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

Submitted To

Federal Aviation Administration
GPS Product Team

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Submitted by

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

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 #69, includes data collected from 1 January through 31 March 2010. The next quarterly report will be issued July 31, 2010.

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 99.965% 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 2010. 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 nineteen outages were reported in the NANU’s this quarter. Eighteen outages were scheduled while one was an unscheduled outage.

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 17.342 meters on Satellite PRN 32. 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 2.329 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 were 5.48 meters at Maspalomas and 5.35 meters at Bishkek, respectively.

From the analysis performed on data collected between 1 January and 31 March 2010, 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).

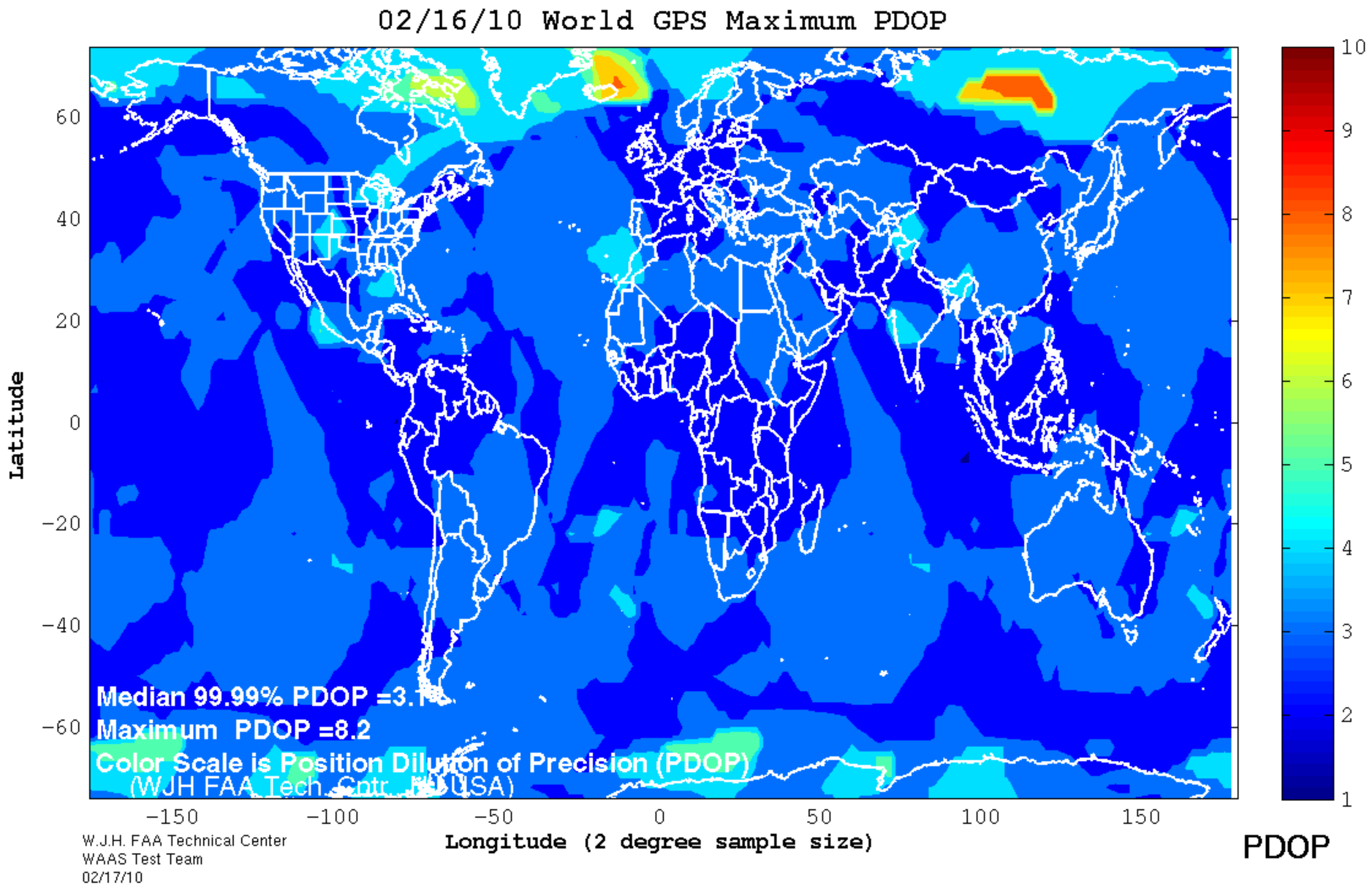
Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by the GPS test team was used to calculate the PDOP at every 5^o point between longitudes of 180W to 180E 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 4.281 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%)
3 – 9 January	3.1365	99.998	98.958
10 – 16 January	3.1209	99.998	99.028
17 – 23 January	3.0989	99.998	99.028
24 – 30 January	3.0646	99.998	99.097
31 Jan – 6 February	3.0372	99.999	99.167
7 – 13 February	3.0614	99.999	99.236
14 – 20 February	4.2814	99.965	97.153
21 – 27 February	3.1010	99.999	99.444
28 Feb – 6 March	3.1429	99.998	99.375
7 – 13 March	3.2005	99.996	98.958
14 – 20 March	3.3018	99.994	98.819
21 – 27 March	3.2956	99.993	98.681
28 March – 3 April	3.2667	99.992	98.750



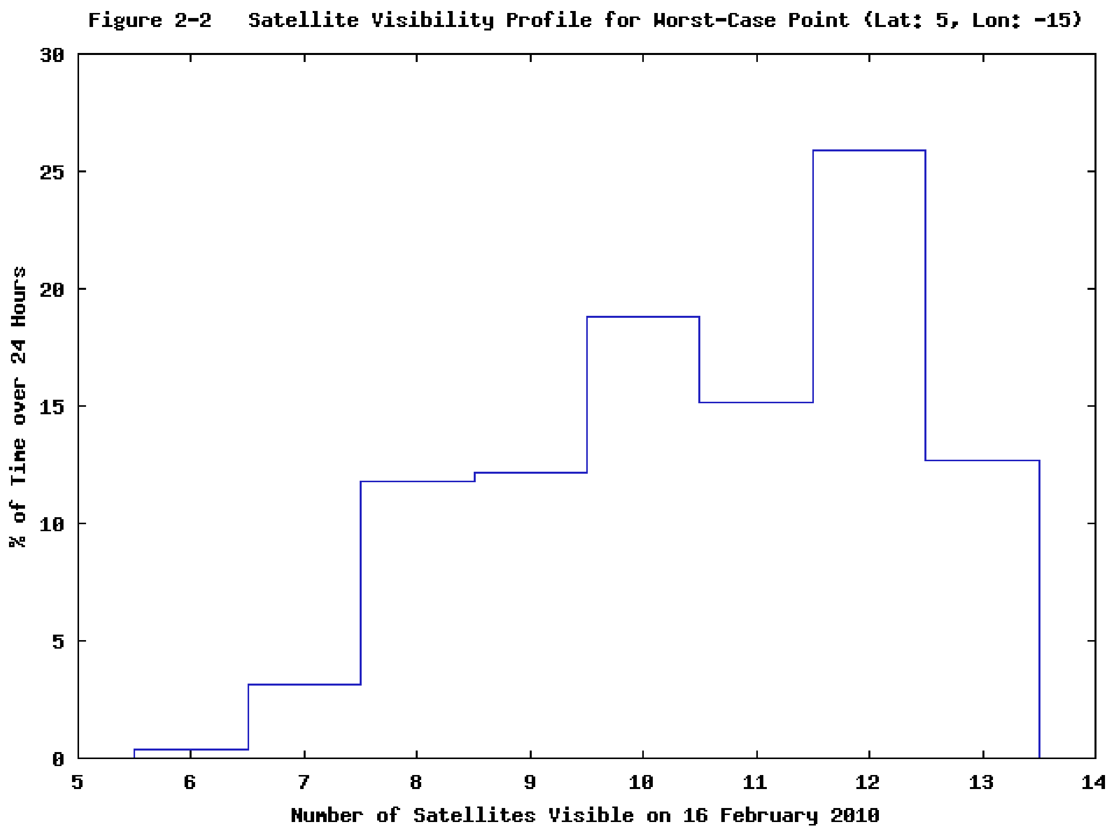


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lat: 5, Lon: -15)
% of Time over 24 Hours
Number of Satellites Visible on 16 February 2010
0
5
10
15
20
25
30
5
6
7
8
9
10
11
12
13
14

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 2010, there were a total of fifteen reported outages. Twelve of these outages were maintenance activities and were reported in advance while three were unscheduled outages. A complete listing of outage NANU's for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-2. Canceled outage NANU's (if any) 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
2010004	24	FCSTSUMM	13-Jan	16:52	14-Jan	00:36		7.733	7.733
2010007	29	FCSTSUMM	14-Jan	18:37	15-Jan	00:53		6.267	6.267
2010008	30	FCSTSUMM	19-Jan	14:55	19-Jan	21:50		6.917	6.917
2010012	4	FCSTSUMM	26-Jan	14:12	27-Jan	00:13		10.017	10.017
2010013	7	FCSTSUMM	28-Jan	06:16	28-Jan	10:00		3.733	3.733
2010017	17	FCSTSUMM	02-Feb	10:26	02-Feb	16:56		6.500	6.500
2010020	21	FCSTSUMM	04-Feb	18:37	04-Feb	22:17		3.667	3.667
2010023	26	FCSTSUMM	08-Feb	20:46	09-Feb	05:28		8.700	8.700
2010025	31	FCSTSUMM	10-Feb	16:06	10-Feb	18:50		2.733	2.733
2010030	2	FCSTSUMM	16-Feb	14:38	16-Feb	18:10		3.533	3.533
2010033	20	UNUSABLE	15-Feb	08:06	19-Feb	21:46	109.667		109.667
2010036	6	FCSTSUMM	22-Feb	17:43	22-Feb	22:40		4.950	4.950
2010038	30	FCSTSUMM	22-Feb	20:51	24-Feb	16:53		44.033	44.033
2010043	27	FCSTSUMM	02-Mar	05:18	02-Mar	07:52		2.567	2.567
2010044	15	FCSTSUMM	03-Mar	08:05	03-Mar	11:40		3.583	3.583
2010047	32	FCSTSUMM	16-Mar	20:17	17-Mar	04:00		7.717	7.717
2010056	12	FCSTSUMM	30-Mar	05:49	30-Mar	09:50		4.017	4.017
2010057	22	FCSTSUMM	31-Mar	13:00	31-Mar	17:44		4.733	4.733
2010058	22	FCSTSUMM	31-Mar	13:46	31-Mar	17:44		3.967	3.967
	Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime						**109.67**	**135.37**	**245.03**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2010001	29	FCSTDV	14-Jan	18:30	15-Jan	06:30	12	See Nanu 2010007
2010003	24	FCSTDV	13-Jan	16:30	14-Jan	16:30	24	See Nanu 2010004
2010006	30	FCSTDV	19-Jan	14:45	20-Jan	02:45	12	See Nanu 2010008
2010009	4	FCSTMX	26-Jan	14:00	27-Jan	02:00	12	See Nanu 2010012
2010010	7	FCSTMX	28-Jan	05:30	28-Jan	17:30	12	See Nanu 2010013
2010014	17	FCSTDV	02-Feb	10:15	02-Feb	22:15	12	See Nanu 2010017
2010015	21	FCSTMX	04-Feb	18:00	05-Feb	06:00	12	See Nanu 2010020
2010019	26	FCSTDV	08-Feb	20:30	09-Feb	20:30	24	See Nanu 2010023
2010021	31	FCSTMX	10-Feb	16:00	11-Feb	04:00	12	See Nanu 2010025
2010027	2	FCSTMX	16-Feb	14:00	17-Feb	02:00	12	See Nanu 2010030
2010028	23	FCSTMX	18-Feb	21:00	19-Feb	09:00	12	CANC
2010029	20	UNUSUFN	15-Feb	08:06	N/A	N/A	N/A	See Nanu 2010033
2010032	6	FCSTMX	22-Feb	14:00	23-Feb	02:00	12	See Nanu 2010036
2010034	16	FCSTMX	24-Feb	17:30	25-Feb	05:30	12	CANC
2010035	30	UNUSUFN	22-Feb	20:51	N/A	N/A	N/A	See Nanu 2010038
2010039	27	FCSTMX	02-Mar	05:00	02-Mar	17:00	12	See Nanu 2010043
2010040	15	FCSTMX	03-Mar	08:00	03-Mar	20:00	12	See Nanu 2010044
2010046	32	FCSTDV	16-Mar	20:00	17-Mar	08:00	12	See Nanu 2010047
2010048	22	FCSTMX	25-Mar	13:00	26-Mar	01:00	12	See Nanu 2010057
2010048	22	FCSTMX	25-Mar	13:00	26-Mar	01:00	12	CANC
2010049	12	FCSTMX	30-Mar	05:00	30-Mar	17:00	12	See Nanu 2010056
2010050	9	FCSTDV	23-Mar	23:30	24-Mar	11:30	12	See Nanu 2010051
2010051	9	FCSTEXTD	23-Mar	23:30	N/A	N/A	N/A	See Nanu 0
2010053	22	FCSTMX	31-Mar	13:00	01-Apr	01:00	12	See Nanu 2010058
2010054	19	FCSTMX	02-Apr	18:00	03-Apr	06:00	12	See Nanu 2010061
						Total Forecast Downtime	**288.00**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
2010031	23	FCSTCANC	18-Feb	17:00	See Nanu 2010028
2010037	16	FCSTCANC	24-Feb	17:30	See Nanu 2010034
2010052	22	FCSTCANC	25-Mar	13:00	See Nanu 2010048

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-10**	**1-Oct-99**
	31-Mar-10	**31-Mar-10**
Total Forecast Downtime (hrs):	288.00	7627.55
Total Actual Downtime (hrs):	245.03	26076.92
Total Actual Scheduled Downtime (hrs):	135.37	3927.35
Total Actual Unscheduled Downtime (hrs):	109.67	22149.57
Total Satellite Observed MTTR (hrs):	12.90	43.39
Scheduled Satellite Observed MTTR (hrs):	7.52	8.91
Unscheduled Satellite Observed MTTR (hrs):	109.67	138.43
# Total Satellite Outages:	19	601
# Scheduled Satellite Outages:	18	441
# Unscheduled Satellite Outages:	1	160
Percent Operational -- Scheduled Downtime:	99.798	99.827
Percent Operational -- All Downtime:	99.989	98.850

General NANU's

2010002: 2SOPS installed new ground software on 11 Jan 2010.
2010005: Outage times for SVN24 (PRN24) were from J013/1652z to J014/0200z.
2010011: GPS Master Control Station requests that operational military and civil users provide any impacts encountered that are believed to be related to the new software or started after the 11 January 2010 install.
2010016: The GPS Master Control Station (MCS) is completing a minor software upgrade on 3 Feb 10.
2010018: CANCEL GENERAL NANU 2010016 IMMEDIATELY
2010022: Attention military users with SAASM receivers. For information about an anomaly on a limited number of these receivers, please go to http://gpsoc.afspc.af.smil.mil
2010024: ON APPROXIMATELY 11 FEB 10 SVN35 WILL RESUME TRANSMITTING L-BAND UTILIZING PRN25. AT L-BAND ACTIVATION, SVN35/PRN25 WILL BE UNUSABLE UNTIL FURTHER NOTICE.
2010026: Correction to NANU 2010025. Outage times for SVN52 (PRN31) were from J041/1606z to J041/1950z.
2010041: The 2nd Space Operations Squadron will be installing a ground software upgrade on 5 March 2010
2010042: On 01 MAR 2010, SVN35 discontinued transmitting L-Band. PRN25 is available for future satellite service.
2010045: The 2nd Space Operations Squadron will be installing a ground software upgrade on 5 March 2010
2010055: SVN25 has been placed into its final orbit for permanent disposal following its decommissioning. The satellite will no longer contribute to GPS operations.

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 2010.

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	7741481	0	100%
Anchorage	7515404	0	100%
Atlanta	7773414	0	100%
Barrow	7771213	0	100%
Bethel	7467174	0	100%
Billings	7759172	0	100%
Boston	7550430	0	100%
Cleveland	7392721	0	100%
Cold Bay	7687800	0	100%
Fairbanks	7621719	0	100%
Gander	7772443	0	100%
Honolulu	7611409	0	100%
Houston	7646055	0	100%
Iqaluit	7657157	0	100%
Juneau	7645301	0	100%
Kansas City	7560486	0	100%
Kotzebue	7774729	0	100%
Los Angeles	7572593	0	100%
Merida	7771413	0	100%
Miami	7564865	0	100%
Minneapolis	7555296	0	100%
Oakland	6813611	0	100%
Salt Lake City	7545103	0	100%
San Jose Del Cabo	7688370	0	100%
San Juan	7373641	0	100%
Seattle	7774771	0	100%
Tapachula	7728174	0	100%
Washington, DC	7602154	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 17.342 meters on satellite PRN 32.

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 2010	**Boston**	57,386,296	0	100%
1 Jan – 31 Mar 2010	**Honolulu**	60,432,836	0	100%
1 Jan – 31 Mar 2010	**Los Angeles**	59,031,905	0	100%
1 Jan – 31 Mar 2010	**Miami**	59,339,364	0	100%
1 Jan – 31 Mar 2010	**San Juan**	61,028,227	0	100%
1 Jan – 31 Mar 2010	**Juneau**	62,057,442	0	100%
1 Jan – 31 Mar 2010	**Global**	359,276,070	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 2010 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	1.998	3.769	9.475	12.248
Anchorage	1.724	4.513	4.032	8.789
Atlanta	2.376	4.171	11.112	13.724
Barrow	1.516	4.679	3.450	10.972
Bethel	1.741	4.572	3.970	9.017
Billings	2.098	3.626	11.780	14.588
Boston	2.504	3.661	10.230	8.391
Cleveland	2.350	3.761	11.781	8.374
Cold Bay	2.046	4.666	5.029	8.945
Fairbanks	1.595	4.633	3.741	10.117
Gander	2.450	3.574	9.620	10.159
Honolulu	4.339	4.868	7.011	14.173
Houston	2.129	4.151	9.310	10.007
Iqaluit	1.804	3.670	7.285	16.700
Juneau	1.798	4.177	5.449	8.743
Kansas City	2.328	3.809	12.217	10.041
Kotzebue	1.614	4.580	3.709	10.289
Los Angeles	1.942	4.215	8.199	8.915
Merida	2.538	4.437	8.681	19.787
Miami	2.299	4.561	9.002	18.457
Minneapolis	2.307	3.657	11.306	7.271
Oakland	2.024	4.309	7.138	8.728
Salt Lake City	2.074	3.770	9.162	8.806
San Jose Del Cabo	2.321	4.286	8.385	10.491
San Juan	2.614	4.736	9.595	19.526
Seattle	2.124	3.798	5.917	9.322
Tapachula	3.552	5.356	9.925	16.723
Washington, DC	2.522	3.826	11.458	9.635

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 2010.

Figure 5-1 Global Vertical Error Histogram

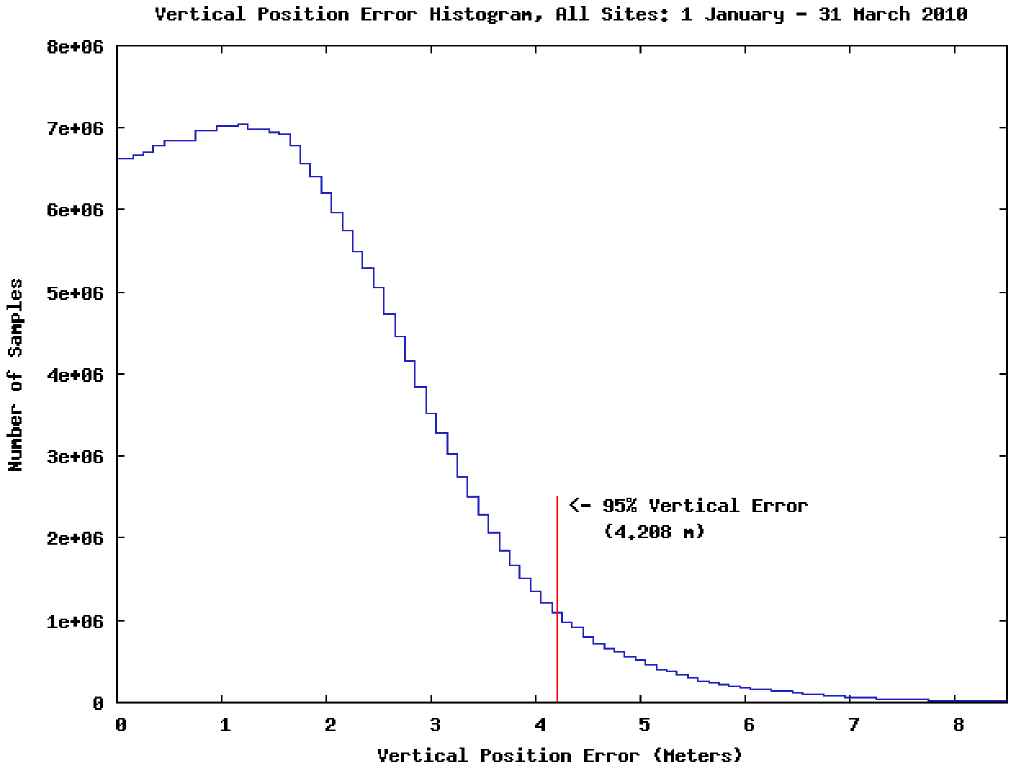
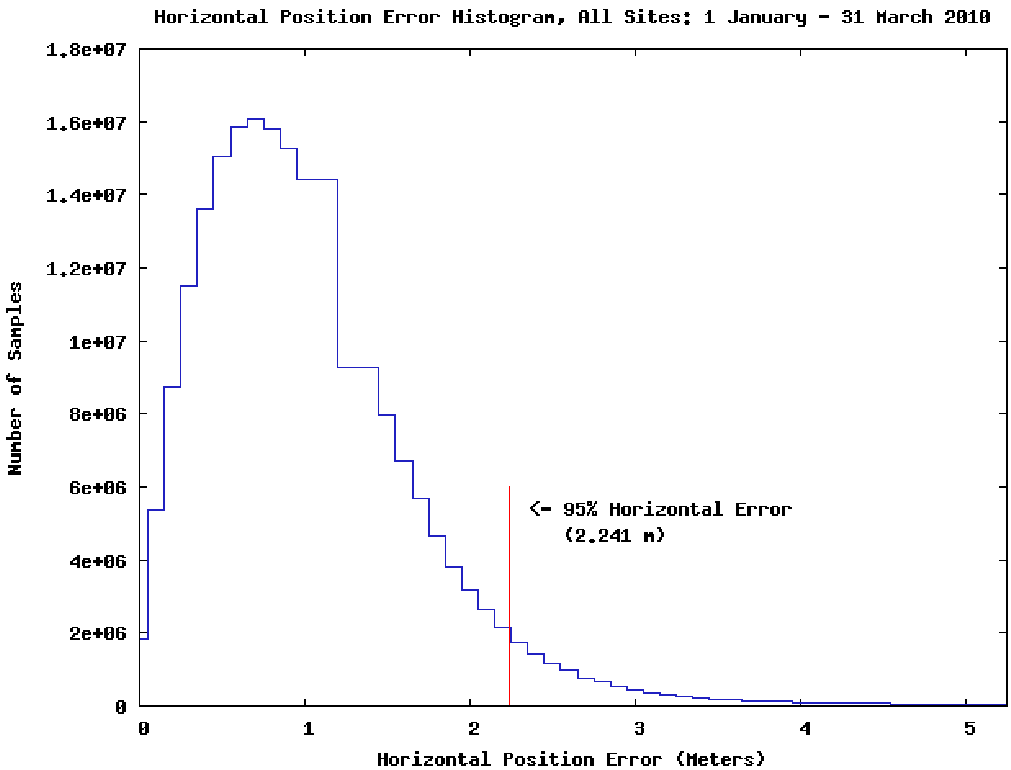


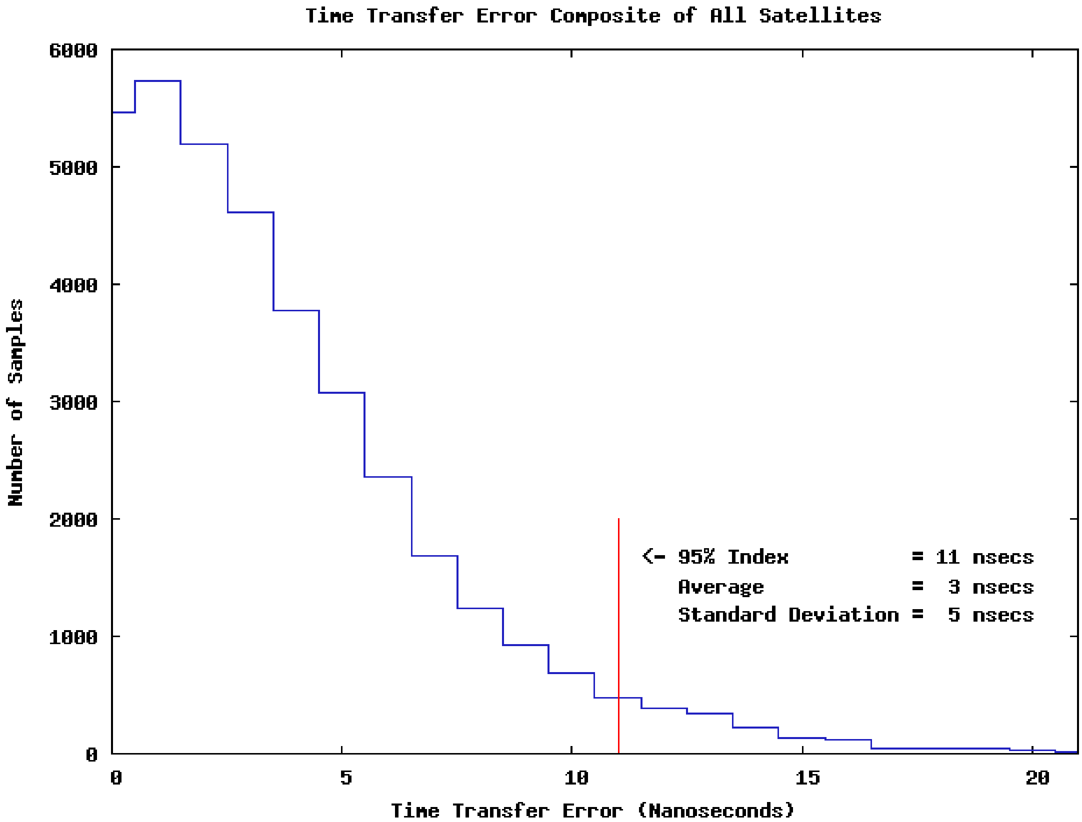
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 2010 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 2010.

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	1.630	0.894	1.199	2.943	13.142	12851612
3	1.707	0.568	1.283	3.080	9.531	11229394
4	1.466	0.553	1.164	2.763	11.358	12592675
5	1.475	-0.252	1.247	2.744	10.609	12655174
6	1.589	0.578	1.189	2.830	12.310	11469412
7	1.450	0.632	1.082	2.659	11.438	10816673
8	1.910	1.082	1.328	3.441	11.282	11622067
9	1.967	0.856	1.433	3.448	9.992	10826153
10	2.329	1.524	1.436	3.938	11.895	11668666
11	1.842	1.079	1.265	3.226	12.097	11190517
12	1.497	0.667	1.186	2.771	13.398	13159947
13	1.435	0.614	1.094	2.642	10.009	12477831
14	1.701	0.783	1.241	3.187	12.801	13123430
15	1.377	0.135	1.099	2.524	11.129	11498936
16	1.652	1.084	1.107	2.922	8.452	11770379
17	1.410	0.534	1.168	2.783	14.256	12685845
18	1.734	0.844	1.270	3.078	15.113	12071246
19	1.855	1.261	1.133	3.241	11.968	11387076
20	1.946	1.213	1.313	3.559	12.472	12138860
21	1.804	0.953	1.319	3.109	10.325	11122770
22	1.910	0.797	1.298	3.352	15.345	11479366
23	1.721	0.911	1.210	3.088	11.188	11648786
24	2.202	1.094	1.385	3.716	14.525	11124539
26	1.596	0.423	1.263	3.004	11.763	12624912
27	2.127	1.172	1.518	3.758	10.760	12422392
28	1.954	1.381	1.222	3.415	11.496	11463555
29	1.515	0.233	1.168	2.737	13.212	12227546
30	1.797	0.526	1.381	3.367	15.512	12146705
31	1.544	0.457	1.272	2.973	12.647	12939627
32	1.901	1.048	1.249	3.390	17.342	12839979

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

PRN	Range Rate Error RMS (mm/s)	95% Range Rate Error (mm/s)	Max Range Rate Error (mm/s)	Samples
2	1.424	2.675	152.61	12851612
3	1.968	2.980	176.86	11229394
4	1.420	2.590	138.88	12592675
5	1.553	2.814	183.49	12655174
6	1.504	2.621	228.65	11469412
7	1.444	2.672	119.22	10816673
8	1.842	3.084	192.08	11622067
9	1.819	2.880	214.46	10826153
10	1.876	2.961	191.25	11668666
11	1.558	2.781	141.85	11190517
12	1.506	2.858	149.36	13159947
13	1.512	2.827	169.03	12477831
14	1.586	2.813	200.52	13123430
15	1.461	2.719	177.37	11498936
16	1.470	2.788	165.31	11770379
17	1.601	2.774	138.17	12685845
18	1.555	2.822	198.21	12071246
19	1.461	2.738	144.05	11387076
20	1.482	2.842	144.67	12138860
21	1.555	2.878	172.45	11122770
22	1.671	2.940	178.49	11479366
23	1.420	2.714	149.12	11648786
24	1.740	2.820	154.19	11124539
26	1.547	2.736	172.15	12624912
27	2.036	2.867	200.54	12422392
28	1.604	2.677	194.62	11463555
29	1.556	2.732	213.65	12227546
30	1.874	3.016	239.75	12146705
31	1.600	2.880	192.35	12939627
32	1.438	2.667	297.17	12839979

Table 5-4 Range Acceleration Error Statistics (micrometers/second²)

PRN	Range Acceleration Error RMS (μm/s²)	95% Range Acceleration Error (μm/s²)	Max Range Acceleration Error (μm/s²)	Samples
2	14.243	26.753	1526	12851612
3	19.681	29.804	1769	11229394
4	14.198	25.896	1389	12592675
5	15.532	28.136	1835	12655174
6	15.044	26.206	2287	11469412
7	14.437	26.716	1192	10816673
8	18.417	30.838	1921	11622067
9	18.188	28.805	2145	10826153
10	18.759	29.610	1913	11668666
11	15.584	27.811	1419	11190517
12	15.064	28.580	1494	13159947
13	15.116	28.272	1690	12477831
14	15.865	28.129	2005	13123430
15	14.605	27.188	1774	11498936
16	14.700	27.877	1653	11770379
17	16.012	27.738	1382	12685845
18	15.551	28.216	1982	12071246
19	14.609	27.380	1441	11387076
20	14.824	28.419	1447	12138860
21	15.550	28.781	1725	11122770
22	16.707	29.405	1785	11479366
23	14.202	27.140	1491	11648786
24	17.402	28.203	1542	11124539
26	15.471	27.361	1722	12624912
27	20.362	28.669	2005	12422392
28	16.039	26.767	1946	11463555
29	15.557	27.318	2137	12227546
30	18.741	30.161	2398	12146705
31	16.003	28.805	1924	12939627
32	14.383	26.666	2972	12839979

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 32 with an error of 17.342 meters. Satellite 16 had the lowest maximum range error of 8.452 meters.

Figure 5-4 Distribution of Daily Max Range Errors

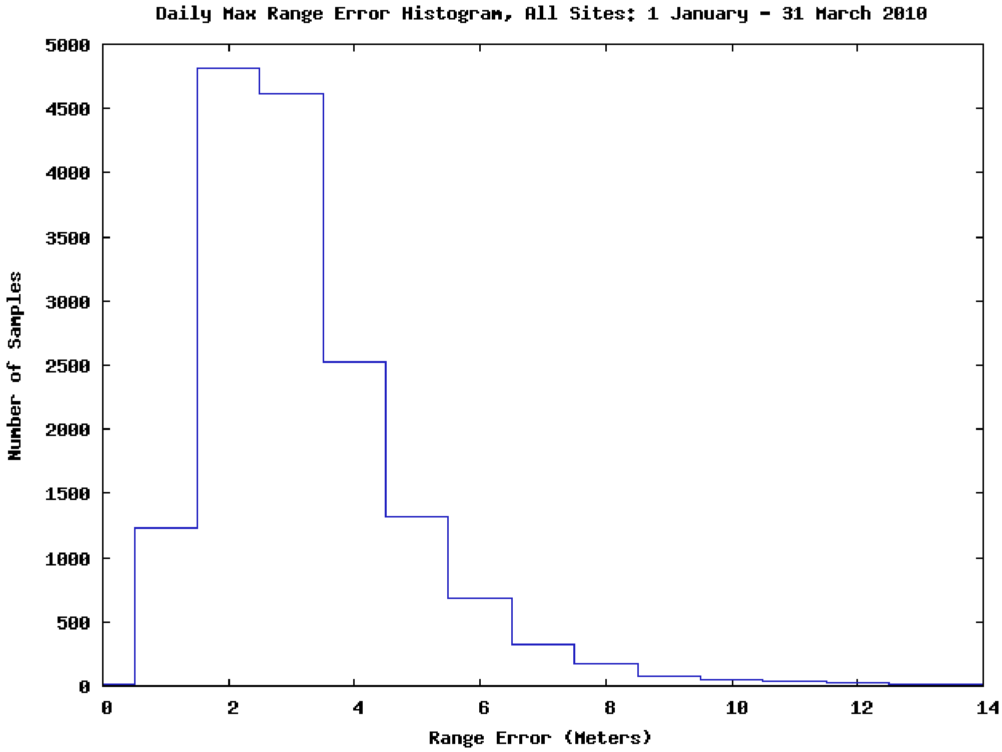


Figure 5-5: Distribution of Daily Max Range Rate Errors

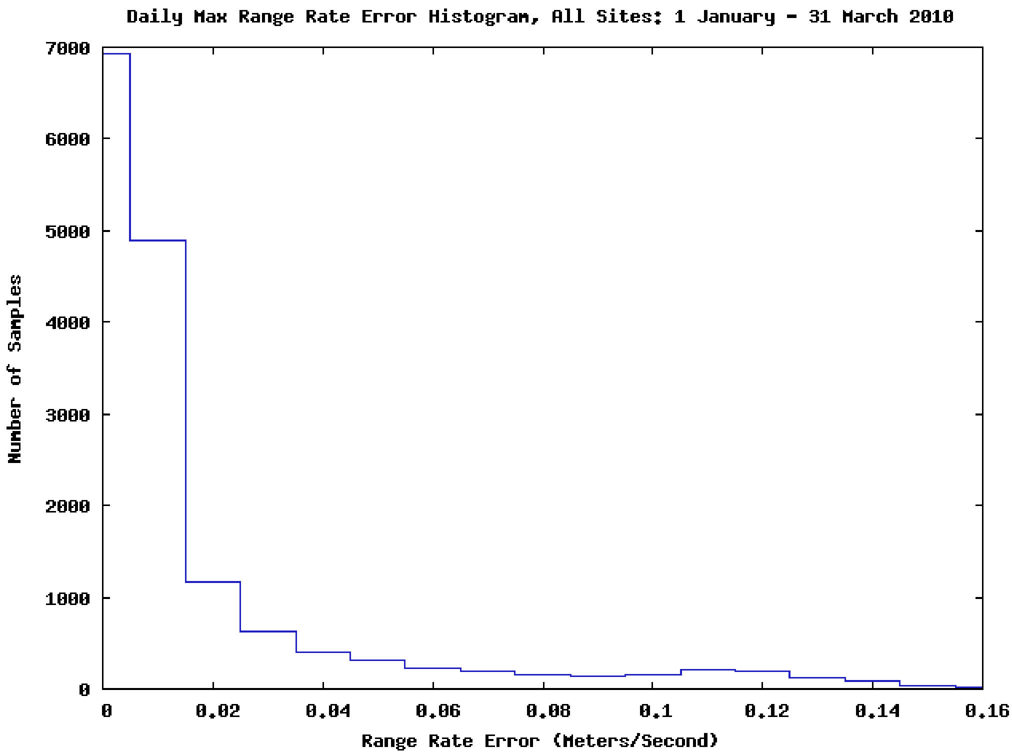


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

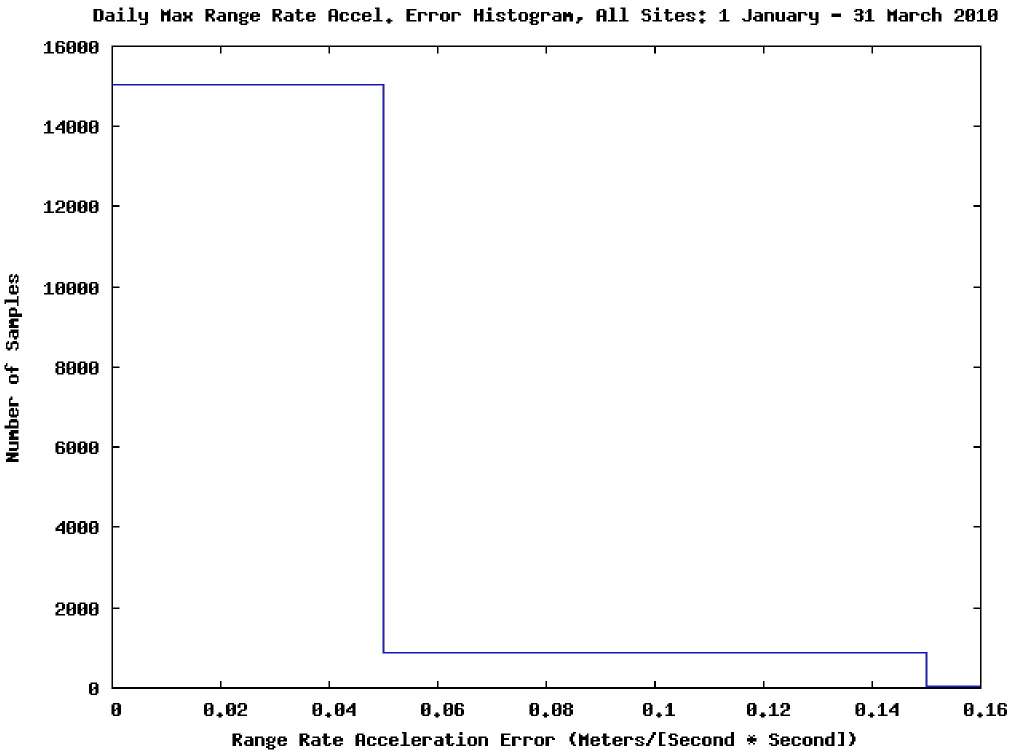
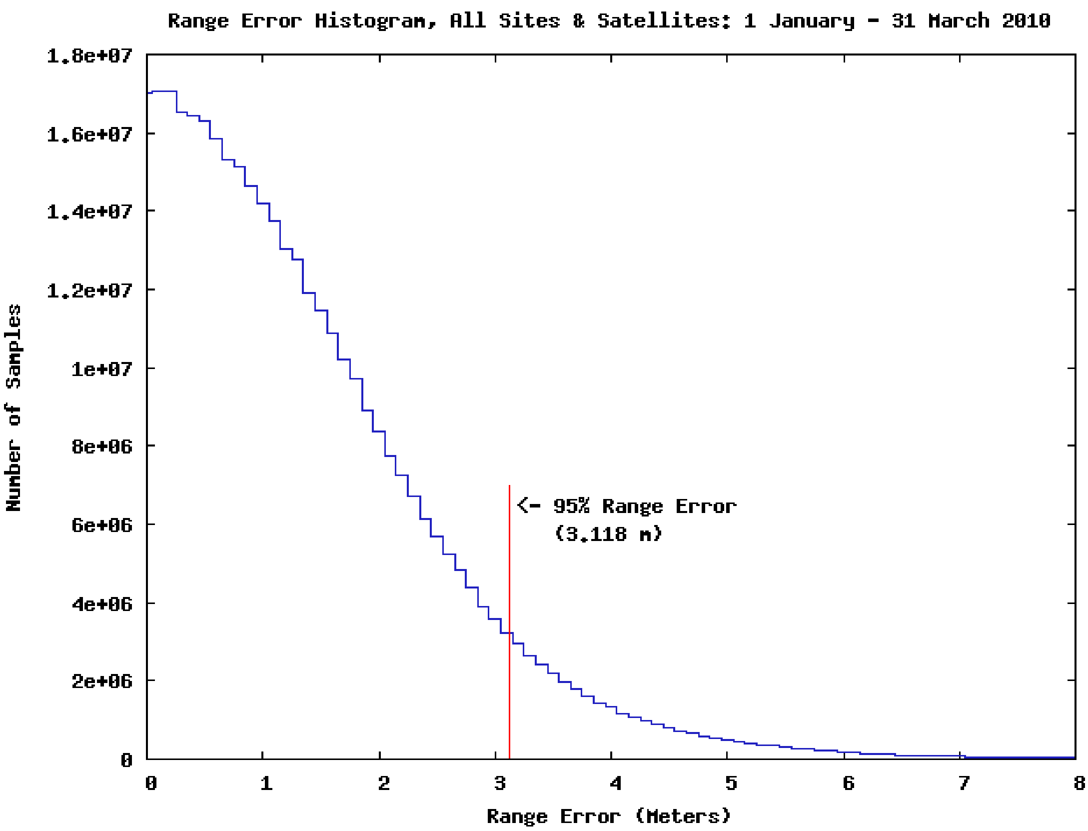


Figure 5-7: Range Error Histogram



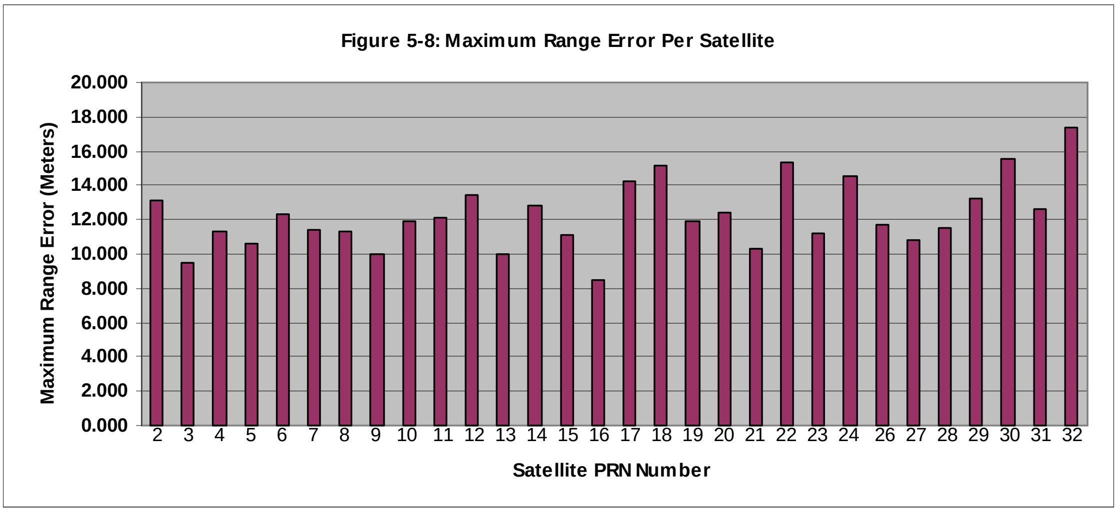


Figure 5-8: Maximum Range Error Per Satellite
Maximum Range Error (Meters)
20.000
18.000
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 26 27 28 29 30 31 32
Satellite PRN Number

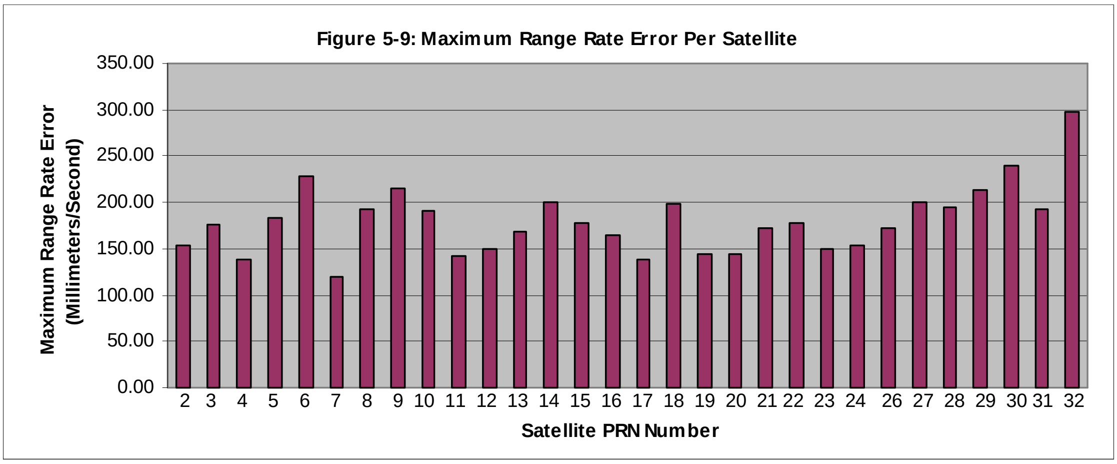


Figure 5-9: Maximum Range Rate Error Per Satellite
Maximum Range Rate Error (Millimeters/Second)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 26 27 28 29 30 31 32
Satellite PRN Number

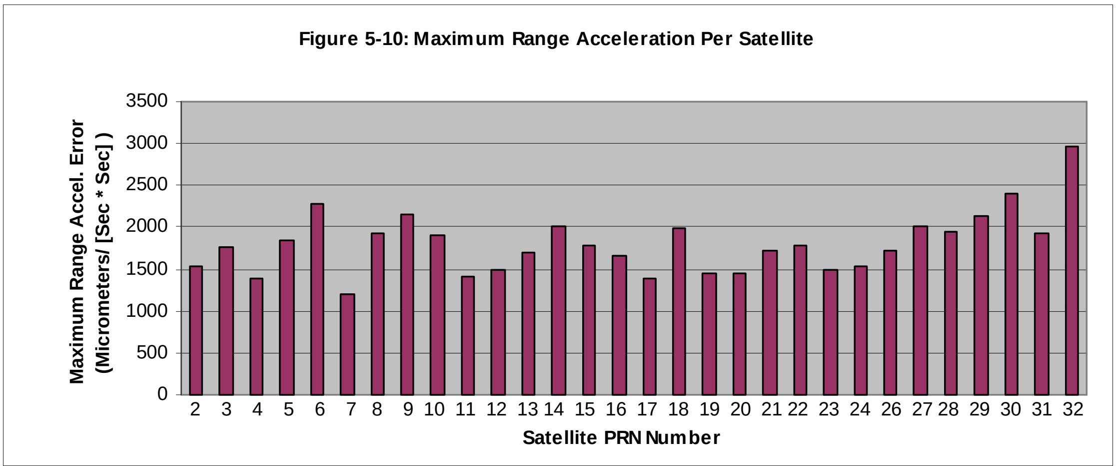


Figure 5-10: Maximum Range Acceleration Per Satellite
Maximum Range Accel. Error (Micrometers/ [Sec * Sec])
3500
3000
2500
2000
1500
1000
500
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 26 27 28 29 30 31 32
Satellite PRN Number

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 19-21 January 2010

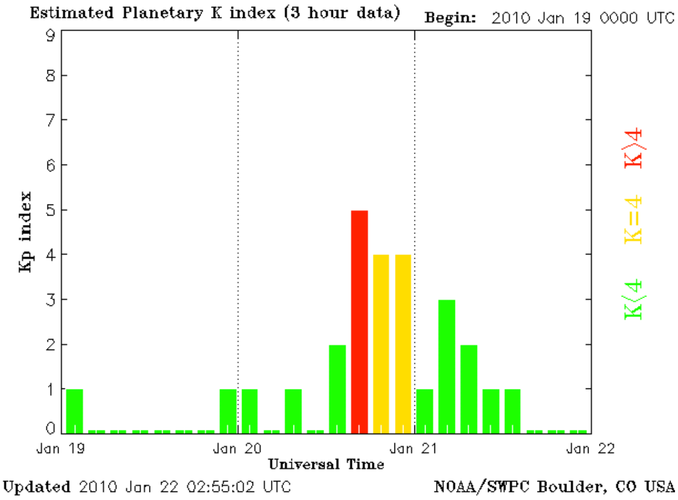


Figure 6-2 K-Index for 14-16 February 2010

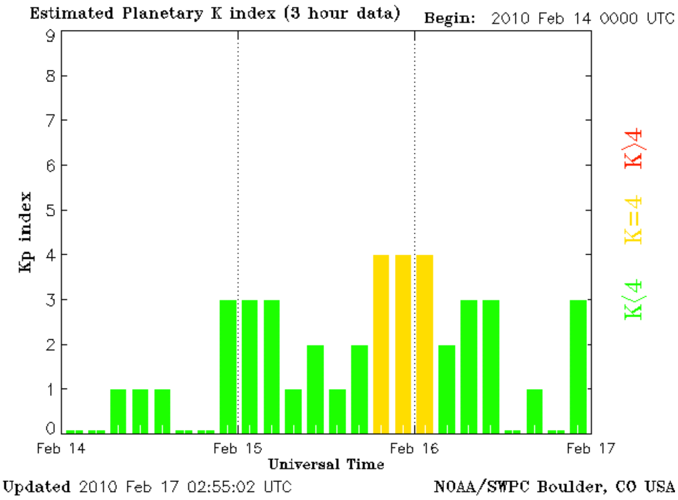


Figure 6-3 K-Index for 1-3 February 2010

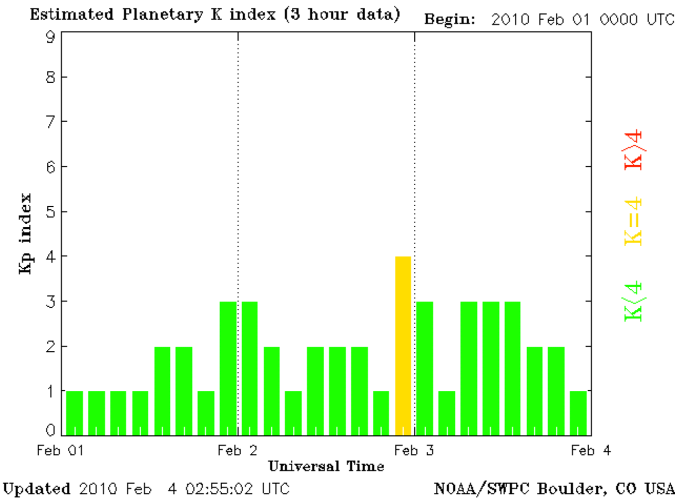


Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for 20 January 2010

Site	95% Horizontal (Meters)	95% Vertical (Meters)	Maximum Horizontal (Meters)	Maximum Vertical (Meters)
Albuquerque	2.16	3.58	2.75	5.41
Anchorage	1.48	4.27	2.13	7.16
Atlanta	2.32	3.68	2.67	5.70
Barrow	1.43	4.78	2.07	7.92
Bethel	1.68	4.18	2.08	7.06
Billings	2.18	3.44	3.23	4.63
Boston	2.67	3.38	3.60	5.22
Cleveland	2.40	3.64	3.37	5.20
Cold Bay	2.12	4.36	2.52	6.59
Fairbanks	1.24	4.74	1.69	8.02
Gander	2.44	3.36	3.48	4.42
Honolulu	4.34	6.30	5.40	8.28
Houston	2.19	3.83	2.64	5.63
Iqaluit	1.79	3.20	2.05	4.33
Juneau	1.62	4.37	2.67	6.11
Kansas City	2.39	3.55	2.82	5.33
Kotzebue	1.26	4.24	1.68	8.14
Los Angeles	2.13	3.85	2.92	5.96
Merida	2.36	4.34	2.84	9.01
Miami	2.05	4.08	2.43	5.28
Minneapolis	2.50	4.05	3.31	5.21
Oakland	2.29	4.26	3.14	6.75
Salt Lake City	2.13	3.53	2.48	5.14
San Jose Del Cabo	1.89	3.87	2.41	5.04
San Juan	2.35	4.08	3.21	7.26
Seattle	2.61	4.50	3.26	5.86
Tapachula	2.71	4.75	3.09	8.68
Washington, DC	2.42	3.83	2.96	5.08

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 have been 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 processing and are forced into the 50.1 meter histogram bin and are believed to influence the outliers in the 99.99% statistics. MAS1 performance is an outlier that appears to be related to receiver glitches that cause complete loss of tracking for a short interval, see figure 7-4 for an example. SANT is experiencing a diurnal North/South error during the later part of the quarter, see figures 7-5 and 7-6 (green traces) for examples.

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. A value of zero indicates no data.

(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
MAS1	Maspalomas, Spain
MATE	Matera, Italy
NNOR	New Norcia, Australia
POL2	Bishkek, Kyrghyzstan
SANT	Santiago, Chile
SUTM	Sutherland, South Africa
TIDB	Tidbinbilla, Australia
USUD	Usuda, Japan

Figure 7-1 Selected IGS Site Locations

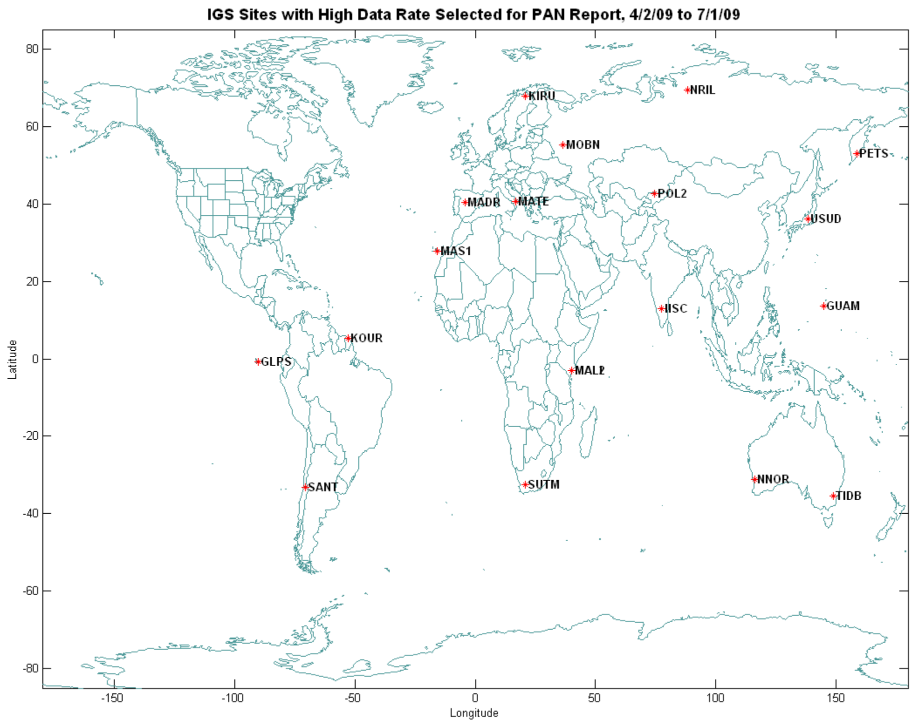


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
GLPS	2.82	4.59	5.83	10.94	91.35%
GUAM	2.15	4.73	5.19	18.6	99.19%
IISC	2.14	4.69	4.54	11.57	93.71%
KIRU	1.77	4.51	4.41	10.23	99.99%
KOUR	2.85	4.49	6.07	12.37	99.97%
MADR	2.15	4.36	8.57	10.04	99.33%
MAL2	2.38	4.6	9.71	19.26	98.81%
MAS1	5.48	4.55	9.79	21.09	99.95%
MATE	2.23	4.54	5.76	9.71	92.00%
MOBN	2.56	4.62	7.55	12.14	100.00%
NNOR	2.11	4.61	4.96	15.44	100.00%
NRIL	1.77	4.23	4.62	12.02	95.81%
PETS	2.47	5.03	6.3	13.41	99.47%
POL2	2.44	5.35	19.17	30.82	73.75%
SANT	4.22	4.88	10.35	10.24	99.93%
SUTM	1.93	3.68	5.01	8.4	98.88%
TIDB	2.06	3.66	4.97	12.74	99.89%
USUD	2.46	5.12	7.42	10.7	99.90%

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

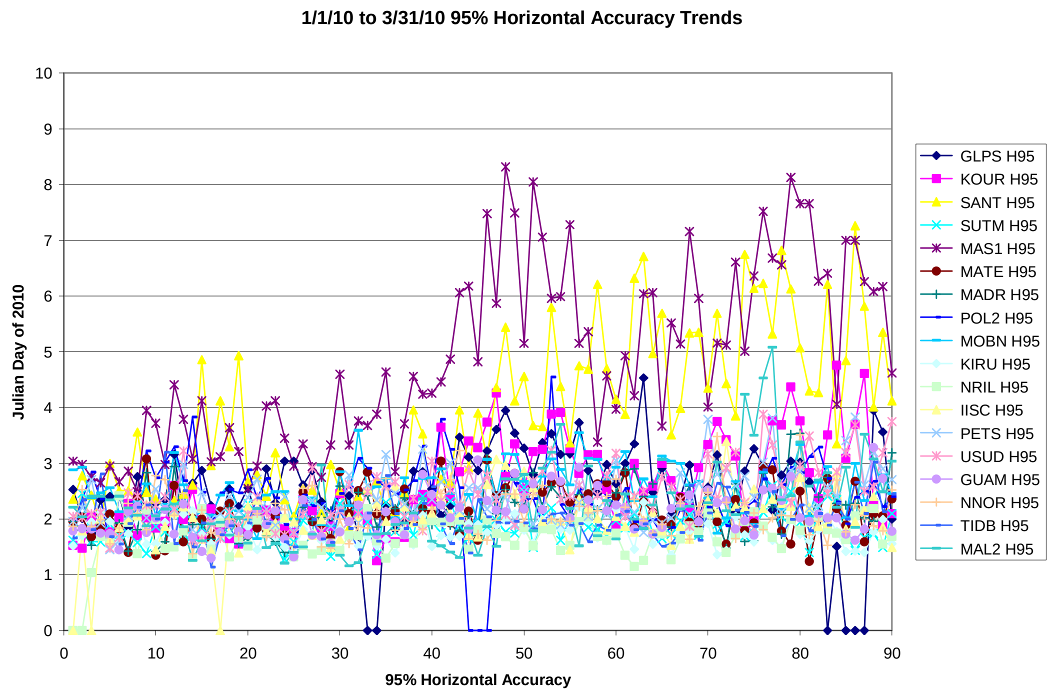


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites

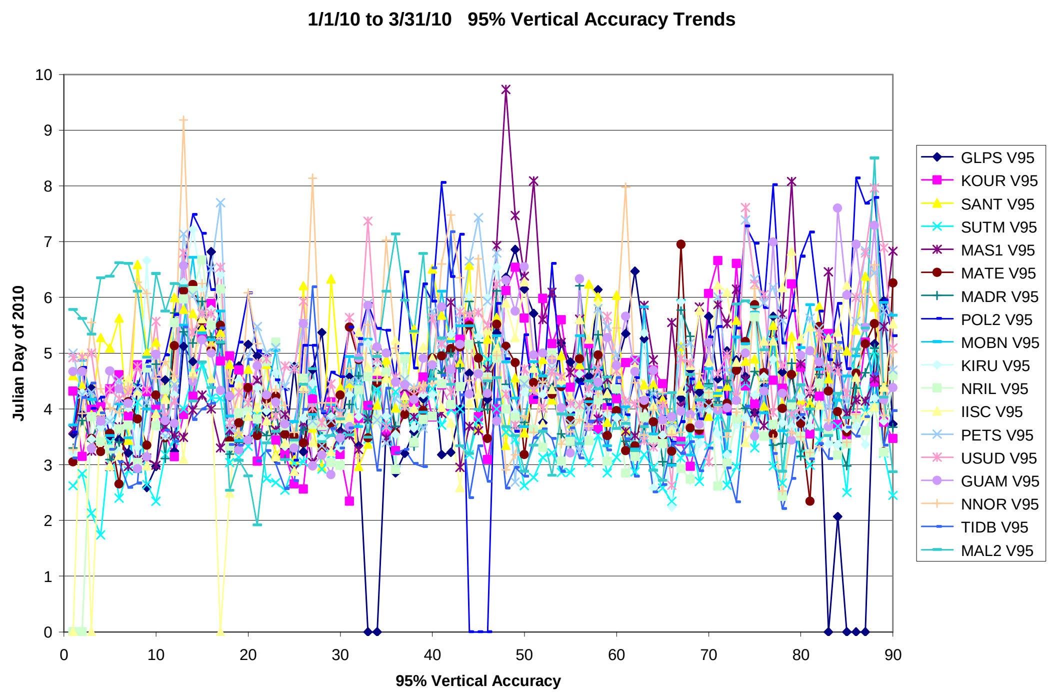


Figure 7-4 Example of Receiver Glitches at MAS1

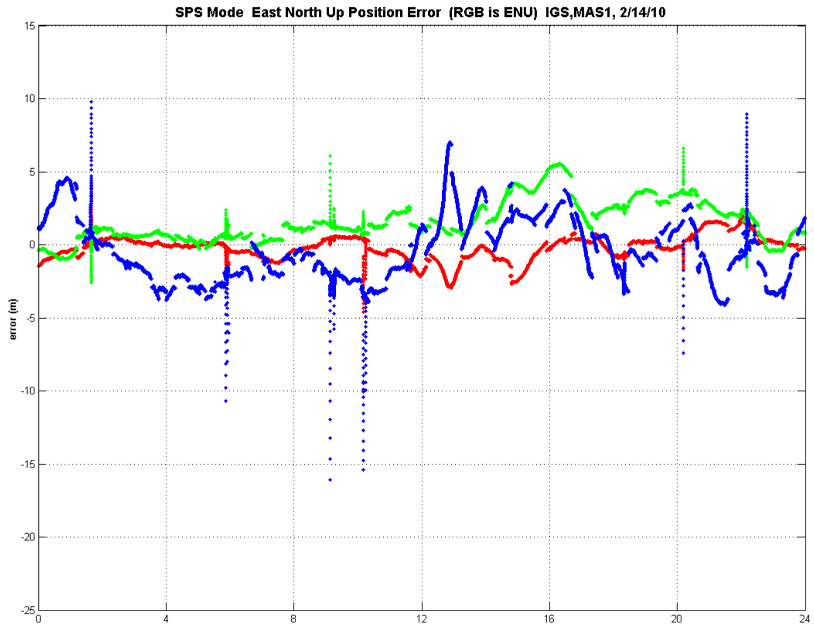


Figure 7-5 Example 1 of Receiver Performance at SANT

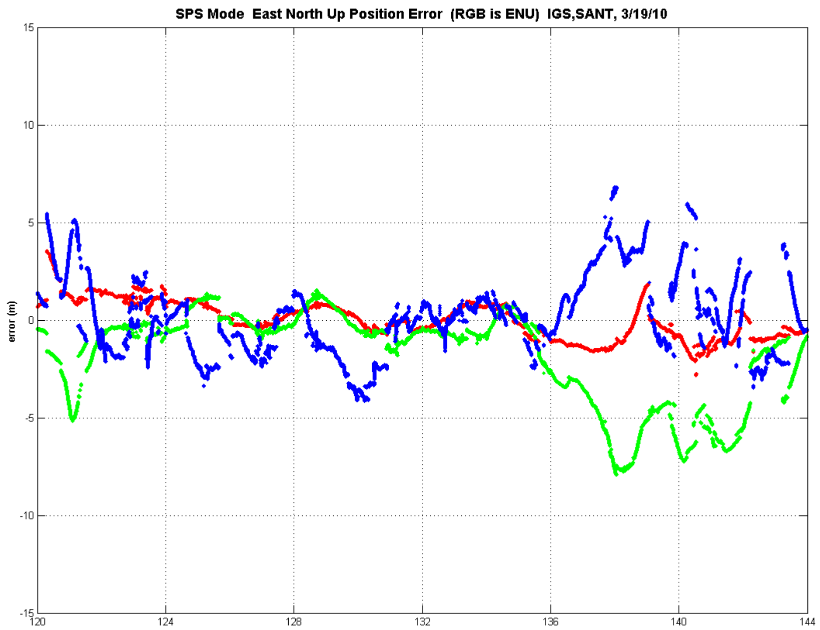
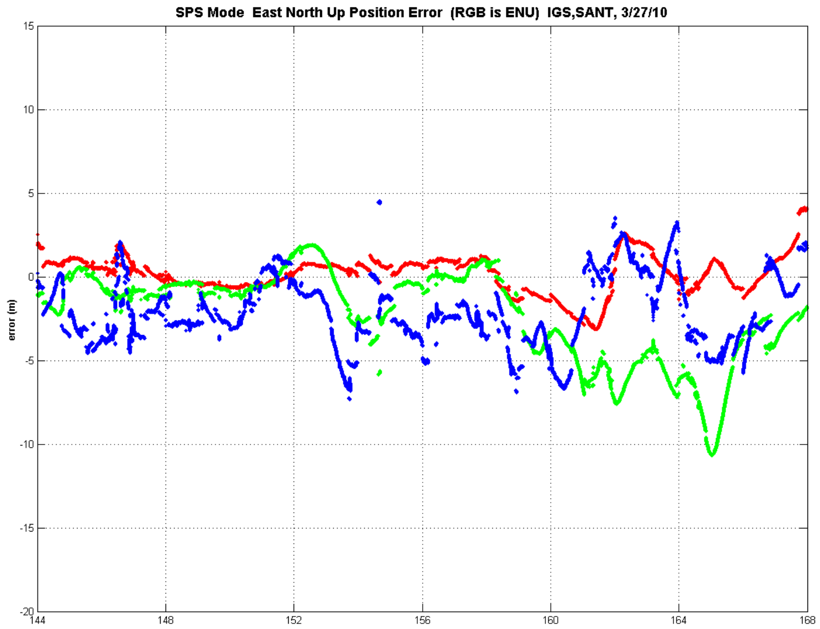


Figure 7-6 Example 2 of Receiver Performance at SANT



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	≥ 99.965% ≥ 97.153%
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)	2.240 m 4.208 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)	4.339 m 5.356 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)	11 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	2.329 meters

```
#  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 - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2010 01 01	2	0 0 0 0 0 1 1 2	0	0 0 0 0 0 0 0 0	1	1 0 0 0 0 0 3 1
2010 01 02	1	0 0 0 0 0 2 1 0	0	0 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 1
2010 01 03	3	0 1 1 2 2 1 0 0	4	0 0 0 3 3 1 0 0	3	0 1 1 2 2 0 0 0
2010 01 04	1	0 0 1 1 0 0 1 0	1	0 0 2 2 0 0 0 0	2	0 0 2 1 0 0 0 0
2010 01 05	1	0 0 0 0 1 1 1 0	0	0 0 0 0 0 0 0 0	1	0 0 0 0 0 1 0 0
2010 01 06	0	1 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 0	1	0 1 0 0 0 0 0 0
2010 01 07	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 0 1
2010 01 08	0	0 0 0 0 0 1 0 0	1	0 0 2 0 0 0 0 0	2	0 0 1 0 0 1 0 0
2010 01 09	1	0 0 0 0 1 1 0 0	1	0 0 0 1 1 0 0 0	1	0 0 0 0 1 1 0 1
2010 01 10	2	0 0 0 1 1 1 1 0	3	0 0 0 2 3 1 0 0	2	0 0 0 1 1 1 0 1
2010 01 11	4	0 2 2 1 2 2 1 0	7	0 0 2 4 3 1 1 0	6	0 2 2 2 2 2 1 1
2010 01 12	2	0 2 0 0 0 0 2 1	0	0 0 0 0 0 0 0 0	3	1 2 0 0 0 0 1 2
2010 01 13	4	2 2 1 0 1 1 1 2	5	1 2 1 1 2 3 0 0	6	3 2 1 1 1 2 0 2
2010 01 14	3	2 2 0 1 1 1 1 0	2	1 0 0 2 2 0 0 0	4	2 1 0 1 1 1 1 1
2010 01 15	2	0 1 1 0 0 1 2 1	1	0 0 1 0 0 0 0 1	3	1 0 1 0 0 1 2 2
2010 01 16	1	0 0 0 0 0 2 0 0	0	0 0 0 1 0 0 0 0	1	0 0 0 0 0 0 0 0
2010 01 17	1	0 1 0 0 1 1 0 0	0	0 0 0 0 0 0 0 0	1	0 1 0 0 0 0 0 1
2010 01 18	2	0 1 0 0 1 1 0 1	1	0 0 0 0 0 1 0 0	3	0 1 1 0 1 1 1 1
2010 01 19	2	1 0 0 0 0 2 1 0	0	0 0 0 1 0 0 0 0	1	1 0 0 0 0 0 0 1
2010 01 20	6	1 0 2 1 2 3 2 2	14	0 0 1 0 4 5 4 2	14	1 0 1 0 2 5 4 4
2010 01 21	4	2 2 2 1 1 1 0 0	9	2 2 3 4 3 1 0 0	4	1 3 2 1 1 0 0 0
2010 01 22	2	1 1 0 1 1 1 0 1	1	0 0 0 2 0 0 0 0	2	1 1 0 0 0 0 0 1
2010 01 23	4	2 1 1 2 1 0 1 1	7	1 0 2 4 3 1 0 0	4	2 1 2 2 1 0 0 1
2010 01 24	2	0 1 1 2 1 0 0 0	10	0 1 3 4 4 2 1 0	4	1 1 2 2 1 0 0 1
2010 01 25	3	0 1 2 0 2 2 0 0	2	0 0 2 1 2 0 0 0	3	0 0 1 0 2 0 0 2
2010 01 26	1	1 1 0 0 0 0 0 0	1	0 0 1 0 0 0 1 0	3	2 1 1 0 0 0 1 1
2010 01 27	0	0 0 0 1 0 0 0 0	0	0 0 0 1 0 0 0 0	2	1 0 0 1 1 1 0 1
2010 01 28	2	0 0 0 0 2 1 1 0	0	0 0 0 0 0 1 0 0	3	1 0 0 0 1 1 2 1
2010 01 29	0	0 0 0 0 0 0 0 0	0	0 0 0 1 0 0 0 0	2	0 0 0 1 0 0 0 1
2010 01 30	3	1 1 1 0 1 1 1 2	2	0 0 0 0 2 1 1 1	4	1 1 1 0 1 1 1 2
2010 01 31	3	2 1 0 1 1 1 1 1	4	1 0 0 2 3 2 0 0	3	2 1 0 1 1 0 1 1
2010 02 01	7	1 0 2 1 3 2 1 3	11	0 0 1 3 5 3 2 1	6	1 1 1 1 2 2 1 3
2010 02 02	7	3 2 1 1 1 1 1 3	10	1 2 1 3 3 3 1 3	9	3 2 1 2 2 2 1 4
2010 02 03	7	3 0 3 2 2 2 1 1	18	4 0 4 4 4 4 1 1	9	3 1 3 3 3 2 2 1
2010 02 04	2	2 1 0 0 1 0 0 1	0	0 0 0 0 0 0 0 0	2	2 1 0 0 0 1 1 1
2010 02 05	0	0 1 0 0 0 0 0 0	1	0 0 0 1 1 0 0 0	3	0 0 0 0 1 2 1 1
2010 02 06	2	0 0 0 0 1 2 1 0	8	0 0 0 1 4 4 1 0	4	0 0 0 0 2 3 1 1
2010 02 07	2	0 0 0 0 0 1 2 2	1	0 0 0 1 0 0 1 1	3	1 0 0 0 0 1 1 2
2010 02 08	3	2 2 1 1 0 0 0 2	1	1 1 0 0 0 0 0 1	3	2 2 1 0 0 0 0 1
2010 02 09	1	0 1 0 1 0 1 0 0	0	0 0 0 0 0 0 0 0	3	1 0 1 0 1 2 0 1
2010 02 10	1	0 1 0 1 0 0 0 0	1	0 0 0 2 1 0 0 0	3	1 1 1 1 1 1 1 1
2010 02 11	4	2 2 2 0 2 0 0 1	3	1 1 2 2 1 0 0 0	5	2 2 2 1 2 2 1 1
2010 02 12	4	2 2 1 0 1 1 1 1	5	0 3 3 1 1 2 0 0	6	1 3 2 0 1 2 1 1
2010 02 13	2	1 1 0 0 0 1 1 1	1	0 1 0 0 0 0 1 0	3	1 1 0 0 0 2 1 2
2010 02 14	3	0 0 0 3 2 0 0 1	3	0 0 0 3 2 0 0 1	4	0 0 1 1 1 0 0 3
2010 02 15	8	2 3 1 1 1 1 3 3	16	2 3 3 4 3 3 3 3	14	3 3 1 2 1 2 4 4
2010 02 16	11	4 1 3 3 1 1 1 3	14	4 2 3 5 1 1 1 1	9	4 2 3 3 0 1 0 3
2010 02 17	2	2 1 0 0 0 0 0 2	3	2 2 1 1 0 0 0 1	4	2 2 0 0 0 0 0 2
2010 02 18	2	0 0 0 0 2 1 1 0	8	4 0 0 0 3 3 2 0	4	0 0 0 0 2 2 2 1
2010 02 19	3	1 0 0 0 1 1 2 2	4	1 0 1 1 3 0 1 1	3	1 0 0 0 1 1 1 2
2010 02 20	0	0 0 0 0 1 0 0 0	0	0 0 0 0 0 1 0 0	1	0 0 0 0 0 0 0 1
2010 02 21	3	3 0 0 0 2 0 1 0	0	0 0 0 0 1 0 0 0	1	0 0 0 0 1 0 0 1
2010 02 22	3	0 1 0 1 1 2 1 1	6	0 0 0 3 2 1 1 1	4	1 1 0 1 1 1 1 2
2010 02 23	2	2 1 0 0 0 1 0 0	2	1 1 0 1 1 0 0 0	2	2 1 0 0 0 0 1 0
2010 02 24	2	0 2 0 1 0 1 0 0	2	0 1 0 1 0 1 1 1	3	1 3 0 0 0 1 0 1
2010 02 25	2	1 0 0 0 0 1 1 2	1	0 0 0 1 0 0 1 1	2	1 0 0 0 0 0 1 2
2010 02 26	1	2 0 0 0 1 0 0 0	0	1 0 0 0 0 0 0 0	2	1 0 0 0 0 0 0 1
2010 02 27	0	0 0 0 0 0 1 0 0	0	0 0 0 0 0 0 1 0	2	0 0 0 0 0 1 1 1
2010 02 28	2	0 0 1 0 2 0 0 1	1	0 0 1 0 1 0 0 0	2	0 0 1 0 1 1 0 1

2010 03 01	4	1	1	1	1	2	1	1	1	5	2	1	1	1	3	1	1	1	5	1	1	1	1	2	2	1	2
2010 03 02	3	0	0	0	2	2	1	1	1	8	0	0	0	4	4	2	0	0	4	0	0	0	2	2	2	1	2
2010 03 03	5	1	2	0	1	2	2	2	2	-1	0	1	0	3	-1	-1	-1	-1	6	1	2	0	2	2	2	2	2
2010 03 04	4	1	2	1	0	2	1	1	1	7	0	2	1	0	4	3	1	0	6	2	3	2	0	2	1	1	1
2010 03 05	1	0	0	1	1	1	0	0	0	7	0	0	3	4	3	0	0	0	2	0	0	1	1	1	1	0	1
2010 03 06	3	2	0	0	0	0	1	1	2	1	1	0	0	0	0	0	0	1	3	2	0	0	0	1	1	1	1
2010 03 07	3	1	2	2	0	1	0	0	0	6	1	3	4	1	1	0	0	0	4	2	3	2	0	0	0	0	1
2010 03 08	1	1	1	1	0	0	0	0	0	1	0	0	1	1	0	1	0	0	3	1	1	1	0	0	1	1	1
2010 03 09	2	0	0	0	0	2	1	1	1	0	0	0	0	0	1	0	0	0	2	0	0	0	0	1	1	0	1
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2010 03 12	6	2	3	2	1	2	1	1	1	13	1	2	2	3	5	4	0	0	9	2	4	2	2	2	2	1	2
2010 03 13	2	1	0	0	0	1	1	1	0	1	0	0	1	2	0	0	0	0	4	1	0	0	0	0	2	2	1
2010 03 14	2	1	1	1	0	1	1	0	1	9	1	0	4	2	4	2	0	1	6	2	1	1	1	2	2	1	2
2010 03 15	2	1	0	0	0	1	1	2	1	1	0	0	0	0	0	1	1	0	3	1	0	0	0	0	2	2	1
2010 03 16	3	0	1	2	0	1	1	1	1	2	0	1	0	0	2	0	1	0	4	1	0	1	0	1	1	1	2
2010 03 17	5	1	3	2	1	1	0	1	2	4	1	3	2	0	0	0	0	1	7	1	4	2	1	0	0	1	3
2010 03 18	4	3	2	0	0	1	0	1	1	2	1	2	0	0	0	1	1	1	5	2	3	0	0	0	1	2	2
2010 03 19	2	0	0	1	0	1	1	1	1	2	0	0	1	1	1	1	1	1	4	0	0	1	1	0	2	2	2
2010 03 20	5	1	2	2	1	2	1	2	0	9	1	1	4	1	3	2	3	0	7	1	3	3	1	2	1	2	1
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2010 03 24	2	0	0	0	0	2	1	0	1	4	0	0	0	0	3	3	0	0	3	0	0	0	0	2	2	0	2
2010 03 25	4	1	2	0	1	2	1	2	1	2	0	0	0	0	1	1	2	0	5	1	1	0	1	2	2	2	1
2010 03 26	2	0	1	1	0	1	0	0	2	8	0	0	2	2	5	0	0	1	4	0	1	1	0	2	0	0	2
2010 03 27	1	1	2	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	3	2	2	0	0	1	1	1	1
2010 03 28	4	0	3	2	1	1	1	1	0	12	0	3	4	3	4	2	1	0	7	0	3	2	2	2	2	1	1
2010 03 29	5	2	1	1	1	2	1	0	3	2	0	0	1	1	1	1	0	0	4	2	0	1	1	1	2	0	2
2010 03 30	4	2	1	1	0	1	1	2	2	4	2	1	1	1	0	1	2	2	5	2	1	0	1	1	1	2	2
2010 03 31	5	2	2	1	2	1	0	1	2	6	1	1	1	4	0	0	1	2	4	1	2	0	1	1	1	0	2

Appendix C Performance Analysis (PAN) Problem Report

Background:

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