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

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GPS Product Team

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Executive Summary

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

This report, Report #93, includes data collected from 1 January through 31 March 2016. The next quarterly report will be issued July 31, 2016.

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

PDOP availability is based on Position Dilution of Precision (PDOP). Utilizing the weekly almanac posted on the US Coast Guard navigation web site, the coverage for every 5° grid point between 180W to 180E and 80S and 80N was calculated for every minute over a 24-hour period for each of the weeks covered in the reporting period. For this reporting period, the global availability based on PDOP less than six for CONUS was 100%.

NANU summary and evaluation was achieved by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 January and 31 March 2016. Using this data, we compute a set of statistics that give a relative idea of constellation health for both the current and combined history of past quarters. A total of ten outages were reported in the NANU's this quarter. Eight outages were scheduled ahead of time while two unscheduled NANUs occurred.

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

Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error standard was verified for each satellite from 24-hour accuracy values computed using data collected at the following six sites: Boston, Honolulu, Los Angeles, Miami, San Juan and Juneau. This data was also collected in one-second samples. All sites achieved 100% reliability, meeting the SPS specification. The maximum range error recorded was 19.571 meters on Satellite PRN 14. The SPS specification states that the range error should never exceed 30 meters for less than 99.79% of the day for a worst-case point and 99.94% globally. The maximum RMS range error value of 2.496 was recorded on satellite PRN 19. The SPS specification states that RMS URE cannot exceed 6 meters in any 24-hour interval.

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

The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products. During the evaluation period, the maximum 95% horizontal and vertical SPS errors were 7.58 meters at Maspalomas, Spain and 6.63 meters at Bogota, Colombia.

From the analysis performed on data collected between 1 January and 31 March 2016, the GPS performance met all SPS requirements that were evaluated.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

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

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

The analysis of the data is divided into the four performance categories stated in the Standard Positioning Service Performance Specification (September 2008). These categories are:

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

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

1.2 Report Overview

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

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

Section 4 summarizes service reliability performance. Although the specification calls for yearly evaluations, this SPS requirement will be reported at quarterly intervals.

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

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

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

Section 8 provides a summary of GPS Test NOTAMs.

Section 9 provides four appendices to summarize the data found in this report and provide further information.

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

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

Appendix D provides a glossary of terms used in this PAN report. This glossary was obtained directly from the GPS SPS specification document (September 2008).

1.3 Summary of Performance Requirements and Metrics

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

Table 1-1 SPS SIS Performance Requirements Standards

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

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

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

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

2 PDOP Availability Standard

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

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

PDOP Availability Standard	Conditions and Constraints
≥ 98% global PDOP of 6 or less ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval

Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by the WAAS test team 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 2.811 or better 99.9% of the time for each of the 24-hour intervals.

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

Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value	Global Average Availability (Spec: ≥ 98%)	Worst-Case Point Availability (Spec: ≥ 88%)
27 Dec – 2 Jan	2.8332	100%	100%
3 – 9 Jan	2.8479	100%	100%
10 – 16 Jan	2.8443	100%	100%
17 – 23 Jan	2.8264	100%	100%
24 – 30 Jan	2.8065	100%	100%
31 Jan – 6 Feb	2.7794	100%	100%
7 – 13 Feb	2.7571	100%	100%
14 – 20 Feb	2.7359	100%	100%
21 – 27 Feb	2.7173	100%	100%
28 Feb – 5 Mar	2.8444	100%	100%
6 – 12 Mar	2.7068	100%	100%
13 – 19 Mar	2.7024	100%	100%
20 – 26 Mar	2.6970	100%	100%

Figure 2-1 World GPS Maximum PDOP

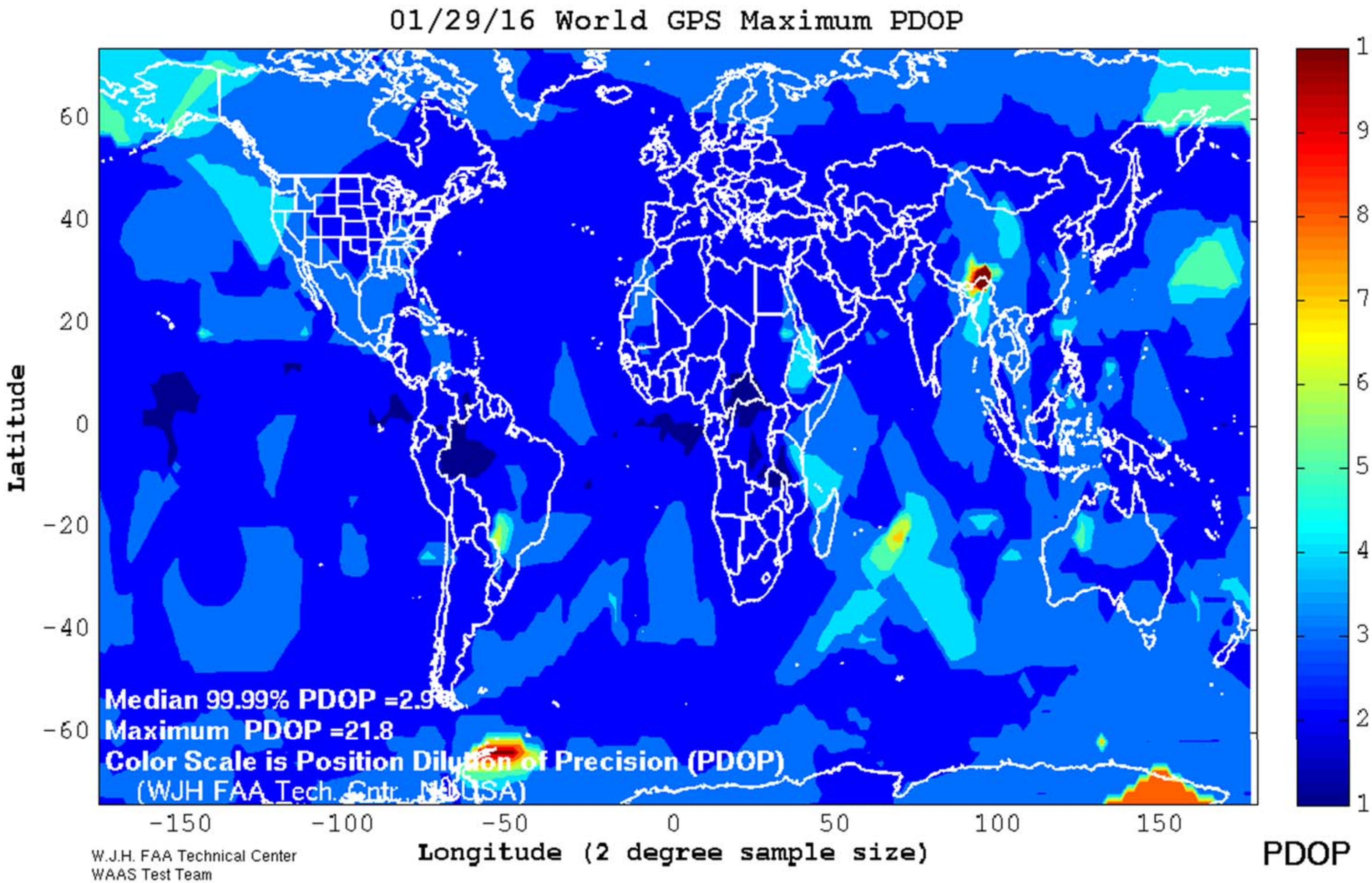
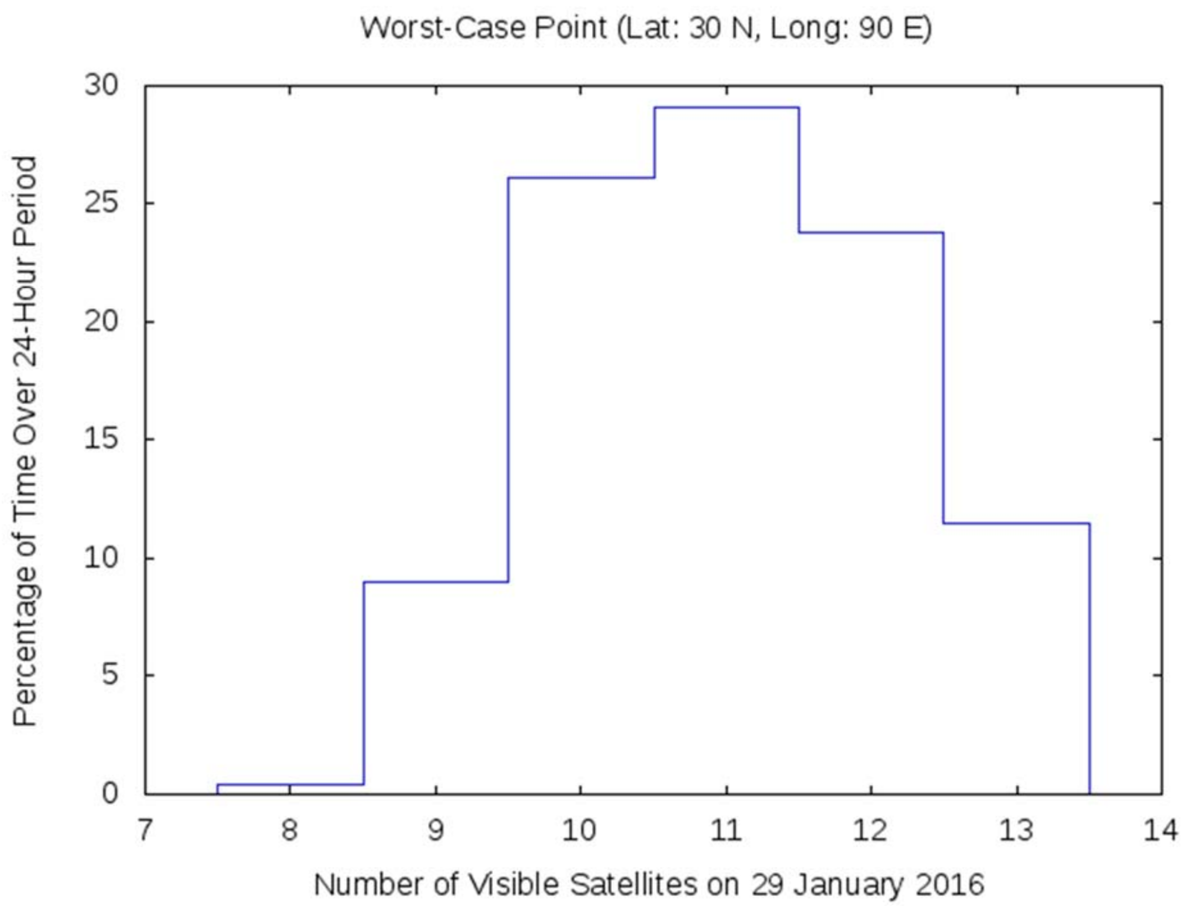


Figure 2-2 Satellite Visibility Profile for Worst-Case Point



3 NANU Summary and Evaluation

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

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

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANU's). During this reporting period, 1 January through 31 March 2016, there were a total of ten reported outages. Eight of those outages were maintenance activities and were reported in advance, while two were unscheduled outages. A complete listing of outage NANU's for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-2. Canceled outage NANU's (if any) are provided in Table 3-3. The minimum duration a scheduled outage was forecasted ahead of time was 45.217 hours. Only NANU 2016023 exceeded the 48-hour requirement, the rest were well above the requirement. The maximum response time for a NANU issued for an unscheduled outage was 0.717 hours. Therefore the probability of continuity not being affected due to an unscheduled failure interruption was 100%, which met the specification requirement.

Table 3-1 NANUs Affecting Satellite Availability

NANU#	PRN	TYPE	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2016001	27	FCSTSUMM	7-Jan-16	15:58	7-Jan-16	23:30		7.53	7.53
2016004	25	UNUSABLE	9-Jan-16	21:22	9-Jan-16	23:58	2.60		2.60
2016005	28	FCSTSUMM	15-Jan-16	1:09	15-Jan-16	7:00		5.85	5.85
2016010	12	FCSTSUMM	29-Jan-16	7:12	29-Jan-16	13:56		6.73	6.73
2016014	19	FCSTSUMM	26-Feb-16	0:38	26-Feb-16	7:18		6.67	6.67
2016018	13	UNUSABLE	28-Feb-16	14:39	1-Mar-16	0:06	33.45		33.45
2016020	15	FCSTSUMM	4-Mar-16	0:24	4-Mar-16	5:52		5.47	5.47
2016021	25	FCSTSUMM	8-Mar-16	4:24	8-Mar-16	9:20		4.93	4.93
2016024	21	FCSTSUMM	18-Mar-16	18:43	18-Mar-16	19:58		1.25	1.25
2016026	14	FCSTSUMM	29-Mar-16	14:14	29-Mar-16	20:41		6.45	6.45
Totals of Unscheduled, Scheduled & Total Downtime							36.05	44.88	80.93

GENERAL NANUs

2016009 - Resume Transmitting L-band signal on SVN49 using PRN4. Will not be included in broadcast almanac

2016012 - Notice of Potential Time Transfer Anomaly

2016016 - Notice of No Time Transfer Anomaly, User Equipment Issue

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2015101	27	FCSTDV	7-Jan	15:45	8-Jan	3:45	12	2016001
2016002	28	FCSTDV	15-Jan	1:00	15-Jan	13:00	12	2016005
2016003	25	UNUSUFN	9-Jan	21:22				2016004
2016007	12	FCSTDV	29-Jan	7:00	29-Jan	19:00	12	2016010
2016013	19	FCSTDV	26-Feb	0:35	26-Feb	12:35	12	2016014
2016015	15	FCSTDV	4-Mar	0:15	4-Mar	12:15	12	2016020
2016017	13	UNUSUFN	28-Feb	14:39				2016018
2016019	25	FCSTDV	8-Mar	4:00	8-Mar	16:00	12	2016021
2016023	21	FCSTMX	18-Mar	18:00	19-Mar	6:00	12	2016024
2016025	14	FCSTDV	29-Mar	14:00	30-Mar	14:00	24	2016026
						Total Forecasted Downtime	108	

Table 3-3 Cancelled NANUs

NANU#	PRN	Type	Start Date	Start Time	Comments
None	-	-	-	-	-

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published "Notice: Advisory to Navstar Users" messages (NANU's). This data has been summarized in Table 3-4. The "Total Satellite Observed MTTR" was calculated by taking the average downtime of all satellite outage occurrences. Scheduled 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 Satellite Maintenance Statistics

Satellite Reliability/Maintainability/Availability (RMA) Parameter	1-Jan-16 31-Mar-16	1-Jan-00 31-Mar-16
Total Forecast Downtime (hrs):	108	11150.82
Total Actual Downtime (hrs):	80.93	38735.83
Total Actual Scheduled Downtime (hrs):	44.88	6320.35
Total Actual Unscheduled Downtime (hrs):	36.05	32415.48
Total Satellite Observed MTTR (hrs):	8.09	45.68
Scheduled Satellite Observed MTTR (hrs):	5.61	9.39
Unscheduled Satellite Observed MTTR (hrs):	18.03	185.23
# Total Satellite Outages:	10	848
# Scheduled Satellite Outages:	8	673
# Unscheduled Satellite Outages:	2	175
Percent Operational -- Scheduled Downtime:	99.93	99.86
Percent Operational -- All Downtime:	99.88	99.12

3.2 Service Availability Standard

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

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

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

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

To verify availability, the data collected from receivers at the twenty-eight WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-5. The data was collected at one-second intervals between 1 January and 31 March 2016.

Table 3-5 Accuracies Exceeding Threshold Statistics

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-hour Threshold Failures	Quarters Service Availability %
Albuquerque	7860677	0	100%
Anchorage	7841874	0	100%
Atlanta	7811329	0	100%
Barrow	7853885	0	100%
Bethel	7859036	0	100%
Billings	7843053	0	100%
Boston	7849686	0	100%
Cleveland	7846817	0	100%
Cold Bay	7836668	0	100%
Fairbanks	7858023	0	100%
Gander	7853365	0	100%
Honolulu	7750165	0	100%
Houston	7860694	0	100%
Iqaluit	7847909	0	100%
Juneau	7859957	0	100%
Kansas City	7860559	0	100%
Kotzebue	7857912	0	100%
Los Angeles	7860051	0	100%
Merida	7847863	0	100%
Miami	7860555	0	100%
Minneapolis	7846789	0	100%
Oakland	7852246	0	100%
Salt Lake City	7839219	0	100%
San Jose Del Cabo	6823437	0	100%
San Juan	7860244	0	100%
Seattle	7856789	0	100%
Tapachula	7860358	0	100%
Washington, DC	7860087	0	100%
Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)			

4 Service Reliability Standard

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

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

Table 4-1 shows a comparison to the service reliability standard for range data collected at a set of six receivers across North America. Although the specification calls for yearly evaluations, we will be evaluating this SPS requirement at quarterly intervals. Additional range analysis results can be found in table 5-2. The maximum User Range Error recorded this quarter was 19.571 meters on satellite PRN 14.

Table 04-1 User Range Error Accuracy

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Percentage
1 Jan – 31 Mar 2016	**Boston**	64,778,974	0	100%
1 Jan – 31 Mar 2016	**Honolulu**	67,491,574	0	100%
1 Jan – 31 Mar 2016	**Los Angeles**	65,615,439	0	100%
1 Jan – 31 Mar 2016	**Miami**	65,113,349	0	100%
1 Jan – 31 Mar 2016	**Merida**	67,532,226	0	100%
1 Jan – 31 Mar 2016	**Juneau**	66,424,785	0	100%
1 Jan – 31 Mar 2016	**Global**	396,956,347	0	100%

5 Accuracy Standard

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

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

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

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

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

5.1 Position Accuracy

The data used for this section was collected for every second from 1 January through 31 March 2016 at the selected WAAS locations. Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter. Every twenty-four hour analysis period this quarter passed both the worst-case and global average position accuracy requirements set forth by the SPS specification.

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

Site	95% Vertical (Meters)	95% Horizontal (Meters)	99.99% Vertical (Meters)	99.99% Horizontal (Meters)
Albuquerque	3.742	1.892	10.697	4.079
Anchorage	4.227	1.698	8.701	4.141
Atlanta	3.828	2.091	8.948	4.843
Barrow	4.774	1.601	10.036	4.732
Bethel	4.432	1.745	7.210	3.777
Billings	3.719	1.937	10.257	6.299
Boston	3.590	2.254	9.505	6.364
Cleveland	3.675	2.336	9.572	4.950
Cold Bay	4.260	1.774	7.162	4.094
Fairbanks	4.465	1.640	10.070	5.822
Gander	3.641	2.061	7.109	7.321
Honolulu	4.884	6.485	13.225	10.876
Houston	4.049	2.097	9.358	4.298
Iqaluit	4.310	2.074	9.386	5.741
Juneau	3.696	1.741	9.187	4.996
Kansas City	3.775	2.039	11.484	5.679
Kotzebue	4.568	1.722	8.916	3.555
Los Angeles	4.185	1.995	9.605	4.193
Merida	4.181	2.695	9.277	6.440
Miami	4.000	2.279	9.531	4.680
Minneapolis	3.663	2.100	11.949	5.809
Oakland	4.238	1.971	9.334	4.634
Salt Lake City	3.652	1.870	10.877	6.859
San Jose Del Cabo	4.308	2.974	10.973	8.573
San Juan	4.594	3.722	13.306	9.220
Seattle	3.731	1.896	8.701	6.547
Tapachula	4.518	3.714	9.959	8.607
Washington, DC	3.725	2.292	9.227	5.182

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-eight WAAS sites from 1 January to 31 March 2016.

Figure 5-1 Global Vertical Error Histogram

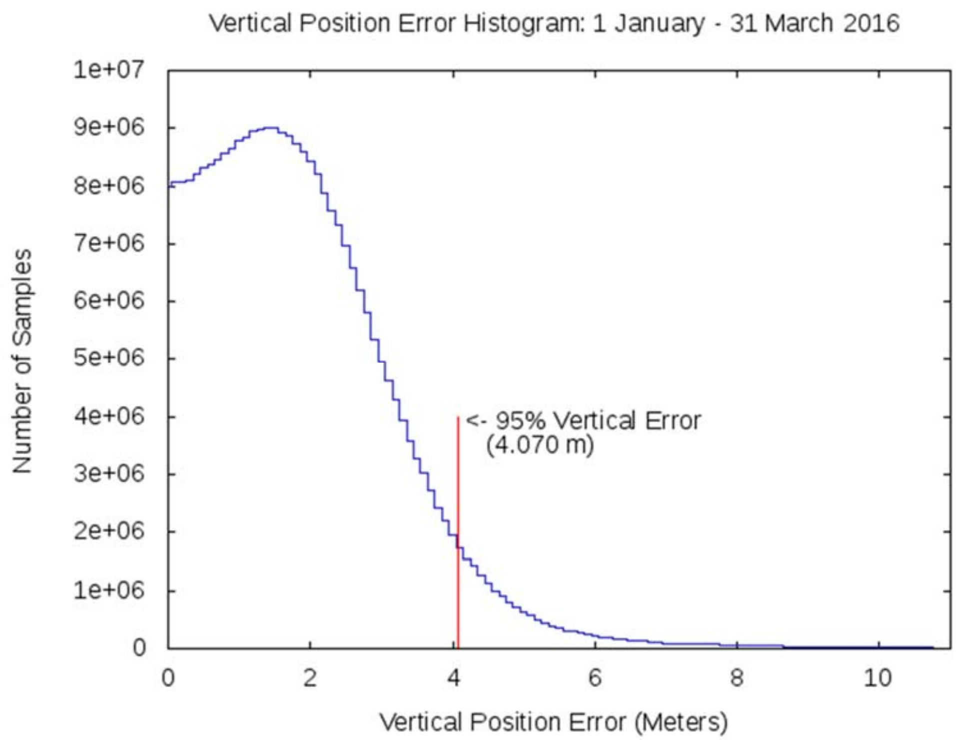
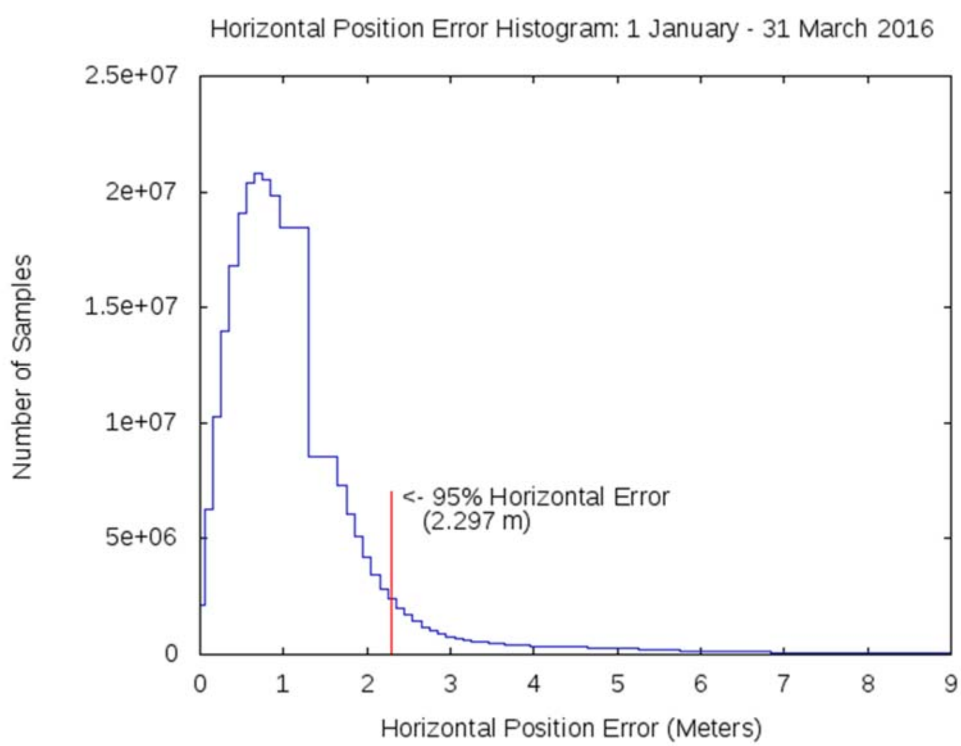


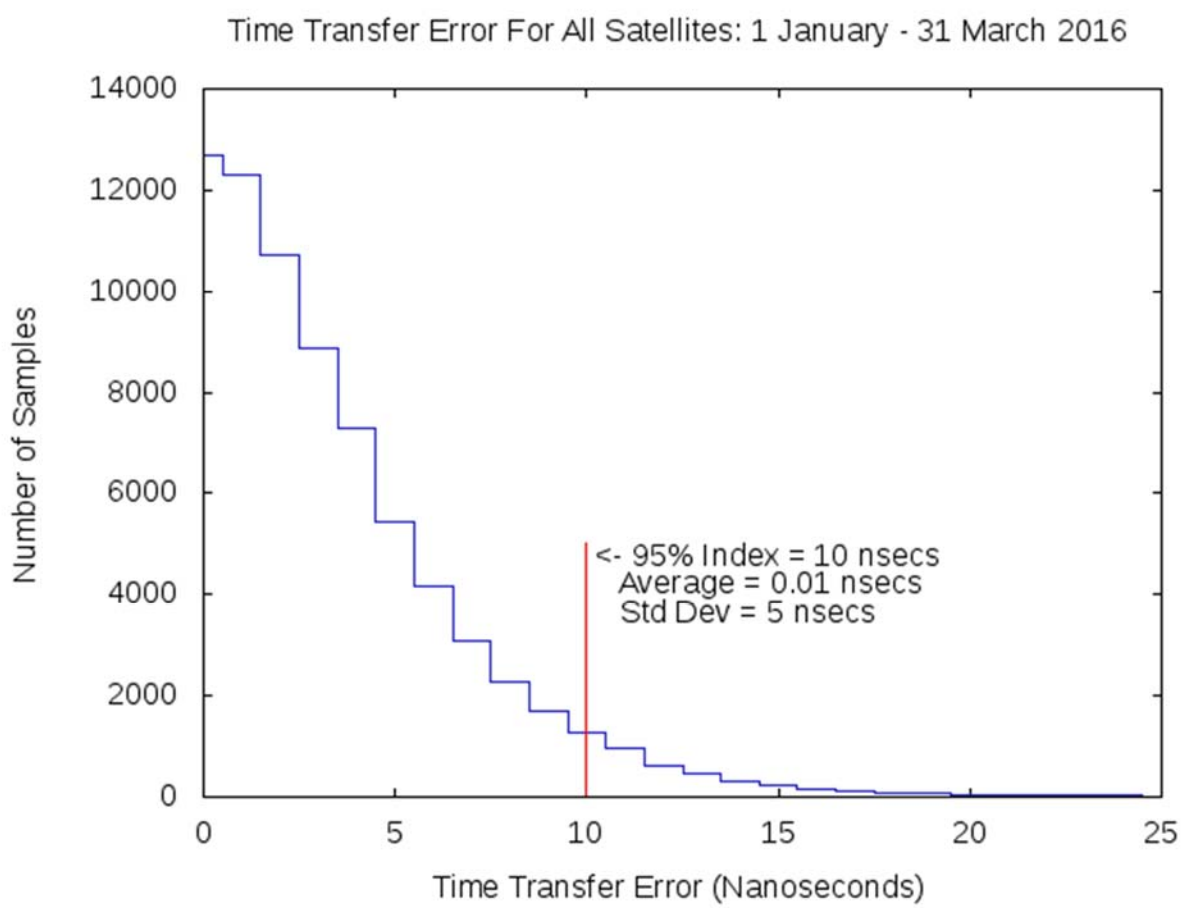
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 January and 31 March 2016 was downloaded 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 maximum instantaneous UTC offset error (UTCOE) for the quarter was 55 nanoseconds. The mean, standard deviation and 95% index of Time Transfer Error, and the maximum UTCOE are all within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Error



5.3 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 January and 31 March 2016. A weighted average filter was used for the calculation of the range rate error and the range acceleration error. All Range Domain SPS specifications were met.

Table 5-2 Range Error Statistics

PRN	RMS Range Error ($\leq$ 6 m) (Meters)	Range Error Mean (Meters)	1σ Range Error (Meters)	95% Range Error (Meters)	Max Range Error (SPS Spec. $\leq$ 30 m) (Meters)	Samples
1	1.299	0.420	1.098	2.532	12.832	13270064
2	2.156	1.619	1.245	3.866	17.842	14075846
3	1.445	0.124	1.228	2.747	13.721	13784565
5	1.638	0.412	1.430	3.066	13.940	13129868
6	1.517	0.407	1.285	3.024	15.106	13348580
7	1.825	0.214	1.319	3.251	13.558	12410854
8	1.785	0.852	1.320	3.244	12.254	12224603
9	1.697	0.413	1.225	3.018	14.275	13036637
10	1.380	0.359	1.058	2.492	14.242	12570727
11	1.794	1.178	1.177	3.305	15.351	12038123
12	1.549	0.520	1.342	3.017	16.692	13408664
13	1.668	0.409	1.391	3.058	17.412	12662212
14	1.695	0.933	1.141	2.939	19.571	13880530
15	1.569	0.577	1.291	2.900	16.042	12263634
16	1.833	1.048	1.209	3.209	14.251	12736725
17	1.754	0.724	1.351	3.275	13.548	14027065
18	1.768	1.233	1.092	3.062	16.857	13149240
19	2.496	1.919	1.353	4.342	16.196	13413718
20	2.013	1.477	1.201	3.566	16.238	13715074
21	1.917	1.394	1.143	3.345	15.700	12543088
22	2.025	1.422	1.181	3.452	15.238	12378277
23	1.760	0.480	1.250	3.110	13.006	12442116
24	1.625	0.092	1.343	2.982	17.095	13470853
25	1.421	0.577	1.160	2.660	11.691	13594452
26	1.555	0.760	1.074	2.724	12.214	12294600
27	1.549	0.850	1.127	2.825	12.786	12558836
28	2.250	1.183	1.480	3.922	14.341	12988142
29	1.594	0.792	1.156	2.992	15.126	12777426
30	1.849	0.629	1.275	3.320	17.915	12354319
31	1.535	0.321	1.141	2.726	11.612	13433037
32	1.795	0.109	1.225	3.161	16.369	6974472

Table 5-3 Range Rate Error Statistics

PRN	Range Rate Error RMS (mm/s)	95% Range Rate Error (mm/s)	Max Range Rate Error (mm/s)	Samples
1	1.391	2.666	119.190	13270064
2	1.544	2.943	181.800	14075846
3	1.448	2.759	142.940	13784565
5	1.587	3.026	208.500	13129868
6	1.431	2.751	160.150	13348580
7	1.559	2.881	122.790	12410854
8	1.656	2.828	138.760	12224603
9	1.417	2.695	177.070	13036637
10	1.321	2.502	128.480	12570727
11	1.547	2.926	125.550	12038123
12	1.621	3.149	127.320	13408664
13	1.531	2.859	169.790	12662212
14	1.465	2.809	120.520	13880530
15	1.452	2.794	109.150	12263634
16	1.543	2.925	154.590	12736725
17	1.644	3.045	122.750	14027065
18	1.559	2.854	200.900	13149240
19	1.513	2.936	96.970	13413718
20	1.484	2.838	144.600	13715074
21	1.553	2.962	70.180	12543088
22	1.448	2.749	92.090	12378277
23	1.460	2.757	149.320	12442116
24	1.823	3.079	165.290	13470853
25	1.371	2.657	82.850	13594452
26	1.362	2.550	214.640	12294600
27	1.340	2.553	88.830	12558836
28	1.755	2.873	140.210	12988142
29	1.530	2.915	229.780	12777426
30	1.398	2.653	140.450	12354319
31	1.515	2.772	149.260	13433037
32	1.554	2.714	151.190	6974472

Table 5-4 Range Acceleration Error Statistics

PRN	Range Acceleration Error RMS (μm/s^2)	95% Range Acceleration Error (μm/s^2)	Max Range Acceleration Error (μm/s^2)	Samples
1	10.291	20.058	1190	13270064
2	10.479	20.336	1830	14075846
3	10.409	20.211	1420	13784565
5	10.742	24.460	2090	13129868
6	10.364	20.075	1610	13348580
7	11.187	21.550	1230	12410854
8	12.453	20.671	1390	12224603
9	10.378	20.087	1770	13036637
10	10.227	20.038	1280	12570727
11	10.653	20.811	1260	12038123
12	10.425	24.487	1270	13408664
13	10.911	20.541	1700	12662212
14	10.250	20.396	1030	13880530
15	10.276	20.344	1090	12263634
16	10.658	22.211	1540	12736725
17	11.550	22.524	1200	14027065
18	11.159	22.213	2010	13149240
19	10.252	20.413	960	13413718
20	10.286	20.502	1430	13715074
21	10.645	23.957	710	12543088
22	10.228	21.293	920	12378277
23	10.419	20.572	1490	12442116
24	13.585	24.508	1630	13470853
25	10.109	20.110	840	13594452
26	10.489	20.271	2150	12294600
27	10.303	20.213	880	12558836
28	13.270	21.106	1390	12988142
29	10.619	21.983	2290	12777426
30	10.341	20.072	1410	12354319
31	10.860	20.535	1490	13433037
32	11.693	20.000	1510	6974472

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the maximum range error, range rate error and range acceleration error for all satellites. The highest maximum range error occurred on satellite 14 with an error of 19.571 meters. Satellite 31 had the lowest maximum range error of 11.612 meters. Figure 5-7 is histogram of satellite range error for all satellites over the entire quarter. Figures 5-8, 5-9, and 5-10 show the individual maximums per satellite for range error, range rate error, and range acceleration error respectively.

Figure 5-4 Distribution of Daily Max Range Errors

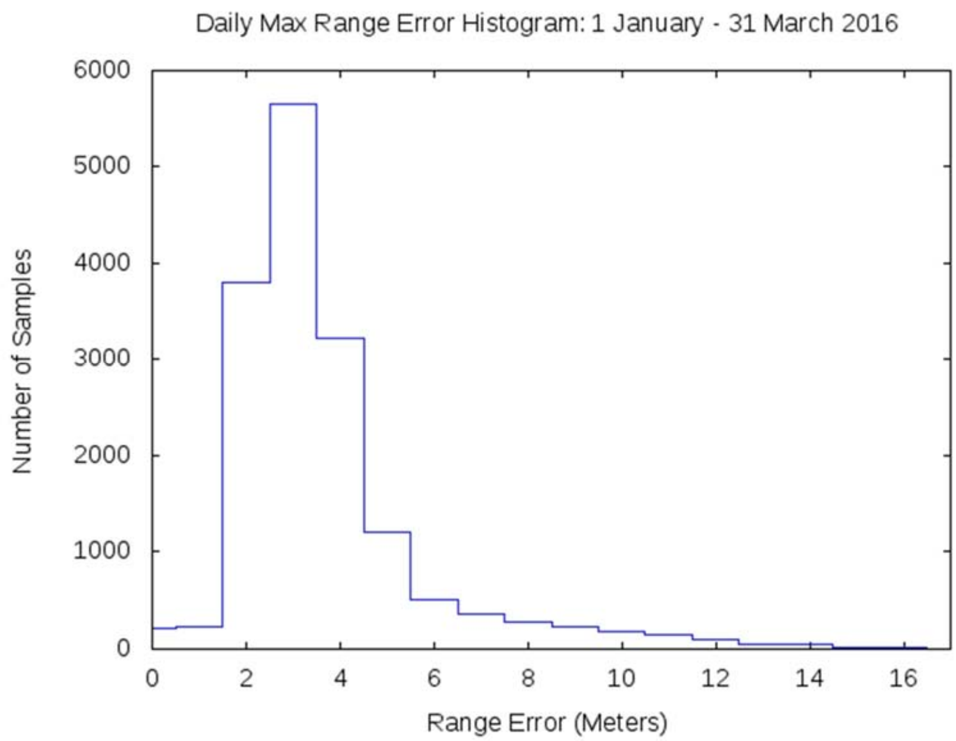


Figure 5-5 Distribution of Daily Max Range Rate Errors

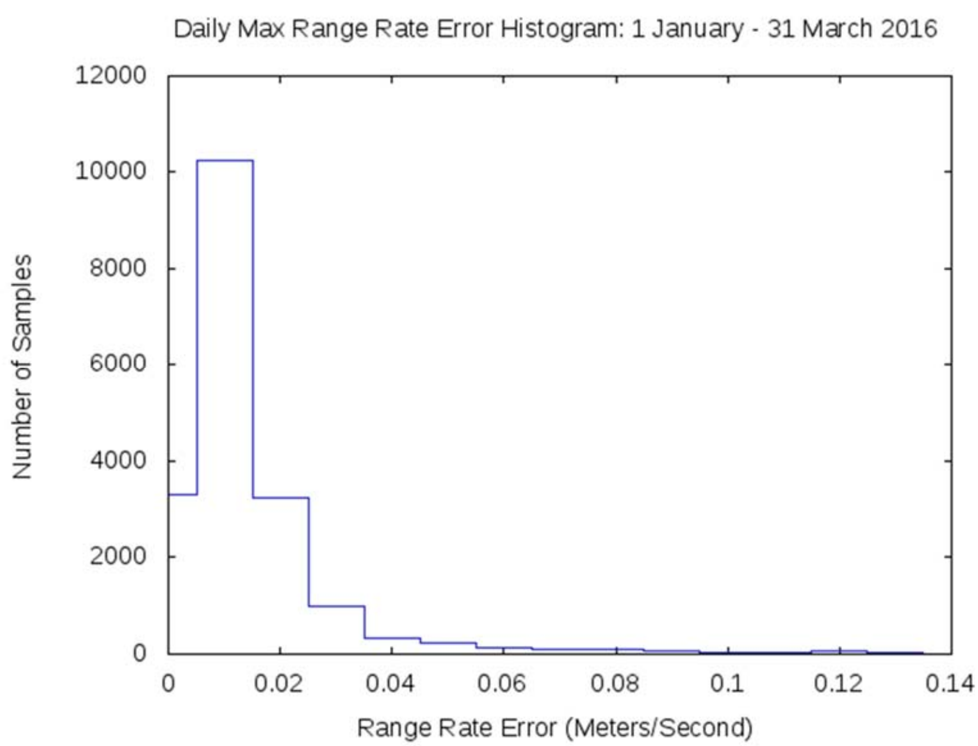


Figure 5-6 Distribution of Daily max Range Acceleration Errors

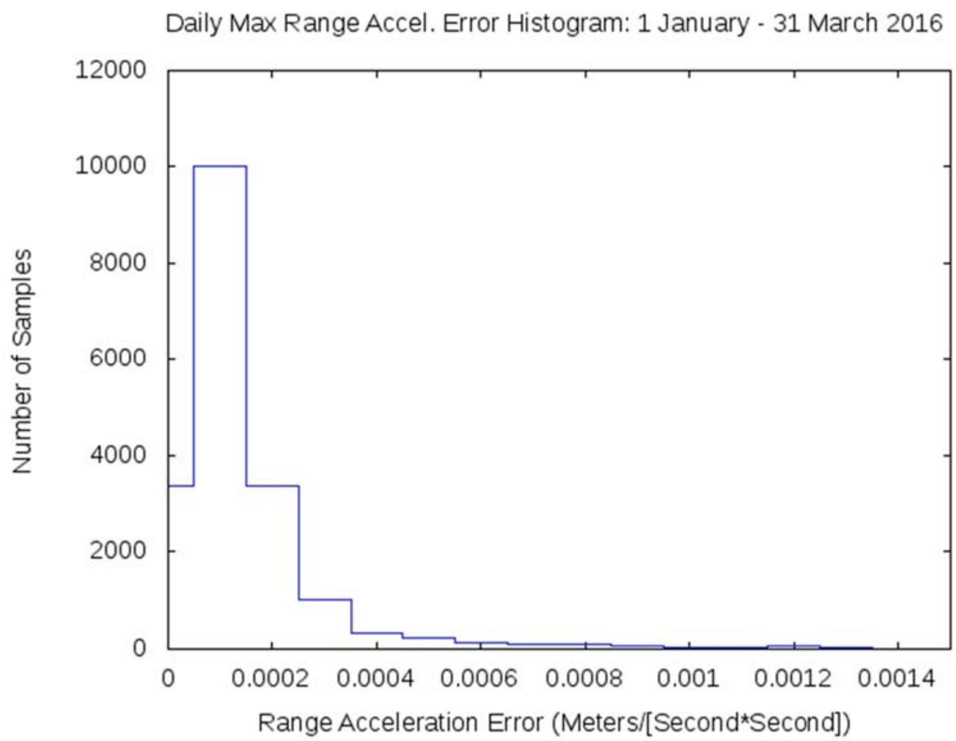


Figure 5-7 Range Error Histogram

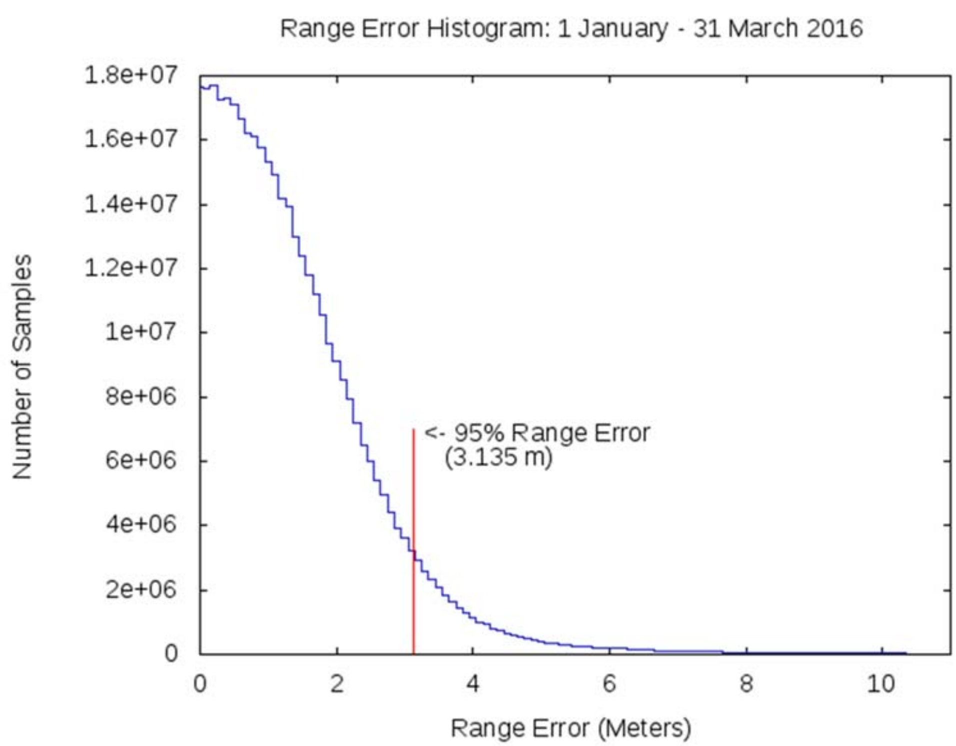


Figure 5-8 Maximum Range Error Per Satellite

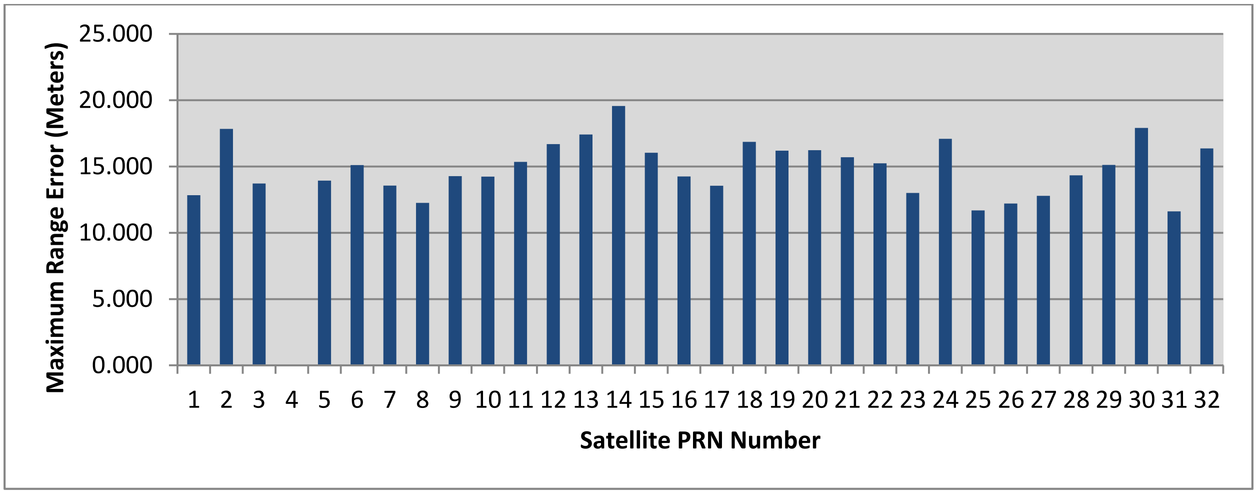


Figure 5-9 Maximum Range Rate Error Per Satellite

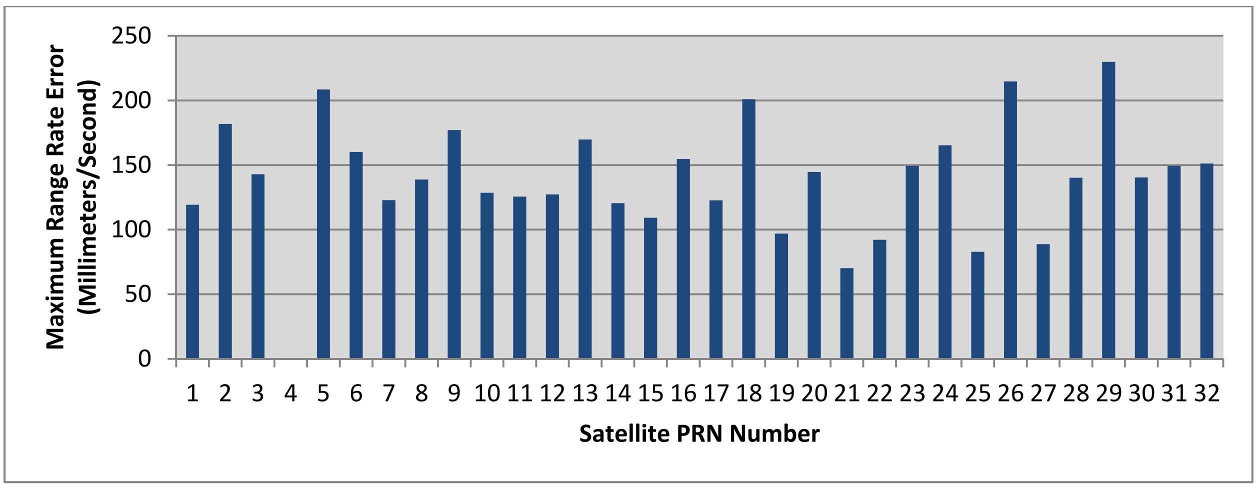
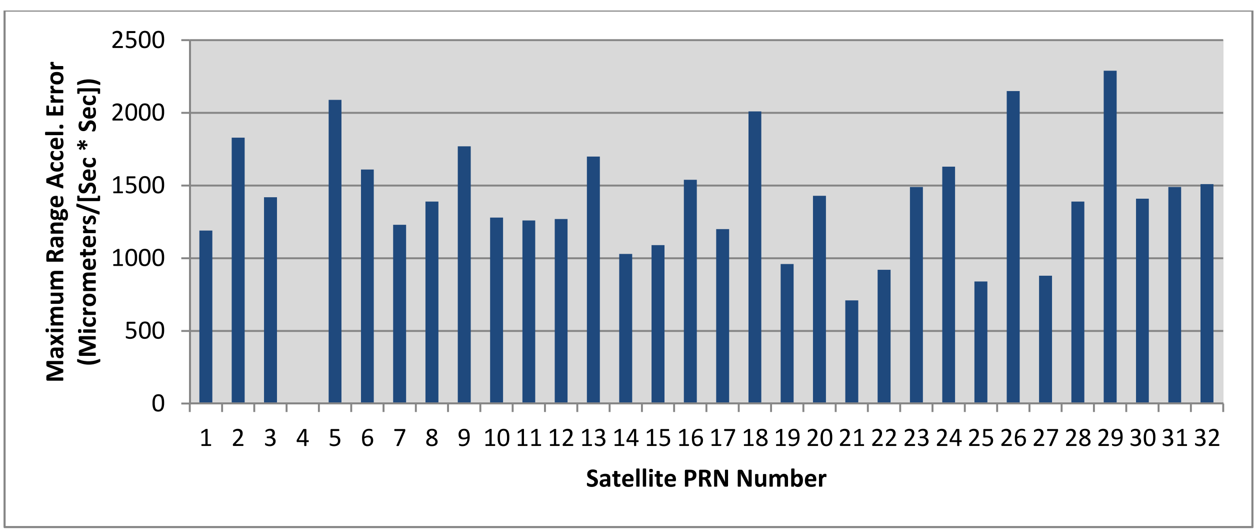


Figure 5-10 Maximum Range Acceleration Error Per Satellite



6 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 Weather Prediction Center (SWPC), 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://swpc.noaa.gov. It briefly explains some of the ideas behind the association of the aurora with geomagnetic activity and a bit about how the ‘K-index’ or ‘K-factor’ works.

> *The aurora is caused by the interaction of high-energy particles (usually electrons) with neutral atoms in the earth's upper atmosphere. These high-energy particles can ‘excite’ (by collisions) valence electrons that are bound to the neutral atom. The ‘excited’ electron can then ‘de-excite’ and return back to its initial, lower energy state, but in the process it releases a photon (a light particle). The combined effect of many photons being released from many atoms results in the aurora display that you see.*
>
> *The details of how high energy particles are generated during geomagnetic storms constitute an entire discipline of space science in its own right. The basic idea, however, is that the Earth’s magnetic field (let us say the ‘geomagnetic field’) is responding to an outwardly propagating disturbance from the Sun. As the geomagnetic field adjusts to this disturbance, various components of the Earth’s field change form, releasing magnetic energy and thereby accelerating charged particles to high energies. These particles, being charged, are forced to stream along the geomagnetic field lines. Some end up in the upper part of the earth’s neutral atmosphere and the auroral mechanism begins.*
>
> *An instrument called a magnetometer may also measure the disturbance of the geomagnetic field. At NOAA’s operations center magnetometer data is received from dozens of observatories in one-minute intervals. The data is received at or near to ‘real-time’ and allows NOAA to keep track of the current state of the geomagnetic conditions. In order to reduce the amount of data NOAA converts the magnetometer data into three-hourly indices, which give a quantitative, but less detailed measure of the level of geomagnetic activity. The K-index scale has a range from 0 to 9 and is directly related to the maximum amount of fluctuation (relative to a quiet day) in the geomagnetic field over a three-hour interval.*
>
> *The K-index is therefore updated every three hours. The K-index is also necessarily tied to a specific geomagnetic observatory. For locations where there are no observatories, one can only estimate what the local K-index would be by looking at data from the nearest observatory, but this would be subject to some errors from time to time because geomagnetic activity is not always spatially homogenous.*
>
> *Another item of interest is that the location of the aurora usually changes geomagnetic latitude as the intensity of the geomagnetic storm changes. The location of the aurora often takes on an ‘oval-like’ shape and is appropriately called the auroral oval.*

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

Figure 6-1 K-Index for 5-7 March 2016

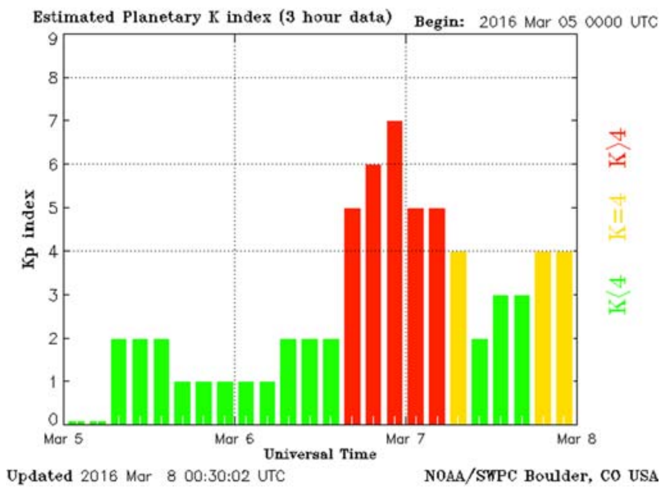


Figure 6-2 K-Index for 16-18 February 2016

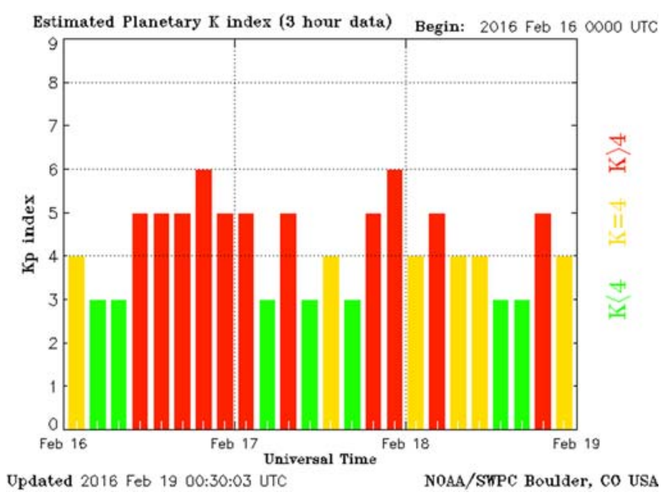


Figure 6-3 K-Index for 15-17 Marc 2016

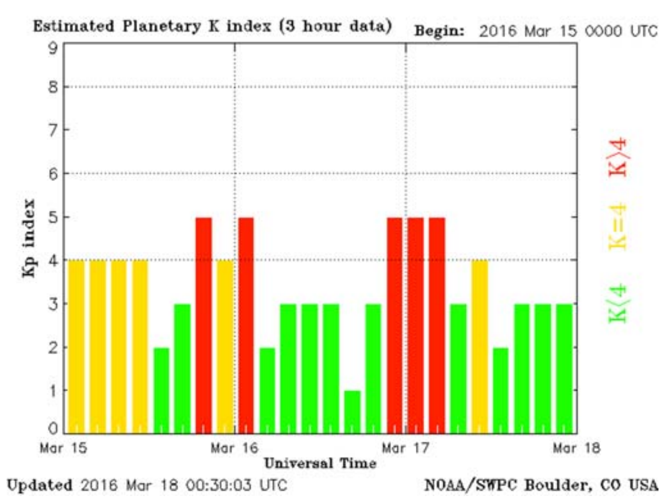


Table 6-1 shows the position accuracy information for the quarter's worst-case storm day, March 6, 2016 (see Figure 6-1). The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for March 6, 2016

Site	95% Horizontal (Meters)	95% Vertical (Meters)	Maximum Horizontal (Meters)	Maximum Vertical (Meters)
Albuquerque	1.669	9.127	2.327	11.114
Anchorage	3.430	3.901	4.724	6.306
Atlanta	1.680	7.702	2.005	9.082
Barrow	3.026	4.187	5.710	10.759
Bethel	2.289	3.112	4.065	4.346
Billings	2.487	8.708	2.877	11.316
Boston	4.452	8.072	6.565	9.614
Cleveland	2.762	7.892	3.537	9.656
Cold Bay	2.724	3.563	3.893	6.260
Fairbanks	2.346	3.216	6.158	10.745
Gander	5.977	6.249	8.042	7.492
Honolulu	5.415	5.635	6.037	8.661
Houston	1.503	8.121	2.155	9.566
Iqaluit	4.418	6.310	6.135	10.577
Juneau	4.237	7.124	5.459	10.410
Kansas City	2.112	9.647	2.619	11.943
Kotzebue	2.011	3.116	4.236	6.538
Los Angeles	2.035	8.646	2.504	10.059
Merida	1.903	7.347	2.209	10.009
Miami	1.744	6.664	2.599	8.436
Minneapolis	3.971	9.103	5.765	12.127
Oakland	2.232	8.649	3.105	9.554
Salt Lake City	1.896	8.897	2.772	11.164
San Jose Del Cabo	2.060	7.988	2.938	9.204
San Juan	5.440	7.968	7.402	10.167
Seattle	3.032	7.267	4.097	9.858
Tapachula	2.263	7.902	3.340	9.983
Washington, DC	2.076	7.533	2.364	9.001

7 IGS Data

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

Sites with high data rate (1 Hz) with good availability which are outside of the WAAS service area that also provide a good geographic distribution have been selected. The Ecuadorian site, GLPS, and the 3 Russian Federation sites, MOBN, NRIL, and PETS, were not in service. To facilitate differentiating between GPS accuracy issues and receiver tracking problems, an automatic data screening function excluded errors greater than 500 meters and or times when VDOP or HDOP were greater than 10. The remaining receiver tracking issues are still included in the processing and are forced into the 50.1 meter histogram bin. These issues cause the outliers seen in the 99.99% statistics and are visible in the 95% accuracy trend plots.

High quality broadcast navigation data and Klobuchar model data is created by voting across all available IGS high rate RINEX navigation data. Some manual review may be necessary to recover missing navigation data where the number of IGS sites reporting navigation data was below the voting threshold (i.e. 4).

Table 7.1 and Figure 7-1 show the IGS site information and locations. The Russian Federation sites and Ecuador's site were unavailable for this reporting period. Table 7.2 shows the GPS SPS Accuracy Performance observed at a selection of High Rate IGS sites. Figure 7-2 shows the 95% horizontal accuracy trends at these sites. Figure 7-3 shows the 95% vertical accuracy trends at these sites. A value of zero indicates no data. The ramping error in the trend plots for the equatorial sites is due to seasonal variations in the ionosphere that cannot be corrected by the Klobuchar thin shell model of the ionosphere utilized by single frequency GPS SPS receivers.

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

Table 7-1 Selected IGS Site Information

ID	City	Country
BOGT	Bogota	Colombia
GLPS	Puerto Ayora	Ecuador
GUAM	Dededo	Guam
IISC	Bangalore	India
KIRU	Kiruna	Sweden
KOUR	Kourou	French Guyana
MADR	Robledo	Spain
MAL2	Malindi	Kenya
MAS1	Maspalomas	Spain
MATE	Matera	Italy
MOBN*	Obninsk	Russian Federation
NNOR	New Norcia	Australia
NRIL*	Norilsk	Russian Federation
PETS*	Petropavlovsk-Kamchatka	Russian Federation
POL2	Bishkek	Kyrgyzstan
SUTM	Sutherland	South Africa
TIDB	Tidbinbilla	Australia
UNSA	Salta	Argentina
USUD	Usuda	Japan

Figure 7-1 Selected IGS Site Locations

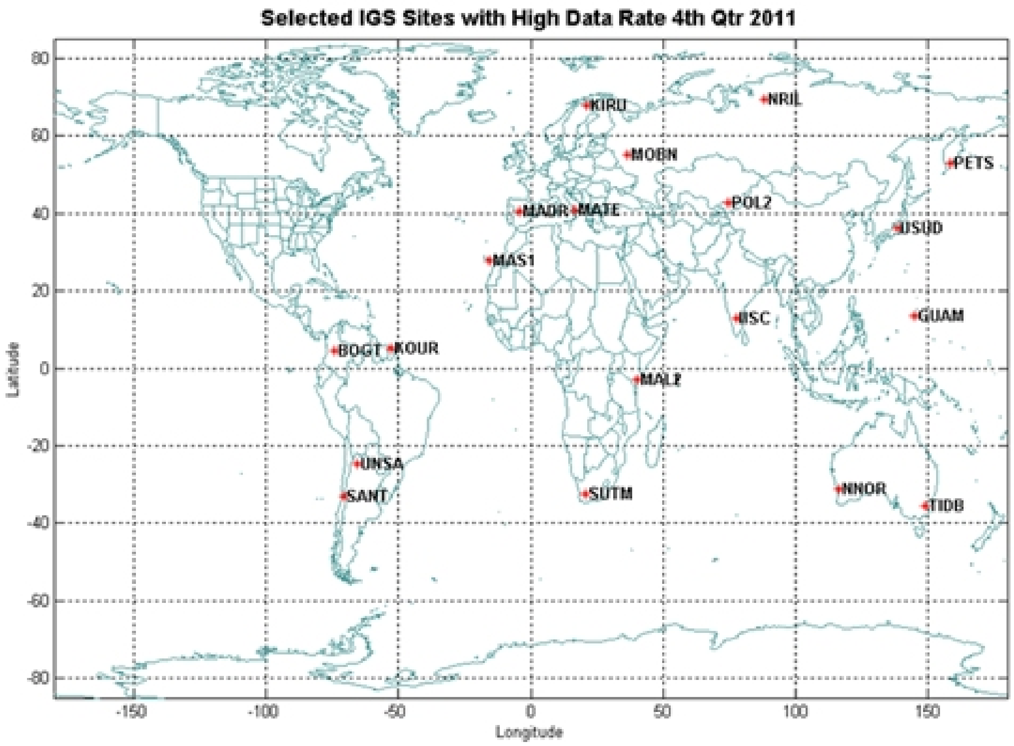


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

Site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
BOGT	5.74	6.63	15.77	16.17	97.62%
GLPS	-	-	-	-	-
GUAM	2.32	4.84	4.59	19.18	99.18%
IISC	2.57	4.91	6.64	11.78	96.31%
KIRU	1.67	4.09	5.22	7.98	99.99%
KOUR	4.08	5.77	8.27	14.35	99.99%
MADR	1.9	3.56	5.7	7.42	99.99%
MAL2	3.25	4.21	8.07	8.48	89.81%
MAS1	7.58	5.31	11.76	14.14	99.97%
MATE	1.85	4.01	5.1	8.09	36.07%
MOBN	--	--	--	--	--
NNOR	1.87	3.66	4.38	9.11	99.96%
NRIL	--	--	--	--	--
PETS	--	--	--	--	--
POL2	1.98	4.79	12.52	17.89	87.19%
SANT	5.27	4.82	10.8	12.91	90.00%
SUTM	1.93	3.46	4.39	7.22	98.33%
TIDB	1.89	4.08	9.09	13.4	98.91%
UNSA	4.38	4.89	8.65	15.06	75.55%
USUD	2.7	4.64	8.75	18.25	95.66%

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

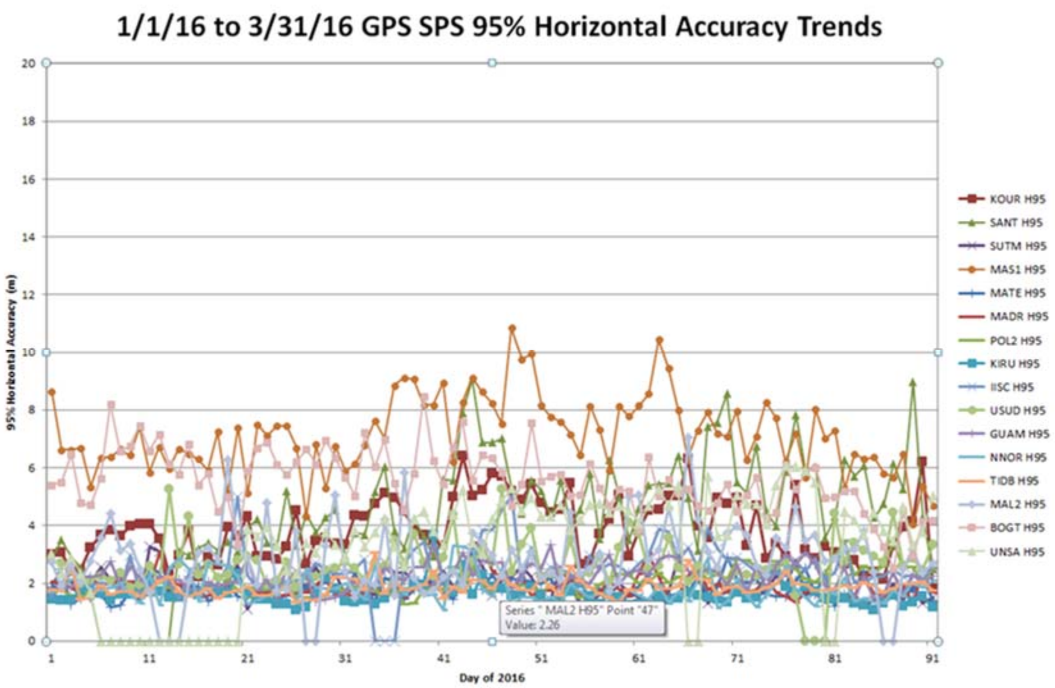
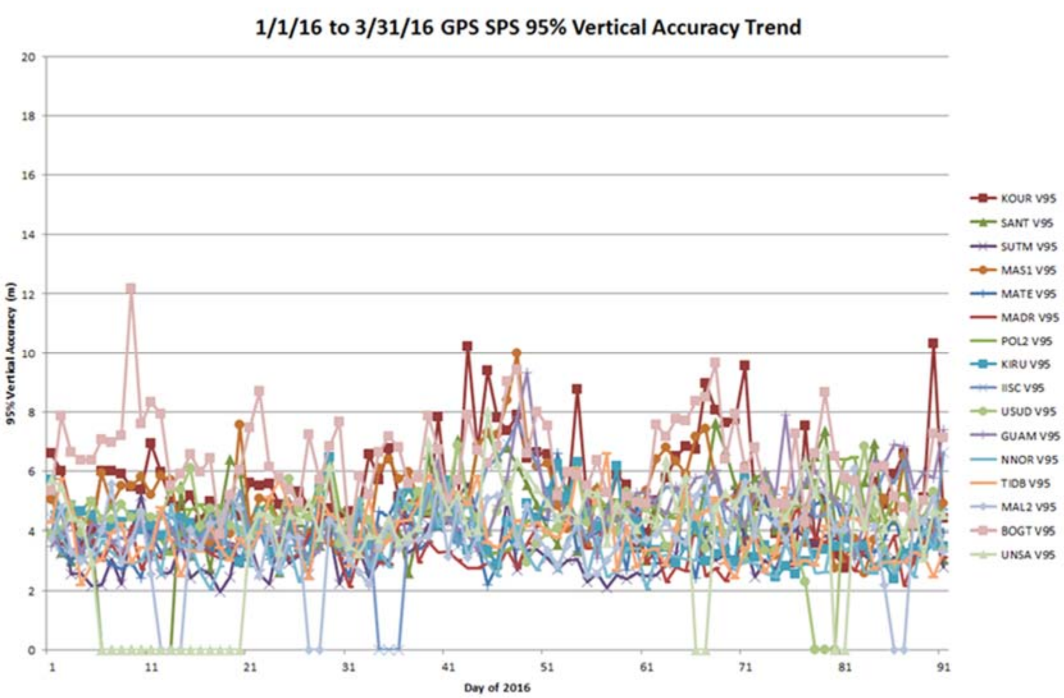


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites



8 RAIM Performance

Receiver autonomous integrity monitoring (RAIM) is a technology developed to assess the integrity of GPS signals in a GPS receiver system. It is especially important in safety critical GPS applications, such as aviation. In order for a GPS receiver to perform RAIM or fault detection (FD) function, a minimum of five visible satellites with satisfactory geometry must be visible. RAIM has various kinds of implementations; one of them performs consistency checks between all position solutions obtained with various subsets of the visible satellites. The receiver provides an alert to the pilot if the consistency checks fail.

Availability is a performance indicator of the RAIM algorithm. Availability is a function of the geometry of the constellation in view and of other environmental conditions. All the analysis performed here is utilizing the "Fault-Detection with no baro-aiding and SA off" RAIM implementation. Additional modes will be assessed at a future date. The test statistic used is a function of the pseudorange measurement residual (the difference between the expected measurement and the observed measurement) and the amount of redundancy. The test statistic is compared with a threshold value, and is determined based on the requirements for the probability of false alarm (Pfa), the probability of missed detection (Pmd), and the expected measurement noise. In aviation systems, the Pfa is fixed at 1/15000.

The horizontal protection limit (HPL) is a figure which represents the radius of a circle in the horizontal plane, centered on the GPS position solution, and is guaranteed to contain the true position of the receiver to within the specifications of the RAIM scheme (i.e. meets the Pfa and Pmd). The HPL is calculated as a function of the RAIM threshold and the satellite geometry at the time of the measurement. The HPL is compared with the horizontal alarm limit (HAL) to determine if RAIM is available. The RNP values shown here are measured in nautical miles, the computed HPL must be less than the RNP value for the service to be available.

8.1 Site Performance

Table 8-1 shows the RAIM performance for the twenty-eight sites evaluated. For all sites collected, the minimum percent of time in RNP 0.1 mode was 99.70% at Los Angeles, California. The minimum percent of time spent in RNP 0.3 mode was 99.99% at three locations (Tapachula, Mexico – Oakland, CA – Seattle, WA). The maximum 99% HPL value was 145.96 meters at Los Angeles, California.

Table 8-1 RAIM Site Statistics

CITY	99% HPL	Percent RNP 0.1	Percent RNP 0.3
Albuquerque	104.693	99.99	100
Anchorage	130.869	99.99	100
Atlanta	106.197	99.88	99.99
Barrow	114.757	100.00	100
Bethel	145.594	99.98	100
Billings	114.238	99.86	100
Boston	111.244	99.96	100
Cleveland	107.542	100.00	100
Cold Bay	114.192	99.99	100
Fairbanks	124.571	99.87	100
Gander	130.991	99.97	99.99
Honolulu	133.192	100	100
Houston	93.709	100	100
Iqaluit	149.672	99.99	100
Juneau	125.771	99.83	100
Kansas City	104.377	99.96	100
Kotzebue	142.307	99.99	100
Los Angeles	99.023	99.95	100
Merida	72.867	99.99	100
Miami	107.739	99.99	100
Minneapolis	119.04	100	100
Oakland	104.18	99.99	100
Salt Lake City	112.486	99.98	100
San Jose Del Cabo	85.083	99.99	100
San Juan	83.442	99.99	100
Seattle	113.901	100	100
Tapachula	90.636	99.98	100
Washington DC	105.714	99.98	100

8.2 RAIM Coverage

Figures 8-1 through 8-2 show the world wide RAIM coverage for both RNP 0.1 and RNP 0.3 respectively. Figures 8-3 through 8-4 show the daily RAIM coverage trends between 1 January and 31 March 2016.

Figure 8-1 RAIM RNP 0.1 Coverage

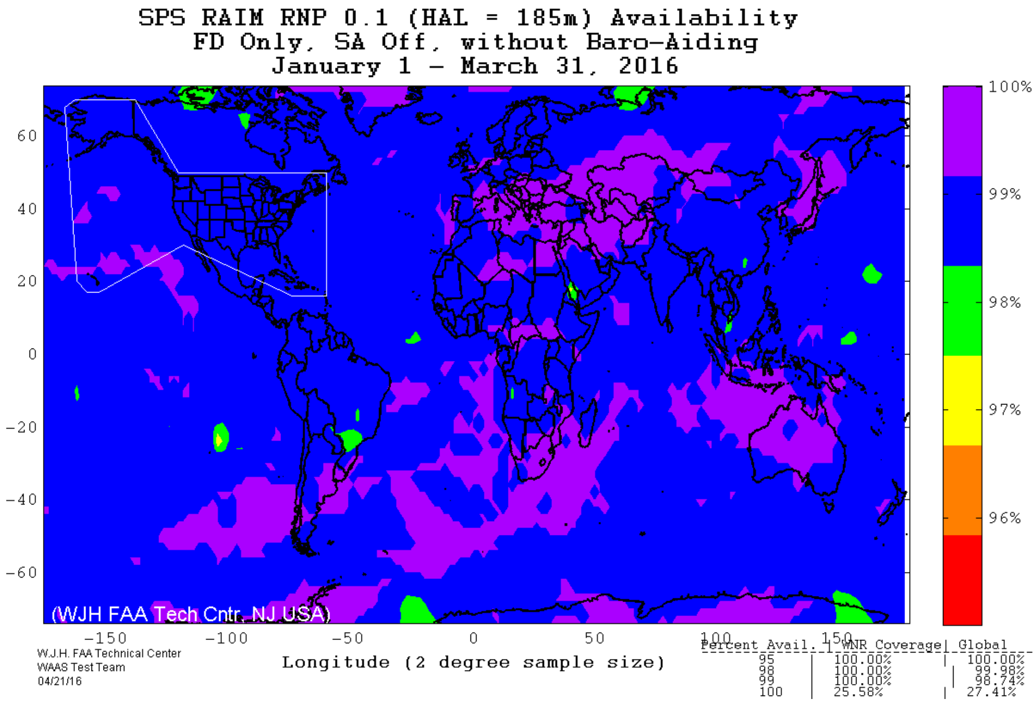


Figure 8-2 RAIM RNP 0.3 Coverage

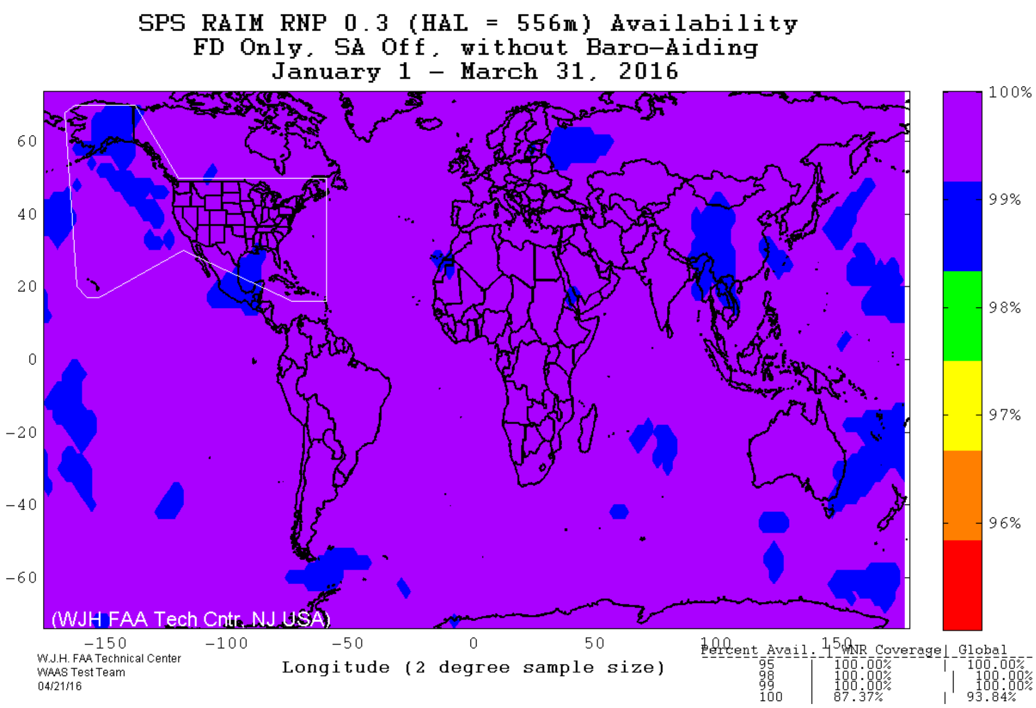


Figure 8-3 RAIM World Wide Coverage Trend

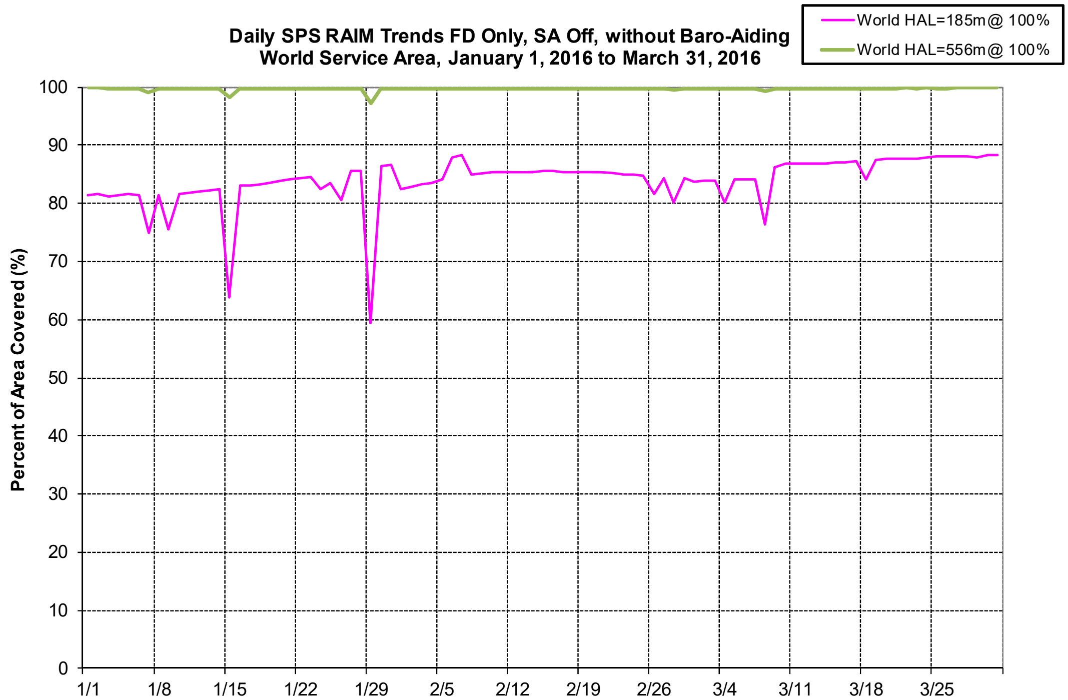
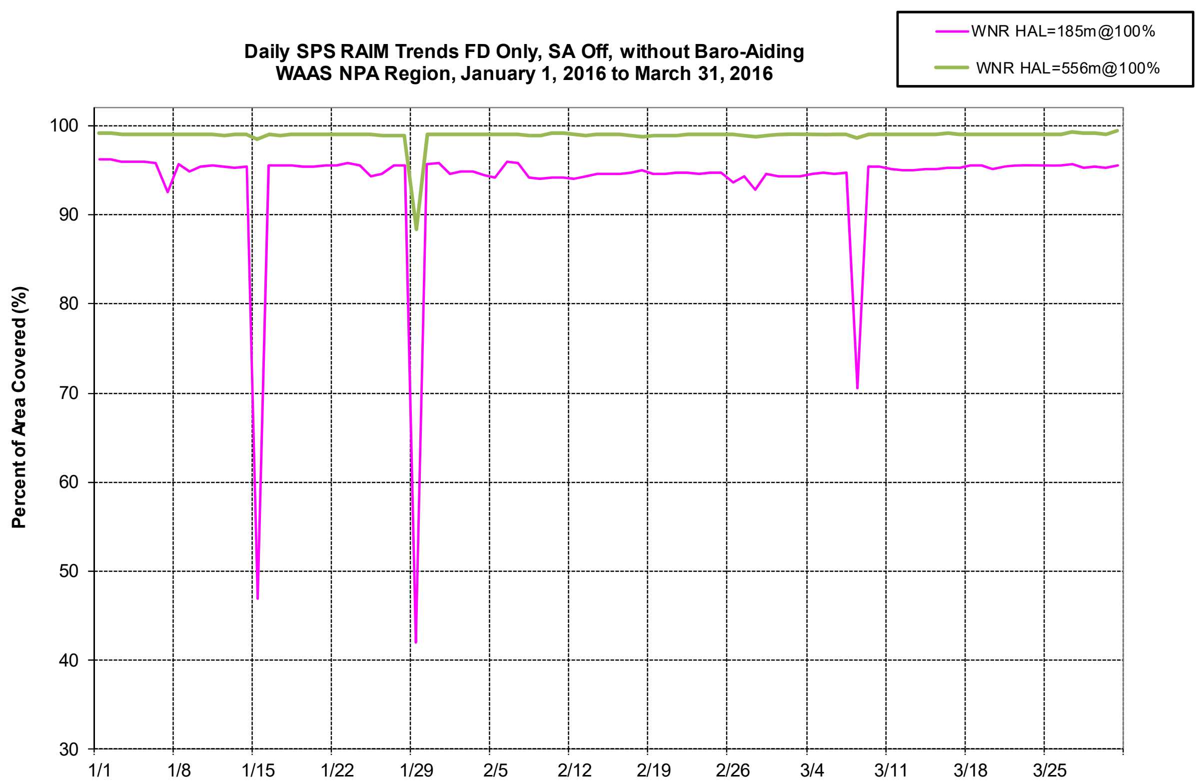


Figure 8-4 RAIM RNP Coverage Trend for WAAS NPA Service Area



8.3 RAIM Airport Analysis

Figures 8-5 and 8-6 shows RAIM RNP 0.1 and RNP 0.3 availability at all U.S. and Canadian airports that have an RNAV (GPS) published approach or better.

Figure 8-5 RAIM RNP 0.1 Airport Availability

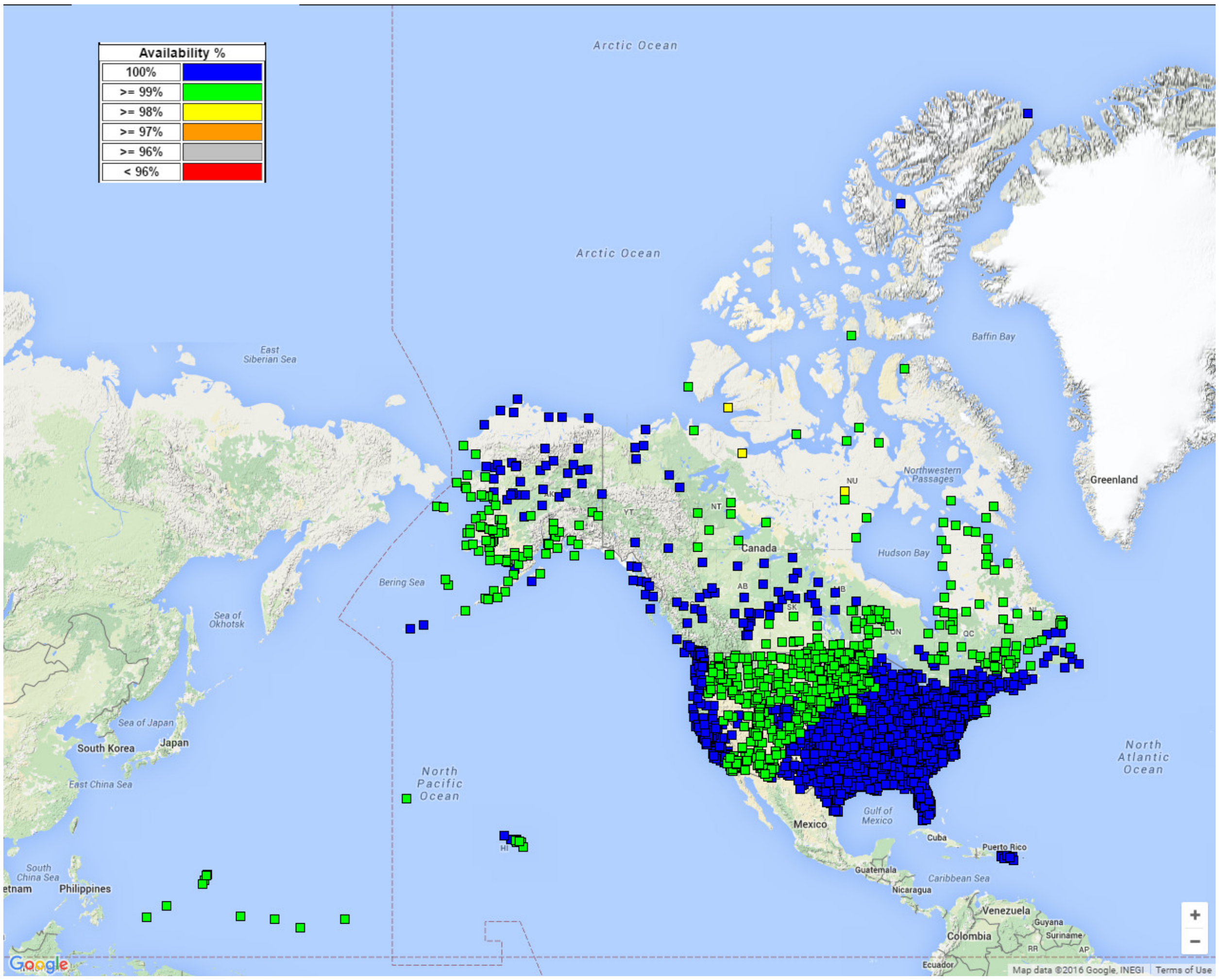
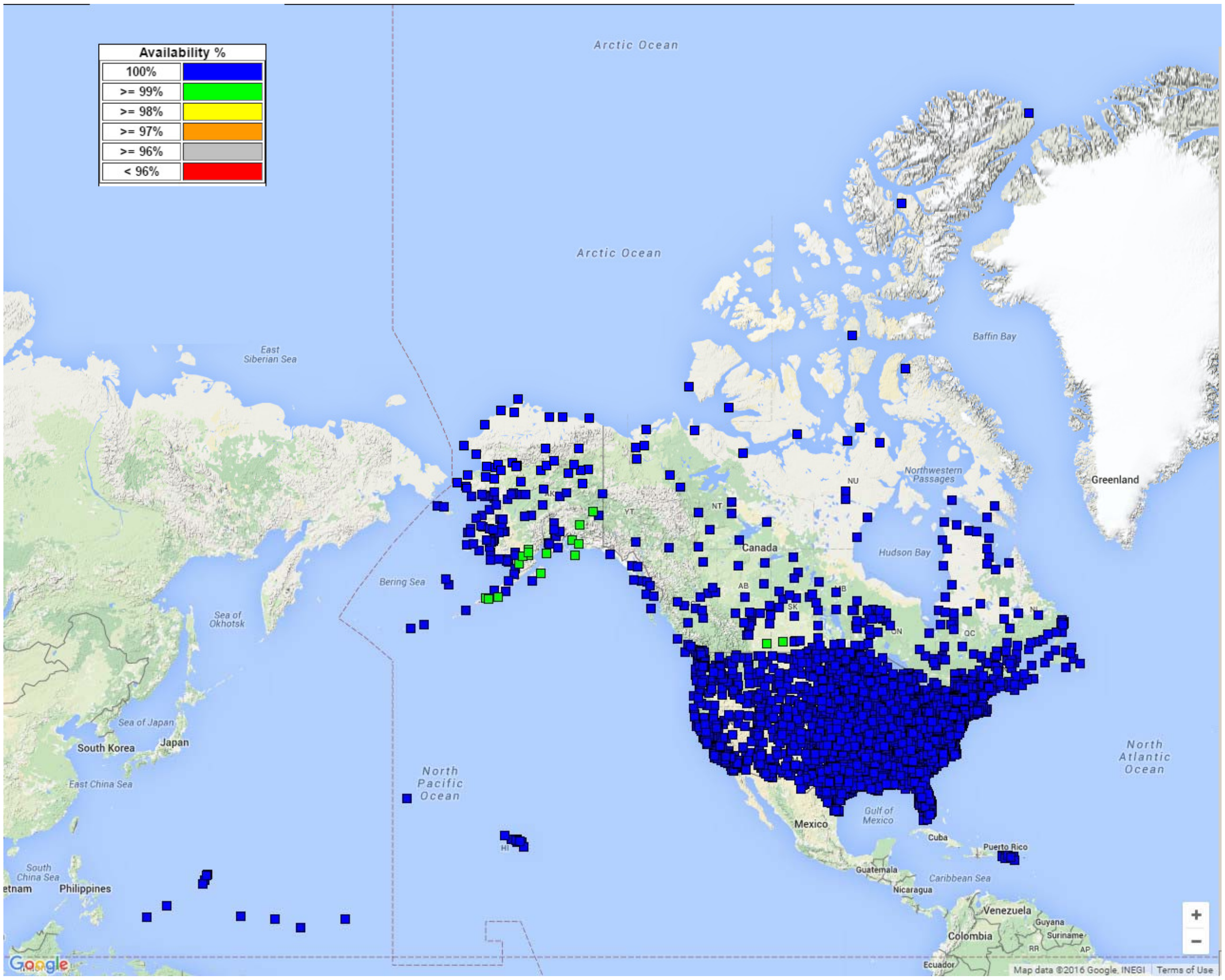


Figure 8-6 RAIM RNP 0.3 Airport Availability



Figures 8-7 and 8-8 respectively show the number of RAIM RNP 0.1 and RAIM RNP 0.3 outages for every airport in the U.S. and Canada that have a RNAV (GPS) published approach or better.

Figure 8-7 RAIM RNP 0.1 Airport Outages

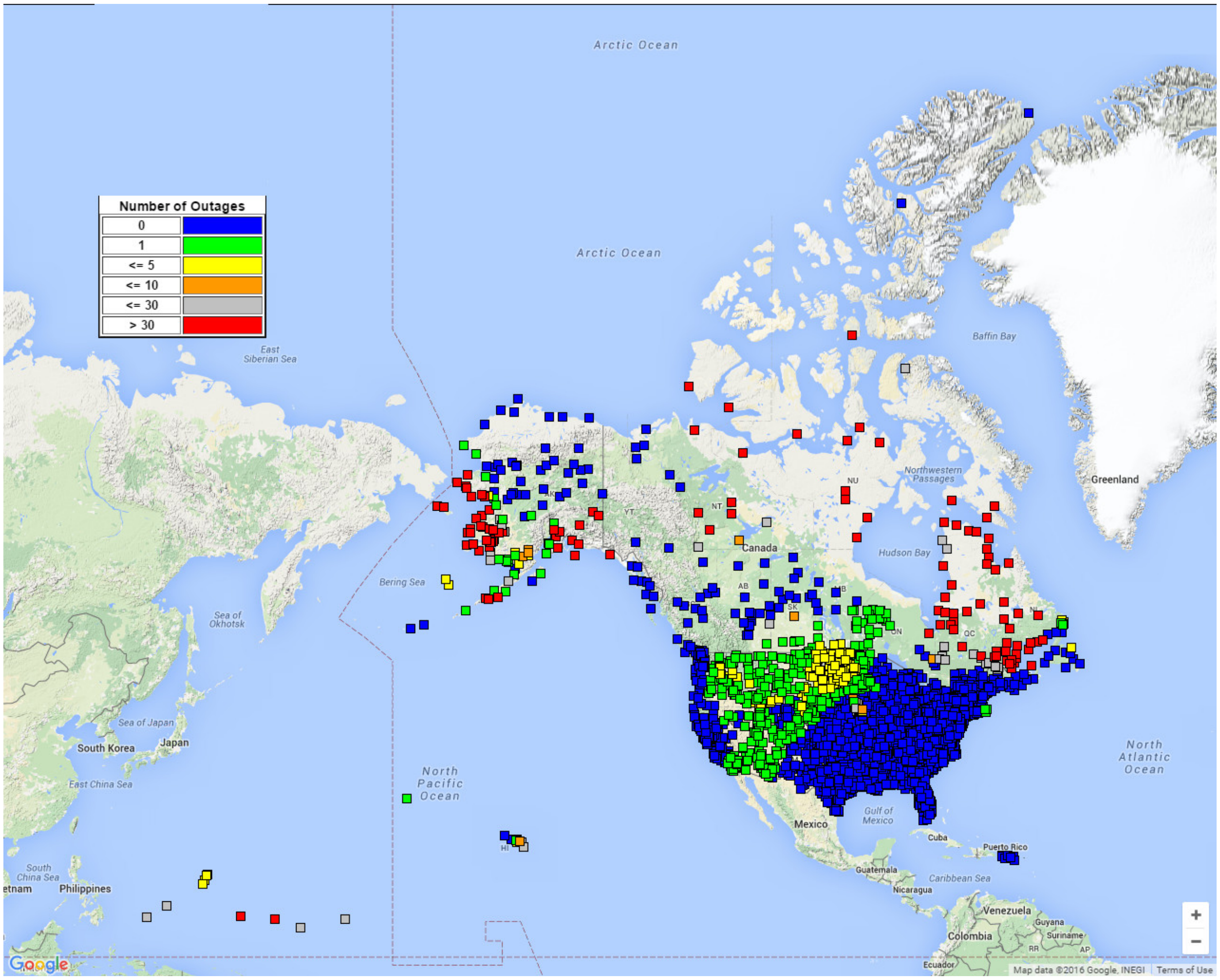
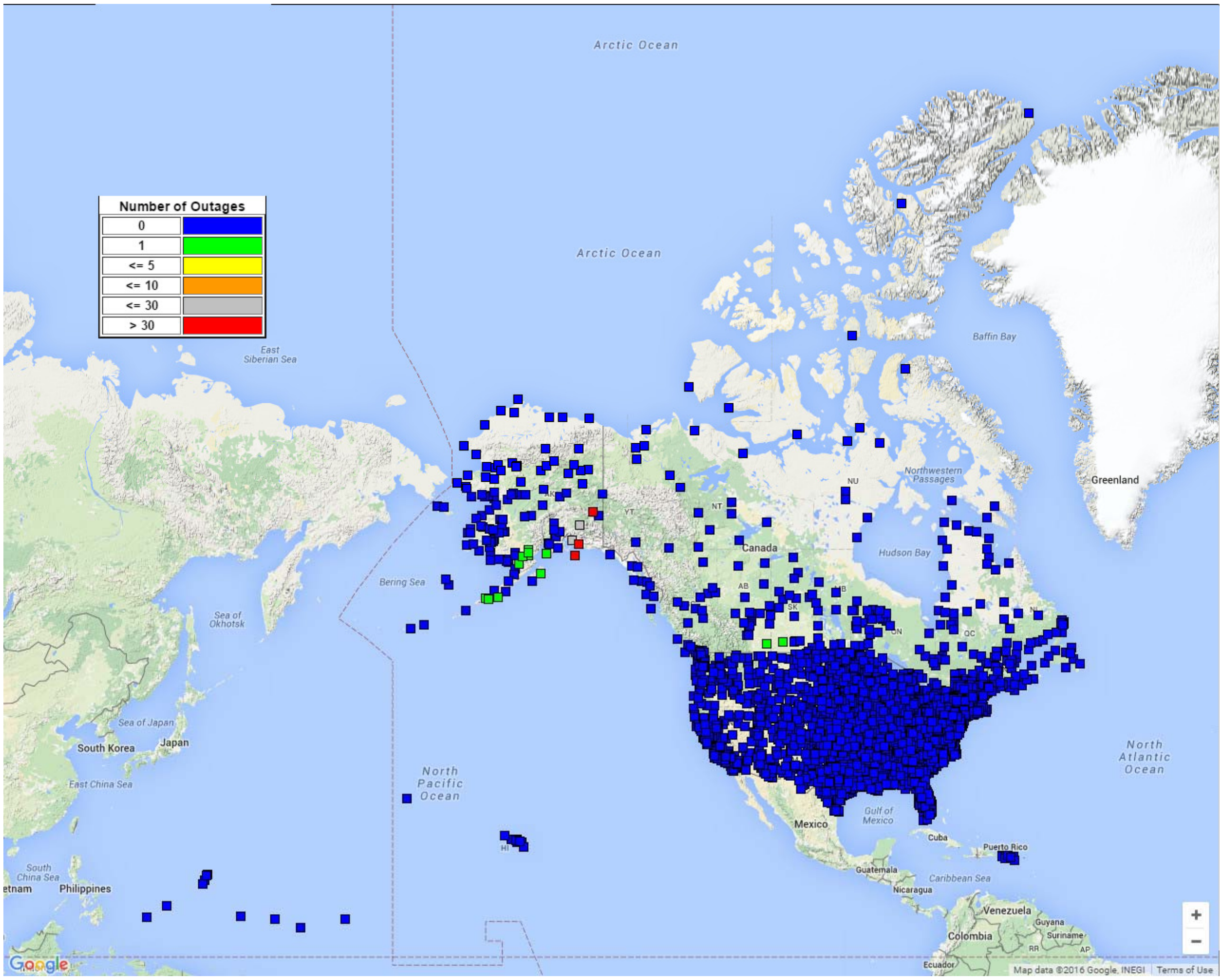


Figure 8-8 RAIM RNP 0.3 Airport Outages



9 GPS Test NOTAMs Summary

GPS test NOTAM: Global Positioning System test Notices to Airmen - GPS test NOTAMs are issued in the event that GPS is predicted to be unreliable and/or unavailable at a defined location for specific times, as indicated in the NOTAM, due to scheduled testing events.

Status and Problem Reporting	Conditions and Constraints
Scheduled event affecting service • Appropriate GPS Test NOTAM issued to the FAA at least 5 hours prior to the event	• For any SPS SIS

9.1 GPS Test NOTAMs Issued

GPS test NOTAMs were tracked and trended from GPS test NOTAMs posted on the FAA Pilot Web website (https://pilotweb.nas.faa.gov/PilotWeb/). During this reporting period, 1 January through 31 March 2016, there were a total of 35 GPS test NOTAMs. The total number of days affected in this reporting period is 47. Tables 8.1 and 8.2 below list the statistics of areas affected and durations. Note that the minimum, average, and maximum durations are on a per GPS test NOTAM basis.

Table 9-1 GPS test NOTAM Durations

Cumulative Duration	101.47 hours
Minimum Duration	0.98 hours
Media Duration	2.50 hours
Average Duration	3.90 hours
Maximum Duration	10.50 hours

Table 9-2 GPS Test NOTAM Affected Areas (Square Miles) by Altitude

	40,000 feet	25,000 feet	10,000 feet	4,000 feet	50 feet
Minimum	195,909	130,341	47,632	45,868	44,999
Average	649,388	556,700	360,097	342,210	235,265
Maximum	1,142,343	1,015,285	794,506	682,408	557,309

9.2 Tracking and Trending of GPS Test NOTAMs

The GPS Test NOTAMs that are tracked and trended for this reporting period were done with a specialized software analysis tool that is designed to not only trend but also archive GPS Test NOTAMs. It is designed to trend archived GPS Test NOTAMs for any specified time frame. In addition to the data provided in this report, this tool will provide all data presented here along with airports with affected procedures via a web interface. The web interface is available at the following URL: http://waas.faa.gov/static/sog/notam/index.html.

The five plots below illustrate a visual depiction of the affected areas at their corresponding altitudes along with the impacted RNAV routes (indicated in red). Note that some GPS Test NOTAMs occupy the same area and position but differ in effective dates and/or durations.

Figure 9-1 GPS Test NOTAMs @ FL400

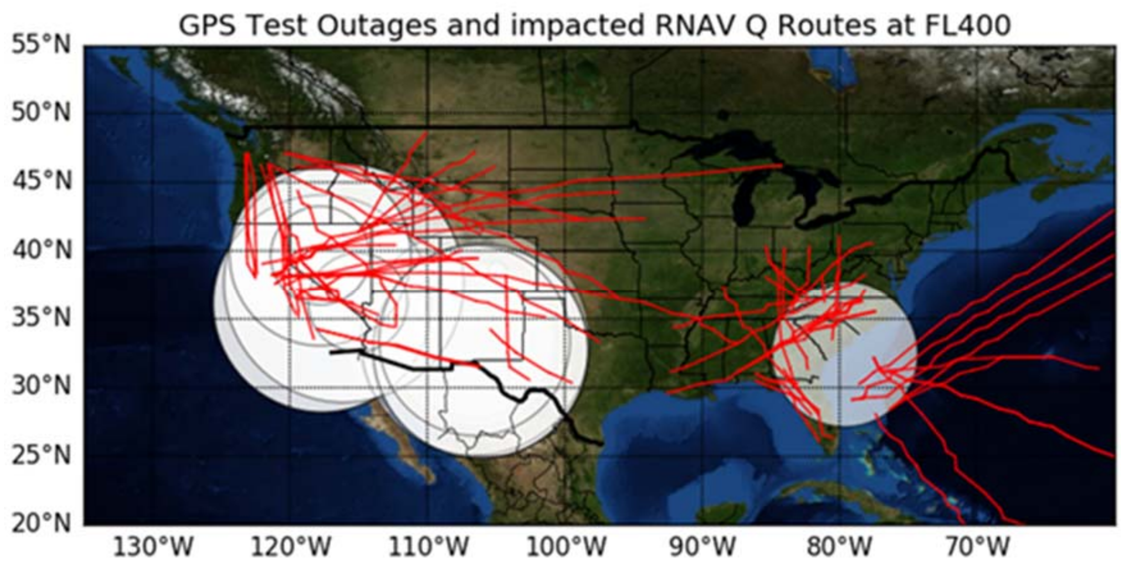


Figure 9-2 GPS NOTAMs @ FL250

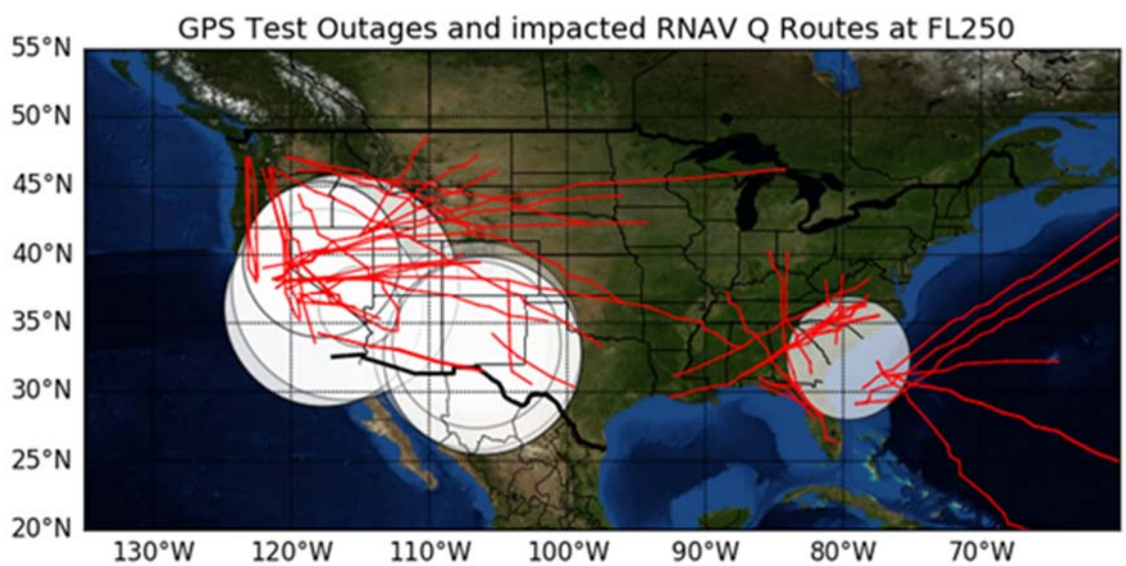


Figure 9-3 GPS NOTAMs @ 10k Feet

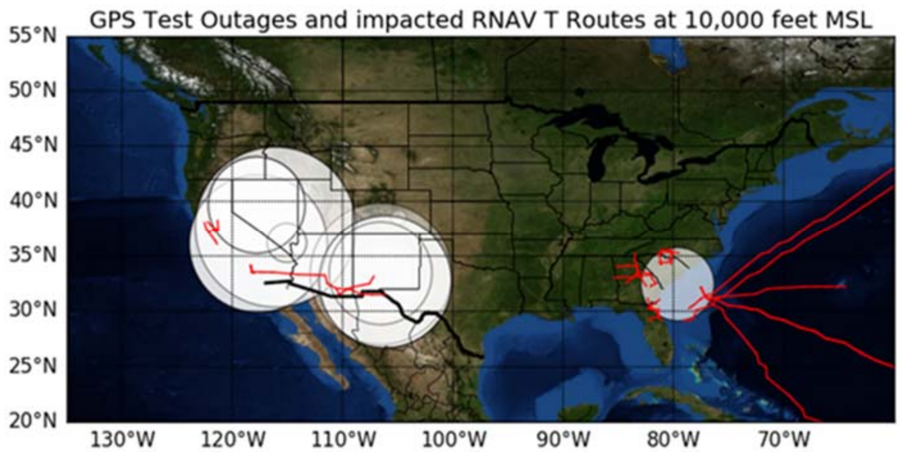


Figure 9-4 GPS NOTAMs @ 4k Feet

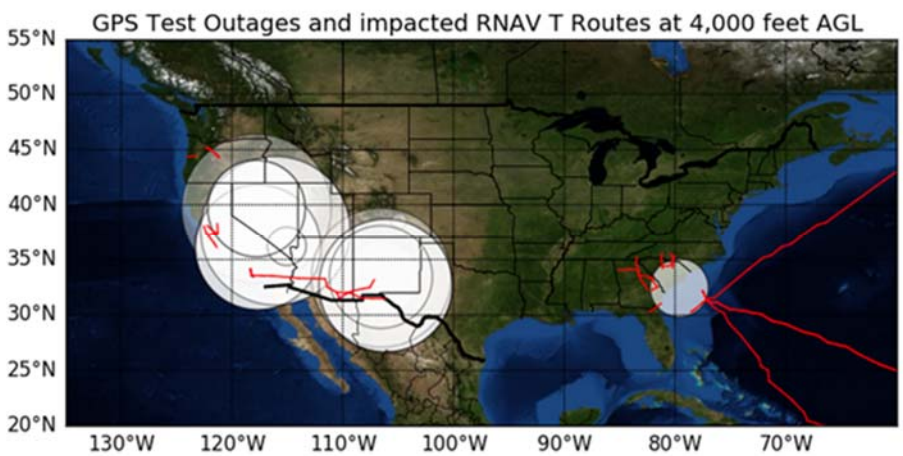
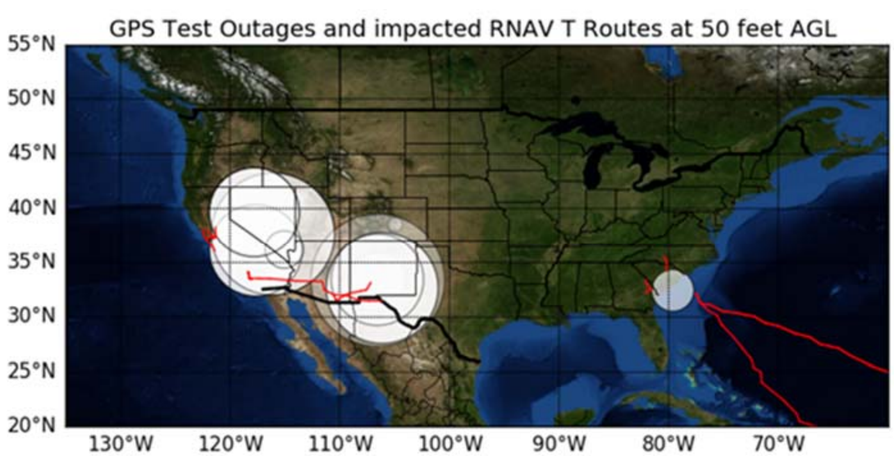


Figure 9-5 GPS NOTAMs @ 50 Feet



9.3 GPS Availability

The impacts to GPS availability are listed below for the corresponding locations and times. The percent impact to GPS availability over CONUS indicates that GPS is impacted for X % of the total area (total area of CONUS), centered at the indicated latitude/longitude. The last five columns in each table represent the impact to GPS availability at the corresponding altitude range. Altitudes 4,000 feet and under are with respect to above ground level (AGL), all remaining altitudes are with respect to MSL (mean sea level). Each row of the following table represents one GPS Test NOTAM. The remaining tables each represent one GPS Test NOTAM.

Table 9-3 NOTAM Impact to GPS Availability

					Percent Impact at Each Site			
START DATE	**END DATE**	**LAT**	**LONG**	**50**	**4000**	**10000**	**FL250**	**FL400**
2016-01-12 05:30:00	2016-01-15 13:00:00	331058N	1063418W	2.68	4.23	5.47	8.77	11.66
2016-01-26 17:30:00	2016-01-26 20:00:00	360822N	1173846W	6.30	10.01	11.56	14.55	16.62
2016-01-27 05:30:00	2016-01-30 08:00:00	373832N	1160400W	12.28	16.51	18.16	21.88	23.74
2016-01-27 07:30:00	2016-01-29 09:00:00	361304N	1150307W	1.14	1.24	1.24	3.51	5.16
2016-01-27 17:30:00	2016-01-27 20:30:00	360822N	1173846W	6.30	10.01	11.56	14.55	16.62
2016-01-29 21:00:00	2016-01-29 23:59:00	393835N	1174702W	7.22	8.05	7.84	12.80	15.89
2016-01-30 00:01:00	2016-01-30 01:00:00	393835N	1174702W	7.22	8.05	7.84	12.80	15.89
2016-02-02 03:00:00	2016-02-06 05:00:00	361304N	1150307W	1.14	1.24	1.24	3.51	5.16
2016-02-02 07:30:00	2016-02-06 11:00:00	361304N	1150307W	1.14	1.24	1.24	3.51	5.16
2016-02-02 17:30:00	2016-02-02 18:30:00	393835N	1174702W	7.22	8.05	7.84	12.80	5.37
2016-02-02 21:30:00	2016-02-02 23:00:00	393835N	1174702W	7.22	8.05	7.84	12.80	5.37
2016-02-03 05:30:00	2016-02-03 08:00:00	373832N	1160400W	12.28	16.51	18.16	21.88	23.74
2016-02-10 05:30:00	2016-02-12 08:00:00	332339N	1063058W	12.18	12.69	13.11	17.23	20.74
2016-02-10 05:30:00	2016-02-12 08:00:00	373832N	1160400W	12.28	16.51	18.16	21.88	23.74
2016-02-10 23:00:00	2016-02-11 00:30:00	393835N	1174702W	7.22	16.62	7.84	12.80	15.89
2016-02-16 04:30:00	2016-02-21 13:30:00	332659N	1063329W	6.60	7.74	7.84	12.18	15.07
2016-03-08 07:30:00	2016-03-12 13:30:00	324029N	1060700W	8.26	11.04	11.04	15.07	17.54
2016-03-10 05:30:00	2016-03-12 07:30:00	332812N	1062535W	2.06	4.13	3.30	8.98	10.73
2016-03-15 16:30:00	2016-03-16 18:30:00	360822N	1173846W	6.30	10.01	11.56	14.55	16.62
2016-03-21 11:00:00	2016-03-21 19:00:00	322655N	793719W	1.03	1.86	2.89	5.06	7.22

					Percent Impact at Each Site			
START DATE	**END DATE**	**LAT**	**LONG**	**50**	**4000**	**10000**	**FL250**	**FL400**
2016-03-21 17:30:00	2016-03-25 23:30:00	383140N	1045437W	0.21	0.21	0.21	0.21	0.21
2016-03-22 03:00:00	2016-03-23 13:30:00	324029N	1060700W	8.26	11.04	11.04	15.07	17.54
2016-03-24 05:30:00	2016-03-26 13:30:00	324029N	1060700W	8.26	11.04	11.04	15.07	17.54
2016-03-29 16:30:00	2016-03-30 18:30:00	360822N	1173846W	6.30	10.01	11.56	14.55	16.62
2016-03-30 11:00:00	2016-03-31 17:00:00	322655N	793719W	1.03	1.86	2.89	5.06	7.22
2016-03-30 18:30:00	2016-03-30 22:30:00	324029N	1060700W	8.26	11.04	11.04	15.07	17.54

10 Appendices

10.1 Appendix A: Performance Summary

Table 10-1 Performance Summary

User Range Error Accuracy	**Conditions and Constraints**	**Measured Performance**
Single Frequency C/A-Code • ≤ 7.8m 95% Global Average URE during normal operations over All AODs • ≤ 6.0m 95% Global Average URE during operations at Zero AOD • ≤ 12.8m 95% Global Average URE during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1	≤ 3.135 m N/A N/A
Single Frequency C/A-Code • ≤ 30m 99.94% Global Average URE during normal operations • ≤ 30m 99.79% Worst Case single point average during normal operations.	• For any healthy SPS SIS. • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 • Standard based on measurement interval of one year; average of daily values within service volume • Standard based on 3 service failures per year, lasting no more than 6 hours each	100% Global 100% WCP
User Range Rate Error Accuracy	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	≤ 2.820 mm/sec
User Range Acceleration Error Accuracy	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 2 mm/sec^2 95% Global average URAE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	≤ 0.021 mm/s^2

Per-Satellite Coverage	Conditions and Constraints	Measured Performance
Terrestrial Service Volume: • 100% Coverage	• For any health or marginal SPS SIS	100%
Constellation Coverage	**Conditions and Constraints**	
Terrestrial Service Volume: • 100% Coverage	• For any health or marginal SPS SIS	100%
Status and Problem Reporting	**Conditions and Constraints**	
Scheduled event affecting service • Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	• For any SPS SIS	≥ 45.217 hours Prior to event
Unscheduled outage or problem affecting service • Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	• For any SPS SIS	≤ 0.717 hours After event
Unscheduled Failure Interruption Continuity • ≥ 0.9998 Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption.	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Given that the SPS SIS is available from the slot at the start of the hour.	100%
Operational Satellite Count	**Conditions and Constraints**	
• ≥ 0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not	• Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operation satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not.	100%
PDOP Availability	**Conditions and Constraints**	
• ≥ 98% global PDOP of 6 or less • ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval	100 % 100 %
Service Availability	**Conditions and Constraints**	
• ≥ 99% Horizontal Service Availability, average location • ≥ 99% Vertical Service Availability, average location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	100% Horizontal 100% Vertical
• ≥ 90% Horizontal Service Availability, worst-case location • ≥ 90% Vertical Service Availability, worst-case location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	100% Horizontal 100% Vertical

Position/Time Accuracy	Conditions and Constraints	
Global Average Position Domain Accuracy • ≤ 9m 95% Horizontal Error • ≤ 15m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 2.297 m Horizontal ≤ 4.070 m Vertical
Worst Site Position Domain Accuracy • ≤ 17m 95% Horizontal Error • ≤ 37m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 6.485 m Horiz. ≤ 4.884 m Vert.
Time Transfer Domain Accuracy • ≤ 40 nanoseconds time transfer error 95% of time (SIS only)	• Defined for a time transfer solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 10 nanoseconds
Instantaneous UTCOE Integrity • NTE ±120 nanoseconds 99.999% of time without a timely alert (SIS only)	• For any healthy SPS SIS • Worst case for delayed alert is 6 hours	≤ 55 nanoseconds

Per-Slot Availability	Conditions and Constraints	
• ≥ 0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS • ≥ 0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a healthy SPS SIS	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard.	100% 100%

Constellation Availability	Conditions and Constraints	
• ≥ 0.98 Probability that at least 21 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration • ≥ 0.99999 Probability that at least 20 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration	• Calculated as an average over all slots in the 24-slot constellation, normalized annually. • Applies to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.	100% 100%

10.2 Appendix B: Geomagnetic Data

Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center

Current Quarter Daily Geomagnetic Data

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2016 01 01	17	5 4 4 3 1 2 2 1	33	5 5 6 5 3 2 2 2	27	6 5 5 3 2 1 2 2
2016 01 02	6	2 2 2 2 2 2 1 1	15	2 2 3 5 3 3 2 1	10	3 2 3 2 2 2 2 2
2016 01 03	5	0 1 2 1 2 2 1 2	5	0 0 2 2 3 2 0 1	7	1 2 2 1 2 2 1 3
2016 01 04	4	0 1 2 0 2 2 2 0	3	1 1 2 0 1 1 1 0	5	1 2 2 0 1 2 2 1
2016 01 05	5	1 1 1 2 1 2 2 1	3	0 1 0 1 0 2 1 2	7	1 1 1 2 1 2 3 2
2016 01 06	12	4 2 2 3 2 2 2 3	27	2 2 6 6 3 3 1 2	17	5 3 3 3 3 2 3 4
2016 01 07	11	4 2 2 3 3 2 2 0	22	2 2 3 6 4 4 2 1	14	4 3 3 4 3 3 2 1
2016 01 08	6	1 2 1 2 3 2 1 1	20	1 1 3 6 5 2 1 0	8	1 3 2 2 3 1 1 2
2016 01 09	5	1 2 1 1 2 1 2 1	7	1 0 2 4 3 1 1 0	6	2 1 2 1 2 1 2 1
2016 01 10	7	1 2 1 2 3 2 2 1	11	1 0 3 4 4 2 1 1	7	2 2 1 2 2 1 2 2
2016 01 11	9	1 2 2 2 2 2 3 3	14	1 1 3 2 3 4 4 3	14	2 3 3 2 2 3 4 4
2016 01 12	10	3 2 3 2 2 3 2 2	17	3 2 3 3 5 2 3 3	15	4 3 3 2 2 2 3 3
2016 01 13	11	3 4 2 2 2 2 3 1	16	4 3 3 3 4 3 2 1	14	4 4 2 2 2 2 3 2
2016 01 14	6	1 1 2 2 2 2 1 2	19	1 1 5 5 4 3 1 1	8	2 2 3 2 2 2 2 3
2016 01 15	4	2 2 1 1 0 2 1 1	5	1 1 1 2 3 1 1 1	6	2 2 2 1 1 1 1 1
2016 01 16	3	0 1 1 1 2 1 1 0	2	0 0 1 3 0 0 0 0	4	0 1 1 2 2 0 1 1
2016 01 17	3	0 0 1 0 2 2 1 1	3	0 0 2 1 2 1 0 0	4	0 0 2 1 1 1 1 1
2016 01 18	4	0 0 0 0 1 2 1 3	2	0 0 0 1 2 1 0 1	5	0 0 0 1 1 2 1 3
2016 01 19	7	2 2 3 2 1 2 2 1	9	2 3 3 4 2 0 0 0	11	4 3 3 3 1 1 0 1
2016 01 20	12	0 1 3 3 3 3 3 3	-1	-1-1-1-1-1-1-1-1	25	1 2 4 4 4 5 5 4
2016 01 21	15	-1-1-1-1-1 3 3 3	23	-1-1-1-1-1 4 3 4	32	4 6 5 3 3 4 4 4
2016 01 22	10	3 3 3 2 2 2 2 1	15	3 2 3 4 4 3 2 2	14	4 4 3 3 2 2 3 2
2016 01 23	10	1 3 4 2 3 2 1 1	17	2 3 4 2 5 3 3 1	12	2 3 4 2 3 3 2 1
2016 01 24	9	2 2 1 1 1 3 4 2	12	2 2 2 2 3 4 3 2	11	3 2 2 1 2 3 4 2
2016 01 25	3	1 1 1 0 2 2 1 0	0	0 0 0 1 0 0 0 0	3	1 1 1 1 1 0 0 0
2016 01 26	3	0 0 1 1 2 2 2 0	2	0 0 1 1 1 1 0 0	4	0 1 1 1 1 1 2 1
2016 01 27	3	0 2 1 1 1 1 1 1	1	0 1 1 0 1 0 0 0	5	1 3 1 2 1 1 0 1
2016 01 28	5	1 1 2 2 2 2 1 0	22	0 0 6 6 3 1 0 0	6	1 1 3 3 1 1 1 1
2016 01 29	3	0 0 0 1 2 2 1 1	1	0 0 2 1 0 0 0 0	3	0 1 1 1 1 1 1 1
2016 01 30	3	0 1 1 0 2 2 1 1	1	0 0 1 1 1 0 0 0	3	0 0 1 1 0 1 1 1
2016 01 31	8	1 2 3 2 2 1 1 3	15	0 0 3 4 5 3 2 2	10	2 2 3 2 2 2 2 4
2016 02 01	6	2 3 3 2 0 1 1 0	8	2 3 4 3 0 0 0 0	9	3 3 3 2 0 1 1 0
2016 02 02	4	0 0 1 0 2 1 1 3	5	0 0 0 1 3 3 1 1	6	0 1 2 1 1 2 2 3
2016 02 03	10	4 4 2 1 1 1 1 1	11	4 4 2 3 1 1 1 1	14	4 5 2 1 1 1 1 1
2016 02 04	5	0 1 2 1 3 2 1 1	10	0 0 2 3 5 2 1 1	6	0 1 2 2 3 2 2 1
2016 02 05	8	2 3 2 2 2 2 2 1	18	1 4 2 5 4 3 2 2	12	3 3 3 2 2 2 3 2
2016 02 06	5	1 2 2 1 1 2 1 2	11	2 1 1 5 3 1 1 1	8	2 3 2 2 1 2 2 3
2016 02 07	6	2 0 1 1 2 3 2 2	13	1 0 0 4 3 5 2 1	8	2 1 1 2 2 4 2 2
2016 02 08	11	4 3 4 2 2 1 1 0	21	5 4 5 4 2 2 1 0	17	5 4 4 2 2 1 1 1
2016 02 09	8	2 1 1 3 3 2 1 2	19	1 0 2 6 5 2 1 1	10	2 1 2 4 3 1 1 3
2016 02 10	4	2 1 2 1 1 1 1 1	6	1 1 2 4 2 0 0 0	5	3 2 2 1 1 0 1 1
2016 02 11	8	2 1 2 2 2 2 2 3	16	1 2 3 4 5 3 1 2	11	3 2 2 2 2 2 2 4
2016 02 12	11	4 2 2 3 2 2 2 2	19	3 2 2 5 5 3 2 1	13	4 3 2 4 3 2 2 2
2016 02 13	7	2 3 2 2 2 2 1 1	10	1 2 3 5 1 0 0 1	7	2 3 3 2 1 1 1 1
2016 02 14	6	2 2 2 2 2 2 1 1	16	1 1 4 4 4 4 3 0	10	3 3 3 2 2 3 2 1
2016 02 15	10	2 2 3 2 2 1 1 4	7	1 1 2 3 3 2 0 2	11	2 2 3 2 2 1 1 4
2016 02 16	25	3 3 3 4 5 4 4 4	76	3 3 5 7 7 7 6 4	38	4 3 3 5 5 5 6 5
2016 02 17	21	5 2 4 3 3 3 3 4	48	4 4 5 6 6 5 4 5	34	5 3 5 3 4 3 5 6
2016 02 18	20	4 4 3 4 2 3 4 3	40	3 4 5 6 5 5 5 2	29	4 5 4 4 3 3 5 4
2016 02 19	10	3 3 2 2 2 3 2 2	27	3 2 4 6 4 4 3 3	15	3 3 2 3 3 3 3 3
2016 02 20	5	2 2 2 1 1 1 1 1	7	2 2 4 1 2 2 0 0	6	3 2 2 1 1 1 1 1

2016 02 21	3	1	1	0	0	2	2	1	1	2	1	1	0	0	2	0	1	0	4	1	2	1	0	1	1	2	2
2016 02 22	3	0	1	0	1	2	2	1	1	2	0	0	0	2	1	1	0	0	4	1	0	0	1	1	1	1	1
2016 02 23	5	2	1	1	0	1	2	2	2	2	1	0	0	0	1	1	1	2	6	2	1	1	1	1	1	2	3
2016 02 24	5	2	2	1	1	2	2	1	1	9	2	1	3	3	4	1	1	0	7	3	2	2	1	2	1	1	2
2016 02 25	6	1	2	2	1	1	2	2	2	2	1	0	1	1	1	0	0	0	5	1	2	2	1	1	1	1	2
2016 02 26	5	2	2	1	1	2	2	1	0	3	1	0	0	0	3	1	0	0	7	3	3	1	1	2	1	1	0
2016 02 27	3	0	1	2	1	1	1	1	1	4	0	0	3	3	1	0	0	0	4	0	1	2	1	0	1	1	1
2016 02 28	4	1	1	2	1	2	1	1	0	4	0	0	1	2	3	1	0	0	4	1	1	2	1	1	0	1	1
2016 02 29	4	2	1	1	1	1	1	1	2	3	1	0	1	2	2	0	0	1	5	2	0	1	1	1	1	1	2
2016 03 01	8	3	2	2	1	2	2	1	3	7	1	1	2	3	3	1	1	1	9	3	2	2	2	2	2	1	3
2016 03 02	7	3	1	1	2	3	2	1	0	6	1	0	0	3	3	3	1	0	7	3	1	1	2	2	3	1	1
2016 03 03	7	1	3	2	3	2	1	1	1	11	1	1	2	5	3	2	0	2	8	2	3	2	3	2	1	1	2
2016 03 04	2	2	1	0	1	1	1	0	0	2	1	1	0	2	0	1	0	0	4	3	1	0	1	0	1	1	0
2016 03 05	3	0	0	2	1	2	1	1	0	8	0	0	2	4	4	1	0	0	4	0	0	2	2	2	1	1	1
2016 03 06	19	1	1	2	2	2	4	5	5	28	0	0	1	1	1	7	4	5	35	1	1	2	2	2	5	6	7
2016 03 07	17	4	4	3	2	2	2	3	4	30	3	4	4	5	5	5	3	3	24	5	5	4	2	3	3	4	4
2016 03 08	6	2	2	2	2	2	1	2	0	18	2	2	3	4	5	4	2	1	8	3	2	2	2	2	1	2	1
2016 03 09	6	2	1	2	2	2	1	1	2	12	1	2	3	4	4	3	1	0	7	2	2	2	2	2	2	2	2
2016 03 10	7	2	3	2	1	2	1	1	2	12	1	1	3	4	4	3	0	1	10	3	3	2	2	3	2	2	2
2016 03 11	21	1	3	3	3	6	3	3	2	33	1	3	4	4	7	4	3	2	23	2	3	3	3	6	4	4	3
2016 03 12	11	3	2	2	3	2	3	3	1	10	2	2	2	2	1	4	3	1	13	4	3	2	3	1	3	3	1
2016 03 13	4	1	2	1	1	2	1	1	0	3	1	2	1	0	2	0	0	0	4	1	2	1	1	1	0	0	1
2016 03 14	11	1	2	2	2	2	3	3	4	8	0	0	3	3	1	1	3	3	14	2	2	2	2	1	3	4	5
2016 03 15	17	3	4	4	3	1	3	3	3	33	3	4	6	6	3	3	3	3	24	4	4	4	4	2	3	5	4
2016 03 16	13	4	2	3	2	2	2	2	4	26	4	3	4	5	5	2	2	4	22	5	2	3	3	3	1	3	5
2016 03 17	16	4	4	4	3	2	2	2	2	40	5	5	3	6	6	4	3	2	21	5	5	3	4	2	3	3	3
2016 03 18	6	1	1	3	2	2	1	1	2	23	1	1	3	6	5	4	2	1	8	2	2	3	2	2	2	2	3
2016 03 19	12	2	3	3	3	3	3	3	0	38	2	3	5	7	5	4	3	0	18	2	3	4	4	3	4	2	1
2016 03 20	6	1	3	1	1	2	2	2	1	21	1	2	1	3	4	6	4	2	10	2	3	2	2	2	3	4	2
2016 03 21	7	1	1	2	3	2	2	1	2	9	2	1	3	4	2	2	1	1	8	2	2	2	2	2	2	1	3
2016 03 22	6	2	2	1	2	2	1	1	2	9	2	1	4	4	2	0	0	0	8	3	2	2	3	2	0	1	2
2016 03 23	7	1	2	3	2	2	2	1	2	15	1	4	5	4	2	0	2	1	10	2	3	4	2	2	1	2	3
2016 03 24	7	3	2	2	1	2	2	1	2	3	2	0	2	1	1	0	1	1	7	3	2	2	2	1	1	1	2
2016 03 25	6	3	1	1	1	2	2	1	1	4	3	1	0	2	2	0	0	0	6	3	2	1	1	1	1	1	0
2016 03 26	2	0	0	1	0	1	2	1	1	0	0	0	0	0	1	0	0	0	3	0	1	1	0	1	1	1	1
2016 03 27	10	2	2	3	3	2	3	2	2	12	2	2	3	3	4	3	2	1	13	3	2	3	3	2	3	3	2
2016 03 28	9	2	4	1	1	2	2	2	2	6	1	3	1	2	1	1	2	2	10	2	4	1	1	2	1	3	3
2016 03 29	8	3	3	2	2	2	2	1	1	22	3	2	3	6	5	2	1	1	11	3	3	3	3	2	2	1	1
2016 03 30	10	3	1	2	1	3	3	3	2	21	2	1	2	5	6	3	2	1	12	3	2	2	2	4	2	3	2
2016 03 31	5	3	2	2	1	1	1	0	1	4	2	1	1	2	2	1	1	0	5	3	3	2	1	1	1	0	1

10.3 Appendix C: Performance Analysis (PAN) Problem 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 WAAS as a GPS augmentation system. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Performance Analysis (PAN) report. The PAN report contains data collected at various National Satellite Test Bed (NSTB) and Wide Area Augmentation System (WAAS) reference station locations. This PAN Problem Report will be issued only when the performance data fails to meet the GPS Standard Positioning Service (SPS) Signal Specification.

Problem Description:

There were no problems this quarter.

10.4 Appendix D: Glossary

The terms and definitions discussed below are taken from the Standard Positioning Service Performance Specification (September 2008). An understanding of these terms and definitions is a necessary prerequisite to full understanding of the Signal Specification.

General Terms and Definitions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SPS SIS User Range Error (URE) Statistic:

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

- A constellation SPS SIS URE statistic is defined to be the average of all satellite SPS SIS URE statistics over a specified time interval.

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

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

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

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

User Range Accuracy (URA): A conservative representation of each satellite's expected (1σ) SIS URE performance (excluding residual group delay) based on historical data. A URA value is provided that is representative over the curve fit interval of the navigation data from which the URA is read. The URA is a coarse representation of the URE statistic in that it is quantized to levels represented in ICD IS-GPS-200G.

11 GPS Broadcast Orbit Versus NGA Precise Orbits and URA (IAURA) Bounding Analyses

As part of the WAAS off-line monitoring process, the accuracy of the GPS broadcast ephemeris is periodically compared to the NGA precise orbit information to monitor the validity of an a priori assumption concerning the accuracy of the GPS broadcast ephemeris information. That a priori assumption is part of a brute force computer simulation analysis utilized as part of the safety proof of the WAAS MT-28 functionality. That brute force analysis searches a simulated error sphere around a GPS satellite for a worst-case projection of post correction ephemeris error to any user. A pessimistic extrapolation of historical data was used as an a priori to limit the radius of the searched sphere to a finite distance. This periodic off-line monitoring verifies that the original logic of the a priori assumption remains sound.

The assumption being validated is:

Height Error:	+/- 15 meters (standard deviation < 2.8 m),
Along Track Error:	+/- 65 meters (standard deviation < 12.2 m)
Cross Track Error:	+/- 30 meters (standard deviation < 5.6 m)

C/A Nav data URA bounding and L2C CNAV IAURA bounding performance are also evaluated.

For C/A Nav data, all IGS high rate 15 minute broadcast navigation data RINEX format files are downloaded and merged into 24 hour broadcast navigation data files which are then added to RINEX nav data files from all WAAS peripheral reference stations. A majority voting algorithm is used to screen the navigation data after a LSB recovery algorithm is applied. NGA APC precise ephemeris referenced to the GPS satellite antenna phase center is downloaded from the NGA site. GPS satellite positions are computed every 15 minutes and differenced with the precise orbits. The resulting error information is then segregated into the Height, Along Track, and Cross Track (HAC) error data. The standard deviation of those errors is then computed for each dimension for each satellite. Figures 11-1.1 through 11-1.4 show the standard deviation results.

The assumption is valid if a 5.33 scaling of the standard deviation across all satellites is within the a priori. Three months of data from 1/1/16 to 3/31/16 is presented. Only data points where GPS is healthy and valid precise data is available are considered. Figure 11-2 shows the availability of C/A Nav data. There were no points where GPS was healthy and the NGA data was missing. There are no points where GPS C/A GPS Nav data is unavailable other than during NANUs.

For L2C CNAV data, raw 300 bit L2C and L5 CNAV message data is obtained from the WAAS G3 test receivers located at the WAAS ZAU reference station. Those receivers are located at the Chicago ARTCC in Aurora IL. CNAV data was only available while the satellites were in view of Chicago. This is the reason for the sparseness in the CNAV data. Because of the sparseness of the data, CNAV data from rising and setting satellites was used for the entire 3 hour fit interval, even though on rising and setting satellites there would have normally been an ephemeris set update at the 2 hour points. Those missing updates may or may not have provided improvement to the accuracy. L2C is used because there are more L2C capable satellites than L5 capable satellites.

The sign convention for this analysis is error = broadcast ECEF - precise ECEF. Along track is positive in the direction of the velocity vector. Cross track completes a right hand system with height and along track.

Figures 11-3.1 and 11-3.2 are URA (IAURA) over bounding plots. URA bounding using C/A Nav data used the maximum of the range indicated by the broadcast URA index. IAURA bounding using CNAV data used the algorithm from IS-GPS-200 / IS-GPS-705. The error used in the analysis is at the location of maximum error in the footprint (usually edge of coverage). Review of the bounding plots, the QQ plots, and the histograms indicates that CNAV data is not as conservative as using the max URA from the C/A Nav data. The CNAV over bounding plot does not pass. Sparseness of data may have contributed to the failure to over bound. (i.e. using the full 3 hour fit interval at the beginning and end of tracks)

Figures 11-4.1 thru 11-4.48 are plots of the height, along track, and cross track error relative to NGA precise orbits by PRN number. These plots do not include clock error.

Figures 11-5.1 thru 11-5.13 are QQ plots of the URA (IAURA) normalized total range error (height, along track, cross track, and clock) projected onto the surface of the earth. +/- 13.9° from the bore sight of the satellite is used to approximate the surface of the earth. The max URA of the broadcast URA index range is used for the C/A Nav data, IAURA is used for the CNAV data. The range of the QQ plot axis has been fixed at +/- 5. Annotations are provided for any instances beyond that range.

Errors larger than 3 times URA (IAURA) were investigated.

Figures 11-6.1 thru 11-6.50 are histograms of the height error, along track error, cross track error, and URA (IAURA) normalized range error.

Figures 11-7.1 thru 11-7.50 are the timelines of the URA (IAURA) normalized range error. Missing data point are in red and are NANUs for the C/A data. The large number of red points in the CNAV data is the points where the satellites are out of view of ZAU.

Figure 11-1 GPS Broadcast Orbit Accuracy Standard Deviation Plots

Figure 11-1.1, GPS Broadcast Orbit Accuracy Standard Deviations Using C/A Nav Data

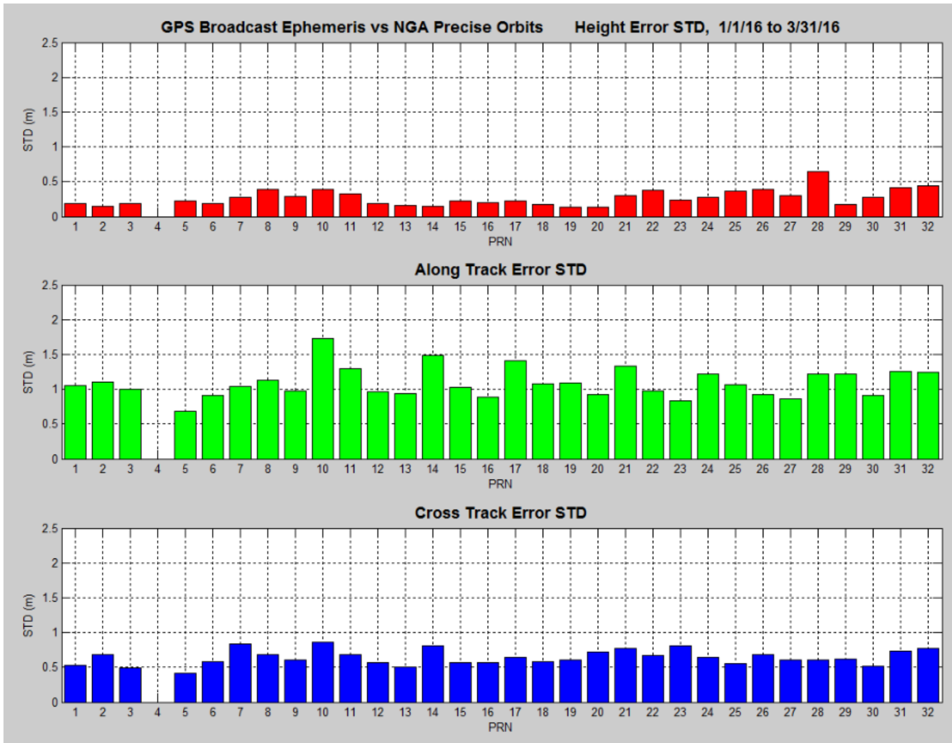


Figure 11-1.2, GPS Broadcast Orbit Accuracy Standard Deviations Using L2C CNAV Data

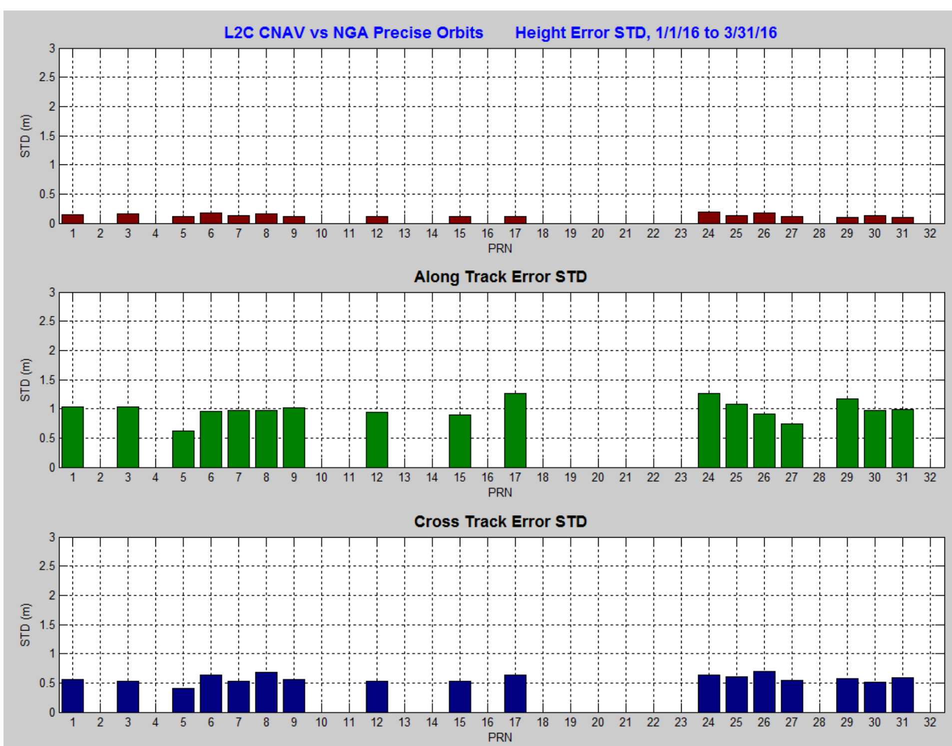


Figure 11-1.3, GPS Broadcast Orbit Error Means Using C/A Nav Data

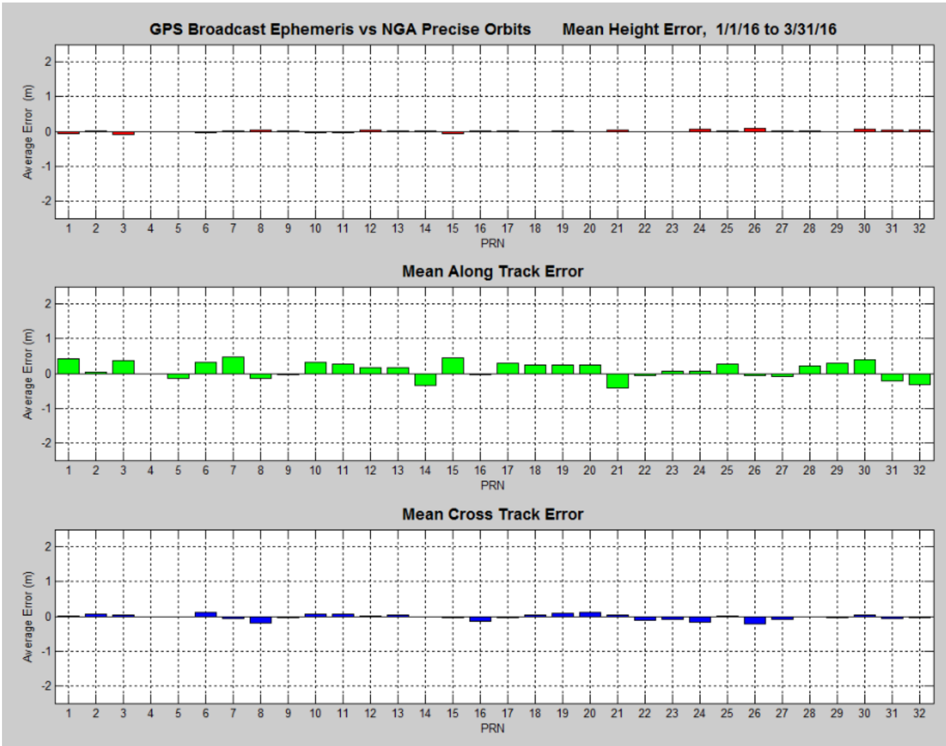


Figure 11-1.4, GPS Broadcast Orbit Error Means Using L2C CNAV Data

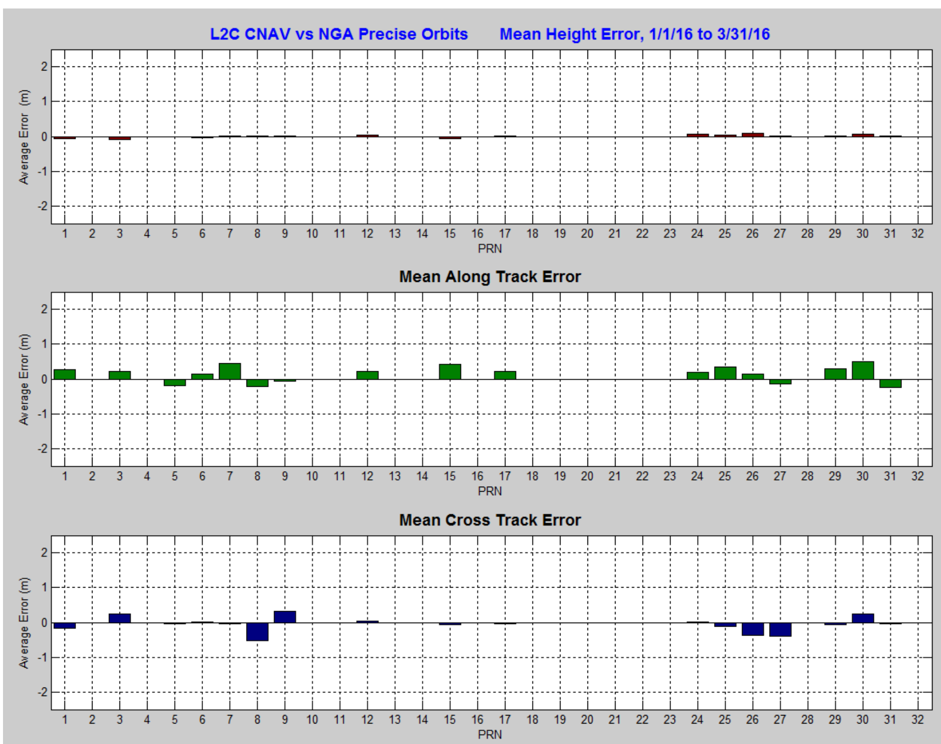


Figure 11-2 Broadcast Ephemeris vs. NGA Precise Data Availability Plots

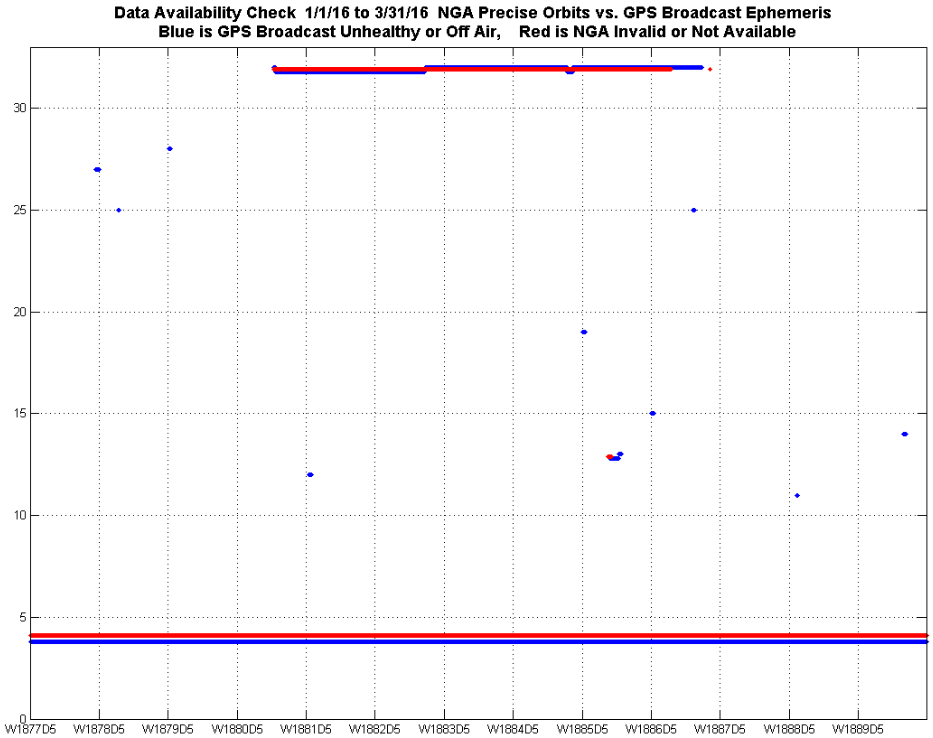


Figure 11-3 Current GPS Constellation

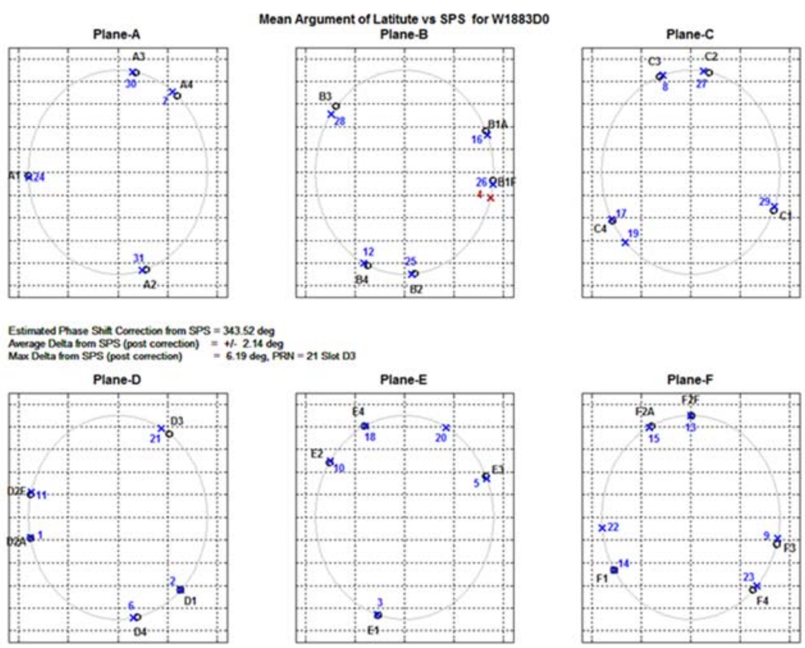


Figure 11-4 URA Over-Bounding Plots

Figure 11-3.1, 1/1/16 to 3/31/16 URA Over-bounding Using C/A Nav Data

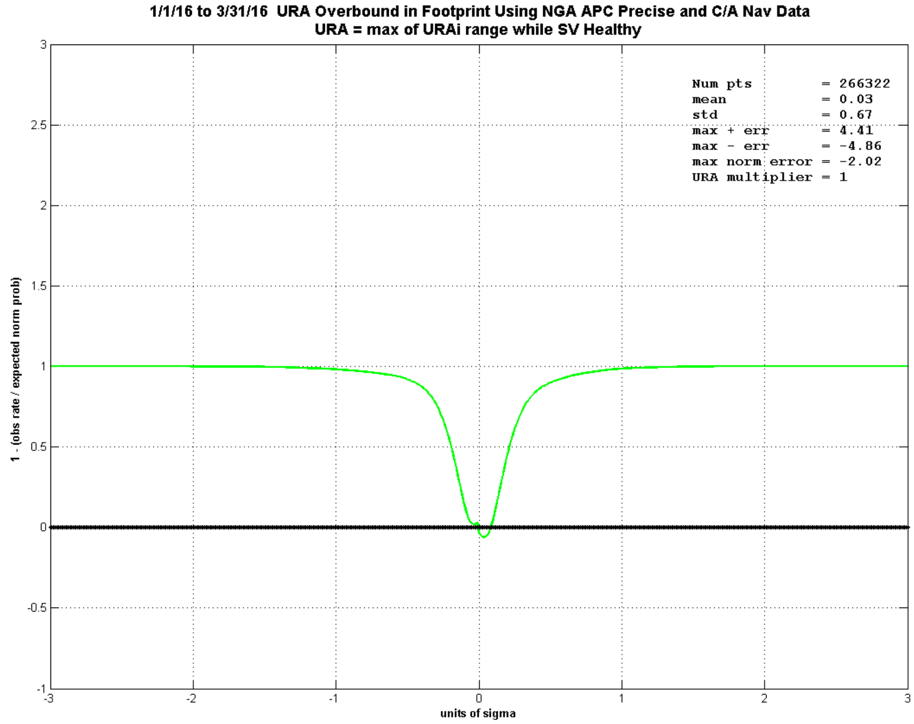


Figure 11-3.2, 1/1/16 to 3/31/16 IAURA Over-bounding Using L2C CNAV Data

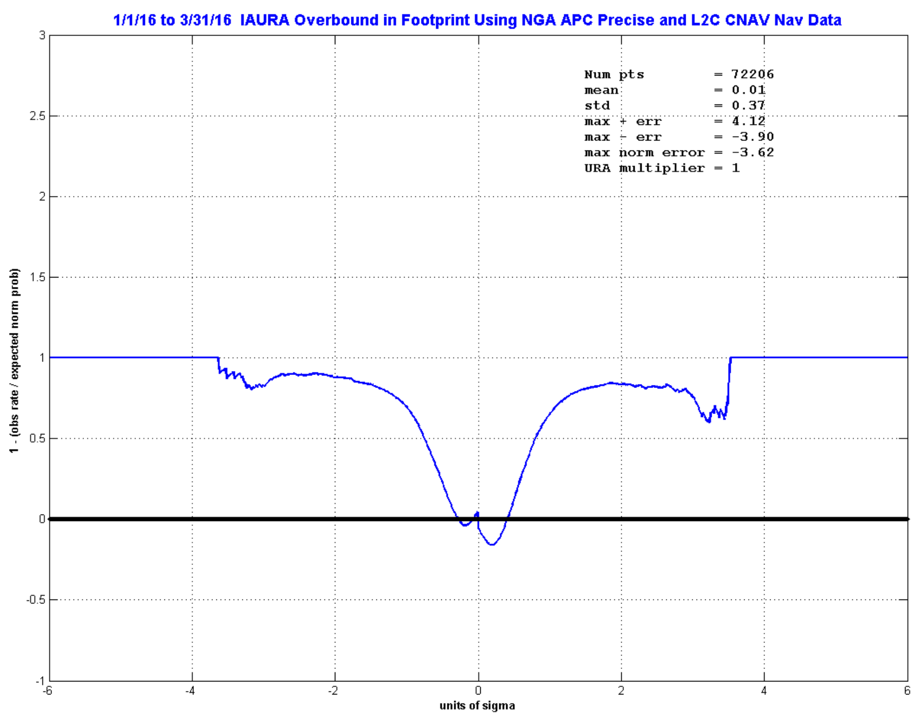


Figure 11-5 Orbit Error Plots For All Satellites

Figure 11-4.1, Orbit Error PRN-1 (SVN-63) Using C/A Nav Data

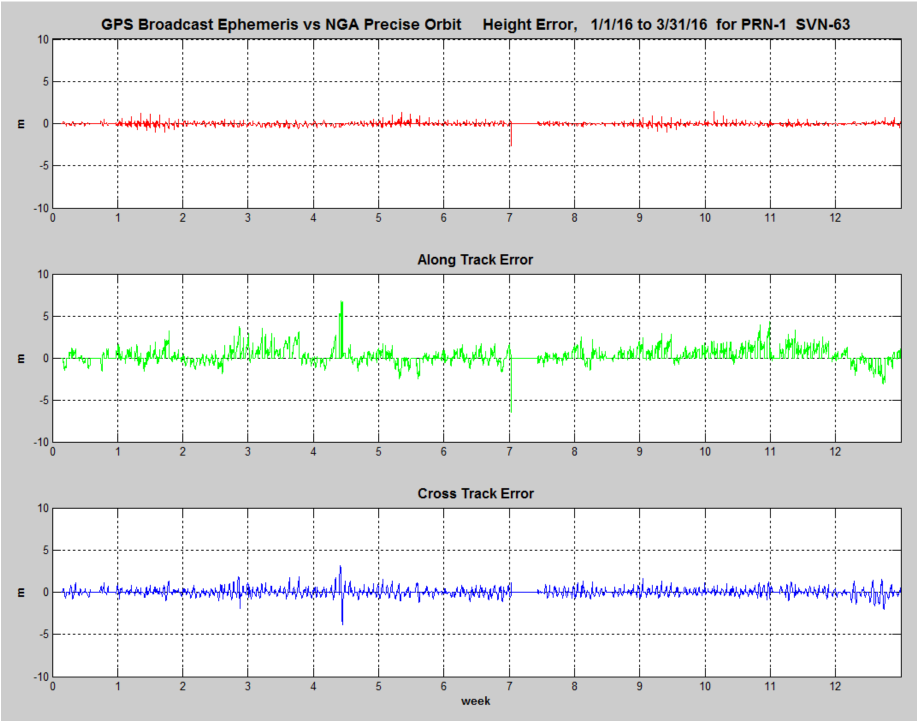


Figure 11-4.2, Orbit Error PRN-1 (SVN-63) Using L2C CNAV Data

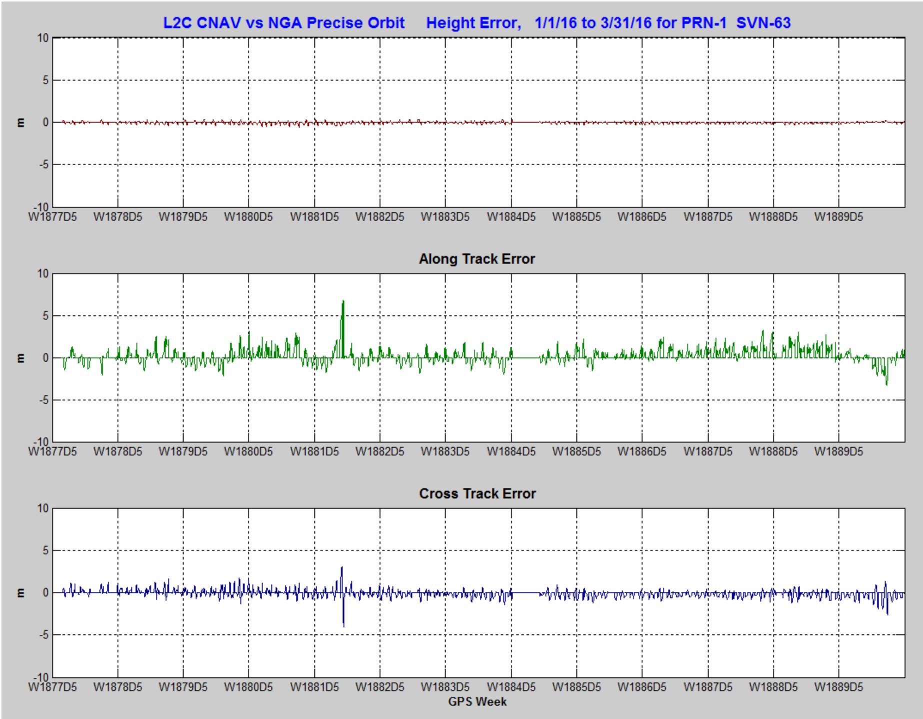


Figure 11-4.3, Orbit Error PRN-2 (SVN-61) Using C/A Nav Data

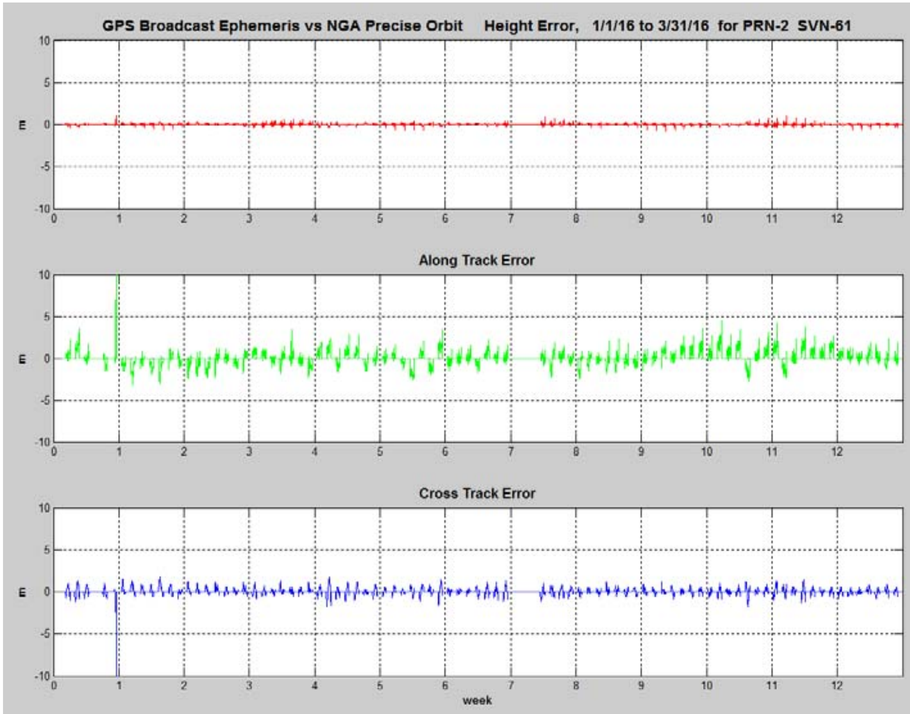


Figure 11-4.4, Orbit Error PRN-3 (SVN-69) Using C/A Nav Data

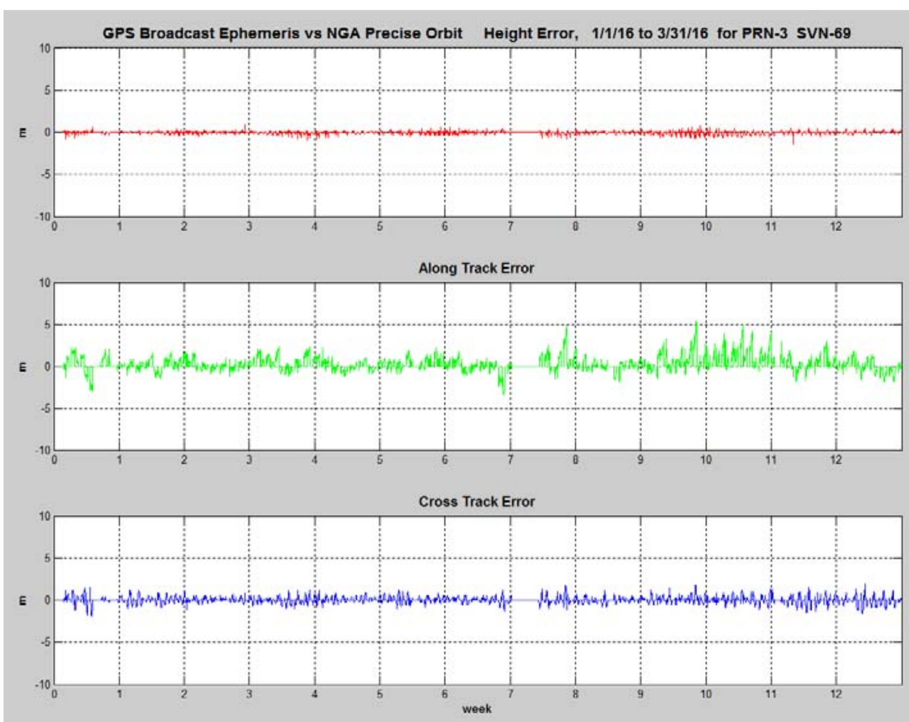


Figure 11-4.5, Orbit Error PRN-3 (SVN-69) Using L2C CNAV Data

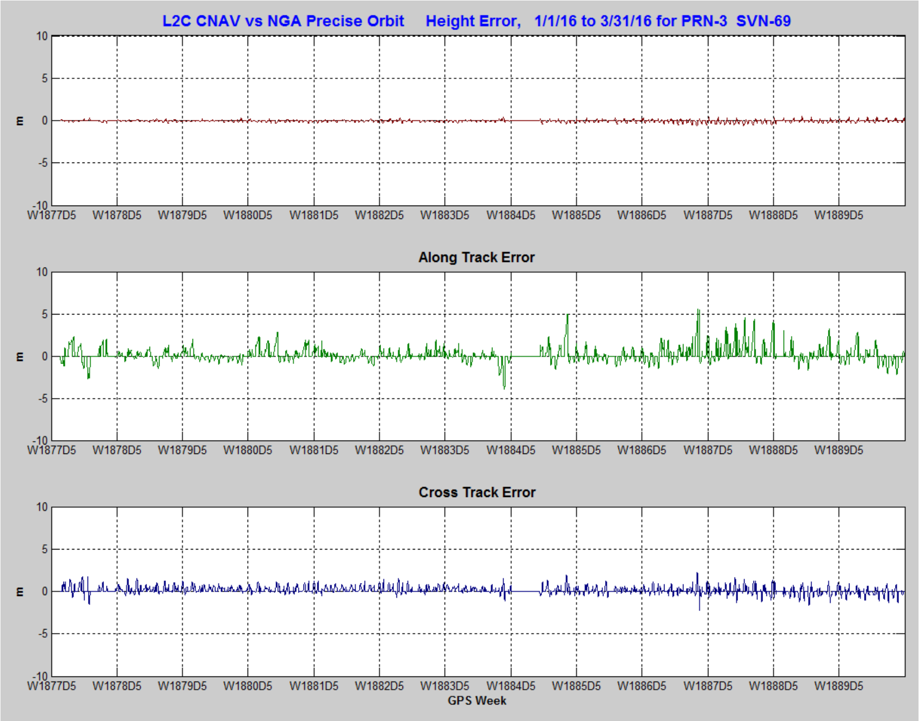


Figure 11-4.6, Orbit Error PRN-5 (SVN-50) Using C/A Nav Data

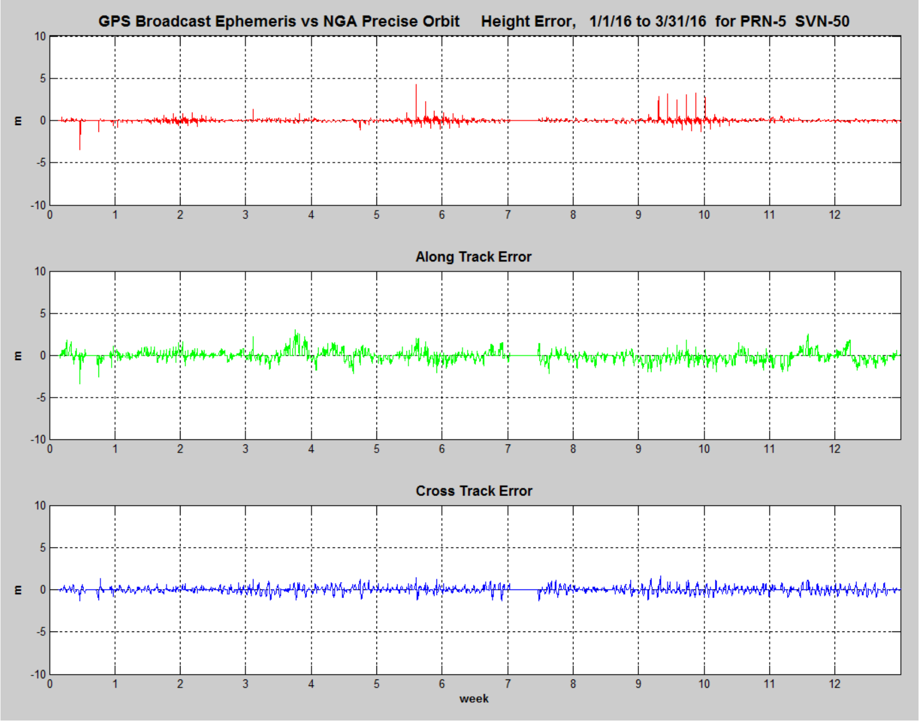


Figure 11-4.7, Orbit Error PRN-5 (SVN-50) Using L2C CNAV Data

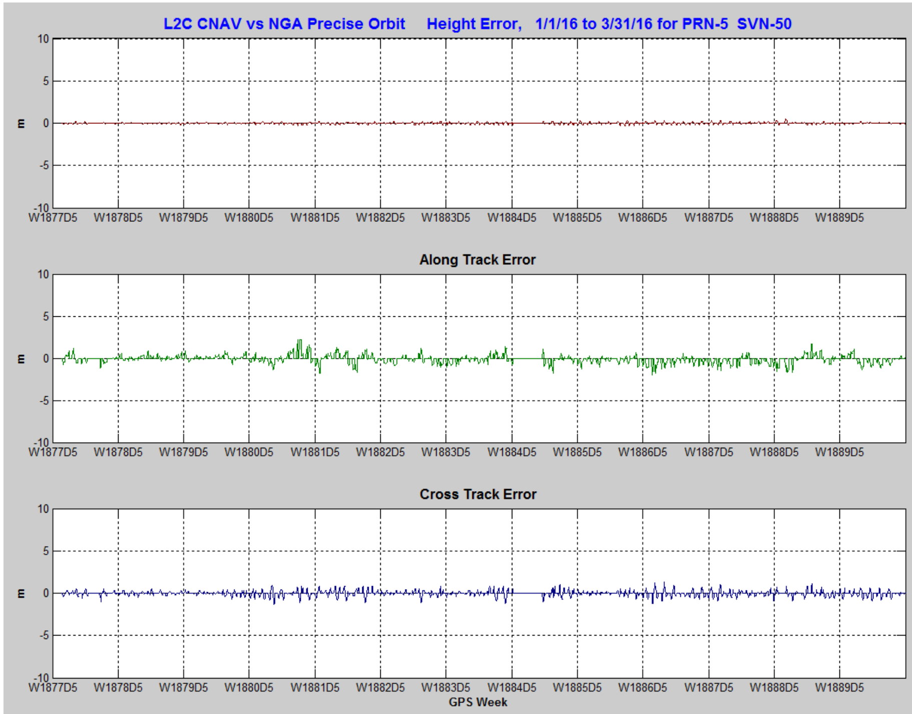


Figure 11-4.8, Orbit Error PRN-6 (SVN-67) Using C/A Nav Data

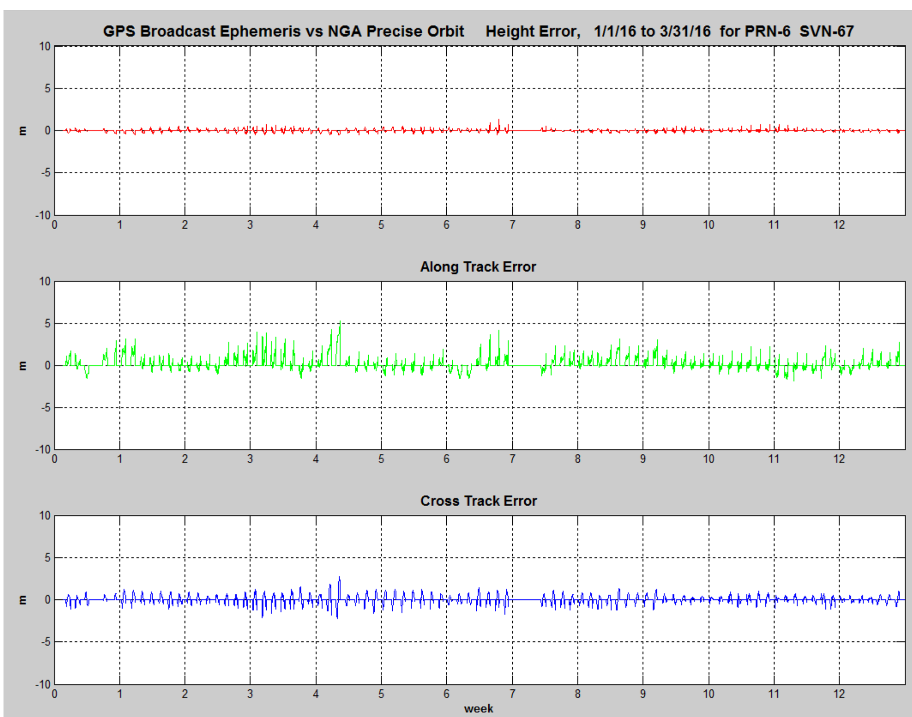


Figure 11-4.9, Orbit Error PRN-6 (SVN-67) Using L2C CNAV Data

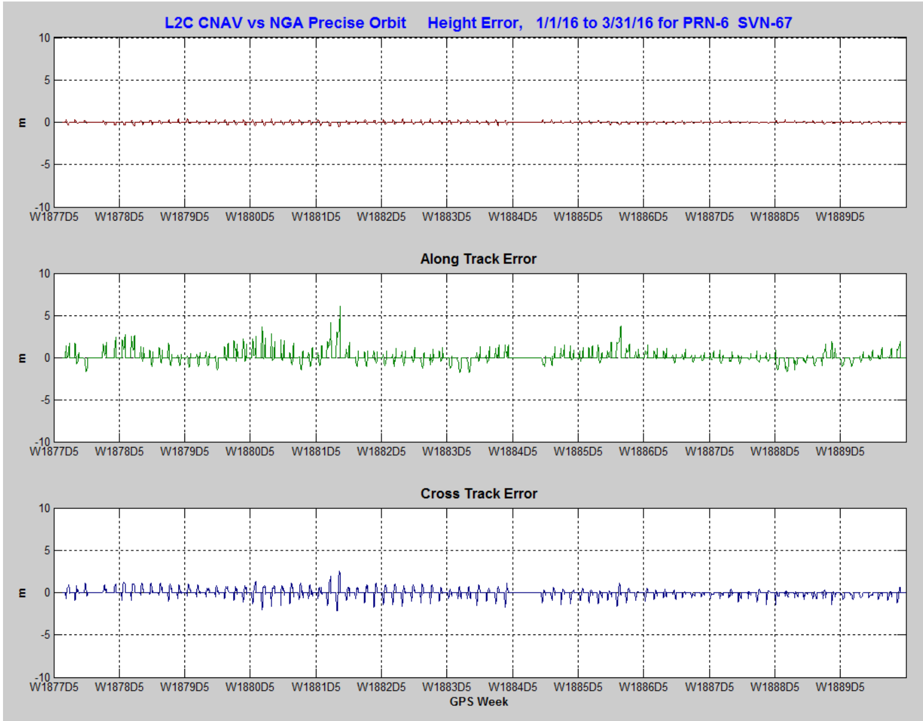


Figure 11-4.10, Orbit Error PRN-7 (SVN-48) Using C/A Nav Data

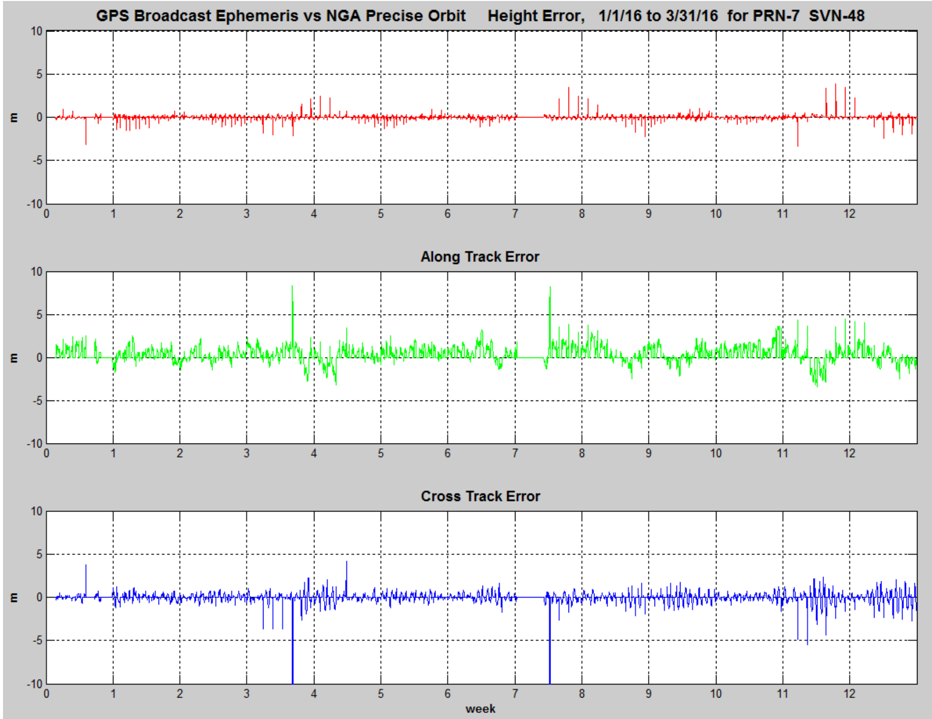


Figure 11-4.11, Orbit Error PRN-7 (SVN-48) Using L2C CNAV Data

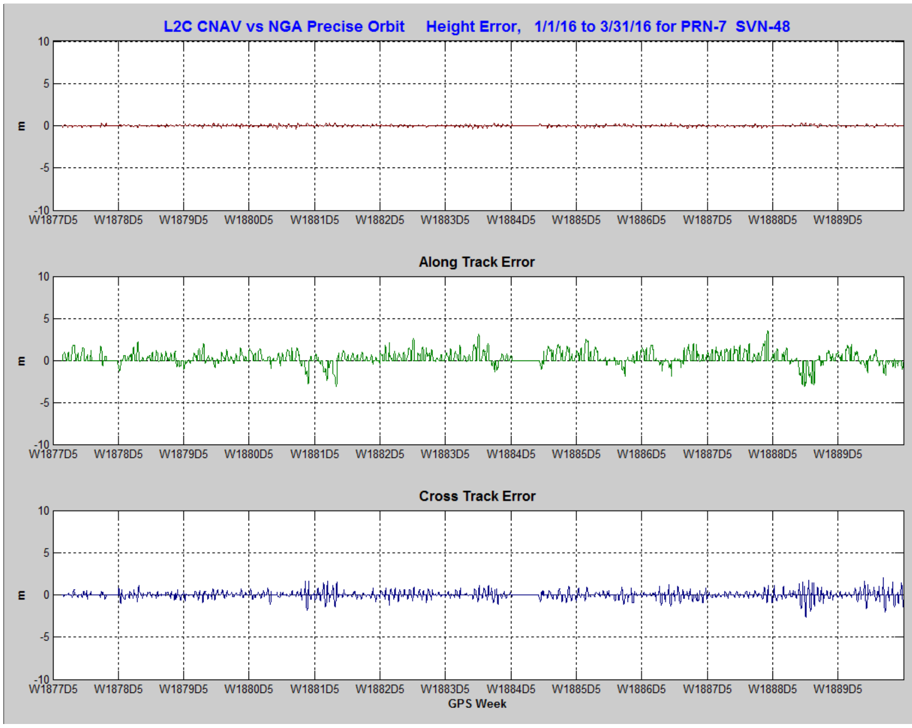


Figure 11-4.12, Orbit Error PRN-8 (SVN-72) Using C/A Nav Data

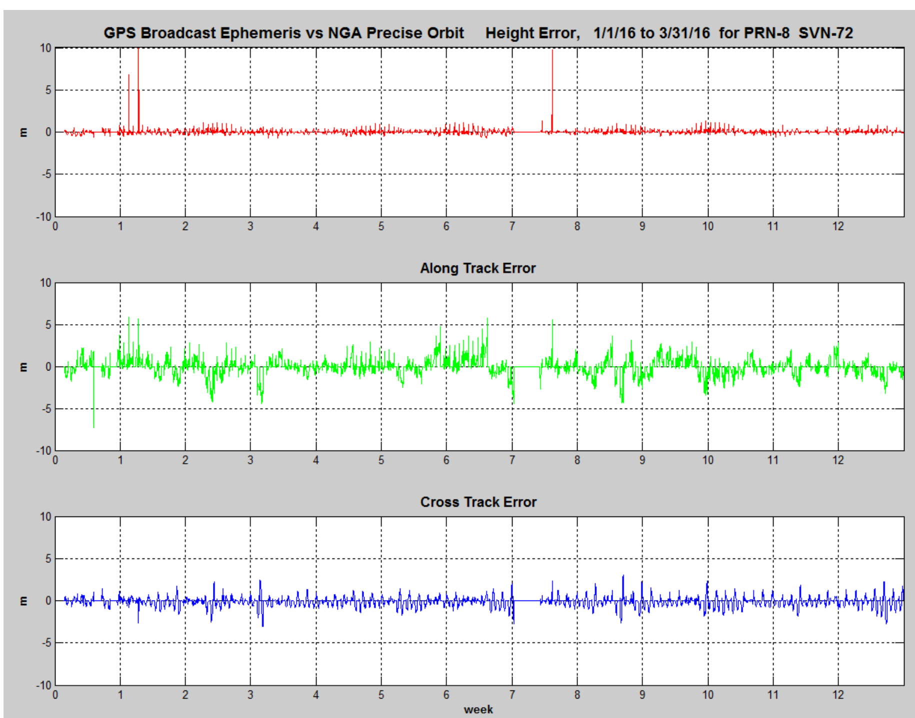


Figure 11-4.13, Orbit Error PRN-8 (SVN-72) Using L2C CNAV Data

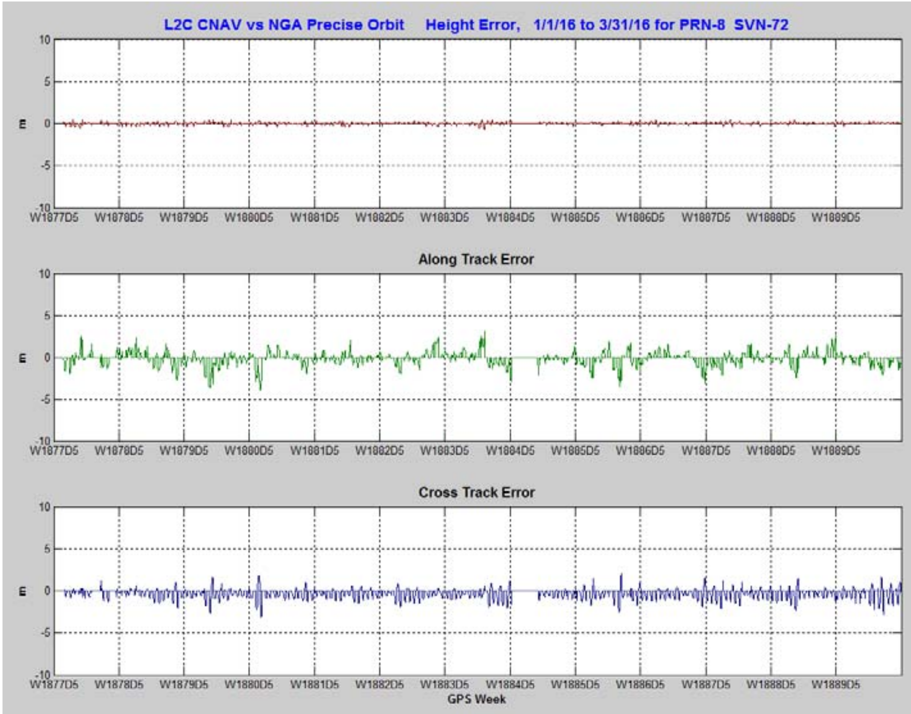


Figure 11-4.14, Orbit Error PRN-9 (SVN-68) Using C/A Nav Data

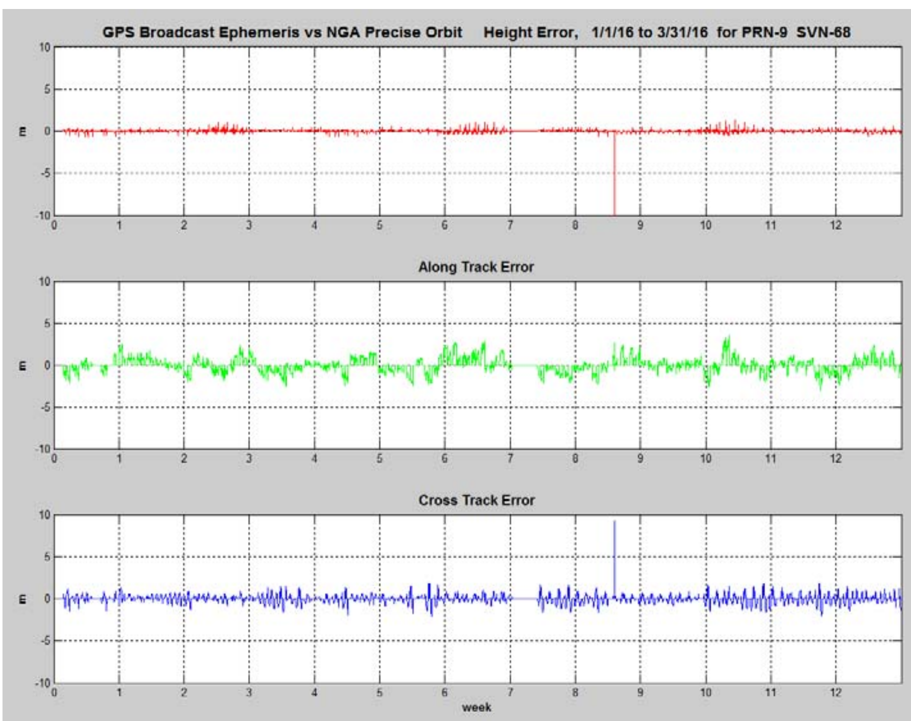


Figure 11-4.15, Orbit Error PRN-9 (SVN-68) Using L2C CNAV Data

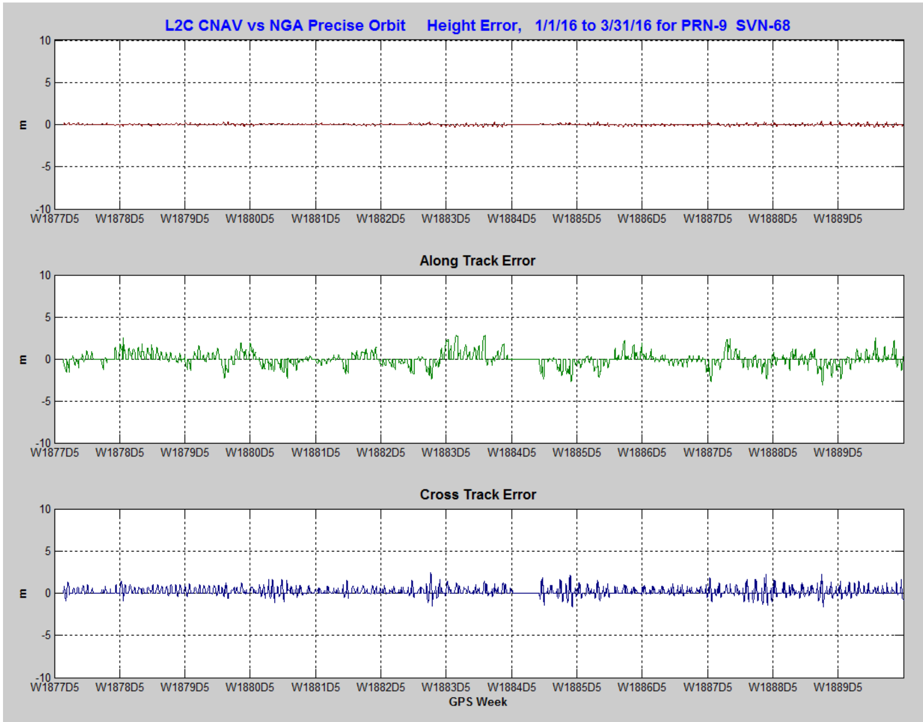


Figure 11-4.16, Orbit Error PRN-10 (SVN-40/73) Using C/A Nav Data

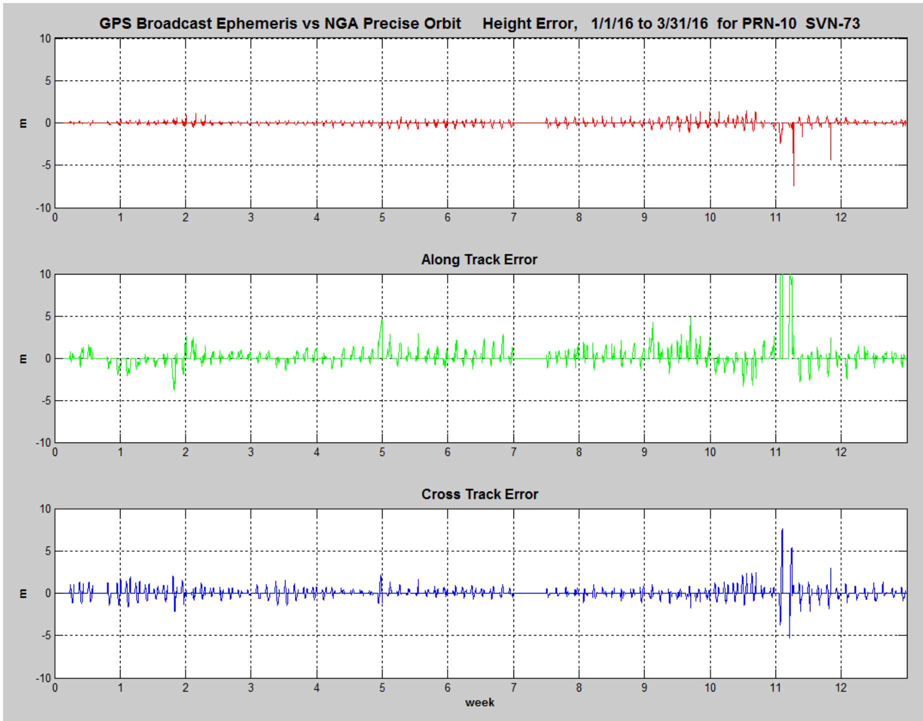


Figure 11-4.17, Orbit Error PRN-11 (SVN-46) Using C/A Nav Data

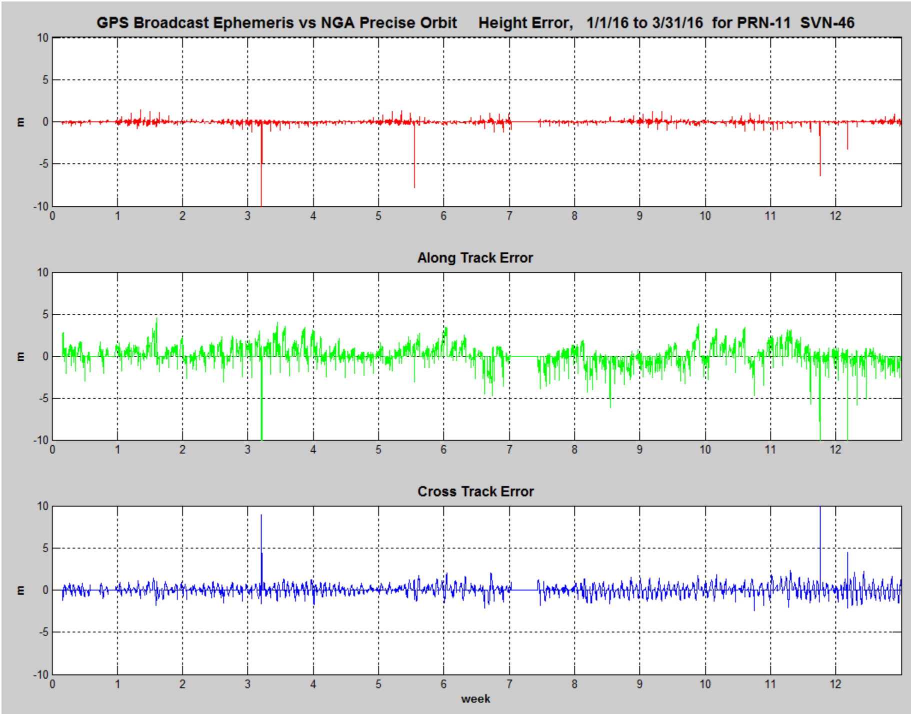


Figure 11-4.18, Orbit Error PRN-12 (SVN-58) Using C/A Nav Data

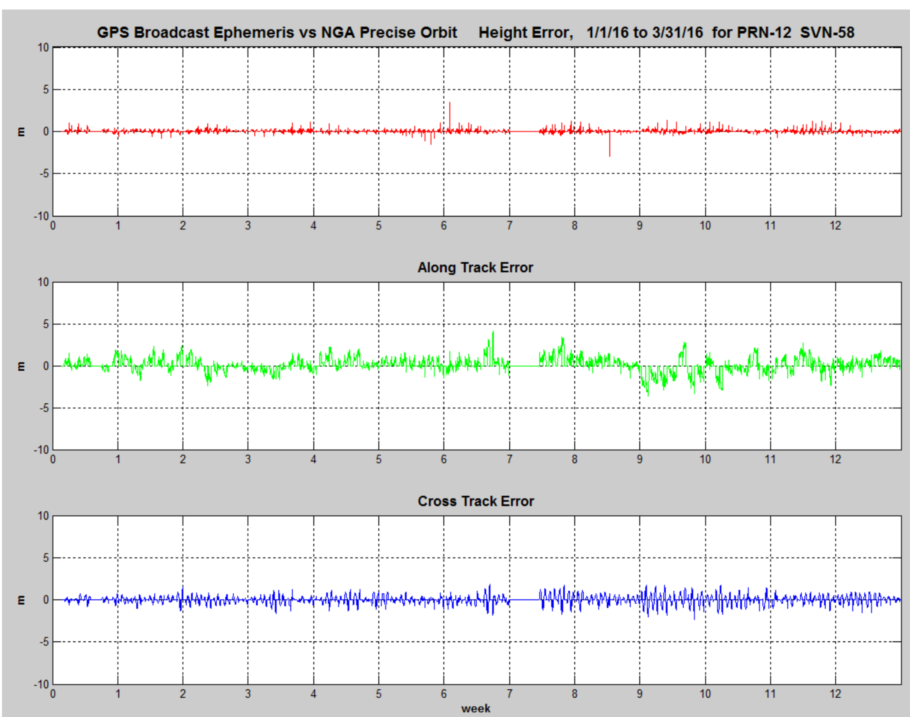


Figure 11-4.19, Orbit Error PRN-12 (SVN-58) Using L2C CNAV Data

Figure 11-4.20, Orbit Error PRN-13 (SVN-43) Using C/A Nav Data

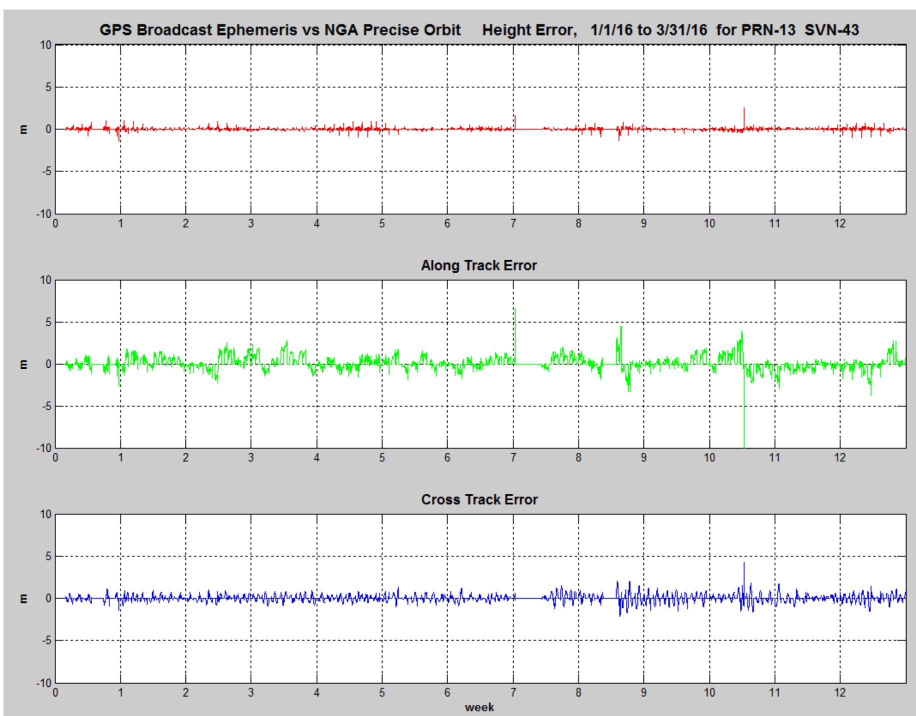


Figure 11-4.21, Orbit Error PRN-14 (SVN-41) Using C/A Nav Data

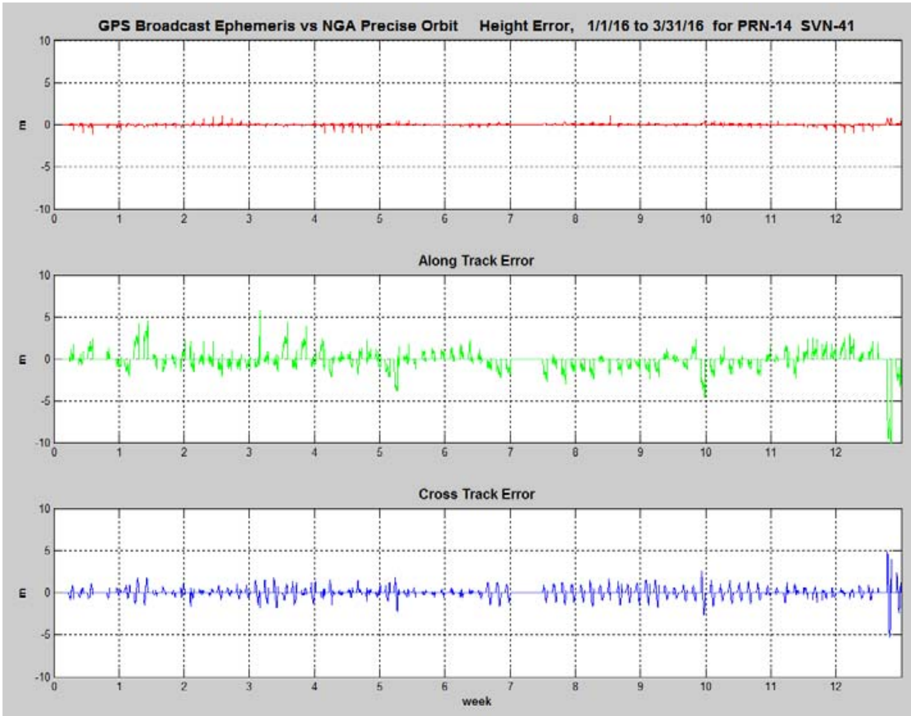


Figure 11-4.22, Orbit Error PRN-15 (SVN-55) Using C/A Nav Data

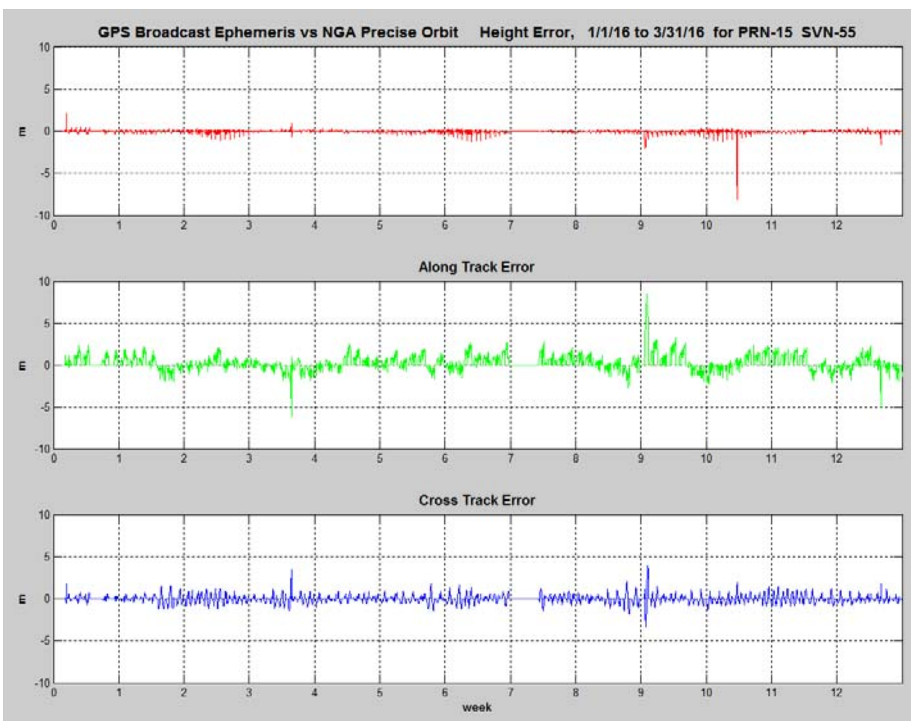


Figure 11-4.23, Orbit Error PRN-15 (SVN-55) Using L2C CNAV Data

Figure 11-4.24, Orbit Error PRN-16 (SVN-56) Using C/A Nav Data

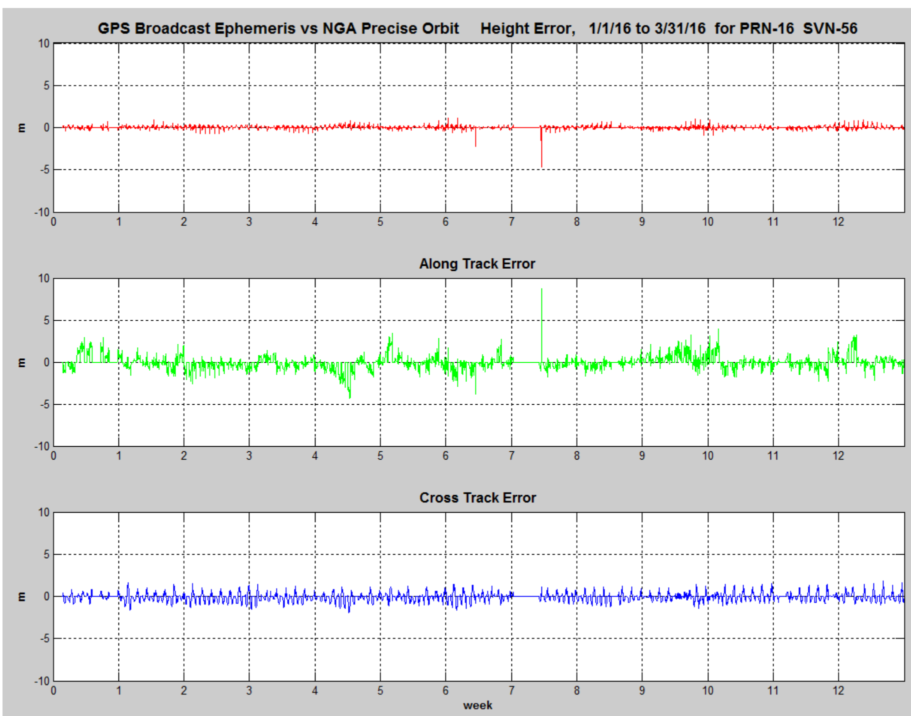


Figure 11-4.25, Orbit Error PRN-17 (SVN-53) Using C/A Nav Data

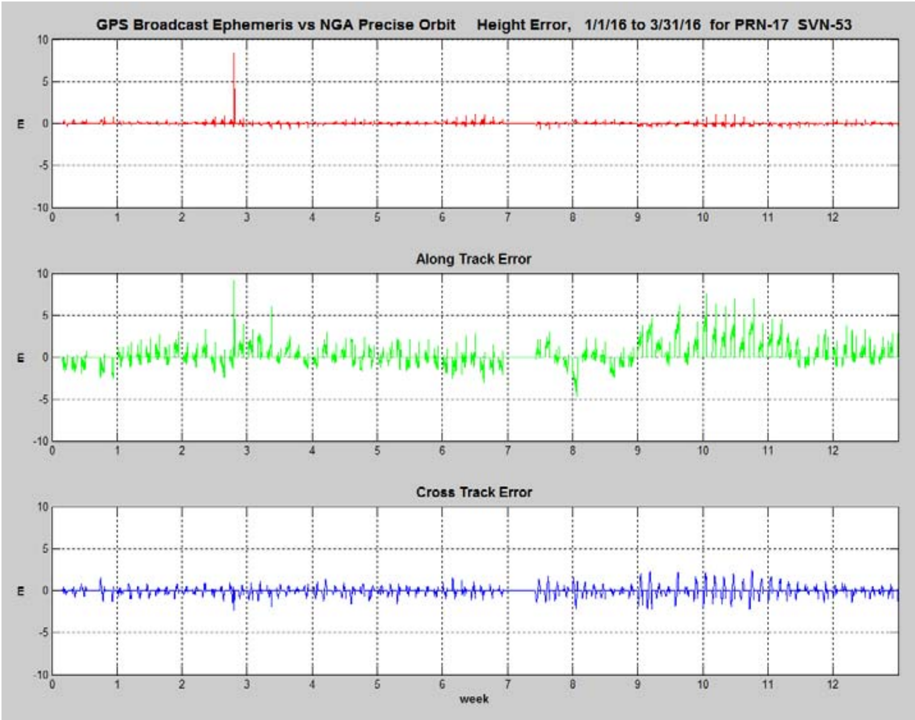


Figure 11-4.26, Orbit Error PRN-17 (SVN-53) Using L2C CNAV Data

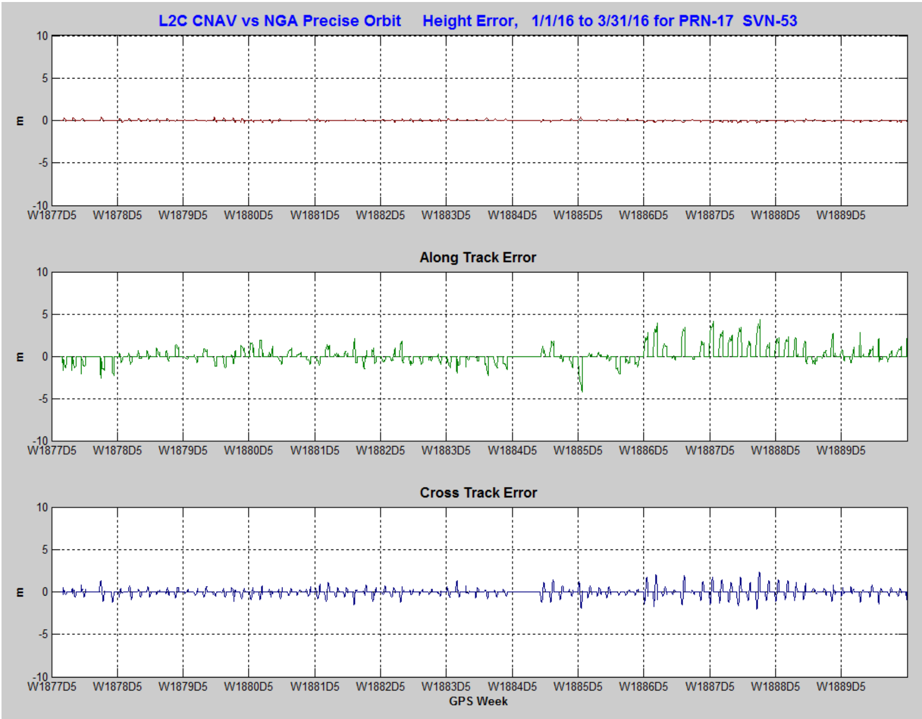


Figure 11-4.27, Orbit Error PRN-18 (SVN-54) Using C/A Nav Data

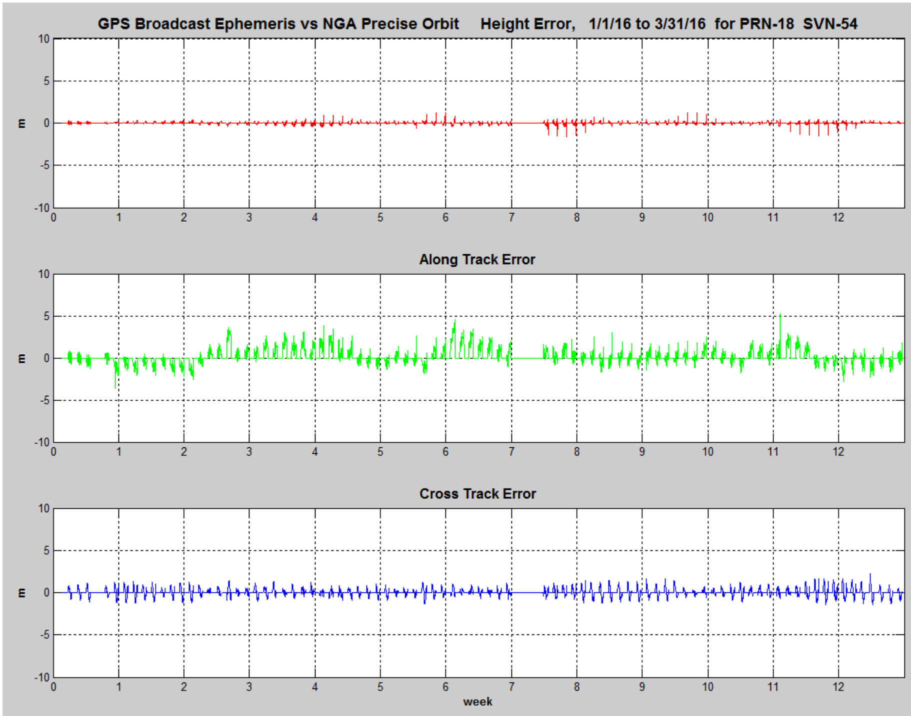


Figure 11-4.28, Orbit Error PRN-19 (SVN-59) Using C/A Nav Data

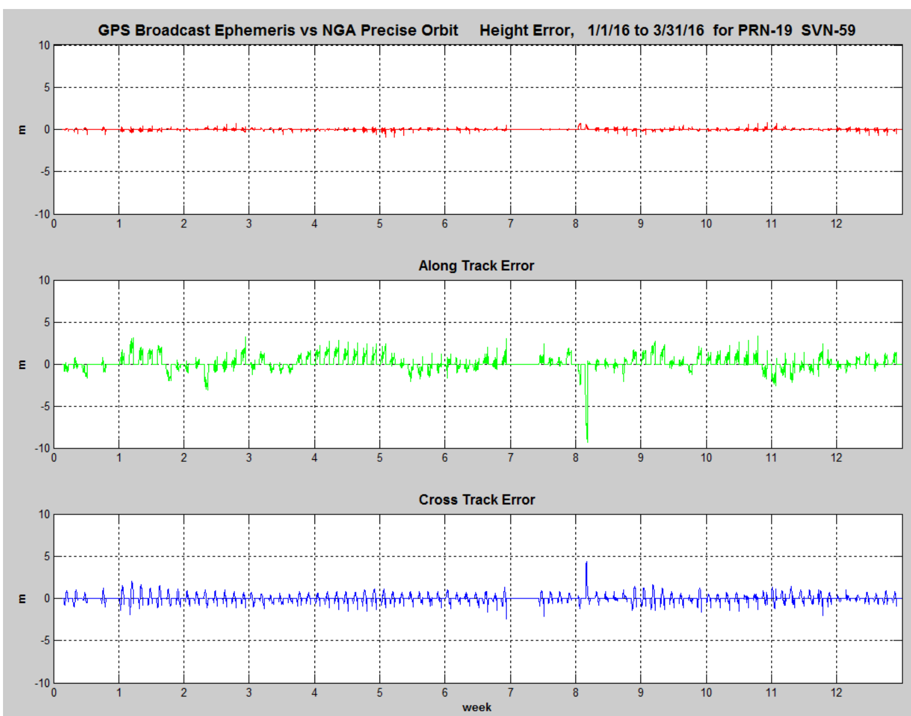


Figure 11-4.29, Orbit Error PRN-20 (SVN-51) Using C/A Nav Data

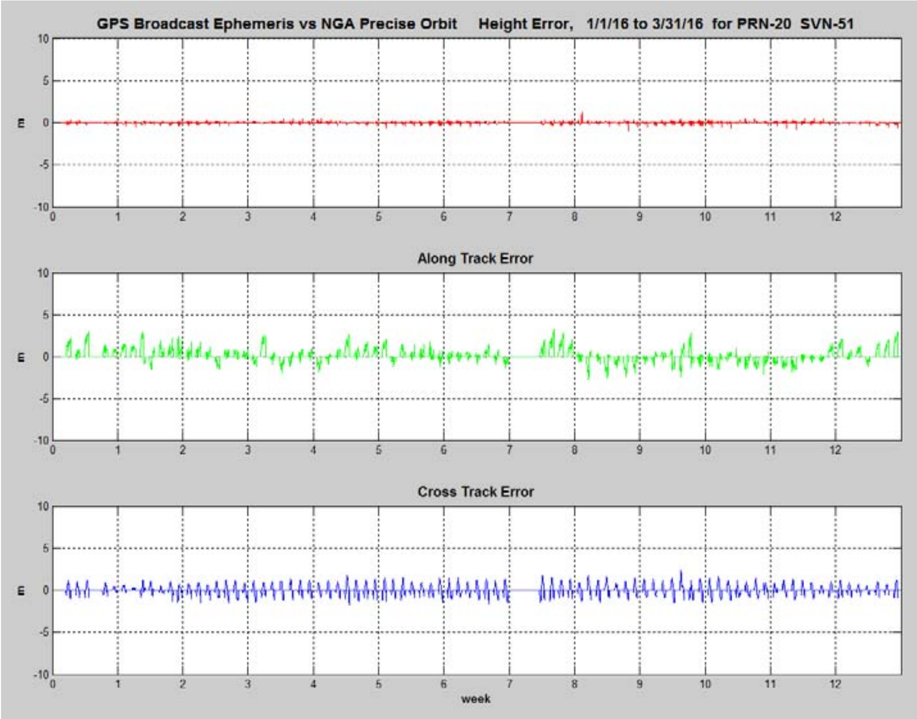


Figure 11-4.30, Orbit Error PRN-21 (SVN-45) Using C/A Nav Data

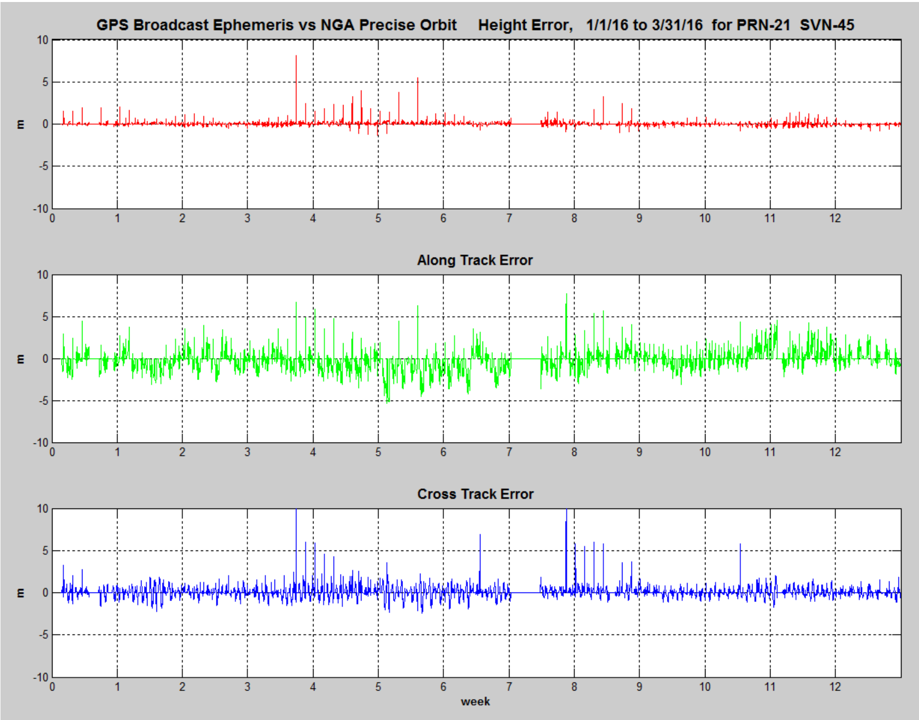


Figure 11-4.31, Orbit Error PRN-22 (SVN-47) Using C/A Nav Data

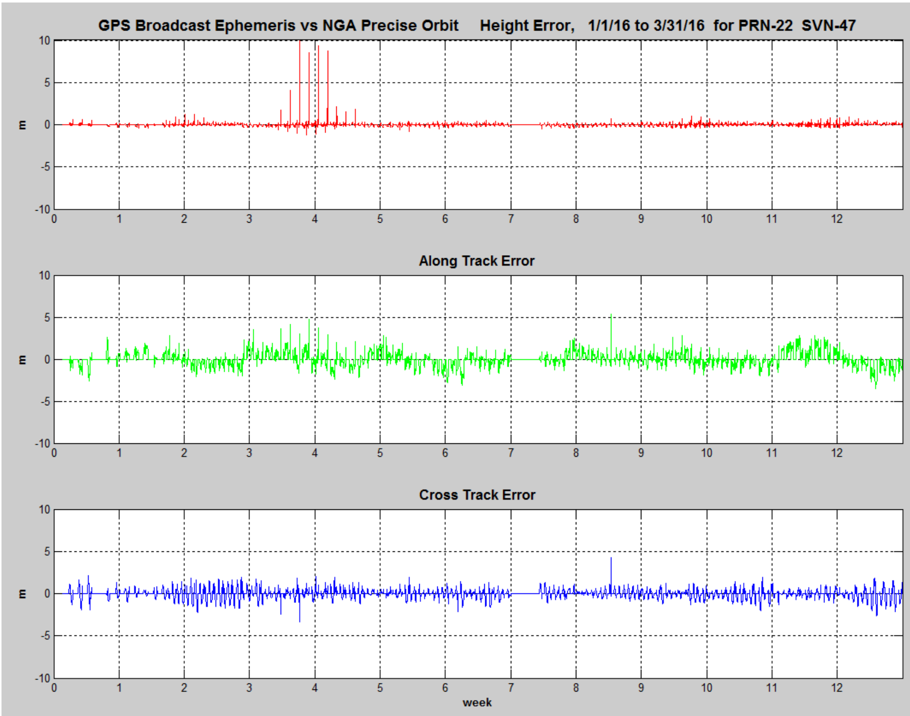


Figure 11-4.32, Orbit Error PRN-23 (SVN-60) Using C/A Nav Data

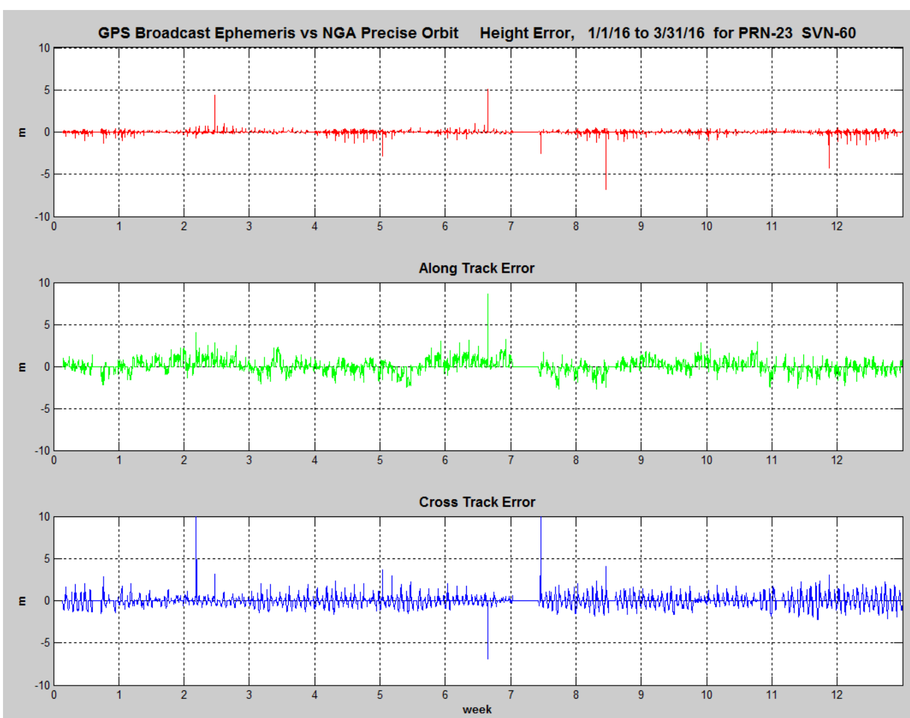


Figure 11-4.33, Orbit Error PRN-24 (SVN-65) Using C/A Nav Data

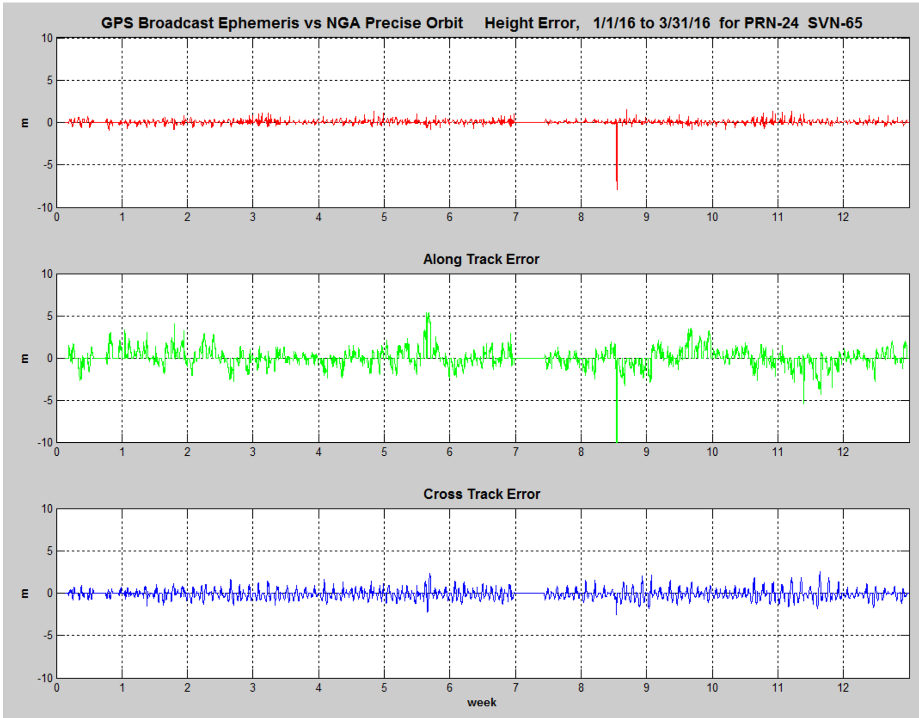


Figure 11-4.34, Orbit Error PRN-24 (SVN-65) Using L2C CNAV Data

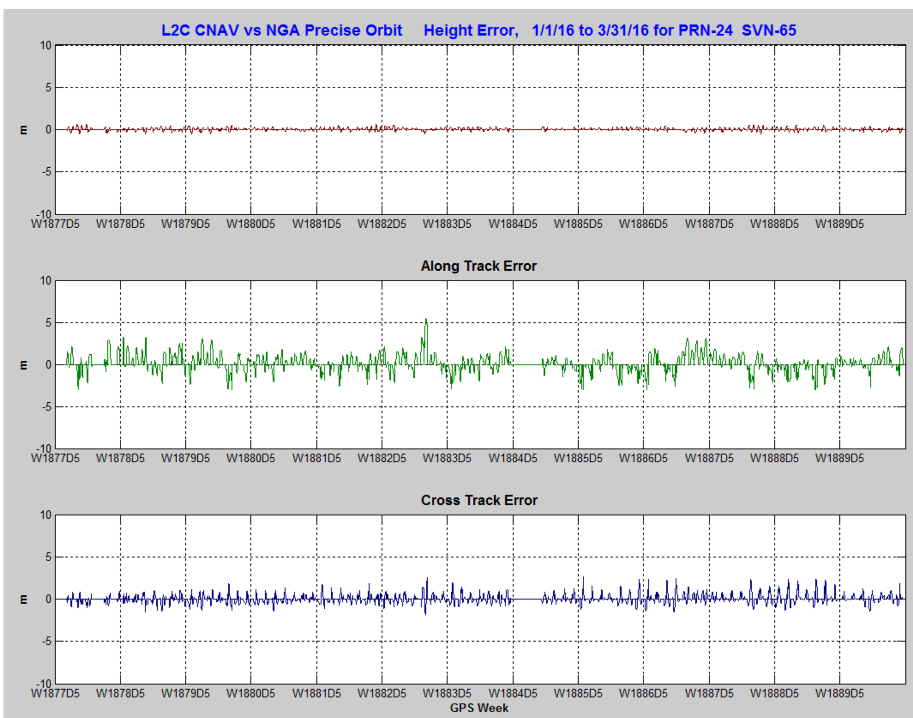


Figure 11-4.35, Orbit Error PRN-25 (SVN-62) Using C/A Nav Data

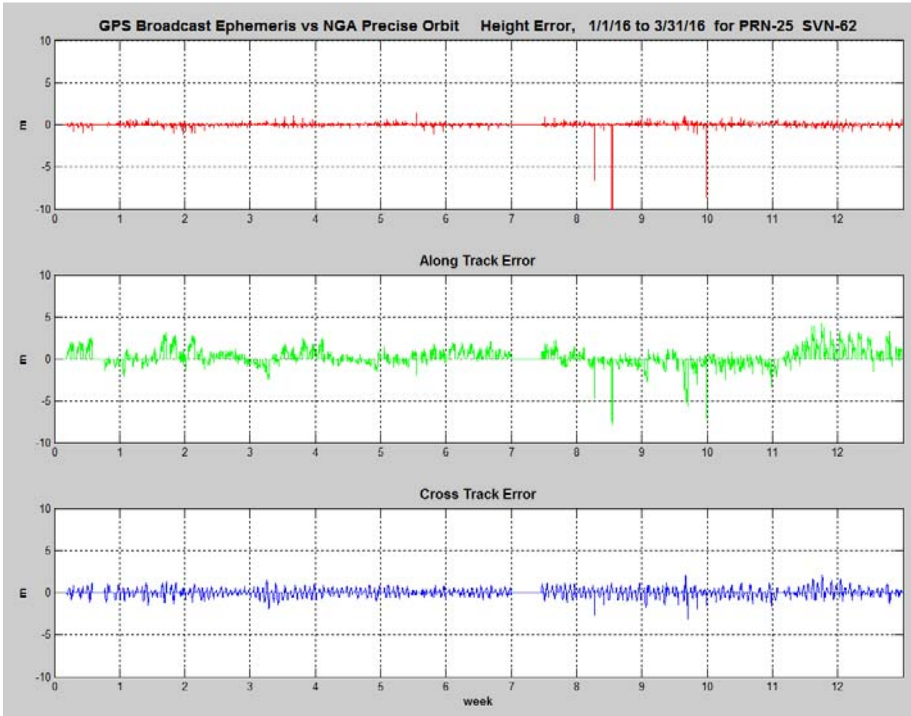


Figure 11-4.36, Orbit Error PRN-25 (SVN-62) Using L2C CNAV Data

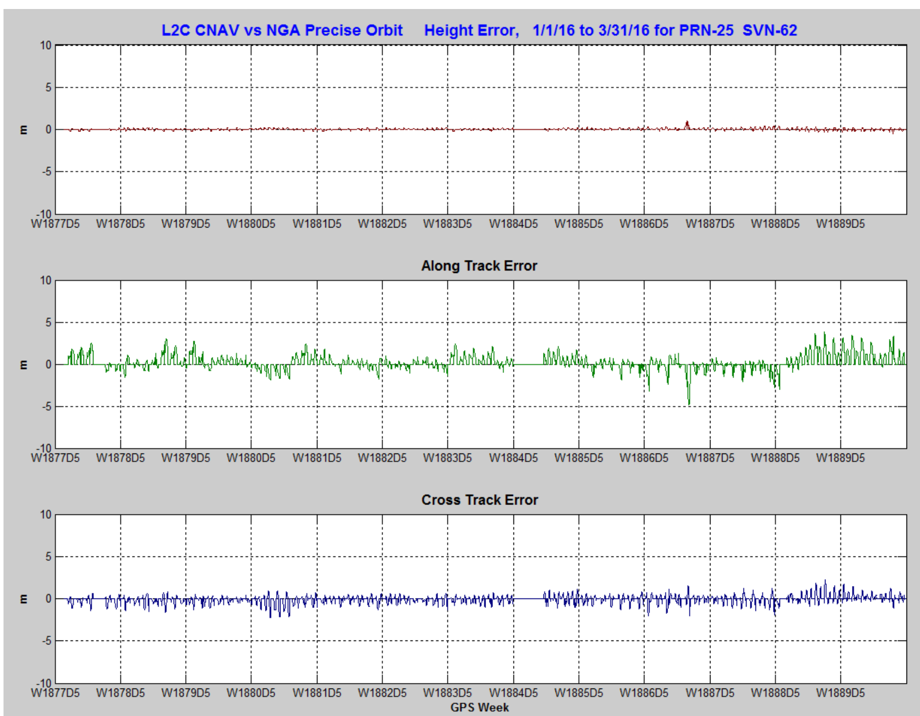


Figure 11-4.37, Orbit Error PRN-26 (SVN-26/71) Using C/A Nav Data

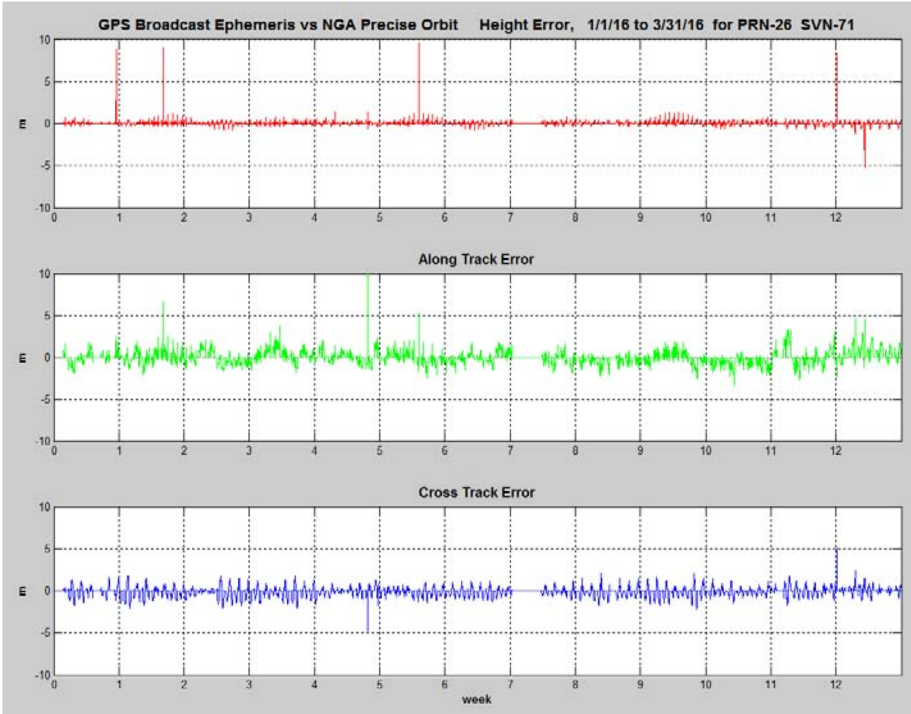


Figure 11-4.38, Orbit Error PRN-26 (SVN-71) Using L2C CNAV Data

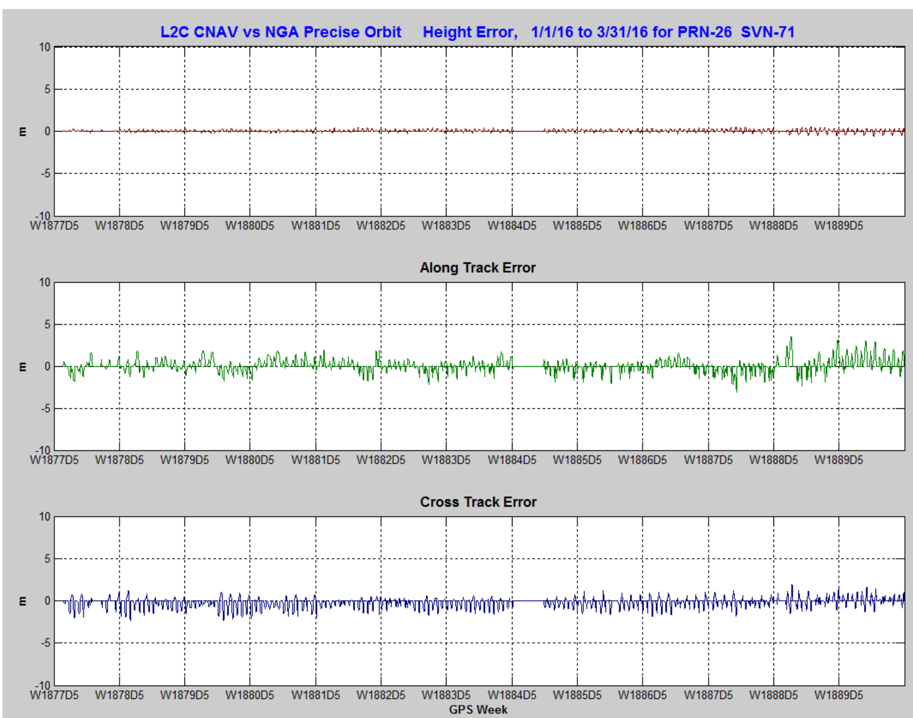


Figure 11-4.39, Orbit Error PRN-27 (SVN-66) Using C/A Nav Data

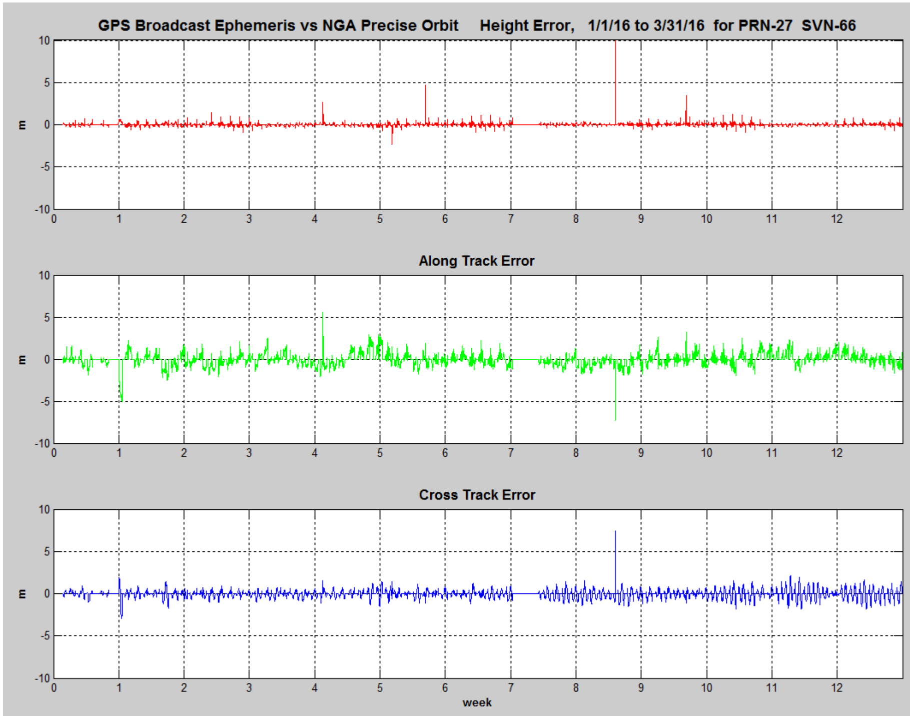


Figure 11-4.40, Orbit Error PRN-27 (SVN-66) Using L2C CNAV Data

Figure 11-4.41, Orbit Error PRN-28 (SVN-44) Using C/A Nav Data

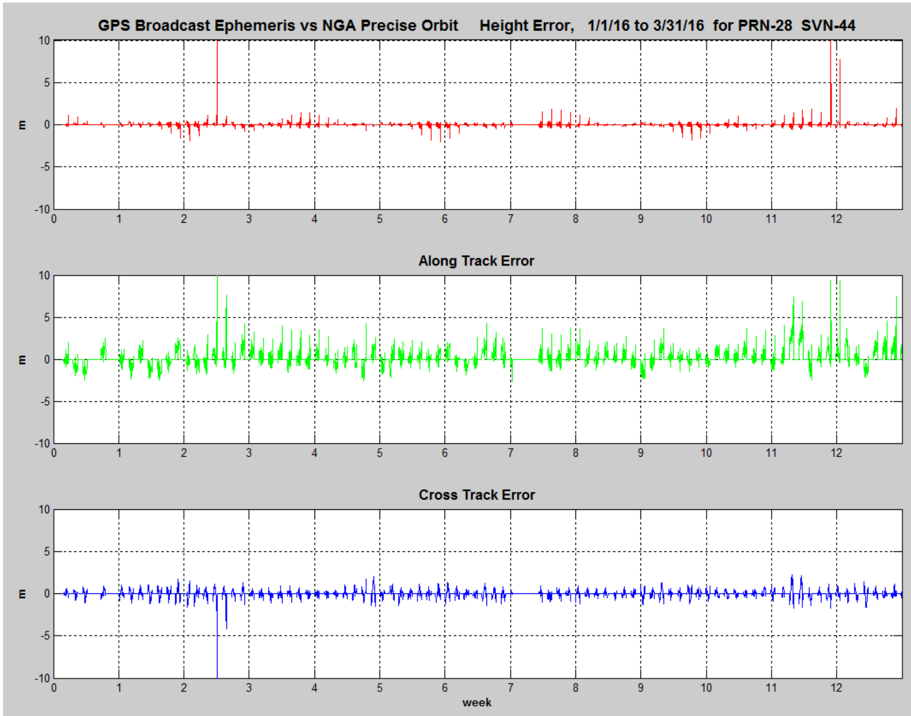


Figure 11-4.42, Orbit Error PRN-29 (SVN-57) Using C/A Nav Data

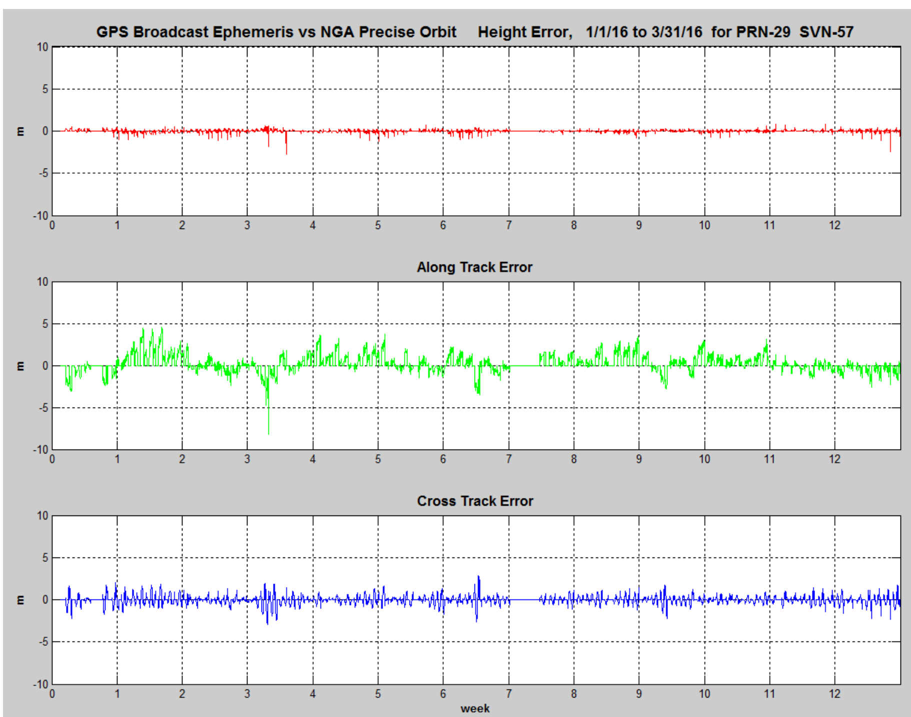


Figure 11-4.43, Orbit Error PRN-29 (SVN-57) Using L2C CNAV Data

Figure 11-4.44, Orbit Error PRN-30 (SVN-64) Using C/A Nav Data

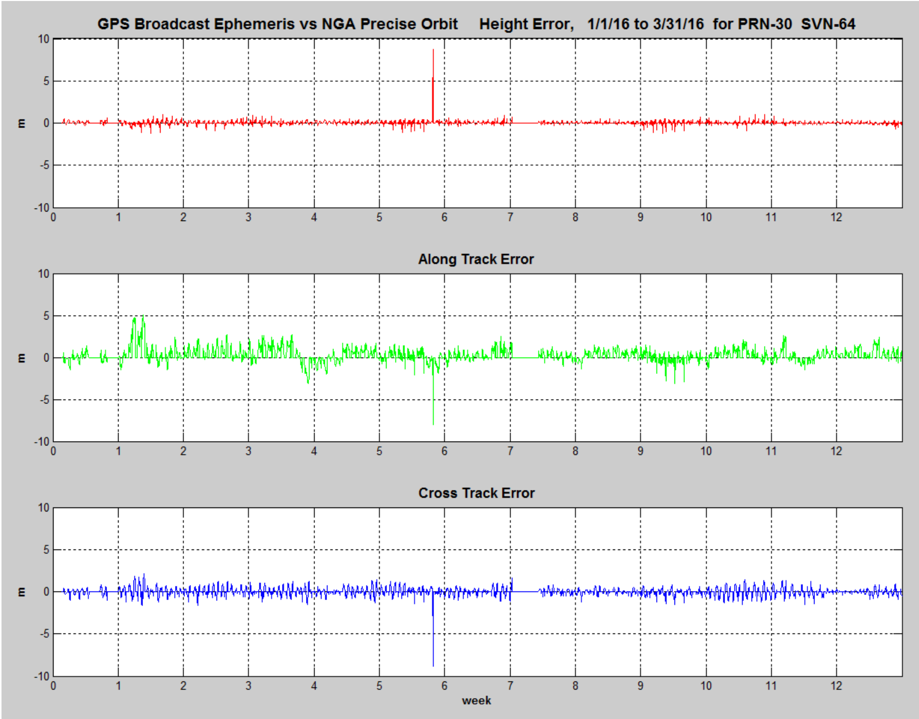


Figure 11-4.45, Orbit Error PRN-30 (SVN-64) Using L2C CNAV Data

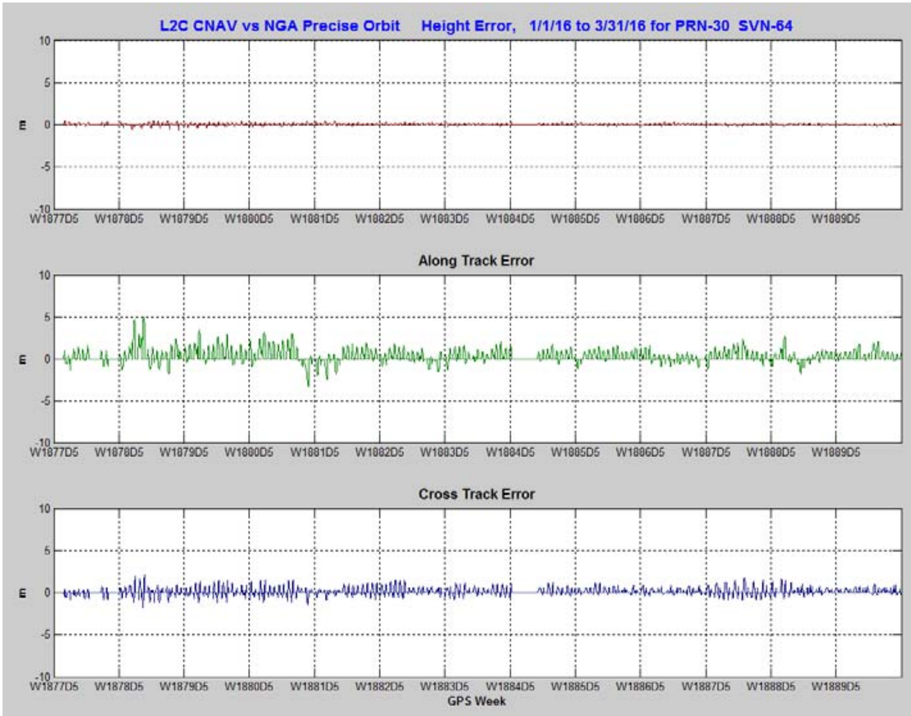


Figure 11-4.46, Orbit Error PRN-31 (SVN-52) Using C/A Nav Data

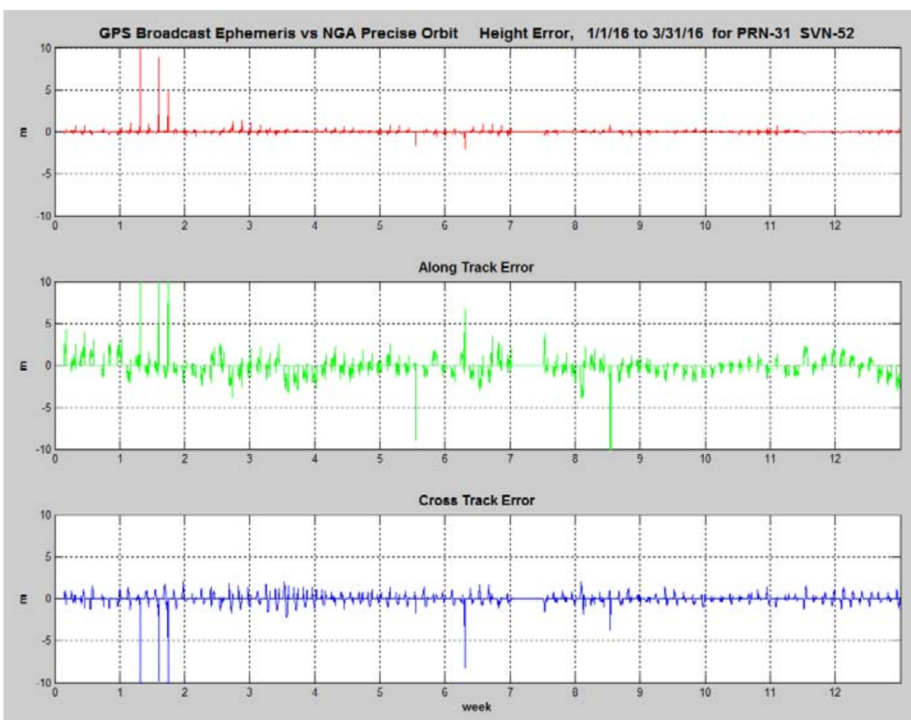


Figure 11-4.47, Orbit Error PRN-31 (SVN-52) Using L2C CNAV Data

Figure 11-4.48, Orbit Error PRN-32 (SVN-23) Using C/A Nav Data

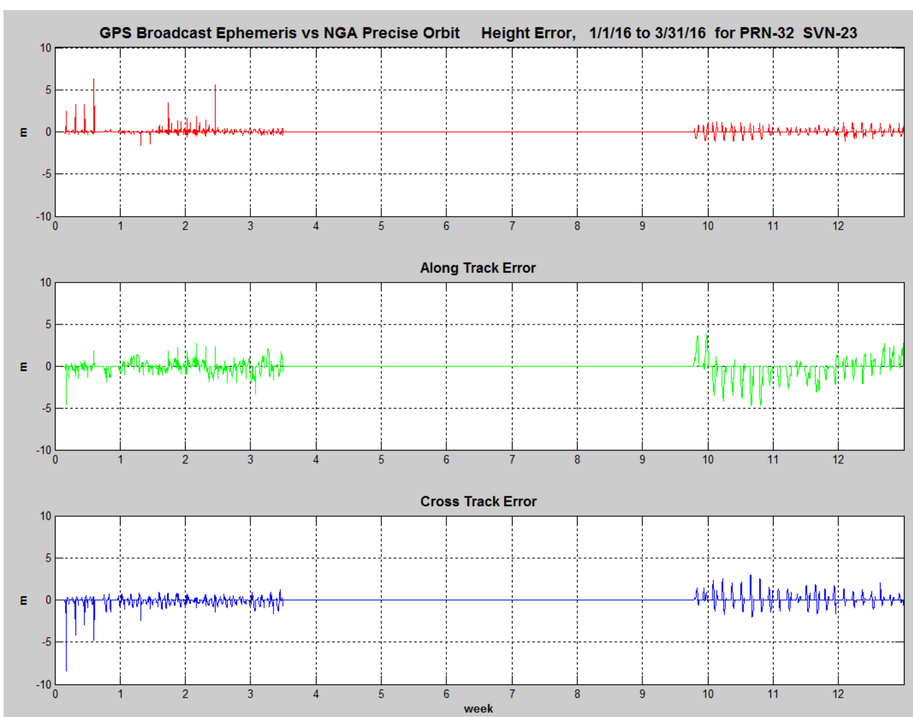


Figure 11-6 QQ Plots of URA Normalized Error for All Satellites

Figure 11-5.1, QQ Plots of Range Error PRNs 1 to 5 Using C/A Nav Data

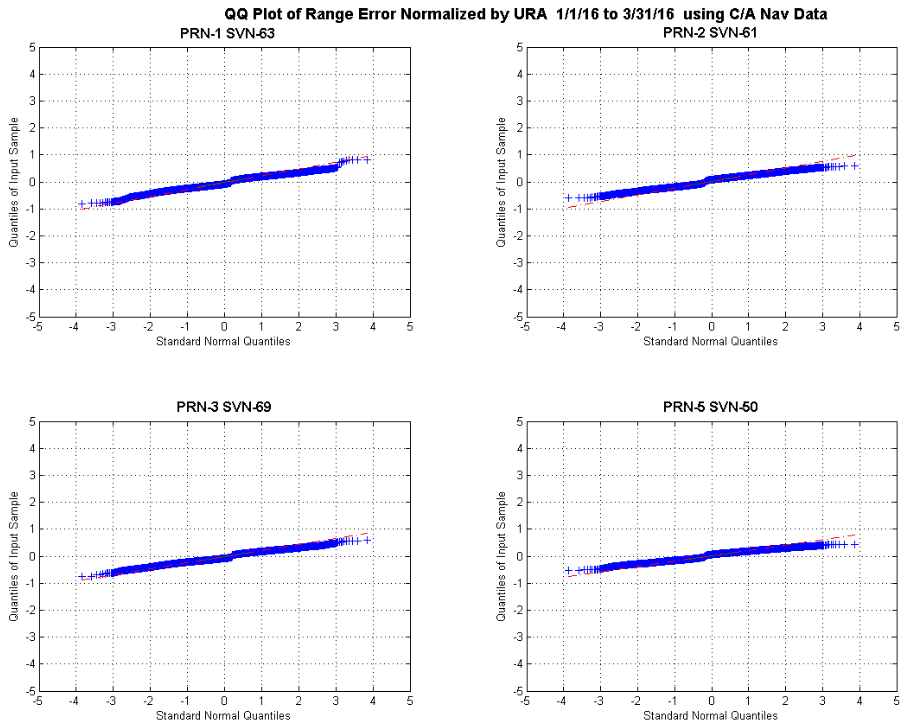


Figure 11-5.2, QQ Plots of Range Error PRNs 6 to 9 Using C/A Nav Data

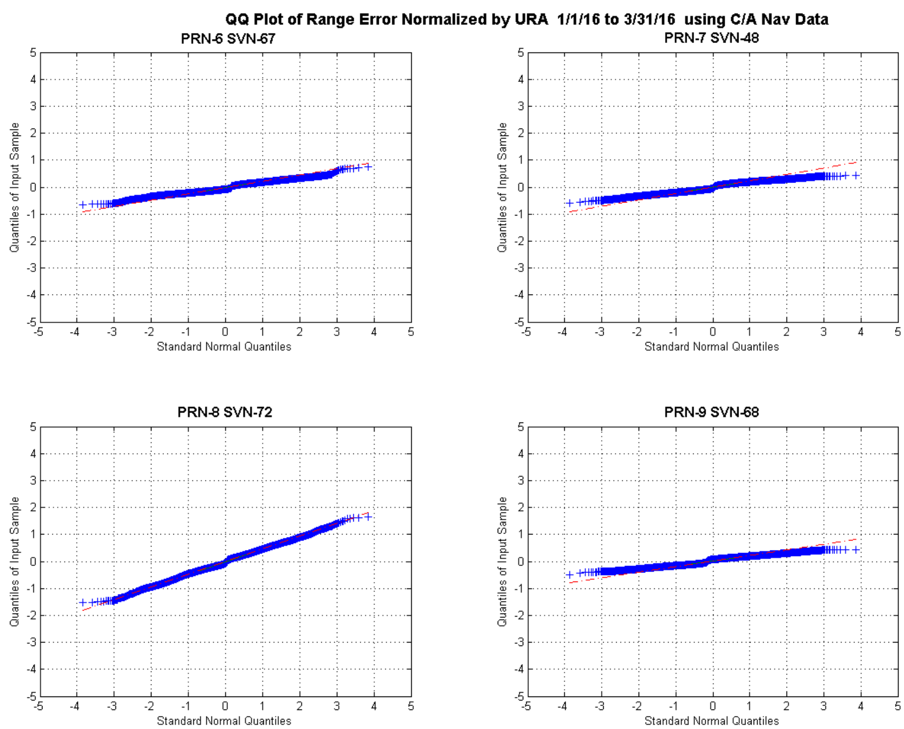


Figure 11-5.3, QQ Plots of Range Error PRNs 10 to 13 Using C/A Nav Data

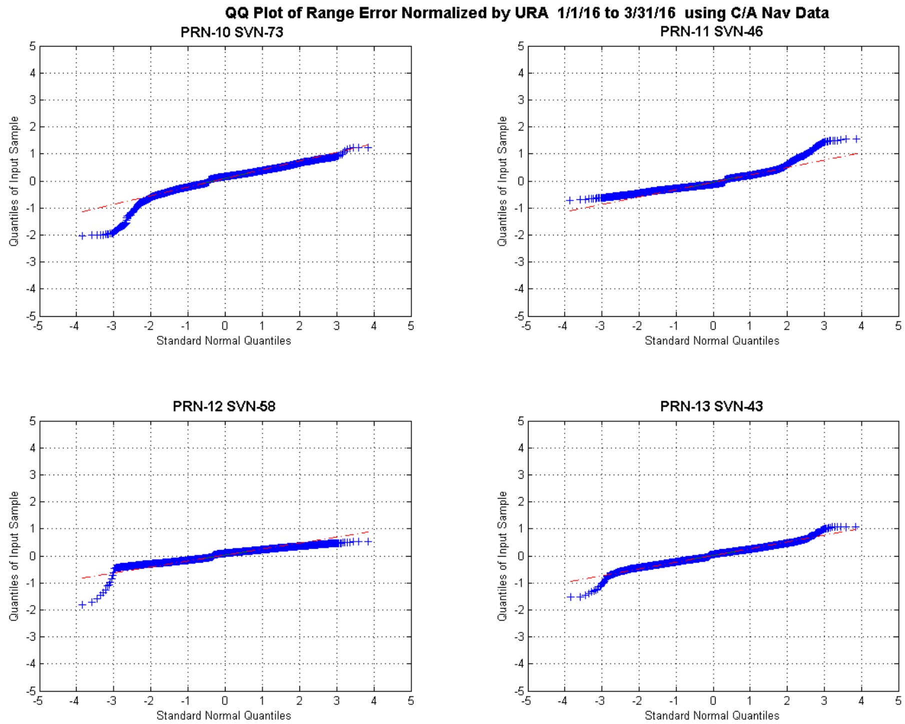


Figure 11-5.4, QQ Plots of Range Error PRNs 14 to 17 Using C/A Nav Data

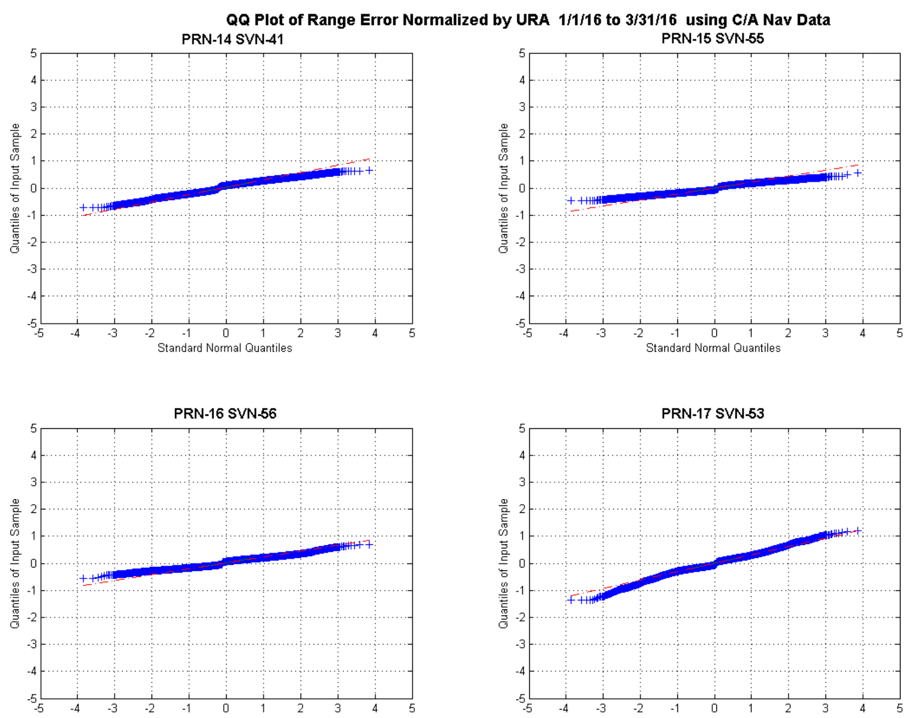


Figure 11-5.5, QQ Plots of Range Error PRNs 18 to 21 Using C/A Nav Data

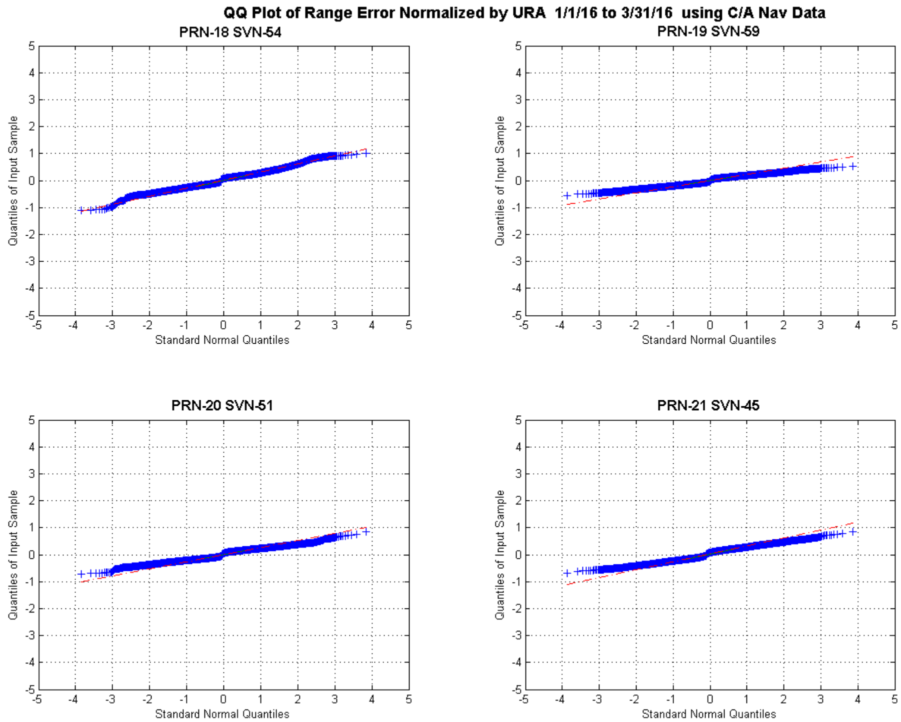


Figure 11-5.6, QQ Plots of Range Error PRNs 22 to 25 Using C/A Nav Data

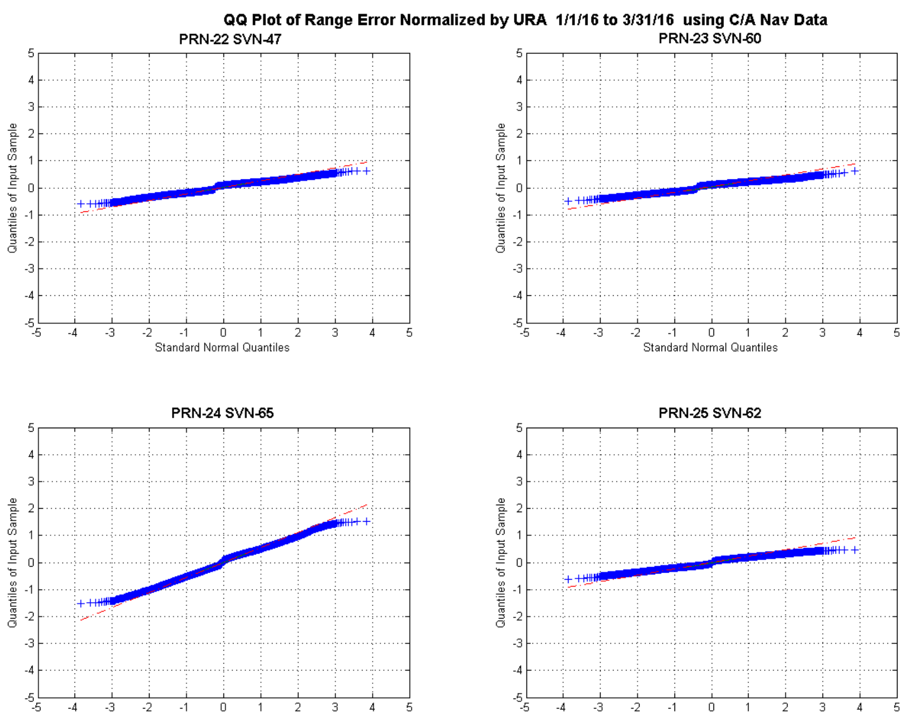


Figure 11-5.7, QQ Plots of Range Error PRNs 26 to 29 Using C/A Nav Data

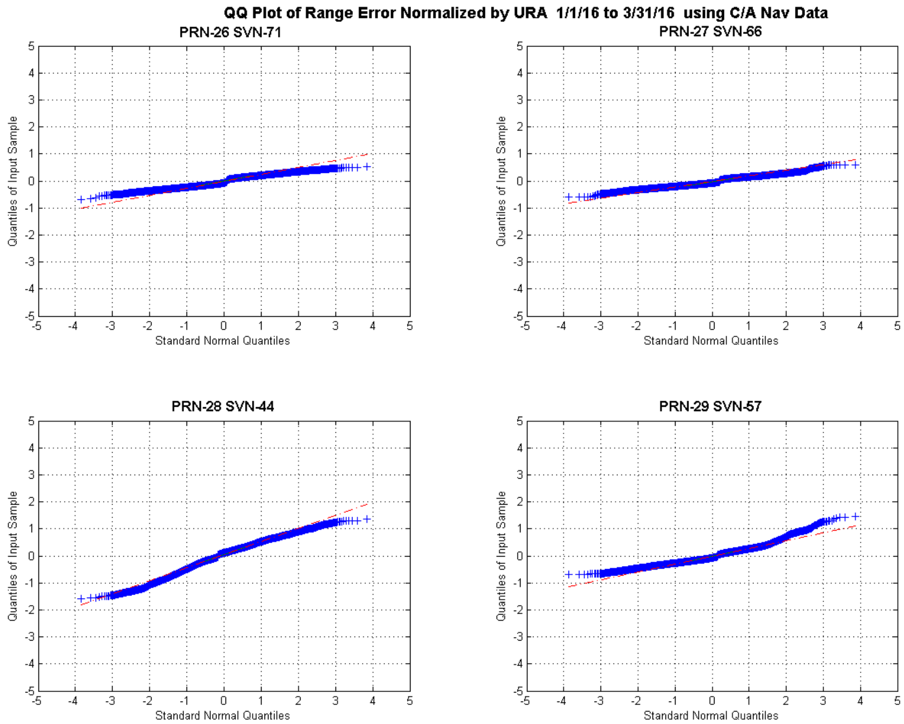


Figure 11-5.8, QQ Plots of Range Error PRNs 30 to 32 Using C/A Nav Data

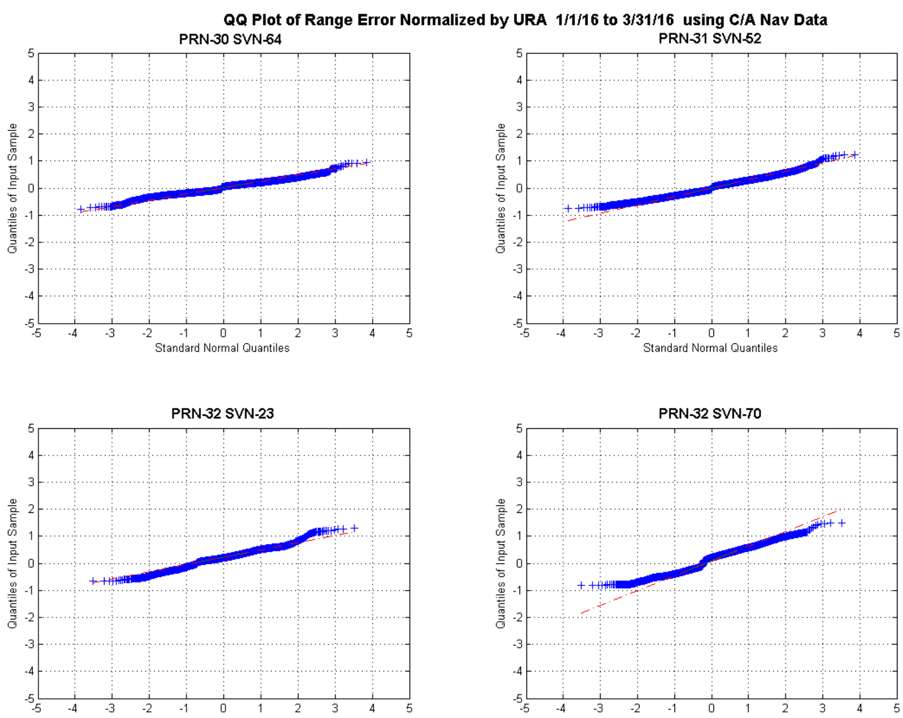


Figure 11-5.9, QQ Plots of Range Error PRNs 1, 3, 5, and 6 Using L2C CNAV Data

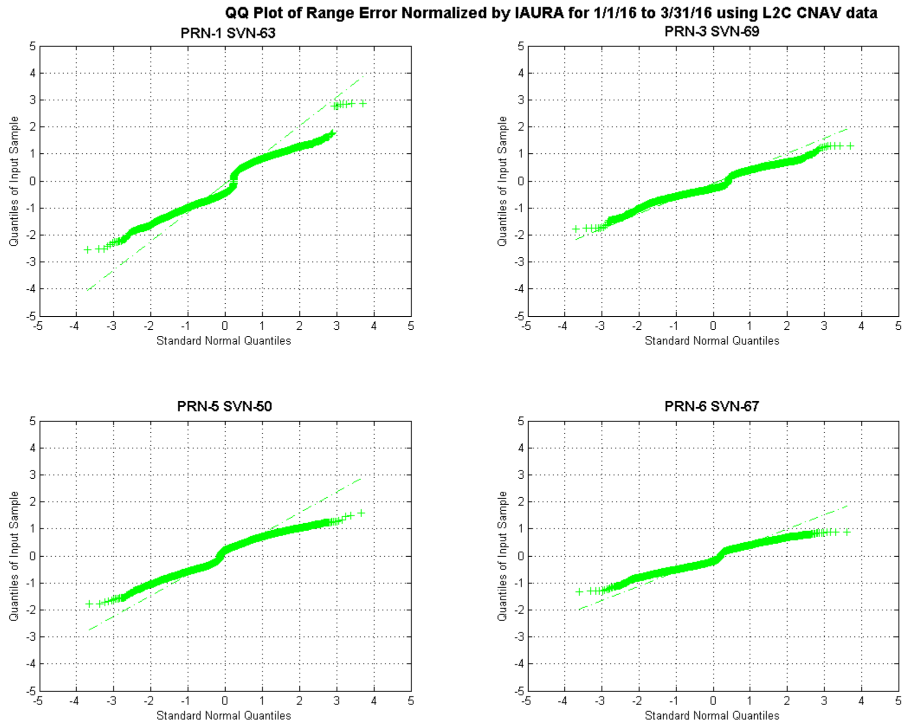


Figure 11-5.10, QQ Plots of Range Error PRNs 7, 8, 9, and 12 Using L2C CNAV Data

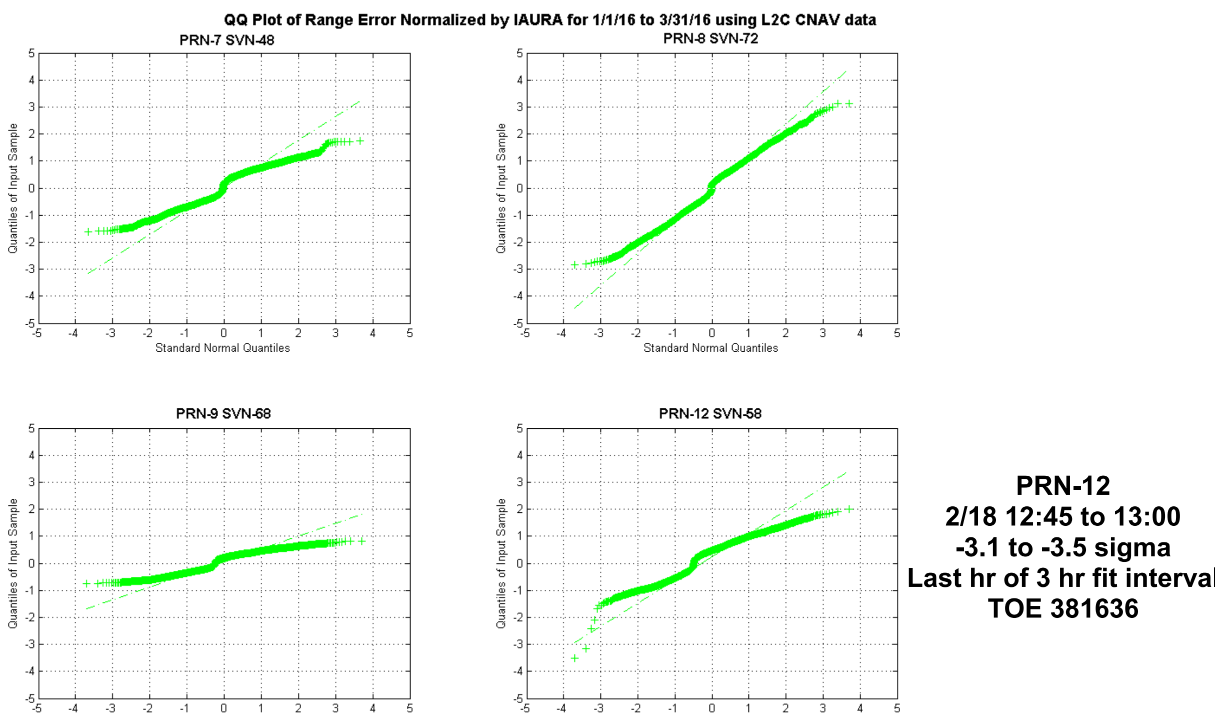


Figure 11-5.11, QQ Plots of Range Error PRNs 15, 17, 24, and 25 Using L2C CNAV Data

PRN-15
3/4 09:30 to 13:00
-2.99 to -3.61 sigma
-1.6m to -1.9m error
Total IAURA only
0.46m to 0.58m

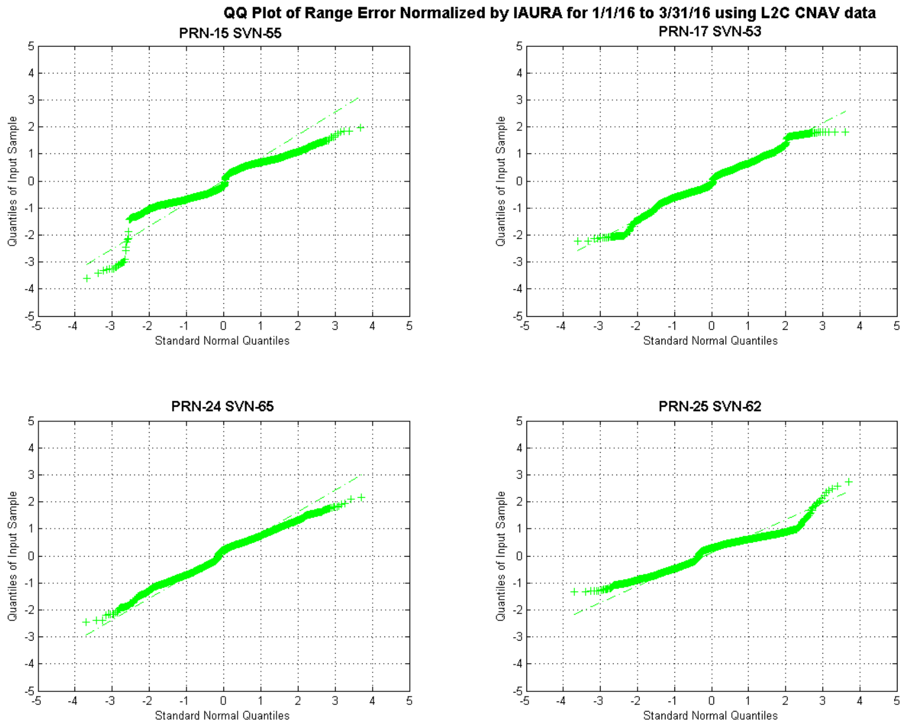
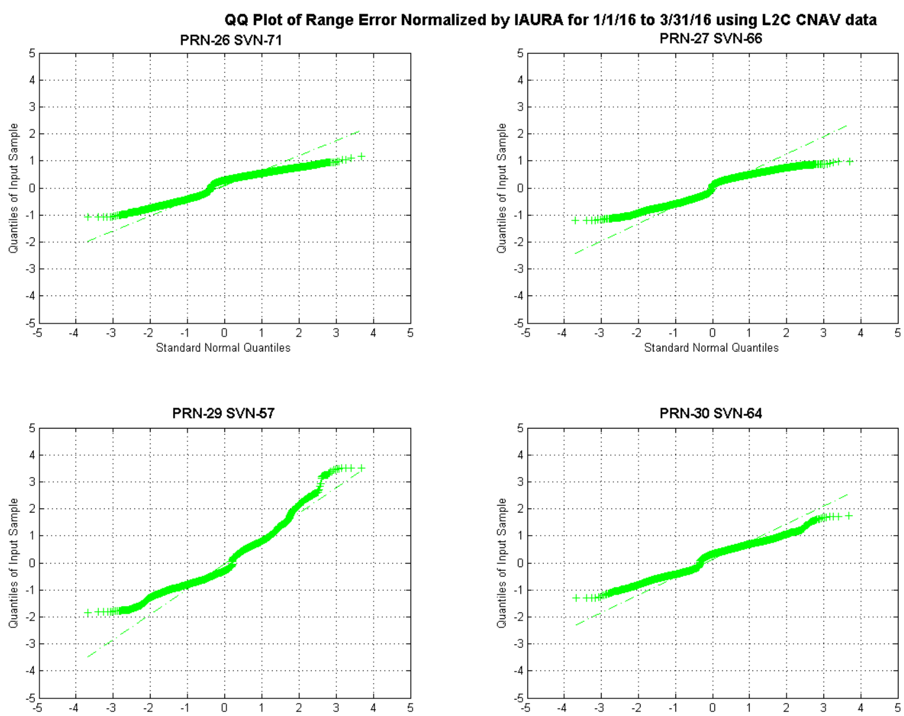


Figure 11-5.12, QQ Plots of Range Error PRNs 26, 27, 29, and 30 Using L2C CNAV Data



PRN-29
2/13 20:00 to 2/14 01:00
-3.13 to -3.52 sigma
-2.9m to -3.6m error
Total IAURA only
0.9m to 1.03m

Figure 11-5.13, QQ Plots of Range Error PRN-31 Using L2C CNAV Data

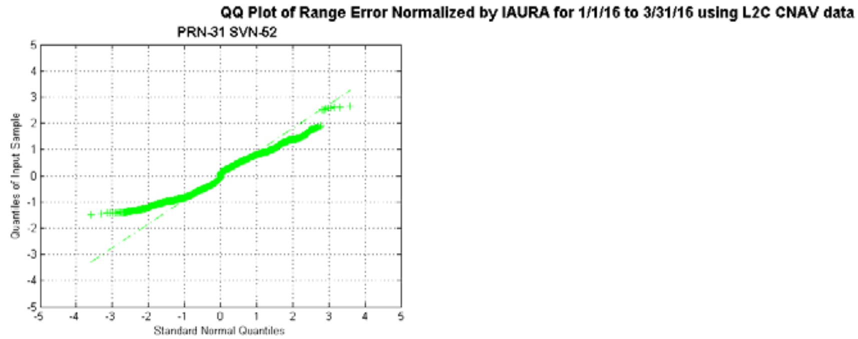


Figure 11-7 Histogram Plots of H, A, C, and Range Error for All Satellites

Figure 11-6.1 Histograms of H, A, C, and Range Error PRN-1 Using C/A Nav Data

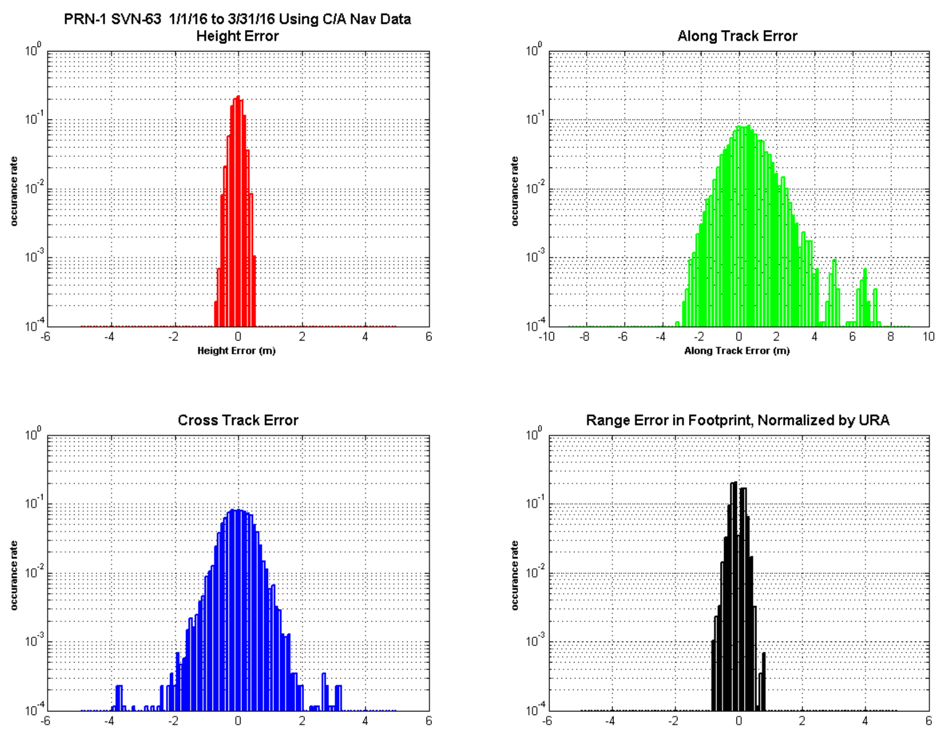


Figure 11-6.2, Histograms of H, A, C, and Range Error PRN-1 Using L2C CNAV Data

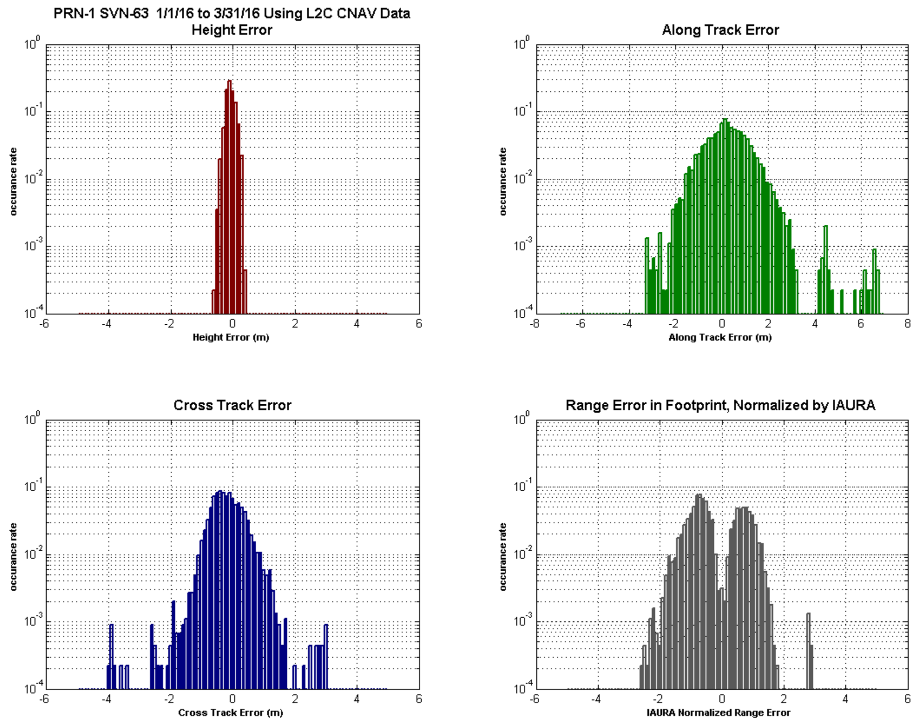


Figure 11-6.3, Histograms of H, A, C, and Range Error PRN-2 Using C/A Nav Data

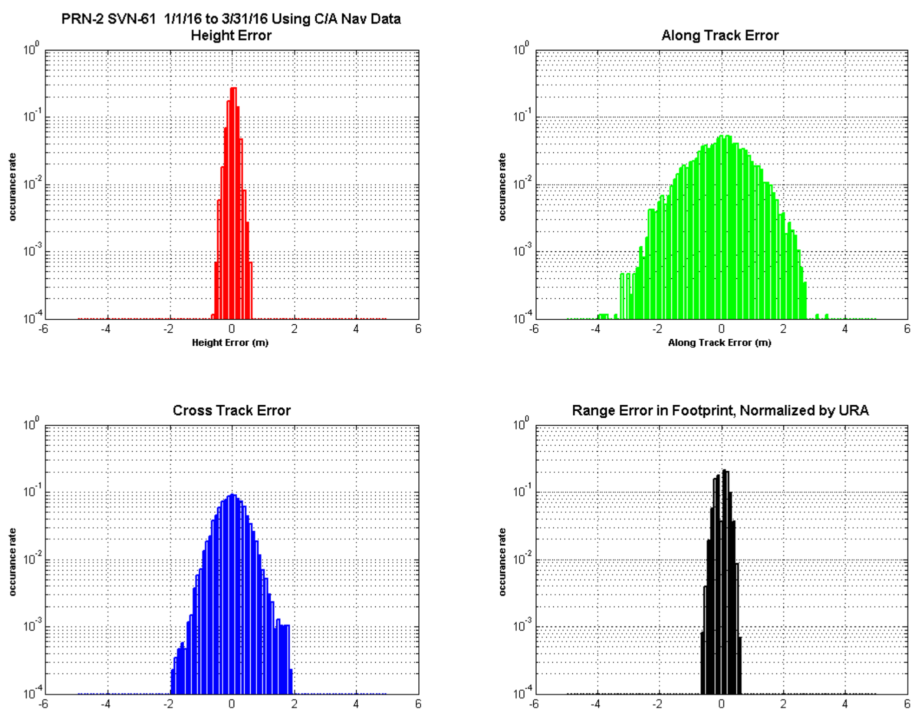


Figure 11-6.4, Histograms of H, A, C, and Range Error PRN-3 Using C/A Nav Data

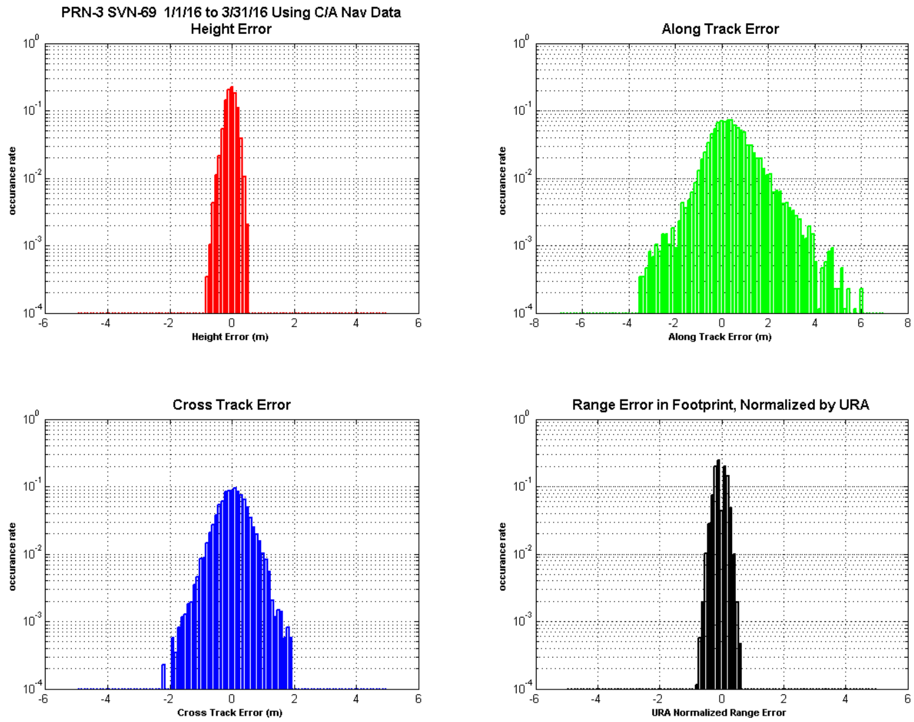


Figure 11-6.5, Histograms of H, A, C, and Range Error PRN-3 Using L2C CNAV

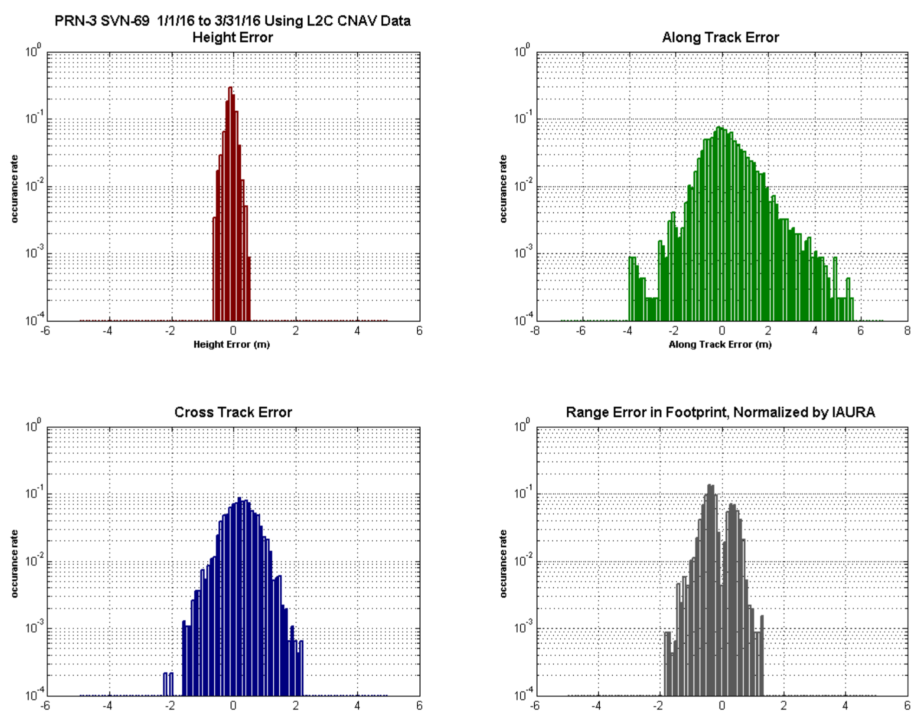


Figure 11-6.6, Histograms of H, A, C, and Range Error PRN-4 Using C/A Nav Data

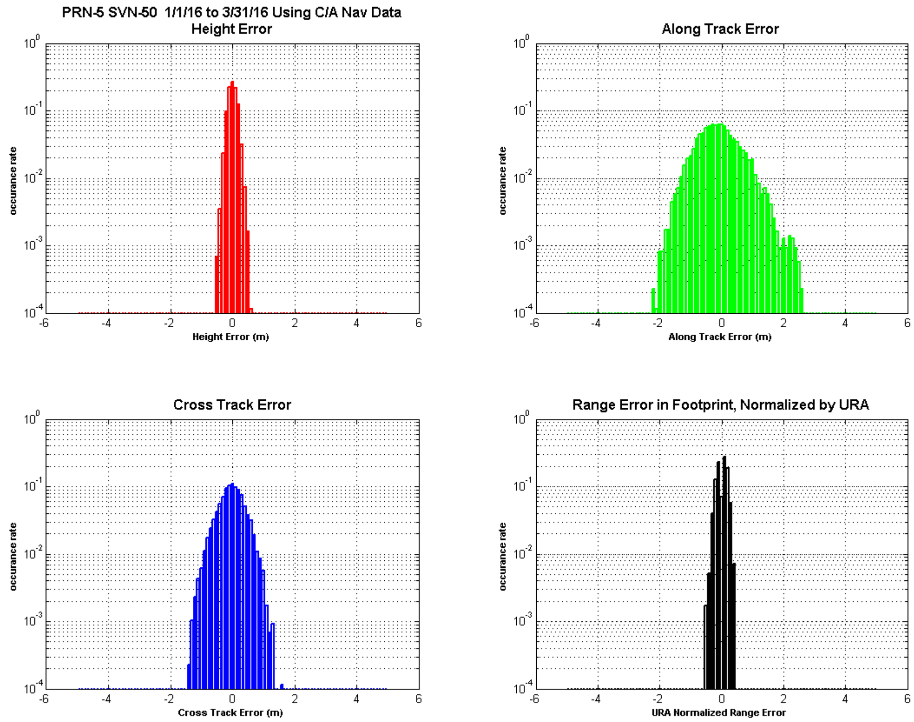


Figure 11-6.7, Histograms of H, A, C, and Range Error PRN-5 Using C/A Nav Data

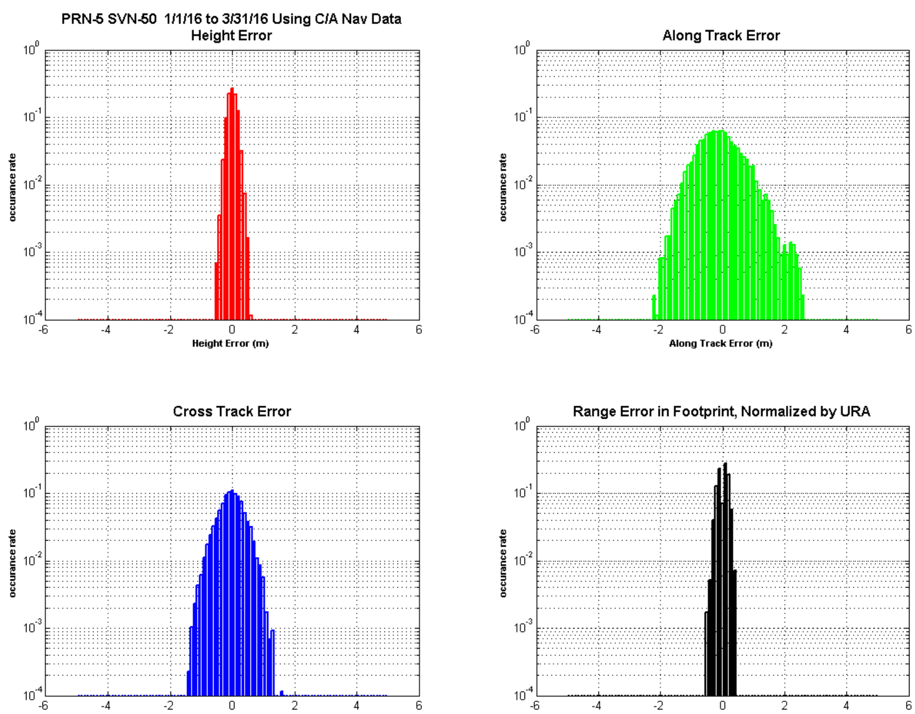


Figure 11-6.8, Histograms of H, A, C, and Range Error PRN-5 Using L2C CNAV Data

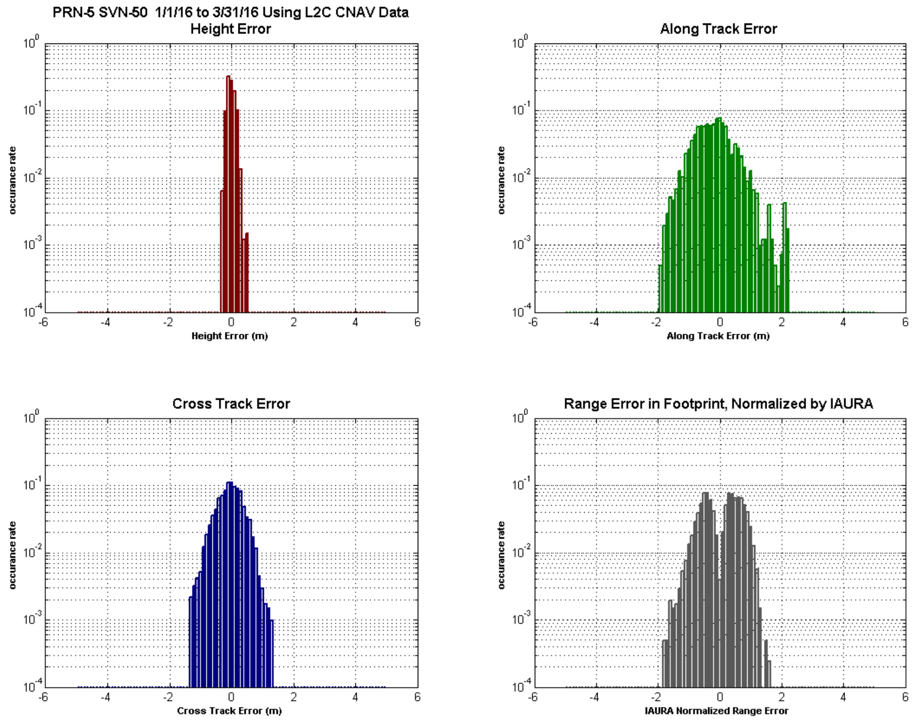


Figure 11-6.9, Histograms of H, A, C, and Range Error PRN-6 Using C/A Nav Data

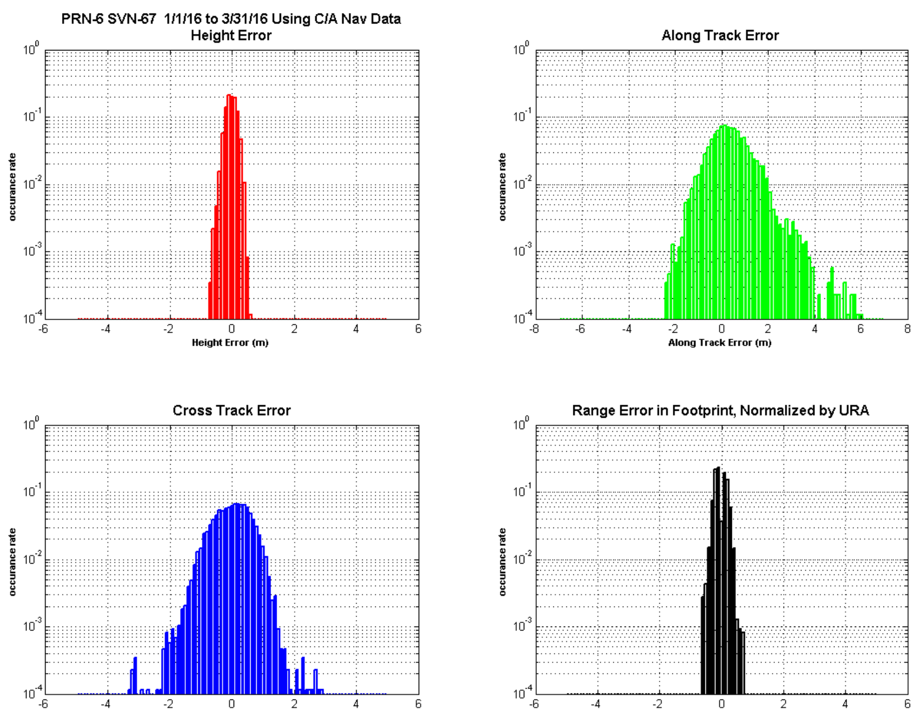


Figure 11-6.10, Histograms of H, A, C, and Range Error PRN-6 Using L2C CNAV Data

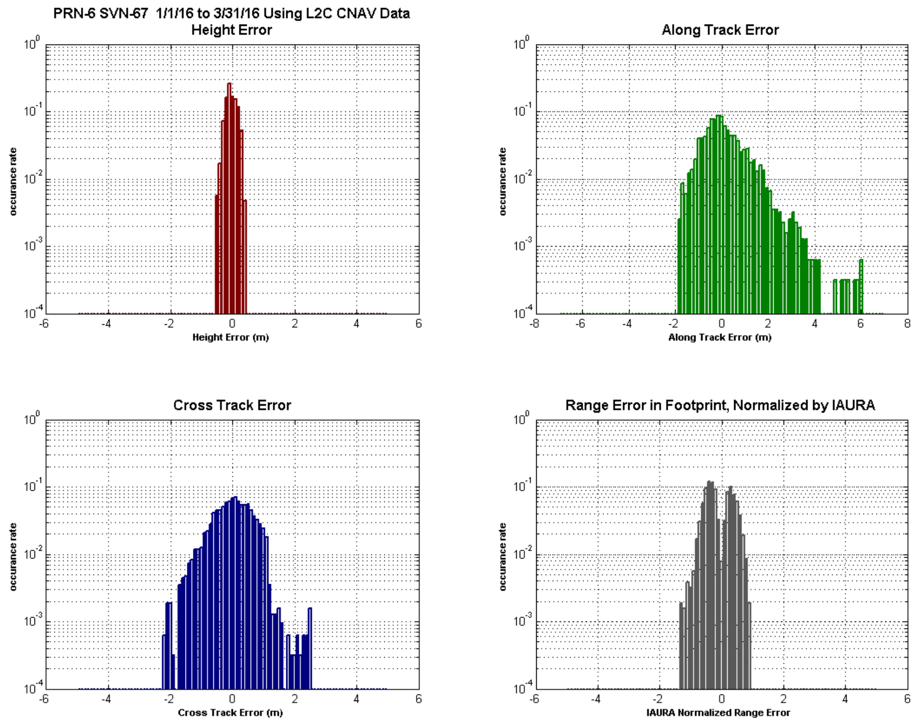


Figure 11-6.11, Histograms of H, A, C, and Range Error PRN-7 Using C/A Nav Data

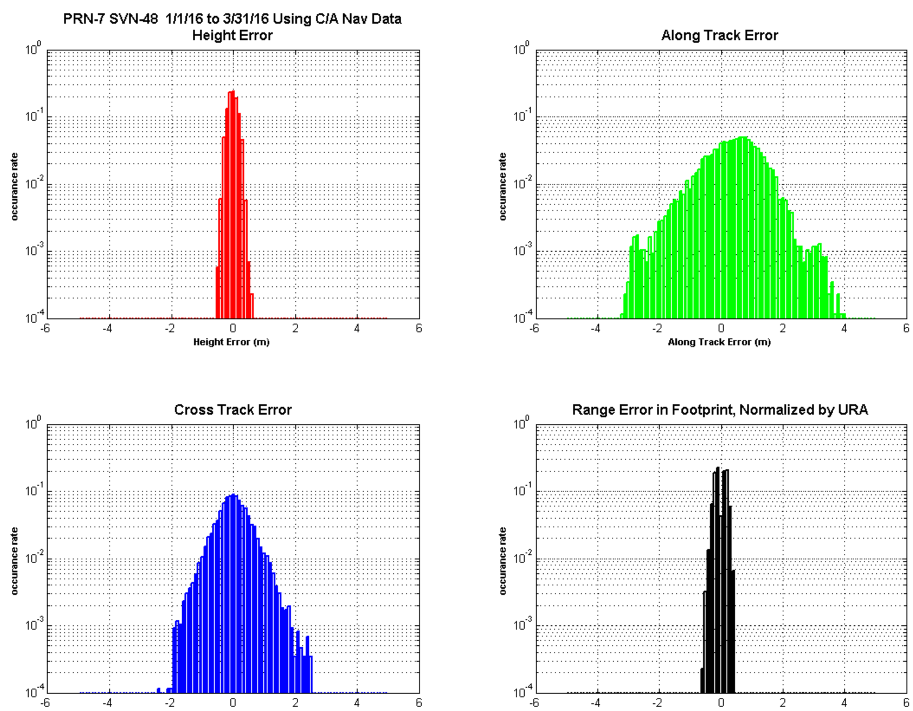


Figure 11-6.12, Histograms of H, A, C, and Range Error PRN-7 Using L2C CNAV Data

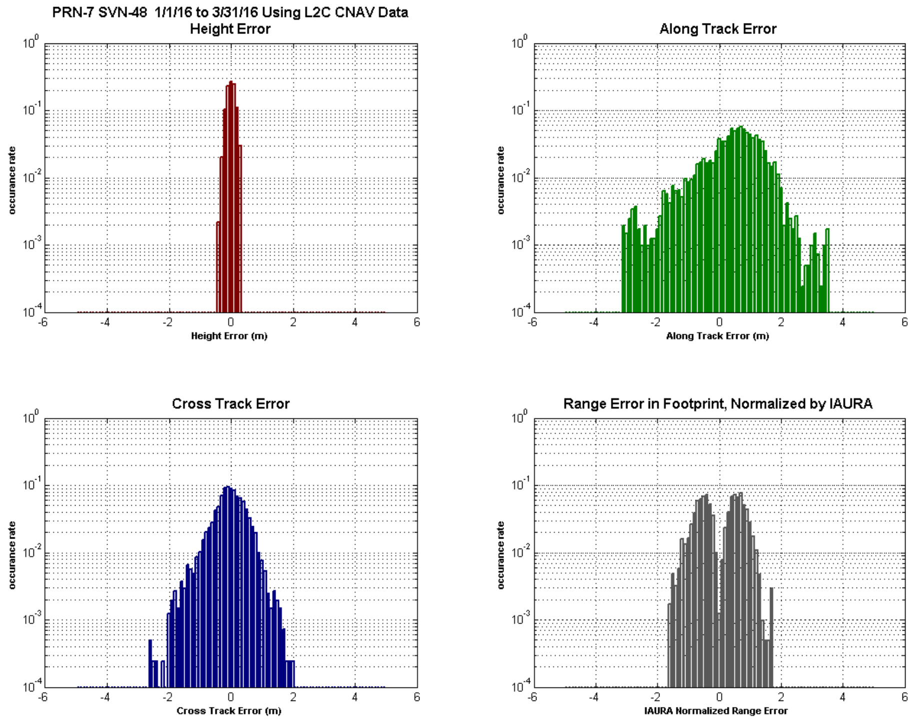


Figure 11-6.13, Histograms of H, A, C, and Range Error PRN-8 Using C/A Nav Data

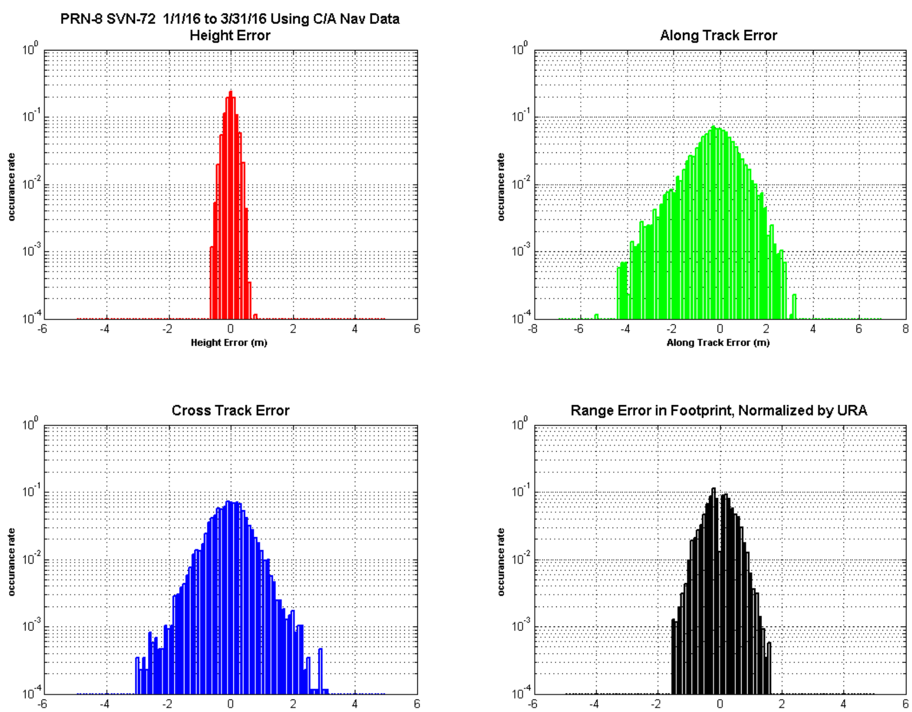


Figure 11-6.14, Histograms of H, A, C, and Range Error PRN-8 Using L2C CNAV Data

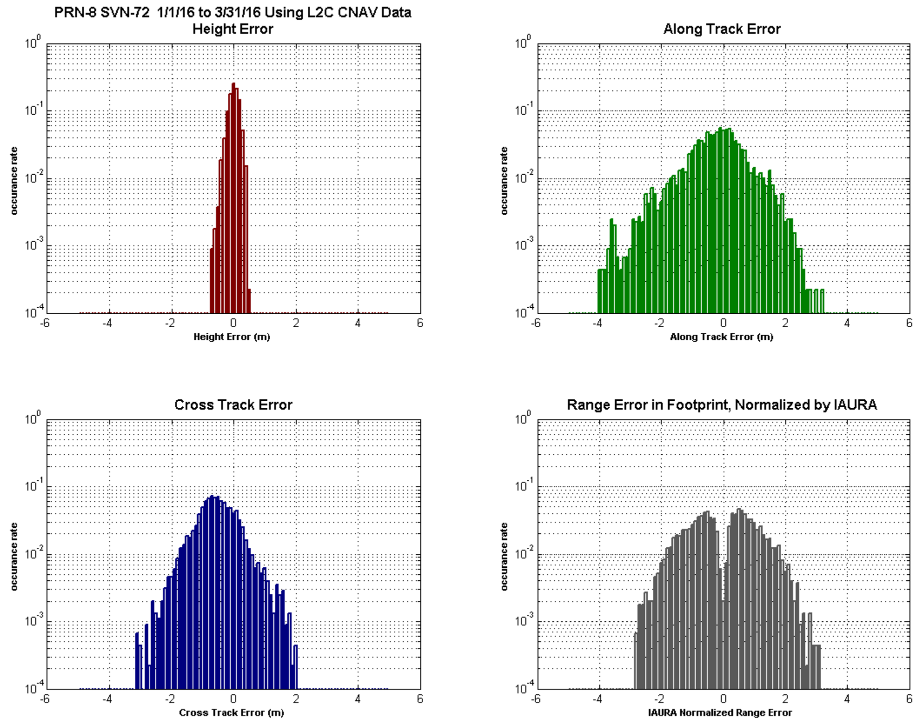


Figure 11-6.15, Histograms of H, A, C, and Range Error PRN-9 Using C/A Nav Data

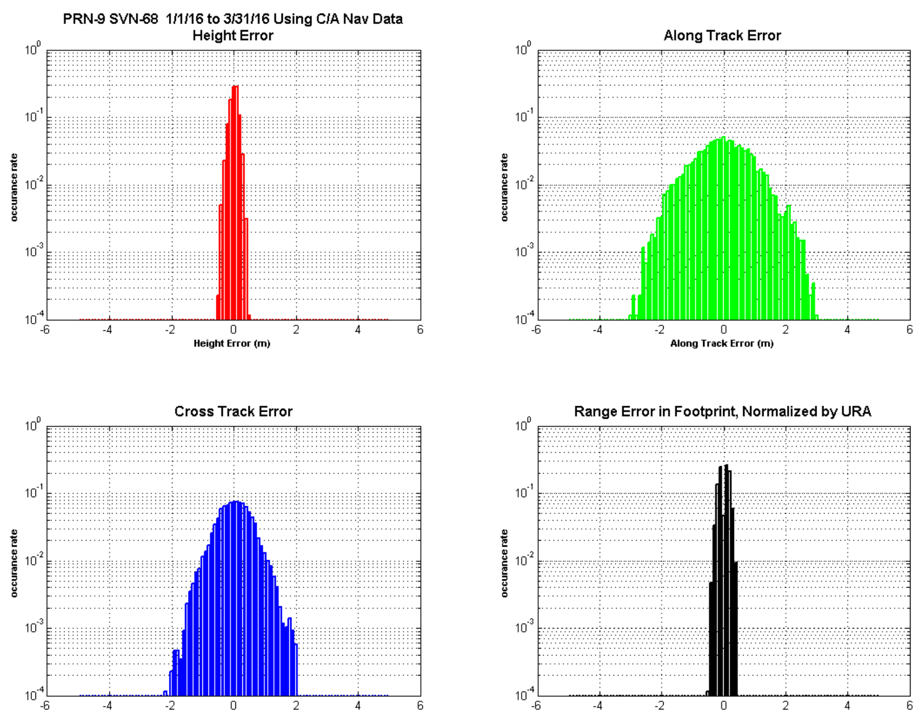


Figure 11-6.16, Histograms of H, A, C, and Range Error PRN-9 Using L2C CNAV Data

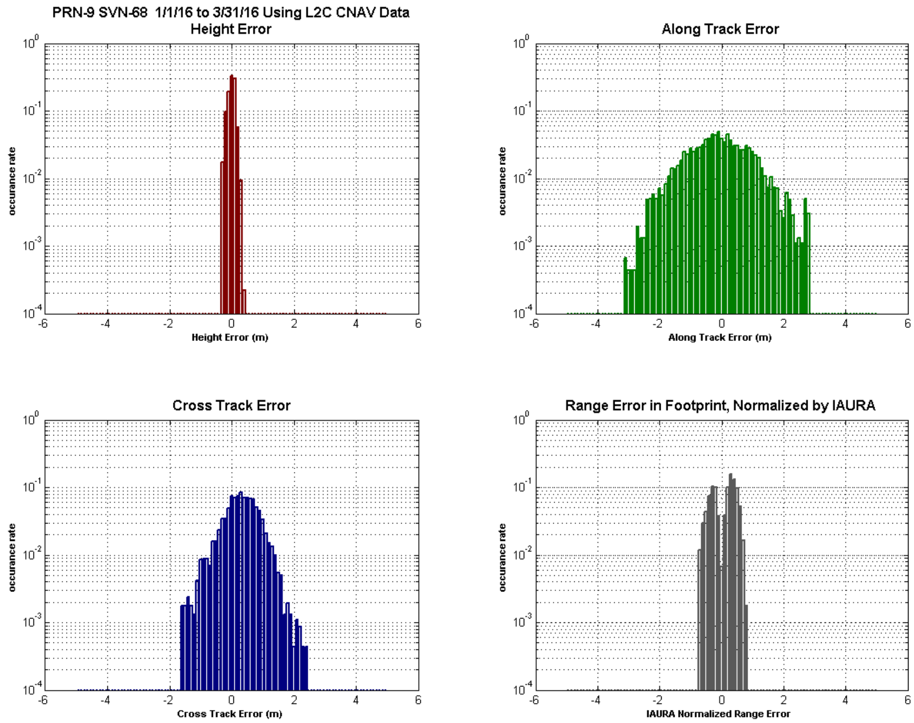


Figure 11-6.17, Histograms of H, A, C, and Range Error PRN-10 Using C/A Nav Data

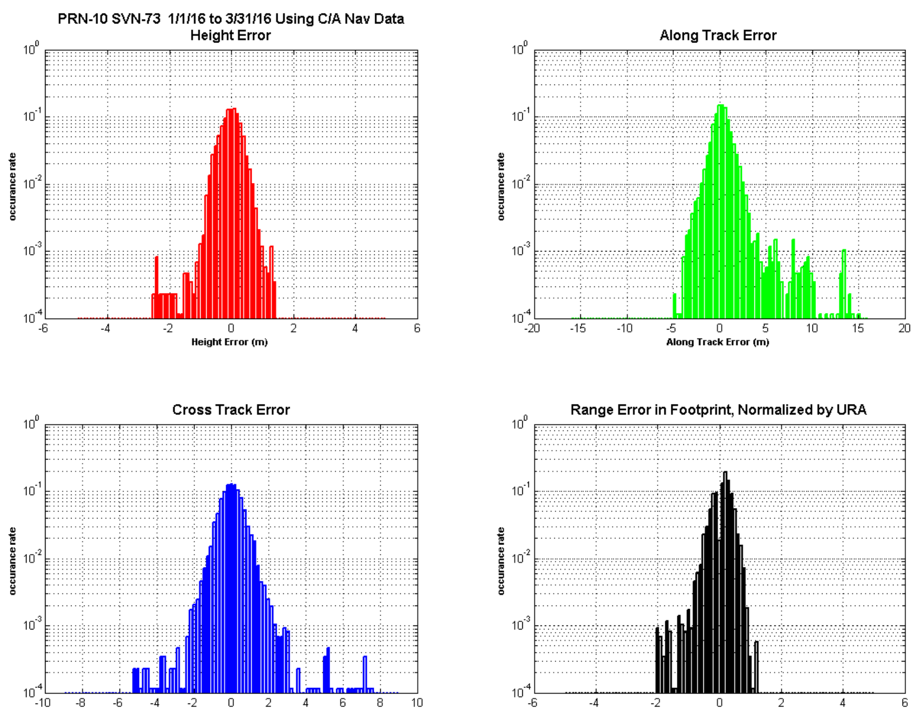


Figure 11-6.18, Histograms of H, A, C, and Range Error PRN-11 Using C/A Nav Data

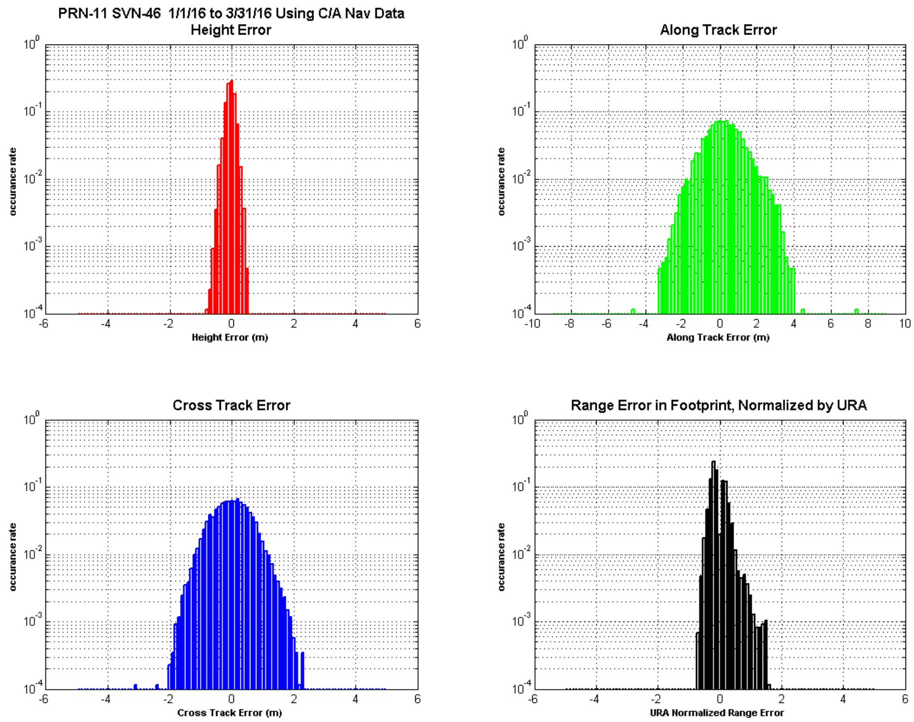


Figure 11-6.19, Histograms of H, A, C, and Range Error PRN-12 Using C/A Nav Data

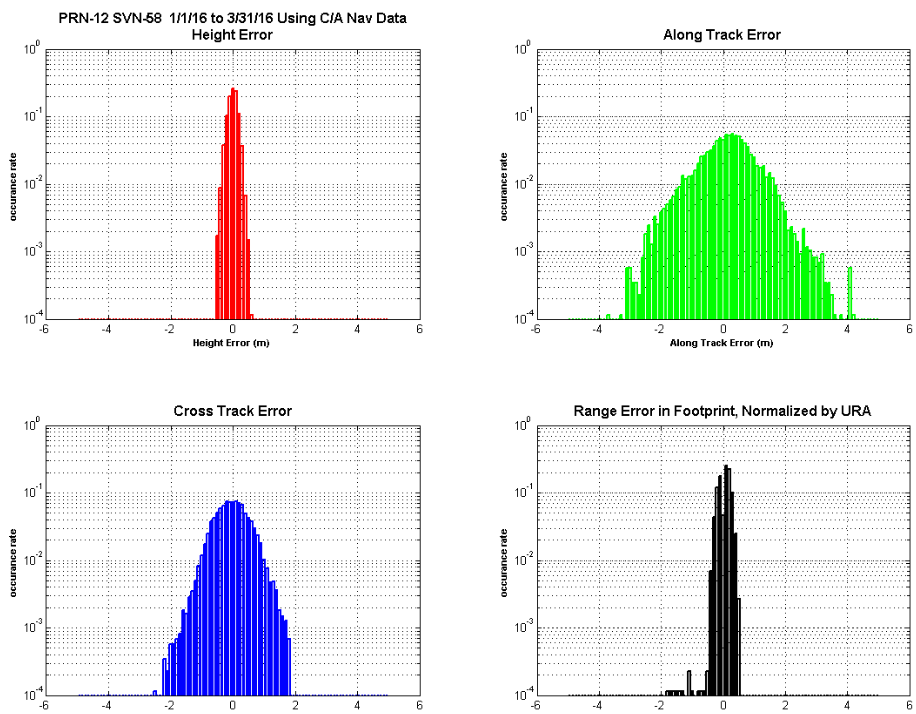


Figure 11-6.20, Histograms of H, A, C, and Range Error PRN-12 Using L2C CNAV Data

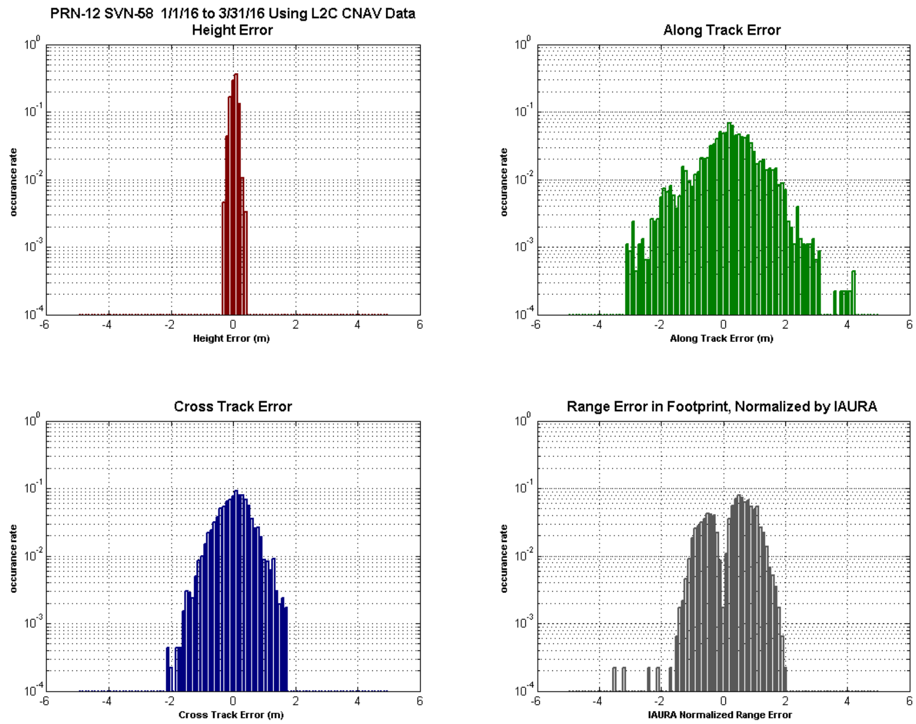


Figure 11-6.21, Histograms of H, A, C, and Range Error PRN-13 Using C/A Nav Data

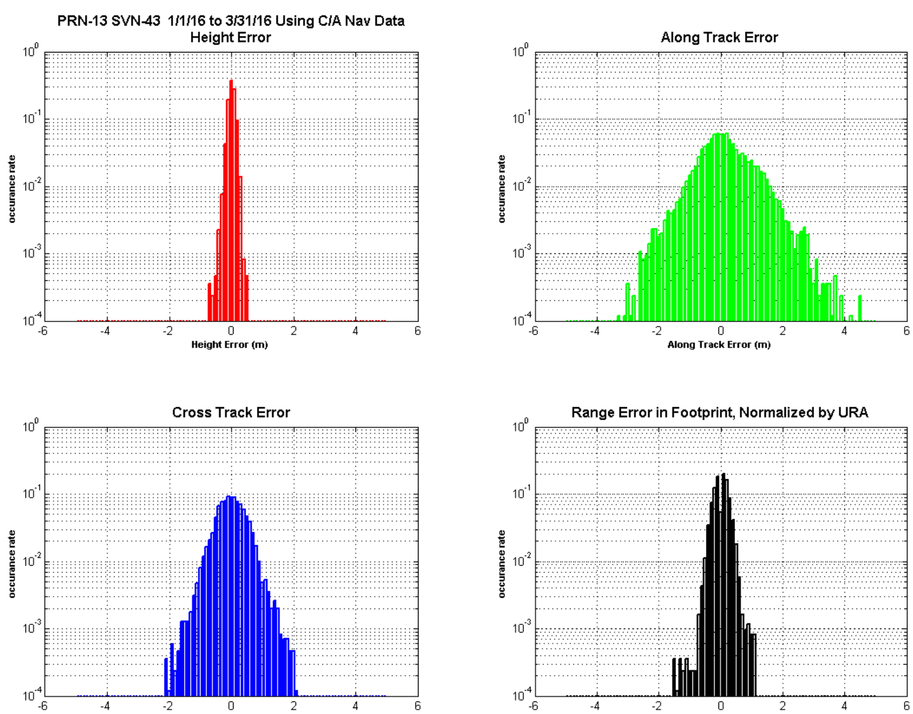


Figure 11-6.22, Histograms of H, A, C, and Range Error PRN-14 Using C/A Nav Data

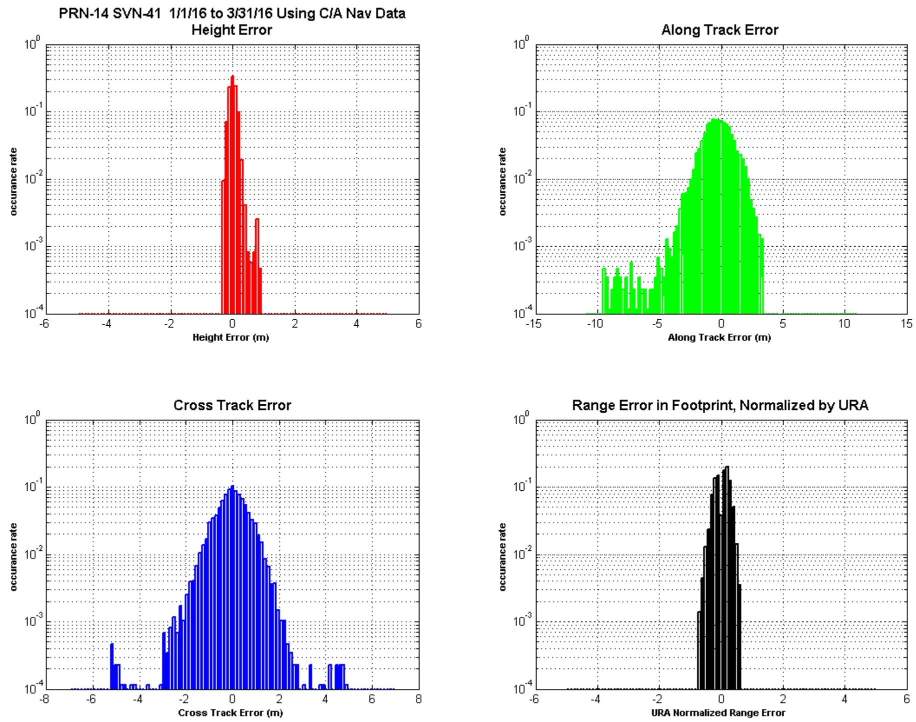


Figure 11-6.23, Histograms of H, A, C, and Range Error PRN-15 Using C/A Nav Data

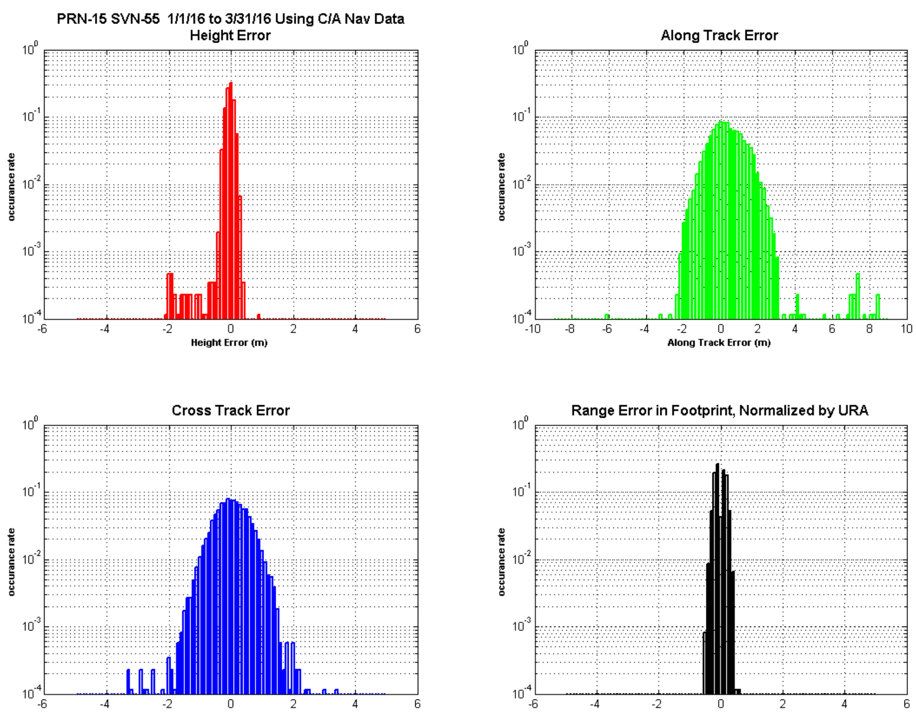


Figure 11-6.24, Histograms of H, A, C, and Range Error PRN-15 Using L2C CNAV Data

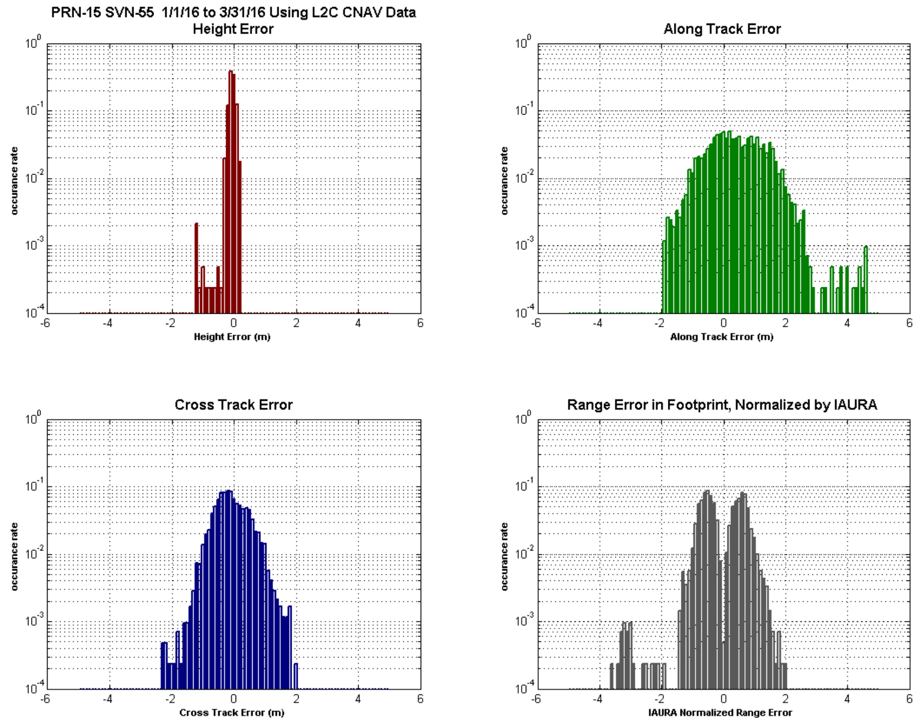


Figure 11-6.25, Histograms of H, A, C, and Range Error PRN-16 Using C/A Nav Data

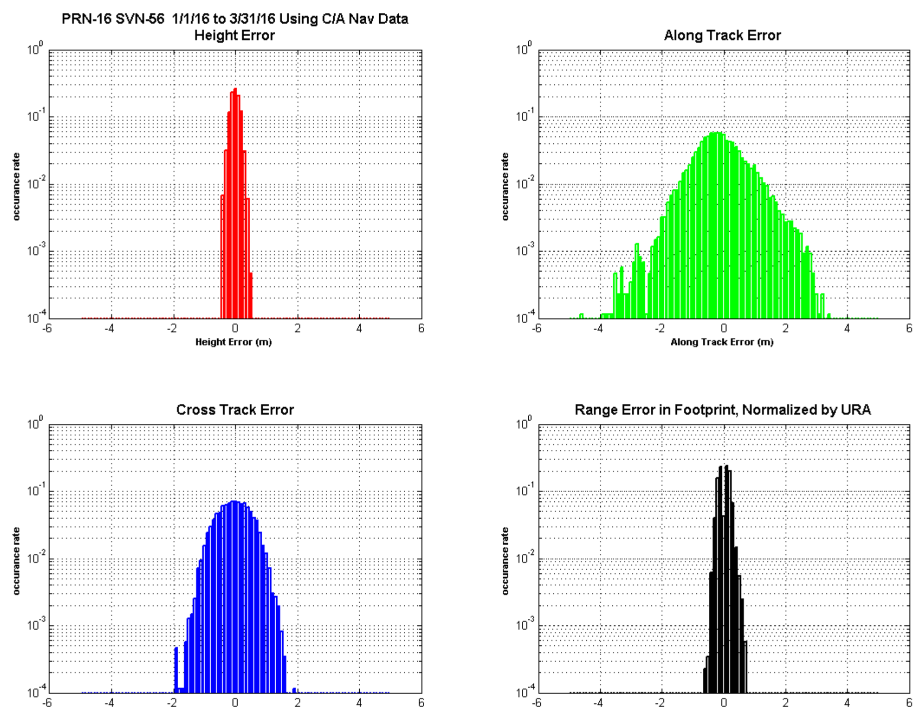


Figure 11-6.26, Histograms of H, A, C, and Range Error PRN-17 Using C/A Nav Data

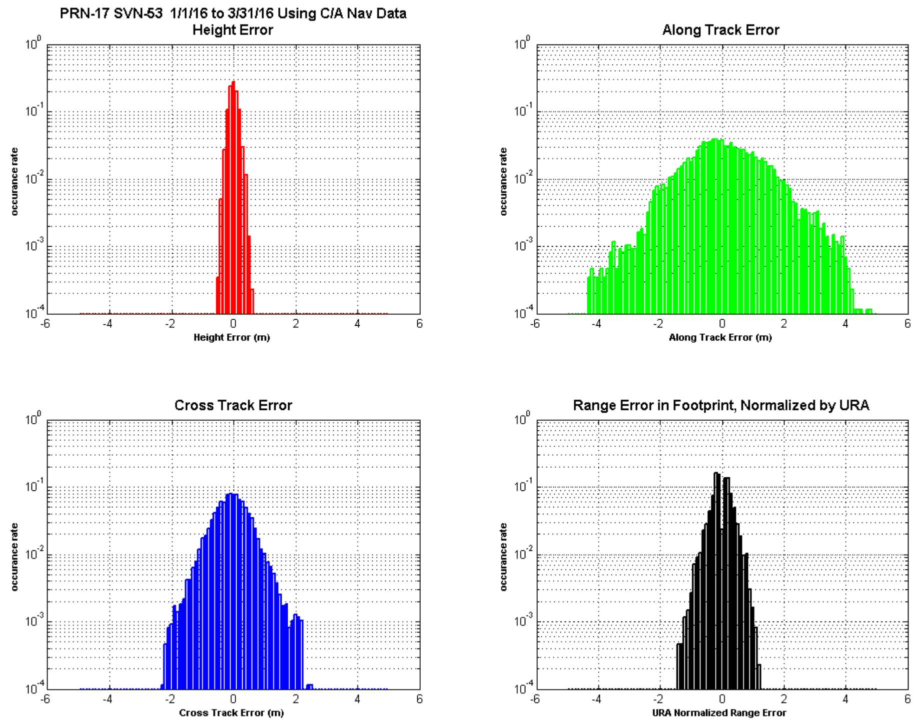


Figure 11-6.27 Histograms of H, A, C, and Range Error PRN-17 Using L2C CNAV Data

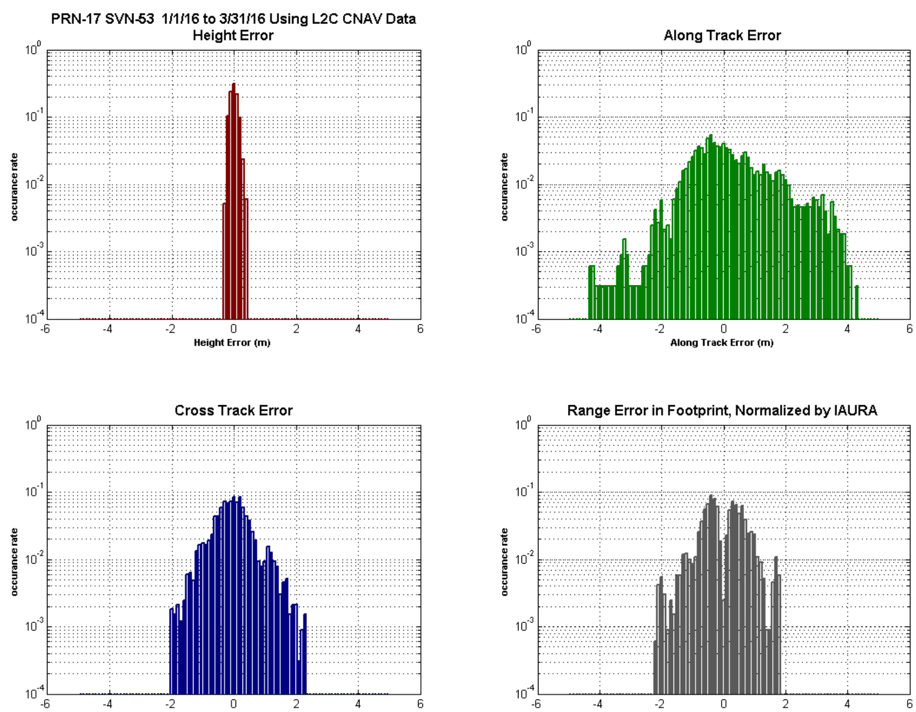


Figure 11-6.28, Histograms of H, A, C, and Range Error PRN-18 Using C/A Nav Data

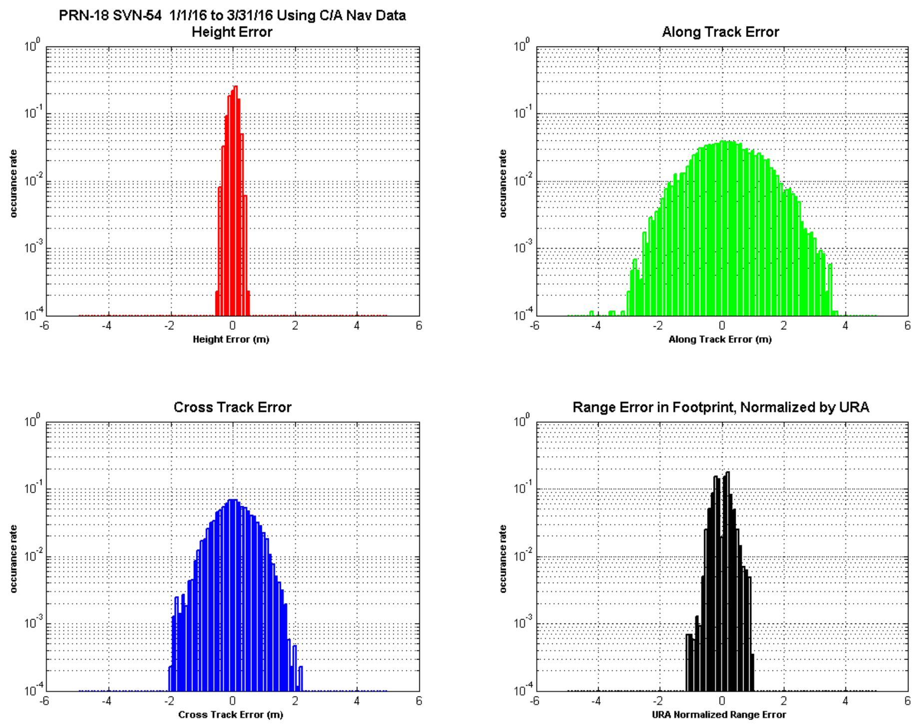


Figure 11-6.29, Histograms of H, A, C, and Range Error PRN-19 Using C/A Nav Data

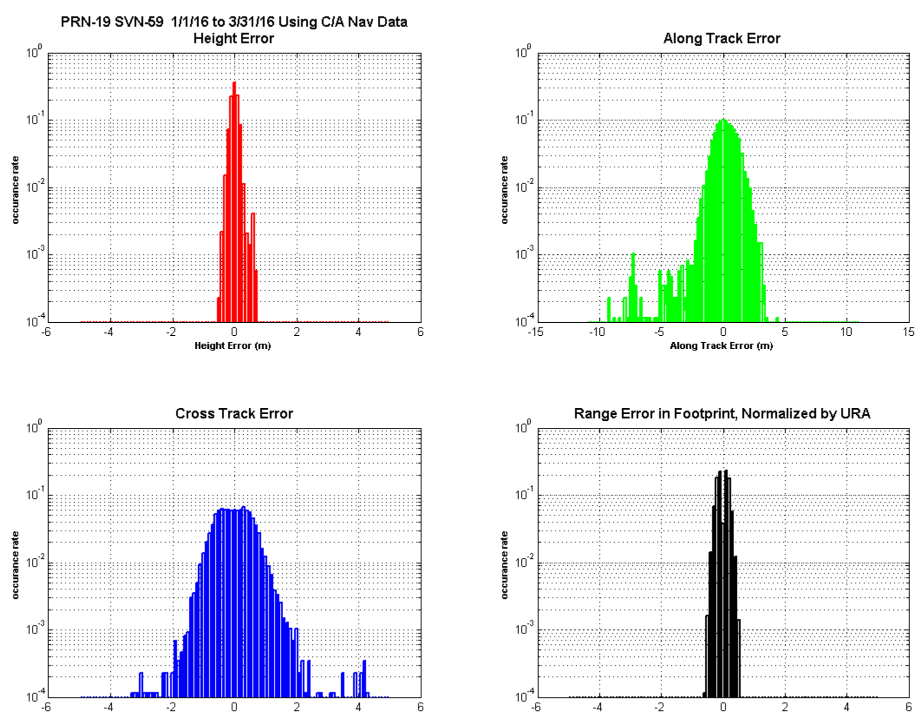


Figure 11-6.30, Histograms of H, A, C, and Range Error PRN-20 Using C/A Nav Data

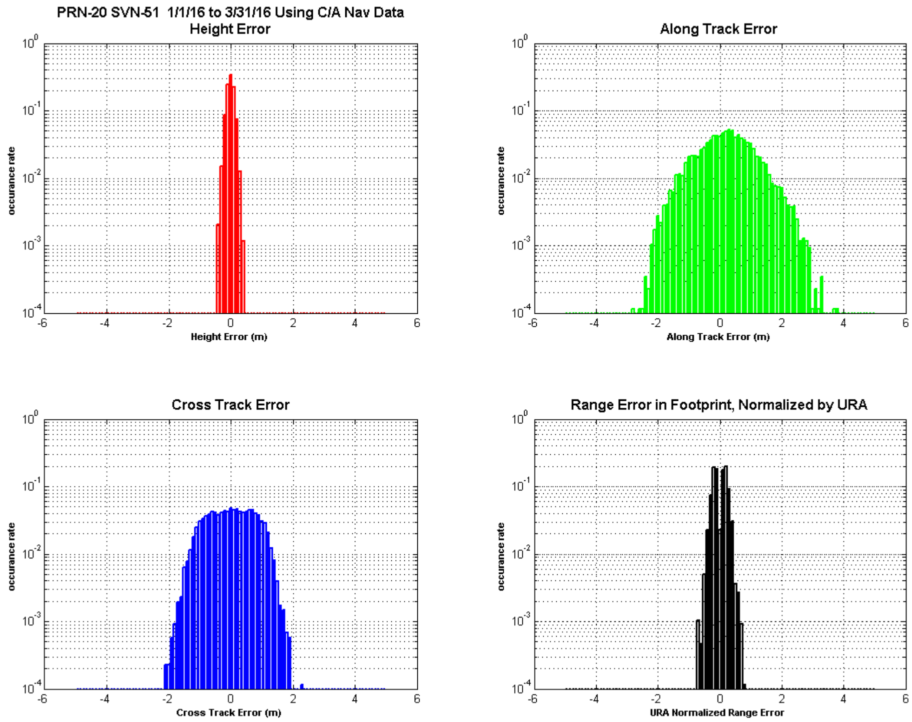


Figure 11-6.31, Histograms of H, A, C, and Range Error PRN-21 Using C/A Nav Data

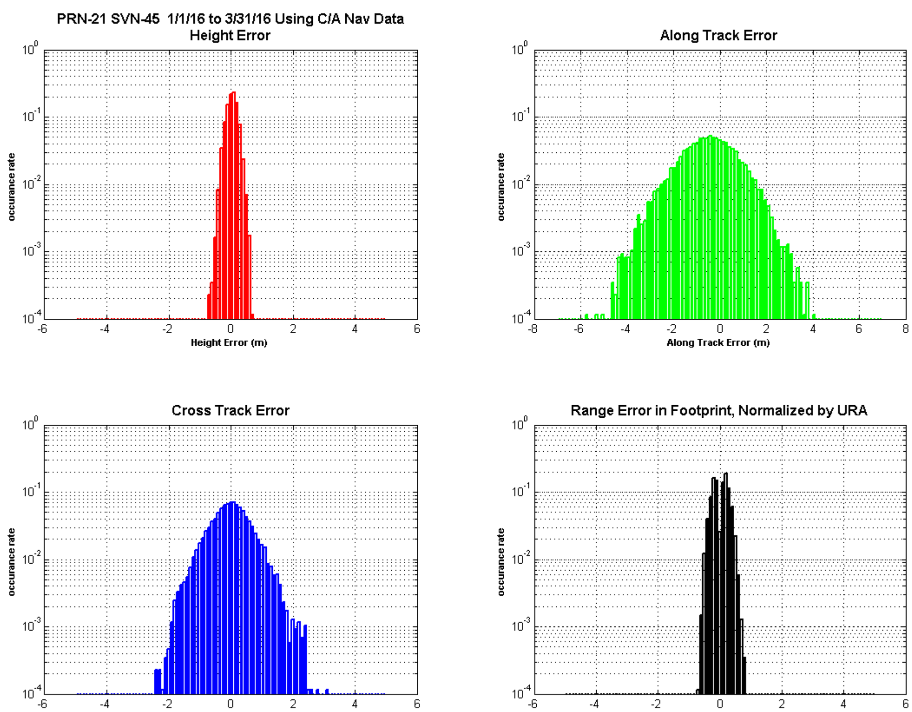


Figure 11-6.32, Histograms of H, A, C, and Range Error PRN-22 Using C/A Nav Data

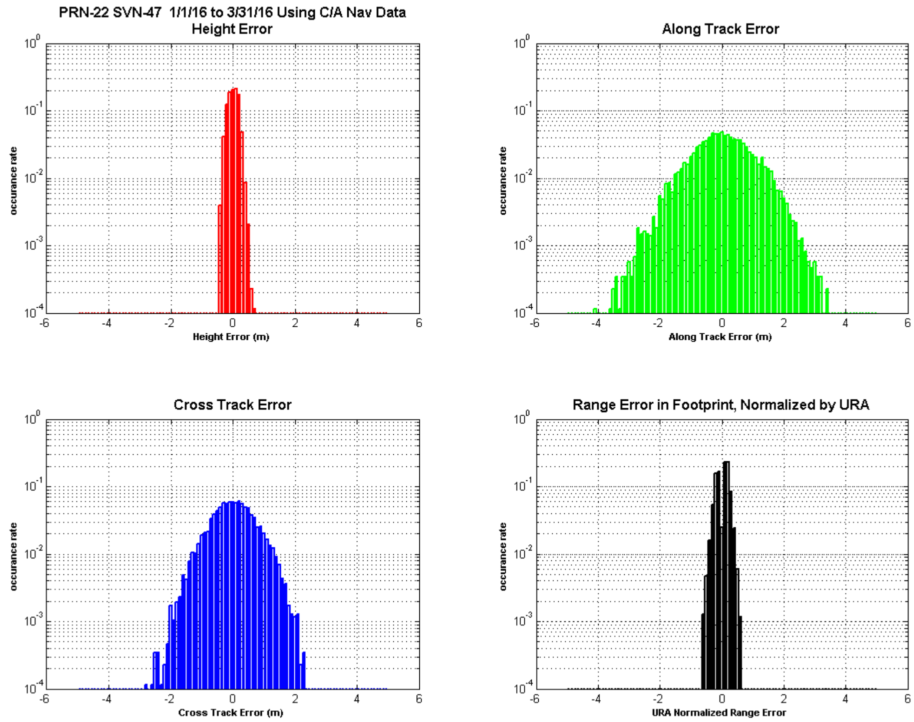


Figure 11-6.33, Histograms of H, A, C, and Range Error PRN-23 Using C/A Nav Data

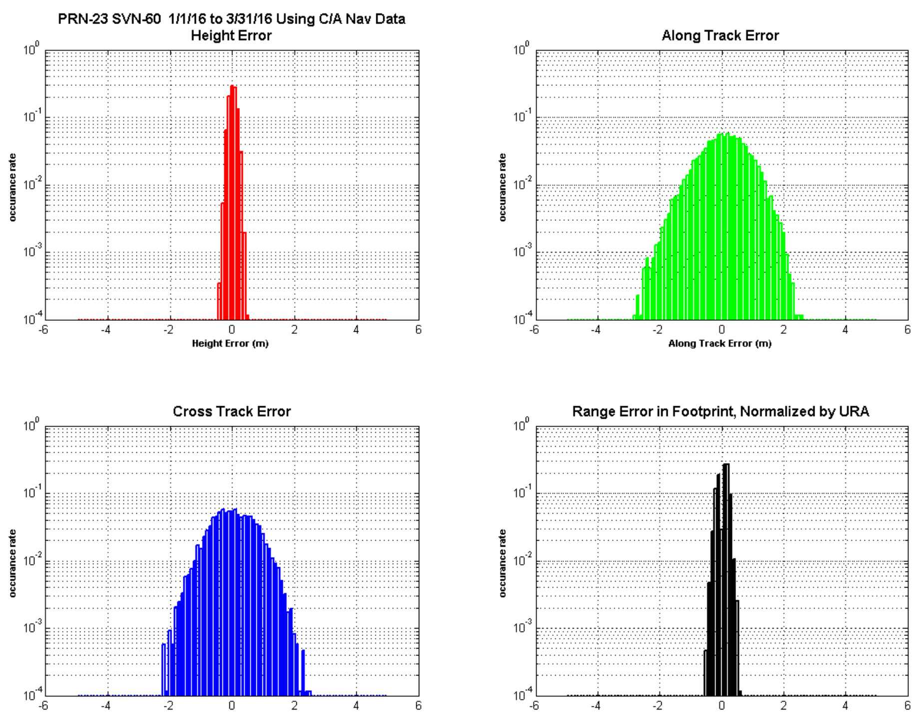


Figure 11-6.34, Histograms of H, A, C, and Range Error PRN-24 Using C/A Nav Data

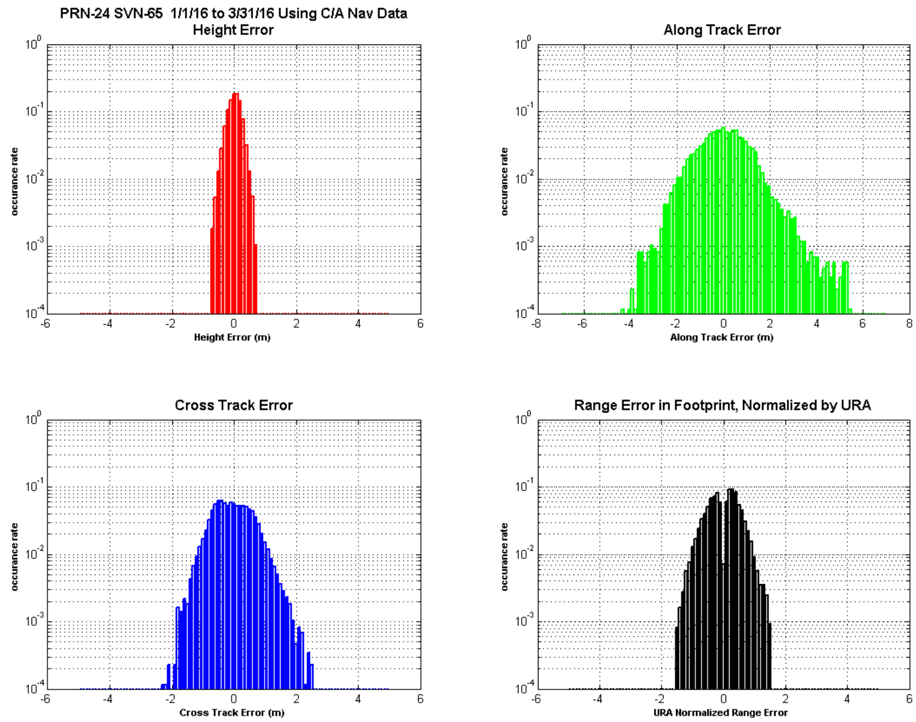


Figure 11-6.35, Histograms of H, A, C, and Range Error PRN-24 Using L2C CNAV Data

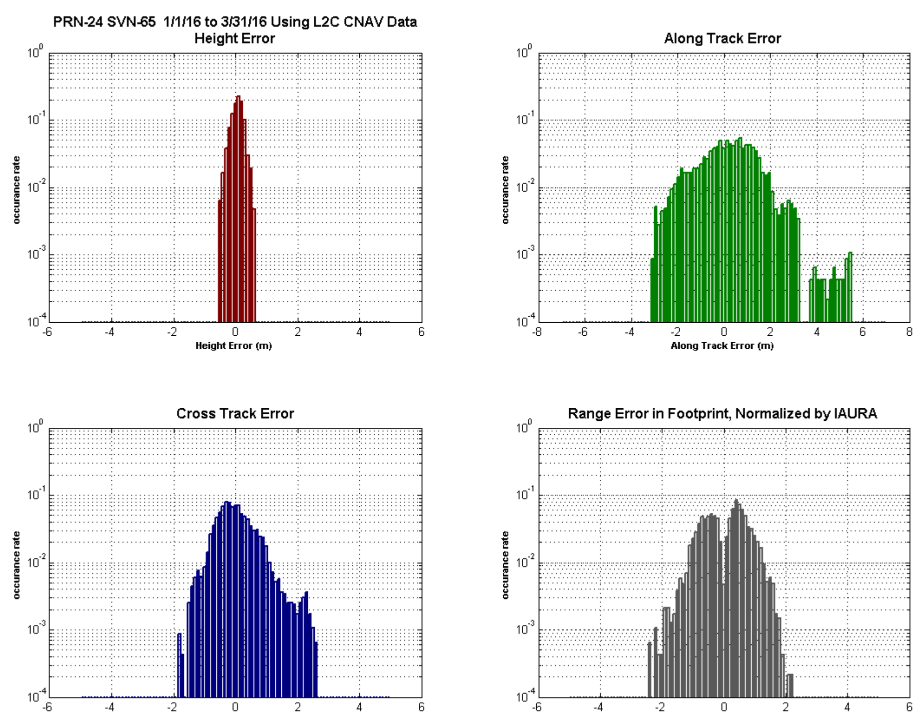


Figure 11-6.36, Histograms of H, A, C, and Range Error PRN-25 Using C/A Nav Data

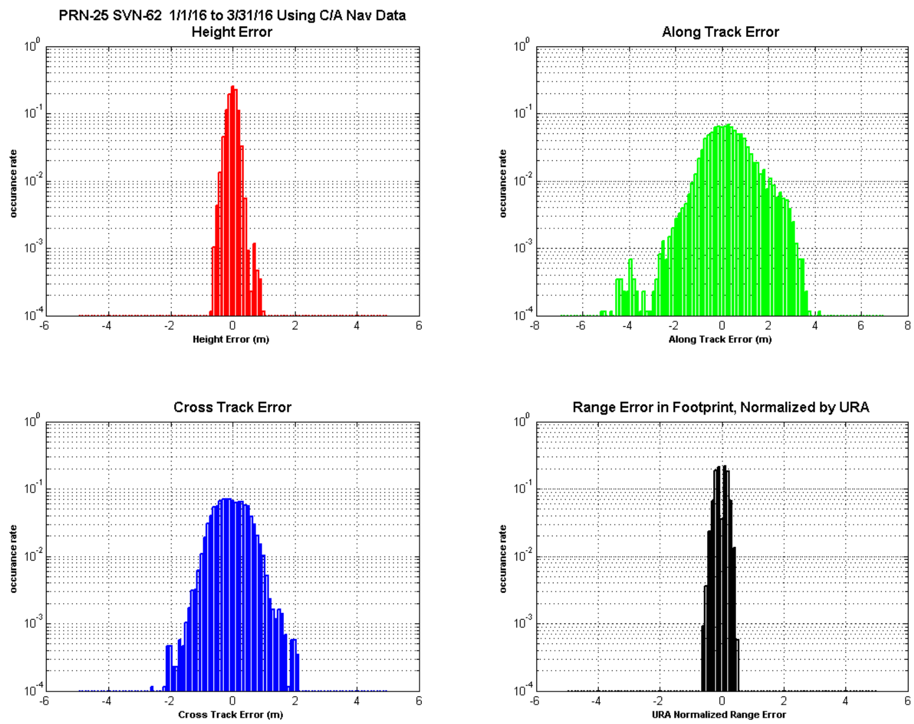


Figure 11-6.37, Histograms of H, A, C, and Range Error PRN-25 Using L2C CNAV Data

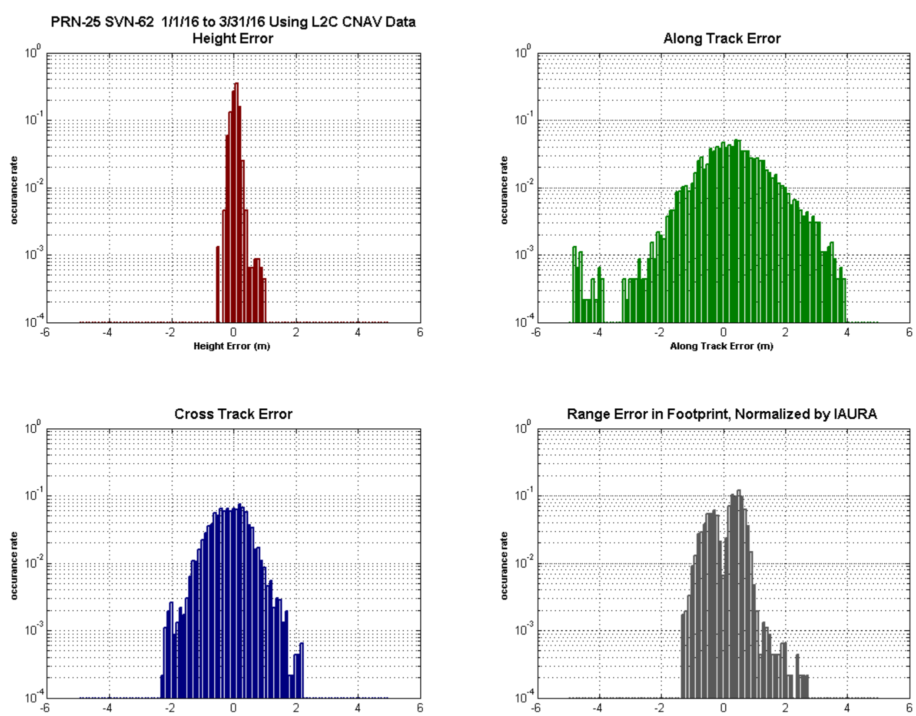


Figure 11-6.38, Histograms of H, A, C, and Range Error PRN-26 Using C/A Nav Data

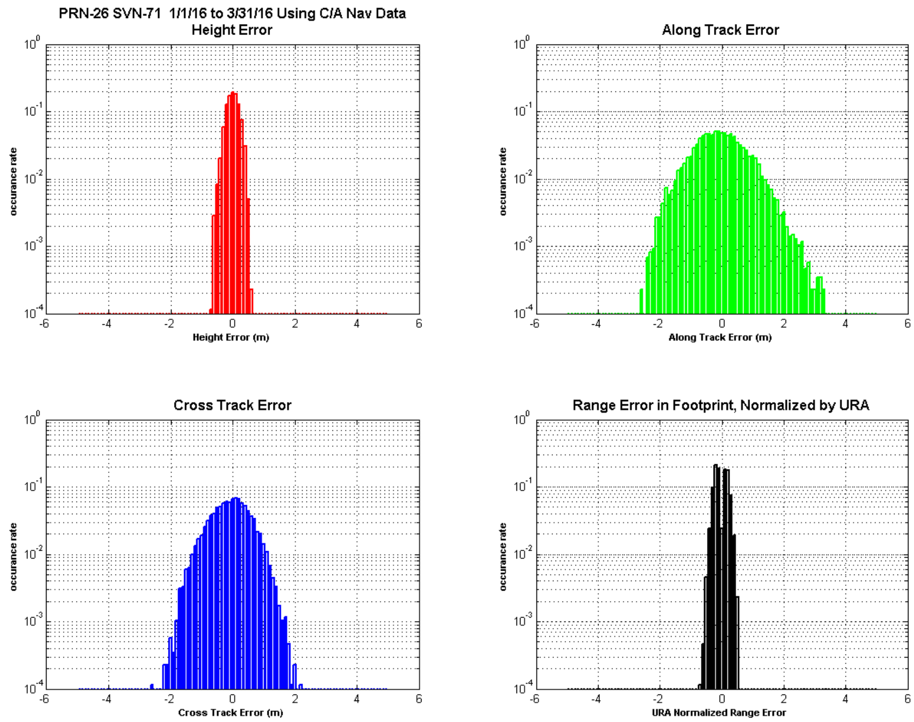


Figure 11-6.39, Histograms of H, A, C, and Range Error PRN-26 Using L2C CNAV Data

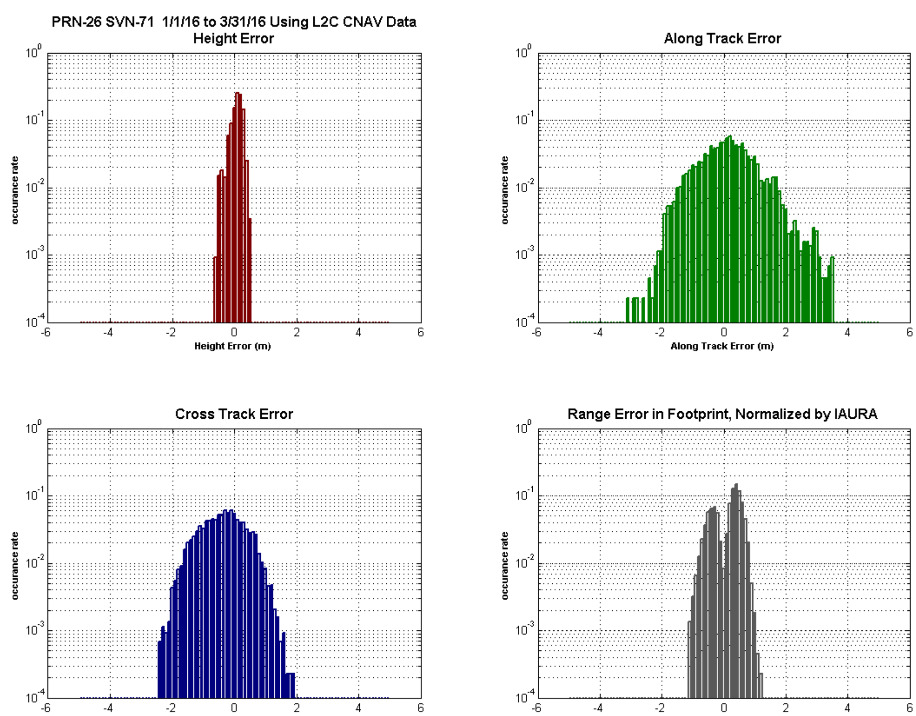


Figure 11-6.40, Histograms of H, A, C, and Range Error PRN-27 Using C/A Nav Data

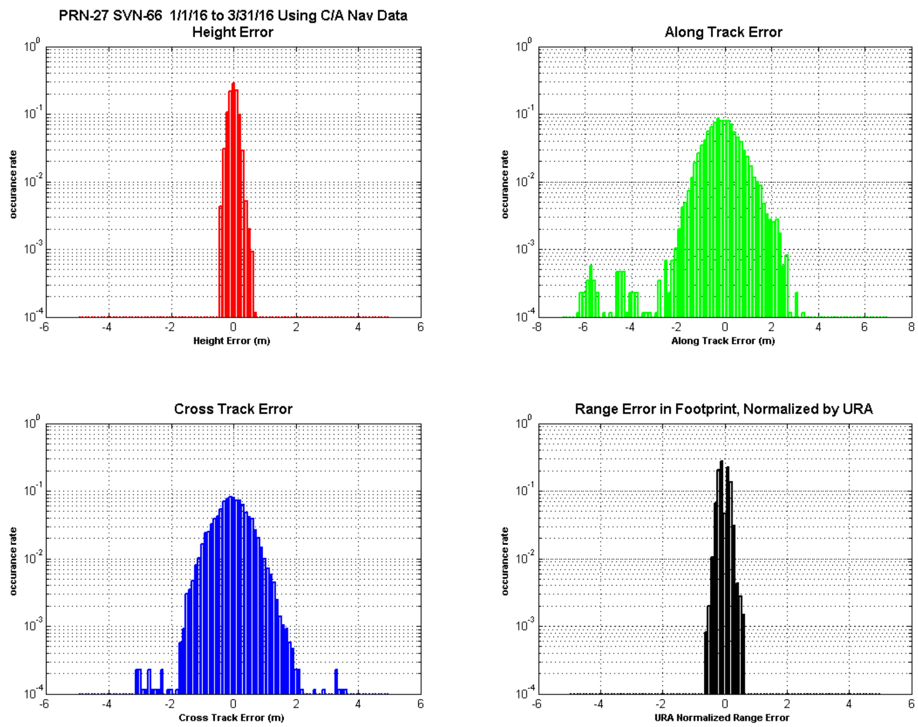


Figure 11-6.41, Histograms of H, A, C, and Range Error PRN-27 Using L2C CNAV Data

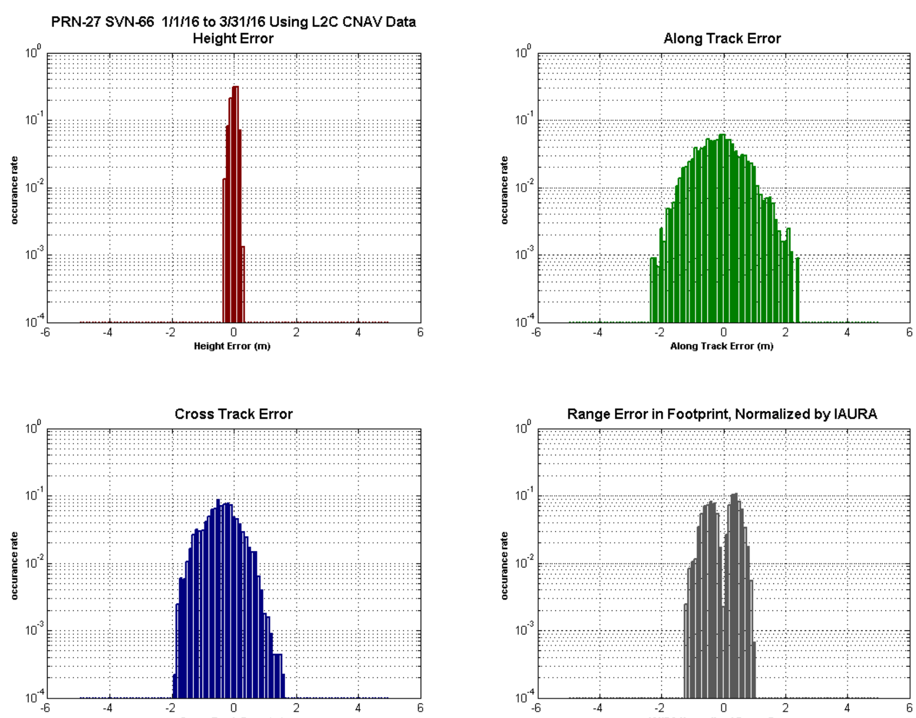


Figure 11-6.42, Histograms of H, A, C, and Range Error PRN-28 Using C/A Nav Data

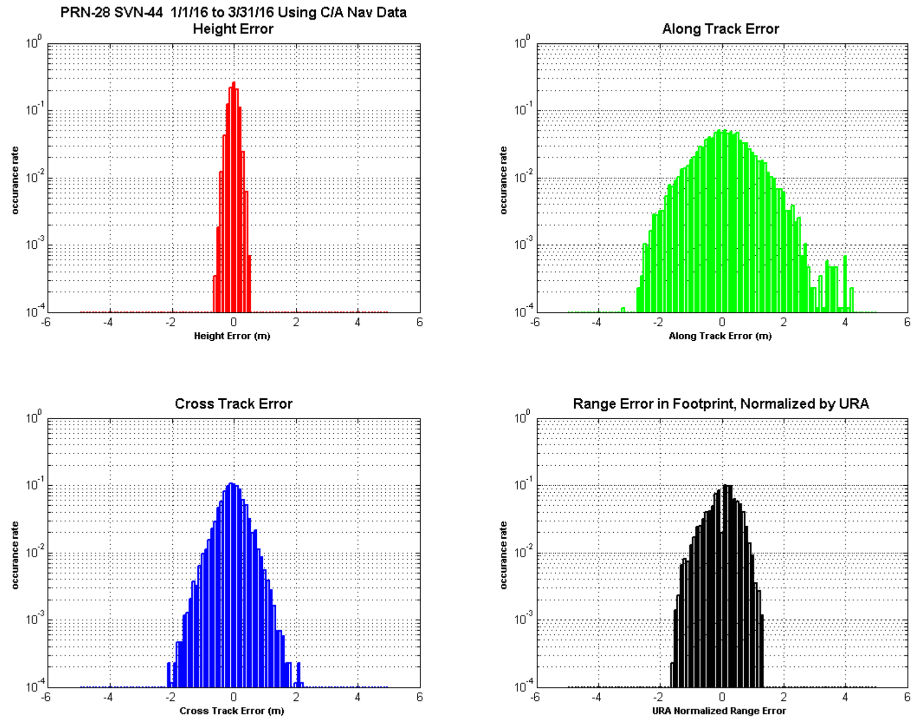


Figure 11-6.43, Histograms of H, A, C, and Range Error PRN-29 Using C/A Nav Data

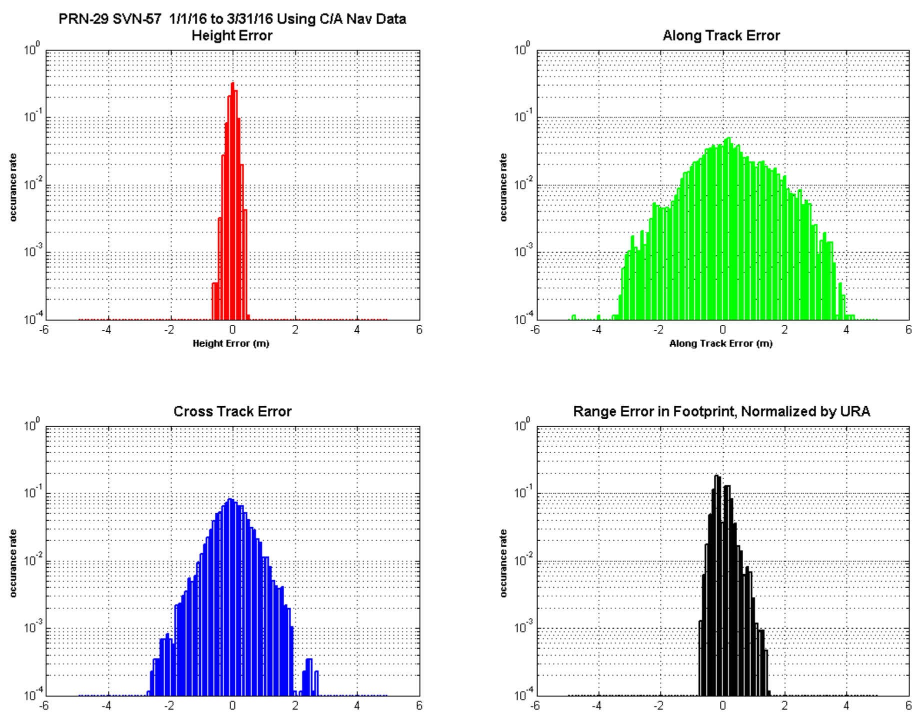


Figure 11-6.44, Histograms of H, A, C, and Range Error PRN-29 Using L2C CNAV Data

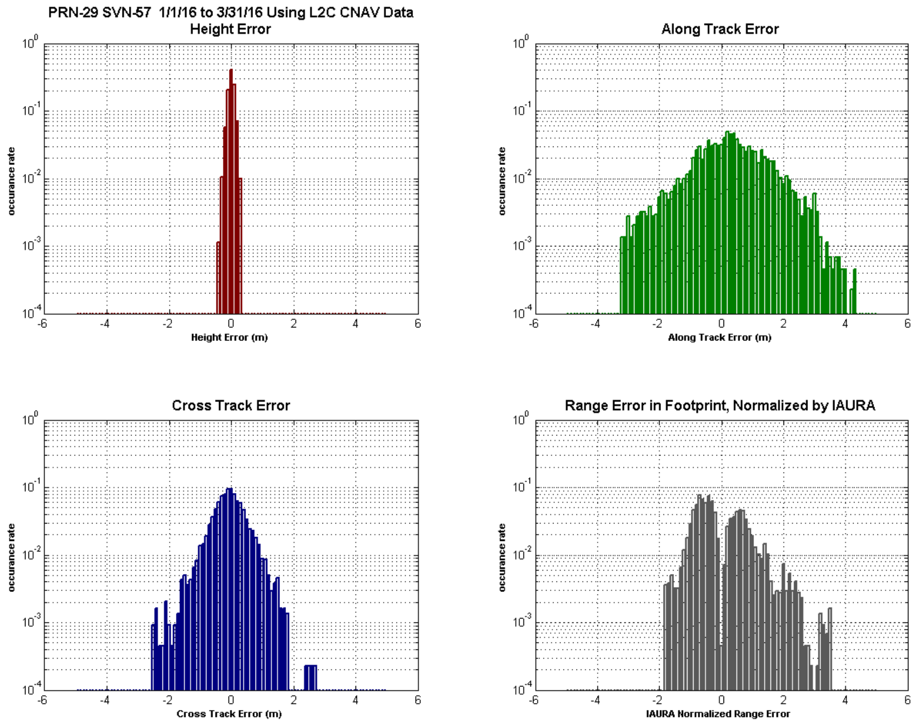


Figure 11-6.45, Histograms of H, A, C, and Range Error PRN-30 Using C/A Nav Data

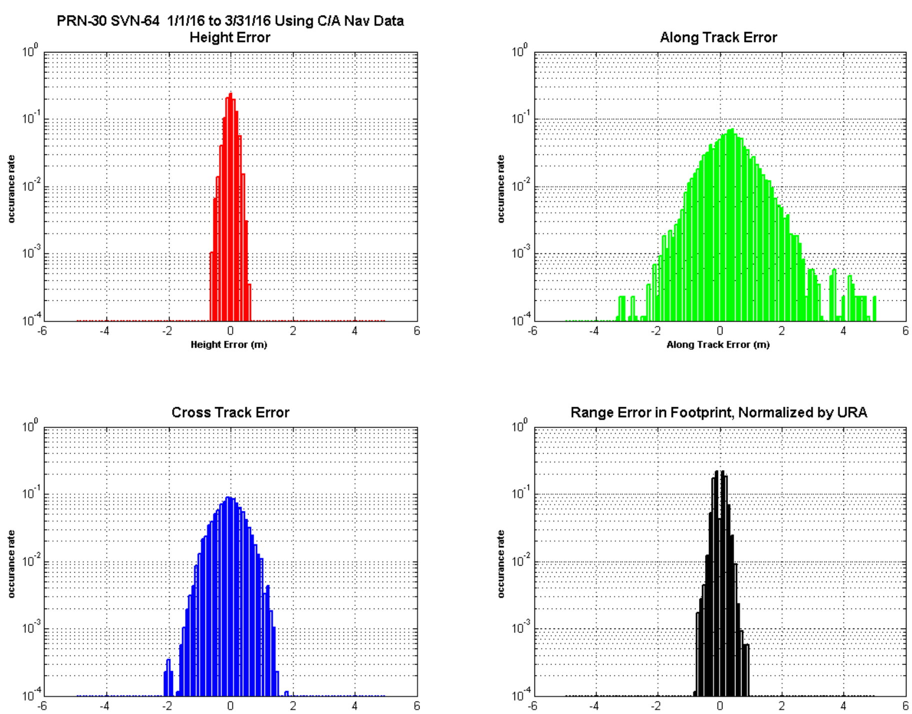


Figure 11-6.46, Histograms of H, A, C, and Range Error PRN-30 Using L2C CNAV Data

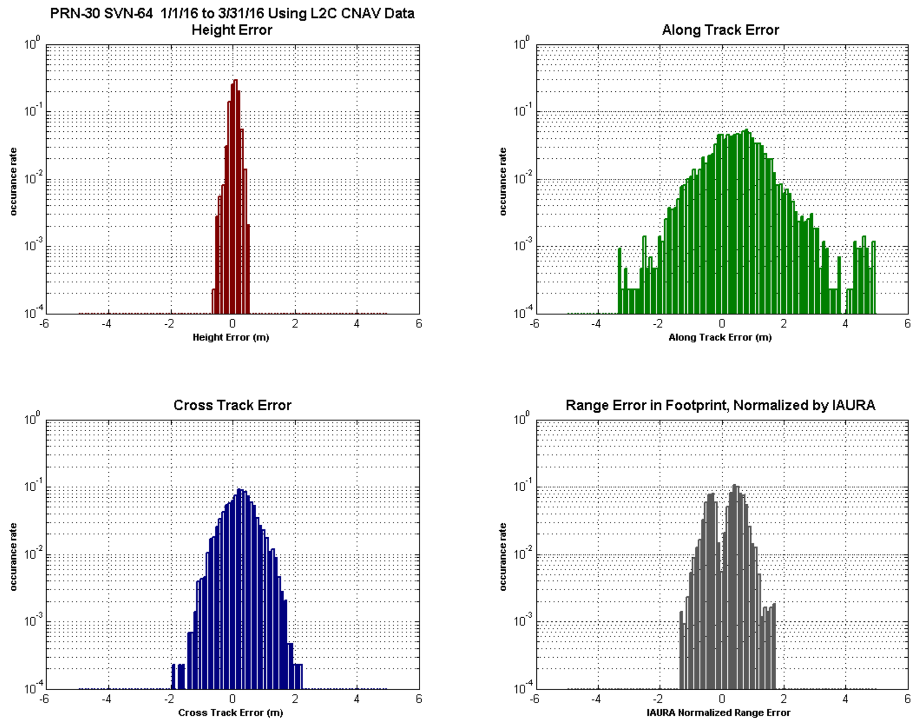


Figure 11-6.47, Histograms of H, A, C, and Range Error PRN-31 Using C/A Nav Data

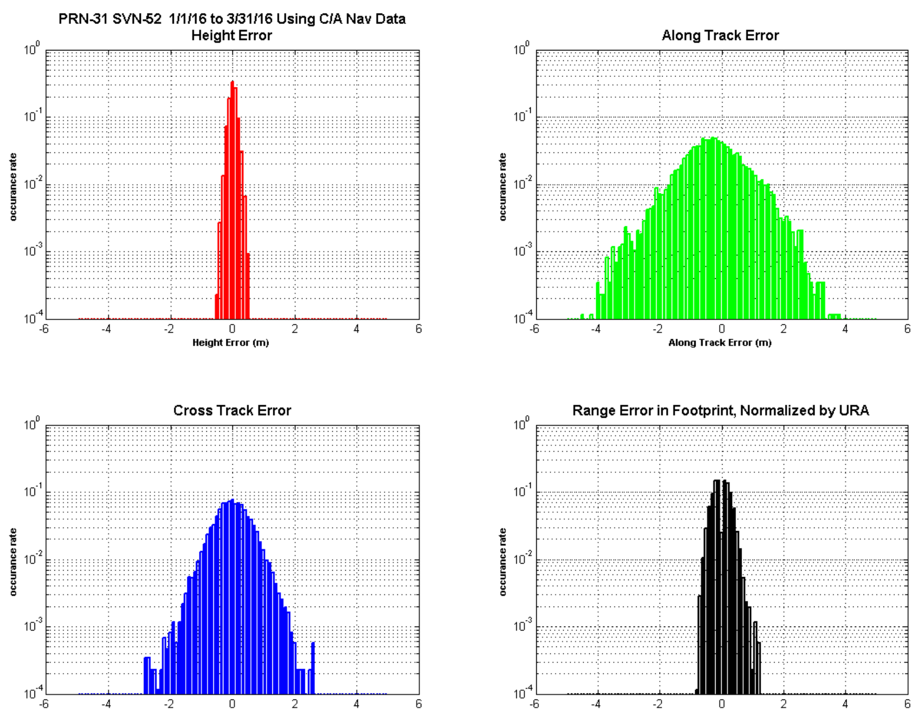


Figure 11-6.48, Histograms of H, A, C, and Range Error PRN-31 Using L2C CNAV Data

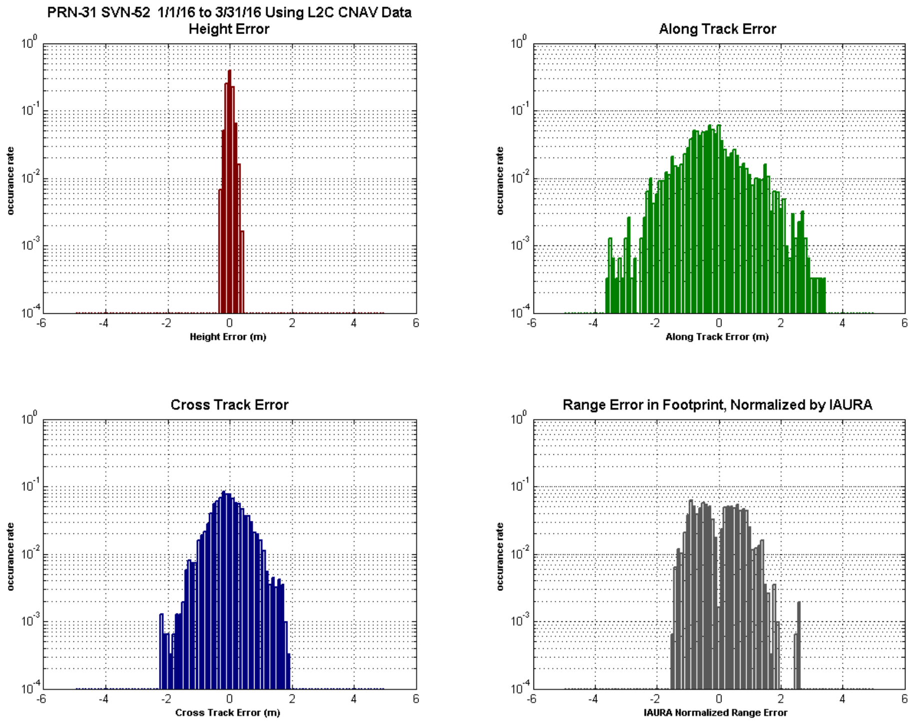


Figure 11-6.49, Histograms of H, A, C, and Range Error PRN-32 SVN-23 Using C/A Nav Data

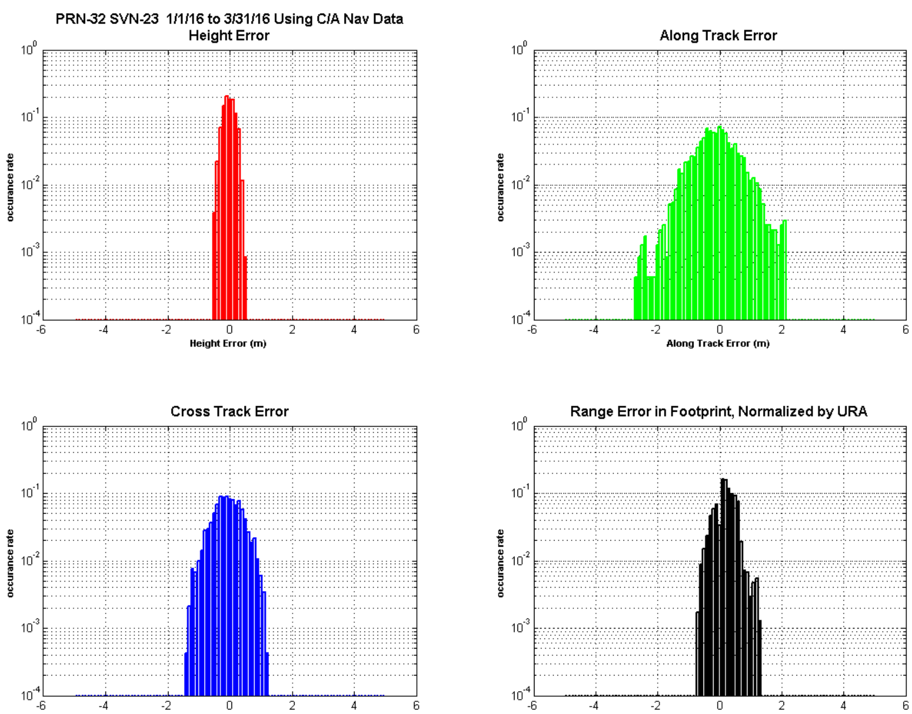


Figure 11-6.50, Histograms of H, A, C, and Range Error PRN-32 SVN-70 Using C/A Nav Data

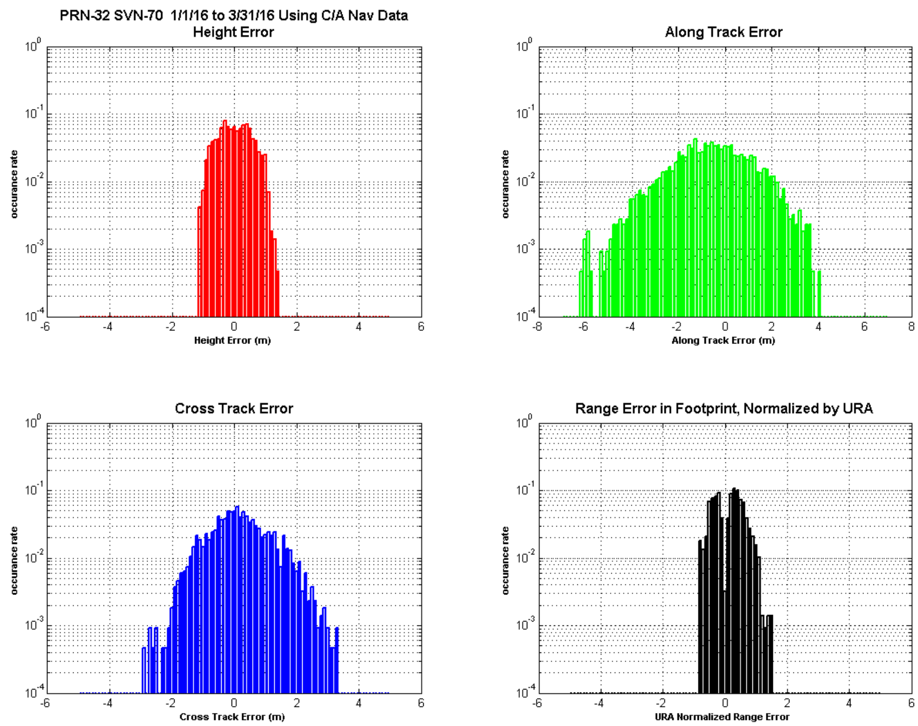


Figure 11-7 Timeline of URA Normalized Range Error for All Satellites

Figure 11-7.1 Timeline of URA Normalized Range Error PRN-1 SVN-63 Using C/A Nav Data

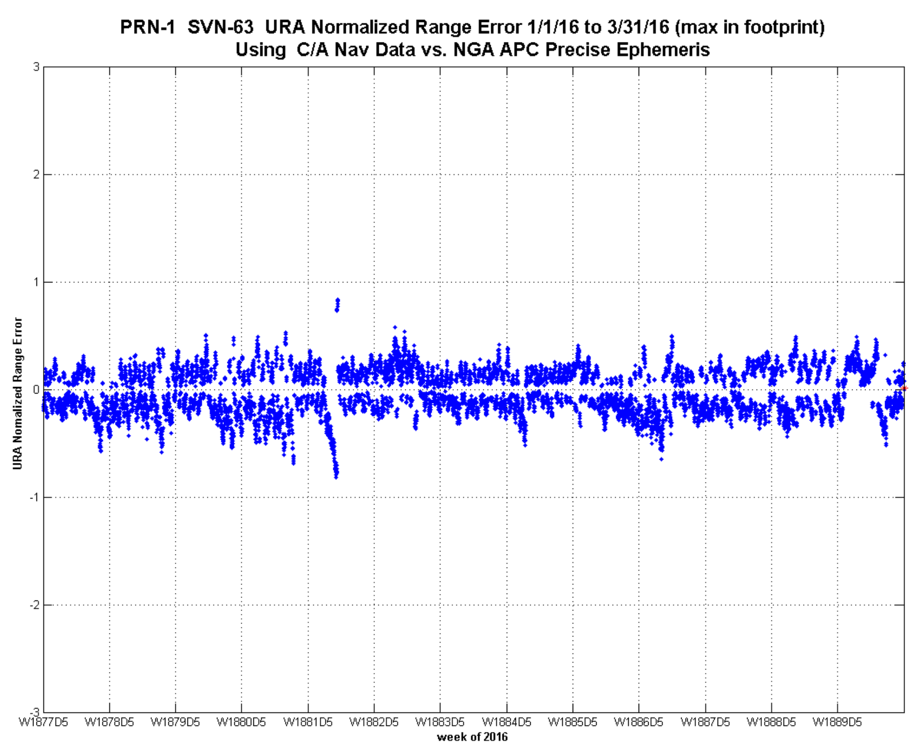
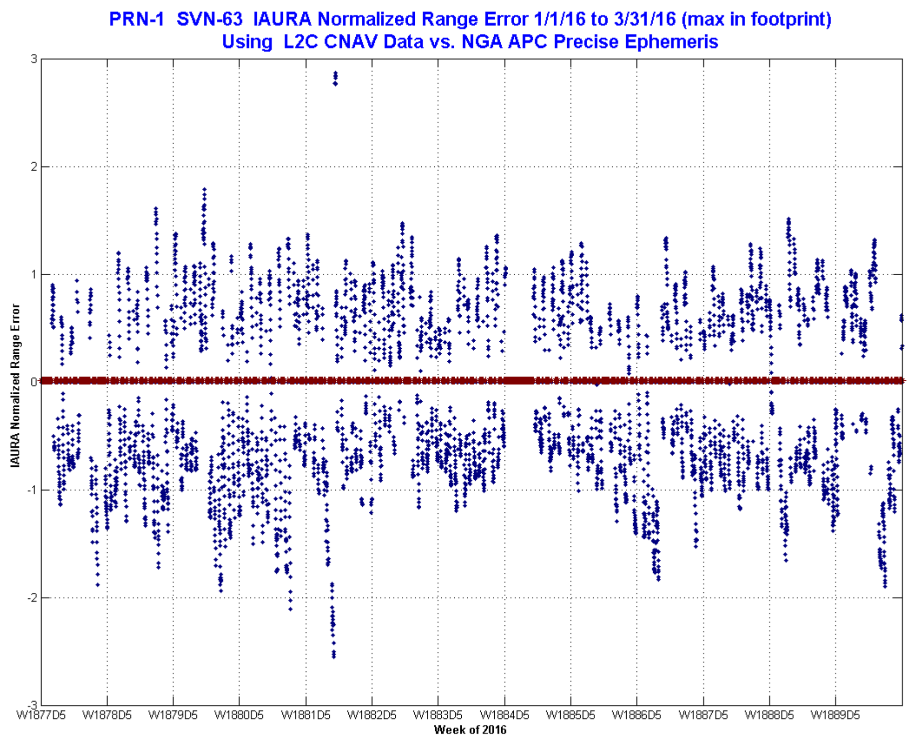


Figure 11-7.2 Timeline of IAURA Normalized Range Error PRN-1 SVN-63 Using L2C CNAV Data



Dark red is SV out of view from receiver ZAU, Aurora IL (All CNAV PRNs)

Figure 11-7.3, Timeline of URA Normalized Range Error PRN-2 SVN-61 Using C/A Nav Data

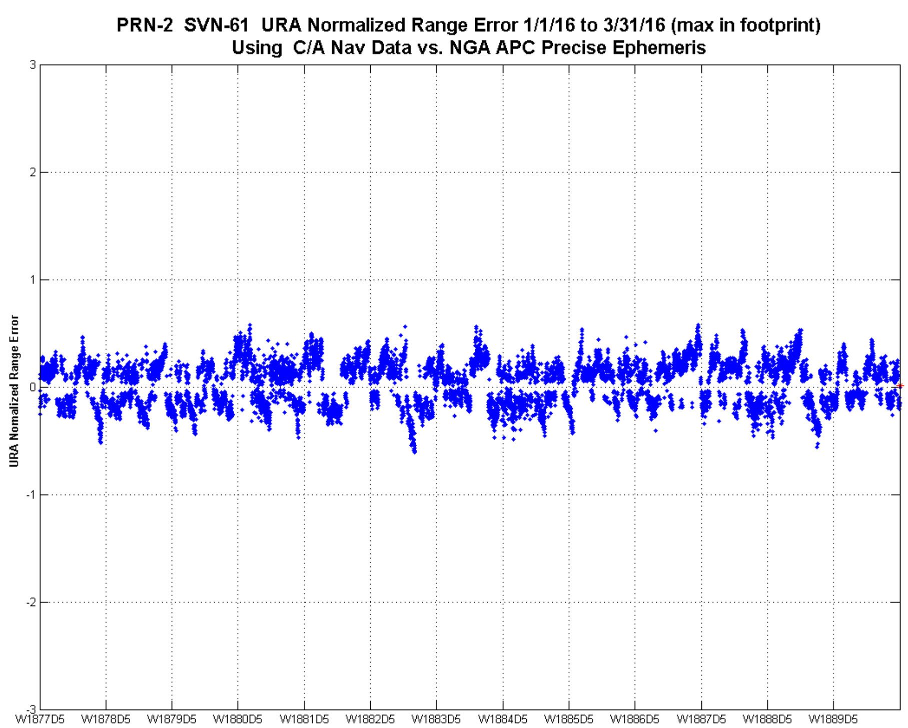


Figure 11-7.4, Timeline of URA Normalized Range Error PRN-3 SVN-33 Using C/A Nav Data

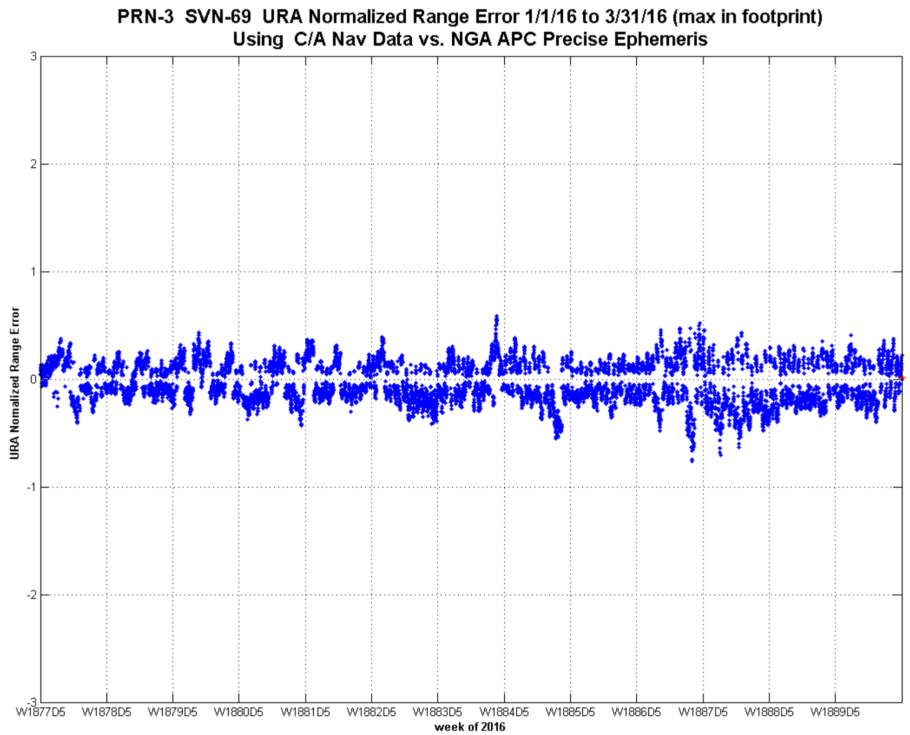


Figure 11-7.5, Timeline of IAURA Normalized Range Error PRN-3 SVN-33 Using L2C CNAV Data

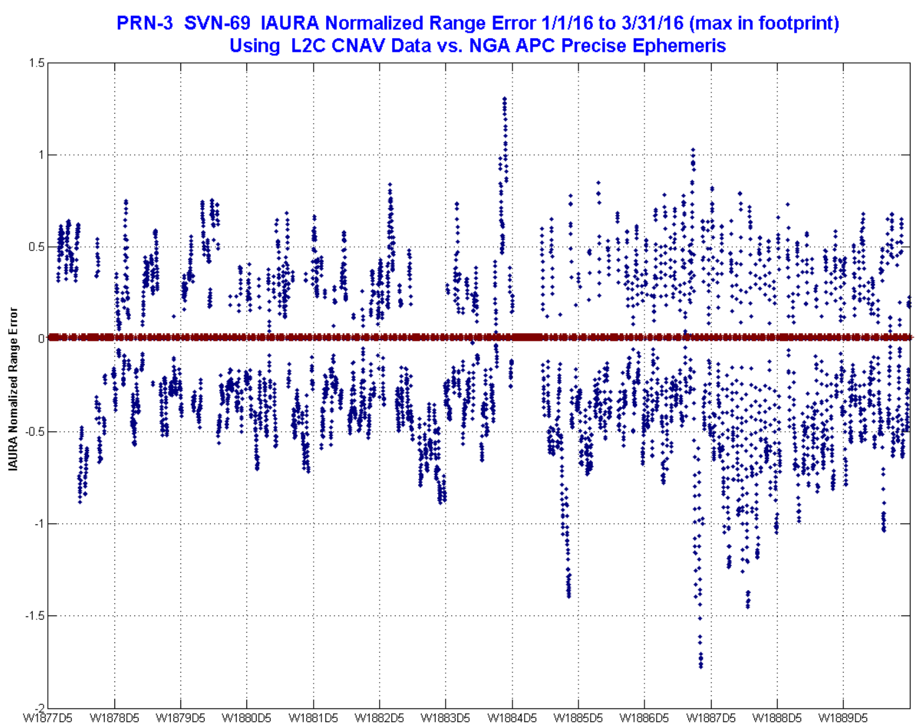


Figure 11-7.6, Timeline of URA Normalized Range Error PRN-5 SVN-50 Using C/A Nav Data

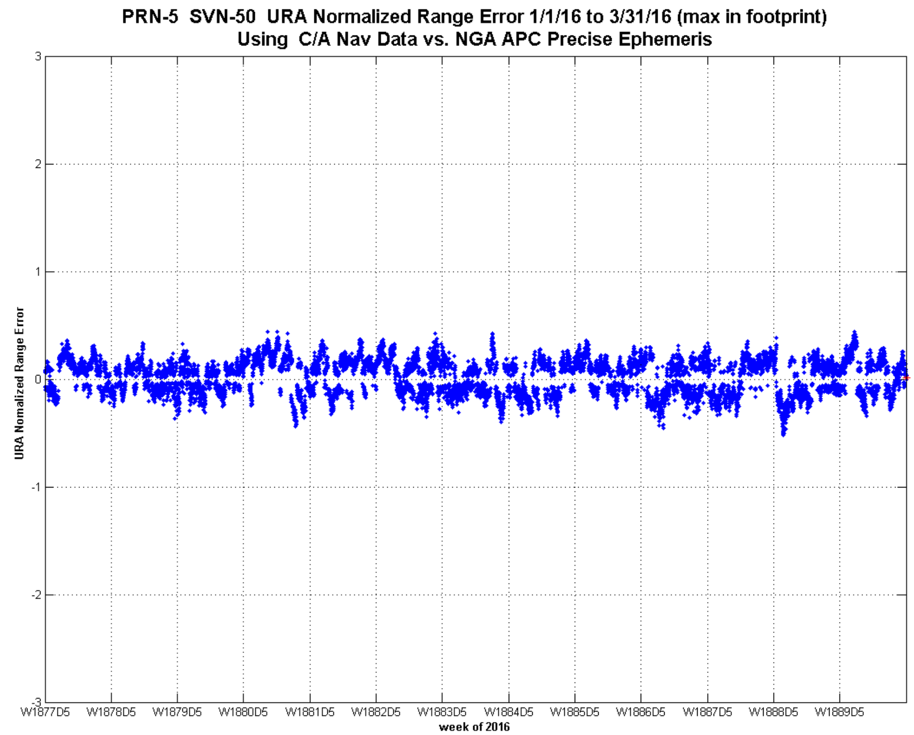


Figure 11-7.7, Timeline of IAURA Normalized Range Error PRN-5 SVN-50 Using L2C CNAV Data

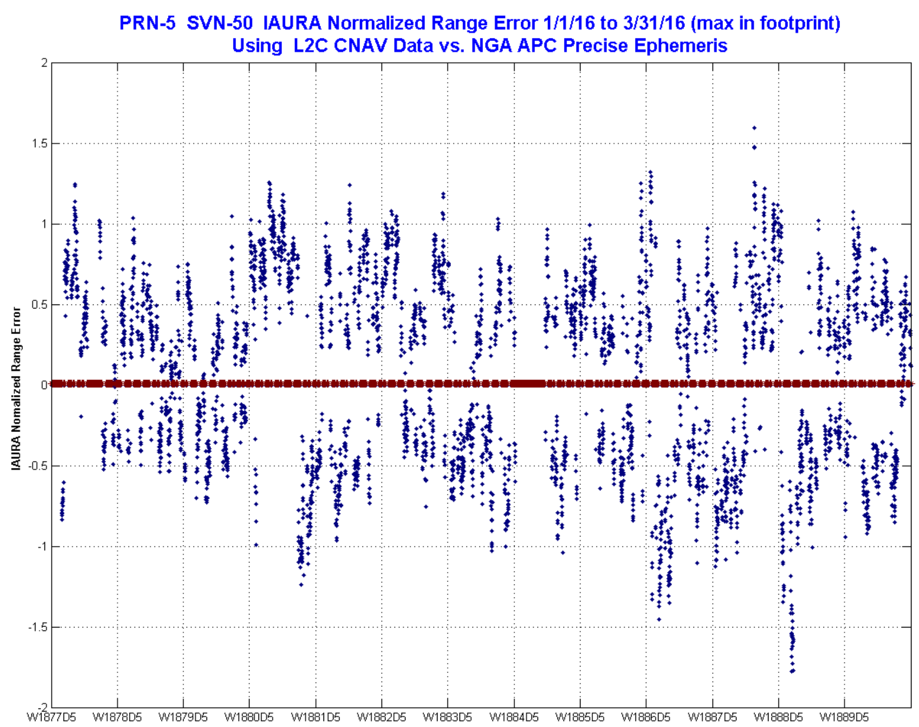


Figure 11-7.8, Timeline of URA Normalized Range Error PRN-6 SVN-67 Using C/A Nav Data

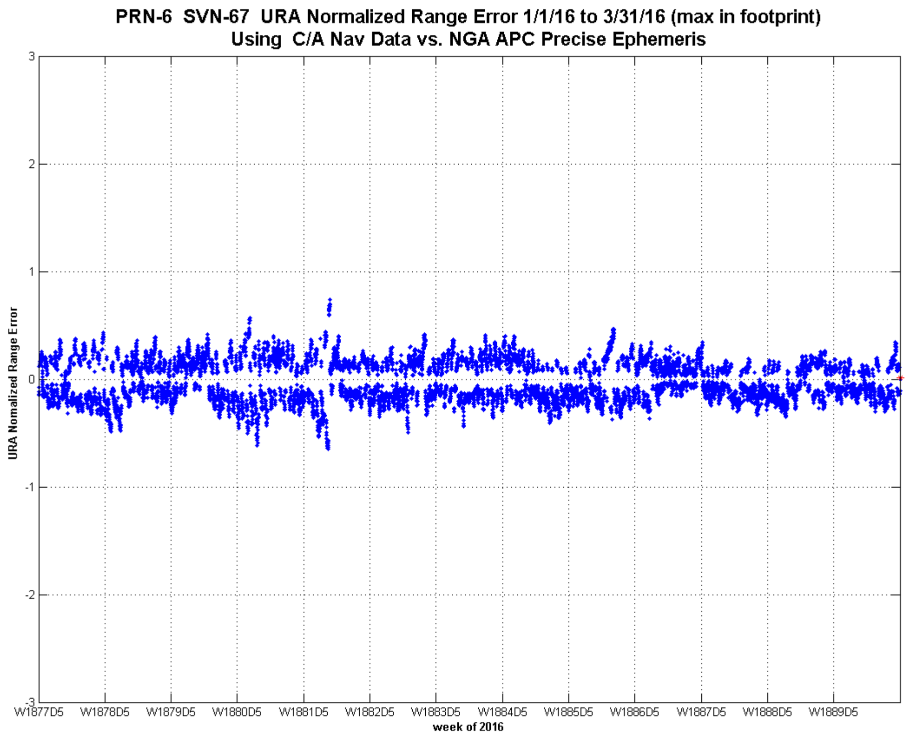


Figure 11-7.10, Timeline of IAURA Normalized Range Error PRN-6 SVN-67 Using L2C CNAV Data

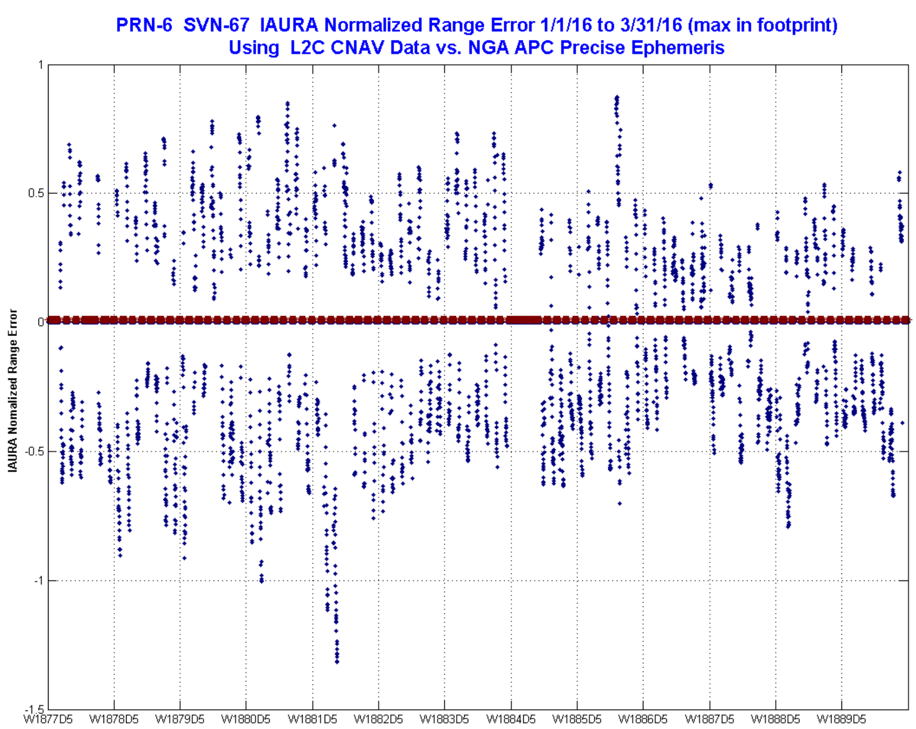


Figure 11-7.11, Timeline of URA Normalized Range Error PRN-7 SVN-48 Using C/A Nav Data

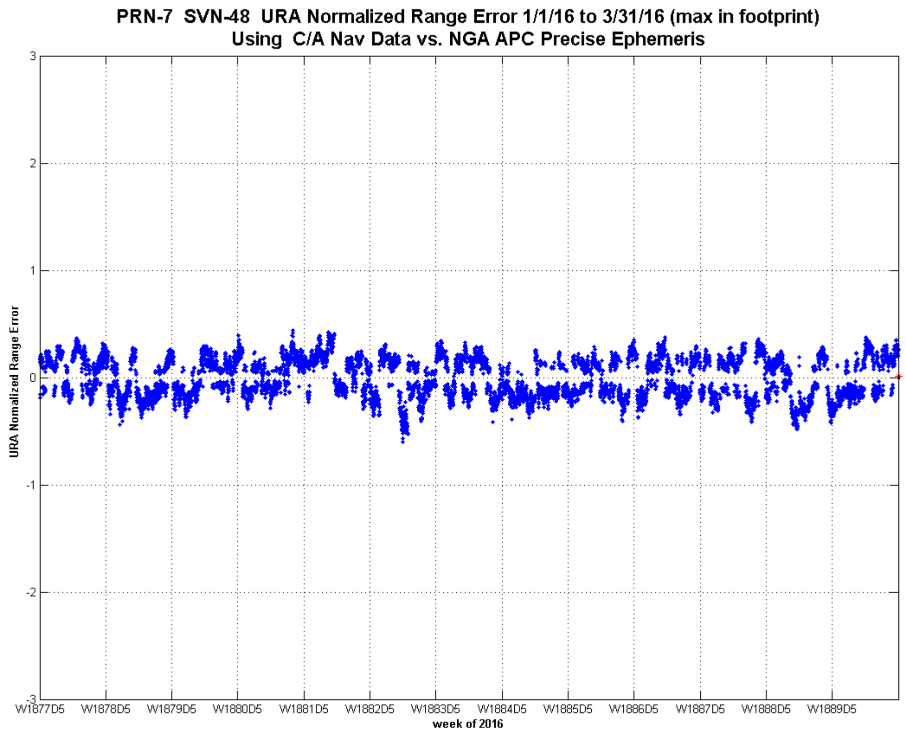


Figure 11-7.12, Timeline of IAURA Normalized Range Error PRN-7 SVN-48 Using L2C CNAV Data

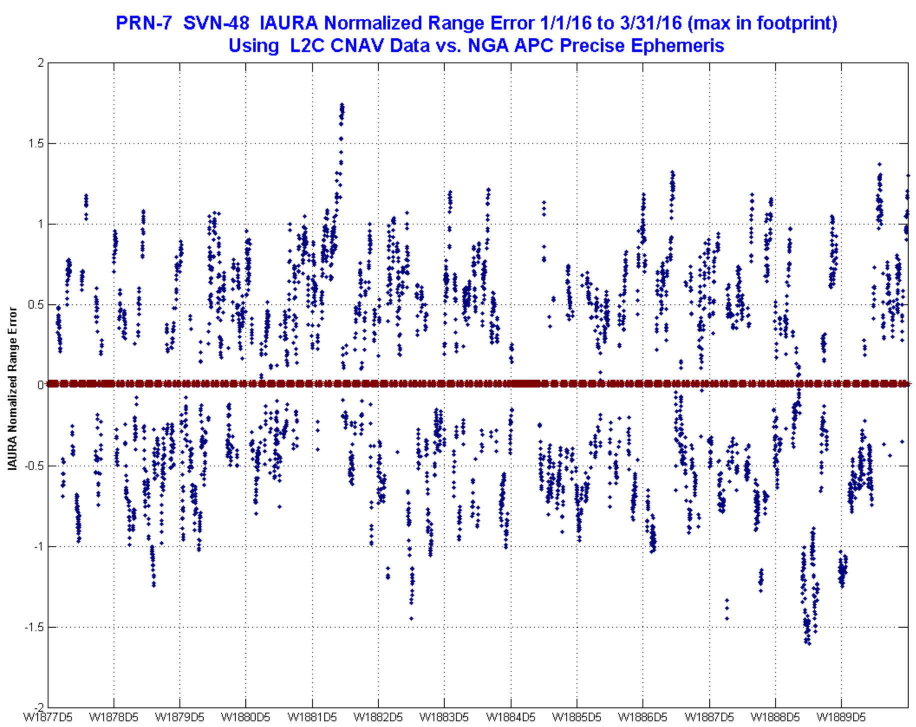


Figure 11-7.13, Timeline of URA Normalized Range Error PRN-8 SVN-72 Using C/A Nav Data

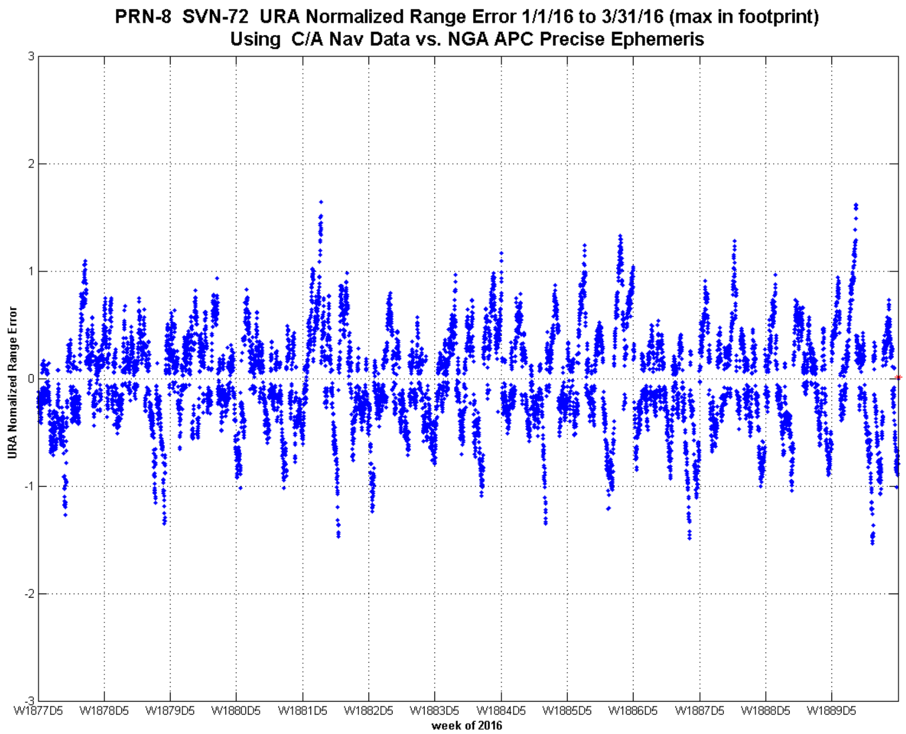


Figure 11-7.14, Timeline of URA Normalized Range Error PRN-8 SVN-72 Using L2C CNAV Data

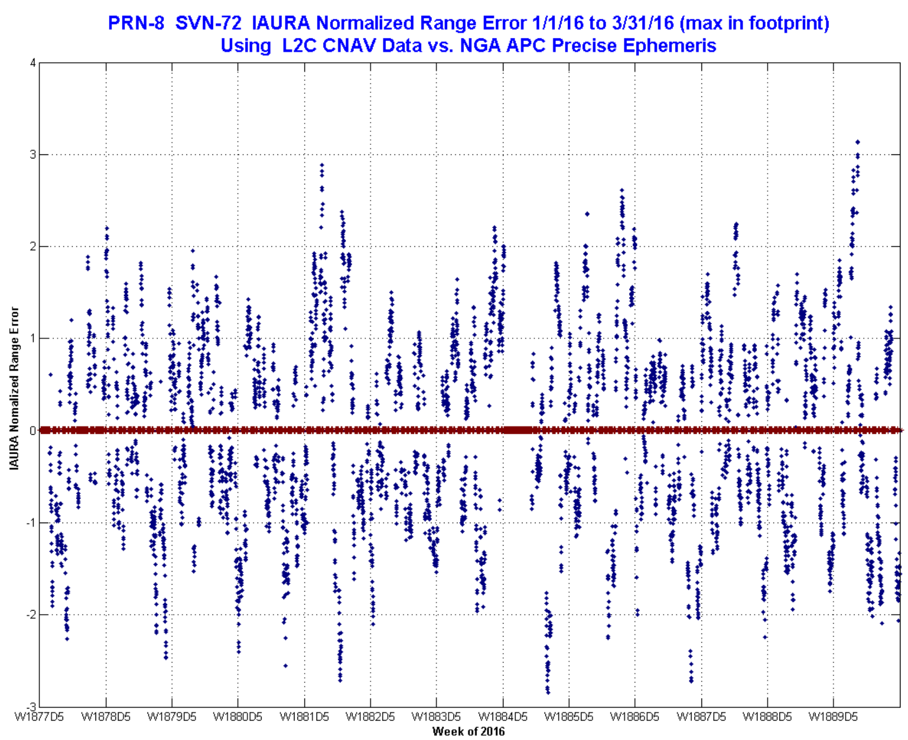


Figure 11-7.15, Timeline of URA Normalized Range Error PRN-9 SVN-68 Using C/A Nav Data

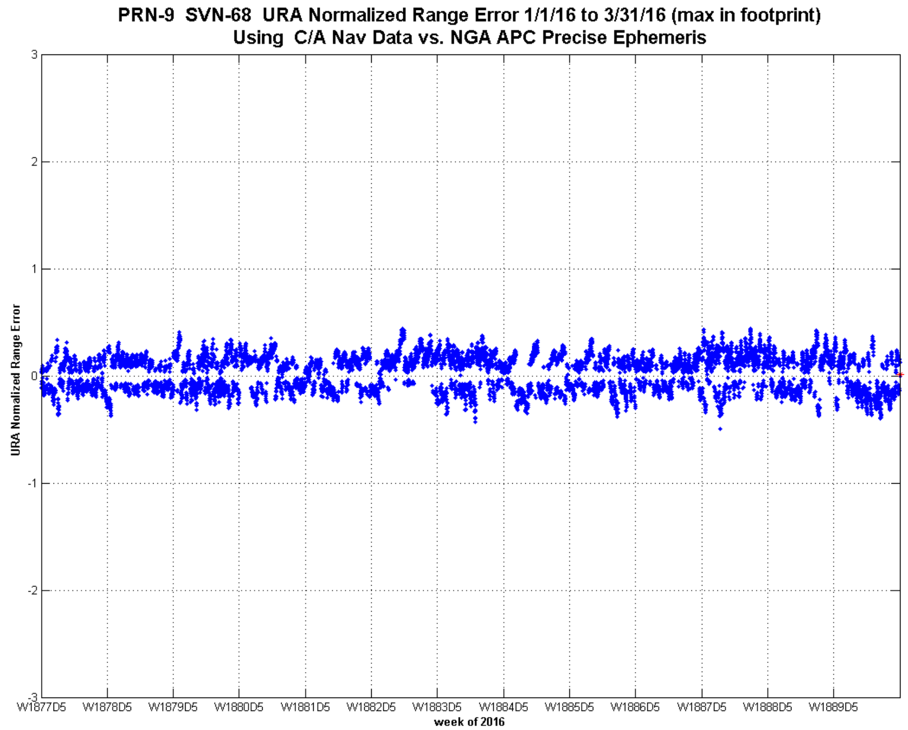


Figure 11-7.16, Timeline of IAURA Normalized Range Error PRN-9 SVN-68 Using L2C CNAV Data

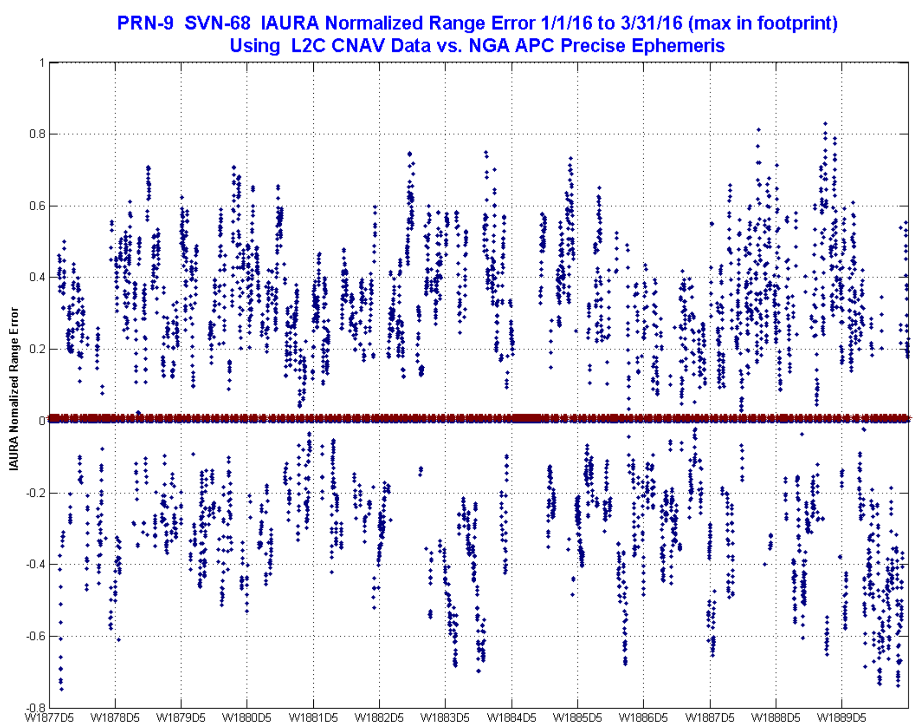


Figure 11-7.17, Timeline of URA Normalized Range Error PRN-10 SVN-73 Using C/A Nav Data

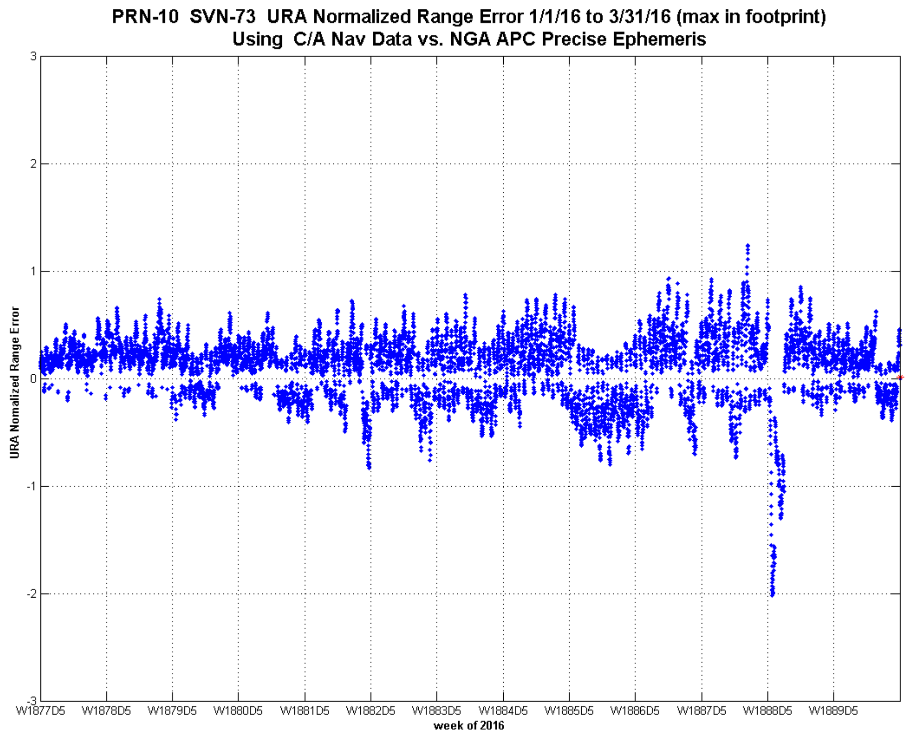


Figure 11-7.18, Timeline of URA Normalized Range Error PRN-11 SVN-46 Using C/A Nav Data

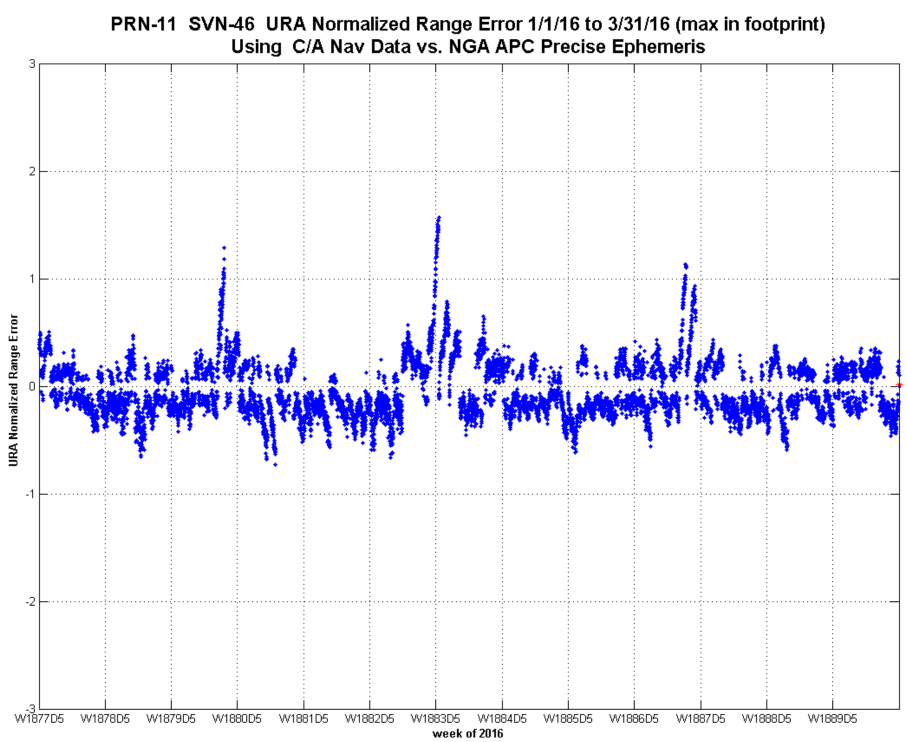


Figure 11-7.19, Timeline of URA Normalized Range Error PRN-12 SVN-58 Using C/A Nav Data

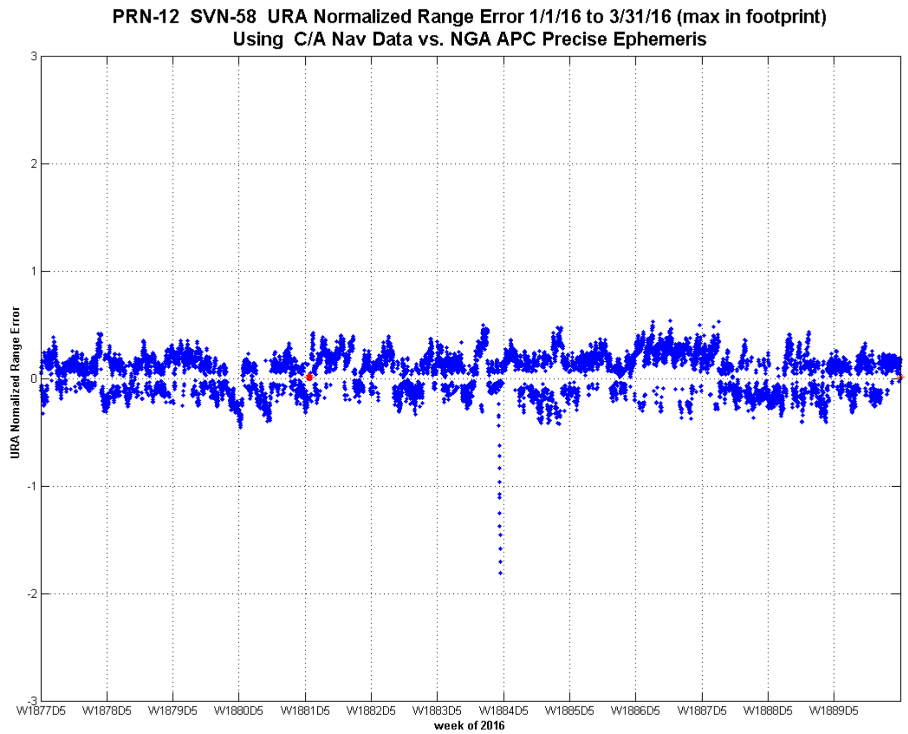


Figure 11-7.20, Timeline of IAURA Normalized Range Error PRN-12 SVN-58 Using L2C CNAV Data

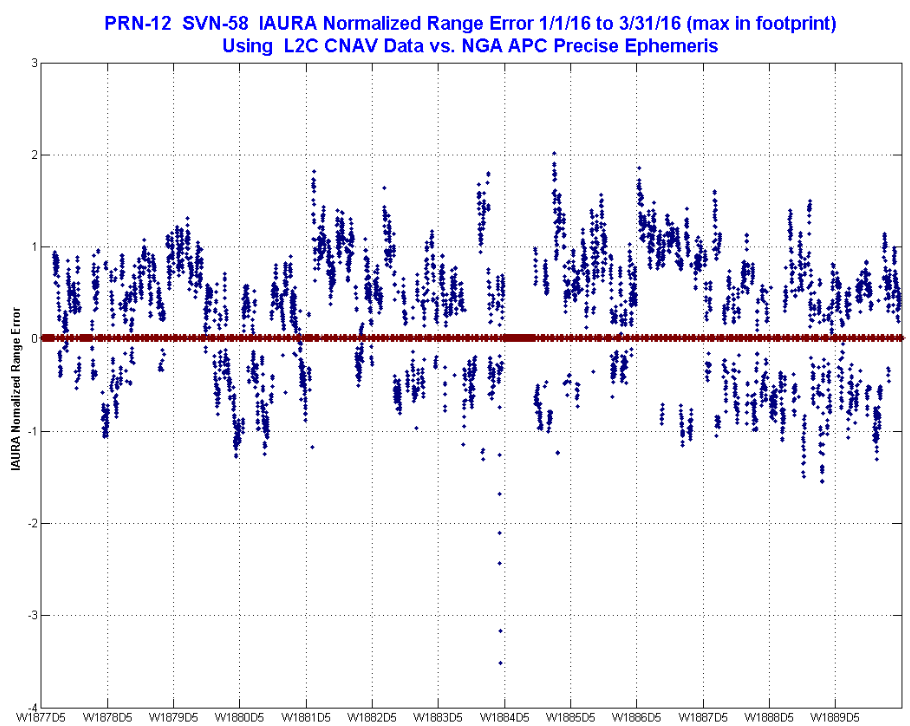


Figure 11-7.21, Timeline of URA Normalized Range Error PRN-13 SVN-43 Using C/A Nav Data

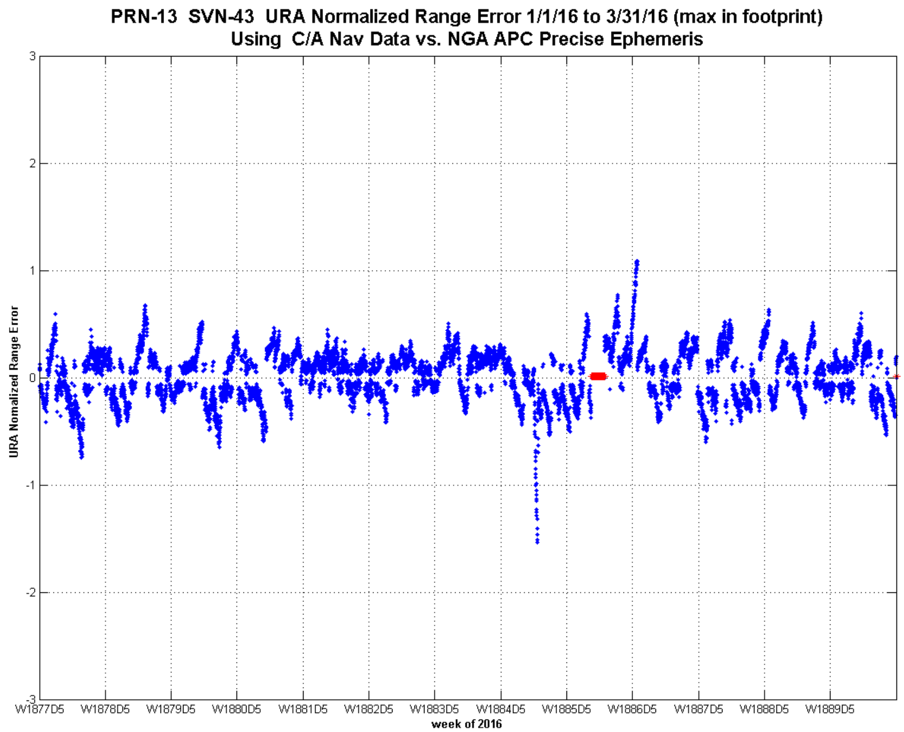


Figure 11-7.22, Timeline of URA Normalized Range Error PRN-14 SVN-41 Using C/A Nav Data

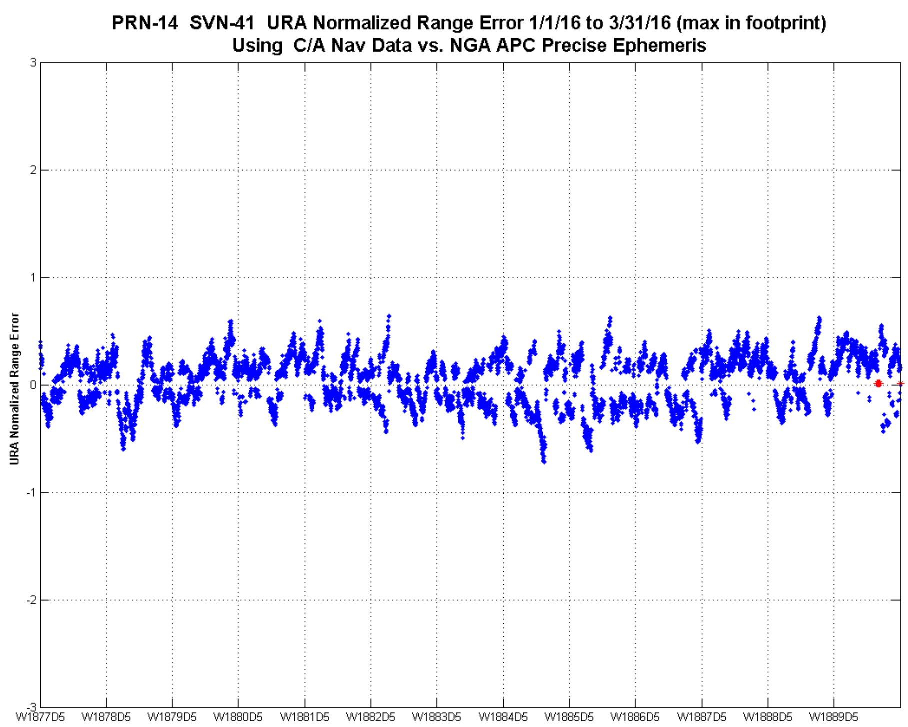


Figure 11-7.23, Timeline of URA Normalized Range Error PRN-15 SVN-55 Using C/A Nav Data

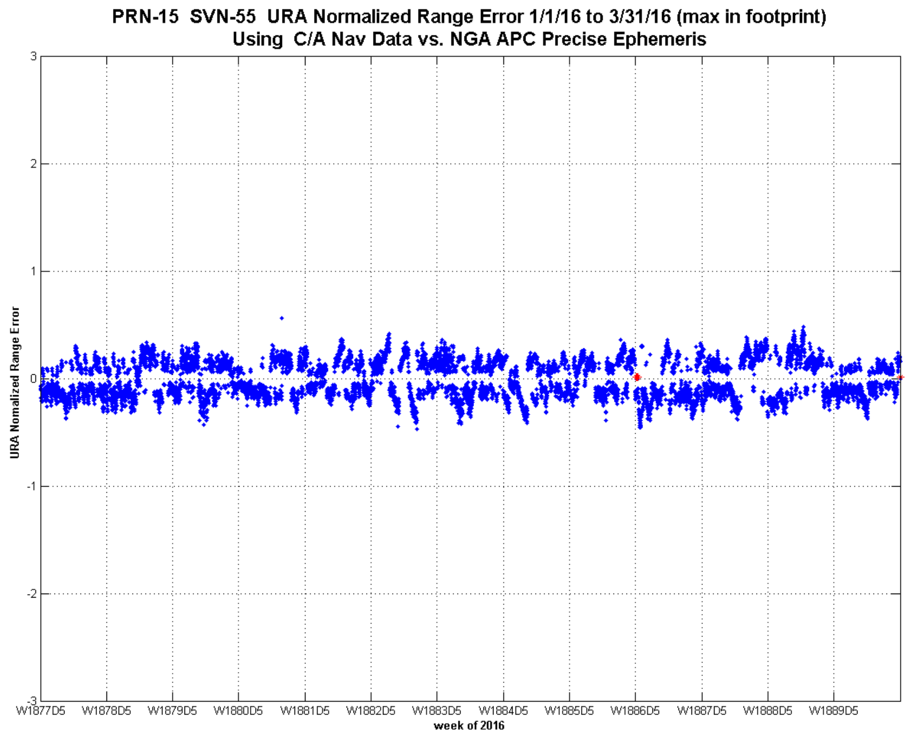


Figure 11-7.24, Timeline of IAURA Normalized Range Error PRN-15 SVN-55 Using L2C CNAV Data

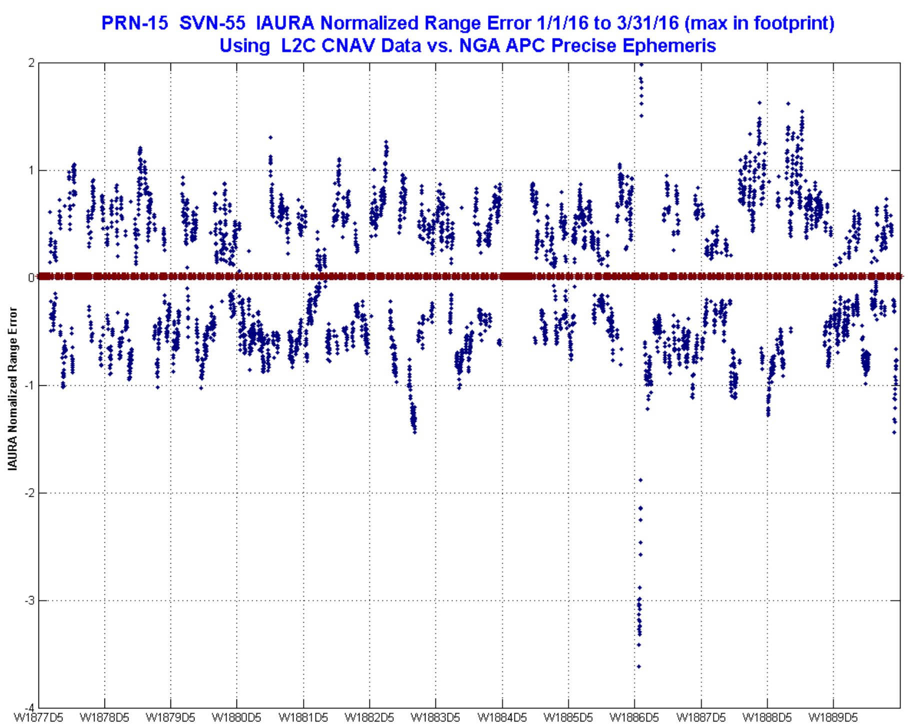


Figure 11-7.25, Timeline of URA Normalized Range Error PRN-16 SVN-56 Using C/A Nav Data

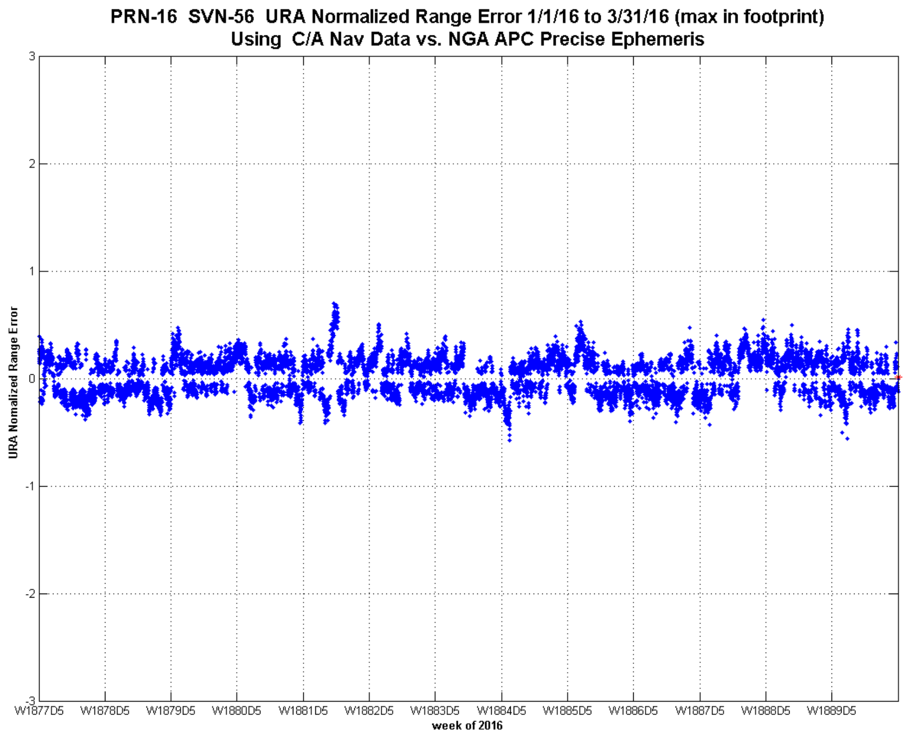


Figure 11-7.26, Timeline of URA Normalized Range Error PRN-17 SVN-53 Using C/A Nav Data

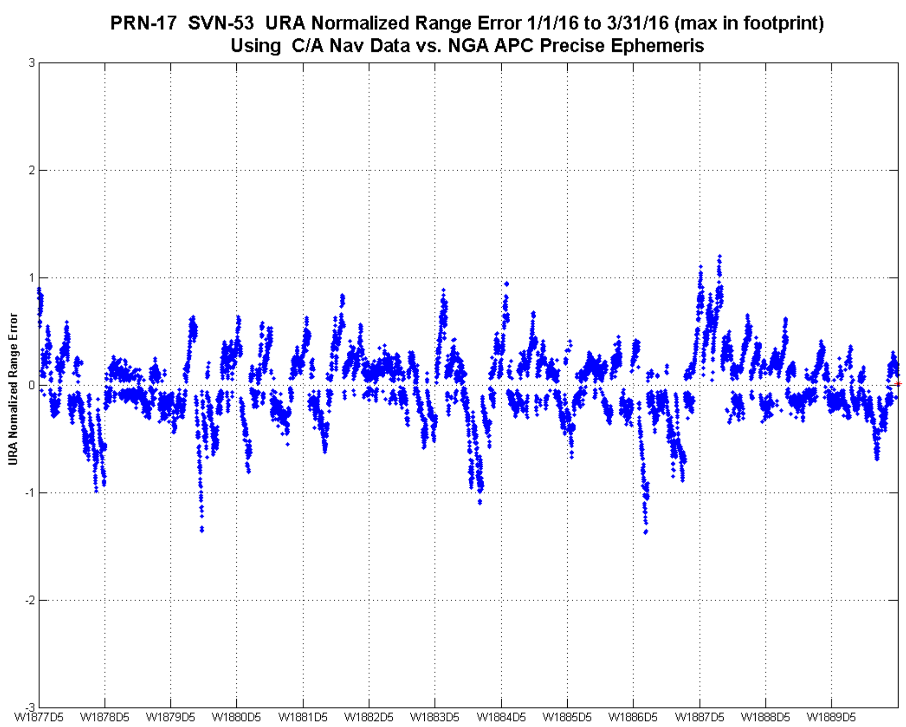


Figure 11-7.27, Timeline of IAURA Normalized Range Error PRN-17 SVN-53 Using L2C CNAV Data

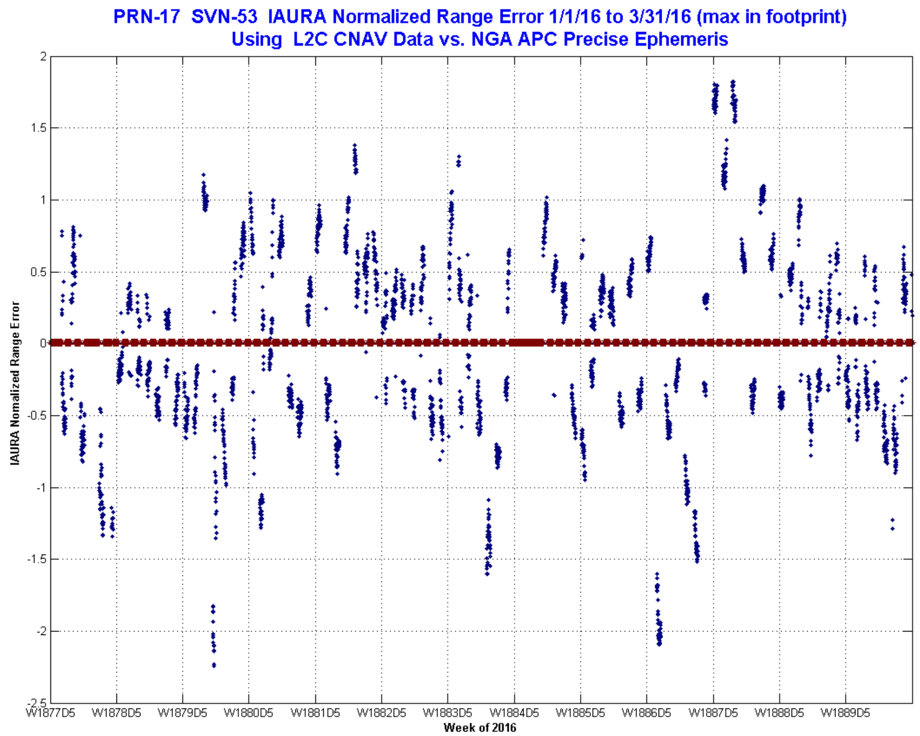


Figure 11-7.28, Timeline of URA Normalized Range Error PRN-18 SVN-54 Using C/A Nav Data

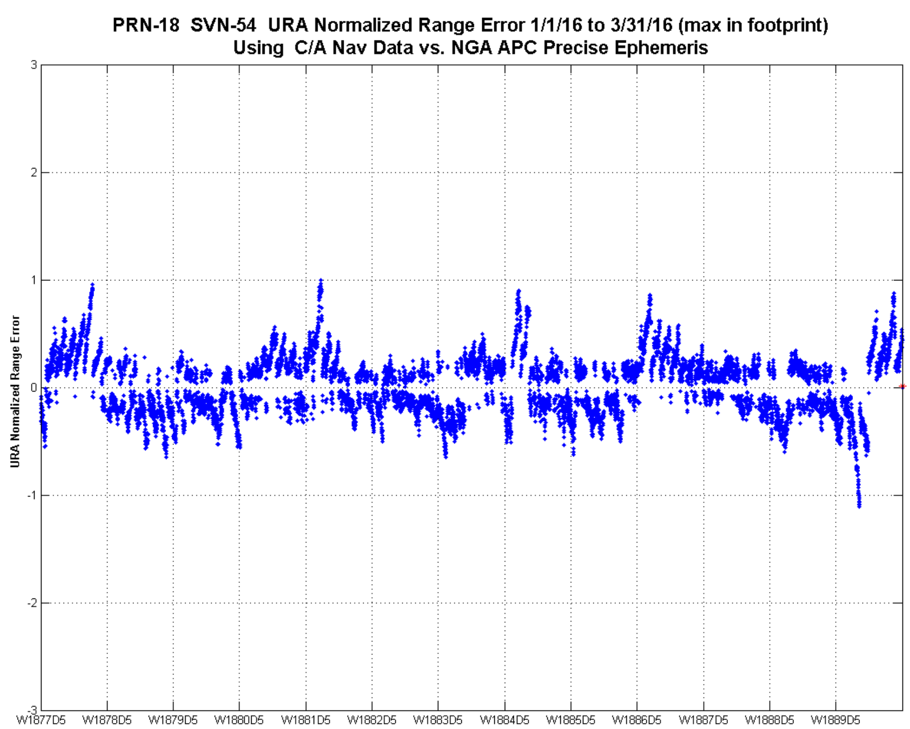


Figure 11-7.29, Timeline of URA Normalized Range Error PRN-19 SVN-59 Using C/A Nav Data

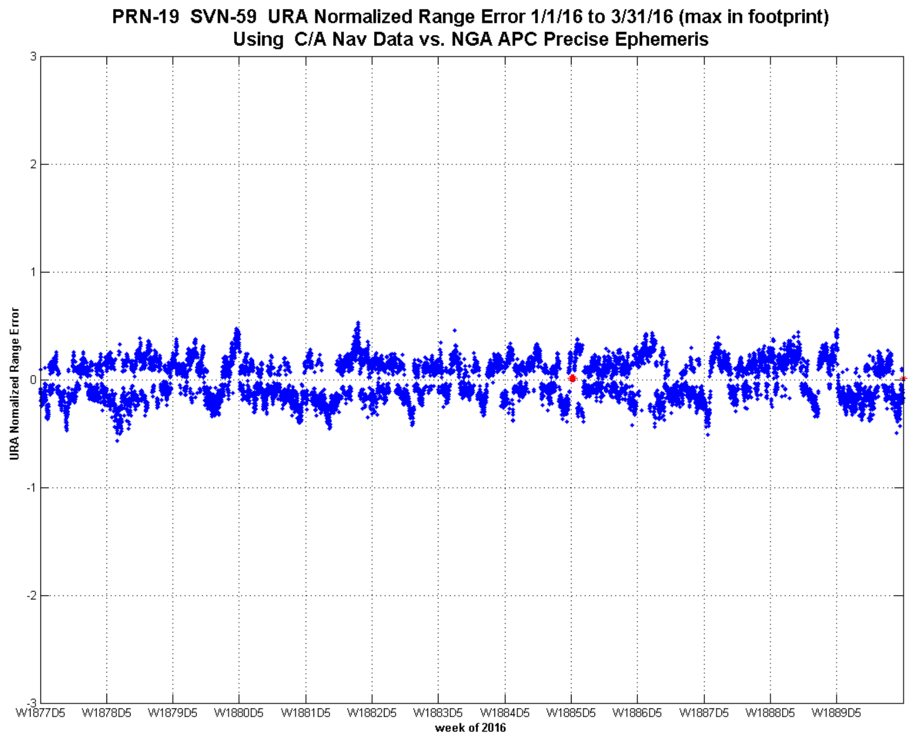


Figure 11-7.30, Timeline of URA Normalized Range Error PRN-20 SVN-51 Using C/A Nav Data

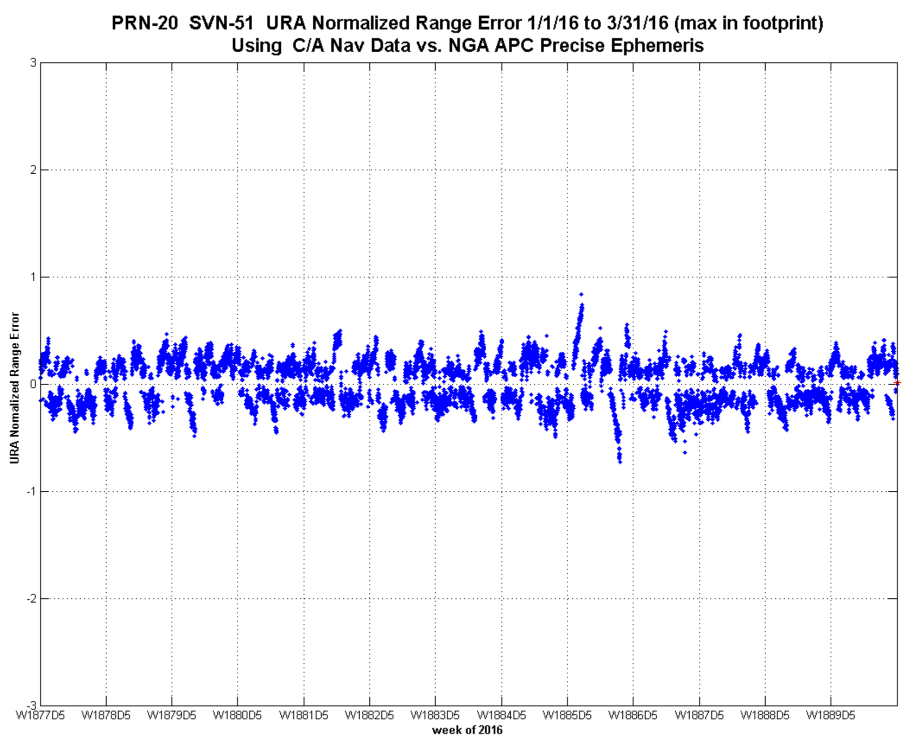


Figure 11-7.31, Timeline of URA Normalized Range Error PRN-21 SVN-45 Using C/A Nav Data

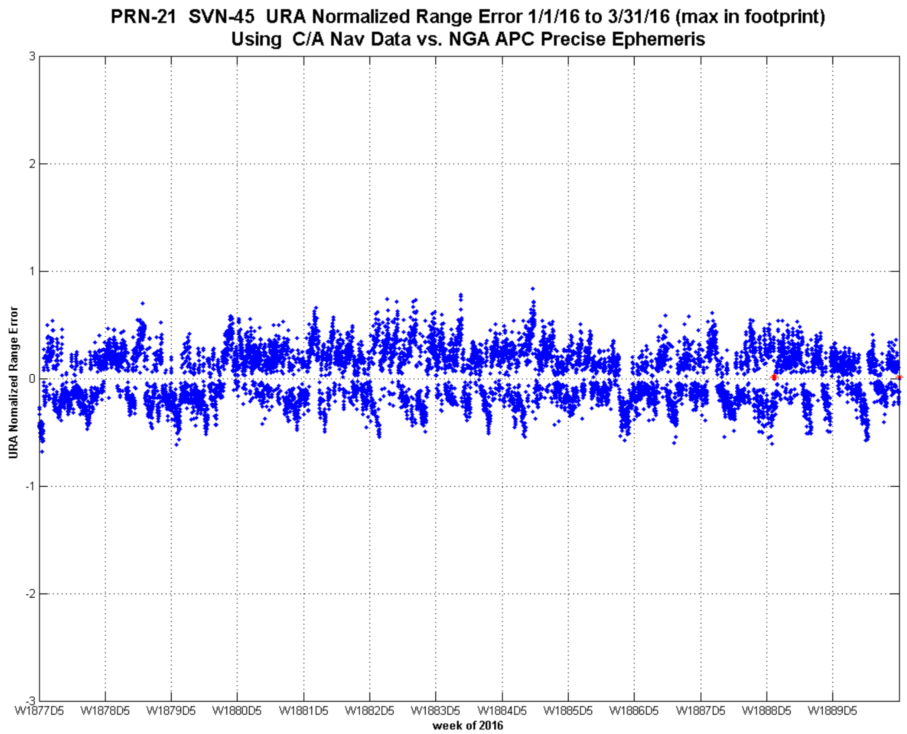


Figure 11-7.32, Timeline of URA Normalized Range Error PRN-22 SVN-47 Using C/A Nav Data

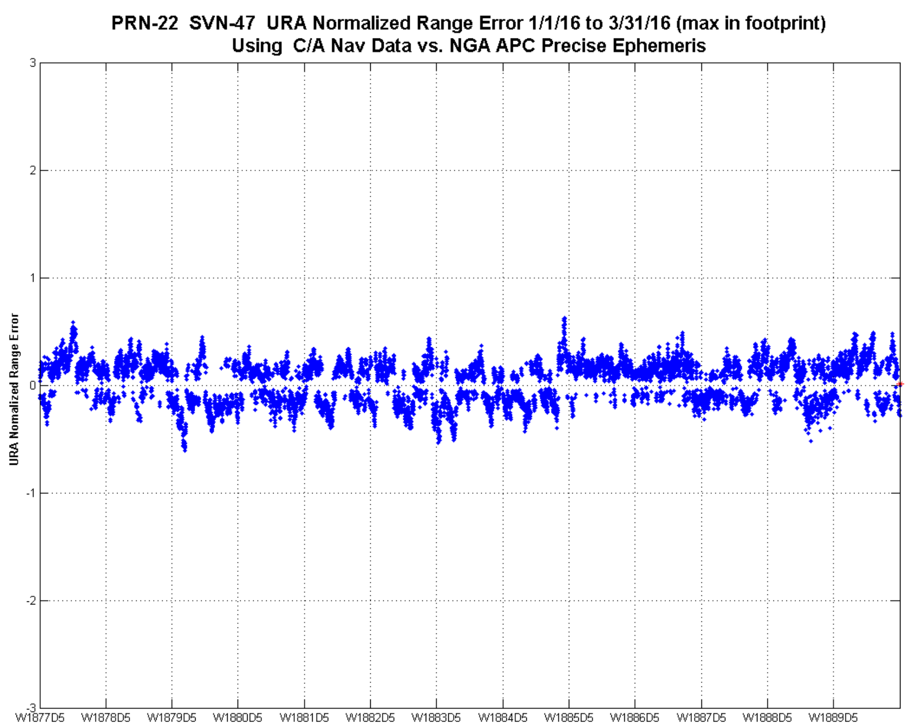


Figure 11-7.33, Timeline of URA Normalized Range Error PRN-23 SVN-60 Using C/A Nav Data

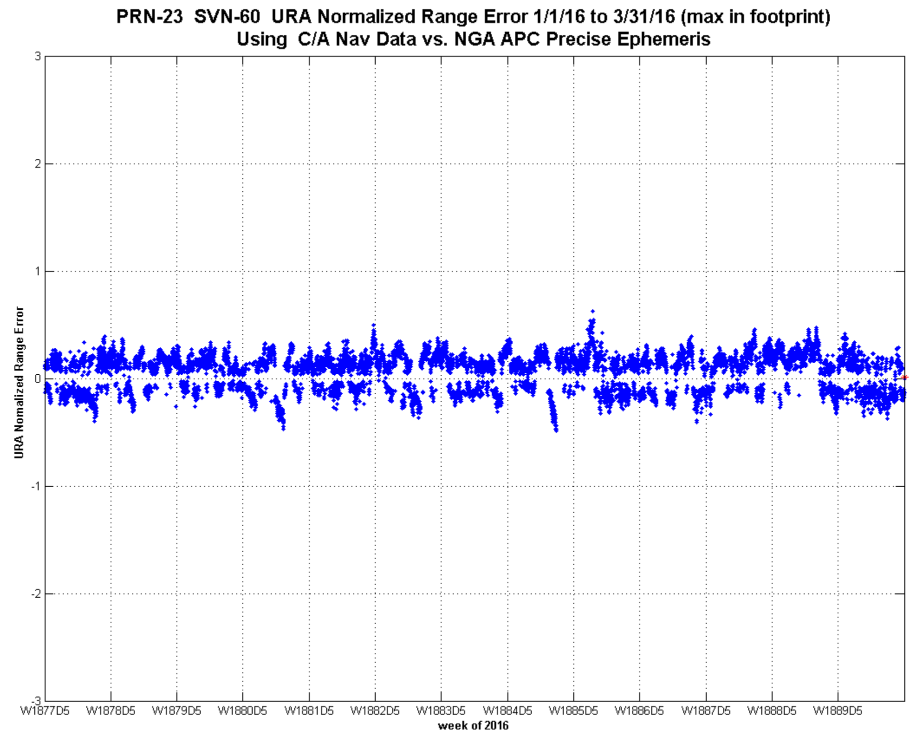


Figure 11-7.34, Timeline of URA Normalized Range Error PRN-24 SVN-65 Using C/A Nav Data

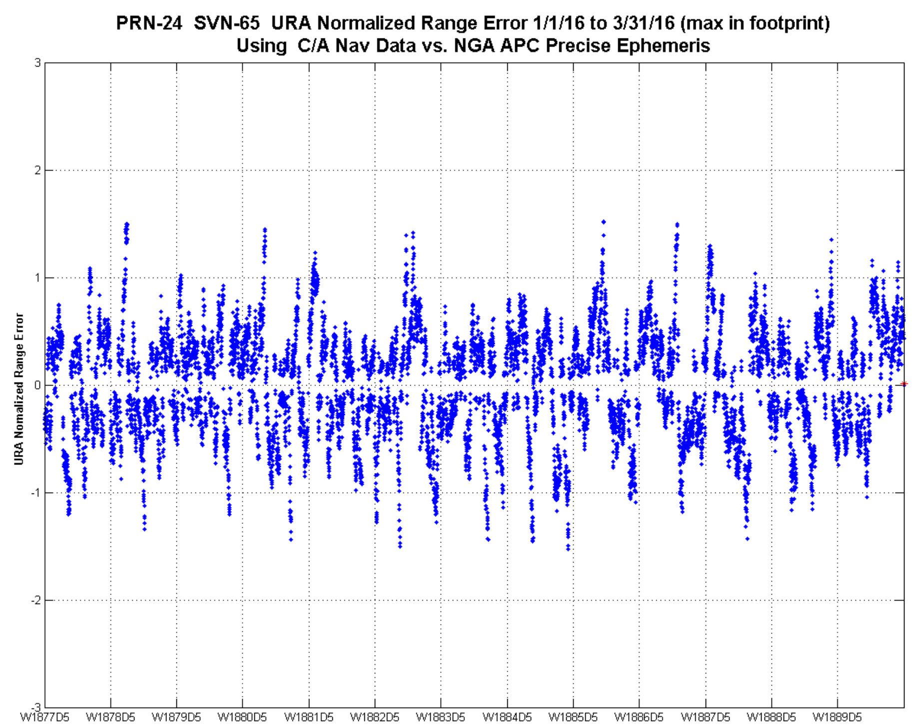


Figure 11-7.35, Timeline of IAURA Normalized Range Error PRN-24 SVN-65 Using L2C CNAV Data

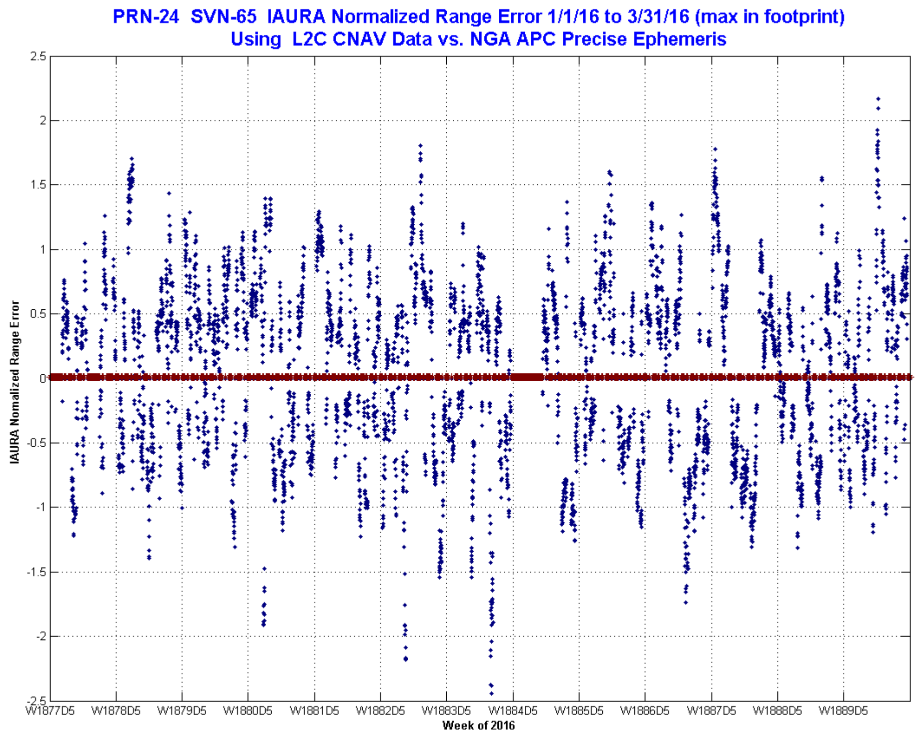


Figure 11-7.36, Timeline of URA Normalized Range Error PRN-25 SVN-62 Using C/A Nav Data

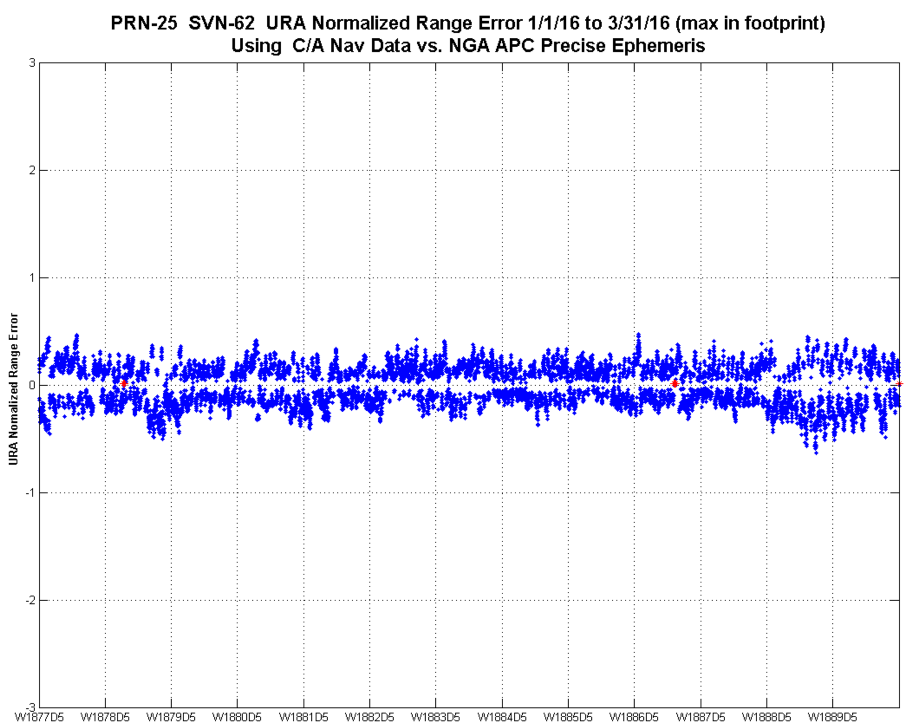


Figure 11-7.37, Timeline of IAURA Normalized Range Error PRN-25 SVN-62 Using L2C CNAV Data

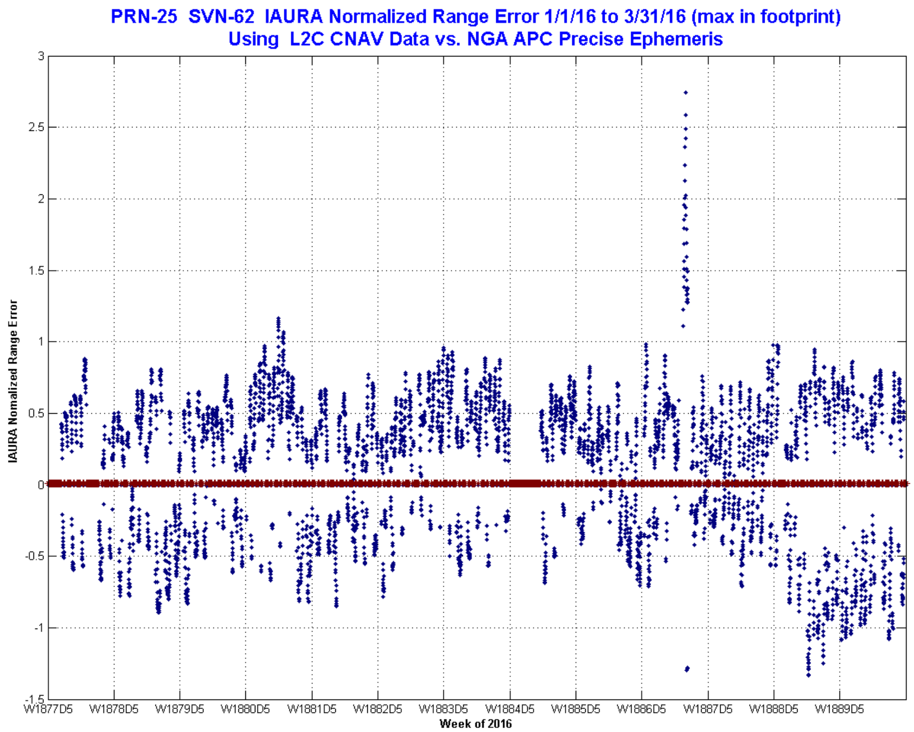


Figure 11-7.38, Timeline of URA Normalized Range Error PRN-26 SVN-71 Using C/A Nav Data

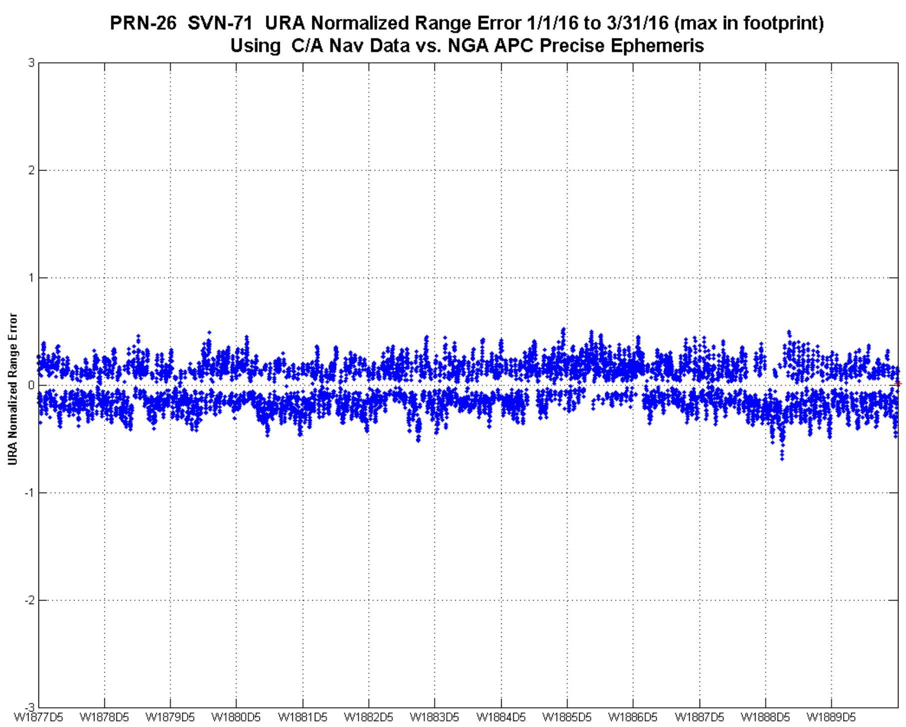


Figure 11-7.39, Timeline of URA Normalized Range Error PRN-26 SVN-71 Using L2C CNAV Data

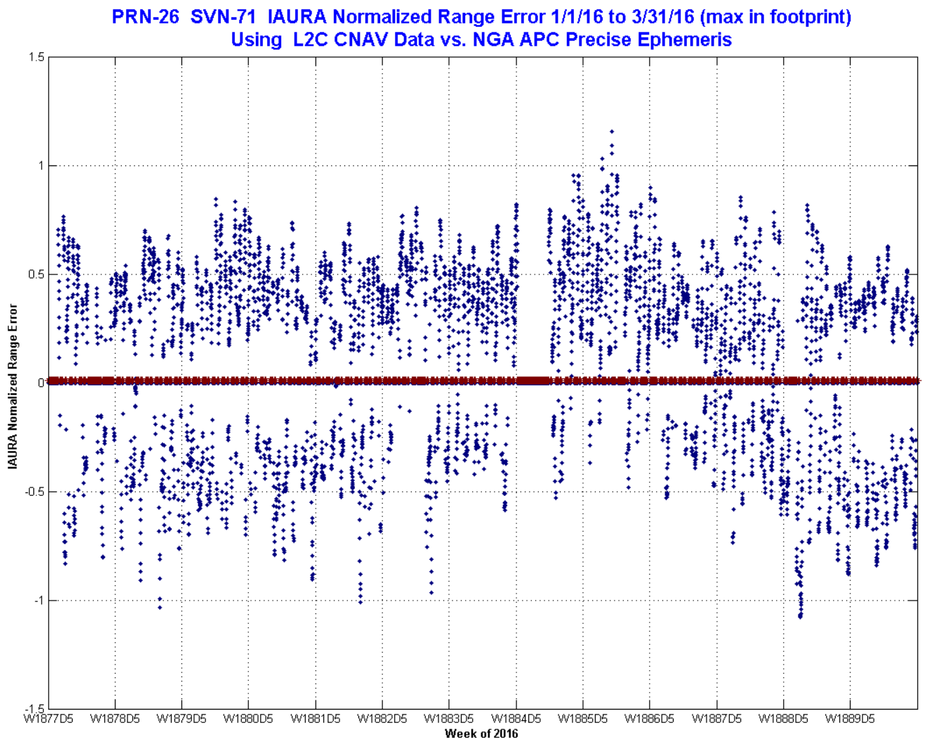


Figure 11-7.40, Timeline of URA Normalized Range Error PRN-27 SVN-66 Using C/A Nav Data

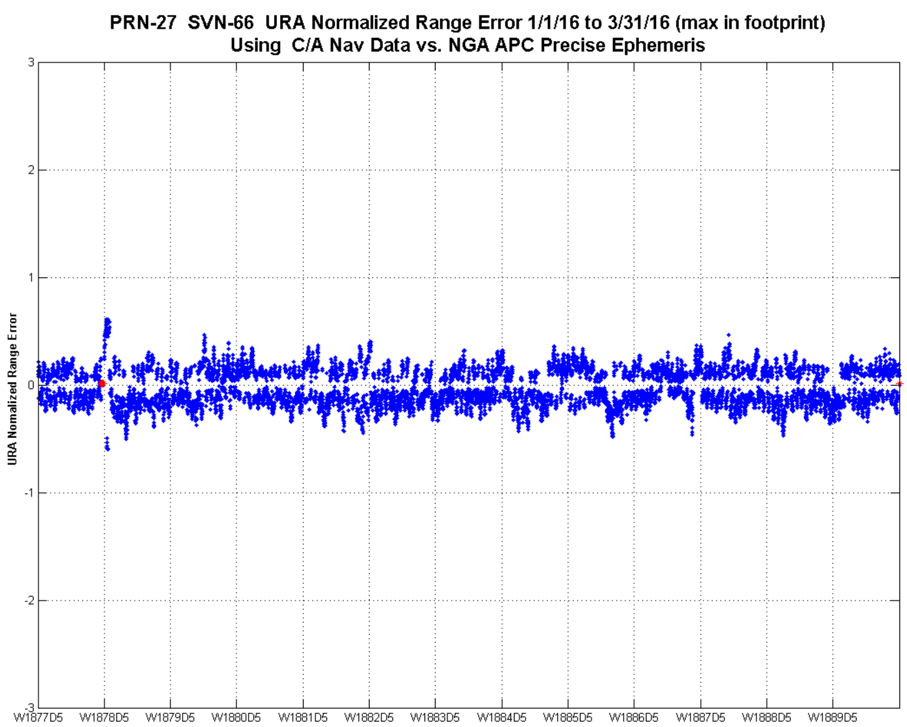


Figure 11-7.41, Timeline of IAURA Normalized Range Error PRN-27 SVN-66 Using L2C CNAV Data

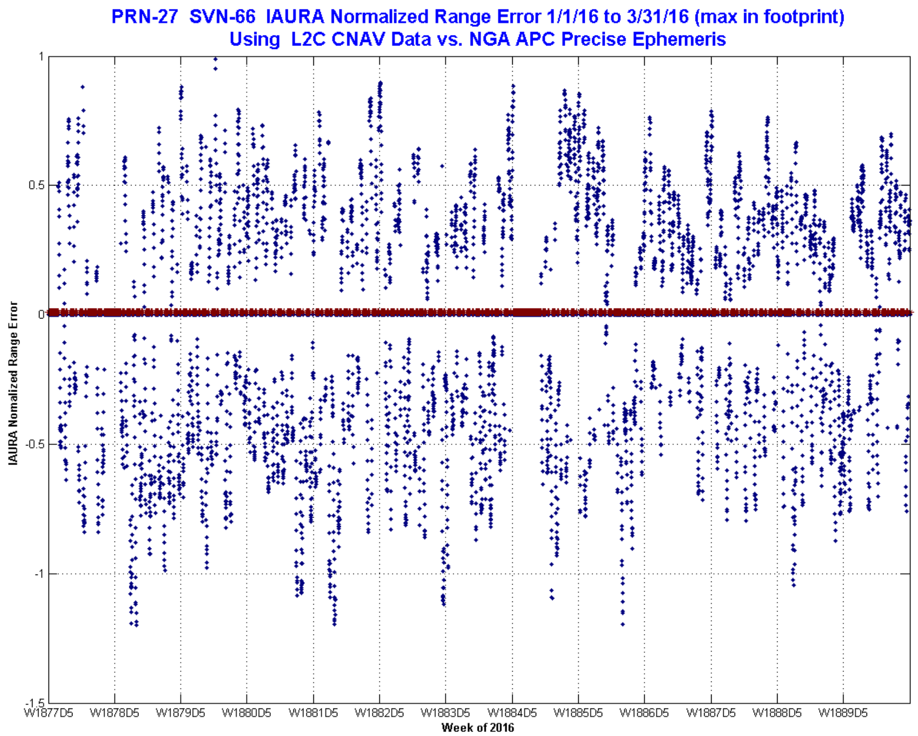


Figure 11-7.42, Timeline of URA Normalized Range Error PRN-28 SVN-44 Using C/A Nav Data

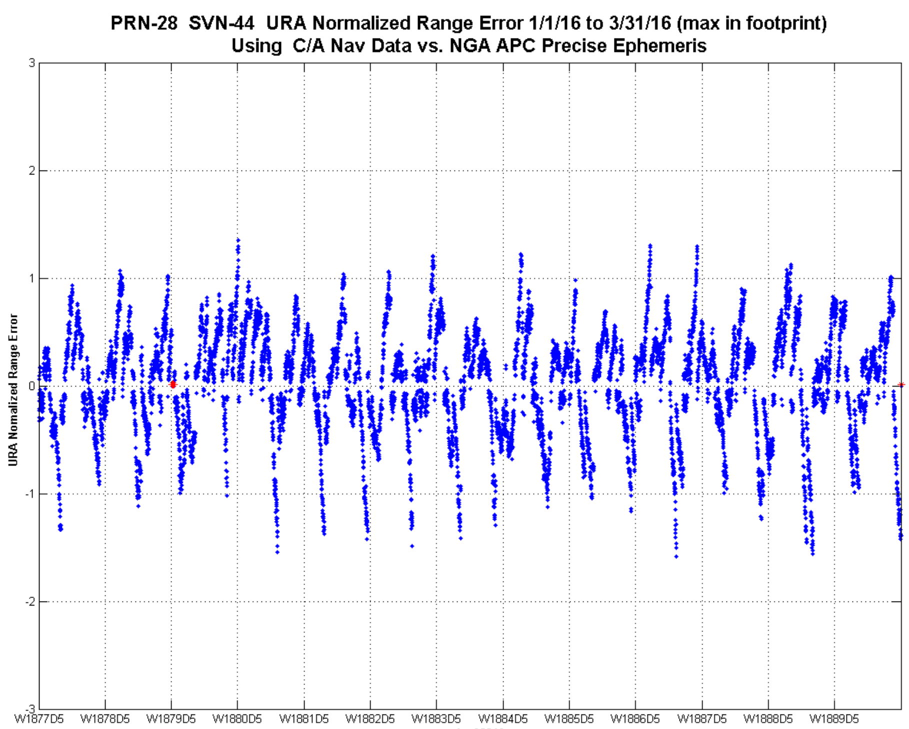


Figure 11-7.43, Timeline of URA Normalized Range Error PRN-29 SVN-57 Using C/A Nav Data

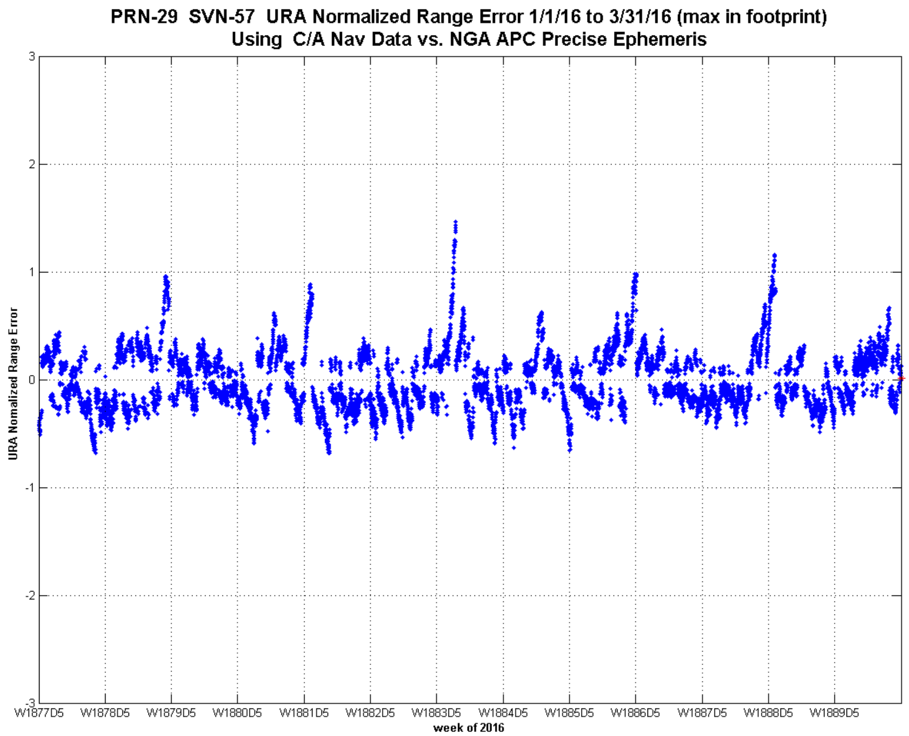


Figure 11-7.44, Timeline of IAURA Normalized Range Error PRN-29 SVN-57 Using L2C CNAV Data

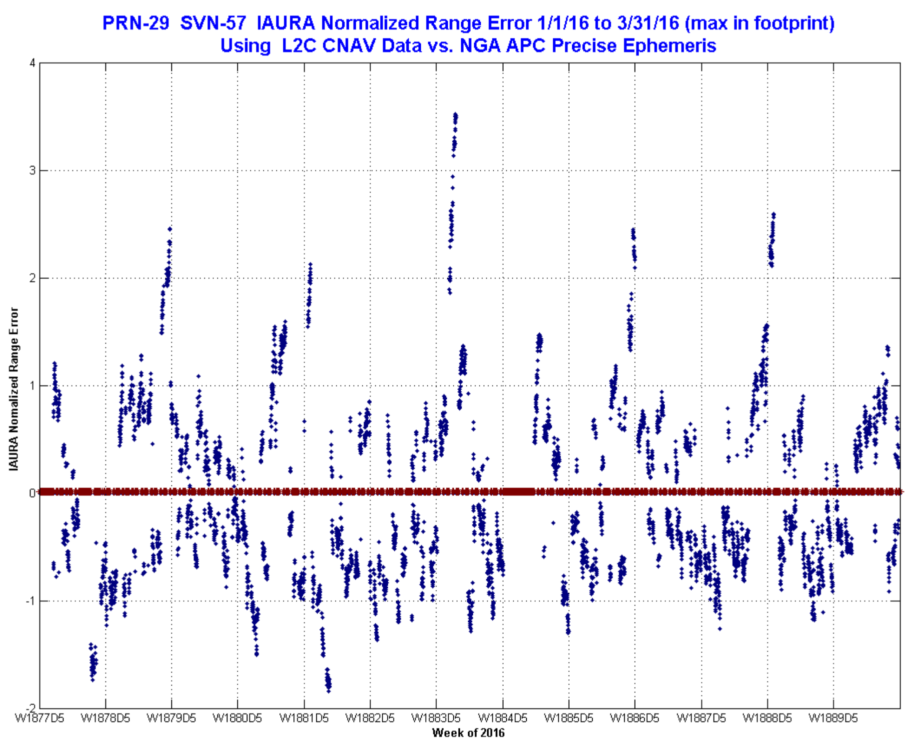


Figure 11-7.45, Timeline of URA Normalized Range Error PRN-30 SVN-64 Using C/A Nav Data

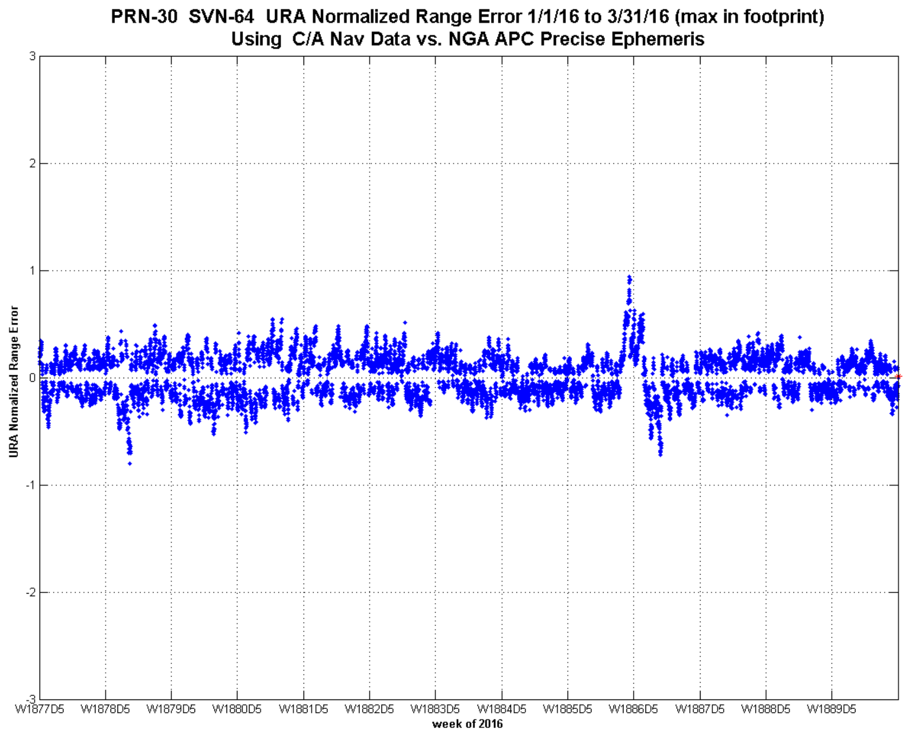


Figure 11-7.46, Timeline of IAURA Normalized Range Error PRN-30 SVN-64 Using L2C CNAV Data

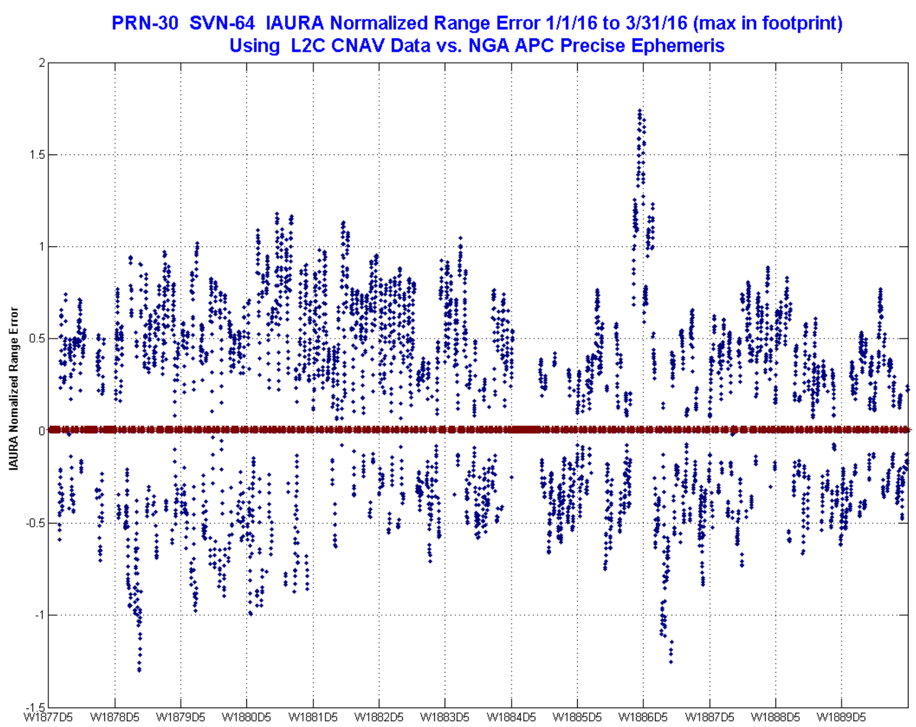


Figure 11-7.47, Timeline of URA Normalized Range Error PRN-31 SVN-52 Using C/A Nav Data

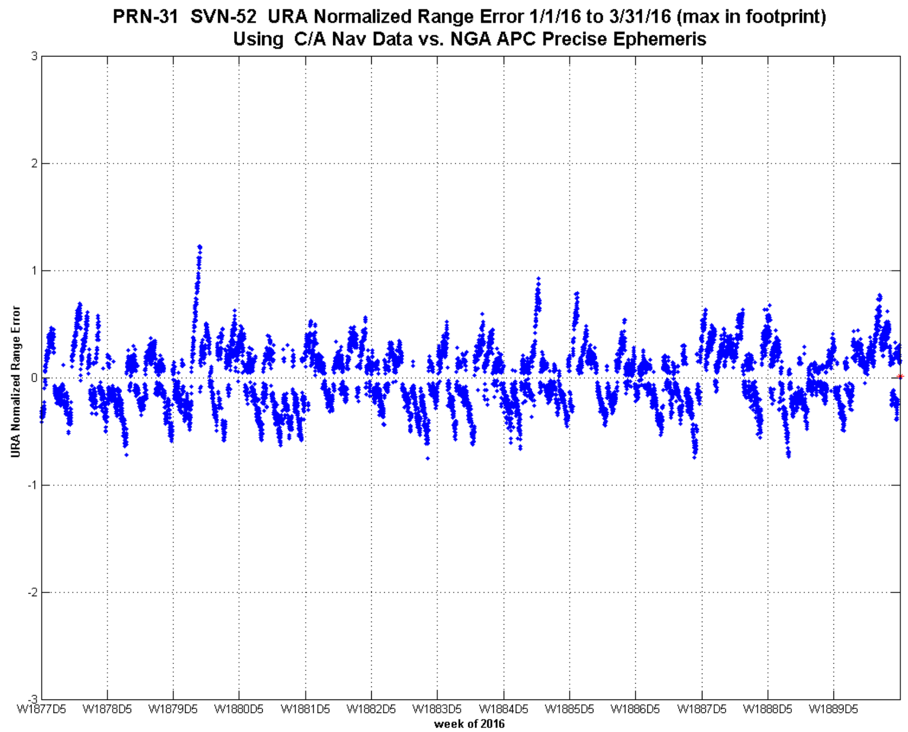


Figure 11-7.48, Timeline of IAURA Normalized Range Error PRN-31 SVN-52 Using L2C CNAV Data

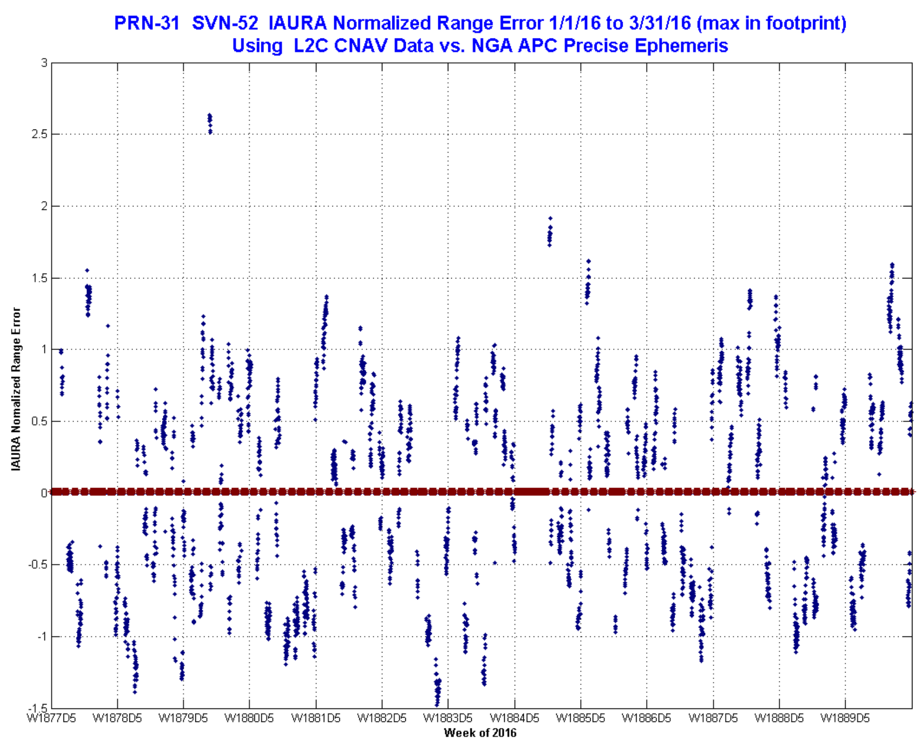


Figure 11-7.49, Timeline of URA Normalized Range Error PRN-32 SVN-23 Using C/A Nav Data

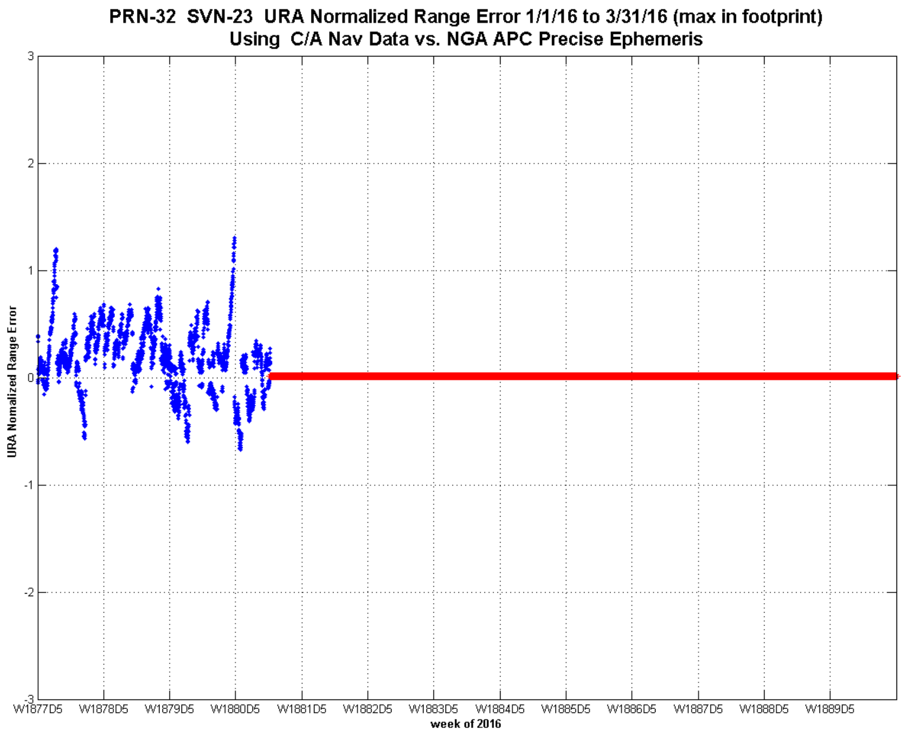


Figure 11-7.50, Timeline of URA Normalized Range Error PRN-32 SVN-70 Using C/A Nav Data