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

**Submitted To**

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

**Report #37**
**April 30, 2002**
**Reporting Period: 1 January – 31 March 2002**

**Submitted by**

**William J. Hughes Technical Center**
**NSTB/WAAS T&E Team**
**ACT 360**
**Atlantic City International Airport, NJ  08405**

# EXECUTIVE SUMMARY

The GPS Product Team (AND 730) has tasked the Navigation Branch (ACT 360) at the William J. Hughes Technical Center to document Global Positioning System (GPS) Standard Positioning Service (SPS) performance in quarterly GPS Performance Analysis (PAN) Reports. The report contains the analysis performed on data collected at the following NSTB and Wide Area Augmentation System (WAAS) Reference Station locations: Atlantic City, Columbus, Denver, Grand Forks, Green Bay, Greenwood, Prescott, Anchorage (WAAS), Billings (WAAS), Chicago (WAAS), Kansas City (WAAS), Salt Lake City (WAAS), Miami (WAAS) and Atlanta (WAAS). This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification Annex A.

This report, Report #37, includes data collected from 1 January through 31 March 2002. The next quarterly report will be issued 31 July 2002.

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

Coverage performance was based on Position Dilution of Precision (PDOP). Utilizing the weekly almanac posted on the US Coast Guard navigation web site, the coverage for every $5^{o}$ grid point between 180W to 180E and 80S and 80N was calculated for every minute over a 24-hour period for each of the weeks covered in the reporting period. For this reporting period, the coverage based on PDOP less than six for the CONUS was 99.583% or better.

Availability was verified by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 January and 31 March 2002 and by calculating the satellite availability from the data obtained from the fourteen sites. A total of eighteen outages were reported in the NANU’s. Fifteen of the outages were scheduled and three were unscheduled. The quarterly availabilities for Salt Lake City was 99.986%; while Atlantic City, Columbus, Denver, Grand Forks, Green Bay, Greenwood, Prescott, Anchorage, Billings, Chicago, Atlanta, Kansas City and Miami were all 100%. Each of these availabilities is within the SPS value of 99.85%. These availability percentages were calculated using DOP data collected at one-second intervals.

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

Position accuracies were verified by calculating the 95% and 99.99% values of horizontal and vertical errors. Range performance was verified for each satellite using the data collected from the NSTB Atlantic City site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 28.452 meters on Satellite PRN 20. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 0.971435 Meters/second on Satellite PRN 13. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 9.452 Millimeters/second$^2$ on Satellite PRN 20. The SPS specification states that the range acceleration error should never exceed 19 Millimeters/second$^2$.

A GLONASS/GPS performance section was added to the PAN report. In April 1999, ACT-360 was tasked to monitor, analyze and characterize GLONASS and GPS/GLONASS system performance. The objective of this task is to evaluate the ability of GLONASS to provide navigation by itself and with SPS GPS and to assess the incremental benefit to WAAS obtained from using GLONASS. A GPS/GLONASS receiver was used in the NSTB laboratory at the FAA Technical Center. The GPS/GLONASS performance (from an Ashtech GG24) was compared against GPS-only performance. The 95% horizontal error and vertical error for the GPS/GLONASS solution were 6.576 Meters and 11.034 Meters, respectively.

From the analysis performed on data collected between 1 January and 31 March 2002, the GPS performance met all SPS requirements that were evaluated.

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# 1.0 Introduction

## 1.1 Objective of GPS SPS Performance Analysis Report

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS for IFR and is developing Wide Area Augmentation System (WAAS) and Local Area Augmentation (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 Analysis report. This report contains data collected at the following National Satellite Test Bed (NSTB) and WAAS reference station locations:

- Atlantic City, NJ
- Columbus, NE
- Denver, CO
- Grand Forks, ND
- Elko, NV
- Green Bay, WI
- Greenwood, MS
- Prescott, AZ
- Billings, MT
- Anchorage, AK
- Chicago, IL
- Kansas City, KS
- Salt Lake City, UT
- Miami, FL
- Atlanta, GA

(Future reports will include all WAAS sites but a database that can handle all that data needs to be developed. ACT-360 is in the process of setting up an Oracle database for this purpose.)

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

- Coverage Performance
- Satellite Availability Performance
- Service Reliability Standard
- Positioning, Ranging and Timing Accuracy Standard.

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

## 1.2 Summary of Performance Requirements and Metrics

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

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

## 1.3 Report Overview

Section 2 of this report summarizes the results obtained from the coverage calculation program called SPS_CoverageArea developed by ACT-360. The SPS_CoverageArea program uses the GPS satellite almanacs to compute each satellite position as a function of time for a selected day of the week. This program establishes a 5-degree grid between 180 degrees east and 180 degrees west, and from 80 degrees north and 80 degrees south. The program then computes the PDOP at each grid point (1485 total grid points) every minute for the entire day and stores the results. After the PDOP's have been saved the 99.99% index of 1-minute PDOP at each grid point is determined and plotted as contour lines (Figure 2-1). The program also saves the number of satellites used in PDOP calculation at each grid point for analysis.

Section 3 summarizes the GPS availability performance by providing the "Notice: Advisory to Navstar Users" (NANU) messages to calculate the total time of forecasted and actual satellite outages. This section also includes the maximum and minimum of the PDOP, HDOP and VDOP for each of the thirteen NSTB/WAAS sites.

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

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

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

Section 7 provides the analysis on GPS/GLONASS performance. A GPS/GLONASS receiver was used in the NSTB laboratory at the FAA Technical Center.

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. The SPS specification was met in all instances this quarter.

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

**Table 1-1 SPS Performance Requirements**

| Coverage Standard | Conditions and Constraints | Evaluated in This Report |
|---|---|---|
| ≥ 99.9% global average | • Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe<br>• 4 satellites must provide PDOP of 6 or less<br>• 5° mask angle with no obscura<br>• Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac | ✓ |
| ≥ 96.9% at worst-case point | • Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe<br>• 4 satellites must provide PDOP of 6 or less<br>• 5° mask angle with no obscura<br>• Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac | ✓ |
| **Satellite Availability Standard** | **Conditions and Constraints** | |
| ≥ 99.85% global average | • Conditioned on coverage standard<br>• Standard based on a typical 24 hour interval, averaged over the globe<br>• Typical 24 hour interval defined using averaging period of 30 days | ✓ |
| ≥ 99.16% single point average | • Conditioned on coverage standard<br>• Standard based on a typical 24 hour interval, for the worst-case point on the globe<br>• Typical 24 hour interval defined using averaging period of 30 days | ✓ |
| ≥ 95.87% global average on worst-case day | • Conditioned on coverage standard<br>• Standard represents a worst-case 24 hour interval, averaged over the globe | ✓ |
| ≥ 83.92% at worst-case point on worst-case day | • Conditioned on coverage standard<br>• Standard based on a worst-case 24 hour interval, for the worst-case point on the globe | ✓ |
| **Service Availability Standard** | **Conditions and Constraints** | |
| ≥ 99.97% global average | • Conditioned on coverage and service availability standards<br>• 500 meter NTE predictable horizontal error reliability threshold<br>• Standard based on a measurement interval of one year; average of daily values over the globe<br>• Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval | ✓ |

| | | |
|---|---|---|
| ≥ 99.79% single point average | • Conditioned on coverage and service availability standards<br>• 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold<br>• Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe<br>• Standard based on a maximum of 18 hours of major service failure behavior over the sample interval | ✓ |
| Accuracy Standard | Conditions and Constraints | |
| Predictable Accuracy<br>≤ 100 m horz. error 95% of time<br>≤ 156 m vert. error 95% of time<br>≤ 300 m horz. error 99.99% of time<br>≤ 500 m vert. error 99.99% of time | • Conditioned on coverage, service availability and service reliability standards<br>• Standard based on a measurement interval of 24 hours, for any point on the globe | ✓ |
| <u>Repeatable Accuracy</u><br>≤ 141 m horz. error 95% of time<br>≤ 221 m vert. error 95% of time | • Conditioned on coverage, service availability and service reliability standards<br>• Standard based on a measurement interval of 24 hours, for any point on the globe | ✓ |
| <u>Relative Accuracy</u><br>≤ 1.0 m horz. error 95% of time<br>≤ 1.5 m vert. error 95% of time | • Conditioned on coverage, service availability and service reliability standards<br>• Standard based on a measurement interval of 24 hours, for any point on the globe<br>• Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time | Future Reports |
| <u>Time Transfer Accuracy</u><br>≤ 340 nanoseconds time transfer error 95% of time | • Conditioned on coverage, service availability and service reliability standards<br>• Standard based upon SPS receiver time as computed using the output of the position solution<br>• Standard based on a measurement interval of 24 hours, for any point on the globe<br>• Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory | ✓ |
| <u>Range Domain Accuracy</u><br>≤ 150 m NTE range error<br>≤ 2 m/s NTE range rate error<br>≤ 8 mm/s$^2$ range acceleration error 95% of time<br>≤ 19 mm/s$^2$ NTE range acceleration error | • Conditioned on satellite indicating healthy status<br>• Standard based on a measurement interval of 24 hours, for any point on the globe<br>• Standard restricted to range domain errors allocated to space/control segments<br>• Standards are not constellation values -- each satellite is required to meet the standards<br>• Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard | ✓ |

## 2.0 Coverage Performance

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

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

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

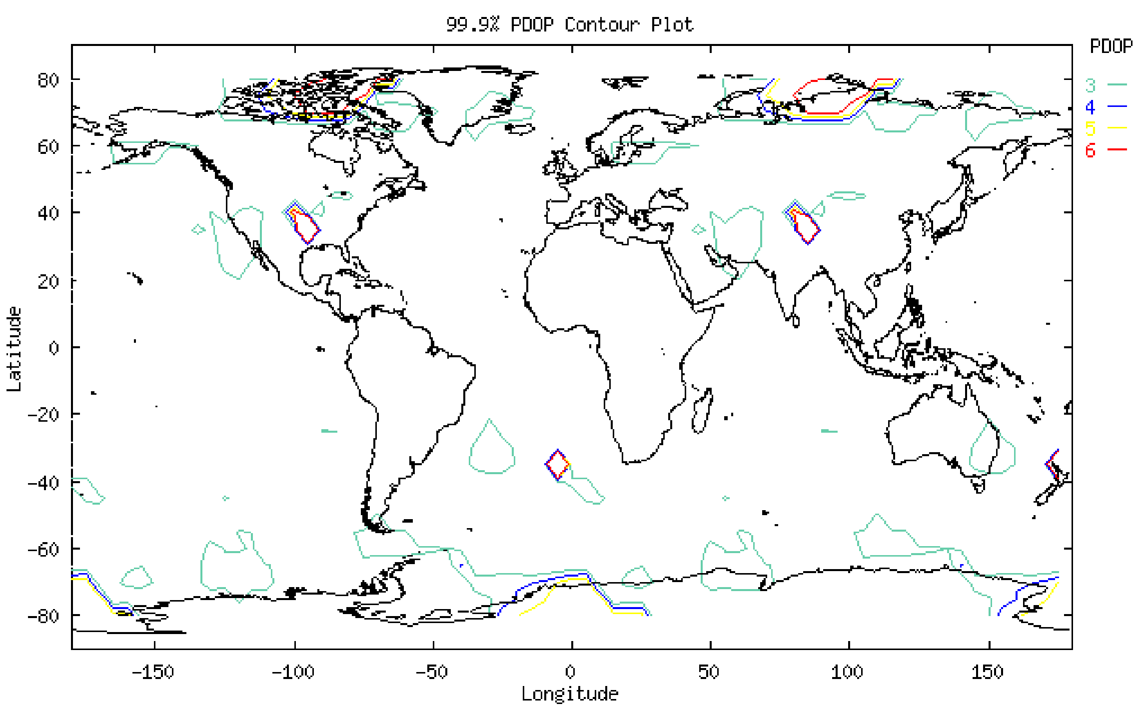
Almanacs for GPS weeks 97-109 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACT-360 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.19503 or better 99.9% for each of the 24-hour intervals.

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

**Table 2-1 Coverage Statistics**

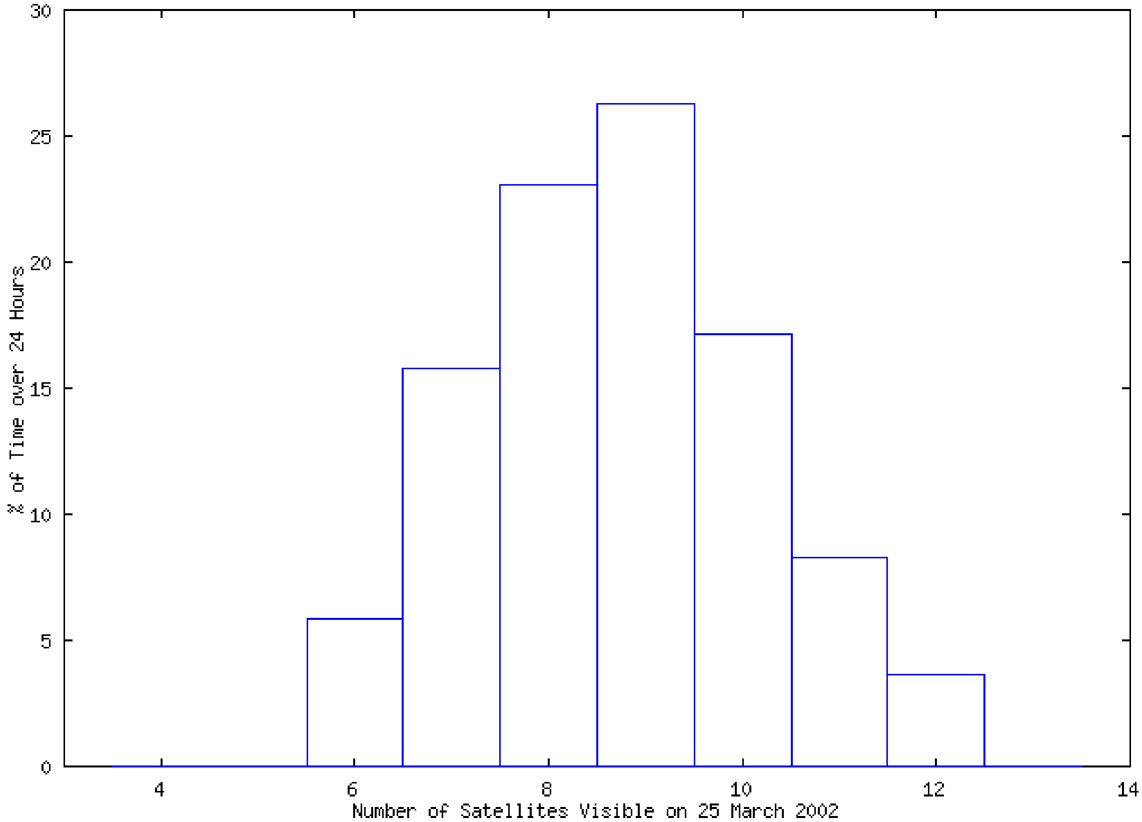
| GPS Week | Global 99.9% PDOP Value* | Global Average* (Spec: ≥ 99.9%) | Worst-Case Point (Spec: ≥ 96.9%) |
|---|---|---|---|
| 123 | 3.02986 | 100% | 99.931% |
| 124 | 3.08791 | 100% | 100% |
| 125 | 3.19503 | 100% | 100% |
| 126 | 3.18854 | 100% | 100% |
| 127 | 3.18816 | 100% | 99.792% |
| 128 | 3.13980 | 100% | 99.931% |
| 129 | 3.11303 | 100% | 100% |
| 130 | 3.09211 | 100% | 100% |
| 131 | 3.07164 | 100% | 100% |
| 132 | 3.04833 | 100% | 100% |
| 133 | 3.05545 | 100% | 100% |
| 134 | 3.09082 | 100% | 99.931% |
| 135 | 3.12436 | 99.999% | 99.653% |

Figure 2-1 SPS Coverage (24-Hour Period: 25 March 2002)




Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -65, Lat: 70)



# 3.0 Service Availability Performance

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

## 3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANU's). During this reporting period, 1 January through 31 March 2002, there were a total of seventeen reported outages. Twelve of these outages were maintenance activities and were reported in advance. Five 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 |
|---|---|---|---|---|---|---|---|---|---|
| 2003 | 23 | U | 7-Jan | 19:00 | N/A | N/A | | | |
| 2006 | 24 | U | 31-Dec | 18:03 | 7-Jan | 15:19 | 165.27 | | 165.27 |
| 2008 | 11 | S | 7-Jan | 5:21 | 7-Jan | 7:49 | | 2.47 | 2.47 |
| 2011 | 21 | S | 10-Jan | 6:15 | 10-Jan | 12:18 | | 6.05 | 6.05 |
| 2013 | 23 | U | 7-Jan | 19:00 | 14-Jan | 22:06 | 171.10 | | 171.10 |
| 2014 | 26 | S | 15-Jan | 5:39 | 15-Jan | 12:26 | | 6.78 | 6.78 |
| 2015 | 8 | S | 16-Jan | 14:59 | 16-Jan | 23:03 | | 7.07 | 7.07 |
| 2019 | 20 | S | 29-Jan | 5:20 | 29-Jan | 7:06 | | 1.77 | 1.77 |
| 2021 | 18 | S | 31-Jan | 19:01 | 31-Jan | 21:15 | | 2.23 | 2.23 |
| 2023 | 3 | S | 5-Feb | 1:16 | 5-Feb | 7:47 | | 6.52 | 6.52 |
| 2024 | 4 | S | 7-Feb | 8:18 | 7-Feb | 14:57 | | 6.65 | 6.65 |
| 2026 | 5 | S | 11-Feb | 16:16 | 11-Feb | 21:15 | | 4.98 | 4.98 |
| 2028 | 10 | S | 14-Feb | 13:18 | 14-Feb | 16:31 | | 3.22 | 3.22 |
| 2031 | 23 | S | 21-Feb | 22:40 | 22-Feb | 4:07 | | 5.45 | 5.45 |
| 2032 | 6 | S | 26-Feb | 20:22 | 27-Feb | 2:40 | | 6.30 | 6.30 |
| 2033 | 18 | S | 28-Feb | 0:57 | 28-Feb | 5:07 | | 4.17 | 4.17 |
| 2037 | 24 | U | 9-Mar | 18:22 | N/A | N/A | | | |
| 2038 | 24 | U | 9-Mar | 18:22 | 9-Mar | 18:38 | 0.27 | | 0.27 |
| 2039 | 22 | S | 18-Mar | 22:01 | 19-Mar | 8:47 | | 10.77 | 10.77 |
| 2043 | 18 | S | 25-Mar | 22:59 | 26-Mar | 3:24 | | 4.42 | 4.42 |
| **Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime** | | | | | | | **336.64** | **78.85** | **415.49** |
| Type: | S = Scheduled | | U = Unscheduled | | | | | | |

**Table 3-2 NANUs Forecasted to Affect Satellite Availability**

| NANU # | PRN | Type | Start Date | Start Time | End Date | End Time | Total | Comments |
|---|---|---|---|---|---|---|---|---|
| 2002 | 21 | F | 10-Jan | 6:00 | 10-Jan | 18:00 | 12 | See NANU 2011 |
| 2005 | 11 | F | 8-Jan | 4:30 | 8-Jan | 16:30 | 12 | See NANU 2008 |
| 2010 | 26 | F | 15-Jan | 5:15 | 15-Jan | 17:15 | 12 | SeeNANU 2014 |
| 2012 | 8 | F | 16-Jan | 14:45 | 17-Jan | 2:45 | 12 | See NANU 2015 |
| 2016 | 20 | F | 29-Jan | 5:00 | 29-Jan | 17:00 | 12 | See NANU 2019 |
| 2017 | 18 | F | 31-Jan | 18:00 | 1-Feb | 6:00 | 12 | See NANU 2021 |
| 2018 | 3 | F | 5-Feb | 1:00 | 5-Feb | 13:00 | 12 | See NANU 2023 |
| 2020 | 4 | F | 7-Feb | 8:00 | 7-Feb | 20:00 | 12 | See NANU 2024 |
| 2022 | 5 | F | 11-Feb | 16:00 | 12-Feb | 4:00 | 12 | See NANU 2026 |
| 2025 | 10 | F | 14-Feb | 12:30 | 15-Feb | 0:30 | 12 | See NANU 2028 |
| 2027 | 23 | F | 21-Feb | 22:15 | 22-Feb | 10:15 | 12 | See NANU 2031 |
| 2029 | 6 | F | 26-Feb | 19:45 | 27-Feb | 7:45 | 12 | See NANU 2032 |
| 2030 | 18 | F | 28-Feb | 0:00 | 28-Feb | 12:00 | 12 | See NANU 2033 |
| 2034 | 22 | F | 18-Mar | 21:00 | 19-Mar | 9:00 | 12 | See NANU 2039 |
| 2040 | 18 | F | 25-Mar | 22:00 | 26-Mar | 10:00 | 12 | See NANU 2043 |
| 2041 | 30 | F | 26-Mar | 10:30 | 26-Mar | 22:30 | 12 | See NANU 2042 |
| | | | | | | | | |
| | | | | | **Total Forecast Downtime** | | **180** | |

**Table 3-3 NANUs Canceled**

| NANU# | PRN | Type | Start Date | Start Time | Comments |
|---|---|---|---|---|---|
| 2042 | 30 | C | 26-Mar | 10:30 | See NANU 2041 |
| | | | | | |

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 Jan - 31 Mar, 2002** | **1 October, 1999- 31 Mar, 2002** |
|---|---|---|
| Total Forecast Downtime (hrs): | 180.00 | 2408.25 |
| Total Actual Downtime (hrs): | 415.49 | 4104.47 |
| Total Actual Scheduled Downtime (hrs): | 78.85 | 1318.76 |
| Total Actual Unscheduled Downtime (hrs): | 336.64 | 2785.71 |
| Total Satellite Observed MTTR (hrs): | 23.08 | 21.83 |
| Scheduled Satellite Observed MTTR (hrs): | 5.26 | 9.03 |
| Unscheduled Satellite Observed MTTR (hrs): | 112.21 | 66.33 |
| # Total Satellite Outages: | 18 | 188 |
| # Scheduled Satellite Outages: | 15 | 146 |
| # Unscheduled Satellite Outages: | 3 | 42 |
| Percent Operational -- Scheduled Downtime: | 99.87 | 99.78 |
| Percent Operational -- All Downtime: | 99.94 | 99.33 |

### 3.2 Service Availability

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

To verify availability, the data collected from receivers at the nine NSTB/WAAS sites was reduced to calculate DOP information and reported in Tables 3-5 to 3-7. The data was collected at one-second intervals between 1 January and 31 March 2002.

**Table 3-5 PDOP Statistics**

| NSTB/WAAS Site | Min PDOP | Max PDOP | VDOP at Max PDOP | Mean PDOP | 99.99% PDOP | 99.99% VDOP | Number of Samples |
|---|---|---|---|---|---|---|---|
| **Atlantic City** | 1.206 | 5.469 | 4.547 | 1.855 | 3.827 | 3.342 | 7775714 |
| **Columbus** | 1.180 | 6.000 | 5.283 | 1.794 | 5.582 | 5.031 | 7774276 |
| **Denver** | 1.180 | 5.993 | 5.132 | 1.791 | 5.534 | 4.846 | 7597273 |
| **Grand Forks** | 1.167 | 5.605 | 5.280 | 1.769 | 5.211 | 4.898 | 7745735 |
| **Green Bay** | 1.128 | 5.940 | 5.124 | 1.804 | 5.478 | 5.071 | 7462989 |
| **Greenwood** | 1.264 | 6.000 | 5.475 | 1.855 | 4.675 | 4.188 | 7451187 |
| **Prescott** | 1.349 | 5.997 | 5.115 | 2.128 | 5.406 | 5.159 | 7200532 |
| **Billings** | 1.099 | 4.743 | 4.028 | 1.758 | 4.661 | 3.989 | 7307633 |
| **Anchorage** | 1.211 | 5.999 | 5.454 | 1.783 | 4.896 | 4.298 | 7715890 |
| **Chicago** | 1.247 | 5.296 | 4.815 | 1.786 | 4.973 | 4.513 | 7529430 |
| **Kansas City** | 1.203 | 6.000 | 5.740 | 1.798 | 5.654 | 5.029 | 7573127 |
| **Salt Lake City** | 1.172 | 6.991 | 6.258 | 1.769 | 6.342 | 5.688 | 7731398 |
| **Miami** | 1.208 | 5.323 | 4.898 | 1.809 | 4.260 | 3.782 | 7319221 |
| **Atlanta** | 1.248 | 5.365 | 5.056 | 1.856 | 4.414 | 3.944 | 7556438 |

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

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

- Notice of Advisory to Navstar Users (NANU's) messages are used to verify that satellite outages did occur. (See Section 3.1 for more details about NANU's for this quarter.)

- A satellite outage detection program developed by ACT-360 verifies satellite outages that are not verified through a NANU. For example, a satellite outage can occur for just a few seconds during an upload. This satellite detection program monitors all the receivers and keeps track of what satellites the receiver should be tracking versus what satellites the receiver is actually tracking. At least six receivers need to be tracking the satellite prior to the outage and no receiver can be tracking the satellite for the program to detect an outage. This program is also being enhanced so that false locks and late ephemeris problems can also be detected. This program will also output flags from the receivers so that problems with the receiver or TRS software, if any, can be tracked more easily.

- Data from co-located receivers is analyzed for times that the PDOP goes above six. This helps in determining whether the problem is due to the environment.

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

**Table 3-6 Maximum PDOP Statistics**

| Site | GPS Week/ Day | Max PDOP | Number of Seconds of Whole Day PDOP > 6 | NANU/SOD, Satellite PRN Number | Number of Samples | Availability on days when PDOP > 6 |
|---|---|---|---|---|---|---|
| **Salt Lake City** | 1147_6 | 6.982 | 367 | None | 86391 | 99.575 |
| **Salt Lake City** | 1148_0 | 6.989 | 358 | None | 86390 | 99.585 |
| **Salt Lake City** | 1148_1 | 6.991 | 347 | 2013, PRN23 | 86352 | 99.598 |
| **Worst-Case Point on Worst-Case Day = 99.575% (SPS Spec. ≥ 83.92%)** | | | | | | |

**Global Average on Worst-Case Day = 99.967% (SPS Spec. ≥ 95.87%)**

**Table 3-7 PDOP > 6 Statistics**

| NSTB/WAAS Site | Total Number of Seconds of PDOP Monitoring | Total Seconds with PDOP > 6 | Overall % Availability |
|---|---|---|---|
| **Atlantic City** | 7775714 | 0 | 100% |
| **Columbus** | 7774276 | 0 | 100% |
| **Denver** | 7597273 | 0 | 100% |
| **Grand Forks** | 7745735 | 0 | 100% |
| **Green Bay** | 7462989 | 0 | 100% |
| **Greenwood** | 7451187 | 0 | 100% |
| **Prescott** | 7200532 | 0 | 100% |
| **Billings** | 7307633 | 0 | 100% |
| **Anchorage** | 7715890 | 0 | 100% |
| **Chicago** | 7529430 | 0 | 100% |
| **Kansas City** | 7573127 | 0 | 100% |
| **Salt Lake City** | 7731398 | 1072 | 99.986% |
| **Miami** | 7319221 | 0 | 100% |
| **Atlanta** | 7556438 | 0 | 100% |
| **Worst Single Point Average = 99.986% (SPS Spec. ≥ 99.16%)** | | | |

**Global Average over Reporting Period = 99.999% (SPS Spec. > 99.85%)**

## 4.0 Service Reliability Standard

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

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

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

**Table 4-1 Service Reliability Based on Horizontal Error**

| NSTB/WAAS Site | Number of Samples This Quarter | Maximum Horizontal Error (Meters) |
|---|---|---|
| **Atlantic City** | 7775714 | 16.6 |
| **Columbus** | 7774276 | 11.1 |
| **Denver** | 7597273 | 33.3 |
| **Grand Forks** | 7745735 | 16.3 |
| **Green Bay** | 7462989 | 18.8 |
| **Greenwood** | 7451187 | 11.0 |
| **Prescott** | 7200532 | 12.0 |
| **Billings** | 7307633 | 12.0 |
| **Anchorage** | 7715890 | 30.7 |
| **Chicago** | 7529430 | 13.3 |
| **Kansas City** | 7573127 | 11.6 |
| **Salt Lake City** | 7731398 | 12.0 |
| **Miami** | 7319221 | 13.8 |
| **Atlanta** | 7556438 | 10.8 |

## 5.0 Accuracy Characteristics

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

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

### 5.1 Position Accuracies

The data used for this section was collected for every second between 1 January through 31 March 2002 at the NSTB and WAAS selected locations.

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

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

| NSTB Site | 95% Horizontal (Meters) | 95% Vertical (Meters) | 99.99% Horizontal (Meters) | 99.99% Vertical (Meters) |
|---|---|---|---|---|
| **Atlantic City** | 5.896 | 11.209 | 15.160 | 20.123 |
| **Columbus** | 5.459 | 10.312 | 10.278 | 17.245 |
| **Denver** | 5.279 | 11.101 | 10.021 | 20.182 |
| **Grand Forks** | 6.282 | 9.099 | 13.878 | 15.062 |
| **Green Bay** | 6.027 | 9.709 | 12.926 | 17.141 |
| **Greenwood** | 5.259 | 11.351 | 9.630 | 22.609 |
| **Prescott** | 5.007 | 11.918 | 10.761 | 21.503 |
| **Billings** | 6.264 | 9.673 | 11.946 | 17.829 |
| **Anchorage** | 7.226 | 7.860 | 14.051 | 18.702 |
| **Chicago** | 5.758 | 9.842 | 11.976 | 16.014 |
| **Kansas City** | 5.518 | 10.165 | 10.758 | 17.878 |
| **Salt Lake City** | 5.418 | 11.062 | 10.665 | 21.323 |
| **Miami** | 6.040 | 13.574 | 12.344 | 22.243 |
| **Atlanta** | 5.522 | 11.194 | 9.893 | 19.758 |

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all fourteen NSTB and WAAS sites from 1 January to 31 March 2002.

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

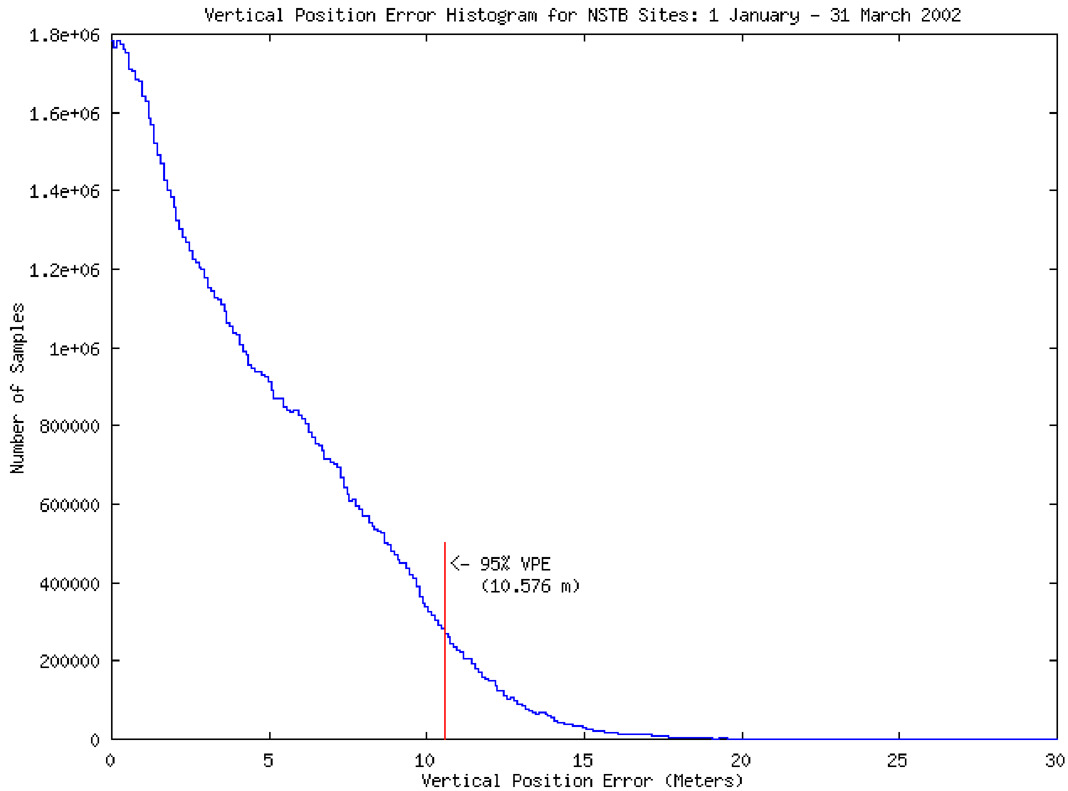
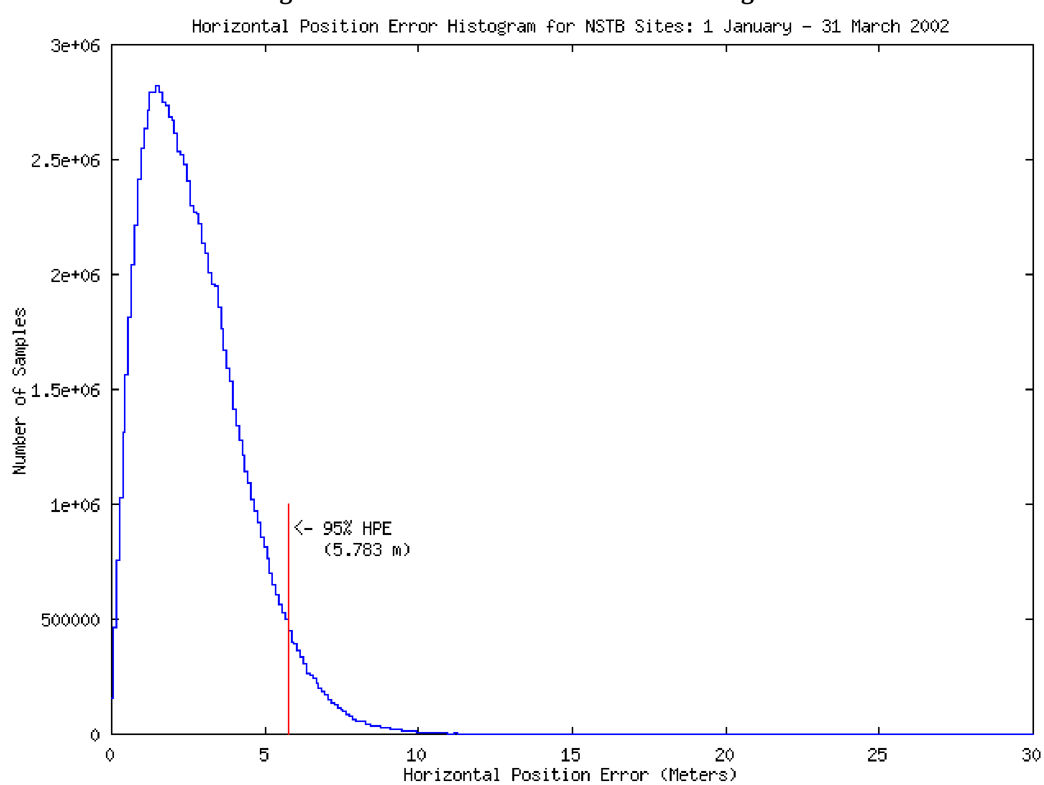



**Figure 5-2 Combined Horizontal Error Histogram**



### 5.2 Repeatable Accuracy

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

**Table 5-2 Repeatability Statistics**

| NSTB Site | 95% Horizontal (m) | 95% Vertical (m) |
|---|---|---|
| **Atlantic City** | 1.569 | 4.029 |
| **Columbus** | 1.567 | 4.200 |
| **Denver** | 1.727 | 4.715 |
| **Grand Forks** | 1.815 | 5.300 |
| **Green Bay** | 1.919 | 5.251 |
| **Greenwood** | 1.573 | 4.925 |
| **Prescott** | 1.604 | 4.292 |
| **Billings** | 1.870 | 5.037 |
| **Anchorage** | 2.449 | 4.364 |
| **Chicago** | 1.714 | 4.189 |
| **Kansas City** | 1.426 | 3.957 |
| **Salt Lake City** | 1.571 | 4.494 |
| **Miami** | 1.655 | 4.200 |
| **Atlanta** | 1.733 | 4.392 |

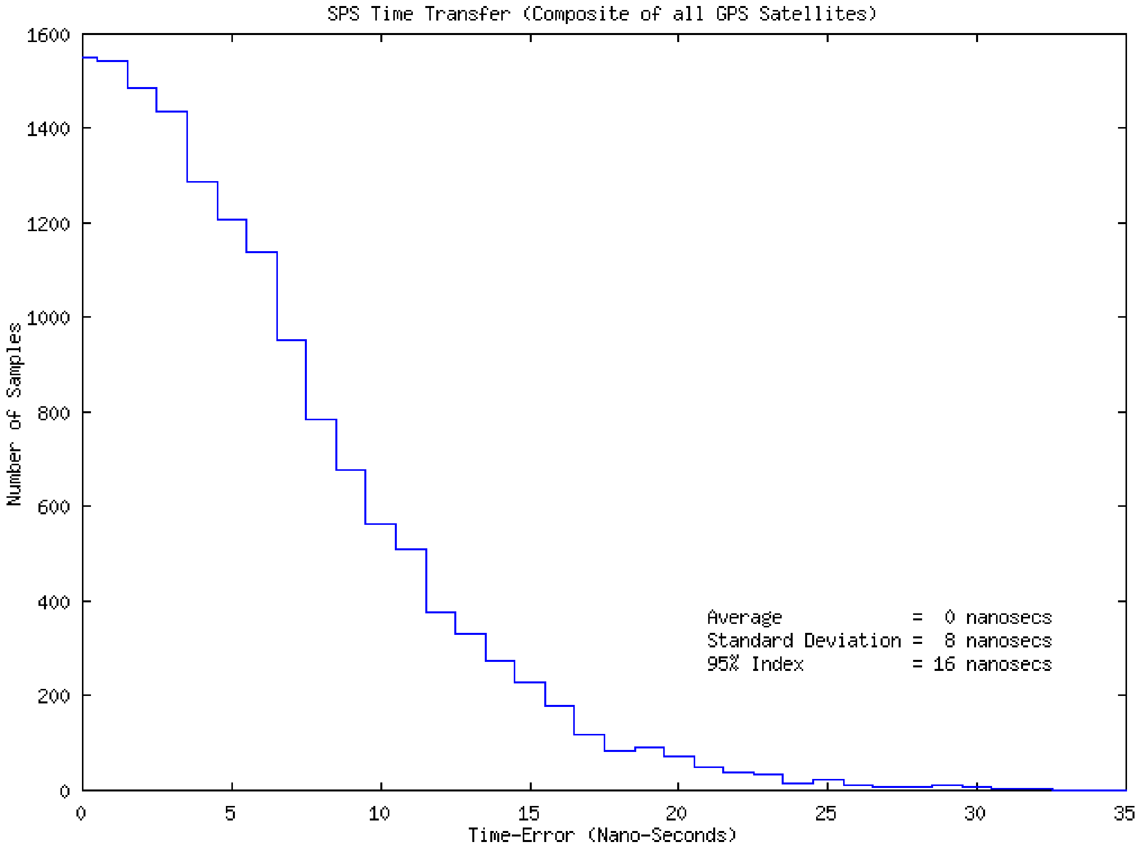
### 5.3 Relative Accuracy

To be included in future reports.

### 5.4 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 2002 was down loaded from USNO Internet site. The USNO data file contains the time difference between the USNO master clock and GPS system time for each GPS satellites during the time period. Over 10,000 samples of GPS time error are contained in the USNO data file. In order to evaluate the GPS time transfer error, the data file was used to create a histogram (Fig 5-3) to represent the distribution of GPS time error. The histogram was created by taking the absolute value of time difference between the USNO master clock and GPS system time, then creating data bins with one nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Fig 5-3. The mean, standard deviation, and 95% index are within the requirements of GPS SPS time error.

**Figure 5-3 Time Transfer Errors**



### 5.5 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 January and 31 March 2002. The Millennium at Anderson was used to collect range measurement. Future PAN reports will contain statistics from all WAAS sites.

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

**Table 5-3 Range Error Statistics (meters)**

| PRN | Range Error Mean | Range Error RMS | 1s | 95% Range Error | Max Range Error (SPS Spec. ≤ 150 m) | Samples |
|---|---|---|---|---|---|---|
| 1 | -3.962 | 5.181 | 3.339 | 9.634 | 15.573 | 2219787 |
| 2 | -3.827 | 5.494 | 3.942 | 10.828 | 17.780 | 2268682 |
| 3 | -3.005 | 4.899 | 3.869 | 9.886 | 18.395 | 1902098 |
| 4 | -4.275 | 5.589 | 3.600 | 10.119 | 14.962 | 2153961 |
| 5 | -0.533 | 2.711 | 2.658 | 5.418 | 16.321 | 2518474 |
| 6 | -0.972 | 2.852 | 2.681 | 5.831 | 11.854 | 2404861 |
| 7 | -4.679 | 5.893 | 3.583 | 10.180 | 15.589 | 2240755 |
| 8 | -4.300 | 5.738 | 3.799 | 9.969 | 18.947 | 2163005 |
| 9 | -1.318 | 3.278 | 3.001 | 6.534 | 12.513 | 2228896 |
| 10 | -2.132 | 4.119 | 3.524 | 7.938 | 14.391 | 2093923 |
| 11 | -4.351 | 5.785 | 3.812 | 10.877 | 17.797 | 2124430 |
| 13 | -4.873 | 5.766 | 3.082 | 10.043 | 18.458 | 2436668 |
| 14 | -0.290 | 2.459 | 2.441 | 4.899 | 11.619 | 2210290 |
| 15 | -1.288 | 3.770 | 3.543 | 7.384 | 19.430 | 1957726 |
| 17 | -1.727 | 3.844 | 3.434 | 7.757 | 11.993 | 1836350 |
| 18 | -1.494 | 3.245 | 2.881 | 6.307 | 11.183 | 2116485 |
| 20 | -2.636 | 4.126 | 3.175 | 7.677 | 28.452 | 2501480 |
| 21 | -1.051 | 3.265 | 3.092 | 6.653 | 14.831 | 1954118 |
| 22 | -1.264 | 3.459 | 3.220 | 6.983 | 13.010 | 1978277 |
| 23 | -1.243 | 3.591 | 3.369 | 7.117 | 11.056 | 2062283 |
| 24 | -3.902 | 5.323 | 3.620 | 9.945 | 14.018 | 2098916 |
| 25 | -0.114 | 2.656 | 2.654 | 5.365 | 9.921 | 2237666 |
| 26 | -2.408 | 4.132 | 3.359 | 7.897 | 14.867 | 1832979 |
| 27 | -6.228 | 7.456 | 4.099 | 12.637 | 19.041 | 1811229 |
| 28 | -5.092 | 6.304 | 3.716 | 11.170 | 19.356 | 1999786 |
| 29 | -0.971 | 3.000 | 2.838 | 6.249 | 11.259 | 2227081 |
| 30 | -0.686 | 2.451 | 2.353 | 4.966 | 21.076 | 2461048 |
| 31 | -4.339 | 6.006 | 4.154 | 11.212 | 17.490 | 1877835 |

**Table 5-4 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 (SPS Spec. ≤ 2 m) | Samples |
|---|---|---|---|---|---|---|
| 1 | 0.00003 | 0.00275 | 0.00274 | 0.0047 | 0.893348 | 2219787 |
| 2 | 0.00011 | 0.00316 | 0.00316 | 0.00461 | 0.237918 | 2268682 |
| 3 | -0.00011 | 0.00386 | 0.00386 | 0.00474 | 0.465037 | 1902098 |
| 4 | -0.00015 | 0.00242 | 0.00241 | 0.00424 | 0.147574 | 2153961 |
| 5 | 0.00007 | 0.00653 | 0.00653 | 0.00402 | 0.646728 | 2518474 |
| 6 | -0.00007 | 0.00419 | 0.00419 | 0.00417 | 0.495731 | 2404861 |
| 7 | 0.00004 | 0.00238 | 0.00238 | 0.00413 | 0.144026 | 2240755 |
| 8 | 0.00028 | 0.00256 | 0.00254 | 0.00439 | 0.153678 | 2163005 |
| 9 | 0.00009 | 0.00405 | 0.00405 | 0.00428 | 0.484189 | 2228896 |
| 10 | -0.00021 | 0.00287 | 0.00286 | 0.00420 | 0.161983 | 2093923 |
| 11 | -0.00019 | 0.00501 | 0.00501 | 0.00481 | 0.485909 | 2124430 |
| 13 | -0.00006 | 0.00583 | 0.00583 | 0.00480 | 0.971435 | 2436668 |
| 14 | 0.00007 | 0.00193 | 0.00193 | 0.00364 | 0.146641 | 2210290 |
| 15 | -0.00011 | 0.00337 | 0.00337 | 0.00446 | 0.379788 | 1957726 |
| 17 | -0.00015 | 0.00328 | 0.00327 | 0.00405 | 0.343642 | 1836350 |
| 18 | -0.00013 | 0.00223 | 0.00222 | 0.00409 | 0.03694 | 2116485 |
| 20 | -0.00035 | 0.00840 | 0.00840 | 0.00461 | 0.68308 | 2501480 |
| 21 | 0.00006 | 0.00307 | 0.00307 | 0.00418 | 0.239722 | 1954118 |
| 22 | 0.00007 | 0.00279 | 0.00279 | 0.00418 | 0.24731 | 1978277 |
| 23 | -0.00021 | 0.00251 | 0.00250 | 0.00404 | 0.211268 | 2062283 |
| 24 | -0.00008 | 0.00247 | 0.00247 | 0.00408 | 0.234369 | 2098916 |
| 25 | 0.00015 | 0.00276 | 0.00276 | 0.00391 | 0.180027 | 2237666 |
| 26 | -0.00026 | 0.00359 | 0.00358 | 0.00418 | 0.508695 | 1832979 |
| 27 | 0.00035 | 0.00347 | 0.00346 | 0.00491 | 0.223539 | 1811229 |
| 28 | 0.00023 | 0.00280 | 0.00279 | 0.00447 | 0.196144 | 1999786 |
| 29 | 0.00008 | 0.00226 | 0.00226 | 0.00375 | 0.221652 | 2227081 |
| 30 | 0.00012 | 0.00709 | 0.00709 | 0.00403 | 0.945772 | 2461048 |
| 31 | -0.00020 | 0.00405 | 0.00405 | 0.00503 | 0.868046 | 1877835 |

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

| PRN | Range Acceleration Error Mean | Range Acceleration Error RMS | Range Acceleration 1 s | % ≤ 0.008 (SPS Spec. 95% of Time) | Max Range Acceleration Error (SPS Spec. ≤ 0.019 m/s2) | Samples |
|---|---|---|---|---|---|---|
| 1 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.004595 | 2219787 |
| 2 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.002393 | 2268682 |
| 3 | 0.00000 | 0.00003 | 0.00003 | 100% | 0.004654 | 1902098 |
| 4 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.001461 | 2153961 |
| 5 | 0.00000 | 0.00006 | 0.00006 | 100% | 0.006468 | 2518474 |
| 6 | 0.00000 | 0.00004 | 0.00004 | 100% | 0.004962 | 2404861 |
| 7 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.00144 | 2240755 |
| 8 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.001542 | 2163005 |
| 9 | 0.00000 | 0.00004 | 0.00004 | 100% | 0.004849 | 2228896 |
| 10 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.001603 | 2093923 |
| 11 | 0.00000 | 0.00004 | 0.00004 | 100% | 0.004842 | 2124430 |
| 13 | 0.00000 | 0.00005 | 0.00005 | 100% | 0.006026 | 2436668 |
| 14 | 0.00000 | 0.00001 | 0.00001 | 100% | 0.001473 | 2210290 |
| 15 | 0.00000 | 0.00003 | 0.00003 | 100% | 0.003803 | 1957726 |
| 17 | 0.00000 | 0.00003 | 0.00003 | 100% | 0.003397 | 1836350 |
| 18 | 0.00000 | 0.00001 | 0.00001 | 100% | 0.000361 | 2116485 |
| 20 | 0.00000 | 0.00008 | 0.00008 | 100% | 0.006872 | 2501480 |
| 21 | 0.00000 | 0.00003 | 0.00003 | 100% | 0.002425 | 1954118 |
| 22 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.002482 | 1978277 |
| 23 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.002113 | 2062283 |
| 24 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.002321 | 2098916 |
| 25 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.00181 | 2237666 |
| 26 | 0.00000 | 0.00003 | 0.00003 | 100% | 0.005078 | 1832979 |
| 27 | 0.00000 | 0.00003 | 0.00003 | 100% | 0.002195 | 1811229 |
| 28 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.001938 | 1999786 |
| 29 | 0.00000 | 0.00002 | 0.00002 | 100% | 0.002201 | 2227081 |
| 30 | 0.00000 | 0.00007 | 0.00007 | 99.999% | 0.009452 | 2461048 |
| 31 | 0.00000 | 0.00003 | 0.000073 | 99.999% | 0.008687 | 1877835 |

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the maximum range error, range rate error and range acceleration error for all satellites. None of the range errors for any of the satellites exceeded the 150-meter SPS requirement. The highest maximum range error occurred on satellite 20 with an error of 28.452 meters. Satellite 25 had the lowest maximum range error of 9.921 meters.

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

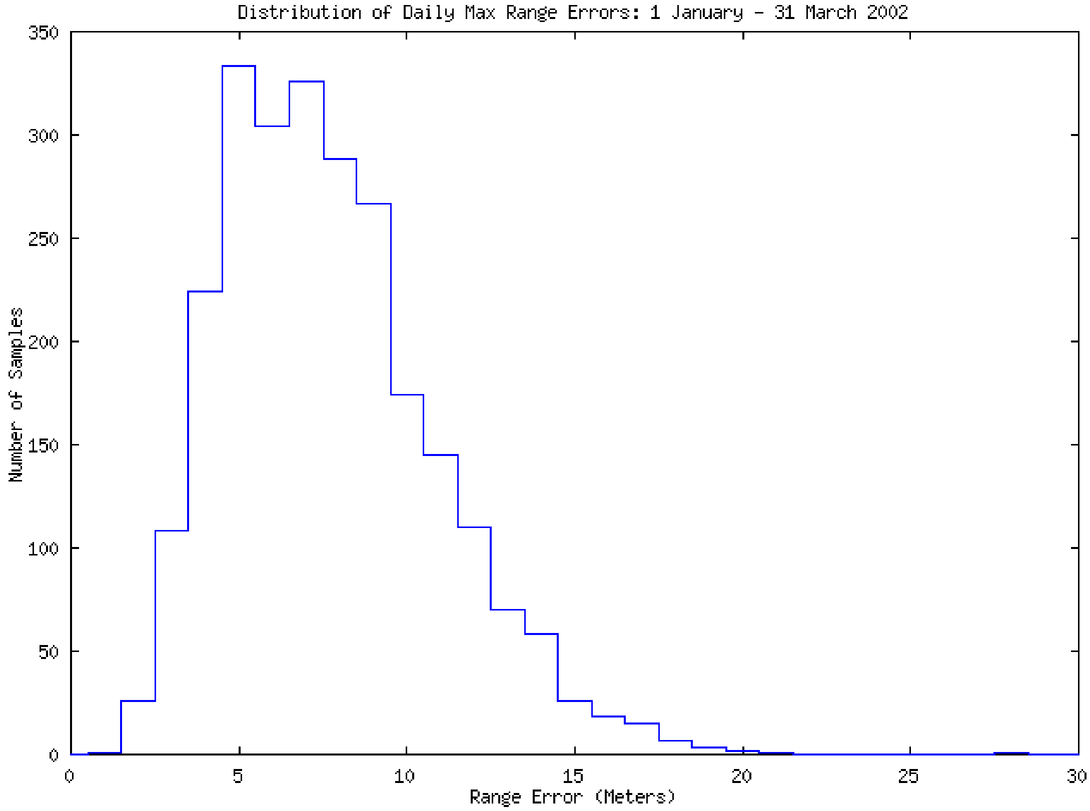



**Figure 5-5: Distribution of Daily Max Range Rate Errors**

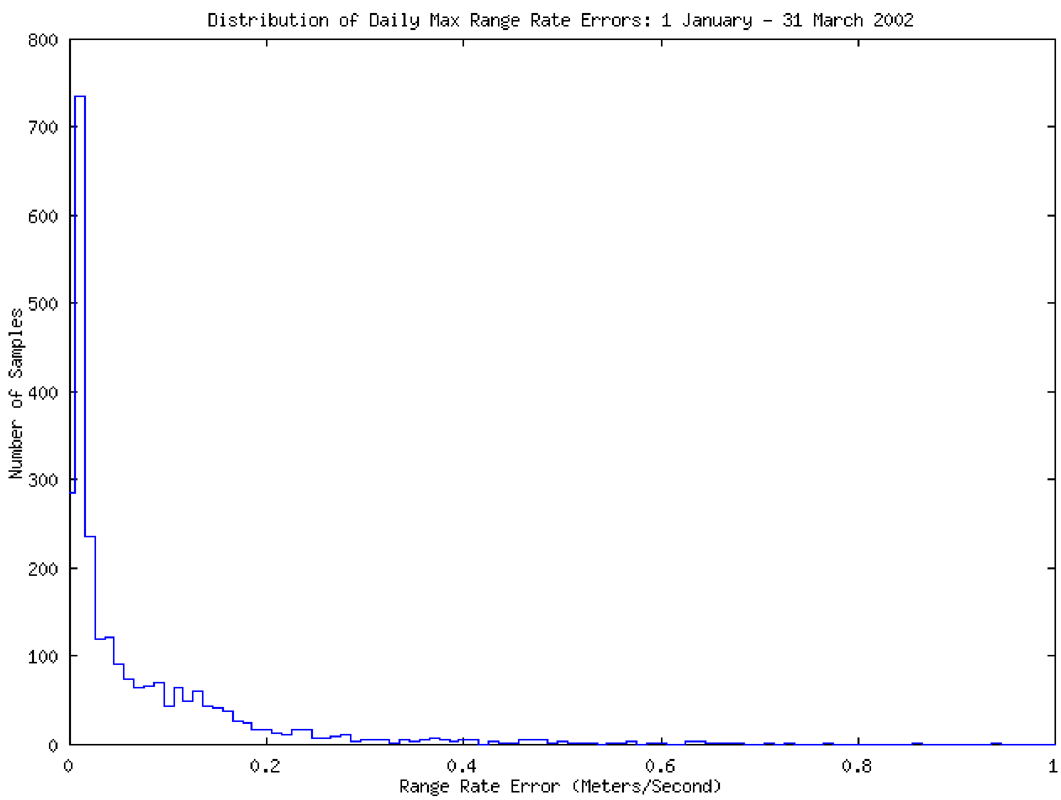


**Figure 5-6: Distribution of Daily Max Acceleration Rate Errors**

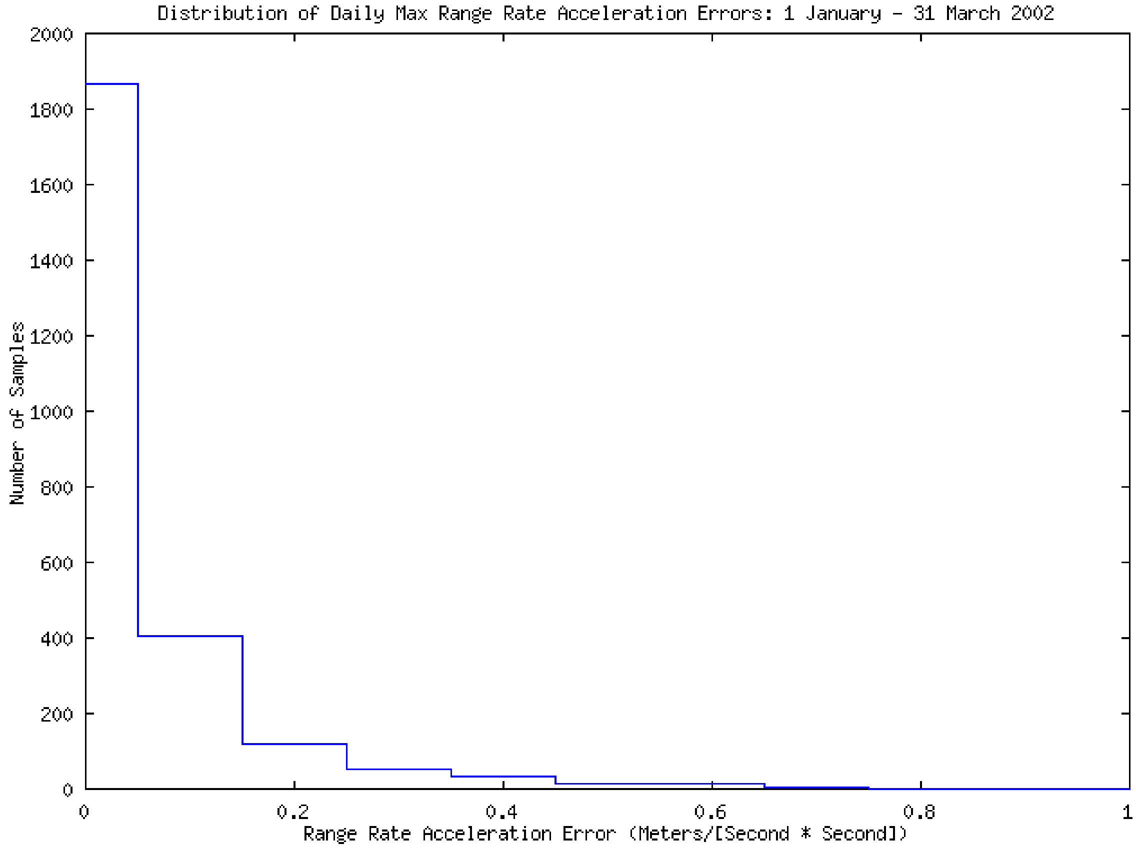


**Figure 5-7: Maximum Range Error Per Satellite**

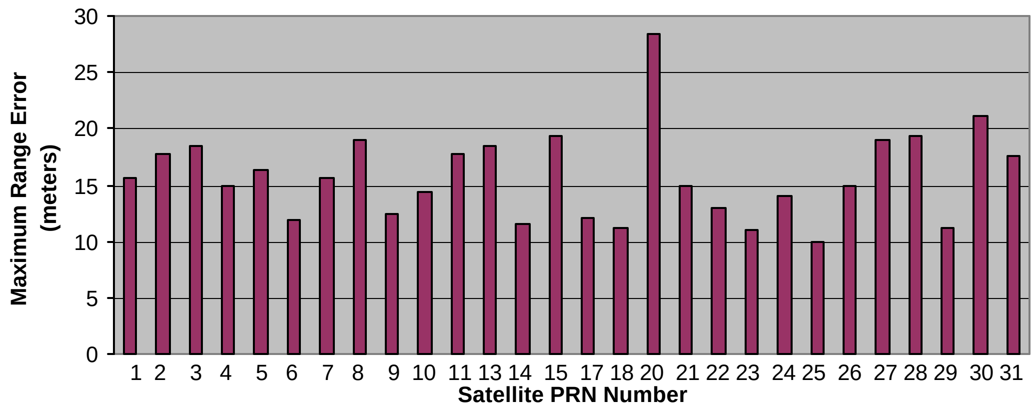



**Figure 5-8: Maximum Range Rate Error Per Satellite**

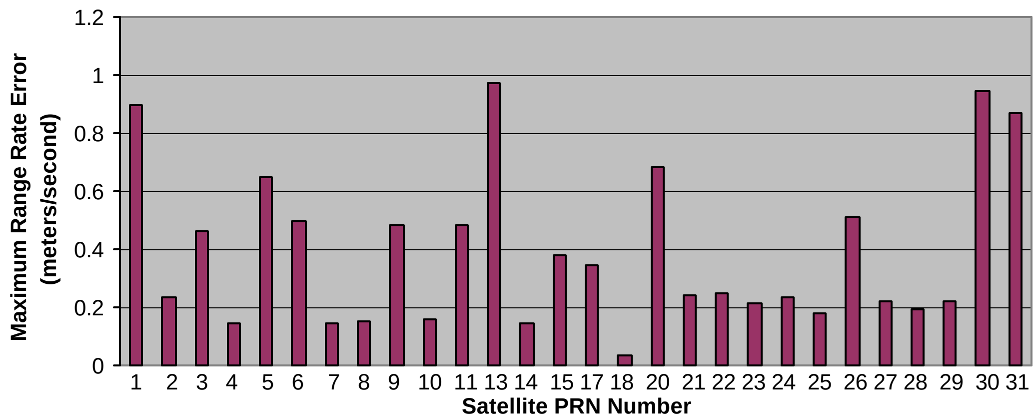
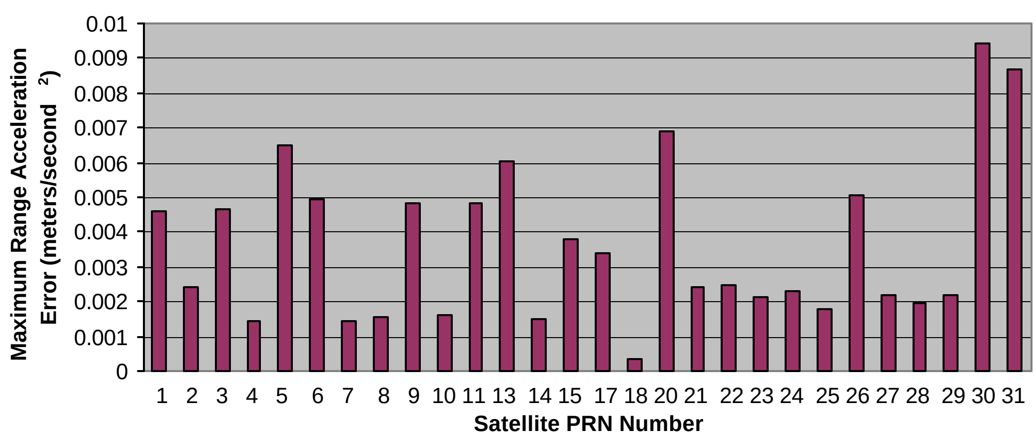



**Figure 5-9: Maximum Range Acceleration Per Satellite**



## 6.0 Solar Storms

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

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

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

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

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

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

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

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

**Figure 6-1 K-Index for 23-25 March 2002**

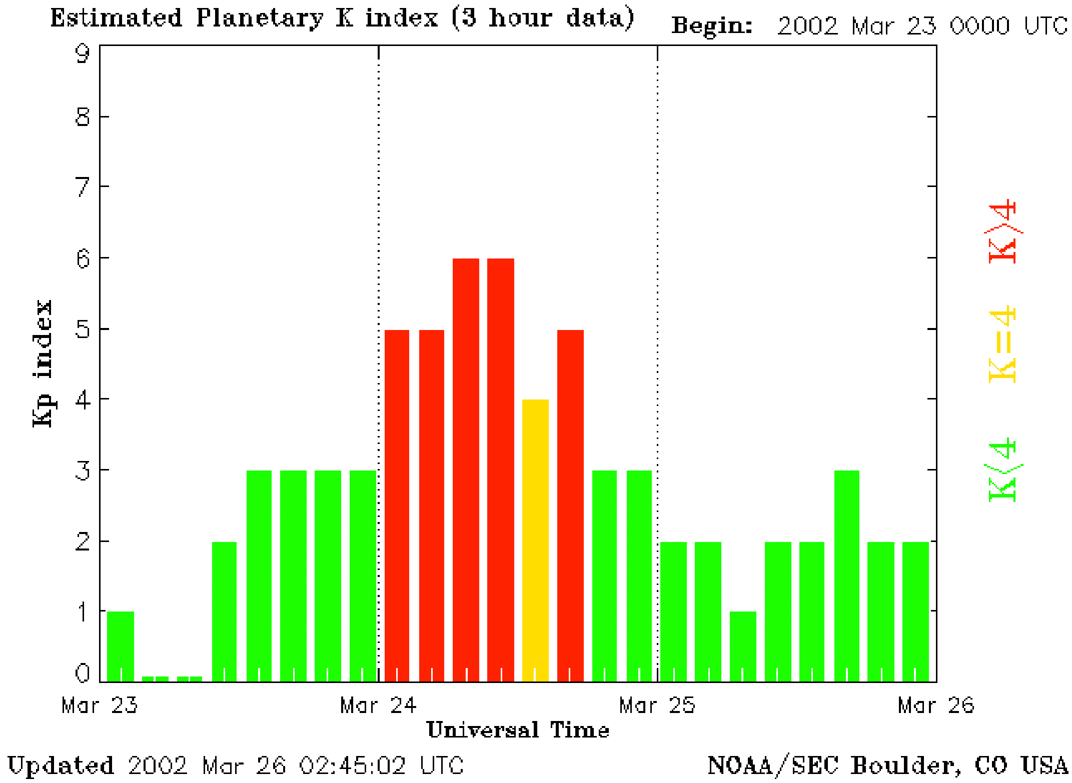


**Figure 6-2 K-Index for 18-20 March 2002**

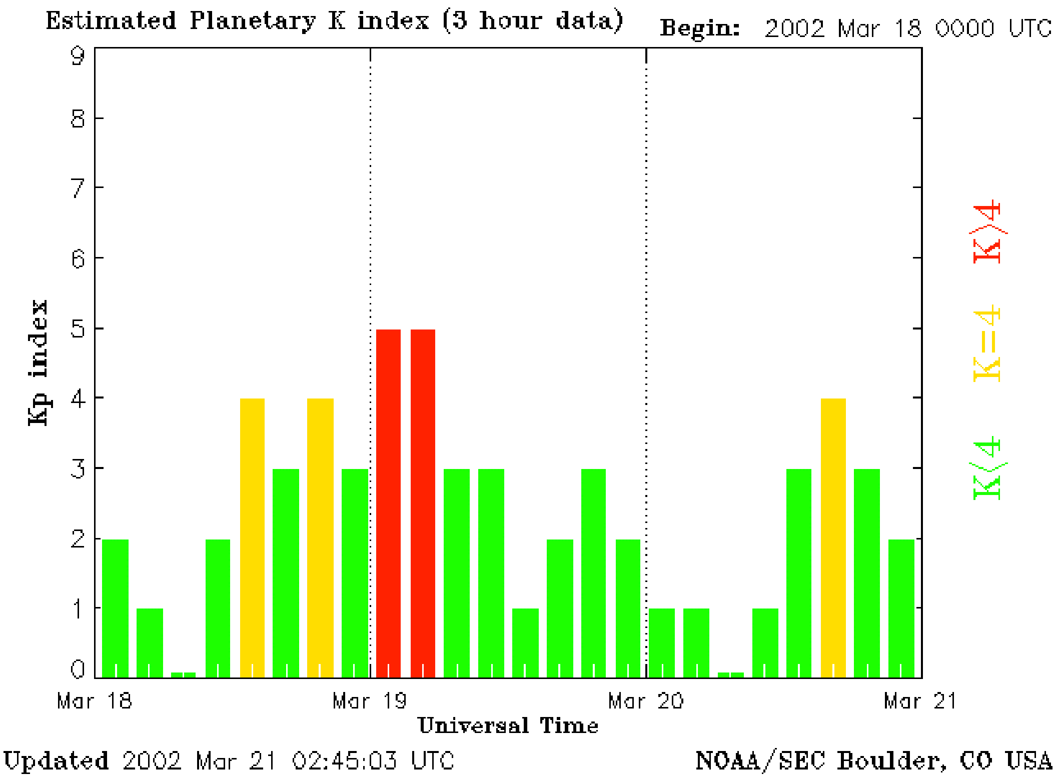
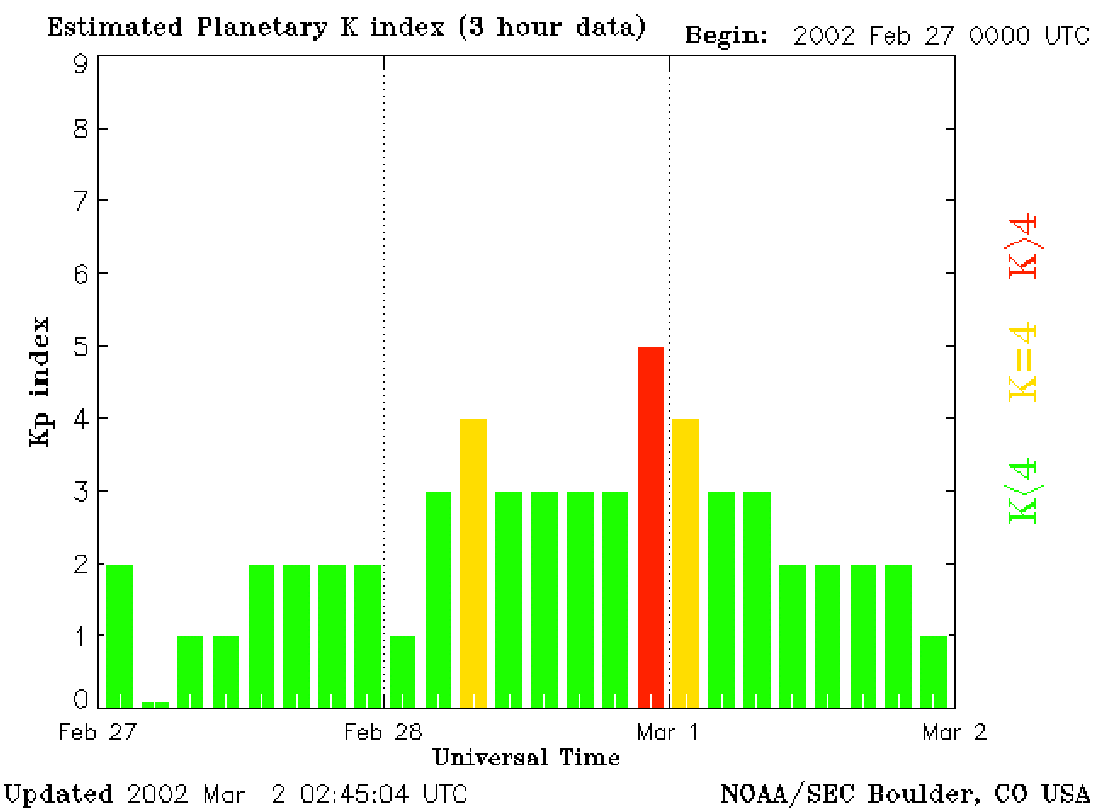



**Figure 6-3 K-Index for 27 February – 1 March 2002**



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

**Table 6-1 PDOP Statistics for 24 March 2002**

| NSTB/WAAS Site | Min PDOP | Max PDOP | Mean PDOP | 99.99% PDOP | 99.99% VDOP |
|---|---|---|---|---|---|
| **Atlantic City** | 1.212 | 3.808 | 1.798 | 3.803 | 3.335 |
| **Columbus** | 1.256 | 3.099 | 1.737 | 3.099 | 2.653 |
| **Denver** | 1.215 | 2.881 | 1.767 | 2.878 | 2.418 |
| **Grand Forks** | 1.246 | 4.069 | 1.769 | 4.057 | 3.570 |
| **Green Bay** | 1.171 | 3.636 | 1.749 | 3.636 | 3.185 |
| **Greenwood** | 1.309 | 3.385 | 1.747 | 3.384 | 2.836 |
| **Prescott** | 1.401 | 5.070 | 2.094 | 5.070 | 4.767 |
| **Billings** | 1.121 | 2.840 | 1.718 | 2.840 | 2.403 |
| **Anchorage** | 1.257 | 4.870 | 1.758 | 4.867 | 4.653 |
| **Chicago** | 1.266 | 2.971 | 1.697 | 2.969 | 2.466 |
| **Kansas City** | 1.276 | 2.283 | 1.709 | 2.281 | 1.988 |
| **Salt Lake City** | 1.184 | 3.137 | 1.736 | 3.133 | 2.661 |
| **Miami** | 1.208 | 3.339 | 1.760 | 3.339 | 3.064 |
| **Atlanta** | 1.313 | 3.374 | 1.769 | 3.374 | 2.932 |

**Table 6-2 Horizontal & Vertical Accuracy Statistics for 24 March 2002**

| NSTB Site | 95% Horizontal (Meters) | 95% Vertical (Meters) | 99.99% Horizontal (Meters) | 99.99% Vertical (Meters) |
|---|---|---|---|---|
| **Atlantic City** | 4.090 | 8.671 | 4.786 | 11.206 |
| **Columbus** | 5.502 | 9.091 | 8.322 | 11.230 |
| **Denver** | 5.680 | 9.375 | 7.284 | 13.677 |
| **Grand Forks** | 7.631 | 8.205 | 10.058 | 16.092 |
| **Green Bay** | 5.365 | 8.330 | 8.114 | 13.289 |
| **Greenwood** | 4.872 | 9.716 | 5.747 | 12.096 |
| **Prescott** | 4.957 | 11.284 | 6.885 | 13.098 |
| **Billings** | 7.175 | 8.221 | 9.473 | 12.540 |
| **Anchorage** | 10.043 | 8.733 | 11.998 | 15.333 |
| **Chicago** | 5.341 | 7.787 | 6.265 | 10.572 |
| **Kansas City** | 4.989 | 8.958 | 6.240 | 11.198 |
| **Salt Lake City** | 6.474 | 9.735 | 7.490 | 13.142 |
| **Miami** | 5.962 | 12.826 | 7.112 | 18.388 |
| **Atlanta** | 5.219 | 10.177 | 6.555 | 17.183 |

# 7.0 GLONASS/GPS Performance

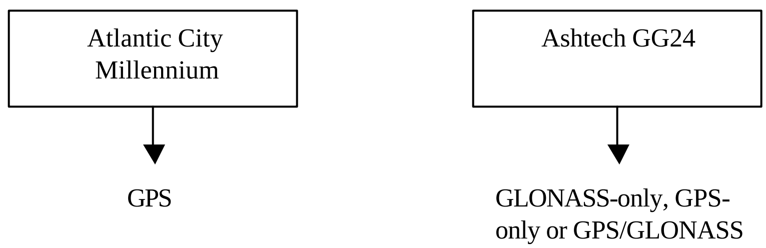
## 7.1 Introduction

In April 1999, ACT-360 was tasked to monitor, analyze and characterize GLONASS and GPS/GLONASS system performance. The objective of this task is to evaluate the ability of GLONASS to provide navigation by itself and with SPS GPS and to assess the incremental benefit to WAAS obtained from using GLONASS.

## 7.2 Approach

The GPS, GLONASS and blended data will be collected daily at one-second intervals. Since ACT-360 already collects the GPS data from the NSTB reference station sites, existing techniques and software programs will be used for the GLONASS and blended data collection and analysis. Initially, GPS/GLONASS receivers will be placed only at one site, Atlantic City. The Ashtech GG24 provides the three solutions but only one at a time. Therefore we have the Ashtech permanently outputting a blended solution.

**Figure 7-1 Receivers with Corresponding Solutions**




Analysis will include the comparison of the different solutions obtained from the Ashtech GG24 and the NSTB Millennium receiver. The GPS/GLONASS receiver solutions will be compared to the Millennium GPS-only and GPS/WAAS-corrected solutions.

The following table summarizes the performance data that will be reported on a quarterly basis.

| Performance | GPS | GLONASS | GPS+GLONASS |
|---|---|---|---|
| **Coverage** | X | X | X |
| **Service Availability** | X | X | X |
| **Position Accuracy** | X | X | X |
| **Range Accuracy** | X | X | X |
| **Time Accuracy** | X | X | X |
| **Satellite Visibility** | X | X | X |
| **Ionospheric Effects** | X | X | X |

## 7.3 Quarter Results

For this quarter, data collected from the Atlantic City Ashtech GG24 Glonass/GPS receiver and the Millennium GPS receiver will be analyzed and compared.

Tables 7-1 and 7-2 provide PDOP and Position Accuracy statistics for the two receivers from 1 January through 31 March 2002. The statistics are cumulative.

**Table 7-1 PDOP Statistics for Ashtech GG24 & Atlantic City**

| Receiver | Solution | Maximum PDOP | Minimum PDOP | Mean PDOP | 95% PDOP | Number of Samples |
|---|---|---|---|---|---|---|
| Ashtech GG24 | GPS/GLONASS | 5.808 | 1.000 | 1.699 | 2.302 | 7542135 |
| Millenium | GPS Only Atlantic City | 5.469 | 1.206 | 1.855 | 2.470 | 7775714 |

**Table 7-2 Position Accuracy Statistics for Ashtech GG24 & Atlantic City**

| Receiver | Solution | 95% Horizontal (m) | 95% Vertical (m) | 99.99% Horizontal (m) | 99.99% Vertical (m) | Number of Samples |
|---|---|---|---|---|---|---|
| Ashtech GG24 | GPS/GLONASS | 6.576 | 11.034 | 27.216 | 46.701 | 7542135 |
| Millenium | GPS Only Atlantic City | 5.896 | 11.209 | 15.160 | 20.123 | 7775714 |

Figures 7-2 and 7-3 show the Horizontal and Vertical Error histograms for the GG24 GLONASS/GPS solution.

**Figure 7-2 Horizontal Position Error Histogram for GPS/GLONASS**

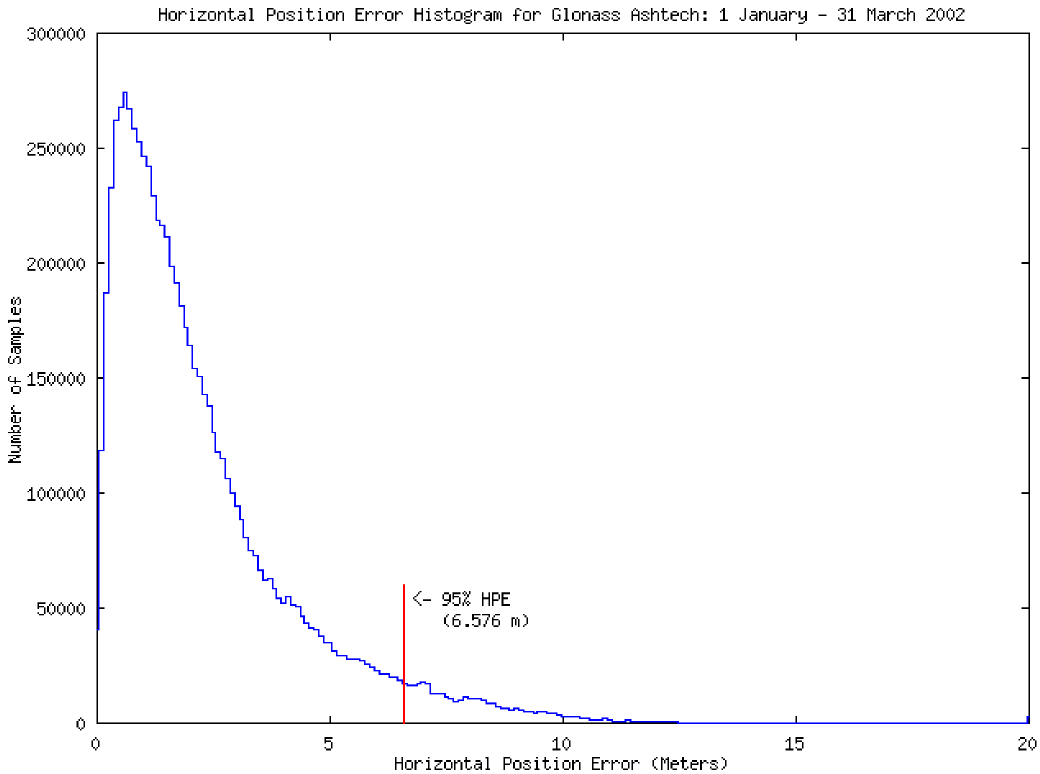



**Figure 7-3 Vertical Position Error Histogram for GPS/GLONASS**

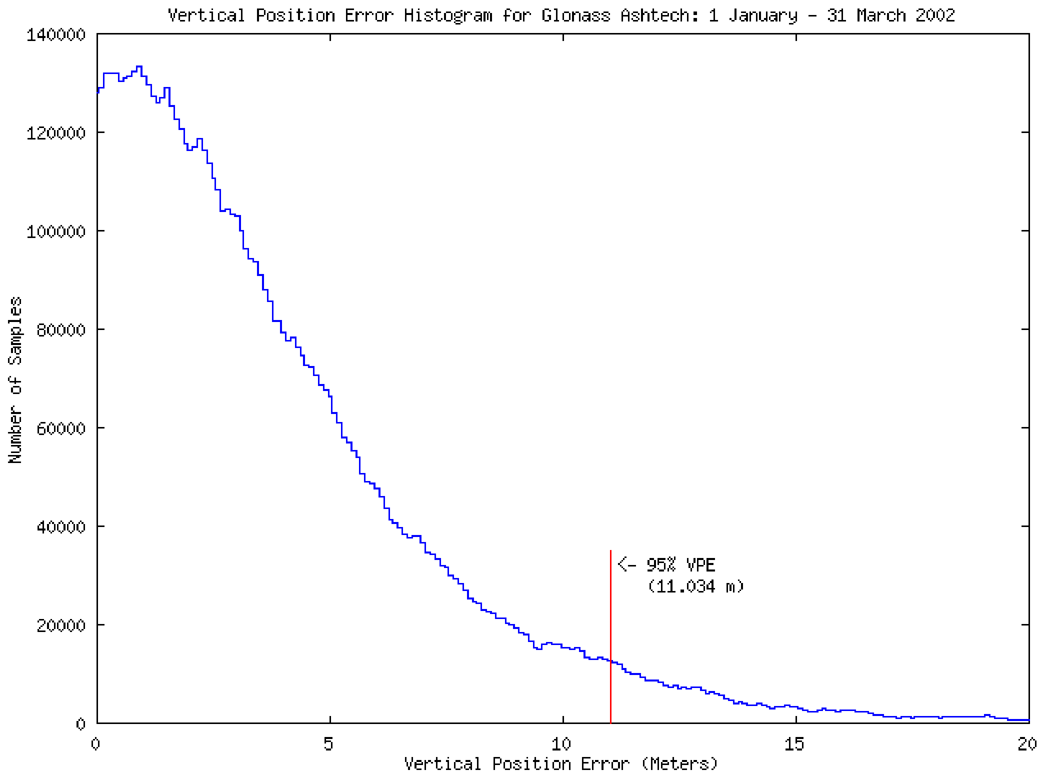
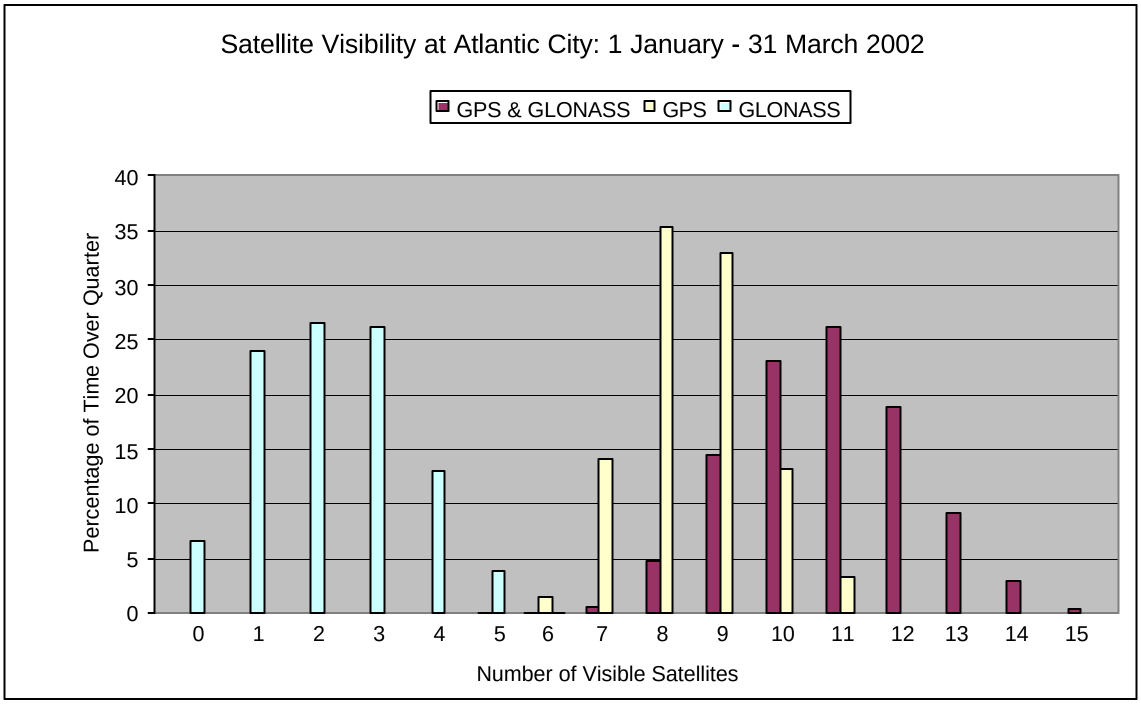



**Figure 7-4 Glonass and GPS Satellite Visibility**


Satellite Visibility at Atlantic City: 1 January - 31 March 2002
GPS & GLONASS
GPS
GLONASS
Percentage of Time Over Quarter
0
5
10
15
20
25
30
35
40
Number of Visible Satellites
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

# APPENDICES A – D

| *Conditions and Constraints* | *Coverage Standard* | *Measured Performance* |
|---|---|---|
| • Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe<br>• 4 satellites must provide PDOP of 6 or less<br>• 5° mask angle with no obscura<br>• Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac | ≥ 99.9% global average | 100% |
| • Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe<br>• 4 satellites must provide PDOP of 6 or less<br>• 5° mask angle with no obscura<br>• Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac | ≥ 96.9% at worst-case point | 99.653% Availability<br>99.9% PDOP was 3.12436 |
| ***Conditions and Constraints*** | ***Satellite Availability Standard*** | ***Measured Performance*** |
| • Conditioned on coverage standard<br>• Standard based on a typical 24 hour interval, averaged over the globe<br>• Typical 24 hour interval defined using averaging period of 30 days | ≥ 99.85% global average | 99.999% |
| • Conditioned on coverage standard<br>• Standard based on a typical 24 hour interval, for the worst-case point on the globe<br>• Typical 24 hour interval defined using averaging period of 30 days | ≥ 99.16% single point average | 99.986% |
| • Conditioned on coverage standard<br>• Standard represents a worst-case 24 hour interval, averaged over the globe | ≥ 95.87% global average on worst-case day | 99.967% |
| • Conditioned on coverage standard<br>• Standard based on a worst-case 24 hour interval, for the worst-case point on the globe | ≥ 83.92% at worst-case point on worst-case day | 99.575% |
| ***Conditions and Constraints*** | ***Service Reliability Standard*** | ***Measured Performance*** |
| • Conditioned on coverage and service availability standards<br>• 500 meter NTE predictable horizontal error reliability threshold<br>• Standard based on a measurement interval of one year; average of daily values over the globe<br>• Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval | ≥ 99.97% global average | 100% |

| | | |
|---|---|---|
| • Conditioned on coverage and service availability standards<br>• 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold<br>• Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe<br>• Standard based on a maximum of 18 hours of major service failure behavior over the sample interval | ≥ 99.79% single point average | 100% |
| ***Conditions and Constraints*** | ***Accuracy Standard*** | ***Measured Performance*** |
| • Conditioned on coverage, service availability and service reliability standards<br>• Standard based on a measurement interval of 24 hours, for any point on the globe | Predictable Accuracy<br>≤ 100 m horz. error 95% of time<br>≤ 156 m vert. error 95% of time<br>≤ 300 m horz. error 99.99% of time<br>≤ 500 m vert. error 99.99% of time | ≤7.226m HE 95%<br>≤15.160m HE 99.99%<br>≤13.574m VE 95%<br>≤22.609m VE 99.99% |
| • Conditioned on coverage, service availability and service reliability standards<br>• Standard based on a measurement interval of 24 hours, for any point on the globe | Repeatable Accuracy<br>≤ 141 m horz. error 95% of time<br>≤ 221 m vert. error 95% of time | ≤2.449m HE 95%<br>≤5.300m VE 95% |
| • Conditioned on coverage, service availability and service reliability standards<br>• Standard based on a measurement interval of 24 hours, for any point on the globe<br>• Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time | Relative Accuracy<br>≤ 1.0 m horz. error 95% of time<br>≤ 1.5 m vert. error 95% of time | Future Reports |
| • Conditioned on coverage, service availability and service reliability standards<br>• Standard based upon SPS receiver time as computed using the output of the position solution<br>• Standard based on a measurement interval of 24 hours, for any point on the globe<br>• Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory | Time Transfer Accuracy<br>≤ 340 nanoseconds time transfer error 95% of time | ≤16 ns 95% of the time |
| • Conditioned on satellite indicating healthy status<br>• Standard based on a measurement interval of 24 hours, for any point on the globe<br>• Standard restricted to range domain errors allocated to space/control segments<br>• Standards are not constellation values -- each | Range Domain Accuracy<br>≤ 150 m NTE range error<br>≤ 2 m/s NTE range rate error<br>≤ 19 mm/s$^2$ NTE range | 28.452m NTE Range Error<br>0.971435m/s NTE Rate Error<br>9.452mm/s$^2$ NTE Accl. Error |

| | | |
|---|---|---|
| satellite is required to meet the standards<br>• Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard | acceleration error $\leq 8$ mm/s$^2$ range acceleration error 95% of time | $\leq 8$mm/s$^2$ 99.9999% of the time |

## Appendix B Geomagnetic Data

```
Product: Daily Geomagnetic Data     quar_DGD.txt
Issued: 1820 UT 03 Apr 2002
#
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center.
#  Please send comment and suggestions to sec@sec.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
2002 01 01     4  2 1 1 1 2 0 2 1     9  2 2 2 4 3 1 1 1     7  2 2 2 2 2 2 3 2
2002 01 02     7  1 1 1 1 3 3 2 2    -1 -1-1-1-1-1-1-1-1     7  1 1 1 1 3 3 2 2
2002 01 03     6  1 1 1 1 2 3 2 2    -1 -1-1-1-1-1-1-1-1     3  1 1 1 1 1 1 2 1
2002 01 04     4  0 1 1 1 1 2 3 1    -1 -1-1-1-1-1-1-1-1     3  1 1 0 1 1 1 2 1
2002 01 05     2  2 1 0 0 0 1 1 0    -1 -1-1-1-1-1-1-1-1     3  2 0 0 1 1 1 2 1
2002 01 06     3  1 0 0 0 2 2 2 1    -1 -1-1-1-1-1-1-1-1     4  1 0 0 1 1 2 2 2
2002 01 07     8  0 1 1 3 1 3 3 2    -1 -1-1-1-1-1-1-1-1     7  1 1 0 3 2 3 3 2
2002 01 08     6  2 1 3 1 3 1 0 0    -1 -1-1-1-1-1-1-1-1     7  2 1 3 2 2 2 2 1
2002 01 09     2  0 0 0 0 1 2 2 0    -1  0 0 0 0 1 1 0-1     3  1 0 0 0 1 2 2 0
2002 01 10    16  1 2 1 2 4 5 3 3    45  0 1 3 4 6 7 6 3    17  2 1 2 3 4 5 4 3
2002 01 11    12  3 3 3 3 2 3 2 1    37  4 4 5 6 4 5 4 3    21  4 4 4 4 4 4 3 2
2002 01 12    12  3 3 3 3 2 3 2 1    30  2 3 5 6 4 5 2 2    15  3 3 4 4 3 3 3 2
2002 01 13    10  1 2 3 2 3 2 2 3    25  2 2 5 5 5 4 2 2    11  2 2 4 3 3 2 2 3
2002 01 14     7  2 2 1 1 3 2 1 2    11  1 1 2 3 4 2 2 3     8  3 2 1 2 3 3 2 2
2002 01 15     4  1 1 1 2 2 1 1 1    11  1 1 1 4 4 3 1 1     6  1 2 2 2 2 2 2 2
2002 01 16     3  1 0 2 0 1 1 1 0     4  3 1 2 2 0 0 0 0     4  1 1 3 1 1 2 1 1
2002 01 17     6  3 1 0 2 2 2 1 1     8  0 0 1 4 2 4 1 0     6  3 1 1 2 2 3 1 2
2002 01 18     5  2 1 1 1 3 2 1 0    10  1 1 0 3 1 2 5 0     5  2 1 0 3 2 2 1 1
2002 01 19    11  0 2 2 3 3 4 2 2    27  0 1 1 2 6 6 3 4    11  1 1 2 2 4 4 3 3
2002 01 20     6  2 3 1 1 1 1 2 1     8  1 1 0 4 1 3 2 1     7  3 2 1 2 2 3 2 2
2002 01 21     7  2 2 2 2 2 1 2 2    14  2 2 2 5 4 2 2 1     9  3 2 2 3 3 2 3 2
2002 01 22     5  1 1 2 1 2 2 1 1     7  0 0 2 3 4 1 1 0     6  1 1 3 2 2 2 2 2
2002 01 23     4  2 0 1 2 1 1 2 1    10  1 0 1 4 3 2 3 2     6  2 0 1 2 2 3 3 2
2002 01 24     3  1 1 0 0 2 1 1 1     1  1 1 0 0 0 1 0 0     4  1 2 0 0 1 2 2 2
2002 01 25     6  0 1 1 1 3 2 3 1    12  0 0 1 0 3 4 5 1     8  1 0 1 1 3 3 4 2
2002 01 26     6  1 1 2 2 2 2 2 1     6  1 1 2 3 1 2 2 0     7  2 2 2 2 2 2 2 2
2002 01 27     4  1 1 1 1 1 2 1 1     5  1 2 1 2 3 1 1 0     7  3 3 1 2 2 2 2 2
2002 01 28     6  2 0 1 2 2 2 2 2     9  1 0 1 4 4 1 1 1     6  2 1 1 2 3 2 2 2
2002 01 29     2  1 1 1 1 0 0 0 0     2  0 1 0 2 1 0 0 0     4  2 1 1 2 1 1 1 1
2002 01 30     1  0 0 0 0 0 1 1 1    -1  0 0 1 0 2 2 0-1     3  1 0 1 0 1 1 1 2
2002 01 31     6  2 1 0 0 2 2 2 3    -1  1 1 0 0-1-1-1-1     5  2 1 0 0 1 2 1 3
2002 02 01    11  3 2 2 2 3 3 3 1    -1 -1-1-1-1-1-1 1 4    11  3 2 2 2 3 4 2 2
2002 02 02    14  2 3 4 3 3 3 2 2    -1  1 5-1-1-1-1-1-1    18  3 3 5 4 4 3 3 2
2002 02 03     6  1 2 0 1 3 3 2 0    -1 -1-1-1-1-1-1-1-1     5  1 2 0 2 2 2 2 0
```

| | | | | | | |
|---|---|---|---|---|---|---|
| 2002 02 04 | 8 | 1 1 0 0 3 3 3 3 | -1 | -1-1-1-1-1-1 1 2 | 6 | 1 1 0 0 2 3 3 3 |
| 2002 02 05 | 15 | 3 2 2 2 3 4 4 3 | -1 | 2 3 2 3 4-1 4 3 | 16 | 4 3 2 2 3 4 4 3 |
| 2002 02 06 | 13 | 2 3 3 2 3 3 3 3 | -1 | 3 4-1 5-1 4 4 4 | 16 | 3 3 4 4 4 3 3 2 |
| 2002 02 07 | 10 | 2 2 2 2 3 3 1 3 | 25 | 3 3 4 6 5 2 1 2 | 14 | 2 3 4 3 4 2 3 3 |
| 2002 02 08 | 9 | 3 1 2 2 3 3 2 1 | -1 | 3-1-1-1-1-1 3-1 | 10 | 3 1 1 2 3 3 3 2 |
| 2002 02 09 | 6 | 2 2 2 2 1 1 2 2 | 9 | 1 2 2 3 3 3 1 2 | 9 | 2 3 2 3 2 2 2 3 |
| 2002 02 10 | 7 | 2 2 3 2 2 1 1 2 | 12 | 2 2 3 4 4 1 1 1 | 8 | 3 2 3 2 2 2 2 2 |
| 2002 02 11 | 8 | 2 1 2 3 3 2 1 2 | 26 | 1 0 2 6 5 5 3 2 | 13 | 2 2 3 4 3 3 3 3 |
| 2002 02 12 | 5 | 3 1 2 1 0 1 1 2 | 6 | 3 2 2 2 0 1 1 2 | 6 | 3 2 2 1 1 2 2 2 |
| 2002 02 13 | 11 | 2 1 3 3 3 3 2 2 | 15 | 1 1 3 4 5 3 2 1 | 10 | 2 1 3 3 3 3 2 1 |
| 2002 02 14 | 2 | 0 0 2 0 1 1 1 0 | 1 | 0 0 1 1 0 1 0 1 | 4 | 1 0 2 1 1 2 2 1 |
| 2002 02 15 | 3 | 0 0 0 0 1 3 1 1 | 4 | 0 0 0 0 0 4 1 0 | 4 | 1 0 0 1 1 2 2 1 |
| 2002 02 16 | 2 | 1 0 0 0 1 2 1 1 | 5 | 0 0 0 0 4 2 1 1 | 5 | 2 0 0 1 1 2 2 2 |
| 2002 02 17 | 6 | 2 2 3 1 1 1 1 1 | 9 | 1 1 4 1 3 3 0 1 | 8 | 1 3 4 2 2 2 2 2 |
| 2002 02 18 | 6 | 1 2 1 0 2 2 2 3 | 7 | 0 0 3 2 0 1 3 3 | 9 | 1 2 2 2 1 3 3 4 |
| 2002 02 19 | 4 | 2 1 1 1 0 1 2 1 | 2 | 1 0 1 0 0 1 2 1 | 4 | 2 1 1 1 1 2 2 1 |
| 2002 02 20 | 6 | 1 0 2 1 2 2 2 3 | 11 | 0 0 4 3 4 2 2 2 | 8 | 2 0 3 2 3 2 2 3 |
| 2002 02 21 | 6 | 1 2 1 1 2 1 2 3 | 9 | 0 1 2 2 3 2 4 2 | 6 | 1 1 2 1 2 2 3 3 |
| 2002 02 22 | 6 | 1 2 1 0 2 1 3 2 | 4 | 1 1 0 0 3 0 2 1 | 5 | 2 2 0 1 1 2 3 2 |
| 2002 02 23 | 3 | 2 2 0 0 1 1 0 1 | 2 | 1 2 0 0 1 0 0 0 | 4 | 2 1 1 0 1 2 2 1 |
| 2002 02 24 | 4 | 1 1 1 1 2 1 1 1 | 5 | 0 0 0 2 4 0 1 0 | 4 | 2 1 1 1 2 1 1 1 |
| 2002 02 25 | 4 | 1 0 2 1 2 2 1 1 | 12 | 0 0 1 5 4 3 1 1 | 7 | 1 0 2 2 3 3 2 2 |
| 2002 02 26 | 8 | 2 2 2 2 2 2 3 2 | 11 | 1 1 4 4 3 1 1 1 | 8 | 2 2 3 2 2 2 2 3 |
| 2002 02 27 | 4 | 2 0 1 1 2 1 1 1 | 5 | 3 1 0 2 2 1 1 1 | 4 | 2 0 1 1 2 2 2 2 |
| 2002 02 28 | 15 | 1 4 3 2 3 2 3 4 | 19 | 1 2 3 4 5 2 3 4 | 17 | 1 3 4 3 3 3 3 5 |
| 2002 03 01 | 9 | 5 2 2 1 2 1 0 0 | 9 | 4 1 3 2 2 1 0 2 | 11 | 4 3 3 2 2 2 2 1 |
| 2002 03 02 | 4 | 1 1 1 1 1 2 1 2 | 3 | 1 1 0 0 1 2 1 1 | 5 | 1 1 1 1 1 3 3 2 |
| 2002 03 03 | 10 | 2 1 2 1 3 2 2 4 | 15 | 1 0 4 3 4 4 2 3 | 10 | 1 1 3 2 3 3 3 4 |
| 2002 03 04 | 9 | 3 0 1 1 2 4 2 2 | 9 | 3 0 1 2 2 3 3 2 | 9 | 2 2 1 2 2 3 3 2 |
| 2002 03 05 | 10 | 2 3 2 2 3 3 2 2 | 26 | 2 4 4 3 4 5 5 2 | 15 | 3 4 2 3 3 4 3 3 |
| 2002 03 06 | 16 | 2 3 1 2 3 4 5 2 | 39 | 3 2 3 5 5 6 6 3 | 15 | 2 3 3 3 3 4 4 3 |
| 2002 03 07 | 5 | 2 1 2 2 2 0 0 2 | -1 | 1 1 3-1-1 2 2 5 | 10 | 2 1 3 3 4 2 2 2 |
| 2002 03 08 | 4 | 1 1 2 2 1 1 1 1 | 10 | 1 1 3 5 1 0 0 0 | 4 | 1 1 2 3 0 1 1 1 |
| 2002 03 09 | 3 | 1 0 0 1 1 2 2 1 | 12 | 0 0 0 4 3 4 1 1 | 5 | 1 0 0 2 3 3 2 1 |
| 2002 03 10 | 6 | 0 1 0 3 3 1 1 2 | 9 | 0 1 0 4 4 2 1 2 | 9 | 1 1 0 4 4 2 2 3 |
| 2002 03 11 | 8 | 2 4 1 2 2 1 2 1 | 10 | 3 2 1 3 4 1 2 1 | 9 | 3 3 2 2 3 2 3 2 |
| 2002 03 12 | 8 | 2 2 3 2 2 2 2 2 | 17 | 2 0 3 5 5 3 2 1 | 10 | 2 1 2 3 3 3 3 3 |
| 2002 03 13 | 6 | 2 0 2 1 3 2 1 1 | -1 | 1 1 2 3 2-1 0 0 | 5 | 2 1 2 2 2 2 2 1 |
| 2002 03 14 | 2 | 1 0 0 0 2 1 0 0 | 1 | 1 0 0 0 1 0 0 0 | 4 | 1 0 0 1 1 2 2 1 |
| 2002 03 15 | 3 | 0 1 1 0 2 1 1 2 | 2 | 0 0 0 0 0 1 2 1 | 6 | 1 0 1 1 2 3 3 2 |
| 2002 03 16 | 5 | 1 1 1 0 3 3 1 0 | 8 | 1 0 0 0 4 4 1 0 | 5 | 1 0 0 1 2 3 2 1 |
| 2002 03 17 | 2 | 0 0 0 0 0 1 2 1 | 0 | 0 0 0 0 0 0 0 0 | 4 | 1 0 0 1 2 2 2 1 |
| 2002 03 18 | 9 | 1 1 0 1 4 2 3 3 | 12 | 1 1 0 3 3 4 2 4 | 12 | 2 1 0 2 4 3 4 3 |
| 2002 03 19 | 15 | 5 4 3 2 1 1 2 2 | 14 | 3 5 4 2 1 1 1 2 | 17 | 5 5 3 3 1 2 3 2 |
| 2002 03 20 | 7 | 1 1 0 0 3 4 2 1 | 15 | 0 0 0 0 3 5 2 5 | 7 | 1 1 0 1 3 4 3 2 |
| 2002 03 21 | 5 | 1 1 2 1 2 1 2 2 | 8 | 2 1 4 3 0 1 2 1 | 8 | 2 1 3 3 1 2 3 2 |
| 2002 03 22 | 7 | 2 3 2 3 2 0 1 0 | 9 | 1 2 2 5 0 1 1 1 | 8 | 2 3 3 3 1 2 2 1 |
| 2002 03 23 | 8 | 1 0 0 2 3 2 2 3 | 16 | 0 0 0 2 4 5 4 3 | 9 | 1 0 0 2 3 3 3 3 |
| 2002 03 24 | 29 | 4 4 5 5 4 4 3 3 | 68 | 4 5 7 6 6 7 3 3 | 47 | 5 5 6 6 4 5 3 3 |
| 2002 03 25 | 7 | 2 2 1 1 2 3 2 1 | -1 | 2 1 1 1 2-1 2 1 | 5 | 2 2 1 2 2 3 2 2 |
| 2002 03 26 | 10 | 2 3 2 3 3 1 1 3 | 15 | 3 3 1 4 3 2 2 4 | 11 | 3 2 1 3 3 3 2 3 |
| 2002 03 27 | 3 | 1 2 2 0 0 1 1 1 | 3 | 2 1 1 0 0 1 1 1 | 5 | 2 1 2 2 2 2 2 1 |
| 2002 03 28 | 2 | 0 0 0 1 0 2 1 0 | 5 | 0 0 0 2 3 3 0 0 | 6 | 1 0 1 2 3 3 3 1 |
| 2002 03 29 | 6 | 0 0 0 1 2 2 1 4 | -1 | 1 0 0-1-1-1-1-1 | 7 | 1 0 0 2 2 3 2 3 |
| 2002 03 30 | 18 | 2 4 3 3 4 4 3 2 | -1 | -1-1-1-1-1-1-1-1 | 17 | 2 4 4 3 4 3 3 2 |
| 2002 03 31 | 12 | 2 3 3 2 3 3 3 2 | -1 | -1-1-1-1-1-1-1-1 | 14 | 2 3 3 3 3 3 4 3 |

**Background:**

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

**Problem Description:**

GPS did not fail SPS specification in any instances during this quarter.

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

**General Terms and Definitions**

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

**Dilution of Precision (DOP).** The magnifying effect on GPS position error induced by mapping GPS ranging errors into position through the position solution. The DOP may be represented in any user local coordinate desired. Examples are HDOP for local horizontal, VDOP for local vertical, PDOP for all three coordinates, and TDOP for time.

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

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

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

**Navigation Data.** Data provided to the SPS receiver via each satellite's ranging signal, containing the ranging signal time of transmission, the transmitting satellite's orbital elements, an almanac containing abbreviated orbital element information to support satellite selection, ranging measurement correction information, and status flags.

**Navigation Message.** Message structure designed to carry navigation data.

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

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

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

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

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

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

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

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

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

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

## Performance Parameter Definitions

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

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

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

- **Predictable Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a position measurement and a surveyed benchmark is within a specified tolerance at any point on or near the Earth.
- **Repeatable Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a position measurement taken at one time and a position measurement taken at another time at the same location is within a specified tolerance at any point on or near the Earth.
- **Relative Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between two receivers' position estimates taken at the same time is within a specified tolerance at any point on or near the Earth.
- **Time Transfer Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a Universal Coordinated Time (commonly referred to as UTC) time estimate from the position solution and UTC as it is managed by the United States Naval Observatory (USNO) is within a specified tolerance.

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

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

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

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

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

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