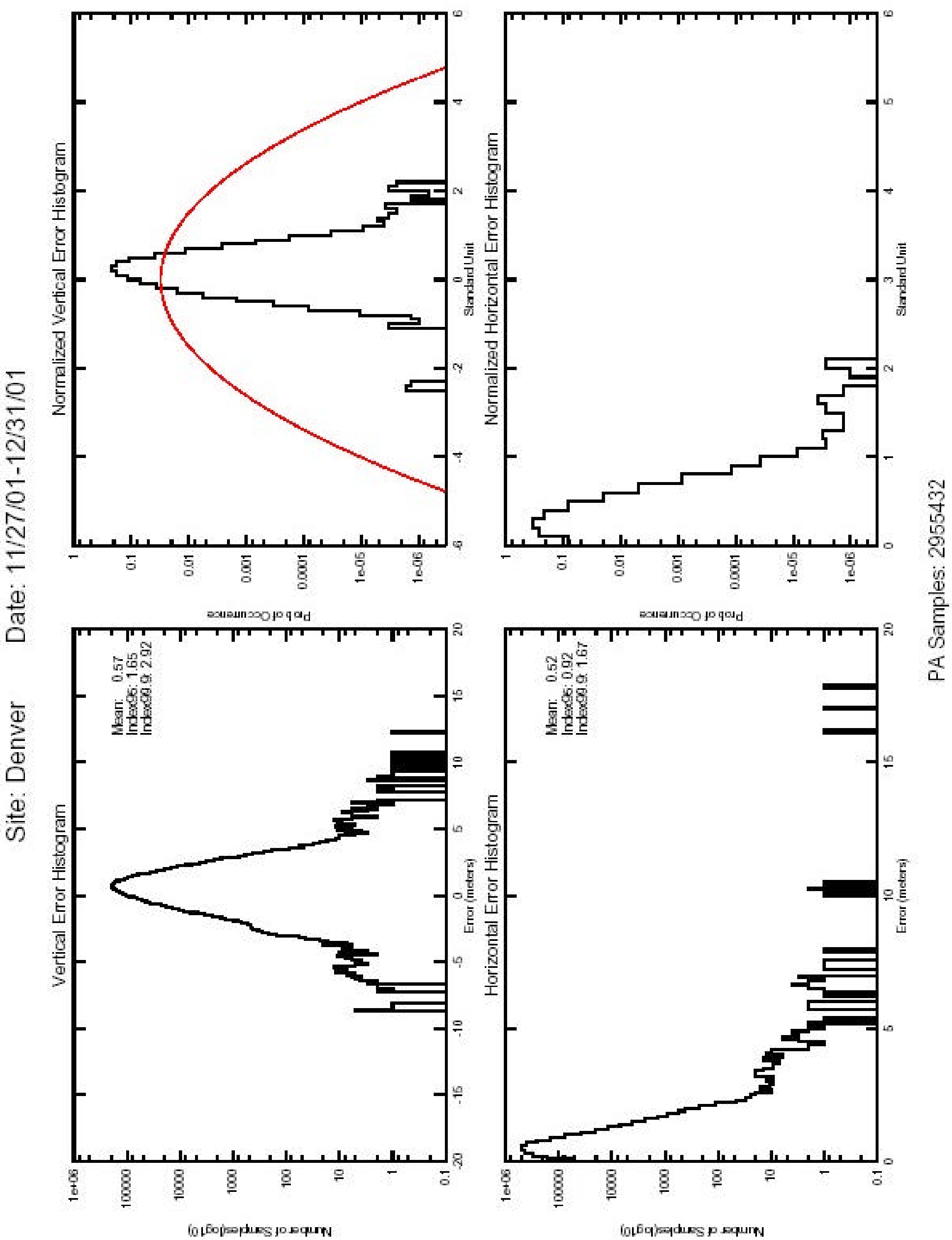


Figure 2.14 Post-GIVE Monitor Horizontal Triangle Chart for Columbus

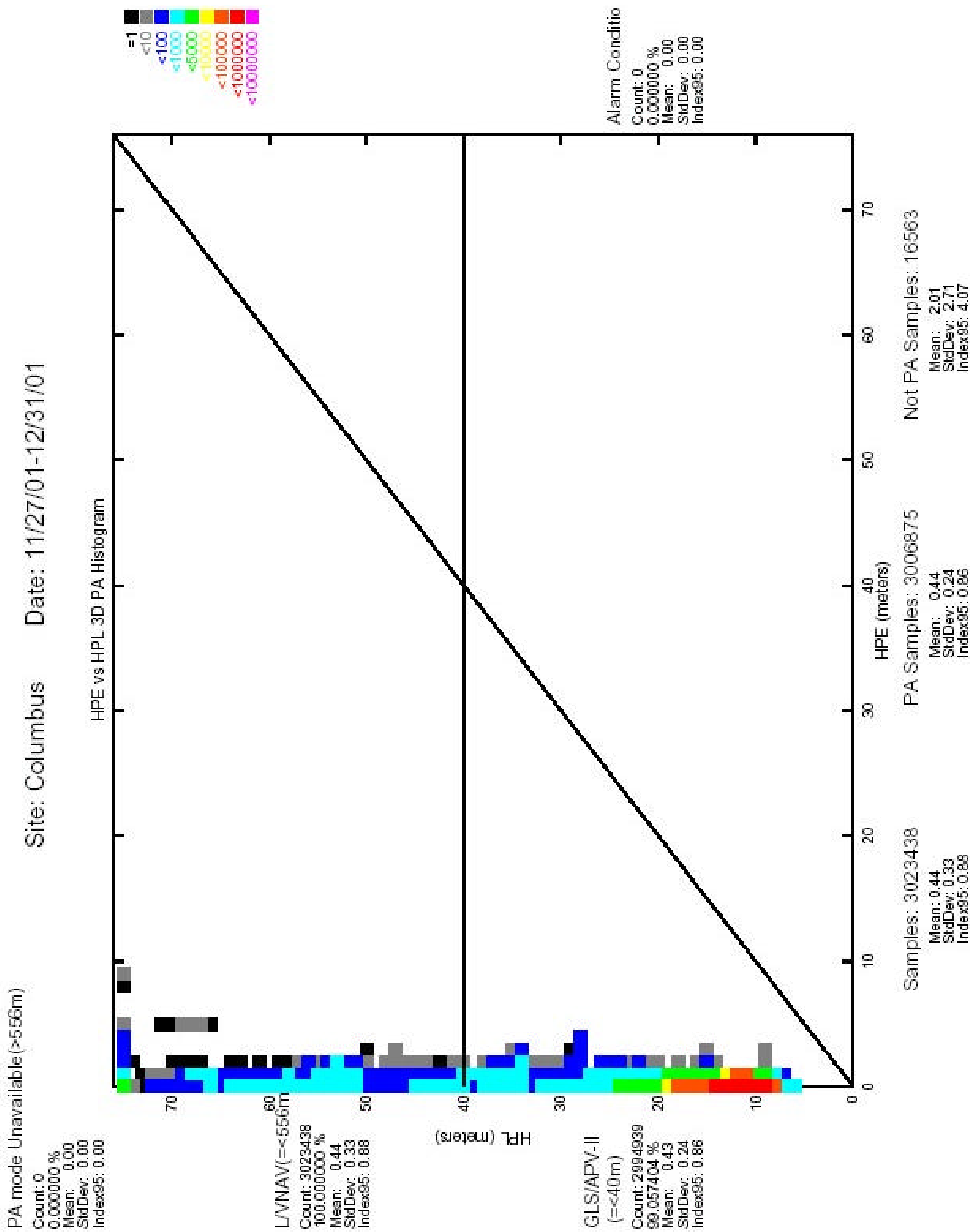


Figure 2.15 Post-GIVE Monitor Vertical Triangle Chart for Columbus

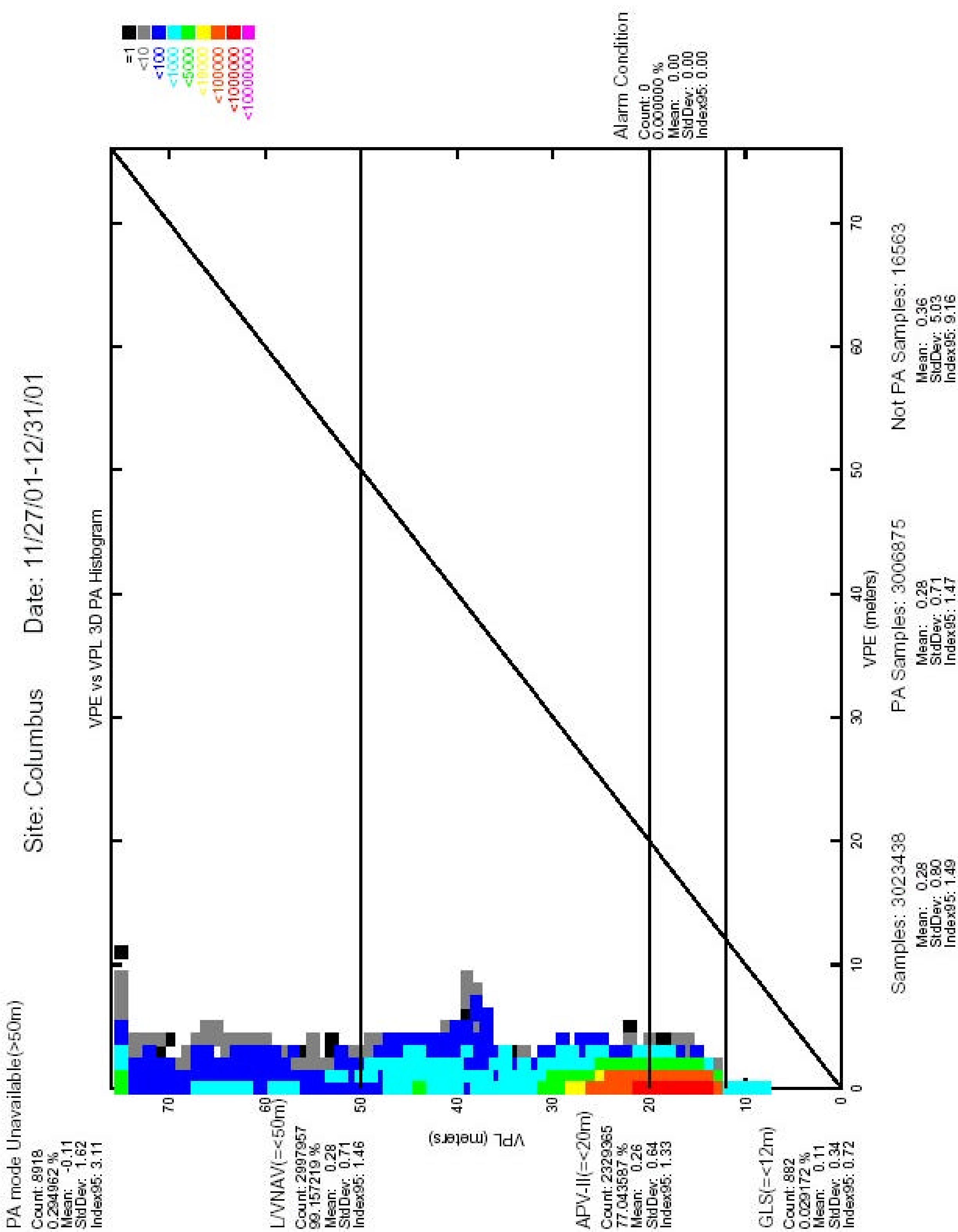
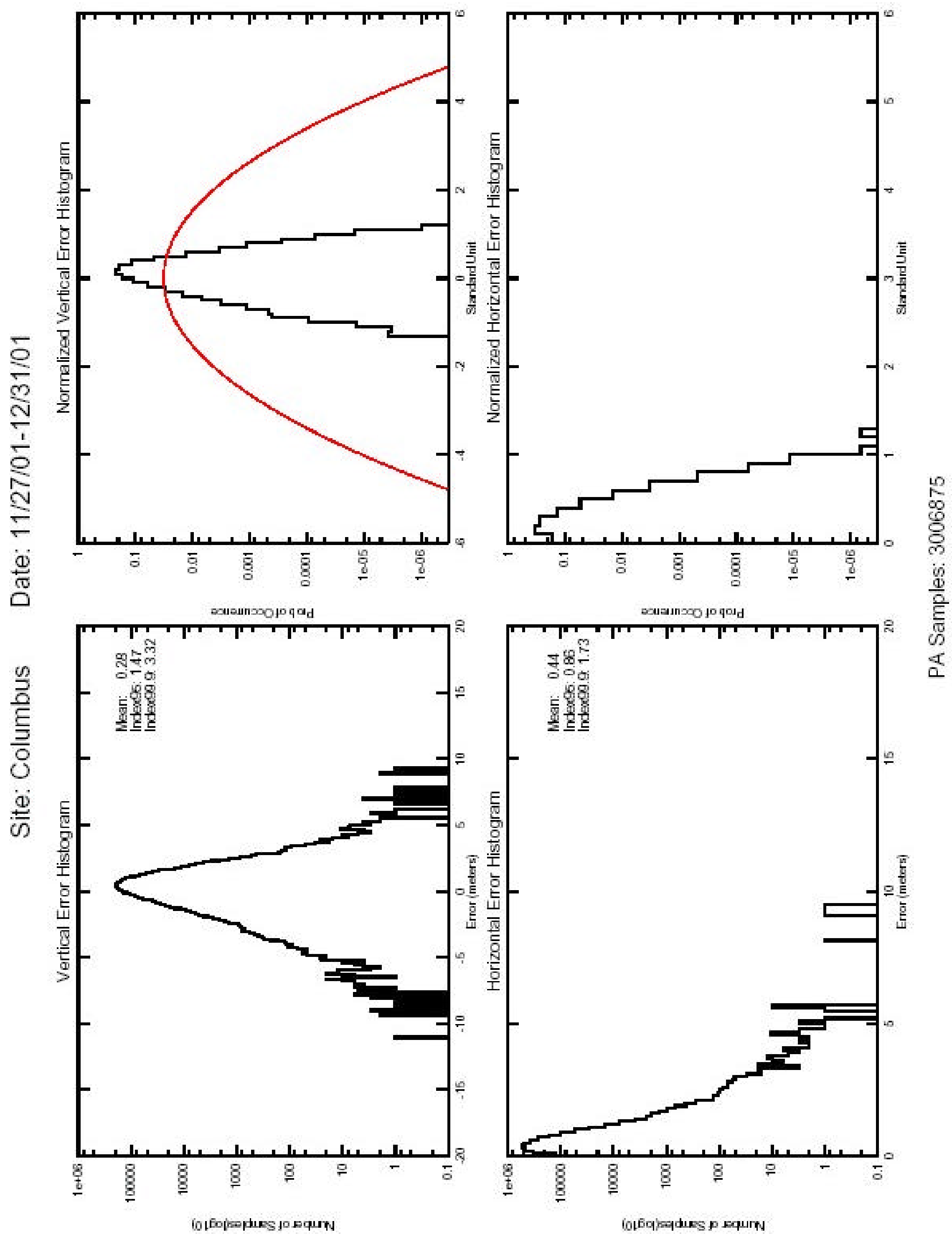


Figure 2.16 Post-GIVE Monitor 2-D Histogram for Columbus



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 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 3.1 and 3.2 show the protection levels that were maintained for 95% of the time for each receiver location for pre- and post-GIVE Monitor periods. Both tables also included the percentage in PA mode as described in section 2.0. Table 3.3 and 3.4 present 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 3.1 and 3.2, along with the 95% VPL value and the WAAS LNAV/VNAV availability at each location for pre- and post-GIVE Monitor periods. The daily WAAS availability, at each receiver location, for the three operational service levels is shown in Figures 3.2 to 3.6. Note the drops in availability are caused by severe ionospheric activity and satellites "not monitored" by WAAS. The data gaps are due to receiver maintenance and WEI installation activities (see Table 1.3 Test Events).

Table 3.1 Pre-GIVE Monitor 95% Protection Level

1-The receiver at down for quarter due to a
2-The receiver at for maintenance a hardware failure

Location	95% HPL (meters)	95% VPL (meters)	Percentage in PA mode
Kansas City	9.88	15.42	99.973
Salt Lake City	10.34	15.63	99.973
Columbus	13.17	19.39	99.381
Denver	10.88	16.38	99.363
Atlanta	9.38	16.66	99.972
Greenwood	11.3	17.43	99.458
Chicago	16.13	23.23	99.063
San Angelo[1]	-	-	-
Atlantic City	37.28	47.7	96.457
Prescott	45.53	26.92	82.855
Miami	54.92	46.56	78.550
Arcata[2]	-	-	-
Billings	83.01	71.54	91.631
Grand Forks	100.5	112.94	42.323
Bangor	184.28	168.46	24.730
Anchorage	136.04	114.91	8.348

San Angelo was maintenance this hardware failure
Arcata was down this quarter due to

Table 3.2 Post-GIVE Monitor 95% Protection Level

Location	95% HPL (meters)	95% VPL (meters)	Percentage in PA mode
Kansas City	14.62	22.80	99.76
Salt Lake City	15.73	24.74	99.76
Columbus	15.87	24.55	99.45
Denver	16.31	24.64	99.44
Atlanta	14.65	24.70	99.76
Greenwood	15.13	24.68	99.47
Chicago	16.75	25.16	99.76
San Angelo[1]	-	-	-
Atlantic City	18.35	28.74	99.47
Prescott	23.01	35.78	99.40
Miami	28.86	37.16	99.76
Arcata[2]	-	-	-
Billings	17.84	26.69	99.76
Grand Forks	25.41	33.50	99.45
Bangor[3]	-	-	-
Anchorage	511.20	374.42	86.65

1-The receiver at San Angelo was down for maintenance this quarter due to a hardware failure
2-The receiver at Arcata was down for maintenance this quarter due to a hardware failure
3- Bangor receiver data was not available due to WEI installation

Table 3.3 Pre-GIVE Monitor 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	99.97	100	72.8	98.82	99.97
Salt Lake City	99.97	100	70	99.25	99.97
Columbus	98.91	100	53.04	94.95	98.92
Denver	99.25	100	65.98	96.91	99.16
Atlanta	99.97	100	61.42	97.77	99.95
Greenwood	99.43	100	60.92	96.29	99.36
Chicago	98.02	100	47.18	90.5	97.44
San Angelo[1]	-	-	-	-	-
Atlantic City	92.23	100	13.09	62.96	92.14
Prescott	77.87	100	22.43	69.2	82.45
Miami	71.05	100	6.02	45.88	75.96
Arcata[2]	-	-	-	-	-
Billings	79.68	100	16.03	55.99	84.17
Grand Forks	32.77	99.99	0.16	15.39	34.85
Bangor	15.73	100	0	4.34	16.87
Anchorage	3.52	99.93	0	0.15	5.85

1-The receiver at San Angelo was down for maintenance this quarter due to a hardware failure
2-The receiver at Arcata was down for maintenance this quarter due to a hardware failure

Table 3.4 Post-GIVE Monitor Availability Statistics

1-The receiver at San Angelo was down for maintenance this quarter due to a hardware failure

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	99.76	100	0	84.06	99.76
Salt Lake City	99.49	100	0	76.58	99.61
Columbus	99.06	100	0.03	77.04	99.16
Denver	99.31	100	0	77.41	99.32
Atlanta	99.69	100	0	70.4	99.70
Greenwood	99.43	100	0.03	70.25	99.41
Chicago	98.58	100	0	77.37	98.55
San Angelo[1]	-	-	-	-	-
Atlantic City	98.20	100	0	48.88	98.08
Prescott	99.12	100	0.01	28.39	98.93
Miami	97.44	100	0	22.82	97.48
Arcata[2]	-	-	-	-	0
Billings	98.02	100	0	70.75	98.34
Grand Forks	98.06	100	0	36.34	97.83
Bangor[3]	-	-	-	-	-
Anchorage	18.23	95.96	0	0	39.70

2-The receiver at Arcata was down for maintenance this quarter due to a hardware failure
3- Bangor receiver data was not available due to WEI installation

As evidenced by these statistics, WAAS performed well throughout this quarter with respect to LNAV/VNAV operational service levels. Every site except Anchorage and Grand Forks, met the horizontal LNAV/VNAV operational service level 100% of the time for the pre-GIVE monitor portion of the quarter. During the post-GIVE monitor period of the quarter, this requirement was met at every site except Anchorage.

Figure 3.1 Pre-GIVE Monitor 95% VPL and LNAV/VNAV Availability

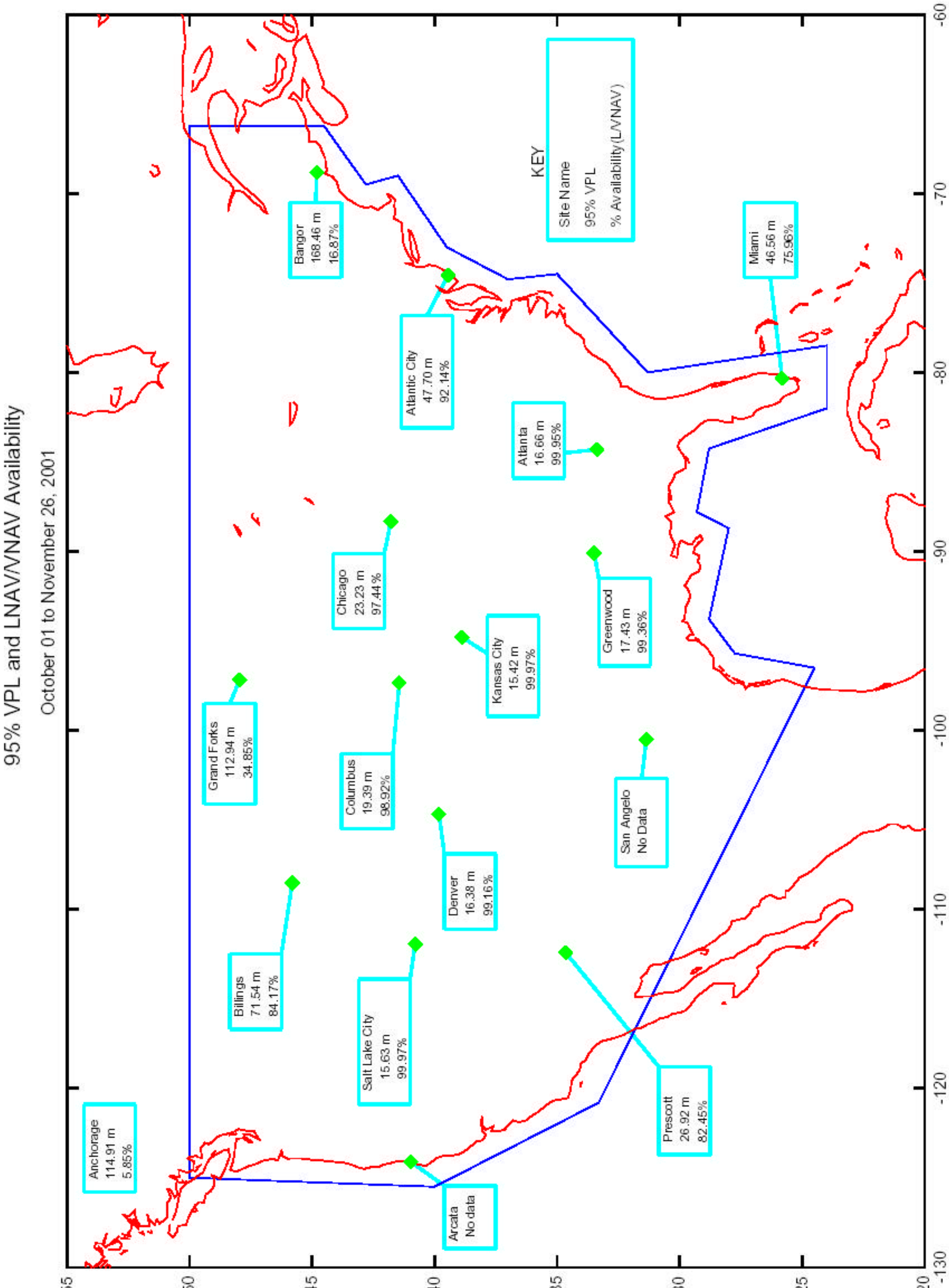


Figure 3.2 Post-GIVE Monitor 95% VPL and LNAV/VNAV Availability

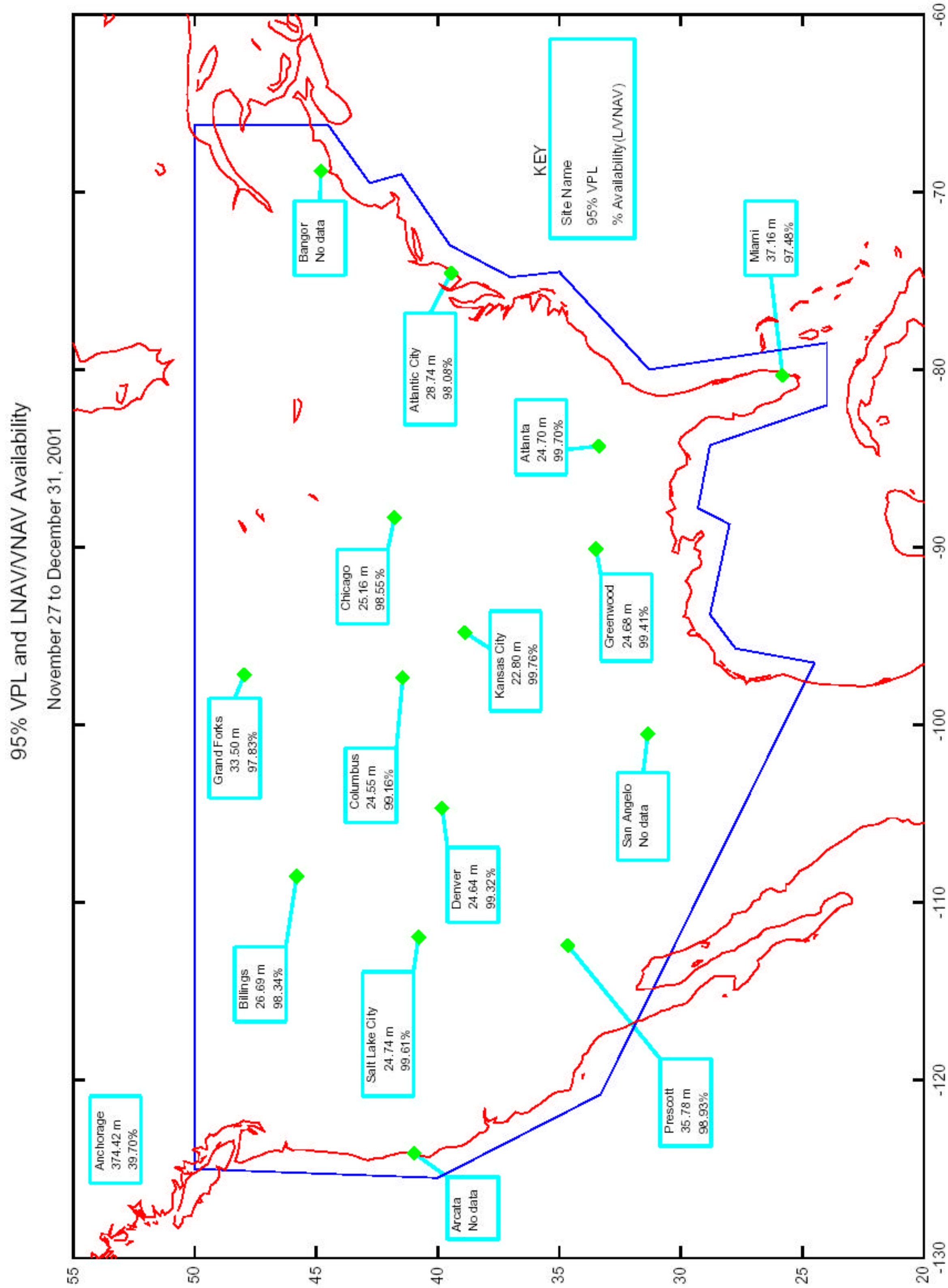


Figure 3.3 Pre-GIVE Monitor APV-I Horizontal Availability Trends

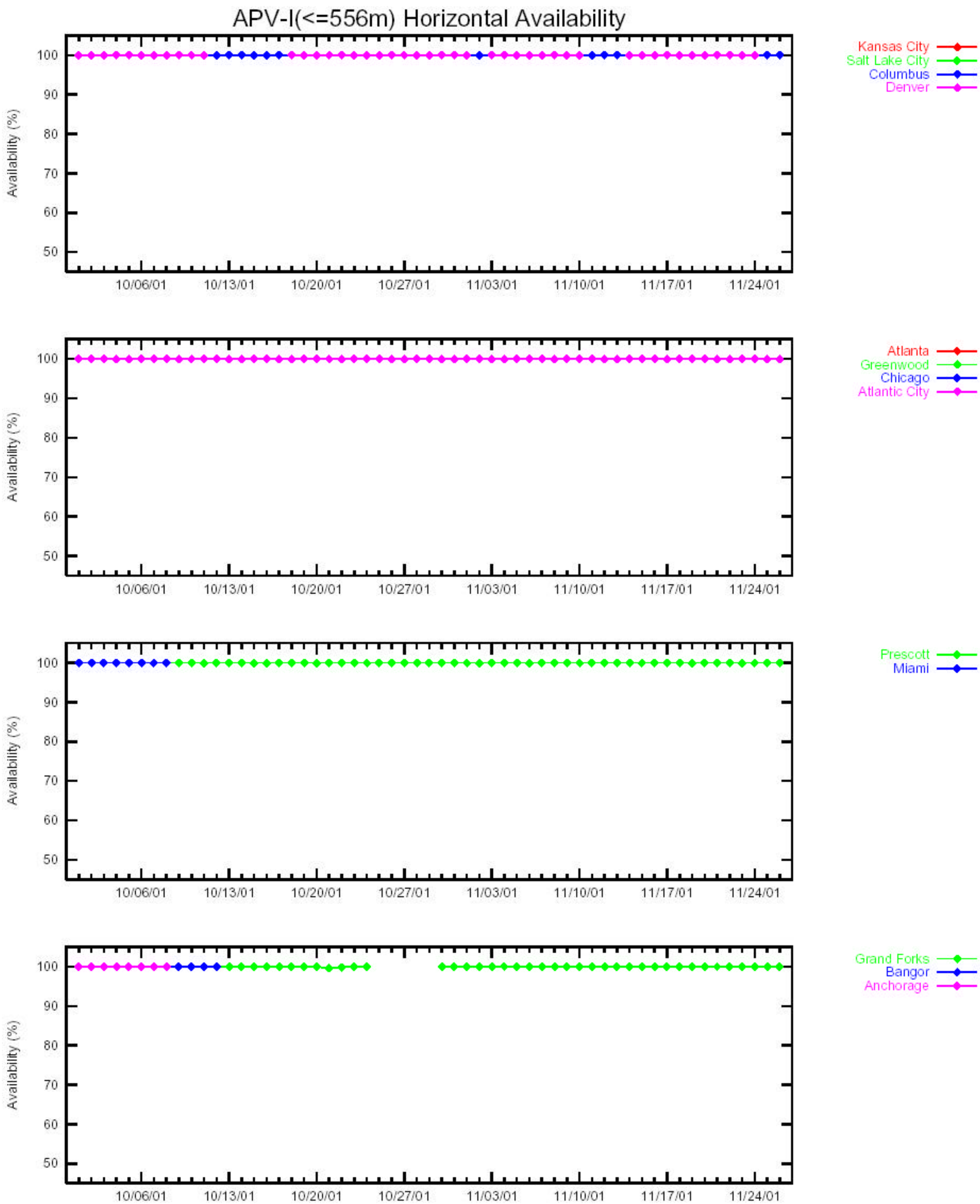


Figure 3.4 Pre-GIVE Monitor GLS/APV-II Horizontal Availability Trends

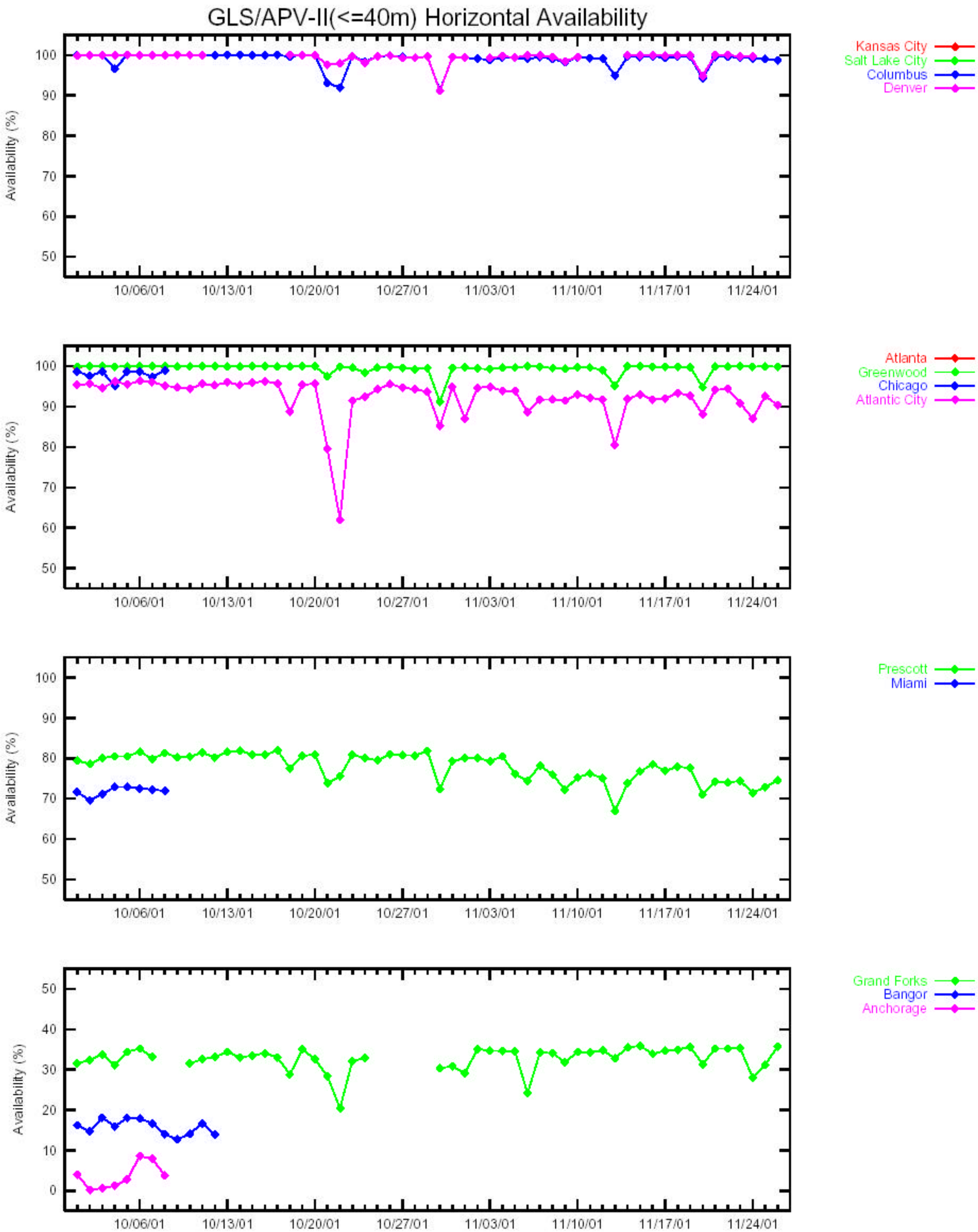


Figure 3.5 Pre-GIVE Monitor APV-I Vertical Availability Trends

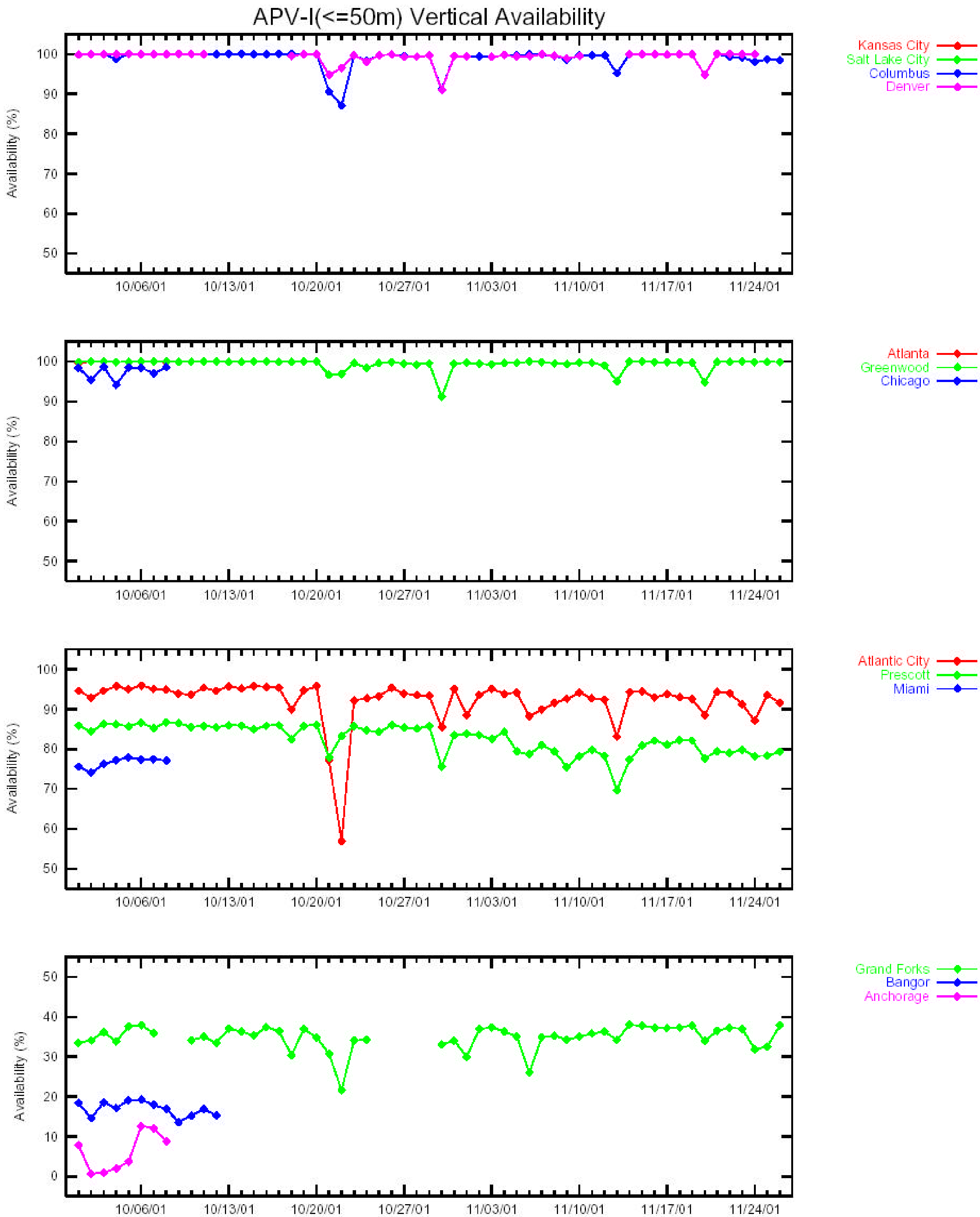


Figure 3.6 Pre-GIVE Monitor APV-II Vertical Availability Trends

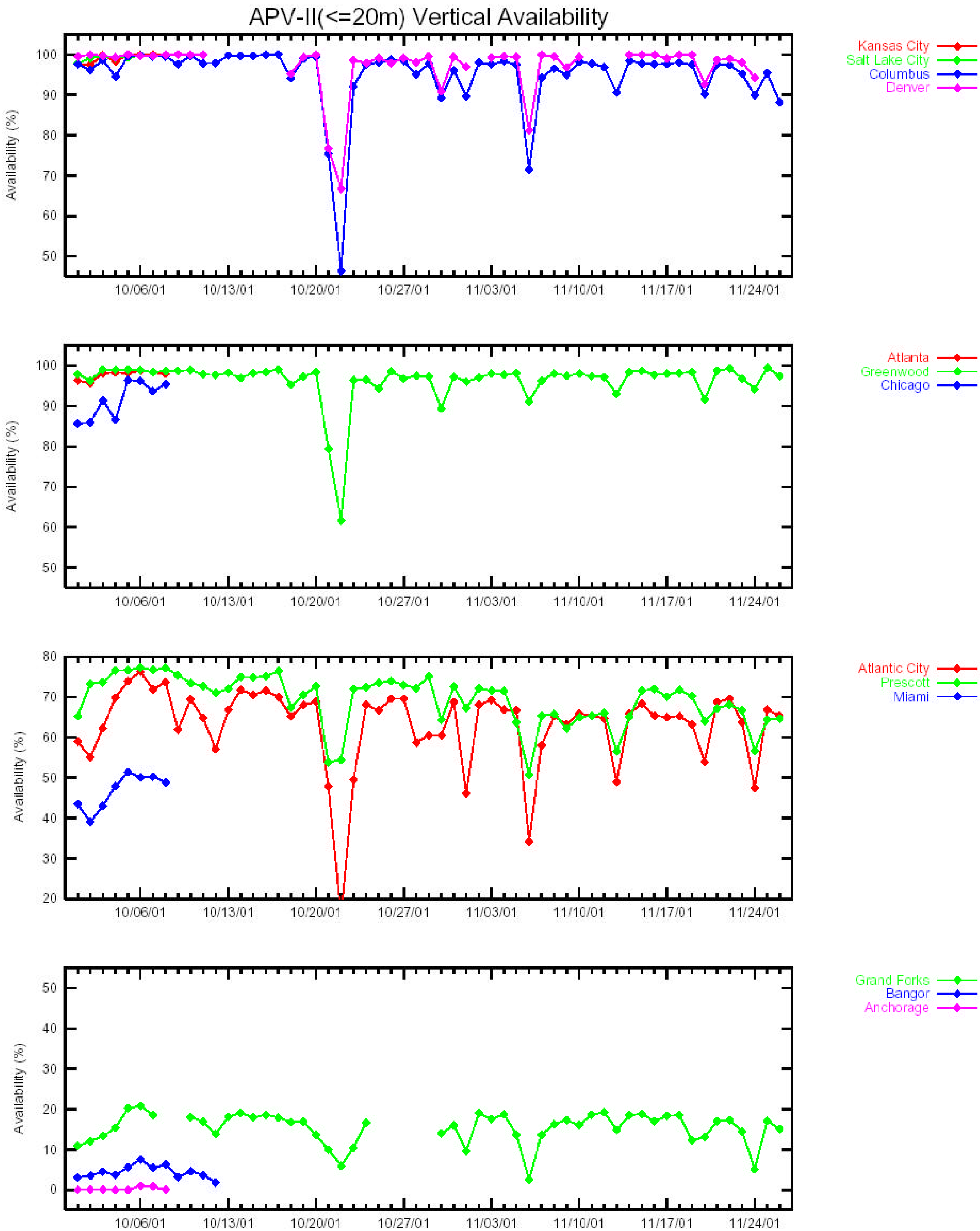


Figure 3.7 Pre-GIVE Monitor GLS Vertical Availability Trends

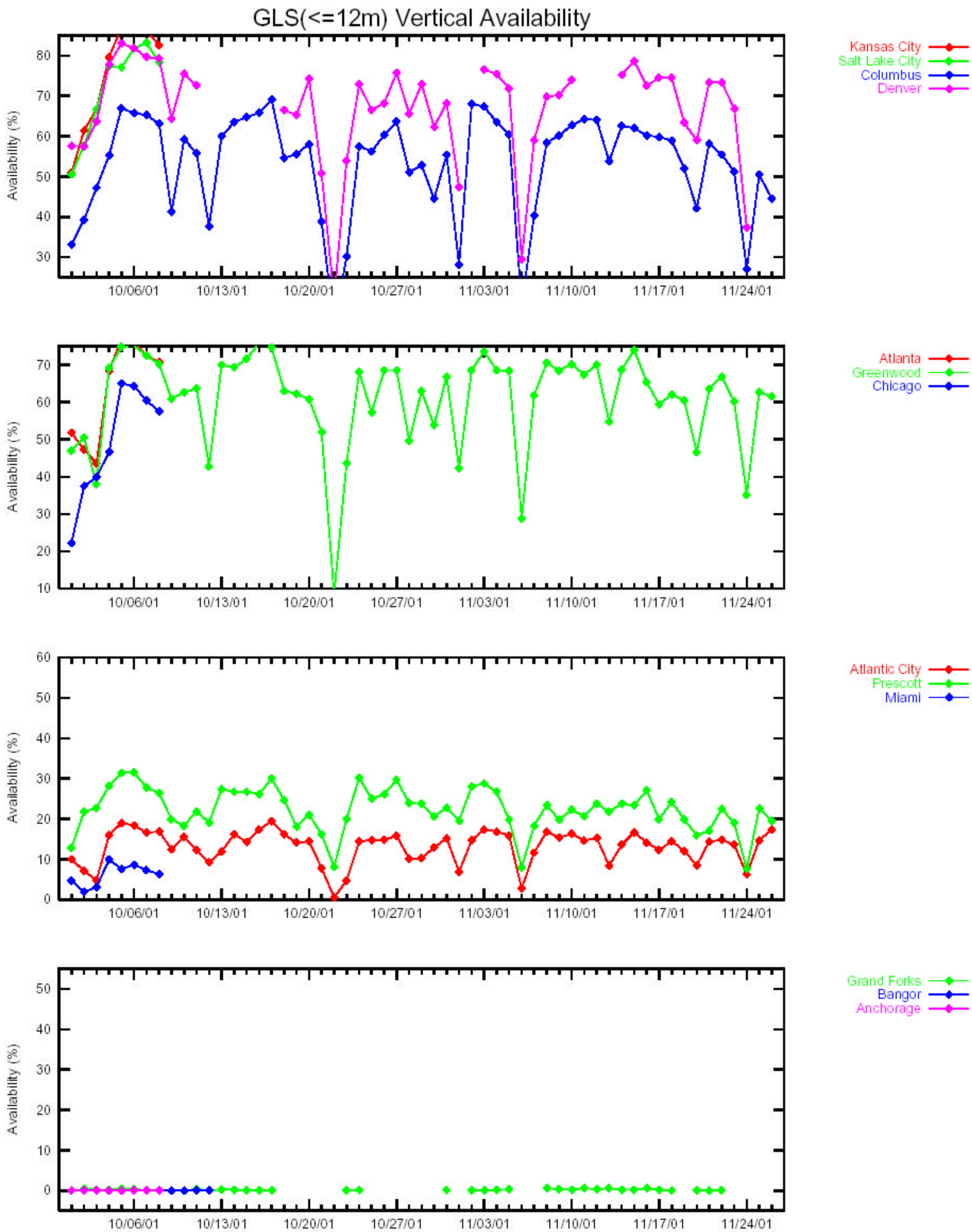


Figure 3.8 Post-GIVE Monitor GLS/APV-I Horizontal Availability Trends

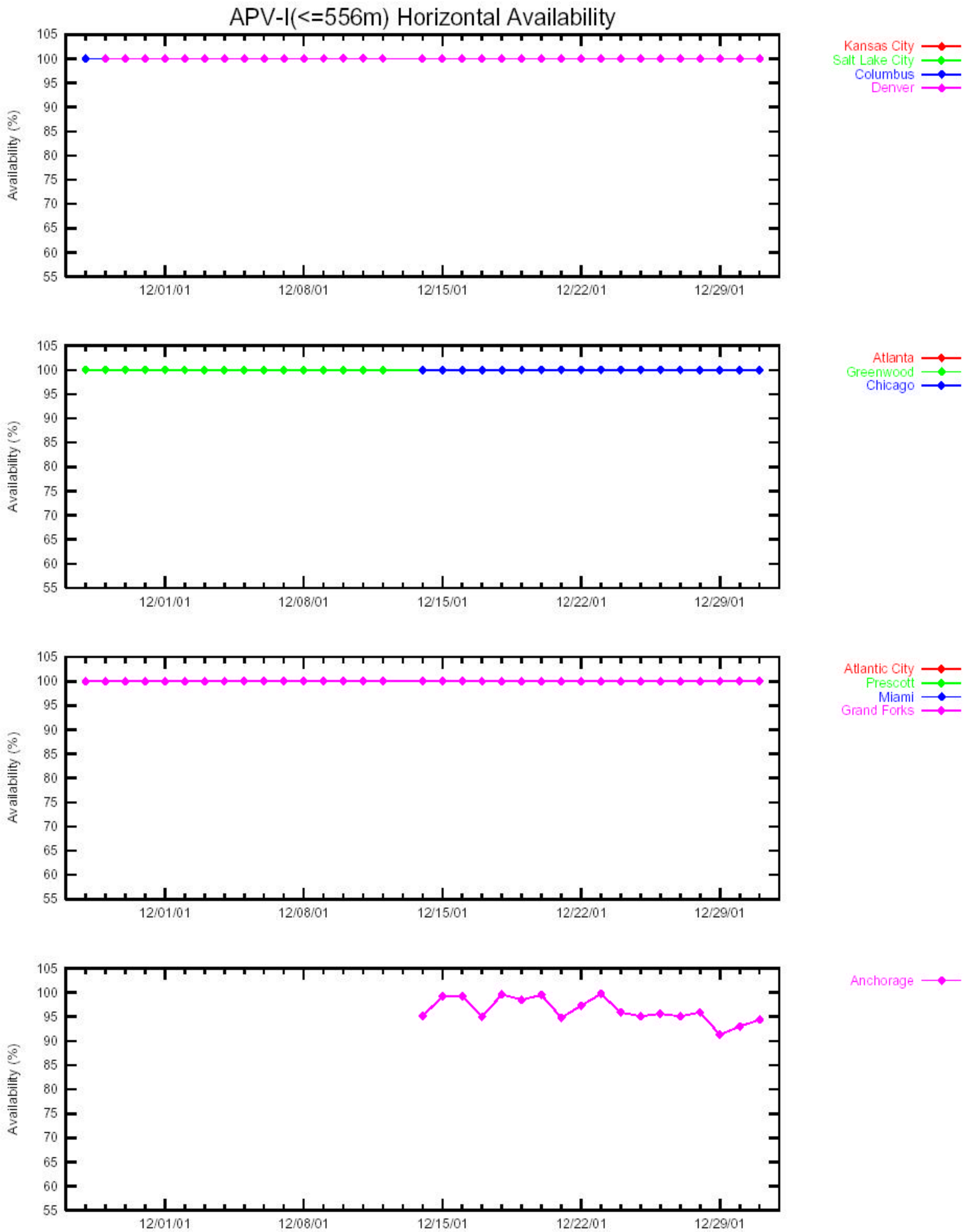


Figure 3.9 Post-GIVE Monitor GLS/APV-II Horizontal Availability Trends

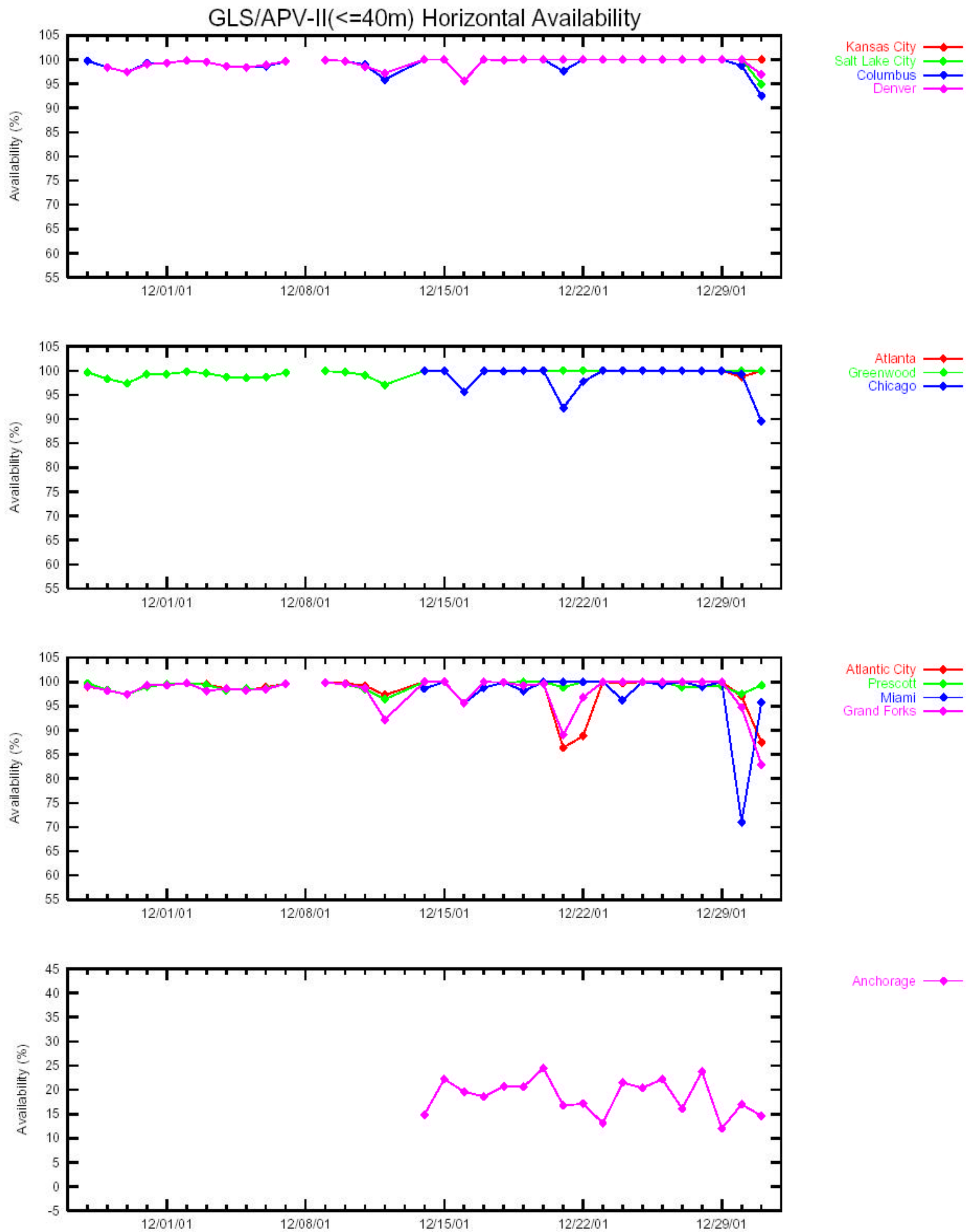


Figure 3.10 Post-GIVE Monitor APV-I Vertical Availability Trends

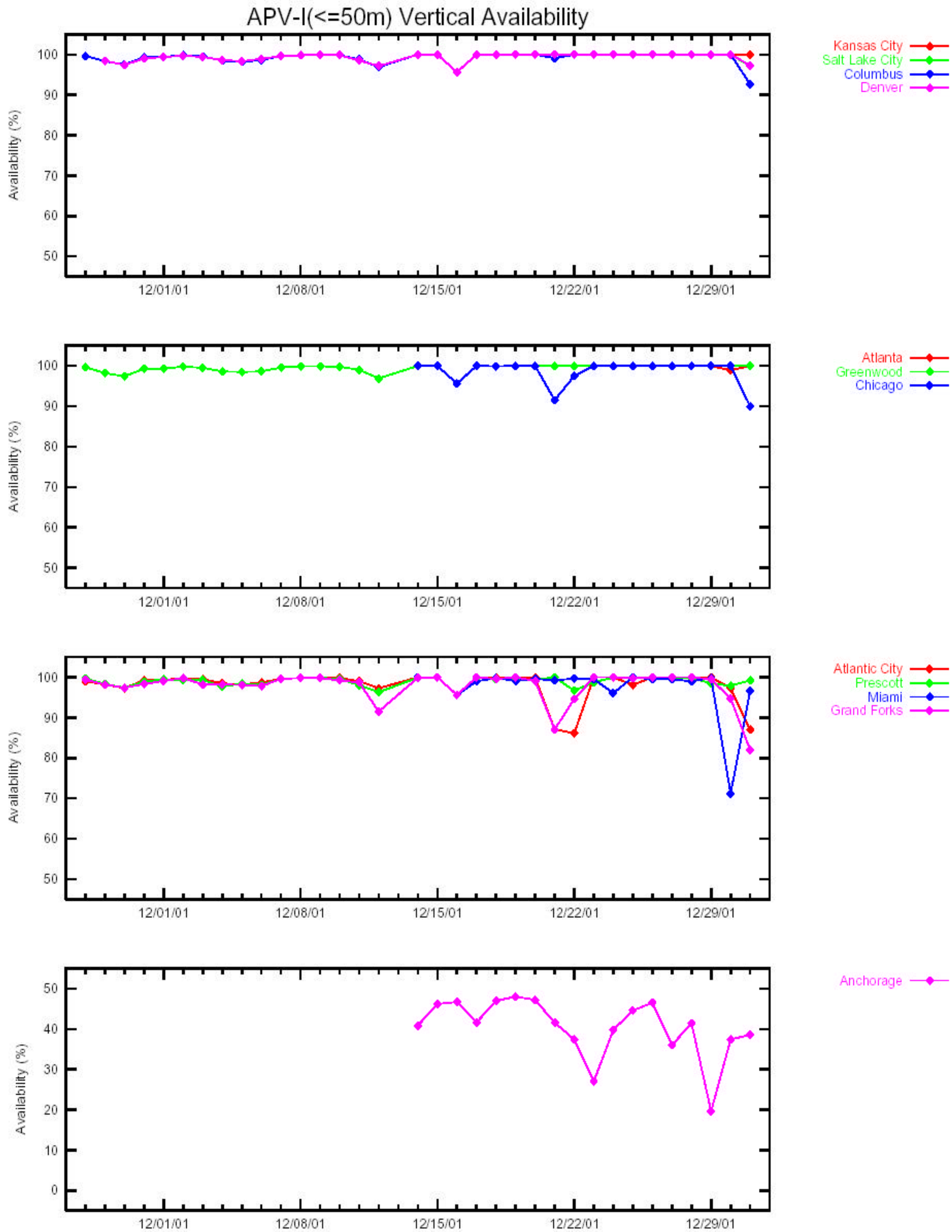
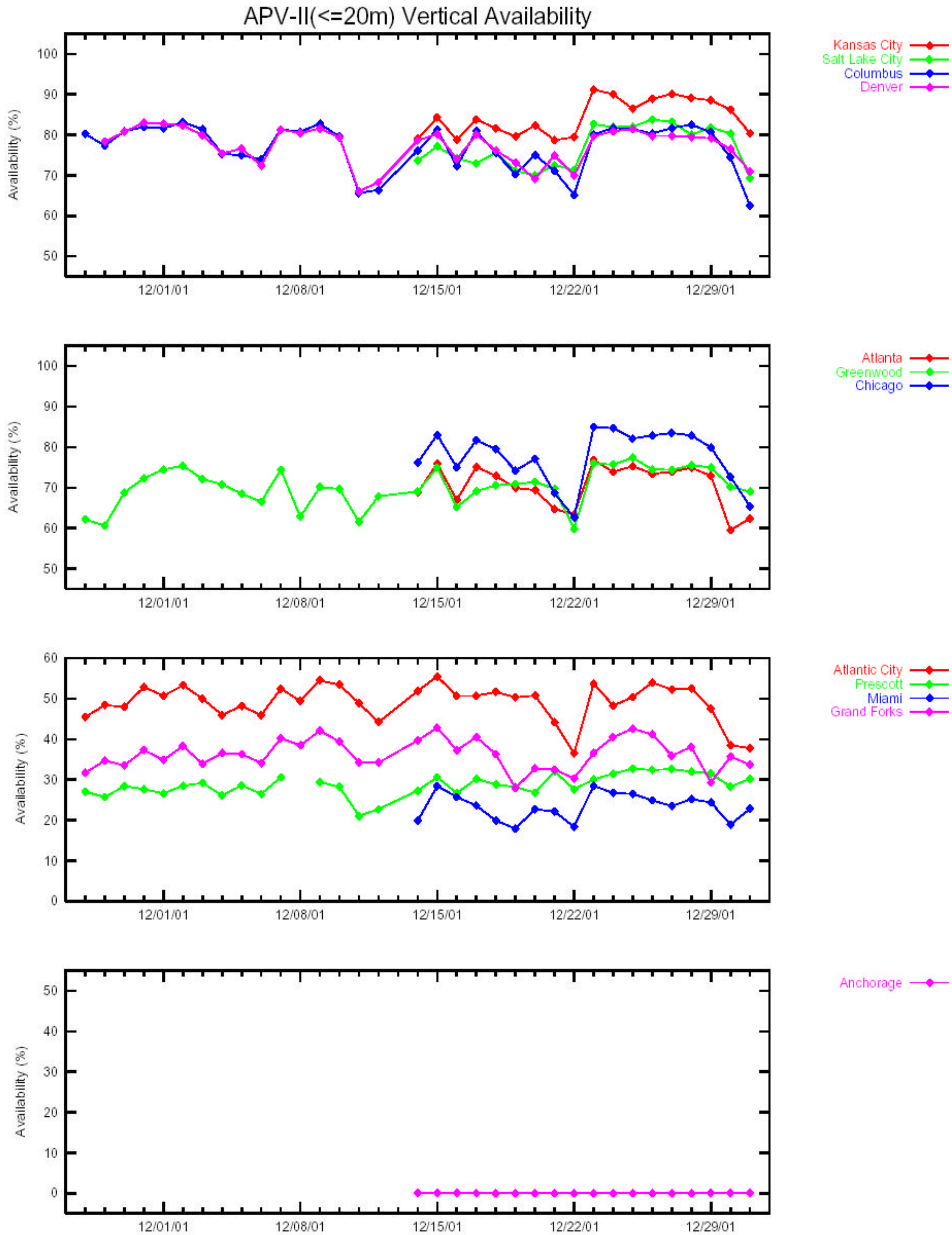


Figure 3.11 Post-GIVE Monitor APV-II Vertical Availability Trends



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 4.1 to 4.2 shows the WAAS coverage area for the pre- and post-GIVE monitor periods of the quarter respectively. 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 addition of the GIVE monitor improved coverage considerably, as can be seen by comparing Figures 4.1 and 4.2. The percent of CONUS that was covered went from around 60% to around 97% after this change to the WAAS. This dramatic increase can be seen in Figure 4.3 on the date that the GIVE monitor was installed. Note the drops in coverage are caused by ionospheric storm activity except on 10/30 where LNAV/VNAV coverage is 0% caused by satellites "not monitored" by WAAS. During this day WAAS availability at all NSTB and WAAS receiver location dropped to approximately 90% due to WAAS setting GPS SVs to not monitored.

Figure 4.1 WAAS Pre-GIVE Monitor Coverage

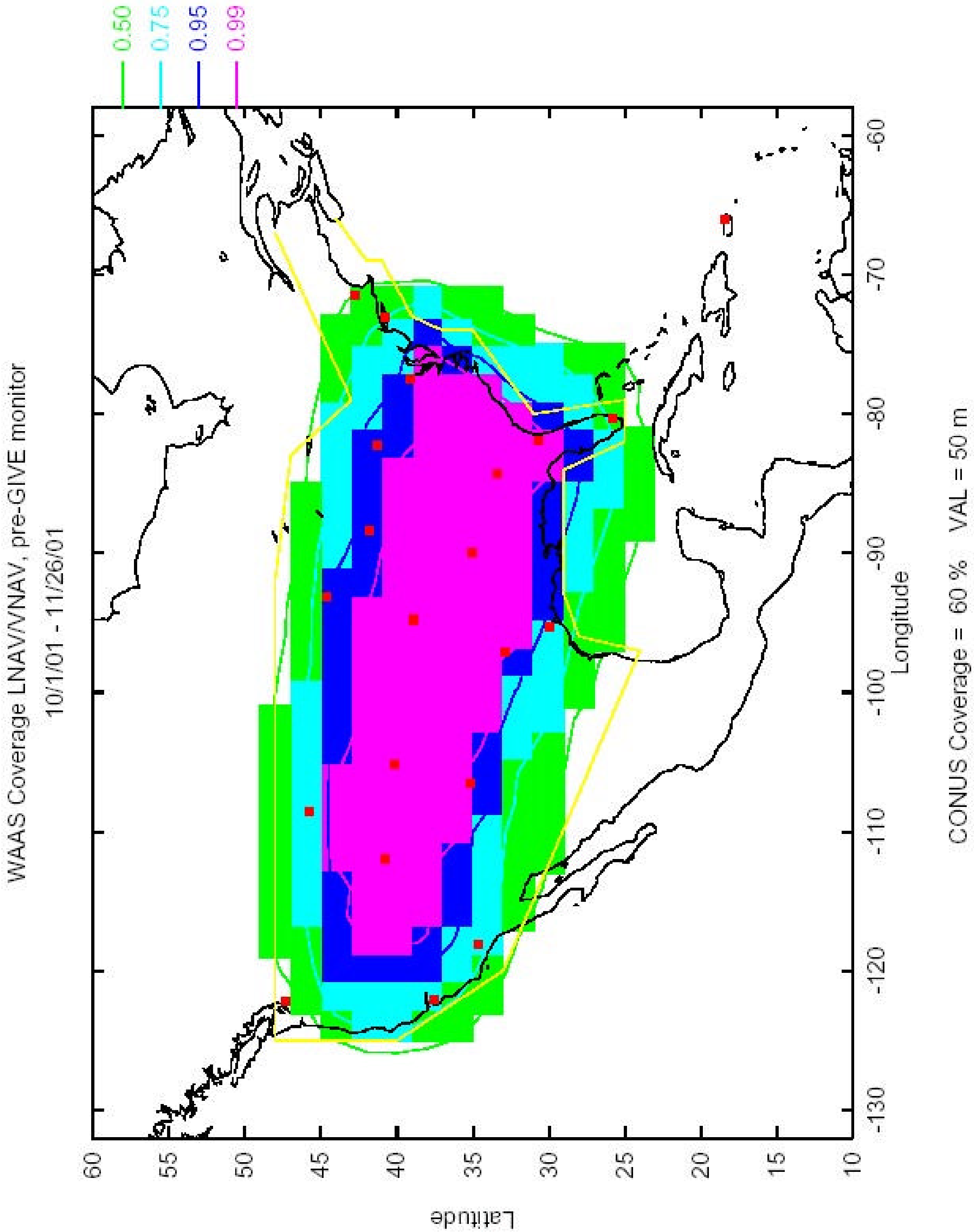


Figure 4.2 WAAS Post-GIVE Monitor Coverage

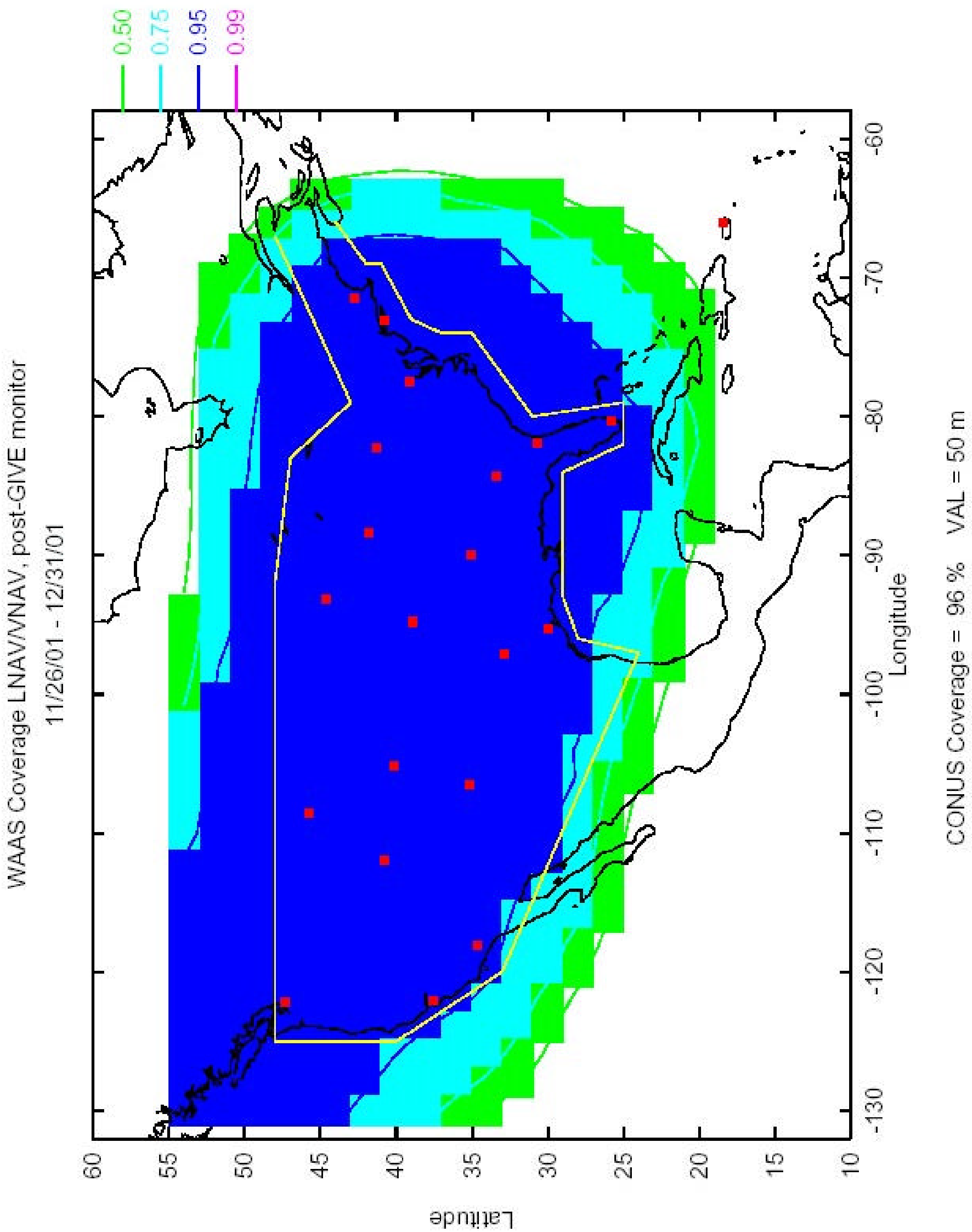
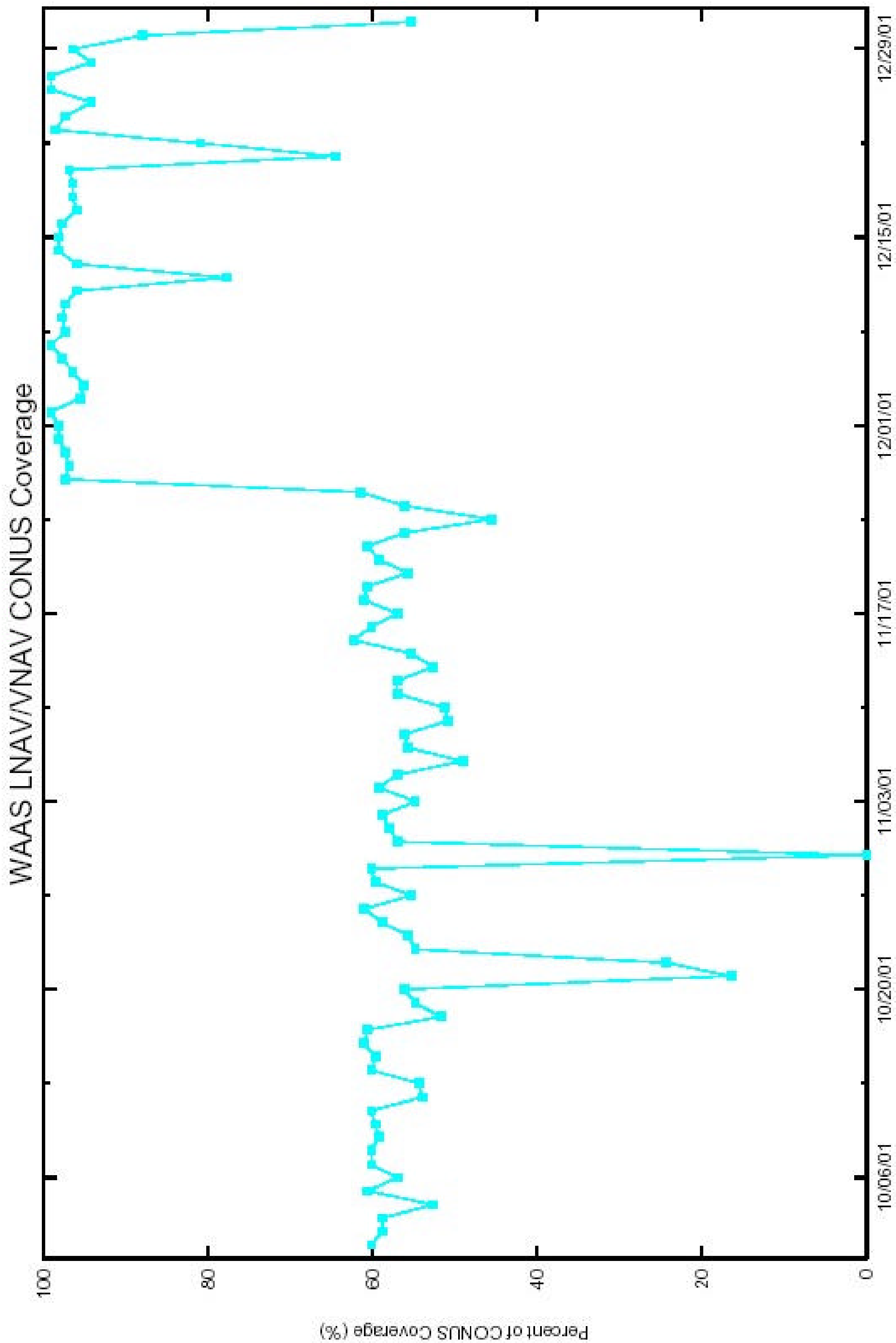


Figure 4.3 Daily WAAS LNAV/VNAV CONUS Coverage



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 5.1 shows all evaluated sites for pre-GIVE portion have the maximum probability of 1. The NPA Continuity of Navigation column of Table 5.2 shows all evaluated sites for post-GIVE portion have the maximum probability of 1.

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 consisting 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 as defined in section 2.0.

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 5.1 shows the probability for NPA continuity of fault detection for the pre-Give period. The probability ranges from 0.805206 to 0.950820. The NPA Continuity of Fault Detection column of Table 5.2 shows the probability for NPA continuity of fault detection for the post-Give period. The probability ranges from 0.803593 to 0.982533. 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 consisting 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 as defined in section 2.0.
- 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 5.1 shows the probability for LNAV/VNAV continuity of function for the pre-GIVE Monitor period range from 0.478022 to 0.997255. Table 5.2 shows the probability for LNAV/VNAV continuity of function for the post-GIVE Monitor period range from 0.416430 to 0.998905.

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 5.1 shows the number of SV alerts and IGP alerts that occurred daily during the reporting period. Note the number of IGP alerts is zero after the new GIVE monitored was installed.

Table 5.1 Pre-GIVE Monitor Continuity

Location	NPA Continuity of Navigation	NPA Continuity of Fault Detection	LNAV/VNAV Continuity Of Function
Kansas City	1	0.939227	0.997232
Salt Lake City	1	0.945355	0.997255
Columbus	1	0.814565	0.976173
Denver	1	0.805206	0.978249
Atlanta	1	0.950820	0.996796
Greenwood	1	0.826866	0.981259
Chicago	1	0.950820	0.973897
San Angelo[1]	-	-	-
Atlantic City	1	0.829596	0.904901
Prescott	1	0.809077	0.924453
Miami	1	0.950820	0.896441
Arcata[2]	-	-	-
Billings	1	0.945355	0.855894
Grand Forks	1	0.822795	0.666558
Bangor	1	0.950000	0.489279
Anchorage	1	0.945055	0.478022

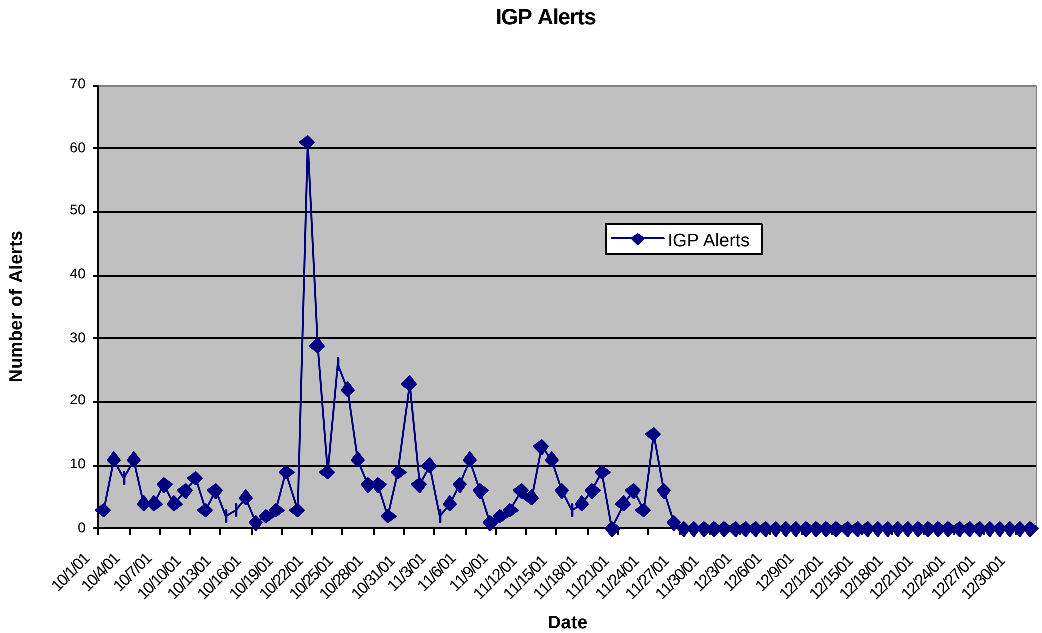
1-The receiver at San Angelo was down for maintenance this quarter due to a hardware failure
2-The receiver at Arcata was down for maintenance this quarter due to a hardware failure

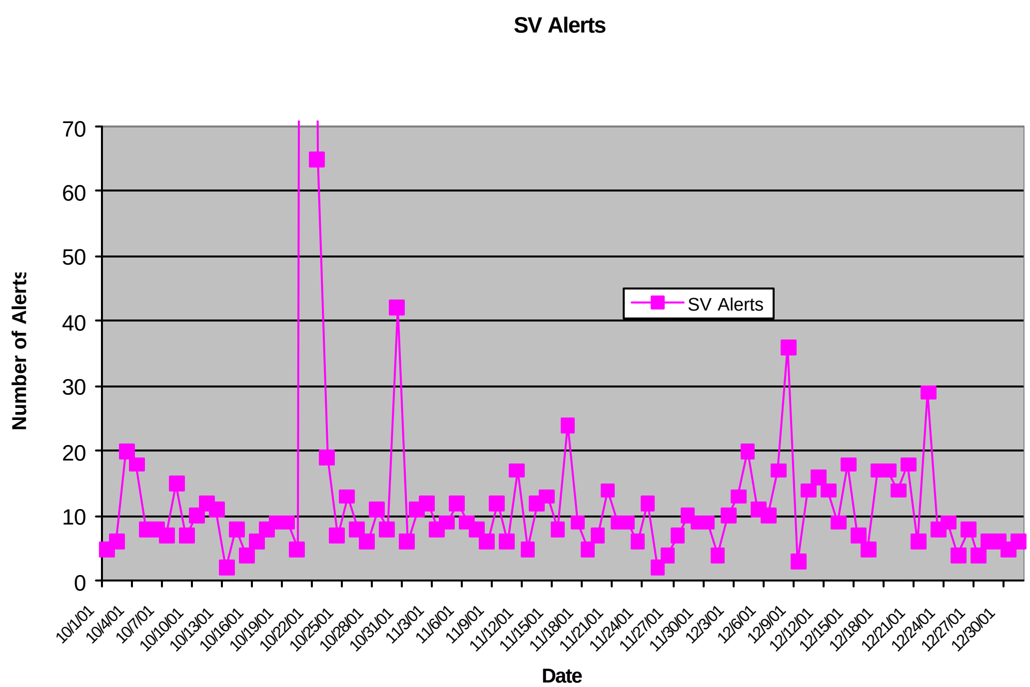
Table 5.2 Post-Give Monitor Continuity

Location	NPA Continuity of Navigation	NPA Continuity of Fault Detection	LNAV/VNAV Continuity Of Function
Kansas City	1	0.982456	0.998905
Salt Lake City	1	0.982533	0.997360
Columbus	1	0.808153	0.967673
Denver	1	0.815085	0.969788
Atlanta	1	0.982533	0.998270
Greenwood	1	0.818945	0.970669
Chicago	1	0.980349	0.986160
San Angelo[1]	-	-	-
Atlantic City	1	0.816986	0.955382
Prescott	1	0.803593	0.961362
Miami	1	0.982533	0.973049
Arcata[2]	-	-	-
Billings	1	0.980349	0.983611
Grand Forks	1	0.812950	0.951808
Bangor[3]	-	-	-
Anchorage	1	0.978070	0.416430

1-The receiver at San Angelo was down for maintenance this quarter due to a hardware failure
2-The receiver at Arcata was down for maintenance this quarter due to a hardware failure
3- Bangor receiver data was not available due to WEI installation

Figure 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 6.1 and 6.2) 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 6.1 Pre-GIVE Monitor Safety Margin Index and HMI Statistics

Location	Safety Margin Index		Number of HMIs
	Horizontal	Vertical	
Kansas City	3.53	2.96	0
Salt Lake City	3.16	3.14	0
Columbus	2.86	2.42	0
Denver	2.22	1.90	0
Atlanta	3.16	3.33	0
Greenwood	3.00	2.54	0
Chicago	2.73	2.96	0
San Angelo[1]	-	-	-
Atlantic City	3.16	1.97	0
Prescott	3.00	3.33	0
Miami	3.75	2.81	0
Arcata[2]	-	-	-
Billings	3.33	2.42	0
Grand Forks	2.14	1.37	0
Bangor	3.33	2.42	0
Anchorage	5.45	4.10	0

1-The receiver at San Angelo was down for maintenance this quarter due to a hardware failure
2-The receiver at Arcata was down for maintenance this quarter due to a hardware failure

Table 6.2 Post-GIVE Monitor Safety Margin Index and HMI Statistics

Location	Safety Margin Index		Number of HMIs
	Horizontal	Vertical	
Kansas City	2.61	4.44	0
Salt Lake City	2.86	3.81	0
Columbus	2.50	4.10	0
Denver	2.61	2.13	0
Atlanta	2.73	3.55	0
Greenwood	2.40	2.96	0
Chicago	2.86	4.44	0
San Angelo[1]	-	-	-
Atlantic City	3.33	2.22	0
Prescott	2.61	5.33	0
Miami	3.53	5.92	0
Arcata[2]	-	-	-
Billings	2.61	4.85	0
Grand Forks	3.16	2.42	0
Bangor[3]	-	-	-
Anchorage	3.16	2.81	0

1-The receiver at San Angelo was down for maintenance this quarter due to a hardware failure
2-The receiver at Arcata was down for maintenance this quarter due to a hardware failure
3- Bangor receiver data was not available due to WEI installation

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, the safety margin index never drops below 1.37 at any site in the pre-GIVE monitor period (see Table 6.1). After the GIVE monitor was installed, the lowest safety margin at any site was 2.13 (see Table 6.2). Also, Table 6.1 and 6.2 show the number of HMIs that occurred during the quarter, of which there were none, before or after the GIVE monitor. An HMI occurs if the position 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 corrected by WAAS.

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. 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 satellite range residual errors were calculated for the NSTB receiver in Columbus during the quarter, and the 95% index is reported in Table 7.1and 7.2 for the pre- and post-GIVE monitor periods, respectively. During the pre-GIVE monitor period, as shown in Table 7.1, all GPS satellite residual errors were less than 2.0 meters 95% of the time except PRN 10 which has an error of 2.22 meters. The probability that the UDRE bounds the residual error during the pre-GIVE period is also presented in Table 7.1. All satellites were bounded at least 99.9% of the time except GPS satellites PRN 10, 14, and 17,, which both were bounded 99.8%. The lower bounding probability for PRN 10, 14, and 17 is primarily due to higher than expected code noise and multipath errors present on the pseudorange measurements.

During the post-GIVE monitor period, as shown in Table 7.2, all GPS satellite residual errors were less than 1.8 meters 95% of the time. The probability that the UDRE bounds the residual error during the post-GIVE period is also presented in Table 7.2. All satellites were bounded 100%.

A GIVE is broadcast by the WAAS for each Ionospheric Grid Point (IGP) that is monitored by the system and is required to bound 99.9% of the ionospheric error. The WAAS broadcasts the ionospheric model using IGP's at predefined geographic locations. Each IGP contains the vertical ionospheric delay and the error in that delay in the form of the GIVE. The ionospheric error is determined by taking the difference between the WAAS ionospheric delay interpolated from the IGP's and GPS dual frequency measurement at that GPS satellite.

GPS satellite ionospheric errors were calculated for the NSTB receiver in Columbus during the quarter, and the 95% index is reported in Table 7.1and 7.2 for the pre- and post-GIVE monitor periods, respectively. During the pre-GIVE monitor period, as shown in Table 7.1, all GPS satellite ionospheric errors were less than 2.0 meters 95% of the time except PRN 11 which has an error of 2.1 meters. The probability that the interpolated GIVE bounds the ionospheric error during the pre-GIVE period is also presented in Table 7.1. All satellites were bounded at least 99% of the time except GPS satellite PRN 3, which both were bounded 98%. The lower bounding probability for PRN 3 is currently under investigation.

During the post-GIVE monitor period, as shown in Table 7.2, all GPS satellite ionospheric errors were less than 1.6 meters 95% of the time except PRN 11 which has an error of 2.3 meters. The probability that the interpolated GIVE bounds the residual error during the post-GIVE period is also presented in Table 7.2. All satellites were bounded 100%.

Table 7.1 Pre-GIVE Monitor Range and Iono Error and 3.29 Sigma Bounding

SV	95% Range Error	Range Error Bounding	95% Iono Error	Iono Error Bounding
1	1.540	100.000	1.390	99.999
2	1.790	99.988	1.530	99.840
3	1.330	100.000	1.390	98.240
4	1.780	99.988	0.980	99.273
5	1.570	100.000	1.490	99.994
6	1.540	100.000	1.180	99.953
7	1.680	99.997	1.450	99.943
8	1.690	100.000	1.240	99.879
9	1.550	100.000	1.540	99.924
10	2.220	99.811	1.480	99.873
11	1.470	100.000	2.100	99.830
13	1.570	100.000	1.840	99.961
14	1.720	99.882	1.200	99.992
15	1.460	99.905	1.050	99.976
17	1.400	99.770	1.050	99.957
18	1.530	99.942	1.200	100.00
20	1.770	99.994	1.250	99.952
21	1.680	99.890	1.370	99.935
22	1.650	100.000	1.360	99.997
23	1.580	99.982	1.010	99.987
24	1.840	99.917	1.140	99.786
25	1.690	99.969	1.170	99.998
26	1.940	100.000	1.160	98.216
27	1.400	100.000	1.300	99.945
28	1.790	100.000	1.190	99.990
29	1.750	99.999	1.000	99.965
30	1.730	100.000	1.280	99.664
31	1.310	100.000	1.460	99.914

Figure 7.1 Pre-GIVE Monitor 95% Range Error(SV 1—SV 16)

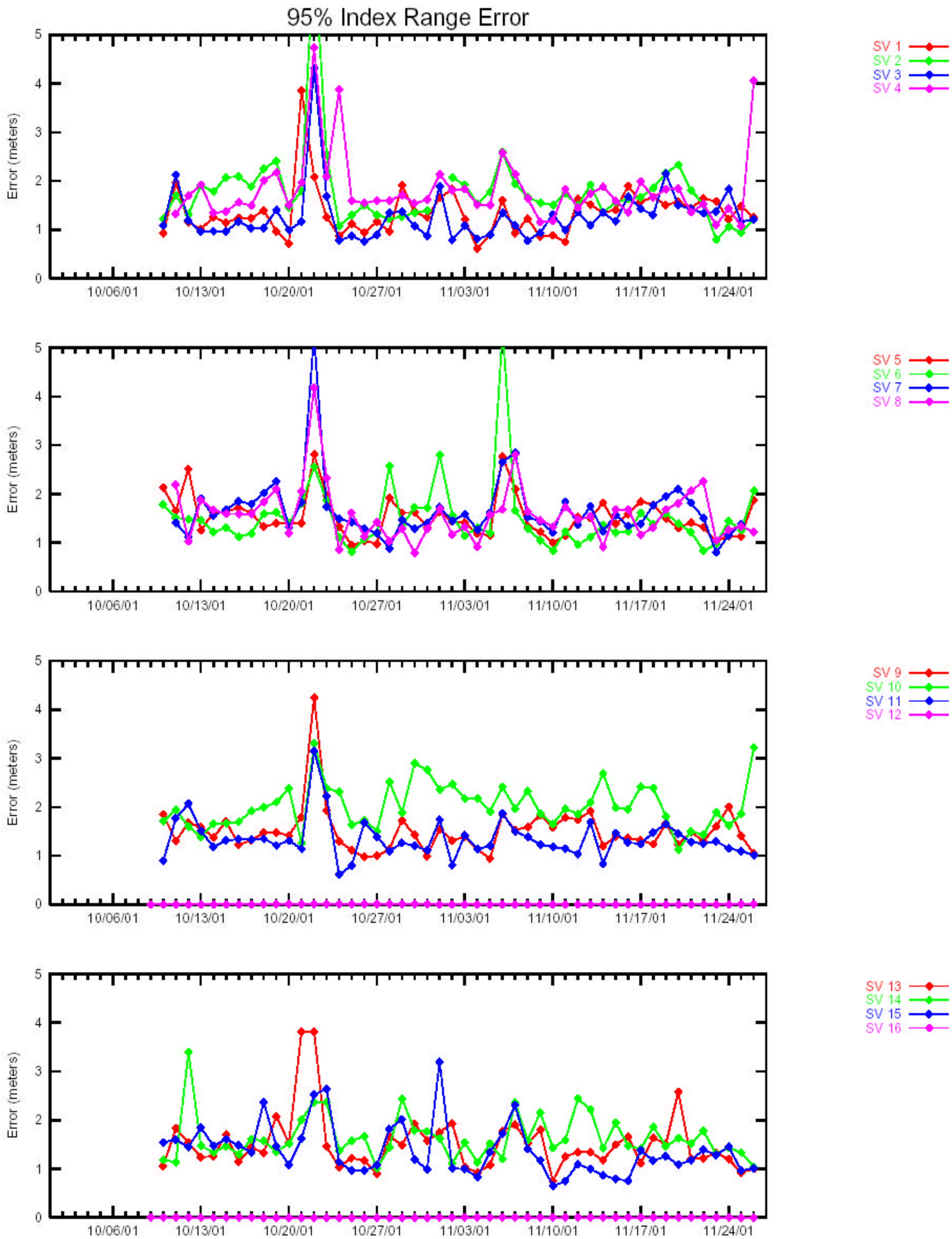


Figure 7.2 Pre-GIVE Monitor 95% Range Error (SV 17—SV 31)

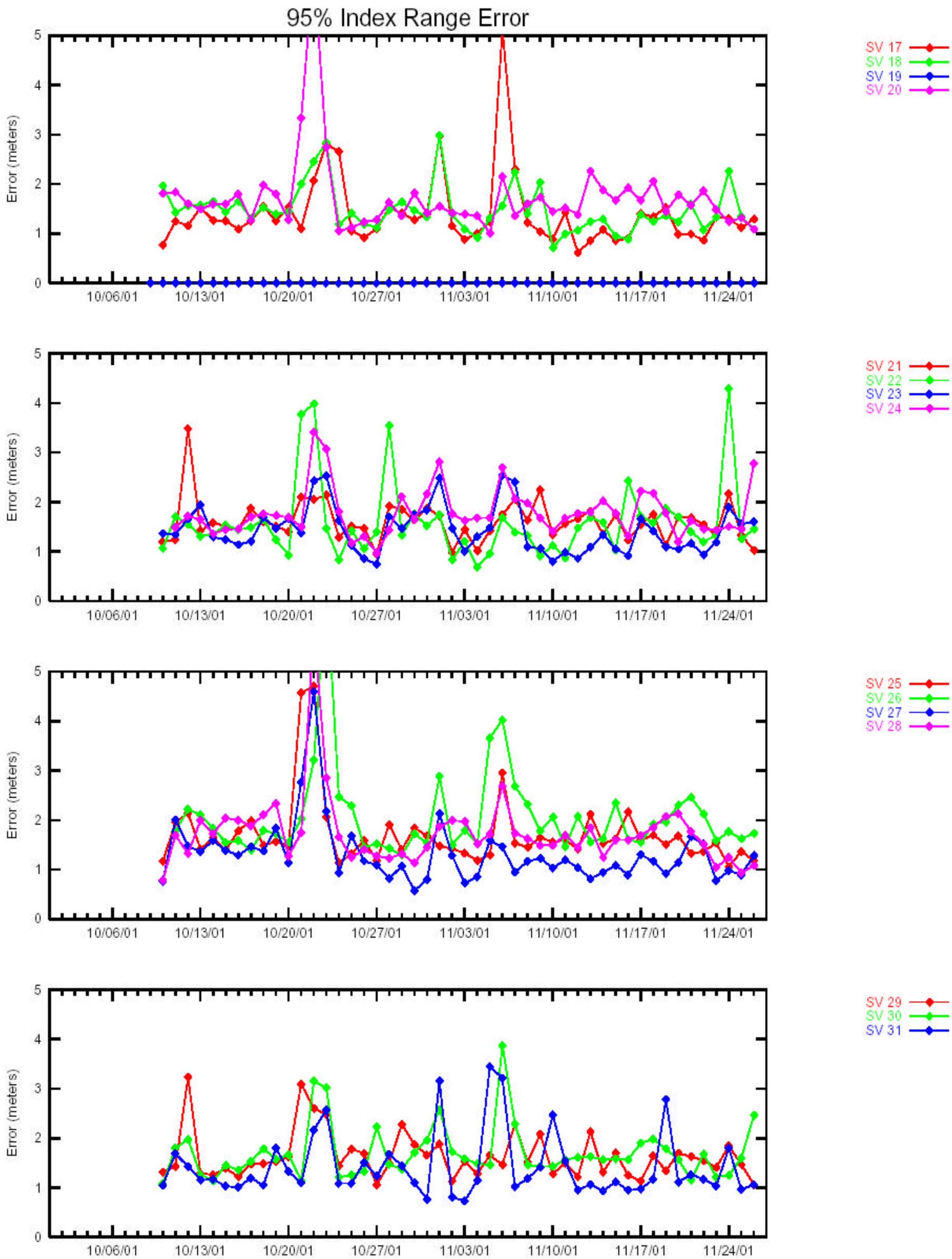


Table 7.2 Post-GIVE Monitor Range and Iono Error and 3.29 Sigma Bounding

SV	95% Range Error	Range Error 3.29 Sigma Bounding	95% Iono Error	Iono Error 3.29 Sigma Bounding
1	1.520	100.00	0.950	100.000
2	1.430	100.00	1.190	100.000
3	1.400	100.00	1.230	100.000
4	1.530	100.00	1.010	100.000
5	1.300	100.00	1.110	100.000
6	1.420	100.00	1.400	100.000
7	1.452	100.00	1.130	100.000
8	1.770	100.00	1.120	100.000
9	1.520	100.00	1.350	100.000
10	1.510	100.00	1.560	100.000
11	1.340	100.00	2.386	100.000
13	1.650	100.00	1.630	100.000
14	1.160	100.00	1.250	100.000
15	1.270	100.00	0.680	100.000
17	1.250	100.00	0.760	100.000
18	1.250	100.00	1.150	100.000
20	1.720	100.00	1.600	100.000
21	1.170	100.00	0.970	100.000
22	1.410	100.00	1.230	100.000
23	1.340	100.00	0.720	100.000
24	1.370	100.00	1.140	100.000
25	1.270	100.00	1.070	100.000
26	1.760	100.00	1.250	100.000
27	1.250	100.00	0.990	100.000
28	1.550	100.00	1.230	100.000
29	1.180	100.00	0.920	100.000
30	1.390	100.00	1.310	100.000
31	1.230	100.00	1.240	100.000

Figure 7.5 Post-GIVE Monitor 95% Range Error (SV 1—SV 16)

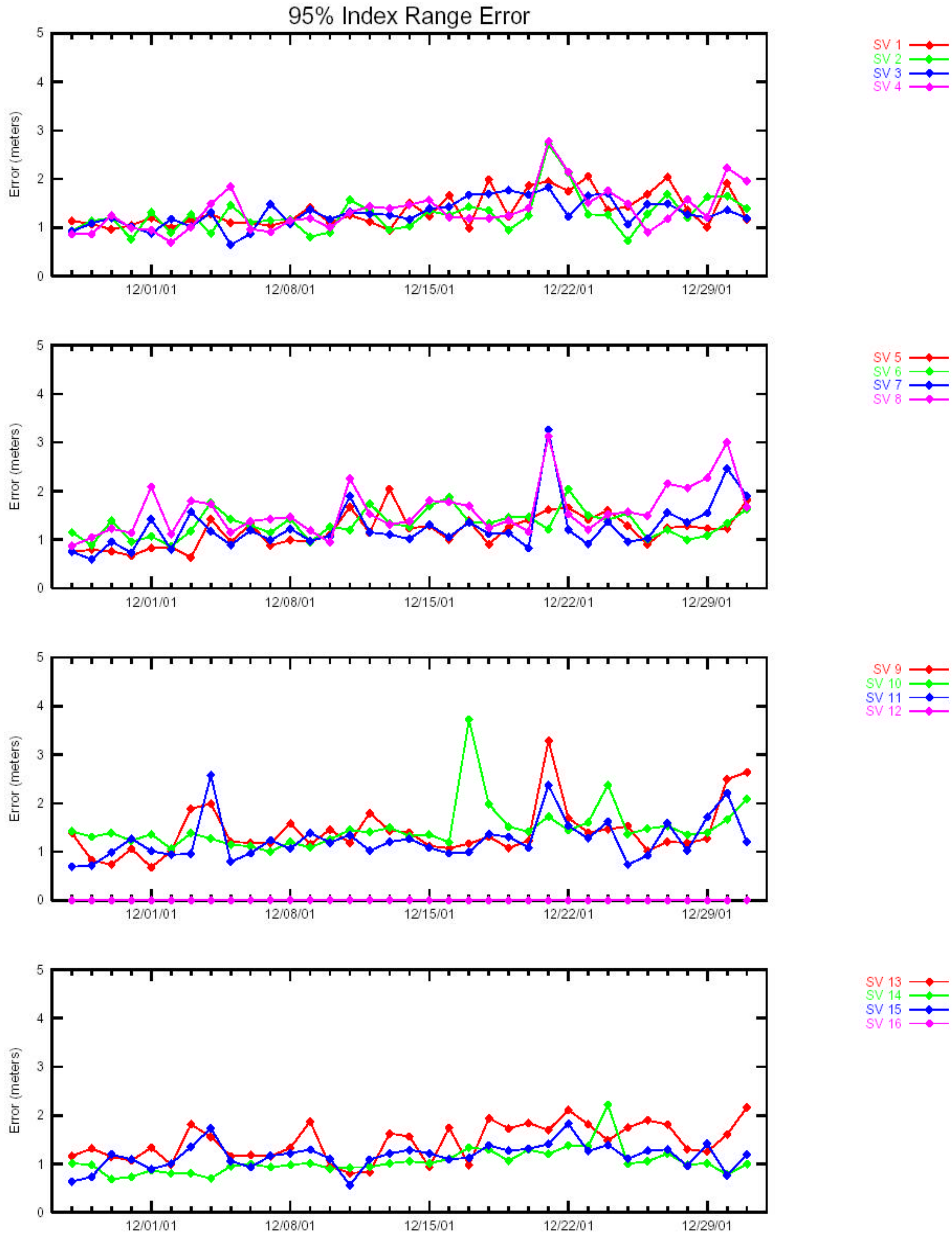
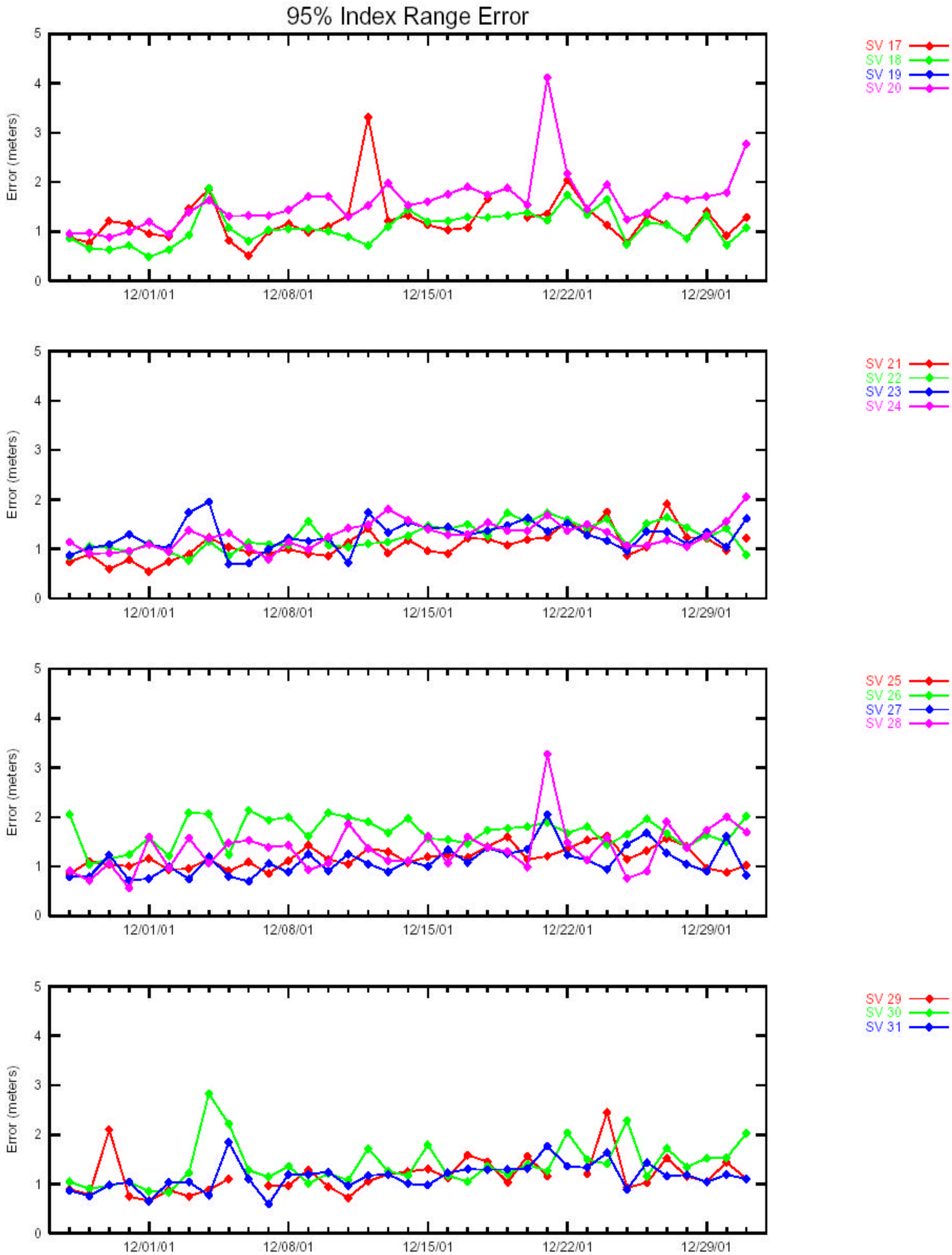


Figure 7.6 Post-GIVE Monitor 95% Range Error (SV 17—SV 31)



Appendix A: Glossary

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

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.

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 ionospheric 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.

MOPS. Minimum Operational Performance Standards.

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.

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.

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.

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.