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

Submitted To

Federal Aviation Administration
GPS Product Team
AND 730
1284 Maryland Avenue SW
Washington, DC 20024

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Submitted by

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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 #50, includes data collected from 1 April through 30 June 2005. The next quarterly report will be issued 31 October 2005.

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 99.306% or better.

Availability was verified by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 April and 30 June 2005 and by calculating the satellite availability from the data obtained from the twenty-one sites. A total of twenty-five outages were reported in the NANU's. Nineteen outages were scheduled while six were unscheduled. The quarterly availabilities for all sites was 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 statistics 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 19.947 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 0.86361 Meters/second on Satellite PRN 4. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 8.55 Millimeters/second^2 on Satellite PRN 4. 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 April and 30 June 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	✓
Repeatable Accuracy ≤ 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	✓
Relative Accuracy ≤ 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
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 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

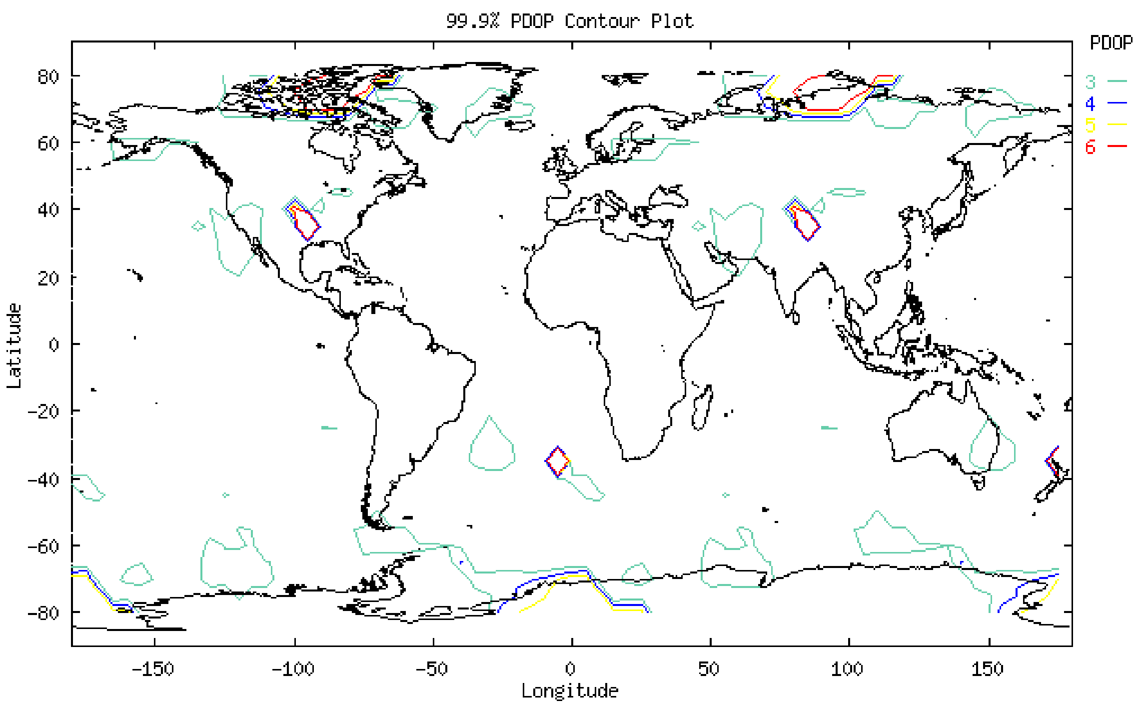
Almanacs for GPS weeks 293-305 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACB 430 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 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 3.26876 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

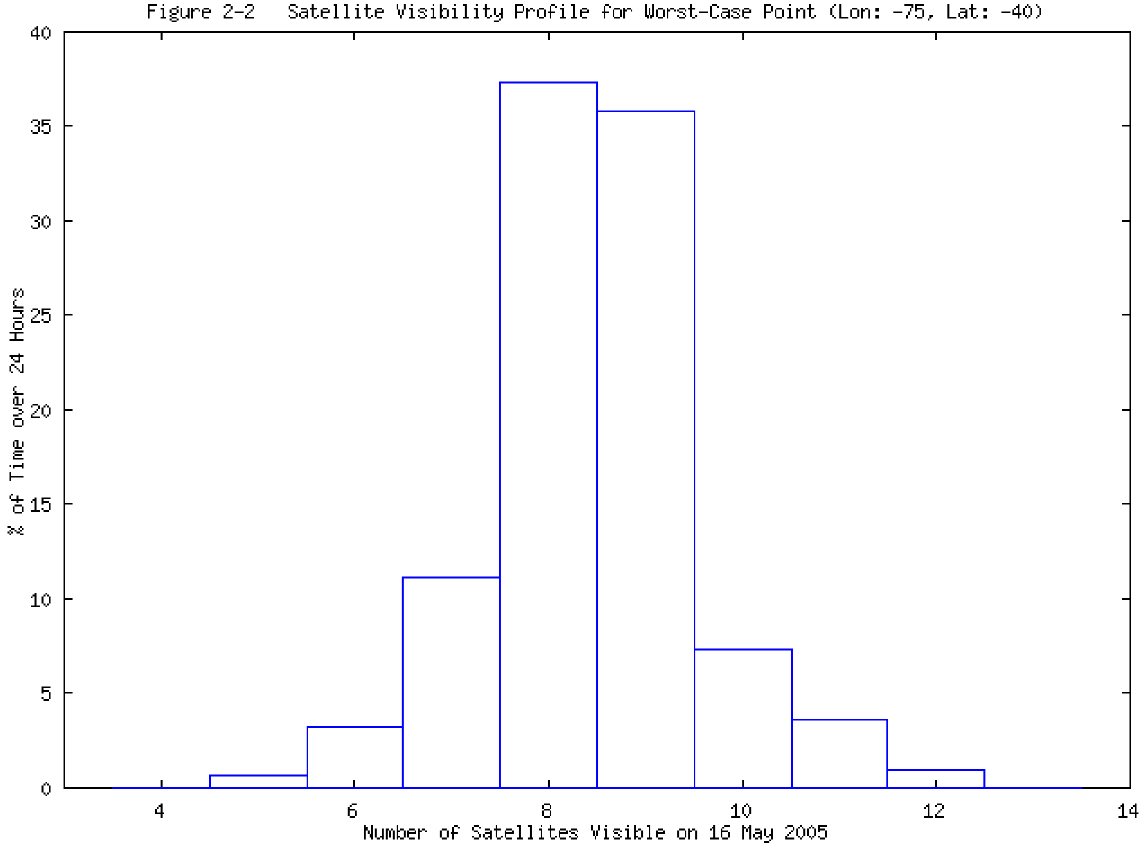
GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
293	3.01709	100	100
294	2.83418	100	100
295	2.89224	100	100
296	2.88979	100	100
297	2.88892	100	100
298	2.89113	100	100
299	3.26612	99.997	99.306
300	3.26876	99.997	99.375
301	2.89034	100	100
302	3.06729	100	100
303	3.06695	100	100
304	2.89104	100	100
305	2.88967	100	100

Figure 2-1 SPS Coverage (24-Hour Period: 16 May 2005)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -75, Lat: -40)



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 April through 30 June 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
2005041	31	UNUSABLE	1-Apr	0:00	4-Apr	9:13	81.21		81.21
42	21	FCSTSUMM	4-Apr	19:30	4-Apr	21:41		2.18	2.18
45	11	FCSTSUMM	7-Apr	15:26	7-Apr	17:47		2.35	2.35
51	7	UNUSABLE	3-Apr	22:38	13-Apr	17:40	235.03		235.03
52	22	FCSTSUMM	13-Apr	21:11	13-Apr	23:58		2.78	2.78
56	18	FCSTSUMM	14-Apr	17:40	15-Apr	0:26		6.76	6.76
57	20	FCSTSUMM	15-Apr	17:47	15-Apr	19:52		2.08	2.08
64	19	FCSTSUMM	25-Apr	17:24	25-Apr	20:30		3.10	3.10
65	8	FCSTSUMM	26-Apr	13:57	26-Apr	15:04		1.11	1.11
66	14	FCSTSUMM	27-Apr	12:24	27-Apr	15:08		2.73	2.73
71	29	FCSTSUMM	28-Apr	16:21	28-Apr	22:20		5.98	5.98
72	28	FCSTSUMM	29-Apr	14:33	29-Apr	16:30		1.95	1.95
75	3	FCSTSUMM	3-May	4:46	3-May	10:31		5.75	5.75
78	16	FCSTSUMM	4-May	16:52	4-May	19:23		2.51	2.51
81	23	FCSTSUMM	6-May	15:00	6-May	18:04		3.06	3.06
82	2	FCSTSUMM	9-May	15:34	9-May	17:56		2.36	2.36
83	6	FCSTSUMM	10-May	12:58	10-May	20:31		7.55	7.55
86	3	FCSTSUMM	12-May	14:51	12-May	18:12		3.35	3.35
87	18	FCSTSUMM	13-May	16:45	13-May	19:38		2.88	2.88
91	5	FCSTSUMM	17-May	20:32	18-May	8:08		11.60	11.60
92	27	UNUSABLE	14-May	20:18	31-May	17:49	405.51		405.51
96	26	UNUSABLE	9-Jun	3:54	13-Jun	23:21	115.45		115.45
97	2	FCSTSUMM	16-Jun	11:31	16-Jun	20:29		8.96	8.96
99	15	UNUSABLE	22-Jun	20:28	22-Jun	20:34	0.10		0.10
??	31	UNUSABLE	14-Apr	16:34	1-Jul	0:00	1855.43		1855.43
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**2692.73**	**79.04**	**2771.77**
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
2004148	31	UNUSUFN	28-Dec	0:42	N/A	N/A	N/A	See NANU 41
2005033	21	FCSTMX	4-Apr	22:30	5-Apr	10:30	RESCD	See NANU 37
34	11	FCSTMX	6-Apr	19:45	7-Apr	7:45	RESCD	See NANU 43
35	14	FCSTMX	8-Apr	21:30	9-Apr	9:30	RESCD	See NANU 38
37	21	FCSTRESCD	4-Apr	16:00	5-Apr	4:00	12	See NANU 42
38	14	FCSTRESCD	8-Apr	14:00	9-Apr	2:00	12	See NANU 47
40	7	UNUSUFN	3-Apr	22:38	N/A	N/A	N/A	See NANU 51
43	11	FCSTRESCD	7-Apr	14:00	8-Apr	2:00	12	See NANU 45
44	28	FCSTMX	11-Apr	14:00	12-Apr	2:00	12	See NANU 46
48	22	FCSTMX	13-Apr	19:45	14-Apr	7:45	12	See NANU 52
49	20	FCSTMX	15-Apr	17:00	16-Apr	5:00	12	See NANU 57
50	18	FCSTDV	14-Apr	17:00	15-Apr	5:00	12	See NANU 56
55	31	UNUSUFN	14-Apr	16:34	N/A	N/A	N/A	See NANU ??
59	19	FCSTMX	25-Apr	16:30	26-Apr	4:30	12	See NANU 64
60	8	FCSTMX	26-Apr	13:30	27-Apr	1:30	12	See NANU 65
61	29	FCSTMX	28-Apr	15:45	29-Apr	3:45	12	See NANU 71
62	14	FCSTMX	27-Apr	11:45	27-Apr	23:45	12	See NANU 66
63	28	FCSTMX	29-Apr	14:00	30-Apr	2:00	12	See NANU 72
67	18	FCSTMX	2-May	14:00	3-May	2:00	12	See NANU 74
68	3	FCSTDV	3-May	4:30	3-May	16:30	12	See NANU 75
69	16	FCSTMX	4-May	16:00	5-May	4:00	12	See NANU 78
70	23	FCSTMX	6-May	14:16	7-May	2:16	12	See NANU 81
76	3	FCSTMX	12-May	14:30	13-May	2:30	12	See NANU 86
77	2	FCSTMX	9-May	15:00	10-May	3:00	12	See NANU 82
79	6	FCSTDV	10-May	12:45	11-May	0:45	12	See NANU 83
80	18	FCSTMX	13-May	16:00	14-May	4:00	12	See NANU 87
85	5	FCSTDV	17-May	20:15	18-May	8:15	EXT	See NANU 90
88	27	UNUSUFN	14-May	20:18	N/A	N/A	N/A	See NANU 92
90	5	FCSTEXTD	17-May	20:15	N/A	N/A	N/A	See NANU 91
93	26	UNUSUFN	9-Jun	3:54	N/A	N/A	N/A	See NANU 96
95	2	FCSTDV	16-Jun	11:15	16-Jun	23:15	12	See NANU 97
98	15	UNUSUFN	22-Jun	20:28	N/A	N/A	N/A	See NANU 99
					Total Forecast Downtime		**252**	

Table 3-3 NANUs Canceled

NANU#	PRN	Type	Start Date	Start Time	Comments
46	28	FCSTCANC	11-Apr	14:00	See NANU 44
47	14	FCSTCANC	8-Apr	14:00	See NANU 38
74	18	FCSTCANC	2-May	14:00	See NANU 67

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 April - 30 Jun. 2005**	**1 October, 1999- 30 Jun. 2005**
Total Forecast Downtime (hrs):	252.00	5285.73
Total Actual Downtime (hrs):	2771.77	14223.47
Total Actual Scheduled Downtime (hrs):	79.04	2904.20
Total Actual Unscheduled Downtime (hrs):	2692.73	11319.27
Total Satellite Observed MTTR (hrs):	110.87	36.85
Scheduled Satellite Observed MTTR (hrs):	4.16	10.45
Unscheduled Satellite Observed MTTR (hrs):	448.79	104.81
# Total Satellite Outages:	25	386
# Scheduled Satellite Outages:	19	278
# Unscheduled Satellite Outages:	6	108
Percent Operational -- Scheduled Downtime:	99.87	99.79
Percent Operational -- All Downtime:	99.80	98.95

NANU 36 pertained to previous quarter’s events.
NANU 39 announced planning process for setting PRN31 healthy.
NANU 53 was disregarded by NANU 54.
NANU 58 corrected a typo in NANU 57.
NANU 84 made a correction to NANU 82.
NANU 89 made a correction to NANU 88.
NANU 95 made a correction to NANU 93.

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 April and 30 June 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	1.491	6.000	5.774	2.357	5.981	5.749	7984420
Mauna Loa	1.249	5.202	4.988	1.788	4.194	3.995	8006646
Billings	1.183	4.301	3.632	1.778	3.943	3.359	7630112
Cold Bay	1.152	5.833	5.551	1.714	5.108	4.847	7575341
Juneau	1.201	5.802	5.551	1.792	4.045	3.617	7610329
Albuquerque	1.240	3.909	3.576	1.776	3.669	3.164	7587062
Anchorage	1.153	5.855	5.705	1.728	5.204	5.058	7198961
Boston	1.239	3.327	3.018	1.732	3.174	2.849	7634752
Washington, D.C.	1.197	5.077	4.763	1.729	3.231	2.798	7638959
Honolulu	1.199	4.419	4.056	1.750	4.192	3.992	7623400
Houston	1.168	3.425	3.123	1.745	3.315	3.018	7633473
Kansas City	1.189	5.499	4.808	1.777	5.245	4.588	7635666
Los Angeles	1.174	3.965	3.609	1.773	3.401	3.066	7632611
Salt Lake City	1.166	6.000	5.828	1.788	5.934	5.761	7630790
Miami	1.254	4.612	4.316	1.784	3.142	2.841	7633425
Minneapolis	1.150	5.464	5.025	1.743	4.994	4.502	7615831
Oakland	1.168	5.738	4.900	1.771	4.199	3.631	7635624
Cleveland	1.171	5.938	5.052	1.772	5.849	5.564	7503234
Seattle	1.177	5.999	5.887	1.772	4.265	4.120	7626505
San Juan	1.183	3.153	2.909	1.727	3.112	2.862	7632426
Atlanta	1.198	5.920	5.482	1.780	5.908	5.467	7542149

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	7984420	0	100%
Mauna Loa	8006646	0	100%
Billings	7630112	0	100%
Cold Bay	7575341	0	100%
Juneau	7610329	0	100%
Albuquerque	7587062	0	100%
Anchorage	7198961	0	100%
Boston	7634752	0	100%
Washington, D.C.	7638959	0	100%
Honolulu	7623400	0	100%
Houston	7633473	0	100%
Kansas City	7635666	0	100%
Los Angeles	7632611	0	100%
Salt Lake City	7630790	0	100%
Miami	7633425	0	100%
Minneapolis	7615831	0	100%
Oakland	7635624	0	100%
Cleveland	7503234	0	100%
Seattle	7626505	0	100%
San Juan	7632426	0	100%
Atlanta	7542149	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	7984420	35.5
Mauna Loa	8006646	10.1
Billings	7630112	14.8
Cold Bay	7575341	8.1
Juneau	7610329	6.1
Albuquerque	7587062	13.3
Anchorage	7198961	6.0
Boston	7634752	24.3
Washington, D.C.	7638959	24.8
Honolulu	7623400	10.7
Houston	7633473	15.0
Kansas City	7635666	23.0
Los Angeles	7632611	10.2
Salt Lake City	7630790	16.0
Miami	7633425	14.4
Minneapolis	7615831	19.8
Oakland	7635624	8.3
Cleveland	7503234	23.2
Seattle	7626505	10.4
San Juan	7632426	12.1
Atlanta	7542149	34.6

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 April through 30 June 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	3.712	6.068	18.760	17.819
Mauna Loa	5.081	6.856	9.880	13.902
Billings	2.640	5.008	14.134	21.555
Cold Bay	2.633	5.263	6.757	11.517
Juneau	2.647	4.757	5.754	11.214
Albuquerque	2.842	5.326	9.772	11.336
Anchorage	2.737	4.887	5.343	11.349
Boston	2.755	5.057	15.544	11.221
Washington, D.C.	2.817	5.632	17.135	11.555
Honolulu	4.883	6.174	10.040	14.051
Houston	3.230	5.489	13.856	11.397
Kansas City	2.826	5.491	21.835	26.278
Los Angeles	3.142	5.842	7.094	12.698
Salt Lake City	2.680	5.395	9.700	16.015
Miami	3.500	5.582	13.044	15.824
Minneapolis	2.662	4.893	18.829	25.849
Oakland	2.912	5.761	6.898	12.663
Cleveland	2.826	5.371	22.159	23.322
Seattle	2.629	5.139	8.000	13.819
San Juan	3.653	5.142	10.203	25.382
Atlanta	2.980	5.842	32.097	40.882

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 April to 30 June 2005.

Figure 5-1 Combined Vertical Error Histogram

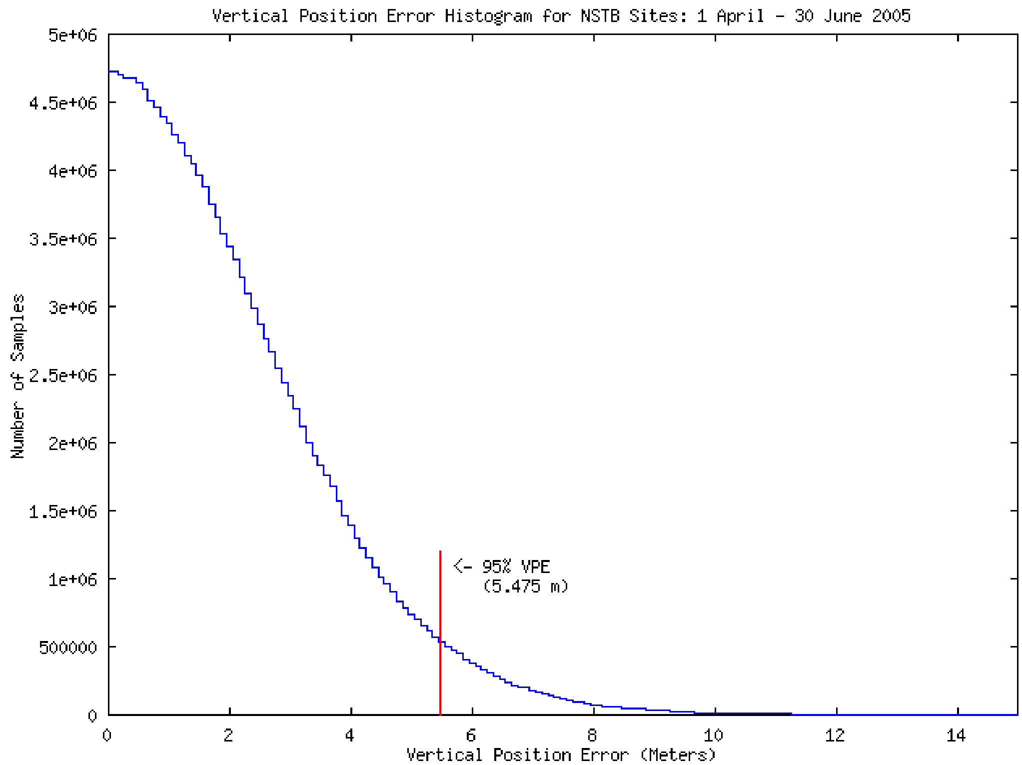
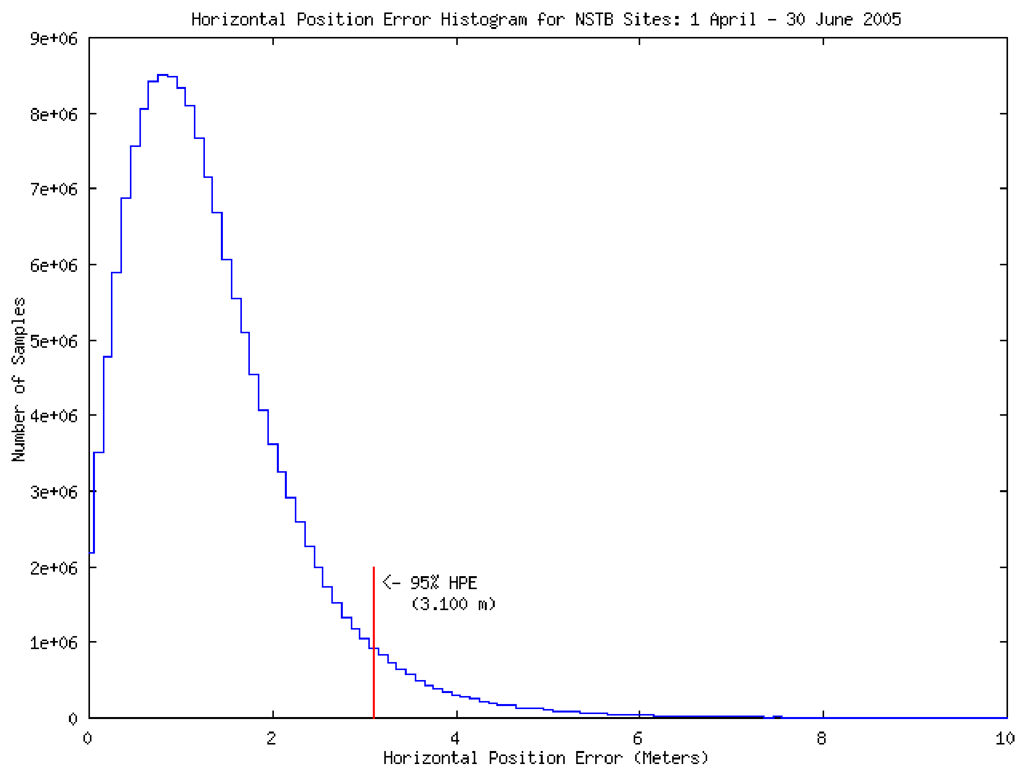


Figure 5-2 Combined Horizontal Error Histogram



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	1.663	4.198
Mauna Loa	1.193	3.750
Billings	0.977	2.123
Cold Bay	1.014	2.246
Juneau	0.871	2.154
Albuquerque	0.817	2.266
Anchorage	0.905	2.269
Boston	0.907	2.163
Washington, D.C.	1.147	2.184
Honolulu	1.245	3.633
Houston	0.930	2.950
Kansas City	1.000	2.466
Los Angeles	0.926	2.568
Salt Lake City	0.879	2.001
Miami	1.003	2.457
Minneapolis	0.917	2.134
Oakland	0.871	1.973
Cleveland	0.995	2.134
Seattle	0.870	2.078
San Juan	1.377	3.255
Atlanta	1.015	2.481

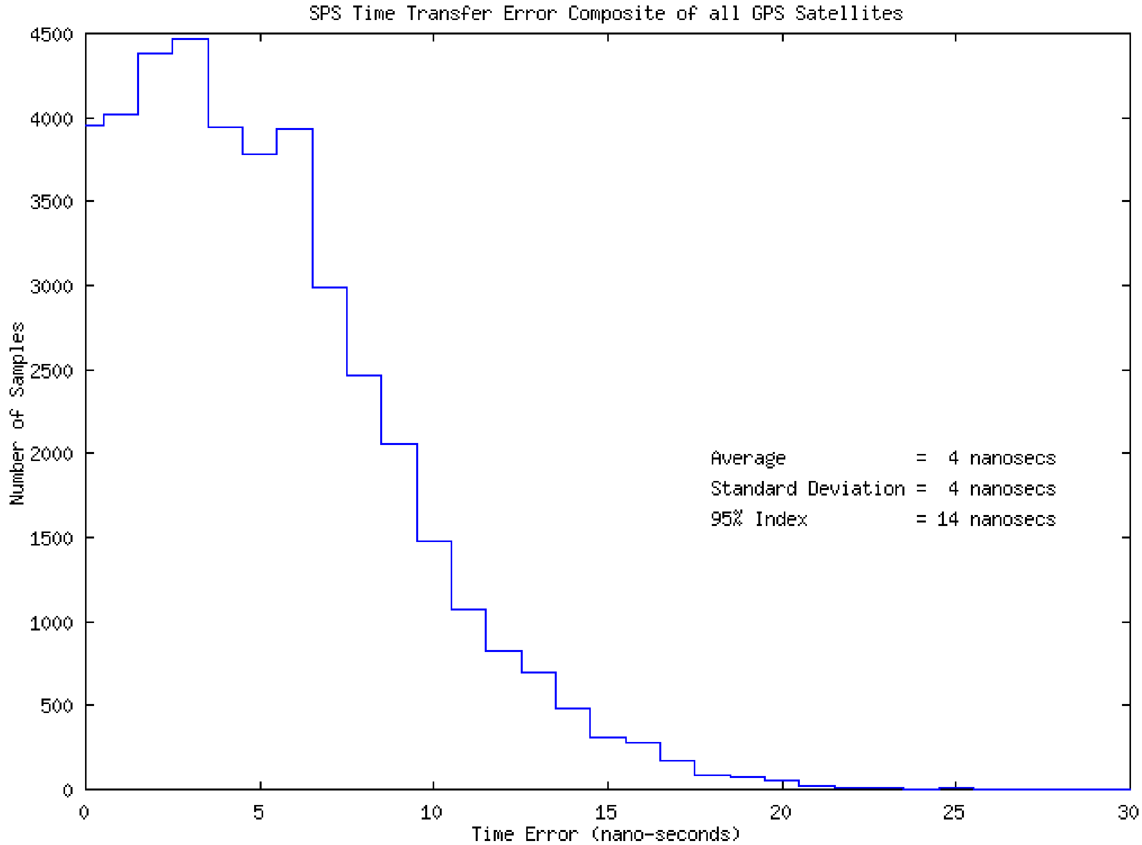
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 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 April and 30 June 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	3.103	4.492	3.249	8.531	14.316	2053914
2	3.254	3.679	1.718	5.951	10.405	1844353
3	2.142	3.597	2.890	7.216	16.534	2417716
4	1.322	2.314	1.899	4.525	19.947	1932745
5	2.534	3.530	2.457	6.650	19.607	1982784
6	1.999	2.964	2.189	5.928	16.227	1805883
7	1.220	2.156	1.778	4.091	7.938	1859426
8	1.625	2.964	2.478	5.805	11.451	1915248
9	2.170	3.150	2.283	6.482	10.347	2411417
10	2.718	3.504	2.212	6.280	15.619	2304509
11	3.320	3.926	2.095	7.021	11.365	2417771
13	1.563	2.695	2.196	5.271	17.641	1791612
14	3.903	4.929	3.011	9.040	12.848	1949613
15	3.517	4.764	3.213	9.062	13.633	1877454
16	2.600	3.466	2.292	6.388	17.068	2341342
18	3.579	4.401	2.562	8.033	11.718	1983254
19	5.000	5.529	2.361	9.300	13.068	2442677
20	3.394	3.991	2.099	6.862	11.781	2182817
21	3.910	4.603	2.429	8.376	11.363	2001228
22	3.822	4.897	3.061	8.853	12.748	2052898
23	4.244	4.795	2.231	7.856	15.887	1917558
24	2.066	2.959	2.119	5.449	11.725	2405723
25	2.501	3.904	2.998	7.316	11.273	1818805
26	1.579	2.705	2.196	5.804	9.108	2254625
27	1.190	2.570	2.278	4.865	8.054	1625035
28	2.751	3.491	2.150	6.573	10.824	2080511
29	2.197	3.026	2.081	6.065	12.380	2454172
30	1.354	2.612	2.233	5.306	9.877	2313540

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	-0.00007	0.00291	0.00291	0.00341	0.25916	2053914
2	-0.00003	0.00183	0.00183	0.00349	0.07807	1844353
3	0.00009	0.00285	0.00285	0.00373	0.24904	2417716
4	0.00010	0.00658	0.00658	0.00487	0.86361	1932745
5	0.00002	0.00487	0.00487	0.00460	0.55915	1982784
6	0.00008	0.00255	0.00255	0.00358	0.51386	1805883
7	0.00006	0.00212	0.00212	0.00312	0.13887	1859426
8	0.00005	0.00308	0.00308	0.00387	0.22619	1915248
9	-0.00010	0.00238	0.00238	0.00356	0.17850	2411417
10	0	0.00270	0.00270	0.00390	0.24922	2304509
11	0.00009	0.00242	0.00242	0.00365	0.28326	2417771
13	0	0.00448	0.00448	0.00391	0.43110	1791612
14	-0.00005	0.00288	0.00288	0.00332	0.20864	1949613
15	0.00014	0.00275	0.00274	0.00351	0.18219	1877454
16	-0.00005	0.00466	0.00466	0.00395	0.42553	2341342
18	0.00005	0.00169	0.00169	0.00327	0.06651	1983254
19	0.00005	0.00196	0.00196	0.00335	0.18637	2442677
20	-0.00007	0.00279	0.00279	0.00379	0.25915	2182817
21	0.00006	0.00250	0.00250	0.00362	0.27482	2001228
22	0.00002	0.00185	0.00185	0.00321	0.15908	2052898
23	-0.00004	0.00185	0.00185	0.00342	0.07939	1917558
24	0.00002	0.00350	0.00350	0.00387	0.40952	2405723
25	-0.00010	0.00217	0.00216	0.00346	0.19929	1818805
26	0.00004	0.00270	0.00270	0.00346	0.26549	2254625
27	-0.00004	0.00234	0.00234	0.00348	0.23894	1625035
28	0.00002	0.00221	0.00221	0.00334	0.15431	2080511
29	0.00001	0.00274	0.00274	0.00349	0.27288	2454172
30	0.00007	0.00199	0.00199	0.00350	0.12300	2313540

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	0.00003	0.00003	100	0.00261	2053914
2	0	0.00001	0.00001	100	0.00076	1844353
3	0	0.00002	0.00002	100	0.00248	2417716
4	0	0.00006	0.00006	99.999	0.00855	1932745
5	0	0.00004	0.00004	100	0.00558	1982784
6	0	0.00002	0.00002	100	0.00510	1805883
7	0	0.00002	0.00002	100	0.00138	1859426
8	0	0.00003	0.00003	100	0.00222	1915248
9	0	0.00002	0.00002	100	0.00179	2411417
10	0	0.00002	0.00002	100	0.00249	2304509
11	0	0.00002	0.00002	100	0.00283	2417771
13	0	0.00004	0.00004	100	0.00444	1791612
14	0	0.00003	0.00003	100	0.00222	1949613
15	0	0.00002	0.00002	100	0.00182	1877454
16	0	0.00004	0.00004	100	0.00426	2341342
18	0	0.00001	0.00001	100	0.00062	1983254
19	0	0.00002	0.00002	100	0.00186	2442677
20	0	0.00002	0.00002	100	0.00264	2182817
21	0	0.00002	0.00002	100	0.00273	2001228
22	0	0.00002	0.00002	100	0.00158	2052898
23	0	0.00001	0.00001	100	0.00078	1917558
24	0	0.00003	0.00003	100	0.00417	2405723
25	0	0.00002	0.00002	100	0.00201	1818805
26	0	0.00002	0.00002	100	0.00258	2254625
27	0	0.00002	0.00002	100	0.00237	1625035
28	0	0.00002	0.00002	100	0.00154	2080511
29	0	0.00002	0.00002	100	0.00272	2454172
30	0	0.00002	0.00002	100	0.00122	2313540

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 19.947 meters. Satellite 7 had the lowest maximum range error of 7.938 meters.

Figure 5-4 Distribution of Daily Max Range Errors

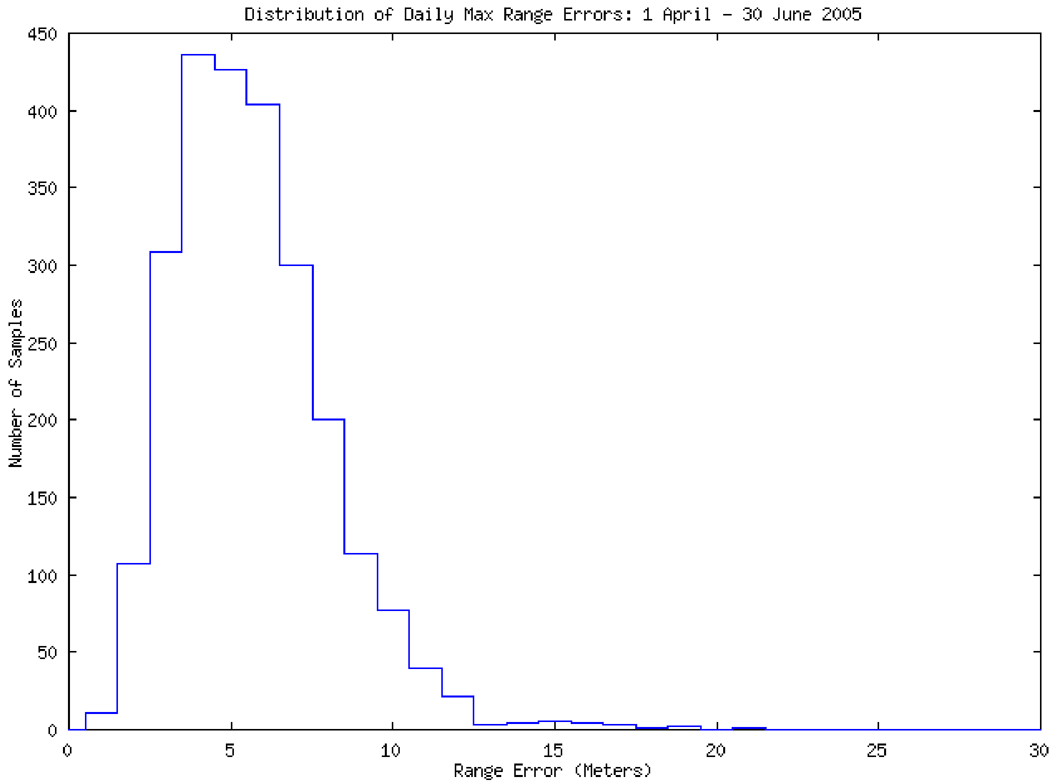


Figure 5-5: Distribution of Daily Max Range Rate Errors

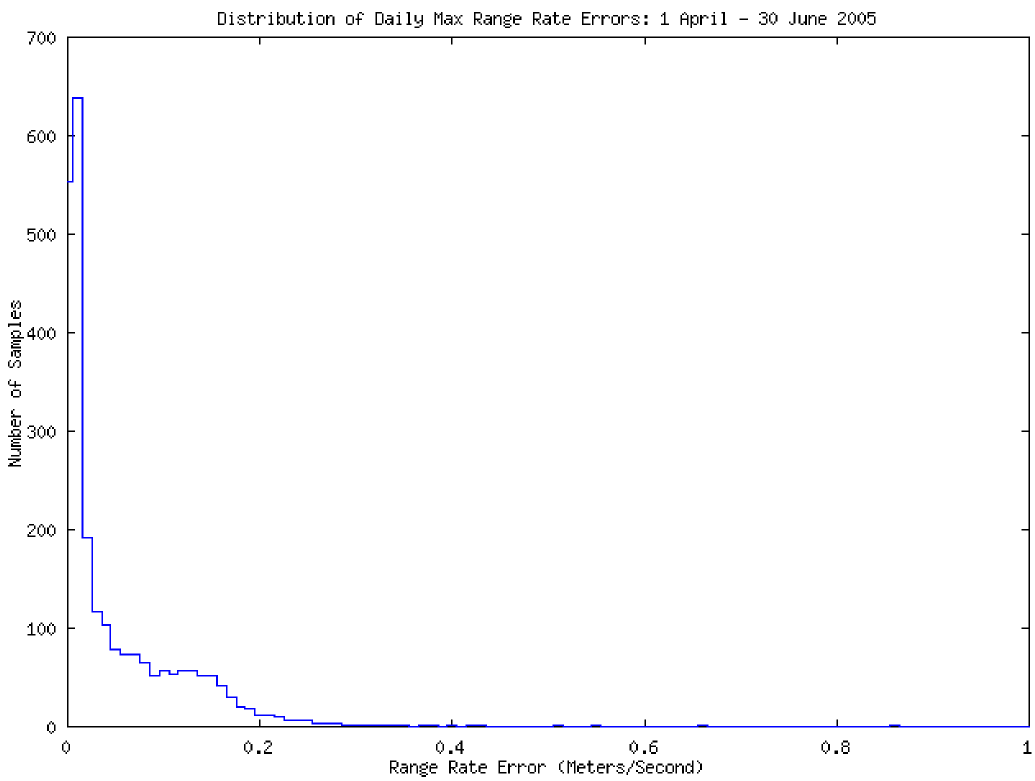


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

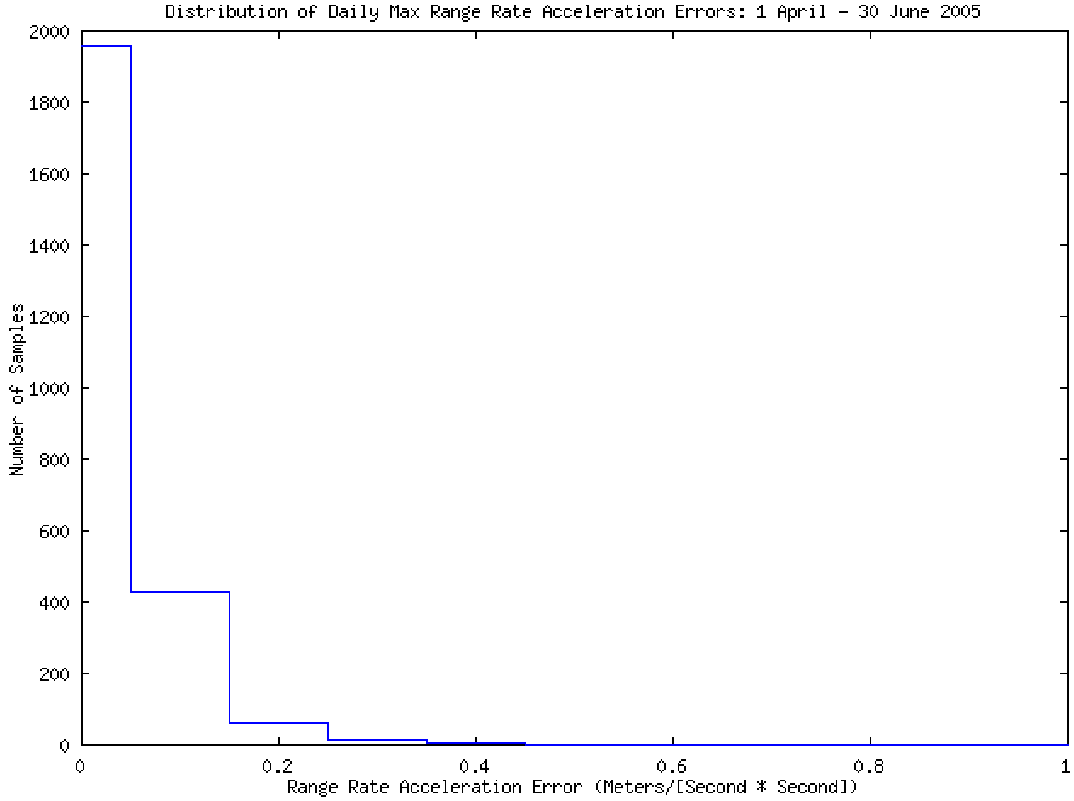


Figure 5-7: Range Error Histogram

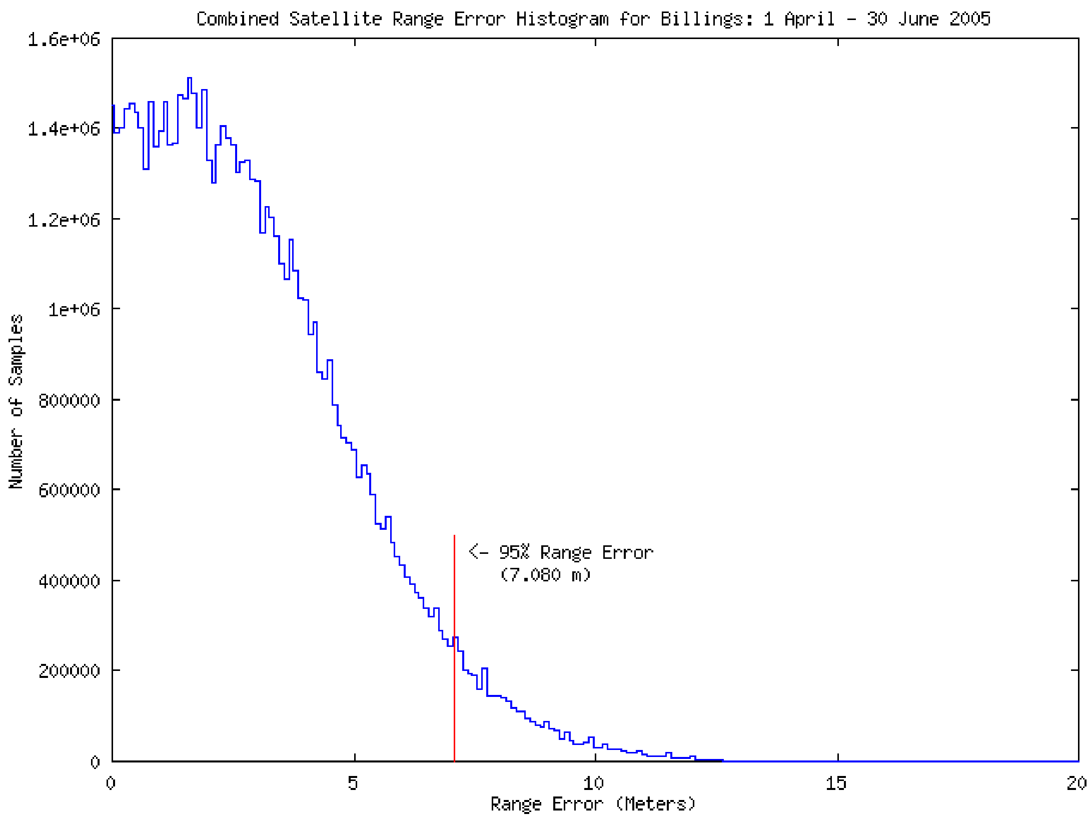


Figure 5-8: Maximum Range Error Per Satellite

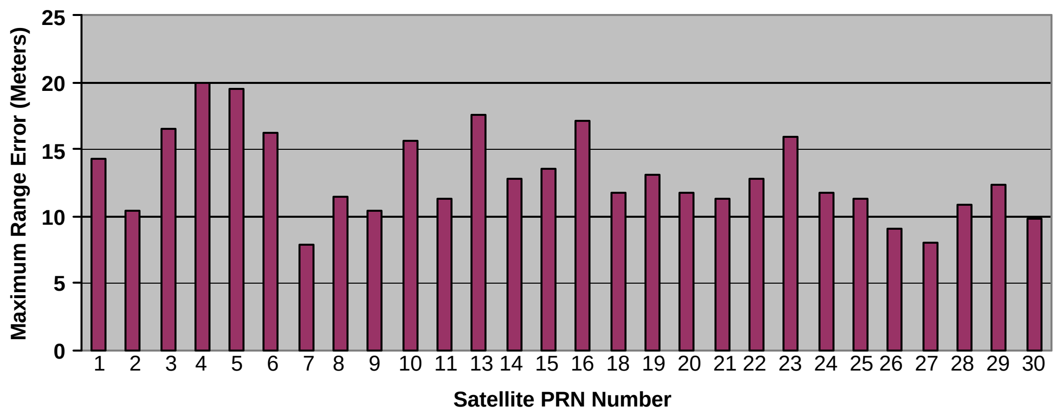


Figure 5-9: Maximum Range Rate Error Per Satellite

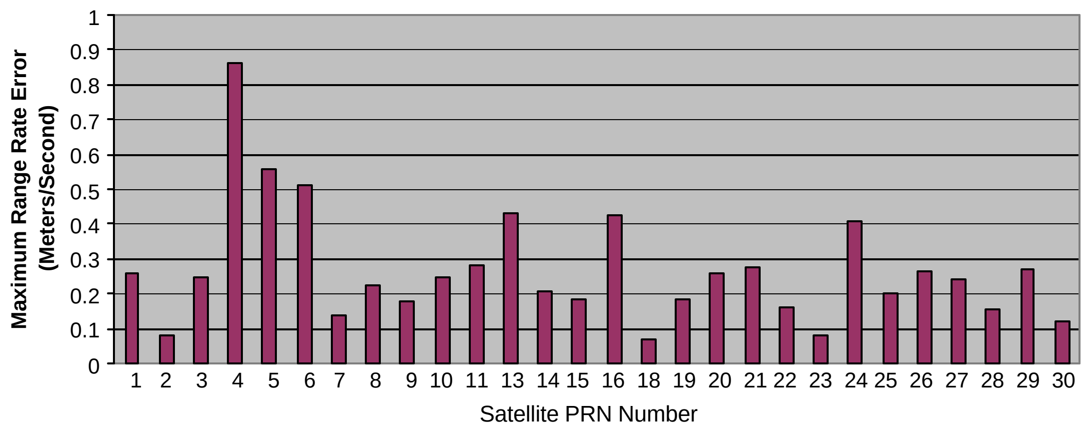
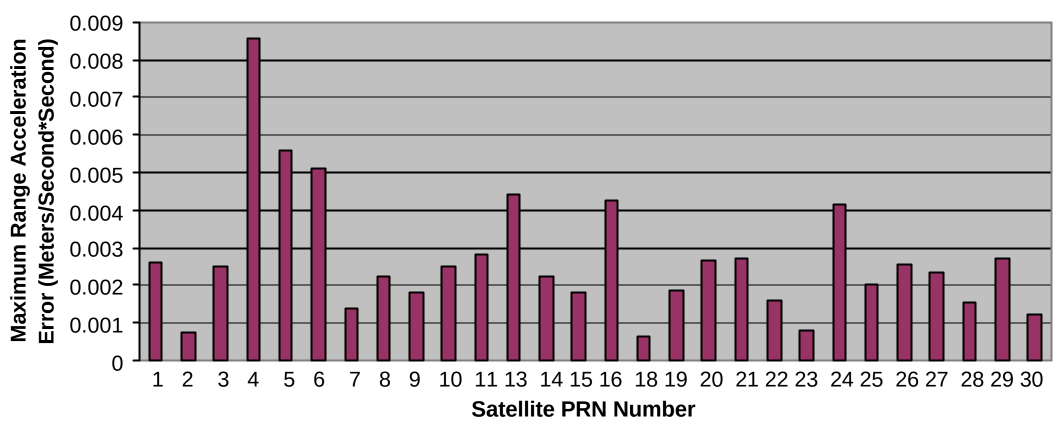


Figure 5-10: Maximum Range Acceleration Per Satellite



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 13-15 May 2005

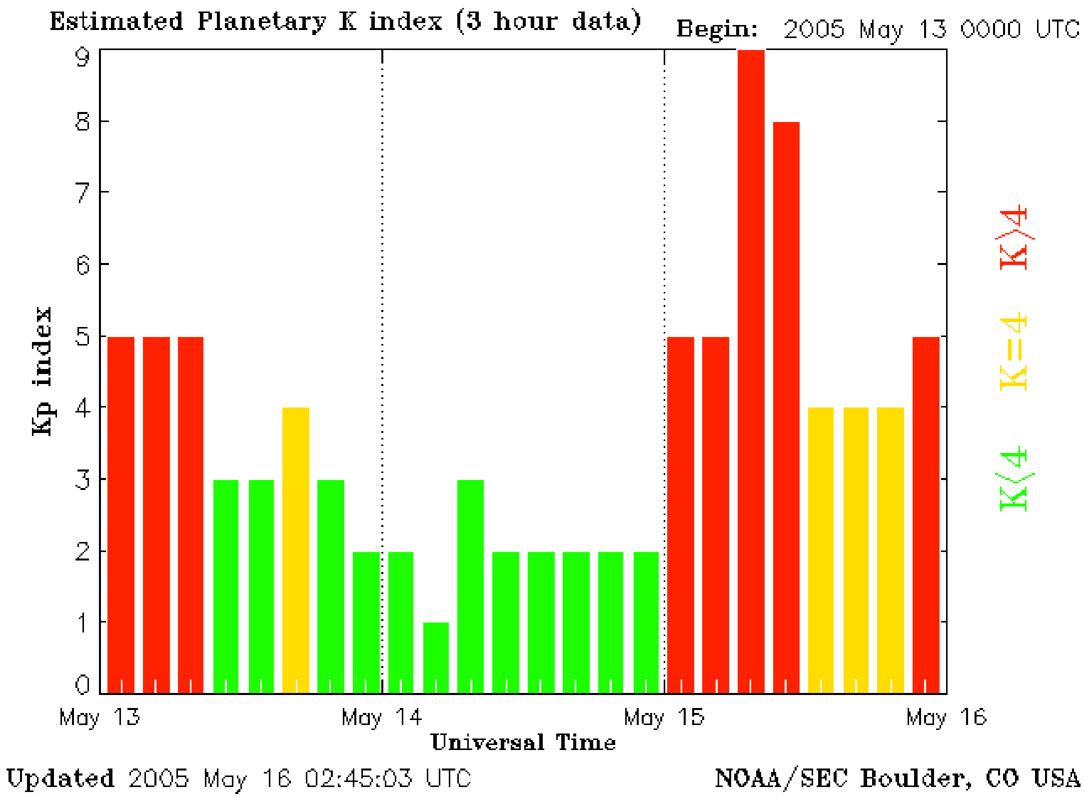


Figure 6-2 K-Index for 28-30 May 2005

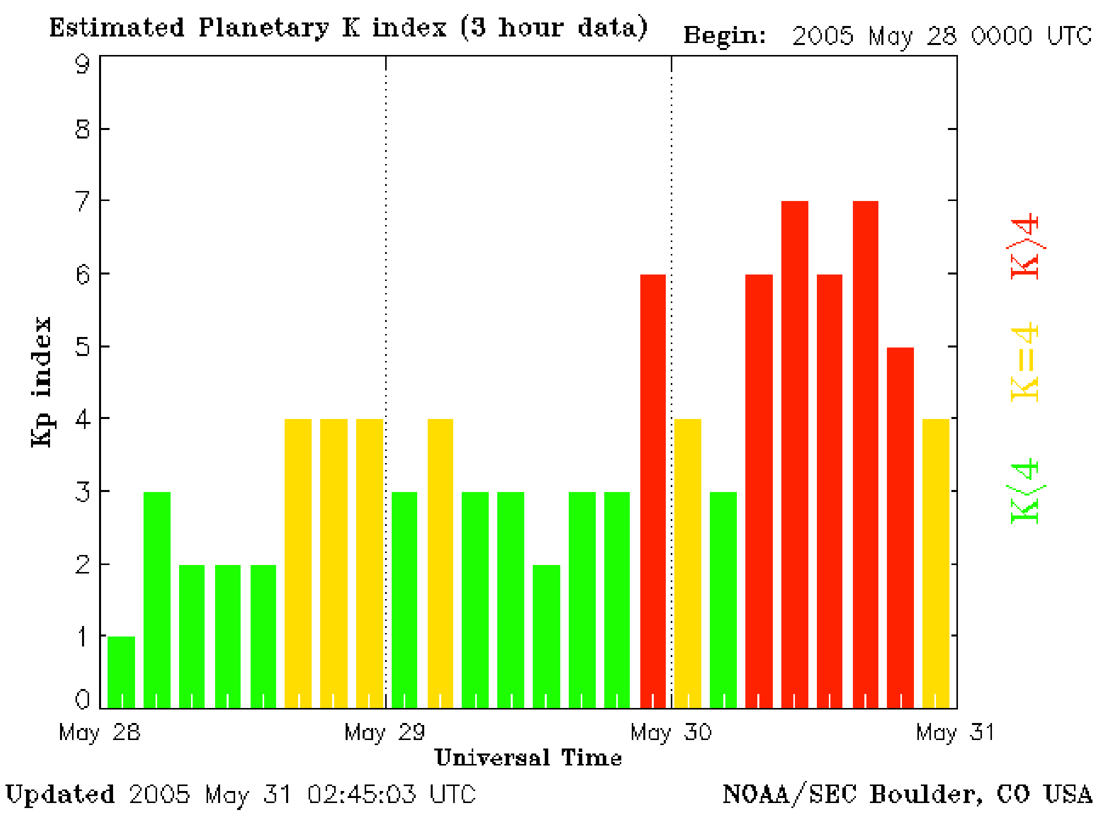
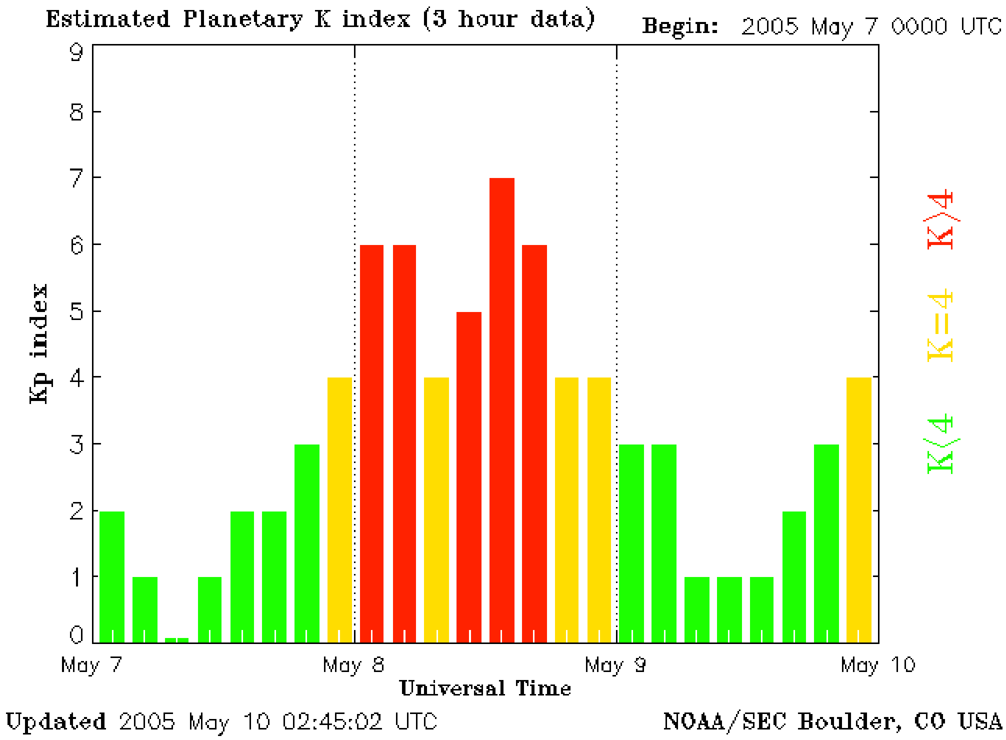


Figure 6-3 K-Index for 7-9 May 2005



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 15 May 2005

Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Bangor	1.529	5.999	2.428	5.993	5.757
Mauna Loa	1.256	4.422	1.798	4.410	4.237
Billings	1.233	3.949	1.810	3.949	3.364
Cold Bay	1.153	3.390	1.746	3.386	2.894
Juneau	1.247	3.605	1.803	3.602	3.304
Albuquerque	1.260	3.411	1.802	3.411	3.016
Anchorage	1.239	3.209	1.748	3.206	2.840
Boston	1.305	2.689	1.754	2.686	2.230
Washington, D.C.	1.197	3.115	1.752	3.115	2.737
Honolulu	1.219	4.111	1.773	4.111	3.909
Houston	1.256	2.756	1.768	2.755	2.585
Kansas City	1.253	3.145	1.795	3.142	2.637
Los Angeles	1.177	1.288	1.794	2.743	2.422
Salt Lake City	1.174	5.954	1.804	5.936	5.763
Miami	1.322	2.779	1.808	2.779	2.580
Minneapolis	1.220	4.969	1.777	4.958	4.442
Oakland	1.171	4.019	1.787	4.015	3.621
Cleveland	1.185	5.874	1.780	5.870	5.582
Seattle	1.224	3.030	1.788	3.027	2.623
San Juan	1.241	3.037	1.756	3.031	2.757
Atlanta	1.231	5.899	1.841	5.899	5.453

Table 6-2 Horizontal & Vertical Accuracy Statistics for 15 May 2005

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Bangor	3.657	5.010	5.356	11.657
Mauna Loa	3.113	7.937	4.275	10.436
Billings	2.894	6.659	4.541	10.603
Cold Bay	3.795	5.485	5.371	9.354
Juneau	2.851	5.414	3.736	8.498
Albuquerque	2.567	9.384	3.779	11.194
Anchorage	3.285	5.292	5.161	9.495
Boston	2.587	5.526	3.688	7.374
Washington, D.C.	2.462	7.157	3.411	10.071
Honolulu	3.116	8.418	3.966	10.864
Houston	2.181	10.528	2.764	11.461
Kansas City	2.722	9.006	3.455	12.102
Los Angeles	2.597	9.645	3.900	12.004
Salt Lake City	3.074	8.134	4.389	10.953
Miami	2.613	9.338	3.180	11.242
Minneapolis	2.893	6.758	3.948	9.805
Oakland	3.795	8.412	3.795	10.922
Cleveland	2.843	6.883	5.578	9.471
Seattle	3.010	6.176	3.976	9.882
San Juan	2.004	7.813	2.227	9.290
Atlanta	2.125	8.803	2.699	11.063

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	99.997%
• 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	99.306% Availability 99.9% PDOP was 3.26876
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	≤5.081m HE 95% ≤32.097m HE 99.99% ≤6.856m VE 95% ≤40.882m 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	≤1.663m HE 95% ≤4.198m 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	≤14 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	19.947m NTE Range Error 0.86361m/s NTE Rate Error 8.55mm/s^2 NTE Accl. Error ≤8mm/s^2 99.999% of the time

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#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center.
#  Please send comment and suggestions to SEC.Webmaster@noaa.gov
#
#              Current Quarter Daily Geomagnetic Data
#
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	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2005 04 01	6	1 3 3 1 1 1 1 1	4	1 2 3 0 1 1 0 0	8	1 3 4 2 2 2 1 1
2005 04 02	1	0 0 0 1 1 1 0 0	3	1 0 0 3 0 1 0 0	4	1 0 1 1 1 2 1 1
2005 04 03	4	2 2 1 1 1 1 1 1	4	1 1 1 3 1 1 1 0	6	1 2 1 1 1 2 2 2
2005 04 04	11	1 2 2 2 2 3 3 4	17	1 1 2 2 3 5 4 4	17	1 2 2 2 2 4 4 5
2005 04 05	30	6 6 4 2 2 2 2 4	-1	5-1-1-1-1 4 3 3	48	7 7 5 3 3 3 3 4
2005 04 06	7	3 2 1 1 2 2 2 2	17	3 2 3 5 3 4 1 2	11	3 2 2 3 2 3 3 3
2005 04 07	4	2 2 2 2 1 1 0 0	11	1 1 3 5 3 2 0 0	8	2 2 3 2 2 2 1 1
2005 04 08	2	2 1 1 0 1 0 1 0	2	1 0 2 1 0 0 0 0	4	2 0 1 1 1 1 2 1
2005 04 09	2	1 1 0 0 0 0 0 2	0	0 0 0 0 0 0 0 0	4	2 1 0 1 1 2 2 1
2005 04 10	2	1 1 0 0 1 1 1 1	2	1 0 0 1 1 0 0 1	4	1 0 0 1 2 2 1 1
2005 04 11	6	1 2 0 0 2 1 3 3	7	2 1 0 3 2 2 2 2	10	1 1 0 1 2 3 4 3
2005 04 12	23	5 5 2 3 3 2 3 4	36	5 3 5 6 5 3 3 3	30	6 5 3 4 4 3 4 4
2005 04 13	18	2 3 3 3 3 3 3 5	53	3 4 6 5 7 6 3 3	26	2 4 4 4 5 5 4 4
2005 04 14	14	3 4 2 3 3 2 3 2	31	3 4 5 6 5 3 2 2	19	4 5 3 3 3 2 3 2
2005 04 15	7	2 2 2 1 2 2 1 3	26	3 4 4 5 5 4 2 2	13	3 4 2 2 3 3 2 3
2005 04 16	4	3 1 1 0 1 1 1 1	5	2 1 1 2 2 1 1 1	7	3 2 1 1 2 2 2 2
2005 04 17	4	2 2 2 0 1 0 1 1	3	1 1 2 0 1 0 1 1	5	1 2 2 1 1 1 1 1
2005 04 18	5	1 2 2 1 1 1 2 2	14	1 3 3 3 5 2 1 1	8	1 3 2 1 2 2 2 2
2005 04 19	6	1 2 3 1 2 1 1 2	8	2 2 4 1 3 1 0 1	8	2 2 4 1 2 2 2 2
2005 04 20	12	2 4 3 3 3 2 1 2	31	3 4 5 6 5 3 2 2	21	2 5 4 4 4 3 2 2
2005 04 21	2	1 0 1 0 1 1 1 0	2	1 0 1 0 0 0 1 1	4	2 0 1 1 1 2 1 1
2005 04 22	7	3 1 0 1 3 2 2 2	8	2 2 1 1 4 2 2 1	9	2 2 1 1 3 2 3 2
2005 04 23	5	1 0 1 1 2 2 2 2	5	1 1 1 2 1 2 1 2	6	1 1 2 2 2 2 2 2
2005 04 24	5	2 2 1 1 2 1 1 2	9	3 3 2 2 3 1 1 2	10	3 4 2 2 2 2 2 2
2005 04 25	9	2 4 3 1 2 0 1 2	9	2 3 3 3 3 1 0 1	11	3 4 3 2 2 1 1 2
2005 04 26	2	1 0 0 1 1 0 1 1	1	0 0 0 1 0 0 1 1	5	1 0 1 1 2 2 2 1
2005 04 27	1	0 0 0 1 1 1 0 0	1	0 0 0 1 1 0 0 0	4	1 0 0 1 2 2 2 1
2005 04 28	1	0 0 0 0 1 0 1 0	1	0 0 0 0 1 0 1 0	4	0 0 1 1 2 1 2 1
2005 04 29	8	0 1 2 1 2 1 3 4	12	0 1 3 3 3 3 3 3	12	1 1 3 2 2 2 4 4
2005 04 30	13	3 2 2 3 3 3 3 3	24	4 3 3 4 5 4 3 3	21	5 4 3 3 4 3 3 3
2005 05 01	14	3 4 3 3 3 2 2 2	36	4 4 6 6 4 4 3 2	26	5 6 4 3 3 3 3 2
2005 05 02	6	2 2 2 1 2 1 2 2	9	2 2 2 2 4 2 1 1	7	2 2 2 1 2 2 2 2
2005 05 03	6	2 1 2 2 2 2 2 1	13	2 2 3 4 4 3 1 1	10	3 2 2 3 3 3 2 1
2005 05 04	4	2 2 1 1 1 1 1 0	3	2 2 0 0 2 0 1 1	7	3 3 1 1 1 2 2 1
2005 05 05	3	1 1 1 1 1 1 1 1	4	1 1 1 3 1 1 0 0	6	1 1 1 3 1 2 2 1
2005 05 06	3	1 0 0 0 2 2 2 1	2	0 0 0 0 1 1 2 1	4	1 0 0 1 2 2 2 2
2005 05 07	10	1 1 0 1 2 2 2 5	7	1 1 0 2 3 1 2 3	10	2 1 0 1 2 2 3 4
2005 05 08	38	6 4 3 4 6 5 3 3	80	6 4 5 7 7 7 5 3	64	6 6 4 5 7 6 4 4
2005 05 09	10	3 3 1 1 1 2 3 3	9	3 3 2 0 0 2 2 4	11	3 3 1 1 1 2 3 4
2005 05 10	6	3 1 2 1 1 0 2 2	11	2 3 4 3 2 1 2 1	10	3 3 3 2 2 2 2 2
2005 05 11	7	1 0 2 2 1 2 3 3	16	1 1 2 5 3 4 2 3	11	1 0 2 3 2 3 3 4
2005 05 12	13	2 4 2 3 2 2 3 3	25	3 3 3 6 2 5 2 3	17	3 4 3 4 2 3 3 3
2005 05 13	21	5 4 4 2 3 3 3 3	43	5 5 6 4 5 6 2 1	27	5 5 5 3 3 4 3 2
2005 05 14	4	1 1 2 1 1 1 1 1	8	1 1 3 2 3 2 2 1	8	2 1 3 2 2 2 2 2
2005 05 15	44	5 5 7 5 2 3 3 4	77	6 5 8 7 4 4 4 4	105	5 5 9 8 4 4 4 5
2005 05 16	18	4 4 5 3 2 2 1 2	78	4 7 7 6 6 7 2 2	33	4 6 5 3 4 5 2 2
2005 05 17	10	3 3 3 2 2 2 2 2	43	3 6 5 6 5 5 2 3	19	4 4 4 3 3 3 2 3
2005 05 18	6	2 2 2 2 2 1 1 1	36	2 3 5 4 6 5 3 5	13	3 3 4 3 4 3 2 2

2005 05 19	7	1 2 3 1 1 1 2 3	1	1 3 4 5 4 2 1 2	11	2 3 3 2 2 2 3 3
2005 05 20	17	2 5 4 3 3 2 2 2	29	3 5 6 3 5 3 2 2	30	3 6 6 4 4 3 2 3
2005 05 21	13	3 3 3 3 2 2 3 3	33	2 5 5 5 5 5 2 2	21	3 4 4 4 3 3 3 3
2005 05 22	10	4 2 2 3 2 1 2 2	19	3 4 4 4 5 1 1 1	14	4 2 3 4 3 2 3 2
2005 05 23	5	2 1 1 0 3 1 1 1	15	2 1 1 1 5 5 1 2	7	2 1 1 1 3 3 2 1
2005 05 24	2	0 0 0 1 1 0 1 2	1	0 0 0 0 0 0 1 2	5	1 1 1 1 1 1 2 2
2005 05 25	2	1 1 1 1 1 1 0 0	3	2 2 1 0 1 1 0 0	6	2 1 2 1 1 2 2 1
2005 05 26	1	0 0 0 0 1 0 1 0	0	0 0 0 0 0 0 0 0	4	1 1 0 1 1 1 1 1
2005 05 27	1	0 0 1 0 1 0 1 0	1	1 1 1 0 0 0 0 0	4	1 1 1 1 1 2 1 1
2005 05 28	9	0 2 2 2 2 3 3 3	7	0 2 1 2 1 2 3 3	13	1 3 2 2 2 4 4 4
2005 05 29	16	3 3 2 3 1 2 3 5	16	3 4 4 2 1 3 3 3	22	3 4 3 3 2 3 3 6
2005 05 30	32	3 3 5 5 5 4 4 4	80	4 3 7 6 6 7 7 3	67	4 3 6 7 6 7 5 4
2005 05 31	10	3 3 2 2 3 2 2 2	27	4 4 6 3 5 2 2 1	17	4 4 3 3 3 3 3 3
2005 06 01	5	2 3 1 1 1 0 1 1	8	3 3 2 2 2 2 2 0	8	3 3 1 2 1 2 2 1
2005 06 02	7	2 1 1 2 2 1 2 3	4	1 1 0 2 1 1 2 2	7	2 2 2 2 1 2 2 3
2005 06 03	10	4 3 3 1 2 1 1 2	6	2 2 2 2 2 1 1 1	8	2 3 3 2 2 2 2 2
2005 06 04	12	1 1 2 2 3 3 4 3	15	2 2 2 3 3 5 3 2	18	2 1 3 2 3 4 5 4
2005 06 05	14	3 2 4 2 2 3 3 3	31	5 5 5 5 3 3 3 2	20	4 3 5 3 2 3 3 3
2005 06 06	7	3 3 2 0 1 1 2 3	12	4 3 4 1 2 1 1 2	13	3 3 3 1 1 2 3 4
2005 06 07	11	3 4 3 2 2 1 2 2	23	3 4 5 5 4 2 1 2	18	4 5 4 2 3 2 3 3
2005 06 08	3	2 1 1 0 1 1 1 1	4	2 2 1 3 0 1 0 0	6	2 2 1 2 1 2 1 1
2005 06 09	3	1 0 0 1 2 1 1 1	5	1 1 0 1 3 3 0 0	5	1 1 0 2 2 2 2 1
2005 06 10	2	1 0 0 0 1 0 1 1	2	1 1 0 2 1 0 0 1	5	2 1 1 1 1 1 1 2
2005 06 11	6	2 1 1 1 1 1 2 3	2	1 0 1 1 0 0 1 2	6	2 1 1 1 1 2 2 3
2005 06 12	23	2 2 4 3 4 4 4 5	48	4 2 3 3 6 5 7 5	35	2 2 4 4 4 5 5 6
2005 06 13	17	5 4 3 2 3 2 3 1	36	4 6 6 4 5 3 2 1	33	5 6 4 4 4 3 3 2
2005 06 14	8	2 1 2 1 1 1 4 2	7	2 2 2 2 2 0 3 2	10	2 2 2 2 2 2 4 3
2005 06 15	14	3 4 3 2 3 2 3 2	30	2 4 6 5 5 3 1 2	21	3 5 5 3 4 3 3 2
2005 06 16	19	1 2 3 4 3 4 4 4	36	1 2 3 6 6 6 3 2	26	1 2 2 6 5 4 4 3
2005 06 17	9	4 3 1 1 2 2 2 1	20	4 4 2 4 4 4 2 2	14	4 4 3 2 2 3 3 2
2005 06 18	5	1 2 2 1 1 1 2 1	8	2 2 3 1 3 2 2 1	7	1 2 3 1 2 2 2 1
2005 06 19	3	1 1 1 1 1 1 1 1	4	1 1 1 1 2 2 0 2	7	2 1 2 2 2 2 2 2
2005 06 20	2	0 0 1 1 1 1 1 0	4	1 1 1 2 2 1 0 2	5	1 1 1 2 1 2 1 1
2005 06 21	1	0 0 0 0 0 1 1 1	1	0 0 0 0 0 0 0 2	4	1 0 0 0 1 1 2 1
2005 06 22	6	2 1 1 1 2 1 1 3	4	2 2 1 1 1 0 1 2	7	2 2 1 2 1 1 2 3
2005 06 23	30	3 4 6 5 4 3 3 3	49	3 5 7 5 6 4 3 3	48	4 4 7 5 5 4 4 3
2005 06 24	7	3 3 2 2 2 1 0 1	16	4 4 2 5 3 0 0 1	17	4 5 3 3 3 1 1 2
2005 06 25	9	2 3 1 1 2 2 3 3	14	3 3 1 4 3 3 2 3	11	3 3 1 2 2 3 2 3
2005 06 26	6	3 2 1 1 2 1 2 1	11	3 3 1 4 3 2 1 0	8	3 3 2 2 2 2 2 1
2005 06 27	3	1 0 0 0 1 1 2 2	3	2 1 0 1 2 1 1 0	4	1 0 0 1 2 2 2 1
2005 06 28	3	1 1 1 0 2 0 0 0	3	1 1 1 0 1 1 1 1	5	1 1 1 1 2 2 2 2
2005 06 29	4	1 1 1 2 1 1 1 1	5	1 2 1 2 2 1 1 1	6	2 1 1 2 2 2 2 2
2005 06 30	4	1 1 1 1 1 1 2 2	8	2 2 1 4 2 2 1 1	8	1 1 1 2 2 3 2 3

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.