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

Submitted To

Federal Aviation Administration
GPS Product Team
AND 730
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Submitted by

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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: Anderson, Atlantic City, Dayton, Elko, Gander, Great Falls and Oklahoma City, Kansas City (WAAS) and Salt Lake City (WAAS). During the reported quarter, the Gander receiver experienced mechanical problems that limited the amount of useful data from this site. Quarterly data from Gander has been omitted from this report, however the receiver has been fixed and data will be included in the next report. This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification Annex A.

This report, Report #31, includes data collected from 2 July through 30 September 2000. The next quarterly report will be issued 31 January 2001.

Analysis of this data includes the following categories: Coverage Performance, Service Availability Performance, Position Performance, Range Performance, Solar Storm Effects on GPS SPS performance and GPS/GLONASS 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 99.9% or better.

Availability was verified by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 2 July and 30 September 2000 and by calculating the satellite availability from the data obtained from the nine sites. A total of fourteen outages were reported in the NANUs. Eleven of the outages were scheduled and three were unscheduled. The quarterly availabilities for Anderson, Atlantic City, Dayton, Elko, Great Falls, Oklahoma City, Kansas City, and Salt Lake City were 99.98%, 99.97%, 99.97%, 99.98%, 99.99%, 99.99%, 100%, 99.99%, respectively. Each of these availabilities is within the SPS value of 99.85%. In this quarter, the following events caused availability to exceed the GPS SPS specifications: Satellite PRN 9 (NANU #118), Satellite PRN 20 (NANU #117), satellite PRN 23 (NANU # 152) and Satellite PRN 25 (NANU #145). Both the 95% and 99.99% horizontal and vertical accuracy requirement passed. 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 Anderson site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 52.5 meters on Satellite PRN 23. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 1.84 Meters/second on Satellite PRN 21. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 18 Millimeters/second^2 on Satellite PRN 21. 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 (collected from a Novatel Millenium receiver). The 95% horizontal error and vertical error for the GPS/GLONASS solution were 6.884 Meters and 29.494 Meters, respectively. Now that Selective Availability (SA) has been turned off, it appears that there is a bias in the data collected from the Ashtech GG24 receiver. SA previously masked this bias. It is believed this is why the GPS (Millenium receiver) solution had better performance than GPS/GLONASS (Ashtech GG24 receiver). This issue is under investigation and will be reported on in future reports.

From the analysis performed on data collected between 2 July and 30 September 2000, the GPS performance met all SPS requirements that were evaluated except for the three instances where availability dropped below specification. All three instances were due to satellite maintenance and were forecasted appropriately.

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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:

- Anderson, SC
- Atlantic City, NJ
- Dayton, OH
- Elko, NV
- Gander, NFLD (Canada)
- Great Falls, ND
- Oklahoma City, OK
- Kansas City, KS
- Salt Lake City, UT

(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.

Table 1-2 and 1-3 lists the non-precision and precision, respectively, performance parameters that will be evaluated for the Wide Area Augmentation System (WAAS) in future versions of 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 nine 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. This quarter the GPS SPS specification for availability was not met on three individual 24 hour periods.

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

Attachment A provides data from the Ionospheric Storm in July.

Table 1-1 SPS Performance Requirements

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

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

Table 1-2 Future WAAS Performance Summary
En Route through Non-Precision Approach (from FAA-Spec-2892B)

Performance Parameter	*Requirements from WAAS Specification*
Accuracy	100 m (95% Horizontal Position) 500 m (99.999% Horizontal Position)
Integrity	10^{-7} probability of Hazardously Misleading Information 8 seconds to alarm Alarm Limit: 556 m - Total System HPL bound error - WAAS
Availability	0.999 Navigation and fault detection functions are operational Signal-in-Space meets accuracy and continuity requirements
Service Volume	50% in CONUS 35% of Total Service Volume

Table 1-3 Future WAAS Performance Summary
Precision Approach (from FAA-Spec-2892B)

Performance Parameter	*Requirements from WAAS Specification*
Accuracy	7.6 m (95% Horizontal Position) 7.6 m (95% Vertical Position)
Integrity	$4x10^{-8}$ probability of Hazardously Misleading Information 6.2 seconds to alarm
Availability	0.95 Navigation and fault detection functions are operational Signal-in-Space meets accuracy and continuity requirements
Service Volume	50% in CONUS

2.0 Coverage Performance

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

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

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

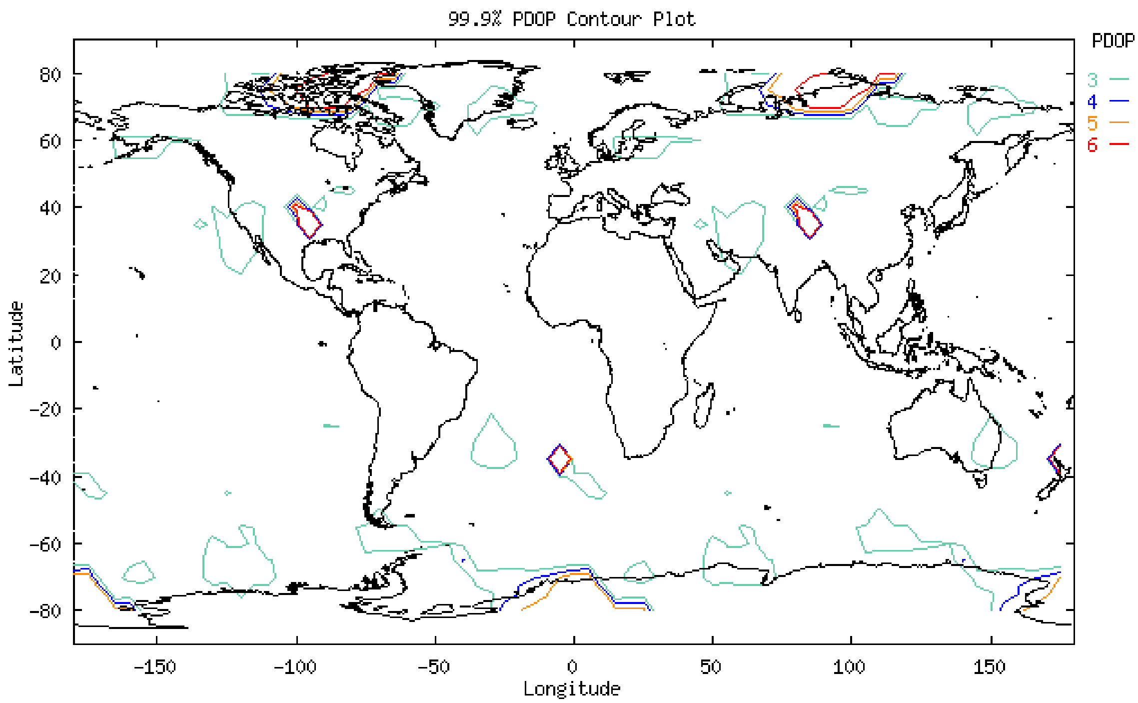
Almanacs for GPS weeks 45-57 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACT-360 was used to calculate the PDOP at every 5° point between longitudes of 180W to 180E and 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 3.75 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

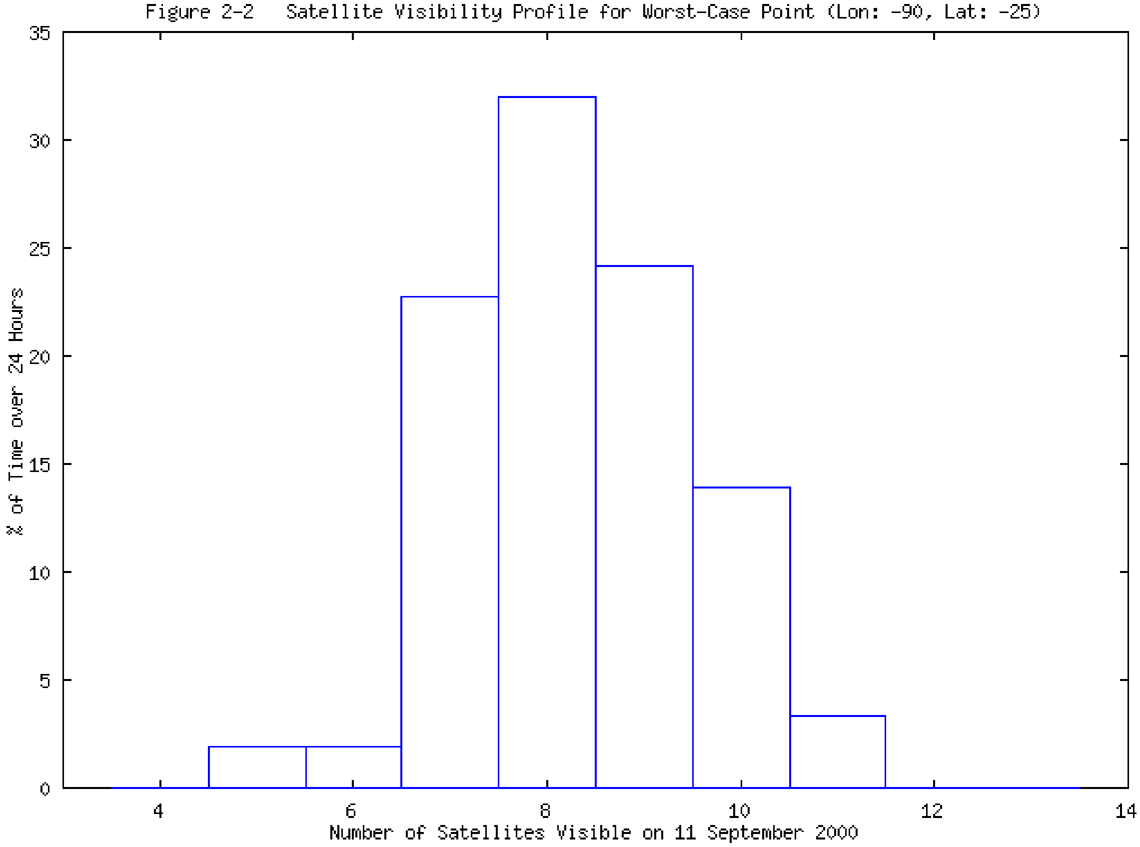
GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
45	3.11	100%	99.65%
46	3.11	100%	99.65%
47	3.13	100%	99.65%
48	3.14	100%	99.65%
49	3.40	99.99%	99.37%
50	3.41	99.99%	99.23%
51	3.41	99.99%	99.16%
52	3.35	99.99%	98.96%
53	3.35	99.99%	98.96%
54	3.35	99.99%	98.89%
55	3.75	99.98%	98.26%
56	3.35	99.98%	98.75%
57	3.36	99.98%	98.75%

Figure 2-1 SPS Coverage (24-Hour Period: 11 September 2000)



Developed by FAA William J. Hughes Technical Center

Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -90, Lat: -25)



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 (NANUs). During this reporting period, 2 July through 30 September 2000, there were a total of fourteen reported outages. Eleven of these outages were maintenance activities and were reported in advance. Three were unscheduled outages. A complete listing of outage NANUs for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANUs for the reporting period can be found in Table 3-2. Canceled outage NANUs 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
117	20	S	18-Jul	20:22	19-Jul	10:48		14.26	14.26
118	9	S	19-Jul	17:03	19-Jul	21:32		4.48	4.48
121	13	S	25-Jul	12:55	25-Jul	19:43		6.80	6.80
122	2	S	27-Jul	4:07	27-Jul	5:53		1.46	1.46
124	4	S	28-Jul	4:01	3-May	14:13		10.20	10.20
125	26	S	1-Aug	5:55	1-Aug	11:21		5.26	5.26
129	2	S	9-Aug	6:11	9-Aug	10:31		4.33	4.33
130	6	S	10-Aug	12:24	10-Aug	17:26		5.03	5.03
134	29	S	24-Aug	16:45	24-Aug	22:33		5.80	5.80
133*	18	S	18-Aug	7:42	N/A	N/A		N/A	N/A
142	7	S	14-Sep	19:13	14-Sep	21:48		2.58	2.58
154	20	S	29-Sep	11:13	29-Sep	15:58		3.75	3.75
123**	16	U	27-Jul	7:07	N/A	N/A	0.00	0.00	0.00
131***	28	U	17-Aug	13:51	N/A	N/A	0.00	0.00	0.00
135****	24	U	2-Sep	11:01	N/A	N/A	N/A	0.00	0.00
136****	24	U	2-Sep	11:01	2-Sep	15:55	4.90	0.00	4.90
139****	24	U	7-Sep	17:42	N/A	N/A	N/A	0.00	0.00
140****	24	U	7-Sep	17:42	11-Sep	8:20	60.63	0.00	60.63
148****	23	U	27-Sep	13:54	N/A	N/A	N/A	0.00	0.00
152****	23	U	27-Sep	13:54	28-Sep	23:13:00	31.32	0.00	31.32
Unscheduled and Scheduled Downtime and Total Actual Downtime							**96.85**	**63.95**	**160.80**
Type:	S = Scheduled		U = Unscheduled						

* **Note:**	NANU 133 announced the decommisioning of PRN 18
** **Note**:	NANU 123 is of type UNUSUFN, declaring satellite PRN 16 unusable until further notice. Information received after the end of the quarter showed that the PRN 16 was decomissioned. As a result, the remaining time for the quarter is not regarded here as outage time for PRN 16.
*** **Note**:	Nanu 131 is of type USABINIT, declaring PRN 28 launched and operational
**** **Note**:	NANU 135, NANU 136, NANU 139, and NANU 140 refer to PRN 24 being declared unusable until further notice and coming back on line sometime thereafter. NANU 148 and NANU 152 are the same situation with regards to PRN 23

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
110	21	F	11-Jul	9:00	11-Jul	21:00	12.00	See NANU 111
112	9	F	19-Jul	10:45	20-Jul	22:45	12.00	See NANU 113
114	20	F	18-Jul	19:30	19-Jul	11:30	16.00	See NANU 117
115	13	F	25-Jul	12:30	26-Jul	0:30	12.00	See NANU 121
116	2	F	27-Jul	3:30	27-Jul	15:30	12.00	See NANU 122
119	4	F	28-Jul	3:30	28-Jul	15:30	12.00	See NANU 124
120	26	F	1-Aug	5:30	1-Aug	17:30	12.00	See NANU 125
126	6	F	10-Aug	11:30	10-Aug	23:30	12.00	See NANU 128
127	2	F	9-Aug	5:45	9-Aug	17:45	12.00	See NANU 129
132	29	F	24-Aug	16:15	25-Aug	4:15	12.00	See NANU 134
137	25	F	12-Sep	20:00	13-Sep	8:00	12.00	See NANU 141
138	7	F	14-Sep	19:00	15-Sep	1:00	6.00	See NANU 142
143	11	F	26-Sep	8:30	28-Sep	8:30	48.00	See NANU 147
144	20	F	29-Sep	8:00	29-Sep	20:00	12.00	See NANU 154
145	13	F	27-Sep	19:00	28-Sep	7:00	12.00	See NANU 146
113	9	F/Rescheduled	19-Jul	16:30	20-Jul	4:30	12.00	See NANU 118
128	6	F/Rescheduled	10-Aug	11:00	10-Aug	23:00	12.00	See NANU 130
146	25	F/Rescheduled	28-Sep	19:00	29-Sep	7:00	12.00	See NANU 151
151	25	F/Rescheduled	26-Jun	14:15	28-Jun	12:30	46.25	See NANU 107
						Total Forecast Downtime	**284.25**	

Table 3-3 NANUs Canceled

NANU#	PRN	Type	Start Date	Start Time	Comments
111	21	C	11-Jul	9:00	See NANU 110
141	25	C	12-Sep	20:00	See NANU 137
147	11	C	26-Sep	8:30	See NANU 143

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published "Notice: Advisory to Navstar Users" messages (NANUs). 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 NANUs. 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 July - 30 September, 2000**	**12 December, 1998- 30 September, 2000**
Total Forecast Downtime (hrs):	284.25	2281.47
Total Actual Downtime (hrs):	160.80	4140.40
Total Actual Scheduled Downtime (hrs):	63.95	960.61
Total Actual Unscheduled Downtime (hrs):	96.85	3154.79
Total Satellite Observed MTTR (hrs):	11.49	19.68
Scheduled Satellite Observed MTTR (hrs):	5.81	7.03
Unscheduled Satellite Observed MTTR (hrs):	32.28	60.19
# Total Satellite Outages:	14	143
# Scheduled Satellite Outages:	11	111
# Unscheduled Satellite Outages:	3	32
Percent Operational -- Scheduled Downtime:	99.70%	99.78%

3.2 Service Availability

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

To verify availability, the data collected from receivers at the nine NSTB/WAAS sites was reduced to calculate DOP information and reported in Tables 3-5 to 3-7. The data was collected at one-second intervals between 2 July and 30 September 2000. In this quarter, satellite outages on the following: Satellite PRN 9 (NANU #118), Satellite PRN 20 (NANU #117), Satellite PRN 23 (NANU # 152) and Satellite PRN 25 (NANU #145) caused availability to exceed the GPS SPS specifications (see appendix C).

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
Anderson	1.282	9.976	9.205	2.040	5.759	5.346	7719343
Atlantic City	1.285	10.145	9.400	1.882	3.951	3.516	7696679
Dayton	1.233	10.145	8.992	1.852	4.283	3.750	7631528
Elko	1.206	7.007	6.623	1.911	5.753	5.218	7700683
Gander*	-	-	-	-	-	-	-
Great Falls	1.374	7.761	7.102	2.130	5.939	5.312	7489956
Oklahoma City	1.152	6.103	4.601	1.828	3.358	2.866	7724265
Kansas City	1.154	5.928	5.411	1.838	3.866	3.257	7202080
Salt Lake City	1.190	7.074	6.609	1.842	4.582	4.119	6445241

* Not analyzed due to mechanical problems.

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.

- A PDOP calculation program developed by Intermetrics was used to verify that certain satellite outage do cause the PDOP to go above six.

- Data from co-located receivers is also 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.

All of the Satellite Availability data evaluated met the requirements stated in the SPS.

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
Atlantic City	57_4	10.014	1053	152 (PRN23) 145 (PRN25)	85315	98.766%
Worst-Case Point on Worst-Case Day = 98.766% (SPS Spec. ≥ 83.92%)						

Global Average on Worst-Case Day = 99.800 % (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
Anderson	7719343	1019	99.98
Atlantic City	7696679	2102	99.97
Dayton	7631528	1838	99.97
Elko	7700683	1478	99.98
Gander*	-	-	-
Great Falls	7489956	5	99.99
Oklahoma City	7724265	62	99.99
Kansas City	7202080	0	100
Salt Lake City	6445241	669	99.99
Worst Single Point Average = 99.97% (SPS Spec. ≥ 99.16%)			

* Not analyzed due to mechanical problems.

Global Average over Reporting Period = 99.988% (SPS Spec. > 99.85%)

4.0 Service Reliability Standard

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

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

Table 4-1 has the 99.9% horizontal errors reported by a receiver at each of the nine 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)
Anderson	7719343	31.8
Atlantic City	7696679	28.9
Dayton	7631528	42.2
Elko	7700683	21.9
Gander	-	-
Great Falls	7489956	22.2
Oklahoma City	7724265	29.2
Kansas City	7202080	31.3
Salt Lake City	6445241	21.8

None of the horizontal error exceeded the 500 meter threshold for this quarter.

5.0 Accuracy Characteristics

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

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

	against the standard

5.1 Position Accuracies

The data used for this section was collected for every second between 2 July through 30 September 2000 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)
Anderson	6.190	8.929	10.779	21.374
Atlantic City	7.562	9.917	12.060	22.722
Dayton	5.509	7.488	9.514	15.000
Elko	5.881	7.816	9.686	20.117
Gander *	-	-	-	-
Great Falls	7.623	7.627	11.162	15.699
Oklahoma City	6.209	7.464	9.285	12.955
Kansas City	5.833	7.280	9.276	13.117
Salt Lake City	5.992	7.392	9.025	13.920

* Not analyzed due to mechanical problems.

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all seven NSTB and two WAAS sites from 2 July to 30 September 2000.

Figure 5-1 Combined Vertical Error Histogram

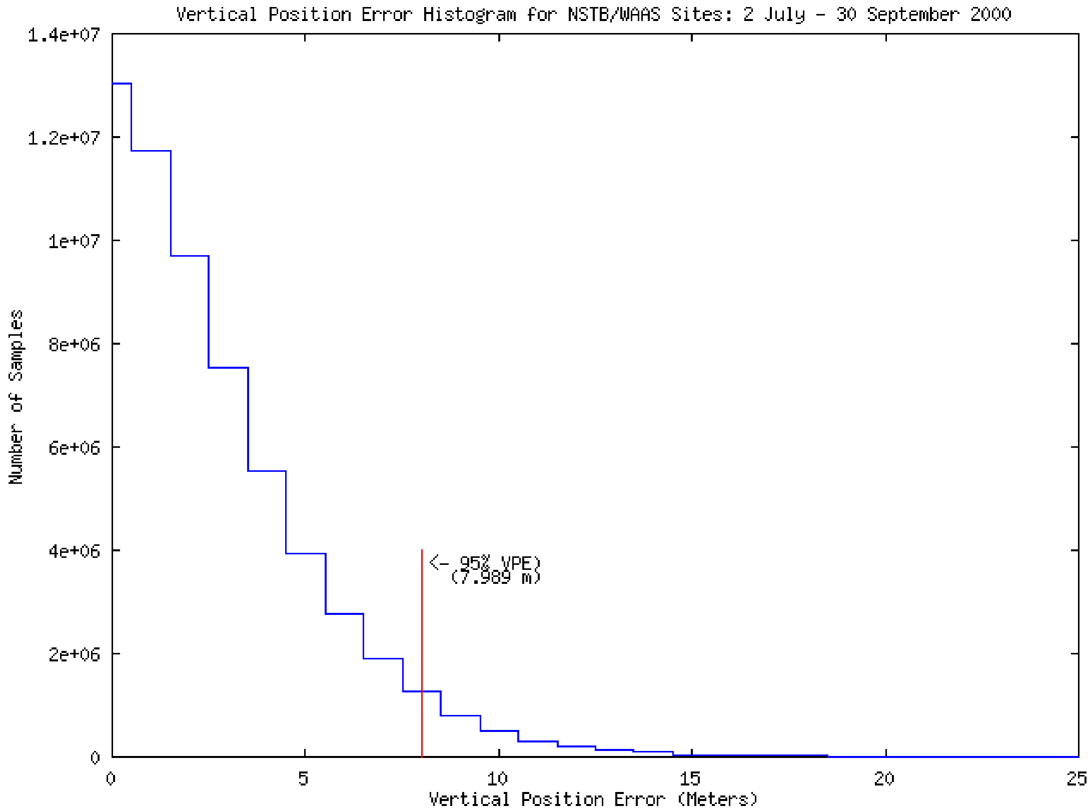
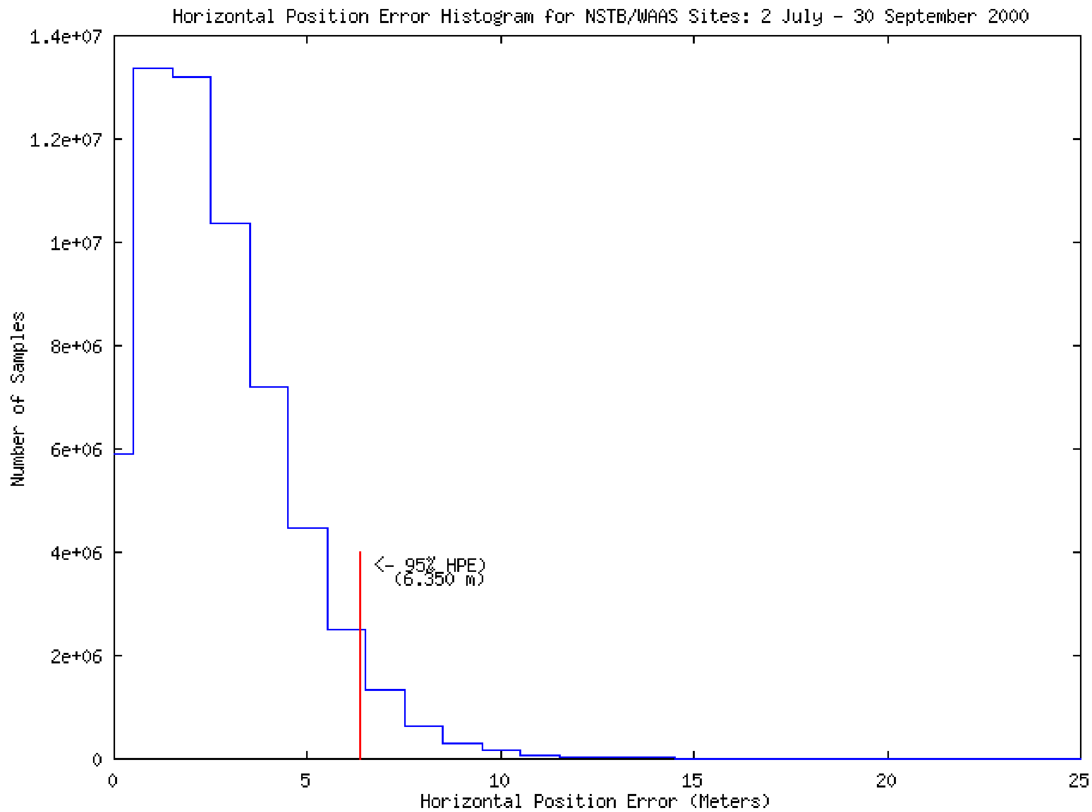


Figure 5-2 Combined Horizontal Error Histogram



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)
Anderson	2.888	7.721
Atlantic City	3.765	8.993
Dayton	2.596	5.848
Elko	2.792	6.415
Gander	-	-
Great Falls	2.543	5.108
Oklahoma City	2.612	5.321
Kansas City	2.562	5.198
Salt Lake City	2.611	5.506

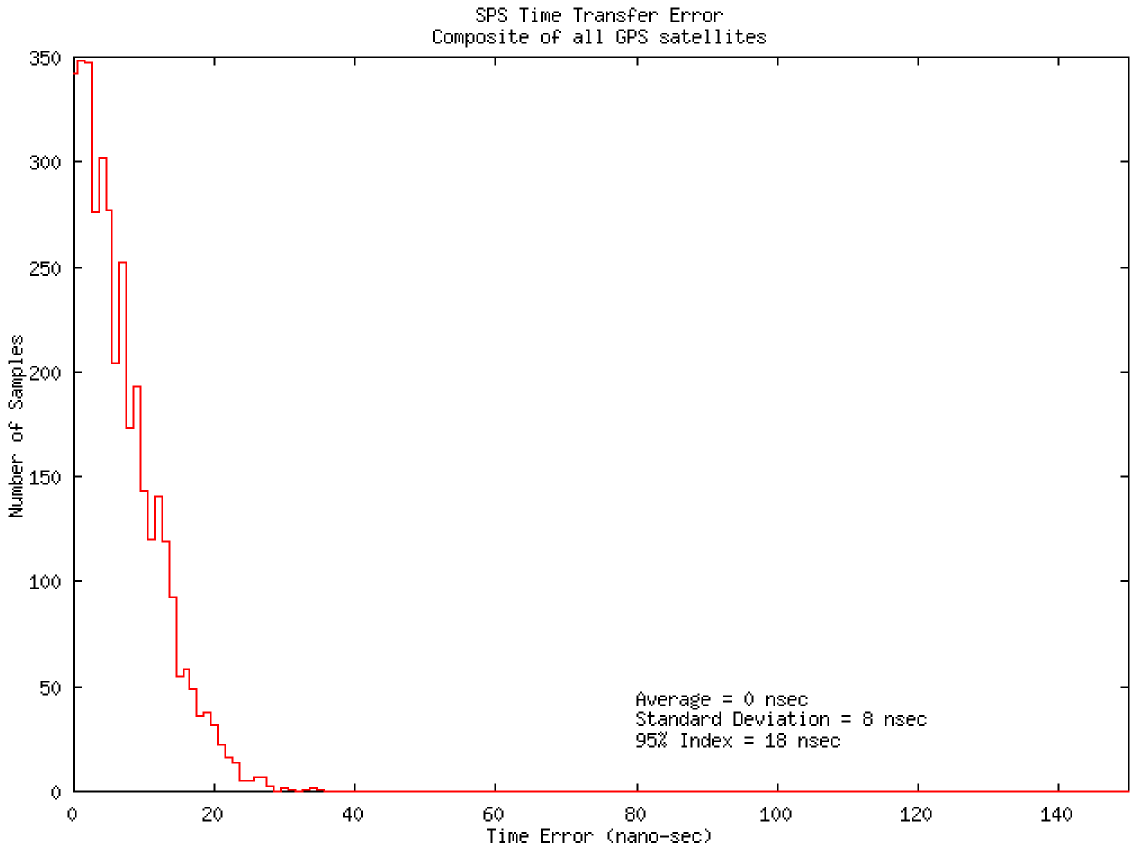
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 2 July and 30 September 2000 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 Error


SPS Time Transfer Error
Composite of all GPS satellites
Number of Samples
350
300
250
200
150
100
50
0
20
40
60
80
100
120
140
Time Error (nano-sec)
Average = 0 nsec
Standard Deviation = 8 nsec
95% Index = 18 nsec

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 2 July and 30 September 2000. The Millenium at Elko 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	-0.970	3.137	2.512	5.224	19.010	1783284
2	0.303	2.513	2.137	10.379	14.350	1990480
3	-0.981	3.062	2.632	6.037	27.570	2168307
4	0.498	2.372	1.985	4.979	22.150	2013066
5	-0.105	3.135	2.827	11.222	27.990	2340564
6	-0.349	3.218	2.777	8.997	22.710	2017596
7	0.981	2.451	2.246	6.312	22.830	2222840
8	-0.640	2.784	2.167	11.143	16.200	1756109
9	-0.739	3.501	3.172	11.575	27.220	2278162
10	0.173	3.003	2.379	5.733	29.960	1882142
11	-0.066	2.465	2.269	6.145	41.360	2310013
13	-0.300	2.377	2.164	5.939	26.790	2225147
15	0.486	3.426	3.024	11.183	17.810	1958520
16	0.197	3.083	2.871	4.636	12.720	518973
17	0.096	3.376	2.676	8.263	20.880	1932497
18	-0.827	3.284	2.635	6.802	13.700	2069304
19	-0.589	2.547	2.275	7.203	35.390	2362716
20	0.019	3.763	2.835	12.829	30.160	2044986
21	-0.548	3.409	2.924	6.625	49.960	1936537
22	-0.372	3.609	2.778	15.348	32.630	2258649
23	0.755	2.601	2.045	5.371	52.500	2076253
24	-0.876	3.843	3.216	7.086	18.300	2262049
25	-0.415	3.039	2.558	6.919	25.170	1704514
26	-0.974	3.126	2.510	6.331	15.630	1898197
27	-0.892	3.313	2.741	8.517	16.290	620074
29	-0.176	3.827	3.201	10.751	17.530	2298308
30	-0.909	3.008	2.587	8.683	22.520	2301789
31	-0.348	2.968	2.566	7.331	26.860	1798609

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. $\leq$ 2 m)	Samples
1	-0.00009	0.00493	0.00493	0.00914	0.31919	1783284
2	-0.00005	0.00536	0.00563	0.01012	0.022760	1990480
3	0.00031	0.00875	0.00874	0.01405	1.05340	2168307
4	-0.00002	0.00568	0.00568	0.01151	0.18392	2013066
5	-0.00030	0.00936	0.00935	0.01547	0.94442	2340564
6	0.00050	0.00862	0.00860	0.01737	0.47293	2017596
7	-0.00001	0.00566	0.00566	0.01127	0.19774	2222840
8	-0.00013	0.00445	0.00444	0.00898	0.18900	1756109
9	0.00011	0.00971	0.00971	0.01822	0.82892	2278162
10	-0.00008	0.00562	0.00562	0.00994	0.93049	1882142
11	0.00018	0.01103	0.01102	0.01599	1.50692	2310013
13	-0.00018	0.00792	0.00791	0.01507	0.98601	2225147
15	0.00009	0.00768	0.00767	0.01336	0.77202	1958520
16	0.00001	0.00869	0.00868	0.01712	0.49820	518973
17	-0.00001	0.00562	0.00562	0.01038	0.27809	1932497
18	-0.00001	0.00574	0.00573	0.01024	0.39724	2069304
19	0.00001	0.00909	0.00908	0.01619	1.34729	2362716
20	0.00010	0.00566	0.00564	0.01109	0.21787	2044986
21	-0.00040	0.00618	0.00618	0.01081	1.84296	1936537
22	-0.00001	0.00706	0.00705	0.01413	0.31452	2258649
23	-0.00004	0.00543	0.00542	0.01010	0.37171	2076253
24	-0.00018	0.00549	0.00548	0.01084	0.19403	2262049
25	-0.00018	0.00751	0.00750	0.01274	0.79071	1704514
26	-0.00015	0.00521	0.00520	0.00978	0.25197	1898197
27	-0.00031	0.00651	0.00649	0.01309	0.16829	620074
29	-0.00032	0.00592	0.00591	0.01245	0.27629	2298308
30	-0.00010	0.00806	0.00805	0.01600	0.74409	2301789
31	-0.00006	0.00754	0.00753	0.01335	1.20916	1798609

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

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1s	% ≤ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. ≤ 0.019 m/s2)	Samples
1	0.00000	0.00004	0.00004	1.00000	0.00317	1783284
2	0.00000	0.00005	0.00005	1.00000	0.00224	1990480
3	0.00000	0.00008	0.00008	1.00000	0.01068	2168307
4	0.00000	0.00005	0.00005	1.00000	0.00186	2013066
5	0.00000	0.00008	0.00008	0.99999	0.00955	2340564
6	0.00000	0.00008	0.00008	1.00000	0.00473	2017596
7	0.00000	0.00005	0.00005	1.00000	0.00201	2222840
8	0.00000	0.00004	0.00004	1.00000	0.00196	1756109
9	0.00000	0.00008	0.00008	1.00000	0.00832	2278162
10	0.00000	0.00004	0.00004	1.00000	0.00928	1882142
11	0.00000	0.00011	0.00011	0.99999	0.01506	2310013
13	0.00000	0.00006	0.00006	1.00000	0.00992	2225147
15	0.00000	0.00008	0.00008	1.00000	0.00773	1958520
16	0.00000	0.00007	0.00007	1.00000	0.00500	518973
17	0.00000	0.00004	0.00004	1.00000	0.00272	1932497
18	0.00000	0.00006	0.00006	1.00000	0.00397	2069304
19	0.00000	0.00009	0.00009	0.99999	0.01349	2362716
20	0.00000	0.00004	0.00004	1.00000	0.00216	2044986
21	0.00000	0.00007	0.00007	1.00000	0.01842	1936537
22	0.00000	0.00006	0.00006	1.00000	0.00308	2258649
23	0.00000	0.00005	0.00005	1.00000	0.00370	2076253
24	0.00000	0.00005	0.00005	1.00000	0.00192	2262049
25	0.00000	0.00007	0.00007	1.00000	0.00787	1704514
26	0.00000	0.00004	0.00004	1.00000	0.00250	1898197
27	0.00000	0.00005	0.00005	1.00000	0.00175	620074
29	0.00000	0.00005	0.00005	1.00000	0.00277	2298308
30	0.00000	0.00007	0.00007	1.00000	0.00745	2301789
31	0.00000	0.00007	0.00007	1.00000	0.01210	1798609

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 23 with an error of 52.5meters. Satellite 16 had the lowest maximum range error of 12.720.

Figure 5-4 Distribution of Daily Max Range Errors

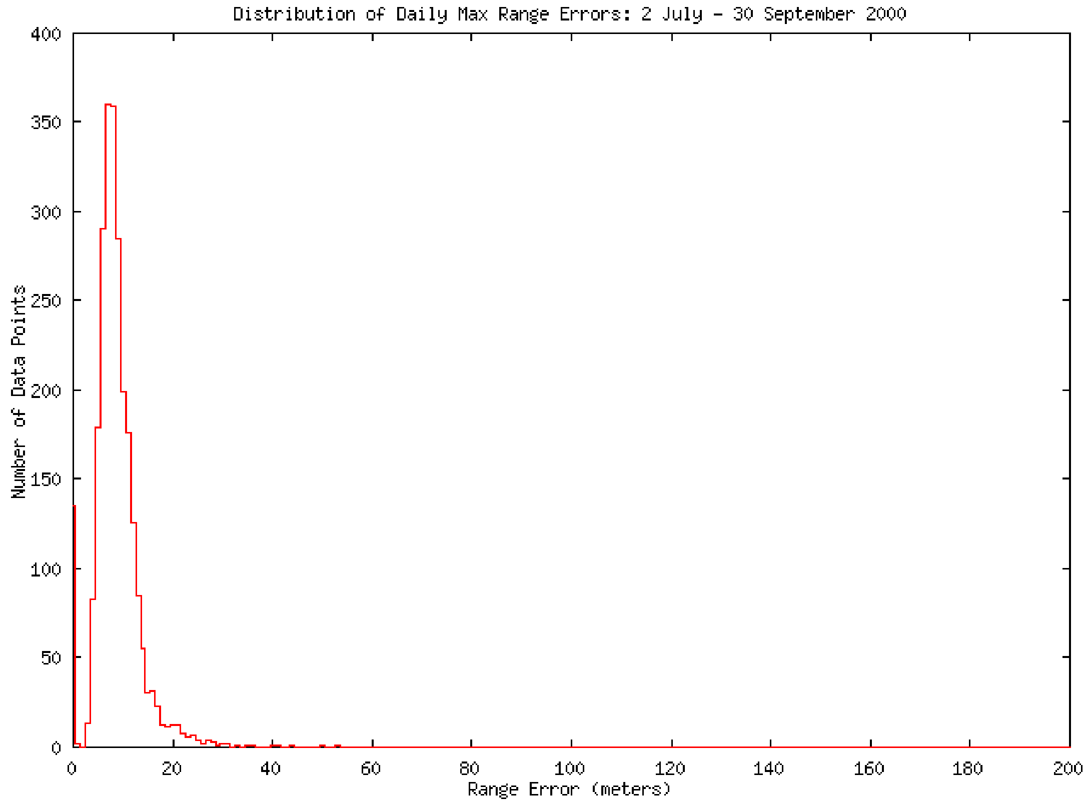


Figure 5-5: Distribution of Daily Max Range Rate Errors

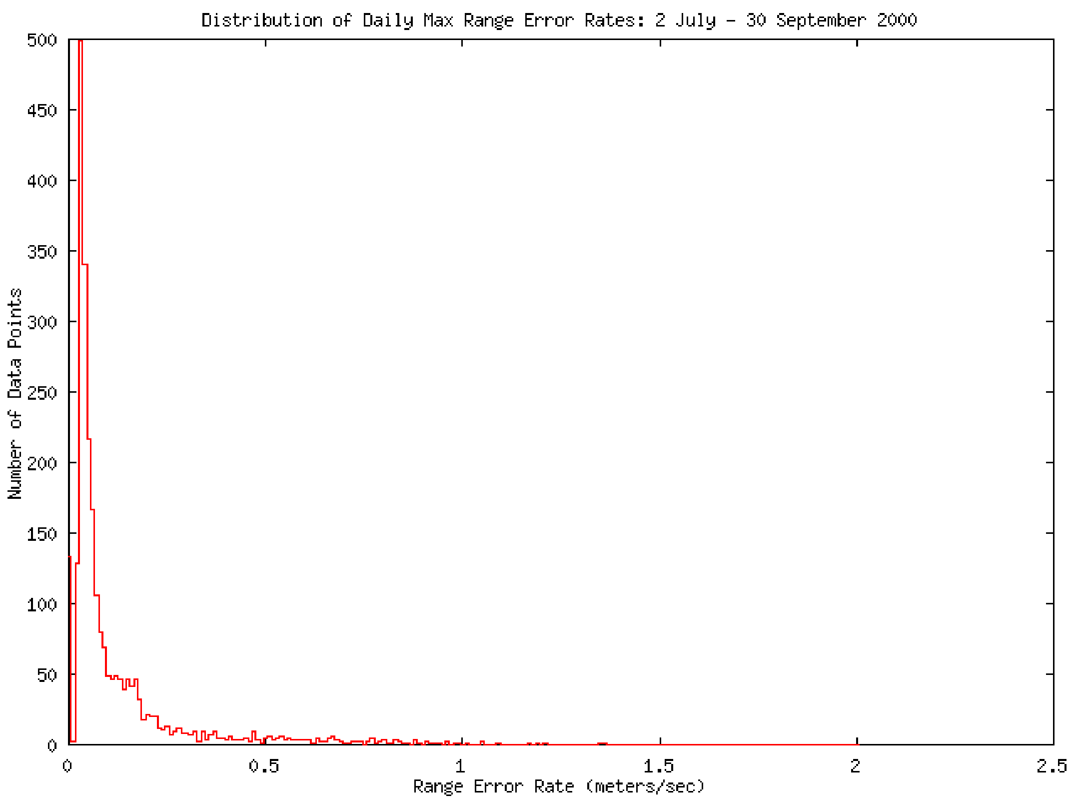


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

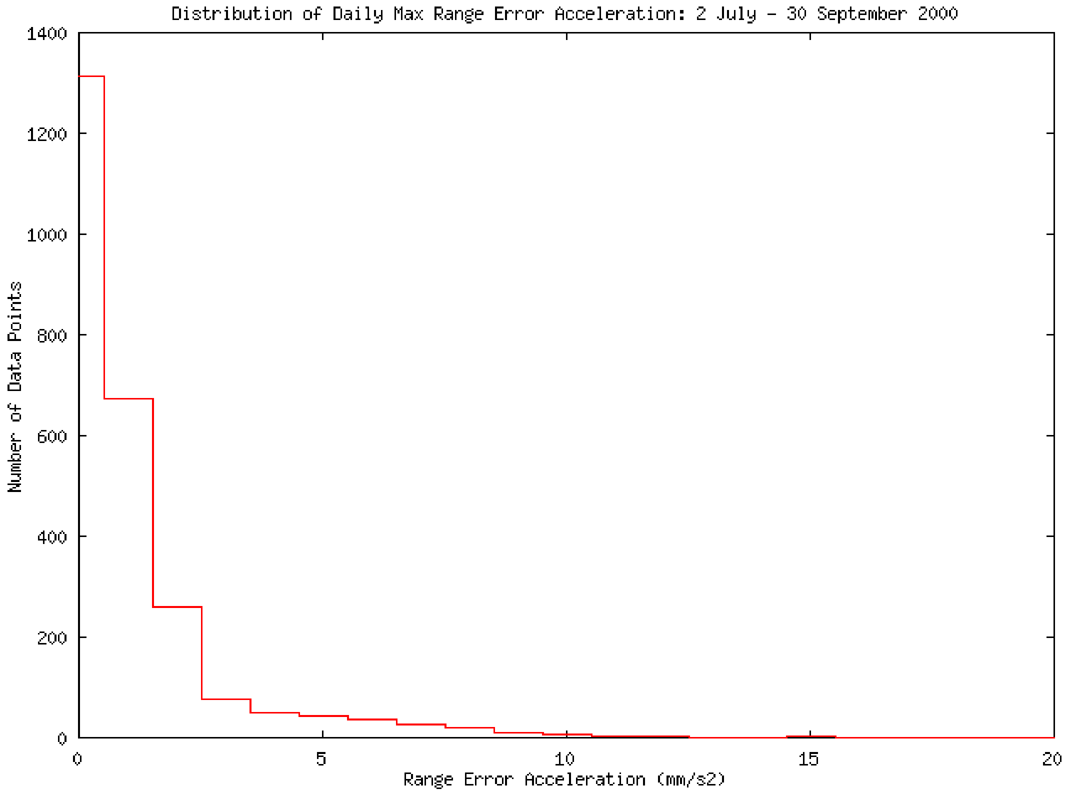


Figure 5-7 Maximum Range Error Per Satellite

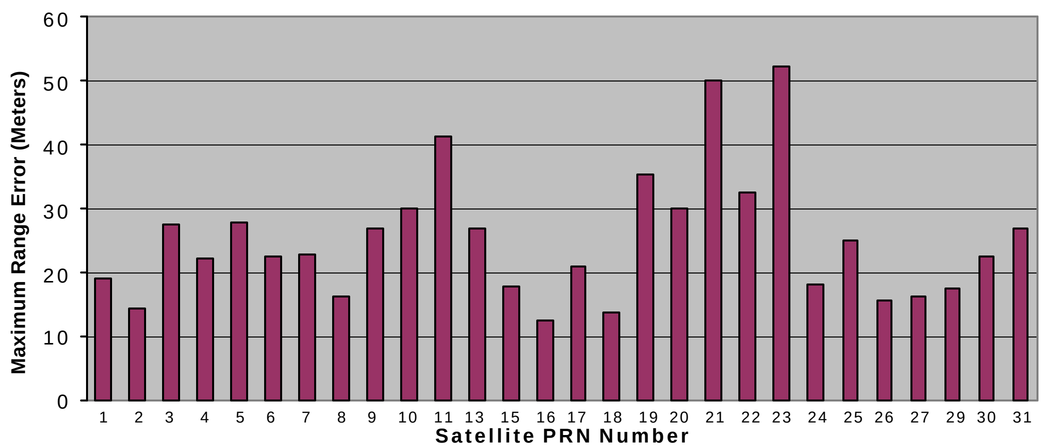


Figure 5-8 Maximum Range Rate Error Per Satellite

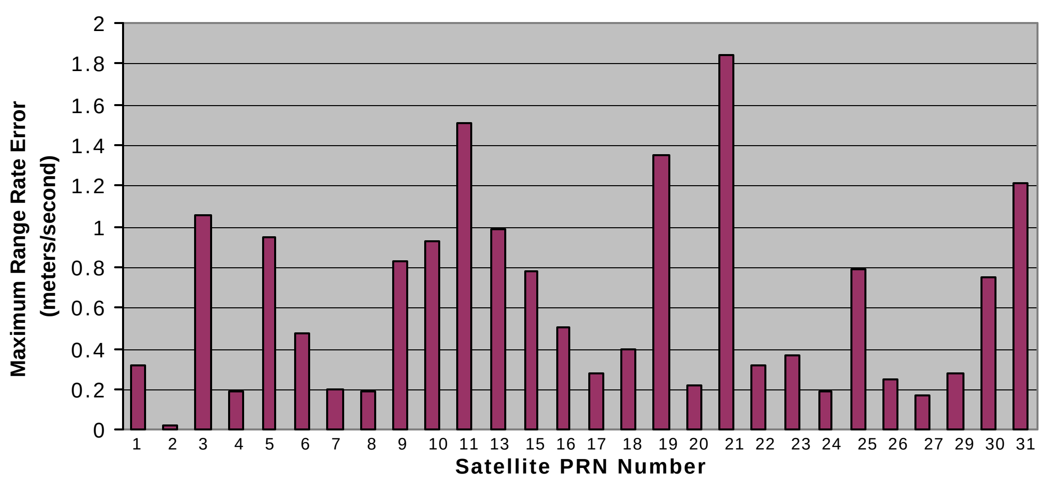
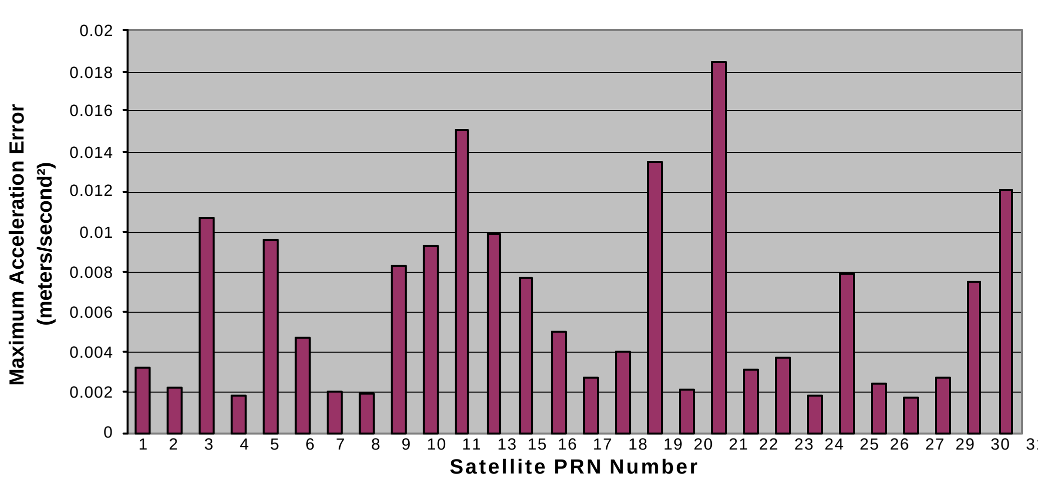


Figure 5-9 Maximum Range Acceleration Error Per Satellite



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 15-17 July 2000

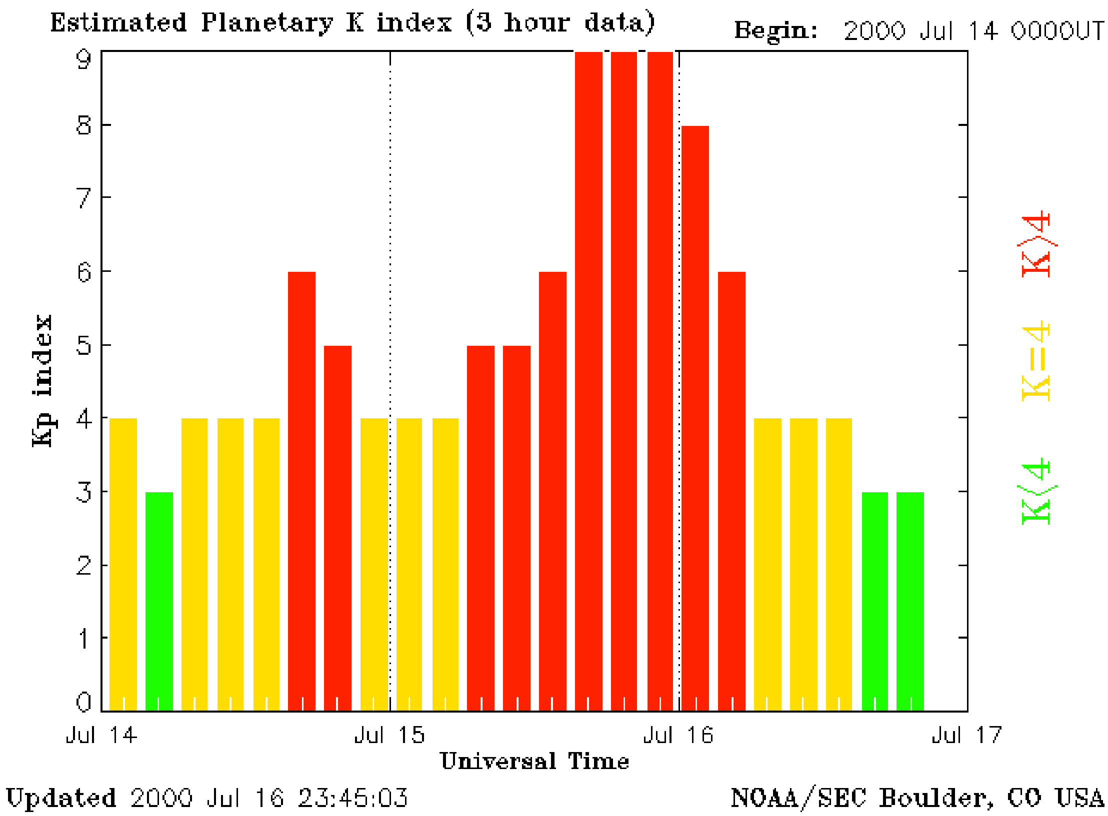


Figure 6-2 K-Index for 11-13 August 2000

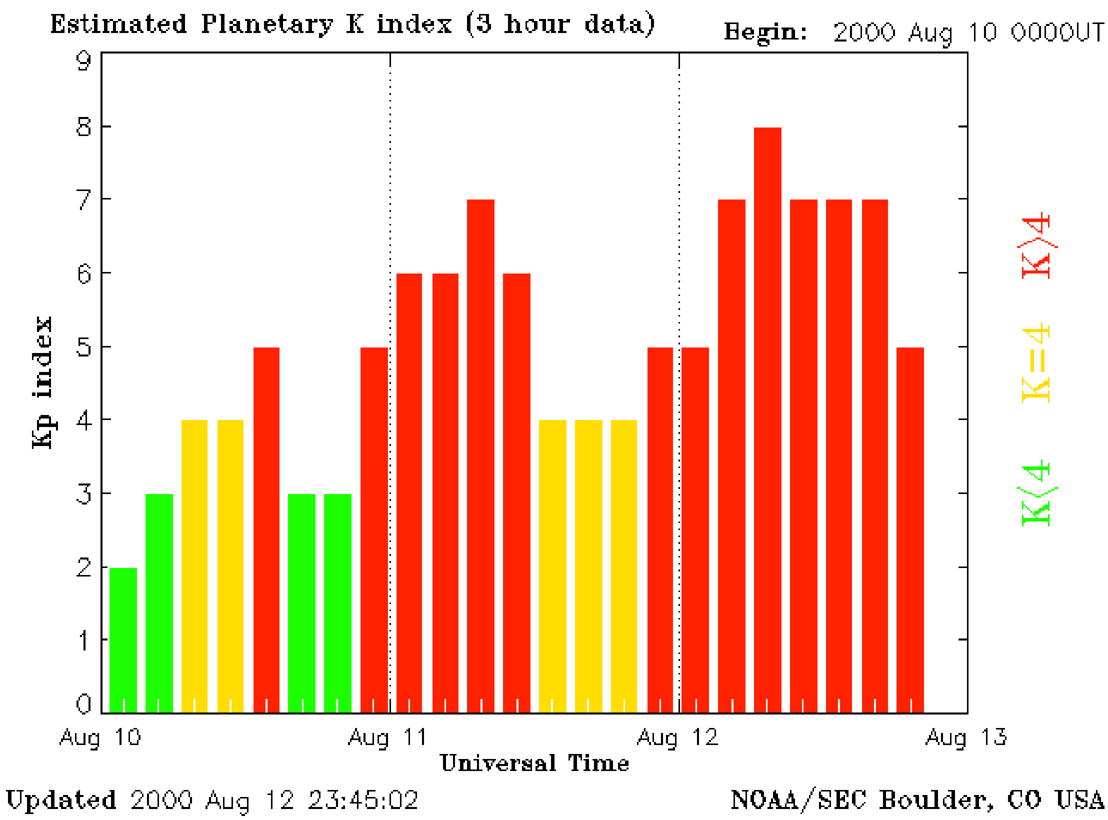
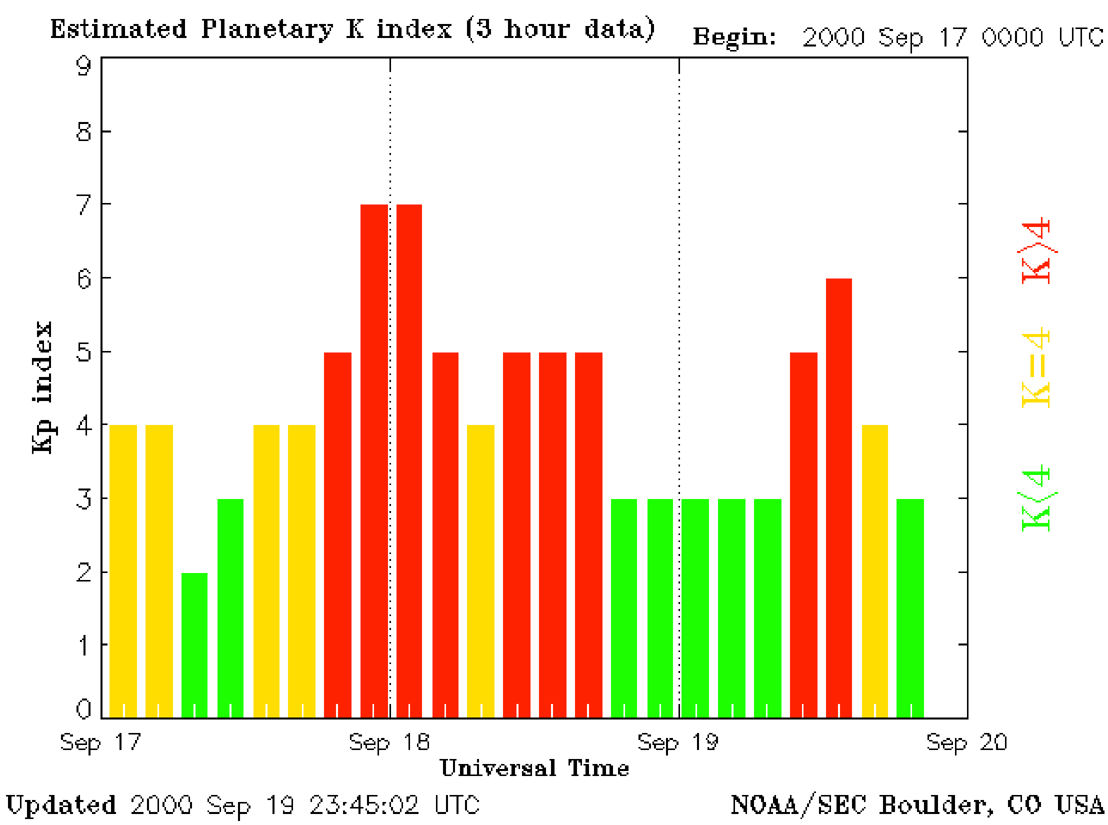


Figure 6-3 K-Index for 18-20 September 2000



Tables 6-1 and 6-2 below show the PDOP and position accuracy information, respectively, for the days corresponding to Figure 6-1. The PDOP's and position accuracies show a significant difference between the days with storms and the days without storms. However, the GPS SPS performance met the availability requirements during all storms that occurred during this quarter.

Table 6-1 PDOP Statistics*

NSTB Site	Min	Max	Mean	95%	95% VDOP
Anderson					
7-16-00	1.287	5.999	2.01	2.72	2.33
Atlantic City					
7-16-00	1.321	3.964	1.85	2.50	2.13
Dayton					
7-16-00	1.329	3.786	1.83	2.41	2.03
Elko					
7-16-00	1.309	5.529	1.87	2.74	2.32
Great Falls					
7-16-00	1.376	5.997	2.11	2.95	2.43
Oklahoma City					
7-16-00	1.170	3.460	3.34	2.41	2.05

Table 6-2 Horizontal & Vertical Accuracy Statistics*

NSTB Site	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)
Anderson				
7-16-00	21.9	10.9	30.9	24.9
Atlantic City				
7-16-00	12.6	10.7	28.8	45.0
Dayton				
7-16-00	12.3	9.19	21.8	26.9
Elko				
7-16-00	6.73	9.42	14.9	13.0
Great Falls				
7-16-00	8.77	8.37	13.4	13.4
Oklahoma City				
7-16-00	11.1	8.28	21.7	12.5

7.0 GLONASS/GPS Performance

7.1 Introduction

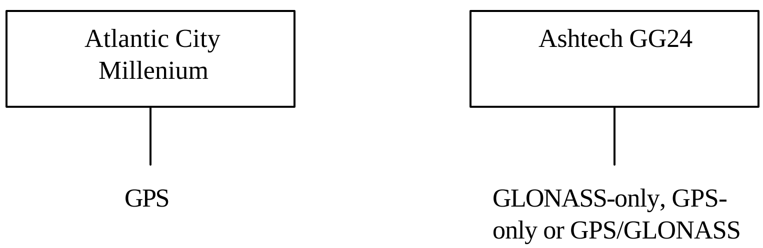
This section is new to the PAN report. In April 1999, ACT-360 was tasked to monitor, analyze and characterize GLONASS and GPS/GLONASS system performance. The objective of this task is to evaluate the ability of GLONASS to provide navigation by itself and with SPS GPS and to assess the incremental benefit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

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 3S Navigation R-100/30T receiver provides three solutions (GPS, GLONASS and blended) simultaneously. Unfortunately, we are discontinuing use of the 3S receiver due to poor reliability. As a result we are no longer able to analyze 3S data. 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 Millenium receiver. The GPS/GLONASS receiver solutions will be compared to the Millenium 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

Data will also be provided at an NSTB website. Graphical representation of the previous day's performance data (e.g. position accuracies, availabilities, satellite visibility) will be made available at the website.

7.3 Quarter Results

For this quarter, data collected from the Atlantic City Ashtech GG24 Glonass/GPS receiver and the Millenium GPS receiver will be analyzed and compared. Now that Selective Availability (SA) has been turned off, it appears that there is a bias in the data collected from the Ashtech GG24 receiver. SA previously masked this bias. It is believed this is why the GPS (Millenium receiver) solution had better performance than GPS/GLONASS (Ashtech GG24 receiver). This issue is under investigation and will be reported on in future reports.

Tables 7-1 and 7-2 provide PDOP and Position Accuracy statistics for the two receivers from 2 July through 30 September 2000. The statistics are cumulative.

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

Receiver	Solution	Maximum PDOP	Minimum PDOP	Mean PDOP	95% PDOP	Number of Samples
Ashtech GG24	GPS/GLONASS	104.494	1.140	1.718	2.385	6427924
Millenium	GPS Only Atlantic City	10.145	1.285	1.882	2.566	7696679

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

Receiver	Solution	95% Horizontal (m)	95% Vertical (m)	99.99% Horizontal (m)	99.99% Vertical (m)	Number of Samples
Ashtech GG24	GPS/GLONASS	6.884	29.494	22.277	55.019	6427924
Millenium	GPS Only Atlantic City	7.562	9.917	12.060	22.722	7696679

Figures 7-3 and 7-4 show the Horizontal and Vertical Error histograms for the GG24 GLONASS/GPS solution and the Millenium GPS-only solution, respectively.

Figure 7-2 Horizontal Position Error Histograms for GPS/GLONASS

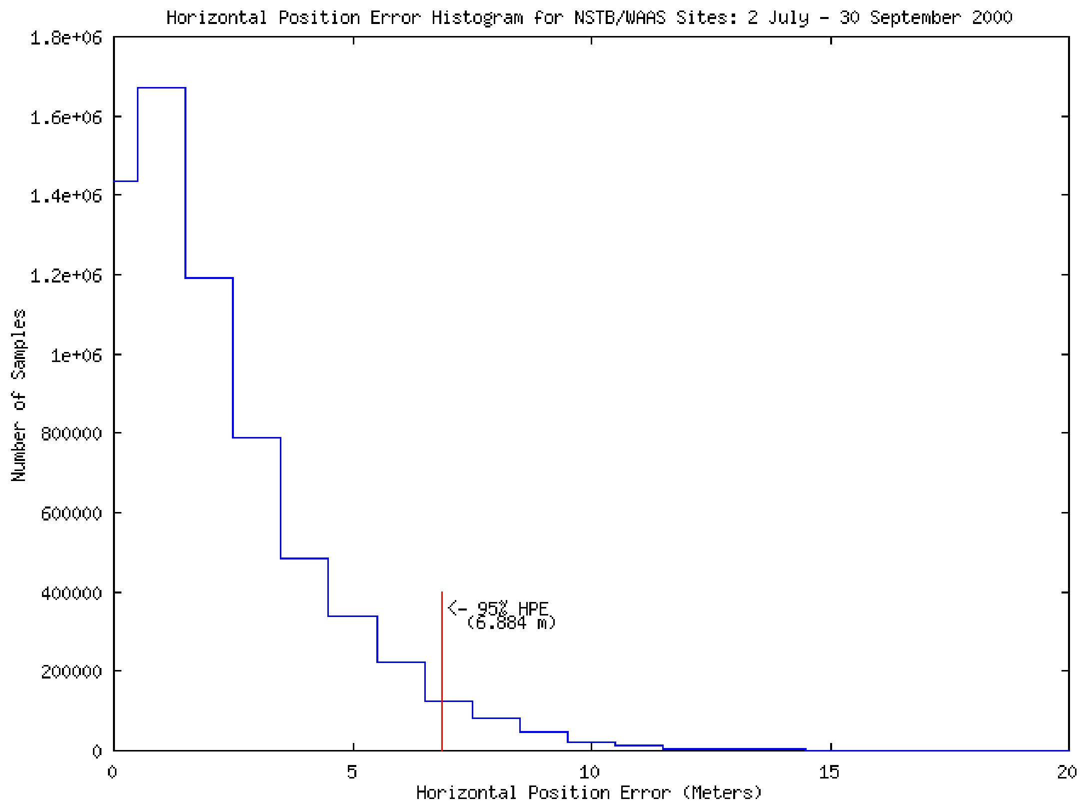


Figure 7-3 Vertical Position Error Histograms for GPS/GLONASS

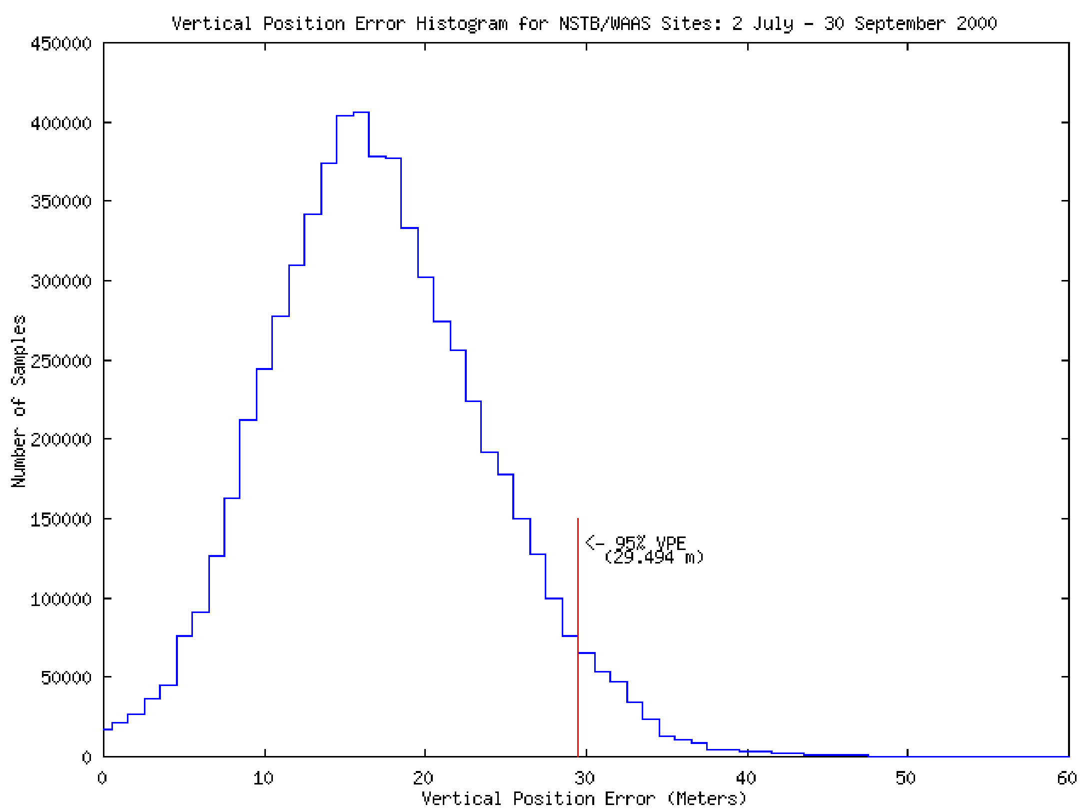
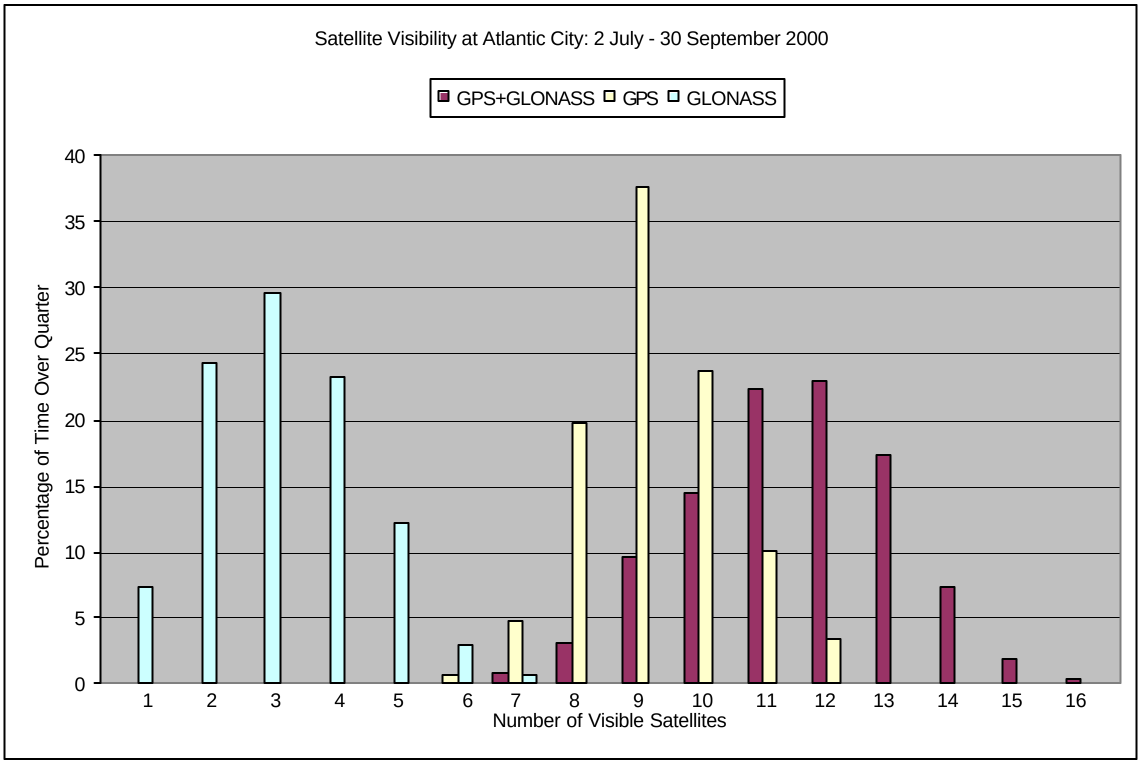


Figure 7-3 Glonass and GPS Satellite Visibility



APPENDICES A – D

Conditions and Constraints	*Coverage Standard*	*Measured Performance*
• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 99.9% global average	99.991%
• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 96.9% at worst-case point	99.148% Availability 99.9% PDOP was 3.75
Conditions and Constraints	***Satellite Availability Standard***	***Measured Performance***
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.85% global average	99.988%
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.16% single point average	99.97% 3 individual failures (see appendix C)
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	99.586%
• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	≥ 83.92% at worst-case point on worst-case day	98.766%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.97% global average	100%

• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.79% single point average	100%
Conditions and Constraints	***Accuracy Standard***	***Measured Performance***
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	Predictable Accuracy ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	≤7.623m horz error 95% ≤12.060m horz error 99.99% ≤9.917m vert error 95% ≤22.722m vert error 99.99%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	Repeatable Accuracy ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	≤3.765m horz error 95% ≤8.993m vert error 95%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	Relative Accuracy ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	Future Reports
• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	≤18 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each	Range Domain Accuracy ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range	52.5m NTE Range Error 1.84 m/s NTE Rate Error 18 mm/s^2 NTE Accel. Error

satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	acceleration error $\leq 8\ mm/s^2$ range acceleration error 95% of time	$\leq 8 mm/s^2$ 100% of the time

Appendix B Geomagnetic Data

Product: Daily Geomagnetic Data quar_DGD.txt
Issued: 2120 UT 07 Oct 2000
#
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 - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2000 07 01	7	2 1 2 1 1 1 3 3	-1	3 1 2 4-1 0 2 2	9	3 2 3 2 2 2 3 2
2000 07 02	3	1 2 1 0 1 1 1 1	3	1 1 1 1 0 1 2 1	6	2 1 1 2 2 2 2 2
2000 07 03	8	2 2 1 3 3 1 2 2	8	2 2 2 3 3 1 2 1	10	2 2 2 3 3 3 3 3
2000 07 04	10	3 2 1 2 4 2 2 2	6	2 2 0 3 2 1 1 2	9	3 2 1 2 3 3 3 2
2000 07 05	6	1 1 2 2 3 2 1 1	21	2 1 4 6 4 3 1 1	13	2 1 3 4 3 4 2 1
2000 07 06	6	1 2 2 1 2 2 2 2	13	4 2 1 1 4 2 4 1	7	2 2 2 2 2 2 3 2
2000 07 07	6	2 1 1 1 2 2 1 3	6	3 2 1 2 0 1 1 2	8	2 2 1 3 3 3 2 3
2000 07 08	6	2 2 1 1 3 2 2 0	8	2 2 0 1 3 4 1 0	7	2 2 1 2 2 3 2 1
2000 07 09	6	0 1 2 1 2 2 1 3	8	0 2 3 1 4 1 1 1	7	1 1 2 2 2 2 2 3
2000 07 10	18	1 3 4 3 4 4 3 3	20	2 3 4 4 3 4 4 3	19	2 3 4 3 4 4 4 3
2000 07 11	31	3 5 4 5 4 4 3 5	28	3 4 4 4 5 4 4 4	31	4 5 4 5 5 4 4 5
2000 07 12	12	4 3 1 3 1 2 3 2	5	3 2 1 2 0 1 1 1	12	4 3 2 3 2 3 2 3
2000 07 13	18	2 1 3 4 5 4 2 2	28	1 2 3 5 5 6 3 2	33	2 2 3 5 7 5 2 3
2000 07 14	33	3 3 3 3 3 6 6 4	49	4 4 3 5 4 7 6 4	35	4 3 4 4 4 6 5 4
2000 07 15	148	3 3 3 3 6 8 9 9	-1	3 4 5 6 7-1-1-1	152	4 4 5 5 6 9 9 9
2000 07 16	32	6 6 4 4 3 3 2 2	-1	-1-1-1-1-1-1-1-1	46	8 6 4 4 4 3 3 3
2000 07 17	8	2 3 2 3 2 1 2 2	-1	-1-1-1-1-1 1 1 2	9	3 3 2 3 2 2 2 2
2000 07 18	8	2 2 2 1 2 2 1 4	-1	2 3 2 2 2-1-1 2	13	3 2 2 2 3 3 4 4
2000 07 19	10	2 1 0 2 2 3 4 3	-1	2 0-1-1 1 4 3 4	15	3 1 1 2 3 4 4 5
2000 07 20	28	5 5 5 4 3 2 3 3	57	5 7 6 5 6 4 3 3	43	5 6 6 6 5 3 4 3
2000 07 21	6	2 2 1 2 2 1 2 2	11	2 3 1 3 3 2 2 3	9	3 2 1 2 3 3 2 3
2000 07 22	11	1 2 2 4 2 2 3 3	43	1 3 4 6 4 7 5 2	18	2 3 4 5 3 4 3 3
2000 07 23	20	2 2 1 1 3 3 6 4	26	5 3 1 1 4 5 5 3	20	3 3 2 2 3 4 5 4
2000 07 24	4	2 3 1 0 1 0 1 1	6	3 3 2 1 1 1 0 1	8	2 3 2 2 2 3 2 2
2000 07 25	4	1 1 1 1 1 1 2 2	6	2 2 1 1 1 2 2 2	7	2 2 1 2 2 3 2 3
2000 07 26	16	2 2 4 2 3 2 4 4	20	2 3 4 3 4 5 3 2	20	3 3 4 4 4 3 4 4
2000 07 27	6	3 1 0 0 1 2 2 3	-1	3 2 0 3-1-1-1 2	9	4 2 1 2 1 2 2 3
2000 07 28	16	2 3 4 3 4 3 3 2	43	2 3 6 4 6 6 5 2	30	3 3 5 5 5 5 4 3
2000 07 29	17	4 3 3 4 4 2 2 2	30	4 3 5 6 5 3 2 2	27	3 3 4 6 5 3 3 3
2000 07 30	10	3 4 2 2 2 2 1 2	-1	2 3-1-1-1-1-1-1	10	3 3 1 2 3 2 2 2
2000 07 31	17	3 3 3 4 2 3 3 4	-1	-1-1-1-1-1 3 4 3	19	3 3 4 4 2 3 4 5
2000 08 01	11	3 2 2 3 2 3 2 3	23	2 2 2 4 4 6 3 3	15	3 3 3 3 2 4 4 3
2000 08 02	9	3 3 1 2 2 2 2 2	19	4 4 3 5 2 2 3 2	14	4 3 3 3 2 3 3 3
2000 08 03	8	2 2 3 1 2 1 3 2	21	2 4 4 4 5 3 2 2	12	3 3 3 3 2 3 3 2

2000 08 04	13	3 2 3 2 3 3 3 3	24	3 3 5 3 5 4 3 2	18	3 3 4 3 3 4 3 3
2000 08 05	19	2 3 4 4 3 3 3 4	35	2 3 6 4 5 5 4 4	26	3 3 5 5 4 4 3 4
2000 08 06	15	4 4 1 2 3 2 3 3	19	4 4 3 3 4 4 2 2	18	4 4 3 3 3 3 3 3
2000 08 07	8	1 2 2 2 3 1 2 3	22	3 2 3 6 5 1 1 2	9	2 2 3 3 3 2 2 2
2000 08 08	7	1 1 3 2 2 2 2 2	-1	2 1 3 2-1 2 1 1	9	2 2 3 2 2 2 3 2
2000 08 09	-1	1 2 1-1-1 1 1 3	-1	2 2 1-1-1 0 1 2	7	2 2 1 2 2 2 2 3
2000 08 10	16	1 3 4 3 4 2 3 3	29	2 4 5 5 5 4 3 3	23	2 3 4 4 5 3 3 5
2000 08 11	39	5 5 5 4 4 2 4 6	72	5 7 7 6 5 4 5 5	60	6 6 7 6 4 4 4 5
2000 08 12	55	4 6 6 5 6 6 4 3	110	5 7 6 7 7 8 6 3	109	5 7 8 7 7 7 5 4
2000 08 13	16	4 5 3 2 2 1 2 3	14	3 5 3 1 2 1 1 3	16	4 5 3 2 2 3 2 3
2000 08 14	11	1 1 1 1 2 2 3 5	9	1 1 0 1 2 4 3 3	12	2 2 2 2 3 3 3 4
2000 08 15	9	3 4 1 2 1 2 2 1	18	3 4 2 5 2 1 2 4	12	4 4 2 3 2 3 2 2
2000 08 16	9	2 3 3 1 2 1 2 3	11	2 2 3 3 4 2 1 1	11	2 3 3 2 3 3 2 3
2000 08 17	9	2 3 2 2 2 1 2 3	15	2 2 5 5 1 1 1 1	11	2 4 4 4 2 3 3 2
2000 08 18	3	2 2 0 1 1 0 1 1	-1	1 1 0 0 3-1-1 0	6	2 2 2 2 2 2 2 2
2000 08 19	3	1 1 0 0 2 2 1 1	2	1 1 0 0 0 1 1 1	6	2 1 1 2 2 3 2 2
2000 08 20	3	0 0 0 1 1 2 2 1	2	0 0 0 1 0 2 2 0	7	2 1 1 2 2 3 2 2
2000 08 21	9	1 3 2 3 1 1 2 3	18	1 4 4 5 3 3 2 1	12	2 3 3 4 2 3 2 3
2000 08 22	3	2 2 1 1 1 0 0 1	3	3 2 0 0 0 0 0 1	5	2 2 1 1 1 2 2 2
2000 08 23	5	0 0 1 3 2 2 1 2	9	0 0 1 4 4 3 1 0	11	1 1 2 4 4 4 2 2
2000 08 24	7	3 3 2 1 2 1 1 1	8	2 3 2 1 3 1 1 1	10	3 3 2 2 2 2 2 2
2000 08 25	3	0 1 0 1 1 1 2 1	2	0 1 0 0 0 1 1 1	7	1 1 1 2 2 2 2 2
2000 08 26	4	0 1 2 2 2 1 1 1	8	1 1 3 3 3 1 1 1	9	1 2 3 2 3 3 3 1
2000 08 27	7	1 1 1 1 3 1 2 3	10	1 1 1 1 4 4 2 1	9	2 2 1 1 3 3 2 3

	Middle Latitude		High Latitude		Estimated	
	- Fredericksburg -		---- College ----		--- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2000 08 28	17	3 1 2 3 4 4 3 4	36	1 1 2 5 5 6 6 3	21	2 2 2 4 4 4 4 5
2000 08 29	21	5 4 4 3 3 3 3 2	58	4 5 7 6 4 6 5 3	31	5 5 5 4 4 4 4 3
2000 08 30	12	4 3 2 2 2 2 2 3	21	3 2 3 6 4 2 2 2	13	3 3 3 3 3 3 2 3
2000 08 31	12	3 3 2 3 3 2 2 3	26	3 2 3 6 5 4 2 2	15	4 3 3 4 3 3 3 3
2000 09 01	12	3 2 4 3 3 1 2 2	29	3 3 6 6 3 2 3 2	17	3 3 4 4 3 3 3 3
2000 09 02	18	4 4 4 3 4 2 1 2	40	4 4 6 6 5 5 1 2	23	4 3 4 5 4 3 3 3
2000 09 03	6	1 3 1 1 1 1 2 2	5	1 3 0 0 1 2 2 2	9	2 3 1 2 2 2 3 3
2000 09 04	11	1 1 2 1 2 2 4 4	10	2 1 2 3 2 2 4 2	14	1 1 2 2 2 4 5 4
2000 09 05	8	1 1 1 1 2 4 2 2	6	2 1 1 0 2 3 2 1	8	2 2 2 2 2 3 3 3
2000 09 06	11	2 0 0 2 2 3 4 4	8	2 0 1 0 2 3 3 3	11	2 1 2 1 2 3 3 4
2000 09 07	12	3 3 3 2 3 2 2 3	25	3 2 4 6 4 4 2 2	16	3 3 4 3 3 3 3 3
2000 09 08	14	3 2 3 3 4 3 2 3	27	2 0 4 4 6 4 4 3	21	3 3 3 5 4 4 3 3
2000 09 09	6	3 2 2 2 2 1 0 0	4	3 2 1 1 1 1 0 0	7	3 2 2 2 2 2 1 2
2000 09 10	2	0 0 1 1 1 1 1 1	4	0 1 0 3 2 1 1 1	5	1 1 1 2 2 2 2 2
2000 09 11	3	0 0 0 1 2 2 1 2	2	0 0 0 0 1 2 1 0	5	1 0 1 2 2 2 2 2
2000 09 12	11	2 3 2 3 3 1 2 3	30	2 2 2 6 5 5 4 3	20	2 3 2 5 5 3 4 4
2000 09 13	8	3 4 1 1 1 1 1 1	11	3 4 1 4 2 2 1 0	10	3 4 2 2 2 3 2 2
2000 09 14	3	1 2 2 1 1 1 0 0	-1	-1 3-1 3 0 1 0-1	6	1 3 2 2 2 2 1 1
2000 09 15	13	1 4 1 1 3 2 3 4	23	4 2 4 4 4 4 3 4	10	1 3 1 1 2 2 3 4
2000 09 16	14	2 2 3 2 2 1 3 5	38	3 1 5 5 5 5 5 5	21	4 2 4 4 3 3 3 5
2000 09 17	32	5 4 2 2 3 4 5 6	59	4 5 2 3 6 4 4 8	40	4 4 2 3 4 4 5 7
2000 09 18	28	5 4 4 4 4 5 2 3	41	6 4 3 4 4 7 2 2	45	7 5 4 5 5 5 3 3
2000 09 19	15	3 2 2 3 5 2 2 3	43	3 5 3 6 6 4 5 4	27	3 3 3 5 6 4 3 4
2000 09 20	12	4 4 0 2 3 1 2 2	20	3 4 1 3 6 2 2 2	13	4 4 1 2 3 2 3 2
2000 09 21	7	2 2 1 2 3 1 2 2	19	2 3 5 5 3 2 2 1	9	2 2 2 3 3 3 2 2
2000 09 22	6	2 2 2 1 2 1 2 1	10	2 4 2 3 3 1 1 1	7	3 2 2 2 3 2 2 2
2000 09 23	6	2 3 1 1 2 1 1 2	13	2 4 1 4 1 1 1 4	7	2 3 1 1 2 2 2 2
2000 09 24	9	1 1 1 1 2 3 4 3	-1	-1-1-1-1-1-1-1-1	10	1 0 1 2 3 3 4 3
2000 09 25	13	2 2 3 3 3 2 3 4	30	2 1 5 6 4 5 3 3	16	2 2 3 4 4 3 3 4
2000 09 26	17	4 4 3 3 3 2 3 3	37	3 3 5 6 6 4 3 3	21	4 4 4 4 4 4 3 3
2000 09 27	8	3 2 2 2 2 1 2 2	13	3 2 3 5 2 2 2 1	11	3 3 3 3 3 2 2 2
2000 09 28	9	2 4 2 3 2 2 0 0	20	2 3 2 5 5 4 1 1	12	2 4 2 3 4 3 2 1
2000 09 29	5	2 2 1 2 2 1 1 1	6	1 1 0 3 3 2 1 1	7	3 2 1 2 2 2 2 2
2000 09 30	25	3 3 4 5 4 3 4 4	69	2 4 7 7 6 5 4 6	45	3 4 6 6 5 5 5 5

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:
Three satellite outages caused availability to fall below specification during weeks 47 and 57. Outages on 19 July, 2000 (47_3) caused reports from TRS at Elko to report an availability of 98.888%. On 27 September, 2000 (57_3) an outage caused both TRS at Atlantic City and TRS at Dayton to report availabilities of 98.784% and 98.943% respectively. This availability degradation continued into 28 September, 2000 (57_4) at levels of 98.766% for TRS at Atlantic City and 98.919% for TRS at Dayton. All availabilities levels listed here are below specification.

Problem Analysis:

Week_Day	Site	Availability (Spec ≥ 99.16)	95% Vert. Error (Meters)	99.9% Vert. Error (Meters)	95% Horz. Error (Meters)	99.9% Horz. Error (Meters)	Exceeded Spec.
47_3	Elko	98.888%	7.21	26.5	6.27	10.6	X
57_3	Atlantic City	98.784%	8.04	29.3	5.31	10.7	X
57_3	Dayton	98.934%	7.39	21.2	5.37	8.93	X
57_4	Atlantic City	98.766%	9.06	35.6	5.64	11.9	X
57_4	Dayton	98.919%	7.34	23.3	5.63	11.9	X

Conditions During Failure
Satellite 9 Unusable
NANU #2000118 states that satellite PRN 9 underwent scheduled maintenance beginning 19 July, 2000 (47_3) at 1703 Zulu and was labeled “unhealthy.” The satellite regained “healthy” status on 19 July, 2000 (47_3) at 2132 Zulu.

Satellite 23 Unusable
NANU #2000117 states that satellite PRN 23 underwent scheduled maintenance on 19 July, 2000 (47_3) and was labeled “unhealthy.” The scheduled maintenance actually began on 18 July, 2000 (47_2) at 2022 Zulu and continued until 19 July, 2000 (47_3) at 1048 Zulu, when it regained “healthy” status. However, availability was not seriously affected until 19 July, 2000 (47_3).

Satellite 23 Unusable
NANU #2000148 states that satellite PRN 23 was set “unhealthy” due to an unscheduled outage on 27 September, 2000 (57_3) at 1354 Zulu. The satellite remained in an “unhealthy” status until 28 September, 2000 (57_4) at 2313 Zulu. The end of the outage was announced by NANU #2000152.

Problem Resolution

Availability specifications were not met for the TRS locations at Elko, Atlantic City, and Dayton for the aforementioned dates. These failures can be directly attributed to a series of satellite outages that occurred at those times. As soon as these satellites regained “healthy” status, availability returned to levels above those set by the GPS SPS.

Appendix D Glossary

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.

ATTACHMENT A

Ionospheric Storm Summary

The Effect of the July 15th-16th Geomagnetic Storm on GPS and WAAS

A large Coronal Mass Ejection (CME) resulted in a very strong geomagnetic storm late on July 15th that lasted into July 16th. This storm was discussed in Section 6 of this PAN report. The purpose of this section is to provide some additional detail on the impact that this storm had on the ionosphere and the resulting impacts to GPS and the Wide Area Augmentation System (WAAS) (which is still under development).

Magnitude of the Storm Effects on the Ionosphere

Figure 1 shows the slant ionospheric range delay from the Miami WAAS Reference Station (WRS) to the Inmarsat AOR-W Geo-synchronous satellite (used as the WAAS GEO). The normal peak ionospheric slant range for this site is in the 20-30 meter range; Figure 1 shows the slant range delay reach nearly 70 meters. Adjusting for obliquity and receiver bias, the vertical ionospheric peak reached over 40 meters for this pierce point. Figure 2 shows a smaller effect in Jacksonville, Florida, and Figure 3 shows a much smaller effect at the New York WRS.

Impact on GPS SPS Error

Figure 4 shows the vertical error using the GPS SPS solution at the WAAS WRS receiver in Miami. Figure 4 shows a vertical error in excess of 50 meters. Figure 5 shows the results for Jacksonville, where a much smaller vertical error of less than 30 meters was observed.

In some cases, the impact of an ionospheric storm may appear greater to some receivers. This is not only due to the fact that the ionospheric delay is affected differently at different locations, but also because the ionospheric storm may cause dropouts of one or more GPS satellites in some receivers. The result is that some receivers may end up with a smaller set of GPS satellites with a worse geometry, which can result in a much poorer position solution. Future PAN reports will contain additional detail regarding this observation.

Impact on the Wide Area Augmentation System (WAAS) (under development)

Ionospheric storms will affect the WAAS in three ways: (1) the maximum delay will increase greatly over a "normal" day, over a certain region, and that region may be less accurately modeled by a plane, resulting in a larger Grid Ionospheric Vertical Error (GIVE) at some Ionospheric Grid Points (IGP's), (2) the rapid fluctuations in the ionosphere may cause a larger "uncertainty" in the WAAS's computation, resulting in a larger (GIVE) at some IGP's, and (3) scintillation and the rapid ionospheric fluctuations may cause WAAS measurements to drop out (particularly at L2) resulting in some IGP's going unmonitored or also cause in increase in GIVE's.

The user of WAAS will be impacted by the effect on IGP's and GIVE values just discussed (resulting in a larger VPL and HPL, which affects WAAS availability for precision and approach). The WAAS user receiver might also be affected by dropouts of GPS satellites, which will also result in higher VPL (due to poorer geometry of remaining GPS satellites).

Figure 6 shows the impact of the Jul 15th-16th storm on a single IGP, at 80 West, 25 North (near Miami, Florida). The thin line shows the normal increase of the ionosphere's vertical delay, up until just prior to second-of-week 600,000 (Week 1070). The thin line then begins to rapidly fluctuate to the maximum value, which in the case of IGP delay corresponds to "DO NOT USE". After the storm, the ionosphere delay value stays low for the entire next day, which is a typical post-storm feature. Figure 6 also shows the independently computed ionospheric vertical delay around Miami. The independent computation shows a bias of several meters (which will be corrected in future computations); however, the independent value shows that the ionospheric delay was starting a steep increase at the time the WAAS IGP starting hitting the "DO NOT USE" value.

Figure 7 shows a data for the WAAS IGP at 40 North, 100 West, which is close to Columbus, Nebraska, where an NSTB reference station is located. This IGP shows only one instance where the IGP vertical delay went to "DO NOT USE", also, the independent computation of the vertical delay from the NSTB TRS receiver there showed a rapid increase about this time (though not as large as seem in Miami). Figure 8 shows the corresponding GIVE for this grid point. This figure shows a rapid increase in the GIVE value to 15 meters, and then fluctuations to 45 meters. This figure also shows an independent computation of "irregularity" in the ionosphere. This independent computation differences the vertical delay of the highest elevation ionospheric pierce point available at the TRS receiver, with the value which is interpolated by using the next three IGP's to define a plane. This difference of measured and plane approximation gives a measurement of irregularity. Figure 8 shows that the irregularity increases at the time that the WAAS set the GIVE to higher values.

The previous discussion showed that the WAAS reacted to the storm conditions by setting IGP's to a "DO NOT USE" value or by increasing the GIVE values. The net effect is a decrease in availability (in this case, precision approach would not be available over the US for approximately 6 – 8 hours), but in all data analyzed by the WAAS team during this storm, safety was maintained (meaning that there were no instances where the actual vertical error exceeded the computed Vertical Protection Level (VPL). The WAAS system is currently being modified with additional safety software, and the impacts on the availability and integrity of WAAS of future ionospheric storms will be documented.

Figure 1

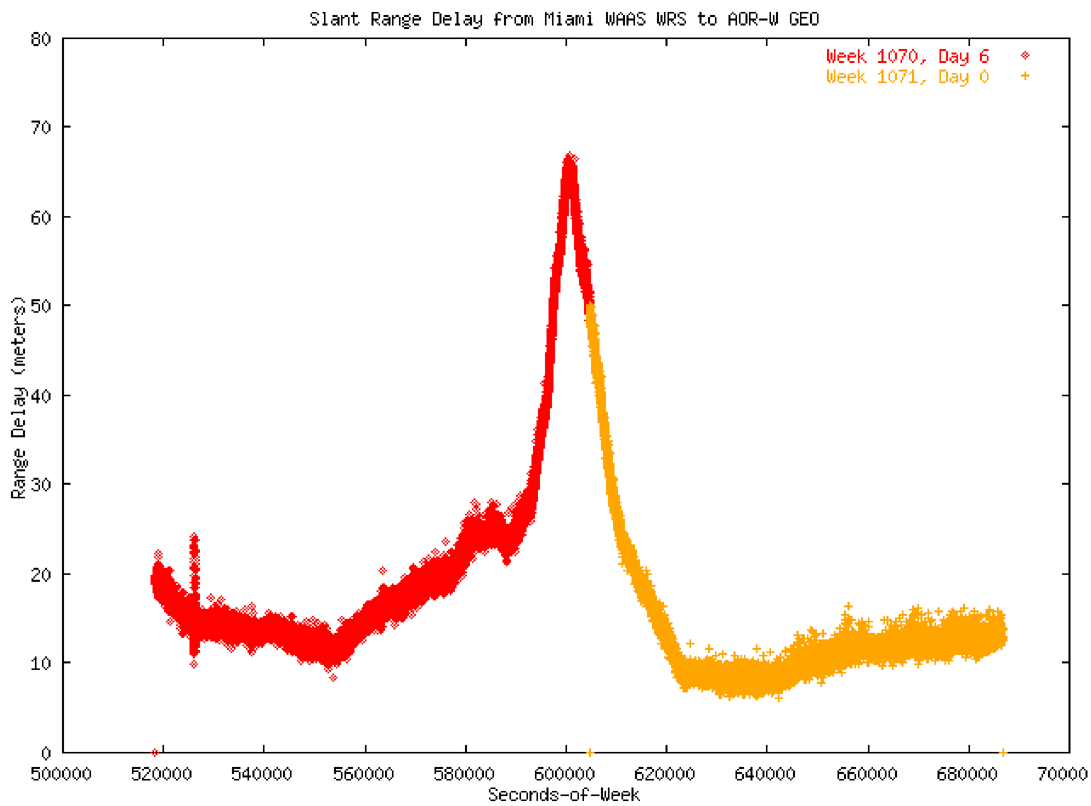


Figure 2

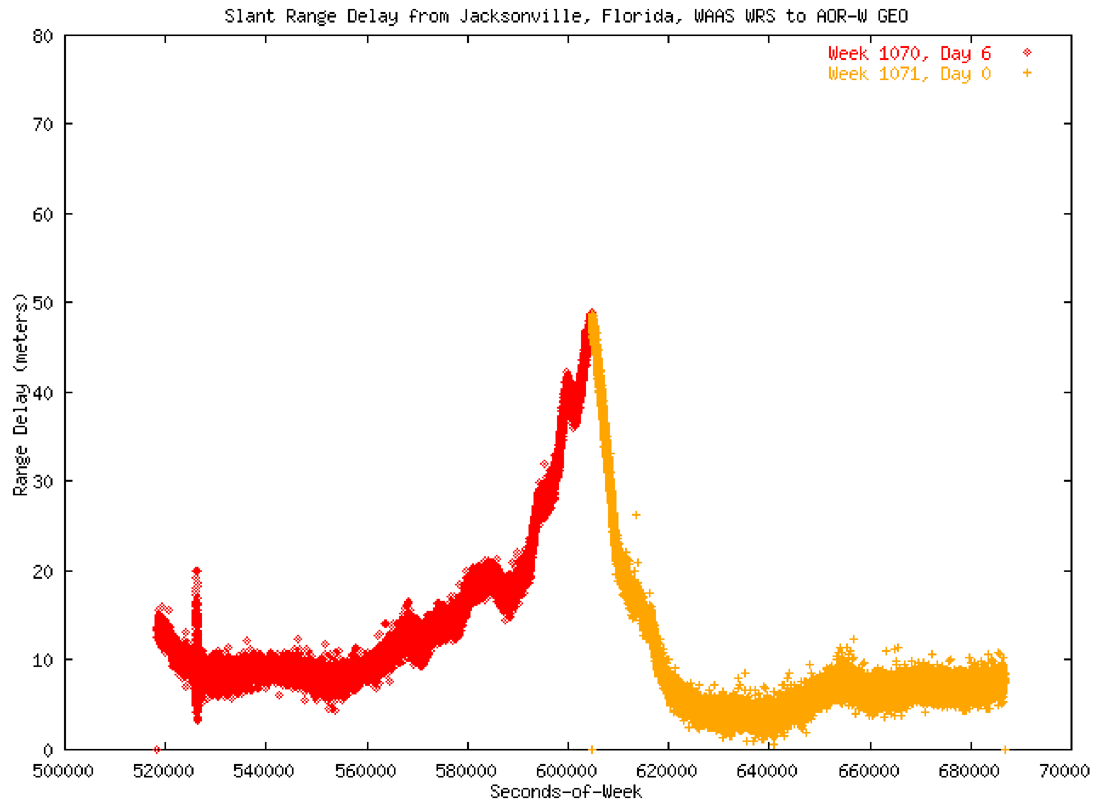


Figure 3

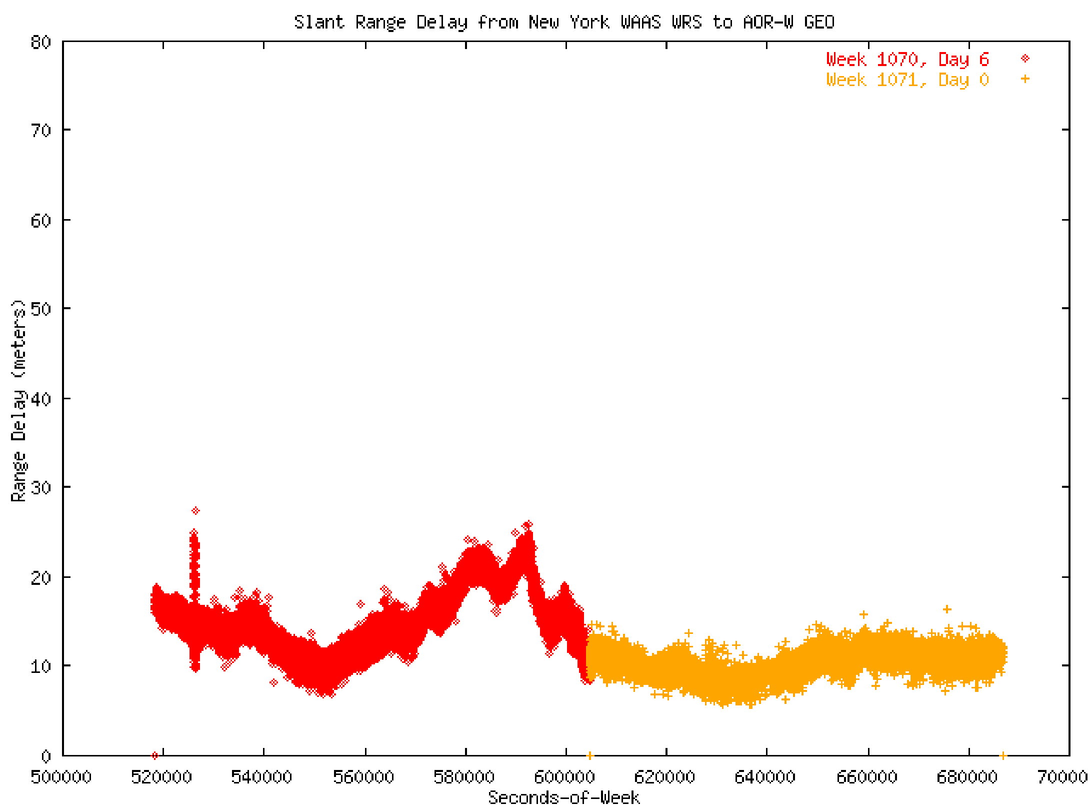


Figure 4

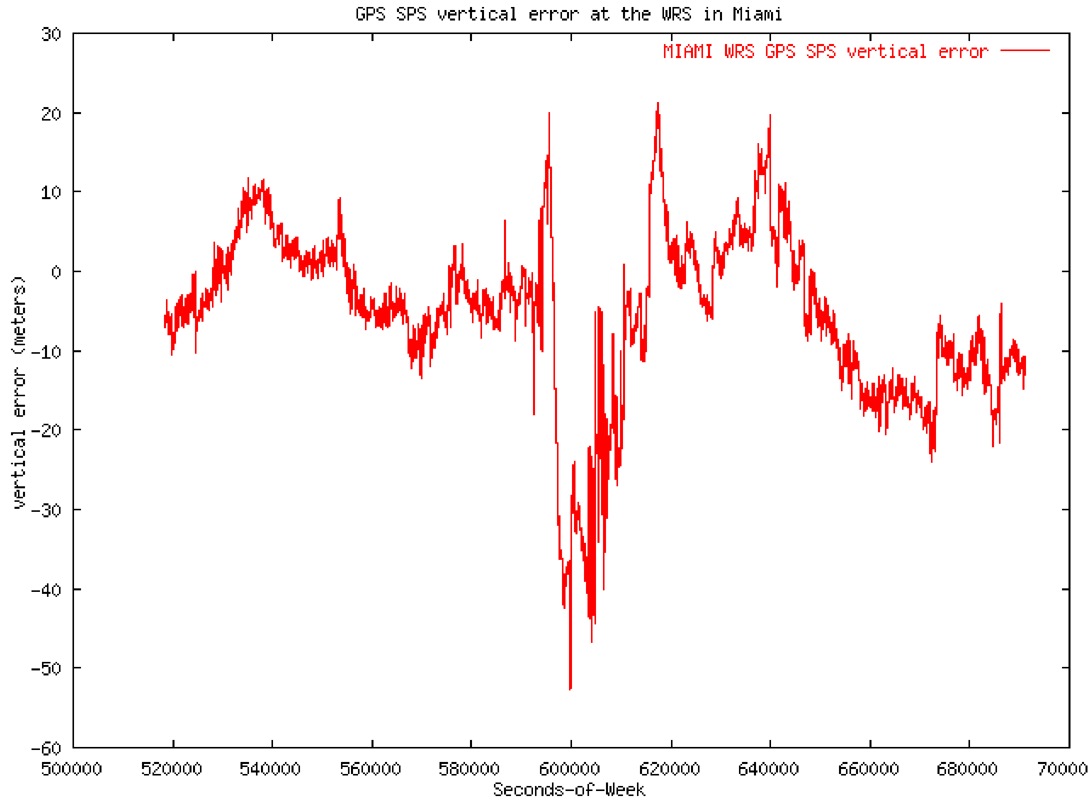


Figure 5

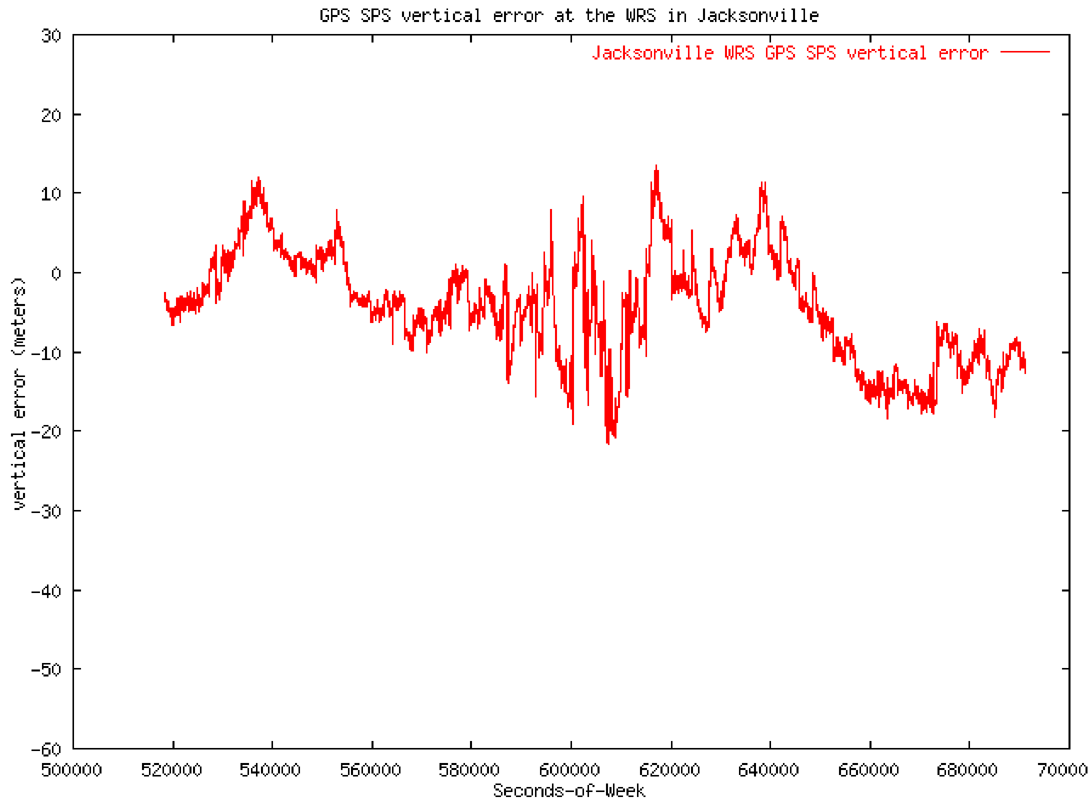


Figure 6

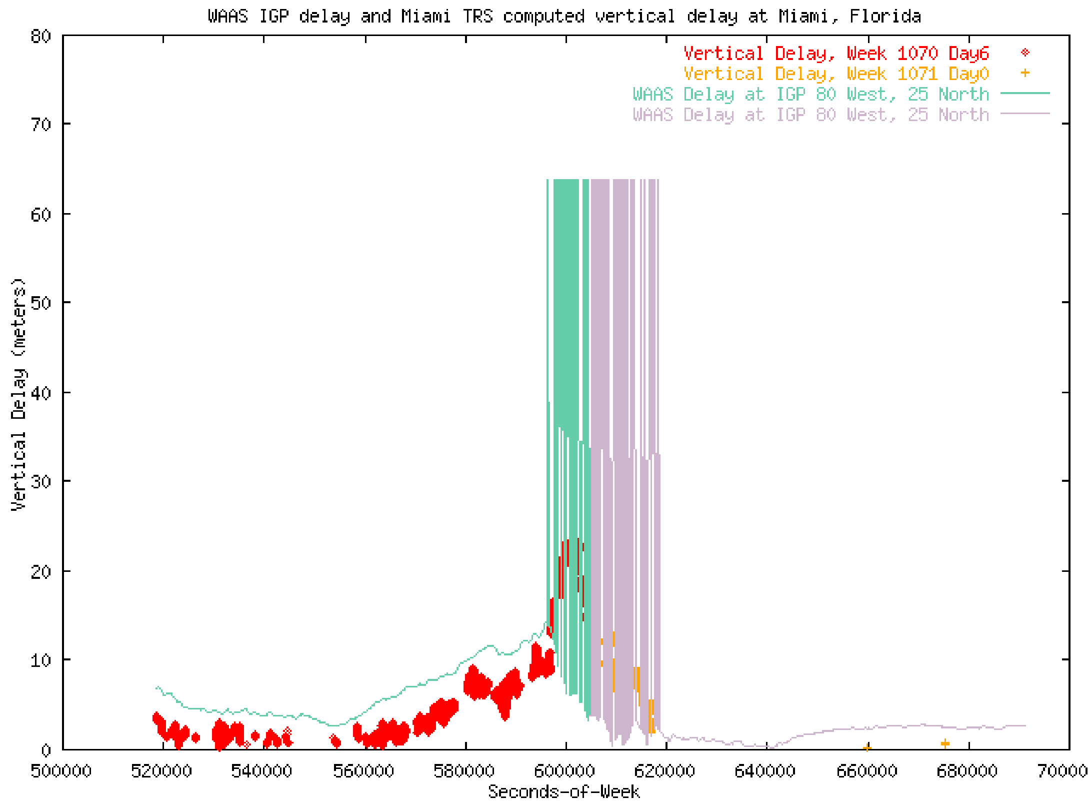


Figure 7

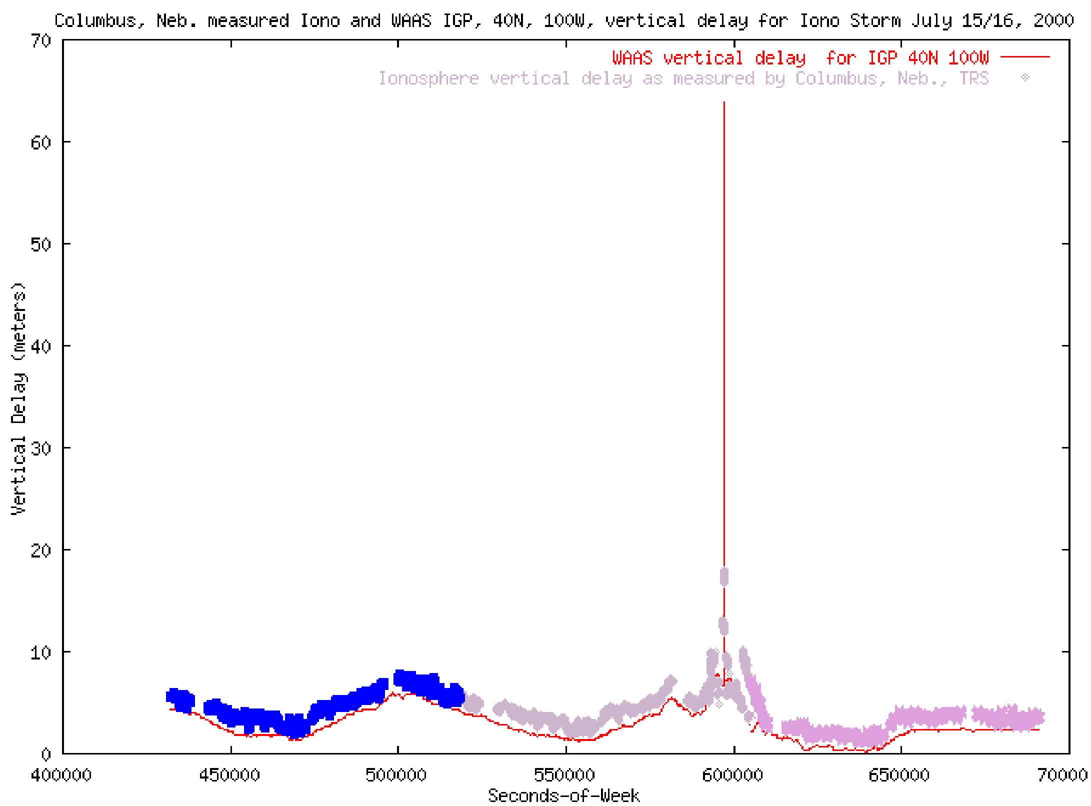
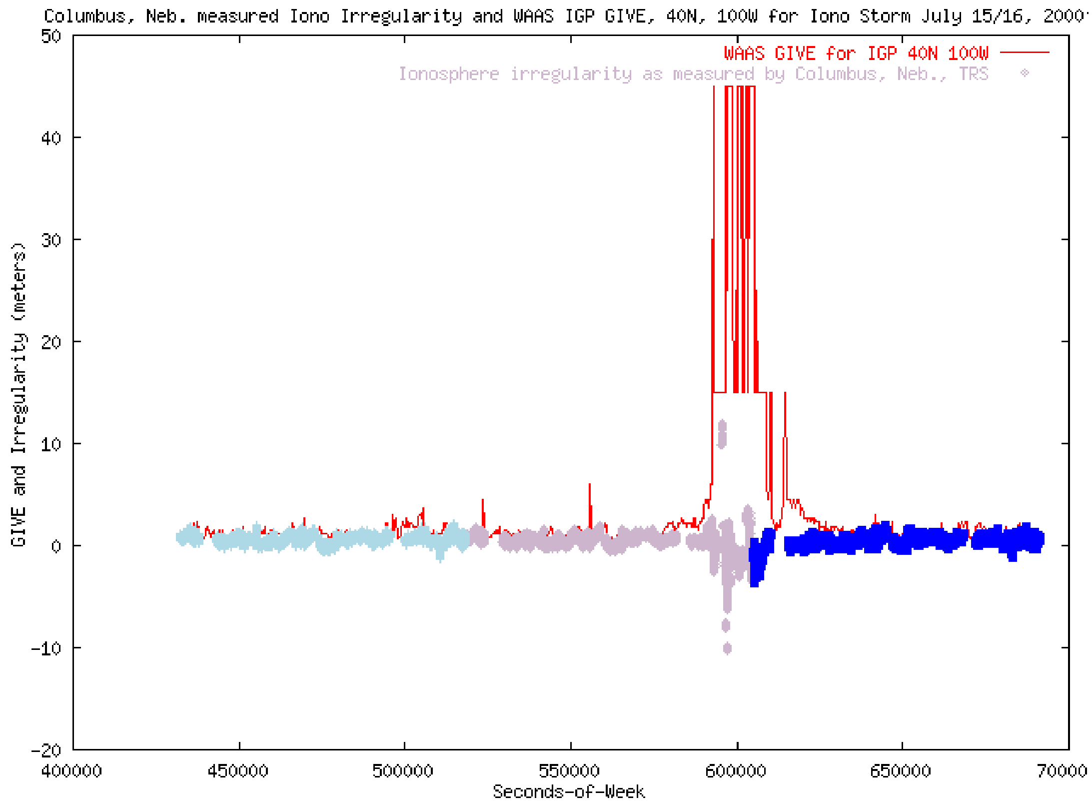


Figure 8


Columbus, Neb. measured Iono Irregularity and WAAS IGP GIVE, 40N, 100W for Iono Storm July 15/16, 2000
WAAS GIVE for IGP 40N 100W
Ionosphere irregularity as measured by Columbus, Neb., TRS
GIVE and Irregularity (meters)
Seconds-of-Week
50
40
30
20
10
0
-10
-20
400000
450000
500000
550000
600000
650000
70000