# 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 #70**
**July 31, 2010**
**Reporting Period: 1 April – 30 June 2010**


**Submitted by**

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# EXECUTIVE SUMMARY


The GPS Product Team has tasked the Navigation Branch at the William J. Hughes Technical Center to document the Global Positioning System (GPS) Standard Positioning Service (SPS) performance in quarterly GPS Performance Analysis (PAN) Reports. The report contains the analysis performed on data collected at twenty-eight Wide Area Augmentation System (WAAS) Reference Stations. This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification (September 2008).

This report, Report #70, includes data collected from 1 April through 30 June 2010. The next quarterly report will be issued July 31, 2010.

Analysis of this data includes the following standards and categories: PDOP Availability, NANU Summary and Evaluation, Service Availability, 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 00.988% 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 2010. Using this data, we compute a set of statistics that give a relative idea of constellation health for both the current and combined history of past quarters. A total of twenty outages were reported in the NANU’s this quarter. Seventeen outages were scheduled while three were unscheduled outages.

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

Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error standard was verified for each satellite from 24-hour accuracy values computed using data collected at the following six sites: Boston, Honolulu, Los Angeles, Miami, San Juan and Juneau. This data was also collected in one-second samples. All sites achieved 100% reliability, meeting the SPS specification. The maximum range error recorded was 26.052 meters on Satellite PRN 10. 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 1.531 recorded on satellite 10. The SPS specification states that RMS URE cannot exceed 6 meters in any 24-hour interval.

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

The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products. During the evaluation period, the maximum 95% horizontal and vertical SPS errors were 3.67 meters at Maspalomas and 5.16 meters at Bishkek, respectively.

From the analysis performed on data collected between 1 April and 30 June 2010, the GPS performance met all SPS requirements that were evaluated. There were no significant problems to report for the duration of the quarter.

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# 1.0 Introduction

### 1.1 Objective of GPS SPS Performance Analysis Report

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

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

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

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

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

### 1.2 Summary of Performance Requirements and Metrics

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

### 1.3 Report Overview

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

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

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

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

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

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

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

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

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

**Table 1-1 SPS SIS Performance Requirements Standards**

| **Per-Satellite Coverage** | **Conditions and Constraints** | **Evaluated in This Report** |
|---|---|---|
| Terrestrial Service Volume:<br>100% Coverage<br><br>Space Service Volume:<br>No Coverage Performance Specified | • For any health or marginal SPS SIS | **Future Report** |
| **Constellation Coverage** | **Conditions and Constraints** | |
| Terrestrial Service Volume:<br>100% Coverage<br><br>Space Service Volume:<br>No Coverage Performance Specified | • For any healthy or marginal SPS SIS | **Future Report** |
| **User Range Error Accuracy** | **Conditions and Constraints** | |
| Single Frequency C/A-Code<br><br>• ≤ 7.8m 9%% Global Average URE during normal operations over All AODs<br>• ≤ 6.0m 95% Global Average URE during operations at Zero AOD<br>• ≤ 12.8m 95% Global Average URE during normal operations at Any AOD | • For any healthy SPS SIS<br>• Neglecting single-frequency ionospheric delay model errors<br>• Including group delay time correction ($T_{GD}$) errors at L1<br>• Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 | ✓ |
| Single Frequency C/A-Code<br><br>• ≤ 30m 99.94% Global Average URE during normal operations<br><br>• ≤ 30m 99.79% Worst Case single point average during normal operations. | • For any healthy SPS SIS.<br>• Neglecting single-frequency ionospheric delay model errors<br>• Including group delay time correction ($T_{GD}$) errors at L1<br>• Including inter-signal bias (P(Y)-code to C/A-code) errors at L1<br>• Standard based on measurement interval of one year; average of daily values within service volume<br>• Standard based on 3 service failures per year, lasting no more than 6 hours each | ✓ |
| **User Range Rate Error Accuracy** | **Conditions and Constraints** | |
| Single-Frequency C/A-Code:<br><br>• ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD | • For any healthy SPS SIS<br>• Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers<br>• Neglecting single-frequency ionospheric delay model errors | ✓ |

| **User Range Acceleration Error Accuracy** | **Conditions and Constraints** | |
|---|---|---|
| Single-Frequency C/A-Code:<br><br>• ≤ 2 mm/sec$^2$ 95% Global average URAE over any 3-second interval during normal operations at Any AOD | • For any healthy SPS SIS<br>• Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers<br>• Neglecting single-frequency ionospheric delay model errors | ✓ |
| **Coordinated Universal Time Offset Error Accuracy** | | |
| • ≤ 40 nanoseconds 95% Global average UTCOE during normal operations at Any AOD. | • For any healthy SPS SIS | ✓ |
| **Instantaneous URE Integrity** | **Conditions and Constraints** | |
| Single-Frequency C/A-Code:<br><br>• ≤ $1x10^{-5}$ Probability over any hour of the SPS SIS Instantaneous URE exceeding the NTE tolerance without a timely alert during normal operations. | • For any healthy SPS SIS<br>• SPS SIS URE NTE tolerance defined to be ±4.42 times the upper bound on the URA value corresponding to the URA index "N" currently broadcast by the satellite.<br>• Given that the maximum SPS SIS instantaneous URE did not exceed the NTE tolerance at the start of the hour<br>• Worst case for delayed alert is 6 hours.<br>• Neglecting singe-frequency ionospheric delay model errors | **Future Report** |
| **Instantaneous UTCOE Integrity** | **Conditions and Constraints** | |
| Single-Frequency C/A-Code:<br><br>• ≤ $1x10^{-5}$ Probability over any hour of the SPS SIS Instantaneous UTCOE exceeding the NTE tolerance without a timely alert during normal operations. | • For any healthy SPS SIS<br>• SPS SIS URE NTE tolerance defined | **Future Report** |
| **Unscheduled Failure Interruption Continuity** | **Conditions and Constraints** | |
| Unscheduled Failure Interruptions:<br><br>• ≥ 0.9998 Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption | • Calculated as an average over all slots in the 24-slot constellation, normalized annually<br>• Given that the SPS SIS is available form the slot at the start of the hour | **Future Report** |

| **Status and Problem Reporting** | **Conditions and Constraints** | |
|---|---|---|
| Scheduled event affecting service<br>• Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event | • For any SPS SIS | ✓ |
| Unscheduled outage or problem affecting service<br>• Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event | • For any SPS SIS | ✓ |
| **Per-Slot Availability** | **Conditions and Constraints** | |
| • ≥ 0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS<br><br>• ≥ 0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a health SPS SIS | • Calculated as an average over all slots in the 24-slot constellation, normalized annually<br><br>• Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard. | **Annually Beginning Quarter 4, 2010** |
| **Constellation Availability** | **Conditions and Constraints** | |
| • ≥ 0.98 Probability that at least 21 slots out of the 24 will be occup0ied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration<br>• ≥ 0.99999 Probability that at least 20 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration | • Calculated as a n average over all slots in the 24-slot constellation, normalized annually.<br><br>• Applies to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard. | **Annually Beginning Quarter 4, 2010** |
| **Operational Satellite Count** | **Conditions and Constraints** | |
| • ≥ 0.95 Probability that the constellation will have a t least 24 operational satellites regardless of whether those operational satellites are located in slots or not | • Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operation satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not. | ✓ |

| **PDOP Availability** | **Conditions and Constraints** | |
|---|---|---|
| • ≥ 98% global PDOP of 6 or less<br><br>• ≥ 88% worst site PDOP of 6 or less | • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval | ✓ |
| **Service Availability** | **Conditions and Constraints** | |
| • ≥ 99% Horizontal Service Availability, average location<br><br>• ≥ 99% Vertical Service Availability, average location | • 17m Horizontal (SIS only) 95% threshold<br>• 37m Vertical (SIS only) 95% threshold<br>• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. | ✓ |
| • ≥ 90% Horizontal Service Availability, worst-case location<br><br>• ≥ 90% Vertical Service Availability, worst-case location | • 17m Horizontal (SIS only) 95% threshold<br>• 37m Vertical (SIS only) 95% threshold<br>• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. | ✓ |
| **Position/Time Accuracy** | **Conditions and Constraints** | |
| Global Average Position Domain Accuracy<br><br>• ≤ 9m 95% Horizontal Error<br>• ≤ 15m 95% Vertical Error | • Defined for a position/time solution meeting the representative user conditions<br>• Standard based on a measurement interval of 24 hours averaged over all points in the service volume. | ✓ |
| Worst Site Position Domain Accuracy<br><br>• ≤ 17m 95% Horizontal Error<br>• ≤ 37m 95% Vertical Error | • Defined for a position/time solution meeting the representative user conditions<br>• Standard based on a measurement interval of 24 hours averaged over all points in the service volume. | ✓ |
| Time Transfer Domain Accuracy<br><br>• ≤ 40 nanoseconds time transfer error 95% of time (SIS only) | • Defined for a time transfer solution meeting the representative user conditions<br>• Standard based on a measurement interval of 24 hours averaged over all points in 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 PDOP of 6 or less<br><br>≥ 88% worst site PDOP of 6 or less | • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval |

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 3.701 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%) |
|---|---|---|---|
| | | | |
| 4 – 10 April | 3.308 | 99.992 | 98.889 |
| 11 – 17 April | 3.340 | 99.990 | 98.681 |
| 18 – 24 April | 3.304 | 99.990 | 98.750 |
| 25 April – 1 May | 3.646 | 99.989 | 98.611 |
| 2 – 8 May | 3.628 | 99.989 | 98.611 |
| 9 – 15 May | 3.646 | 99.988 | 98.542 |
| 16 – 22 May | 3.585 | 99.988 | 98.611 |
| 23 – 29 May | 3.622 | 99.988 | 98.542 |
| 30 May – 5 June | 3.582 | 99.988 | 98.194 |
| 6 – 12 June | 3.612 | 99.988 | 98.472 |
| 13 – 19 June | 3.625 | 99.988 | 98.472 |
| 20 – 26 June | 3.619 | 99.988 | 98.472 |
| 27 June – 3 July | 3.701 | 99.988 | 98.472 |

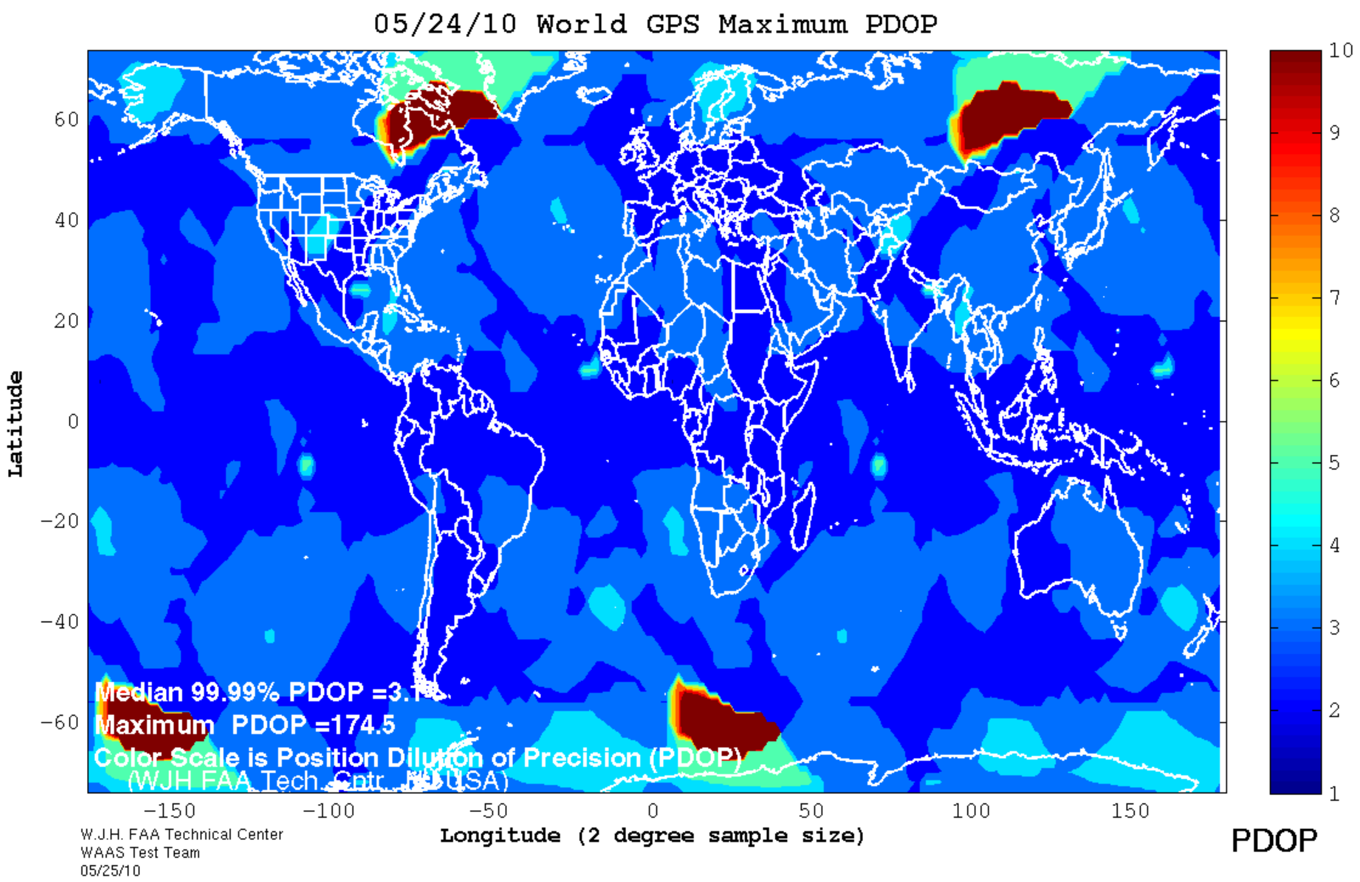
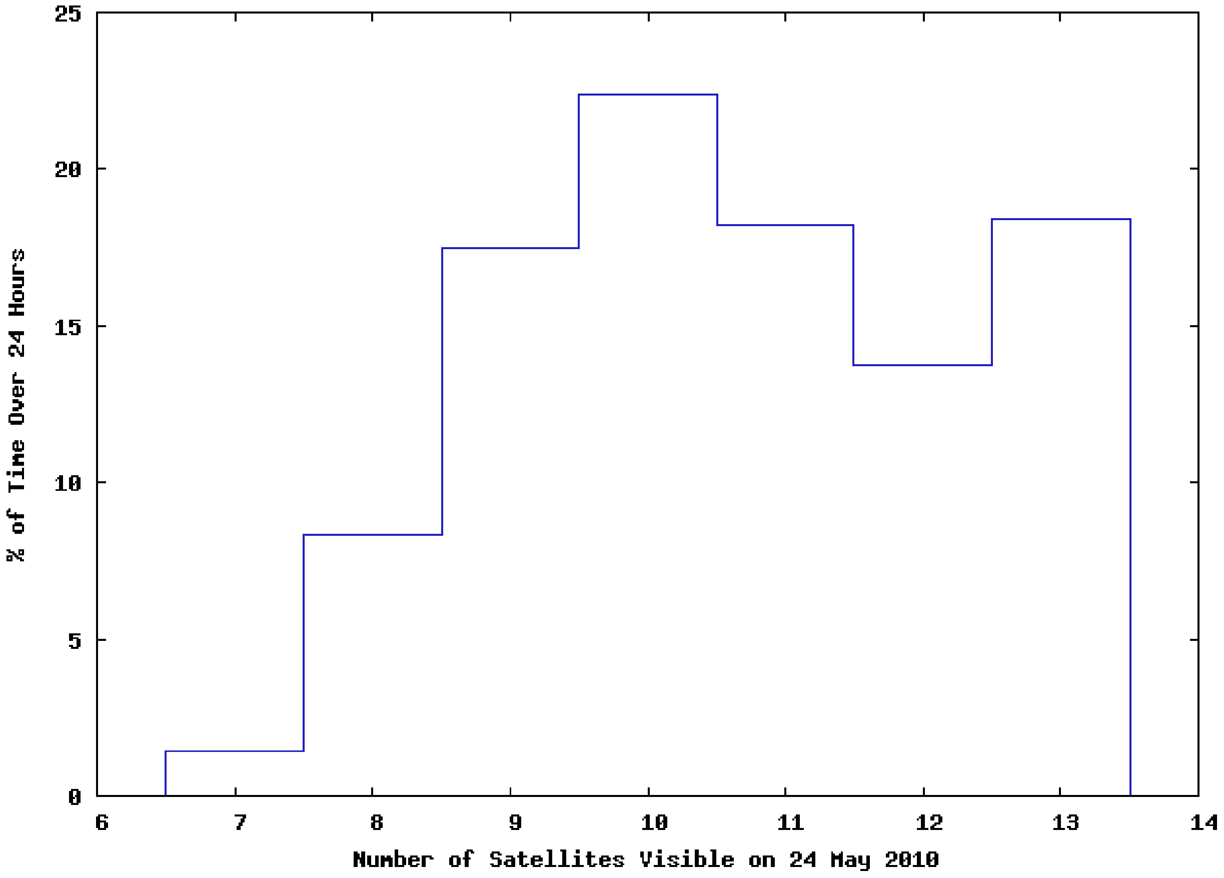


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lat: -60: Lon: -165)



# 3.0 NANU Summary and Evaluation

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

| Status and Problem Reporting | Conditions and Constraints |
|---|---|
| Scheduled event affecting service<br>• Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event | • For any SPS SIS |
| Unscheduled outage or problem affecting service<br>• Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event | • For any SPS SIS |

## 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 2010, there were a total of twenty reported outages. Seventeen of these outages were maintenance activities and were reported in advance while three 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 (if any) are provided in Table 3-3. The minimum duration a scheduled outage was forecasted ahead of time was 97.515 hours, which exceeded the 48-hour requirement. The maximum response time for a NANU issued for an unscheduled outage was 1.166 hours.

**Table 3-1 NANUs Affecting Satellite Availability**

| NANU # | PRN | Type | Start Date | Start Time | End Date | End Time | Total Unscheduled | Total Scheduled | Total |
|---|---|---|---|---|---|---|---|---|---|
| 2010061 | 19 | FCSTSUMM | 02-Apr | 06:09:00 PM | 02-Apr | 09:48:00 PM | | 3.65 | 3.65 |
| 2010063 | 28 | FCSTSUMM | 06-Apr | 05:14:00 AM | 06-Apr | 08:35:00 AM | | 3.35 | 3.35 |
| 2010064 | 29 | FCSTSUMM | 07-Apr | 12:16:00 PM | 07-Apr | 04:15:00 PM | | 3.983333333 | 3.983333333 |
| 2010067 | 2 | FCSTSUMM | 09-Apr | 08:41:00 AM | 09-Apr | 06:35:00 PM | | 9.9 | 9.9 |
| 2010069 | 9 | FCSTSUMM | 23-Mar | 11:47:00 PM | 12-Apr | 02:16:00 PM | | 470.4833333 | 470.4833333 |
| 2010071 | 14 | FCSTSUMM | 14-Apr | 09:12:00 PM | 15-Apr | 12:27:00 AM | | 3.25 | 3.25 |
| 2010075 | 13 | FCSTSUMM | 20-Apr | 06:32:00 PM | 20-Apr | 10:07:00 PM | | 3.583333333 | 3.583333333 |
| 2010076 | 18 | FCSTSUMM | 21-Apr | 02:16:00 PM | 21-Apr | 06:07:00 PM | | 3.85 | 3.85 |
| 2010079 | 23 | FCSTSUMM | 22-Apr | 05:21:00 PM | 22-Apr | 10:28:00 PM | | 5.116666667 | 5.116666667 |
| 2010080 | 17 | FCSTSUMM | 27-Apr | 03:19:00 AM | 27-Apr | 06:42:00 AM | | 3.383333333 | 3.383333333 |
| 2010084 | 11 | FCSTSUMM | 29-Apr | 07:01:00 PM | 29-Apr | 10:09:00 PM | | 3.133333333 | 3.133333333 |
| 2010085 | 16 | FCSTSUMM | 03-May | 12:24:00 PM | 03-May | 03:42:00 PM | | 3.3 | 3.3 |
| 2010086 | 5 | FCSTSUMM | 04-May | 07:57:00 AM | 04-May | 11:04:00 AM | | 3.116666667 | 3.116666667 |
| 2010089 | 9 | FCSTSUMM | 07-May | 04:05:00 AM | 07-May | 11:47:00 AM | | 7.7 | 7.7 |
| 2010091 | 13 | FCSTSUMM | 11-May | 10:36:00 PM | 12-May | 04:27:00 AM | | 5.85 | 5.85 |
| 2010092 | 13 | FCSTSUMM | 11-May | 10:36:00 PM | 12-May | 04:47:00 AM | | 6.183333333 | 6.183333333 |
| 2010093 | 22 | FCSTSUMM | 14-May | 11:54:00 AM | 14-May | 06:53:00 PM | | 6.983333333 | 6.983333333 |
| 2010096 | 16 | UNUSABLE | 21-May | 10:23:00 AM | 21-May | 06:59:00 PM | 8.6 | | 8.6 |
| 2010097 | 32 | UNUSABLE | 21-May | 08:01:00 AM | 25-May | 05:02:00 PM | 105.0166667 | | 105.0166667 |
| 2010101 | 16 | UNUSABLE | 24-Jun | 04:14:00 PM | 25-Jun | 01:09:00 AM | 8.916666667 | | 8.916666667 |
| | **Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime** | | | | | | **122.53** | **546.82** | **669.35** |

### General NANU's

NANU 2010098 advised of a launch of PRN 25

NANU 2010068 advised users that testing in PRN 1 signal characterization will continue for six months

| NANU # | PRN | Type | Start Date | Start Time | End Date | End Time | Total | Comments |
|---|---|---|---|---|---|---|---|---|
| | | **Table 3-2 NANUs Forecasted to Affect Satellite Availability** | | | | | | |
| 2010059 | 28 | FCSTMX | 06-Apr | 05:00 | 06-Apr | 17:00 | 12 | See Nanu 2010063 |
| 2010060 | 29 | FCSTMX | 07-Apr | 11:30 | 07-Apr | 23:30 | 12 | See Nanu 2010064 |
| 2010062 | 2 | FCSTDV | 09-Apr | 08:30 | 09-Apr | 20:30 | 12 | See Nanu 2010067 |
| 2010065 | 18 | FCSTMX | 13-Apr | 15:00 | 14-Apr | 03:00 | 12 | See Nanu 2010070 |
| 2010065 | 18 | FCSTMX | 13-Apr | 15:00 | 14-Apr | 03:00 | 12 | See Nanu 2010076 |
| 2010066 | 14 | FCSTMX | 14-Apr | 21:00 | 15-Apr | 09:00 | 12 | See Nanu 2010071 |
| 2010070 | 18 | FCSTRESCD | 21-Apr | 14:00 | 22-Apr | 02:00 | 12 | See Nanu 2010065 |
| 2010072 | 13 | FCSTMX | 20-Apr | 18:00 | 21-Apr | 06:00 | 12 | See Nanu 2010075 |
| 2010073 | 18 | FCSTMX | 21-Apr | 14:00 | 22-Apr | 02:00 | 12 | See Nanu 2010076 |
| 2010074 | 23 | FCSTMX | 22-Apr | 17:00 | 23-Apr | 05:00 | 12 | See Nanu 2010079 |
| 2010077 | 17 | FCSTMX | 27-Apr | 03:00 | 27-Apr | 15:00 | 12 | See Nanu 2010080 |
| 2010078 | 11 | FCSTMX | 29-Apr | 18:00 | 30-Apr | 06:00 | 12 | See Nanu 2010084 |
| 2010081 | 16 | FCSTMX | 03-May | 12:00 | 04-May | 00:00 | 12 | See Nanu 2010085 |
| 2010082 | 5 | FCSTMX | 04-May | 07:30 | 04-May | 19:30 | 12 | See Nanu 2010086 |
| 2010083 | 9 | FCSTDV | 07-May | 03:45 | 07-May | 15:45 | 12 | See Nanu 2010089 |
| 2010087 | 13 | FCSTDV | 11-May | 16:15 | 12-May | 04:15 | 12 | See Nanu 2010091 |
| 2010087 | 13 | FCSTDV | 11-May | 16:15 | 12-May | 04:15 | 12 | See Nanu 2010090 |
| 2010088 | 22 | FCSTDV | 14-May | 11:45 | 15-May | 02:15 | 14.5 | See Nanu 2010093 |
| 2010090 | 13 | FCSTEXTD | 12-May | 04:15 | N/A | N/A | N/A | See Nanu 2010092 |
| 2010094 | 32 | UNUSUFN | 21-May | 08:01 | N/A | N/A | N/A | See Nanu 2010097 |
| 2010095 | 16 | UNUSUFN | 21-May | 10:23 | N/A | N/A | N/A | See Nanu 2010096 |
| 2010099 | 16 | UNUSUFN | 24-Jun | 16:14 | N/A | N/A | N/A | See Nanu 2010101 |
| | | | | | | **Total Forecast Downtime** | **218.50** | |

| NANU# | PRN | Type | Start Date | Start Time | Comments |
|---|---|---|---|---|---|
| | **Table 3-3 NANUs Canceled** | | | | |
| None | | | | | |

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-10<br>30-Jun-10 | 1-Oct-99<br>30-Jun-10 |
|---|---|---|
| Total Forecast Downtime (hrs): | 218.50 | 7733.30 |
| Total Actual Downtime (hrs): | 669.35 | 28073.44 |
| Total Actual Scheduled Downtime (hrs): | 546.82 | 4394.70 |
| Total Actual Unscheduled Downtime (hrs): | 122.53 | 23678.74 |
| Total Satellite Observed MTTR (hrs): | 33.47 | 45.57 |
| Scheduled Satellite Observed MTTR (hrs): | 32.17 | 9.72 |
| Unscheduled Satellite Observed MTTR (hrs): | 40.84 | 144.38 |
| # Total Satellite Outages: | 20 | 616 |
| # Scheduled Satellite Outages: | 17 | 452 |
| # Unscheduled Satellite Outages: | 3 | 164 |
| Percent Operational -- Scheduled Downtime: | 99.192 | 98.799 |
| Percent Operational -- All Downtime: | 99.971 | 99.812 |

**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<br><br>• ≥ 99% Vertical Service Availability, average location | • 17m Horizontal (SIS only) 95% threshold<br>• 37m Vertical (SIS only) 95% threshold<br>• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. |
| • ≥ 90% Horizontal Service Availability, worst-case location<br><br>• ≥ 90% Vertical Service Availability, worst-case location | • 17m Horizontal (SIS only) 95% threshold<br>• 37m Vertical (SIS only) 95% threshold<br>• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. |

To verify availability, the data collected from receivers at the twenty-eight WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-5. The data was collected at one-second intervals between 1 April and 30 June 2010.

**Table 3-5 Accuracies Exceeding Threshold Statistics**

| Site | Total Number of Seconds of SPS Monitoring | Instances of 24-hour Threshold Failures | Quarters Service Availability % |
|---|---|---|---|
| **Albuquerque** | 7852409 | 0 | 100% |
| **Anchorage** | 7853114 | 0 | 100% |
| **Atlanta** | 7766651 | 0 | 100% |
| **Barrow** | 7849214 | 0 | 100% |
| **Bethel** | 7793379 | 0 | 100% |
| **Billings** | 7854061 | 0 | 100% |
| **Boston** | 7855096 | 0 | 100% |
| **Cleveland** | 7768373 | 0 | 100% |
| **Cold Bay** | 7848085 | 0 | 100% |
| **Fairbanks** | 7849226 | 0 | 100% |
| **Gander** | 7844936 | 0 | 100% |
| **Honolulu** | 7834674 | 0 | 100% |
| **Houston** | 7853724 | 0 | 100% |
| **Iqaluit** | 7828087 | 0 | 100% |
| **Juneau** | 7848561 | 0 | 100% |
| **Kansas City** | 7852192 | 0 | 100% |
| **Kotzebue** | 7847334 | 0 | 100% |
| **Los Angeles** | 7853184 | 0 | 100% |
| **Merida** | 7840058 | 0 | 100% |
| **Miami** | 7854608 | 0 | 100% |
| **Minneapolis** | 7778282 | 0 | 100% |
| **Oakland** | 7767901 | 0 | 100% |
| **Salt Lake City** | 7854860 | 0 | 100% |
| **San Jose Del Cabo** | 7852395 | 0 | 100% |
| **San Juan** | 7765884 | 0 | 100% |
| **Seattle** | 7768208 | 0 | 100% |
| **Tapachula** | 6443052 | 0 | 100% |
| **Washington, DC** | 7855127 | 0 | 100% |
| **Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)** | | | |

## 4.0 User Range Error Accuracy 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.*

| User Range Error Accuracy | Conditions and Constraints |
|---|---|
| Single Frequency C/A-Code<br><br>• ≤ 30m 99.94% Global Average URE during normal operations<br><br>• ≤ 30m 99.79% Worst Case single point average during normal operations. | • For any healthy SPS SIS.<br>• Neglecting single-frequency ionospheric delay model errors<br>• Including group delay time correction ($T_{GD}$) errors at L1<br>• Including inter-signal bias (P(Y)-code to C/A-code) errors at L1<br>• Standard based on measurement interval of one year; average of daily values within service volume<br>• Standard based on 3 service failures per year, lasting no more than 6 hours each |

Table 4-1 shows a comparison to the service reliability standard for range data collected at a set of six receivers across North America. Although the specification calls for yearly evaluations, we will be evaluating this SPS requirement at quarterly intervals. Additional range analysis results can be found in table 5-2 on page 21. The maximum User Range Error recorded this quarter was 26.052 meters on satellite PRN 10.

**Table 4-1 User Range Error Accuracy**

| Date Range of Data Collection | Site | Number of Samples This Quarter | Number of Samples where SPS URE > 30m NTE | Percentage |
|---|---|---|---|---|
| 1 Apr – 30 Jun 2010 | **Boston** | 64,389,476 | 0 | 100% |
| 1 Apr – 30 Jun 2010 | **Honolulu** | 66,998,175 | 0 | 100% |
| 1 Apr – 30 Jun 2010 | **Los Angeles** | 66,674,429 | 0 | 100% |
| 1 Apr – 30 Jun 2010 | **Miami** | 64,332,177 | 0 | 100% |
| 1 Apr – 30 Jun 2010 | **San Juan** | 67,348,224 | 0 | 100% |
| 1 Apr – 30 Jun 2010 | **Juneau** | 67,133,249 | 0 | 100% |
| 1 Apr – 30 Jun 2010 | **Global** | 396,875,730 | 0 | 100% |

# 5.0 Accuracy Standard

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

| Position/Time Accuracy | Conditions and Constraints |
|---|---|
| Global Average Position Domain Accuracy<br>• ≤ 9m 95% Horizontal Error<br>• ≤ 15m 95% Vertical Error | • Defined for a position/time solution meeting the representative user conditions<br>• Standard based on a measurement interval of 24 hours averaged over all points in the service volume. |
| Worst Site Position Domain Accuracy<br><br>• ≤ 17m 95% Horizontal Error<br>• ≤ 37m 95% Vertical Error | • Defined for a position/time solution meeting the representative user conditions<br>• Standard based on a measurement interval of 24 hours averaged over all points in the service volume. |
| Time Transfer Domain Accuracy<br><br>• ≤ 40 nanoseconds time transfer error 95% of time (SIS only) | • Defined for a time transfer solution meeting the representative user conditions<br>• Standard based on a measurement interval of 24 hours averaged over all points in the service volume. |

| User Range Accuracy | Conditions and Constraints |
|---|---|
| Single Frequency C/A-Code<br>• ≤ 7.8m 9%% Global Average URE during normal operations over All AODs<br>• ≤ 6.0m 95% Global Average URE during operations at Zero AOD<br>• ≤ 12.8m 95% Global Average URE during normal operations at Any AOD | • For any healthy SPS SIS<br>• Neglecting single-frequency ionospheric delay model errors<br>• Including group delay time correction ($T_{GD}$) errors at L1<br>• Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 |
| Single-Frequency C/A-Code:<br><br>• ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD | • For any healthy SPS SIS<br>• Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers<br>• Neglecting single-frequency ionospheric delay model errors |
| Single-Frequency C/A-Code:<br><br>• ≤ 2 mm/sec$^2$ 95% Global average URAE over any 3-second interval during normal operations at Any AOD | • For any healthy SPS SIS<br>• Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers<br>• Neglecting single-frequency ionospheric delay model errors |
| **Coordinated Universal Time Offset Error Accuracy** | **Conditions and Constraints** |
| • ≤ 40 nanoseconds 95% Global average UTCOE during normal operations at Any AOD. | • For any healthy SPS SIS |

### 5.1 Position Accuracy

The data used for this section was collected for every second from 1 April through 30 June 2010 at the selected WAAS locations.

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

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

| Site | 95% Horizontal (Meters) | 95% Vertical (Meters) | 99.99% Horizontal (Meters) | 99.99% Vertical (Meters) |
|---|---|---|---|---|
| **Albuquerque** | 2.204 | 3.978 | 6.709 | 9.406 |
| **Anchorage** | 1.990 | 3.641 | 4.199 | 7.662 |
| **Atlanta** | 2.206 | 3.987 | 7.739 | 8.920 |
| **Barrow** | 1.635 | 3.881 | 3.351 | 9.675 |
| **Bethel** | 2.018 | 3.717 | 4.239 | 9.337 |
| **Billings** | 1.960 | 3.732 | 6.084 | 7.809 |
| **Boston** | 2.013 | 3.714 | 7.822 | 7.630 |
| **Cleveland** | 1.979 | 3.658 | 7.494 | 7.043 |
| **Cold Bay** | 2.093 | 3.774 | 4.111 | 7.932 |
| **Fairbanks** | 1.867 | 3.729 | 3.455 | 8.533 |
| **Gander** | 2.046 | 3.595 | 7.633 | 8.698 |
| **Honolulu** | 3.932 | 4.407 | 9.330 | 10.898 |
| **Houston** | 2.633 | 3.778 | 7.711 | 8.318 |
| **Iqaluit** | 1.691 | 3.490 | 6.781 | 17.807 |
| **Juneau** | 1.951 | 3.459 | 3.672 | 7.462 |
| **Kansas City** | 2.007 | 3.935 | 7.201 | 7.533 |
| **Kotzebue** | 1.929 | 3.818 | 3.798 | 8.672 |
| **Los Angeles** | 2.426 | 4.164 | 6.471 | 9.561 |
| **Merida** | 3.587 | 4.037 | 10.731 | 15.537 |
| **Miami** | 2.785 | 3.995 | 7.801 | 13.184 |
| **Minneapolis** | 1.942 | 3.709 | 6.664 | 7.455 |
| **Oakland** | 2.329 | 4.128 | 6.231 | 10.100 |
| **Salt Lake City** | 1.994 | 3.973 | 6.473 | 9.897 |
| **San Jose Del Cabo** | 4.019 | 4.247 | 8.780 | 16.363 |
| **San Juan** | 2.794 | 4.120 | 8.239 | 15.161 |
| **Seattle** | 2.090 | 3.651 | 4.708 | 7.904 |
| **Tapachula** | 4.510 | 5.117 | 13.213 | 17.422 |
| **Washington, DC** | 2.100 | 3.840 | 8.000 | 8.132 |

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-eight WAAS sites from 1 April to 30 June 2010.

**Figure 5-1 Global Vertical Error Histogram**

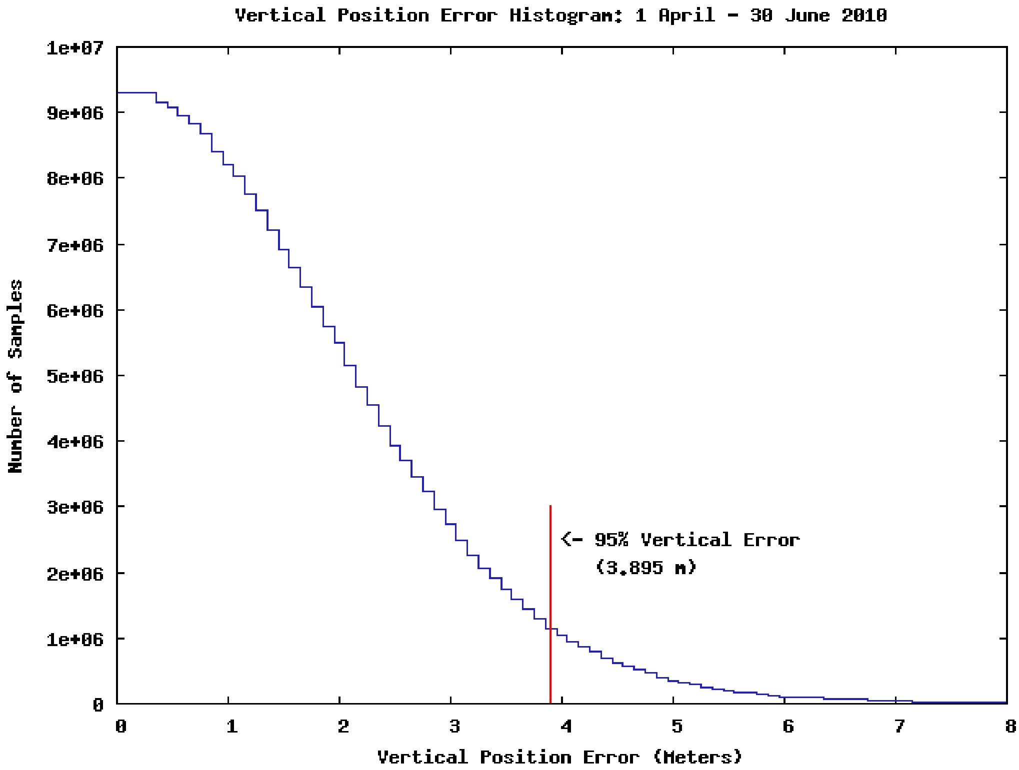
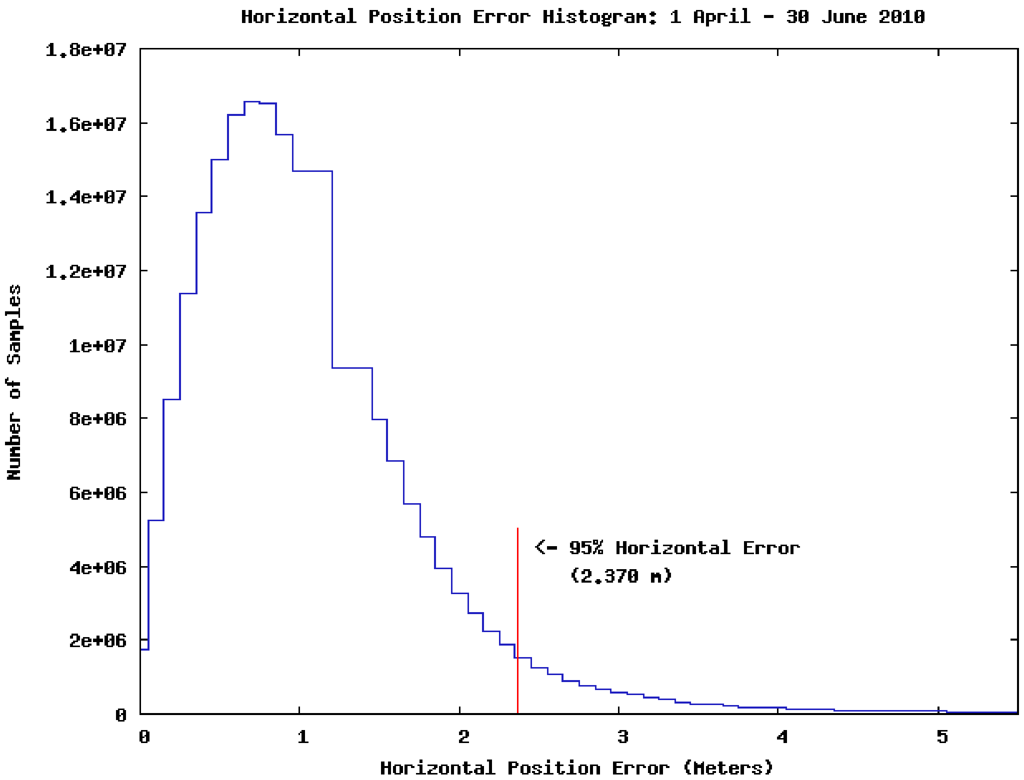


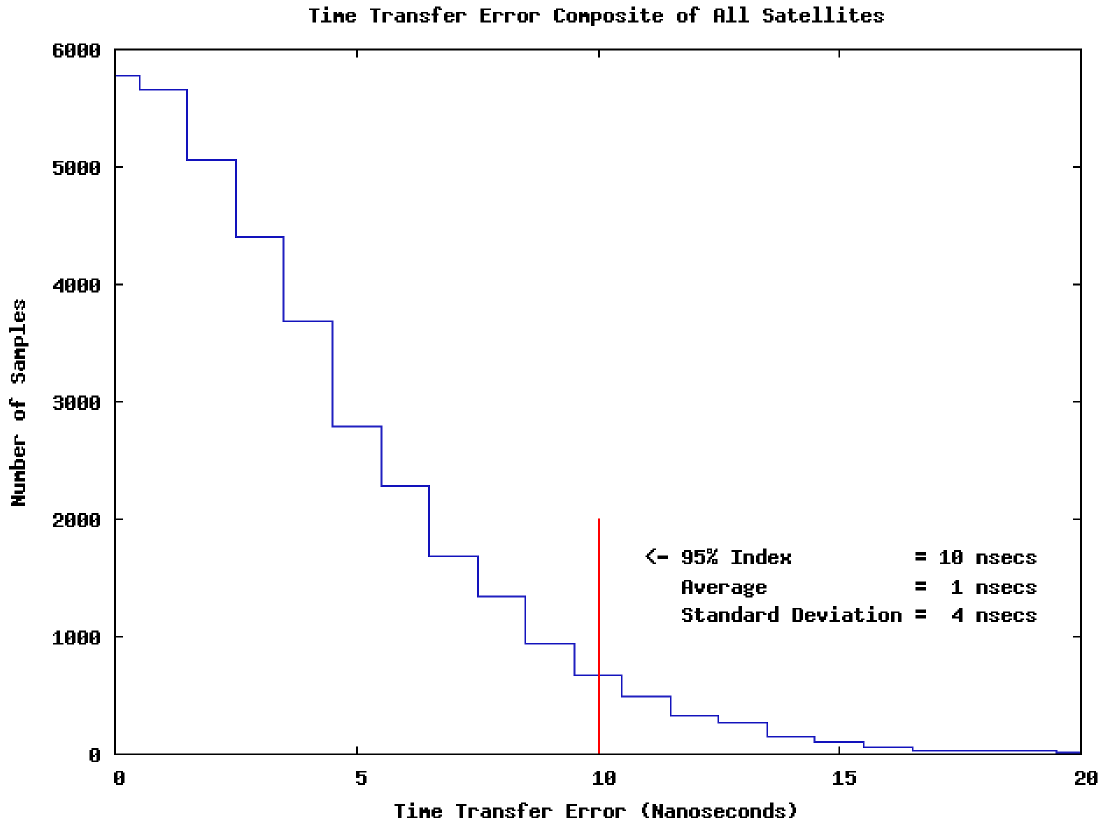

**Figure 5-2 Global Horizontal Error Histogram**



### 5.2 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 2010 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 2010.

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

**Table 5-2 Range Error Statistics (meters)**

| PRN | RMS Range Error (≤ 6 m) | Range Error Mean | 1σ | 95% Range Error | Max Range Error (SPS Spec. ≤ 30 m) | Samples |
|---|---|---|---|---|---|---|
| 2 | 1.605 | 0.775 | 1.289 | 3.050 | 13.220 | 14230316 |
| 3 | 1.734 | 0.415 | 1.323 | 3.117 | 11.692 | 12441332 |
| 4 | 1.534 | 0.448 | 1.253 | 2.930 | 12.986 | 14111593 |
| 5 | 1.533 | -0.448 | 1.350 | 2.892 | 11.135 | 14037235 |
| 6 | 1.428 | 0.120 | 1.142 | 2.631 | 13.059 | 12842719 |
| 7 | 1.574 | -0.409 | 1.253 | 2.895 | 10.590 | 12319251 |
| 8 | 1.857 | 0.587 | 1.459 | 3.464 | 12.194 | 13123992 |
| 9 | 1.807 | 0.259 | 1.365 | 3.248 | 21.115 | 11341938 |
| 10 | 2.165 | 1.227 | 1.531 | 3.984 | 26.052 | 12897504 |
| 11 | 1.473 | 0.631 | 1.111 | 2.704 | 11.984 | 12426468 |
| 12 | 1.473 | 0.235 | 1.292 | 2.879 | 14.111 | 14396385 |
| 13 | 1.463 | -0.132 | 1.209 | 2.775 | 13.927 | 13785945 |
| 14 | 1.399 | 0.487 | 1.093 | 2.537 | 13.138 | 14101707 |
| 15 | 1.344 | -0.216 | 1.139 | 2.554 | 23.128 | 12850730 |
| 16 | 1.620 | 0.624 | 1.260 | 2.941 | 13.125 | 13006738 |
| 17 | 1.544 | 0.276 | 1.309 | 2.975 | 14.289 | 14228498 |
| 18 | 1.579 | 0.889 | 1.164 | 2.834 | 14.091 | 13065045 |
| 19 | 1.577 | 0.922 | 1.106 | 2.914 | 19.570 | 12618029 |
| 20 | 1.556 | 0.747 | 1.218 | 2.959 | 17.814 | 14279397 |
| 21 | 1.671 | 1.060 | 1.172 | 2.934 | 13.684 | 12325982 |
| 22 | 1.643 | 0.709 | 1.138 | 2.948 | 14.232 | 12300203 |
| 23 | 1.455 | 0.188 | 1.155 | 2.677 | 13.377 | 12962021 |
| 24 | 1.697 | 0.640 | 1.240 | 2.971 | 10.955 | 12900941 |
| 26 | 1.432 | 0.192 | 1.176 | 2.694 | 18.981 | 12967507 |
| 27 | 1.872 | 0.593 | 1.481 | 3.408 | 15.207 | 13649066 |
| 28 | 1.857 | 0.785 | 1.384 | 3.320 | 12.579 | 12815978 |
| 29 | 1.352 | 0.203 | 1.112 | 2.550 | 11.836 | 13829664 |
| 30 | 1.747 | 0.128 | 1.441 | 3.376 | 21.953 | 13346177 |
| 31 | 1.480 | -0.094 | 1.218 | 2.729 | 13.218 | 14153707 |
| 32 | 1.654 | 0.845 | 1.192 | 2.977 | 13.067 | 13519662 |

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

| PRN | Range Rate Error RMS (mm/s) | 95% Range Rate Error (mm/s) | Max Range Rate Error (mm/s) | Samples |
|---|---|---|---|---|
| 2 | 1.467 | 2.810 | 64.57 | 14230316 |
| 3 | 1.819 | 2.923 | 157.43 | 12441332 |
| 4 | 1.509 | 2.683 | 113.18 | 14111593 |
| 5 | 1.462 | 2.814 | 54.87 | 14037235 |
| 6 | 1.490 | 2.660 | 121.10 | 12842719 |
| 7 | 1.436 | 2.739 | 65.75 | 12319251 |
| 8 | 1.975 | 3.130 | 152.51 | 13123992 |
| 9 | 1.842 | 2.904 | 221.86 | 11341938 |
| 10 | 1.946 | 3.107 | 174.18 | 12897504 |
| 11 | 1.447 | 2.725 | 79.69 | 12426468 |
| 12 | 1.490 | 2.919 | 96.06 | 14396385 |
| 13 | 1.444 | 2.780 | 81.33 | 13785945 |
| 14 | 1.443 | 2.760 | 77.57 | 14101707 |
| 15 | 1.417 | 2.753 | 81.82 | 12850730 |
| 16 | 1.446 | 2.790 | 142.39 | 13006738 |
| 17 | 1.528 | 2.800 | 126.30 | 14228498 |
| 18 | 1.443 | 2.750 | 58.87 | 13065045 |
| 19 | 1.393 | 2.681 | 64.67 | 12618029 |
| 20 | 1.448 | 2.811 | 81.13 | 14279397 |
| 21 | 1.511 | 2.871 | 126.55 | 12325982 |
| 22 | 1.657 | 2.867 | 152.09 | 12300203 |
| 23 | 1.407 | 2.690 | 251.98 | 12962021 |
| 24 | 1.628 | 2.781 | 162.81 | 12900941 |
| 26 | 1.424 | 2.648 | 262.79 | 12967507 |
| 27 | 1.950 | 2.908 | 252.12 | 13649066 |
| 28 | 1.599 | 2.800 | 126.41 | 12815978 |
| 29 | 1.446 | 2.729 | 114.63 | 13829664 |
| 30 | 2.017 | 3.060 | 284.91 | 13346177 |
| 31 | 1.521 | 2.771 | 107.27 | 14153707 |
| 32 | 1.503 | 2.639 | 138.01 | 13519662 |

**Table 5-4 Range Acceleration Error Statistics (micrometers/second$^2$)**

| PRN | Range Acceleration Error RMS ($\mu m/s^2$) | 95% Range Acceleration Error ($\mu m/s^2$) | Max Range Acceleration Error ($\mu m/s^2$) | Samples |
|---|---|---|---|---|
| 2 | 10.220 | 21.206 | 650 | 14230316 |
| 3 | 13.898 | 24.145 | 1590 | 12441332 |
| 4 | 10.994 | 20.111 | 1100 | 14111593 |
| 5 | 10.196 | 21.361 | 550 | 14037235 |
| 6 | 11.369 | 20.678 | 1220 | 12842719 |
| 7 | 10.350 | 20.789 | 650 | 12319251 |
| 8 | 14.985 | 26.086 | 1520 | 13123992 |
| 9 | 14.149 | 22.373 | 2210 | 11341938 |
| 10 | 14.853 | 23.843 | 1760 | 12897504 |
| 11 | 10.622 | 20.445 | 800 | 12426468 |
| 12 | 10.107 | 21.210 | 950 | 14396385 |
| 13 | 10.216 | 20.920 | 800 | 13785945 |
| 14 | 10.314 | 21.076 | 780 | 14101707 |
| 15 | 10.073 | 20.757 | 820 | 12850730 |
| 16 | 10.294 | 21.034 | 1430 | 13006738 |
| 17 | 11.169 | 21.057 | 1260 | 14228498 |
| 18 | 10.261 | 21.667 | 590 | 13065045 |
| 19 | 10.216 | 20.429 | 630 | 12618029 |
| 20 | 10.131 | 20.887 | 810 | 14279397 |
| 21 | 10.457 | 24.238 | 1260 | 12325982 |
| 22 | 12.437 | 22.778 | 1550 | 12300203 |
| 23 | 10.279 | 20.470 | 2280 | 12962021 |
| 24 | 12.268 | 20.800 | 1620 | 12900941 |
| 26 | 10.618 | 20.193 | 2630 | 12967507 |
| 27 | 15.270 | 21.702 | 2530 | 13649066 |
| 28 | 11.740 | 21.641 | 1270 | 12815978 |
| 29 | 10.535 | 20.698 | 1140 | 13829664 |
| 30 | 15.167 | 23.334 | 2850 | 13346177 |
| 31 | 11.067 | 20.904 | 1060 | 14153707 |
| 32 | 11.427 | 19.901 | 1370 | 13519662 |

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 10 with an error of 26.052 meters. Satellite 7 had the lowest maximum range error of 10.590 meters.

**Figure 5-4 Distribution of Daily Max Range Errors**

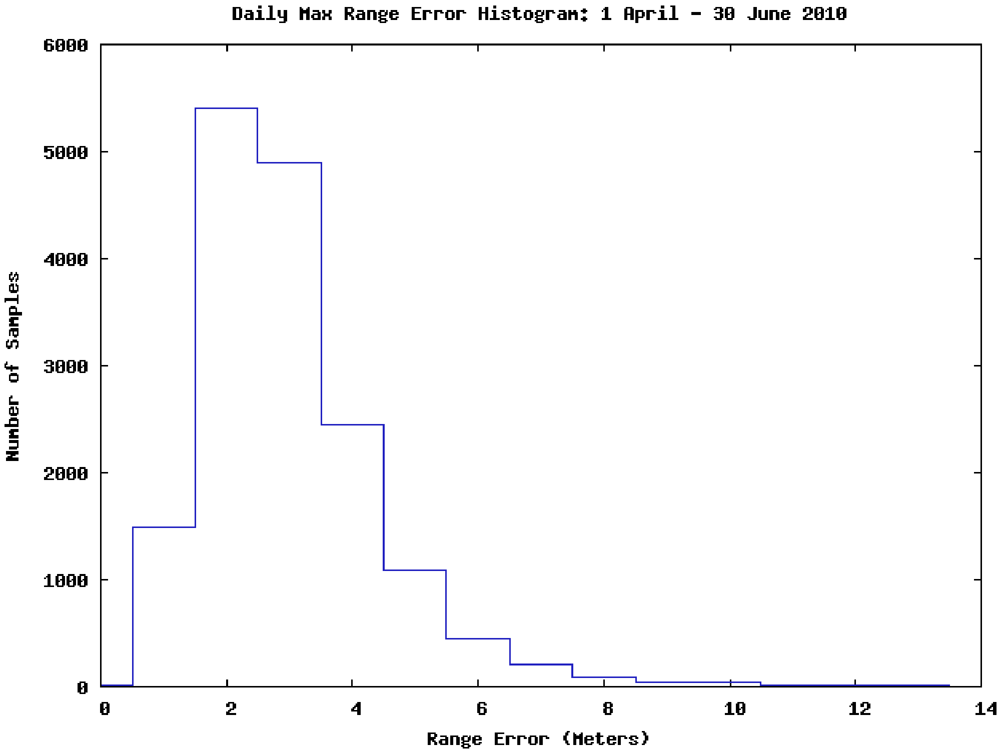



**Figure 5-5: Distribution of Daily Max Range Rate Errors**

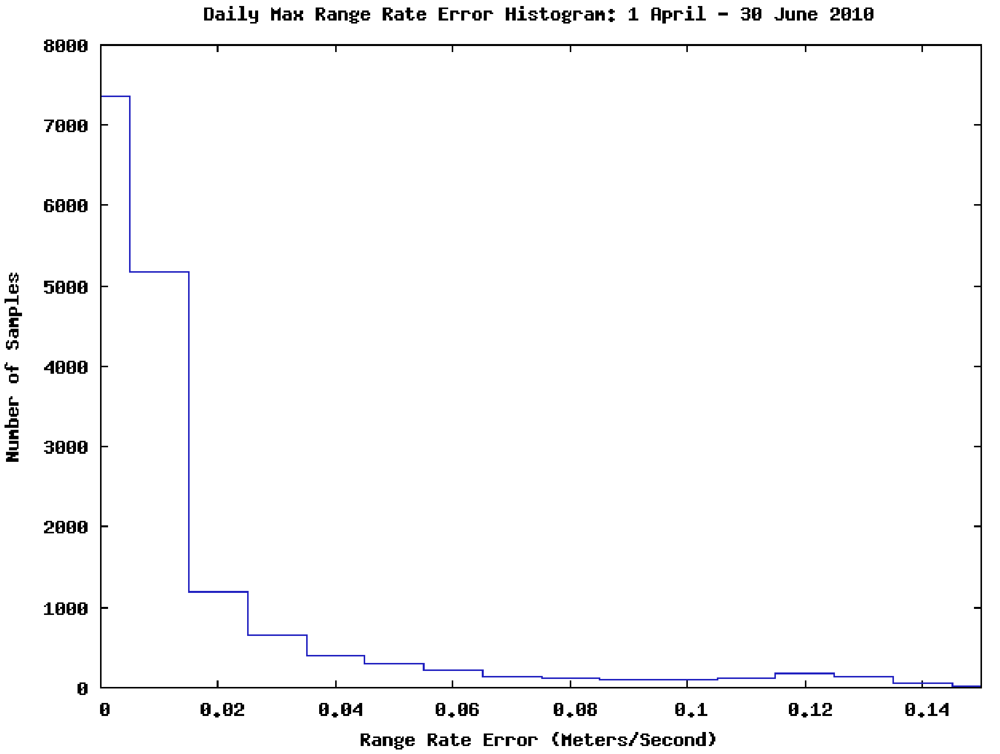


**Figure 5-6: Distribution of Daily Max Acceleration Rate Errors**

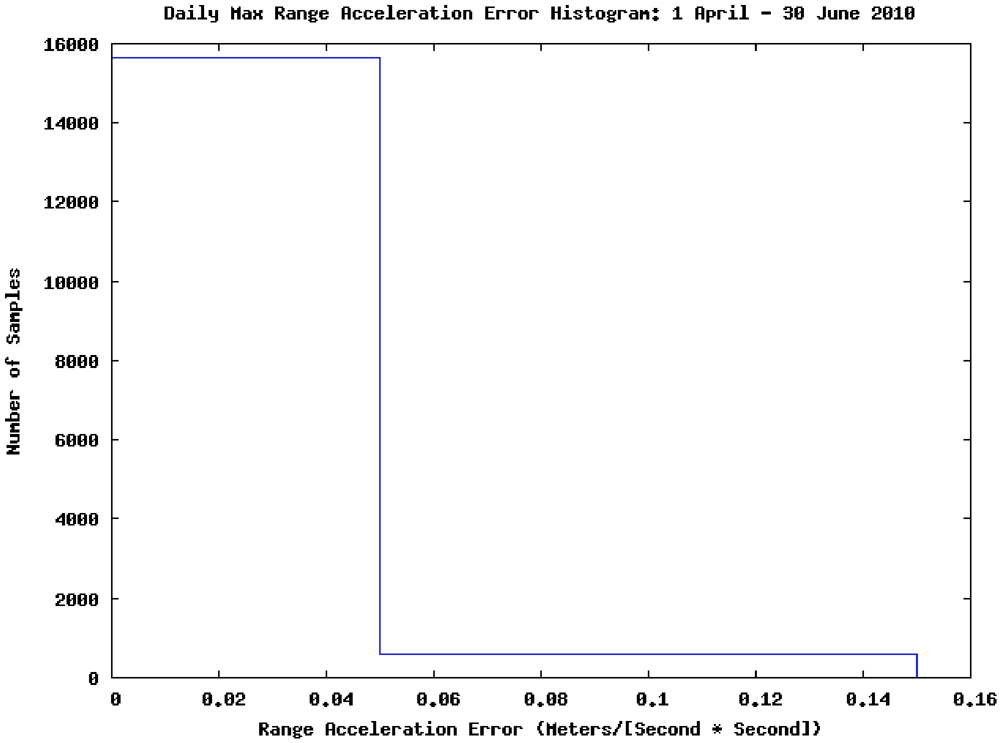
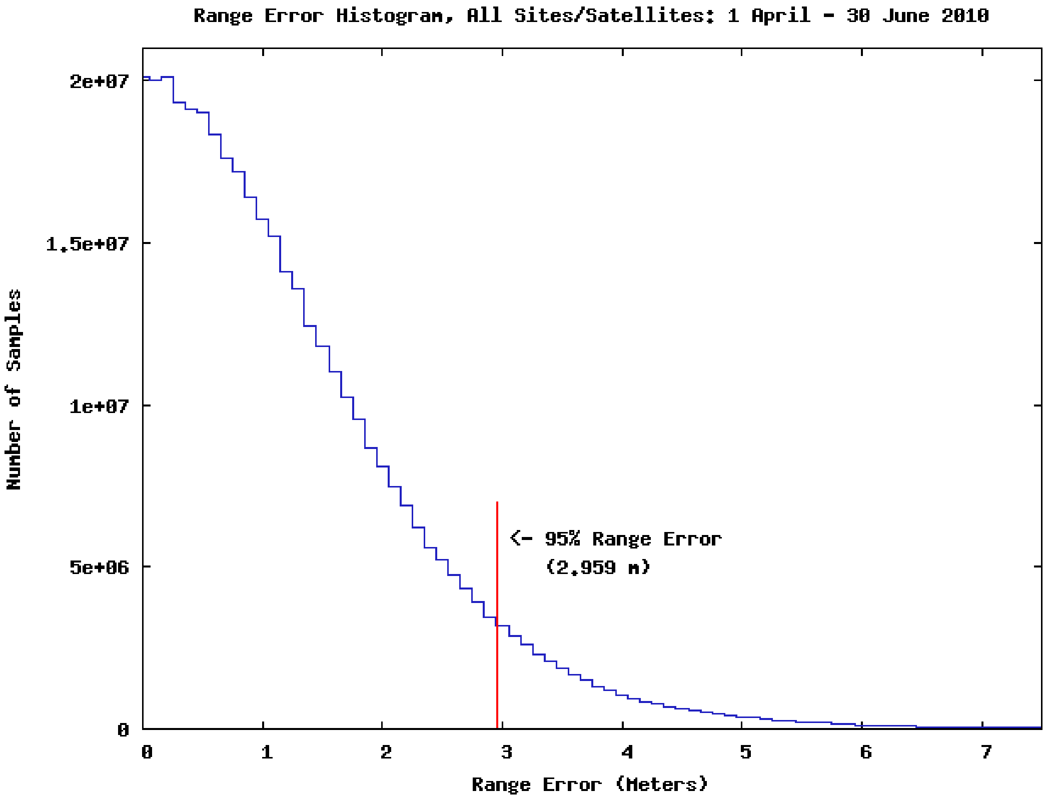



**Figure 5-7: Range Error Histogram**



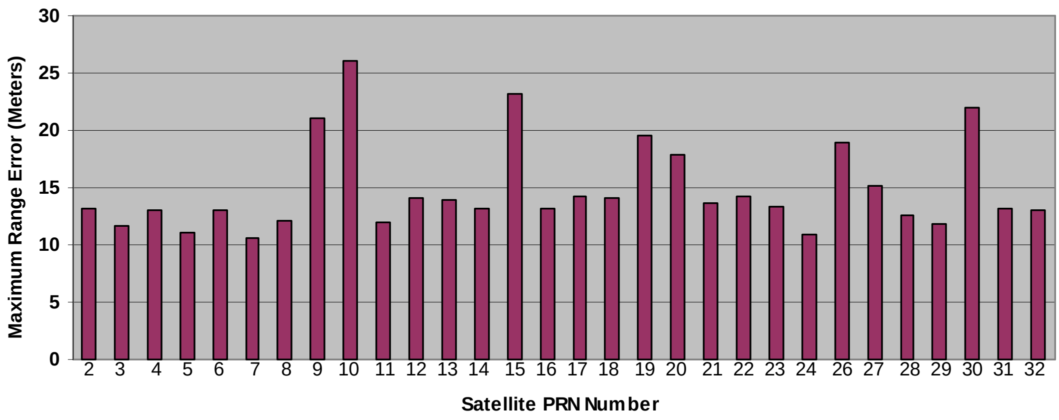


Figure 5-8: Maximum Range Error Per Satellite

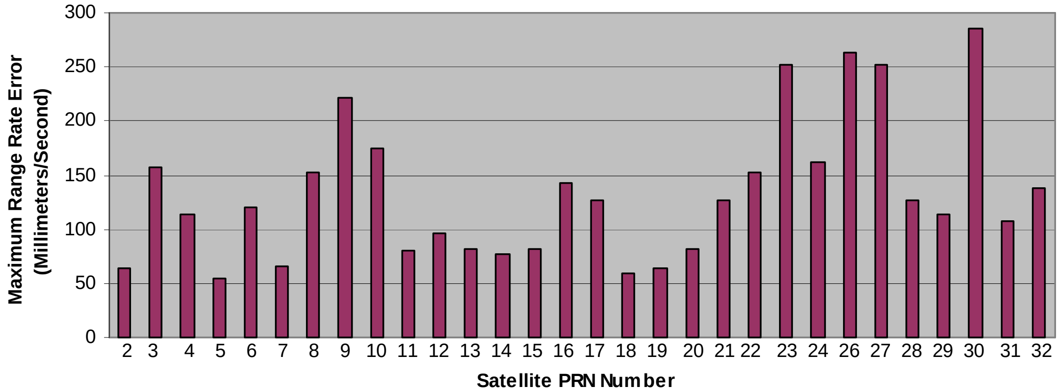


Figure 5-9: Maximum Range Rate Error Per Satellite

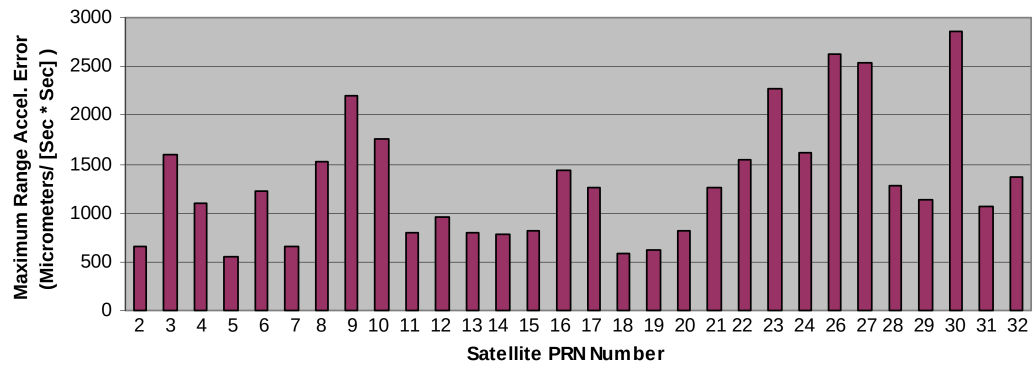


Figure 5-10: Maximum Range Acceleration Per Satellite

# 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 5-7 April 2010**

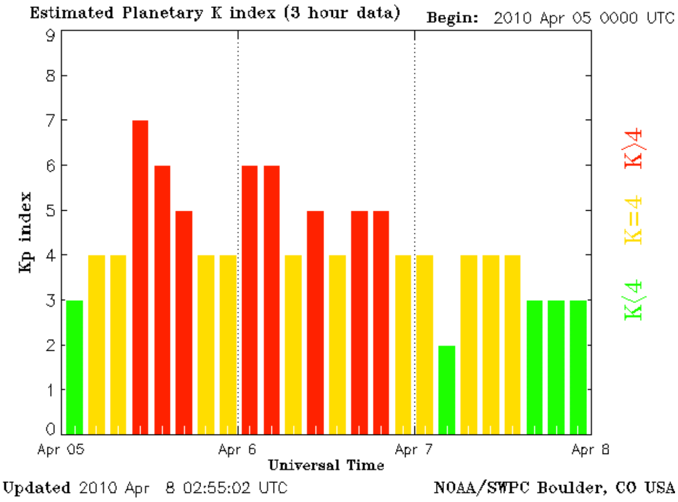



**Figure 6-2 K-Index for 2-4 May 2010**

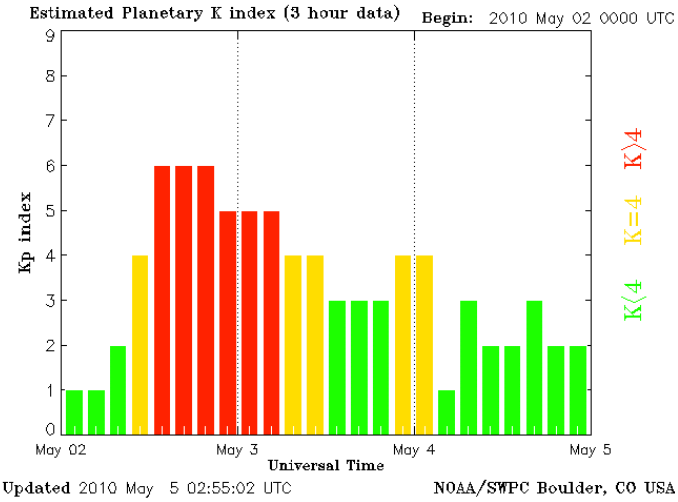



**Figure 6-3 K-Index for 29-31 May 2010**

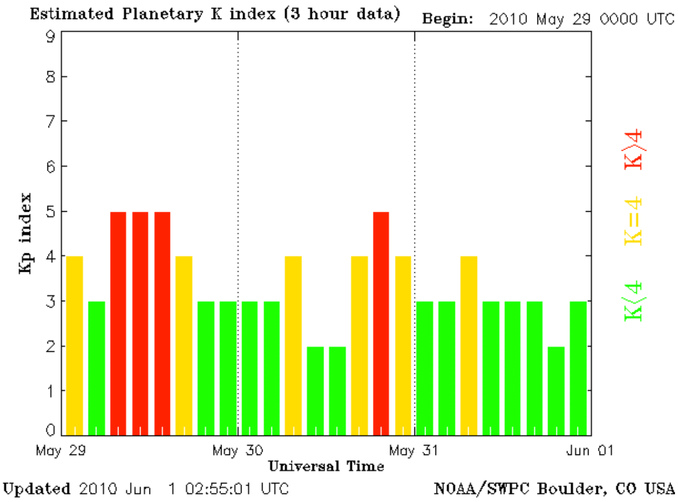


Table 6-1 shows the position accuracy information for the day corresponding to Figure 6-1. The GPS SPS performance met all requirements during all storms that occurred during this quarter.

**Table 6-1 Horizontal & Vertical Accuracy Statistics for 5 April 2010**

| Site | 95% Horizontal (Meters) | 95% Vertical (Meters) | Maximum Horizontal (Meters) | Maximum Vertical (Meters) |
|---|---|---|---|---|
| **Albuquerque** | 3.21 | 5.61 | 6.53 | 7.32 |
| **Anchorage** | 1.80 | 4.85 | 2.53 | 6.00 |
| **Atlanta** | 4.09 | 3.77 | 7.60 | 7.30 |
| **Barrow** | 1.55 | 4.66 | 3.49 | 11.30 |
| **Bethel** | 1.83 | 5.35 | 2.25 | 6.41 |
| **Billings** | 1.89 | 5.82 | 4.08 | 7.41 |
| **Boston** | 2.32 | 4.58 | 3.72 | 5.87 |
| **Cleveland** | 1.81 | 4.23 | 5.15 | 5.73 |
| **Cold Bay** | 2.32 | 5.59 | 3.03 | 6.34 |
| **Fairbanks** | 2.11 | 4.92 | 2.75 | 6.12 |
| **Gander** | 2.32 | 3.87 | 3.33 | 4.70 |
| **Honolulu** | 5.07 | 5.57 | 6.64 | 6.79 |
| **Houston** | 4.62 | 4.22 | 8.14 | 7.14 |
| **Iqaluit** | 1.62 | 3.16 | 5.41 | 15.10 |
| **Juneau** | 1.69 | 4.60 | 2.00 | 6.14 |
| **Kansas City** | 2.01 | 3.86 | 6.28 | 4.75 |
| **Kotzebue** | 1.64 | 4.89 | 5.58 | 7.25 |
| **Los Angeles** | 3.20 | 6.65 | 6.65 | 7.28 |
| **Merida** | 3.65 | 3.65 | 7.51 | 9.23 |
| **Miami** | 3.99 | 3.86 | 7.74 | 7.39 |
| **Minneapolis** | 1.59 | 3.73 | 5.75 | 5.35 |
| **Oakland** | 3.01 | 6.90 | 5.51 | 8.19 |
| **Salt Lake City** | 2.53 | 6.31 | 5.56 | 8.47 |
| **San Jose Del Cabo** | 3.96 | 4.65 | 8.75 | 10.30 |
| **San Juan** | 5.59 | 5.69 | 6.56 | 11.60 |
| **Seattle** | 2.47 | 6.30 | 3.35 | 7.70 |
| **Tapachula** | 2.84 | 4.25 | 6.11 | 12.60 |
| **Washington, DC** | 2.48 | 4.05 | 5.54 | 5.82 |

# 7.0 IGS Analysis

GPS SPS accuracy performance was evaluated at a selection of high rate IGS stations[1]. The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products.

High data rate (1 Hz) sites that had high availability in 2006, were outside of the WAAS service area, and provided a good geographic distribution have been selected. To facilitate differentiating between GPS accuracy issues and receiver tracking problems, an automatic data screening function excluded errors greater than 500 meters and or times when VDOP or HDOP were greater than 10. The remaining receiver tracking issues are still included in the processing and are forced into the 50.1 meter histogram bin and are believed to influence the outliers in the 99.99% statistics.

Table 7.1 and Figure 7-1 show the IGS site information and locations. Table 7.2 shows the GPS SPS Accuracy Performance observed at a selection of High Rate IGS sites. Figure 7-2 shows the 95% horizontal accuracy trends at these sites. Figure 7-3 shows the 95% vertical accuracy trends at these sites. A value of zero indicates no data.

(1) J.M. Dow, R.E. Neilan, G. Gendt, "The International GPS Service (IGS): Celebrating the 10th Anniversary and Looking to the Next Decade," Adv. Space Res. 36 vol. 36, no. 3, pp. 320-326, 2005. Doi: 10.1016/j.asr.2005.05.125

Table 7-1 Selected IGS Site Information

| ID | City | Country |
|---|---|---|
| GLPS | Puerto Ayora | Ecuador |
| GUAM | Dededo | Guam |
| IISC | Bangalore | India |
| KIRU | Kiruna | Sweden |
| KOUR | Kourou | French Guyana |
| MADR | Robledo | Spain |
| MAL2 | Malindi | Kenya |
| MAS1 | Maspalomas | Spain |
| MOBN | Obninsk | Russian Federation |
| NNOR | New Norcia | Australia |
| NRIL | Norilsk | Russian Federation |
| PETS | Petropavlovsk-Kamchatka | Russian Federation |
| POL2 | Bishkek | Kyrghyzstan |
| SANT | Santiago | Chile |
| SUTM | Sutherland | South Africa |
| TIDB | Tidbinbilla | Australia |
| USUD | Usuda | Japan |

Figure 7-1 Selected IGS Site Locations

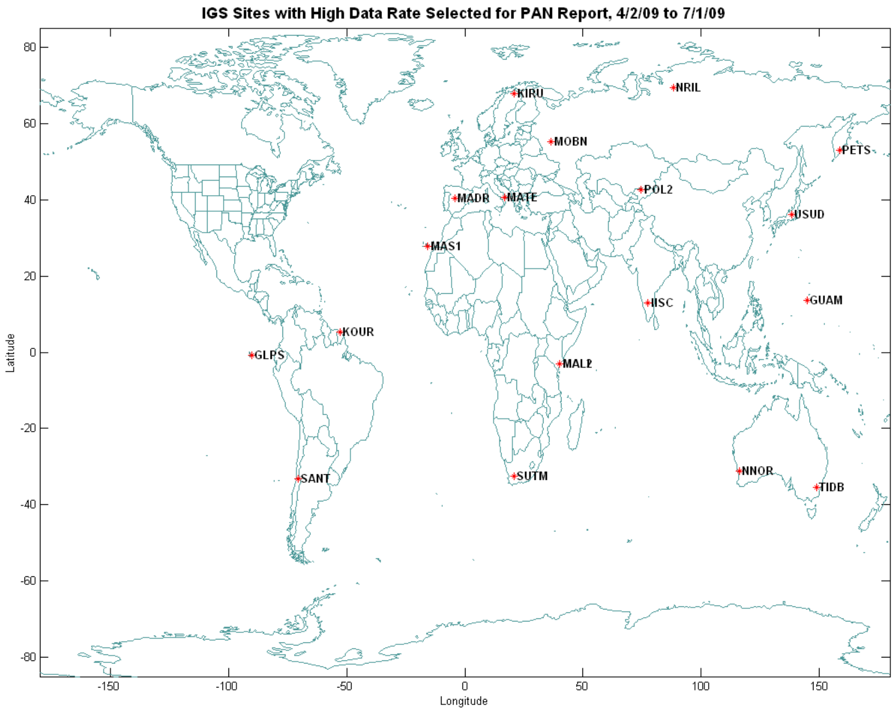



**Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites**

| site | 95% Horizontal Error (m) | 95% Vertical Error (m) | 99.99% Horizontal Error (m) | 99.99% Vertical Error (m) | Percent Data Available |
|---|---|---|---|---|---|
| GLPS | 2.59 | 3.98 | 8.27 | 35.39 | 86.33% |
| GUAM | 2.13 | 4.66 | 5.59 | 16.14 | 99.19% |
| IISC | 1.99 | 4.52 | 5.25 | 11.02 | 99.29% |
| KIRU | 1.79 | 4.14 | 5.93 | 14.85 | 99.97% |
| KOUR | 2.41 | 3.92 | 7.43 | 12.97 | 92.14% |
| MADR | 2.24 | 4.13 | 7.04 | 10.30 | 99.25% |
| MAL2 | 2.80 | 4.24 | 5.09 | 15.09 | 98.65% |
| MAS1 | 3.67 | 4.42 | 8.59 | 17.67 | 94.20% |
| MATE | 2.41 | 4.38 | 10.20 | 17.81 | 88.78% |
| MOBN | 2.43 | 4.33 | 6.20 | 10.50 | 99.29% |
| NNOR | 2.19 | 4.86 | 4.61 | 13.02 | 99.98% |
| NRIL | 1.81 | 3.95 | 4.65 | 11.69 | 98.00% |
| PETS | 2.46 | 4.45 | 5.19 | 11.11 | 94.91% |
| POL2 | 2.76 | 5.16 | 20.67 | 23.98 | 75.73% |
| SANT | 3.25 | 4.56 | 14.17 | 12.26 | 98.89% |
| SUTM | 1.87 | 3.72 | 6.24 | 10.25 | 86.84% |
| TIDB | 2.29 | 3.79 | 4.49 | 19.81 | 99.96% |
| USUD | 2.88 | 4.31 | 7.39 | 9.68 | 99.96% |

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

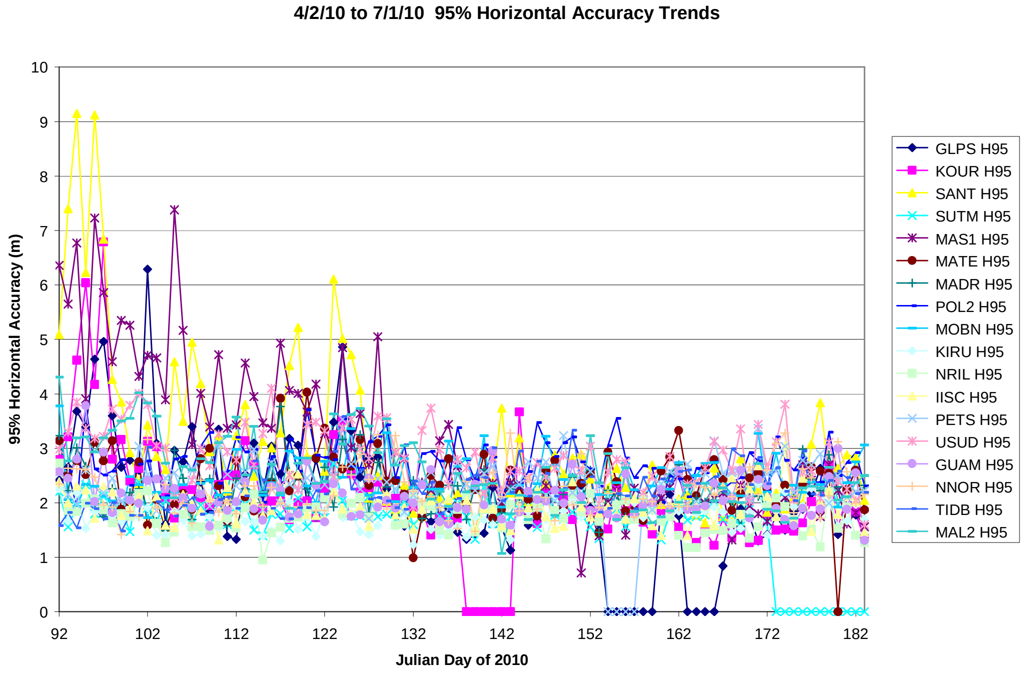
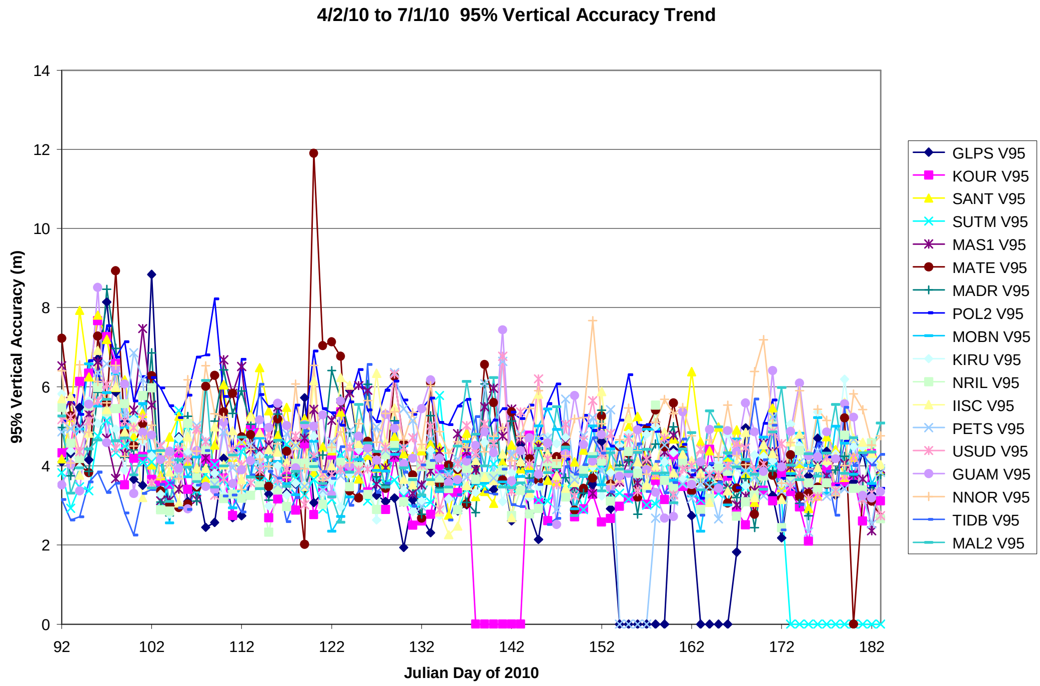



**Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites**



# APPENDICES A – D

| User Range Error Accuracy | Conditions and Constraints | Measured Performance |
|---|---|---|
| Single Frequency C/A-Code<br><br>• ≤ 7.8m 95% Global Average URE during normal operations over All AODs<br>• ≤ 6.0m 95% Global Average URE during operations at Zero AOD<br>• ≤ 12.8m 95% Global Average URE during normal operations at Any AOD | • For any healthy SPS SIS<br>• Neglecting single-frequency ionospheric delay model errors<br>• Including group delay time correction ($T_{GD}$) errors at L1<br>• Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 | ≤ 3.984m<br><br>N/A<br><br>N/A |
| Single Frequency C/A-Code<br><br>• ≤ 30m 99.94% Global Average URE during normal operations<br><br>• ≤ 30m 99.79% Worst Case single point average during normal operations. | • For any healthy SPS SIS.<br>• Neglecting single-frequency ionospheric delay model errors<br>• Including group delay time correction ($T_{GD}$) errors at L1<br>• Including inter-signal bias (P(Y)-code to C/A-code) errors at L1<br>• Standard based on measurement interval of one year; average of daily values within service volume<br>• Standard based on 3 service failures per year, lasting no more than 6 hours each | 100% Global<br><br>100% WCP |
| **User Range Rate Error Accuracy** | **Conditions and Constraints** | |
| Single-Frequency C/A-Code:<br><br>• ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD | • For any healthy SPS SIS<br>• Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers<br>• Neglecting single-frequency ionospheric delay model errors | ≤ 3.130 mm/sec |
| **User Range Acceleration Error Accuracy** | **Conditions and Constraints** | |
| Single-Frequency C/A-Code:<br><br>• ≤ 2 mm/sec$^2$ 95% Global average URAE over any 3-second interval during normal operations at Any AOD | • For any healthy SPS SIS<br>• Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers<br>• Neglecting single-frequency ionospheric delay model errors | ≤ 0.0261 mm/s$^2$ |
| **Coordinated Universal Time Offset Error Accuracy** | | |
| • ≤ 40 nanoseconds 95% Global average UTCOE during normal operations at Any AOD. | • For any healthy SPS SIS | 10 nanoseconds |

| Status and Problem Reporting | Conditions and Constraints | Measured Performance |
|---|---|---|
| Scheduled event affecting service<br>• Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event | • For any SPS SIS | ≥ 97.516 hours |
| Unscheduled outage or problem affecting service<br>• Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event | • For any SPS SIS | ≤ 1.166 hours |
| **Operational Satellite Count** | **Conditions and Constraints** | |
| • ≥ 0.95 Probability that the constellation will have a t least 24 operational satellites regardless of whether those operational satellites are located in slots or not | • Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operation satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not. | ≥ 99.298% |
| **PDOP Availability** | **Conditions and Constraints** | |
| • ≥ 98% global PDOP of 6 or less<br><br>• ≥ 88% worst site PDOP of 6 or less | • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval | ≥ 99.988%<br><br>≥ 98.194% |
| **Service Availability** | **Conditions and Constraints** | |
| • ≥ 99% Horizontal Service Availability, average location<br><br>• ≥ 99% Vertical Service Availability, average location | • 17m Horizontal (SIS only) 95% threshold<br>• 37m Vertical (SIS only) 95% threshold<br>• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. | 100% Horizontal<br><br>100% Vertical |
| • ≥ 90% Horizontal Service Availability, worst-case location<br><br>• ≥ 90% Vertical Service Availability, worst-case location | • 17m Horizontal (SIS only) 95% threshold<br>• 37m Vertical (SIS only) 95% threshold<br>• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval. | 100% Horizontal<br><br>100% Vertical |
| **Position/Time Accuracy** | **Conditions and Constraints** | |
| Global Average Position Domain Accuracy<br><br>• ≤ 9m 95% Horizontal Error<br>• ≤ 15m 95% Vertical Error | • Defined for a position/time solution meeting the representative user conditions<br>• Standard based on a measurement interval of 24 hours averaged over all points in the service volume. | ≤ 4.510m Horizontal<br><br>≤ 5.117m Vertical |
| Worst Site Position Domain Accuracy<br><br>• ≤ 17m 95% Horizontal Error<br>• ≤ 37m 95% Vertical Error | • Defined for a position/time solution meeting the representative user conditions<br>• Standard based on a measurement interval of 24 hours averaged over all points in the service volume. | ≤ 10.587m Horizontal<br><br>≤ 10.843m Vertical |
| Time Transfer Domain Accuracy<br><br>• ≤ 40 nanoseconds time transfer error 95% of time (SIS only) | • Defined for a time transfer solution meeting the representative user conditions<br>• Standard based on a measurement interval of 24 hours averaged over all points in the service volume. | 10 nanoseconds |

```
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
#  Please send comment and suggestions to SWPC.Webmaster@noaa.gov
#
#            Current Quarter Daily Geomagnetic Data

                  Middle Latitude        High Latitude          Estimated
                - Fredericksburg -     ---- College ----     --- Planetary ---
  Date          A     K-indices        A     K-indices        A     K-indices
2010 04 01      9  3 2 2 1 3 3 1 2    20  2 2 3 3 6 4 1 2    12  3 3 2 2 4 3 1 3
2010 04 02     10  3 2 3 3 2 1 2 2    21  2 3 5 5 4 3 2 1    12  3 2 3 3 2 2 2 3
2010 04 03      5  2 1 0 1 2 2 2 2     9  2 1 1 2 3 3 3 1     8  2 1 1 0 2 3 2 3
2010 04 04     11  3 2 4 1 2 1 2 3    16  3 3 4 2 4 3 2 3    13  3 3 4 1 2 2 3 4
2010 04 05     28  2 3 4 6 5 3 3 3    75  3 3 6 8 7 6 3 3    49  3 4 4 7 6 5 4 4
2010 04 06     22  5 4 3 3 3 4 3 3    84  4 5 6 7 7 6 6 6    46  6 6 4 5 4 5 5 4
2010 04 07     15  4 2 4 3 3 2 2 3    46  3 2 6 6 6 6 3 2    21  4 2 4 4 4 3 3 3
2010 04 08      9  4 2 2 2 1 1 1 3    20  3 3 4 5 4 2 2 3    11  4 2 2 2 2 1 2 3
2010 04 09      4  2 2 1 1 0 1 2 1     6  3 1 1 3 2 1 0 0     6  3 2 1 1 1 1 1 1
2010 04 10      3  1 1 0 0 2 2 0 0     1  1 1 0 0 0 0 1 0     3  1 1 0 0 0 1 1 1
2010 04 11      8  1 0 1 0 3 3 3 3    13  1 0 1 1 4 5 3 2     8  1 0 1 0 3 3 3 3
2010 04 12     18  6 4 3 1 1 2 2 1    17  5 3 4 2 3 3 2 0    22  6 4 3 1 1 3 2 1
2010 04 13      2  0 0 2 1 0 1 0 1     3  0 0 2 2 1 0 0 1     3  1 0 1 1 0 1 0 2
2010 04 14      8  1 0 0 1 0 1 2 5     5  1 1 0 1 1 1 2 3     9  1 1 0 0 1 1 2 5
2010 04 15      5  3 3 1 1 1 1 0 0     6  3 3 1 2 1 1 0 0     8  4 3 1 1 1 1 0 1
2010 04 16      2  1 1 0 0 1 1 1 0     2  2 1 0 0 0 0 1 0     4  2 1 0 0 0 1 1 1
2010 04 17      1  0 0 1 0 0 0 1 1     2  1 0 1 0 0 0 1 1     2  1 0 0 0 0 0 1 1
2010 04 18      1  0 0 0 0 0 0 1 1     1  0 0 0 1 0 0 1 1     2  1 1 0 1 0 1 0 1
2010 04 19      3  1 1 1 1 1 1 0 1     6  1 3 2 3 2 0 0 0     5  1 2 2 2 1 1 1 1
2010 04 20      4  0 1 1 1 2 1 1 2     4  0 0 1 1 3 2 1 0     5  1 1 1 1 2 1 1 2
2010 04 21      4  0 2 2 1 2 1 1 1     7  1 2 2 3 3 2 1 0     6  1 2 2 1 2 2 1 1
2010 04 22      4  0 1 1 1 1 1 2 2     3  1 1 1 0 0 1 2 2     6  1 1 1 0 1 2 3 3
2010 04 23      7  4 2 2 1 1 0 1 2     9  4 3 3 2 0 0 1 2    13  5 4 2 1 1 1 2 2
2010 04 24      8  4 4 0 0 1 1 1 0     5  2 2 1 2 3 0 0 0     8  3 4 0 1 1 1 2 1
2010 04 25      2  1 2 0 1 0 0 0 0     1  1 1 0 0 0 0 0 0     3  1 2 0 0 1 1 0 1
2010 04 26      0  0 0 1 0 0 0 0 0     0  0 0 0 1 0 0 0 0     2  0 1 1 0 1 0 0 1
2010 04 27      3  2 1 0 0 0 1 1 2     2  1 1 0 1 0 0 1 0     4  2 1 0 1 1 2 1 2
2010 04 28      2  1 1 1 1 1 0 0 1     1  0 0 0 1 1 0 0 1     4  1 0 1 0 2 1 1 2
2010 04 29      4  3 2 0 1 1 0 1 1     4  3 3 0 0 0 0 0 0     6  3 3 0 0 1 1 1 1
2010 04 30      2  1 1 1 1 1 0 1 0     3  1 1 0 1 1 1 1 1     4  2 1 1 0 1 1 0 1
2010 05 01      1  0 1 0 0 1 0 0 1     1  0 1 0 1 1 1 0 0     4  0 2 0 1 1 2 1 2
2010 05 02     18  0 1 1 2 5 4 4 4    25  0 1 2 6 4 5 4 3    39  1 1 2 4 6 6 6 5
2010 05 03     19  5 4 3 3 3 2 2 3    30  4 4 5 6 4 2 2 3    27  5 5 4 4 3 3 3 4
2010 05 04      7  3 2 2 2 2 1 1 2    16  3 2 3 5 3 3 1 2    10  4 1 3 2 2 3 2 2
2010 05 05      6  3 2 2 0 1 2 2 1     8  3 3 2 2 1 2 2 1     8  3 2 2 1 1 2 3 2
2010 05 06      6  0 3 2 1 1 2 2 2    17  0 2 5 4 4 3 2 2    10  1 3 3 2 2 2 2 3
2010 05 07     10  4 3 2 1 2 1 2 2    13  3 3 3 3 4 2 2 1     9  3 3 2 1 3 1 2 2
2010 05 08      4  2 1 2 1 1 1 1 1     8  1 2 4 3 2 1 0 1     6  2 2 2 1 2 2 2 2
2010 05 09      1  1 0 0 0 0 0 0 1     0  1 0 0 0 0 0 0 0     4  1 0 0 1 1 1 1 1
2010 05 10      4  1 1 0 1 1 1 3 1     2  1 0 0 0 1 1 1 1     5  1 1 0 1 1 2 2 2
2010 05 11      6  2 2 2 2 2 1 1 1     5  2 2 1 2 1 1 1 1     8  2 2 2 2 1 3 3 1
2010 05 12      4  1 1 1 1 2 1 1 1     8  2 2 0 3 4 1 0 1     5  2 1 1 2 2 1 1 1
2010 05 13      2  1 0 0 1 1 1 1 0     1  1 0 0 1 0 0 0 0     4  1 0 1 1 1 1 1 1
2010 05 14      1  0 0 0 0 1 1 1 0     1  0 1 0 0 0 0 1 0     3  1 0 0 0 0 2 1 1
2010 05 15      2  1 1 0 0 1 1 0 0     2  1 1 0 1 1 0 0 0     4  2 1 0 1 1 1 1 1
2010 05 16      3  1 1 1 0 1 1 1 1     2  1 0 0 0 1 1 1 1     4  1 1 0 0 1 1 2 2
2010 05 17      4  2 1 1 1 1 1 1 1     6  1 2 1 3 3 0 1 1     6  2 2 1 1 2 1 2 1
2010 05 18      4  1 2 2 1 2 0 1 1    10  1 1 3 4 4 1 0 0     6  2 2 2 2 2 1 1 1
2010 05 19      7  1 1 1 2 3 3 1 2     8  1 1 1 1 3 4 1 2     8  1 1 1 2 3 3 2 2
2010 05 20      9  3 1 2 2 3 2 1 3    13  3 2 4 3 4 2 1 1     9  4 1 2 1 2 2 1 3
2010 05 21      4  3 1 1 0 1 0 1 1     3  1 1 2 0 1 1 0 1     5  3 1 2 0 1 1 1 1
2010 05 22      2  0 1 1 1 0 0 1 0     1  0 1 1 1 0 0 0 0     4  0 2 1 1 1 1 0 1
2010 05 23      0  0 1 0 0 0 0 0 0     0  0 0 0 0 0 0 0 0     2  1 0 0 0 0 1 1 1
2010 05 24      0  0 0 0 0 1 0 0 0     0  0 0 0 0 0 0 0 0     2  1 0 0 0 0 1 1 1
2010 05 25      4  1 1 1 1 1 1 2 2     4  1 1 1 2 2 1 1 2     5  1 1 1 1 1 1 2 3
2010 05 26      5  2 2 1 1 2 1 1 2     4  1 2 2 2 1 1 0 1     6  2 2 1 1 1 1 2 2
2010 05 27      1  1 0 0 0 0 1 1 0     1  1 0 0 2 0 0 0 0     4  2 0 0 0 1 1 1 2
2010 05 28      7  1 3 2 2 2 1 2 2    16  1 3 1 5 5 1 1 2    10  1 3 2 2 3 2 3 3
2010 05 29     15  2 2 4 3 3 3 3 3    53  2 4 7 5 6 6 4 3    33  4 3 5 5 5 4 3 3
```

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010 05 30 | 14 | 2 | 2 | 4 | 2 | 1 | 2 | 4 | 4 | 25 | 3 | 3 | 6 | 4 | 2 | 3 | 4 | 3 | 19 | 3 | 3 | 4 | 2 | 2 | 4 | 5 | 4 |
| 2010 05 31 | 14 | 3 | 2 | 4 | 3 | 3 | 2 | 2 | 3 | 37 | 3 | 3 | 5 | 6 | 6 | 4 | 3 | 3 | 16 | 3 | 3 | 4 | 3 | 3 | 3 | 2 | 3 |
| 2010 06 01 | 9 | 4 | 2 | 1 | 1 | 2 | 1 | 3 | 1 | 16 | 4 | 3 | 4 | 2 | 3 | 3 | 3 | 2 | 12 | 4 | 3 | 2 | 1 | 2 | 2 | 4 | 2 |
| 2010 06 02 | 4 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 2 | 3 | 1 | 1 | 2 | 1 | 1 | 1 | 6 | 2 | 3 | 0 | 0 | 2 | 2 | 1 | 3 |
| 2010 06 03 | 13 | 1 | 2 | 2 | 4 | 2 | 3 | 3 | 3 | 18 | 2 | 2 | 3 | 5 | 5 | 2 | 2 | 2 | 13 | 1 | 2 | 2 | 4 | 3 | 1 | 3 | 3 |
| 2010 06 04 | 11 | 4 | 3 | 2 | 3 | 1 | 1 | 2 | 2 | 21 | 4 | 3 | 3 | 6 | 3 | 2 | 1 | 2 | 16 | 5 | 4 | 2 | 4 | 2 | 2 | 1 | 2 |
| 2010 06 05 | 6 | 2 | 2 | 1 | 0 | 1 | 1 | 2 | 3 | 5 | 2 | 2 | 3 | 0 | 0 | 1 | 0 | 2 | 6 | 2 | 2 | 2 | 0 | 0 | 1 | 1 | 3 |
| 2010 06 06 | 5 | 2 | 1 | 1 | 1 | 1 | 0 | 2 | 3 | 6 | 2 | 1 | 2 | 3 | 1 | 1 | 2 | 1 | 7 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 3 |
| 2010 06 07 | 4 | 2 | 1 | 0 | 1 | 1 | 1 | 2 | 1 | 8 | 3 | 1 | 1 | 3 | 3 | 2 | 1 | 1 | 6 | 3 | 1 | 0 | 1 | 2 | 2 | 2 | 1 |
| 2010 06 08 | 3 | 2 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 |
| 2010 06 09 | 3 | 1 | 0 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 |
| 2010 06 10 | 5 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 7 | 3 | 3 | 1 | 3 | 1 | 0 | 0 | 1 | 6 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 2 |
| 2010 06 11 | 4 | 1 | 2 | 1 | 0 | 2 | 1 | 1 | 1 | 7 | 1 | 2 | 1 | 2 | 3 | 3 | 0 | 1 | 5 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2010 06 12 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 0 | 1 | 1 | 2 | 2 |
| 2010 06 13 | 5 | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 8 | 0 | 2 | 3 | 4 | 1 | 1 | 1 | 1 | 6 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 2010 06 14 | 3 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 7 | 1 | 2 | 3 | 4 | 0 | 0 | 0 | 2 | 5 | 2 | 2 | 1 | 2 | 1 | 1 | 0 | 2 |
| 2010 06 15 | 9 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 13 | 1 | 2 | 2 | 5 | 2 | 3 | 2 | 2 | 10 | 1 | 2 | 2 | 3 | 2 | 3 | 3 | 3 |
| 2010 06 16 | 13 | 2 | 2 | 3 | 2 | 3 | 2 | 3 | 4 | 42 | 4 | 4 | 5 | 5 | 6 | 6 | 2 | 3 | 19 | 3 | 4 | 3 | 3 | 3 | 3 | 4 | 4 |
| 2010 06 17 | 8 | 1 | 2 | 3 | 2 | 1 | 2 | 3 | 1 | 18 | 2 | 3 | 6 | 4 | 0 | 1 | 2 | 1 | 10 | 2 | 3 | 3 | 2 | 1 | 2 | 3 | 2 |
| 2010 06 18 | 4 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 5 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 0 | 5 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2010 06 19 | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 4 | 2 | 1 | 0 | 1 | 0 | 1 | 1 | 2 |
| 2010 06 20 | 2 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 2 |
| 2010 06 21 | 6 | 2 | 1 | 3 | 0 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 0 | 0 | 0 | 1 | 0 | 5 | 2 | 0 | 3 | 0 | 1 | 1 | 2 | 2 |
| 2010 06 22 | 5 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 6 | 2 | 1 | 1 | 1 | 1 | 2 | 3 | 2 |
| 2010 06 23 | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 1 | 1 | 1 | 2 | 2 | 1 | 0 | 0 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |
| 2010 06 24 | 5 | 0 | 0 | 1 | 1 | 2 | 2 | 3 | 2 | 4 | 0 | 0 | 0 | 0 | 2 | 3 | 2 | 1 | 7 | 1 | 0 | 0 | 0 | 2 | 2 | 3 | 3 |
| 2010 06 25 | 8 | 2 | 0 | 1 | 1 | 2 | 2 | 2 | 4 | 5 | 1 | 1 | 0 | 3 | 2 | 1 | 1 | 2 | 8 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 3 |
| 2010 06 26 | 9 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 20 | 2 | 4 | 5 | 5 | 1 | 2 | 2 | 3 | 15 | 3 | 4 | 3 | 3 | 2 | 3 | 4 | 3 |
| 2010 06 27 | 12 | 3 | 4 | 3 | 2 | 2 | 2 | 2 | 2 | 22 | 2 | 4 | 5 | 5 | 4 | 2 | 2 | 2 | 13 | 3 | 4 | 3 | 2 | 2 | 2 | 3 | 3 |
| 2010 06 28 | 6 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 1 | 7 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 7 | 3 | 2 | 2 | 2 | 1 | 2 | 2 | 2 |
| 2010 06 29 | 8 | 2 | 2 | 1 | 1 | 2 | 1 | 3 | 3 | 18 | 2 | 3 | 4 | 5 | 3 | 2 | 2 | 3 | 11 | 2 | 3 | 2 | 2 | 1 | 1 | 3 | 4 |
| 2010 06 30 | 15 | 4 | 4 | 3 | 2 | 2 | 2 | 3 | 3 | 29 | 5 | 3 | 5 | 5 | 5 | 3 | 1 | 2 | 19 | 5 | 4 | 4 | 2 | 3 | 3 | 2 | 3 |

## Appendix C Performance Analysis (PAN) Problem Report

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

**Problem Description:**

There were no problems to report for the quarter.

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

**General Terms and Definitions**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**SPS SIS User Range Error (URE) Statistic:**

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

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

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

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

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

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