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

Submitted To

Federal Aviation Administration
GPS Product Team
AND 730
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Submitted by

William J. Hughes Technical Center
NSTB/WAAS T&E Team
ACB 430
Atlantic City International Airport, NJ 08405

EXECUTIVE SUMMARY

The GPS Product Team (AND 730) has tasked the Navigation Branch (ACB 430) at the William J. Hughes Technical Center to document 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-one NSTB and 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 Annex A.

This report, Report #51, includes data collected from 1 July through 30 September 2005. The next quarterly report will be issued 31 January 2006.

Analysis of this data includes the following categories: Coverage performance, Service Availability Performance, Position Performance, Range Performance and Solar Storm Effects on GPS SPS performance.

Coverage performance was 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 coverage based on PDOP less than six for the CONUS was 98.958% or better.

Availability was verified by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 July and 30 September 2005 and by calculating the satellite availability from the data obtained from the twenty-one sites. A total of eleven outages were reported in the NANU’s. Seven outages were scheduled while four were unscheduled. The quarterly availabilities for all sites were 100%. Each of these availabilities is within the SPS value of 99.85%. These availability percentages were calculated using DOP data collected at one-second intervals.

The statis tics on the days of significant solar activity met all GPS Standard Positioning Service (SPS) specifications.

Position accuracies were verified by calculating the 95% and 99.99% values of horizontal and vertical errors. Range performance was verified for each satellite using the data collected from the Billings WAAS site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 16.019 meters on Satellite PRN 4. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 0.85179 Meters/second on Satellite PRN 13. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 8.50 Millimeters/second^2 on Satellite PRN 13. The SPS specification states that the range acceleration error should never exceed 19 Millimeters/second^2.

The GLONASS/GPS performance section has been permanently removed from this report.

From the analysis performed on data collected between 1 July and 30 September 2005, the GPS performance met all SPS requirements that were evaluated.

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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-one National Satellite Test Bed (NSTB) and WAAS reference station locations:

- Billings, MT
- Cold Bay, AK
- Juneau, AK
- Albuquerque, NM
- Anchorage, AK
- Boston, MA
- Washington, D.C.
- Honolulu, HI
- Houston, TX
- Mauna Loa, HI
- Bangor, ME
- 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

(Future reports will include all WAAS sites but a database that can handle all that data needs to be developed. ACB 430 is in the process of setting up an Oracle database for this purpose.)

The analysis of the data is divided into the four performance categories stated in the Standard Positioning Service Performance Specification (SPS) Annex A (June 2, 1995). These categories are:

- Coverage Performance
- Satellite Availability Performance
- 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.

Appendix E Table 1.2 contains the performance parameters evaluated for the WAAS in this report.

1.3 Report Overview

Section 2 of this report summarizes the results obtained from the coverage calculation program called SPS_CoverageArea developed by ACB 430. The SPS_CoverageArea 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 availability 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 includes the maximum and minimum of the PDOP, HDOP and VDOP for each of the twenty-one NSTB/WAAS sites.

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

Section 5 provides the position and repeatable 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.

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.

Table 1-1 SPS Performance Requirements

Coverage Standard	**Conditions and Constraints**	**Evaluated in This Report**
≥ 99.9% global average	• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	✓
≥ 96.9% at worst-case point	• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	✓
Satellite Availability Standard	**Conditions and Constraints**	
≥ 99.85% global average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	✓
≥ 99.16% single point average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	✓
≥ 95.87% global average on worst-case day	• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	✓
≥ 83.92% at worst-case point on worst-case day	• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	✓
Service Availability Standard	**Conditions and Constraints**	
≥ 99.97% global average	• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	✓
≥ 99.79% single point average	• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	✓

Accuracy Standard	Conditions and Constraints	
Predictable Accuracy ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	✓
<u>Repeatable Accuracy</u> ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	✓
<u>Relative Accuracy</u> ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	Future Reports
<u>Time Transfer Accuracy</u> ≤ 340 nanoseconds time transfer error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	✓
<u>Range Domain Accuracy</u> ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 8 mm/s^2 range acceleration error 95% of time ≤ 19 mm/s^2 NTE range acceleration error	• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	✓

2.0 Coverage Performance

Coverage: *The percentage of time over a specified time interval that a sufficient number of satellites are above a specified mask angle and provide an acceptable position solution geometry at any point on or near the Earth.*

Dilution of Precision (DOP): *A Root Mean Square (RMS) measure of the effects that any given position solution geometry has on position errors. Geometry effects may be assessed in the local horizontal (HDOP), local vertical (VDOP), three-dimensional position (PDOP), or time (TDOP) for example.*

Coverage Standard	Conditions and Constraints
≥ 99.9% global average	• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac
≥ 96.9% at worst-case point	• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac

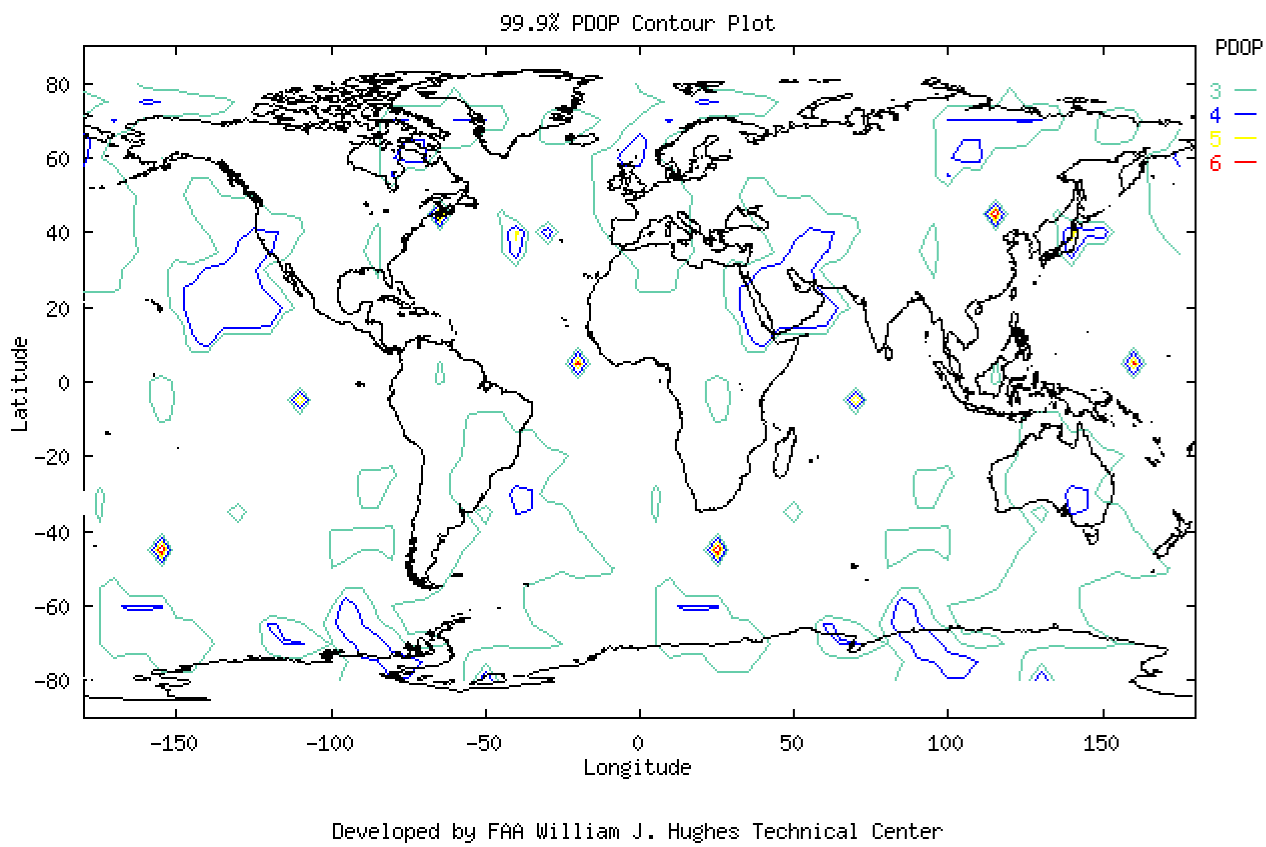
Almanacs for GPS weeks 293-305 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACB 430 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.55597 or better 99.9% of the time for each of the 24-hour intervals.

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

Table 2-1 Coverage Statistics

GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
306	2.88869	100	100
307	2.88162	100	100
308	2.88739	100	100
309	2.88738	100	100
310	2.88536	100	100
311	2.88563	100	100
312	2.88367	100	100
313	2.88898	100	100
314	2.89560	100	100
315	2.89558	100	100
316	3.55597	99.998	98.958
317	3.11335	99.991	99.097
318	3.36094	99.994	99.306

Figure 2-1 SPS Coverage (24-Hour Period: 12 September 2005)



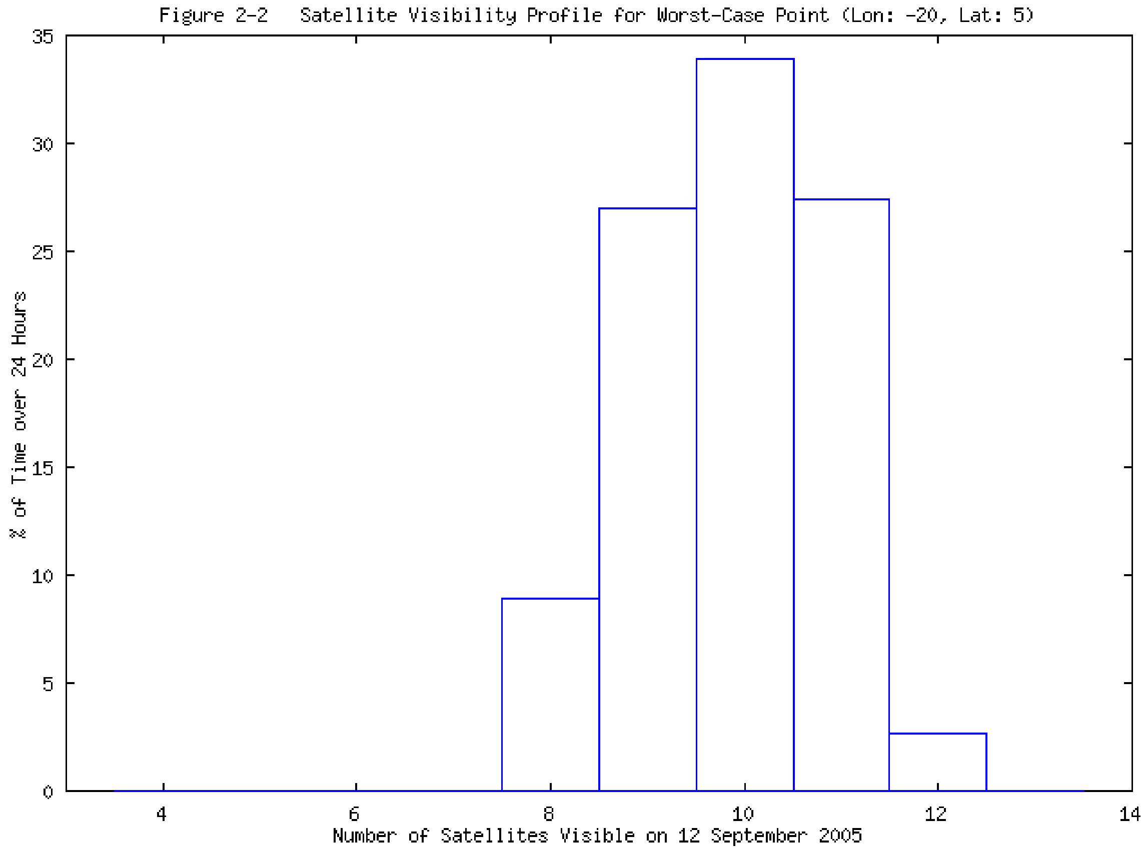


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -20, Lat: 5)
% of Time over 24 Hours
Number of Satellites Visible on 12 September 2005
0
5
10
15
20
25
30
35
4
6
8
10
12
14

3.0 Service Availability Performance

Service Availability: *Given coverage, the percentage of time over a specified time interval that a sufficient number of satellites are transmitting a usable ranging signal within view of any point on or near the Earth.*

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 2005, there were a total of twelve reported outages. Eleven of these outages were maintenance activities and were reported in advance. One was an unscheduled outage. 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
103	27	FCSTSUMM	25-Jul	23:32	26-Jul	6:08		6.60	6.60
104	9	FCSTSUMM	27-Jul	18:10	27-Jul	21:54		3.73	3.73
105	1	UNUSABLE	24-Jul	18:44	2-Aug	16:28	213.73		213.73
108	16	FCSTSUMM	11-Aug	19:46	12-Aug	2:49		7.05	7.05
111	11	FCSTSUMM	15-Aug	23:02	16-Aug	5:43		6.68	6.68
113	26	UNUNOREF	21-Aug	8:36	21-Aug	8:54	0.30		0.30
119	5	UNUSABLE	8-Sep	0:32	16-Sep	19:45	211.21		211.21
120	14	FCSTSUMM	19-Sep	10:38	19-Sep	17:18		6.66	6.66
121	1	FCSTSUMM	20-Sep	11:50	21-Sep	21:45		33.93	33.93
125	19	FCSTSUMM	27-Sep	11:15	28-Sep	5:46		18.51	18.51
126	25	UNUSABLE	28-Sep	4:35	29-Sep	19:05	28.50		28.50
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**453.74**	**83.16**	**536.90**
Type:	S = Scheduled		U = Unscheduled						

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
100	27	FCSTDV	25-Jul	23:15	26-Jul	11:15	12	See NANU 103
101	9	FCSTMX	27-Jul	17:30	28-Jul	5:30	12	See NANU 104
102	1	UNUSUFN	24-Jul	18:44	N/A	N/A	N/A	See NANU 105
106	16	FCSTDV	11-Aug	19:30	12-Aug	7:30	12	See NANU 108
107	11	FCSTDV	15-Aug	22:45	16-Aug	10:45	12	See NANU 111
114	4	FCSTMX	9-Sep	16:00	10-Sep	4:00	12	See NANU 116
115	5	UNUSUFN	8-Sep	0:32	N/A	N/A	N/A	See NANU 119
117	14	FCSTDV	19-Sep	10:30	19-Sep	22:30	12	See NANU 120
118	1	FCSTMX	20-Sep	11:30	23-Sep	18:30	79	See NANU 121
122	19	FCSTMX	27-Sep	10:00	28-Sep	10:00	24	See NANU 125
124	25	UNUSUFN	28-Sep	4:35	N/A	N/A	N/A	See NANU 126
					Total Forecast Downtime		**163**	

Table 3-3 NANUs Canceled					
NANU#	PRN	Type	Start Date	Start Time	Comments
116	4	FCSTCANC	9-Sep	16:00	See NANU 114

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 July - 30 Sep. 2005**	**1 October, 1999- 30 Sep. 2005**
Total Forecast Downtime (hrs):	163.00	5448.73
Total Actual Downtime (hrs):	536.90	14760.37
Total Actual Scheduled Downtime (hrs):	83.16	2987.36
Total Actual Unscheduled Downtime (hrs):	453.74	11773.01
Total Satellite Observed MTTR (hrs):	48.81	37.18
Scheduled Satellite Observed MTTR (hrs):	11.88	10.48
Unscheduled Satellite Observed MTTR (hrs):	113.44	105.12
# Total Satellite Outages:	11	397
# Scheduled Satellite Outages:	7	285
# Unscheduled Satellite Outages:	4	112
Percent Operational -- Scheduled Downtime:	99.87	99.79
Percent Operational -- All Downtime:	99.96	98.96

NANU 109 was disregarded by General NANU 110.
NANU 112 changed a start time for a NANU from the previous quarter.

3.2 Service Availability

Service Availability Standard	Conditions and Constraints
≥ 99.85% global average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days
≥ 99.16% single point average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days
≥ 95.87% global average on worst-case day	• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe
≥ 83.92% at worst-case point on worst-case day	• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe

To verify availability, the data collected from receivers at the nine NSTB/WAAS sites was reduced to calculate DOP information and reported in Tables 3-5 to 3-7. The data was collected at one-second intervals between 1 July and 30 September 2005.

Table 3-5 PDOP Statistics

NSTB/WAAS Site	Min PDOP	Max PDOP	VDOP at Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP	Number of Samples
Bangor	1.497	6.000	5.778	2.293	5.942	5.716	7881007
Mauna Loa	1.242	4.529	4.341	1.761	4.285	3.997	7835107
Billings	1.208	4.660	3.467	1.777	3.940	3.292	7874745
Cold Bay	1.148	4.591	4.310	1.712	4.550	4.279	7786252
Juneau	1.249	5.885	5.167	1.780	3.904	3.727	7870176
Albuquerque	1.240	3.855	3.333	1.759	3.468	3.026	7918412
Anchorage	1.166	5.714	5.541	1.731	4.694	4.052	7873012
Boston	1.243	3.988	3.254	1.724	3.767	3.084	7912386
Washington, D.C.	1.201	6.000	5.644	1.743	5.373	4.662	7869175
Honolulu	1.205	4.520	4.327	1.718	4.376	4.181	7841348
Houston	1.168	3.714	3.200	1.717	3.305	2.794	7831892
Kansas City	1.204	4.723	4.101	1.748	3.324	2.593	7810736
Los Angeles	1.159	5.110	4.044	1.790	5.070	4.014	7922941
Salt Lake City	1.150	6.000	5.823	1.781	4.842	4.043	7866540
Miami	1.206	4.543	4.276	1.764	3.560	3.295	7852855
Minneapolis	1.216	5.187	4.709	1.726	4.454	4.061	6551422
Oakland	1.155	5.130	4.260	1.785	5.090	4.233	7496201
Cleveland	1.160	4.623	4.383	1.762	4.422	4.180	7852127
Seattle	1.148	4.785	4.301	1.768	4.747	4.268	7875376
San Juan	1.190	4.855	4.694	1.726	4.515	4.344	6517120
Atlanta	1.206	5.999	5.578	1.758	5.551	5.086	7728242

Tables 3-6 and 3-7 show the statistics related to maximum PDOP and PDOP greater than six, respectively. Table 3-6 shows the PDOP statistics for the worst-case point on the worst-case day.
NOTE: Global in this report refers to the twenty-one sites used. Although future reports will have all additional sites, a true global availability cannot be determined since there aren't reference stations around the world. Whenever the

PDOP goes above six and an SPS requirement is not met, an investigation is performed to determine what caused the PDOP to go above six. The following is a list of programs/procedures used during times of high PDOP:

- Notice of Advisory to Navstar Users (NANU's) messages are used to verify that satellite outages did occur. (See Section 3.1 for more details about NANU's for this quarter.)
- A satellite outage detection program developed by ACB 430 verifies satellite outages that are not verified through a NANU. For example, a satellite outage can occur for just a few seconds during an upload. This satellite detection program monitors all the receivers and keeps track of what satellites the receiver should be tracking versus what satellites the receiver is actually tracking. At least six receivers need to be tracking the satellite prior to the outage and no receiver can be tracking the satellite for the program to detect an outage. This program is also being enhanced so that false locks and late ephemeris problems can also be detected. This program will also output flags from the receivers so that problems with the receiver or TRS software, if any, can be tracked more easily.
- Data from co-located receivers is analyzed for times that the PDOP goes above six. This helps in determining whether the problem is due to the environment.

The instance of worst performance where the PDOP went above six is reported in Table 3-6. The column labeled "NANU/SOD" reports whether the outage was detected via a NANU or the Satellite Outage Detection (SOD) program along with the Satellite PRN number that had the outage.

Table 3-6 Maximum PDOP Statistics

Site	GPS Week/ Day	Max PDOP	Number of Seconds of Whole Day PDOP > 6	NANU/SOD, Satellite PRN Number	Number of Samples	Availability on days when PDOP > 6
None						
Worst-Case Point on Worst-Case Day = 100% (SPS Spec. ≥ 83.92%)						

Global Average on Worst-Case Day = 100% (SPS Spec. ≥ 95.87%)

Table 3-7 PDOP > 6 Statistics

Site	Total Number of Seconds of PDOP Monitoring	Total Seconds with PDOP > 6	Overall % Availability
Bangor	7881007	0	100%
Mauna Loa	7835107	0	100%
Billings	7874745	0	100%
Cold Bay	7786252	0	100%
Juneau	7870176	0	100%
Albuquerque	7918412	0	100%
Anchorage	7873012	0	100%
Boston	7912386	0	100%
Washington, D.C.	7869175	0	100%
Honolulu	7841348	0	100%
Houston	7831892	0	100%
Kansas City	7810736	0	100%
Los Angeles	7922941	0	100%
Salt Lake City	7866540	0	100%
Miami	7852855	0	100%
Minneapolis	6551422	0	100%
Oakland	7496201	0	100%
Cleveland	7852127	0	100%
Seattle	7875376	0	100%
San Juan	6517120	0	100%
Atlanta	7728242	0	100%
Worst Single Point Average = 100% (SPS Spec. ≥ 99.16%)			

Global Average over Reporting Period = 100% (SPS Spec. > 99.85%)

4.0 Service Reliability Standard

Service Reliability: *Given coverage and service availability, the percentage of time over a specified time interval that the instantaneous predictable horizontal error is maintained within a specified threshold at any point on or near the Earth.*

Service Reliability Standard	Conditions and Constraints
≥ 99.97% global average	• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval
≥ 99.79% single point average	• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval

Table 4-1 has the 99.99% horizontal errors reported by a receiver at each of the twenty-one NSTB/WAAS sites. This will be evaluated against the SPS specification at the end of the year.

Table 4-1 Service Reliability Based on Horizontal Error

Site	Number of Samples This Quarter	Maximum Horizontal Error (Meters)
Bangor	7881007	11.4
Mauna Loa	7835107	12.3
Billings	7874745	6.22
Cold Bay	7786252	6.95
Juneau	7870176	8.72
Albuquerque	7918412	6.21
Anchorage	7873012	6.43
Boston	7912386	6.48
Washington, D.C.	7869175	7.66
Honolulu	7841348	10.8
Houston	7831892	6.56
Kansas City	7810736	4.88
Los Angeles	7922941	6.51
Salt Lake City	7866540	5.93
Miami	7852855	8.47
Minneapolis	6551422	6.37
Oakland	7496201	7.69
Cleveland	7852127	8.09
Seattle	7875376	5.37
San Juan	6517120	7.75
Atlanta	7728242	6.53

5.0 Accuracy Characteristics

Accuracy: *Given coverage, service availability and service reliability, the percentage of time over a specified time interval that the difference between the measured and expected user position or time is within a specified threshold at any point on or near the Earth.*

Accuracy Standard	Conditions and Constraints
Predictable Accuracy ≤ 100 meters horizontal error 95% of time ≤ 156 meters vertical error 95% of time ≤ 300 meters horizontal error 99.99% of time ≤ 500 meters vertical error 99.99% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe
Repeatable Accuracy ≤ 141 meters horizontal error 95% of time ≤ 221 meters vertical error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe
Relative Accuracy ≤ 1.0 meters horizontal error 95% of time ≤ 1.5 meters vertical error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time
Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory
Range Domain Accuracy ≤ 150 meters NTE range error ≤ 2 meters/second NTE range rate error ≤ 8 millimeters/second^2 range acceleration error 95% of time ≤ 19 millimeters/second^2 NTE range acceleration error	• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard

5.1 Position Accuracies

The data used for this section was collected for every second between 1 July through 30 September 2005 at the NSTB and WAAS selected locations.

Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter.

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)
Bangor	3.338	5.706	10.232	15.052
Mauna Loa	5.031	6.728	10.160	20.348
Billings	2.293	4.238	5.332	8.942
Cold Bay	2.461	5.018	5.234	12.031
Juneau	2.405	4.007	5.183	8.840
Albuquerque	2.463	4.156	6.011	9.424
Anchorage	2.538	4.479	5.827	10.592
Boston	2.279	4.120	5.160	9.140
Washington, D.C.	2.259	4.419	5.733	10.399
Honolulu	4.428	5.315	10.348	16.096
Houston	2.696	4.248	6.355	8.923
Kansas City	2.298	4.296	4.707	9.434
Los Angeles	2.662	4.778	5.766	10.053
Salt Lake City	2.360	4.334	5.315	9.108
Miami	2.931	4.431	8.150	10.339
Minneapolis	2.236	3.904	4.732	8.280
Oakland	2.552	4.960	5.437	10.294
Cleveland	2.278	4.217	4.987	10.594
Seattle	2.395	4.258	5.046	9.391
San Juan	3.097	4.249	6.778	12.012
Atlanta	2.408	4.363	6.313	13.921

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-one NSTB and WAAS sites from 1 July to 30 September 2005.

Figure 5-1 Combined Vertical Error Histogram

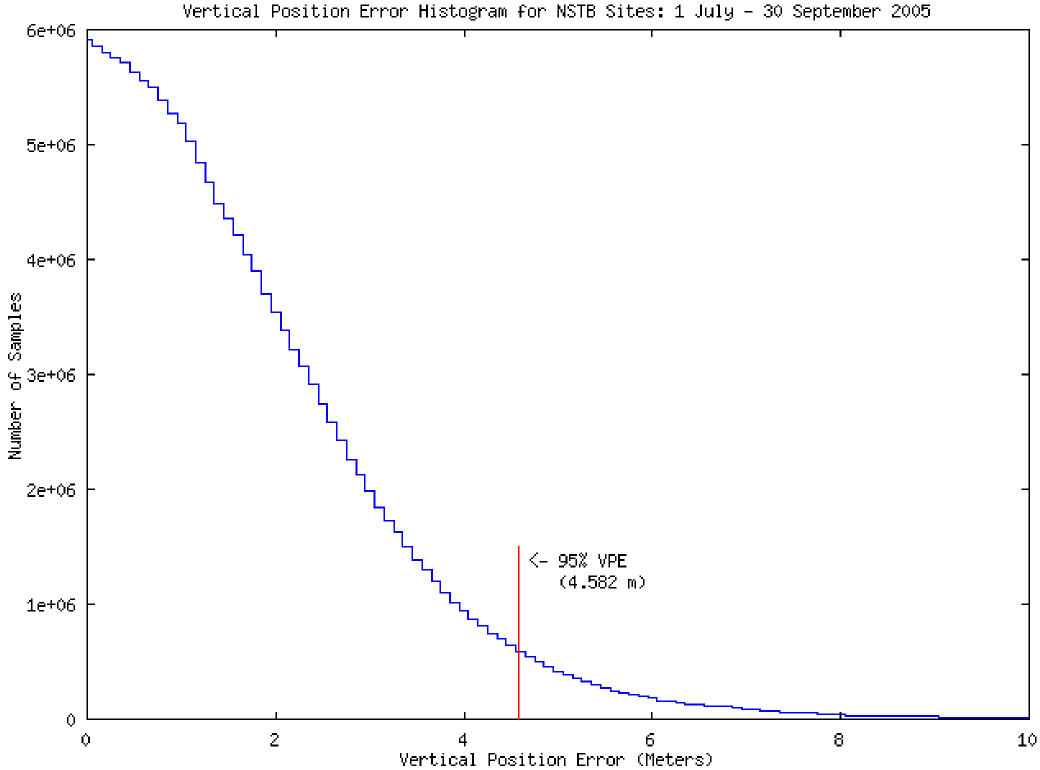
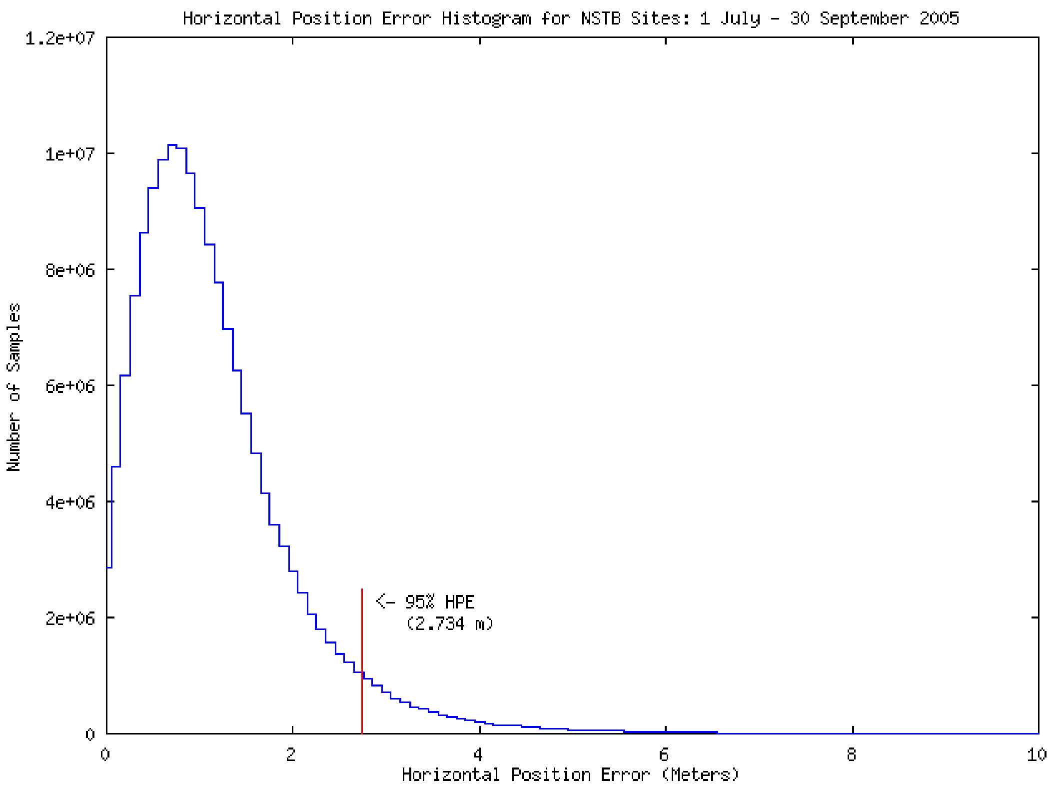


Figure 5-2 Combined Horizontal Error Histogram



5.2 Repeatable Accuracy

Table 5-2 provides the repeatability statistics, which met all of the evaluated requirements stated in the SPS.

Table 5-2 Repeatability Statistics

Site	95% Horizontal (m)	95% Vertical (m)
Bangor	1.392	4.433
Mauna Loa	1.150	2.753
Billings	0.779	1.712
Cold Bay	1.009	2.464
Juneau	0.873	2.154
Albuquerque	1.058	1.946
Anchorage	0.842	2.013
Boston	0.775	1.939
Washington, D.C.	0.757	1.820
Honolulu	0.855	3.079
Houston	1.066	2.358
Kansas City	0.851	2.017
Los Angeles	1.067	1.854
Salt Lake City	0.881	2.249
Miami	0.695	2.012
Minneapolis	0.761	1.998
Oakland	1.047	1.660
Cleveland	0.796	2.273
Seattle	1.008	1.761
San Juan	0.659	1.909
Atlanta	0.904	2.026

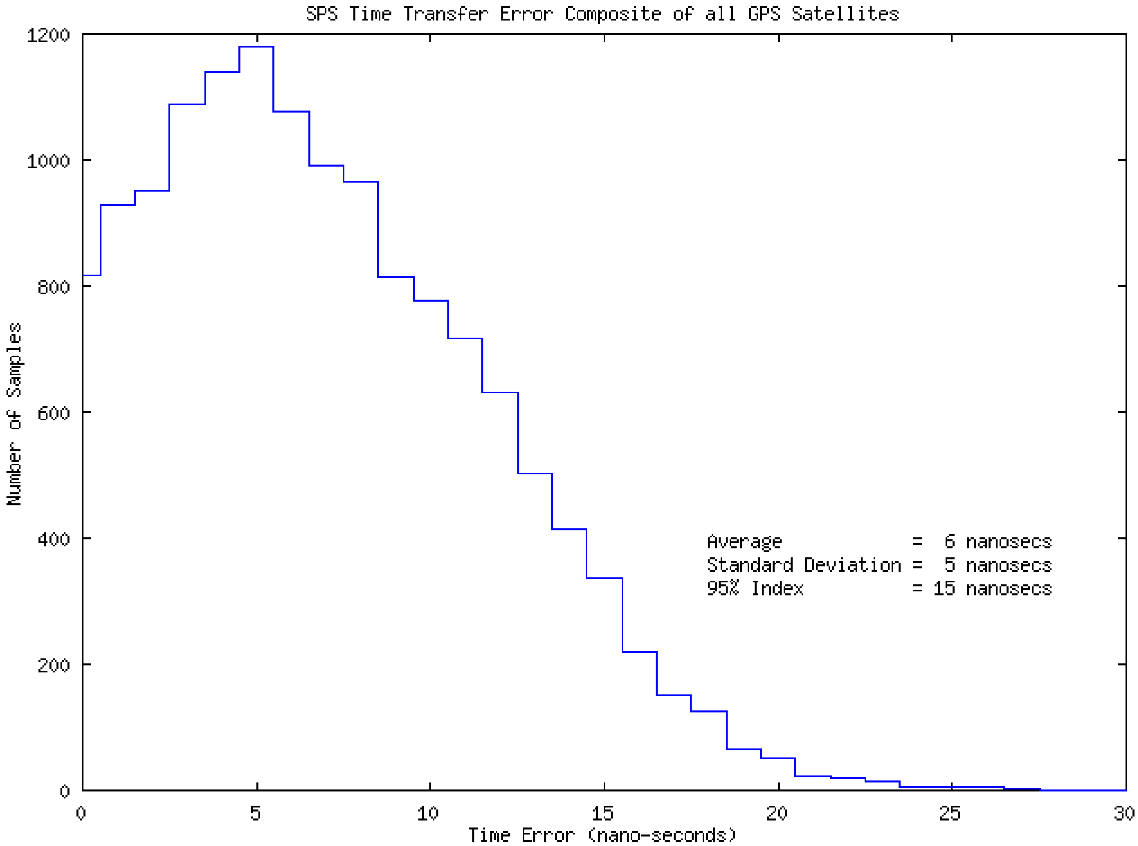
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 July and 30 September 2005 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



5.5 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 2005. The WAAS receiver at Houston was used to collect range measurement. Future PAN reports will contain statistics from all WAAS sites.

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 5-3 Range Error Statistics (meters)

PRN	Range Error Mean	Range Error RMS	1s	95% Range Error	Max Range Error (SPS Spec. ≤ 150 m)	Samples
1	0.906	2.633	2.472	5.140	9.975	1836199
2	3.915	4.296	1.770	6.773	9.741	1922747
3	1.479	2.602	2.141	4.923	9.895	2506106
4	1.364	2.527	2.127	4.985	16.019	1922910
5	2.231	3.230	2.335	6.154	11.923	1955853
6	1.963	2.547	1.623	4.608	7.013	1890910
7	2.345	2.987	1.850	5.351	9.337	2092900
8	1.594	3.161	2.730	5.928	10.371	1999262
9	1.582	2.389	1.791	4.399	8.960	2443480
10	3.115	3.704	2.004	6.133	11.026	2368900
11	2.345	2.985	1.846	5.453	10.186	2505116
13	1.170	2.498	2.207	4.867	15.652	1822266
14	2.040	2.826	1.956	5.450	10.754	1969129
15	1.845	2.765	2.059	5.263	9.978	1955878
16	2.517	3.128	1.858	5.588	9.729	2362919
18	2.637	3.115	1.658	5.237	7.830	2075957
19	4.151	4.555	1.874	7.172	10.666	2497990
20	2.618	3.331	2.060	6.256	10.284	2228348
21	3.240	3.576	1.514	5.739	8.990	2082687
22	2.450	3.070	1.849	5.394	8.492	2126630
23	3.632	4.236	2.181	7.287	11.015	1953939
24	0.896	2.546	2.384	5.154	15.440	2475236
25	1.398	2.722	2.336	5.357	8.851	1813338
26	1.154	2.064	1.711	3.957	9.356	2501922
27	1.704	3.054	2.534	6.058	10.035	2111116
28	2.630	3.412	2.174	6.160	10.592	2170989
29	1.853	2.559	1.765	4.741	9.635	2585807
30	1.337	2.392	1.983	4.633	8.251	2409555

Table 5-4 Range Rate Error Statistics (meters/second)

PRN	Range Rate Error Mean	Range Rate Error RMS	Range Rate Error 1σ	95% Range Rate Error	Max Range Rate Error (SPS Spec. ≤ 2 m)	Samples
1	0.00005	0.00228	0.00228	0.00332	0.16191	1836199
2	0	0.00182	0.00182	0.00352	0.05670	1922747
3	-0.00001	0.00283	0.00283	0.00364	0.23246	2506106
4	0.00011	0.00656	0.00655	0.00465	0.70470	1922910
5	0	0.00386	0.00386	0.00415	0.28146	1955853
6	-0.00003	0.00239	0.00239	0.00350	0.19548	1890910
7	0.00001	0.00214	0.00214	0.00322	0.14469	2092900
8	0.00005	0.00304	0.00304	0.00381	0.28287	1999262
9	-0.00008	0.00266	0.00266	0.00360	0.25424	2443480
10	0.00012	0.00342	0.00342	0.00406	0.31224	2368900
11	0.00010	0.00272	0.00271	0.00364	0.37683	2505116
13	0.00010	0.00541	0.00541	0.00395	0.85179	1822266
14	-0.00004	0.00327	0.00327	0.00331	0.36702	1969129
15	0.00005	0.00234	0.00234	0.00341	0.18477	1955878
16	-0.00010	0.00301	0.00301	0.00376	0.24621	2362919
18	-0.00009	0.00180	0.00180	0.00348	0.06403	2075957
19	-0.00003	0.00183	0.00183	0.00332	0.15620	2497990
20	0.00004	0.00327	0.00327	0.00379	0.31313	2228348
21	-0.00004	0.00197	0.00197	0.00352	0.19857	2082687
22	-0.00004	0.00194	0.00194	0.00314	0.17342	2126630
23	0.00006	0.00176	0.00176	0.00336	0.04390	1953939
24	0.00009	0.00396	0.00396	0.00401	0.34313	2475236
25	0.00001	0.00209	0.00209	0.00340	0.16622	1813338
26	0.00010	0.00355	0.00355	0.00355	0.28931	2501922
27	0	0.00221	0.00221	0.00354	0.19019	2111116
28	0.00001	0.00212	0.00212	0.00331	0.17123	2170989
29	0.00006	0.00317	0.00317	0.00344	0.39447	2585807
30	0.00010	0.00228	0.00228	0.00351	0.15653	2409555

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1 s	% ≤ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. ≤ 0.019 m/s2)	Samples
1	0	0.00002	0.00002	100	0.00161	1836199
2	0	0.00001	0.00001	100	0.00058	1922747
3	0	0.00002	0.00002	100	0.00229	2506106
4	0	0.00006	0.00006	100	0.00720	1922910
5	0	0.00003	0.00003	100	0.00281	1955853
6	0	0.00002	0.00002	100	0.00187	1890910
7	0	0.00002	0.00002	100	0.00141	2092900
8	0	0.00003	0.00003	100	0.00263	1999262
9	0	0.00002	0.00002	100	0.00254	2443480
10	0	0.00003	0.00003	100	0.00313	2368900
11	0	0.00002	0.00002	100	0.00376	2505116
13	0	0.00005	0.00005	99.999	0.00850	1822266
14	0	0.00003	0.00003	100	0.00362	1969129
15	0	0.00002	0.00002	100	0.00184	1955878
16	0	0.00003	0.00003	100	0.00243	2362919
18	0	0.00002	0.00002	100	0.00063	2075957
19	0	0.00002	0.00002	100	0.00156	2497990
20	0	0.00003	0.00003	100	0.00309	2228348
21	0	0.00002	0.00002	100	0.00196	2082687
22	0	0.00002	0.00002	100	0.00172	2126630
23	0	0.00001	0.00001	100	0.00042	1953939
24	0	0.00003	0.00003	100	0.00330	2475236
25	0	0.00002	0.00002	100	0.00164	1813338
26	0	0.00003	0.00003	100	0.00283	2501922
27	0	0.00002	0.00002	100	0.00188	2111116
28	0	0.00002	0.00002	100	0.00171	2170989
29	0	0.00003	0.00003	100	0.00403	2585807
30	0	0.00002	0.00002	100	0.00147	2409555

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. None of the range errors for any of the satellites exceeded the 150-meter SPS requirement. The highest maximum range error occurred on satellite 4 with an error of 16.019 meters. Satellite 6 had the lowest maximum range error of 7.013 meters.

Figure 5-4 Distribution of Daily Max Range Errors

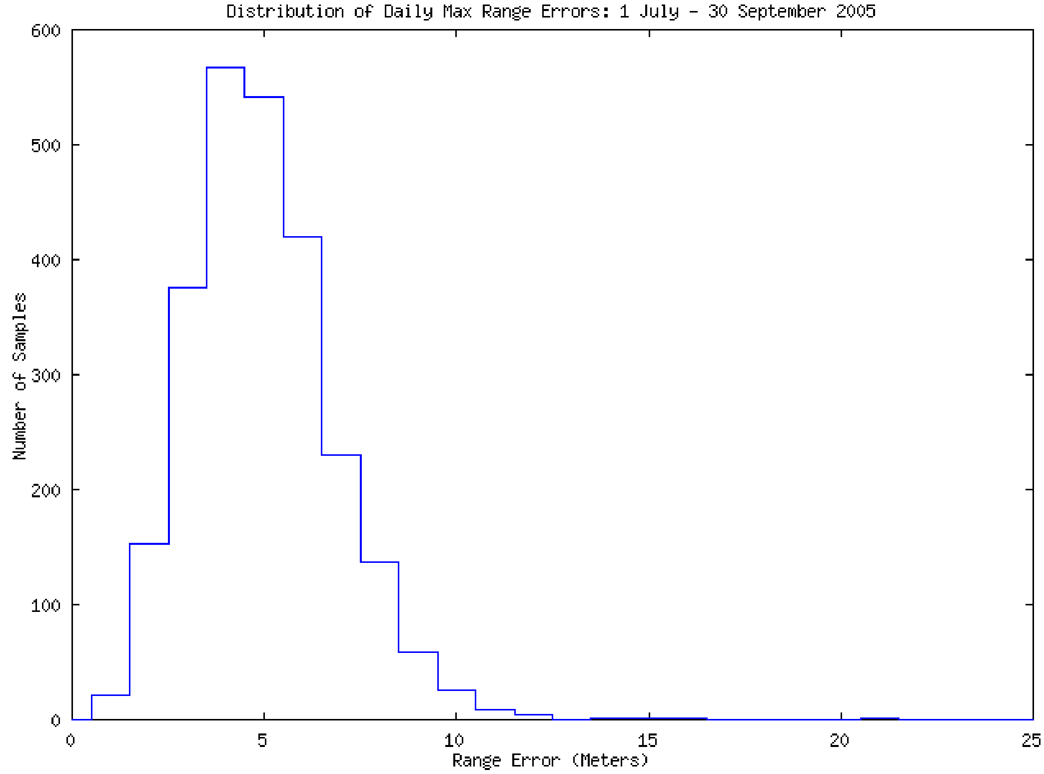


Figure 5-5: Distribution of Daily Max Range Rate Errors

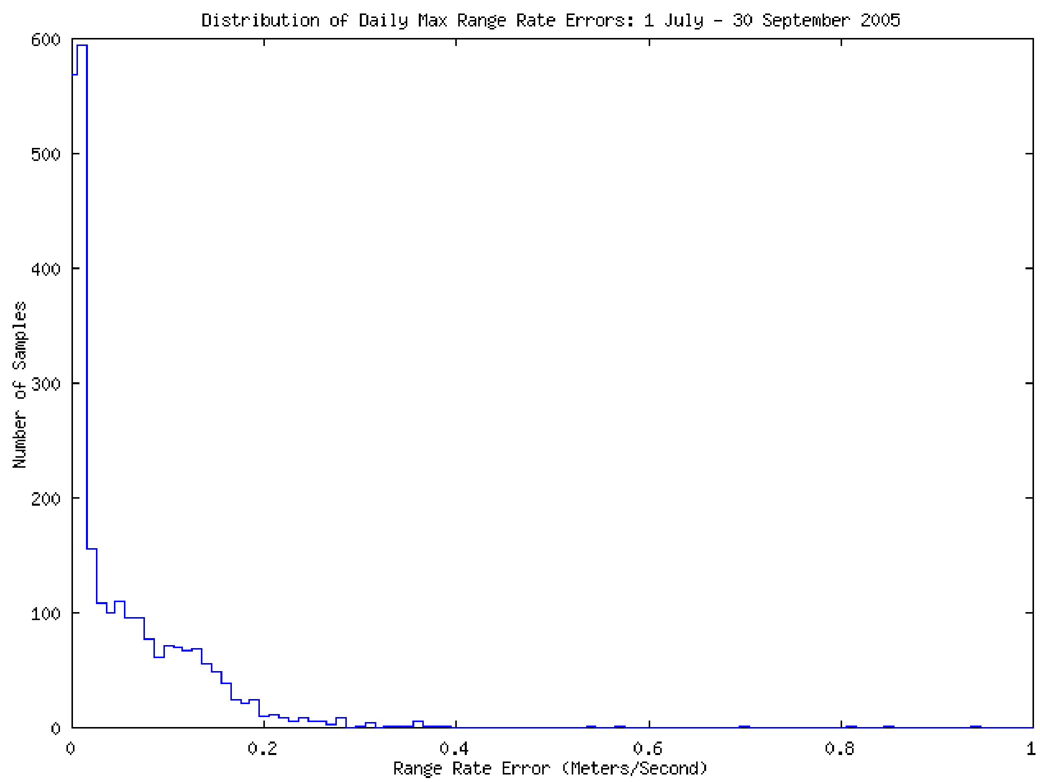


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

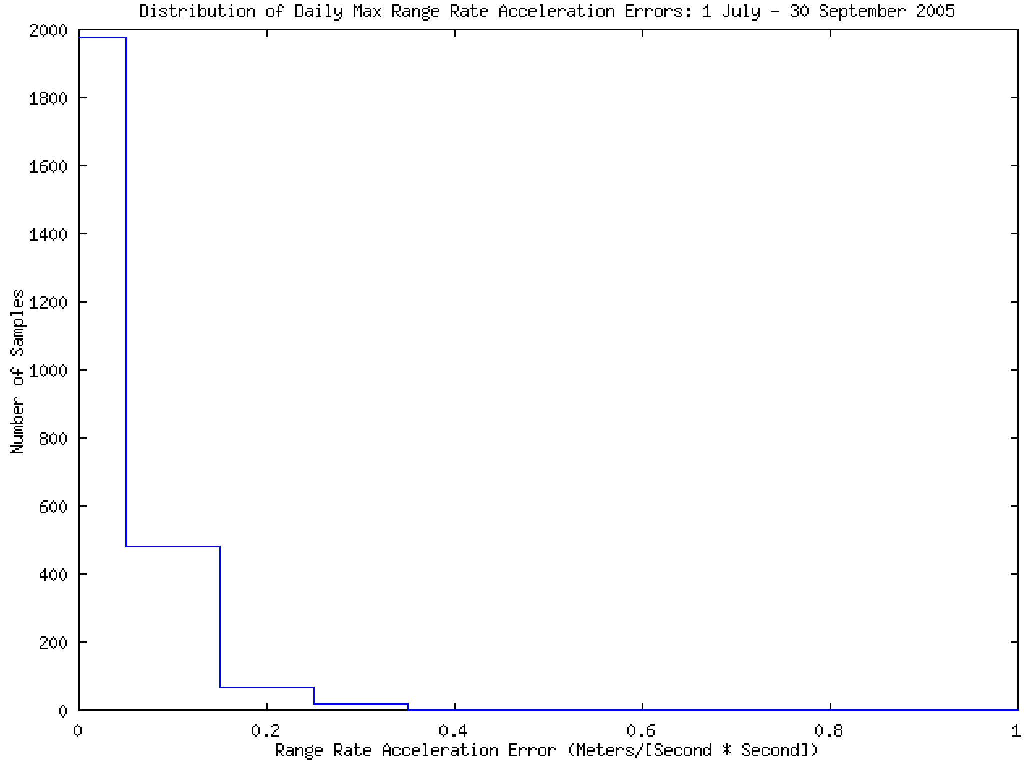


Figure 5-7: Range Error Histogram

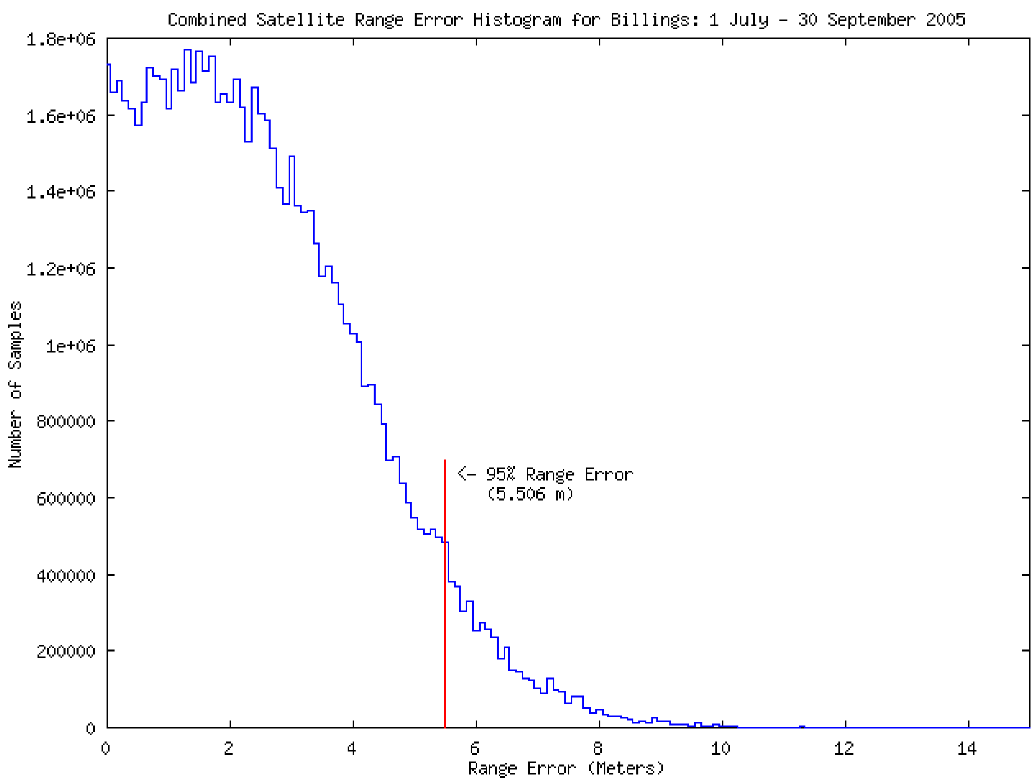


Figure 5-8: Maximum Range Error Per Satellite

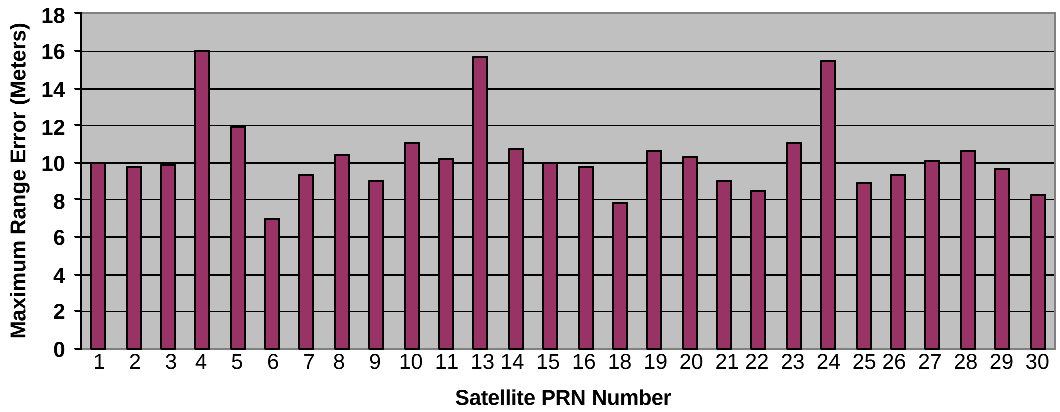


Figure 5-9: Maximum Range Rate Error Per Satellite

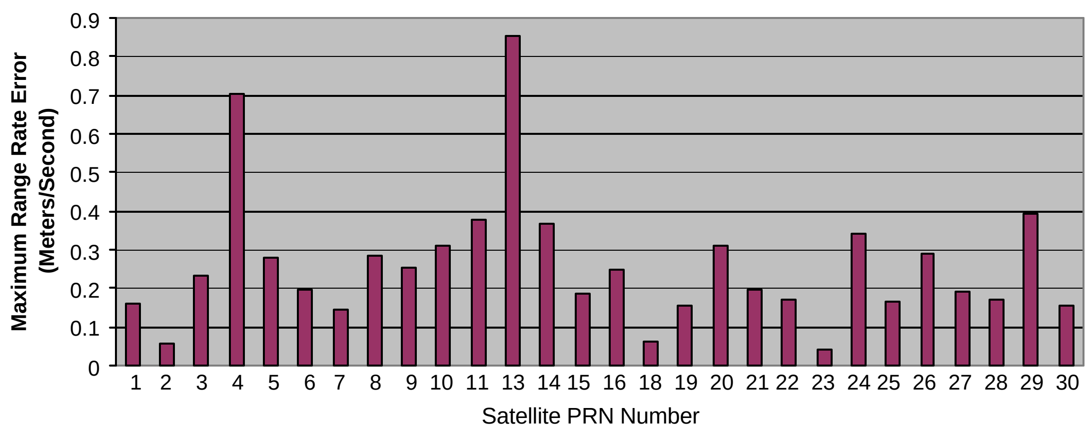
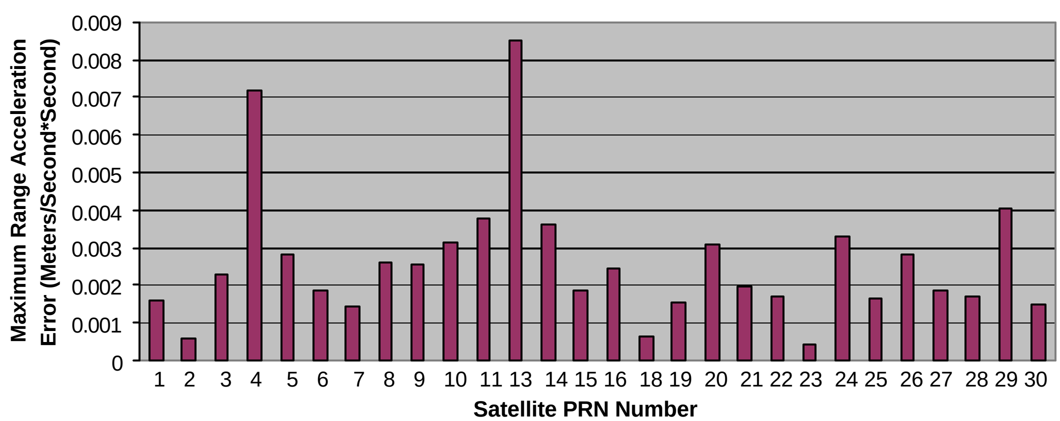


Figure 5-10: Maximum Range Acceleration Per Satellite



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 11-13 September 2005

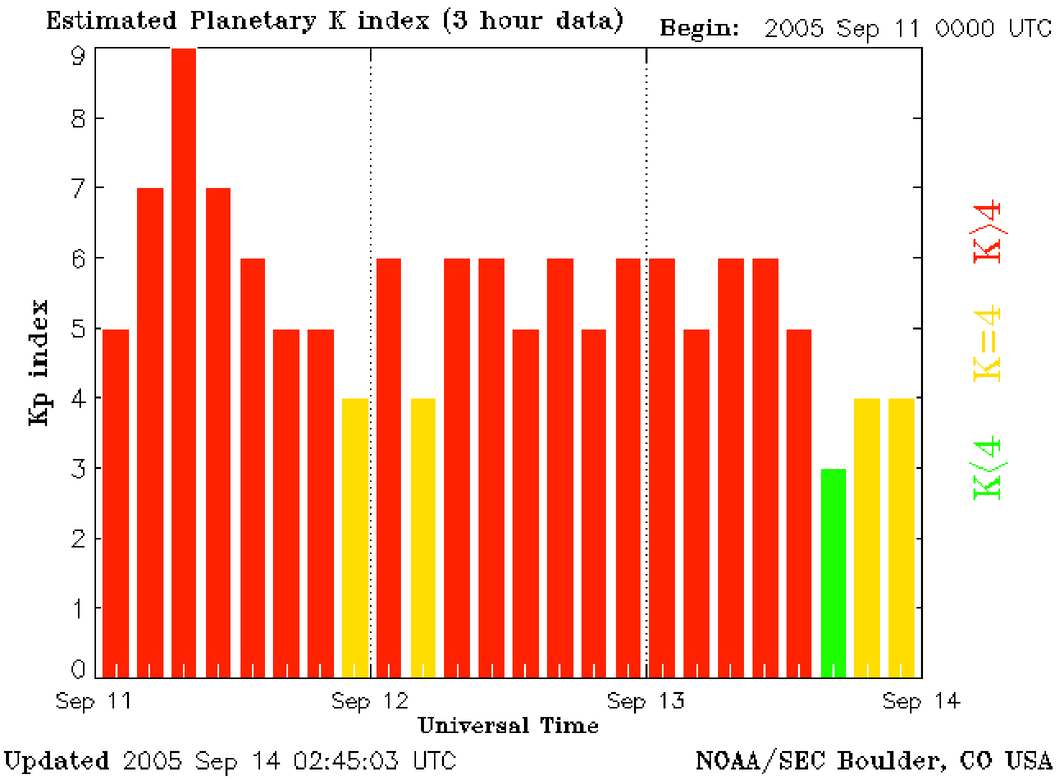


Figure 6-2 K-Index for 24-26 August 2005

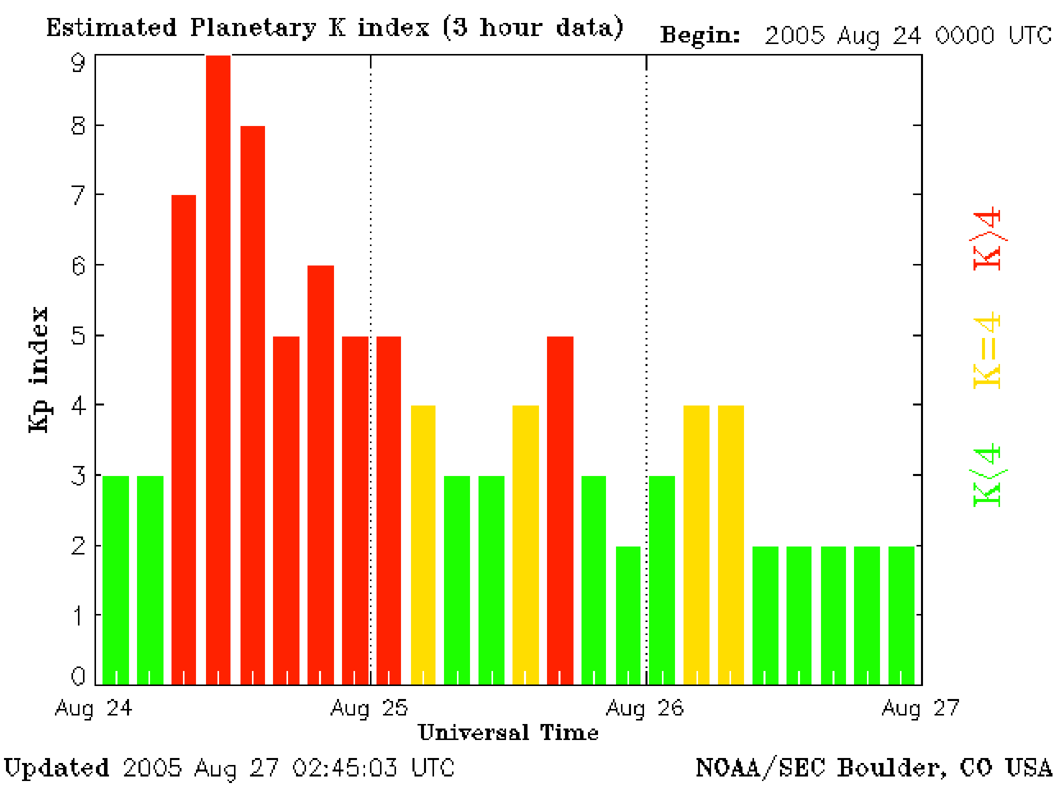
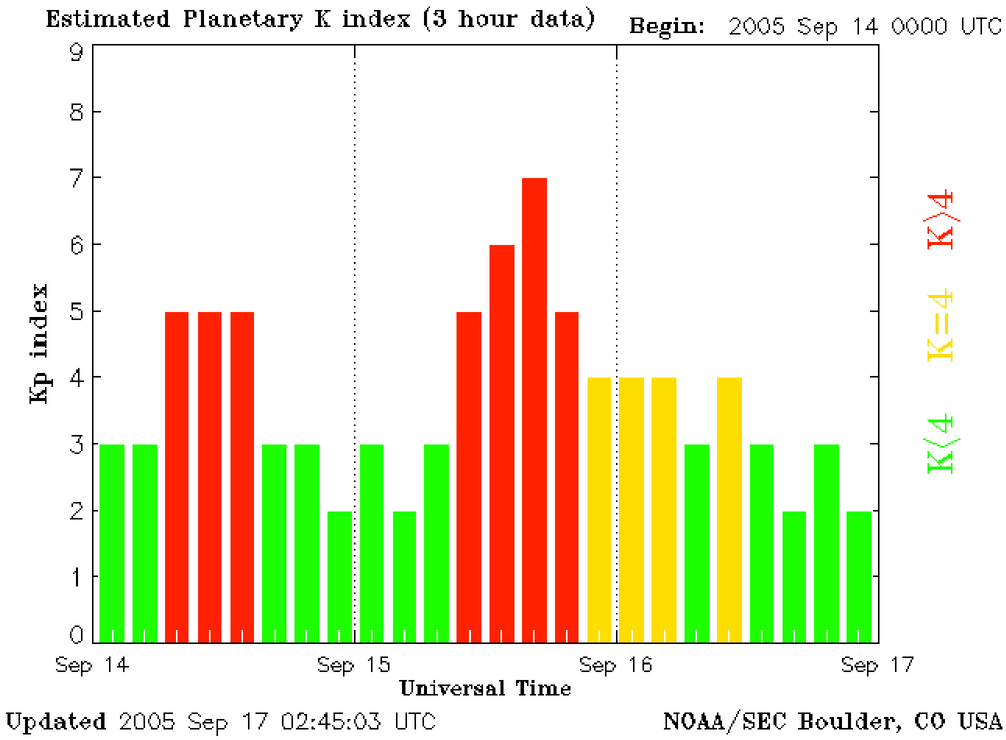


Figure 6-3 K-Index for 14-16 September 2005



Tables 6-1 and 6-2 below show the PDOP and position accuracy information, respectively, for the days corresponding to Figure 6-1. The GPS SPS performance met the availability requirements during all storms that occurred during this quarter.

Table 6-1 PDOP Statistics for 11 September 2005

Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Bangor	1.537	5.848	2.281	5.835	5.057
Mauna Loa	1.304	4.297	1.824	4.291	3.770
Billings	1.219	4.470	1.822	4.460	3.346
Cold Bay	1.149	4.550	1.770	4.548	4.281
Juneau	1.288	5.885	1.822	5.878	5.163
Albuquerque	1.243	3.108	1.781	3.105	2.466
Anchorage	1.202	3.960	1.784	3.960	3.820
Boston	1.264	2.791	1.731	2.790	2.298
Washington, D.C.	1.273	2.664	1.740	2.664	2.286
Honolulu	1.241	3.338	1.727	3.338	2.732
Houston	1.172	2.671	1.751	2.669	2.438
Kansas City	1.213	3.327	1.765	3.326	2.596
Los Angeles	1.162	5.060	1.839	5.060	4.004
Salt Lake City	1.152	4.909	1.810	4.904	4.094
Miami	1.247	3.354	1.773	3.351	3.108
Minneapolis	Site	was	down	this	day
Oakland	1.158	5.069	1.860	5.069	4.209
Cleveland	1.268	2.940	1.762	2.939	2.500
Seattle	1.151	4.733	1.837	4.733	4.254
San Juan	1.235	3.268	1.762	3.264	3.043
Atlanta	1.213	4.384	1.785	4.384	3.962

Table 6-2 Horizontal & Vertical Accuracy Statistics for 11 September 2005

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Bangor	2.730	5.967	5.191	9.910
Mauna Loa	8.182	10.853	12.189	14.436
Billings	1.888	6.163	5.936	7.217
Cold Bay	2.968	6.613	4.526	8.758
Juneau	2.880	4.562	4.512	7.207
Albuquerque	2.248	5.184	2.678	5.909
Anchorage	3.544	4.983	5.304	10.265
Boston	2.199	5.562	3.758	7.249
Washington, D.C.	2.194	5.844	3.181	7.109
Honolulu	8.052	7.545	10.783	12.377
Houston	2.855	4.398	4.481	6.133
Kansas City	2.079	5.735	3.097	7.958
Los Angeles	2.683	6.703	5.171	10.517
Salt Lake City	1.967	5.967	5.908	7.718
Miami	3.170	4.610	5.985	6.180
Minneapolis	Site	was	down	this day
Oakland	2.629	6.810	5.315	10.762
Cleveland	1.864	5.270	3.633	7.359
Seattle	2.192	5.895	3.755	9.729
San Juan	3.589	4.462	5.901	6.865
Atlanta	2.612	5.885	4.703	7.306

APPENDICES A – D

Conditions and Constraints	***Coverage Standard***	***Measured Performance***
• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 99.9% global average	99.998%
• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 96.9% at worst-case point	98.958% Availability 99.9% PDOP was 3.55597
Conditions and Constraints	***Satellite Availability Standard***	***Measured Performance***
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.85% global average	100%
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.16% single point average	100%
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	100%
• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	≥ 83.92% at worst-case point on worst-case day	100%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• Conditioned on coverage and service avail. standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.97% global average	100%
• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.79% single point average	100%

Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	Predictable Accuracy ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	≤5.031m HE 95% ≤10.348m HE 99.99% ≤6.728m VE 95% ≤20.348m VE 99.99%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	Repeatable Accuracy ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	≤1.392m HE 95% ≤4.433m VE 95%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	Relative Accuracy ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	Future Reports
• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	≤15 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	Range Domain Accuracy ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range acceleration error ≤ 8 mm/s^2 range acceleration error 95% of time	16.019m NTE Range Error 0.85179m/s NTE Rate Error 8.50mm/s^2 NTE Accl. Error ≤8mm/s^2 99.999% of the time

Prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center.

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2005 07 01	12	2 1 1 1 2 3 4 4	12	3 2 2 1 2 4 3 3	16	2 2 2 1 3 4 4 4
2005 07 02	12	4 2 2 2 2 2 3 3	14	4 3 2 3 4 2 2 2	13	4 3 2 2 2 2 3 3
2005 07 03	9	4 2 2 2 2 1 2 2	14	3 3 3 4 4 2 1 1	11	4 3 2 3 3 2 2 2
2005 07 04	5	2 2 1 1 1 1 1 2	3	2 2 1 0 1 1 0 1	7	1 3 2 1 2 2 2 2
2005 07 05	3	1 1 1 1 2 1 0 1	4	1 2 1 1 3 0 0 0	5	1 1 1 2 2 1 1 1
2005 07 06	3	1 1 1 0 1 1 1 1	3	1 2 1 1 0 1 1 1	5	1 1 1 1 2 2 2 2
2005 07 07	6	1 1 2 1 2 2 1 3	6	1 2 1 1 3 2 1 2	8	2 1 2 1 2 2 2 3
2005 07 08	5	2 1 1 1 2 1 1 2	3	2 2 1 0 0 1 1 1	5	2 2 1 1 1 2 2 2
2005 07 09	13	2 2 3 3 3 3 3 3	33	2 2 4 4 4 7 3 3	19	3 3 3 3 4 4 3 4
2005 07 10	28	4 4 4 4 4 3 4 5	67	3 5 5 5 7 7 6 3	47	4 4 5 5 6 5 5 5
2005 07 11	14	3 3 4 2 2 2 4 2	29	3 3 4 4 6 3 5 2	23	4 3 5 3 4 3 4 3
2005 07 12	17	3 4 3 4 4 2 2 2	71	4 4 7 7 7 6 2 1	48	5 6 5 6 6 5 3 2
2005 07 13	20	3 4 4 3 4 3 3 3	47	2 4 5 6 7 5 3 2	30	3 4 5 5 5 4 3 4
2005 07 14	7	1 3 3 2 1 1 1 1	20	2 4 3 3 5 5 0 0	11	2 4 3 3 2 2 1 1
2005 07 15	4	0 1 1 1 1 1 2 2	-1	1 1 1 1 2 1-1-1	6	1 2 2 1 1 2 2 2
2005 07 16	10	3 2 3 0 2 2 3 3	-1	-1 3 5 1 2 2 2 2	9	2 2 2 1 1 3 3 3
2005 07 17	15	3 2 2 4 3 2 3 4	41	3 2 5 7 5 5 2 3	22	3 2 3 5 3 3 3 5
2005 07 18	19	3 4 5 3 2 1 2 4	49	4 4 8 4 5 3 1 2	34	5 6 6 3 3 2 2 3
2005 07 19	8	3 1 2 1 1 2 2 3	8	2 3 3 1 2 2 1 2	10	3 2 3 1 2 2 2 3
2005 07 20	14	3 3 3 2 3 3 3 3	33	3 3 3 6 6 4 3 3	20	4 3 3 3 4 3 3 4
2005 07 21	19	5 4 4 3 2 2 2 3	35	5 4 6 6 2 3 3 2	29	5 5 4 5 2 3 2 3
2005 07 22	8	3 2 1 1 2 2 3 2	15	3 3 2 2 4 3 3 3	13	3 3 2 2 3 3 3 3
2005 07 23	2	1 0 1 0 1 1 1 1	3	2 1 1 2 1 1 0 0	5	2 1 1 1 1 1 2 1
2005 07 24	3	0 1 0 1 2 1 1 1	3	1 1 1 1 1 1 1 1	5	1 1 1 1 3 2 2 1
2005 07 25	3	2 1 1 0 1 0 1 2	2	1 1 1 0 0 1 1 1	6	2 2 1 1 1 2 2 2
2005 07 26	4	1 1 1 1 1 1 1 2	3	1 1 2 2 0 1 1 1	6	1 1 2 1 2 2 2 2
2005 07 27	15	3 2 2 1 3 2 4 5	14	1 3 3 3 3 2 3 4	17	2 2 3 2 3 3 4 5
2005 07 28	18	3 5 3 2 4 2 2 3	27	3 4 3 4 6 4 2 3	28	3 5 4 4 5 3 3 4
2005 07 29	14	3 3 3 2 3 3 3 3	29	3 4 3 6 4 5 3 2	19	3 4 3 4 3 4 3 3
2005 07 30	11	4 3 3 3 1 1 1 2	17	3 4 5 4 1 1 2 1	16	4 4 4 3 1 1 2 2
2005 07 31	10	2 2 2 1 3 1 2 4	8	2 2 2 1 3 2 2 2	9	2 3 2 1 3 2 2 3
2005 08 01	18	4 5 3 3 2 2 2 3	21	3 2 5 4 4 4 2 2	16	4 1 3 4 3 3 3 3
2005 08 02	9	2 3 1 2 2 2 3 2	18	2 3 2 6 4 1 1 1	12	3 3 2 3 3 2 2 2
2005 08 03	6	1 2 1 1 1 2 2 3	7	3 2 1 1 1 2 2 2	11	2 3 2 1 2 3 3 3
2005 08 04	9	3 2 3 3 2 1 1 2	19	3 3 4 5 4 2 1 2	14	3 3 4 3 2 2 2 3
2005 08 05	6	1 2 1 2 2 2 2 2	9	1 1 2 1 3 3 3 2	9	2 2 1 1 2 3 3 3
2005 08 06	25	4 5 4 4 3 3 4 3	57	4 5 7 6 6 5 3 3	34	5 5 5 5 4 3 4 3
2005 08 07	12	2 3 3 4 3 1 2 2	24	3 4 4 6 3 3 2 2	18	3 5 4 4 2 2 2 3
2005 08 08	6	2 2 2 1 2 2 1 2	9	2 2 2 1 4 2 1 2	8	2 2 3 1 2 2 1 3
2005 08 09	8	2 3 2 2 2 0 3 2	9	2 2 2 3 2 3 3 2	10	3 3 2 2 2 2 3 3
2005 08 10	9	2 1 3 3 3 2 1 1	39	3 2 6 6 6 5 1 0	22	3 2 4 5 5 3 2 2
2005 08 11	2	1 0 1 1 1 1 0 0	4	1 0 2 2 3 1 0 0	6	1 1 2 1 2 2 2 2
2005 08 12	3	1 1 1 0 1 0 1 2	6	1 1 2 3 3 0 1 1	6	1 1 1 1 2 2 2 3
2005 08 13	14	3 3 2 3 3 1 3 4	11	2 3 2 3 3 1 2 3	16	3 4 2 3 3 2 3 3
2005 08 14	6	2 2 1 1 1 1 2 1	9	3 2 2 3 3 1 1 1	10	4 4 2 2 2 2 2 2
2005 08 15	6	1 1 0 1 2 2 2 3	5	1 1 0 0 1 2 2 3	8	1 1 1 1 2 3 2 3
2005 08 16	12	3 3 2 3 3 2 2 3	23	3 4 2 5 5 3 2 3	19	3 4 4 4 3 3 3 3
2005 08 17	11	3 3 2 2 3 2 2 3	18	3 4 3 4 4 3 2 2	18	4 4 3 2 3 3 3 4
2005 08 18	9	3 2 2 3 2 1 2 2	17	3 3 4 4 4 2 2 2	16	3 3 4 4 3 2 3 3
2005 08 19	6	2 1 2 2 2 1 1 2	5	1 1 1 3 2 1 1 1	7	2 1 2 3 2 2 1 2
2005 08 20	2	2 0 0 0 1 1 1 0	2	1 1 1 0 1 1 1 0	5	2 1 1 0 2 2 2 2
2005 08 21	5	1 1 1 1 2 3 1 1	6	1 1 2 2 1 3 1 1	8	1 1 1 1 2 4 2 2

2005 08 22	7	2	3	0	1	3	2	1	2	10	2	1	1	3	4	2	2	2	12	3	4	1	2	2	3	3	3
2005 08 23	7	2	2	2	2	2	2	2	1	17	1	2	4	5	4	3	1	2	9	3	2	2	2	2	3	2	2
2005 08 24	72	2	3	6	8	7	5	4	3	112	6	2	6	9	7	6	6	4	110	3	3	7	9	8	5	6	5
2005 08 25	18	5	3	3	3	3	3	3	2	37	4	3	4	5	6	6	3	2	24	5	4	3	3	4	5	3	2
2005 08 26	5	2	3	2	1	0	1	1	1	14	3	4	4	4	0	1	2	1	11	3	4	4	2	2	2	2	2
2005 08 27	4	2	1	2	1	1	0	1	1	8	2	1	4	3	2	0	0	1	7	3	1	2	2	2	2	1	1
2005 08 28	5	1	2	2	1	0	1	1	3	3	2	1	0	0	1	1	1	2	7	2	2	0	1	1	1	2	3
2005 08 29	5	2	3	2	0	1	1	0	1	7	2	3	3	3	1	0	0	0	9	2	4	2	1	2	1	1	1
2005 08 30	3	0	0	0	0	0	1	3	2	1	0	0	0	0	0	0	2	1	4	1	0	0	0	1	1	3	2
2005 08 31	17	1	2	2	2	4	4	4	4	60	1	2	2	3	7	7	7	4	36	2	2	2	3	5	6	6	5
2005 09 01	11	4	4	2	2	2	1	1	2	26	3	4	4	5	6	1	1	2	21	5	5	3	3	4	2	2	2
2005 09 02	24	3	3	4	3	3	4	5	4	55	2	3	6	6	6	6	6	3	33	3	4	5	4	4	5	5	4
2005 09 03	20	5	4	4	4	2	1	2	3	42	4	4	6	6	6	4	2	2	32	6	6	4	5	3	3	2	4
2005 09 04	18	4	4	4	3	3	2	2	3	55	3	4	7	7	6	3	3	2	26	4	4	5	5	3	3	2	3
2005 09 05	9	3	2	3	3	2	1	2	1	22	3	2	5	5	4	3	2	2	14	4	2	3	4	2	3	3	2
2005 09 06	6	3	1	0	2	2	2	1	1	17	3	2	1	5	4	4	1	1	9	3	2	0	2	2	3	1	2
2005 09 07	18	3	3	1	2	1	5	5	1	15	2	3	3	5	4	1	1	0	15	4	3	2	3	2	4	4	1
2005 09 08	5	1	2	1	1	2	1	1	2	7	1	3	2	3	1	1	1	2	8	3	2	1	1	1	2	2	3
2005 09 09	12	1	2	0	1	4	3	4	3	29	1	1	0	4	6	6	4	3	17	1	2	0	1	4	4	4	4
2005 09 10	15	2	2	3	2	3	3	4	4	52	4	3	5	4	5	7	6	4	30	2	2	5	3	4	5	5	5
2005 09 11	53	5	6	7	5	5	3	4	3	131	6	7	8	8	7	6	6	5	105	5	7	9	7	6	5	5	4
2005 09 12	32	4	3	5	4	3	5	4	5	136	5	5	9	8	6	7	6	5	66	6	4	6	6	5	6	5	6
2005 09 13	26	4	5	4	5	4	1	3	3	96	5	5	8	7	8	2	4	3	51	6	5	6	6	5	3	4	4
2005 09 14	13	3	2	4	3	2	2	3	2	49	3	4	7	6	6	4	3	2	25	3	3	5	5	5	3	3	2
2005 09 15	22	3	2	3	3	5	5	3	3	76	3	2	4	7	7	8	4	3	43	3	2	3	5	6	7	5	4
2005 09 16	11	3	2	2	4	3	2	2	1	54	3	4	6	8	5	2	3	1	18	4	4	3	4	3	2	3	2
2005 09 17	10	0	2	1	3	3	3	2	3	31	1	2	2	5	6	6	3	2	12	2	2	1	3	3	3	3	3
2005 09 18	8	1	3	3	2	2	1	1	1	20	2	2	4	6	4	2	1	1	12	1	3	4	4	3	2	2	1
2005 09 19	8	2	2	2	2	2	2	3	1	9	2	1	3	3	2	3	2	0	8	2	2	2	2	2	2	2	1
2005 09 20	3	0	1	1	2	2	0	1	1	13	0	1	3	4	5	2	1	0	6	1	2	2	2	2	1	2	1
2005 09 21	3	1	1	2	2	1	1	0	0	5	1	0	2	3	3	2	0	0	5	1	1	2	2	2	1	1	1
2005 09 22	6	1	2	2	1	2	2	2	1	10	1	1	2	3	3	4	2	1	8	2	2	2	1	2	3	2	1
2005 09 23	5	1	2	3	1	1	1	1	1	10	0	2	5	3	2	1	0	0	8	1	3	3	1	2	2	2	2
2005 09 24	2	1	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	4	1	1	1	0	1	1	1	1
2005 09 25	3	0	0	0	2	2	1	0	2	11	1	0	0	4	5	1	0	2	5	1	0	0	2	3	2	0	2
2005 09 26	9	3	2	2	2	3	2	2	2	16	2	2	3	5	4	2	1	3	14	4	3	2	3	4	2	2	3
2005 09 27	10	3	4	2	2	2	2	1	2	22	2	4	4	6	3	3	1	1	13	3	4	2	3	2	2	1	3
2005 09 28	12	3	2	4	2	2	3	2	2	-1	-1	-1	-1	-1	-1	-1	-1	-1	12	3	3	4	2	2	3	2	2
2005 09 29	5	2	1	1	2	2	1	1	1	10	1	2	3	4	3	2	1	1	6	2	1	1	2	2	2	1	1
2005 09 30	6	0	1	1	2	3	2	2	2	22	0	0	2	5	6	4	1	2	11	1	2	1	3	4	3	2	2

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 this quarter.

The terms and definitions discussed below are taken from the Standard Positioning Service Performance Specification (SPS) (June 2, 1995). An understanding of these terms and definitions is a necessary prerequisite to full understanding of the Signal Specification.

General Terms and Definitions

Block I and Block II Satellites. The Block I is a GPS concept validation satellite; it does not have all of the design features and capabilities of the production model GPS satellite, the Block II. The FOC 24 satellite constellation is defined to consist entirely of Block II/IIA satellites. For the purposes of this Signal Specification, the Block II satellite and a slightly modified version of the Block II known as the Block IIA provide an identical service.

Dilution of Precision (DOP). The magnifying effect on GPS position error induced by mapping GPS ranging errors into position through the position solution. 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.

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

Major Service Failure. A condition over a time interval during which one or more SPS performance standards are not met and the civil community was not warned in advance.

Minimum SPS Receiver Capabilities. Minimum standards for signal reception and processing capabilities that are incorporated into the design of an SPS receiver. This ensures consistent performance with the SPS performance standards.

Navigation Data. Data provided to the SPS receiver via each satellite's ranging signal, containing 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.

Navigation Message. Message structure designed to carry navigation data.

Operational Satellite. A GPS satellite that is capable of, but may or may not be, transmitting a usable ranging signal. For the purposes of the SPS, any satellite contained within the transmitted navigation message almanac is considered to be an operational satellite.

Position Solution. The use of ranging signal measurements and navigation data from at least four satellites to solve for three position coordinates and a time offset.

Selective Availability. Protection technique employed by the DOD to deny full system accuracy to unauthorized users.

Service Disruption. A condition over a time interval during which one or more SPS performance standards are not supported, but the civil community was warned in advance.

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

SPS Performance Standard. A quantifiable minimum level for a specified aspect of GPS SPS performance.

Standard Positioning Service (SPS). Three-dimensional position and time determination capability provided to a user equipped with a minimum capability GPS SPS receiver in accordance with GPS national policy and the performance specifications.

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

SPS Signal, or SPS Ranging Signal. An electromagnetic signal originating from an operational satellite. The SPS ranging signal consists of a Pseudo Random Noise (PRN) Coarse/Acquisition (C/A) code, a timing reference and sufficient data to support the position solution generation process.

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

Performance Parameter Definitions

The definitions provided below establish the basis for correct interpretation of the GPS SPS performance standards. The GPS performance parameters contained in the SPS are defined differently than other radio navigation systems in the Federal Radio Navigation Plan. For a more comprehensive treatment of these definitions and their implications on system use, refer to Annex B of the SPS.

Coverage. The percentage of time over a specified time interval that a sufficient number of satellites are above a specified mask angle and provide an acceptable position solution geometry at any point on or near the Earth. The term "near the Earth" means on or within approximately 200 kilometers of the Earth's surface.

Positioning Accuracy. Given reliable service, the percentage of time over a specified time interval that the difference between the measured and expected user position or time is within a specified tolerance at any point on or near the Earth. This general accuracy definition is further refined through the more specific definitions of four different aspects of positioning accuracy:

- **Predictable Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a position measurement and a surveyed benchmark is within a specified tolerance at any point on or near the Earth.

- **Repeatable Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a position measurement taken at one time and a position measurement taken at another time at the same location is within a specified tolerance at any point on or near the Earth.

- **Relative Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between two receivers' position estimates taken at the same time is within a specified tolerance at any point on or near the Earth.

- **Time Transfer Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a Universal Coordinated Time (commonly referred to as UTC) time estimate from the position solution and UTC as it is managed by the United States Naval Observatory (USNO) is within a specified tolerance.

Range Domain Accuracy. Range domain accuracy deals with the performance of each satellite’s SPS ranging signal. Range domain accuracy is defined in terms of three different aspects:

- **Range Error.** Given reliable service, the percentage of time over a specified time interval that the difference between an SPS ranging signal measurement and the “true” range between the satellite and an SPS user is within a specified tolerance at any point on or near the Earth.

- **Range Rate Error.** Given reliable service, the percentage of time over a specified time interval that the instantaneous rate-of-change of range error is within a specified tolerance at any point on or near the Earth.

- **Range Acceleration Error.** Given reliable service, the percentage of time over a specified time interval that the instantaneous rate-of-change of range rate error is within a specified tolerance at any point on or near the Earth.

Service Availability. Given coverage, the percentage of time over a specified time interval that a sufficient number of satellites are transmitting a usable ranging signal within view of any point on or near the Earth.

Service Reliability. Given service availability, the percentage of time over a specified time interval that the instantaneous predictable horizontal error is maintained within a specified reliability threshold at any point on or near the Earth. Note that service reliability does not take into consideration the reliability characteristics of the SPS receiver or possible signal interference. Service reliability may be used to measure the total number of major failure hours experienced by the satellite constellation over a specified time interval.