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

Submitted To

Federal Aviation Administration
GPS Product Team

1284 Maryland Avenue SW
Washington, DC 20024

Report #65
April 30, 2009
Reporting Period: 1 January – 31 March 2009

Submitted by

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EXECUTIVE SUMMARY

The GPS Product Team has tasked the Navigation Branch at the William J. Hughes Technical Center to document the 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 twenty-eight Wide Area Augmentation System (WAAS) Reference Stations. This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification (October 2001).

This report, Report #65, includes data collected from 1 January through 31 March 2009. The next quarterly report will be issued July 31, 2009.

Analysis of this data includes the following standards and categories: PDOP Availability, NANU Summary and Evaluation, Service Availability, Service Reliability, Position and Range Accuracy and Solar Storm Effects on GPS SPS performance.

PDOP availability is 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 global availability based on PDOP less than six for the CONUS was 99.994% or better.

NANU summary and evaluation was achieved by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 January and 31 March 2009. Using this data, we compute a set of statistics that give a relative idea of constellation health for both the current and combined history of past quarters. A total of nine outages were reported in the NANU's this quarter. Nine outages were scheduled while there were no unscheduled outages.

The quarterly service availability standard was verified using 24-hour position accuracy values computed from data collected at one-second intervals. All of the sites achieved a 100% availability, which exceeds the SPS "average location" value of 99% and the "worst-case location" value of 90%.

Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error and Service Reliability standards were verified for each satellite from 24-hour accuracy values computed using data collected at the following six sites: Boston, Honolulu, Los Angeles, Miami, San Juan and Juneau. This data was also collected in one-second samples. All sites achieved 100% reliability, meeting the SPS specification. The maximum range error recorded was 19.179 meters on Satellite PRN 23. The SPS specification states that the range error should never exceed 30 meters for less than 99.79% of the day for a worst-case point and 99.94% globally. The maximum RMS range error value of 2.420 recorded on satellite 10. The SPS specification states that RMS URE cannot exceed 6 meters in any 24-hour interval.

Geomagnetic storms had little to no effect on GPS performance this quarter. All sites met all GPS Standard Positioning Service (SPS) specifications on those days with the most significant solar activity.

The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products. During the evaluation period, the maximum 95% horizontal and vertical SPS errors are 3.51 meters at Maspalomas and 5.70 meters at Usuda, respectively.

From the analysis performed on data collected between 1 January and 31 March 2009, the GPS performance met all SPS requirements that were evaluated. There were no significant problems to report for the duration of the quarter.

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1.0 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS and WAAS for IFR operations and is developing Local Area Augmentation (LAAS), which is an additional GPS augmentation system. 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 twenty-eight WAAS reference station locations:

- Bethel, AK
- Billings, MT
- Fairbanks, AK
- Cold Bay, AK
- Kotzebue, AK
- Juneau, AK
- Albuquerque, NM
- Anchorage, AK
- Boston, MA
- Washington, D.C.
- Honolulu, HI
- Houston, TX
- Kansas City, KS
- Los Angeles, CA
- Salt Lake City, UT
- Miami, FL
- Minneapolis, MI
- Oakland, CA
- Cleveland, OH
- Seattle, WA
- San Juan, PR
- Atlanta, GA
- Barrow, AK
- Merida, Mexico
- Gander, Canada
- Tapachula, Mexico
- San Jose Del Cabo, Mexico
- Iqaluit, Canada

The analysis of the data is divided into the four performance categories stated in the Standard Positioning Service Performance Specification (October 2001). These categories are:

- PDOP Availability Standard
- Service Availability Standard
- 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.

1.3 Report Overview

Section 2 of this report summarizes the results obtained from the coverage calculation program developed by the GPS test team. The SPS coverage area 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 constellation 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 evaluates the Service Availability Standard using 24-hour 95% horizontal and vertical position accuracy values.

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 on a measurement interval of one year. Data for the quarter is provided for completeness.

Section 5 provides the position 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 an analysis of GPS-SPS accuracy performance from a selection of high rate IGS stations around the world.

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.

Appendix D provides a glossary of terms used in this PAN report. This glossary was obtained directly from the GPS SPS specification document (October 2001).

Table 1-1 SPS Performance Requirements

PDOP Availability Standard	Conditions and Constraints	Evaluated in This Report
≥ 98% global Position Dilution of Precision (PDOP) of 6 or less ≥ 88% worst site PDOP of 6 or less	• Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. • Based on using only satellites transmitting standard code and indicating "health" in the broadcast navigation message (sub-frame 1).	✓
Service Availability Standard	**Conditions and Constraints**	
≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	• 36 meter horizontal (SIS only) 95% threshold. • 77 meter vertical (SIS only) 95% threshold. • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	✓
≥ 95.87% global average on worst-case day	• Based on using only satellites transmitting standard code and indicating "healthy" in the broadcast navigation message (sub-frame 1).	✓
Service Reliability Standard	**Conditions and Constraints**	
≥ 99.94% global average	• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	✓
≥ 99.79% single point average	• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values from the worst-case point within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	✓

Accuracy Standard	**Conditions and Constraints**	
Global Average Positioning Domain Accuracy • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only)	• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	✓
Worst Site Positioning Domain Accuracy • ≤ 36 meters 95% All-in-View Horizontal Error (SIS only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS only)	• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours for any point within the service volume.	✓
Time Transfer Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for time transfer solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	✓
SPS SIS URE STANDARD	**Conditions and Constraints**	
≤ 6 meters RMS SIS SPS URE across the entire constellation	• Average of the constellation's individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point thing the service volume.	✓

2.0 PDOP Availability Standard

PDOP Availability: *The percentage of time over any 24-hour interval that the PDOP value is less than or equal to its threshold for any point within the service volume.*

Dilution of Precision (DOP): *The magnifying effect on GPS position error induced by mapping GPS ranging errors into position within the specified coordinate system through the geometry of the position solution. The DOP varies as a function of satellite positions relative to user position. 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. .*

PDOP Availability Standard	Conditions and Constraints
≥ 98% global Position Dilution of Precision (PDOP) of 6 or less ≥ 88% worst site PDOP of 6 or less	• Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. • Based on using only satellites transmitting standard code and indicating “health” in the broadcast navigation message (sub-frame 1).

Almanacs for GPS weeks 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 the GPS test team 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 3.1875 or better 99.9% of the time for each of the 24-hour intervals.

Figure 2-1 is a contour plot of PDOP values over the entire globe. Inside each contour area, the PDOP value is greater than or equal to the contour value shown in the legend for that color line. That areas’ value is also less than the next higher contour value, unless another contour line lies within the current area. A single “DOP hole” where the PDOP value is greater than 6 was evaluated for satellite visibility for one 24-hour interval from the week shaded in Table 2-1. The histogram in figure 2-2 shows the satellite visibility at the DOP hole position for the 24 hour interval in question.

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

Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
28 Dec – 3 Jan	3.1875	99.994	98.958
4 Jan – 10 Jan	3.1506	99.994	98.958
11 – 17 Jan	3.1136	99.996	98.889
18 – 24 Jan	3.1266	99.995	98.958
25 – 31 Jan	2.9649	100	99.861
1 – 7 Feb	2.8552	100	100
8 – 14 Feb	2.8628	100	100
15 – 21 Feb	2.9585	99.997	99.444
22 – 28 Feb	3.0206	99.995	98.958
1 – 7 Mar	2.8973	99.996	99.236
8 – 14 Mar	2.8276	100	100
15 – 21 Mar	2.8733	99.998	99.583
22 – 28 Mar	2.9396	99.995	99.028

Figure 2-1 PDOP Availability Plot (24-Hour Period: 1 January 2009)

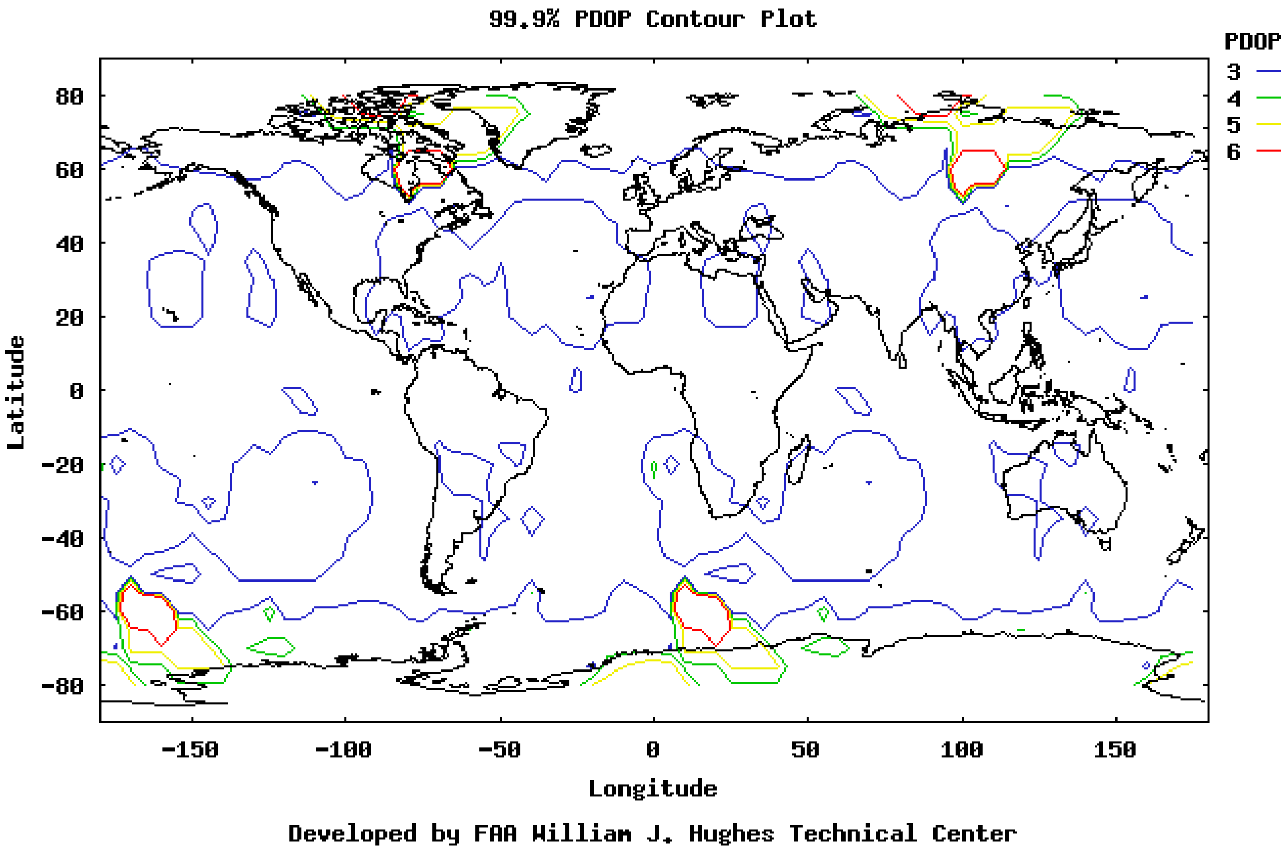
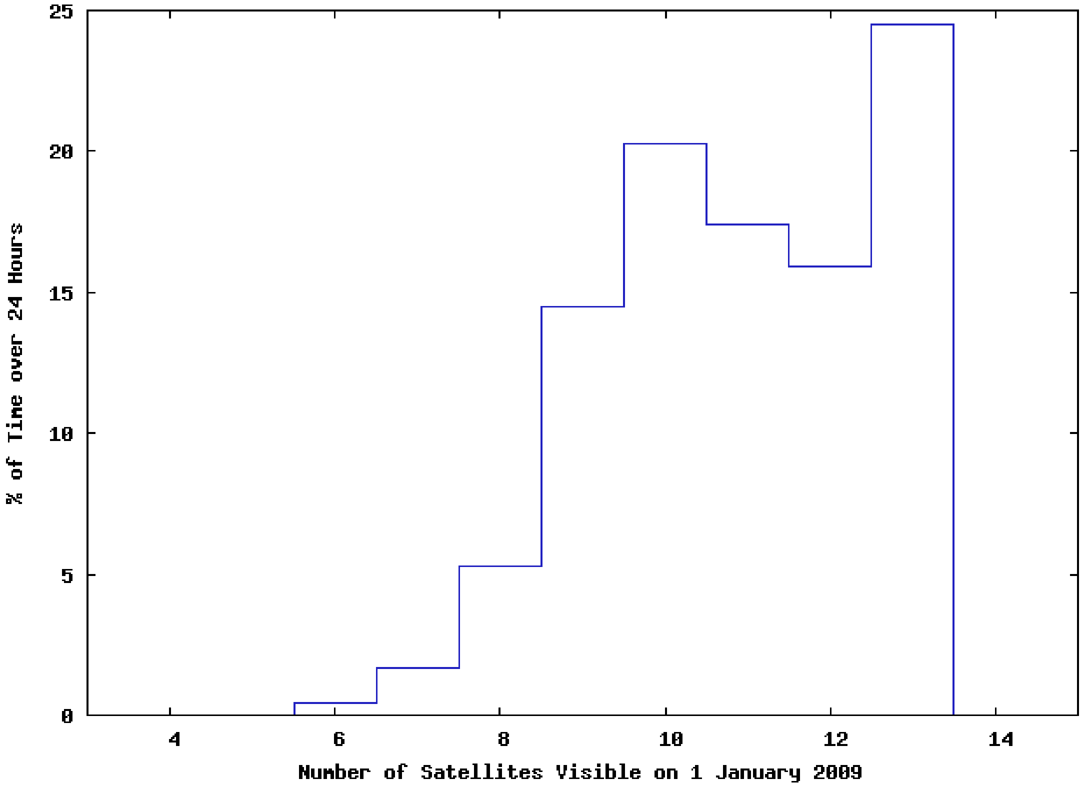


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lat: -60, Lon: -165)



3.0 NANU Summary and Evaluation

NANU: Notice Advisory to NAVSTAR Users - a periodic bulletin alerting users to changes in the satellite system performance.

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 January through 31 March 2009, there were a total of nine reported outages. All nine of these outages were maintenance activities and were reported in advance. There were no 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
2009002	15	FCSTSUMM	8-Jan	19:38	9-Jan	2:21		6.72	6.72
2009004	19	FCSTSUMM	11-Feb	22:34	12-Feb	5:03		6.48	6.48
2009006	5	FCSTSUMM	17-Feb	14:24	17-Feb	16:49		2.42	2.42
2009013	6	FCSTSUMM	23-Feb	20:23	24-Feb	3:52		7.48	7.48
2009014	8	FCSTSUMM	25-Feb	2:13	25-Feb	3:21		1.13	1.13
2009015	27	FCSTSUMM	26-Feb	4:32	26-Feb	5:44		1.20	1.20
2009016	26	FCSTSUMM	26-Feb	17:45	27-Feb	4:08		10.38	10.38
2009018	4	FCSTSUMM	3-Mar	3:55	3-Mar	9:45		5.83	5.83
2009019	10	FCSTSUMM	6-Mar	7:37	6-Mar	13:21		5.73	5.73
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**0.00**	**47.38**	**47.38**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2009003	19	FCSTDV	11-Feb	22:30	12-Feb	12:30	14	See Nanu 2009004
2009005	5	FCSTMX	17-Feb	14:00	18-Feb	2:00	12	See Nanu 2009006
2009007	6	FCSTMX	23-Feb	20:00	24-Feb	8:00	12	See Nanu 2009013
2009008	8	FCSTMX	25-Feb	2:00	25-Feb	14:00	12	See Nanu 2009014
2009009	27	FCSTMX	26-Feb	4:00	26-Feb	16:00	12	See Nanu 2009015
2009010	4	FCSTMX	27-Feb	3:30	27-Feb	15:30	12	See Nanu 2009011
2009011	4	FCSTRESCD	3-Mar	3:30	3-Mar	15:30	12	See Nanu 2009018
2009012	26	FCSTDV	26-Feb	17:30	27-Feb	19:30	26	See Nanu 2009016
2009017	10	FCSTDV	6-Mar	7:30	6-Mar	21:45	14.25	See Nanu 2009019
2009022	18	FCSTDV	2-Apr	16:00	3-Apr	6:30	14.5	See Nanu 2009024
						Total Forecast Downtime	**140.75**	

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

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

Table 3-4 GPS Block II/IIA Satellite RMA Data		
Satellite Reliability/Maintainability/Availability (RMA) Parameter	**1-Jan-09**	**1-Oct-99**
	31-Mar-09	**31-Mar-09**
Total Forecast Downtime (hrs):	140.75	7655.55
Total Actual Downtime (hrs):	47.38	27451.47
Total Actual Scheduled Downtime (hrs):	47.38	3895.26
Total Actual Unscheduled Downtime (hrs):	0.00	23556.21
Total Satellite Observed MTTR (hrs):	5.26	45.37
Scheduled Satellite Observed MTTR (hrs):	5.26	8.77
Unscheduled Satellite Observed MTTR (hrs):	-	146.31
# Total Satellite Outages:	9	605
# Scheduled Satellite Outages:	9	444
# Unscheduled Satellite Outages:	0	161
Percent Operational -- Scheduled Downtime:	99.93	99.83
Percent Operational -- All Downtime:	100.00	98.83

GENERAL NANU's

Nanu 2009001 said that PRN1 discontinued transmitting L-Band and is available for future satellite vehicles
Nanu 2009020 said that PRN 5 will be unusable until further notice
Nanu 2009023 said that PRN 5 was decommissioned

Service Availability: The percentage of time over any 24-hour interval that the predicted 95% positioning error is less than its threshold for any given point within the service volume.

• **Horizontal Service Availability:** The percentage of time over any 24-hour interval that the predicted 95% horizontal error is less than its threshold for any point within the service volume.
• **Vertical Service Availability:** The percentage of time over any 24-hour interval that the predicted 95% vertical error is less than its threshold for any point within the service volume.

Service Availability Standard	Conditions and Constraints
≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	• 36 meter horizontal (SIS only) 95% threshold. • 77 meter vertical (SIS only) 95% threshold. • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.
≥ 95.87% global average on worst-case day	• Based on using only satellites transmitting standard code and indicating “healthy” in the broadcast navigation message (sub-frame 1).

To verify availability, the data collected from receivers at the twenty-eight WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-5. The data was collected at one-second intervals between 1 January and 31 March 2009.

Table 3-5 Accuracies Exceeding Threshold Statistics

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-hour Threshold Failures	Quarters Service Availability %
Albuquerque	7739392	0	100%
Anchorage	7734703	0	100%
Atlanta	7199728	0	100%
Barrow	7735369	0	100%
Bethel	7735126	0	100%
Billings	7738639	0	100%
Boston	7738074	0	100%
Cleveland	7649168	0	100%
Cold Bay	7460803	0	100%
Fairbanks	7735309	0	100%
Gander	7675073	0	100%
Honolulu	7723411	0	100%
Houston	7738701	0	100%
Iqaluit	7715416	0	100%
Juneau	7302605	0	100%
Kansas City	7370045	0	100%
Kotzebue	7725121	0	100%
Los Angeles	7735121	0	100%
Merida	7731635	0	100%
Miami	7730946	0	100%
Minneapolis	7638782	0	100%
Oakland	7649254	0	100%
Salt Lake City	7736051	0	100%
San Jose Del Cabo	7737589	0	100%
San Juan	7280373	0	100%
Seattle	7222913	0	100%
Tapachula	7736979	0	100%
Washington, DC	7739638	0	100%
Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)			

4.0 Service Reliability Standard

Service Reliability: *The percentage of time over a specified time interval that the instantaneous SIS SPS URE is maintained within a specified reliability threshold at any given point within the service volume, for all healthy GPS satellites.*

Service Reliability Standard	Conditions and Constraints
≥ 99.94% global average	• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.
≥ 99.79% single point average	• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values from the worst-case point within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.

Table 4-1 shows a comparison to the service reliability standard for range data collected at a set of six receivers across North America. Although the specification calls for yearly evaluations, we will be evaluating this SPS requirement at quarterly intervals. Additional range analysis results can be found in table 5-2 on page 21. The maximum User Range Error recorded this quarter was 13.610 meters on satellite PRN 13.

Table 4-1 Service Reliability Based on User Range Error

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Service Reliability Percentage
1 Jan – 31 Mar 2009	**Boston**	64,949,203	0	100%
1 Jan – 31 Mar 2009	**Honolulu**	67,953,539	0	100%
1 Jan – 31 Mar 2009	**Los Angeles**	66,436,600	0	100%
1 Jan – 31 Mar 2009	**Miami**	65,894,670	0	100%
1 Jan – 31 Mar 2009	**San Juan**	64,419,149	0	100%
1 Jan – 31 Mar 2009	**Juneau**	61,352,719	0	100%
1 Jan – 31 Mar 2009	**Global**	391,005,880	0	100%

5.0 Accuracy Standard

Positioning Accuracy: The statistical difference, at a 95% probability, between position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

• **Horizontal Positioning Accuracy:** The statistical difference, at a 95% probability, between horiz position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.
• **Vertical Positioning Accuracy:** The statistical difference, at a 95% probability, between vertical position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

Accuracy Standard	Conditions and Constraints
Global Average Positioning Domain Accuracy • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only)	• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.
Worst Site Positioning Domain Accuracy • ≤ 36 meters 95% All-in-View Horizontal Error (SIS only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS only)	• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours for any point within the service volume.
Time Transfer Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for time transfer solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.
SPS SIS URE STANDARD	**Conditions and Constraints**
≤ 6 meters RMS SIS SPS URE across the entire constellation	• Average of the constellation's individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point thing the service volume.

5.1 Position Accuracy

The data used for this section was collected for every second from 1 January through 31 March 2009 at the selected WAAS locations.

Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter. Every twenty-four hour analysis period this quarter passed both the worst-case and global position accuracy requirements set forth by the SPS specification.

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

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Albuquerque	2.154	4.095	4.621	9.436
Anchorage	1.847	4.772	3.699	8.911
Atlanta	2.441	4.538	5.846	10.668
Barrow	1.590	5.304	3.149	11.899
Bethel	1.903	4.867	3.916	9.199
Billings	2.297	4.047	4.690	8.169
Boston	2.526	4.378	5.543	8.628
Cleveland	2.569	4.292	6.551	11.136
Cold Bay	2.129	4.884	4.625	8.789
Fairbanks	1.722	4.918	3.318	9.556
Gander	2.383	4.060	4.823	9.280
Honolulu	3.157	4.708	5.380	10.134
Houston	2.157	4.499	5.068	10.409
Iqaluit	10.436	4.373	12.956	17.947
Juneau	1.903	4.457	4.506	8.590
Kansas City	2.494	4.244	4.721	9.844
Kotzebue	1.751	4.942	3.279	10.747
Los Angeles	2.090	4.671	4.259	8.963
Merida	2.249	4.747	4.970	12.738
Miami	2.285	4.866	5.605	10.877
Minneapolis	2.459	4.194	4.473	9.595
Oakland	2.175	4.734	4.270	8.882
Salt Lake City	2.248	4.137	4.330	8.580
San Jose Del Cabo	2.257	4.622	5.401	8.167
San Juan	2.200	4.709	5.050	9.996
Seattle	2.236	4.369	4.790	8.311
Tapachula	3.031	4.521	7.771	9.303
Washington, DC	2.630	4.437	6.030	10.961

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-eight WAAS sites from 1 January to 31 March 2009.

Figure 5-1 Global Vertical Error Histogram

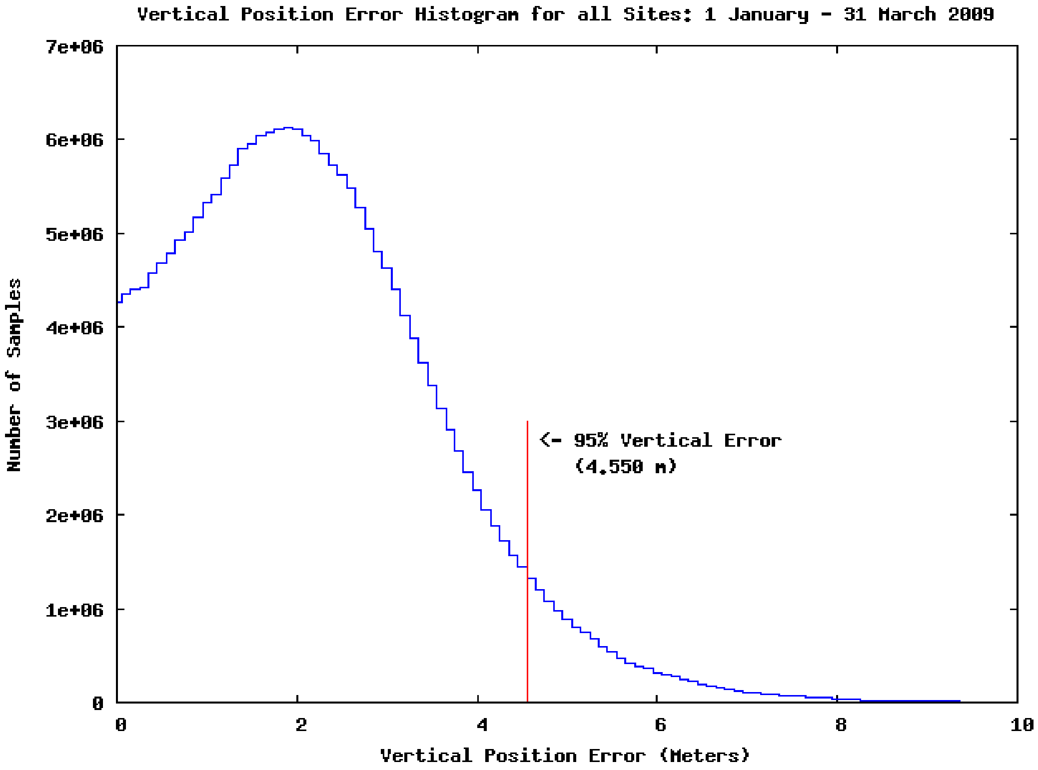
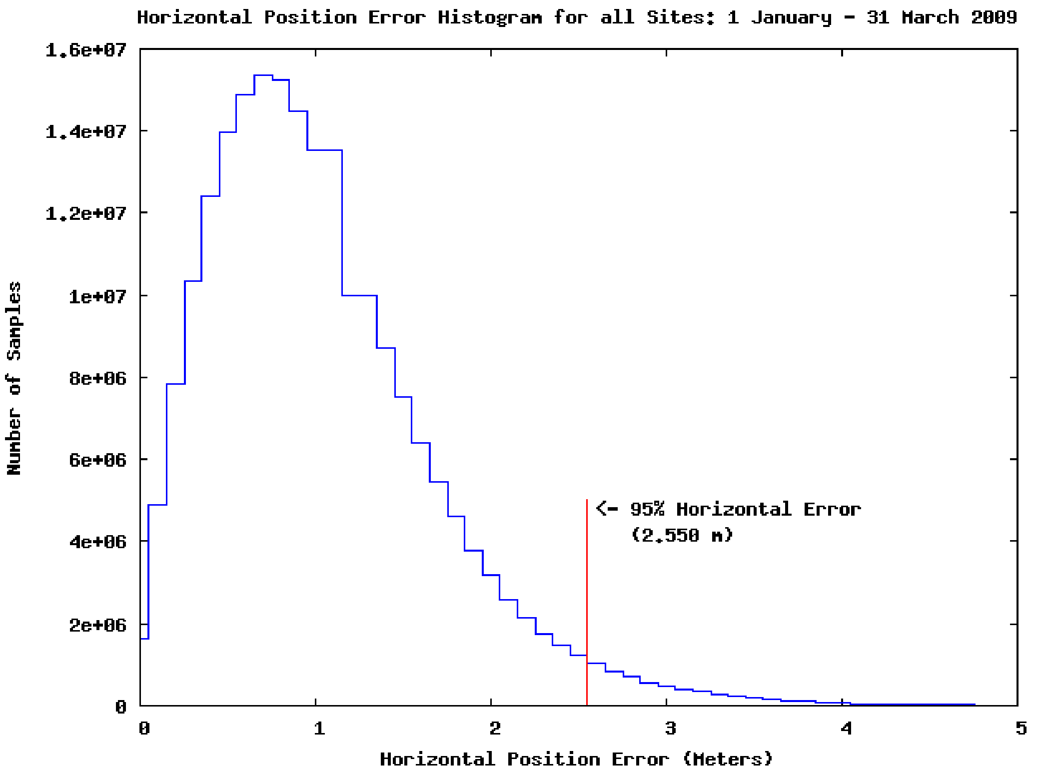


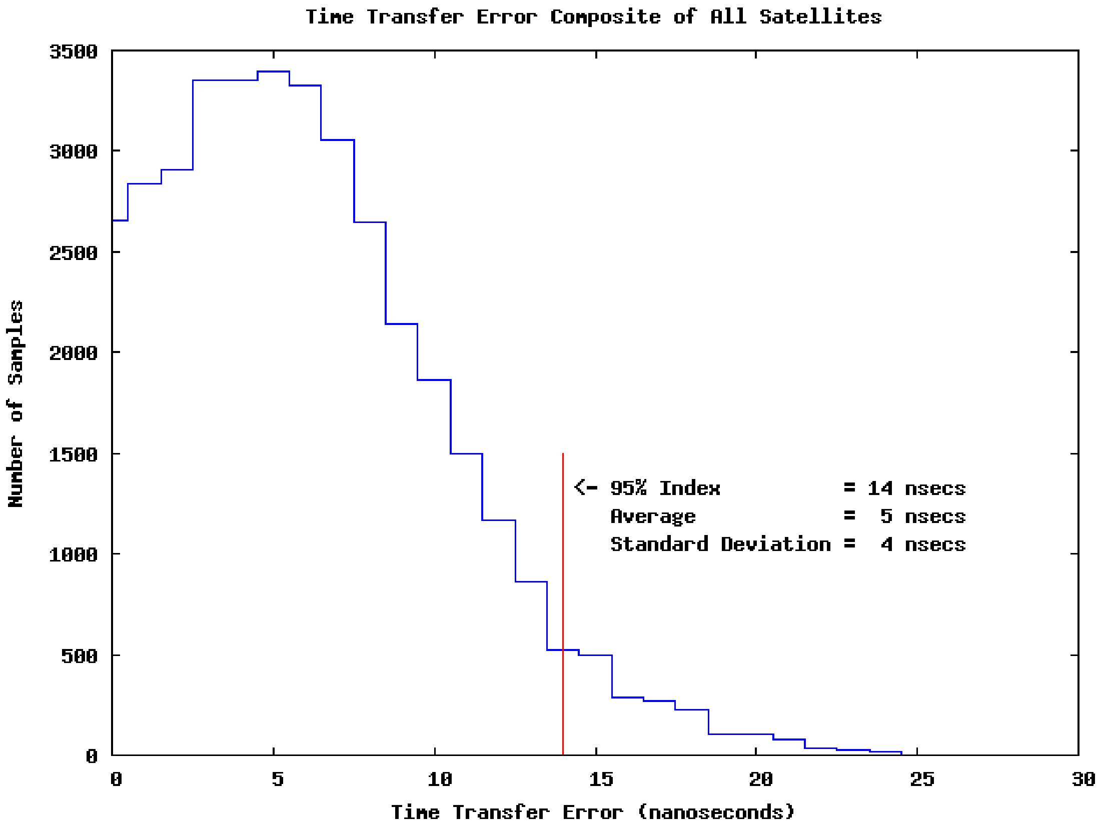
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 2009 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



5.3 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 January and 31 March 2009. The WAAS receiver at Houston was used to collect range measurement.

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 5-2 Range Error Statistics (meters)

PRN	RMS Range Error (≤ 6 m)	Range Error Mean	1σ	95% Range Error	Max Range Error (SPS Spec. ≤ 30 m)	Samples
2	1.71582	1.13728	1.17251	3.05713	7.210	13442879
3	1.82058	1.00454	1.27878	3.21842	16.815	11865242
4	1.52846	0.63791	1.15306	2.82650	7.572	13268573
5	2.26710	1.62748	1.37287	3.86400	9.944	12397356
6	1.63018	0.87350	1.21336	2.84960	19.668	12210571
7	1.41582	0.88057	0.98571	2.59904	17.557	11555295
8	2.10231	1.36803	1.29197	3.63315	9.289	12376161
9	1.97998	1.09183	1.40179	3.49904	7.707	12387774
10	2.42058	1.79501	1.40689	4.13857	10.398	12953353
11	1.88151	1.32995	1.17967	3.19857	10.685	11865476
12	1.51095	0.83271	1.16355	2.72944	8.630	13757971
13	1.39082	0.73271	1.05953	2.54736	18.028	13264733
14	1.82162	1.30981	1.07250	3.10297	8.400	13620584
15	1.40515	0.69145	1.09773	2.60652	6.753	12072592
16	1.77358	1.37567	1.04888	3.00862	18.092	12476615
17	1.45181	0.64428	1.12792	2.74491	10.070	13609225
18	1.89463	1.39592	1.14311	3.19288	7.068	12325940
19	2.08052	1.73018	1.06934	3.44241	13.618	11986738
20	1.94708	1.50258	1.14471	3.38531	8.339	13642610
21	1.86116	1.27315	1.24307	3.12821	16.238	11550346
22	2.03954	1.45459	1.16866	3.36947	7.910	11999747
23	1.73076	1.18112	1.16373	3.02502	19.179	12379204
24	2.31859	1.67738	1.20535	3.72176	11.534	11760971
25	1.62147	0.98234	1.11669	2.92706	17.916	11790139
26	1.69659	1.02673	1.19797	3.04926	7.920	11587134
27	2.02884	1.26031	1.33691	3.59529	12.940	13791453
28	2.17922	1.60625	1.19713	3.68775	10.439	12024106
29	1.49244	0.66386	1.09740	2.72380	8.420	13119995
30	1.78148	0.49741	1.37968	3.29142	10.683	12629206
31	1.50190	0.74379	1.11686	2.79695	10.238	13459961
32	1.90710	1.44303	1.13217	3.25827	9.486	13833930

Table 5-3 Range Rate Error Statistics (meters/second)

PRN	Range Rate Error RMS	Range Rate Error Mean	Range Rate Error 1σ	95% Range Rate Error	Max Range Rate Error	Samples
2	1.320E-03	-1.883E-06	1.316E-03	2.559E-03	0.05647	13442879
3	1.875E-03	-2.892E-05	1.870E-03	2.846E-03	0.17762	11865242
4	1.494E-03	-6.555E-06	1.489E-03	2.457E-03	0.11794	13268573
5	1.917E-03	-1.611E-05	1.913E-03	2.460E-03	0.16793	12397356
6	1.345E-03	-3.387E-05	1.340E-03	2.362E-03	0.14987	12210571
7	1.318E-03	1.073E-05	1.315E-03	2.516E-03	0.07086	11555295
8	1.660E-03	-2.734E-05	1.657E-03	2.914E-03	0.15905	12376161
9	1.809E-03	-4.563E-06	1.806E-03	2.781E-03	0.17227	12387774
10	2.054E-03	-1.536E-06	2.052E-03	2.926E-03	0.17407	12953353
11	1.391E-03	-2.891E-06	1.387E-03	2.558E-03	0.12803	11865476
12	1.378E-03	-1.237E-06	1.375E-03	2.698E-03	0.04650	13757971
13	1.353E-03	1.064E-05	1.350E-03	2.588E-03	0.07506	13264733
14	1.334E-03	-3.349E-05	1.329E-03	2.533E-03	0.07826	13620584
15	1.334E-03	-4.216E-05	1.331E-03	2.573E-03	0.04981	12072592
16	1.333E-03	-1.455E-05	1.331E-03	2.587E-03	0.05188	12476615
17	1.458E-03	1.394E-05	1.456E-03	2.606E-03	0.18894	13609225
18	1.317E-03	-1.122E-05	1.313E-03	2.560E-03	0.04913	12325940
19	1.316E-03	-8.430E-06	1.312E-03	2.506E-03	0.05185	11986738
20	1.318E-03	1.213E-05	1.315E-03	2.561E-03	0.04898	13642610
21	1.377E-03	-1.502E-05	1.372E-03	2.655E-03	0.06952	11550346
22	1.571E-03	7.249E-06	1.567E-03	2.814E-03	0.14438	11999747
23	1.304E-03	5.268E-06	1.300E-03	2.516E-03	0.03974	12379204
24	1.561E-03	1.808E-06	1.558E-03	2.620E-03	0.14005	11760971
25	1.568E-03	-1.535E-06	1.565E-03	2.272E-03	0.14738	11790139
26	1.394E-03	-3.412E-05	1.390E-03	2.446E-03	0.10490	11587134
27	1.803E-03	-2.368E-05	1.801E-03	2.718E-03	0.16923	13791453
28	1.558E-03	-1.026E-05	1.554E-03	2.590E-03	0.13140	12024106
29	1.364E-03	-1.158E-05	1.360E-03	2.529E-03	0.13470	13119995
30	2.112E-03	-1.589E-05	2.108E-03	2.897E-03	0.22568	12629206
31	1.396E-03	-2.070E-05	1.392E-03	2.544E-03	0.10403	13459961
32	1.238E-03	1.595E-05	1.234E-03	2.361E-03	0.12931	13833930

Table 5-4 Range Acceleration Error Statistics (meters/second^2)

PRN	Range Acceleration Error RMS	Range Acceleration Error Mean	Range Acceleration 1σ	Max Range Acceleration Error	Samples
2	1.005E-05	0	1.005E-05	2.003E-05	13442879
3	1.471E-05	0	1.471E-05	2.245E-05	11865242
4	1.172E-05	0	1.172E-05	1.977E-05	13268573
5	1.634E-05	0	1.634E-05	1.878E-05	12397356
6	1.100E-05	0	1.100E-05	1.952E-05	12210571
7	1.019E-05	0	1.019E-05	2.002E-05	11555295
8	1.228E-05	0	1.228E-05	2.195E-05	12376161
9	1.403E-05	0	1.403E-05	2.089E-05	12387774
10	1.627E-05	0	1.627E-05	2.269E-05	12953353
11	1.068E-05	0	1.068E-05	2.008E-05	11865476
12	1.006E-05	0	1.006E-05	2.022E-05	13757971
13	1.018E-05	0	1.018E-05	2.007E-05	13264733
14	1.018E-05	0	1.018E-05	2.009E-05	13620584
15	1.002E-05	0	1.002E-05	2.008E-05	12072592
16	1.006E-05	0	1.006E-05	2.025E-05	12476615
17	1.107E-05	0	1.107E-05	2.009E-05	13609225
18	1.004E-05	0	1.004E-05	2.023E-05	12325940
19	1.004E-05	0	1.004E-05	2.004E-05	11986738
20	1.002E-05	0	1.002E-05	2.009E-05	13642610
21	1.016E-05	0	1.016E-05	2.050E-05	11550346
22	1.146E-05	0	1.146E-05	2.153E-05	11999747
23	1.004E-05	0	1.004E-05	2.005E-05	12379204
24	1.225E-05	0	1.225E-05	2.008E-05	11760971
25	1.319E-05	0	1.319E-05	1.683E-05	11790139
26	1.107E-05	0	1.107E-05	1.942E-05	11587134
27	1.397E-05	0	1.397E-05	2.026E-05	13791453
28	1.228E-05	0	1.228E-05	2.011E-05	12024106
29	1.058E-05	0	1.058E-05	2.006E-05	13119995
30	1.704E-05	0	1.704E-05	2.153E-05	12629206
31	1.069E-05	0	1.069E-05	2.004E-05	13459961
32	1.019E-05	0	1.019E-05	1.825E-05	13833930

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. The highest maximum range error occurred on satellite 13 with an error of 13.610 meters. Satellite 6 had the lowest maximum range error of 6.189 meters.

Figure 5-4 Distribution of Daily Max Range Errors

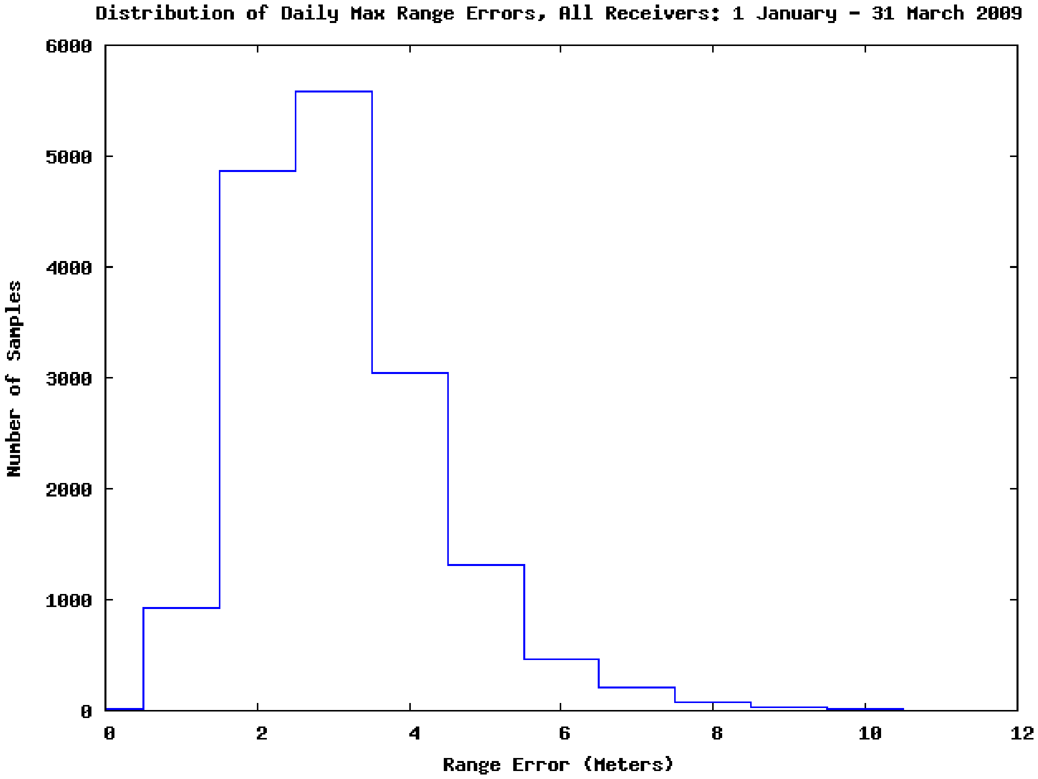


Figure 5-5: Distribution of Daily Max Range Rate Errors

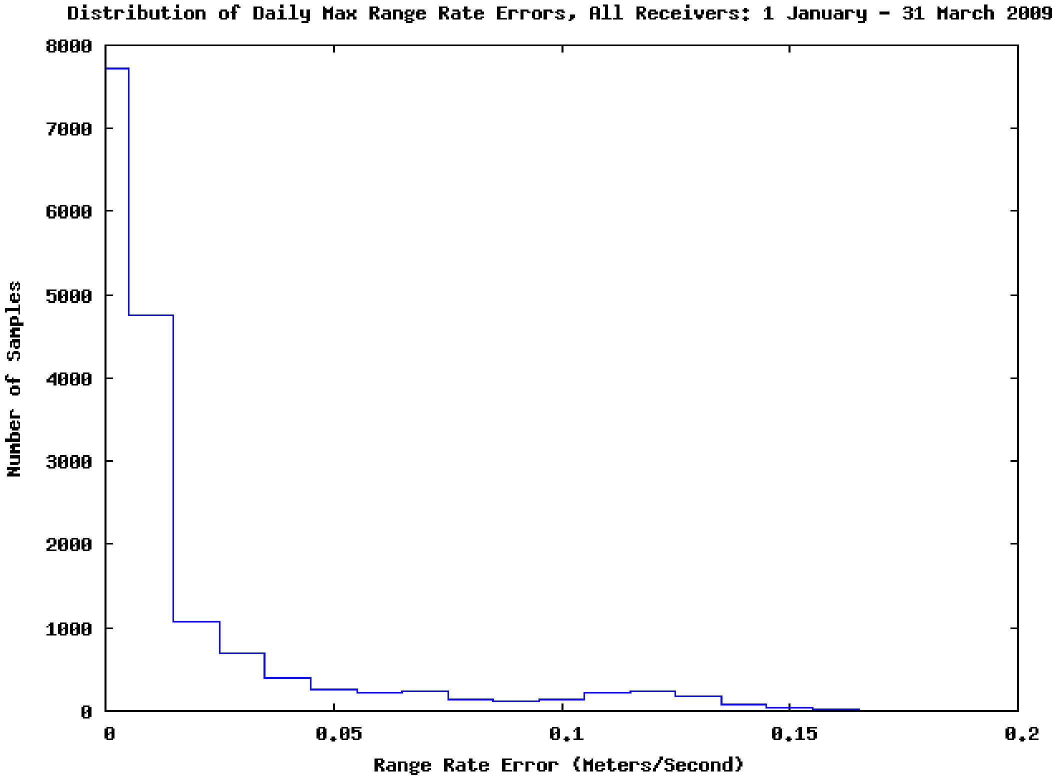


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

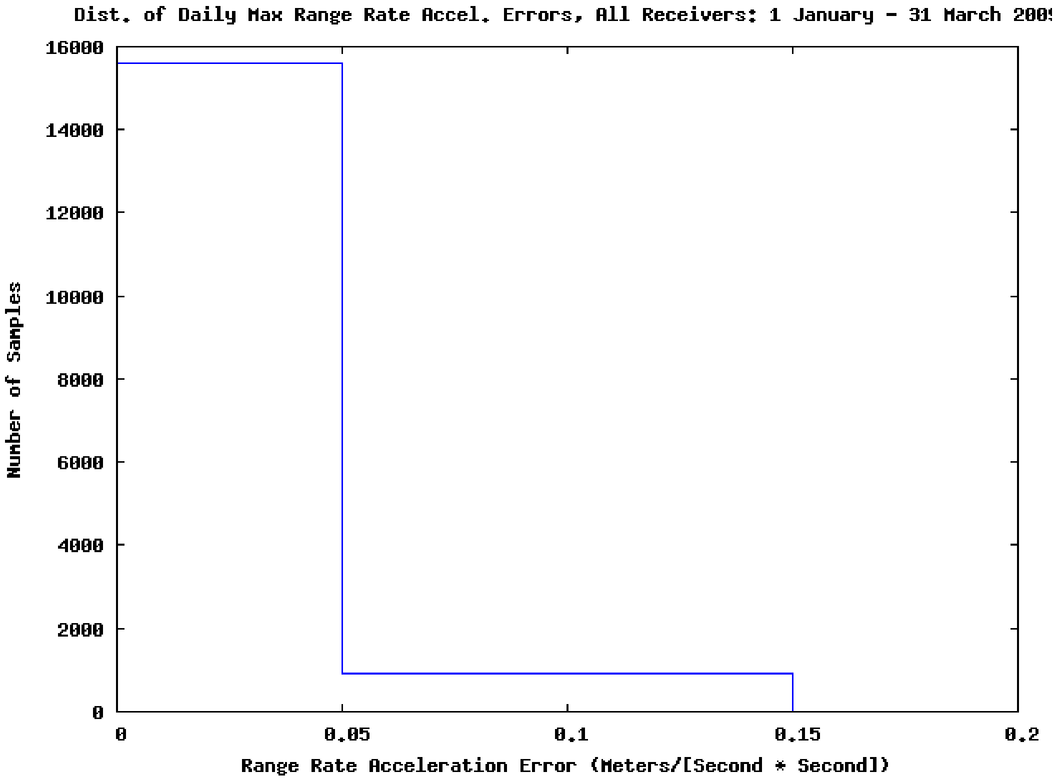
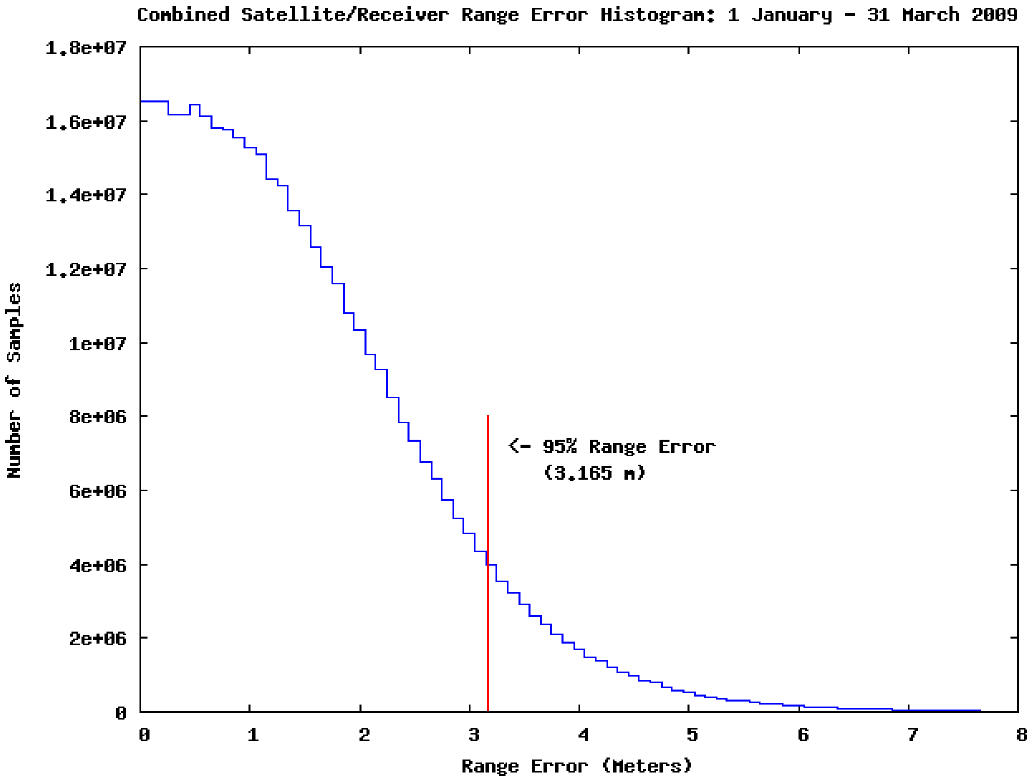


Figure 5-7: Range Error Histogram



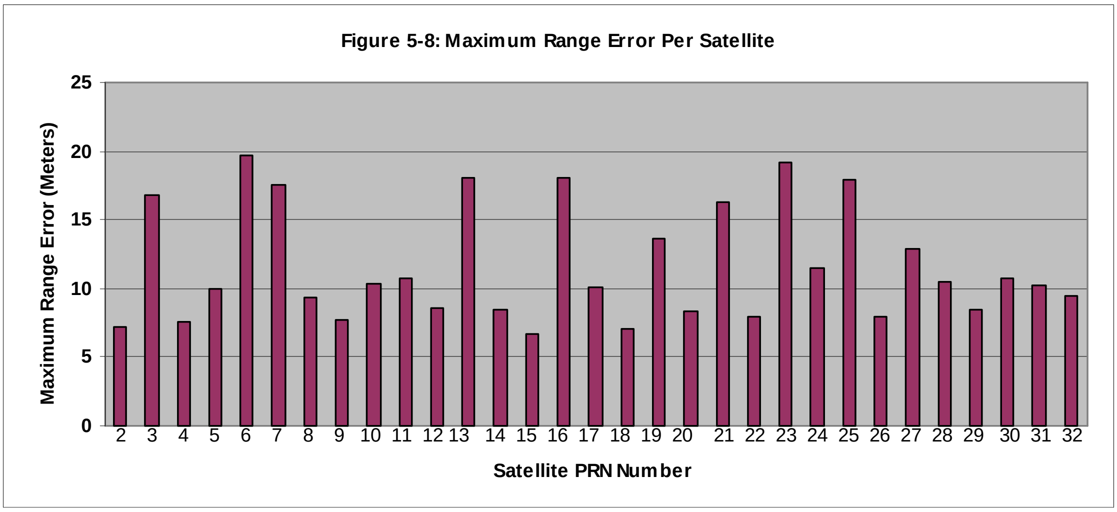


Figure 5-8: Maximum Range Error Per Satellite
Maximum Range Error (Meters)
0
5
10
15
20
25
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

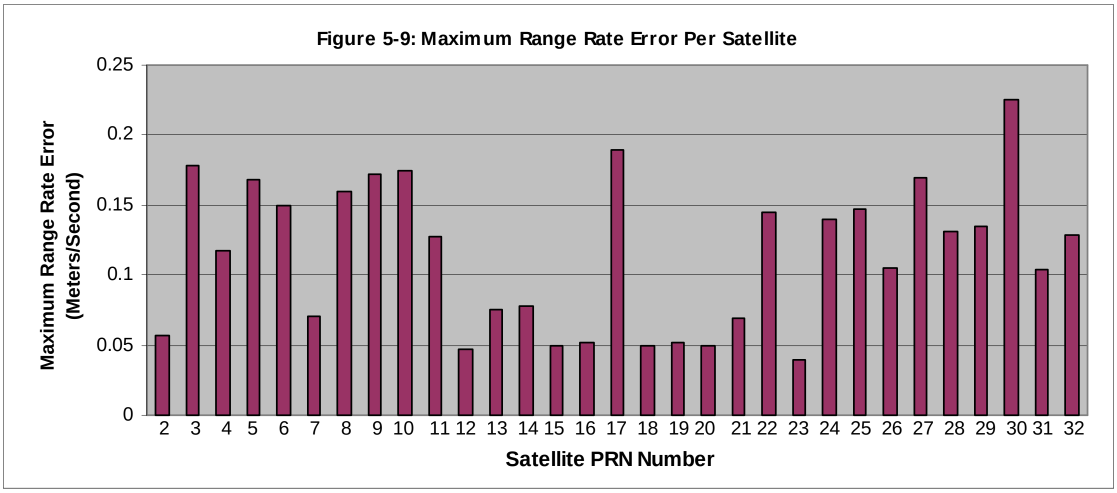


Figure 5-9: Maximum Range Rate Error Per Satellite
Maximum Range Rate Error (Meters/Second)
0
0.05
0.1
0.15
0.2
0.25
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

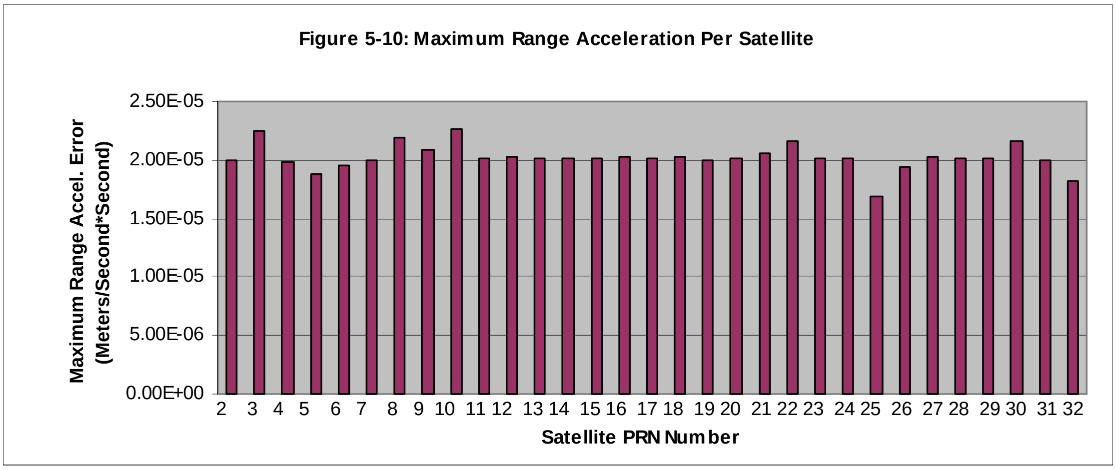


Figure 5-10: Maximum Range Acceleration Per Satellite
Maximum Range Accel. Error (Meters/Second*Second)
0.00E+00
5.00E-06
1.00E-05
1.50E-05
2.00E-05
2.50E-05
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

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 12-14 March 2009

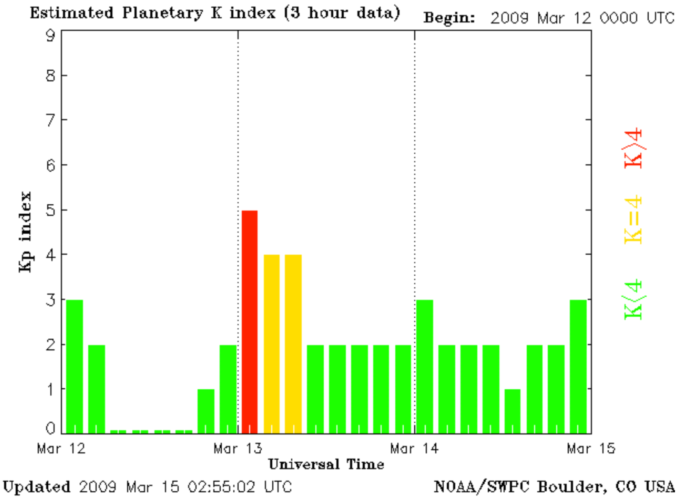


Figure 6-2 K-Index for 3-5 February 2009

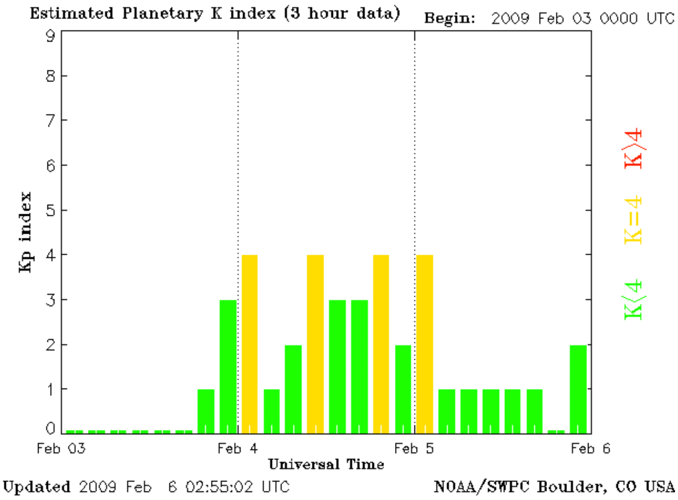


Figure 6-3 K-Index for 24-26 March 2009

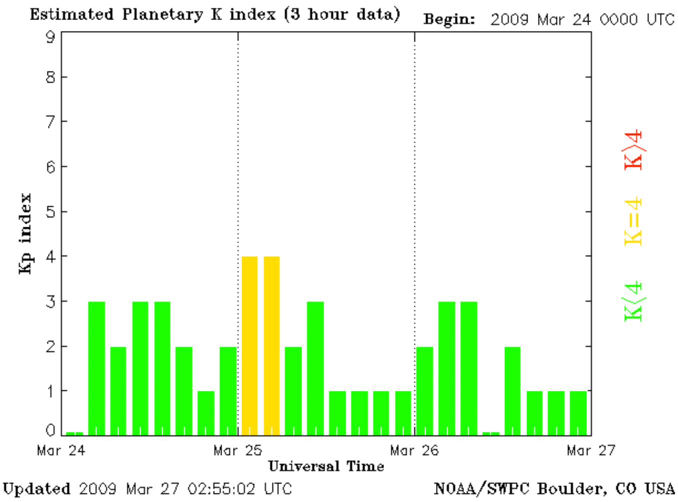


Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for 13 March 2009

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Albuquerque	1.330	3.040	1.730	3.710
Anchorage	1.230	3.540	1.620	4.720
Atlanta	1.560	3.730	2.330	4.420
Barrow	1.200	3.910	2.200	5.410
Bethel	1.310	3.740	2.000	4.920
Billings	1.330	3.050	1.800	3.860
Boston	1.860	3.710	3.160	4.530
Cleveland	1.870	3.670	3.110	4.680
Cold Bay	1.790	3.970	2.740	4.770
Fairbanks	1.330	4.150	1.880	6.670
Gander	2.000	3.820	3.870	5.400
Honolulu	3.620	3.440	4.630	4.180
Houston	1.280	3.900	1.500	4.490
Iqaluit	1.530	3.670	5.220	14.200
Juneau	1.420	3.550	1.810	4.080
Kansas City	1.480	3.710	2.130	4.380
Kotzebue	1.270	4.040	2.000	5.300
Los Angeles	1.220	4.030	1.680	5.700
Merida	1.780	4.530	2.420	6.040
Miami	1.450	4.240	1.880	4.970
Minneapolis	1.690	3.590	2.230	4.380
Oakland	1.220	4.160	2.600	5.760
Salt Lake City	1.240	3.280	1.620	3.880
San Jose Del Cabo	1.560	3.580	2.320	4.670
San Juan	1.500	4.270	1.930	5.180
Seattle	1.310	3.590	1.630	4.480
Tapachula	2.440	2.920	3.190	3.660
Washington, DC	1.840	3.650	2.760	4.930

7.0 IGS Analysis

GPS SPS accuracy performance was evaluated at a selection of high rate IGS stations[(1)]. The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products.

High data rate (1 Hz) sites that had high availability in 2006, were outside of the WAAS service area, and provided a good geographic distribution were selected. To facilitate differentiating between GPS accuracy issues and receiver tracking problems, an automatic data screening function excluded errors greater than 500 meters and or times when VDOP or HDOP were greater than 10. The remaining receiver tracking issues are still included in the statistics and are forced into the 50.1-meter histogram bin and are believed to influence the outliers in the 99.99% statistics.

Table 7.1 and Figure 7.1 show the IGS site information and locations. Table 7.2 shows the GPS SPS Accuracy Performance observed at a selection of High Rate IGS sites. Figure 7.2 shows the 95% horizontal accuracy trends at these sites. Figure 7.3 shows the 95% vertical accuracy trends at these sites.

During the evaluation period, the maximum 95% horizontal and vertical SPS errors are 3.51 meters at Maspalomas and 6.58 meters at Usuda. The minimum 95% horizontal and vertical SPS errors are 1.73 meters at Norilsk and 3.84 meters at Maspalomas. The maximum 99.99% horizontal and vertical SPS errors are 19.54 meters at Santiago and 40.14 meters at Kourou. The 95% minimum and maximum values for this quarter are for the same sites and are almost the same values as last quarter. Maspalomas and Kourou had the most logged outliers between 15 meters and 50 meters where the DOP as not large. These outliers look like receiver tracking problems.

(1) J.M. Dow, R.E. Neilan, G. Gendt, "The International GPS Service (IGS): Celebrating the 10th Anniversary and Looking to the Next Decade," Adv. Space Res. 36 vol. 36, no. 3, pp. 320-326, 2005. Doi: 10.1016/j.asr.2005.05.125

Table 7-1 Selected IGS Site Information

ID	City	Country
GLPS	Puerto Ayora	Ecuador
GUAM	Dededo	Guam
IISC	Bangalore	India
KIRU	Kiruna	Sweden
KOUR	Kourou	French Guyana
MADR	Robledo	Spain
MALI	Malindi	Kenya
MAS1	Maspalomas	Spain
MOBN	Obninsk	Russian Federation
NNOR	New Norcia	Australia
NRIL	Norilsk	Russian Federation
PETS	Petropavlovsk-Kamchatka	Russian Federation
POL2	Bishkek	Kyrghyzstan
SANT	Santiago	Chile
SUTM	Sutherland	South Africa
TIDB	Tidbinbilla	Australia
USUD	Usuda	Japan

Figure 7-1 Selected IGS Site Locations

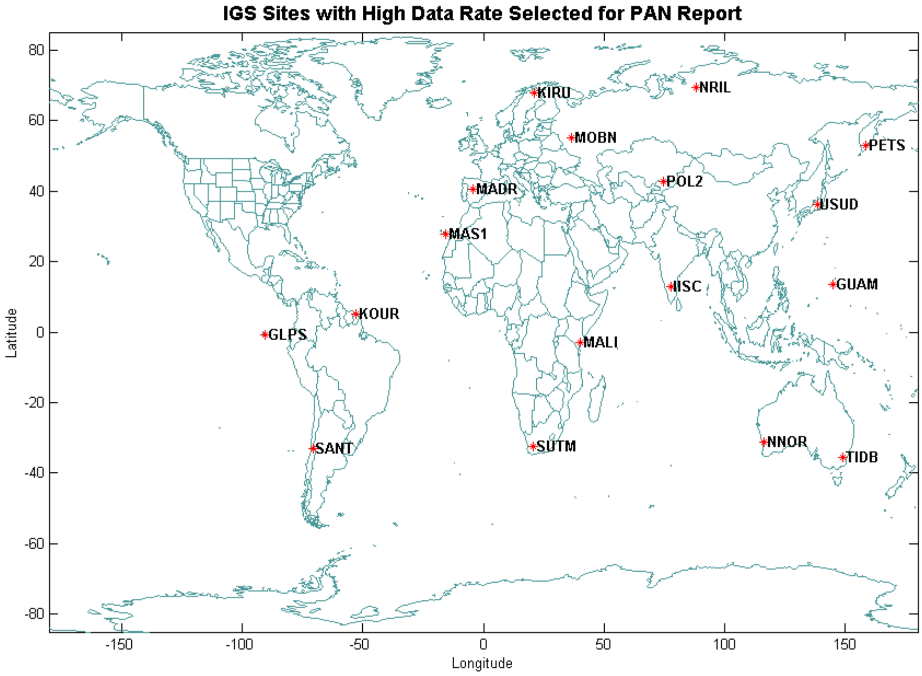


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

Site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
GLPS	2.3	4.43	16.1	13.71	97.92%
GUAM	2.01	5.3	5.27	21.31	98.29%
IISC	1.94	4.54	5.3	10.54	88.34%
KIRU	1.83	4.85	9.85	24.28	99.87%
KOUR	2.32	4.07	8.3	40.14	94.13%
MADR	2.13	4.6	9.7	28.11	98.76%
MAS1	3.51	3.84	15.22	26.05	99.70%
MATE	2.05	4.84	7.43	10.82	91.44%
MOBN	2.47	5.05	7.46	12.31	99.35%
NNOR	2.29	5.12	5.38	11.97	99.71%
NRIL	1.73	4.79	8.29	11.19	51.87%
PETS	2.46	5.44	5.81	15.08	98.92%
POL2	2.17	4.64	11.48	20.95	99.76%
SANT	3.36	4.86	19.54	17.22	99.94%
SUTM	2.01	4.37	6.61	12.31	79.39%
TIDB	2.58	4.78	12.76	15.87	97.73%
USUD	2.48	5.7	6.58	19.22	91.19%

Figure 7-2 GPS SPS 95% Horizontal Accuracy Trends at Selected IGS Sites

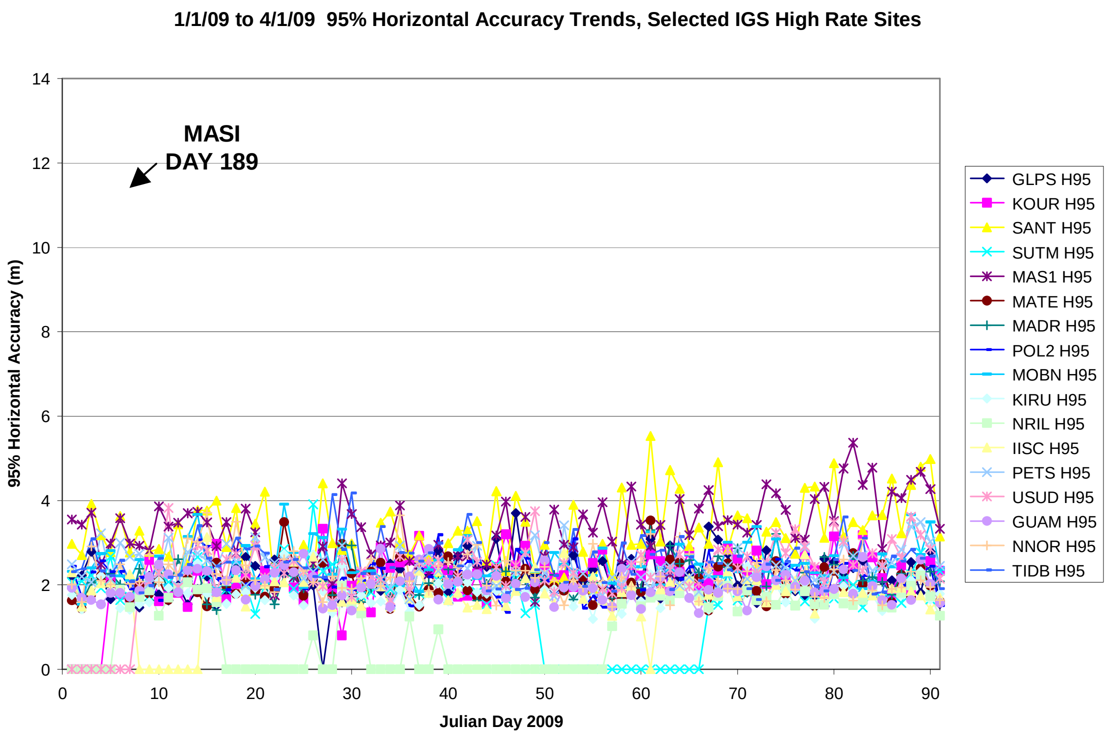
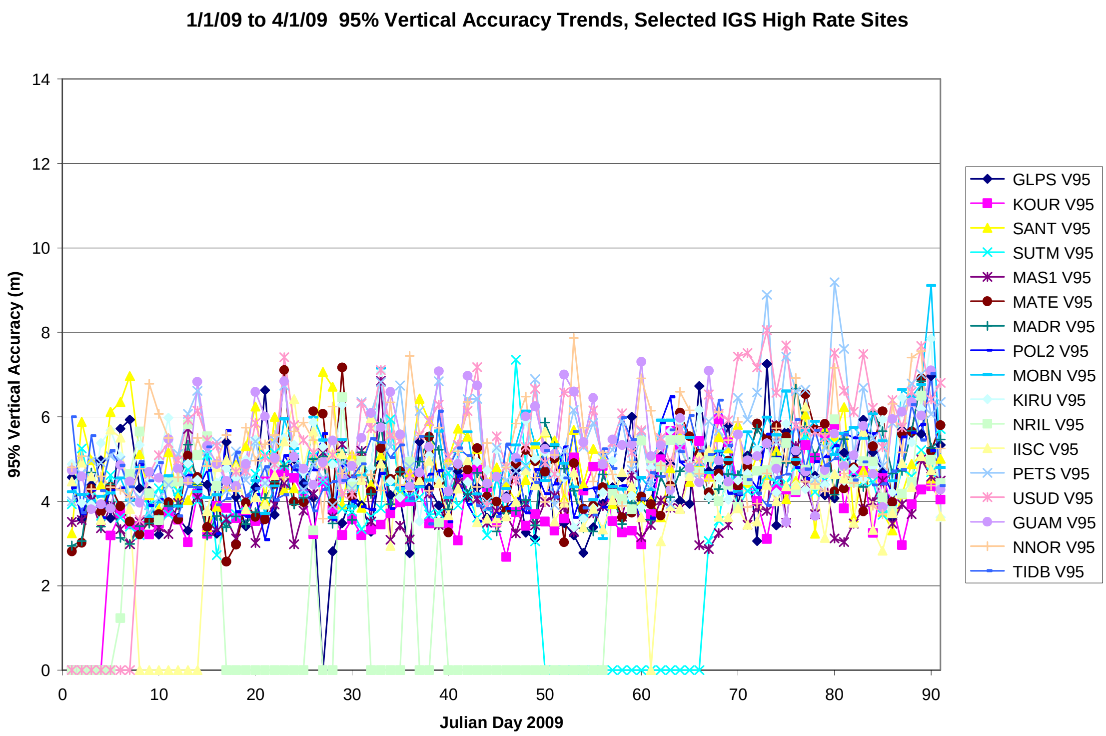


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites



APPENDICES A – D

Conditions and Constraints	*PDOP Availability Standard*	*Measured Performance*
• Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. • Based on using only satellites transmitting standard code and indicating "health" in the broadcast navigation message (sub-frame 1).	≥ 98% global Position Dilution of Precision (PDOP) of 6 or less ≥ 88% worst site PDOP of 6 or less	≥ 99.994 % ≥ 98.889%
Conditions and Constraints	***Service Availability Standard***	***Measured Performance***
• 36 meter horizontal (SIS only) 95% threshold. • 77 meter vertical (SIS only) 95% threshold. • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	100%
• Based on using only satellites transmitting standard code and indicating "healthy" in the broadcast navigation message (sub-frame 1).	≥ 95.87% global average on worst-case day	100%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	≥ 99.94% global average	100%
• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values from the worst-case point within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	≥ 99.79% single point average	100%

Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	Global Average Positioning Domain Accuracy • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only)	3.620 m 4.530 m
• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours for any point within the service volume.	Worst Site Positioning Domain Accuracy • ≤ 36 meters 95% All-in-View Horiz Error (SIS only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS only)	14.140 m 22.156 m
• Defined for time transfer solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	Time Transfer Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	14 nanoseconds 95%
• Average of the constellation's individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point in the service volume.	≤ 6 meters RMS SIS SPS URE across the entire constellation	2.420 meters

Appendix B Geomagnetic Data

```
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
#  Please send comment and suggestions to SWPC.Webmaster@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
2009 01 01	5	1 2 2 2 1 1 1 1	12	1 1 4 4 4 2 0 0	6	1 2 3 3 2 1 0 1
2009 01 02	3	0 1 0 0 1 2 2 2	2	0 0 0 0 1 1 1 2	3	0 1 0 0 1 1 2 2
2009 01 03	8	3 3 2 3 2 1 0 1	15	1 1 2 6 2 3 1 1	9	3 3 2 4 2 2 0 1
2009 01 04	5	2 1 0 2 1 1 1 3	3	1 0 0 2 1 2 1 0	4	2 1 0 1 1 2 1 0
2009 01 05	3	1 1 1 1 1 1 1 0	4	0 0 1 3 1 2 0 0	4	1 1 1 1 1 1 1 2
2009 01 06	2	2 1 0 0 0 1 0 0	5	0 0 0 3 2 3 0 0	3	2 1 0 1 1 1 0 0
2009 01 07	1	0 0 1 0 0 1 1 0	1	0 0 2 1 0 0 0 0	3	0 0 1 0 0 1 1 1
2009 01 08	2	0 0 0 0 2 1 1 1	4	0 0 1 2 3 2 0 0	3	0 0 0 0 2 1 1 1
2009 01 09	4	1 1 1 0 2 2 1 1	5	0 0 2 1 4 1 1 0	4	1 1 1 0 2 1 1 1
2009 01 10	2	2 1 0 1 0 0 0 0	3	1 1 1 3 0 0 1 0	4	2 1 1 1 0 0 1 1
2009 01 11	1	1 0 0 0 0 1 0 0	1	0 0 0 2 0 0 0 0	2	1 0 0 0 0 1 1 1
2009 01 12	0	0 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 0
2009 01 13	2	0 1 1 0 1 1 1 1	1	0 0 0 0 1 1 0 0	3	1 1 1 0 1 1 0 1
2009 01 14	6	2 2 2 2 2 1 1 1	8	1 0 0 4 4 1 0 0	5	2 2 1 2 2 1 0 2
2009 01 15	4	1 1 1 1 1 2 2 1	5	0 1 1 3 2 0 2 1	4	1 1 2 1 0 1 2 2
2009 01 16	2	1 1 0 0 1 1 1 0	1	1 1 0 0 1 0 1 0	2	2 1 0 0 0 0 1 0
2009 01 17	2	0 1 1 0 0 1 1 0	1	0 0 0 1 1 0 1 0	2	0 1 1 0 0 1 1 1
2009 01 18	2	1 0 0 0 0 1 1 1	1	0 0 0 1 1 0 0 0	2	0 0 0 0 0 0 1 1
2009 01 19	7	4 2 2 0 1 1 1 2	4	2 1 2 2 0 1 0 1	9	4 2 2 0 1 1 2 2
2009 01 20	1	1 0 1 0 0 0 1 0	1	2 1 0 0 0 0 0 0	3	2 0 0 0 0 0 1 1
2009 01 21	2	0 0 0 1 0 2 1 0	2	0 0 0 2 1 1 0 0	2	0 0 0 1 0 1 1 1
2009 01 22	0	0 0 0 0 0 0 1 0	0	0 0 0 1 0 0 0 0	1	0 0 0 0 0 0 0 1
2009 01 23	1	0 0 1 0 1 0 0 0	0	0 0 0 0 0 0 0 0	1	0 0 0 0 0 0 0 1
2009 01 24	1	1 1 0 0 0 0 0 1	0	0 0 0 0 0 0 0 0	1	1 0 0 0 0 0 0 1
2009 01 25	1	0 0 0 0 0 0 0 2	1	0 0 0 0 2 0 0 0	1	0 0 0 0 0 0 0 2
2009 01 26	9	3 2 2 2 3 2 2 1	22	1 0 2 4 6 5 2 0	10	3 2 2 2 3 3 2 0
2009 01 27	2	0 1 0 0 1 2 1 1	2	0 1 0 0 1 1 1 1	4	0 1 0 0 1 1 2 2
2009 01 28	1	0 0 0 2 0 0 1 0	0	0 0 0 1 0 0 0 0	2	0 0 0 1 1 1 0 1
2009 01 29	3	0 2 2 1 1 0 0 0	3	0 0 2 3 0 0 0 0	4	0 2 2 1 1 1 0 1
2009 01 30	3	0 1 1 2 0 0 1 2	1	0 0 0 1 0 0 0 1	4	0 1 0 1 1 1 1 2
2009 01 31	4	1 1 2 1 2 1 1 1	9	1 0 3 3 4 2 1 1	7	1 1 2 2 2 2 1 2
2009 02 01	1	0 2 1 0 0 0 0 0	1	0 1 0 1 0 0 0 0	3	1 2 0 1 1 1 0 1
2009 02 02	0	0 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 0	2	0 0 0 0 1 1 1 1
2009 02 03	2	0 0 0 0 0 0 2 2	1	0 0 0 0 0 0 1 2	4	0 0 0 0 0 0 1 3
2009 02 04	10	2 1 2 4 3 2 2 1	36	2 0 2 6 6 6 4 2	16	4 1 2 4 3 3 4 2
2009 02 05	6	4 2 1 1 2 0 0 1	4	2 1 1 3 1 0 0 0	7	4 1 1 1 1 1 0 2
2009 02 06	1	2 0 0 0 0 0 0 0	0	1 0 0 0 0 0 0 0	2	1 0 0 0 0 0 1 1
2009 02 07	1	0 2 0 0 0 0 0 0	1	0 0 1 0 1 1 0 0	3	1 2 0 0 1 1 1 1
2009 02 08	0	0 0 0 0 0 0 0 0	0	0 0 0 1 0 0 0 0	4	0 0 0 0 1 2 2 1
2009 02 09	0	0 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 1	4	1 0 0 0 1 2 2 2
2009 02 10	0	0 0 0 0 0 1 0 0	0	0 0 0 1 0 0 0 0	3	1 0 0 0 0 2 1 1
2009 02 11	2	1 0 1 0 1 0 1 1	1	0 0 1 1 0 0 1 0	5	2 0 1 1 1 2 2 2
2009 02 12	1	0 0 0 0 1 1 0 0	4	1 1 0 2 3 1 0 0	4	1 0 0 1 2 2 1 1
2009 02 13	2	0 0 0 0 1 1 1 1	0	0 0 0 0 0 1 0 0	3	0 0 0 0 1 2 1 1
2009 02 14	9	1 2 3 3 3 2 1 2	25	0 0 4 5 6 4 1 3	14	1 2 3 3 4 3 2 3
2009 02 15	6	2 3 1 1 2 1 1 1	22	1 2 3 5 6 3 1 1	10	2 4 1 2 3 2 2 2
2009 02 16	2	2 0 0 0 1 1 1 0	2	1 0 0 1 1 1 1 1	3	1 0 0 1 1 1 0 1
2009 02 17	1	0 0 0 0 0 0 1 1	0	0 0 0 0 0 0 0 1	1	1 0 0 0 1 0 0 1
2009 02 18	1	1 0 0 0 0 0 0 1	1	1 0 0 0 0 0 1 0	2	2 0 0 0 0 0 1 1
2009 02 19	0	0 0 0 0 0 1 0 0	0	0 0 0 0 0 1 0 0	1	0 0 0 0 0 1 0 1
2009 02 20	3	1 1 0 0 1 1 2 1	3	0 1 0 1 1 0 1 2	3	1 1 0 0 1 0 1 2
2009 02 21	2	0 0 0 1 1 1 1 1	3	1 0 0 3 2 0 0 0	3	0 0 0 1 1 0 1 1
2009 02 22	3	0 0 2 2 1 0 1 1	4	0 0 2 3 2 0 0 0	3	0 0 2 2 1 0 0 1
2009 02 23	3	1 0 0 0 2 2 1 2	5	0 0 0 2 3 3 1 0	5	1 0 0 0 2 3 2 2
2009 02 24	6	1 3 3 1 1 1 0 1	5	1 1 3 2 2 1 0 0	6	2 3 2 1 1 1 0 1
2009 02 25	2	1 1 1 1 1 0 1 0	2	1 0 0 3 0 0 0 0	3	1 1 0 1 1 1 0 0
2009 02 26	2	1 1 0 0 1 0 0 1	0	0 0 0 0 0 0 0 1	2	1 1 0 0 0 0 1 2
2009 02 27	7	1 1 2 3 3 1 2 1	20	1 0 3 5 6 2 2 1	8	1 1 2 3 3 2 2 2

2009 02 28	4	3 2 2 0 0 0 0 1 1	3	1 2 2 1 0 0 0 1 0	5	3 2 2 0 0 0 0 1 2
2009 03 01	2	2 1 1 0 1 0 0 0 0	1	0 1 1 0 0 0 0 0 0	3	1 1 0 0 0 0 0 1 1
2009 03 02	0	0 0 0 0 0 1 0 0 0	0	0 0 0 0 0 0 0 0 0	2	0 0 0 0 0 0 0 1 1
2009 03 03	5	1 0 2 1 2 2 2 2 2	4	1 0 1 1 0 3 1 1 1	5	1 0 1 1 1 1 2 2 2
2009 03 04	5	2 2 2 1 1 0 2 2 2	6	1 1 3 3 1 1 0 1 1	7	2 3 2 1 1 1 1 2 3
2009 03 05	3	1 3 0 0 0 0 0 0 1	1	1 1 0 1 0 0 0 0 0	3	2 2 0 0 0 0 0 0 1
2009 03 06	0	1 0 0 0 0 0 0 0 1	1	0 0 0 1 0 0 0 0 1	2	1 0 0 0 0 0 1 0 1
2009 03 07	0	0 0 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 0 0	1	0 0 0 0 0 0 1 0 1
2009 03 08	7	1 0 3 3 3 2 1 0	23	1 0 4 6 5 3 2 0	8	2 1 3 3 3 2 1 1
2009 03 09	1	0 0 0 1 1 0 0 0	1	0 0 0 1 1 0 0 0	2	0 0 0 0 0 0 0 1
2009 03 10	3	1 0 0 0 2 2 1 0	1	0 0 0 0 0 2 1 0	3	1 0 0 0 1 2 1 1
2009 03 11	2	0 0 0 0 1 0 1 2	1	0 0 1 0 0 0 0 1	3	0 0 0 0 0 1 1 2
2009 03 12	6	2 2 1 1 1 1 2 3	3	2 2 0 0 0 0 1 1	6	3 2 0 0 0 0 1 2
2009 03 13	10	4 3 2 2 2 1 2 2	24	3 3 4 5 5 4 1 2	16	5 4 4 2 2 2 2 2
2009 03 14	7	3 1 2 1 1 2 1 3	12	1 2 4 4 1 3 2 2	9	3 2 2 2 1 2 2 3
2009 03 15	5	2 2 2 1 2 1 0 1	7	1 3 3 3 2 0 0 1	7	3 3 2 2 1 2 0 2
2009 03 16	4	2 0 1 1 1 2 2 0	4	1 0 2 3 1 1 1 0	5	2 1 1 1 1 2 2 0
2009 03 17	3	1 1 1 0 1 1 1 1	1	0 0 1 0 1 1 0 0	3	1 0 1 0 1 1 1 1
2009 03 18	0	0 0 0 0 0 0 1 0	0	0 0 0 0 0 0 0 0	1	0 0 0 0 0 0 0 1
2009 03 19	3	2 1 1 0 2 0 1 1	3	0 0 1 1 3 0 0 0	3	1 0 1 0 1 0 0 1
2009 03 20	2	1 0 0 0 1 1 1 1	2	0 0 0 1 0 2 1 1	4	2 0 0 0 0 2 1 2
2009 03 21	5	0 1 2 2 2 1 2 2	23	0 1 1 6 6 2 2 2	8	0 1 1 3 3 1 2 3
2009 03 22	4	2 2 1 1 1 0 1 1	1	0 1 0 0 0 1 0 1	4	2 3 0 0 0 0 0 2
2009 03 23	2	1 0 1 0 0 1 2 1	1	1 0 0 0 0 0 1 0	3	1 0 1 0 0 1 1 1
2009 03 24	6	0 2 3 2 2 1 1 1	18	1 2 5 5 3 3 1 1	8	0 3 2 3 3 2 1 2
2009 03 25	7	3 3 2 2 1 1 1 1	9	2 2 4 3 1 1 1 1	10	4 4 2 3 1 1 1 1
2009 03 26	6	1 2 3 1 2 1 1 1	5	1 2 3 0 2 2 1 0	7	2 3 3 0 2 1 1 1
2009 03 27	2	0 0 0 0 1 1 2 1	4	0 0 0 0 2 3 2 1	4	0 0 0 0 1 2 3 2
2009 03 28	2	1 0 0 0 1 0 1 1	2	1 0 0 1 0 0 1 1	4	1 0 0 0 1 2 2 2
2009 03 29	4	2 1 1 1 1 1 1 1	2	1 0 1 1 0 0 0 1	5	1 1 1 1 1 2 1 2
2009 03 30	3	1 2 0 1 2 1 1 0	2	1 0 0 0 1 1 1 0	4	1 1 0 0 2 1 1 1
2009 03 31	2	0 0 1 0 1 0 1 1	2	1 0 0 0 3 0 0 0	4	0 0 1 0 2 2 2 1

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:

There were no problems to report for the quarter.

The terms and definitions discussed below are taken from the Standard Positioning Service Performance Specification (October 2001). An understanding of these terms and definitions is a necessary prerequisite to full understanding of the Signal Specification.

General Terms and Definitions

Almanac Longitude of the Ascending Node (.o): Equatorial angle from the Prime Meridian (Greenwich) at the weekly epoch to the ascending node at the ephemeris reference epoch.

Coarse/Acquisition (C/A) Code: A PRN code sequence used to modulate the GPS L1 carrier.

Corrected Longitude of Ascending Node (Ωk) and Geographic Longitude of the Ascending Node (GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the ascending node, both at arbitrary time T_k.

Dilution of Precision (DOP): The magnifying effect on GPS position error induced by mapping GPS ranging errors into position within the specified coordinate system through the geometry of the position solution. The DOP varies as a function of satellite positions relative to user position. 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.

Equatorial Angle: An angle along the equator in the direction of Earth rotation.

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

Ground track Equatorial Crossing (GEC, λ, 2 SOPS GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the location a ground track intersects the equator when crossing from the Southern to the Northern hemisphere. GEC is equal to Ωk when the argument of latitude (Φ) is zero.

Instantaneous User Range Error (URE): The difference between the pseudo range measured at a given location and the expected pseudo range, as derived from the navigation message and the true user position, neglecting the bias in receiver clock relative to GPS time. A signal-in-space (SIS) URE includes residual orbit, satellite clock, and group delay errors. A system URE (sometimes known as a User Equivalent Range Error, or UERE) contains all line-of-sight error sources, to include SIS, single-frequency ionosphere model error, troposphere model error, multipath and receiver noise.

Longitude of Ascending Node (LAN): A general term for the location of the ascending node – the point that an orbit intersects the equator when crossing from the Southern to the Northern hemisphere.

Longitude of the Ground track Equatorial Crossing (GEC, λ, 2 SOPS GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the location a ground track intersects the equator when crossing from the Southern to the Northern hemisphere. GEC is equal to Ωk when the argument of latitude (Φ) is zero.

Mean Down Time (MDT): A measure of time required to restore function after any downing event.

Mean Time Between Downing Events (MTBDE): A measure of time between any downing events.

Mean Time Between Failures (MTBF): A measure of time between unscheduled downing events.

Mean Time to Restore (MTTR): A measure of time required to restore function after an unscheduled downing event.

Navigation Message: Data contained in each satellite's ranging signal and consisting of 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. The message structure is described in Section 2.1.2 of the SPS Performance Standard.

Operational Satellite: A GPS satellite which is capable of, but is not necessarily transmitting a usable ranging signal.

PDOP Availability: Defined to be the percentage of time over any 24-hour interval that the PDOP value is less than or equal to its threshold for any point within the service volume.

Positioning Accuracy: Defined to be the statistical difference, at a 95% probability, between position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

- **Horizontal Positioning Accuracy:** Defined to be the statistical difference, at a 95% probability, between horizontal position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.
- **Vertical Positioning Accuracy:** Defined to be the statistical difference, at a 95% probability, between vertical position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

Position Solution: An estimate of a user’s location derived from ranging signal measurements and navigation data from GPS.

Position Solution Geometry: The set of direction cosines that define the instantaneous relationship of each satellite's ranging signal vector to each of the position solution coordinate axes.

Pseudo Random Noise (PRN): A binary sequence that appears to be random over a specified time interval unless the shift register configuration and initial conditions for generating the sequence are known. Each satellite generates a unique PRN sequence that is effectively uncorrelated (orthogonal) to any other satellite’s code over the integration time constant of a receiver’s code tracking loop.

Representative SPS Receiver: The minimum signal reception and processing assumptions employed by the U.S. Government to characterize SPS performance in accordance with performance standards defined in Section 3 of the SPS Performance Standard. Representative SPS receiver capability assumptions are identified in Section 2.2 of the SPS Performance Standard.

Right Ascension of Ascending Node (RAAN): Equatorial angle from the celestial principal direction to the ascending node.

Root Mean Square (RMS) SIS URE: A statistic that represents instantaneous SIS URE performance in an RMS sense over some sample interval. The statistic can be for an individual satellite or for the entire constellation. The sample interval for URE assessment used in the SPS Performance Standard is 24 hours.

Selective Availability: Protection technique formerly employed to deny full system accuracy to unauthorized users. SA was discontinued effective midnight May 1, 2000.

Service Availability: Defined to be the percentage of time over any 24-hour interval that the predicted 95% positioning error is less than its threshold for any given point within the service volume.

- **Horizontal Service Availability:** Defined to be the percentage of time over any 24-hour interval that the predicted 95% horizontal error is less than its threshold for any point within the service volume.
- **Vertical Service Availability:** Defined to be the percentage of time over any 24-hour interval that the predicted 95% vertical error is less than its threshold for any point within the service volume.

Service Degradation: A condition over a time interval during which one or more SPS performance standards are not supported.

Service Failure: A condition over a time interval during which a healthy GPS satellite's ranging signal exceeds the Not-to-Exceed (NTE) SPS SIS URE tolerance.

Service Reliability: The percentage of time over a specified time interval that the instantaneous SIS SPS URE is maintained within a specified reliability threshold at any given point within the service volume, for all healthy GPS satellites.

Service Volume: The spatial volume supported by SPS performance standards. Specifically, the SPS Performance Standard supports the terrestrial service volume. The terrestrial service volume covers from the surface of the Earth up to an altitude of 3,000 kilometers.

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

SPS Performance Standard: A quantifiable minimum level for a specified aspect of GPS SPS performance. SPS performance standards are defined in Section 3.0.

SPS Ranging Signal: An electromagnetic signal originating from an operational satellite. The SPS ranging signal consists of a Pseudo Random Noise (PRN) C/A code, a timing reference and sufficient data to support the position solution generation process. A description of the GPS SPS signal is provided in Section 2. The formal definition of the SPS ranging signal is provided in ICDGPS-200C.

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

SPS SIS User Range Error (URE) Statistic:

- A satellite SPS SIS URE statistic is defined to be the Root Mean Square (RMS) difference between SPS ranging signal measurements (neglecting user clock bias and errors due to propagation environment and receiver), and "true" ranges between the satellite and an SPS user at any point within the service volume over a specified time interval.
- A constellation SPS SIS URE statistic is defined to be the average of all satellite SPS SIS URE statistics over a specified time interval.

Time Transfer Accuracy Relative to UTC (USNO): The difference at a 95% probability between user UTC time estimates and UTC (USNO) at any point within the service volume over any 24-hour interval.

Transient Behavior: Short-term behavior not consistent with steady-state expectations.

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

User Navigation Error (UNE): Given a sufficiently stationary and ergodic satellite constellation ranging error behavior over a minimum sample interval, multiplication of the DOP and a constellation ranging error standard deviation value will yield an approximation of the RMS position error. This RMS approximation is known as the UNE (UHNE for horizontal, UVNE for vertical, and so on). The user is cautioned that any divergence away from the stationary and ergodic assumptions will cause the UNE to diverge from a RMS value based on actual measurements.

User Range Accuracy (URA): A conservative representation of each satellite's expected (1ó) SIS URE performance (excluding residual group delay) based on historical data. A URA value is provided that is representative over the curve fit interval of the navigation data from which the URA is read. The URA is a coarse representation of the URE statistic in that it is quantized to levels represented in ICDGPS200C.