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 #66, includes data collected from 1 April through 30 June 2009. The next quarterly report will be issued October 31, 2009.

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

PDOP availability is based on Position Dilution of Precision (PDOP). Utilizing the weekly almanac posted on the US Coast Guard navigation web site, the coverage for every 5^o grid point between 180W to 180E and 80S and 80N was calculated for every minute over a 24-hour period for each of the weeks covered in the reporting period. For this reporting period, the global availability based on PDOP less than six for the CONUS was 99.991% or better.

NANU summary and evaluation was achieved by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 April and 30 June 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 six outages were reported in the NANU’s this quarter. Six outages were scheduled while there were zero 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 16.469 meters on Satellite PRN 25. 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 2.038 recorded on satellite 10. The SPS specification states that RMS URE cannot exceed 6 meters in any 24-hour interval.

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

The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products. During the evaluation period, the maximum 95% horizontal and vertical SPS errors are 2.64 meters at Usuda and 7.37 meters at Petropavlovsk-Kamchatka, respectively.

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

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1.0 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

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

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

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

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

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

1.2 Summary of Performance Requirements and Metrics

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

1.3 Report Overview

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

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

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

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

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

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

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

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

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

Table 1-1 SPS Performance Requirements

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

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

2.0 PDOP Availability Standard

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

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

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

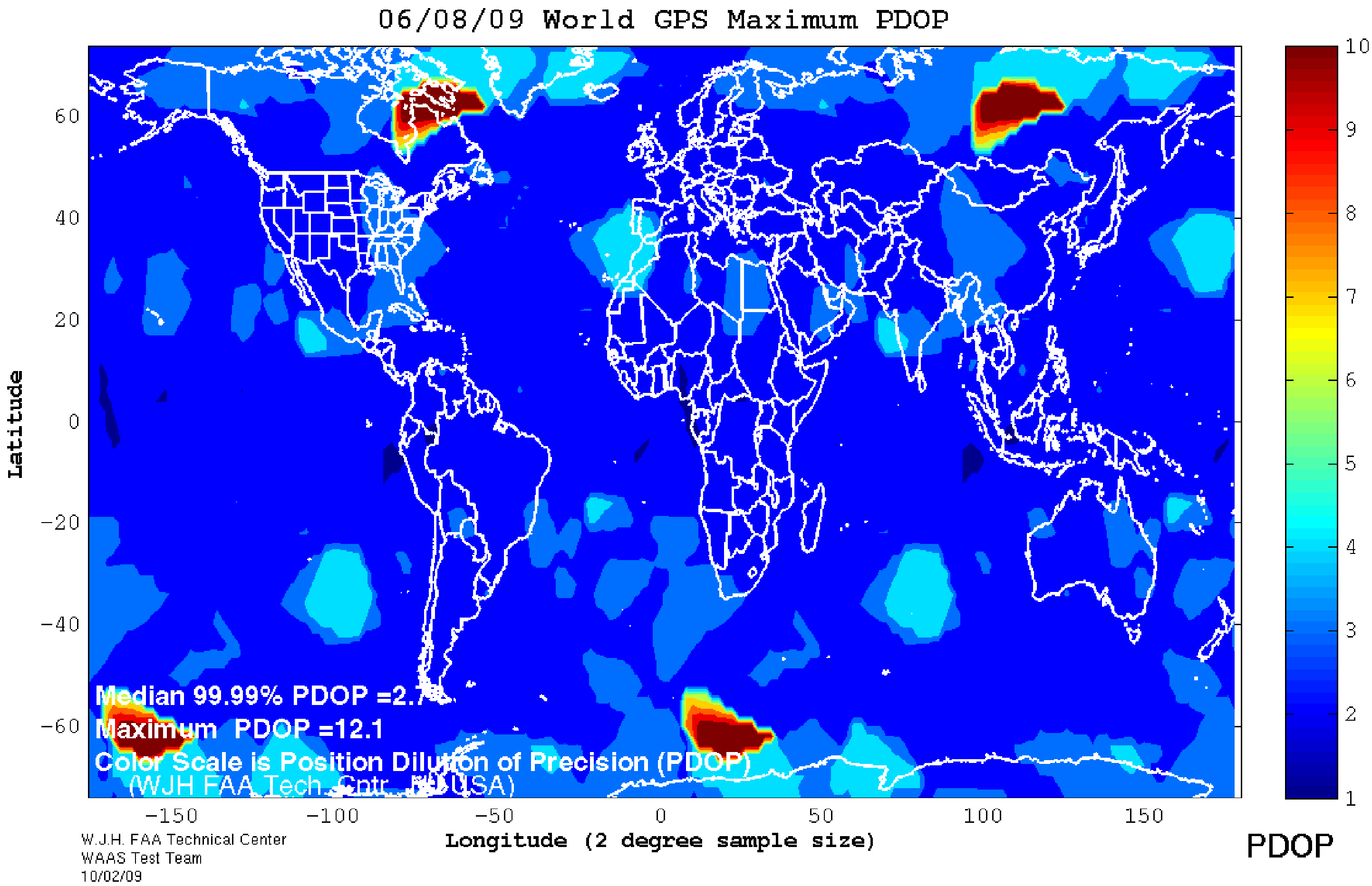
Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by the GPS test team was used to calculate the PDOP at every 5^o point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.52058 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%)
29 Mar – 4 Apr	3.49363	99.994	98.819
5 – 11 Apr	3.51526	99.994	98.958
12 – 18 Apr	3.51724	99.994	98.889
19 – 25 Apr	3.51815	99.994	98.522
26 Apr – 2 May	3.51384	100	100
3 – 9 May	3.48660	100	100
10 – 16 May	3.48626	99.999	99.569
17 – 23 May	3.50181	99.993	98.300
24 – 30 May	3.52058	99.992	98.390
31 May – 6 June	3.45875	99.992	98.512
7 – 13 June	3.45743	99.991	98.298
14 – 20 June	3.46240	99.994	98.292
21 – 27 June	3.43551	99.994	98.303



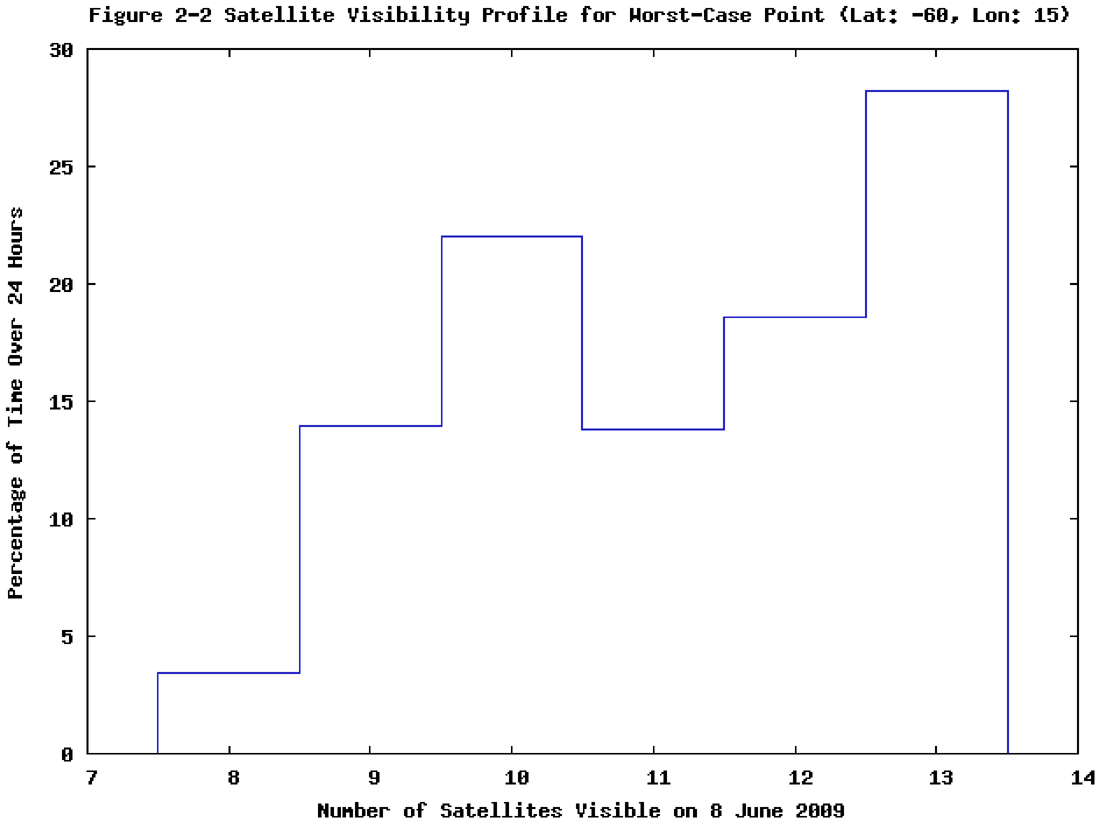


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lat: -60, Lon: 15)
Percentage of Time Over 24 Hours
0
5
10
15
20
25
30
7
8
9
10
11
12
13
14
Number of Satellites Visible on 8 June 2009

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 April through 30 June 2009, there were a total of six reported outages. All six of these outages were maintenance activities and were reported in advance. There were no unscheduled outages. A complete listing of outage NANU's for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-2. Canceled outage NANU's are provided in Table 3-3.

Table 3-1 NANUs Affecting Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2009024	18	FCSTSUMM	02-Apr	16:36	03-Apr	00:45		8.15	8.15
2009029	16	FCSTSUMM	29-Apr	21:40	30-Apr	03:20		5.67	5.67
2009030	16	FCSTSUMM	29-Apr	21:40	30-Apr	03:20		5.67	5.67
2009032	27	FCSTSUMM	12-May	01:05	12-May	12:59		11.90	11.90
2009034	3	FCSTSUMM	18-May	23:18	19-May	04:27		5.15	5.15
2009036	32	FCSTSUMM	19-Jun	14:11	19-Jun	20:14		6.05	6.05
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**0.00**	**42.58**	**42.58**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2009026	30	FCSTDV	16-Apr	06:30	17-Apr	12:00	CANC	See Nanu 2009027
2009028	16	FCSTDV	29-Apr	21:15	30-Apr	12:00	14.75	See Nanu 2009029
2009028	16	FCSTDV	29-Apr	21:15	30-Apr	12:00	14.75	See Nanu 2009030
2009031	27	FCSTDV	12-May	01:00	13-May	06:00	29	See Nanu 2009032
2009033	3	FCSTDV	18-May	23:15	19-May	13:45	14.5	See Nanu 2009034
2009035	32	FCSTDV	19-Jun	14:00	20-Jun	04:00	14	See Nanu 2009036
2009037	25	UNUSUFN	26-Jun	09:40	N/A	N/A	N/A	See Nanu 2009038
2009037	25	UNUSUFN	26-Jun	09:40	N/A	N/A	N/A	See Nanu 2009039
						Total Forecast Downtime	**87**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
2009027	30	FCSTCANC	16-Apr	06:30	See Nanu 2009026

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-Apr-09**	**1-Oct-99**
	30-Jun-09	**30-Jun-09**
Total Forecast Downtime (hrs):	87.00	6795.48
Total Actual Downtime (hrs):	42.58	24967.50
Total Actual Scheduled Downtime (hrs):	42.58	3616.10
Total Actual Unscheduled Downtime (hrs):	0.00	21351.40
Total Satellite Observed MTTR (hrs):	7.10	46.15
Scheduled Satellite Observed MTTR (hrs):	7.10	9.34
Unscheduled Satellite Observed MTTR (hrs):	N/A	138.65
# Total Satellite Outages:	6	541
# Scheduled Satellite Outages:	6	387
# Unscheduled Satellite Outages:	0	154
Percent Operational -- Scheduled Downtime:	99.937	99.825
Percent Operational -- All Downtime:	99.998	98.792

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 April and 30 June 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	7852821	0	100%
Anchorage	7853844	0	100%
Atlanta	7844090	0	100%
Barrow	7854737	0	100%
Bethel	7228233	0	100%
Billings	7854963	0	100%
Boston	7853918	0	100%
Cleveland	7853941	0	100%
Cold Bay	7851791	0	100%
Fairbanks	7855094	0	100%
Gander	7853698	0	100%
Honolulu	7853211	0	100%
Houston	7851136	0	100%
Iqaluit	7847661	0	100%
Juneau	7852787	0	100%
Kansas City	7853301	0	100%
Kotzebue	7852302	0	100%
Los Angeles	7852147	0	100%
Merida	7851601	0	100%
Miami	7852943	0	100%
Minneapolis	7853079	0	100%
Oakland	7853570	0	100%
Salt Lake City	7853125	0	100%
San Jose Del Cabo	7846258	0	100%
San Juan	7852880	0	100%
Seattle	7853706	0	100%
Tapachula	7843889	0	100%
Washington, DC	7853230	0	100%
Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)			

4.0 Service Reliability Standard

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

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

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

Table 4-1 Service Reliability Based on User Range Error

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Service Reliability Percentage
1 Apr – 30 Jun 2009	**Boston**	62,724,630	0	100%
1 Apr – 30 Jun 2009	**Honolulu**	66,053,086	0	100%
1 Apr – 30 Jun 2009	**Los Angeles**	65,054,960	0	100%
1 Apr – 30 Jun 2009	**Miami**	64,266,803	0	100%
1 Apr – 30 Jun 2009	**San Juan**	66,119,194	0	100%
1 Apr – 30 Jun 2009	**Juneau**	66,591,573	0	100%
1 Apr – 30 Jun 2009	**Global**	390,810,246	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 April through 30 June 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	1.963	4.396	3.991	8.156
Anchorage	1.833	3.862	3.585	7.973
Atlanta	2.004	4.607	4.874	8.556
Barrow	1.496	4.050	7.574	9.513
Bethel	1.847	4.048	4.000	8.185
Billings	2.009	3.911	4.158	7.476
Boston	1.897	4.064	4.522	8.705
Cleveland	1.978	4.218	4.492	9.235
Cold Bay	2.078	4.229	4.299	8.074
Fairbanks	1.730	3.999	4.406	8.539
Gander	1.915	3.706	4.673	7.976
Honolulu	3.097	4.365	6.001	11.078
Houston	2.055	4.694	4.347	8.095
Iqaluit	1.680	3.559	6.567	19.719
Juneau	1.830	3.734	4.436	7.704
Kansas City	1.999	4.348	4.342	7.349
Kotzebue	1.706	3.935	6.260	9.282
Los Angeles	2.101	5.028	3.905	8.611
Merida	2.599	4.694	5.428	9.035
Miami	2.230	4.849	4.740	9.799
Minneapolis	2.000	4.017	4.092	7.071
Oakland	2.076	4.869	4.189	8.055
Salt Lake City	1.992	4.415	3.819	8.009
San Jose Del Cabo	2.820	4.384	5.199	8.074
San Juan	2.217	4.472	3.889	8.873
Seattle	2.142	4.253	4.060	7.360
Tapachula	3.043	4.120	5.876	8.160
Washington, DC	2.004	4.303	4.825	8.688

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

Figure 5-1 Global Vertical Error Histogram

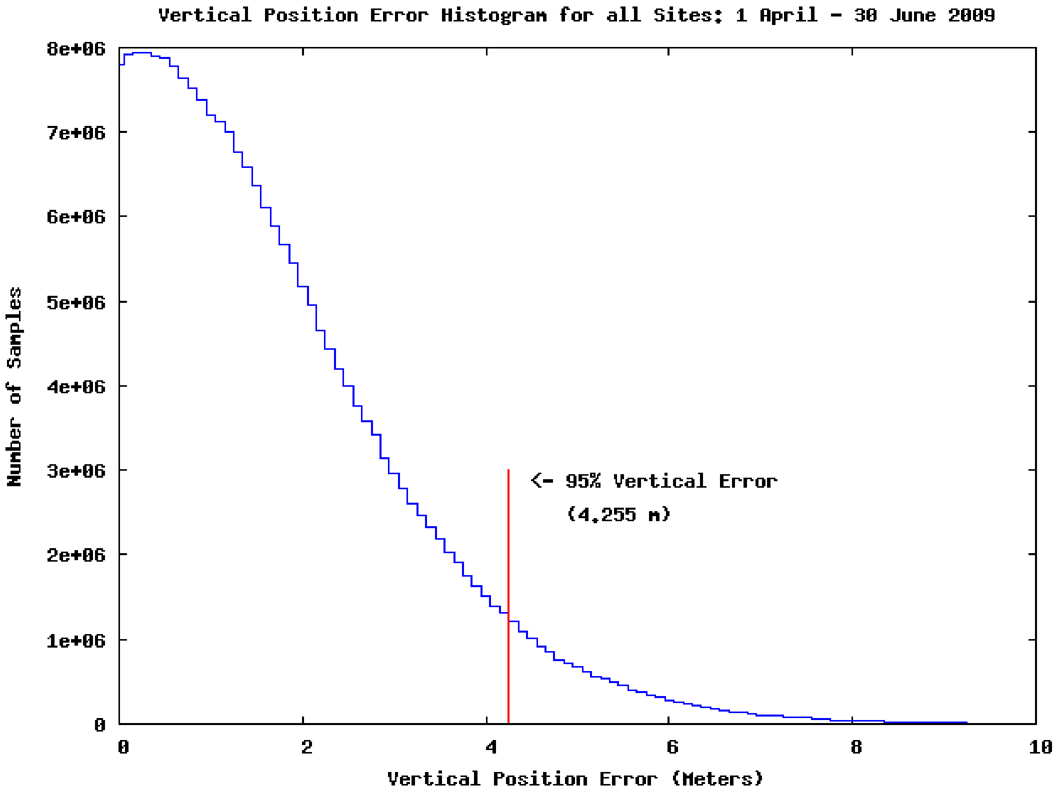
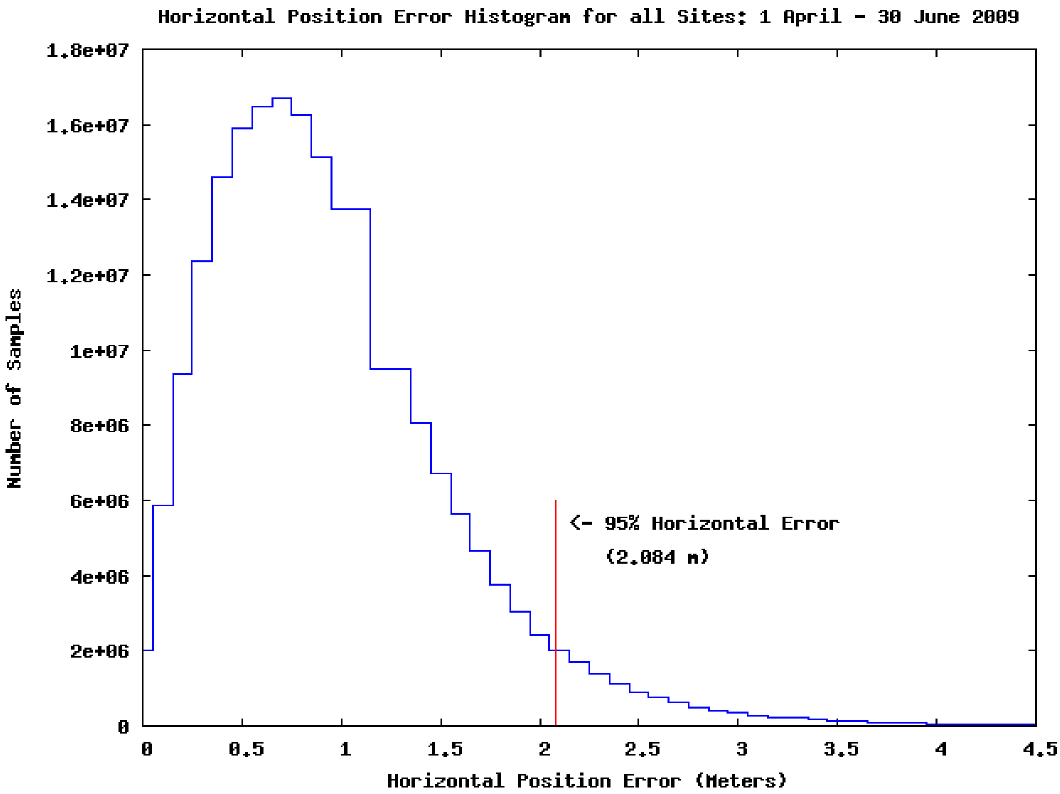


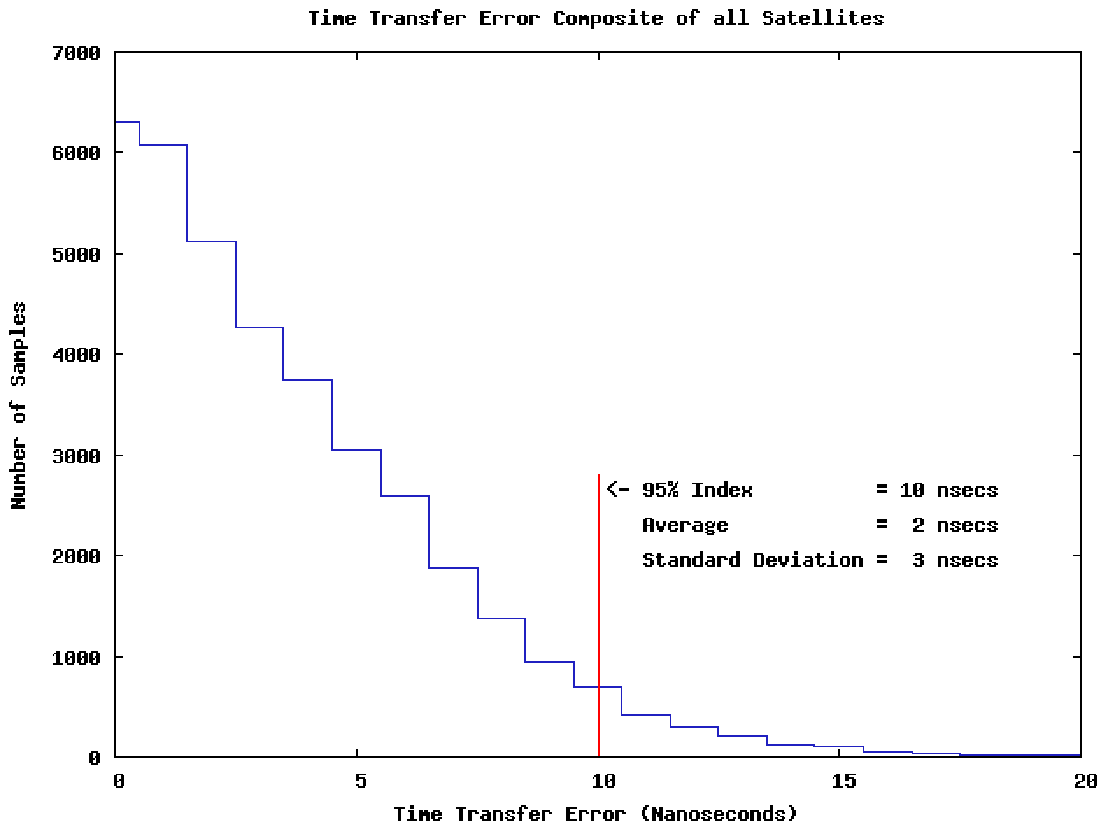
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 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 April and 30 June 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	1.5655	0.9370	1.1539	2.7975	10.869	14053238
3	1.6199	0.5968	1.2038	2.8787	8.062	12215615
4	1.4998	0.7309	1.0772	2.7574	9.844	13843391
6	1.3112	0.6290	1.0042	2.3379	7.520	12674213
7	1.4083	0.2859	1.1310	2.5831	8.152	12040914
8	1.9196	1.0496	1.4186	3.5310	10.276	12811620
9	1.7790	0.6194	1.3524	3.1908	9.258	12738375
10	2.0438	1.4158	1.3238	3.6184	10.867	13626635
11	1.6283	1.0247	1.1006	2.8586	7.580	12230337
12	1.3747	0.6334	1.1128	2.5105	11.633	14126392
13	1.2666	0.3381	1.0465	2.3865	7.240	13913546
14	1.5664	1.1021	0.9611	2.6606	7.720	13921224
15	1.2729	0.1437	1.0972	2.3901	11.476	12497478
16	1.6374	1.0315	1.1631	2.8735	7.245	12957956
17	1.3444	0.3469	1.1377	2.5562	7.467	14040094
18	1.7352	1.2113	1.1143	2.9649	12.048	12561659
19	1.6733	1.2713	0.9870	2.9080	6.465	12494772
20	1.6975	1.1732	1.1216	3.0448	11.910	14094884
21	1.8054	1.3781	1.0748	3.0041	10.959	11841257
22	1.7660	1.1429	1.0557	3.0334	10.122	12228833
23	1.4273	0.6629	1.0969	2.5828	6.234	12750371
24	1.8373	1.0012	1.1817	3.1305	11.463	12241973
25	1.8410	0.6886	1.3581	3.2704	16.469	11654337
26	1.4108	0.4951	1.0726	2.5331	10.329	12679237
27	1.9466	1.0348	1.3992	3.4721	11.926	13420455
28	1.8784	1.1396	1.2429	3.2602	9.758	12425172
29	1.2572	0.4868	0.9643	2.3616	10.588	13722339
30	1.6980	0.5230	1.2722	3.0593	12.626	13069740
31	1.4149	0.3943	1.1504	2.6072	7.394	13925466
32	1.8134	1.3266	1.1150	3.1427	9.873	14008723

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	14053238	0.0013754	-0.0000259	0.0013714	0.0025986	14053238
3	12215615	0.0019571	-0.0000612	0.0019525	0.0027961	12215615
4	13843391	0.0013429	-0.0000318	0.0013386	0.0024345	13843391
6	12674213	0.0012670	-0.0000425	0.0012613	0.0023355	12674213
7	12040914	0.0013795	-0.0000210	0.0013757	0.0025257	12040914
8	12811620	0.0019823	-0.0000576	0.0019783	0.0029532	12811620
9	12738375	0.0018157	0.0000298	0.0018126	0.0027797	12738375
10	13626635	0.0018006	0.0000165	0.0017971	0.0029424	13626635
11	12230337	0.0014486	-0.0000201	0.0014457	0.0025085	12230337
12	14126392	0.0014691	-0.0000115	0.0014656	0.0027121	14126392
13	13913546	0.0014140	0.0000298	0.0014105	0.0025441	13913546
14	13921224	0.0014201	-0.0000122	0.0014180	0.0025454	13921224
15	12497478	0.0014107	-0.0000094	0.0014065	0.0026097	12497478
16	12957956	0.0014219	-0.0000348	0.0014186	0.0025768	12957956
17	14040094	0.0014602	-0.0000178	0.0014582	0.0025972	14040094
18	12561659	0.0014049	-0.0000159	0.0014021	0.0025810	12561659
19	12494772	0.0013209	-0.0000217	0.0013166	0.0024535	12494772
20	14094884	0.0014447	0.0000399	0.0014405	0.0026027	14094884
21	11841257	0.0014494	-0.0000145	0.0014461	0.0027341	11841257
22	12228833	0.0016623	0.0000053	0.0016600	0.0027516	12228833
23	12750371	0.0013919	0.0000071	0.0013876	0.0025089	12750371
24	12241973	0.0014598	0.0000082	0.0014563	0.0026238	12241973
25	11654337	0.0015999	-0.0000021	0.0015934	0.0023133	11654337
26	12679237	0.0014162	0.0000021	0.0014136	0.0024612	12679237
27	13420455	0.0018155	-0.0000052	0.0018110	0.0027568	13420455
28	12425172	0.0015424	-0.0000158	0.0015390	0.0025852	12425172
29	13722339	0.0014368	-0.0000273	0.0014348	0.0025289	13722339
30	13069740	0.0019118	-0.0000313	0.0019089	0.0028945	13069740
31	13925466	0.0014956	-0.0000276	0.0014925	0.0025679	13925466
32	14008723	0.0014297	0.0000221	0.0014253	0.0023733	14008723

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	0.0000103	0.0000000	0.0000103	0.0000201	14053238
3	0.0000160	0.0000000	0.0000160	0.0000225	12215615
4	0.0000108	0.0000000	0.0000108	0.0000195	13843391
6	0.0000104	0.0000000	0.0000104	0.0000194	12674213
7	0.0000106	0.0000000	0.0000106	0.0000200	12040914
8	0.0000156	0.0000000	0.0000156	0.0000221	12811620
9	0.0000142	0.0000000	0.0000142	0.0000208	12738375
10	0.0000138	0.0000000	0.0000138	0.0000229	13626635
11	0.0000115	0.0000000	0.0000115	0.0000201	12230337
12	0.0000110	0.0000000	0.0000110	0.0000203	14126392
13	0.0000109	0.0000000	0.0000109	0.0000201	13913546
14	0.0000107	0.0000000	0.0000107	0.0000200	13921224
15	0.0000104	0.0000000	0.0000104	0.0000201	12497478
16	0.0000110	0.0000000	0.0000110	0.0000201	12957956
17	0.0000111	0.0000000	0.0000111	0.0000200	14040094
18	0.0000105	0.0000000	0.0000105	0.0000203	12561659
19	0.0000104	0.0000000	0.0000104	0.0000200	12494772
20	0.0000112	0.0000000	0.0000112	0.0000203	14094884
21	0.0000105	0.0000000	0.0000105	0.0000212	11841257
22	0.0000130	0.0000000	0.0000130	0.0000214	12228833
23	0.0000106	0.0000000	0.0000106	0.0000201	12750371
24	0.0000111	0.0000000	0.0000111	0.0000200	12241973
25	0.0000134	0.0000000	0.0000134	0.0000174	11654337
26	0.0000111	0.0000000	0.0000111	0.0000198	12679237
27	0.0000139	0.0000000	0.0000139	0.0000203	13420455
28	0.0000121	0.0000000	0.0000121	0.0000201	12425172
29	0.0000114	0.0000000	0.0000114	0.0000201	13722339
30	0.0000151	0.0000000	0.0000151	0.0000214	13069740
31	0.0000117	0.0000000	0.0000117	0.0000200	13925466
32	0.0000116	0.0000000	0.0000116	0.0000189	14008723

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 25 with an error of 16.469 meters. Satellite 23 had the lowest maximum range error of 6.234 meters.

Figure 5-4 Distribution of Daily Max Range Errors

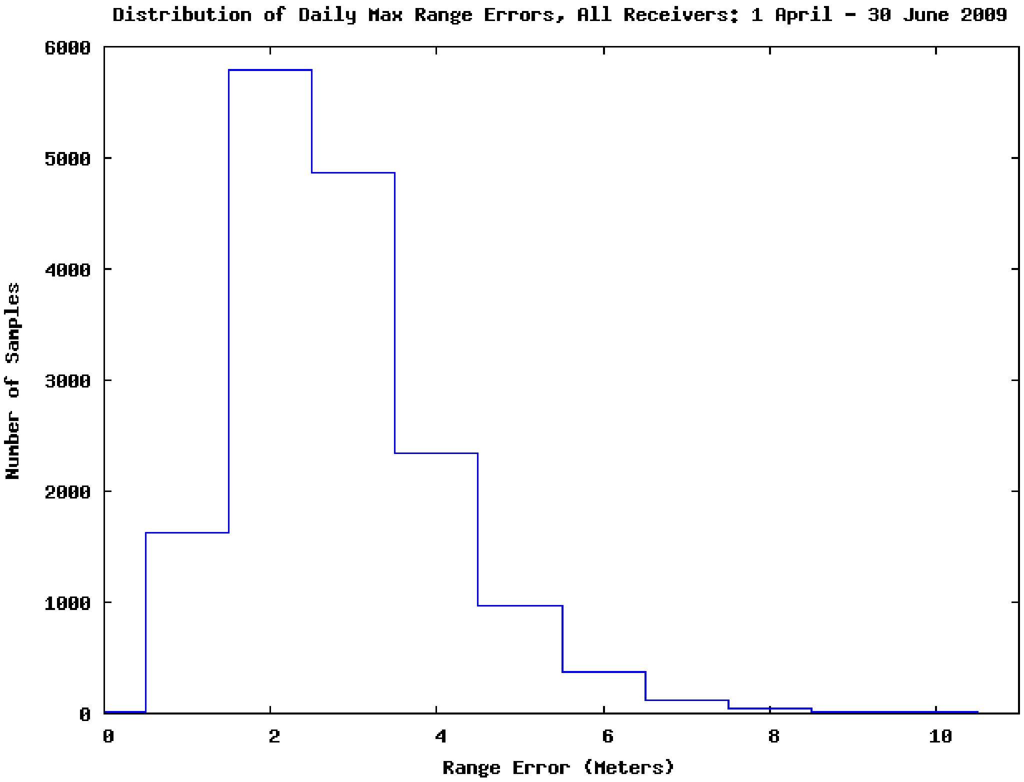


Figure 5-5: Distribution of Daily Max Range Rate Errors

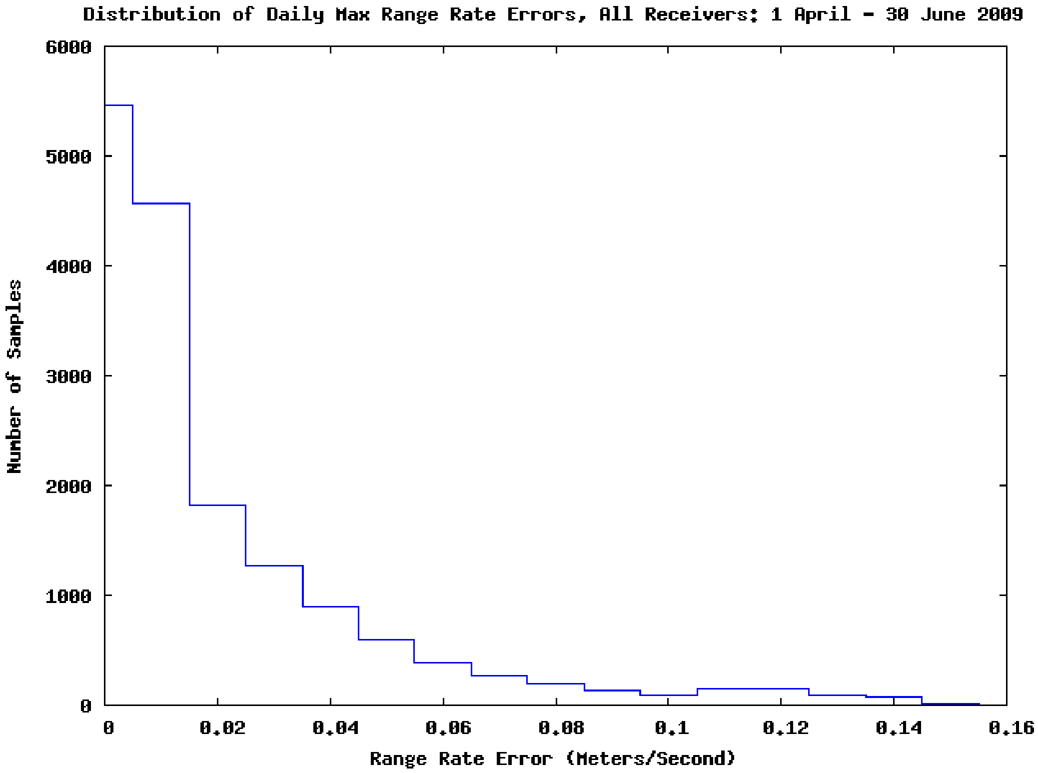


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

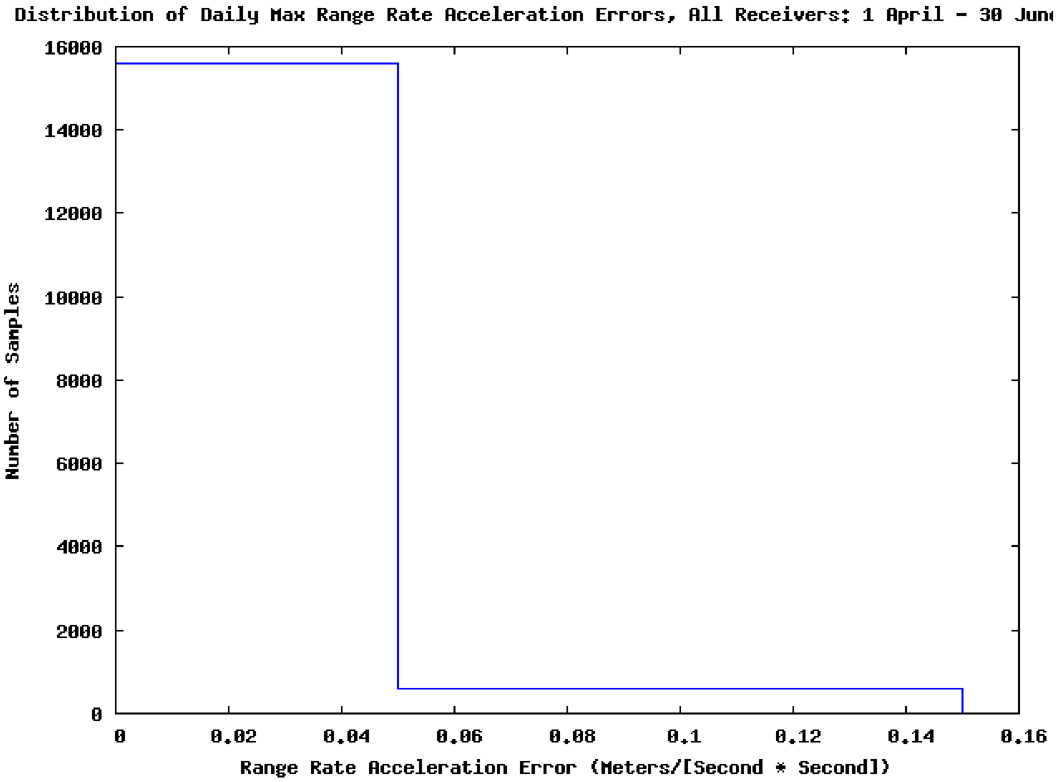


Figure 5-7: Range Error Histogram

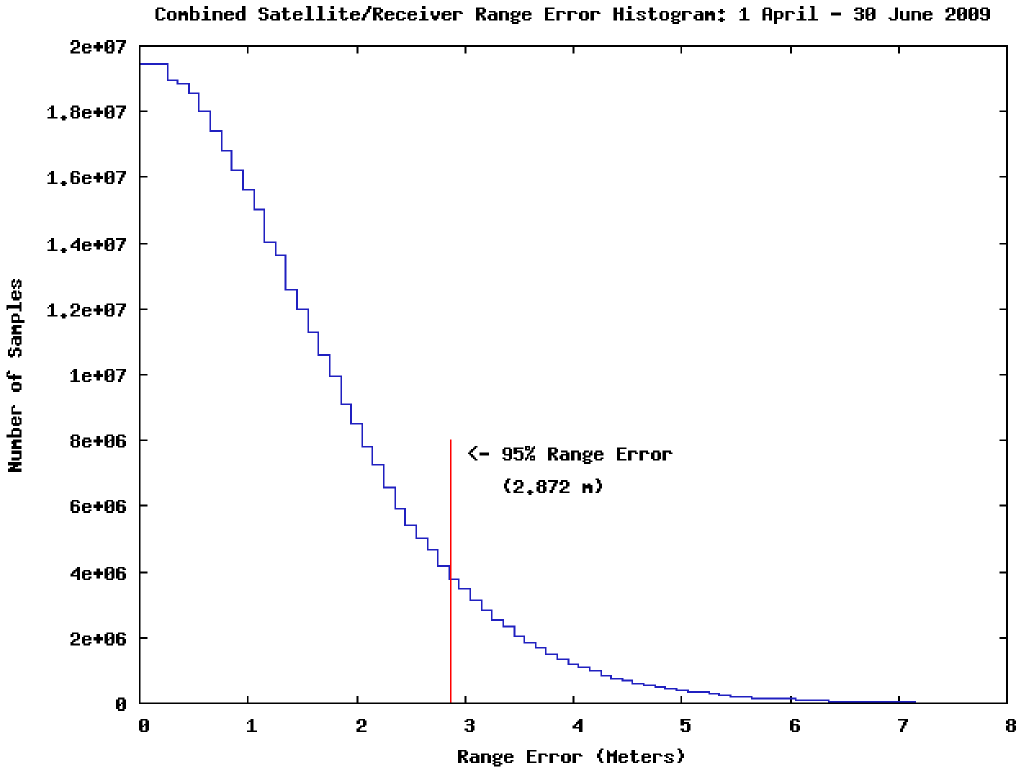


Figure 5-8: Maximum Range Error Per Satellite

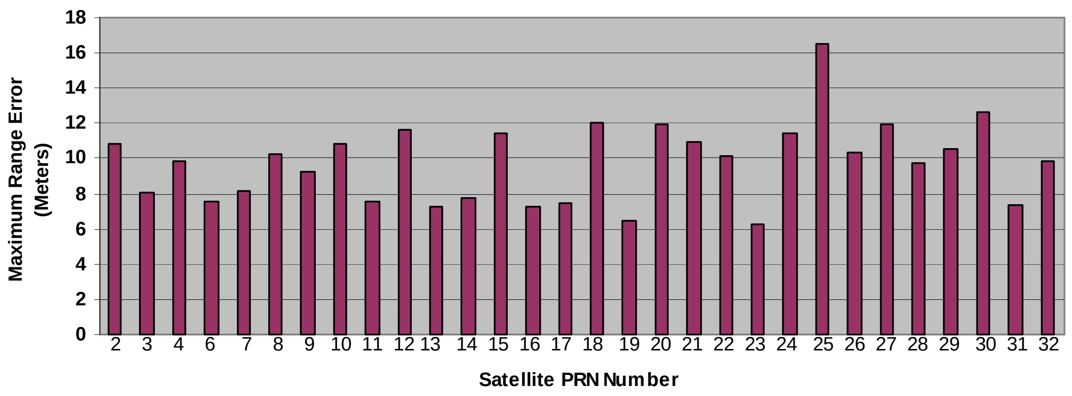


Figure 5-9: Maximum Range Rate Error Per Satellite

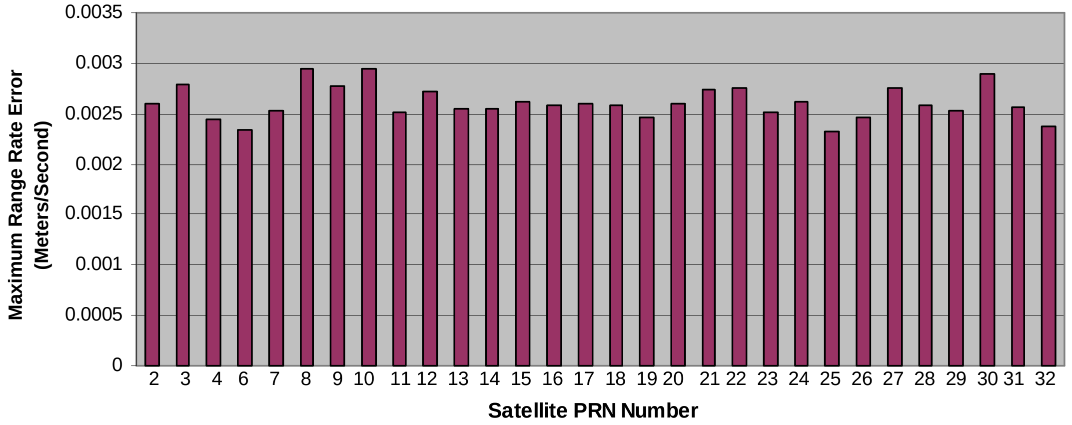
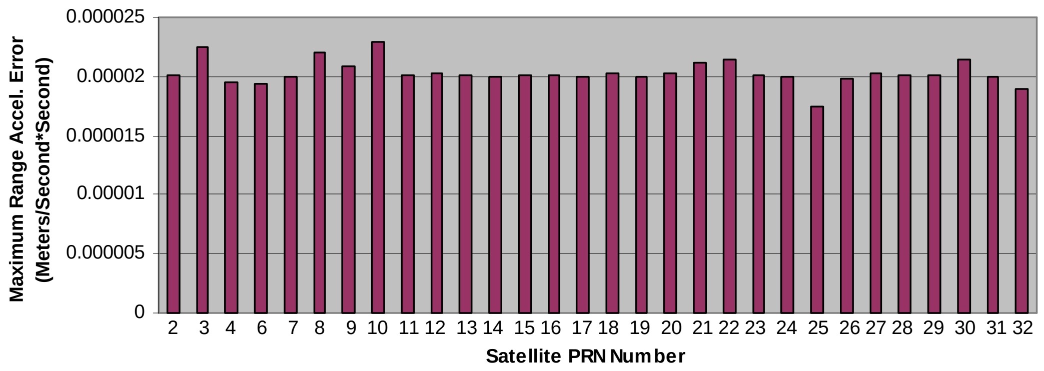


Figure 5-10: Maximum Range Acceleration Per Satellite



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 23-25 June 2009

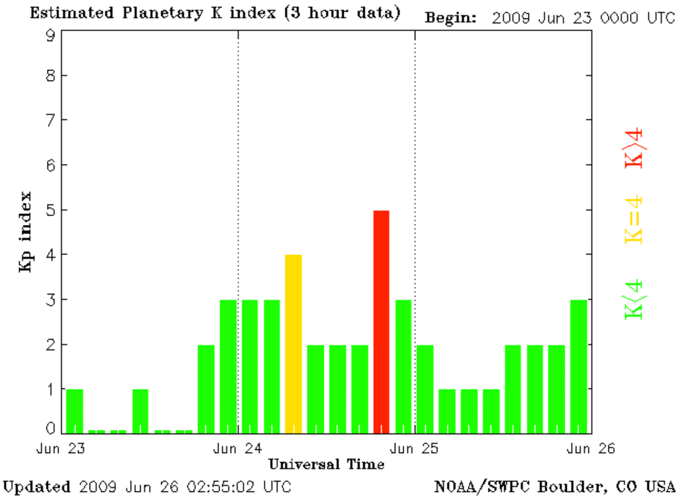


Figure 6-2 K-Index for 7-9 May 2009

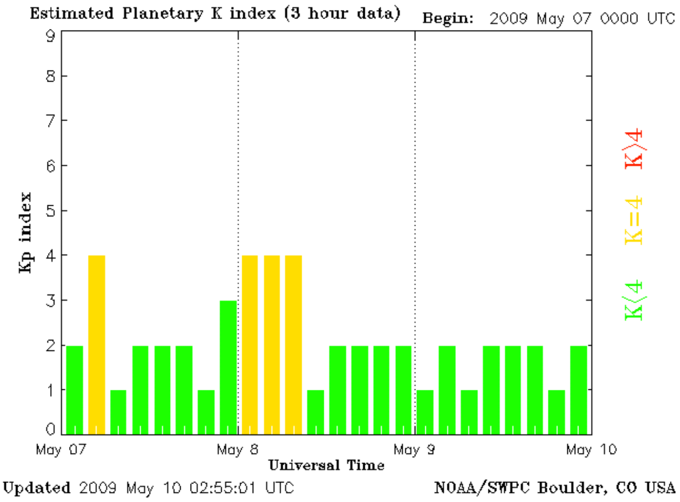


Figure 6-3 K-Index for 28-30 June 2009

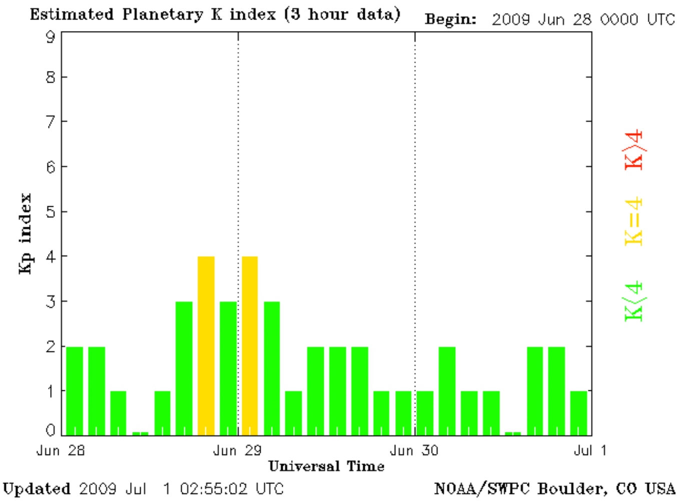


Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for 24 June 2009

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Albuquerque	1.94	2.52	2.36	3.39
Anchorage	1.43	2.33	1.96	3.88
Atlanta	1.62	4.06	2.32	5.74
Barrow	1.08	2.70	1.72	3.37
Bethel	1.51	2.31	2.05	3.65
Billings	2.06	2.52	2.69	4.06
Boston	1.64	3.34	2.31	4.62
Cleveland	1.49	4.35	1.74	5.84
Cold Bay	1.82	2.14	2.25	3.42
Fairbanks	1.27	2.41	1.61	3.73
Gander	1.25	2.63	2.55	5.20
Honolulu	2.01	3.69	2.52	4.83
Houston	1.71	2.67	2.19	4.78
Iqaluit	1.07	2.63	2.84	10.20
Juneau	1.47	1.90	2.12	2.75
Kansas City	1.67	2.90	2.21	4.75
Kotzebue	1.19	2.74	1.63	4.26
Los Angeles	2.07	2.92	3.02	4.83
Merida	1.78	3.11	2.06	5.38
Miami	1.63	3.74	1.98	5.30
Minneapolis	1.75	3.59	4.17	5.18
Oakland	2.23	2.87	3.12	3.62
Salt Lake City	2.07	2.30	2.48	3.38
San Jose Del Cabo	1.45	2.64	2.23	4.65
San Juan	1.43	4.24	2.25	5.85
Seattle	2.38	2.20	3.26	2.61
Tapachula	1.76	2.19	2.37	3.26
Washington, DC	1.69	4.47	1.91	5.57

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 J135 data from NNOR and day J150 data from MATE has been excluded due to what is believed to be receiver problems. Each had a long outage followed by a period of high error after restarting.

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) only had data available for the first 2 to 3 weeks of the 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.

During the evaluation period, the maximum 95% horizontal and vertical SPS errors are 2.64 and 5.35 meters at Usuda. The minimum 95% horizontal and vertical SPS errors are 1.81 meters at Kiruna and 3.88 meters at Tidbinbilla. The maximum 99.99% horizontal and vertical SPS errors are 19.77 meters at Matera and 27.63 meters at Kourou.

(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
MOBN	Obninsk, Russian Federation
NNOR	New Norcia, Australia
NRIL	Norilsk, Russian Federation
PETS	Petropavlovsk-Kamchatka, Russian Federation
POL2	Bishkek, Kyrghyzstan
SANT	Santiago, Chile
SUTM	Sutherland, South Africa
TIDB	Tidbinbilla, Australia
USUD	Usuda, Japan

Figure 7-1 Selected IGS Site Locations

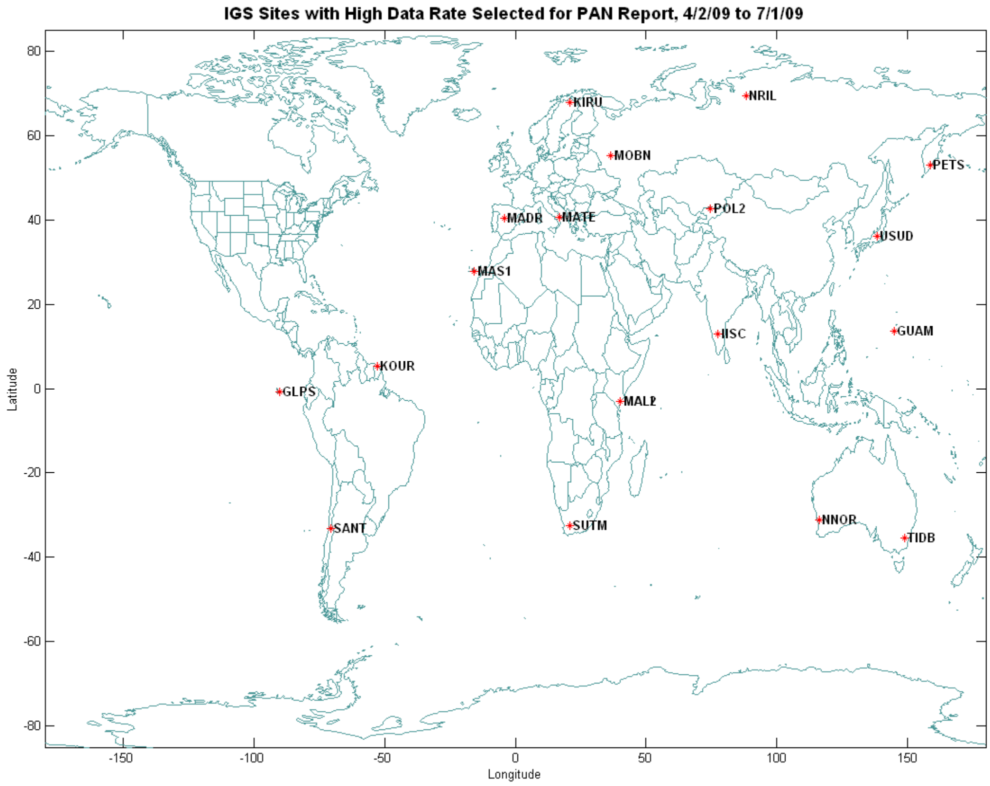


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
GLPS	1.88	4.49	4.23	9.22	98.68%
GUAM	1.96	4.84	5.11	14.59	97.51%
IISC	1.91	4.25	4.92	11.69	98.94%
KIRU	1.81	4.14	7.99	17.05	99.98%
KOUR	1.89	4.17	12.1	27.63	99.45%
MADR	2.12	4.9	6.17	11.55	99.44%
MAS1	2.6	4.9	9.71	20.58	99.20%
MATE	2.05	4.74	19.77	13.13	88.09%
MOBN	2.46	5.93	7.37	16.53	12.60%
NNOR	2.18	4.58	18.5	14.56	99.82%
NRIL	1.82	5.1	4.35	10.11	23.93%
PETS	2.41	7.37	4.72	11.91	12.57%
POL2	2.16	4.71	7.08	12.19	97.35%
SANT	2.6	4.74	5.42	11.39	99.95%
SUTM	1.89	4	6.31	11.01	98.28%
TIDB	2.5	3.86	9.32	17.47	99.50%
USUD	2.64	5.35	7.34	11.99	99.98%

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

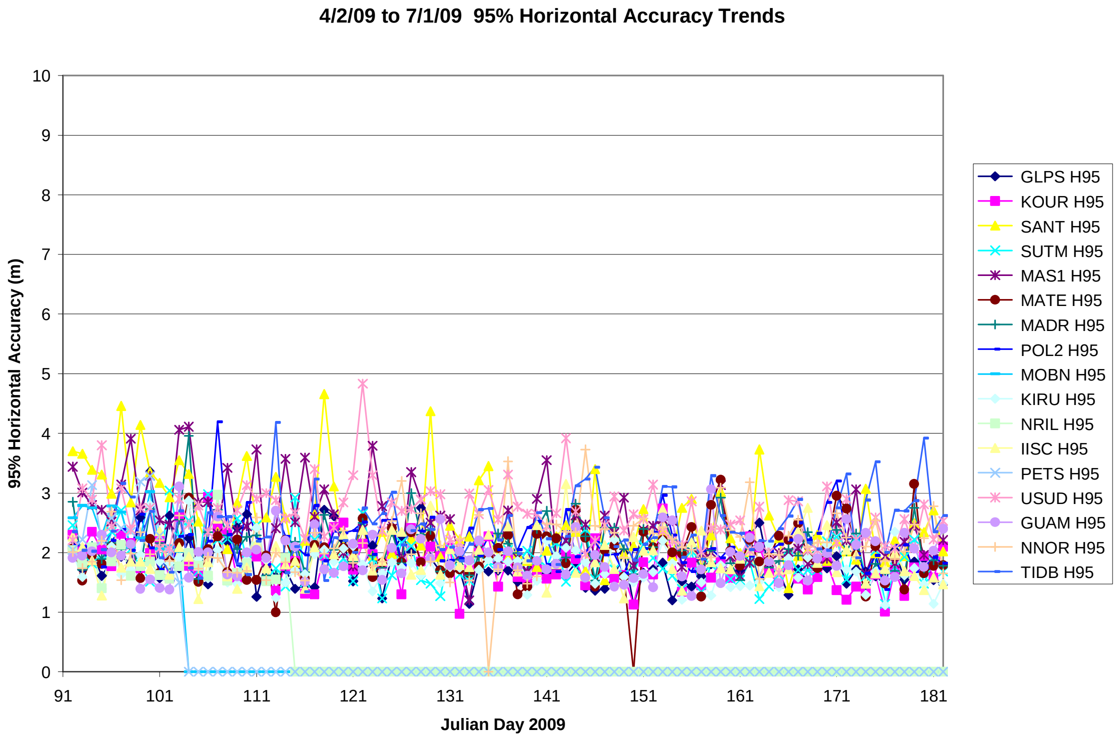
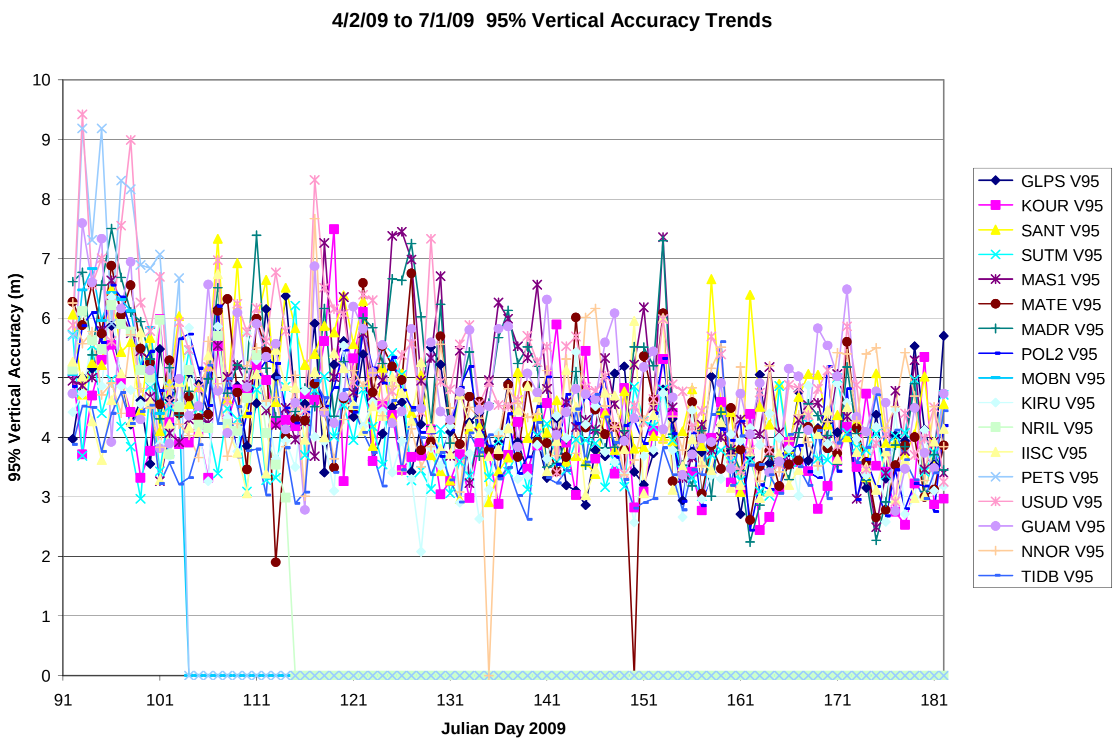


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites



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	≥ 99.991 % ≥ 98.292 %
Conditions and Constraints	***Service Availability Standard***	***Measured Performance***
• 36 meter horizontal (SIS only) 95% threshold. • 77 meter vertical (SIS only) 95% threshold. • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	100%
• Based on using only satellites transmitting standard code and indicating "healthy" in the broadcast navigation message (sub-frame 1).	≥ 95.87% global average on worst-case day	100%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	≥ 99.94% global average	100%
• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values from the worst-case point within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	≥ 99.79% single point average	100%

Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	Global Average Positioning Domain Accuracy • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only)	2.084 m 4.255 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)	3.097 m 5.028 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	2.038 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

Date	Middle Latitude - Fredericksburg - A	Middle Latitude - Fredericksburg - K-indices	High Latitude ---- College ---- A	High Latitude ---- College ---- K-indices	Estimated --- Planetary --- A	Estimated --- Planetary --- K-indices
2009 04 01	3	1 0 0 1 1 0 2 2	2	0 0 0 2 1 0 0 1	4	1 0 0 1 1 2 2 2
2009 04 02	0	0 0 0 0 1 0 0 0	1	0 0 1 1 0 0 0 0	3	1 0 0 0 1 1 1 2
2009 04 03	2	0 0 1 0 1 1 0 1	0	0 0 0 0 0 0 0 0	2	0 0 0 0 1 1 1 1
2009 04 04	0	0 0 0 0 0 1 0 0	0	0 0 0 0 1 0 0 0	2	0 0 0 0 0 1 0 1
2009 04 05	3	1 1 1 1 1 1 1 0	2	1 1 0 2 0 0 1 0	4	1 1 1 1 1 1 1 1
2009 04 06	2	0 0 0 2 1 1 1 1	1	0 0 0 0 0 1 0 1	3	1 0 0 1 1 1 0 1
2009 04 07	2	0 0 1 1 1 0 1 1	1	0 0 1 1 0 0 0 0	2	0 0 1 1 1 0 0 1
2009 04 08	4	0 1 1 1 2 1 2 1	3	1 2 0 1 1 0 1 1	5	0 0 1 1 2 2 2 2
2009 04 09	9	2 3 3 1 2 2 2 2	12	1 3 3 4 2 3 2 1	12	3 4 3 2 1 3 2 2
2009 04 10	6	2 1 2 2 2 1 2 1	8	1 1 3 3 3 2 2 0	8	2 2 2 2 1 1 3 2
2009 04 11	7	3 1 2 1 2 2 1 2	16	2 2 2 5 4 4 1 1	9	3 2 2 2 2 2 1 3
2009 04 12	4	2 2 2 0 0 1 1 2	3	1 2 2 1 1 0 0 1	8	2 2 2 1 1 2 2 3
2009 04 13	3	2 2 2 0 1 0 0 0	3	1 2 2 0 0 0 0 0	4	2 2 2 0 0 0 0 1
2009 04 14	1	1 0 0 1 0 0 0 0	2	0 0 0 2 2 0 0 0	2	1 0 0 1 1 0 0 1
2009 04 15	2	2 0 0 0 1 1 1 1	2	1 1 0 2 0 0 0 0	3	2 1 0 0 1 1 1 1
2009 04 16	3	1 1 1 0 1 2 1 1	7	1 1 3 2 3 2 0 1	6	1 2 2 1 1 2 1 3
2009 04 17	4	2 1 1 0 2 1 0 2	4	1 0 0 3 3 1 0 1	5	2 0 0 1 2 1 1 2
2009 04 18	8	2 3 3 1 2 1 1 2	13	2 3 4 3 2 3 2 2	8	2 3 3 1 2 2 1 2
2009 04 19	4	2 2 1 0 1 0 1 2	3	2 1 1 0 2 0 1 1	4	2 2 1 0 1 0 1 2
2009 04 20	3	2 2 1 0 1 1 0 1	3	1 2 2 1 0 0 0 1	4	2 2 1 0 1 2 0 1
2009 04 21	3	1 1 2 1 1 0 1 1	3	1 1 2 2 0 0 0 0	5	1 1 2 1 1 1 1 1
2009 04 22	2	2 1 0 1 1 0 0 1	5	1 1 0 3 3 0 0 0	4	2 1 0 1 1 1 0 2
2009 04 23	0	0 0 0 0 1 0 0 0	1	1 0 0 1 0 0 0 0	3	0 0 0 1 1 1 2 1
2009 04 24	5	2 1 2 1 2 1 1 1	4	2 1 1 1 1 0 2 1	5	2 1 2 1 2 1 2 1
2009 04 25	2	0 1 0 1 1 1 1 1	2	1 1 0 1 1 1 0 1	4	1 1 0 1 1 2 1 2
2009 04 26	3	1 1 1 1 1 1 0 1	2	1 1 0 2 0 0 0 1	5	1 1 1 1 1 2 1 2
2009 04 27	3	2 1 0 1 0 1 1 1	2	1 1 0 2 0 0 1 0	4	2 2 0 1 1 1 1 1
2009 04 28	2	0 0 0 0 1 1 1 1	1	0 1 0 0 0 0 1 1	2	0 0 0 0 1 1 1 1
2009 04 29	3	0 0 1 1 1 1 2 1	3	0 1 0 2 2 0 1 0	3	0 0 0 0 1 1 1 1
2009 04 30	2	1 1 0 1 1 0 0 0	1	1 1 0 1 0 0 0 0	3	1 0 0 0 2 1 0 1
2009 05 01	2	0 0 1 1 1 0 0 2	1	0 0 1 2 0 0 0 0	5	1 0 1 1 1 2 1 2
2009 05 02	3	0 1 1 1 2 0 0 2	2	0 1 2 1 0 0 0 1	5	1 1 2 0 2 1 1 2
2009 05 03	2	0 0 0 1 2 1 0 1	1	1 0 0 1 0 1 0 0	5	2 0 0 1 1 2 2 2
2009 05 04	2	0 1 1 1 1 0 0 0	3	1 1 1 3 1 0 0 0	4	1 1 1 2 1 1 1 1
2009 05 05	2	0 0 0 1 1 0 0 2	0	0 0 0 0 0 0 0 1	2	0 0 0 0 1 2 1 2
2009 05 06	6	2 2 1 1 2 1 2 2	3	2 1 0 1 1 1 1 1	6	2 1 1 1 2 2 2 3
2009 05 07	7	3 3 1 1 1 1 2 2	7	3 2 2 3 1 2 1 1	10	2 4 1 2 2 2 1 3
2009 05 08	12	4 3 4 1 2 1 2 2	23	4 5 5 4 4 1 1 1	13	4 4 4 1 2 2 2 2
2009 05 09	6	0 2 1 2 2 2 2 2	11	0 2 3 5 2 2 1 0	6	1 2 1 2 2 2 1 2
2009 05 10	3	0 2 0 1 2 1 1 1	4	1 2 1 1 2 1 0 1	4	1 2 0 0 1 0 2 2
2009 05 11	2	1 1 0 1 1 1 1 0	3	1 1 1 2 2 1 0 0	4	2 1 1 1 1 1 1 1
2009 05 12	0	0 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 0	2	0 0 0 0 0 1 1 1
2009 05 13	2	1 0 0 0 1 1 0 1	1	1 0 0 0 1 0 0 0	3	1 0 0 0 1 1 1 1
2009 05 14	8	1 1 1 2 3 2 3 2	4	0 2 1 2 1 1 2 1	8	1 2 1 2 2 2 4 2
2009 05 15	2	1 0 0 1 1 1 0 1	1	1 1 0 0 0 0 0 1	2	1 0 0 0 1 1 0 2
2009 05 16	3	1 1 0 1 1 1 1 1	2	1 1 0 0 1 0 1 1	5	1 1 0 2 1 2 2 2
2009 05 17	2	1 1 0 0 1 0 0 1	1	1 0 0 0 0 0 1 1	3	1 1 0 0 0 1 1 2
2009 05 18	2	1 0 0 0 1 0 0 2	1	0 0 1 0 0 1 0 1	4	2 1 0 0 1 1 0 2
2009 05 19	2	1 1 1 0 1 1 0 0	3	1 1 2 2 0 0 0 0	5	2 2 1 1 1 1 1 2
2009 05 20	4	1 1 0 0 1 0 3 2	2	1 1 0 0 0 0 1 1	4	1 1 0 0 1 1 2 2
2009 05 21	2	1 0 1 1 1 0 1 1	3	1 1 1 3 0 0 0 1	5	2 1 1 1 1 1 2 2
2009 05 22	4	0 0 1 2 2 2 1 1	5	1 1 1 1 4 1 0 0	5	1 0 1 2 2 2 1 2
2009 05 23	3	0 0 1 1 0 1 2 2	2	0 0 1 1 0 1 1 1	4	0 0 1 1 0 2 2 2
2009 05 24	4	1 2 1 1 1 1 1 1	3	2 1 1 1 1 0 0 1	4	2 2 1 0 0 1 1 2
2009 05 25	1	0 0 0 1 1 0 1 0	1	0 0 1 0 0 0 1 0	3	1 0 0 1 1 1 0 2
2009 05 26	2	1 0 1 0 1 0 0 1	1	1 0 1 0 0 0 0 0	4	1 0 1 0 1 1 1 2

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

Appendix D Glossary

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.