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

Submitted To

Federal Aviation Administration
GPS Product Team

1284 Maryland Avenue SW
Washington, DC 20024

Report #58
July 31, 2007
Reporting Period: 1 April – 30 June 2007

Submitted by

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

EXECUTIVE SUMMARY

The GPS Product Team has tasked the Navigation Branch at the William J. Hughes Technical Center to document the Global Positioning System (GPS) Standard Positioning Service (SPS) performance in quarterly GPS Performance Analysis (PAN) Reports. The report contains the analysis performed on data collected at twenty-two Wide Area Augmentation System (WAAS) Reference Stations. This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification (October 2001).

This report, Report #58, includes data collected from 1 April through 30 June 2007. The next quarterly report will be issued 31 October 2007.

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

PDOP availability is based on Position Dilution of Precision (PDOP). Utilizing the weekly almanac posted on the US Coast Guard navigation web site, the coverage for every 5^{o} grid point between 180W to 180E and 80S and 80N was calculated for every minute over a 24-hour period for each of the weeks covered in the reporting period. For this reporting period, the global availability based on PDOP less than six for the CONUS was 99.997% or better.

NANU summary and evaluation was achieved by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 April and 30 June 2007. Using this data, we compute a set of statistics that give a relative idea of constellation health for the both the current and a combined history of past quarters. A total of thirteen outages were reported in the NANU's this quarter. Eleven outages were scheduled while two were unscheduled.

The quarterly service availability standard was verified using 24-hour position accuracy values computed from data collected at one-second intervals. All of the sites achieved a 100% availability which exceeds the SPS "average location" value of 99% and the "worst-case location" value of 90%.

Accuracy standards were verified by calculating the 24-hour 95% horizontal and vertical position error values. The User Range Error and Service Reliability standards were verified for each satellite from 24-hour accuracy values computed using data collected at the following six sites: Boston, Honolulu, Los Angeles, Miami, San Juan and Juneau. This data was also collected in one-second samples. Although some of the sites did not achieve 100% reliability, all sites met the SPS specification. The maximum range error recorded was 310.264 meters on Satellite PRN 18. The SPS specification states that the range error should never exceed 30 meters for less than 99.79% of the day for a worst case point and 99.94% globally. The maximum RMS range error value of 2.325 was recorded on satellite 28. The SPS specification states that RMS URE cannot exceed 6 meters in any 24-hour interval.

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

From the analysis performed on data collected between 1 April and 30 June 2007, the GPS performance met all SPS requirements that were evaluated. Please see the GPS problem report section in Appendix C for further discussion on a specific event that occurred 11 April 2007.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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-two WAAS reference station locations:

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

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

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

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

1.2 Summary of Performance Requirements and Metrics

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

1.3 Report Overview

Section 2 of this report summarizes the results obtained from the coverage calculation program called SPS_CoverageArea developed by the GPS test team. 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 constellation performance by providing the "Notice: Advisory to Navstar Users" (NANU) messages to calculate the total time of forecasted and actual satellite outages. This section also evaluates the Service Availability Standard using 24-hour 95% horizontal and vertical position accuracy values.

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

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

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

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

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

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

Table 1-1 SPS Performance Requirements

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

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

2.0 PDOP Availability Standard

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

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

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

Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by the GPS test team was used to calculate the PDOP at every 5^o point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.1177 or better 99.9% of the time for each of the 24-hour intervals.

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

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

Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 98%)	Worst-Case Point (Spec: ≥ 88%)
1-7 Apr	3.02592	99.999	99.583
8-14 Apr	3.03712	99.998	99.583
15-21 Apr	3.03876	99.998	99.514
22-28 Apr	3.1177	99.998	99.517
29 Apr – 5 May	3.01449	99.999	99.722
6-12 May	3.01432	99.999	99.722
13-19 May	3.01430	99.999	99.722
20-26 May	3.01345	99.999	99.722
27 May – 2 June	3.00879	99.998	99.514
3-9 June	3.01753	99.997	99.514
10-16 June	3.01751	99.997	99.514
17-23 June	3.01757	99.997	99.514
24-30 June	3.01758	99.997	99.514

Figure 2-1 PDOP Availability Plot (24-Hour Period: 25 June 2007)

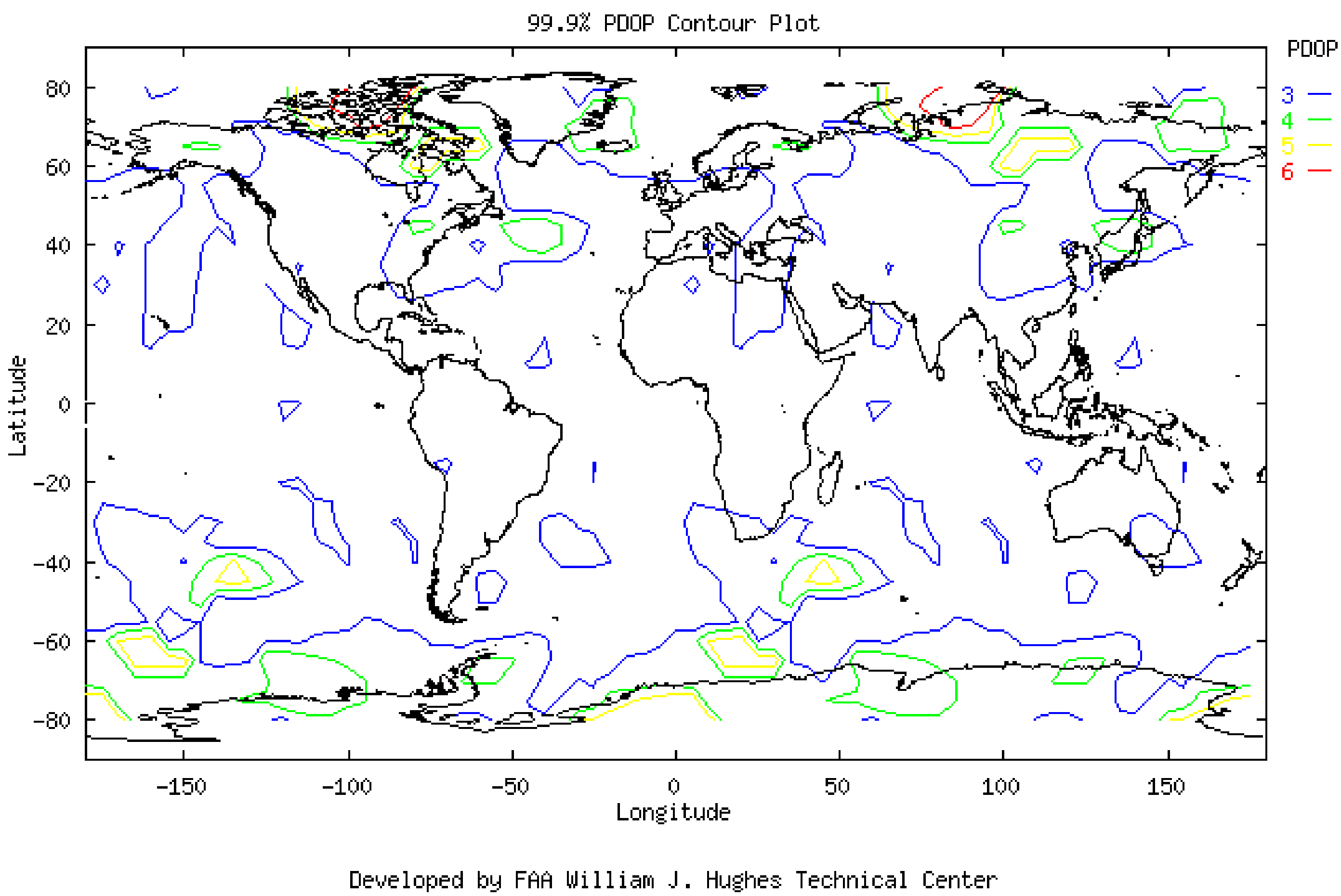
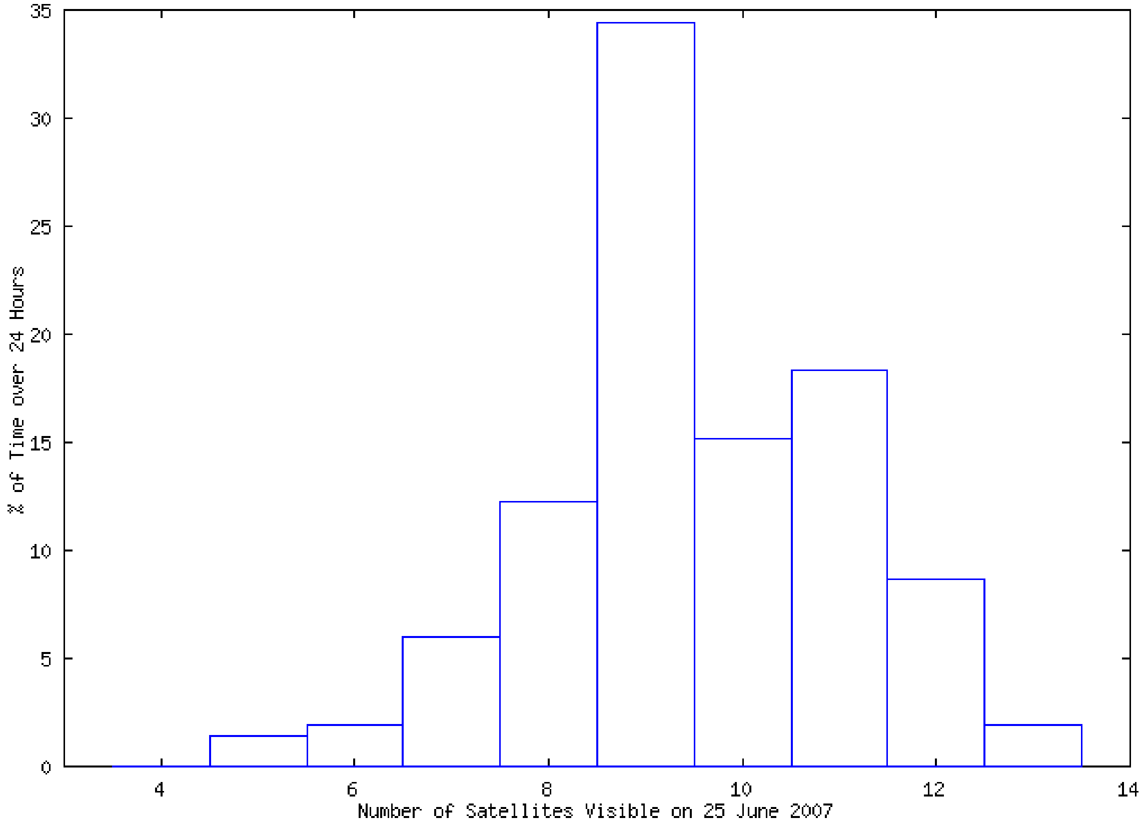


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lat: -95, Lon: 75)



3.0 NANU Summary and Evaluation

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

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published “Notice: Advisory to Navstar Users” messages (NANU’s). During this reporting period, 1 April through 30 June 2007, there were a total of thirteen reported outages. Eleven of these outages were maintenance activities and were reported in advance. Two were unscheduled outages. A complete listing of outage NANU’s for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU’s for the reporting period can be found in Table 3-2. Canceled outage NANU’s 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
2007056	23	UNUSABLE	6-Apr	19:42	6-Apr	20:44	1.03		1.03
2007057	18	FCSTSUMM	10-Apr	17:04	10-Apr	21:24		4.33	4.33
2007058	14	FCSTSUMM	14-Apr	14:09	15-Apr	2:58		12.82	12.82
2007060	25	UNUSABLE	22-Apr	10:10	25-Apr	22:40	84.50		84.50
2007062	14	FCSTSUMM	2-May	17:33	2-May	22:37		5.07	5.07
2007065	20	FCSTSUMM	10-May	19:11	11-May	2:17		7.10	7.10
2007067	24	FCSTSUMM	14-May	13:50	14-May	16:59		3.15	3.15
2007069	1	FCSTSUMM	17-May	20:46	18-May	2:39		5.88	5.88
2007071	4	FCSTSUMM	24-May	8:35	24-May	15:03		6.47	6.47
2007073	5	FCSTSUMM	30-May	15:17	30-May	17:16		1.98	1.98
2007075	30	FCSTSUMM	5-Jun	9:58	5-Jun	15:41		5.72	5.72
2007077	25	FCSTSUMM	11-Jun	17:47	12-Jun	3:11		9.40	9.40
2007082	3	FCSTSUMM	23-Jun	23:41	24-Jun	5:54		6.22	6.22
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**85.53**	**68.13**	**153.67**

	Table 3-2 NANUs Forecasted to Affect Satellite Availability							
NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2007053	18	FCSTDV	10-Apr	13:30	11-Apr	1:30	12	See Nanu 2007057
2007054	14	FCSTMX	14-Apr	14:00	15-Apr	6:00	16	See Nanu 2007058
2007055	23	UNUSUFN	6-Apr	19:42	N/A	N/A	N/A	See Nanu 2007056
2007059	25	UNUSUFN	22-Apr	10:10	N/A	N/A	N/A	See Nanu 2007060
2007061	14	FCSTDV	2-May	17:00	3-May	7:30	14.5	See Nanu 2007062
2007063	20	FCSTDV	10-May	19:00	11-May	10:30	15.5	See Nanu 2007065
2007064	24	FCSTMX	14-May	13:30	14-May	21:30	8	See Nanu 2007067
2007066	1	FCSTDV	17-May	21:00	18-May	23:00	26	See Nanu 2007068
2007068	1	FCSTRESCD	17-May	20:30	18-May	23:00	26.5	See Nanu 2007069
2007070	4	FCSTDV	24-May	7:30	24-May	21:30	14	See Nanu 2007071
2007072	5	FCSTMX	30-May	15:00	30-May	18:00	3	See Nanu 2007073
2007074	30	FCSTDV	5-Jun	9:45	5-Jun	23:45	14	See Nanu 2007075
2007076	25	FCSTDV	11-Jun	17:30	12-Jun	19:30	26	See Nanu 2007077
2007078	3	FCSTDV	23-Jun	23:30	24-Jun	13:30	14	See Nanu 2007082
2007079	25	FCSTMX	27-Jun	2:00	27-Jun	4:00	CANC	See Nanu 2007083
2007080	22	FCSTMX	27-Jun	17:30	27-Jun	19:30	CANC	See Nanu 2007084
						Total Forecast Downtime	**189.5**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
2007083	25	FCSTCANC	27-Jun	2:49	See Nanu 2007079
2007084	22	FCSTCANC	27-Jun	18:06	See Nanu 2007080

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

Table 3-4 GPS Block II/IIA Satellite RMA Data		
Satellite Reliability/Maintainability/Availability (RMA) Parameter	**1 Apr - 30 Jun, 2007**	**1 October, 1999- 30 Jun. 2007**
Total Forecast Downtime (hrs):	189.50	6559.48
Total Actual Downtime (hrs):	153.67	23454.28
Total Actual Scheduled Downtime (hrs):	68.13	3502.77
Total Actual Unscheduled Downtime (hrs):	85.54	19951.51
Total Satellite Observed MTTR (hrs):	11.82	46.44
Scheduled Satellite Observed MTTR (hrs):	6.19	9.62
Unscheduled Satellite Observed MTTR (hrs):	42.77	141.50
# Total Satellite Outages:	13	505
# Scheduled Satellite Outages:	11	364
# Unscheduled Satellite Outages:	2	141
Percent Operational -- Scheduled Downtime:	99.90	99.81
Percent Operational -- All Downtime:	99.99	98.74

3.2 Service Availability Standard

Service Availability: The percentage of time over any 24-hour interval that the predicted 95% positioning error is less than its threshold for any given point within the service volume.

• **Horizontal Service Availability:** The percentage of time over any 24-hour interval that the predicted 95% horizontal error is less than its threshold for any point within the service volume.
• **Vertical Service Availability:** The percentage of time over any 24-hour interval that the predicted 95% vertical error is less than its threshold for any point within the service volume.

Service Availability Standard	Conditions and Constraints
≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	• 36 meter horizontal (SIS only) 95% threshold. • 77 meter vertical (SIS only) 95% threshold. • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.
≥ 95.87% global average on worst-case day	• Based on using only satellites transmitting standard code and indicating "healthy" in the broadcast navigation message (sub-frame 1).

To verify availability, the data collected from receivers at the twenty-two WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-5. The data was collected at one-second intervals between 1 April and 30 June 2007.

Table 3-5 Accuracies Exceeding Threshold Statistics

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-hour Threshold Failures	Quarters Service Availability %
Billings	7818960	0	100%
Albuquerque	7820594	0	100%
Anchorage	7816062	0	100%
Boston	7818543	0	100%
Washington, DC	7827053	0	100%
Honolulu	7764528	0	100%
Houston	7821639	0	100%
Kansas City	7763323	0	100%
Los Angeles	5147623	0	100%
Salt Lake City	7823670	0	100%
Miami	7805731	0	100%
Minneapolis	7816508	0	100%
Oakland	7795363	0	100%
Cleveland	7797497	0	100%
Seattle	7796193	0	100%
San Juan	7777720	0	100%
Atlanta	7812266	0	100%
Juneau	7763126	0	100%
Cold Bay	7750482	0	100%
Fairbanks	7717441	0	100%
Bethel	7699117	0	100%
Kotzebue	7612416	0	100%
Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)			

4.0 Service Reliability Standard

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

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

Table 4-1 shows a comparison to the service reliability standard for range data collected at a receiver in Billings, Montana. Although the specification calls for yearly evaluations, we will be evaluating this SPS requirement at quarterly intervals. Additional range analysis results can be found in table 5-2 on page 21. The maximum User Range Error recorded this quarter was 310.264 meters at Boston on satellite PRN 18.

Table 4-1 Service Reliability Based on User Range Error

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Service Reliability Percentage
1 April – 31 Mar 2007	**Boston**	62,317,507	0	100%
1 April – 31 Mar 2007	**Honolulu**	61,540,458	23,939	99.961%
1 April – 31 Mar 2007	**Los Angeles**	61,086,502	2,240	99.996%
1 April – 31 Mar 2007	**Miami**	63,641,914	4,542	99.993%
1 April – 31 Mar 2007	**San Juan**	65,555,088	0	100%
1 April – 31 Mar 2007	**Juneau**	62,497,070	12,111	99.981%
1 April – 31 Mar 2007	**Global**	376,638,539	42,832	99.989%

5.0 Accuracy Standard

Positioning Accuracy: The statistical difference, at a 95% probability, between position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

• **Horizontal Positioning Accuracy:** The statistical difference, at a 95% probability, between horiz position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.
• **Vertical Positioning Accuracy:** The statistical difference, at a 95% probability, between vertical position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

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

5.1 Position Accuracy

The data used for this section was collected for every second between 1 April through 30 June 2007 at the NSTB and WAAS selected locations.

Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter. Every twenty-four hour analysis period this quarter passed both the worst-case and global position accuracy requirements set forth by the SPS specification.

Table 5-1 Horizontal & Vertical Accuracy Statistics for the Quarter

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Billings	2.132	4.003	40.368	46.74
Albuquerque	2.171	4.114	42.160	28.326
Anchorage	2.105	4.060	60.480	103.135
Boston	2.375	4.549	14.740	13.711
Washington, DC	2.422	4.914	26.449	62.85
Honolulu	3.547	4.577	85.712	276.825
Houston	2.392	4.439	27.112	31.736
Kansas City	2.286	4.411	32.483	48.99
Los Angeles	2.309	4.325	4.350	8.168
Salt Lake City	2.171	4.537	49.508	45.859
Miami	2.561	4.842	13.892	28.459
Minneapolis	2.235	4.266	34.666	65.144
Oakland	2.212	4.677	60.751	14.255
Cleveland	2.409	4.669	28.275	65.189
Seattle	2.226	4.289	52.700	50.278
San Juan	2.648	4.67	7.713	15.755
Atlanta	2.39	4.809	23.244	58.959
Juneau	2.106	3.855	53.433	77.483
Cold Bay	2.261	4.318	61.843	64.274
Fairbanks	1.985	4.113	49.570	87.347
Bethel	2.079	3.971	67.453	105.39
Kotzebue	2.009	4.180	48.372	91.49

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-two WAAS sites from 1 April to 30 June 2007.

Figure 5-1 Global Vertical Error Histogram

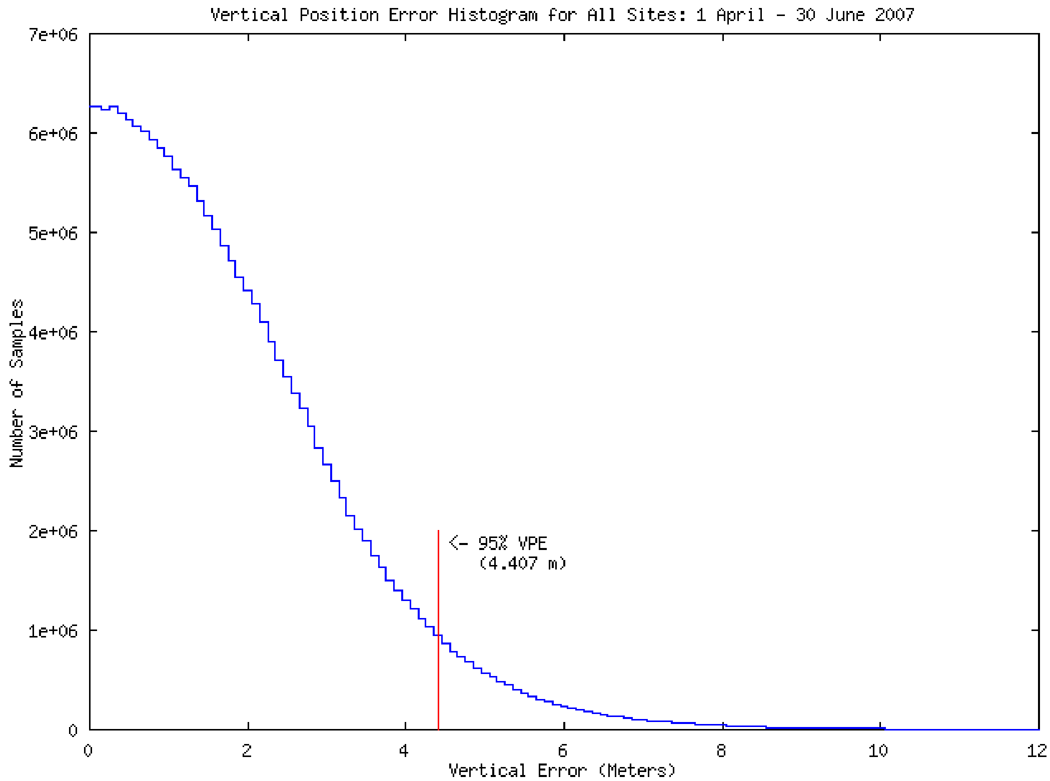
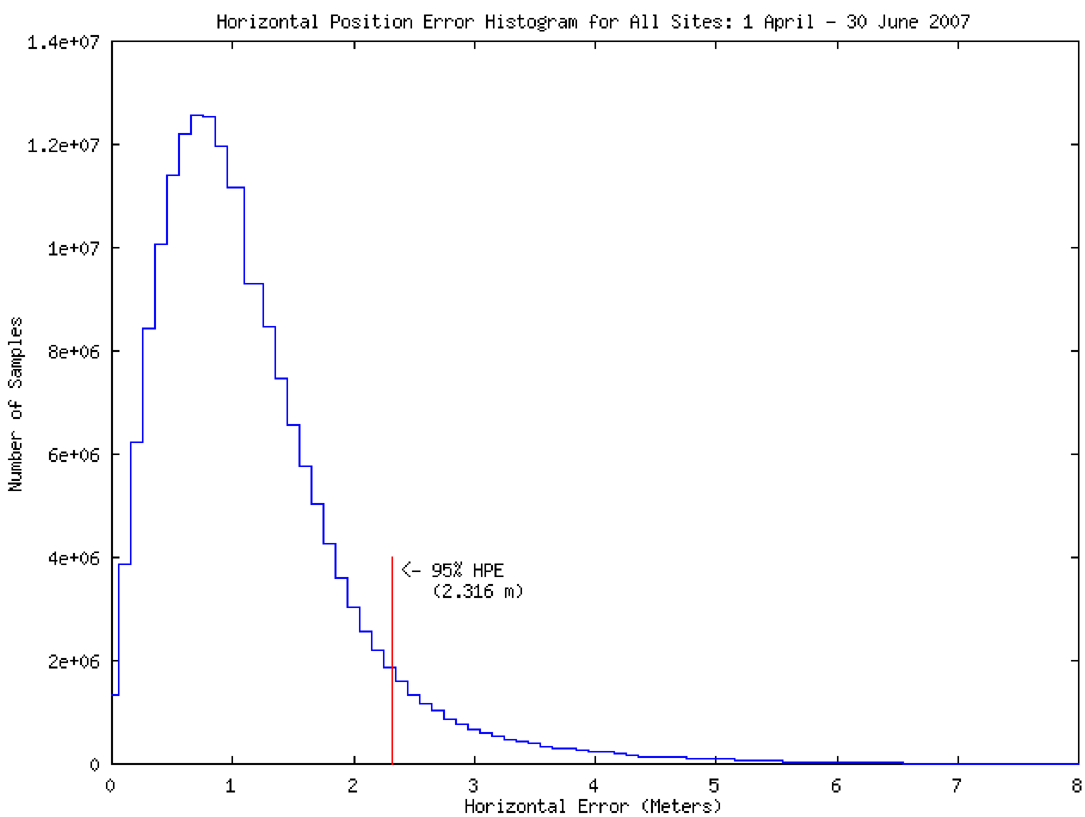


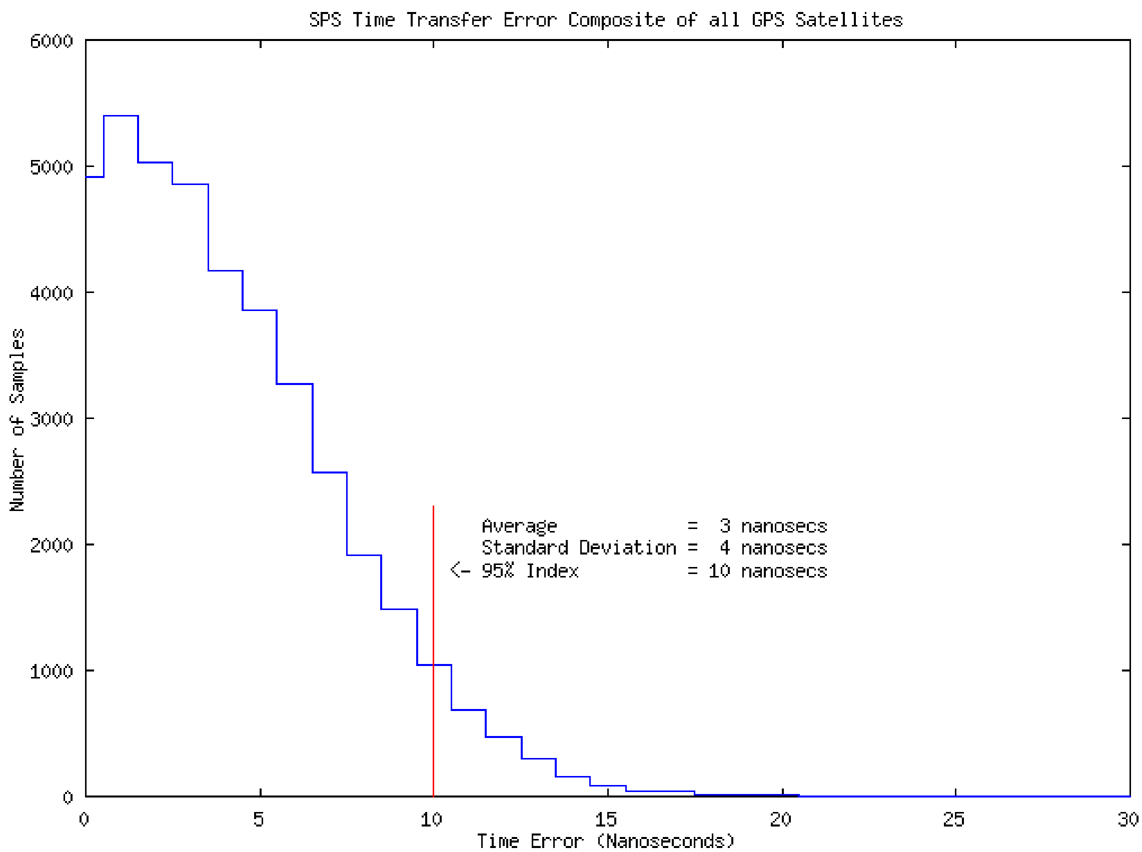
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 2007 was down loaded from USNO Internet site. The USNO data file contains the time difference between the USNO master clock and GPS system time for each GPS satellites during the time period. Over 10,000 samples of GPS time error are contained in the USNO data file. In order to evaluate the GPS time transfer error, the data file was used to create a histogram (Fig 5-3) to represent the distribution of GPS time error. The histogram was created by taking the absolute value of time difference between the USNO master clock and GPS system time, then creating data bins with one nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Fig 5-3. The mean, standard deviation, and 95% index are within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Errors



5.3 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 April and 30 June 2007. The WAAS receiver at Houston was used to collect range measurement.

A weighted average filter was used for the calculation of the range rate error and the range acceleration error. All Range Domain SPS specifications were met.

Table 5-2 Range Error Statistics (meters)

PRN	RMS Range Error (≤ 6 m)	Range Error Mean	1s	95% Range Error	Max Range Error (SPS Spec. ≤ 30 m)	Samples
1	2.240	0.887	1.588	3.993	10.439	12088894
2	1.548	0.805	1.223	2.843	37.578	13447733
3	1.731	0.274	1.343	3.152	16.537	11766445
4	1.628	0.370	1.324	3.012	8.760	13251066
5	1.823	1.212	1.159	3.203	34.203	13226608
6	1.529	0.590	1.170	2.893	213.848	13154041
7	1.785	1.153	1.187	3.233	213.945	13629565
8	2.262	0.921	1.677	4.122	11.068	12262331
9	1.843	0.615	1.411	3.385	12.279	12303707
10	1.923	0.793	1.346	3.424	85.071	12983348
11	1.705	0.688	1.351	3.157	10.925	11668435
12	1.361	0.379	1.165	2.590	9.388	13825646
13	1.318	-0.006	1.174	2.546	12.092	13324895
14	1.550	0.697	1.132	2.860	19.969	13061639
16	1.508	0.584	1.179	2.833	214.980	12502047
17	1.755	0.416	1.373	3.314	9.283	13557558
18	1.717	0.830	1.201	3.094	310.264	12077113
19	1.826	1.177	1.257	3.348	31.462	12134005
20	1.721	0.885	1.345	3.331	9.803	13590074
21	1.800	1.024	1.280	3.264	214.183	11136165
22	1.849	0.742	1.211	3.297	211.011	11850585
23	1.430	0.316	1.189	2.681	19.436	12540971
24	1.978	0.837	1.337	3.590	213.698	11848952
25	1.574	0.199	1.285	2.929	57.942	11590172
26	1.686	0.346	1.347	3.108	86.294	11483181
27	2.045	0.899	1.567	3.755	13.969	12094297
28	2.325	0.994	1.545	4.193	12.524	12056655
29	2.025	0.303	1.483	3.656	84.645	11883684
30	1.826	0.346	1.379	3.419	214.889	12674120
31	1.552	-0.023	1.289	2.945	214.924	13624607

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

PRN	Range Rate Error RMS	Range Rate Error Mean	Range Rate Error 1s	95% Range Rate Error	Max Range Rate Error	Samples
1	0.00227	0.00002	0.00226	0.00309	0.18468	12088894
2	0.00156	0.00002	0.00156	0.00295	0.23870	13447733
3	0.00190	-0.00003	0.00190	0.00333	0.17715	11766445
4	0.00149	-0.00002	0.00149	0.00289	0.05123	13251066
5	0.00158	-0.00002	0.00158	0.00277	0.15190	13226608
6	0.00158	-0.00002	0.00157	0.00313	0.34238	13154041
7	0.00156	-0.00002	0.00156	0.00307	0.34314	13629565
8	0.00198	-0.00003	0.00197	0.00335	0.21831	12262331
9	0.00214	-0.00001	0.00214	0.00332	0.27621	12303707
10	0.00183	0.00006	0.00183	0.00320	0.25040	12983348
11	0.00162	0.00001	0.00162	0.00310	0.15476	11668435
12	0.00149	-0.00003	0.00149	0.00292	0.06328	13825646
13	0.00157	0.00001	0.00157	0.00300	0.07031	13324895
14	0.00159	-0.00002	0.00158	0.00296	0.29305	13061639
16	0.00163	-0.00003	0.00163	0.00322	0.34314	12502047
17	0.00171	-0.00002	0.00170	0.00311	0.15011	13557558
18	0.00164	-0.00004	0.00162	0.00314	0.30615	12077113
19	0.00163	0.00000	0.00162	0.00302	0.29263	12134005
20	0.00159	0.00003	0.00159	0.00308	0.13265	13590074
21	0.00180	0.00001	0.00179	0.00356	0.34344	11136165
22	0.00165	0.00003	0.00164	0.00324	0.34159	11850585
23	0.00159	0.00001	0.00158	0.00298	0.95011	12540971
24	0.00196	0.00001	0.00196	0.00339	0.34379	11848952
25	0.00151	0.00000	0.00151	0.00290	0.09395	11590172
26	0.00164	-0.00005	0.00163	0.00304	0.17653	11483181
27	0.00197	-0.00001	0.00196	0.00332	0.17900	12094297
28	0.00182	-0.00004	0.00181	0.00312	0.14081	12056655
29	0.00211	0.00001	0.00210	0.00353	0.21890	11883684
30	0.00193	-0.00002	0.00193	0.00352	0.34102	12674120
31	0.00170	-0.00004	0.00169	0.00315	0.34141	13624607

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

PRN	Range Acceleration Error RMS	Range Acceleration Error Mean	Range Acceleration 1σ	Max Range Acceleration Error	Samples
1	0.00002	0	0.00002	0.000024098	12088894
2	0.00001	0	0.00001	0.000023446	13447733
3	0.00001	0	0.00001	0.000026224	11766445
4	0.00001	0	0.00001	0.000023183	13251066
5	0.00001	0	0.00001	0.000023215	13226608
6	0.00001	0	0.00001	0.000024024	13154041
7	0.00001	0	0.00001	0.000023612	13629565
8	0.00002	0	0.00002	0.000024583	12262331
9	0.00002	0	0.00002	0.000025835	12303707
10	0.00001	0	0.00001	0.000023816	12983348
11	0.00001	0	0.00001	0.000024263	11668435
12	0.00001	0	0.00001	0.000023593	13825646
13	0.00001	0	0.00001	0.000024234	13324895
14	0.00001	0	0.00001	0.000023764	13061639
16	0.00001	0	0.00001	0.000024202	12502047
17	0.00001	0	0.00001	0.000023563	13557558
18	0.00001	0	0.00001	0.000024231	12077113
19	0.00001	0	0.00001	0.000024101	12134005
20	0.00001	0	0.00001	0.000023953	13590074
21	0.00001	0	0.00001	0.000025154	11136165
22	0.00001	0	0.00001	0.000024486	11850585
23	0.00001	0	0.00001	0.000024181	12540971
24	0.00002	0	0.00002	0.000024614	11848952
25	0.00001	0	0.00001	0.000023602	11590172
26	0.00001	0	0.00001	0.000023681	11483181
27	0.00002	0	0.00002	0.000024607	12094297
28	0.00001	0	0.00001	0.000023894	12056655
29	0.00002	0	0.00002	0.000027302	11883684
30	0.00001	0	0.00001	0.000024867	12674120
31	0.00001	0	0.00001	0.000023582	13624607

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the maximum range error, range rate error and range acceleration error for all satellites. The highest maximum range error occurred on satellite 18 with an error of 310.264 meters. Satellite 4 had the lowest maximum range error of 8.760 meters.

Figure 5-4 Distribution of Daily Max Range Errors

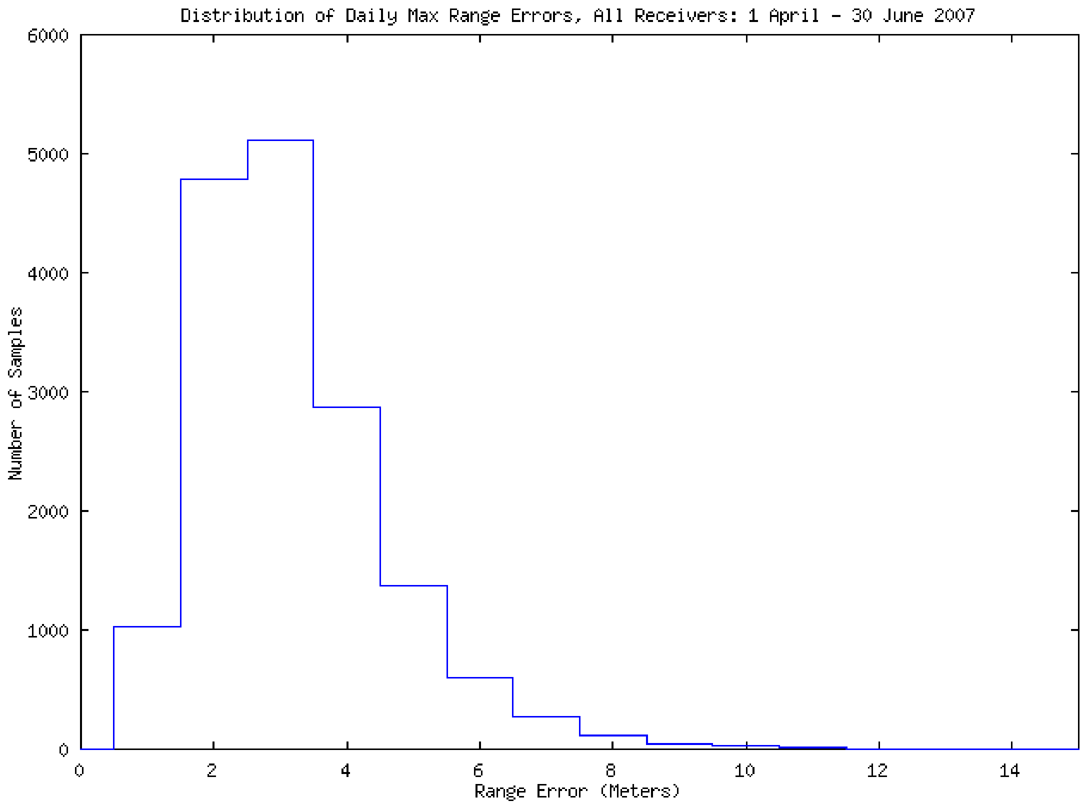


Figure 5-5: Distribution of Daily Max Range Rate Errors

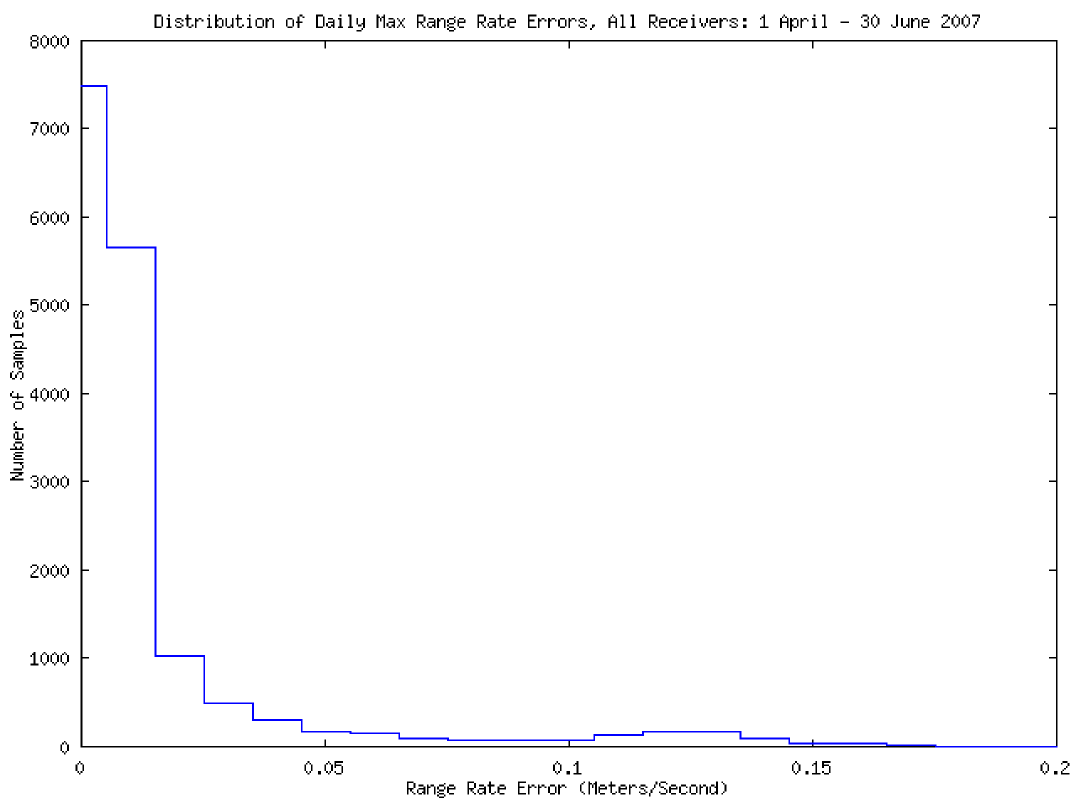


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

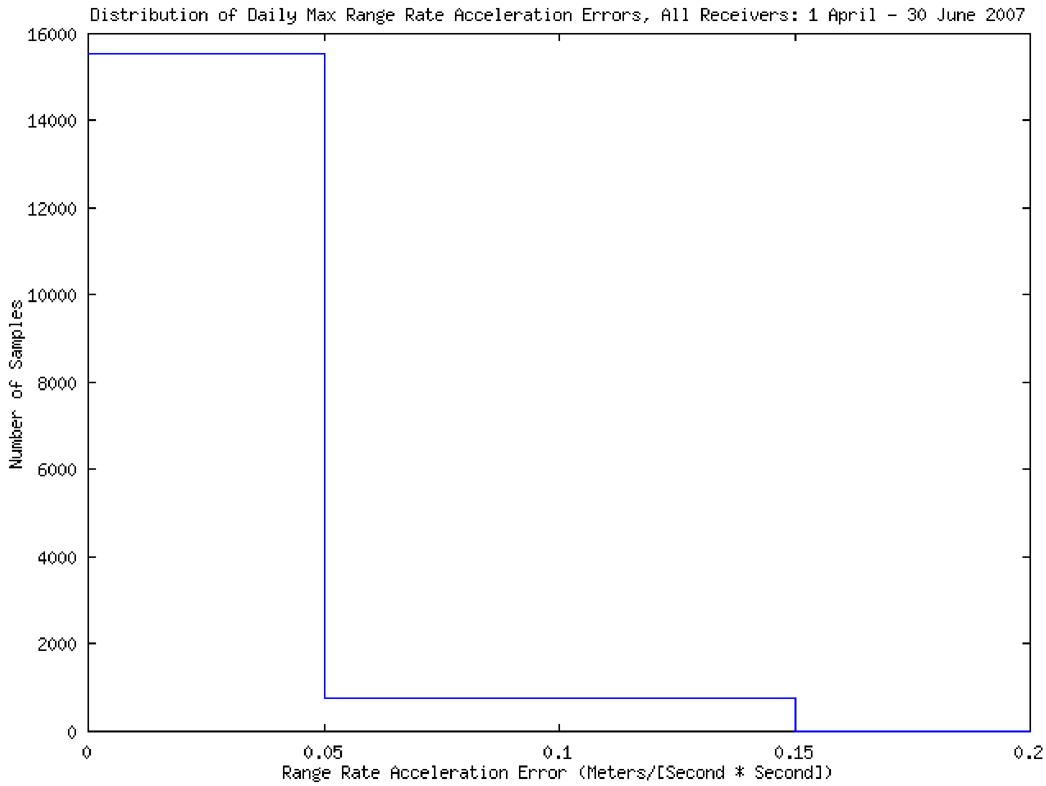


Figure 5-7: Range Error Histogram

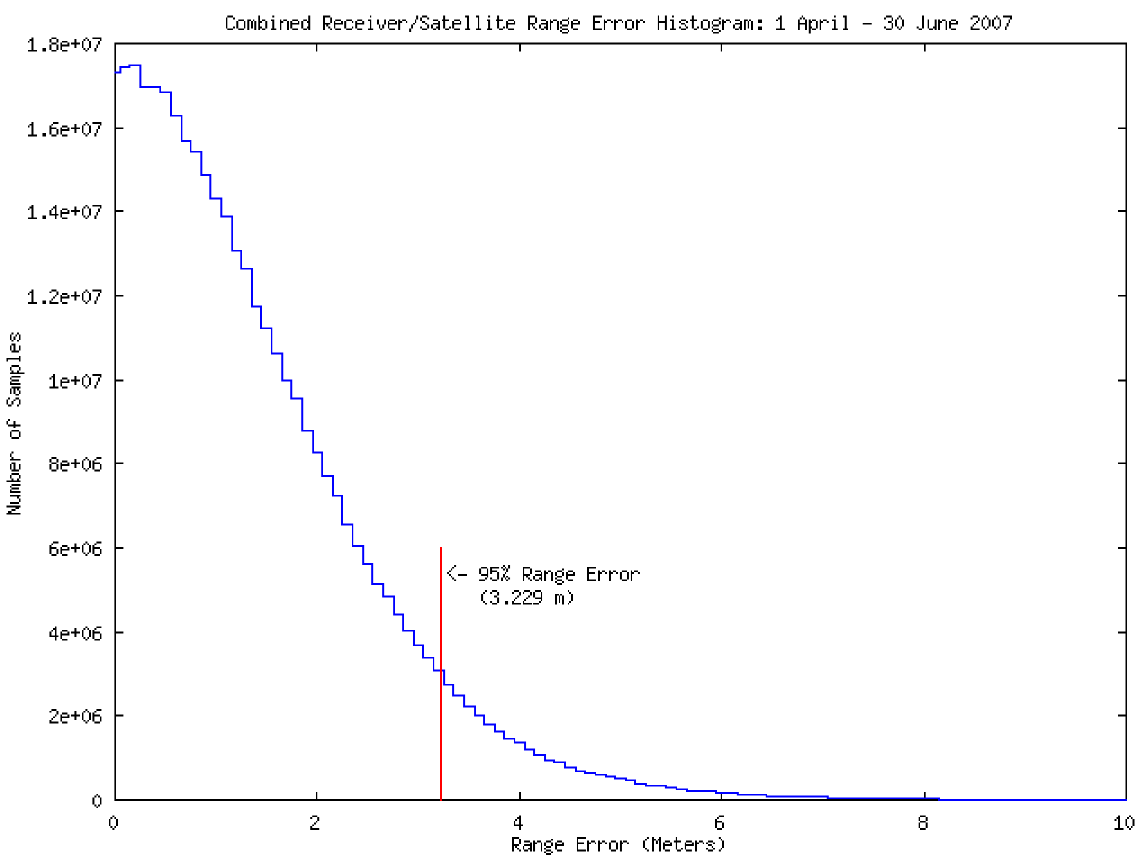


Figure 5-8: Maximum Range Error Per Satellite

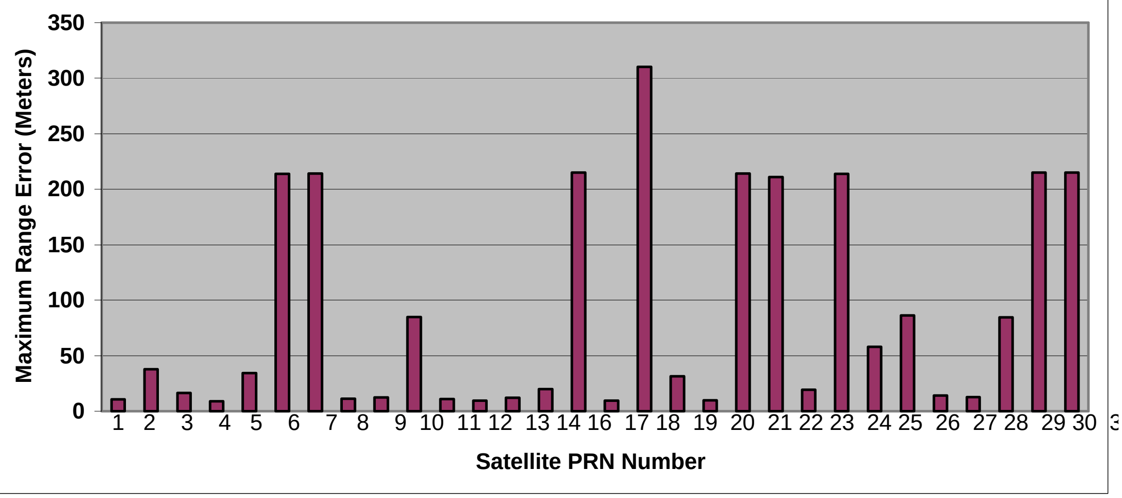


Figure 5-9: Maximum Range Rate Error Per Satellite

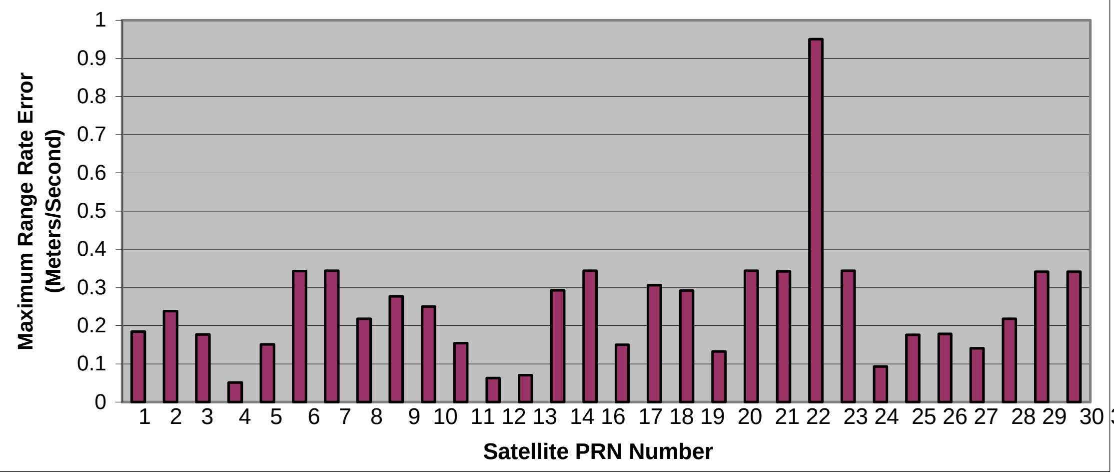
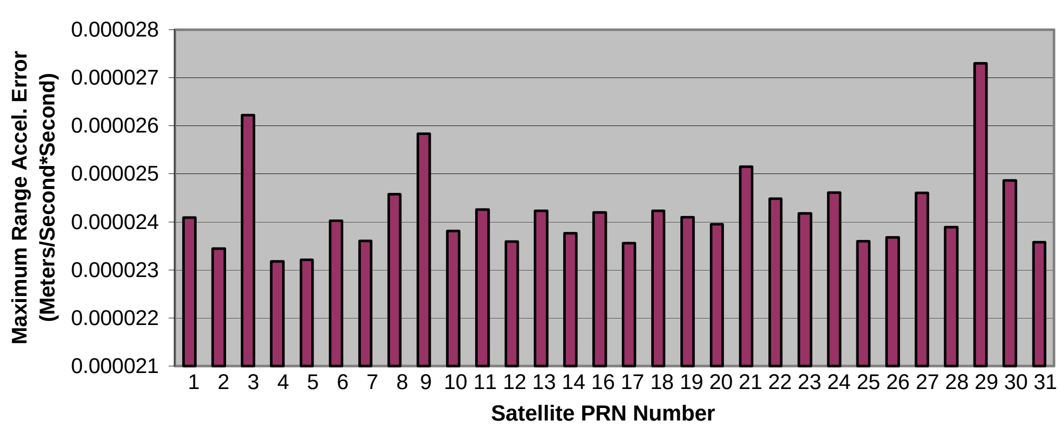


Figure 5-10: Maximum Range Acceleration Per Satellite



6.0 Solar Storms

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

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

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

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

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

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

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

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

Figure 6-1 K-Index for 23-25 May 2007

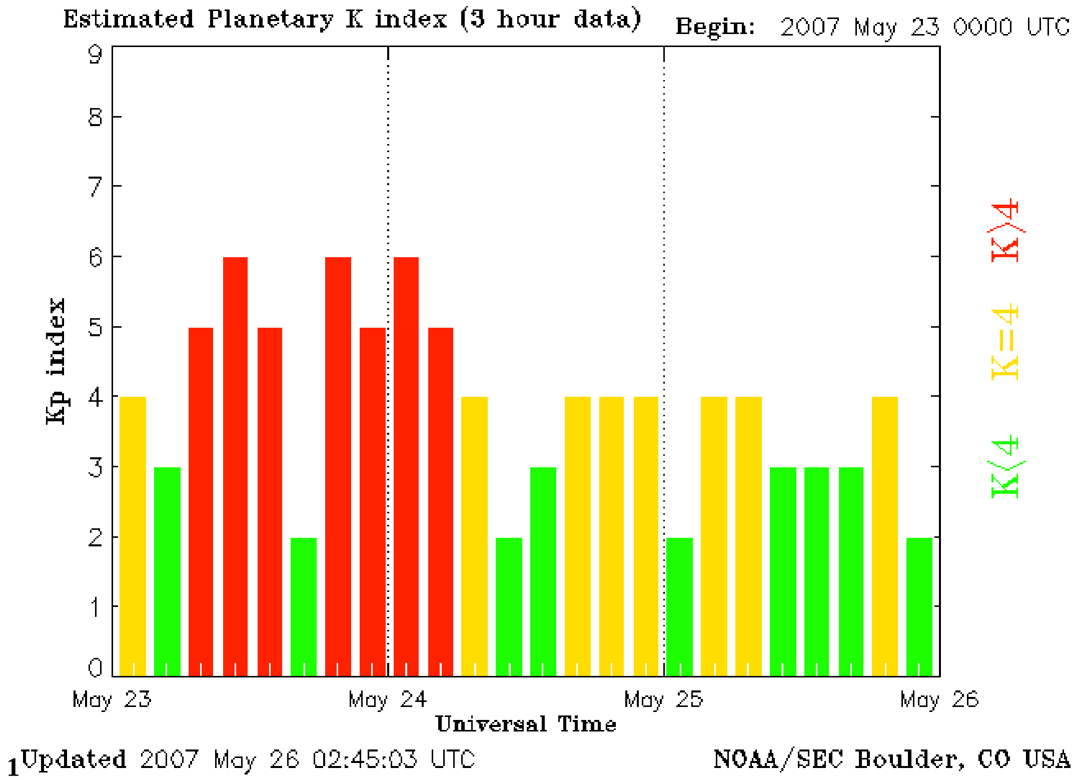


Figure 6-2 K-Index for 26-30 April 2007

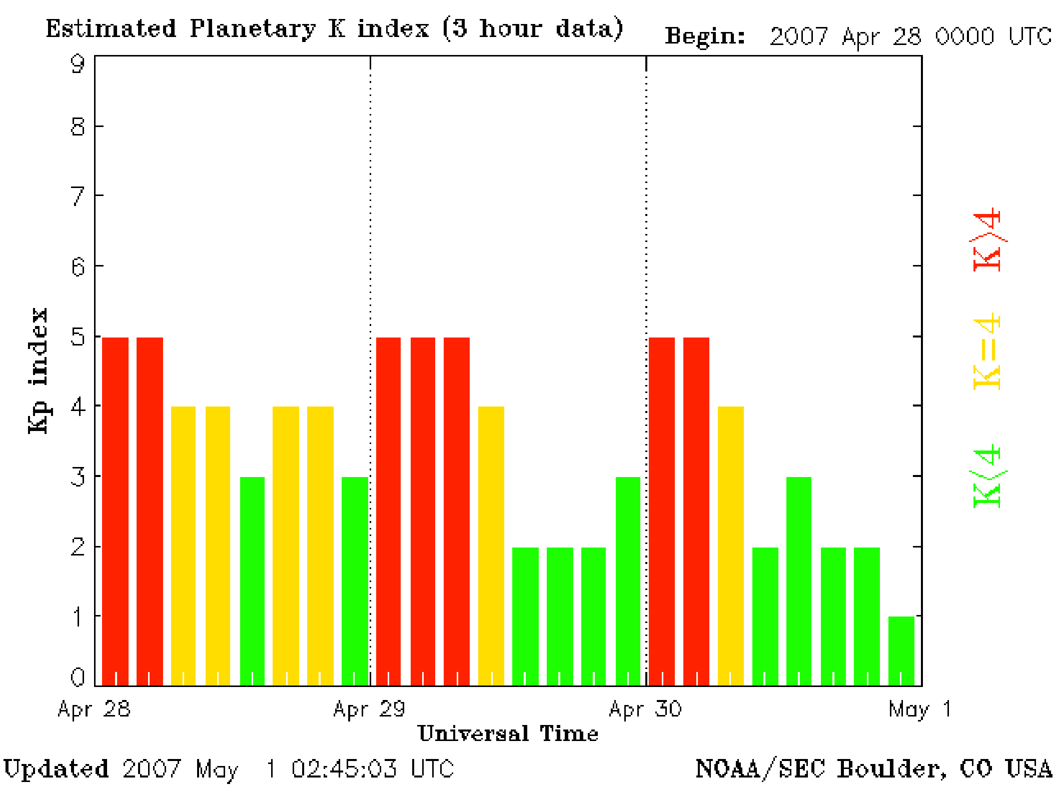
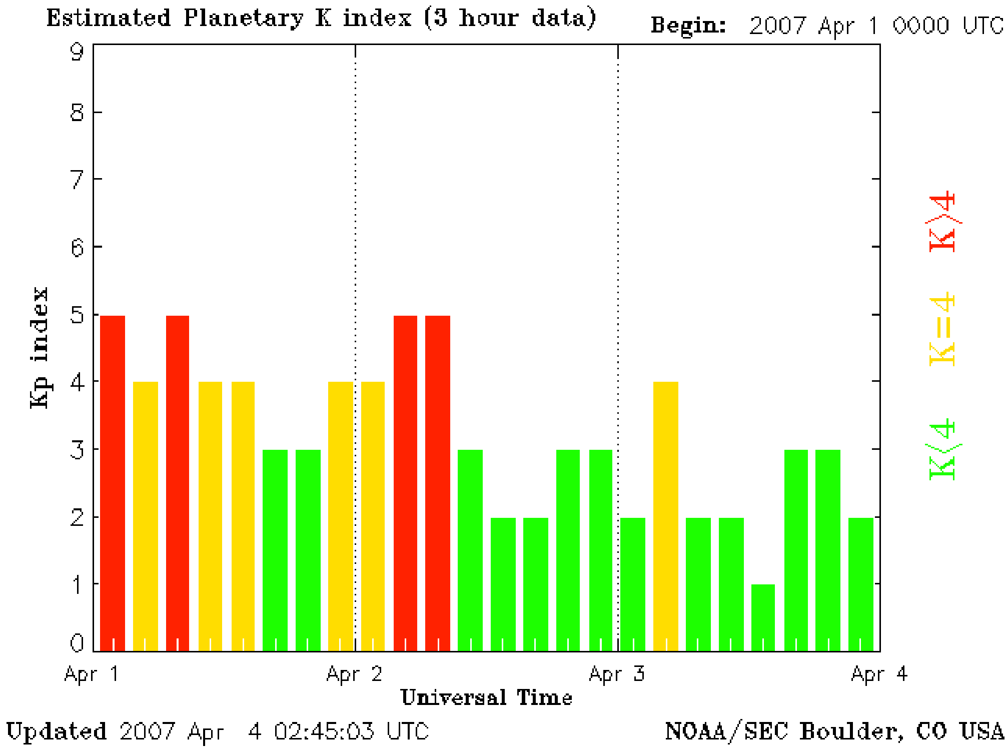


Figure 6-3 K-Index for 1-3 April 2007



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

Table 6-1 Horizontal & Vertical Accuracy Statistics for 29 January 2007

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Billings	2.223	3.1.93	3.871	5.048
Albuquerque	2.094	3.645	2.893	5.133
Anchorage	1.626	2.920	2.974	4.784
Boston	3.018	4.352	6.851	7.620
Washington, DC	3.619	3.928	5.413	8.873
Honolulu	2.791	4.055	3.234	6.036
Houston	2.729	3.493	4.118	4.270
Kansas City	2.254	3.436	3.705	5.177
Los Angeles	1.934	4.568	2.940	6.634
Salt Lake City	2.187	4.349	2.664	5.590
Miami	2.741	4.129	3.442	5.464
Minneapolis	2.464	3.145	4.791	7.014
Oakland	2.286	5.160	3.099	5.867
Cleveland	2.304	3.919	5.511	7.825
Seattle	2.236	3.674	3.877	4.683
San Juan	3.326	4.390	4.136	8.806
Atlanta	3.145	3.497	3.969	6.174
Juneau	1.581	2.609	3.408	3.470
Cold Bay	2.404	3.463	3.094	5.364
Fairbanks	1.935	3.250	3.593	5.206
Bethel	1.895	3.254	2.691	5.262
Kotzebue	1.882	3.321	3.274	6.030

APPENDICES A – D

Conditions and Constraints	***PDOP Availability Standard***	***Measured Performance***
• Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. • Based on using only satellites transmitting standard code and indicating "health" in the broadcast navigation message (sub-frame 1).	≥ 98% global Position Dilution of Precision (PDOP) of 6 or less ≥ 88% worst site PDOP of 6 or less	≥ 99.997% ≥ 99.514%
Conditions and Constraints	***Service Availability Standard***	***Measured Performance***
• 36 meter horizontal (SIS only) 95% threshold. • 77 meter vertical (SIS only) 95% threshold. • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	100%
• Based on using only satellites transmitting standard code and indicating "healthy" in the broadcast navigation message (sub-frame 1).	≥ 95.87% global average on worst-case day	100%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	≥ 99.94% global average	99.989%
• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values from the worst-case point within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	≥ 99.79% single point average	≥ 99.961%

Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	Global Average Positioning Domain Accuracy • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only)	2.316 m 4.407 m
• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours for any point within the service volume.	Worst Site Positioning Domain Accuracy • ≤ 36 meters 95% All-in-View Horiz Error (SIS only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS only)	3.547 m 4.914 m
• Defined for time transfer solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	Time Transfer Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	10 nanoseconds 95%
• Average of the constellation's individual satellite SPS SIS RMS URE values over any 24-hours interval, for any point in the service volume.	≤ 6 meters RMS SIS SPS URE across the entire constellation	1.755 meters

```
#  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
#
```

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2007 04 01	17	3 3 4 3 3 2 3 4	40	4 4 6 5 6 4 3 3	30	5 4 5 4 4 3 3 4
2007 04 02	16	3 4 3 2 2 4 3 3	39	3 5 6 6 5 3 3 2	24	4 5 5 3 2 2 3 3
2007 04 03	10	3 3 2 2 2 3 1 2	16	3 2 4 4 1 4 3 2	11	2 4 2 2 1 3 3 2
2007 04 04	6	2 3 2 1 2 0 2 1	13	3 3 3 4 3 2 1 1	8	3 3 2 2 1 1 1 2
2007 04 05	3	1 1 1 0 1 1 1 1	4	1 1 2 0 1 2 0 2	4	1 1 2 1 1 1 0 2
2007 04 06	2	1 2 1 0 0 1 1 0	3	1 1 3 1 0 0 0 0	4	1 2 1 1 0 1 1 1
2007 04 07	2	2 1 0 0 1 1 0 0	2	2 1 0 0 1 0 0 0	3	3 1 0 0 0 0 0 1
2007 04 08	2	0 0 0 1 1 1 0 2	2	0 0 0 1 0 0 0 1	3	0 0 0 0 0 0 0 3
2007 04 09	8	3 3 3 2 1 1 1 1	11	3 3 3 4 3 0 0 1	9	4 3 3 1 1 0 1 1
2007 04 10	6	2 0 0 2 3 2 1 2	6	1 0 0 3 3 2 2 1	7	2 0 0 1 2 3 2 3
2007 04 11	3	1 2 1 1 0 0 1 1	2	1 1 1 0 0 0 0 1	4	2 2 1 0 0 1 0 1
2007 04 12	7	2 2 1 2 3 2 1 1	15	2 2 1 5 5 2 1 0	8	2 2 1 3 3 2 2 1
2007 04 13	1	0 0 1 1 0 0 0 0	0	1 0 0 0 0 0 0 0	2	1 0 1 0 0 0 0 1
2007 04 14	3	0 1 1 0 2 1 0 2	2	0 1 1 0 0 1 0 1	4	0 1 0 0 1 2 1 3
2007 04 15	2	1 1 1 1 1 1 0 0	4	1 2 2 2 1 1 1 0	4	2 2 1 1 1 1 0 0
2007 04 16	0	0 0 0 0 0 0 0 0	0	0 0 0 0 0 0 0 0	1	0 0 0 0 0 0 0 1
2007 04 17	6	0 2 2 2 2 1 1 3	-1	0 1 1 4-1 3 3 1	8	1 1 1 2 2 2 3 3
2007 04 18	6	3 2 1 1 1 1 2 2	5	2 2 2 1 1 1 1 2	9	4 3 1 1 1 1 2 3
2007 04 19	4	2 2 2 1 1 0 1 0	8	2 1 3 4 2 1 1 0	6	3 2 2 1 1 0 0 1
2007 04 20	2	1 1 1 0 0 0 0 1	2	1 1 1 0 0 0 0 1	3	1 1 1 1 1 0 0 2
2007 04 21	2	1 1 0 0 1 0 1 1	0	1 0 0 0 0 0 0 0	2	1 1 0 0 0 1 1 1
2007 04 22	8	2 2 1 2 2 1 3 3	10	2 2 1 4 3 3 1 1	10	2 2 2 2 2 3 3 3
2007 04 23	10	3 4 4 1 1 1 0 0	11	4 4 4 1 0 2 0 0	18	4 5 4 1 1 2 1 1
2007 04 24	5	1 1 0 0 1 3 2 2	3	2 1 1 1 0 1 1 1	4	2 1 1 0 1 2 2 2
2007 04 25	4	2 2 1 1 2 1 1 0	3	2 1 0 0 1 2 2 0	5	3 1 0 0 2 2 1 1
2007 04 26	4	2 0 0 0 1 3 2 1	3	2 0 0 2 1 1 1 1	6	2 0 0 0 2 3 2 2
2007 04 27	10	2 2 2 2 3 3 2 3	14	1 1 1 4 4 3 2 4	16	3 1 1 3 2 4 4 4
2007 04 28	20	4 4 4 3 3 3 3 3	43	4 4 5 7 5 4 3 3	26	5 5 4 4 3 4 4 3
2007 04 29	16	5 3 3 3 2 1 2 3	20	3 4 4 5 3 3 2 2	23	5 5 5 4 2 2 2 3
2007 04 30	13	4 4 4 2 1 2 1 1	28	4 5 5 5 2 3 2 2	20	5 5 4 2 3 2 2 1
2007 05 01	5	2 2 3 0 1 1 1 1	9	1 2 5 1 2 1 0 1	8	3 3 3 1 1 2 2 2
2007 05 02	1	1 0 0 0 0 1 0 1	1	1 1 0 0 0 0 0 0	3	1 1 0 0 0 1 0 1
2007 05 03	2	0 1 1 1 1 1 1 1	3	0 0 2 1 1 1 1 1	4	1 0 2 1 1 1 2 1
2007 05 04	1	0 0 0 1 1 1 1 0	2	1 0 0 1 0 0 0 2	2	1 0 0 1 0 0 1 0
2007 05 05	0	0 0 0 0 0 0 0 0	1	0 0 1 1 0 0 0 1	3	1 0 1 1 0 0 0 1
2007 05 06	0	0 0 0 0 0 0 0 1	0	0 0 0 0 0 0 0 1	2	1 0 0 0 0 1 1 1
2007 05 07	11	1 0 3 2 3 3 3 3	23	1 1 3 4 3 6 3 4	18	1 1 3 2 3 5 4 4
2007 05 08	11	2 4 3 2 3 1 2 2	24	3 4 5 5 4 3 2 1	14	2 4 4 2 2 2 3 3
2007 05 09	3	1 1 1 1 1 1 1 1	10	2 3 3 4 2 1 1 1	5	1 2 2 1 1 1 1 1
2007 05 10	2	1 0 0 0 0 1 2 1	2	1 1 0 1 0 1 1 1	3	1 0 0 0 1 1 1 2
2007 05 11	2	0 0 0 0 1 1 1 1	2	0 1 0 0 0 0 2 1	2	0 0 0 0 1 1 1 1
2007 05 12	2	0 2 0 1 1 1 0 0	2	2 1 0 1 0 0 0 1	3	1 1 0 0 0 0 0 1
2007 05 13	2	0 2 1 0 1 0 0 0	2	1 1 1 0 0 0 0 1	3	1 2 1 0 1 0 1 1
2007 05 14	1	0 0 0 0 1 1 1 0	2	0 0 1 1 0 0 0 2	3	0 0 0 0 1 1 2 1
2007 05 15	4	1 1 1 1 2 1 2 1	5	0 2 2 2 3 1 0 0	6	1 1 1 1 2 2 2 2
2007 05 16	3	1 1 1 1 1 0 1 1	2	0 1 1 0 0 0 1 1	4	1 1 1 1 1 1 1 2
2007 05 17	4	2 1 0 0 1 1 2 2	3	0 1 1 1 2 0 1 2	6	1 2 1 1 1 1 2 3
2007 05 18	15	2 2 4 4 4 2 2 2	22	2 1 5 5 4 4 2 2	18	3 2 4 4 4 3 3 3
2007 05 19	10	2 2 3 2 3 2 3 2	16	3 3 3 5 3 2 2 1	12	2 3 3 2 2 3 3 3
2007 05 20	6	3 2 1 1 1 1 2 2	5	2 2 1 3 1 0 1 1	6	3 2 1 1 1 1 1 2
2007 05 21	6	3 1 0 0 1 1 2 3	3	2 1 0 0 0 1 1 2	6	3 1 0 0 1 1 2 3
2007 05 22	10	1 2 2 2 3 2 3 3	15	1 1 1 5 4 2 3 3	11	1 2 1 2 2 3 4 3
2007 05 23	28	4 4 4 5 3 2 5 4	51	4 3 6 7 6 3 4 4	42	4 3 5 6 5 2 6 5
2007 05 24	21	5 4 4 2 3 3 3 3	35	5 4 5 3 5 5 3 4	28	6 5 4 2 3 4 4 4
2007 05 25	9	1 2 3 2 2 2 3 2	31	2 3 5 6 4 5 3 2	16	2 4 4 3 3 3 4 2
2007 05 26	10	3 3 2 2 3 2 2 2	32	3 4 5 5 6 4 2 2	16	4 4 3 3 3 3 3 2
2007 05 27	10	2 3 3 3 2 2 2 2	17	3 3 3 5 3 3 2 2	12	3 3 3 3 2 2 2 2
2007 05 28	5	3 2 1 1 1 0 1 1	4	3 2 2 1 0 0 0 0	5	3 2 1 1 1 0 0 1

2007 05 29	5	1	1	2	1	1	2	1	2	3	1	1	1	1	2	1	0	0	4	1	1	1	0	1	2	1	1
2007 05 30	3	2	1	1	1	1	1	0	0	2	1	1	1	0	0	0	1	0	4	2	1	1	0	1	1	1	1
2007 05 31	2	1	0	0	0	1	1	1	2	1	1	0	0	0	0	0	0	2	4	1	0	0	0	1	1	1	3
2007 06 01	5	2	1	1	1	1	2	2	2	5	2	2	1	2	1	1	1	1	6	2	2	1	1	1	2	2	2
2007 06 02	5	2	2	2	1	1	1	1	2	4	2	2	2	0	0	1	1	1	7	2	2	2	1	1	2	1	2
2007 06 03	7	1	1	1	1	2	2	3	3	6	2	1	1	0	1	2	3	2	10	2	2	1	1	1	3	4	3
2007 06 04	8	3	3	1	1	2	2	2	1	5	2	3	1	1	1	1	2	0	8	3	3	1	1	2	3	2	2
2007 06 05	2	0	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	3	1	0	0	0	1	1	0	1
2007 06 06	2	0	1	0	0	2	1	0	1	0	0	1	0	0	0	0	0	0	2	0	0	0	0	1	1	0	1
2007 06 07	1	0	0	0	1	1	0	0	1	2	1	1	0	0	0	1	1	1	3	1	0	0	0	1	1	2	1
2007 06 08	7	3	2	2	0	2	2	2	1	6	2	3	2	0	1	2	2	1	8	3	3	1	1	2	2	2	2
2007 06 09	5	1	1	2	2	2	1	1	2	12	1	2	3	4	4	2	1	1	8	1	1	2	2	3	1	2	2
2007 06 10	6	3	1	3	1	1	0	1	1	9	3	2	4	3	1	1	1	0	8	3	2	3	2	1	1	2	1
2007 06 11	1	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2	1	0	0	0	0	1	1	1
2007 06 12	3	1	1	0	0	1	0	1	1	2	0	1	1	0	0	0	1	0	4	1	1	1	0	1	1	1	2
2007 06 13	5	1	0	1	0	2	2	3	2	-1	1	0	0	3	1	-1	-1	1	5	1	0	1	1	1	2	2	2
2007 06 14	13	2	3	3	3	3	2	3	3	27	3	4	3	6	4	4	3	2	20	3	4	3	4	2	4	4	3
2007 06 15	7	2	3	2	1	2	1	1	2	9	2	3	2	3	3	2	1	1	8	2	3	2	1	2	2	1	2
2007 06 16	4	1	1	0	1	2	1	2	1	9	2	2	1	2	4	2	2	1	7	3	2	1	1	3	2	2	1
2007 06 17	3	1	1	1	1	2	1	1	0	9	2	2	1	3	4	1	1	1	6	1	1	1	1	2	2	1	1
2007 06 18	5	1	1	2	1	1	2	2	2	3	0	1	1	1	1	1	1	1	5	1	1	1	2	1	2	2	2
2007 06 19	5	2	2	2	1	2	1	0	1	4	1	1	2	2	1	2	1	0	7	2	3	2	2	1	2	1	1
2007 06 20	2	1	0	0	0	1	1	1	1	2	1	1	0	2	0	0	0	0	4	1	1	0	1	1	2	1	1
2007 06 21	8	0	1	1	2	3	2	3	3	11	1	1	2	2	4	4	2	2	14	1	2	3	3	3	3	3	4
2007 06 22	12	4	2	3	2	2	1	3	3	25	4	3	5	6	3	1	2	2	16	4	3	4	4	2	2	3	3
2007 06 23	8	3	2	3	1	1	1	2	2	14	3	4	5	2	1	1	1	2	11	3	3	3	1	1	2	3	2
2007 06 24	4	2	1	1	1	1	1	2	1	5	2	1	1	3	2	1	1	1	6	3	2	1	1	2	1	2	2
2007 06 25	3	2	1	0	0	1	1	1	1	2	2	1	0	0	1	1	0	1	5	2	1	0	0	2	2	2	2
2007 06 26	4	0	0	0	2	1	1	3	1	3	0	1	0	2	2	0	1	0	5	1	0	0	2	3	1	2	2
2007 06 27	5	2	2	2	1	1	1	1	1	4	2	2	2	0	0	1	1	1	5	2	2	2	0	1	1	2	2
2007 06 28	5	2	0	1	1	1	1	1	3	5	1	1	1	2	3	1	1	1	6	1	1	1	1	2	1	2	3
2007 06 29	5	1	1	1	1	1	1	3	2	6	1	2	1	1	1	1	3	2	13	2	1	2	1	3	2	5	3
2007 06 30	4	2	2	1	1	2	1	0	1	3	2	2	2	1	0	0	1	0	6	3	2	1	1	1	1	1	1

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:

On Tuesday, April 10, 2007 GPS satellite PRN18 suffered a maintenance anomaly. According to the forecast NANU issued on April 6 the satellite was supposed to be set unhealthy for scheduled maintenance some time between 13:30 GMT on April 10 to 1:30 GMT on April 11. This equates to a total forecast maintenance time of 12 hours. At approximately 15:53 GMT on April 10, maintenance was initiated on the satellite; however the satellite health bit was erroneously not set 'unhealthy' prior to the maintenance. This resulted in severe range errors at all sites tracking the satellite between 15:53 and 17:04 GMT when PRN18 was finally set to unhealthy. Both the forecast and summary NANU's are listed below for reference.

```
NOTICE ADVISORY TO NAVSTAR USERS (NANU) 2007053
SUBJ: SVN54 (PRN18) FORECAST OUTAGE JDAY 100/1330 - JDAY 101/0130
1.      NANU TYPE: FCSTDV
        NANU NUMBER: 2007053
        NANU DTG: 061804Z APR 2007
        REFERENCE NANU: N/A
        REF NANU DTG: N/A
        SVN: 54
        PRN: 18
        START JDAY: 100
        START TIME ZULU: 1330
        START CALENDAR DATE: 10 APR 2007
        STOP JDAY: 101
        STOP TIME ZULU: 0130
        STOP CALENDAR DATE: 11 APR 2007

2.  CONDITION: GPS SATELLITE SVN54 (PRN18) WILL BE UNUSABLE ON JDAY 100
    (10 APR 2007) BEGINNING 1330 ZULU UNTIL JDAY 101 (11 APR 2007) ENDING 0130 ZULU.

NOTICE ADVISORY TO NAVSTAR USERS (NANU) 2007057
SUBJ: SVN54 (PRN18) FORECAST OUTAGE SUMMARY JDAY 100/1704 – JDAY 100/2124
1.      NANU TYPE: FCSTSUMM
        NANU NUMBER: 2007057
        NANU DTG: 102139Z APR 2007
        REFERENCE NANU: 2007053
        REF NANU DTG: 061804Z APR 2007
        SVN: 54
        PRN: 18
        START JDAY: 100
        START TIME ZULU: 1704
        START CALENDAR DATE: 10 APR 2007
        STOP JDAY: 100
```

```
    STOP TIME ZULU: 2124
    STOP CALENDAR DATE: 10 APR 2007

2.  CONDITION: GPS SATELLITE SVN54 (PRN18) WAS UNUSABLE ON JDAY 100
    (10 APR 2007) BEGINNING 1704 ZULU UNTIL JDAY 100 (10 APR 2007) ENDING 2124 ZULU.
```

Attached are three figures showing various performance of SPS and WAAS systems. Figure 1 below, shows SPS position performance for three sites during the time PRN18 maintenance was performed while still set to healthy. The red trace shows PRN18 SPS range error measured at Honolulu, HI. The purple, blue and aqua traces show SPS 3D position error at three locations. The green trace shows PRN18 satellite health status; a value of 100 means the satellite is healthy, while a value of zero represents an unhealthy status. This shows how the skewing range error of PRN18 affected those sites tracking it. The sites affected were not limited to these three; however we have limited the total number shown for easier interpretation of the plots.

Figure 1

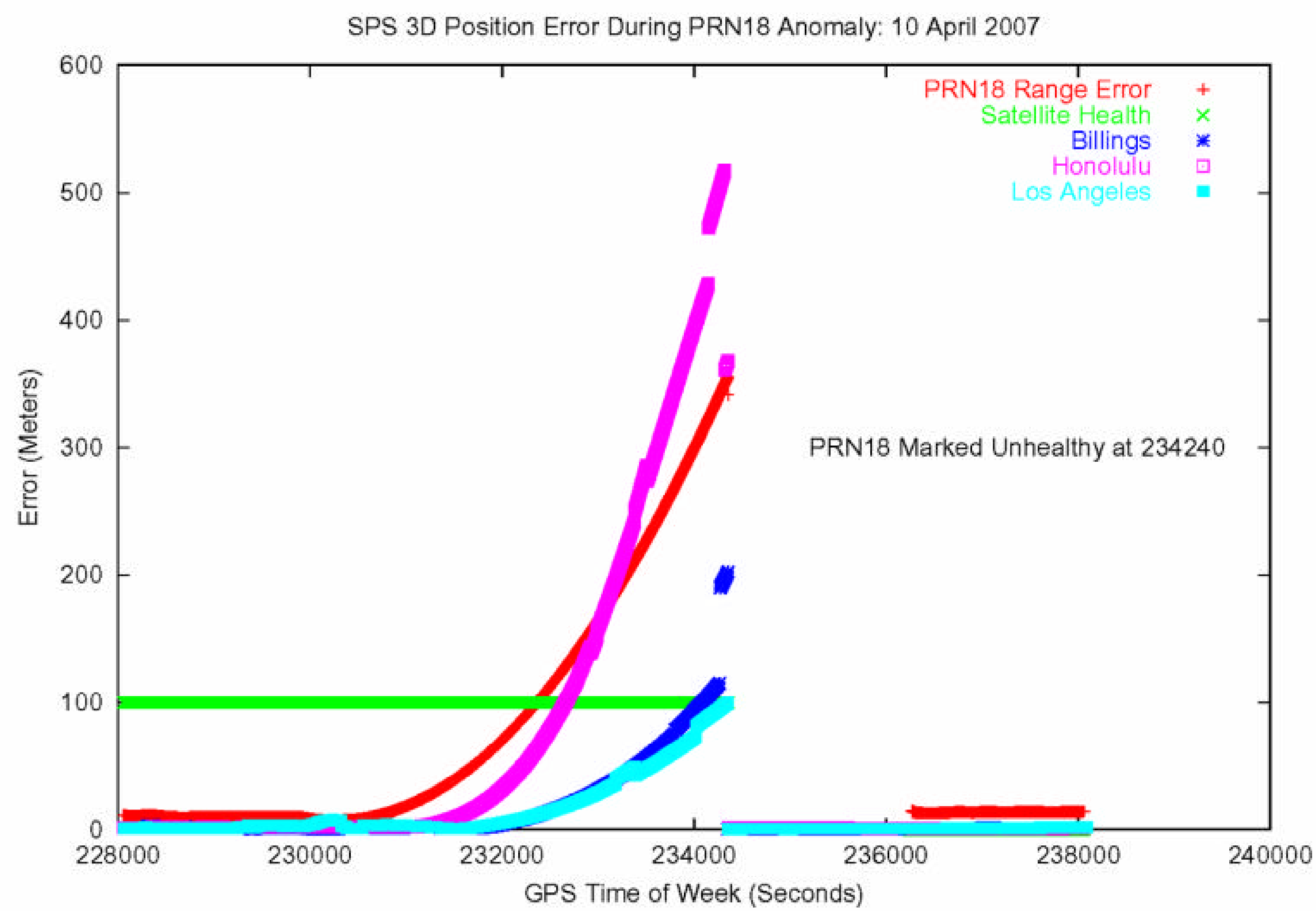


Figure 2 shows WAAS NPA position error performance for the affected time. The purple trace shows WAAS satellite status for PRN18. A value of 3 equates to SPS mode, 6 to NPA, and 9 to PA mode. The green, red and blue traces show NPA 3D position error at the three sites used for this report. As you can see, WAAS successfully managed the satellite error. It correctly compensated for errors early on in the failure, occasionally placing the satellite in NPA mode. As the errors grew however, WAAS maintained the satellite in SPS mode, essentially throwing it out of the WAAS solution. The slightly increased error during the anomaly, especially at Honolulu, is due to the increased DOPS incurred from omitting satellite 18 from the solution.

Figure 2

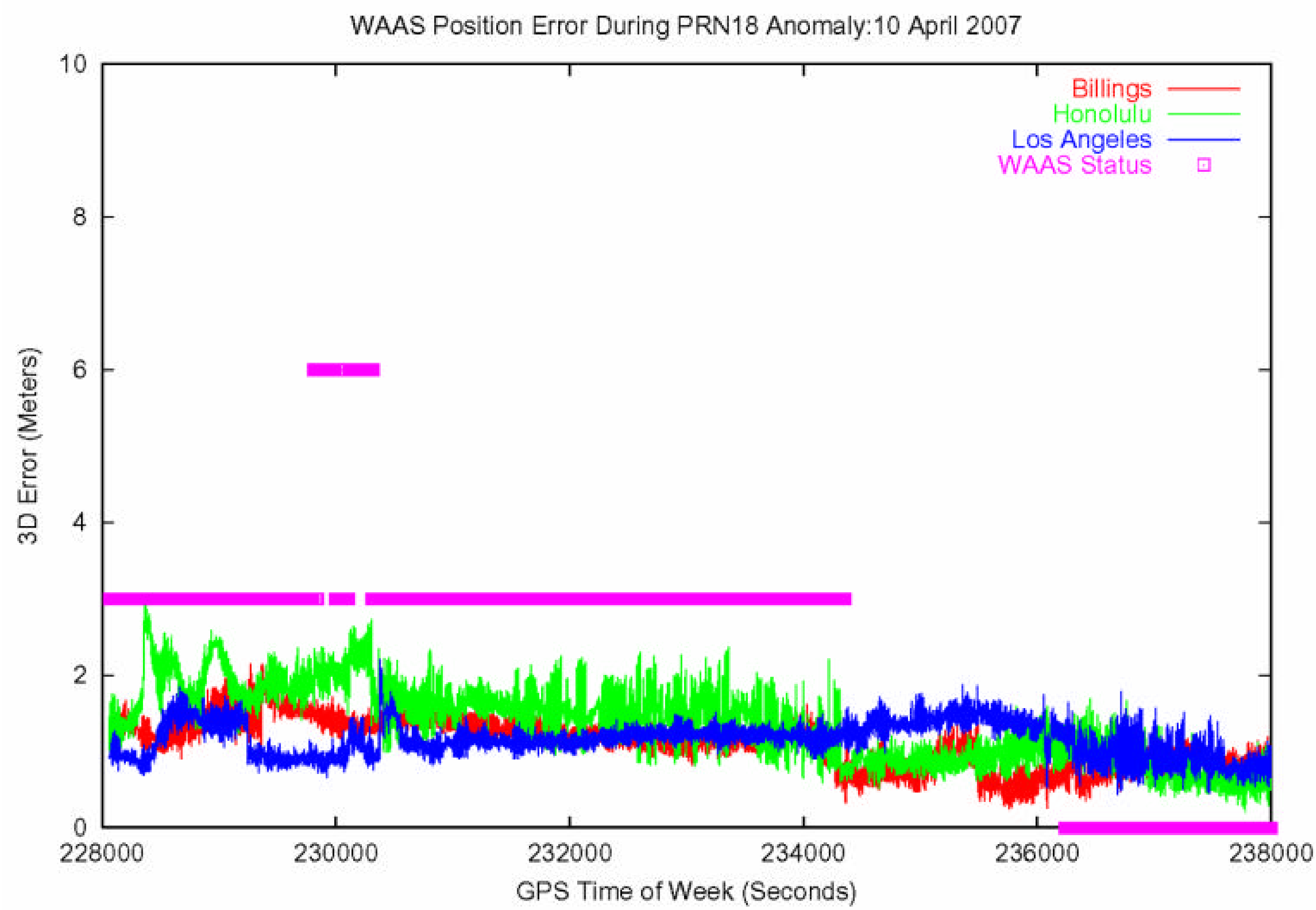


Figure 3 shows more detail into how WAAS compensated for the anomalous errors measured on PRN18 at the Billings, Montana WRS. The green trace in this figure once again shows the range error measure on PRN18. The red trace shows the corrections applied by the WAAS system in order to correct for the satellite's error. The blue trace in this plot shows the system status of PRN18. A value of 100 equates to SPS range status while a value of zero means the satellite was set to "Do Not Use."

Figure 3

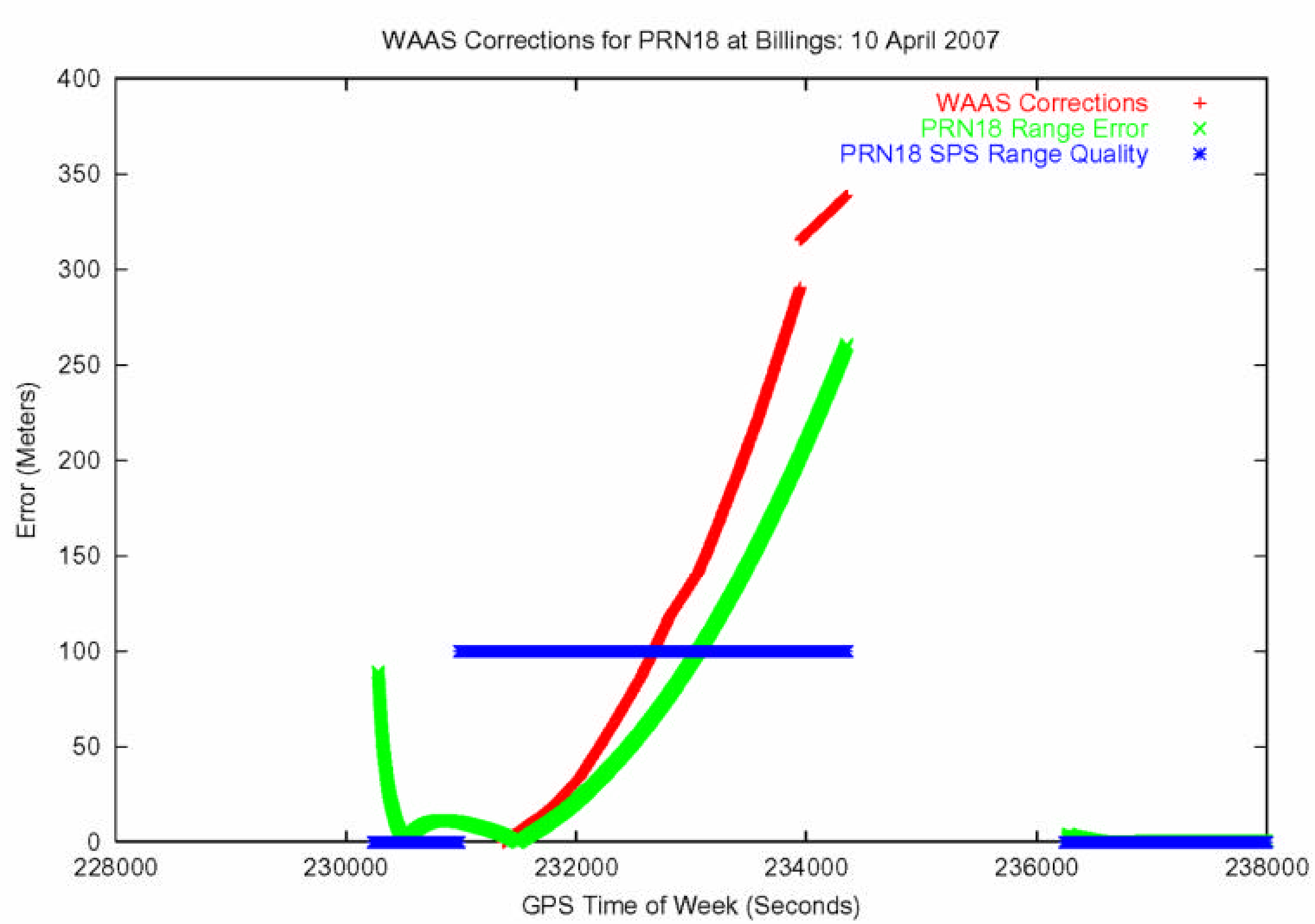


Table 1 below shows the SPS position statistics for all sites covered in the SPS quarterly report. Boston and San Juan avoided any errors incurred by PRN18 since the satellite was set to unhealthy by the time those two receivers tracked the satellite. None of the sites failed the SPS specification for position. The spec requires the 24-hour global 95% error values (all sites combined) to be less than or equal to 13 meters in the horizontal and 22 meters in the vertical. It also calls for the 24-hour 95% error values for any one site to be less than or equal to 36 meters in the horizontal and 77 meters in the vertical.

Table 1 – SPS Position Errors

Site	Vertical Error Mean (Meters)	Vertical Error RMS (Meters)	Vertical Error Std Dev (Meters)	Vertical Error 95% (Meters)	Vertical Error 99.99% (Meters)	Horizontal Error Mean (Meters)	Horizontal Error RMS (Meters)	Horizontal Error Std Dev (Meters)	Horizontal Error 95% (Meters)	Horizontal Error 99.99% (Meters)
Bethel	4.265	14.728	14.098	5.226	158.402	2.225	10.091	9.843	2.027	118.392
Billings	3.672	9.335	8.583	5.342	172.069	1.778	6.644	6.402	2.042	105.491
Cold Bay	4.499	13.145	12.351	6.054	160.343	2.524	12.259	11.998	2.207	163.268
Fairbanks	3.793	12.169	11.563	4.669	129.173	1.934	7.339	7.079	2.001	84.333
Juneau	3.88	12.401	11.778	4.853	160.716	2.05	8.437	8.185	2.185	104.116
Kotzebue	3.534	12.417	11.904	5.069	150.739	1.753	6.83	6.601	1.961	82.805
Albuquerque	3.438	6.837	5.91	6.257	84.736	1.902	7.382	7.134	2.262	93.713
Anchorage	4.421	14.228	13.525	5.633	136.026	2.169	9.129	8.868	2.077	105.387
Boston	2.486	2.916	1.523	5.331	9.417	1.287	1.773	1.22	2.548	11.095
Washington, DC	3.806	9.242	8.422	6.285	103.722	1.706	4.145	3.778	2.826	46.977
Honolulu	7.163	41.203	40.583	5.031	499.457	3.518	12.506	12.001	4.713	125.514
Houston	3.472	6.525	5.525	7.477	70.581	1.622	4.651	4.359	3.143	57.473
Kansas City	3.769	8.181	7.261	5.746	84.597	1.705	5.081	4.787	2.951	60.489
Los Angeles	3.153	3.763	2.053	7.006	13.437	2.199	8.413	8.12	2.015	99.04
Salt Lake City	3.495	7.708	6.87	6.479	89.101	1.79	7.554	7.34	1.901	95.027
Miami	3.012	5.443	4.534	6.367	60.553	1.552	2.808	2.34	3.015	34.838
Minneapolis	3.753	10.145	9.426	5.209	127.283	1.712	5.257	4.97	3.105	65.078
Oakland	3.162	3.979	2.415	7.321	35.087	2.039	8.691	8.449	2.089	101.672
Cleveland	3.966	10.268	9.471	5.661	122.037	1.748	4.466	4.109	3.402	47.596
Seattle	3.815	8.418	7.504	6.536	93.267	2.107	8.233	7.959	2.092	100.047
San Juan	2.299	2.979	1.895	6.626	10.825	1.465	1.835	1.105	2.648	9.648
Atlanta	4.047	9.228	8.293	6.816	95.408	1.679	3.856	3.471	2.69	42.287
Global				5.994					2.623	

Table 2 below shows the SPS range error statistics for the six sites evaluated in the SPS quarterly report. The range errors observed at Boston and San Juan were normal, but the other sites were affected by the maneuver on PRN 18.

Table 2 – SPS Range Errors

Site	Mean	RMS	StdDev	95%	Max	Samples
Boston	2.269	2.299	0.368	2.74	2.886	8463
Honolulu	-107.733	188.25	154.387	461.053	556.379	5857
Los Angeles	-43.44	83.564	71.391	210.755	248.04	6318
Miami	-17.354	54.999	52.192	161.417	223.395	11085
San Juan	1.503	2.29	1.728	5.049	6.167	12380
Juneau	-14.072	44.757	42.49	134.704	182.405	7779

Conclusion

On Tuesday, April 10, 2007 GPS satellite PRN18 was mistakenly maneuvered by the DOD without properly setting the satellite to unhealthy status. The mistake was noticed one hour and eleven minutes into the maneuver, when the satellite was finally set to unhealthy. The oversight resulted in significantly increased range and position errors at all sites with PRN18 in view.

The terms and definitions discussed below are taken from the Standard Positioning Service Performance Specification (October 2001). An understanding of these terms and definitions is a necessary prerequisite to full understanding of the Signal Specification.

General Terms and Definitions

Almanac Longitude of the Ascending Node (.o): Equatorial angle from the Prime Meridian (Greenwich) at the weekly epoch to the ascending node at the ephemeris reference epoch.

Coarse/Acquisition (C/A) Code: A PRN code sequence used to modulate the GPS L1 carrier.

Corrected Longitude of Ascending Node (Ok) and Geographic Longitude of the Ascending Node (GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the ascending node, both at arbitrary time T_k.

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

Equatorial Angle: An angle along the equator in the direction of Earth rotation.

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

Ground track Equatorial Crossing (GEC, ?, 2 SOPS GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the location a ground track intersects the equator when crossing from the Southern to the Northern hemisphere. GEC is equal to Ok when the argument of latitude (?) is zero.

Instantaneous User Range Error (URE): The difference between the pseudo range measured at a given location and the expected pseudo range, as derived from the navigation message and the true user position, neglecting the bias in receiver clock relative to GPS time. A signal-in-space (SIS) URE includes residual orbit, satellite clock, and group delay errors. A system URE (sometimes known as a User Equivalent Range Error, or UERE) contains all line-of-sight error sources, to include SIS, single-frequency ionosphere model error, troposphere model error, multipath and receiver noise.

Longitude of Ascending Node (LAN): A general term for the location of the ascending node – the point that an orbit intersects the equator when crossing from the Southern to the Northern hemisphere.

Longitude of the Ground track Equatorial Crossing (GEC, ?, 2 SOPS GLAN): Equatorial angle from the Prime Meridian (Greenwich) to the location a ground track intersects the equator when crossing from the Southern to the Northern hemisphere. GEC is equal to Ok when the argument of latitude (?) is zero.

Mean Down Time (MDT): A measure of time required to restore function after any downing event.

Mean Time Between Downing Events (MTBDE): A measure of time between any downing events.

Mean Time Between Failures (MTBF): A measure of time between unscheduled downing events.

Mean Time to Restore (MTTR): A measure of time required to restore function after an unscheduled downing event.

Navigation Message: Data contained in each satellite's ranging signal and consisting of the ranging signal time-of-transmission, the transmitting satellite's orbital elements, an almanac containing abbreviated orbital element information to support satellite selection, ranging measurement correction information, and status flags. The message structure is described in Section 2.1.2 of the SPS Performance Standard.

Operational Satellite: A GPS satellite which is capable of, but is not necessarily transmitting a usable ranging signal.

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

Positioning Accuracy: Defined to be the statistical difference, at a 95% probability, between position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

- **Horizontal Positioning Accuracy:** Defined to be the statistical difference, at a 95% probability, between horizontal position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.
- **Vertical Positioning Accuracy:** Defined to be the statistical difference, at a 95% probability, between vertical position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval.

Position Solution: An estimate of a user's location derived from ranging signal measurements and navigation data from GPS.

Position Solution Geometry: The set of direction cosines that define the instantaneous relationship of each satellite's ranging signal vector to each of the position solution coordinate axes.

Pseudo Random Noise (PRN): A binary sequence that appears to be random over a specified time interval unless the shift register configuration and initial conditions for generating the sequence are known. Each satellite generates a unique PRN sequence that is effectively uncorrelated (orthogonal) to any other satellite's code over the integration time constant of a receiver's code tracking loop.

Representative SPS Receiver: The minimum signal reception and processing assumptions employed by the U.S. Government to characterize SPS performance in accordance with performance standards defined in Section 3 of the SPS Performance Standard. Representative SPS receiver capability assumptions are identified in Section 2.2 of the SPS Performance Standard.

Right Ascension of Ascending Node (RAAN): Equatorial angle from the celestial principal direction to the ascending node.

Root Mean Square (RMS) SIS URE: A statistic that represents instantaneous SIS URE performance in an RMS sense over some sample interval. The statistic can be for an individual satellite or for the entire constellation. The sample interval for URE assessment used in the SPS Performance Standard is 24 hours.

Selective Availability: Protection technique formerly employed to deny full system accuracy to unauthorized users. SA was discontinued effective midnight May 1, 2000.

Service Availability: Defined to be the percentage of time over any 24-hour interval that the predicted 95% positioning error is less than its threshold for any given point within the service volume.

- **Horizontal Service Availability:** Defined to be the percentage of time over any 24-hour interval that the predicted 95% horizontal error is less than its threshold for any point within the service volume.
- **Vertical Service Availability:** Defined to be the percentage of time over any 24-hour interval that the predicted 95% vertical error is less than its threshold for any point within the service volume.

Service Degradation: A condition over a time interval during which one or more SPS performance standards are not supported.

Service Failure: A condition over a time interval during which a healthy GPS satellite's ranging signal exceeds the Not-to-Exceed (NTE) SPS SIS URE tolerance.

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

Service Volume: The spatial volume supported by SPS performance standards. Specifically, the SPS Performance Standard supports the terrestrial service volume. The terrestrial service volume covers from the surface of the Earth up to an altitude of 3,000 kilometers.

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

SPS Performance Standard: A quantifiable minimum level for a specified aspect of GPS SPS performance. SPS performance standards are defined in Section 3.0.

SPS Ranging Signal: An electromagnetic signal originating from an operational satellite. The SPS ranging signal consists of a Pseudo Random Noise (PRN) C/A code, a timing reference and sufficient data to support the position solution generation process. A description of the GPS SPS signal is provided in Section 2. The formal definition of the SPS ranging signal is provided in ICDGPS-200C.

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

SPS SIS User Range Error (URE) Statistic:

- A satellite SPS SIS URE statistic is defined to be the Root Mean Square (RMS) difference between SPS ranging signal measurements (neglecting user clock bias and errors due to propagation environment and receiver), and "true" ranges between the satellite and an SPS user at any point within the service volume over a specified time interval.
- A constellation SPS SIS URE statistic is defined to be the average of all satellite SPS SIS URE statistics over a specified time interval.

Time Transfer Accuracy Relative to UTC (USNO): The difference at a 95% probability between user UTC time estimates and UTC (USNO) at any point within the service volume over any 24-hour interval.

Transient Behavior: Short-term behavior not consistent with steady-state expectations.

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

User Navigation Error (UNE): Given a sufficiently stationary and ergodic satellite constellation ranging error behavior over a minimum sample interval, multiplication of the DOP and a constellation ranging error standard deviation value will yield an approximation of the RMS position error. This RMS approximation is known as the UNE (UHNE for horizontal, UVNE for vertical, and so on). The user is cautioned that any divergence away from the stationary and ergodic assumptions will cause the UNE to diverge from a RMS value based on actual measurements.

User Range Accuracy (URA): A conservative representation of each satellite's expected (1ó) SIS URE performance (excluding residual group delay) based on historical data. A URA value is provided that is representative over the curve fit interval of the navigation data from which the URA is read. The URA is a coarse representation of the URE statistic in that it is quantized to levels represented in ICDGPS200C.