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

Submitted To

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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 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-four 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 #54, includes data collected from 1 April through 30 June 2006. The next quarterly report will be issued 31 October 2006.

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 availability based on PDOP less than six for the CONUS was 99.993% 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 2006. 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 twelve outages were reported in the NANU’s this quarter. Eight outages were scheduled while four were unscheduled.

The quarterly service availability standard was verified using 24-hour position accuracy values computed from data collected at one-second intervals. Nine sites failed position error thresholds for the same 24 hour period. Please see the problem section in Appendix C for an explanation of this failure. The rest 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. With the exception of satellite PRN 30, all of the satellites met the URE and service reliability specifications. The maximum range error recorded was 163.461 meters on Satellite PRN 30. The SPS specification states that the range error should never exceed 30 meters. Please review the problem section in Appendix C for further details of this failure. The maximum 24-hour RMS range error value of 2.430 was recorded on satellite 15. 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 2006, the GPS performance did not meet all SPS requirements that were evaluated. Please review the problem section in Appendix C for further details.

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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-four 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
- 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

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 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 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 ACB 430 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 3.88017 or better 99.9% of the time for each of the 24-hour intervals.

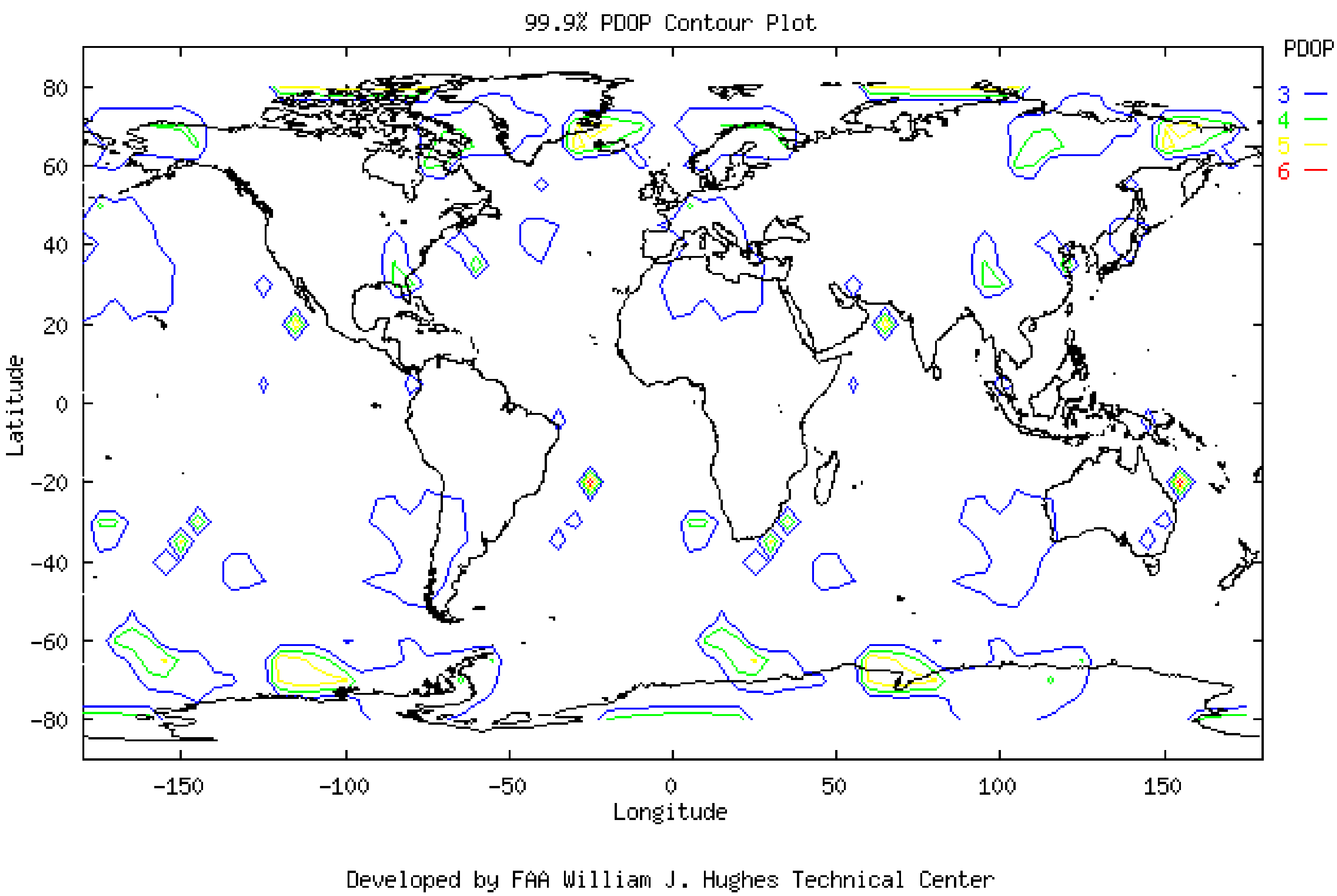
Figure 2-1 is a contour plot of PDOP values over the entire globe. Inside each contour area, the PDOP value is greater than or equal to the contour value shown in the legend for that color line. That areas’ value is also less than the next higher contour value, unless another contour line lies within 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%)
2 – 8 Apr 2006	2.963	100	100
9 – 15 Apr 2006	2.972	100	99.931
16 – 22 Apr 2006	2.964	100	99.931
23 – 29 Apr 2006	2.959	100	99.931
30 Apr – 6 May 2006	2.957	100	99.861
7 – 13 May 2006	2.960	100	99.792
14 – 20 May 2006	2.961	100	99.792
21 – 27 May 2006	3.126	99.999	99.722
28 May – 3 June 2006	3.154	99.998	99.583
4 – 10 June 2006	3.157	99.997	99.444
11 – 17 June 2006	3.157	99.997	99.444
18 – 24 June 2006	3.171	99.996	99.306
25 June – 1 July 2006	3.429	99.993	99.306

Figure 2-1 PDOP Availability Plot (24-Hour Period: 26 June 2006)



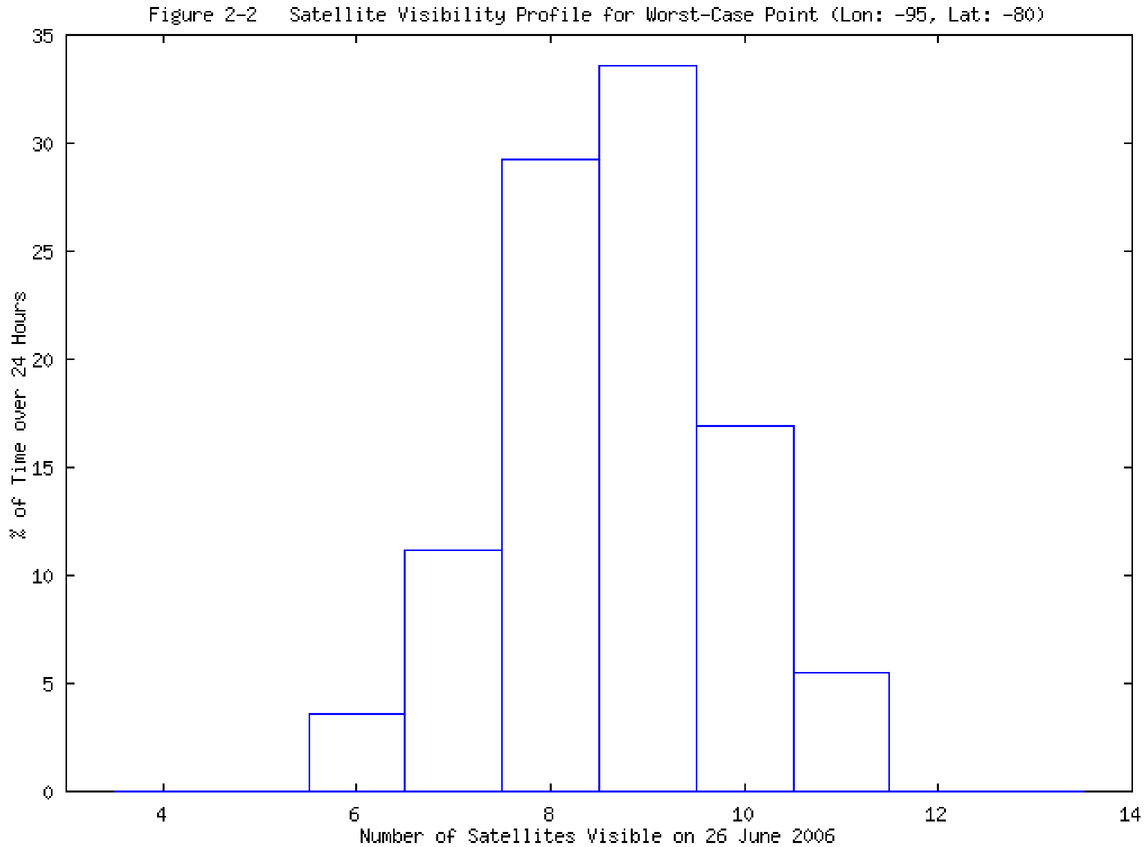


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -95, Lat: -80)
% of Time over 24 Hours
Number of Satellites Visible on 26 June 2006
0
5
10
15
20
25
30
35
4
6
8
10
12
14

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 2006, there were a total of twelve reported outages. Eight of these outages were maintenance activities and were reported in advance. Four 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
34	10	FCSTSUMM	6-Apr	14:16	6-Apr	15:14		0.96	0.96
35	7	FCSTSUMM	7-Apr	9:30	8-Apr	1:17		15.78	15.78
36	6	FCSTSUMM	11-Apr	14:18	11-Apr	20:11		5.88	5.88
38	24	FCSTSUMM	20-Apr	15:46	20-Apr	19:47		4.01	4.01
40	7	FCSTSUMM	27-Apr	15:04	27-Apr	23:24		8.33	8.33
44	25	FCSTSUMM	9-May	21:20	9-May	23:25		2.08	2.08
45	23	FCSTSUMM	16-May	20:15	17-May	2:49		6.56	6.56
50	13	FCSTSUMM	25-May	21:11	26-May	4:13		7.03	7.03
54	30	UNUSABLE	2-Jun	20:14	7-Jun	18:42	118.46		118.46
58	25	UNUSABLE	18-May	6:47	28-Jun	23:43	1000.93		1000.93
60	3	UNUSABLE	18-Jun	15:26	29-Jun	17:29	266.05		266.05
62	6	UNUSABLE	29-Jun	11:05	1-Jul	0:00	36.91		36.91
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**1422.35**	**50.63**	**1472.98**

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
30	10	FCSTMX	6-Apr	14:00	6-Apr	20:00	N/A	See NANU 31
31	10	FCSTRESCD	6-Apr	14:00	7-Apr	2:00	12	See NANU 34
32	7	FCSTDV	7-Apr	9:30	9-Apr	9:30	48	See NANU 35
33	6	FCSTDV	11-Apr	13:45	12-Apr	1:45	12	See NANU 36
37	24	FCSTMX	20-Apr	15:30	21-Apr	3:30	12	See NANU 38
39	7	FCSTDV	27-Apr	14:30	28-Apr	2:30	12	See NANU 40
42	25	FCSTMX	9-May	21:00	10-May	9:00	12	See NANU 44
43	23	FCSTDV	16-May	20:05	17-May	8:05	12	See NANU 45
46	25	UNUSUFN	18-May	6:47	N/A	N/A	N/A	See NANU 58
47	13	FCSTDV	25-May	21:00	26-May	9:00	12	See NANU 50
48	30	FCSTMX	1-Jun	18:00	2-Jun	6:00	CANC	See NANU 49
51	8	FCSTMX	8-Jun	15:30	9-Jun	3:30	CANC	See NANU 53
52	30	UNUSUFN	2-Jun	20:14	N/A	N/A	N/A	See NANU 54
55	3	UNUSUFN	18-Jun	15:26	N/A	N/A	N/A	See NANU 60
56	8	FCSTMX	29-Jun	19:15	30-Jun	1:00	12	See NANU 57
59	6	UNUSUFN	29-Jun	11:05	N/A	N/A	N/A	
					Total Forecast Downtime		**144**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
49	30	FCSTCANC	25-May	22:48	See NANU 48
53	8	FCSTCANC	7-Jun	16:51	See NANU 51
57	8	FCSTCANC	29-Jun	19:15	See NANU 56

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. 2006**
Total Forecast Downtime (hrs):	144.00	5802.73
Total Actual Downtime (hrs):	1472.98	18670.73
Total Actual Scheduled Downtime (hrs):	50.63	3152.12
Total Actual Unscheduled Downtime (hrs):	1422.35	15518.61
Total Satellite Observed MTTR (hrs):	122.75	43.12
Scheduled Satellite Observed MTTR (hrs):	6.33	10.23
Unscheduled Satellite Observed MTTR (hrs):	355.59	124.15
# Total Satellite Outages:	12	433
# Scheduled Satellite Outages:	8	308
# Unscheduled Satellite Outages:	4	125
Percent Operational -- Scheduled Downtime:	99.92	99.80
Percent Operational -- All Downtime:	99.91	98.84

NANU 41 corrected the "Reference NANU" designation of NANU 40.

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-four 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 2006.

Table 3-5 Accuracies Exceeding Threshold Statistics

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-hour Threshold Failures	Quarters Service Availability %
Bethel	3486944	0	100
Billings	7846125	1	98.90
Cold Bay	7819937	0	100
Fairbanks	3548693	1	97.57
Juneau	6765572	0	100
Kotzebue	3442121	0	100
Albuquerque	7847951	0	100
Anchorage	7845693	0	100
Boston	7848050	1	98.90
Washington, D.C.	7834231	1	98.90
Honolulu	7623940	0	100
Houston	7844877	1	98.90
Kansas City	7840740	0	100
Los Angeles	7841244	0	100
Salt Lake City	7754034	0	100
Miami	7846420	1	98.90
Minneapolis	7827581	0	100
Oakland	7844108	0	100
Cleveland	7841382	1	98.90
Seattle	7772569	0	100
San Juan	7828373	1	98.90
Atlanta	7830426	1	98.90
Global Average over Reporting Period = 99.49% (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 163.461 meters on satellite PRN 30.

Table 4-1 Service Reliability Based on User Range Error

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Service Reliability Percentage
1 Apr – 30 June 2006	**Boston**	58,788,448	516	99.9991%
1 Apr – 30 June 2006	**Honolulu**	57,978,838	0	100%
1 Apr – 30 June 2006	**Los Angeles**	61,477,338	0	100%
1 Apr – 30 June 2006	**Miami**	60,617,154	516	99.9991%
1 Apr – 30 June 2006	**San Juan**	63,067,544	521	99.9991%
1 Apr – 30 June 2006	**Juneau**	52,035,614	0	100%
1 Apr – 30 June 2006	**Global**	353,964,936	1,553	99.9995%

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 2006 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)
Bethel	2.565	4.076	6.734	15.711
Billings	2.358	4.362	6.787	8.472
Cold Bay	2.624	4.915	5.380	13.401
Fairbanks	2.331	4.086	4.866	18.299
Juneau	2.388	4.185	5.948	13.732
Kotzebue	2.441	4.333	4.740	18.227
Albuquerque	2.600	4.703	6.501	9.534
Anchorage	2.463	4.449	5.213	14.878
Boston	2.522	4.660	6.098	10.033
Washington, D.C.	2.480	4.954	7.097	9.699
Honolulu	4.497	5.071	8.620	11.611
Houston	2.780	5.003	7.570	10.415
Kansas City	2.413	4.839	6.115	9.733
Los Angeles	2.815	5.247	5.702	13.978
Salt Lake City	2.433	4.752	6.568	11.879
Miami	3.019	4.756	6.529	10.677
Minneapolis	2.861	4.579	10.595	12.338
Oakland	2.642	5.178	5.111	10.741
Cleveland	2.494	4.780	6.554	9.927
Seattle	2.468	4.514	6.793	10.252
San Juan	3.044	4.717	6.613	16.982
Atlanta	2.562	5.013	6.033	10.728

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-four WAAS sites from 1 April to 30 June 2006.

Figure 5-1 Global Vertical Error Histogram

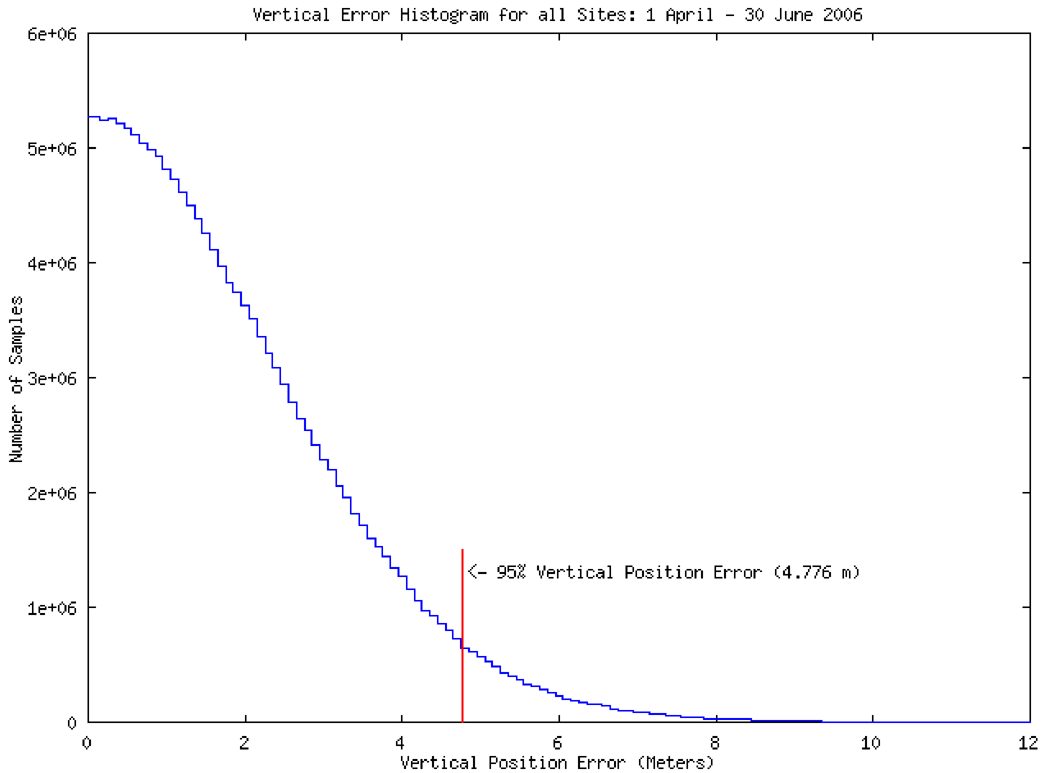
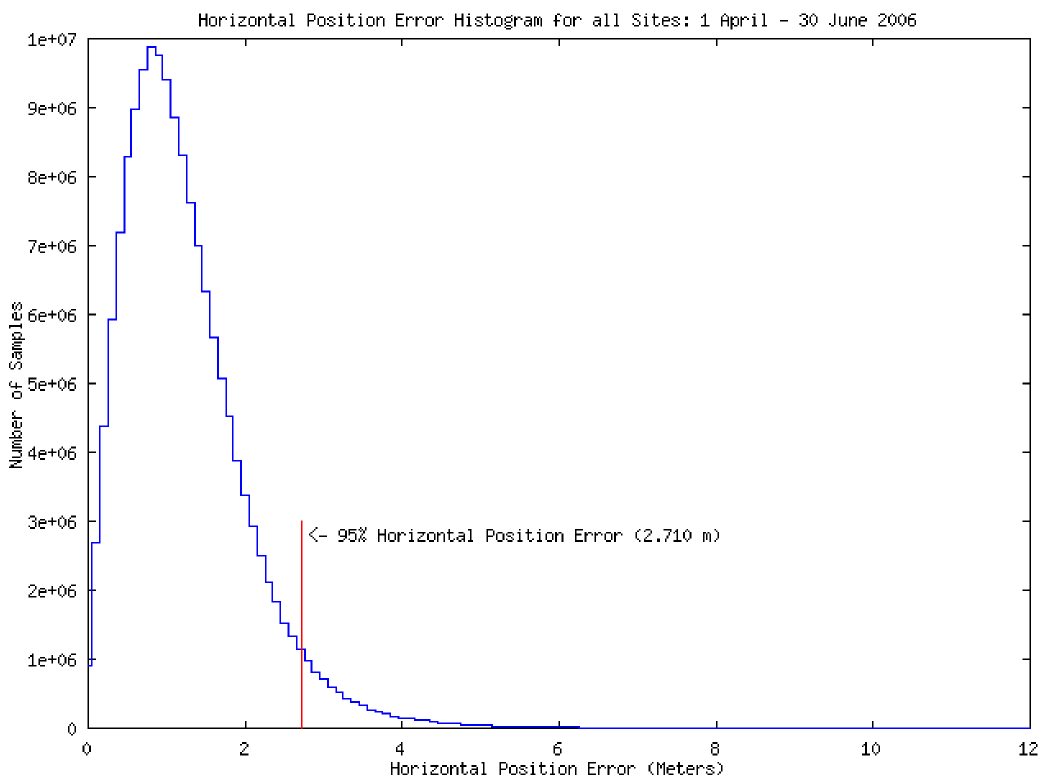


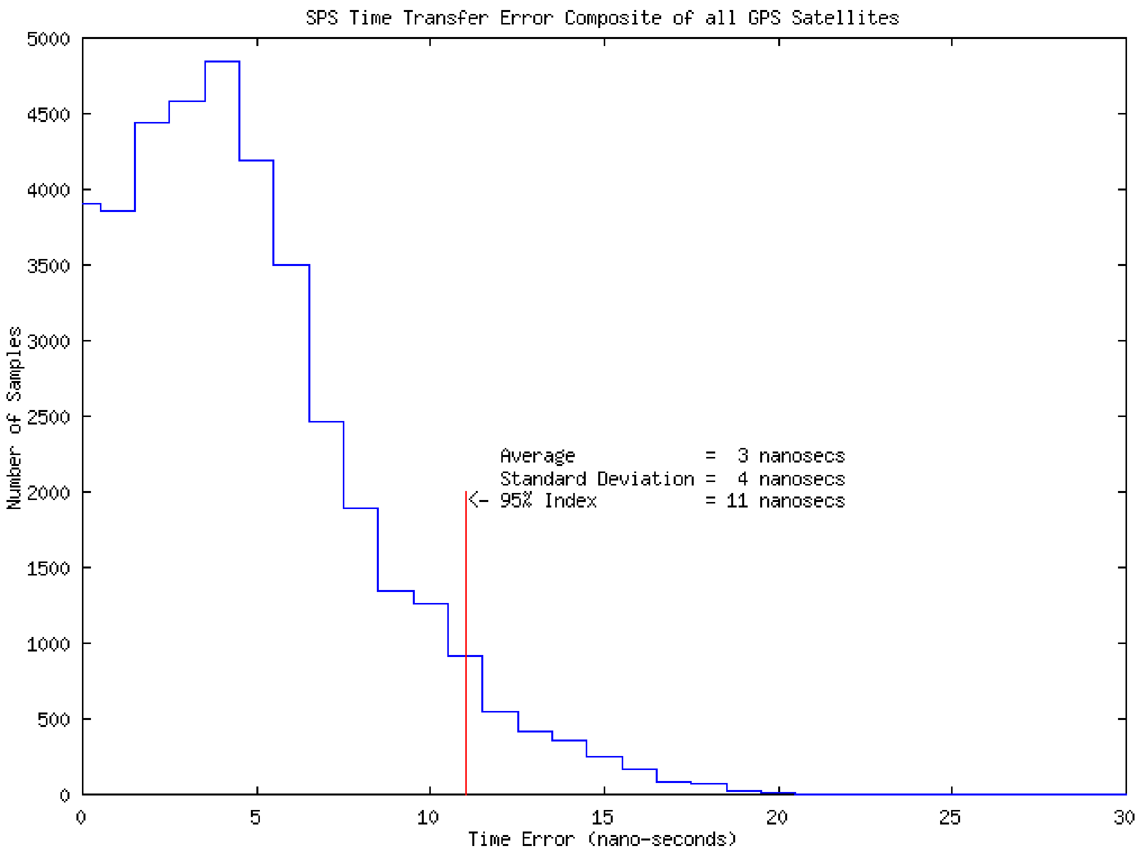
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 2006 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 2006. 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	Range Error Mean	RMS Range Error (≤ 6 m)	1 s	95% Range Error	Max Range Error (SPS Spec. ≤ 30 m)	Samples
1	0.354	2.195	1.694	3.978	26.028	11538072
2	0.550	1.564	1.318	3.006	11.59	12726629
3	0.428	1.747	1.325	3.200	9.288	9480335
4	0.306	1.641	1.362	3.069	9.952	12646910
5	0.832	1.657	1.280	3.102	15.297	12654389
6	0.511	1.761	1.359	3.236	17.608	12135885
7	0.602	1.626	1.315	3.050	11.419	11765498
8	0.380	2.038	1.543	3.751	10.37	11466009
9	0.354	1.972	1.516	3.521	17.669	11545474
10	0.741	1.963	1.435	3.520	10.439	12129510
11	0.594	1.767	1.427	3.273	22.351	10898358
13	-0.123	1.515	1.300	2.834	10.145	12360642
14	0.537	1.663	1.293	3.114	22.988	12683068
15	1.273	2.430	1.607	4.312	12.027	11306194
16	0.441	1.540	1.278	2.895	8.479	11987712
17	0.415	1.856	1.428	3.396	10.499	12832728
18	0.507	1.632	1.277	3.053	14.113	11880014
19	1.040	1.777	1.269	3.248	23.48	11541627
20	0.795	1.730	1.368	3.273	17.872	12941392
21	0.656	1.679	1.316	3.082	12.7	10645333
22	0.961	2.061	1.353	3.657	24.276	11296986
23	0.246	1.578	1.329	2.934	9.72	11612370
24	0.448	2.011	1.560	3.802	12.499	11984680
25	0.516	2.120	1.638	3.923	10.782	6513383
26	-0.102	1.674	1.399	3.092	13.381	11002382
27	0.532	2.157	1.517	3.869	10.76	11177330
28	0.578	2.225	1.503	3.909	12.435	11178119
29	0.127	1.806	1.473	3.330	14.041	11196994
30	0.250	1.730	1.454	3.120	163.461	11142172

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

PRN	Range Rate Error Mean	Range Rate Error RMS	Range Rate Error 1s	95% Range Rate Error	Max Range Rate Error	Samples
1	-0.00004	0.0028	0.0027	0.0039	0.2439	11538072
2	0.00001	0.0018	0.0018	0.0035	0.1557	12726629
3	-0.00003	0.0023	0.0023	0.0038	0.1561	9480335
4	0.00001	0.0019	0.0019	0.0036	0.1056	12646910
5	-0.00002	0.0018	0.0018	0.0034	0.1376	12654389
6	0.00002	0.0020	0.0020	0.0036	0.3023	12135885
7	0.00004	0.0019	0.0019	0.0034	0.1720	11765498
8	-0.00004	0.0023	0.0023	0.0040	0.1721	11466009
9	-0.00001	0.0024	0.0024	0.0041	0.1605	11545474
10	0.00004	0.0021	0.0021	0.0037	0.1860	12129510
11	0.00002	0.0021	0.0021	0.0039	0.1473	10898358
13	0.00002	0.0019	0.0019	0.0036	0.1029	12360642
14	-0.00003	0.0019	0.0019	0.0037	0.0854	12683068
15	0.00007	0.0025	0.0025	0.0039	0.1953	11306194
16	-0.00004	0.0019	0.0019	0.0037	0.0952	11987712
17	-0.00001	0.0019	0.0019	0.0036	0.1665	12832728
18	0.00001	0.0019	0.0019	0.0038	0.0623	11880014
19	-0.00001	0.0019	0.0019	0.0038	0.1226	11541627
20	0.00004	0.0019	0.0019	0.0037	0.1461	12941392
21	0.00004	0.0020	0.0020	0.0040	0.0329	10645333
22	0.00001	0.0020	0.0020	0.0038	0.1753	11296986
23	0.00003	0.0019	0.0019	0.0037	0.0658	11612370
24	0.00005	0.0024	0.0024	0.0040	0.2377	11984680
25	-0.00006	0.0024	0.0024	0.0035	0.2265	6513383
26	-0.00003	0.0019	0.0019	0.0037	0.1377	11002382
27	0.00000	0.0022	0.0022	0.0040	0.1734	11177330
28	-0.00004	0.0021	0.0021	0.0038	0.1607	11178119
29	0.00003	0.0021	0.0020	0.0037	0.1569	11196994
30	-0.00005	0.0026	0.0026	0.0043	0.3481	11142172

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1s	Max Range Acceleration Error	Samples
1	0	0.00002	0.00002	0.00244	11538072
2	0	0.00001	0.00001	0.00157	12726629
3	0	0.00002	0.00002	0.00157	9480335
4	0	0.00001	0.00001	0.00107	12646910
5	0	0.00001	0.00001	0.00138	12654389
6	0	0.00002	0.00002	0.00302	12135885
7	0	0.00001	0.00001	0.00171	11765498
8	0	0.00002	0.00002	0.0017	11466009
9	0	0.00002	0.00002	0.00161	11545474
10	0	0.00002	0.00002	0.00187	12129510
11	0	0.00002	0.00002	0.00148	10898358
13	0	0.00001	0.00001	0.00103	12360642
14	0	0.00001	0.00001	0.00085	12683068
15	0	0.00002	0.00002	0.00196	11306194
16	0	0.00001	0.00001	0.00095	11987712
17	0	0.00001	0.00001	0.00167	12832728
18	0	0.00001	0.00001	0.00058	11880014
19	0	0.00001	0.00001	0.00123	11541627
20	0	0.00001	0.00001	0.00146	12941392
21	0	0.00002	0.00002	0.00033	10645333
22	0	0.00002	0.00002	0.00175	11296986
23	0	0.00001	0.00001	0.00066	11612370
24	0	0.00002	0.00002	0.00238	11984680
25	0	0.00002	0.00002	0.00229	6513383
26	0	0.00001	0.00001	0.00127	11002382
27	0	0.00002	0.00002	0.00174	11177330
28	0	0.00002	0.00002	0.00161	11178119
29	0	0.00002	0.00002	0.00155	11196994
30	0	0.00002	0.00002	0.00175	11142172

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. Satellite 30's range errors exceeded the 30-meter SPS requirement. The highest maximum range error occurred on satellite 30 with an error of 163.461 meters. This constituted an SPS specification failure. Please review appendix C for further details regarding this failure. Satellite 16 had the lowest maximum range error of 8.479 meters.

Figure 5-4 Distribution of Daily Max Range Errors

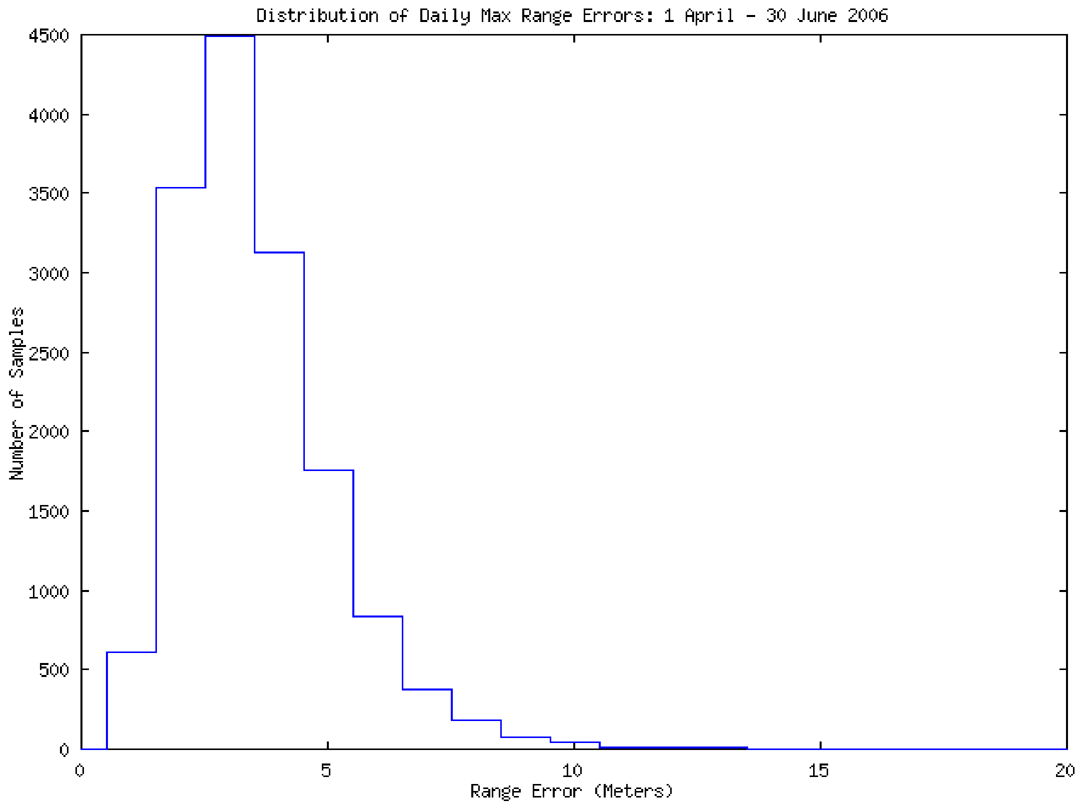


Figure 5-5: Distribution of Daily Max Range Rate Errors

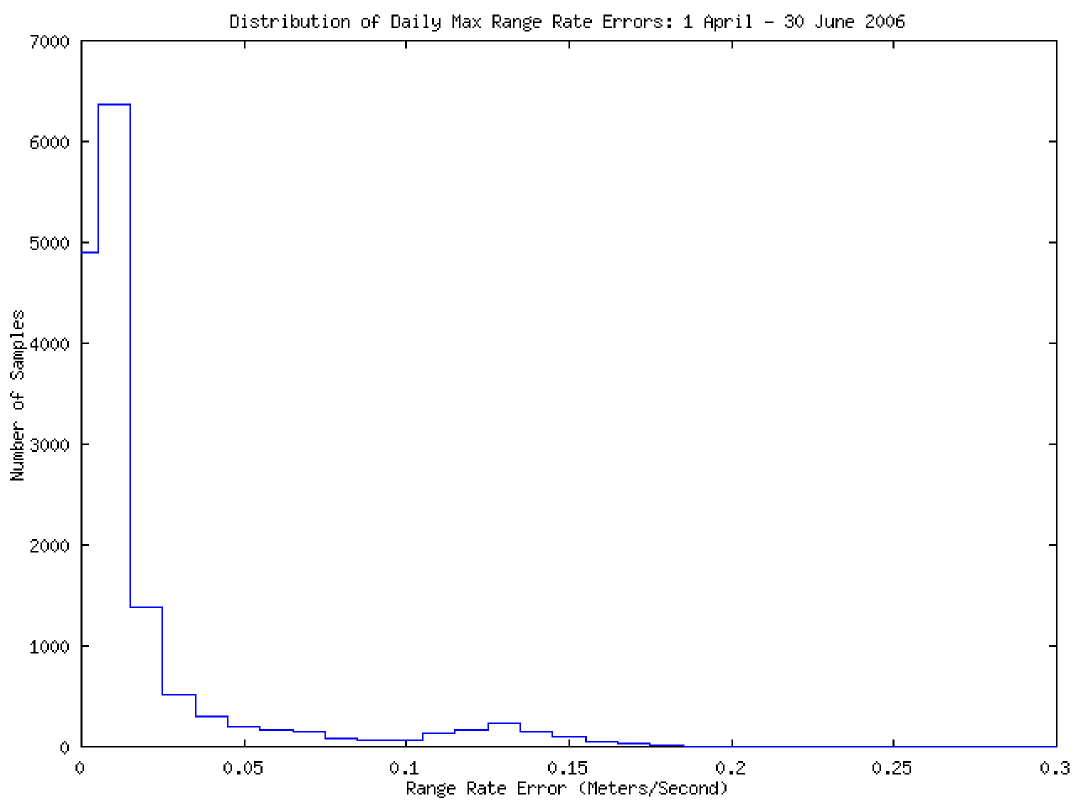


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

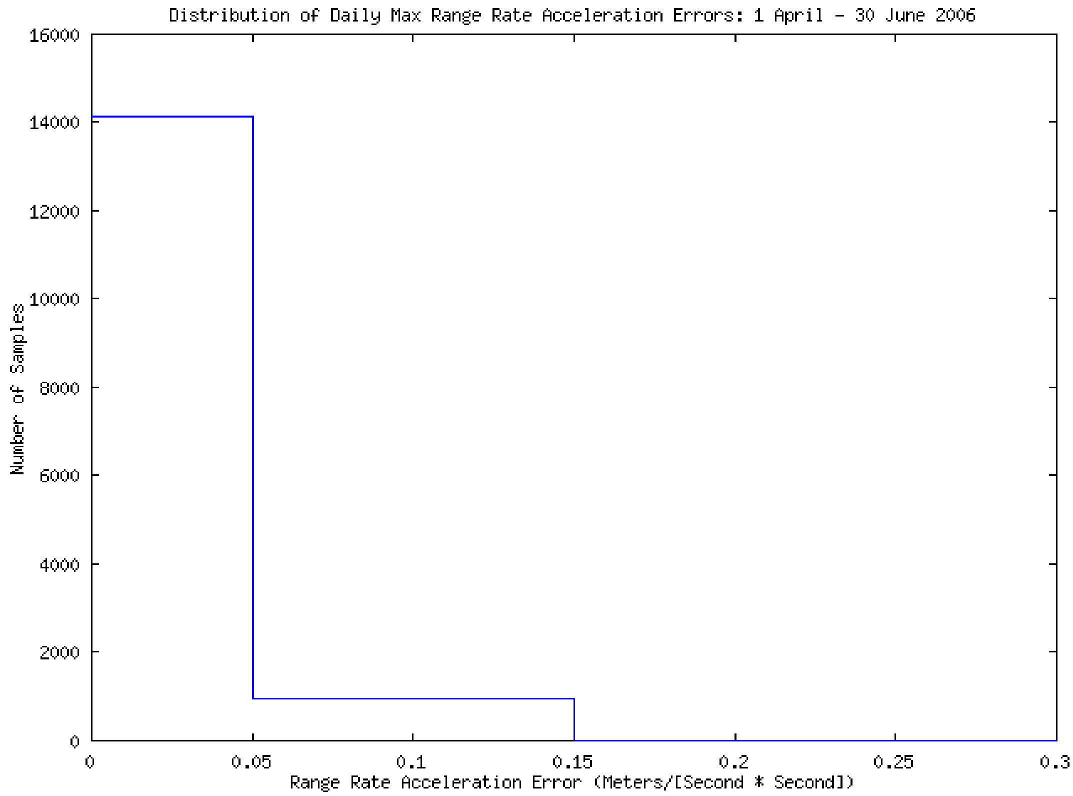


Figure 5-7: Range Error Histogram

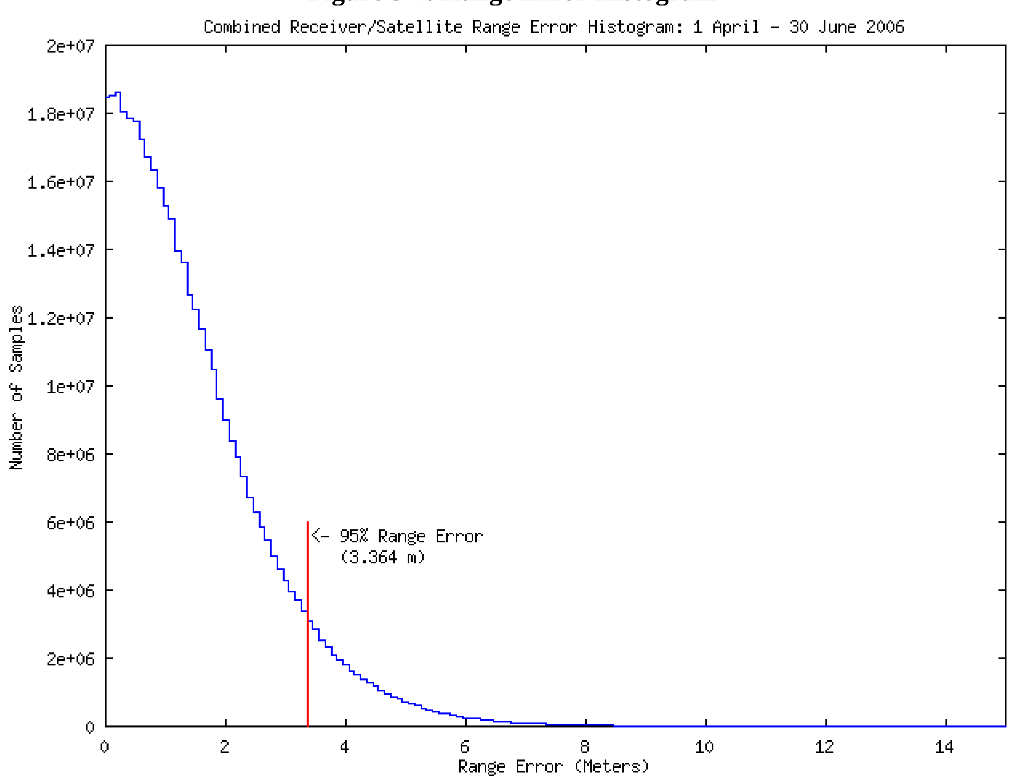


Figure 5-8: Maximum Range Error Per Satellite

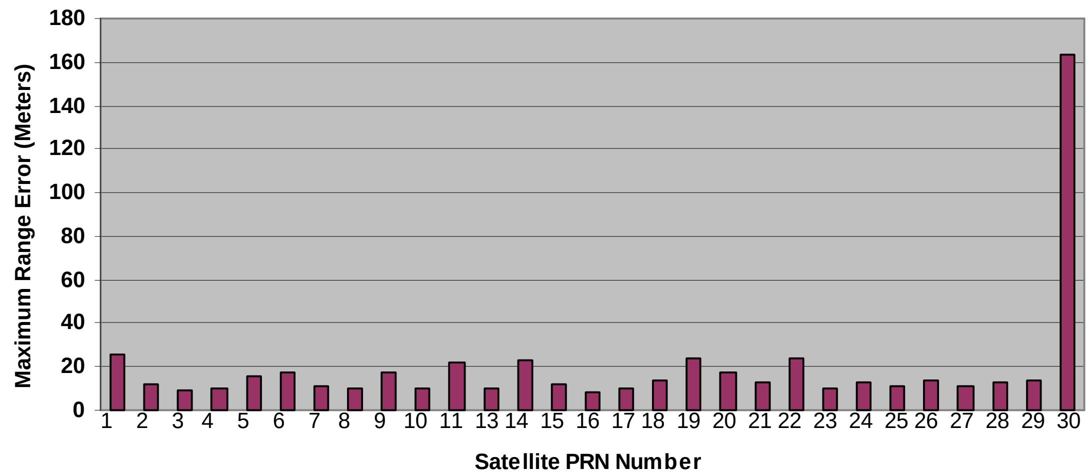


Figure 5-9: Maximum Range Rate Error Per Satellite

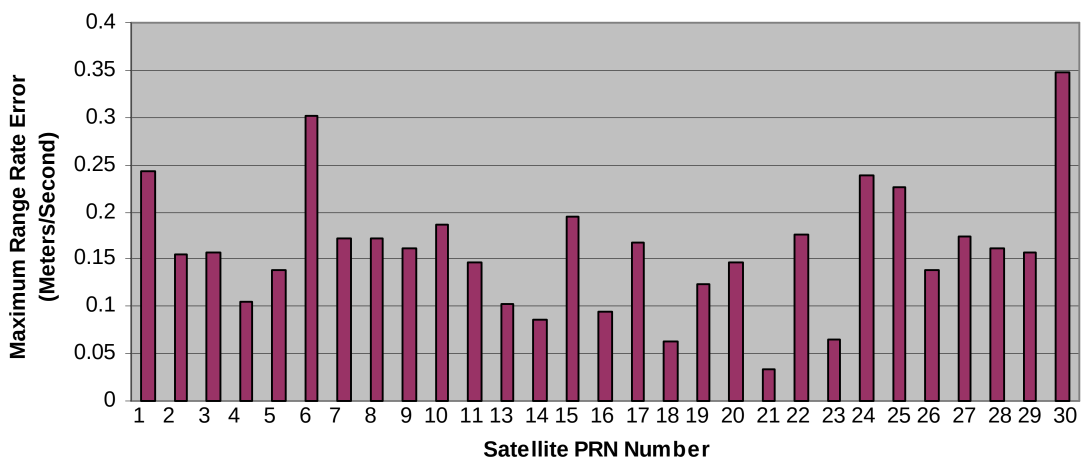
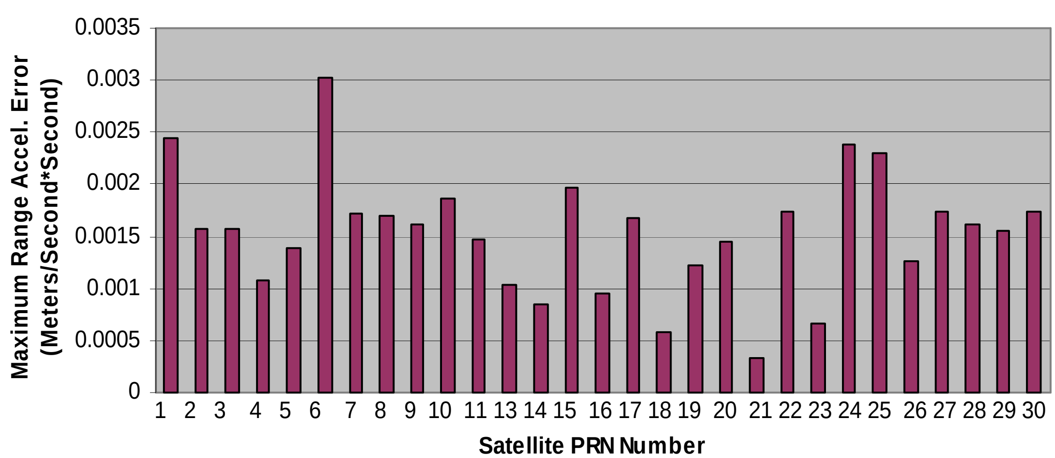


Figure 5-10: Maximum Range Acceleration Per Satellite



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 April 2006

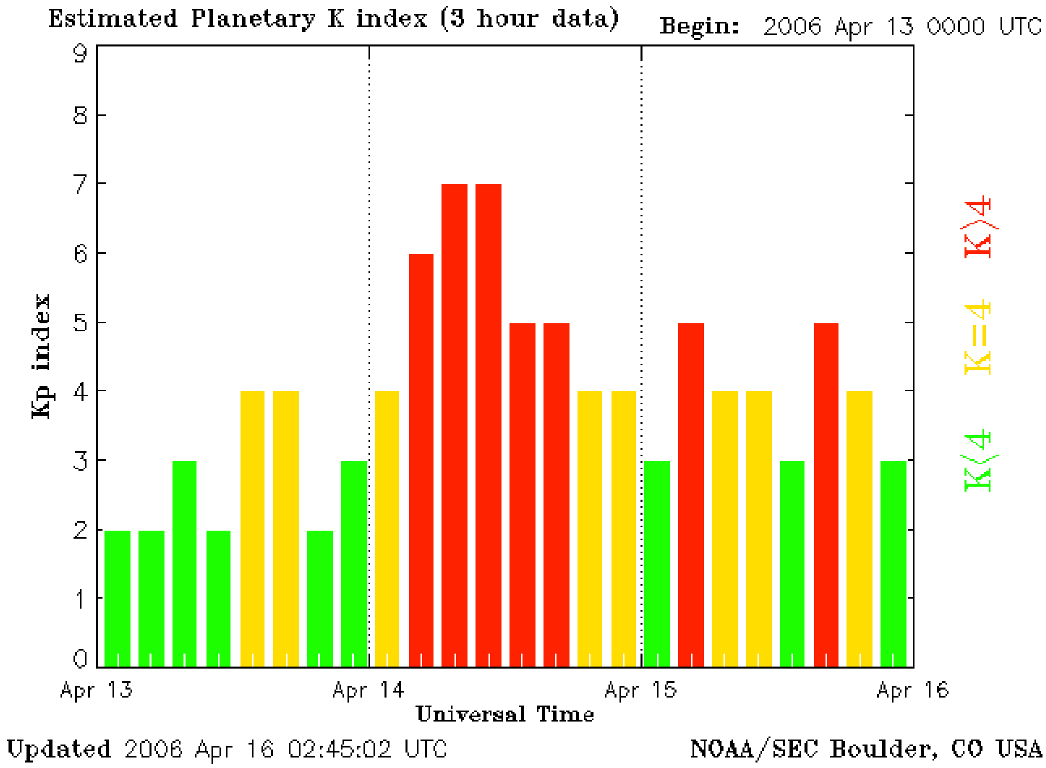


Figure 6-2 K-Index for 7-9 April 2006

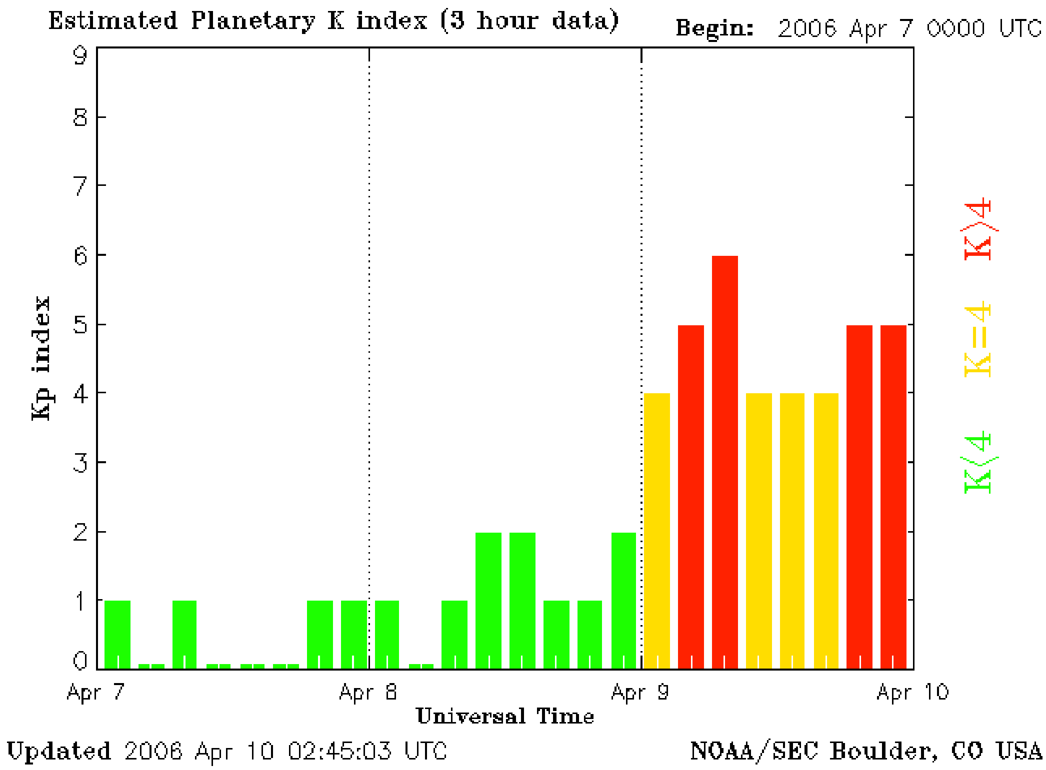
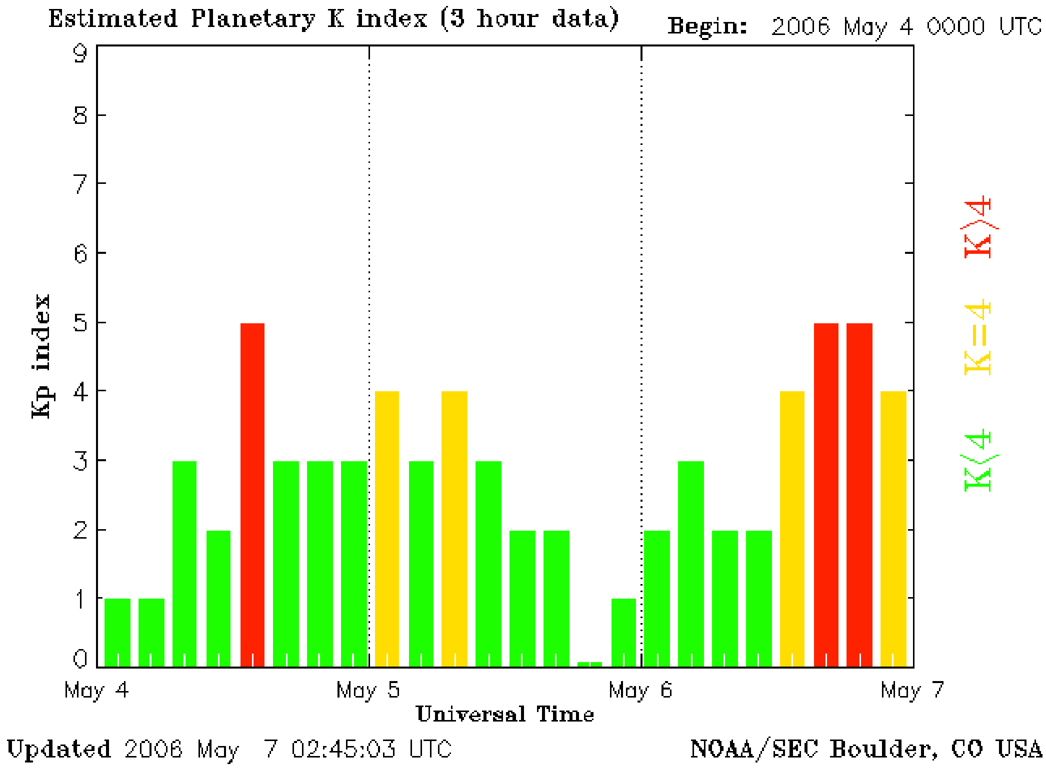


Figure 6-3 K-Index for 4-5 May 2006



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 14 April 2006

Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Mauna Loa	4.819	7.415	5.634	11.636
Billings	2.003	6.001	2.407	8.523
Cold Bay	4.267	4.495	5.647	7.744
Juneau	Site	Down	This	Day
Albuquerque	2.196	4.263	2.800	5.943
Anchorage	2.683	5.061	4.162	7.374
Boston	2.093	5.072	3.683	7.257
Washington, D.C.	2.065	4.525	2.993	6.712
Honolulu	4.480	6.842	5.565	9.850
Houston	2.223	4.013	2.524	5.830
Kansas City	1.889	4.933	2.125	7.441
Los Angeles	2.881	5.268	4.930	6.683
Salt Lake City	2.313	5.256	3.242	7.174
Miami	2.148	2.891	2.601	4.624
Minneapolis	1.739	6.211	2.500	7.870
Oakland	3.011	5.062	4.450	8.829
Cleveland	2.038	5.479	2.958	10.329
Seattle	2.776	5.715	3.397	10.360
San Juan	1.861	4.275	2.120	6.444
Atlanta	2.058	4.309	2.326	6.512

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	≥ 99.923% ≥ 98.264%
Conditions and Constraints	***Service Availability Standard***	***Measured Performance***
• 36 meter horizontal (SIS only) 95% threshold. • 77 meter vertical (SIS only) 95% threshold. • Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	≥ 99% Horizontal Service Availability average location ≥ 99% Vertical Service Availability average location	100%
• Based on using only satellites transmitting standard code and indicating "healthy" in the broadcast navigation message (sub-frame 1).	≥ 95.87% global average on worst-case day	100%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	≥ 99.94% global average	100%
• 30-meter Not-to-Exceed (NTE) SPS SIS URE. • Standard based on a measurement interval of one year; average of daily values from the worst-case point within the service volume. • Standard based on 3 service failures per year, lasting no more than 6 hours each.	≥ 99.79% single point average	100%

Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours averaged over all points within the service volume.	Global Average Positioning Domain Accuracy • ≤ 13 meters 95% All-in-View horizontal error (SIS only) • ≤ 22 meters 95% All-in-View vertical error (SIS only)	2.710 m 4.776 m
• Defined for position solution meeting the representative user conditions. • Standard based on a measurement interval of 24 hours for any point within the service volume.	Worst Site Positioning Domain Accuracy • ≤ 36 meters 95% All-in-View Horiz Error (SIS only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS only)	4.497 m 5.247 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)	11 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	1.831 meters

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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
#
```

	Middle Latitude		High Latitude		Estimated	
	- Fredericksburg -		---- College ----		--- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2006 04 01	1	0 0 0 0 1 0 0 1	0	0 0 0 0 0 1 0 0	2	1 0 0 0 1 0 0 1
2006 04 02	1	0 0 0 0 2 0 0 0	0	0 0 0 0 0 0 0 0	1	1 0 0 0 1 0 0 1
2006 04 03	1	0 0 0 0 1 1 0 1	0	0 0 0 0 0 0 0 0	1	0 0 0 0 0 1 0 1
2006 04 04	4	0 0 1 2 1 1 1 3	13	0 0 1 5 4 3 2 2	7	0 0 1 3 2 2 2 3
2006 04 05	18	3 3 4 4 4 3 2 2	43	2 4 6 6 6 5 3 1	29	3 4 4 5 5 4 3 2
2006 04 06	6	1 2 3 1 1 1 1 2	20	1 3 6 4 4 1 0 1	10	1 3 4 2 2 2 1 2
2006 04 07	2	1 0 1 1 0 0 0 1	2	0 1 2 1 1 0 0 1	3	1 0 1 0 0 0 1 1
2006 04 08	3	1 0 0 1 1 1 1 2	7	1 0 0 4 3 2 1 1	5	1 0 1 2 2 1 1 2
2006 04 09	27	3 3 5 4 4 2 4 5	53	3 5 7 6 5 5 3 4	39	4 5 6 4 4 4 5 5
2006 04 10	11	3 4 3 2 2 2 2 1	30	3 4 6 5 5 3 2 1	18	4 5 4 3 2 2 2 1
2006 04 11	3	1 2 0 1 1 0 0 2	5	2 2 1 2 1 1 0 1	5	2 3 0 1 1 1 0 2
2006 04 12	1	0 0 0 0 1 1 0 0	1	0 1 0 0 0 0 1 0	2	0 1 0 0 0 1 1 1
2006 04 13	9	1 2 2 2 3 2 2 3	22	1 2 3 5 6 3 1 2	13	2 2 3 2 4 4 2 3
2006 04 14	32	4 5 5 5 4 4 3 3	64	3 4 7 7 6 6 3 3	58	4 6 7 7 5 5 4 4
2006 04 15	18	3 4 4 3 3 3 3 3	50	3 4 6 7 5 5 4 3	29	3 5 4 4 3 5 4 3
2006 04 16	8	3 3 2 1 2 2 1 1	18	3 2 4 5 4 3 1 1	10	4 3 2 2 2 2 1 2
2006 04 17	4	2 1 0 0 0 0 1 3	5	2 2 1 2 1 1 1 2	6	2 1 1 0 1 2 1 3
2006 04 18	5	3 3 1 0 0 1 0 1	5	3 3 1 1 0 0 1 0	6	3 3 1 1 1 1 1 2
2006 04 19	2	2 0 1 1 1 0 0 1	3	1 1 1 3 0 0 0 0	4	2 0 1 2 0 2 1 1
2006 04 20	3	0 1 0 1 3 1 0 1	9	0 1 1 1 5 3 0 0	5	0 1 1 1 2 2 0 1
2006 04 21	6	1 2 2 1 2 3 1 1	8	1 1 1 2 2 4 2 1	8	1 2 2 1 2 4 2 2
2006 04 22	10	3 3 3 3 2 2 1 1	38	5 4 4 7 5 2 1 1	18	4 4 3 4 3 2 1 1
2006 04 23	8	1 3 4 1 1 1 0 2	6	2 2 3 2 1 1 0 1	8	1 3 3 1 1 2 1 2
2006 04 24	4	3 1 1 1 1 1 0 1	7	2 1 3 4 1 0 0 1	7	3 2 2 1 1 2 1 2
2006 04 25	1	2 0 0 0 1 0 0 0	3	1 1 0 0 3 1 0 0	5	3 0 0 0 2 2 2 1
2006 04 26	2	2 1 1 0 0 0 0 0	3	1 2 2 1 0 0 0 0	5	2 2 1 1 1 1 2 1
2006 04 27	3	1 1 0 1 1 2 0 1	5	1 2 2 1 3 1 0 0	5	2 2 1 1 1 2 1 2
2006 04 28	10	3 2 4 2 2 1 2 1	11	2 3 3 4 3 1 1 1	12	3 3 5 2 1 1 2 2
2006 04 29	2	0 1 0 1 1 1 0 0	0	1 0 0 0 0 0 0 0	3	1 0 0 0 1 2 1 1
2006 04 30	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
2006 05 01	2	0 0 1 1 0 2 0 0	1	0 0 2 1 0 0 0 0	2	0 0 1 1 0 1 0 1
2006 05 02	4	1 1 1 0 2 1 2 1	2	1 0 1 0 0 1 1 0	4	1 0 1 0 0 1 2 1
2006 05 03	2	2 0 0 0 0 0 1 2	2	2 0 0 0 0 0 1 1	3	1 0 0 0 0 1 1 2
2006 05 04	10	1 1 2 3 3 2 3 3	21	0 1 3 3 6 5 2 1	14	1 1 3 2 5 3 3 3
2006 05 05	8	3 2 3 3 2 0 1 1	21	3 4 5 4 4 3 1 1	13	4 3 4 3 2 2 0 1
2006 05 06	14	2 3 2 2 3 3 4 3	29	1 2 3 3 6 6 3 3	24	2 3 2 2 4 5 5 4
2006 05 07	17	3 4 5 3 3 1 2 2	34	3 4 6 6 5 2 2 2	19	3 4 5 4 3 2 2 3
2006 05 08	5	2 3 2 1 1 0 1 1	11	3 4 3 3 3 0 1 0	8	2 4 3 1 1 1 1 1
2006 05 09	2	0 0 1 1 1 0 1 2	3	1 1 1 2 0 0 1 2	4	0 0 1 2 1 1 1 2
2006 05 10	4	0 0 0 1 1 0 2 3	1	0 0 0 0 0 0 1 2	4	0 0 0 1 1 1 1 3
2006 05 11	21	3 4 3 3 3 5 3 3	23	3 5 5 4 4 2 2 2	18	3 4 4 4 3 2 3 4
2006 05 12	10	3 3 3 2 2 2 2 2	27	4 4 5 5 5 2 2 2	16	4 4 4 2 3 2 2 3
2006 05 13	9	3 3 2 2 2 1 2 2	16	3 3 4 4 4 2 1 1	11	3 4 3 2 2 1 2 2
2006 05 14	6	3 3 1 1 1 1 1 1	9	3 3 2 3 2 1 1 1	8	3 4 2 1 1 1 1 2
2006 05 15	3	1 2 0 0 0 1 2 1	3	1 1 1 2 2 0 1 0	4	1 1 1 1 1 1 1 2
2006 05 16	0	0 0 0 0 1 0 0 1	1	1 0 0 0 1 0 0 0	2	1 0 0 0 1 0 1 1
2006 05 17	4	1 2 1 1 2 1 1 1	4	1 2 1 0 2 2 1 1	5	1 2 1 1 1 1 1 3
2006 05 18	11	2 1 3 2 2 3 4 2	23	1 4 4 4 3 5 4 2	16	2 2 3 2 2 5 4 2
2006 05 19	7	1 2 3 1 1 1 2 3	8	2 3 3 1 2 2 1 1	8	2 2 3 0 1 2 2 3
2006 05 20	5	1 1 2 2 1 1 2 2	9	1 1 3 4 2 1 2 1	7	2 2 2 3 1 2 2 2
2006 05 21	4	2 1 1 1 1 1 2 1	6	3 1 0 2 0 2 2 2	7	3 0 1 2 1 1 3 2
2006 05 22	6	2 1 0 1 2 2 2 3	7	2 2 1 1 3 2 1 2	8	2 2 0 1 2 2 2 4
2006 05 23	4	2 1 1 1 2 1 1 1	5	3 1 1 2 2 1 0 1	7	3 3 2 1 1 1 2 1
2006 05 24	3	1 1 1 1 1 1 1 1	3	0 2 1 2 2 1 0 0	4	1 1 2 1 2 1 0 1
2006 05 25	4	1 1 1 0 2 1 2 2	2	1 1 1 0 0 0 1 1	5	1 1 1 0 1 1 2 2
2006 05 26	1	0 0 0 0 1 1 1 0	3	2 1 0 0 1 1 1 1	5	3 1 0 0 1 1 1 2
2006 05 27	1	1 0 0 1 0 0 0 1	1	1 0 0 0 0 0 0 1	3	2 0 0 0 1 1 1 2
2006 05 28	5	1 2 1 2 1 1 2 2	4	2 2 1 2 2 0 1 0	7	2 2 1 1 2 1 2 3

2006 05 29	1	1	0	0	0	0	1	0	1	1	2	0	0	0	0	0	0	0	3	1	1	0	0	0	1	0	1
2006 05 30	7	1	1	0	2	3	2	3	2	10	1	1	0	4	4	2	2	1	9	2	2	0	2	3	2	3	2
2006 05 31	4	2	1	1	1	2	1	1	1	5	2	2	1	2	1	1	1	1	6	3	2	1	1	1	1	1	2
2006 06 01	10	2	2	2	3	2	2	3	3	15	3	2	3	5	3	2	2	2	13	2	2	2	4	2	2	4	3
2006 06 02	5	2	3	2	1	1	1	1	1	6	3	2	2	2	0	1	1	1	8	3	3	2	1	1	2	2	1
2006 06 03	2	1	1	1	0	1	1	1	1	3	1	1	1	1	1	1	1	1	4	1	1	1	0	1	1	1	1
2006 06 04	1	1	0	0	1	0	0	0	1	1	0	1	1	0	0	0	0	1	2	1	0	0	0	1	1	1	1
2006 06 05	2	1	1	0	0	1	1	1	1	2	1	2	1	0	0	1	1	0	4	1	1	1	0	0	2	1	1
2006 06 06	15	1	2	3	3	3	2	4	4	35	2	2	5	6	4	5	5	3	23	2	2	4	4	3	4	5	4
2006 06 07	18	3	4	3	2	3	2	4	4	35	4	4	5	6	5	4	2	3	24	4	4	4	3	3	3	4	4
2006 06 08	18	4	4	4	2	3	2	3	3	26	3	4	5	4	5	4	2	2	20	4	5	4	2	3	3	3	3
2006 06 09	9	3	2	3	2	2	1	2	2	15	3	3	3	5	3	2	1	1	10	3	2	3	2	2	2	2	2
2006 06 10	7	2	2	2	2	2	2	2	2	8	2	3	2	2	3	2	1	1	8	3	3	2	2	2	2	2	2
2006 06 11	4	2	2	1	0	1	1	2	1	8	3	2	2	1	3	3	0	1	5	2	1	2	1	2	1	1	2
2006 06 12	2	1	0	1	0	1	1	1	1	3	1	9	1	0	3	0	0	0	4	1	0	1	0	1	1	1	1
2006 06 13	2	1	1	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	3	1	1	0	0	0	1	2	1
2006 06 14	6	1	1	0	2	1	1	3	3	3	2	0	0	0	1	1	1	2	7	2	1	1	1	1	2	2	3
2006 06 15	17	2	3	4	4	3	3	3	3	45	3	4	6	7	5	4	2	3	28	2	4	5	5	3	3	3	4
2006 06 16	7	3	2	2	1	1	2	2	2	10	3	3	3	2	2	2	2	2	10	3	3	2	1	2	2	3	3
2006 06 17	7	2	2	3	1	2	1	2	1	16	3	3	4	4	4	2	1	1	10	2	3	4	2	2	2	3	1
2006 06 18	6	0	2	3	2	1	1	1	2	21	1	3	6	5	2	1	1	2	8	1	2	3	3	1	1	1	2
2006 06 19	4	2	1	1	0	3	1	1	0	2	2	1	1	0	0	0	0	1	5	3	1	0	0	0	1	1	2
2006 06 20	2	1	0	0	0	1	1	1	1	2	2	0	0	0	1	1	0	1	4	2	1	0	0	1	1	2	2
2006 06 21	2	0	0	0	0	1	2	1	1	1	0	0	0	0	0	1	0	1	4	1	0	0	0	1	2	1	2
2006 06 22	6	0	2	2	1	2	2	2	1	5	1	2	2	2	2	2	1	1	6	1	2	2	1	1	2	1	1
2006 06 23	1	0	0	0	0	1	0	1	0	3	0	0	0	0	3	0	2	1	2	1	0	0	0	1	1	1	1
2006 06 24	2	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	1	1	4	1	0	0	1	1	2	2	2
2006 06 25	3	1	1	1	1	1	1	1	1	4	2	1	1	3	0	1	0	0	5	2	1	0	1	1	1	1	1
2006 06 26	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	3	1	0	0	0	1	1	1	1
2006 06 27	7	1	1	0	1	4	1	1	3	3	1	0	0	1	2	1	2	1	6	1	1	1	1	2	2	2	3
2006 06 28	12	2	2	3	3	3	2	3	3	32	3	2	6	5	6	2	3	2	18	3	2	4	4	4	2	3	3
2006 06 29	8	2	2	2	2	2	2	2	3	17	3	3	4	3	4	4	1	1	12	3	2	3	3	2	3	3	3
2006 06 30	7	2	2	2	2	2	2	1	2	13	1	2	3	3	5	2	2	1	8	2	2	2	2	3	1	1	2

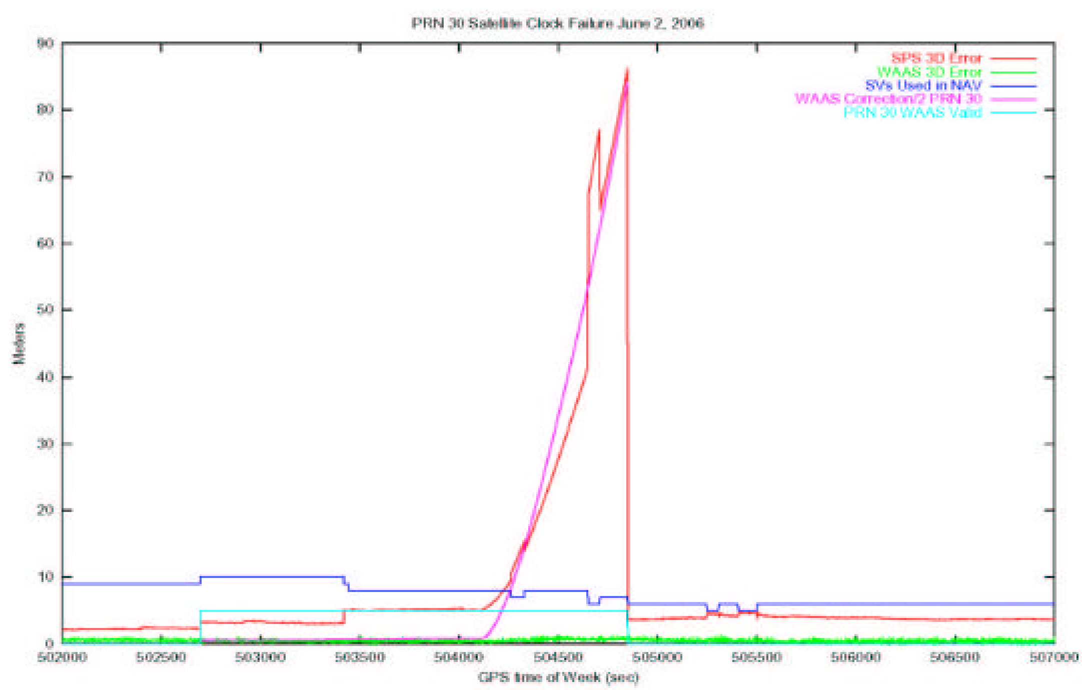
Background:

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS for IFR and is developing WAAS and LAAS, both of which are GPS augmentation systems. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Performance Analysis (PAN) report. The PAN report contains data collected at various National Satellite Test Bed (NSTB) and Wide Area Augmentation System (WAAS) reference station locations. This PAN Problem Report will be issued only when the performance data fails to meet the GPS Standard Positioning Service (SPS) Signal Specification.

Problem Description:

On June 2, 2006 GPS satellite PRN 30 navigation signal rapidly degraded producing large position errors for SPS users not excluding the satellite from the navigation solution. SPS position errors grew to over 80 meters at some locations before the satellite was dropped from the receiver track list. Figure 1 shows the 3D position error at Billings MT for a SPS user (red trace) and a WAAS user (green trace). The WAAS user showed no change in navigation performance since corrections to PRN 30 satellite signal were applied. WAAS range correction divided by 2 for PRN 30 is also shown in figure 1 to illustrate the rapid change of the ranging error that occurred. The problem started at approximately 504179 GPS time of week (20:02:45 GMT) and lasted 11 minutes until 504849 GPS time of week (20:12:55 GMT), until the satellite was dropped from track by all receivers. WAAS provided corrections to PRN 30 until it was lost by all the receivers at which time the satellite state was changed to not monitored. Receivers began tracking satellite PRN 30 at 507346 GPS time of week (20:55:32 GMT) with the GPS satellite status set to unhealthy and the WAAS satellite status set to do not use.

Figure 1 GPS and WAAS Position Error Billings MT



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.