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

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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 #68, includes data collected from 1 October through 31 December 2009. The next quarterly report will be issued April 30, 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° 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 99.983% or better.

NANU summary and evaluation was achieved by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 October and 31 December 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 fifteen outages were reported in the NANU's this quarter. Twelve outages were scheduled while three were 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 13.062 meters on Satellite PRN 10. 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 2.477 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 4.02 meters at Maspalomas and 5.91 meters at Usuda, respectively.

From the analysis performed on data collected between 1 October and 31 December 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

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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° 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 3.589 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%)
4 – 10 October	3.1544	99.998	99.514
11 – 17 October	3.1777	99.999	99.653
18 – 24 October	3.5503	99.998	99.653
25 – 31 October	3.5342	99.998	99.306
1 – 7 November	3.5304	99.983	98.889
8 – 14 November	3.5890	99.999	99.722
15 – 21 November	3.1744	100	99.792
22 – 28 November	3.1283	100	99.861
29 Nov – 5 December	3.1272	100	100
6 – 12 December	3.1220	100	100
13 – 19 December	3.1192	100	100
20 – 26 December	3.1177	100	100
27 Dec – 2 January	3.1227	99.998	99.375

11/02/09 World GPS Maximum PDOP
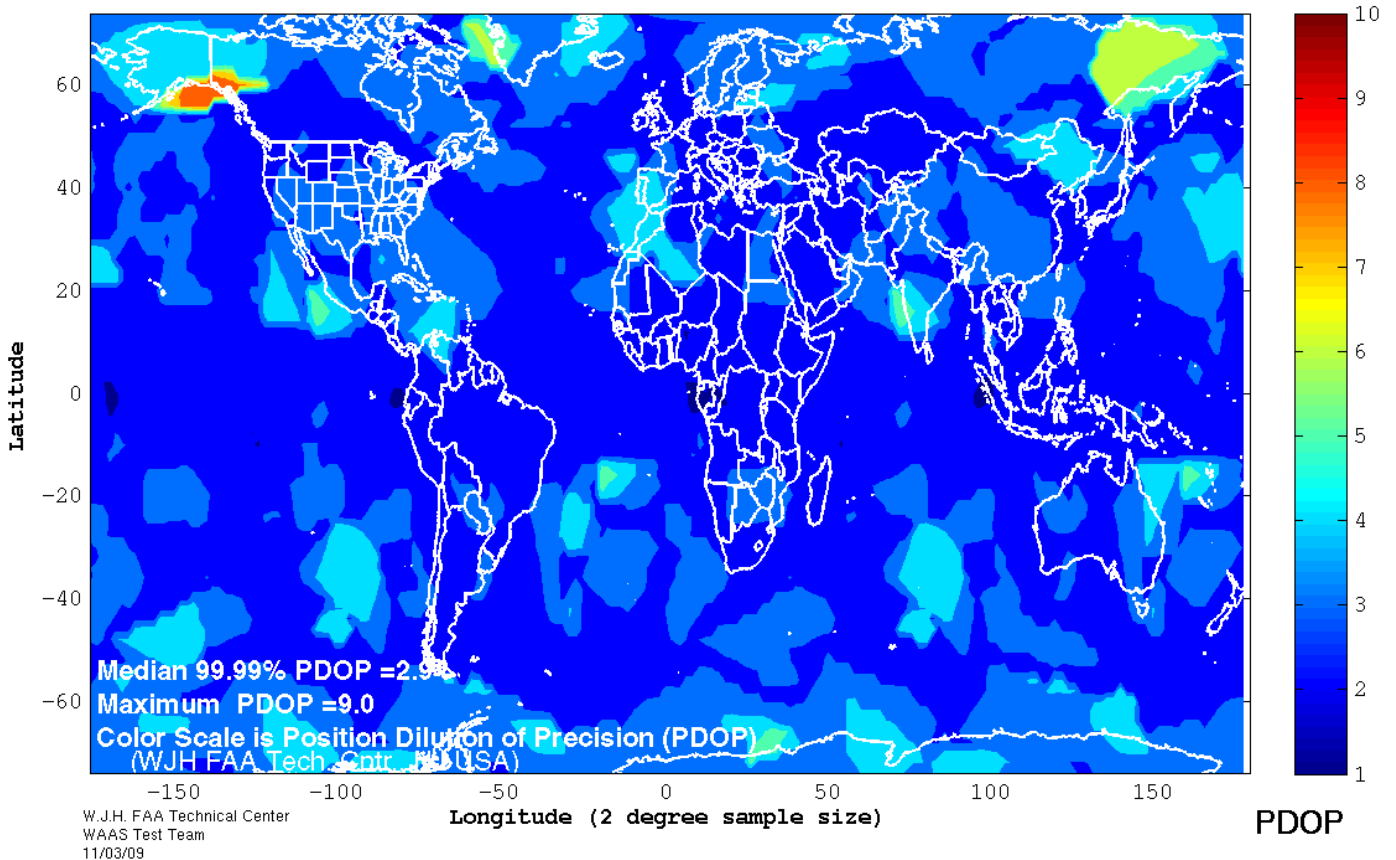
Figure 2-2   Satellite Visibility Profile for Worst-Case Point (Lat: 70, Lon: 140)
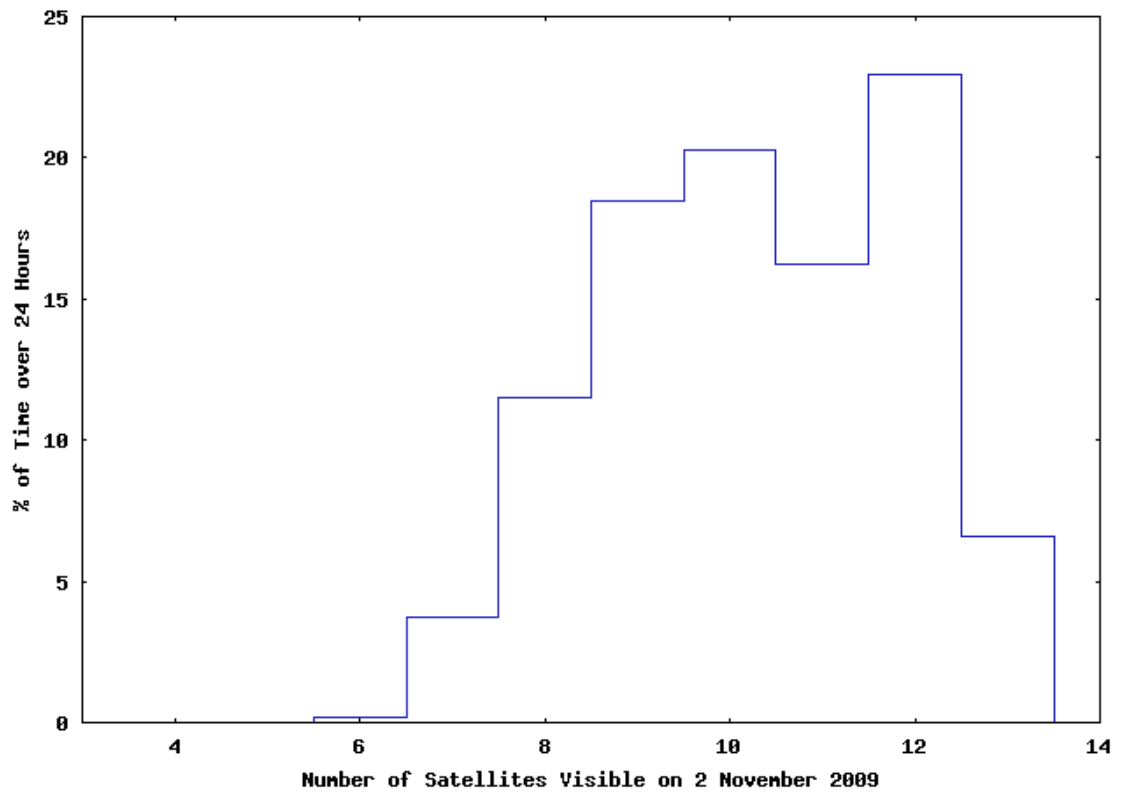
3.0 NANU Summary and Evaluation

> *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 October through 31 December 2009, 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
2009079	31	FCSTSUMM	08-Oct	08:42	08-Oct	14:57		6.25	6.25
2009097	27	FCSTSUMM	22-Oct	16:12	22-Oct	22:03		5.85	5.85
2009098	30	FCSTSUMM	23-Oct	13:27	23-Oct	18:40		5.22	5.22
2009099	30	FCSTSUMM	24-Oct	13:00	25-Oct	00:11		11.18	11.18
2009103	8	UNUSABLE	14-Oct	21:32	27-Oct	00:04	290.53		290.53
2009106	30	FCSTSUMM	31-Oct	13:32	31-Oct	22:40		9.13	9.13
2009108	30	FCSTSUMM	02-Nov	13:06	03-Nov	00:41		11.58	11.58
2009113	25	UNUSABLE	26-Oct	13:38	05-Nov	23:31	249.88		249.88
2009115	25	FCSTSUMM	10-Nov	11:17	10-Nov	16:49		5.53	5.53
2009117	6	FCSTSUMM	12-Nov	21:12	13-Nov	04:43		7.52	7.52
2009118	12	FCSTSUMM	17-Nov	13:38	17-Nov	19:13		5.58	5.58
2009119	8	UNUSABLE	05-Nov	19:02	20-Nov	17:51	358.82		358.82
2009123	5	FCSTSUMM	07-Dec	14:18	07-Dec	14:52		0.57	0.57
2009124	7	FCSTSUMM	09-Dec	07:07	09-Dec	13:11		6.07	6.07
2009125	8	FCSTSUMM	11-Dec	11:37	11-Dec	18:28		6.85	6.85
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**899.23**	**81.33**	**980.57**

Table 3-2 NANUs Forecasted to Affect Satellite Availability							
NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2009078	8	FCSTMX	19-Oct	14:30	20-Oct	02:30	12	CANC
2009081	6	FCSTDV	05-Nov	10:30	06-Nov	00:30	14	CANC
2009084	8	UNUSUFN	14-Oct	21:32	N/A	N/A	N/A	See Nanu 2009103
2009085	27	FCSTMX	22-Oct	16:00	23-Oct	00:00	8	See Nanu 2009097
2009086	30	FCSTMX	23-Oct	13:00	24-Oct	02:00	13	See Nanu 2009098
2009087	30	FCSTMX	24-Oct	13:00	25-Oct	02:00	13	See Nanu 2009099
2009088	30	FCSTMX	25-Oct	13:00	26-Oct	02:00	13	CANC
2009089	30	FCSTMX	27-Oct	13:00	28-Oct	02:00	13	CANC
2009090	30	FCSTMX	31-Oct	13:00	01-Nov	02:00	13	CANC
2009092	30	FCSTMX	31-Oct	13:00	01-Nov	02:00	13	See Nanu 2009106
2009093	18	FCSTMX	01-Nov	13:00	02-Nov	02:00	13	CANC
2009094	30	FCSTMX	02-Nov	13:00	03-Nov	02:00	13	See Nanu 2009108
2009095	18	FCSTMX	03-Nov	13:00	04-Nov	02:00	13	CANC
2009096	30	FCSTMX	04-Nov	13:00	05-Nov	02:00	13	CANC
2009101	25	UNUSUFN	26-Oct	13:38	N/A	N/A	N/A	See Nanu 2009113
2009111	8	UNUSUFN	05-Nov	19:02	N/A	N/A	N/A	See Nanu 2009119
2009112	25	FCSTDV	10-Nov	11:00	11-Nov	01:00	14	See Nanu 2009115
2009114	6	FCSTDV	12-Nov	21:00	13-Nov	12:00	15	See Nanu 2009117
2009116	12	FCSTDV	17-Nov	13:20	18-Nov	02:00	12.67	See Nanu 2009118
2009120	5	FCSTMX	07-Dec	14:00	07-Dec	22:00	8	See Nanu 2009123
2009121	7	FCSTDV	09-Dec	06:45	09-Dec	21:00	14.25	See Nanu 2009124
2009122	8	FCSTDV	11-Dec	11:15	11-Dec	23:30	12.25	See Nanu 2009125
2009130	25	UNUSUFN	18-Dec	15:22	N/A	N/A	N/A	
2009133	24	FCSTDV	06-Jan	16:15	07-Jan	16:15	24	CANC
					Total Forecast Downtime		**264.17**	

Table 3-3 NANUs Canceled					
NANU#	PRN	Type	Start Date	Start Time	Comments
2009082	8	FCSTCANC	19-Oct	14:30	See Nanu 2009078
2009100	30	FCSTCANC	25-Oct	13:00	See Nanu 2009088
2009102	30	FCSTCANC	27-Oct	13:00	See Nanu 2009089
2009104	18	FCSTCANC	01-Nov	13:00	See Nanu 2009093
2009105	30	FCSTCANC	31-Oct	13:00	See Nanu 2009090
2009107	18	FCSTCANC	03-Nov	13:00	See Nanu 2009095
2009109	30	FCSTCANC	04-Nov	13:00	See Nanu 2009096
2009110	6	FCSTCANC	05-Nov	10:30	See Nanu 2009081
2009134	24	FCSTCANC	06-Jan	16:15	See Nanu 2009133

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-Oct-09	1-Oct-99
	31-Dec-09	31-Dec-09
Total Forecast Downtime (hrs):	264.17	7310.07
Total Actual Downtime (hrs):	980.57	26235.51
Total Actual Scheduled Downtime (hrs):	81.33	3778.28
Total Actual Unscheduled Downtime (hrs):	899.23	22457.23
Total Satellite Observed MTTR (hrs):	65.37	45.71
Scheduled Satellite Observed MTTR (hrs):	6.78	9.15
Unscheduled Satellite Observed MTTR (hrs):	299.75	139.49
# Total Satellite Outages:	15	574
# Scheduled Satellite Outages:	12	413
# Unscheduled Satellite Outages:	3	161
Percent Operational -- Scheduled Downtime:	99.881	99.828
Percent Operational -- All Downtime:	99.955	98.808

General NANU's

2009091: PRN 30 and PRN 18 to have healthy status testing
2009126: PRN 6 and PRN 21 remain usable during test of new ground software
2009127: Correction to times of testing on NANU 2009126
2009128: PRN 25 Unusable no earlier than day 352/1500 until further notice
2009129: PRN 24 Unusable during transition into almanac day 355/2200 until further notice
2009131: PRN 25 set unusable day 352/1522 and decommissioned 352/2228
2009132: PRN 24 usable day 356/2311

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 October and 31 December 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	7922576	0	100%
Anchorage	7824178	0	100%
Atlanta	7817442	0	100%
Barrow	7922966	0	100%
Bethel	6875028	0	100%
Billings	7925716	0	100%
Boston	7921871	0	100%
Cleveland	7772746	0	100%
Cold Bay	4114564	0	100%
Fairbanks	7924354	0	100%
Gander	7919173	0	100%
Honolulu	7922439	0	100%
Houston	7503337	0	100%
Iqaluit	7916498	0	100%
Juneau	7923936	0	100%
Kansas City	7924687	0	100%
Kotzebue	7885831	0	100%
Los Angeles	7922678	0	100%
Merida	7924115	0	100%
Miami	7901495	0	100%
Minneapolis	7925267	0	100%
Oakland	7923737	0	100%
Salt Lake City	7922069	0	100%
San Jose Del Cabo	7922710	0	100%
San Juan	7900960	0	100%
Seattle	7480556	0	100%
Tapachula	7836574	0	100%
Washington, DC	7810654	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 13.062 meters on satellite PRN 10.

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 Apr – 30 Jun 2009	**Boston**	64,010,833	0	100%
1 Apr – 30 Jun 2009	**Honolulu**	67,774,730	0	100%
1 Apr – 30 Jun 2009	**Los Angeles**	65,455,440	0	100%
1 Apr – 30 Jun 2009	**Miami**	65,371,438	0	100%
1 Apr – 30 Jun 2009	**San Juan**	68,040,382	0	100%
1 Apr – 30 Jun 2009	**Juneau**	67,915,276	0	100%
1 Apr – 30 Jun 2009	**Global**	398,568,099	0	100%

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 October through 31 December 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	1.926	3.838	4.255	9.467
Anchorage	1.787	4.440	3.883	8.202
Atlanta	2.375	4.370	5.152	9.555
Barrow	1.552	4.656	3.752	8.864
Bethel	1.954	4.764	7.577	10.739
Billings	2.222	3.787	5.093	8.001
Boston	2.497	3.958	4.757	7.030
Cleveland	2.362	3.840	4.810	9.028
Cold Bay	1.991	4.908	5.497	8.831
Fairbanks	1.635	4.553	3.695	8.855
Gander	2.560	3.579	4.456	7.734
Honolulu	3.555	4.886	6.309	8.666
Houston	2.259	4.125	4.008	10.164
Iqaluit	1.848	3.832	3.854	8.684
Juneau	1.878	4.143	4.607	8.721
Kansas City	2.269	4.005	4.545	8.621
Kotzebue	1.625	4.553	3.478	8.992
Los Angeles	1.915	4.474	3.620	8.173
Merida	2.023	4.299	5.648	9.974
Miami	2.076	4.790	4.205	10.259
Minneapolis	2.328	3.898	4.253	7.760
Oakland	1.987	4.421	4.719	10.358
Salt Lake City	2.053	3.903	4.183	9.682
San Jose Del Cabo	2.044	4.375	5.395	7.505
San Juan	2.044	4.831	5.092	10.691
Seattle	2.064	4.039	5.046	11.269
Tapachula	2.678	4.329	7.496	11.250
Washington, DC	2.445	4.059	5.184	8.746

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

Figure 5-1 Global Vertical Error Histogram
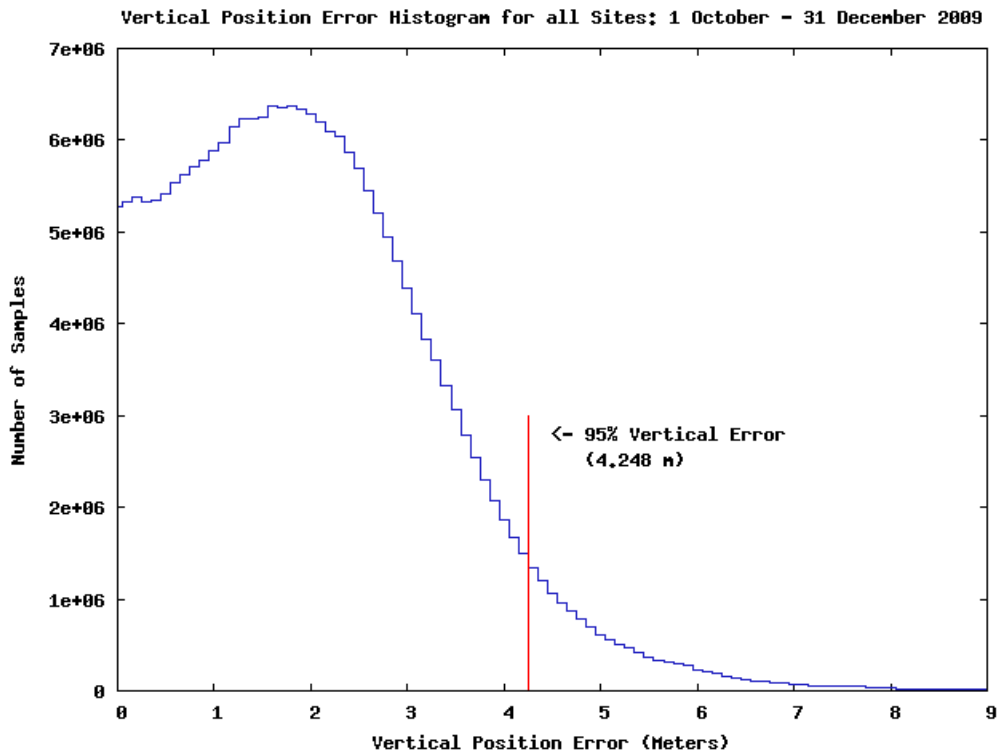
Figure 5-2 Global Horizontal Error Histogram
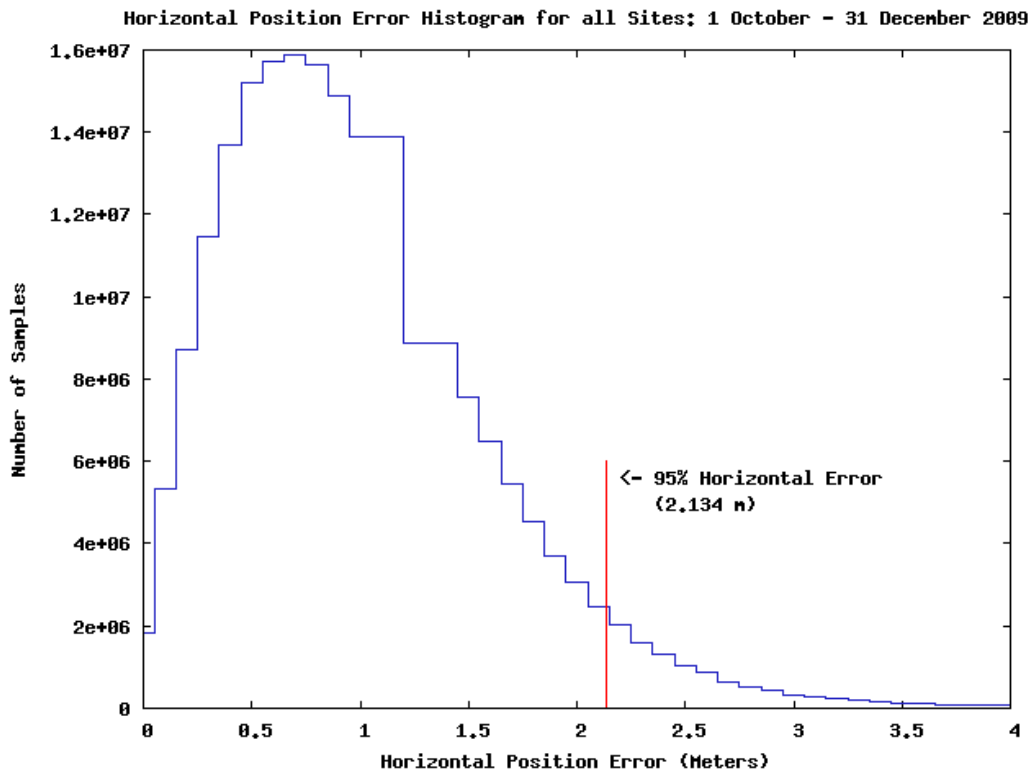
5.2 Time Transfer Accuracy

The GPS time error data between 1 October and 31 December 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
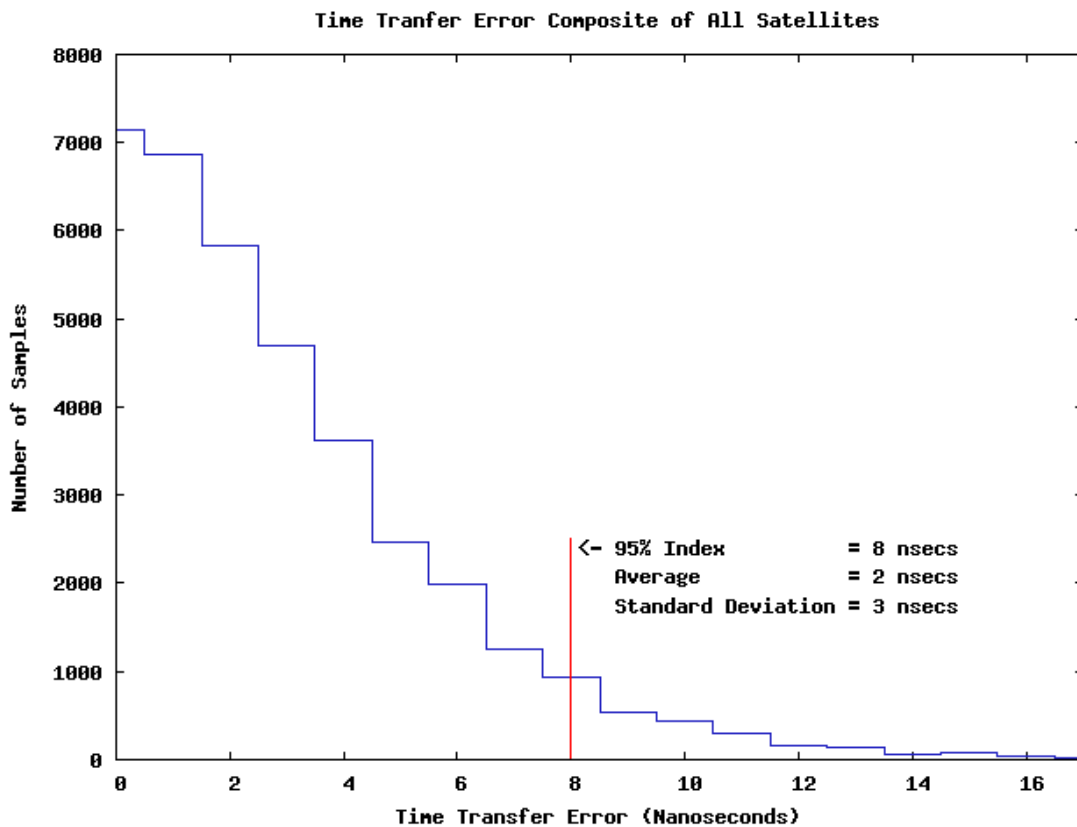
5.3 Range Domain Accuracy

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 October and 31 December 2009.

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 ($\leq$ 6 m)	Range Error Mean	1σ	95% Range Error	Max Range Error (SPS Spec. $\leq$ 30 m)	Samples
2	1.814	1.264	1.181	3.176	8.633	14443095
3	1.951	1.086	1.292	3.268	8.919	12622834
4	1.536	0.920	1.052	2.745	7.432	14102584
5	1.488	0.246	1.334	2.814	7.138	14261622
6	1.735	1.061	1.180	2.926	9.494	12746748
7	1.249	0.598	0.923	2.274	9.068	12220270
8	1.988	0.861	1.399	3.567	12.805	9175922
9	1.818	0.740	1.428	3.321	10.024	13329508
10	2.477	1.872	1.464	4.228	13.062	13464030
11	1.772	1.270	1.084	2.956	7.187	12555664
12	1.494	0.733	1.180	2.765	9.332	14583719
13	1.318	0.799	0.956	2.409	9.070	14163303
14	1.878	1.499	1.041	3.205	8.660	14437924
15	1.431	0.744	1.124	2.662	8.257	12932239
16	1.745	1.289	1.077	2.953	8.677	13241433
17	1.625	0.846	1.181	3.002	10.672	14406784
18	2.217	1.642	1.354	3.732	10.916	13371042
19	1.992	1.569	1.117	3.270	7.864	12763441
20	1.849	1.465	1.052	3.133	7.520	14452181
21	2.186	1.598	1.295	3.623	10.312	12431606
22	2.233	1.747	1.162	3.687	10.617	12737769
23	1.543	1.143	0.950	2.607	6.956	12980213
24	2.095	1.428	1.287	3.628	7.822	1236512
25	1.460	0.683	0.982	2.533	9.803	9115917
26	1.648	1.069	1.091	2.931	9.236	14158619
27	1.920	0.759	1.525	3.506	12.291	13828313
28	2.007	1.365	1.251	3.414	8.711	12886730
29	1.372	0.545	1.039	2.527	8.672	13877321
30	1.744	0.501	1.384	3.260	10.071	13268873
31	1.411	0.742	1.066	2.610	8.651	14257866
32	1.806	1.397	1.021	3.036	9.300	14514017

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	1.379	2.673	69.60	14443095
3	1.747	2.817	161.45	12622834
4	1.372	2.548	125.39	14102584
5	1.536	2.783	63.96	14261622
6	1.294	2.429	112.55	12746748
7	1.341	2.526	190.39	12220270
8	2.075	3.045	279.08	9175922
9	2.001	2.860	174.75	13329508
10	1.807	2.979	158.69	13464030
11	1.389	2.581	115.28	12555664
12	1.438	2.808	52.97	14583719
13	1.415	2.718	77.18	14163303
14	1.342	2.570	96.40	14437924
15	1.355	2.618	34.20	12932239
16	1.358	2.627	92.84	13241433
17	1.426	2.662	126.13	14406784
18	1.439	2.704	72.48	13371042
19	1.308	2.493	152.17	12763441
20	1.354	2.609	100.12	14452181
21	1.458	2.822	47.56	12431606
22	1.595	2.816	172.51	12737769
23	1.267	2.431	80.82	12980213
24	1.653	2.677	125.04	1236512
25	1.210	2.261	127.40	9115917
26	1.341	2.524	101.37	14158619
27	2.105	2.820	168.93	13828313
28	1.435	2.591	114.55	12886730
29	1.412	2.642	147.25	13877321
30	1.779	2.909	150.18	13268873
31	1.435	2.559	127.72	14257866
32	1.294	2.366	117.46	14514017

Table 5-4 Range Acceleration Error Statistics (<u>micro</u>meters/second²)

PRN	Range Acceleration Error RMS (µm/s²)	95% Range Acceleration Error (µm/s²)	Max Range Acceleration Error (µm/s²)	Samples
2	10.064	20.284	700	14443095
3	13.459	22.427	1620	12622834
4	10.608	19.820	1240	14102584
5	10.940	21.153	630	14261622
6	10.467	19.306	1130	12746748
7	10.206	20.019	1880	12220270
8	16.388	24.759	2750	9175922
9	15.772	21.427	1740	13329508
10	13.441	22.680	1590	13464030
11	10.584	20.133	1160	12555664
12	10.013	20.885	530	14583719
13	10.258	21.829	770	14163303
14	10.132	20.000	850	14437924
15	10.018	20.072	340	12932239
16	10.037	20.280	930	13241433
17	10.563	20.177	1250	14406784
18	10.391	20.354	710	13371042
19	10.125	19.984	1520	12763441
20	10.057	20.155	990	14452181
21	10.166	21.129	470	12431606
22	11.688	21.556	1720	12737769
23	10.040	19.969	810	12980213
24	13.408	20.378	1260	1236512
25	10.348	16.529	1270	9115917
26	10.373	19.718	990	14158619
27	16.876	20.524	1690	13828313
28	11.021	20.073	1140	12886730
29	10.608	20.105	1480	13877321
30	13.387	21.467	1510	13268873
31	10.977	20.080	1280	14257866
32	10.552	18.923	1170	14514017

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 10 with an error of 13.062 meters. Satellite 23 had the lowest maximum range error of 6.956 meters.

Figure 5-4   Distribution of Daily Max Range Errors

Distribution of Daily Max Range Errors, All Receivers: 1 October - 31 December 2009
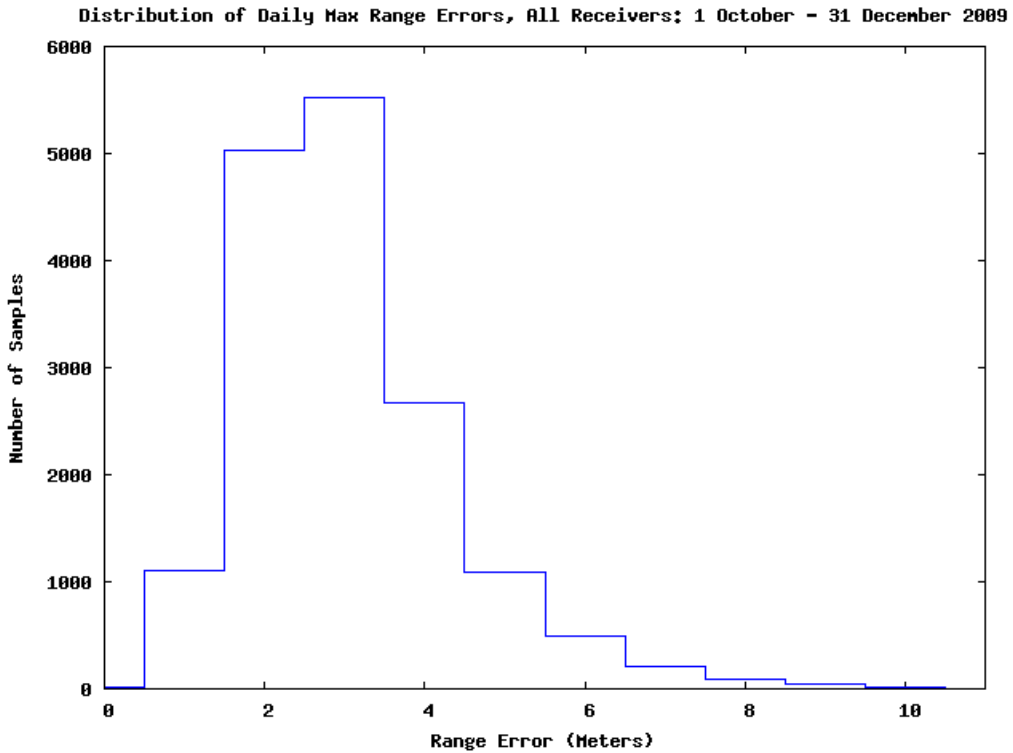
Figure 5-5: Distribution of Daily Max Range Rate Errors

Distribution of Daily Max Range Rate Errors, All Receivers: 1 October - 31 December 200
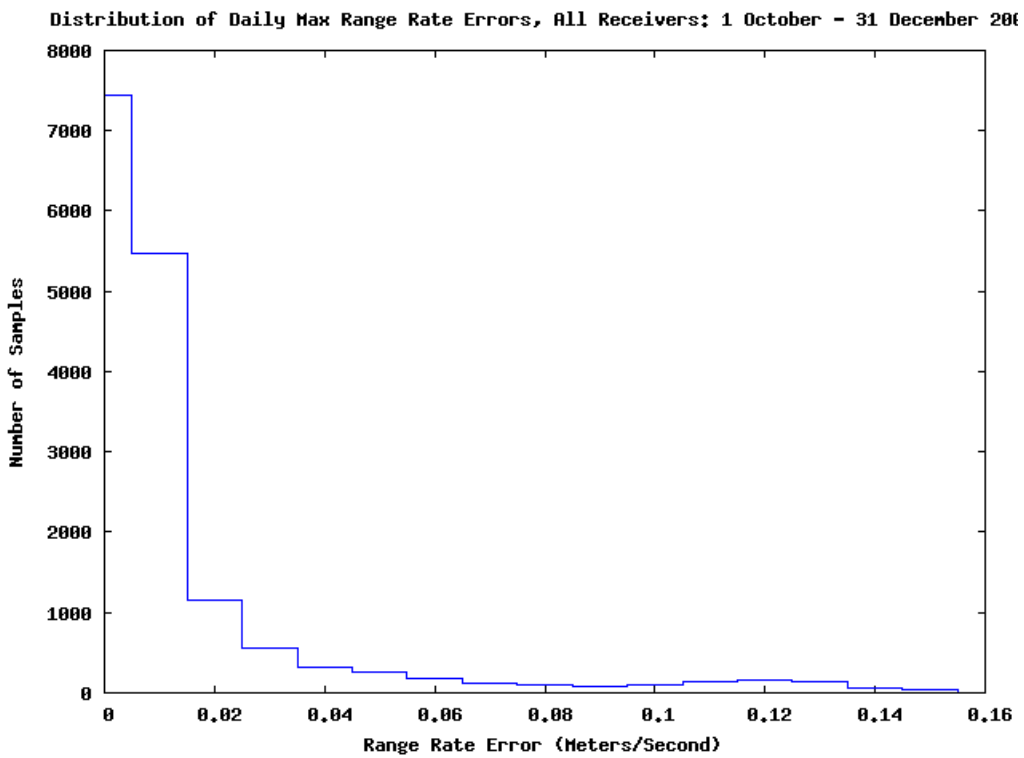
Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

istribution of Daily Max Range Rate Acceleration Errors, All Receivers: 1 October - 31 Decem
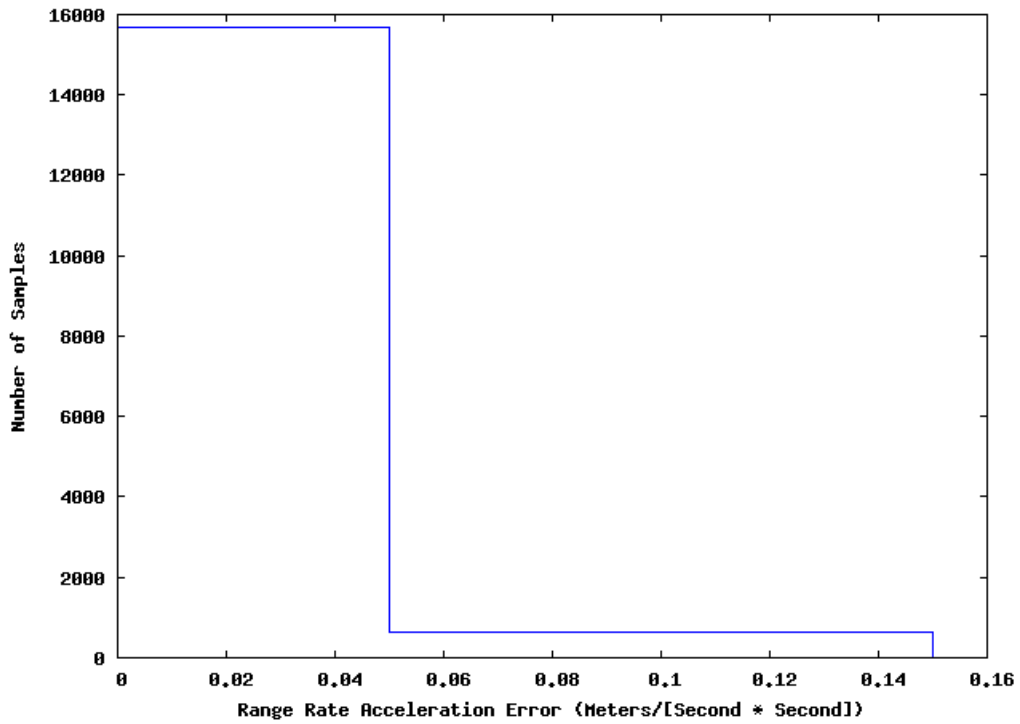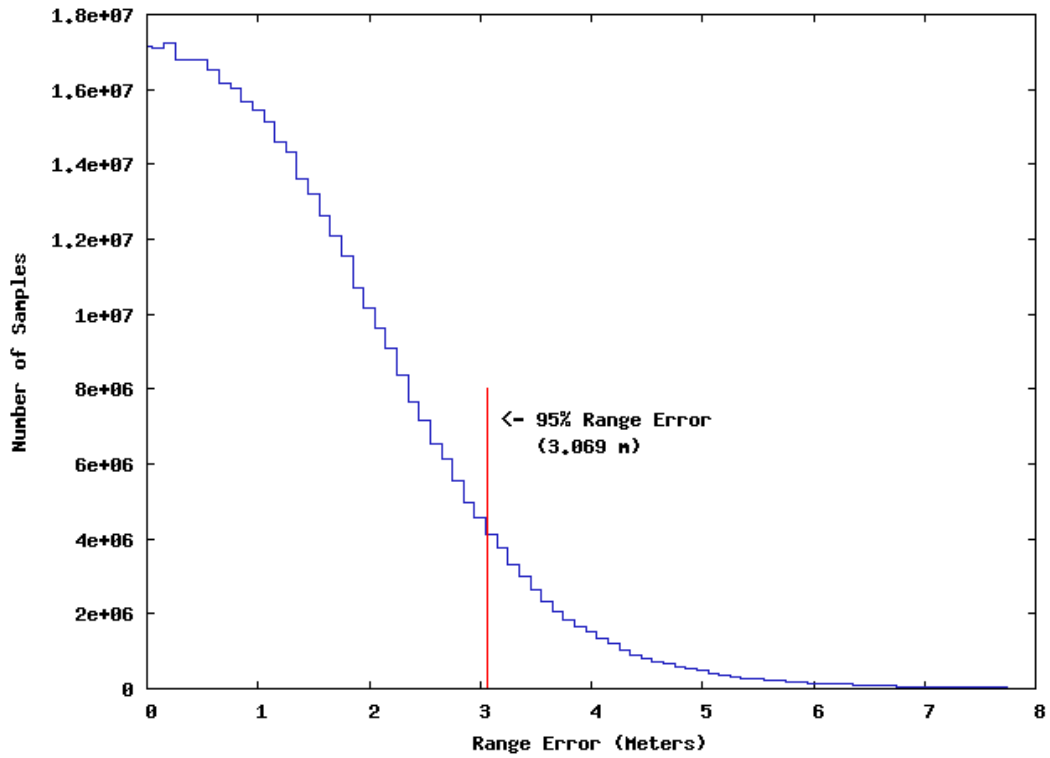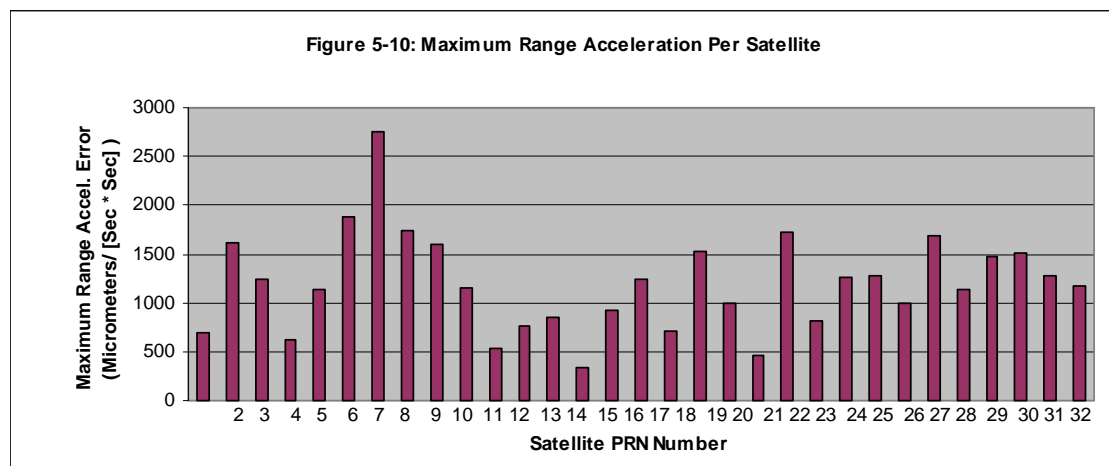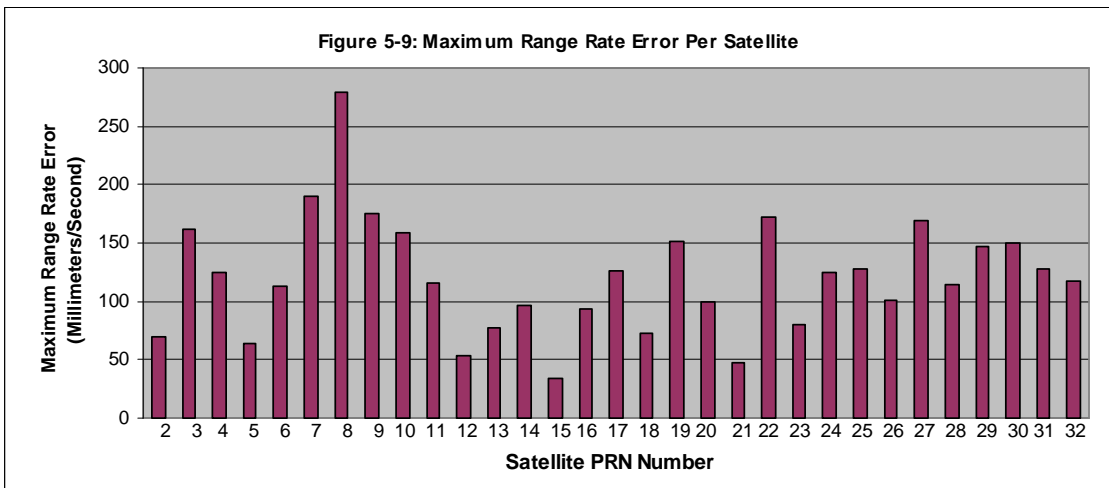

Figure 5-7: Range Error Histogram

Figure 5-8: Maximum Range Error Per Satellite

Figure 5-9: Maximum Range Rate Error Per Satellite

Figure 5-10: Maximum Range Acceleration Per Satellite
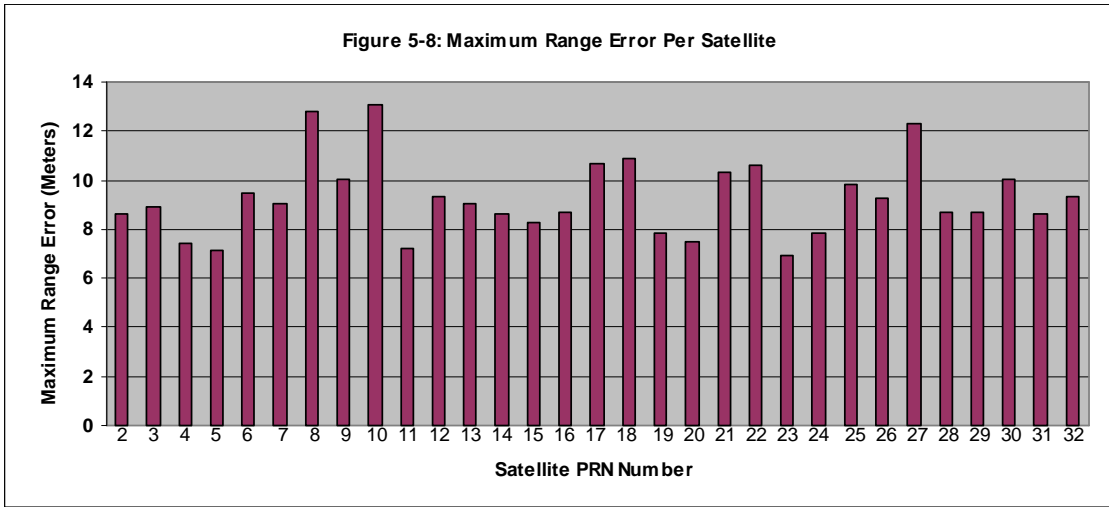
6.0 Solar Storms

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

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

The aurora is caused by the interaction of high-energy particles (usually electrons) with neutral atoms in the earth's upper atmosphere. These high-energy particles can 'excite' (by collisions) valence electrons that are bound to the neutral atom. The 'excited' electron can then 'de-excite' and return back to its initial, lower energy state, but in the process it releases a photon (a light particle). The combined effect of many photons being released from many atoms results in the aurora display that you see.

The details of how high energy particles are generated during geomagnetic storms constitute an entire discipline of space science in its own right. The basic idea, however, is that the Earth's magnetic field (let us say the 'geomagnetic field') is responding to an outwardly propagating disturbance from the Sun. As the geomagnetic field adjusts to this disturbance, various components of the Earth's field change form, releasing magnetic energy and thereby accelerating charged particles to high energies. These particles, being charged, are forced to stream along the geomagnetic field lines. Some end up in the upper part of the earth's neutral atmosphere and the auroral mechanism begins.

An instrument called a magnetometer may also measure the disturbance of the geomagnetic field. At NOAA's operations center magnetometer data is received from dozens of observatories in one-minute intervals. The data is received at or near to 'real-time' and allows NOAA to keep track of the current state of the geomagnetic conditions. In order to reduce the amount of data NOAA converts the magnetometer data into three-hourly indices, which give a quantitative, but less detailed measure of the level of geomagnetic activity. The K-index scale has a range from 0 to 9 and is directly related to the maximum amount of fluctuation (relative to a quiet day) in the geomagnetic field over a three-hour interval.

The K-index is therefore updated every three hours. The K-index is also necessarily tied to a specific geomagnetic observatory. For locations where there are no observatories, one can only estimate what the local K-index would be by looking at data from the nearest observatory, but this would be subject to some errors from time to time because geomagnetic activity is not always spatially homogenous.

Another item of interest is that the location of the aurora usually changes geomagnetic latitude as the intensity of the geomagnetic storm changes. The location of the aurora often takes on an 'oval-like' shape and is appropriately called the auroral oval.

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

Figure 6-1 K-Index for 20-22 October 2009
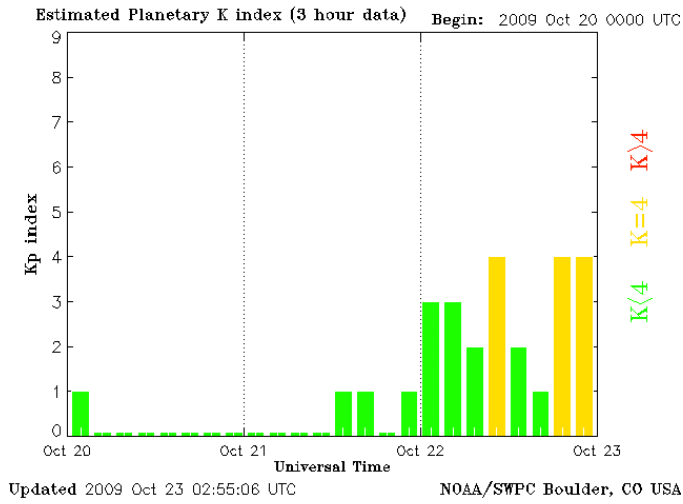
Figure 6-2 K-Index for 29-31 October 2009
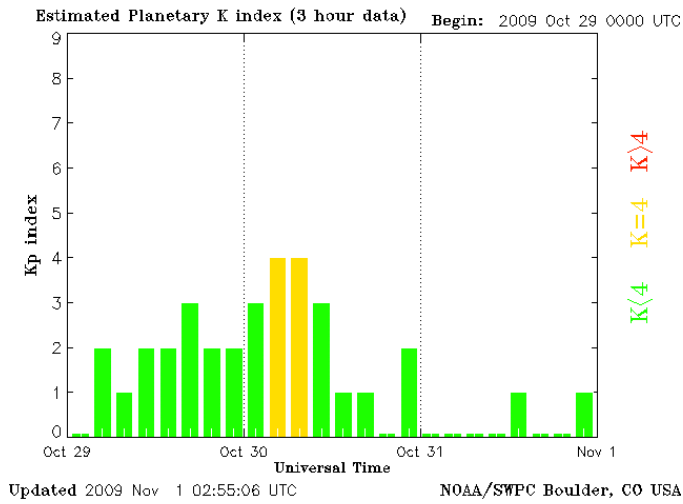
Figure 6-3 K-Index for 23-25 October 2009
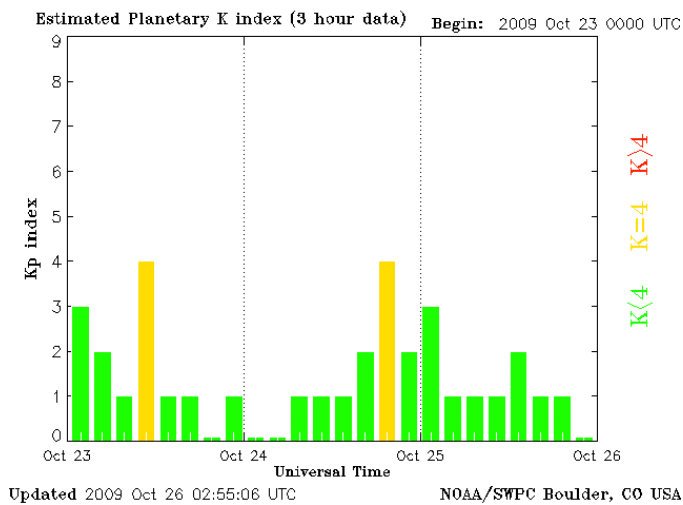
Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1   Horizontal & Vertical Accuracy Statistics for 22 October 2009

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Albuquerque	2.37	3.35	4.25	5.42
Anchorage	2.09	3.57	2.59	5.63
Atlanta	2.08	3.85	3.27	6.24
Barrow	2.38	4.64	3.15	6.54
Bethel	1.90	4.90	2.77	7.66
Billings	1.68	4.13	2.37	7.01
Boston	2.31	3.82	3.09	6.41
Cleveland	1.99	3.99	2.84	5.54
Cold Bay	*Data Not*	*Available*	*Receiver*	*Down*
Fairbanks	2.02	4.20	3.22	6.72
Gander	2.65	3.40	3.40	4.29
Honolulu	3.45	4.16	4.56	7.99
Houston	2.28	3.92	2.71	7.69
Iqaluit	1.98	2.94	2.73	5.01
Juneau	1.98	4.20	2.23	6.19
Kansas City	2.05	3.40	2.52	5.57
Kotzebue	2.03	4.34	2.43	6.16
Los Angeles	1.91	4.61	2.74	5.85
Merida	3.48	4.30	4.57	5.22
Miami	2.94	5.35	3.49	6.89
Minneapolis	2.17	3.57	2.83	6.06
Oakland	2.17	4.38	3.37	6.03
Salt Lake City	2.41	3.58	2.93	4.56
San Jose Del Cabo	2.18	4.43	3.55	5.19
San Juan	3.87	5.87	5.28	8.68
Seattle	2.18	4.02	3.64	5.69
Tapachula	4.84	4.61	6.92	7.01
Washington, DC	2.31	4.49	3.00	6.48

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. Days J280, J295, J303, J308, J317, and J357 data from KOUR and days J329, J330, J336, and J363 from MAS1 have been excluded. The KOUR receiver seemed to be experiencing tracking problems characterized by poor S/No and absence of L2 tracking on individual satellites resulting in large position errors. In particular KOUR had a recurring problem with PRN-7 at 10 degrees elevation. Checks of the NGA precise ephemeris against the broadcast ephemeris verified that there were not problems with the satellite accuracy. Similar tracking problems were also seen at MAS1. Only receiver tracking problems causing position errors greater than 50 meters have been edited. Review of some of the other large errors less than 50 meters indicated similar tracking problems and points where a receiver lost lock on all satellites simultaneously and then reacquired which were accompanied by a short period of instability that caused large position errors. These smaller "glitches" did not greatly impact the statistics and were too numerous to manually verify against precise ephemeris so they were not excluded from the statistics. The poor performance at the POL2 receiver is attributed to problems with receiver, not GPS problems.

On J309, 11/5/09, there was a clock failure on PRN-8 that is visible in data from the GLPS and SANT receivers. See figures 7-4 to 7-7. Start of clock ramp was approximately 12:13 GPS, ephemeris un-healthy at 19:29 GPS. The MALI site in Kenya was not available at all this quarter and the nearby MAL2 site had frequent outages and other tracking problems and could no be used. 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
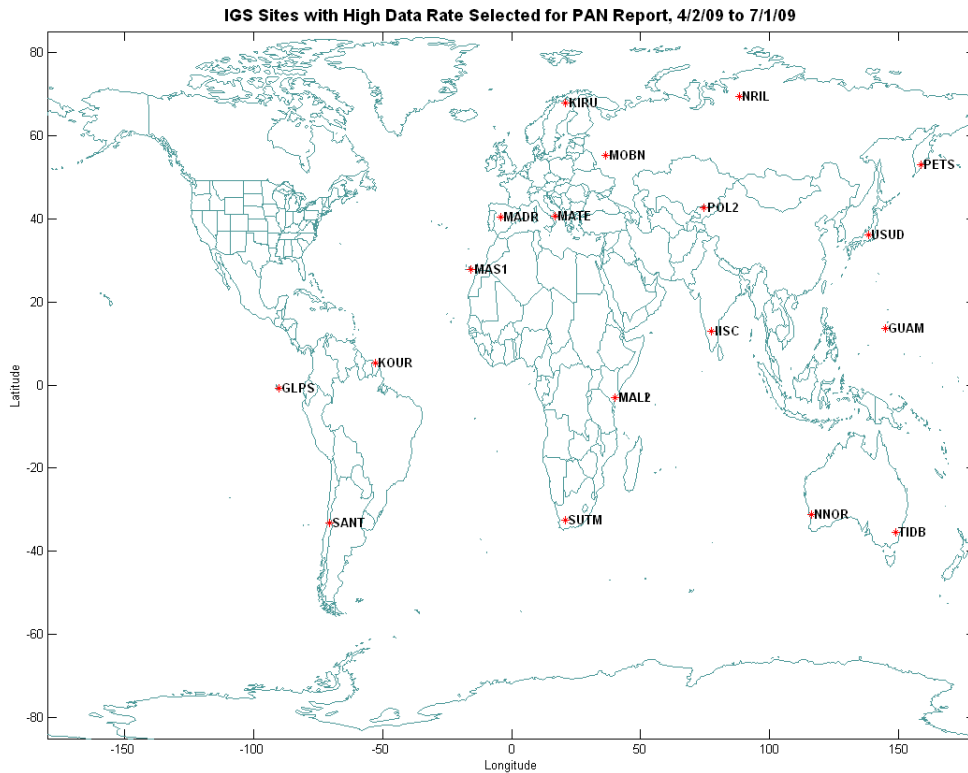
Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
GLPS	2.37	4.5	5.6	10.2	99.78%
GUAM	1.88	4.99	3.93	17.44	99.10%
IISC	1.94	4.17	5.67	14.41	86.59%
KIRU	1.89	4.5	4.46	11.14	99.97%
KOUR	2.28	4.15	6.49	12.86	93.31%
MADR	1.98	4.39	6.31	11.2	99.75%
MAS1	4.02	3.9	7.21	12.17	94.72%
MATE	2.02	4.56	9.27	16.78	88.76%
MOBN	2.46	4.7	6.63	14.26	75.69%
NNOR	2.06	5.27	4.96	14.55	99.61%
NRIL	1.82	4.5	5.61	13.36	62.63%
PETS	2.32	5.09	15.52	18.08	72.74%
POL2	2.38	5.19	17.39	25.21	67.77%
SANT	3.35	4.91	7.32	29.41	99.70%
SUTM	1.84	4.19	5.47	10.54	81.86%
TIDB	2.18	4.52	5.52	13.14	99.51%
USUD	2.19	5.91	8.57	15.89	99.79%

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

10/1/09 to 12/31/09 95% Horizontal Accuracy
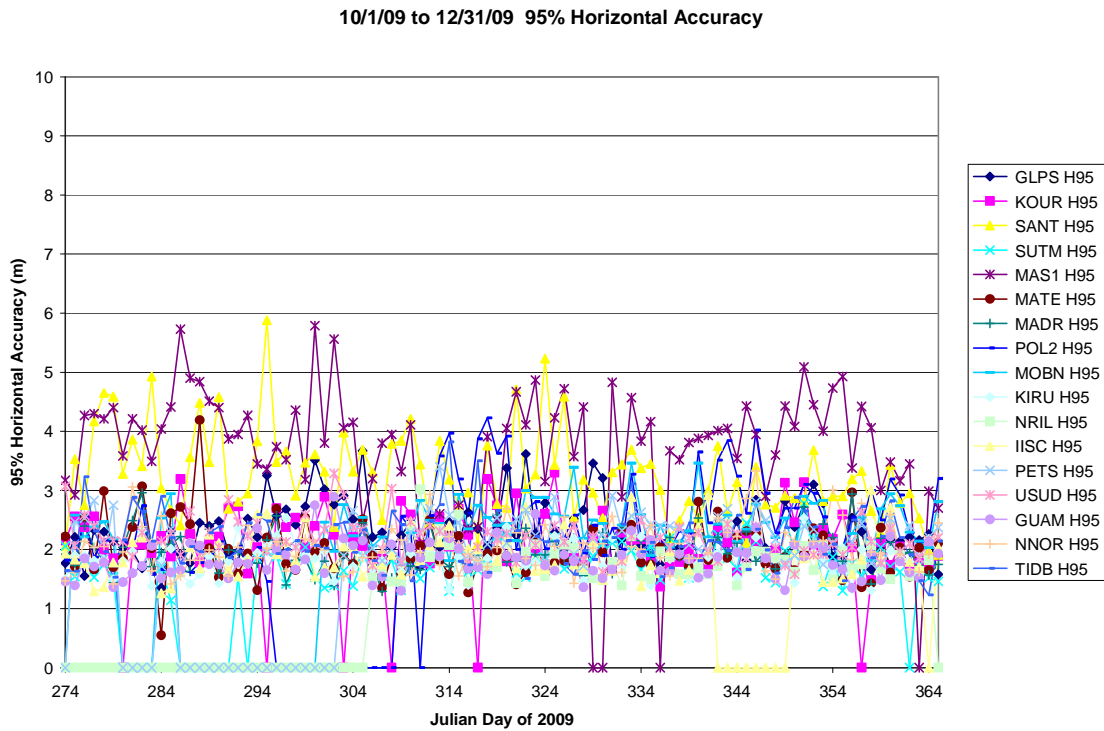
Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites

10/1/09 to 12/31/09 95% Vertical Accuracy
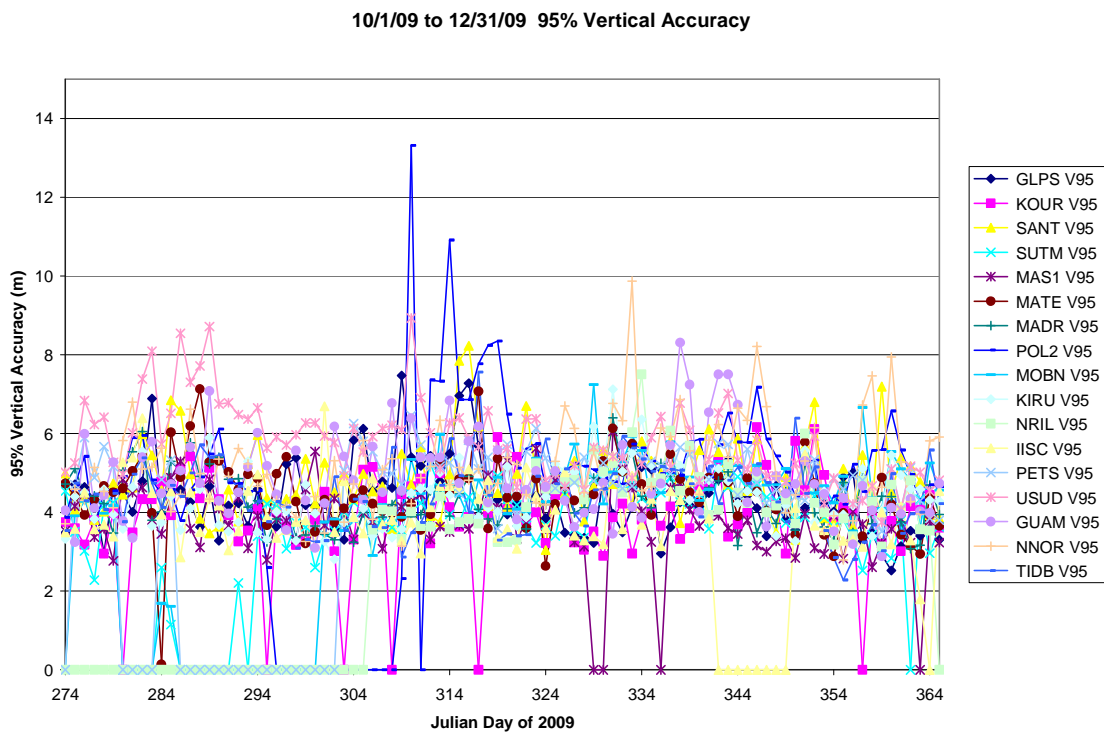
Figure 7-4 GPS SPS Position Error at SANT on 11/5/09 with PRN-8

SPS Mode (PRN-8 included) East North Up Position Error (RGB is ENU) IGS,SANT, 11/5/09
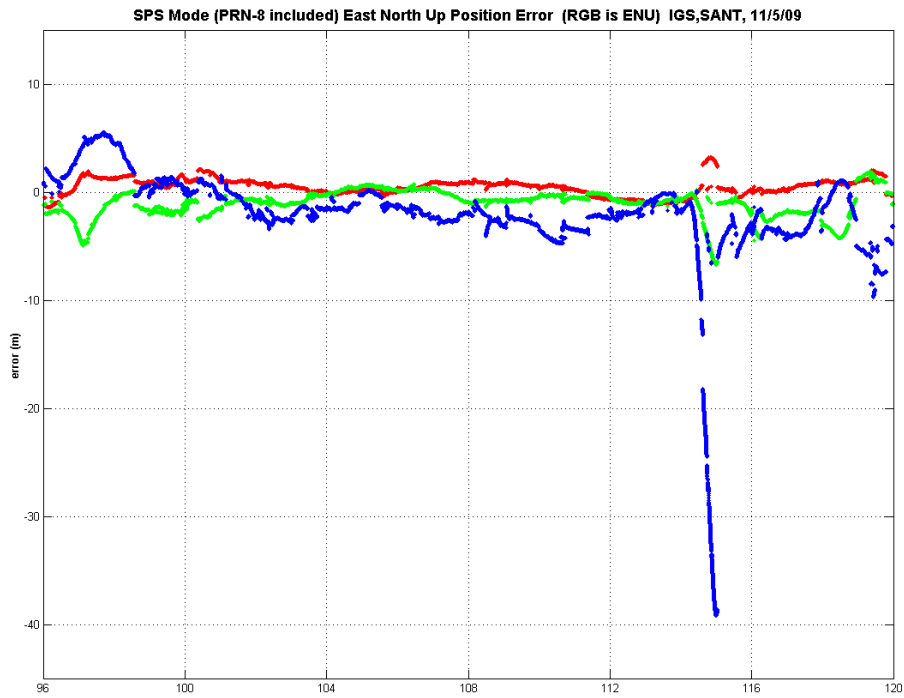
Figure 7-5 GPS SPS Position Error at SANT on 11/5/09 without PRN-8

SPS Mode (PRN-8 excluded) East North Up Position Error (RGB is ENU) IGS,SANT, 11/5/09
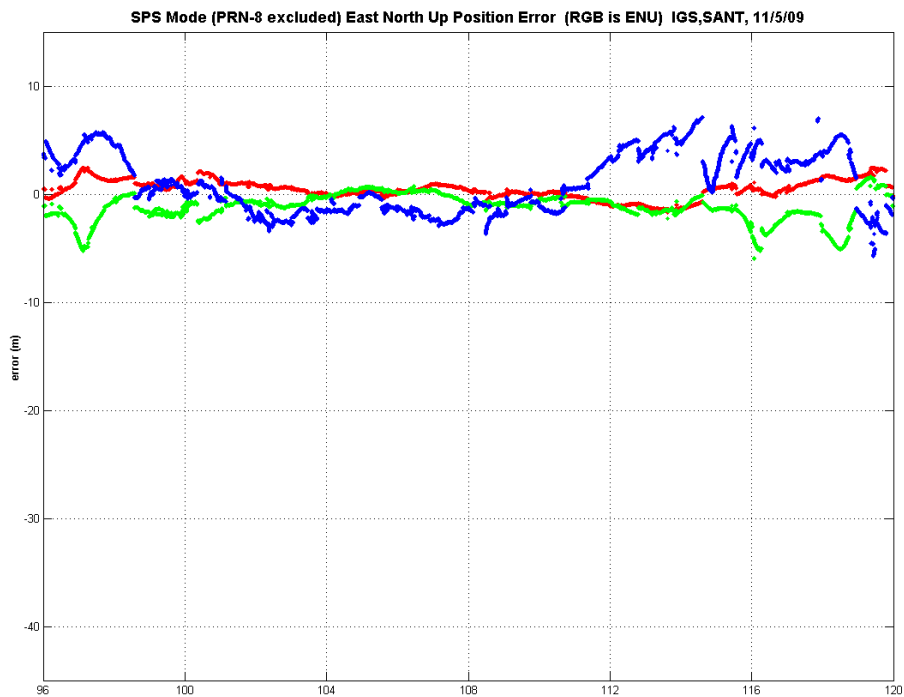
Figure 7-6 GPS SPS Position Error at GLPS on 11/5/09 with PRN-8

SPS Mode (PRN-8 included) East North Up Position Error (RGB is ENU) IGS,GLPS, 11/5/09
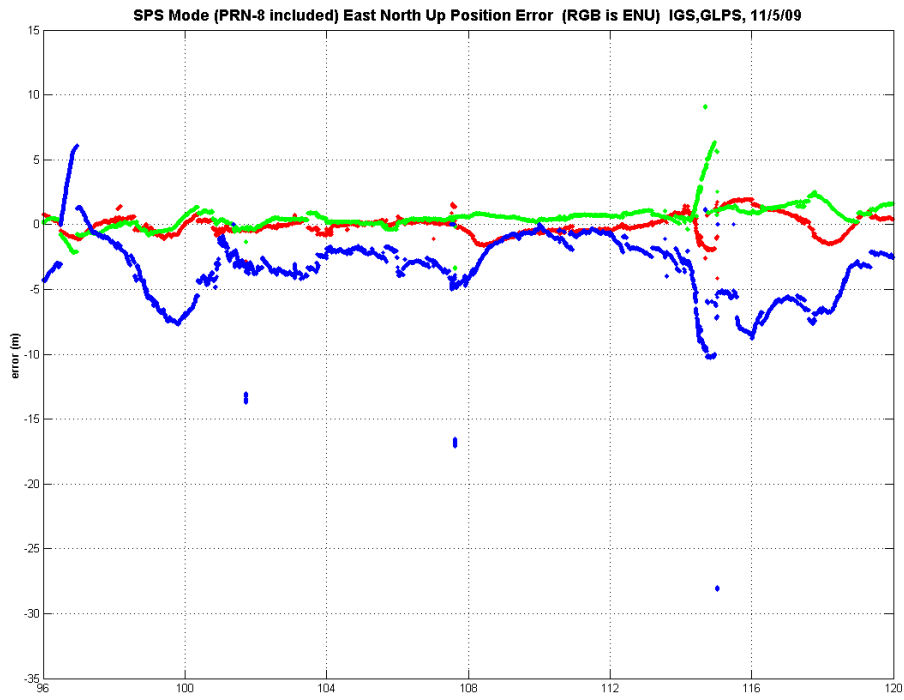
Figure 7-7 GPS SPS Position Error at GLPS on 11/5/09 without PRN-8

SPS Mode (PRN-8 excluded) East North Up Position Error (RGB is ENU) IGS,GLPS, 11/5/09
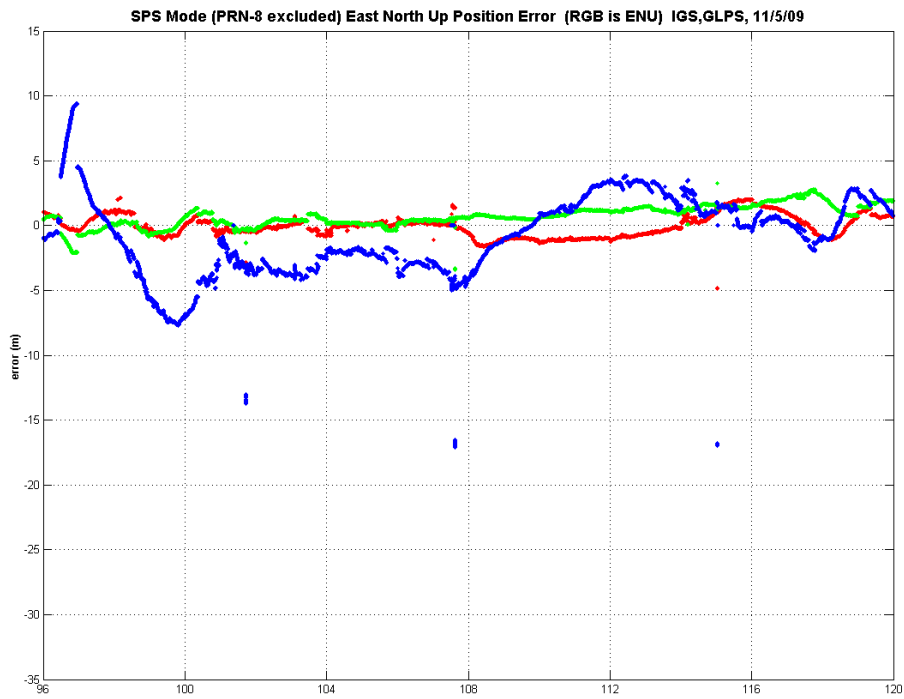
APPENDICES A – D

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	≥ 99.983% ≥ 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)	3.555 m 4.908 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)	13.601 m 16.703 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)	8 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	2.477 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 10 01       2  1 1 0 0 1 1 0 0    0  0 0 0 1 0 0 0 0    2  1 1 0 1 0 0 1 0
2009 10 02       0  0 0 0 0 0 0 0 0    0  0 0 0 1 0 0 0 0    2  1 1 0 0 1 1 0 1
2009 10 03       1  0 0 0 0 1 0 1 0    0  0 0 0 0 0 0 1 0    1  0 0 0 0 1 0 0 1
2009 10 04       4  0 2 0 2 2 1 1 1    2  0 1 1 1 1 0 0 0    4  1 2 1 1 1 0 1 1
2009 10 05       2  0 2 0 0 1 1 0 0    0  0 0 0 0 0 0 1 0    2  0 1 0 0 0 1 0 1
2009 10 06       1  0 0 0 0 1 1 0 0    0  0 0 1 0 0 0 0 0    1  0 1 0 0 0 0 0 0
2009 10 07       1  0 0 0 0 1 1 0 0    0  0 0 0 1 0 0 0 0    2  0 0 0 0 1 0 0 0
2009 10 08       1  0 1 0 0 0 1 0 1    0  0 0 0 0 0 0 0 0    2  1 1 0 0 0 0 1 1
2009 10 09       1  0 1 0 1 0 0 0 0    1  0 0 2 1 0 0 0 0    3  0 1 1 1 1 1 1 1
2009 10 10       0  0 0 0 0 1 0 0 0    2  0 0 1 2 2 0 0 0    2  0 0 0 1 1 0 1 1
2009 10 11       7  2 2 3 1 1 2 2 1    4  1 0 3 2 1 0 1 1    6  1 1 3 1 1 2 2 1
2009 10 12       1  0 0 0 0 1 0 1 0    0  0 0 1 1 0 0 0 0    2  0 0 1 0 0 0 1 1
2009 10 13       2  0 0 1 0 1 0 1 1    2  0 0 1 1 2 0 0 0    2  0 0 1 1 1 1 0 1
2009 10 14       0  0 0 0 0 0 0 0 1    0  0 0 0 0 0 0 0 0    2  0 0 0 1 1 2 1
2009 10 15       3  0 0 1 1 2 1 2 1    2  0 0 2 0 0 1 1 0    4  0 0 2 0 2 1 2 1
2009 10 16       3  3 1 0 0 1 0 0 0    1  1 1 0 0 0 0 0 0    4  2 2 1 0 0 1 1 0
2009 10 17       0  0 0 0 1 0 0 0 0    0  0 0 0 1 0 0 0 0    2  0 0 0 0 1 0 1 1
2009 10 18       0  0 0 0 0 0 0 0 0    1  0 0 1 1 0 1 0 0    1  0 0 0 0 1 1 0 1
2009 10 19       1  0 0 0 0 2 1 0 0    0  0 0 0 0 0 1 0 0    1  0 0 0 0 1 1 0 0
2009 10 20       0  0 0 0 0 0 0 0 0    0  0 0 0 0 0 0 0 0    1  1 0 0 0 0 0 0 0
2009 10 21       1  0 0 0 0 1 0 0 1    0  0 0 0 0 0 0 0 0    1  0 0 0 0 1 1 0 1
2009 10 22      12  3 2 2 4 2 1 3 3   25  1 2 3 6 5 1 2 2   14  3 3 2 4 2 1 4 4
2009 10 23       7  3 2 0 4 2 0 1 0   17  3 2 2 6 2 2 2 1    8  3 2 1 4 1 1 0 1
2009 10 24       5  0 0 1 1 2 3 3 2    5  0 0 1 2 3 1 2 1    8  0 0 1 1 1 2 4 2
2009 10 25       3  3 1 1 1 1 0 0 0    9  2 1 3 3 4 1 0 0    5  3 1 1 1 2 1 1 0
2009 10 26       3  1 0 1 1 0 2 2 1    3  0 0 2 2 0 0 1 1    3  0 0 1 1 0 1 1 1
2009 10 27       2  1 0 1 0 1 1 2 0    2  0 0 2 0 2 0 0 0    3  1 0 1 0 1 1 1 1
2009 10 28       3  2 1 1 2 1 1 0 0   -1 -1 -1 -1 -1 -1 -1 -1 -1  2  1 0 1 2 0 0 0 1
2009 10 29       5  1 1 1 0 2 1 3 1    1  0 0 0 0 0 0 2 0    7  0 2 1 2 2 3 2 2
2009 10 30       8  3 3 3 3 1 0 0 0   15  1 3 5 5 1 1 0 0   11  3 4 4 3 1 1 0 2
2009 10 31       1  0 0 0 0 0 0 1 1    1  0 0 0 1 1 0 0 1    1  0 0 0 0 1 0 0 1
2009 11 01       2  0 2 1 0 0 0 1 0    0  0 0 0 1 0 0 0 0    2  0 1 0 0 0 1 0 0
2009 11 02       2  1 1 2 1 0 1 0 0    1  0 0 2 1 0 0 0 0    2  0 0 1 1 0 0 0 0
2009 11 03       1  0 0 0 0 1 1 1 0    0  0 0 0 0 0 0 0 0    0  0 0 0 0 0 0 0 0
2009 11 04       1  0 0 0 0 1 0 1 0    0  0 0 0 0 0 0 0 0    0  0 0 0 0 0 0 0 0
2009 11 05       0  0 0 1 0 0 0 0 0    0  0 0 1 0 0 0 0 0    1  0 0 1 0 0 0 0 0
2009 11 06       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 11 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 1 0 1
2009 11 08       4  0 1 1 2 2 2 1 1   11  1 0 0 3 4 4 2 2    6  0 1 1 1 2 2 3 2
2009 11 09       2  1 1 1 1 0 1 0 0    5  1 1 3 3 0 0 0 0    4  1 2 2 1 0 1 0 0
2009 11 10       0  0 0 0 0 0 1 0 0    0  0 0 0 0 0 0 0 0    1  0 0 0 0 0 1 0 1
2009 11 11       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 0
2009 11 12       0  0 0 0 0 0 1 0 0    0  0 0 0 0 0 0 0 0    1  0 0 0 0 0 0 0 0
2009 11 13       2  0 0 0 0 1 1 1 1    0  0 0 0 0 0 0 0 0    2  0 0 0 0 0 0 0 1
2009 11 14       3  0 1 2 2 2 0 0 1    5  0 0 2 4 2 0 0 0    5  1 1 2 2 2 0 1 2
2009 11 15       3  1 1 2 1 1 1 1 0    5  0 0 1 1 3 3 1 0    4  1 1 2 0 2 2 1 0
2009 11 16       0  0 0 0 0 0 0 0 0    0  0 0 0 0 0 0 0 0    1  0 0 0 0 1 1 0 0
2009 11 17       0  0 0 0 0 0 0 0 0    0  0 0 0 0 0 0 0 0    1  0 0 0 0 0 1 0 0
2009 11 18       2  0 0 1 1 1 0 0 1    2  0 0 2 2 0 0 0 0    2  0 0 1 1 0 0 0 1
2009 11 19       0  0 0 0 0 0 0 0 1    0  0 0 0 0 0 0 0 0    2  0 1 0 0 0 0 0 2
2009 11 20       2  1 0 0 0 1 1 1 1    0  0 0 0 0 0 0 1 0    1  1 0 0 0 0 0 0 1
2009 11 21       6  3 2 1 1 1 1 2 1    6  1 1 3 3 2 0 1 1    8  3 1 2 2 1 0 3 2
2009 11 22       2  2 0 1 0 1 1 0 0    3  2 1 2 0 1 2 0 0    4  2 0 1 0 1 1 0 0
2009 11 23       0  0 0 0 0 0 1 0 0    1  0 0 0 1 1 0 0 0    0  0 0 0 0 0 0 0 0
2009 11 24       3  0 0 0 0 2 1 2 2    5  0 0 1 1 3 1 2 2    6  0 0 0 1 2 2 2 3
2009 11 25       4  2 2 2 1 1 0 0 1   10  2 1 4 4 3 0 0 0    5  3 2 2 1 1 0 0 1
2009 11 26       3  1 0 1 2 1 1 1 1   14  0 0 4 5 3 3 2 1    6  1 0 1 2 2 2 2 2
2009 11 27       0  0 0 1 0 0 0 0 0    1  0 0 1 1 0 0 0 0    2  0 1 1 1 0 0 0 0
2009 11 28       2  0 0 2 1 0 1 1 0    1  0 0 1 1 0 0 0 0    3  0 0 1 1 1 1 1 1
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2009 11 29    1   0 0 1 0 0 0 1 0 0     0   0 0 0 0 0 0 0 0 0     1   0 0 0 0 0 1 0 1
2009 11 30    1   0 0 1 1 0 0 0 0 0     1   0 0 0 1 2 0 0 0     2   0 0 0 1 1 0 0 0
2009 12 01    0   0 0 0 0 0 1 0 0     0   0 0 0 0 0 0 0 0 0     0   0 0 0 0 0 0 0 0
2009 12 02    0   0 0 1 0 0 0 0 0     0   0 0 0 0 0 0 0 0 0     1   0 0 1 0 0 0 0 0
2009 12 03    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 0
2009 12 04    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 0
2009 12 05    3   0 0 2 0 1 2 1 1     2   0 0 0 2 1 0 1 1     3   0 0 1 0 1 0 2 1
2009 12 06    1   1 1 0 0 0 1 0 0     0   0 0 0 0 0 0 0 0     2   2 1 0 0 0 0 0 0
2009 12 07    2   0 0 0 1 1 2 1 0     1   0 0 1 1 0 0 0 0     2   1 0 0 0 1 0 1 1
2009 12 08    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 0
2009 12 09    0   0 0 0 0 0 1 0 0     0   0 0 0 0 0 0 0 0     0   0 0 0 0 0 0 0 0
2009 12 10    1   0 0 0 0 1 1 1 0     0   0 0 0 0 0 0 0 0     1   0 0 0 0 1 0 0 1
2009 12 11    0   0 0 0 0 0 1 0 0     0   0 0 0 0 0 0 0 0     0   0 0 0 0 0 0 0 0
2009 12 12    2   0 0 1 0 1 1 1 1     0   0 0 0 1 0 0 0 0     1   0 0 0 0 0 0 0 1
2009 12 13    1   0 0 1 1 1 0 0 0     1   0 0 0 1 2 0 0 0     2   0 0 1 1 1 0 0 0
2009 12 14    4   1 3 1 1 0 1 1 0     4   0 2 2 3 0 0 0 0     4   0 3 2 2 0 1 0 0
2009 12 15    0   0 0 0 0 0 0 0 1     0   0 0 0 0 0 0 0 0     0   0 0 0 0 0 0 0 1
2009 12 16    2   1 1 0 1 1 2 0 0     2   0 0 0 2 1 1 0 0     3   2 1 0 1 1 1 0 0
2009 12 17    2   0 0 0 1 1 1 1 0     0   0 0 0 1 0 0 0 0     1   0 0 0 1 0 1 0 0
2009 12 18    2   0 0 1 1 1 2 0 0     2   0 0 2 2 0 0 0 0     2   0 0 1 1 0 0 0 0
2009 12 19    0   0 0 0 0 0 0 0 0     0   0 0 0 1 0 0 0 0     1   0 0 0 0 0 0 0 0
2009 12 20    2   0 0 0 1 1 2 0 0     1   0 0 0 1 1 1 0 0     1   0 0 0 0 1 1 0 0
2009 12 21    1   1 0 0 0 0 1 1 0     0   0 0 0 0 0 0 1 0     1   0 0 0 0 0 0 2 1
2009 12 22    2   0 0 0 0 1 2 1 0     1   0 0 0 1 0 0 0 0     2   0 0 0 0 0 0 1 1
2009 12 23    3   0 1 2 1 1 1 1 1     0   0 0 1 0 0 0 0 0     2   0 1 1 0 0 0 0 1
2009 12 24    1   0 1 0 0 1 1 0 0     0   0 0 0 1 0 0 0 0     2   1 1 0 0 0 0 0 1
2009 12 25    3   0 0 0 0 1 1 2 2     1   0 0 0 1 0 0 1 0     2   0 0 0 0 0 1 2 2
2009 12 26    2   1 1 1 0 1 1 0 0     2   0 0 0 1 0 1 1 1     3   1 2 1 0 0 1 0 0
2009 12 27    1   0 0 0 1 1 1 0 0     2   0 0 1 2 2 0 0 0     2   0 0 1 1 1 1 0 0
2009 12 28    1   0 0 0 1 0 1 0 0     0   0 0 0 1 0 0 0 0     1   0 0 0 1 0 0 0 0
2009 12 29    0   0 0 0 0 0 1 0 0     0   0 0 0 0 0 0 0 0     0   0 0 0 0 0 0 0 0
2009 12 30    0   0 0 0 0 0 1 0 0     0   0 0 0 0 0 0 0 0     0   0 0 0 0 0 0 0 0
2009 12 31    0   0 0 0 0 0 0 0 0     0   0 0 0 0 1 0 0 0     1   0 0 0 0 0 0 0 0
```

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 (1σ) 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.