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 #67, includes data collected from 1 July through 30 September 2009. The next quarterly report will be issued January 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 99.990% or better.

NANU summary and evaluation was achieved by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 July and 30 September 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 twelve outages were reported in the NANU’s this quarter. Ten outages were scheduled while two 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 15.100 meters on Satellite PRN 16. 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 2.12894 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 2.82 meters at Maspalomas and 4.50 meters at Santiago, respectively.

From the analysis performed on data collected between 1 July and 30 September 2009, the GPS performance met all SPS requirements that were evaluated. There were no significant problems to report for the duration of the quarter.

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1.0 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

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

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

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

- PDOP Availability Standard
- Service Availability Standard
- Service Reliability Standard
- Positioning, Ranging and Timing Accuracy Standard

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

1.2 Summary of Performance Requirements and Metrics

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

1.3 Report Overview

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

Section 3 summarizes the GPS constellation performance by providing the "Notice: Advisory to Navstar Users" (NANU) messages to calculate the total time of forecasted and actual satellite outages. This section also evaluates the Service Availability Standard using 24-hour 95% horizontal and vertical position accuracy values.

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

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

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

Section 7 provides an analysis of GPS-SPS accuracy performance from a selection of high rate IGS stations around the world.

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

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

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

Table 1-1 SPS Performance Requirements

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

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

2.0 PDOP Availability Standard

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

Dilution of Precision (DOP): *The magnifying effect on GPS position error induced by mapping GPS ranging errors into position within the specified coordinate system through the geometry of the position solution. The DOP varies as a function of satellite positions relative to user position. The DOP may be represented in any user local coordinate desired. Examples are HDOP for local horizontal, VDOP for local vertical, PDOP for all three coordinates, and TDOP for time. .*

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

Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by the GPS test team was used to calculate the PDOP at every 5^{o} point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was x.xxxxx or better 99.9% of the time for each of the 24-hour intervals.

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

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

Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
28 June – 4 July	3.45835	99.990	98.650
5 – 11 July	3.34512	99.991	98.413
12 – 18 July	3.34378	99.993	98.889
19 – 25 July	3.17108	99.995	98.958
26 July – 1 August	3.01806	99.997	98.958
2 – 8 August	2.95219	99.999	99.653
9 – 15 August	2.89409	100.000	99.931
16 – 22 August	2.87643	100.000	100.000
23 – 29 August	3.06738	99.999	99.514
30 Aug – 5 Sept	3.04728	99.996	99.375
6 – 12 September	3.13203	99.994	98.889
13 – 19 September	3.09266	99.998	99.444
20 – 26 September	3.11903	99.998	99.444
27 Sept – 3 October	3.10616	99.998	99.514

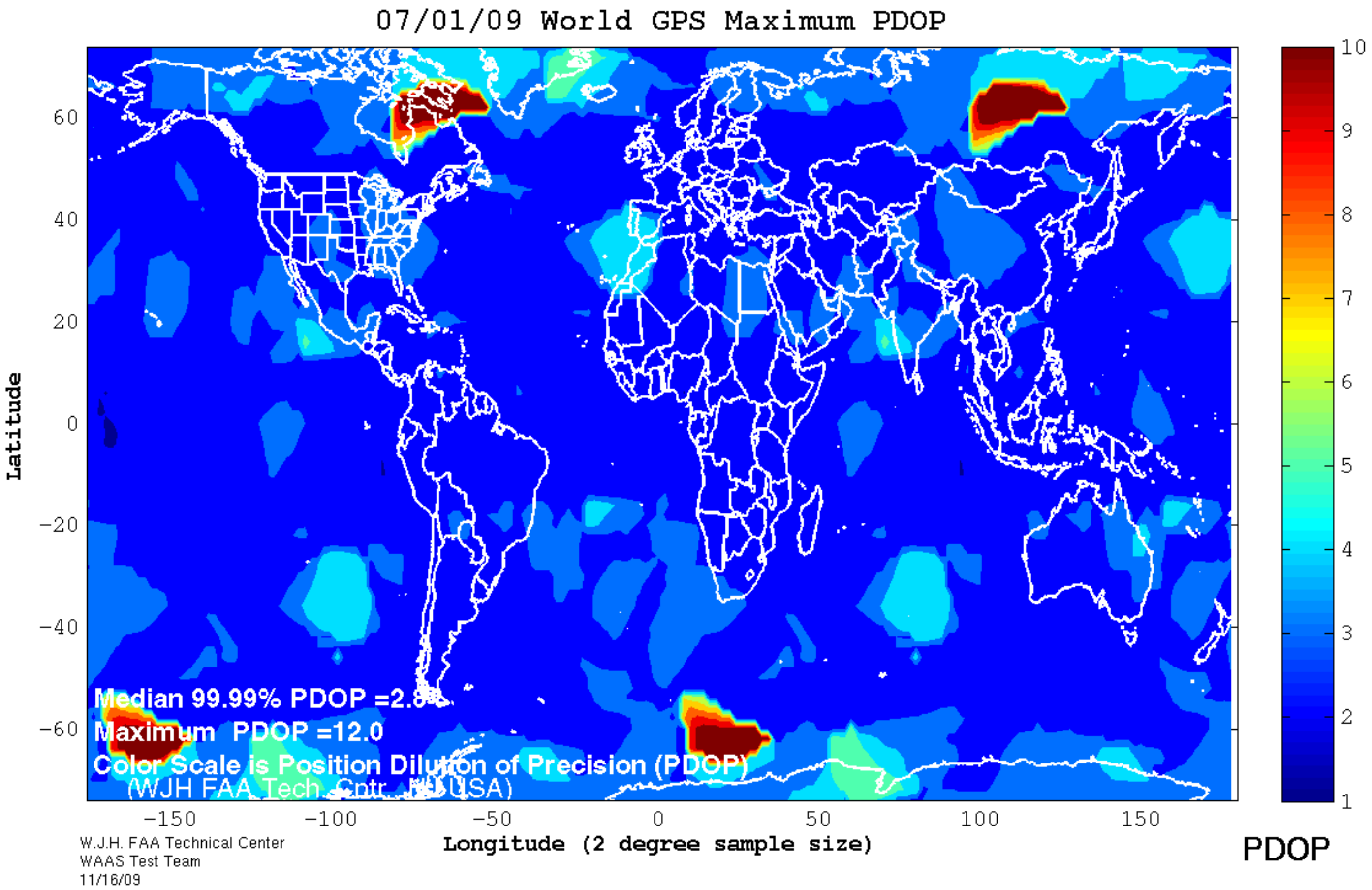
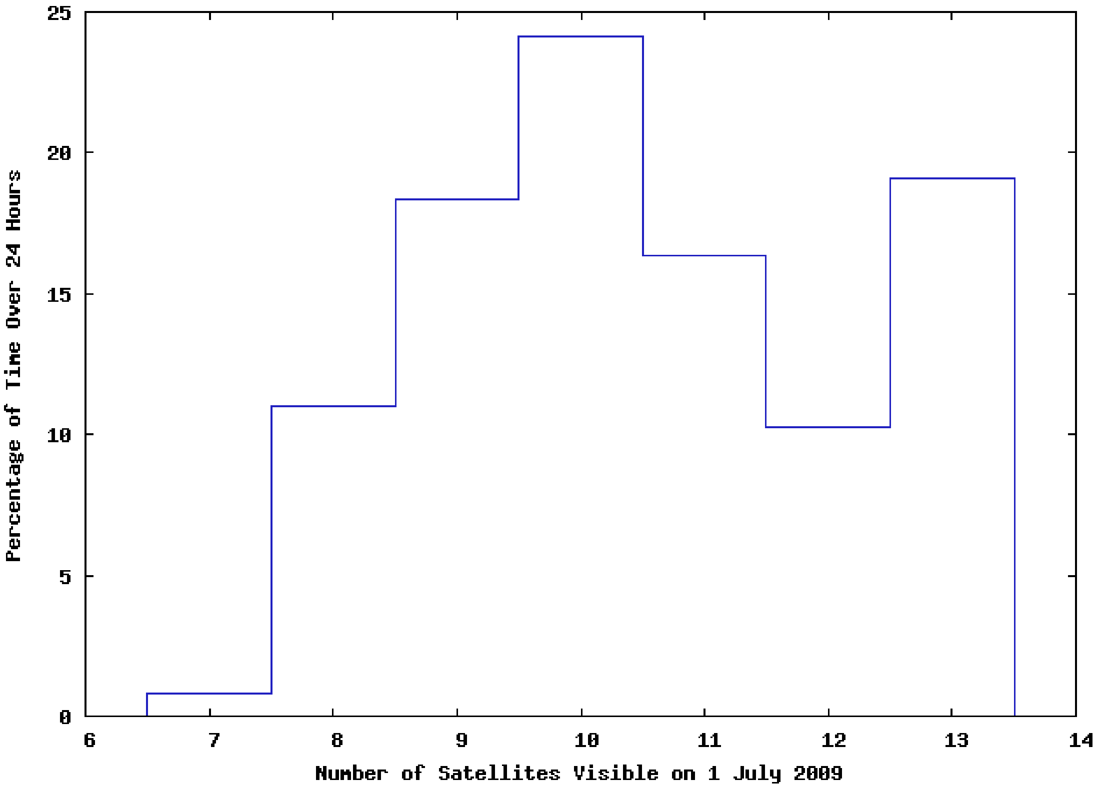


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lat: -60: Lon: -165)



3.0 NANU Summary and Evaluation

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

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANU's). During this reporting period, 1 July through 30 September 2009, there were a total of twelve reported outages. Ten of these outages were maintenance activities and were reported in advance while two 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
2009044	21	FCSTSUMM	24-Jul	03:03	24-Jul	09:06		6.05	6.05
2009047	18	UNUSABLE	25-Jul	01:28	26-Jul	16:00	38.53		38.53
2009050	20	FCSTSUMM	30-Jul	09:15	30-Jul	17:41		8.43	8.43
2009051	30	FCSTSUMM	05-Aug	02:25	05-Aug	09:29		7.06	7.06
2009059	26	FCSTSUMM	02-Sep	08:28	02-Sep	16:34		8.10	8.1
2009062	5	UNUSABLE	05-Sep	22:28	06-Sep	20:21	21.88		21.88
2009063	31	FCSTSUMM	11-Sep	01:27	11-Sep	02:37		1.16	1.16
2009071	23	FCSTSUMM	18-Sep	08:28	18-Sep	15:25		6.95	6.95
2009072	5	FCSTSUMM	22-Sep	10:27	22-Sep	20:53		10.43	10.43
2009074	10	FCSTSUMM	25-Sep	01:13	25-Sep	06:25		5.20	5.20
2009075	26	FCSTSUMM	28-Sep	09:41	28-Sep	14:52		5.18	5.18
2009076	4	FCSTSUMM	29-Sep	03:40	29-Sep	09:42		6.03	6.03
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**60.41**	**64.59**	**125.00**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2009040	21	FCSTDV	24-Jul	02:30	24-Jul	17:00	14.5	See NANU 44
2009041	20	FCSTDV	30-Jul	09:15	30-Jul	23:00	13.75	See NANU 50
2009045	18	UNUSUFN	25-Jul	01:28	N/A	N/A	N/A	See NANU 47
2009049	30	FCSTDV	05-Aug	02:15	05-Aug	16:00	13.75	See NANU 51
2009056	26	FCSTDV	02-Sep	08:00	02-Sep	22:00	14	See NANU 59
2009057	31	FCSTDV	10-Sep	00:30	10-Sep	12:30	12	See NANU 58
2009058	31	FCSTRESCD	11-Sep	00:30	11-Sep	15:00	14.5	See NANU 63
2009060	23	FCSTDV	18-Sep	08:15	18-Sep	20:15	12	See NANU 71
2009061	5	UNUSUFN	05-Sep	22:28	N/A	N/A	N/A	See NANU 62
2009066	24	UNUSUFN	12-Sep	20:17	N/A	N/A	N/A	
2009068	10	FCSTDV	25-Sep	01:00	25-Sep	15:00	14	See NANU 74
2009069	5	FCSTDV	22-Sep	10:00	24-Sep	10:00	48	See NANU 72
2009070	26	FCSTMX	28-Sep	09:30	28-Sep	21:30	12	See NANU 75
2009073	4	FCSTDV	29-Sep	03:00	29-Sep	17:30	14.5	See NANU 76
					Total Forecast Downtime		**183**	

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

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

Table 3-4 GPS Block II/IIA Satellite RMA Data		
Satellite Reliability/Maintainability/Availability (RMA) Parameter	**1-Jul-09**	**1-Oct-99**
	30-Sep-09	**30-Sep-09**
Total Forecast Downtime (hrs):	183.00	7073.65
Total Actual Downtime (hrs):	125.00	25194.02
Total Actual Scheduled Downtime (hrs):	64.59	3712.89
Total Actual Unscheduled Downtime (hrs):	60.41	21481.13
Total Satellite Observed MTTR (hrs):	10.42	45.07
Scheduled Satellite Observed MTTR (hrs):	6.46	9.24
Unscheduled Satellite Observed MTTR (hrs):	30.21	136.82
# Total Satellite Outages:	12	559
# Scheduled Satellite Outages:	10	402
# Unscheduled Satellite Outages:	2	157
Percent Operational -- Scheduled Downtime:	99.906	99.826
Percent Operational -- All Downtime:	99.994	98.819

GENERAL NANU's

NANU's 2009042 & 2009043 were repeats of 2009041
NANU 2009046 was a repeat of 2009045
NANU 2009052 announced PRN25 as unusable until further notice
NANU 2009053 announced the launch of PRN 5
NANU 2009054 announced the decommission of PRN 25
NANU 2009055 announced the initial usability of PRN 5
NANU 2009064 announced PRN 24 was unusable until further notice
NANU 2009065 announced PRN 25 will be included in the almanac, while PRN 24 will be removed
NANU 2009067 announced the initial usability of PRN 25

3.2 Service Availability Standard

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 July and 30 September 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	7942037	0	100%
Anchorage	7940738	0	100%
Atlanta	7929762	0	100%
Barrow	7940194	0	100%
Bethel	7751118	0	100%
Billings	7941398	0	100%
Boston	7938248	0	100%
Cleveland	7938854	0	100%
Cold Bay	6201742	0	100%
Fairbanks	7941328	0	100%
Gander	7942297	0	100%
Honolulu	7936356	0	100%
Houston	7940670	0	100%
Iqaluit	7940007	0	100%
Juneau	7937783	0	100%
Kansas City	7937777	0	100%
Kotzebue	7931546	0	100%
Los Angeles	7940969	0	100%
Merida	7940096	0	100%
Miami	7933971	0	100%
Minneapolis	7933107	0	100%
Oakland	7940303	0	100%
Salt Lake City	7941712	0	100%
San Jose Del Cabo	7877621	0	100%
San Juan	7916818	0	100%
Seattle	7941417	0	100%
Tapachula	7515972	0	100%
Washington, DC	7572700	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 15.100 meters on satellite PRN 16.

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**	64,878,424	0	100%
1 Apr – 30 Jun 2009	**Honolulu**	68,660,166	0	100%
1 Apr – 30 Jun 2009	**Los Angeles**	66,403,193	0	100%
1 Apr – 30 Jun 2009	**Miami**	66,430,403	0	100%
1 Apr – 30 Jun 2009	**San Juan**	68,358,329	0	100%
1 Apr – 30 Jun 2009	**Juneau**	68,278,198	0	100%
1 Apr – 30 Jun 2009	**Global**	403,008,713	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 July through 30 September 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	1.975	3.193	6.611	10.024
Anchorage	1.724	3.453	3.687	7.861
Atlanta	1.947	3.695	6.64	9.219
Barrow	1.444	3.793	3.389	8.125
Bethel	2.022	3.796	6.141	12.505
Billings	2.004	3.275	6.953	9.998
Boston	1.868	3.744	4.181	7.927
Cleveland	1.96	3.635	4.965	8.878
Cold Bay	1.921	3.264	4.264	7.174
Fairbanks	1.548	3.584	3.51	7.869
Gander	1.817	3.376	4.203	10.014
Honolulu	2.592	4.128	4.794	10.643
Houston	1.978	3.345	7.233	10.097
Iqaluit	1.53	3.518	4.704	15.542
Juneau	1.743	3.294	3.878	7.538
Kansas City	2.004	3.513	6.337	10.071
Kotzebue	1.512	3.617	3.21	7.818
Los Angeles	2.058	3.987	6.904	8.733
Merida	2.296	3.762	7.26	8.61
Miami	2.007	3.855	6.994	9.303
Minneapolis	1.991	3.481	5.164	9.154
Oakland	2.085	4.06	5.881	8.401
Salt Lake City	2.028	3.458	6.9	9.678
San Jose Del Cabo	2.439	3.23	7.485	7.579
San Juan	2.083	4.213	6.089	8.493
Seattle	2.062	3.446	5.096	6.564
Tapachula	2.593	3.574	5.812	8.759
Washington, DC	1.894	3.741	5.233	8.821

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-eight WAAS sites from 1 July to 30 September 2009.

Figure 5-1 Global Vertical Error Histogram

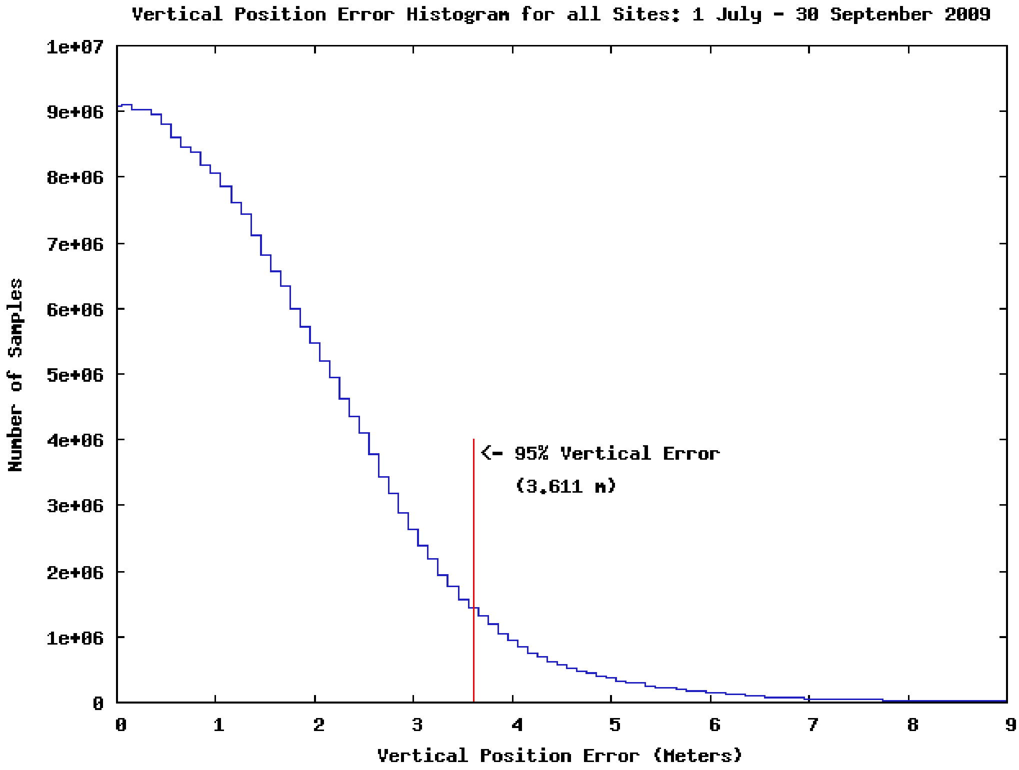
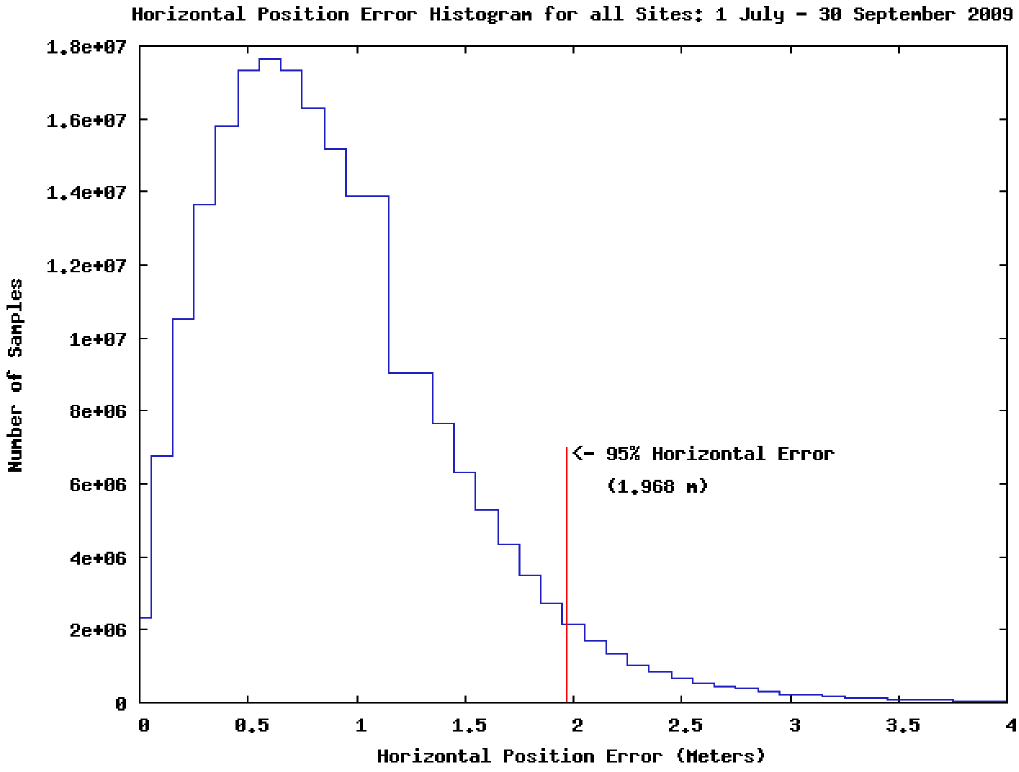


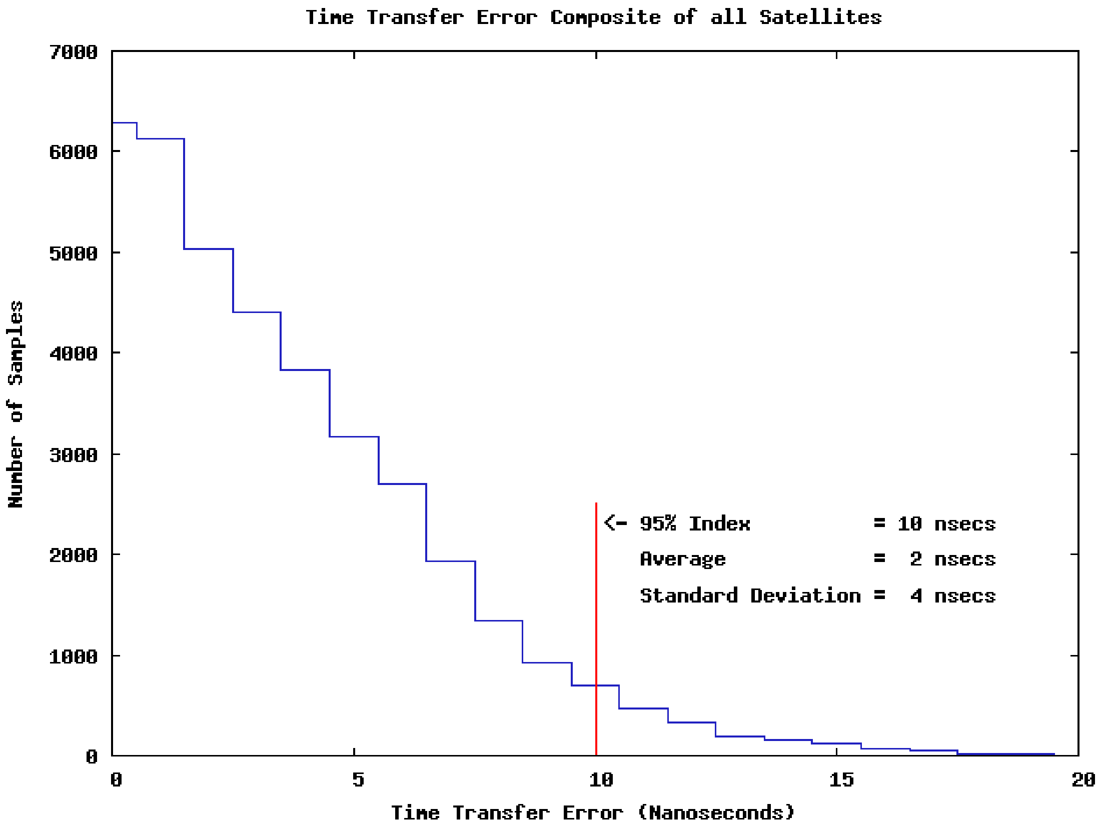
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 July and 30 September 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 July and 30 September 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 (≤ 6 m)	Range Error Mean	1σ	95% Range Error	Max Range Error (SPS Spec. ≤ 30 m)	Samples
2	1.58355	0.91660	1.181408	2.88926	7.092	14564451
3	1.75718	0.81814	1.150388	2.99151	8.210	12601064
4	1.35370	0.45486	1.061349	2.54948	7.320	14229754
5	1.43659	0.02226	1.213201	2.63076	7.715	4777095
6	1.35602	0.67476	0.988333	2.32461	7.379	12869510
7	1.19334	-0.02402	0.974700	2.20374	9.732	12321179
8	1.61481	0.37663	1.279169	3.02042	8.889	13159225
9	1.69872	0.72547	1.348864	3.13658	10.086	13339789
10	2.12894	1.59244	1.228515	3.64660	10.685	13852367
11	1.60210	0.87460	1.108355	2.75153	6.626	12614168
12	1.24057	0.36269	1.050706	2.37683	6.123	14692206
13	1.12781	0.34846	0.935831	2.14523	9.380	14290509
14	1.49296	1.05977	0.960378	2.61416	6.947	14490417
15	1.23969	0.44440	0.999573	2.32342	5.897	12852299
16	1.29582	0.79766	0.920329	2.30937	15.100	13261862
17	1.32929	0.09997	1.132236	2.50500	6.459	14565263
18	1.69073	1.21404	1.040382	2.86421	9.131	12893654
19	1.69550	1.21966	1.067727	2.87049	6.117	12796100
20	1.39038	0.91835	0.909523	2.41672	7.540	14471743
21	1.77581	1.38761	1.008679	2.92243	7.147	12087091
22	1.75723	1.21773	0.973196	2.94579	8.951	12723339
23	1.25349	0.66125	0.938246	2.26667	7.072	12858364
24	1.64444	0.84255	1.114129	2.84615	7.317	10118254
25	1.39537	0.22797	0.962790	2.43524	11.079	9184797
26	1.38880	0.61699	1.064629	2.55035	7.032	14070303
27	1.71653	0.48811	1.415299	3.18051	10.195	14001011
28	1.54866	0.54117	1.176719	2.80012	8.765	12928146
29	1.38990	0.46035	1.094988	2.58533	8.440	14066353
30	1.56234	0.27777	1.234920	2.88779	8.408	13448588
31	1.16675	0.18686	0.995327	2.25449	7.101	14331314
32	1.56429	1.15454	0.915039	2.64539	8.231	14548498

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

PRN	Range Rate Error RMS	Range Rate Error Mean	Range Rate Error 1σ	95% Range Rate Error	Max Range Rate Error	Samples
2	0.001372	-0.000057	0.001368	0.002603	0.08352	14564451
3	0.001725	-0.000039	0.001722	0.002764	0.16147	12601064
4	0.001309	-0.000051	0.001305	0.002448	0.16698	14229754
5	0.001576	-0.000060	0.001572	0.002758	0.13691	4777095
6	0.001322	-0.000015	0.001318	0.002299	0.08479	12869510
7	0.001358	-0.000011	0.001355	0.002504	0.09863	12321179
8	0.001923	-0.000011	0.001920	0.002924	0.19676	13159225
9	0.001835	0.000046	0.001831	0.002800	0.17182	13339789
10	0.001696	0.000008	0.001693	0.002837	0.14373	13852367
11	0.001395	-0.000017	0.001392	0.002532	0.09410	12614168
12	0.001379	0.000010	0.001376	0.002652	0.07183	14692206
13	0.001380	0.000027	0.001377	0.002501	0.08095	14290509
14	0.001356	-0.000001	0.001354	0.002490	0.07079	14490417
15	0.001349	-0.000006	0.001346	0.002553	0.09577	12852299
16	0.001381	0.000007	0.001378	0.002511	0.34549	13261862
17	0.001457	-0.000022	0.001454	0.002603	0.19731	14565263
18	0.001375	-0.000031	0.001373	0.002534	0.11649	12893654
19	0.001350	-0.000025	0.001347	0.002472	0.08738	12796100
20	0.001353	0.000002	0.001352	0.002522	0.08657	14471743
21	0.001362	-0.000030	0.001359	0.002611	0.11733	12087091
22	0.001571	-0.000024	0.001569	0.002592	0.13730	12723339
23	0.001326	0.000003	0.001324	0.002416	0.08380	12858364
24	0.001658	-0.000039	0.001656	0.002654	0.14239	10118254
25	0.001269	0.000022	0.001266	0.002259	0.09116	9184797
26	0.001418	0.000010	0.001416	0.002413	0.11756	14070303
27	0.001880	0.000044	0.001875	0.002741	0.14835	14001011
28	0.001434	0.000005	0.001431	0.002552	0.12321	12928146
29	0.001438	-0.000027	0.001435	0.002548	0.13457	14066353
30	0.001852	-0.000003	0.001850	0.002847	0.16562	13448588
31	0.001415	0.000019	0.001411	0.002448	0.11596	14331314
32	0.001329	-0.000004	0.001327	0.002274	0.09698	14548498

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

PRN	Range Acceleration Error RMS	Range Acceleration Error Mean	Range Acceleration 1σ	Max Range Acceleration Error	Samples
2	0.000010053	0	0.000010053	0.000020091	14564451
3	0.000013618	0	0.000013618	0.000022043	12601064
4	0.000010317	0	0.000010317	0.000019607	14229754
5	0.000012219	0	0.000012219	0.000021900	4777095
6	0.000010892	0	0.000010892	0.000019173	12869510
7	0.000010418	0	0.000010418	0.000020035	12321179
8	0.000015005	0	0.000015005	0.000022277	13159225
9	0.000014240	0	0.000014255	0.000021134	13339789
10	0.000012918	0	0.000012918	0.000022169	13852367
11	0.000010944	0	0.000010944	0.000020000	12614168
12	0.000010153	0	0.000010153	0.000020162	14692206
13	0.000010798	0	0.000010798	0.000020119	14290509
14	0.000010329	0	0.000010329	0.000020019	14490417
15	0.000010295	0	0.000010295	0.000020079	12852299
16	0.000010860	0	0.000010860	0.000020236	13261862
17	0.000011315	0	0.000011315	0.000020114	14565263
18	0.000010504	0	0.000010504	0.000020140	12893654
19	0.000010568	0	0.000010568	0.000020052	12796100
20	0.000010624	0	0.000010624	0.000020205	14471743
21	0.000010159	0	0.000010159	0.000020168	12087091
22	0.000012515	0	0.000012515	0.000020568	12723339
23	0.000010633	0	0.000010633	0.000020114	12858364
24	0.000012977	0	0.000012977	0.000020162	10118254
25	0.000010612	0	0.000010612	0.000016995	9184797
26	0.000011162	0	0.000011162	0.000019487	14070303
27	0.000014951	0	0.000014951	0.000020354	14001011
28	0.000011221	0	0.000011221	0.000020106	12928146
29	0.000011339	0	0.000011339	0.000020072	14066353
30	0.000014109	0	0.000014109	0.000021467	13448588
31	0.000011361	0	0.000011361	0.000020025	14331314
32	0.000010976	0	0.000010976	0.000018681	14548498

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 16 with an error of 15.100 meters. Satellite 15 had the lowest maximum range error of 5.897 meters.

Figure 5-4 Distribution of Daily Max Range Errors

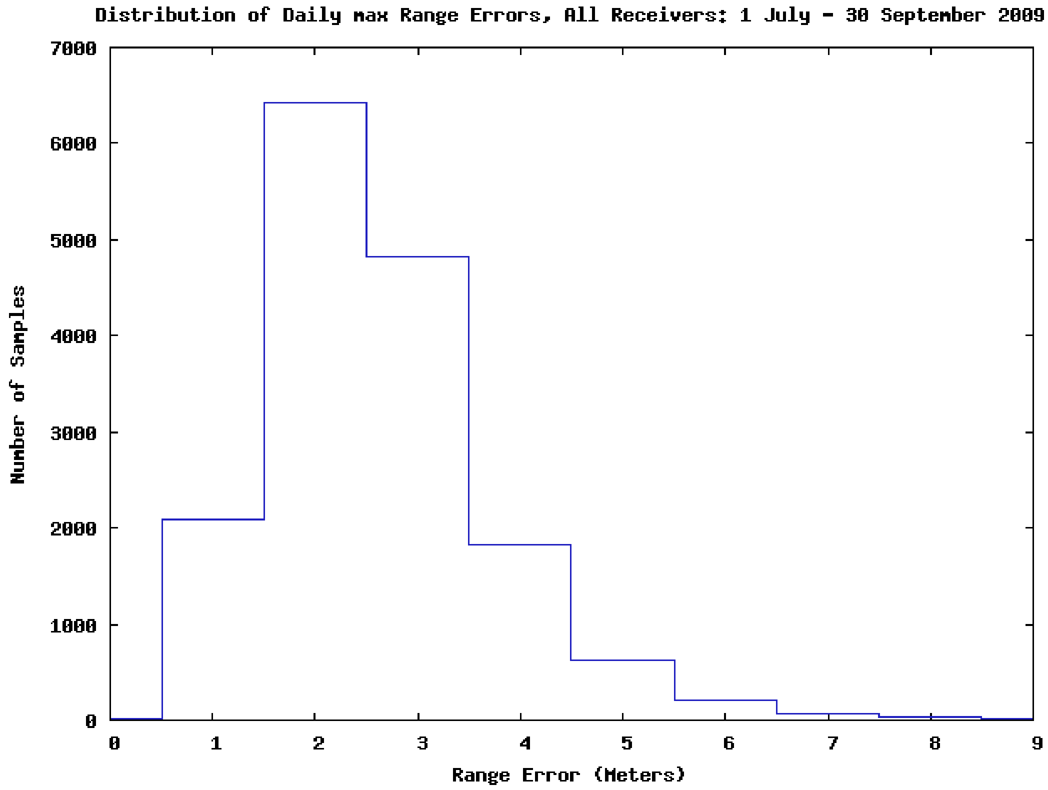


Figure 5-5: Distribution of Daily Max Range Rate Errors

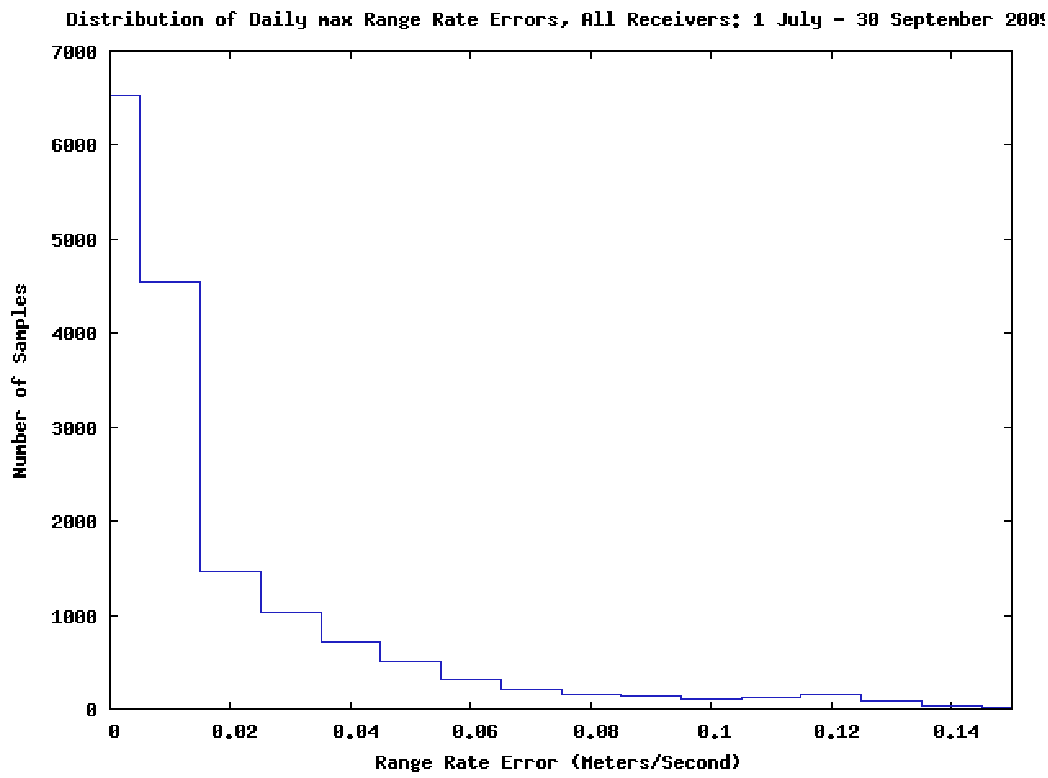


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

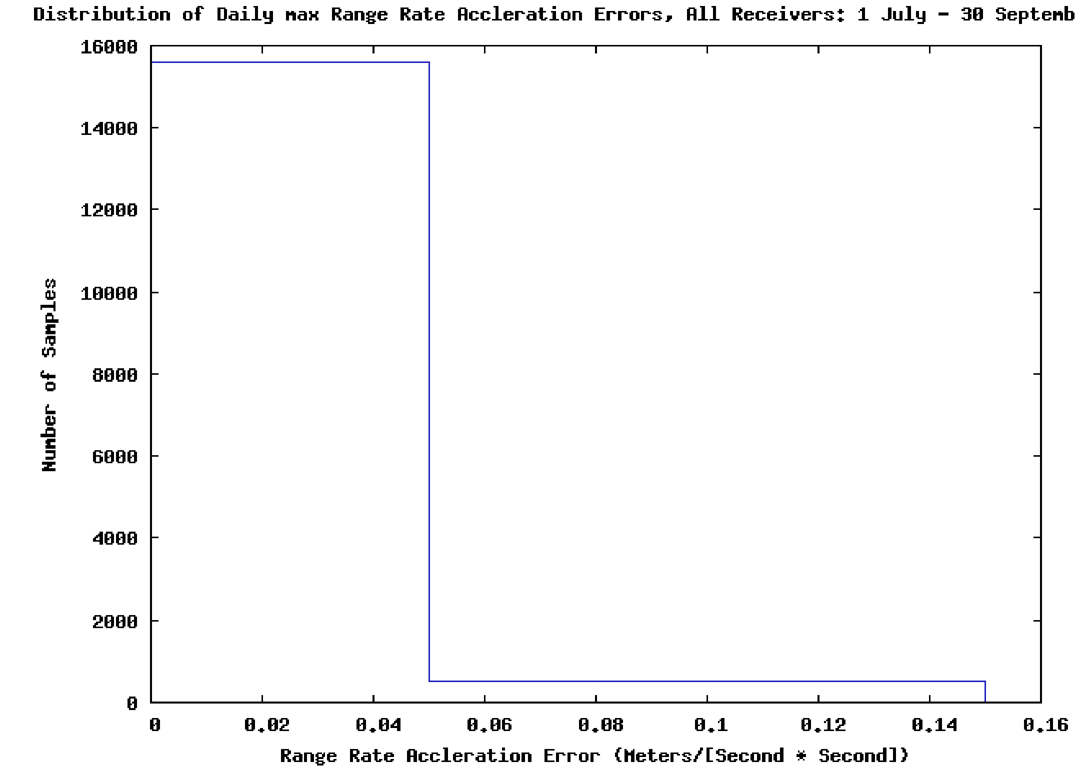
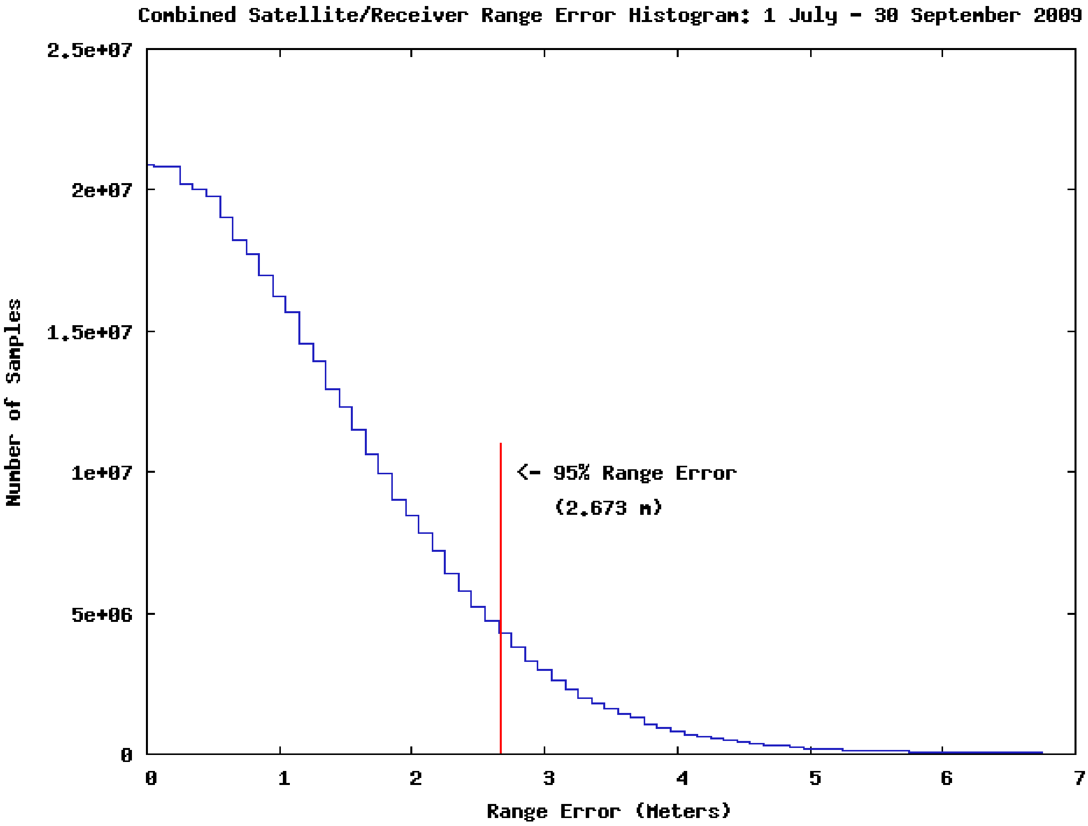


Figure 5-7: Range Error Histogram



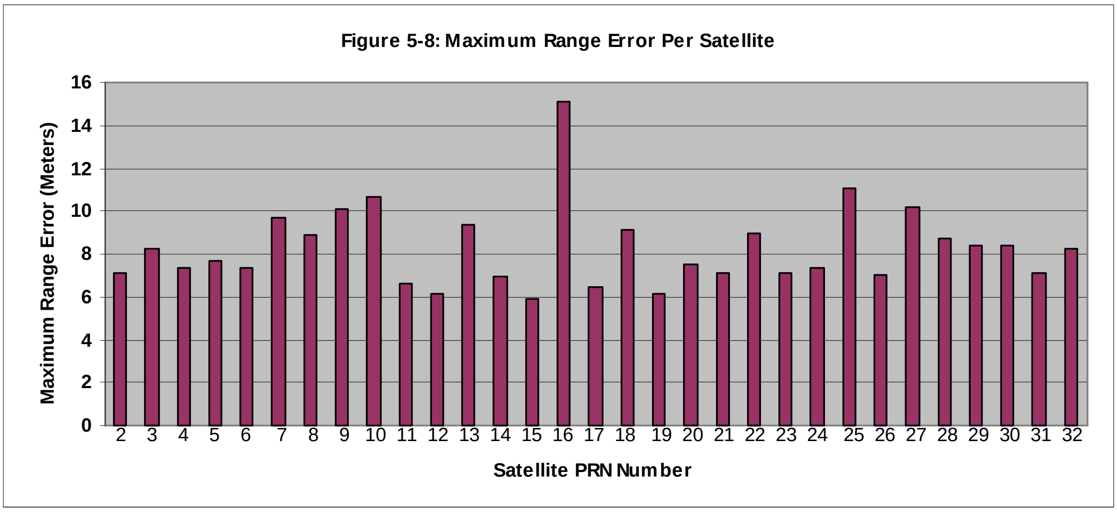


Figure 5-8: Maximum Range Error Per Satellite
Maximum Range Error (Meters)
0
2
4
6
8
10
12
14
16
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

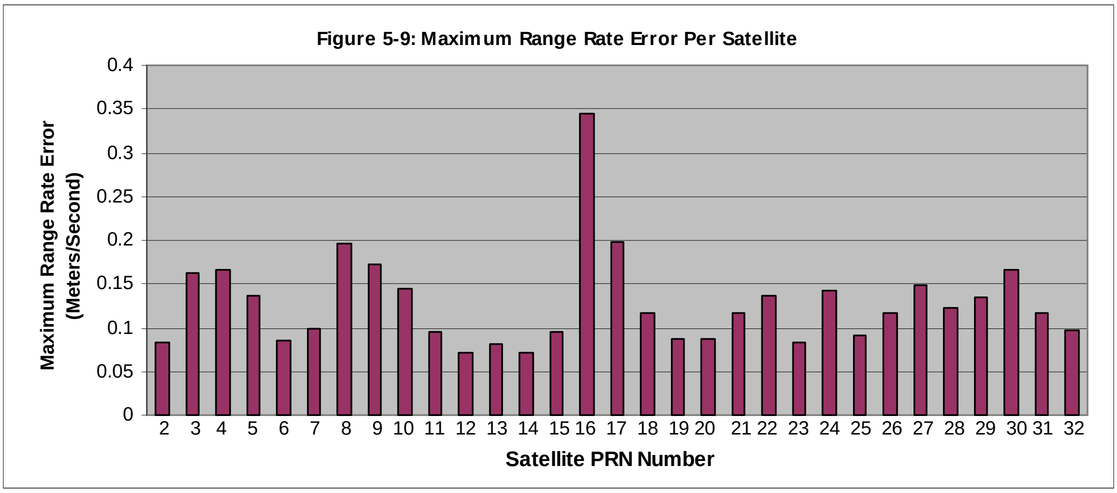


Figure 5-9: Maximum Range Rate Error Per Satellite
Maximum Range Rate Error (Meters/Second)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

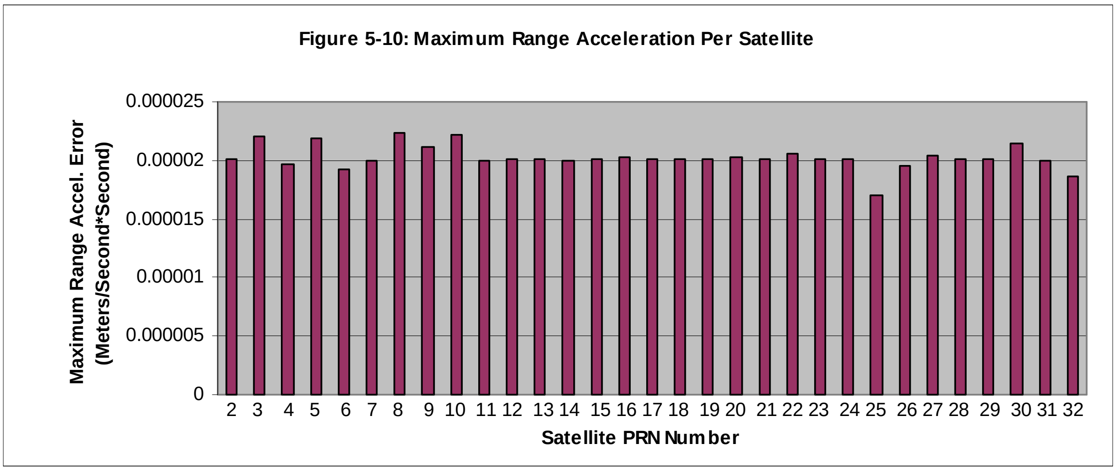


Figure 5-10: Maximum Range Acceleration Per Satellite
Maximum Range Accel. Error (Meters/Second*Second)
0
0.000005
0.00001
0.000015
0.00002
0.000025
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Satellite PRN Number

6.0 Solar Storms

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

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

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

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

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

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

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

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

Figure 6-1 K-Index for 21-23 July 2009

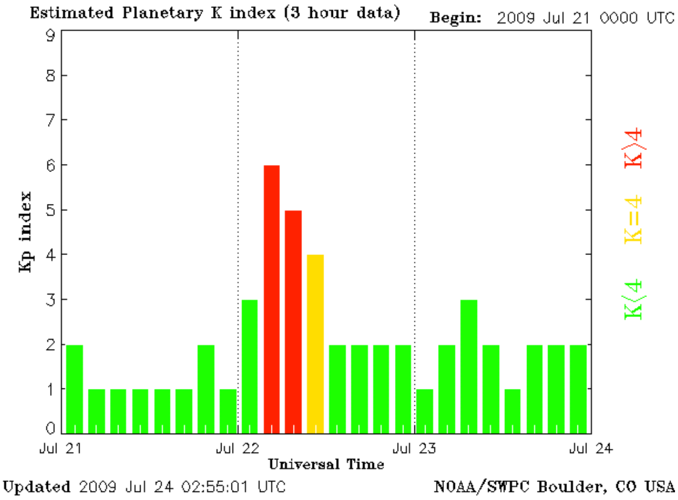


Figure 6-2 K-Index for 29-31 August 2009

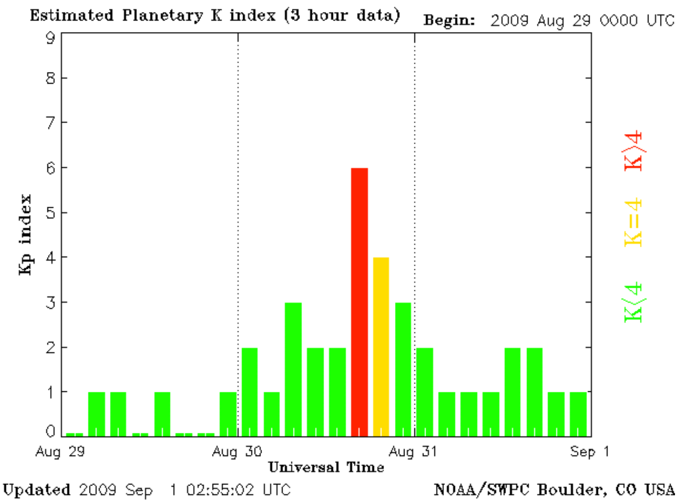


Figure 6-3 K-Index for 5-7 August 2009

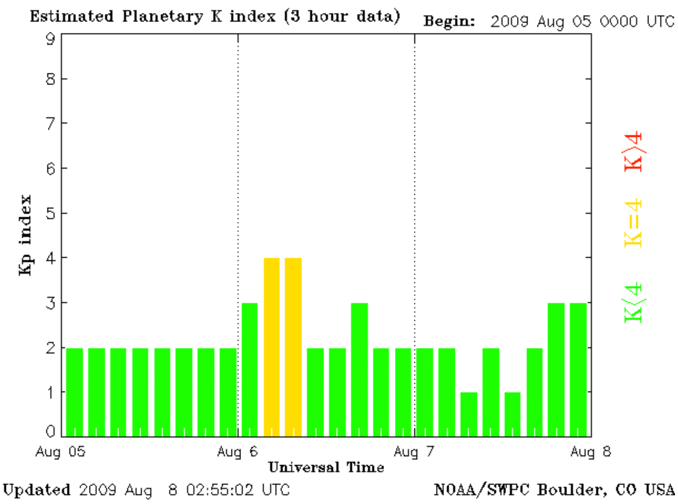


Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

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

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Albuquerque	2.81	2.95	3.11	3.78
Anchorage	1.46	3.12	1.75	4.41
Atlanta	1.69	4.66	2.45	6.15
Barrow	1.21	2.93	1.89	5.22
Bethel	1.46	3.09	1.95	5.07
Billings	2.25	2.62	3.61	2.98
Boston	1.33	3.03	1.95	4.92
Cleveland	1.52	3.89	2.24	5.11
Cold Bay	2.08	2.96	2.60	4.60
Fairbanks	1.46	3.21	4.15	7.27
Gander	1.42	3.02	2.34	3.92
Honolulu	2.12	2.95	2.73	3.90
Houston	2.16	3.96	2.68	4.51
Iqaluit	1.10	2.70	2.62	9.48
Juneau	1.61	2.92	2.28	4.59
Kansas City	2.04	4.24	2.59	5.52
Kotzebue	1.16	3.05	1.63	5.19
Los Angeles	2.63	3.48	3.24	4.15
Merida	2.17	4.30	2.49	5.24
Miami	1.62	4.47	2.04	6.00
Minneapolis	1.72	3.58	2.89	4.99
Oakland	2.63	3.34	5.06	4.29
Salt Lake City	2.54	2.95	3.64	3.73
San Jose Del Cabo	2.33	3.64	2.90	4.73
San Juan	1.99	3.95	2.26	5.00
Seattle	2.77	2.57	3.45	3.98
Tapachula	3.19	4.27	3.56	4.83
Washington, DC	1.40	3.94	2.12	4.73

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 statistics and are forced into the 50.1-meter histogram bin and are believed to influence the outliers in the 99.99% statistics. In addition day J213 data from GLPS has been excluded. GLPS had a 5 hour outage followed by a 2 hour period of larger errors on J213. Days J269 and J245 were reprocessed using a broadcast global navigation data file created by voting across all available IGS high rate RINEX navigation data files because of quality issues with the posted brdc file.

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. The three sites in Russia (MOBN, NRIL, and PETS) did not have data this quarter

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

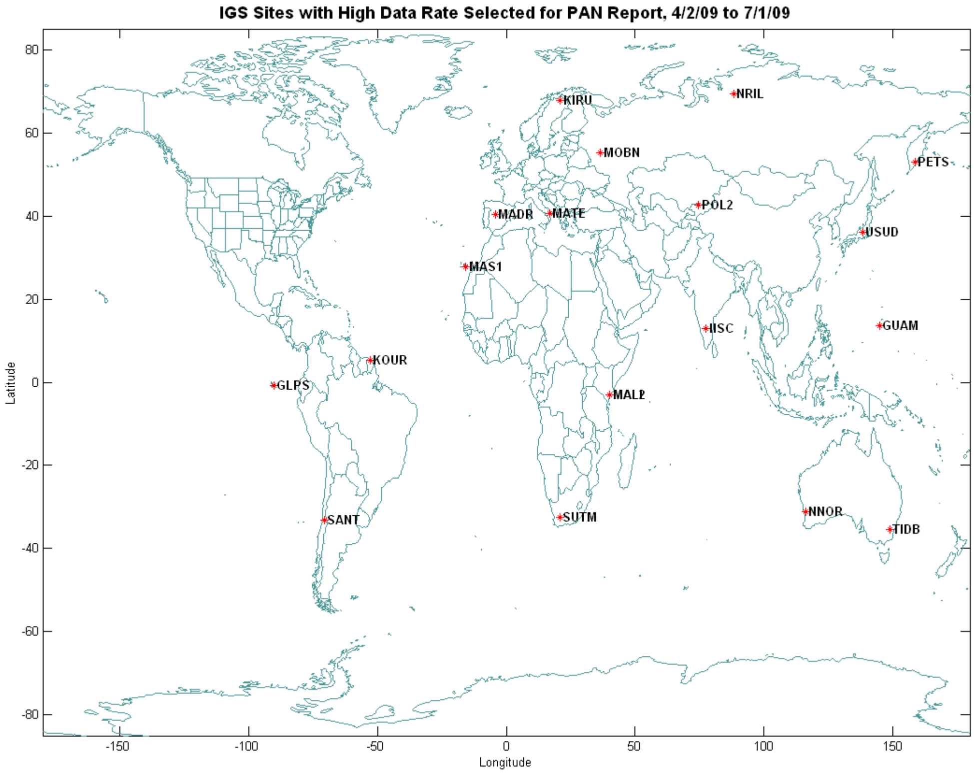


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
GLPS	1.83	4.01	18.8	30.45	97.87%
GUAM	2.02	4.37	7.55	15.91	96.50%
IISC	1.85	3.82	23.67	21.66	91.70%
KIRU	1.74	4.07	4.6	17.36	99.97%
KOUR	1.76	3.68	4.97	10.94	99.97%
MADR	1.98	3.88	7.69	9.97	99.76%
MAS1	2.82	3.82	8.11	15.91	98.54%
MATE	2.04	3.92	5.75	11.6	88.31%
NNOR	2	4.43	4.37	11.73	100.00%
POL2	2.1	3.68	4.31	7.63	99.99%
SANT	2.5	4.5	6.95	9.14	99.99%
SUTM	1.84	3.68	7.72	10.1	97.03%
TIDB	2.29	4.13	7.61	13.67	97.20%
USUD	2.37	4.49	5.78	9.69	99.99%

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

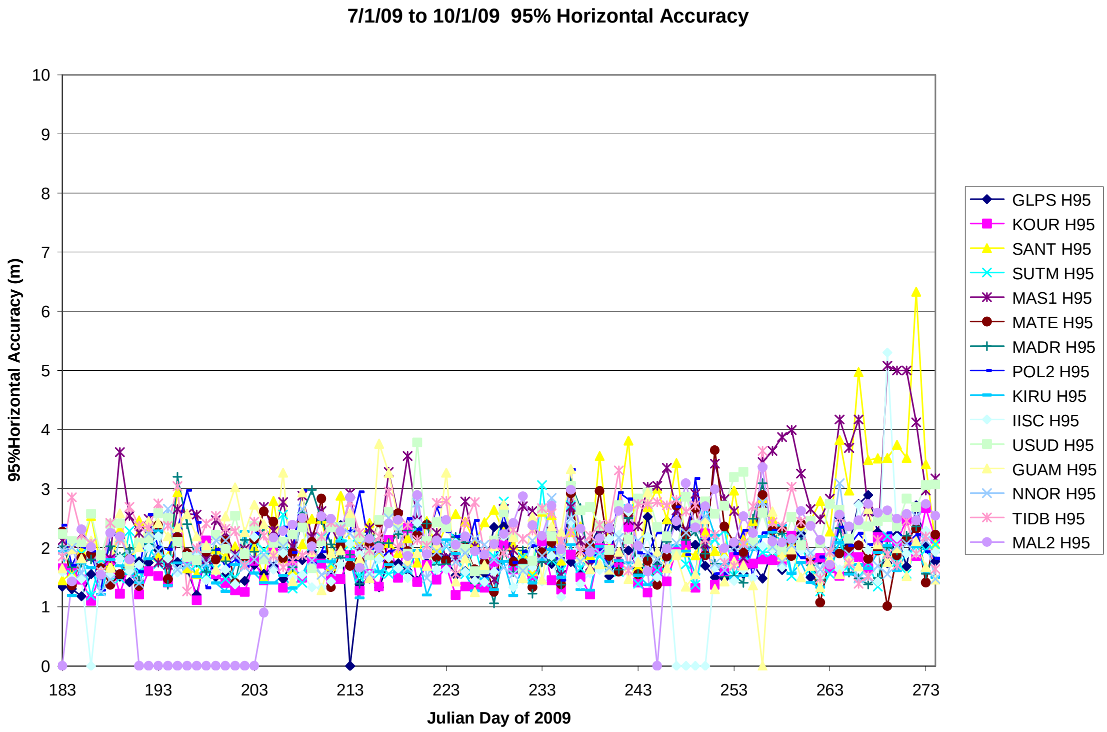
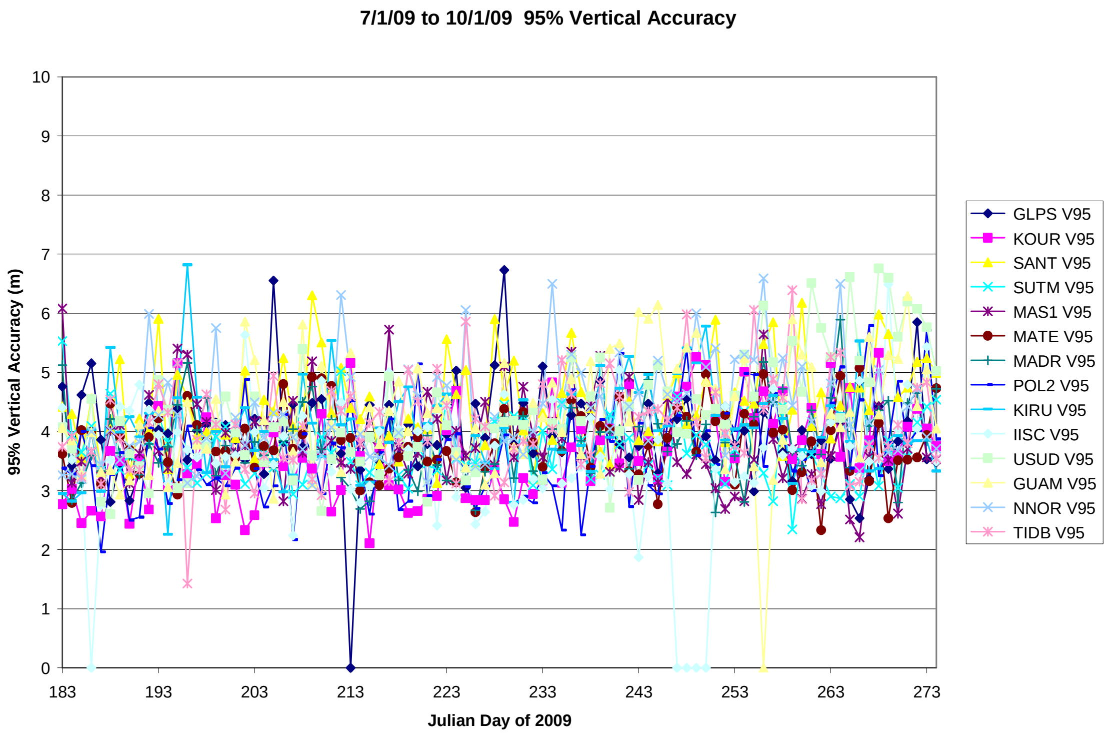


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites



APPENDICES A – D

Appendix A Performance Summary

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	≥ 99.990 % ≥ 98.413 %
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)	1.968 m 3.611 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)	4.213 m 2.593 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)	10 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	2.129 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 07 01     3  1 2 1 1 1 1 0 1     3  1 2 1 0 0 1 1 1     4  2 2 1 0 0 1 1 1
2009 07 02     2  0 1 0 1 1 1 1 0     1  0 1 0 1 0 0 0 1     3  1 1 1 0 0 0 1 2
2009 07 03     3  0 0 0 0 1 2 2 1     2  1 0 0 2 1 0 1 0     5  1 1 0 1 1 2 2 2
2009 07 04     2  2 0 0 0 1 1 1 1     2  1 0 1 1 1 1 0 0     3  2 0 0 0 1 1 1 1
2009 07 05     4  2 2 0 0 1 1 1 2     4  2 2 0 0 0 0 2 2     6  2 2 0 0 1 2 2 2
2009 07 06     3  2 2 0 0 1 0 1 1     3  1 2 1 0 1 0 1 1     4  1 2 1 0 2 1 2 1
2009 07 07     3  0 1 0 1 1 2 2 1     2  1 1 0 1 0 2 1 0     5  1 1 0 1 1 2 2 2
2009 07 08     3  1 0 2 2 1 1 1 0     7  1 0 2 4 3 0 0 0     6  1 1 2 2 1 2 2 1
2009 07 09     6  1 0 2 2 1 1 3 2     3  0 0 2 1 1 1 2 1     6  1 0 2 1 0 1 3 3
2009 07 10     7  3 3 1 1 2 2 1 1     5  2 3 1 1 1 1 1 0     7  3 3 1 1 1 1 1 2
2009 07 11     2  1 1 1 0 1 0 0 1     2  1 1 1 1 1 0 0 0     4  1 1 0 0 1 1 1 2
2009 07 12     4  1 1 1 1 2 2 0 2     2  1 1 1 0 0 0 0 1     5  1 1 1 1 1 2 1 2
2009 07 13     5  0 1 0 1 2 2 2 3     8  1 0 0 1 4 3 2 2    10  1 1 0 1 3 3 2 4
2009 07 14     6  3 3 1 1 1 1 1 1    11  3 2 2 4 4 1 1 0     8  4 3 2 1 2 1 1 2
2009 07 15     3  1 2 1 1 1 0 0 1     5  2 2 2 1 3 2 0 0     5  1 3 2 1 2 0 1 1
2009 07 16     2  0 0 1 0 1 1 1 1     1  0 0 1 1 0 0 0 0     4  1 0 1 0 2 1 1 1
2009 07 17     0  0 0 0 0 0 0 0 0    -1  0-1-1 0 0 0 0 0     2  0 0 0 0 1 1 1 1
2009 07 18     1  0 0 0 0 2 0 1 0     0  0 0 0 0 0 0 0 1     3  0 1 1 0 1 1 1 1
2009 07 19     1  0 0 0 0 1 1 1 0     0  0 0 0 0 0 0 0 0     2  0 0 0 0 1 0 1 1
2009 07 20     3  1 1 1 1 2 1 0 0    17  0 2 2 4 5 5 0 0     6  1 1 1 2 2 1 1 1
2009 07 21     3  1 2 1 1 1 1 1 0     2  1 1 1 2 0 0 0 0     4  2 1 1 1 1 1 2 1
2009 07 22    18  4 5 4 3 3 0 2 1    27  3 5 5 6 2 2 2 1    24  3 6 5 4 2 2 2 2
2009 07 23     8  0 2 3 2 2 2 3 2     8  1 1 3 2 3 2 2 2     8  1 2 3 2 1 2 2 2
2009 07 24     5  2 0 2 2 1 2 1 1     7  2 1 2 2 2 3 1 1     6  2 1 2 2 1 2 2 2
2009 07 25     5  3 3 0 1 1 0 1 1     4  0 0 0 2 3 1 0 1     7  3 3 0 1 1 1 2 2
2009 07 26     1  0 0 1 0 1 1 0 0     1  0 1 0 0 0 0 1 1     3  1 0 0 0 1 1 1 1
2009 07 27     2  1 0 1 0 1 1 1 1     2  1 1 0 1 1 1 1 0     4  1 1 1 0 1 1 1 1
2009 07 28     3  1 1 1 1 1 1 0 1     2  1 1 1 2 1 0 0 0     4  1 2 1 1 1 1 1 1
2009 07 29     2  1 1 0 1 1 1 0 0     1  1 1 0 0 0 0 0 1     2  1 1 0 0 0 1 0 1
2009 07 30     2  0 0 0 1 1 1 1 1    -1  1 0 0 1-1 1-1-1     3  0 0 0 1 1 2 1 1
2009 07 31     4  0 0 3 1 1 1 1 1    -1  1 1 4-1-1 2 1 1     5  0 1 3 1 2 1 1 2
2009 08 01     3  1 1 1 1 1 1 1 1     3  0 1 0 1 2 2 1 1     4  1 1 1 1 2 2 0 2
2009 08 02     2  1 1 0 0 1 0 1 2     2  1 1 0 0 0 0 1 2     3  1 0 0 0 1 1 2 2
2009 08 03     7  3 3 2 2 1 1 1 1     6  2 2 3 3 0 0 0 0    10  3 3 3 2 2 2 2 1
2009 08 04     4  1 2 1 0 1 1 2 1     4  2 2 1 0 2 2 1 0     4  1 1 1 0 1 0 1 1
2009 08 05     5  1 1 2 2 2 1 0 2     8  1 1 3 4 3 0 0 1     6  2 2 2 2 2 2 2 2
2009 08 06     8  2 2 3 1 2 2 2 2    11  2 3 4 3 2 2 1 1    14  3 4 4 2 2 3 2 2
2009 08 07     8  3 2 1 2 1 2 1 3     6  1 1 1 3 1 2 1 2     8  2 2 1 2 1 2 3 3
2009 08 08     2  1 1 0 0 1 1 1 0     3  2 2 0 0 0 1 1 0     4  2 1 0 0 1 1 1 1
2009 08 09     6  2 2 3 1 1 1 1 1    15  2 2 4 5 4 1 1 0     8  2 3 3 2 1 1 2 2
2009 08 10     3  2 0 0 1 1 1 1 1     1  1 0 0 0 0 1 0 0     4  2 0 0 0 1 1 2 2
2009 08 11     2  1 1 0 0 0 0 1 1     3  1 1 1 1 0 1 1 1     4  1 1 0 0 0 1 2 2
2009 08 12     2  0 1 1 1 2 0 0 1     7  0 1 2 3 4 0 0 1     5  2 1 1 1 2 2 1 1
2009 08 13     3  1 1 1 1 1 0 1 1     4  1 0 1 3 2 0 0 0     5  2 2 1 1 2 2 1 1
2009 08 14     2  0 1 1 1 1 0 1 0     1  1 0 1 1 0 0 0 0     4  1 2 1 1 1 1 1 1
2009 08 15     1  0 0 2 0 1 0 0 0     1  0 0 2 0 0 0 0 0     3  1 0 1 0 1 2 1 1
2009 08 16     0  0 0 0 0 1 0 0 0     0  0 0 0 0 0 0 1 1     3  1 0 0 0 1 1 1 2
2009 08 17     2  0 0 0 0 1 1 1 1     1  0 0 0 0 0 0 1 1     3  1 0 0 0 1 1 1 2
2009 08 18     2  1 0 1 0 0 0 2 1     1  0 1 0 0 0 0 1 1     4  1 1 0 0 1 1 1 1
2009 08 19     8  0 0 1 2 3 2 3 3    16  2 1 0 4 4 5 2 2    10  1 0 1 3 3 2 3 4
2009 08 20     8  3 3 2 1 2 1 2 2    12  3 3 3 3 4 1 1 1    11  3 4 3 2 2 1 2 2
2009 08 21     6  1 1 3 2 2 1 2 1    15  2 1 4 3 4 4 1 2     8  2 1 3 2 3 2 1 2
2009 08 22     3  1 2 1 1 1 0 1 1     5  1 3 0 2 2 0 1 2     5  2 3 0 1 1 1 1 1
2009 08 23     3  1 2 1 1 1 0 1 0     3  2 2 1 0 0 0 1 1     5  1 3 2 0 0 1 0 1
2009 08 24     1  1 1 0 0 0 0 0 0     0  1 0 0 0 0 0 0 0     3  1 0 0 0 1 1 0 1
2009 08 25     2  0 1 0 0 1 0 1 1     1  1 0 0 0 0 0 0 1     3  1 1 0 0 1 1 0 2
2009 08 26     4  3 2 1 1 1 0 0 0     4  2 1 3 1 0 0 0 0     4  3 1 2 1 0 0 0 1
2009 08 27     4  1 2 0 1 1 2 2 1     3  1 1 0 0 1 2 1 1     5  1 1 0 0 2 2 2 2
```

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

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.