Satellite Navigation Branch, ANG-E66
NSTB/WAAS T&E Team

GLOBAL POSITIONING SYSTEM STANDARD POSITIONING SERVICE PERFORMANCE ANALYSIS REPORT

October 2022

Report #119
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Executive Summary

The Satellite Navigation Office (AJM-32) has tasked the Satellite Navigation Branch (ANG-E66) at the William J. Hughes Technical Center to document the Global Positioning System (GPS) Standard Positioning Service (SPS) performance in quarterly GPS SPS Performance Analysis (PAN) Reports. The reports contain the analysis performed on data collected at 28 Wide Area Augmentation System (WAAS) Reference Stations. This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the GPS SPS Performance Standard (5th Edition, dated April 2020).

This GPS SPS Performance Analysis Report #119, includes data collected from July 1, 2022 through September 30, 2022 reporting period. The next quarterly report will be issued January 31, 2023.

Analysis of this data represents the standards specified in the GPS SPS Standard and have been categorized as: Position Dilution of Precision (PDOP) Availability, "Notice Advisory to Navstar Users" (NANU) Summary and Evaluation, Service Availability, Position and Range Accuracy, Solar Storms, International GNSS Service (IGS) Data Performance, Receiver Autonomous Integrity Monitoring (RAIM) Performance, and GPS Test Notices to Airmen (NOTAMs) Summary.

PDOP Availability Standard. This global availability is based on PDOP. Using the weekly almanac posted on the United States (U.S.) Coast Guard navigation website, the coverage data for every 2° grid point between 180W to 180E and 74S and 74N 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 99.9994%.

NANU Summary and Evaluation. This evaluation was achieved by reviewing the NANU reports issued between July 1, 2022 and September 30, 2022. Using this data, a set of statistics were computed that give a relative idea of constellation health for both the current and combined history of past quarters. For this quarter, 11 outages were reported in the NANUs. Eight outages were scheduled ahead of time, and three unscheduled NANUs occurred.

Service Availability Standard. The quarterly service availability standard was verified using 24-hour position accuracy values computed from data collected at 1-second intervals. All sites achieved a 100% availability, which exceeds the SPS "average location" value of 99% and the "worst-case location" value of 90%.

Accuracy Standard. Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error (URE) 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, Merida, and Juneau. This data was also collected in 1-second samples. All sites achieved 100% reliability, meeting the SPS Standard. The maximum range error recorded was 24.710 meters on Satellite PRN12. The SPS Standard 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 Root Mean Square (RMS) range error value of 2.040 meters was recorded on satellite PRN19. SPS Standard states that RMS URE cannot exceed 6 meters in any 24-hour interval.

Solar Storms. Geomagnetic storms had little to no effect on GPS performance this quarter. All sites met all GPS SPS Standards on those days with the most significant solar activity.

IGS Data Performance. The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent Global Navigation Satellite System (GNSS) station data to generate precise GNSS products. During the evaluation period, the maximum 95% horizontal and vertical SPS errors were 5.220 meters at Santiago, Chile and 6.370 meters at IISC, respectively.

RAIM Performance. RAIM is a technology developed to assess the integrity of GPS signals in a GPS receiver system. During the evaluation period, the minimum percentage of time in RNP 0.1 mode was 99.876% at Juneau. The minimum percent of time spent in RNP 0.3 mode was 100% at all locations evaluated. The maximum 99% HPL value was 140.228 meters at Anchorage.

GPS Test NOTAMs Summary. During this evaluation period, GPS Test NOTAMs were not evaluated.

From the analysis performed on data collected between July 1, 2022 and September 30, 2022, the GPS performance met all SPS requirements that were evaluated.

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1. INTRODUCTION

1.1 Objective of GPS SPS Performance Analysis Report

In 1993, the Federal Aviation Administration (FAA) began monitoring and analyzing GPS SPS performance data. 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 28 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 to include the performance categories stated in the SPS Performance Standard (5th Edition, April 2020) as well as additional performance categories and are laid out as follows:

1. PDOP Availability Standard
2. Service Availability Standard
3. Service Reliability Standard
4. Positioning, Ranging and Timing Accuracy Standard
5. Solar Storms
6. IGS Data
7. RAIM Performance
8. GPS Test NOTAMs Summary
9. GPS Broadcast Orbit vs. NGA Precise Orbits and URA (IAURA) Bounding Analysis

For the performance categories found in the SPS Performance Standard, the results of these analyses have been compared to the performance parameters stated in the SPS Performance Standard.

1.2 Report Overview

Section 2. 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 2-degree grid between 180-degrees east and 180-degrees west, and from 74-degrees north and 74-degrees south. The program then computes the PDOP at each grid point (13,500 total grid points) every minute for the entire day and stores the results. After the PDOPs have been saved, the 99.99% index of 1-minute PDOP at each grid point is determined and plotted as contour lines (see 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 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 Standard 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 1-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.

Section 6. Provides 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 RAIM performance.

Section 9. Provides a summary of GPS Test NOTAMs.

Section 10. Provides the GPS broadcast orbit versus NGA precise orbits and URA (IAURA) bounding analyses.

Appendix A. Provides a summary of all the results as compared to the SPS Standard.

Appendix B. Provides the geomagnetic data used for Section 6.

Appendix C. Provides the PAN Problem Report

Appendix D. Provides a glossary of terms used in this PAN report. This glossary was obtained directly from the GPS SPS Standard document (April 2020).

1.3 Summary of Performance Requirements and Metrics

Table 1-1 lists the performance parameters from the SPS for the L1 (1575.42 MHz) Coarse/Acquisition (C/A) signal and identifies those parameters verified in this report. The L2C (1227.60 MHz) and L5 (1176.45 MHz) signals are pre-operational, and their use is at the users' own risk. No commitment of signal availability for L2C or L5 will be made until the signals are declared fully operational by the DoD and available for users.

Table 1-1. SPS SIS Performance Requirements Standards Evaluated in This Report

Parameter	Conditions and Constraints
Per-Satellite Coverage Terrestrial Service Volume: 100% Coverage Space Service Volume: No Coverage Performance Specified	For any healthy or marginal SPS SIS.
Constellation Coverage Terrestrial Service Volume: 100% Coverage Space Service Volume: No Performance Specified	For any healthy or marginal SPS SIS.

Parameter	Conditions and Constraints
User Range Error Accuracy Single-Frequency C/A-Code • ≤7.0m 95% Global Average URE during normal operations over All AODs • ≤3.8m 95% Global Average URE during operations at Zero AOD • ≤9.7m 95% Global Average URE during normal operations at Any AOD	For any healthy or marginal 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. Including Inter-Signal Correction (ISC) errors.
User Range Error Accuracy 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 or marginal 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. Including ISC errors. 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 Error Accuracy Single-Frequency C/A-Code: ≤388m 95% Global Statistic URE during Extended Operations after 14 Days without Upload	For any healthy or marginal SPS SIS.

Parameter	Conditions and Constraints
User Range Error Accuracy Single-Frequency C/A-Code: ≤2.0m 95% Global Statistic URE during Normal Operations over all AODs for the ensemble of constellation slots	Across all healthy or marginal SPS SIS from satellites occupying constellation slots. Neglecting SF 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. Including ISC errors.
User Range Rate Error Accuracy Single-Frequency C/A Code: ≤6mm/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 Single-Frequency C/A Code: ≤2mm/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 ≤30 nanoseconds 95% Global average UTCOE during normal operations at Any AOD	For any healthy SPS SIS.

Parameter	Conditions and Constraints
Instantaneous URE Integrity Single-Frequency C/A-Code: $\leq 1x10^{-5}$ Probability over any hour of the SPS SIS Instantaneous URE exceeding the NTE tolerance without a timely alert during normal operations **Note:** Please see results in Section 3 of the WAAS PAN Report located http://www.nstb.tc.faa.gov/DisplayArchive.htm	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 the maximum SPS SIS instantaneous URE did not exceed the NTE tolerance at the start of the hour. UMSI occurs if no timely alert issued after SPS SIS URE NTE tolerance exceeded. Worst case for delayed alert is 6 hours. Neglecting single-frequency ionospheric delay model errors.
Instantaneous UTCOE Integrity Single-Frequency C/A-Code: $\leq 1x10^{-5}$ 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 UTCOE NTE tolerance defined to be ±120 ns. Given 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.
Unscheduled Failure Interruption Continuity 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 the SPS SIS is available from the slot at the start of the hour.
Status and Problem Reporting Scheduled event affecting service Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event for 95% of the events	For any SPS SIS.

Parameter	Conditions and Constraints
Status and Problem Reporting 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 ≥ 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 ≥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. Applied to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.

Parameter	Conditions and Constraints
Operational Satellite Count ≥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 that 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 ≥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 ≥99% Horizontal Service Availability, average location ≥99% Vertical Service Availability, average location	15m Horizontal (SIS only) 95% threshold. 33m 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.
Service Availability ≥90% Horizontal Service Availability, worst-case location ≥90% Vertical Service Availability, worst-case location	15m Horizontal (SIS only) 95% threshold. 33m 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 Global Average Position Domain Accuracy: • ≤8m 95% Horizontal Error • ≤13m 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.

Parameter	Conditions and Constraints
Position/Time Accuracy Worst Site Position Domain Accuracy: • ≤15m 95% Horizontal Error • ≤33m 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.
Position/Time Accuracy Time Transfer Domain Accuracy: ≤30 nanoseconds time transfer error 95% of time (SIS only)	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. PDOP AVAILABILITY STANDARD

PDOP Availability is defined as 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) is defined as 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.

Table 2-1 shows the PDOP Availability Standard parameters.

Table 2-1. PDOP Availability Standard Parameters

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 U.S. Coast Guard web site (https://www.navcen.uscg.gov/). In addition, real-time broadcast satellite ephemeris and summary NANUs were utilized to incorporate satellite maintenance start and stop times. Using this data, an SPS coverage area program developed by the WAAS test team was used to calculate the PDOP at every 2-degree point between longitudes of 180W to 180E and 74S and 74N at 1-minute intervals. This gives 1440 samples for each of the 13,500 grid points in the coverage area. Table 2-2 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-2 also gives the global 99.9% PDOP value for each of the 13 GPS Weeks. The PDOP was 3.243 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 area's 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 2-2. PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value	Global Average Availability (Spec: ≥ 98%)	Worst-case Point Availability (Spec: ≥ 88%)
06/26/2022 - 07/02/2022	2.9819	99.9996	99.6527
07/03/2022 - 07/09/2022	2.9571	99.9997	99.6527
07/10/2022 - 07/16/2022	2.9541	99.9997	99.7023
07/17/2022 - 07/23/2022	2.9536	99.9999	99.8313
07/24/2022 - 07/30/2022	2.9636	99.9999	99.99
07/31/2022 - 08/06/2022	2.9473	100	100
08/07/2022 - 08/13/2022	2.9427	100	100
08/14/2022 - 08/20/2022	2.9232	99.9998	99.871
08/21/2022 - 08/27/2022	3.107	99.9994	99.4345
08/28/2022 - 09/03/2022	3.0404	99.9993	99.4444
09/04/2022 - 09/10/2022	2.9771	99.9992	99.4345
09/11/2022 - 09/17/2022	3.0988	99.9988	99.4444
09/18/2022 - 09/24/2022	2.9641	99.9994	99.5734
09/25/2022 - 10/01/2022	2.9512	99.9994	99.5932

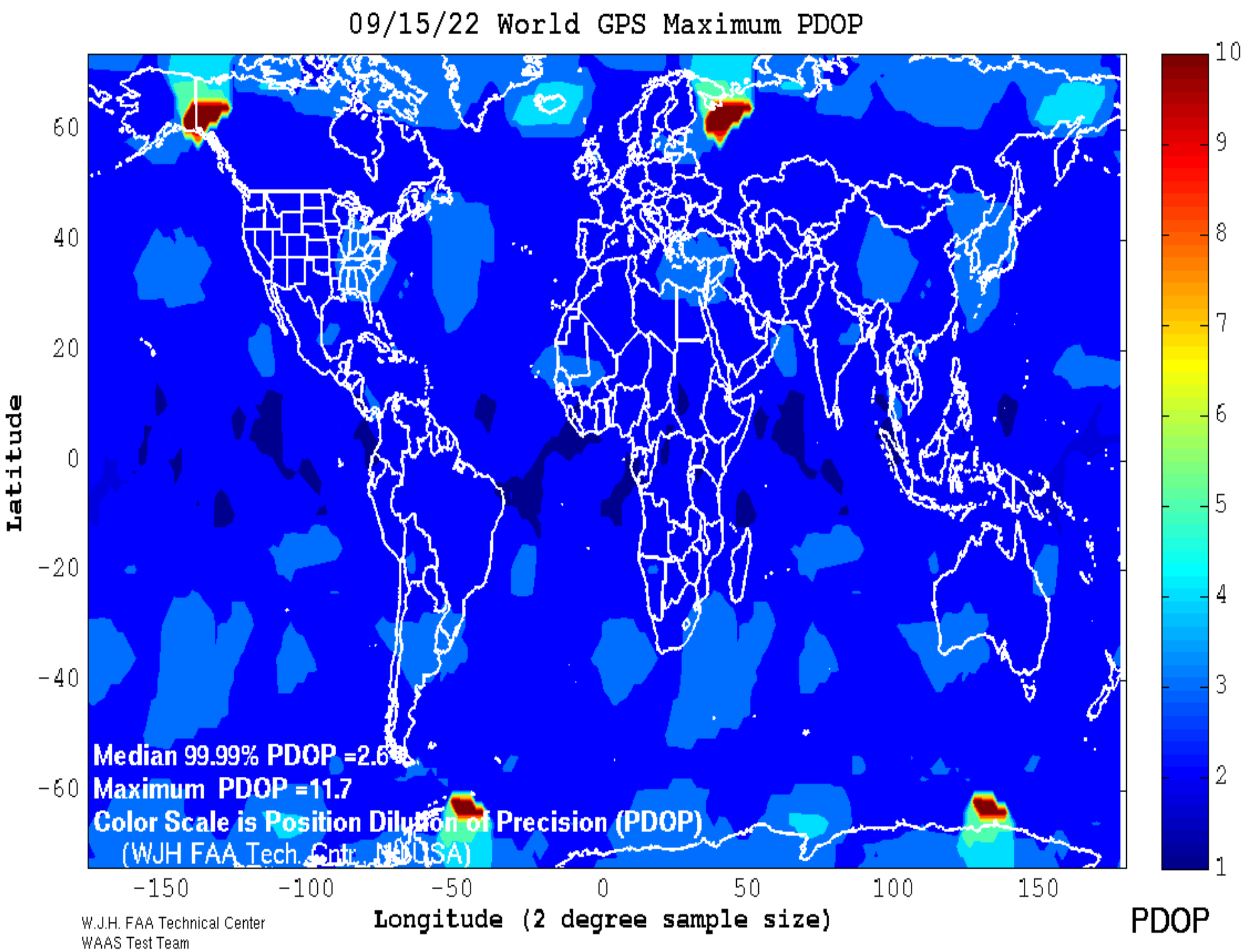


Figure 2-1. World GPS Maximum PDOP

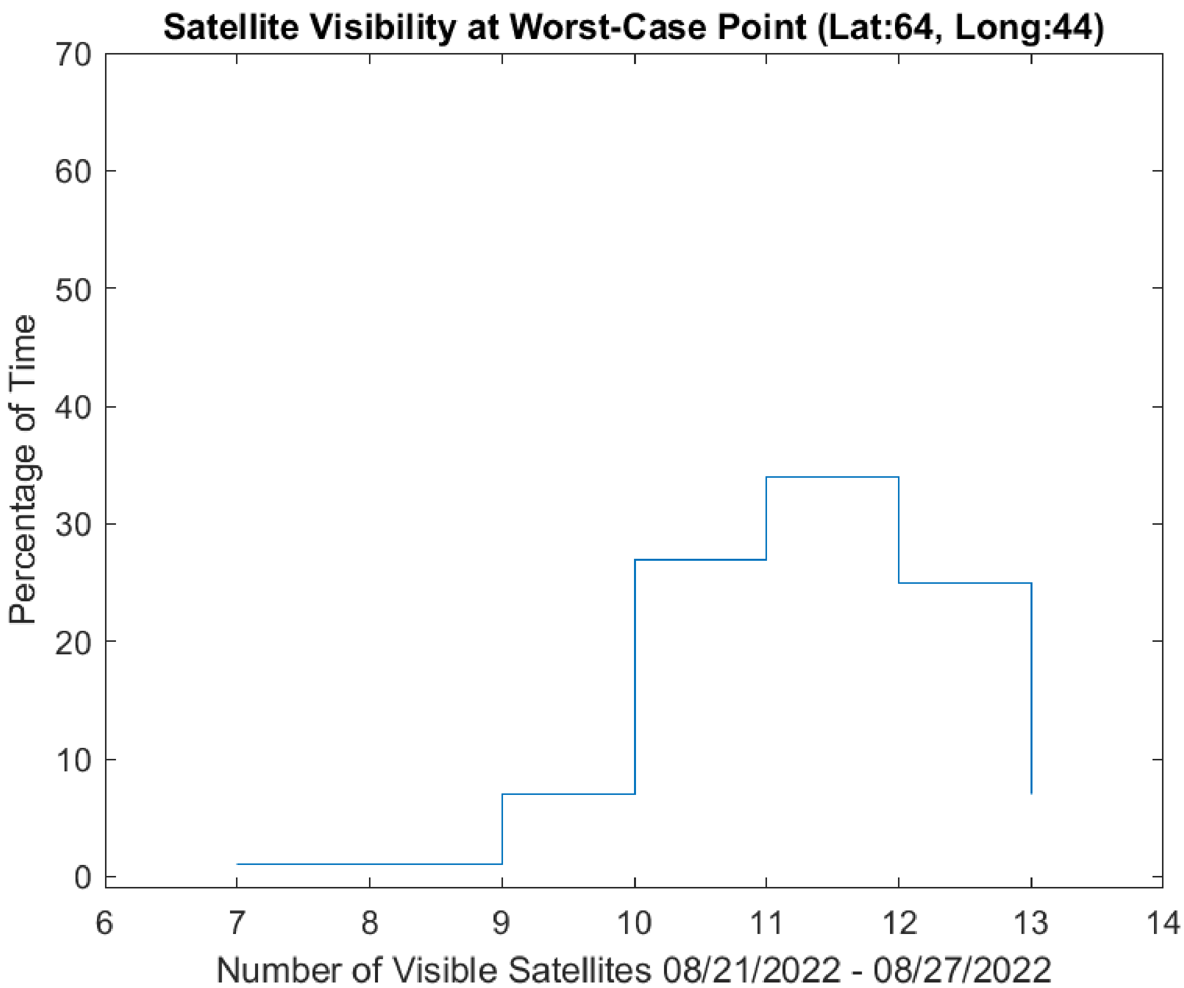


Table 3-1. Parameters for Issuing NANUs

Status and Problem Reporting	Conditions and Constraints
Scheduled event affecting service: Appropriate NANU issued to the U.S. 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 U.S. 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 NANUs. During this reporting period, July 1 through September 30, 2022, there were 11 reported outages. Eight outages were maintenance activities and were reported in advance, and three were unscheduled outages. A complete listing of outage NANUs for the reporting period is provided in Table 3-2. A complete listing of the forecasted outage NANUs for the reporting period can be found in Table 3-3. Canceled outage NANUs (if any) are provided in Table 3-4. The minimum duration a scheduled outage was forecasted ahead of time was 64.9 hours. The maximum response time following an unscheduled outage was 0.617 hours. Therefore, the probability of continuity not being affected due to an unscheduled failure interruption was 100%, which met the specification requirement for the 24-slot GPS constellation. A complete listing of the GPS constellation plane and slot designations is provided in Table 10-2. Figure 10-6 shows a graphical representation of the current GPS Constellation.

Table 3-2. NANUs Affecting Satellite Availability

NANU	PRN	TYPE	Start Date	Start Time (UTC)	End Date	End Time (UTC)	Total Unscheduled (hours)	Total Scheduled (hours)	Total (hours)
2022034	2	FCSTSUMM	14-Jul-22	15:24	14-Jul-22	22:16	0	6.87	6.87
2022036	4	FCSTSUMM	29-Jul-22	02:27	29-Jul-22	07:33	0	5.1	5.1
2022038	31	FCSTSUMM	11-Aug-22	22:39	12-Aug-22	04:28	0	5.82	5.82
2022044	25	UNUSABLE	19-Aug-22	14:56	19-Aug-22	17:23	2.45	0	2.45
2022045	10	FCSTSUMM	23-Aug-22	13:03	29-Aug-22	18:49	0	149.77	149.77
2022048	26	FCSTSUMM	08-Sep-22	12:29	08-Sep-22	17:57	0	5.47	5.47
2022051	30	UNUSABLE	14-Sep-22	20:03	14-Sep-22	22:33	2.5	0	2.5
2022055	23	UNUSABLE	08-Sep-22	06:51	16-Sep-22	15:28	200.62	0	200.62
2022057	6	FCSTSUMM	22-Sep-22	15:01	22-Sep-22	20:41	0	5.67	5.67
2022059	5	FCSTSUMM	29-Sep-22	23:00	30-Sep-22	04:20	0	5.33	5.33
Totals of Unscheduled Scheduled and Total Downtime							205.57	184.03	389.60

Table 3-3. NANUs Forecasted to Affect Satellite Availability

NANU	PRN	TYPE	Start Date	Start Time (UTC)	End Date	End Time (UTC)	Total (hours)	Comments
2022033	2	FCSTDV	14-Jul-22	14:25	15-Jul-22	14:25	24	2022034
2022035	4	FCSTDV	29-Jul-22	02:00	29-Jul-22	14:00	12	2022036
2022037	31	FCSTDV	11-Aug-22	22:15	12-Aug-22	10:15	12	2022038
2022039	10	FCSTMX	23-Aug-22	13:00	02-Sep-22	13:00	240	2022045
2022041	25	UNUSUFN	19-Aug-22	14:56				2022044
2022046	26	FCSTDV	08-Sep-22	12:15	09-Sep-22	00:15	12	2022048
2022047	23	UNUSUFN	08-Sep-22	06:51				2022055
2022049	6	FCSTDV	15-Sep-22	15:00	16-Sep-22	03:00	0	2022052
2022050	30	UNUSUFN	14-Sep-22	20:03				2022051
2022056	6	FCSTDV	22-Sep-22	14:45	23-Sep-22	02:45	12	2022057
2022058	5	FCSTDV	29-Sep-22	22:30	30-Sep-22	10:30	12	2022059
Total Forecasted Downtime							324	

Table 3-4. Canceled NANUs

NANU	PRN	TYPE	Start Date	Start Time (UTC)	Comments
2022052	6	FCSTCANC	15-Sep-22	15:00	2022049
2022043	25	FCSTCANC	19-Aug-22	14:56	2022040

Table 3-5. GPS Satellite Maintenance Statistics

Satellite Reliability/Maintainability/Availability (RMA) Parameter	07/01/2022 to 09/30/2022	01/01/2000 to 09/30/2022
Total Forecasted Downtime (hrs)	324	15143.82
Total Actual Downtime (hrs)	389.60	42463.36
Total Actual Scheduled Downtime (hrs)	184.03	8,622.48
Total Actual Unscheduled Downtime(hrs)	205.57	33,840.88
Total Satellite Observed MTTR (hrs)	49.71	36.19
Scheduled Satellite Observed (hrs)	23.86	9.84
Unscheduled Satellite Observed (hrs)	101.41	112.72
Total Satellite Outages (number)	11	1178

Satellite Reliability/Maintainability/Availability (RMA) Parameter	07/01/2022 to 09/30/2022	01/01/2000 to 09/30/2022
Scheduled Satellite Outages (number)	8	877
Unscheduled Satellite Outages (number)	3	301
Percent Operational -- Scheduled downtime (%)	99.72	99.86
Percent Operational -- All downtime (%)	99.13	99.31

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published NANUs. This data has been summarized in Table 3-5. The Total Satellite Observed MTTR was calculated by taking the average downtime of all satellite outage occurrences. Scheduled downtime was forecasted in advance via NANUs. All other downtime reported via NANU was considered unscheduled. The Percent Operational was calculated based on the ratio of total actual operating hours to total available operating hours for every satellite.

3.2 Service Availability Standard

Service Availability is 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 and Vertical Service availability are the percentage of time over any 24-hour interval that the predicted 95% horizontal error or vertical error is less than its threshold for any point within the service volume, respectively. Table 3-6 shows the Service Availability Standard.

Table 3-6. Service Availability Standard

Service Availability Standard	Conditions and Constraints
≥99% Horizontal Service Availability, average location ≥99% Vertical Service Availability, average location	15m Horizontal (SIS only) 95% threshold. 33m 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	15m Horizontal (SIS only) 95% threshold. 33m 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 28 WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-7. The data was collected at 1-second intervals between July 1, 2022 and September 30, 2022.

Table 3-7. Accuracies Exceeding Threshold Statistics

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-hour Threshold Failures	July 2022 – September 2022 Service Availability (%)
Billings	7947504	0	100
Albuquerque	7947681	0	100
Anchorage	7947672	0	100
Boston	7947675	0	100
Washington D.C.	7947679	0	100
Honolulu	7930482	0	100
Honolulu	7930482	0	100
Houston	7947678	0	100
Kansas City	7947666	0	100
Los Angeles	7947679	0	100
Salt Lake City	7947616	0	100
Miami	7947676	0	100
Minneapolis	7947675	0	100
Oakland	7947678	0	100
Cleveland	7947678	0	100
Seattle	7947679	0	100
San Juan	7947680	0	100
Atlanta	7947680	0	100
Juneau	7947470	0	100
Cold Bay	6563256	0	100
Fairbanks	7933485	0	100
Bethel	7938722	0	100
Kotzebue	7329555	0	100
Barrow	7919005	0	100
Merida	7936071	0	100
Gander	7927522	0	100
Tapachula	7873834	0	100
San Jose Del Cabo	7701240	0	100
Iqaluit	7859971	0	100

4. SERVICE RELIABILITY STANDARD

Service Reliability is 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. Table 4-1 shows the URE Accuracy parameters.

Table 4-1. URE Accuracy Parameters

URE 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 4-2 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 5-3. The maximum URE recorded this quarter was 27.360 meters on satellite PRN20.

Table 4-2. URE Accuracy

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples Where SPS URE > 30m NTE	Percentage (%)
01 JULY - 30 SEPTEMBER 2022	Boston	68321970	0	100
01 JULY - 30 SEPTEMBER 2022	Honolulu	70270385	0	100
01 JULY - 30 SEPTEMBER 2022	Juneau	71286991	0	100
01 JULY - 30 SEPTEMBER 2022	Los Angeles	68619153	0	100
01 JULY - 30 SEPTEMBER 2022	Merida	71196786	0	100
01 JULY - 30 SEPTEMBER 2022	Miami	70266388	0	100
01 JULY - 30 SEPTEMBER 2022	Global	419961673	0	100

5. ACCURACY STANDARD

Positioning Accuracy is 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 and Vertical Positioning Accuracy are the statistical difference, at a 95% probability, between horizontal or vertical position measurements and a surveyed benchmark for any point within the service volume over any 24-hour interval, respectively.

Table 5-1 shows the Accuracy Standard parameters.

Table 5-1. Accuracy Standard Parameters

Position/Time Accuracy	Conditions and Constraints
Position/Time Accuracy Global Average Position Domain Accuracy: • ≤8m 95% Horizontal Error • ≤13m 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.
Position/Time Accuracy Worst Site Position Domain Accuracy: • ≤15m 95% Horizontal Error • ≤33m 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.
Position/Time Accuracy Time Transfer Domain Accuracy: ≤30 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 Error Accuracy Single-Frequency C/A-Code • ≤7.0m 95% Global Average URE during normal operations over All AODs • ≤3.8m 95% Global Average URE during operations at Zero AOD • ≤9.7m 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. Including Inter-Signal Correction (ISC) errors.

Position/Time Accuracy	Conditions and Constraints
User Range Rate Error Accuracy Single-Frequency C/A Code: ≤6mm/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 Single-Frequency C/A Code: ≤2mm/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 ≤30 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 July 1, 2022 through September 30, 2022 at the selected WAAS locations. Table 5-2 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter. Every 24-hour analysis period this quarter passed both the worst-case and global average position accuracy requirements set forth by the SPS specification.

Table 5-2 Horizontal & Vertical Accuracy Statistics for the Quarter

Site	95% Vertical (m)	95% Horizontal (m)	99.99% Vertical (m)	99.99% Horizontal (m)
Albuquerque	3.84	2.03	7.58	4.62
Anchorage	3.82	2.60	6.92	5.16
Atlanta	3.69	1.86	8.04	4.22
Barrow	3.94	2.45	45.23	15.61
Bethel	4.5	2.40	7.80	4.87
Billings	3.54	1.60	6.84	3.40
Boston	3.71	1.86	6.23	3.89
Cleveland	3.64	1.72	6.18	3.12

Cold Bay	4.72	1.68	8.36	3.65
Fairbanks	3.70	2.73	6.86	5.36
Gander	3.13	2.02	6.49	4.94
Honolulu	4.56	5.91	11.85	15.46
Houston	3.97	2.57	8.07	6.13
Juneau	3.21	2.38	6.33	4.37
Kansas City	3.78	1.60	7.04	3.76
Kotzebue	4.15	2.82	7.76	6.03
Los Angeles	4.55	2.66	8.28	5.61
Merida	4.18	3.97	14.82	9.38
Miami	3.74	3.11	10.24	7.83
Minneapolis	3.53	1.64	7.30	3.94
Oakland	5.11	2.37	8.67	4.84
Salt Lake City	4.08	1.72	7.58	3.51
San Jose Del Cabo	3.66	4.17	14.12	10.03
San Juan	4.85	3.36	18.20	10.94
Seattle	4.08	1.61	7.95	3.29
Tapachula	4.63	4.54	13.15	10.30
Washington D.C.	3.74	1.7	6.18	3.5

Figure 5-1 and Figure 5-2 are the combined histograms of the vertical and horizontal errors for all 28 WAAS sites from July 1, 2022 to September 30, 2022.

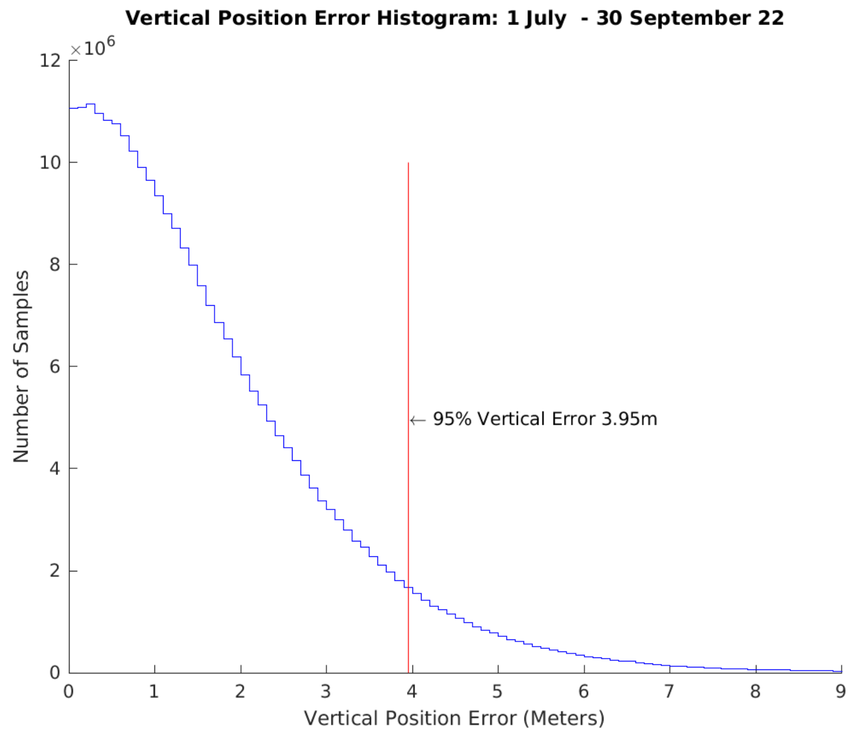


Figure 5-1. Global Vertical Error Histogram

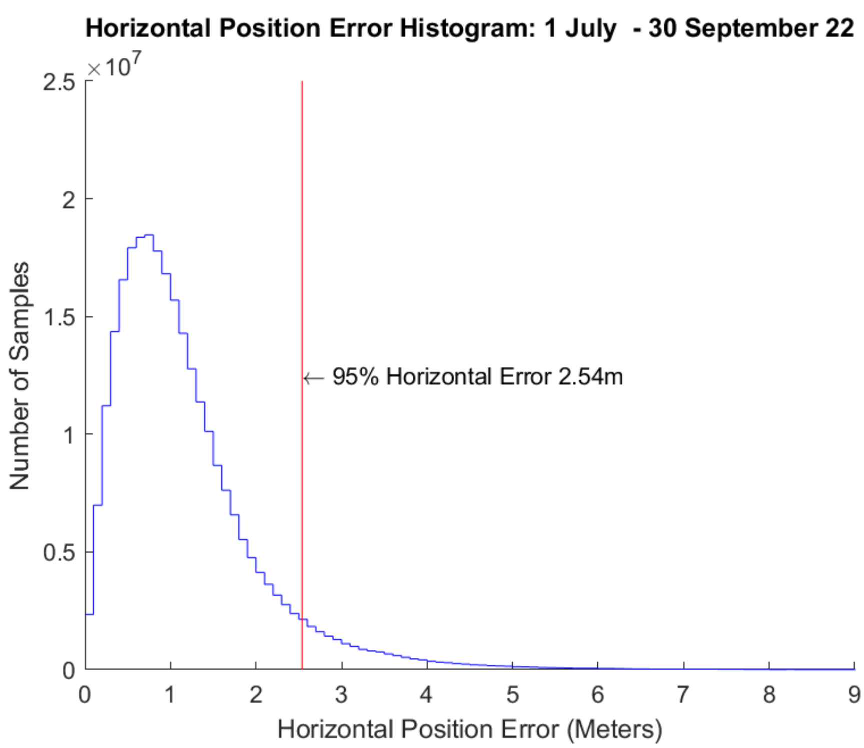


Figure 5-2. Global Horizontal Error Histogram

5.2 Time Transfer Accuracy

The GPS time error data between July 1, 2022 and September 30, 2022 was downloaded from the USNO website. 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. To evaluate the GPS time transfer error, the data file was used to create a histogram (Figure 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 1 nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Figure 5-3. The maximum instantaneous UTC offset error (UTCOE) for the quarter was 2.8 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.

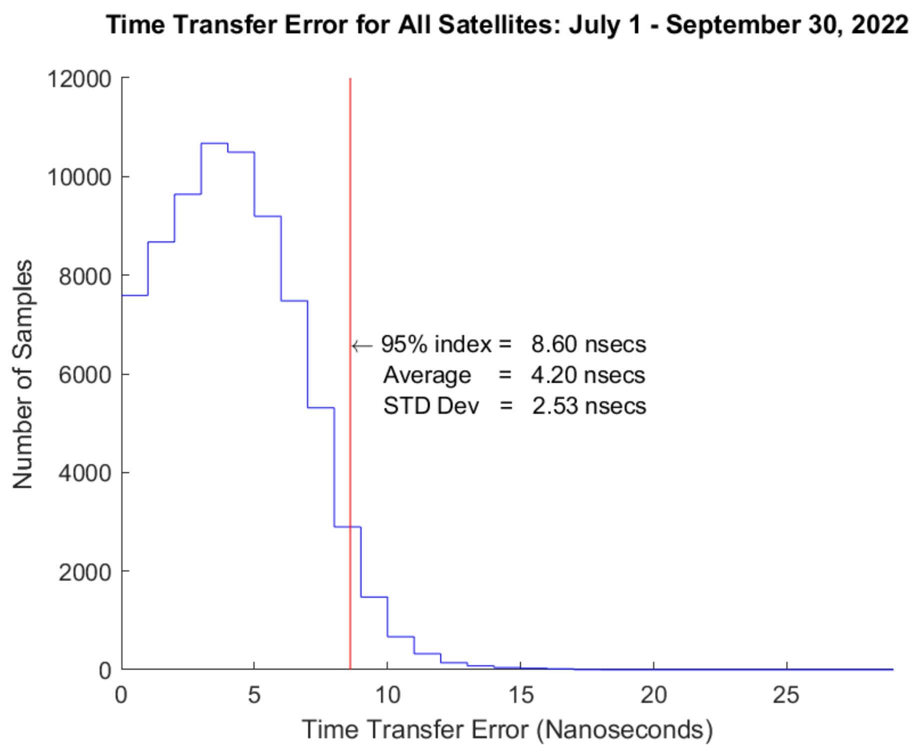


Figure 5-3. Time Transfer Error

5.3 Range Domain Accuracy

Table 5-3 through Table 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 July 1, 2022 and September 30, 2022. A weighted average filter was used for the calculation of the range rate error and the range acceleration error. All Range Domain SPS specifications were met.

Table 5-3. Range Error Statistics

PRN	RMS Range Error (<6m) (Meters)	Range Error Mean (Meters)	1σ Range Error (Meters)	95% Range Error (Meters)	Max Range Error (SPS Spec. < 30m) (Meters)	Samples (Number)
1	1.56	0.08	1.38	3.18	15.65	13914309
2	1.64	0.98	1.08	2.99	16.26	14190730
3	1.76	-0.54	1.38	3.35	17.96	14318989
4	1.65	0.07	1.39	3.05	12.52	12755726
5	1.64	0.07	1.31	3.04	16.77	13769512
6	1.58	-0.05	1.4	3.2	21.13	13991520
7	1.57	0.22	1.28	2.92	15.79	12711473
8	1.82	0.84	1.28	3.24	15.91	12663858
9	1.48	0.1	1.27	2.81	23.19	13400700
10	1.81	0.3	1.26	3.23	16.61	12475438
11	1.42	0.06	1.18	2.75	18.4	14346101
12	1.45	0.43	1.23	2.89	23.02	13824532
13	1.65	-0.08	1.42	3.12	12.31	13677059
14	1.41	0.26	1.23	2.87	20.38	13193158
15	1.74	0.01	1.38	3.22	17.14	12624198
16	1.69	0.7	1.33	3.16	22.72	12821444
17	1.54	0.48	1.29	2.93	19.03	14648048
18	1.74	-0.02	1.31	3.16	17.0	12851200
19	2.04	1.48	1.26	3.66	22.61	14203306
20	1.84	0.92	1.32	3.36	27.36	13426420
21	1.93	0.97	1.53	3.7	15.57	14722887
22	1.9	0.61	1.47	3.4	12.17	14321181
23	1.68	-0.13	1.22	3.04	15.62	12294799
24	1.77	-0.08	1.55	3.45	16.21	13857134
25	1.5	0.54	1.25	2.85	10.91	14168600
26	1.58	0.53	1.24	3.0	16.47	12776254
27	1.75	0.44	1.45	3.46	12.27	13621516
29	1.68	0.63	1.22	3.09	15.99	13206730
30	1.44	0.4	1.17	2.68	16.67	12888768
31	1.83	0.5	1.46	3.37	16.76	13681108
32	1.83	0.03	1.47	3.33	13.66	14614975

Table 5-4. Range Rate Error Statistics

PRN	Range Rate Error RMS (mm/s)	95% Range Rate Error (mm/s)	Max Range Rate Error (mm/s)	Samples (Number)
1	1.67	3.21	236.49	13914309
2	1.63	3.11	137.61	14190730
3	1.84	3.14	154.45	14318989
4	1.58	3.0	246.54	12755726
5	1.83	3.48	317.43	13769512
6	1.63	3.11	273.17	13991520
7	1.7	3.27	247.85	12711473
8	2.09	3.48	153.04	12663858
9	1.64	3.1	288.04	13400700
10	1.65	3.14	111.52	12475438
11	1.59	3.06	245.43	14346101
12	1.71	3.32	116.72	13824532
13	1.73	3.26	144.99	13677059
14	1.56	3.01	158.82	13193158
15	1.71	3.27	124.36	12624198
16	1.72	3.27	198.49	12821444
17	1.81	3.45	239.6	14648048
18	1.58	3.02	147.84	12851200
19	1.75	3.36	288.42	14203306
20	1.68	3.21	164.57	13426420
21	1.81	3.44	248.31	14722887
22	1.79	3.38	193.95	14321181
23	1.58	3.04	104.97	12294799
24	1.59	3.03	142.06	13857134
25	1.57	2.99	135.46	14168600
26	1.57	2.99	222.8	12776254
27	1.61	3.08	165.44	13621516
29	1.65	3.14	124.5	13206730
30	1.56	3.0	136.14	12888768
31	1.71	3.26	143.34	13681108
32	1.66	3.15	148.89	14614975

Table 5-5. Range Acceleration Error Statistics

PRN	Rate Acceleration Error RMS (um/s^2)	95% Range Acceleration Error (um/s^2)	Max Range Acceleration Error (um/s^2)	Samples (Number)
1	12.49	23.93	2390	13914309
2	13.14	25.6	1380	14190730
3	14.77	24.35	1520	14318989
4	11.79	23.11	2440	12755726
5	15.34	29.23	3200	13769512
6	12.38	23.91	2760	13991520
7	12.61	26.57	2440	12711473
8	17.43	29.02	1520	12663858
9	12.36	23.6	2880	13400700
10	12.55	24.75	1100	12475438
11	12.24	23.7	2470	14346101
12	13.12	26.73	1160	13824532
13	13.7	27.93	1450	13677059
14	11.84	23.59	1600	13193158
15	13.05	27.42	1260	12624198
16	13.75	27.19	1980	12821444
17	14.46	28.44	2360	14648048
18	11.82	23.43	1500	12851200
19	13.89	27.86	2850	14203306
20	12.84	26.69	1660	13426420
21	14.07	28.16	2490	14722887
22	13.97	26.85	1940	14321181
23	12.34	23.85	1060	12294799
24	12.21	23.8	1390	13857134
25	12.25	23.99	1350	14168600
26	12.1	24.02	2210	12776254
27	12.09	24.06	1660	13621516
29	12.94	25.47	1240	13206730
30	11.53	23.07	1370	12888768
31	13.04	25.9	1460	13681108
32	12.63	24.01	1490	14614975

Figure 5-4 through Figure 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 PRN20 with an error of 27.360 meters. Satellite PRN25 had the lowest maximum range error of 10.910 meters. Figure 5-7 is histogram of satellite range error for all satellites over the entire quarter. Figure 5-8 through Figure 5-10 show the individual maximums per satellite for range error, range rate error, and range acceleration error, respectively.

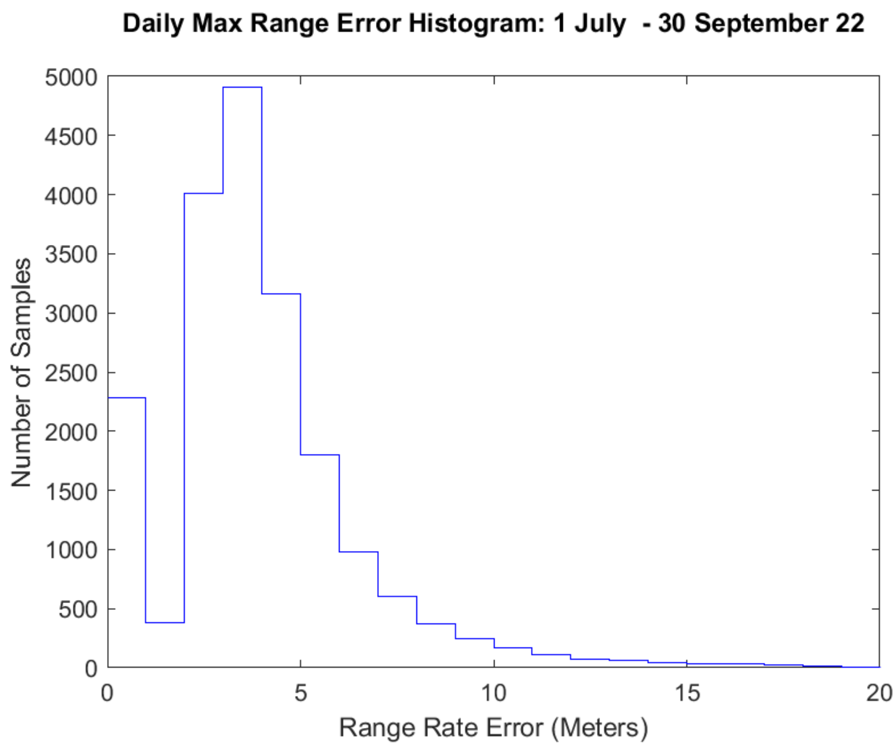


Figure 5-4. Distribution of Daily Max Range Errors

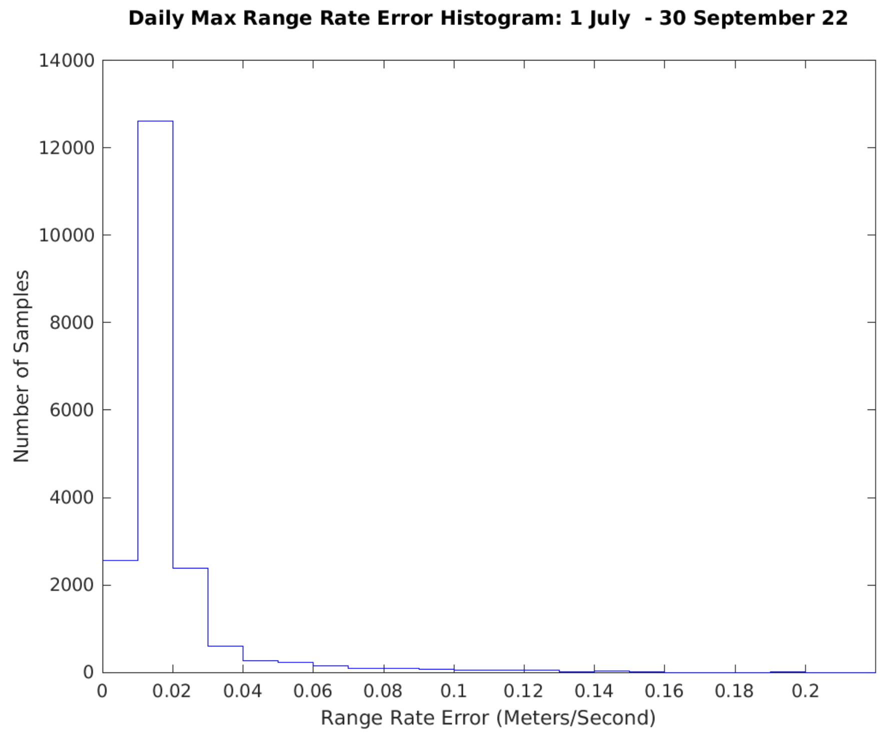


Figure 5-5. Distribution of Daily Max Range Rate Errors

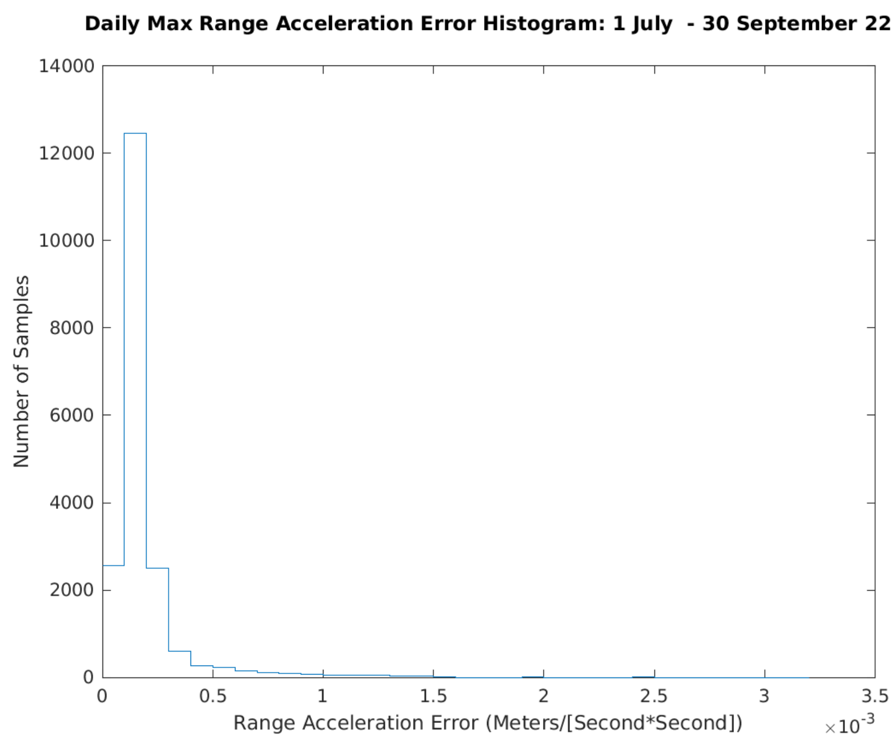


Figure 5-6. Distribution of Daily Max Range Acceleration Errors

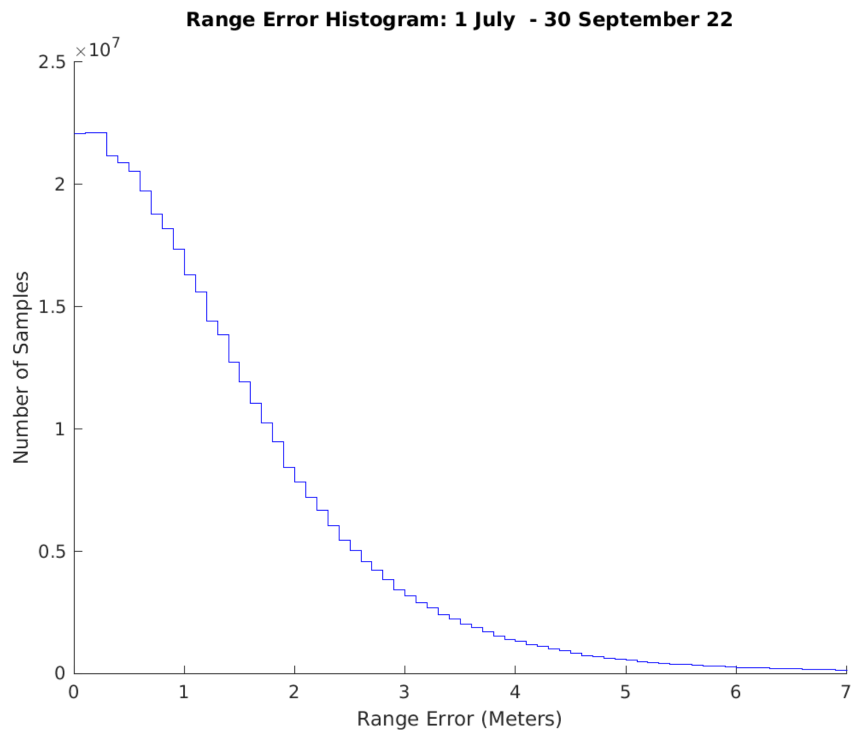


Figure 5-7. Range Error Histogram

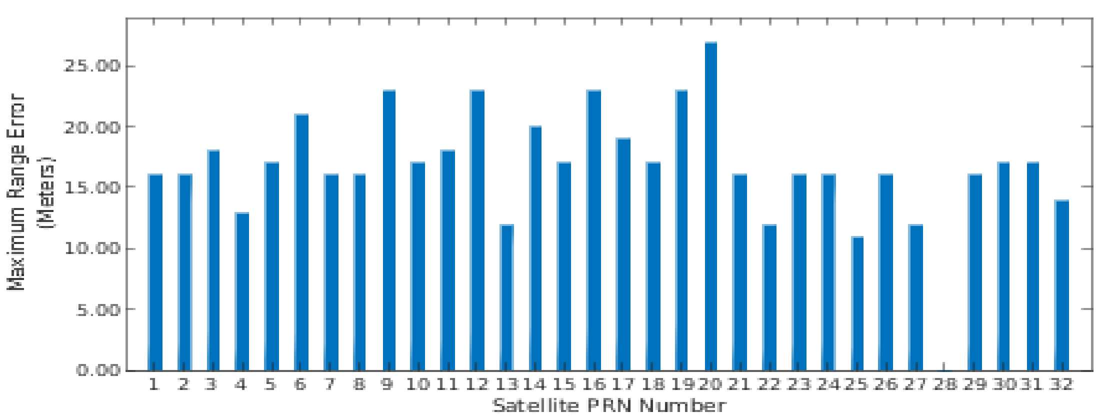


Figure 5-8. Maximum Range Error per Satellite

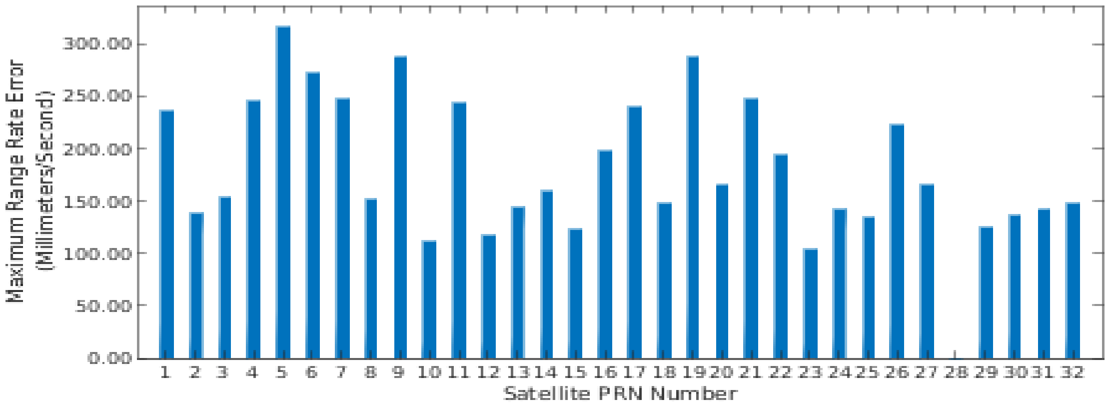


Figure 5-9. Maximum Range Rate Error per Satellite

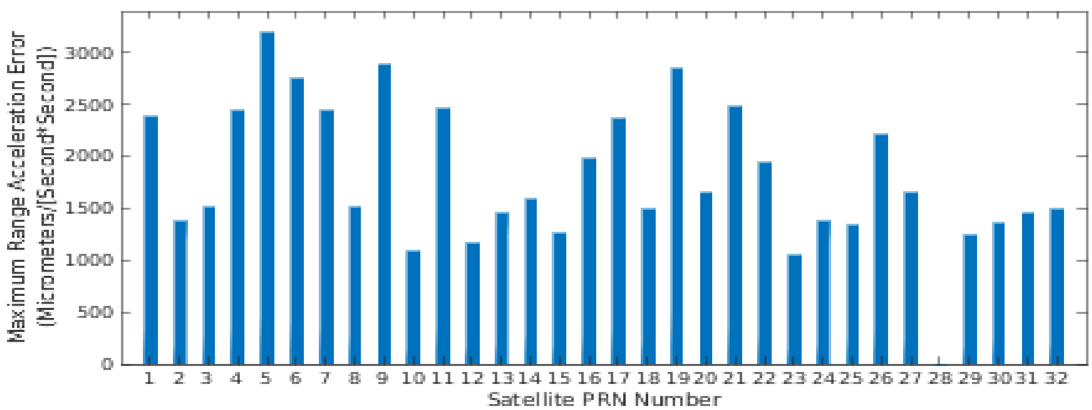


Figure 5-10. Maximum Range Acceleration Error per Satellite

6. SOLAR STORMS

Solar storm activity is being monitored 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.

Figure 6-1 through Figure 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.)

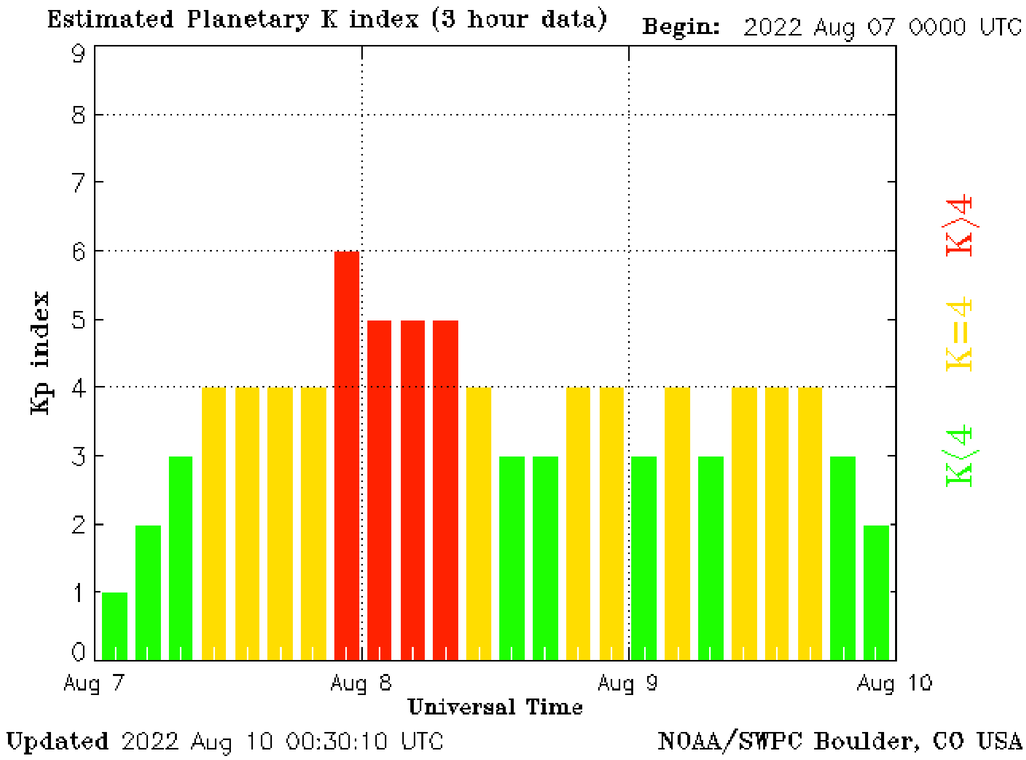


Figure 6-1. K-Index for August 8, 2022

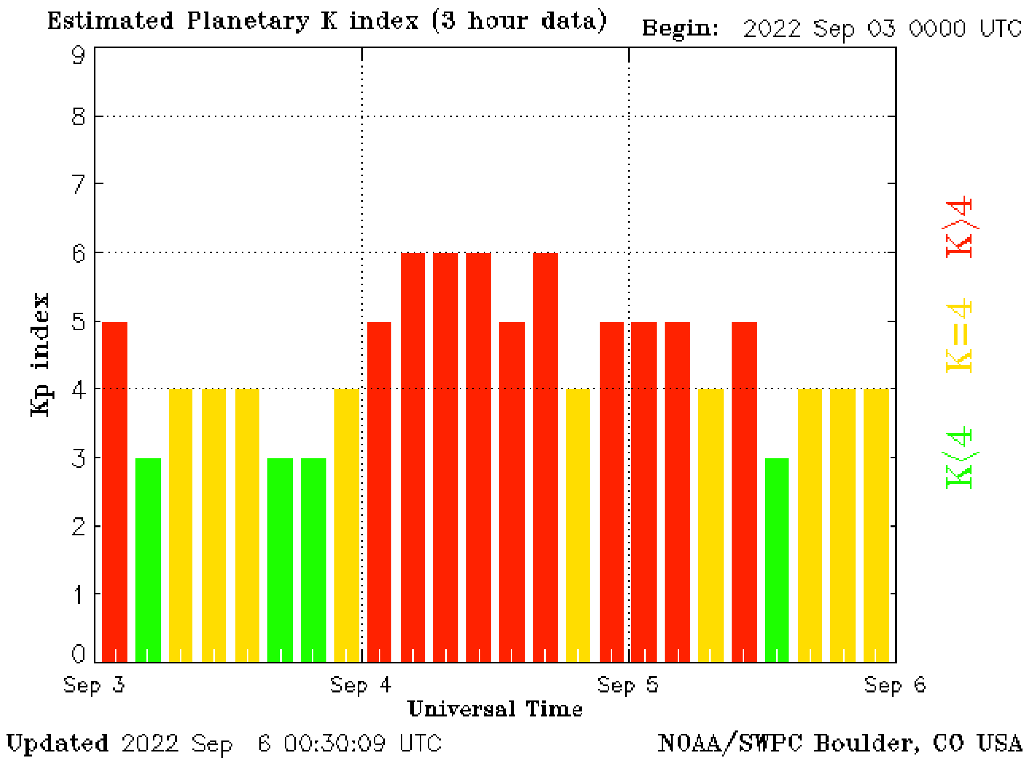


Figure 6-2. K-Index for September 4, 2022

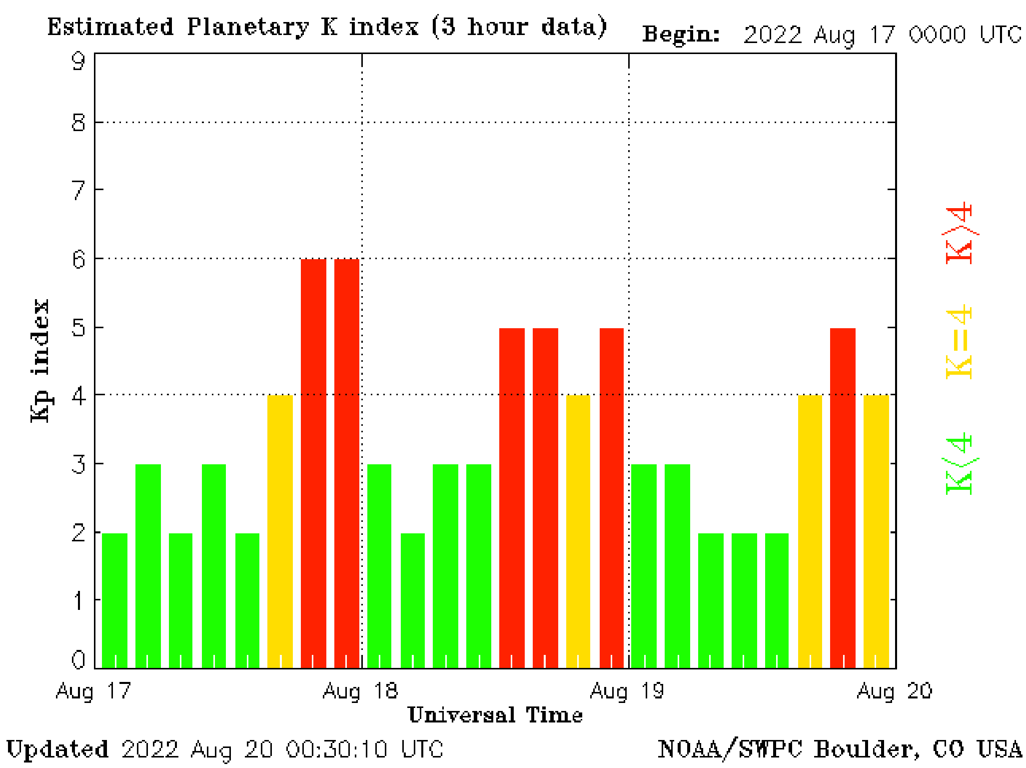


Figure 6-3. K-Index for August 17, 2022

Table 6-1 shows the position accuracy information for the quarter's worst-case storm day, September 4, 2022 based on Figure 6-1 to Figure 6-3 (see Figure 6-2). The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1. Horizontal and Vertical Accuracy Statistics for September 4, 2022

Site	95% Horizontal (Meters)	95% Vertical (Meters)	Max Horizontal (Meters)	Max Vertical (Meters)
Albuquerque	3.539	6.103	4.77	7.282
Anchorage	2.703	5.509	3.983	7.05
Atlanta	2.921	3.951	4.456	4.676
Barrow	2.698	5.185	3.425	7.076
Bethel	2.563	6.07	3.489	7.508
Billings	2.225	5.37	2.504	7.047
Boston	2.198	5.395	2.654	6.049
Cleveland	2.262	4.475	2.706	5.165
Cold Bay	1.922	6.081	2.732	6.572
Fairbanks	2.977	5.076	3.849	7.58
Gander	2.51	5.227	2.818	6.818
Honolulu	6.424	6.708	7.44	8.864
Houston	5.455	4.658	6.202	6.06
Iqaluit	2.609	4.36	3.748	6.734
Juneau	2.632	5.004	3.806	6.457
Kansas City	2.094	5.103	3.33	5.74
Kotzebue	2.919	5.485	4.322	6.473
Los Angeles	3.282	6.671	4.948	7.583
Merida	7.632	8.793	9.719	18.141
Miami	6.234	3.844	8.137	5.947
Minneapolis	2.054	5.604	2.838	6.323
Oakland	2.497	7.345	3.136	8.539
Salt Lake City	2.022	6.226	2.517	7.467
San Jose Del Cabo	6.429	4.566	8.199	10.624
San Juan	4.539	3.446	5.429	7.059
Seattle	1.886	6.216	2.785	8.012
Tapachula	8.261	7.59	10.382	15.339
Washington DC	2.061	5.029	2.677	5.754

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 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 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.

Table 7-1. Selected IGS Sites 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

[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

ID	City	Country
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

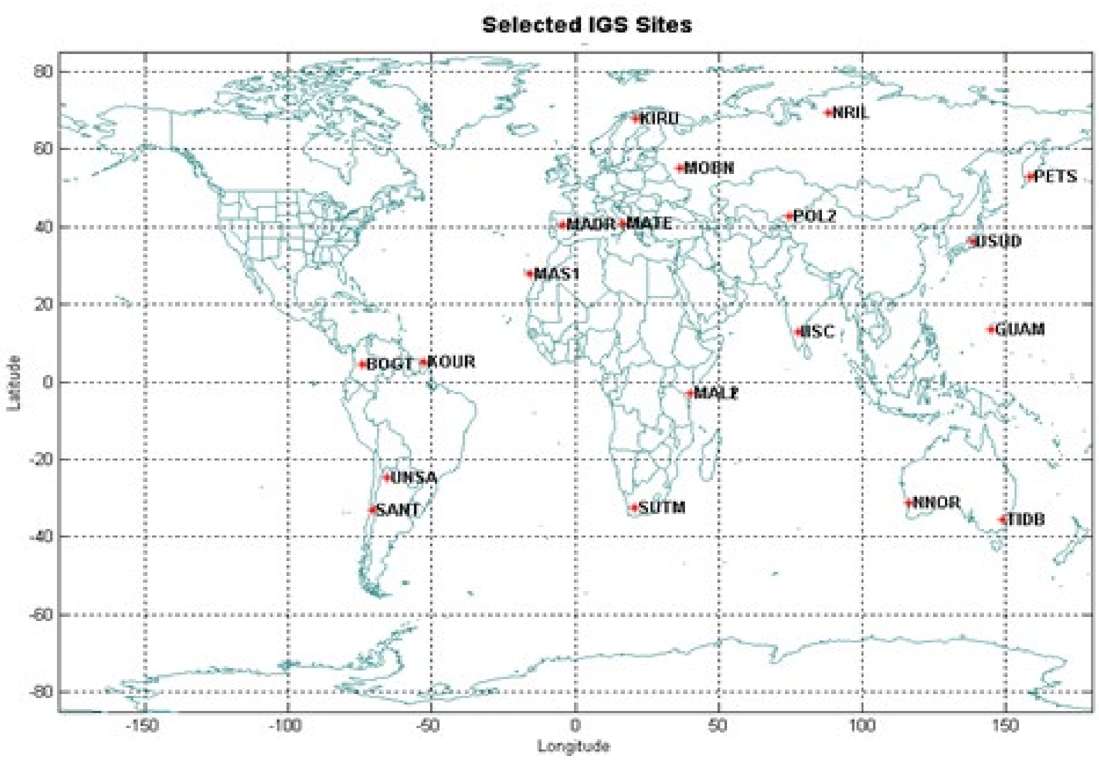


Figure 7-1. Selected IGS Site Locations

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	3.81	5.3	7.66	16.66	99.26
GLPS	3.29	4.9	6.5	10.48	99.75
GUAM	2.74	6.35	7.43	13.62	99.28
IISC	2.55	6.37	8.05	13.21	91.19
KIRU	0	0	0	0	0.00
KOUR	0	0	0	0	0.00
MADR	2.73	3.97	7.67	11.29	99.75
MAL2	0	0	0	0	0.00
MALI	0	0	0	0	0.00
MAS1	0	0	0	0	0.00
MATE	0	0	0	0	0.00
MOBN	0	0	0	0	0.00
NNOR	0	0	0	0	0.00
NRIL	0	0	0	0	0.00
PETS	0	0	0	0	0.00
POL2	2.03	4.45	4.4	11.68	99.70
SANT	5.22	4.54	12.99	12.28	99.77
SUTM	0	0	0	0	0.00
TIDB	1.78	3.26	3.08	10.12	99.71
UNSA	0	0	0	0	0.00
USUD	2.48	5.3	8.13	17.69	99.56

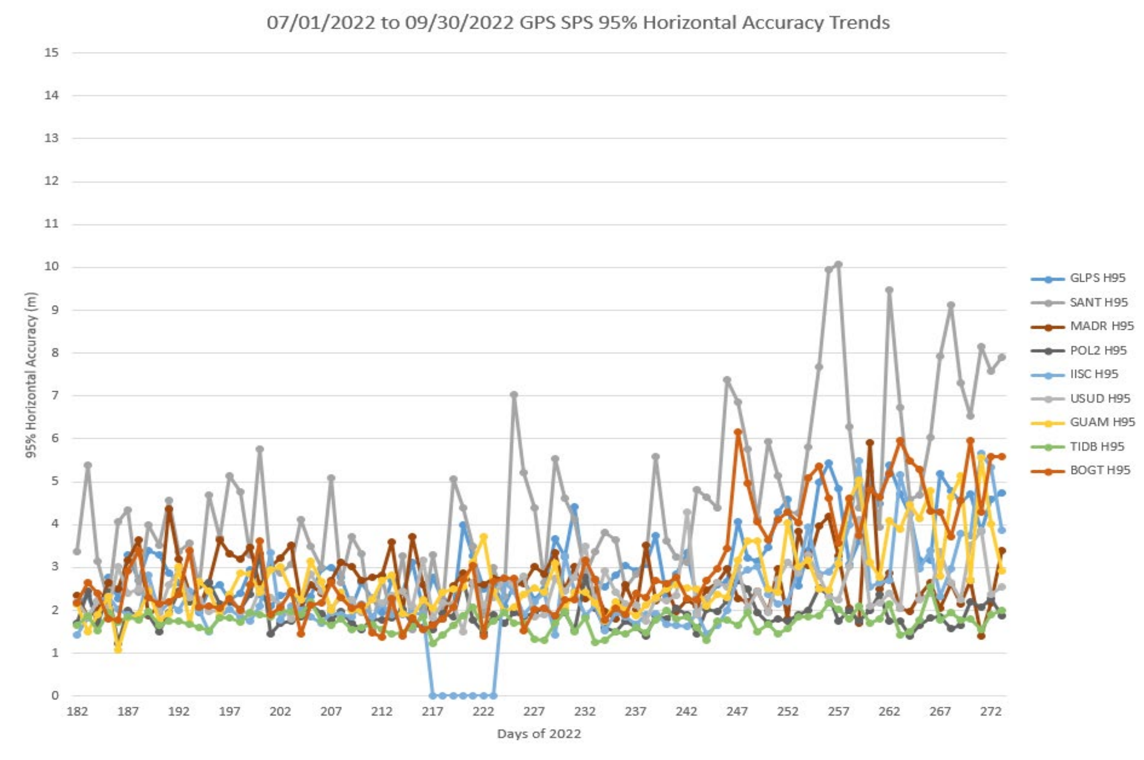


Figure 7-2. GPS SPS 95% Horizontal Accuracy Trends at Selected IGS Sites

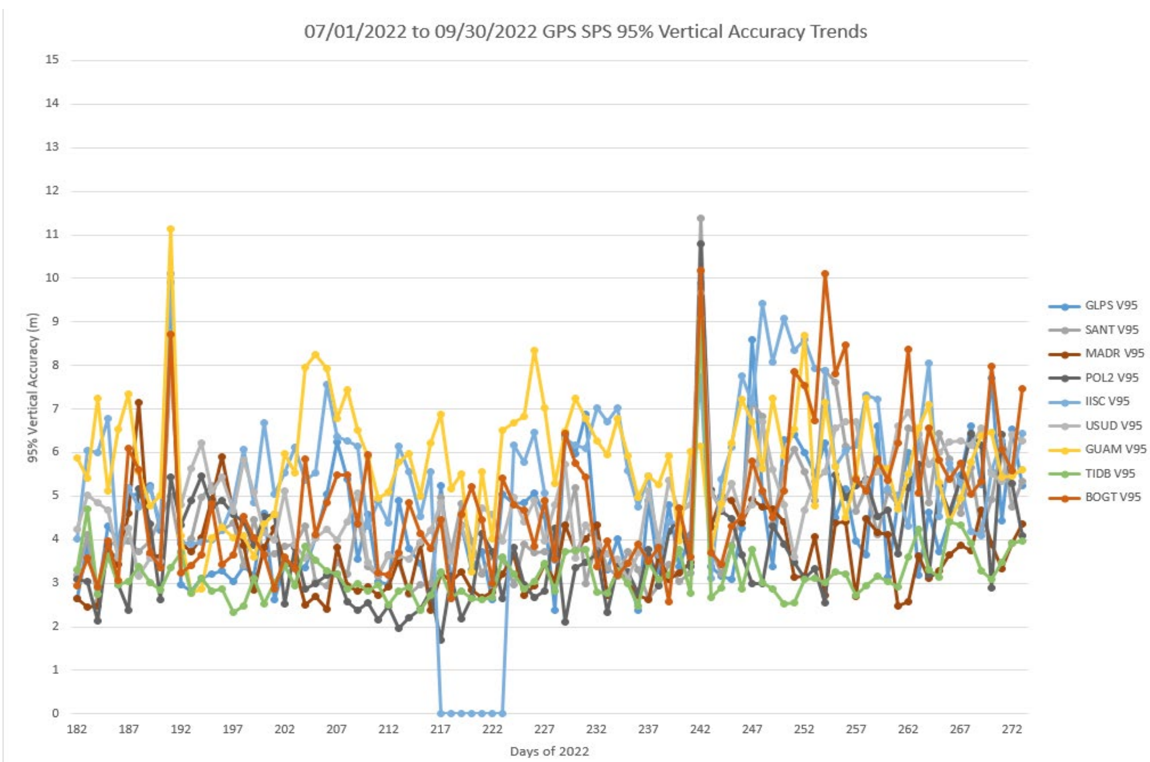


Figure 7-3. GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites

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. 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 1/15,000.

The horizontal protection limit (HPL) is a figure that 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

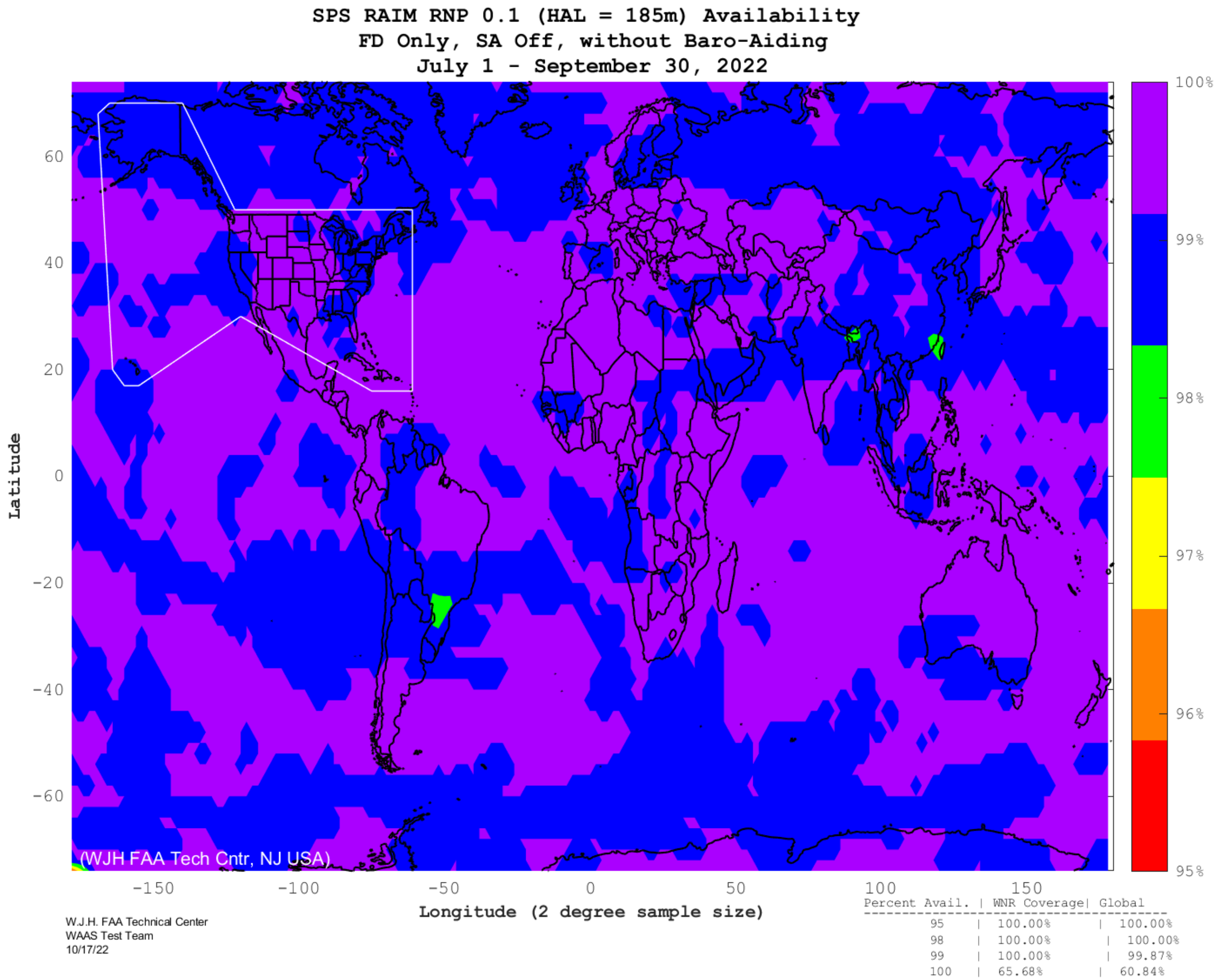
Table 8-1 shows the RAIM performance for the 28 sites evaluated. For all sites collected, the minimum percent of time in RNP 0.1 mode was 99.876% at Juneau. The minimum percent of time spent in RNP 0.3 mode was 100 at all locations evaluated. The maximum 99% HPL value was 140.228 meters at Anchorage.

Table 8-1. RAIM Site Statistics

City	99% HPL (m)	RNP 0.1 (%)	RNP 0.3 (%)
Arcata	113.913	99.97978	100
Atlantic City-a	101.109	100	100
Oklahoma City	107.822	100	100
Albuquerque	97.102	100	100
Anchorage	140.228	99.94364	100
Atlanta	104.665	99.96248	100
Barrow	113.119	99.98991	100
Bethel	123.673	99.98092	100
Billings	109.373	100	100
Boston	117.566	99.99059	100
Cleveland	113.113	99.93608	100
Cold Bay	102.372	99.99627	100
Fairbanks	135.399	99.92044	100
Gander	121.971	99.99746	100
Honolulu	95.803	100	100
Houston	111.773	100	100
Iqaluit	131.272	99.96423	100
Juneau	117.486	99.8763	100
Kansas City	95.91	100	100
Kotzebue	117.981	100	100
Los Angeles	87.343	99.9936	100
Merida	78.938	100	100
Miami	84.479	100	100
Minneapolis	101.162	100	100
Oakland	86.467	99.98733	100
Salt Lake City	95.728	100	100
San Jose Del Cabo	73.801	100	100
San Juan	79.462	100	100
Seattle	107.176	100	100
Tapachula	90.555	100	100
Washington DC	102.484	99.94156	100

8.2 RAIM Coverage

Figure 8-1 and Figure 8-2 show the worldwide RAIM coverage for both RNP 0.1 and RNP 0.3, respectively. Figure 8-3 and Figure 8-4 show the daily RAIM coverage trends between July 1, 2022 and September 30, 2022.



Percent Avail.	WNR Coverage	Global
95	100.00%	100.00%
98	100.00%	100.00%
99	100.00%	99.87%
100	65.68%	60.84%

Figure 8-1. RAIM RNP 0.1 Coverage

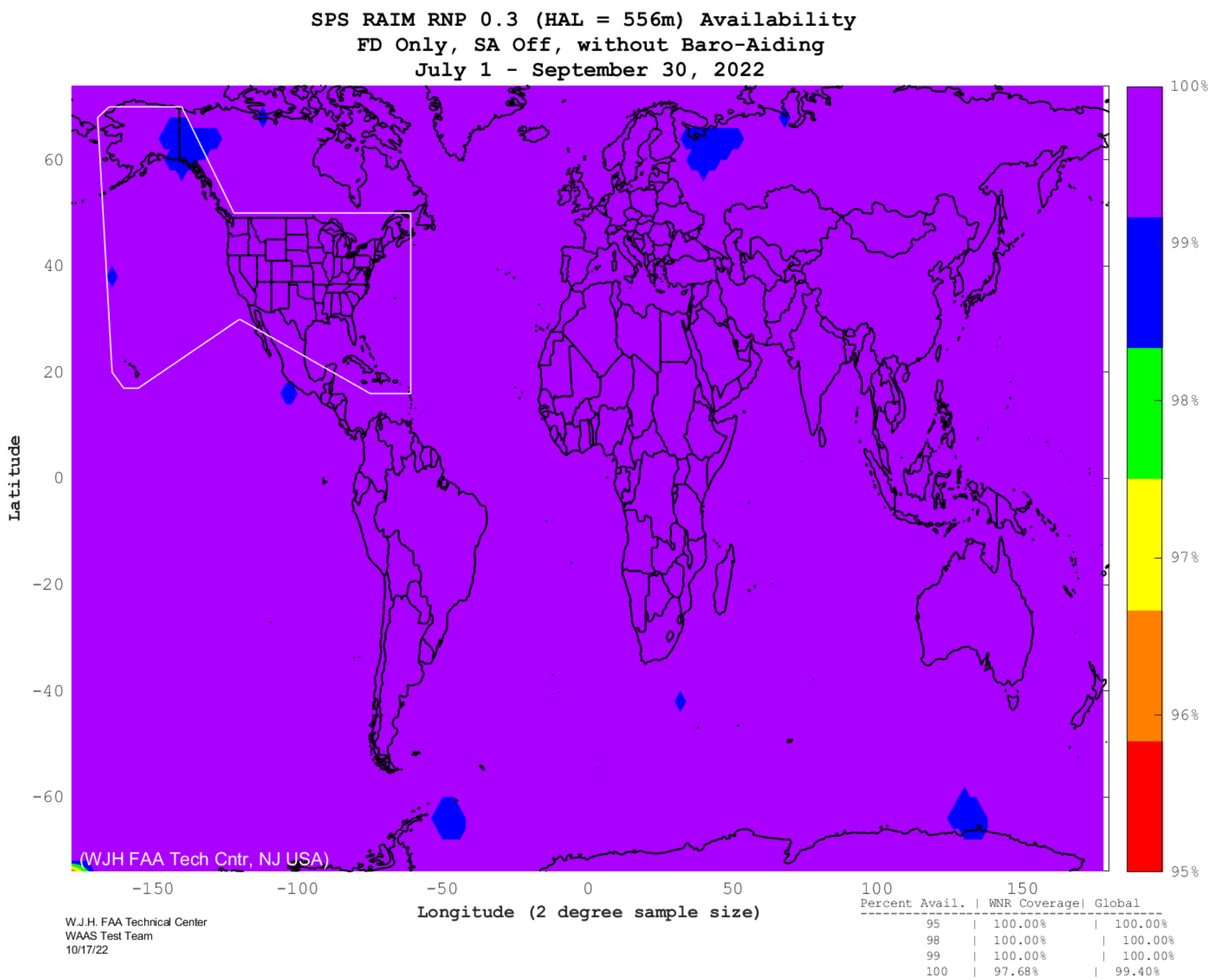


Figure 8-2. RAIM RNP 0.3 Coverage

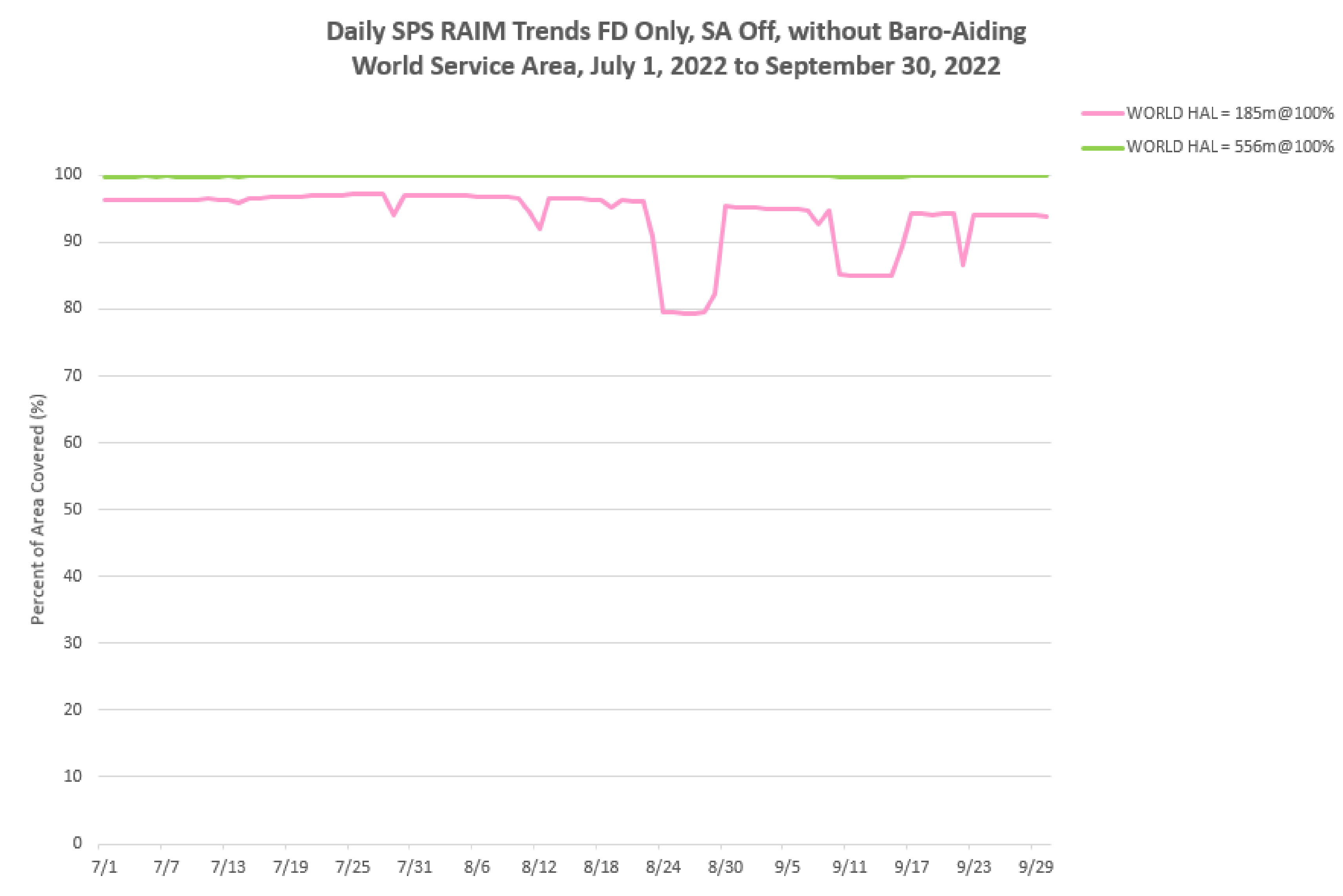


Figure 8-3. RAIM World-wide Coverage Trend

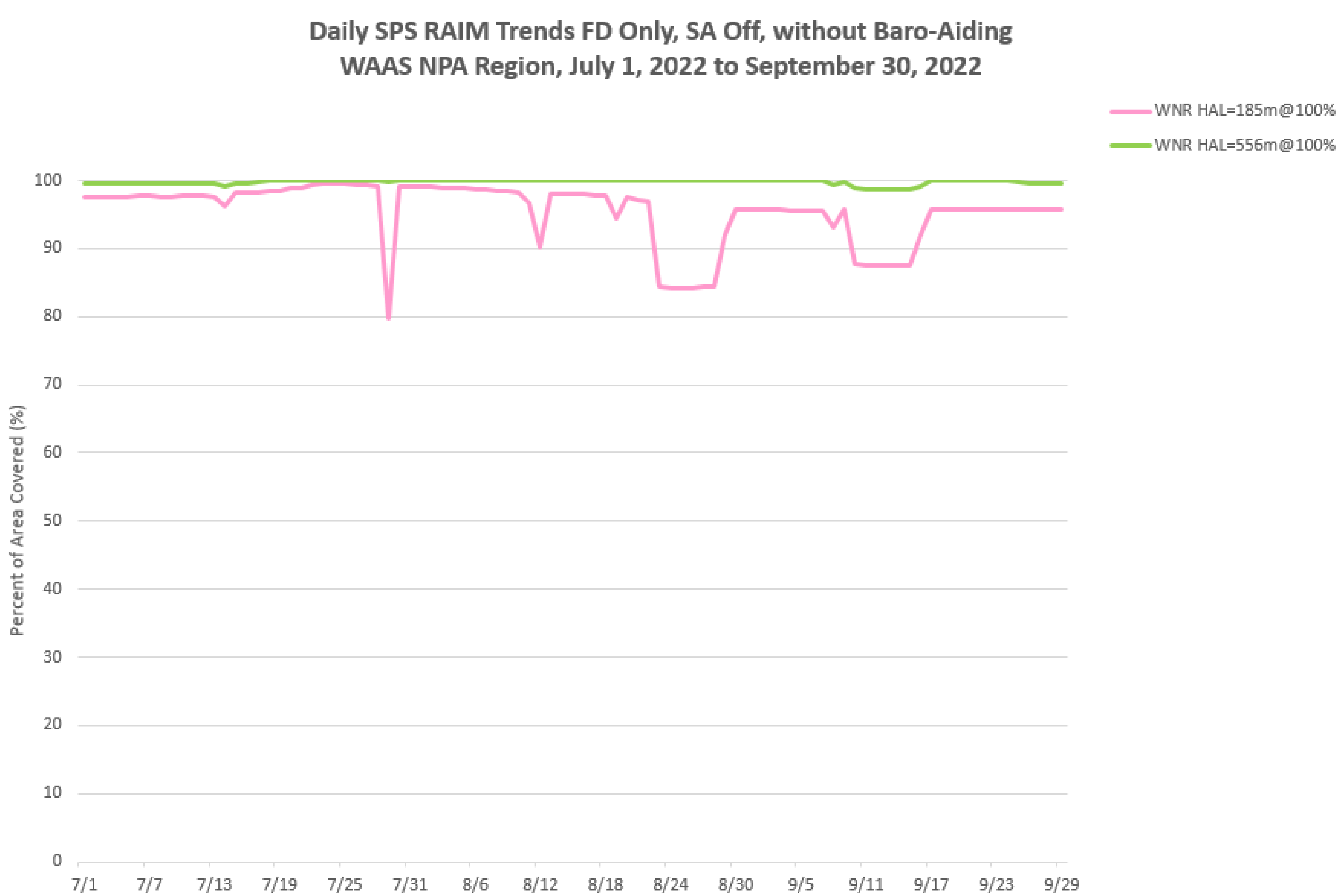


Figure 8-4. RAIM RNP Coverage Trend for WAAS NPA Service Area

8.3 RAIM Airport Analysis

Figure 8-5 and Figure 8-6 show 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.

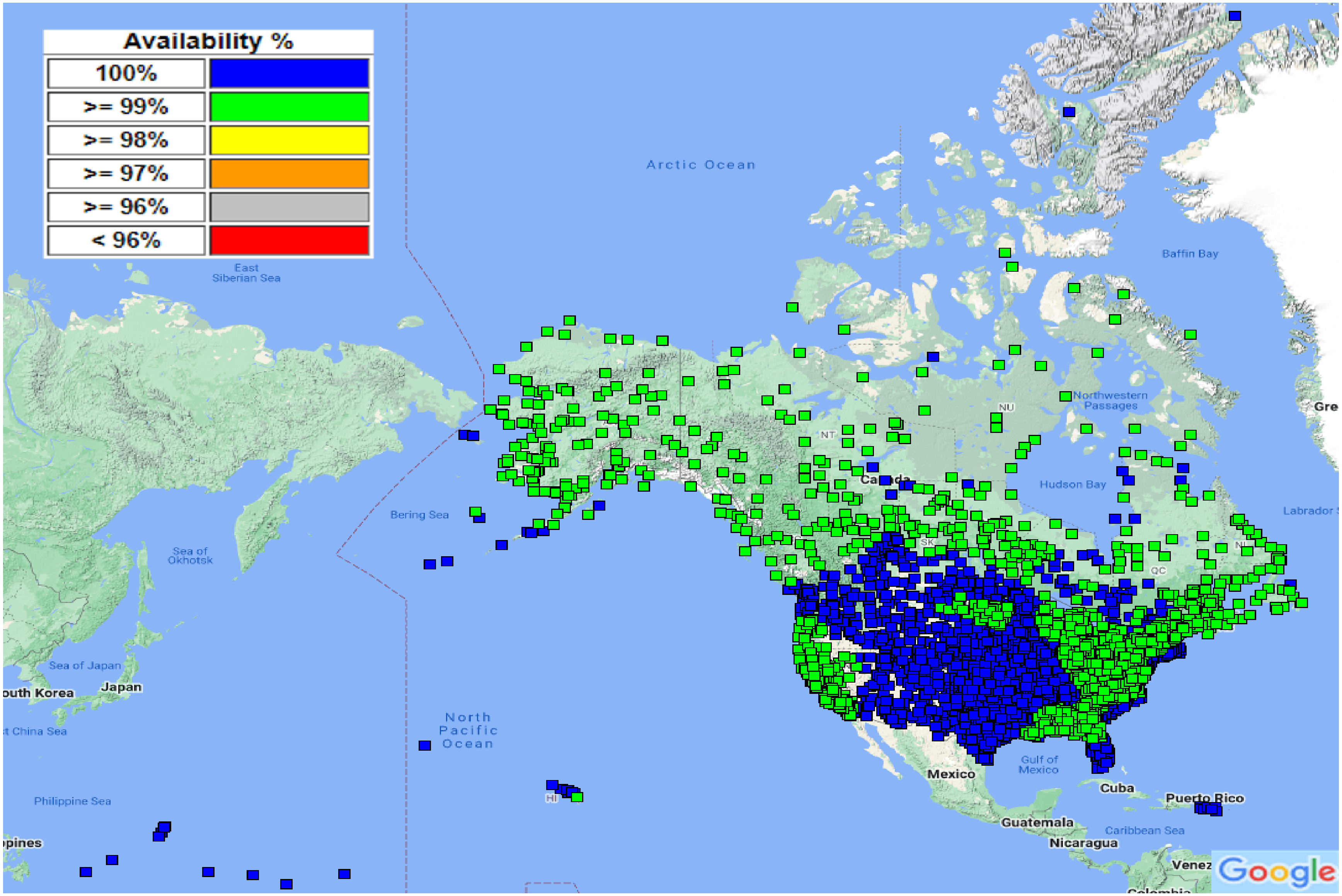


Figure 8-5. RAIM RNP 0.1 Airport Availability

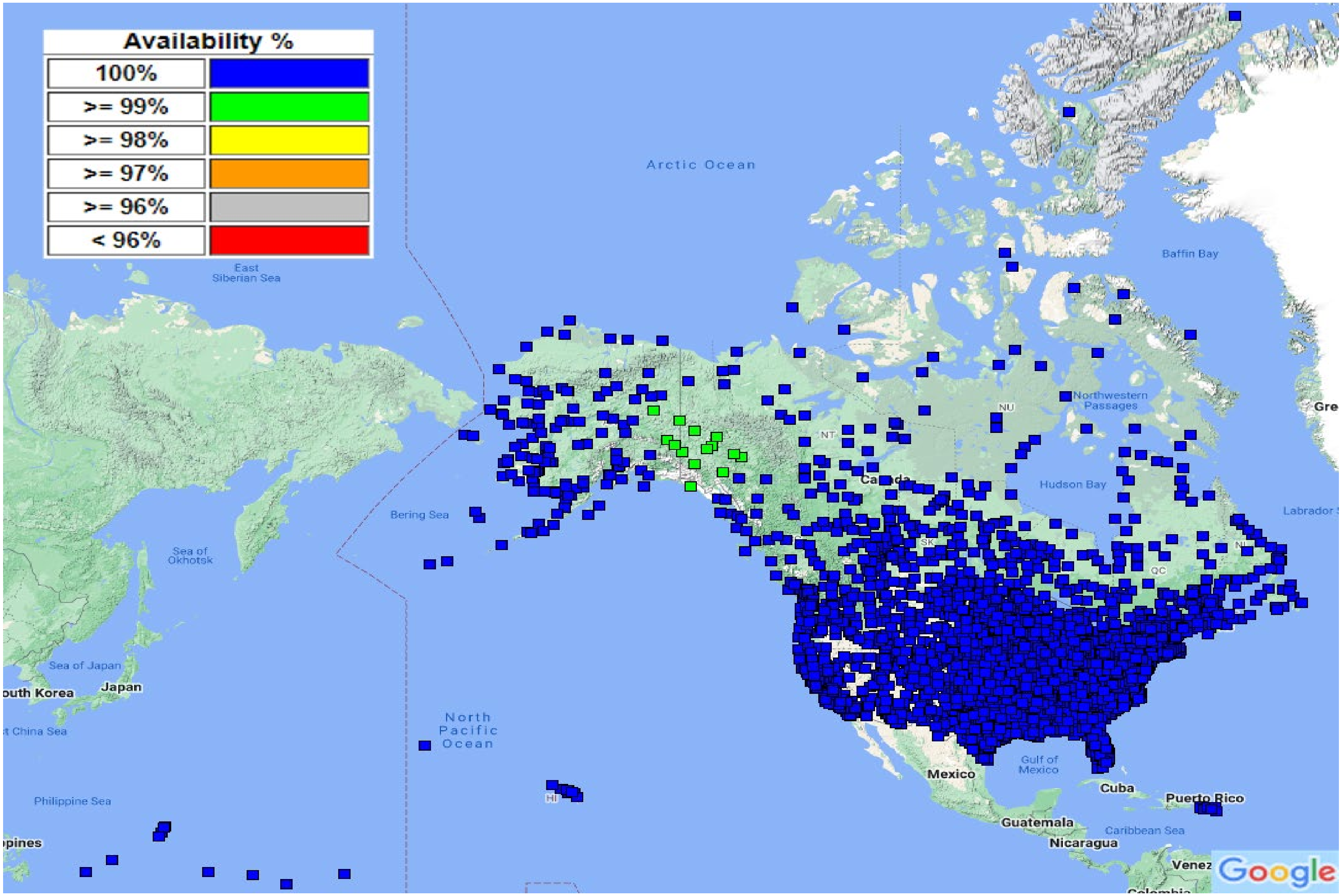


Figure 8-6 RAIM RNP 0.3 Airport Availability

Figure 8-7 and Figure 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.

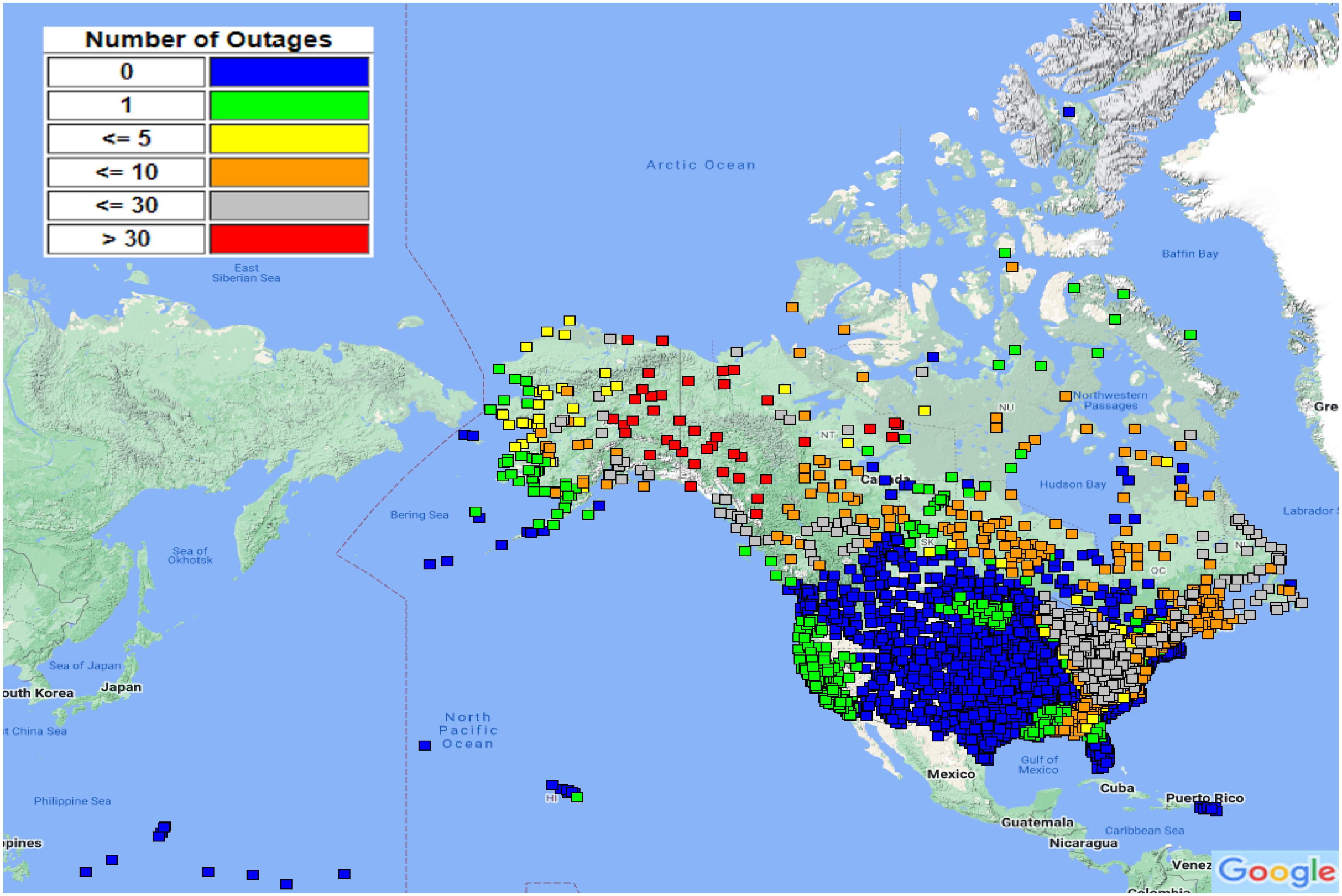


Figure 8-7. RAIM RNP 0.1 Airport Outages

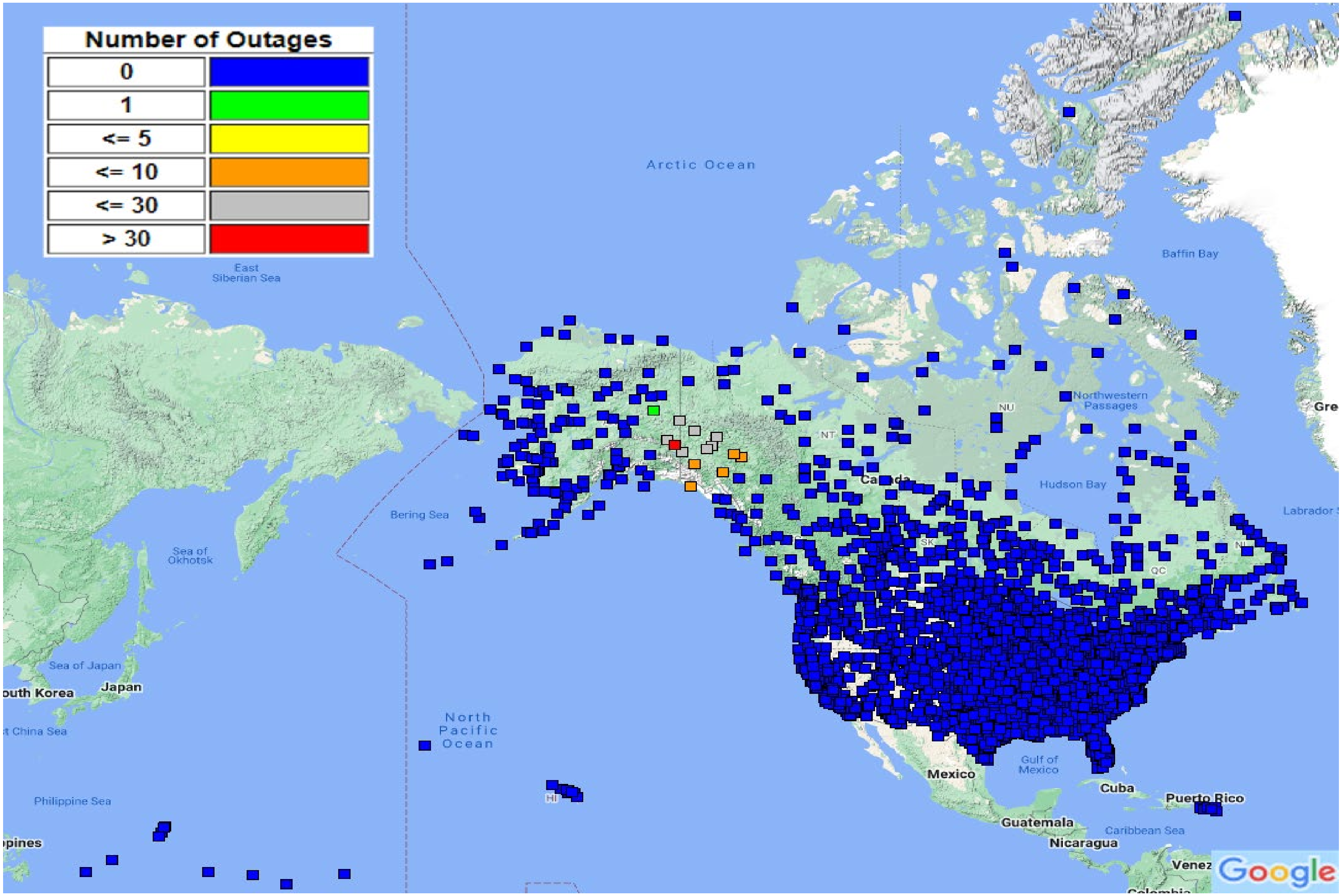


Figure 8-8. RAIM RNP 0.3 Airport Outages

9. GPS TEST NOTAMS SUMMARY

9.1 GPS Test NOTAMs Issued

GPS test NOTAMs were not evaluated for this quarter.

10. GPS BROADCAST ORBIT VERSUS NGA PRECISE ORBITS AND URA (IAURA) BOUNDING ANALYSIS

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 offline monitoring verifies that the original logic of the a priori assumption remains sound.

The assumptions being validated are:

- 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. Figure 10-1 through Figure 10-4 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 July 1 to September 30, 2022 is presented. Only data points in which GPS is healthy and valid precise data is available are considered. There was maintenance on PRN2 on 07/14/22, PRN4 on 07/29/22, PRN31 on 08/11/22, PRN25 on 08/19/22, PRN10 on 08/23/22, PRN26 on 09/08/22, PRN23 on 09/08/22, PRN30 on 09/14/22, PRN6 on 09/22/22, and PRN5 on 09/29/22. Figure 10-5 shows the availability of C/A Nav data. There were no points where GPS was healthy and the NGA data was missing. In addition to NANUs, GPS C/A GPS Nav data was unavailable from September 16 through September 19, 2022 and on September 27, 2022.

For L2C CNAV data, raw 300-bit L2C and L5 CNAV message data is obtained from the WAAS G3 test receivers located at the NSTB ACY reference station. Those receivers are located at the William J. Hughes Technical Center in Atlantic City, New Jersey. CNAV data was only available while the satellites were in view of ACY G3 test receivers. 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. Table 10-1 shows the satellites that are capable of broadcasting L2C, L5 and L1C. In the current GPS constellation, PRN28 is not in use as SV44 was set to Unusable and decommissioned on June 21, 2021. SV78, PRN11, is the most recent satellite added to the constellation on May 25, 2022.

Table 10-1. Signal Capability per Satellite Vehicle

PRN	SV	Block Type	L2C	L5	L1C
1	63	IIF	Yes	Yes	
2	61	IIR			
3	69	IIF	Yes	Yes	
4	74	III	Yes	Yes	Yes
5	50	IIR-M	Yes		
6	67	IIF	Yes	Yes	
7	48	IIR-M	Yes		
8	72	IIF	Yes	Yes	
9	68	IIF	Yes	Yes	
10	73	IIF	Yes	Yes	
11	78	III	Yes	Yes	Yes
12	58	IIR-M	Yes		
13	43	IIR			
14	77	III	Yes	Yes	Yes
15	55	IIR-M	Yes		
16	56	IIR			
17	53	IIR-M	Yes		
18	75	III	Yes	Yes	Yes
19	59	IIR			
20	51	IIR			
21	45	IIR			
22	47	IIR			
23	76	III	Yes	Yes	Yes
24	65	IIF	Yes	Yes	
25	62	IIF	Yes	Yes	
26	71	IIF	Yes	Yes	
27	66	IIF	Yes	Yes	
28	44	IIR			
29	57	IIR-M	Yes		

PRN	SV	Block Type	L2C	L5	L1C
30	64	IIF	Yes	Yes	
31	52	IIR-M	Yes		
32	70	IIF	Yes	Yes	

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.

Figure 10-7 and Figure 10-8 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).

Figure 10-9 through Figure 10-64 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.

Figure 10-65 through Figure 10-78 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. The surface of the Earth Is approximated using +/-13.9-degrees from the bore sight of the satellite. The max URA of the broadcast URA index range is used for the C/A Nav data, and 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) for C/A and 4 times URA (IURA) for CNAV were investigated.

Figure 10-79 through Figure 10-133 are histograms of the height error, along track error, cross track error, and URA (IAURA) normalized range error.

Figure 10-134 through Figure 10-188 are the timelines of the URA (IAURA) normalized range error. Missing data points are in red and are NANUs for the C/A data. The large number of red points in the CNAV data are the points where the satellites are out of view of ACY.

10.1 GPS Broadcast Orbit Accuracy Standard Deviation Plots

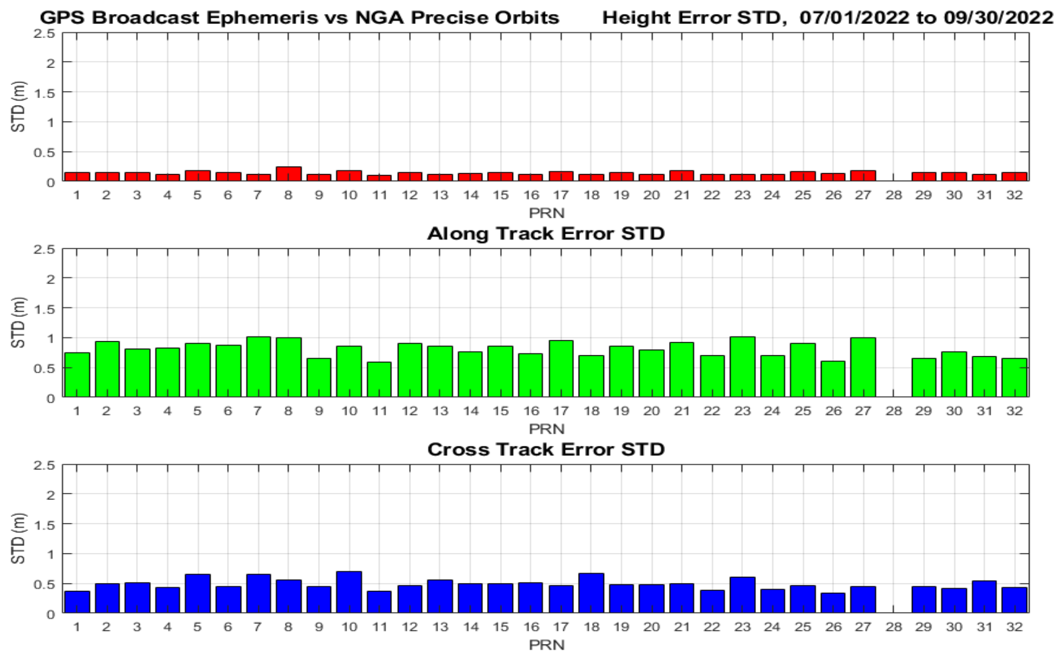


Figure 10-1. GPS Broadcast Orbit Accuracy Standard Deviations Using C/A Nav Data

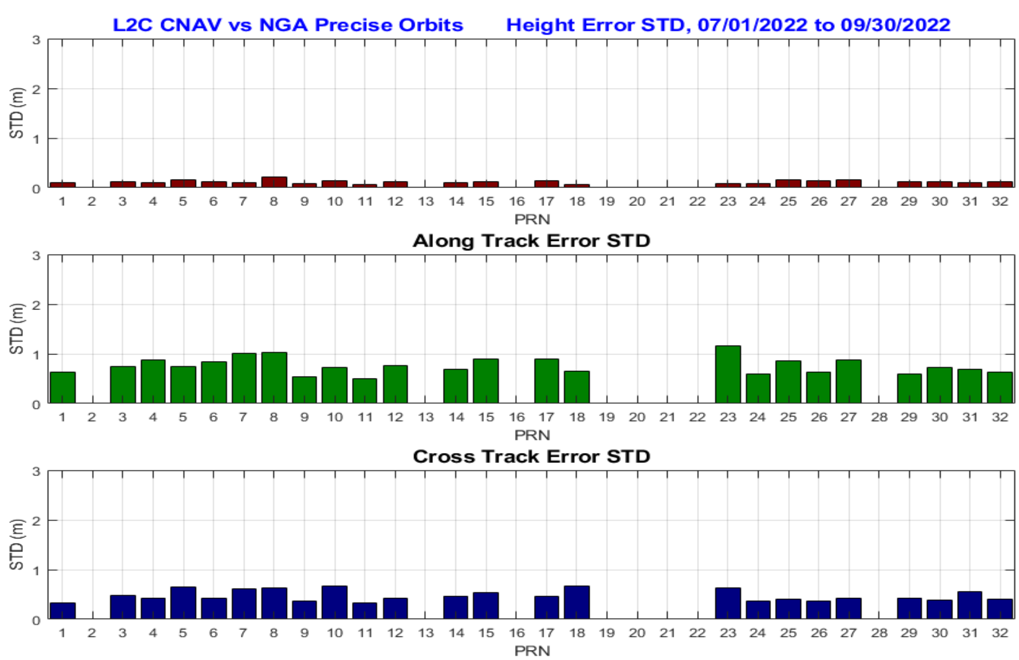


Figure 10-2. GPS Broadcast Orbit Accuracy Standard Deviations Using L2C CNAV Data

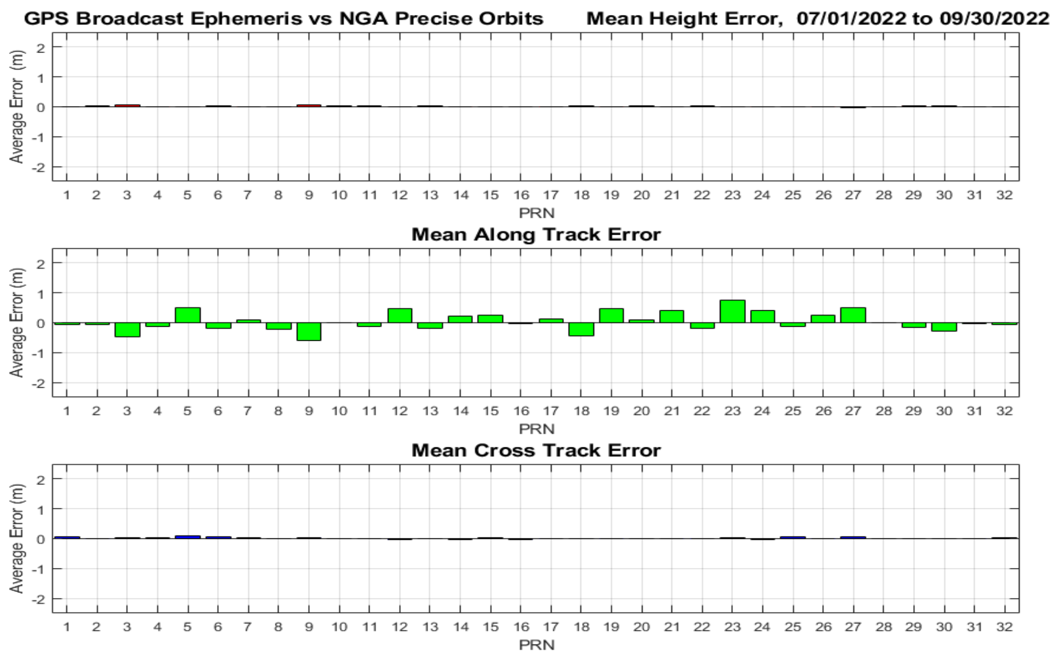


Figure 10-3. GPS Broadcast Orbit Error Means Using C/A Nav Data

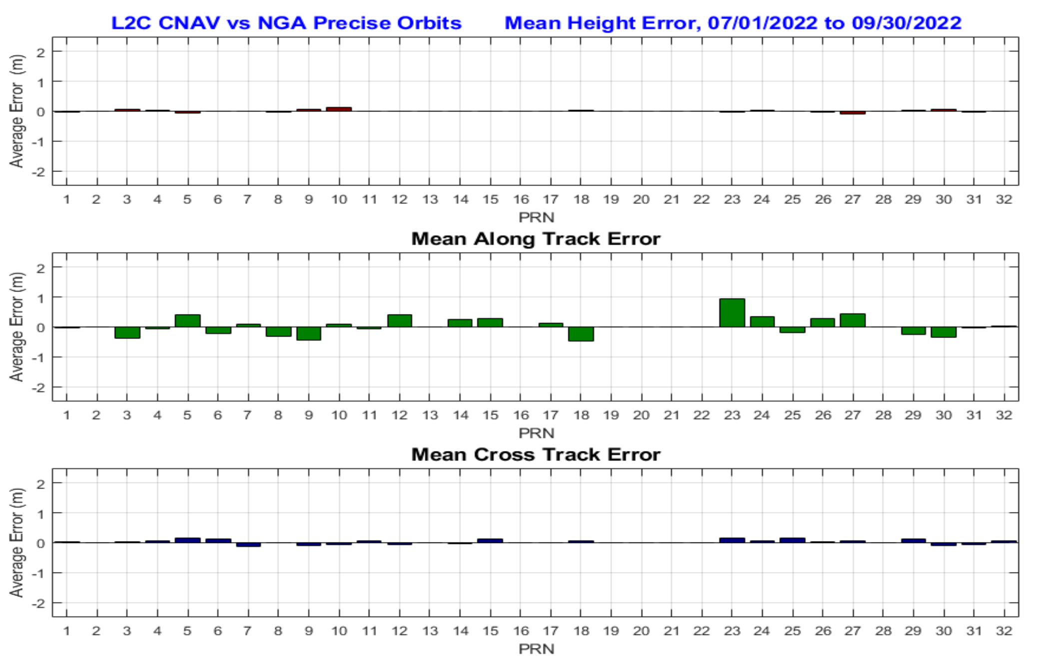


Figure 10-4. GPS Broadcast Orbit Error Means Using L2C CNAV Data

10.2 Broadcast Ephemeris vs. NGA Precise Data Availability Plots

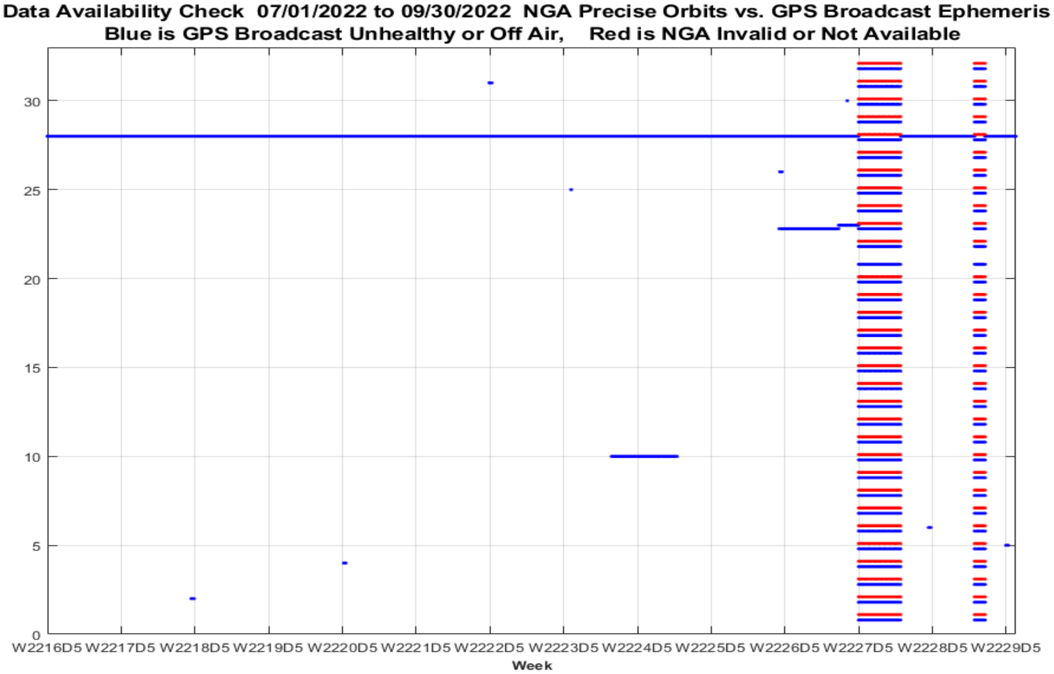


Figure 10-5. Broadcast Ephemeris vs. NGA Precise Data Availability Plots

10.3 Current GPS Constellation

Table 10-2 is a listing of the current GPS Constellation plane and slot designations provided by the United States Coast Guard (USCG) Navigation Center (NavCen) as depicted by their GPS Satellite Locations Slant Chart. Table 10-2 reflects actual orbital configuration and may not match the current GPS Constellation Operational Advisory (AO) status published by the USCG NavCen, which depicts the control station configuration. GPS Constellation slots designated with an Asterisk refer to the expandable slots. Expandable slots are divided into a fore (F) and an aft (A) slot. Figure 10-6 is a graphical representation of the current GPS Constellation during the reporting period.

Table 10-2. GPS Constellation Plane/Slot per SV

Plane	Slot	SV	PRN	Block Type
A	1	65	24	IIF
A	2	52	31	IIR-M
A	2F*			
A	2A*			
A	3	64	30	IIF
A	4	48	7	IIR-M

Plane	Slot	SV	PRN	Block Type
B	1			
B	1F*	71	26	IIF
B	1A*	56	16	IIR
B	2	62	25	IIF
B	3	44	28	IIR
B	4	58	12	IIR-M
B		77	14	III
C	1	57	29	IIR-M
C	2	66	27	IIF
C	3	72	8	IIF
C	4			
C	4F*	53	17	IIR-M
C	4A*	59	19	IIR
D	1	61	2	IIR
D	2			
D	2F*	45	21	IIR
D	2A*	63	1	IIF
D	3	75	18	III
D	4	67	6	IIF
D	1	61	2	IIR
E	1	69	3	IIF
E	2	73	10	IIF
E	3	50	5	IIR-M
E	3F*			
E	3A*			
E	4	51	20	IIR
E		76	23	III
F	1	70	32	IIF
F	2			
F	2F*	43	13	IIR
F	2A*	55	15	IIR-M
F	3	68	9	IIF
F	4	74	4	III
F	1	70	32	IIF

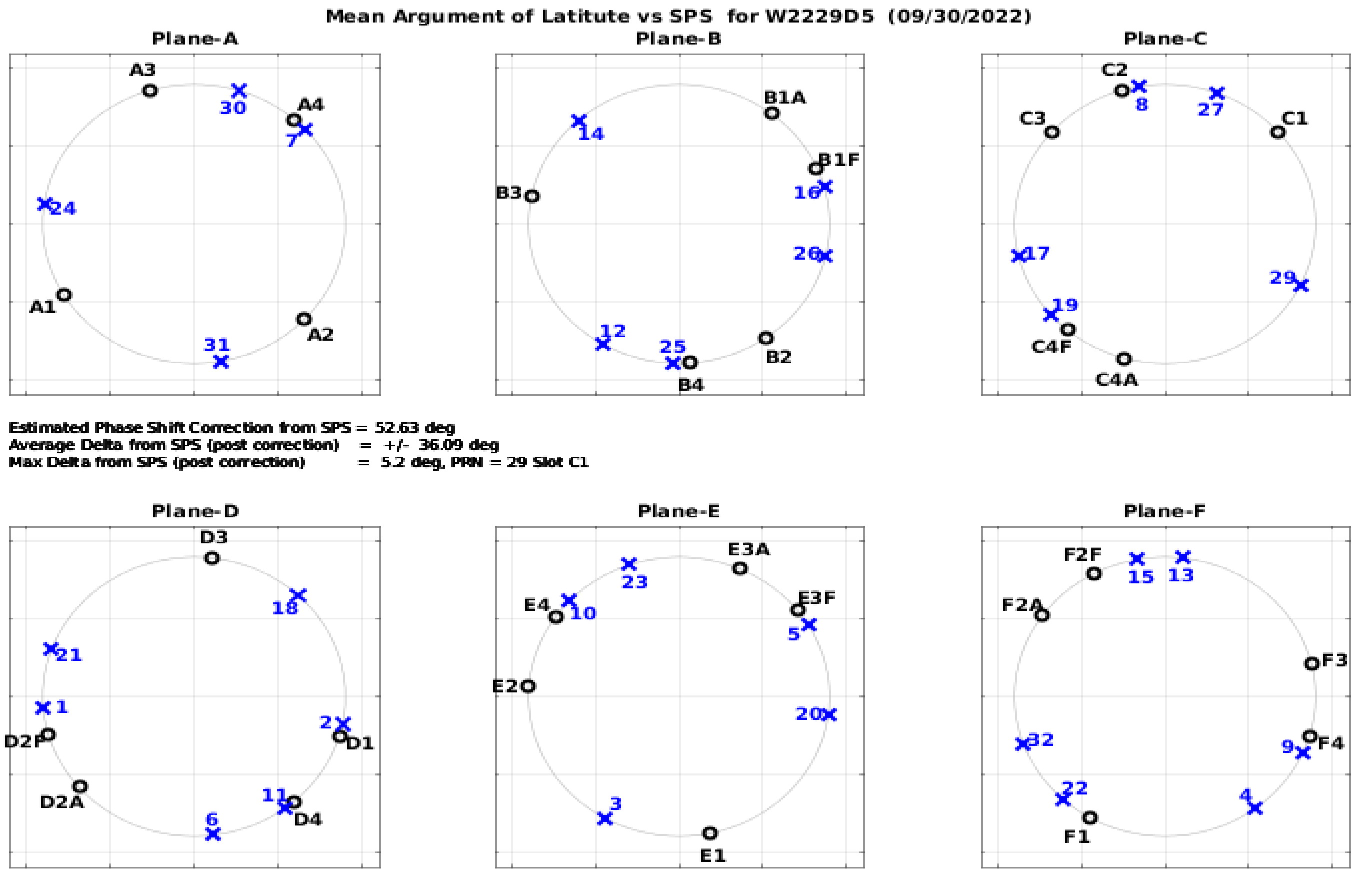


Figure 10-6. Current GPS Constellation

10.4 URA Over-bounding Plots

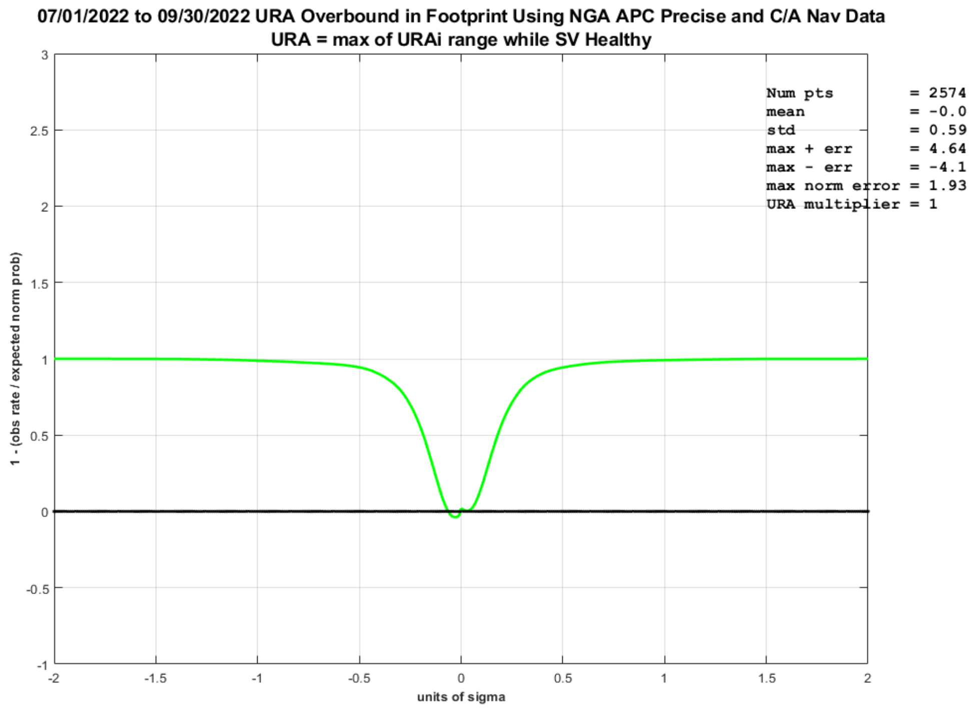


Figure 10-7. URA Over-bounding Using C/A Nav Data

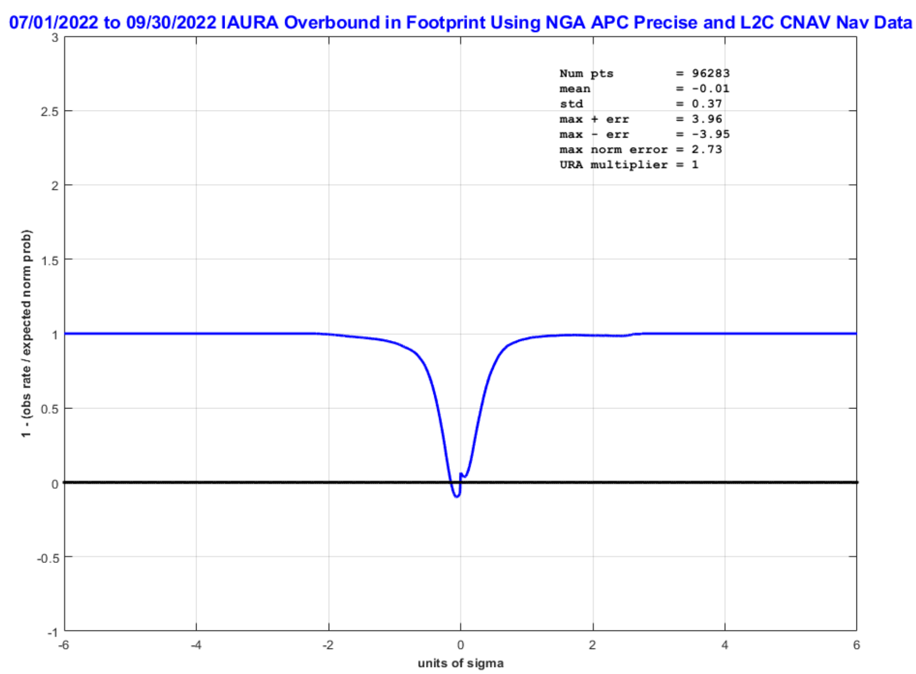


Figure 10-8. IAURA Over-bounding Using L2C CNAV Data

10.5 Orbit Error Plots for All Satellites

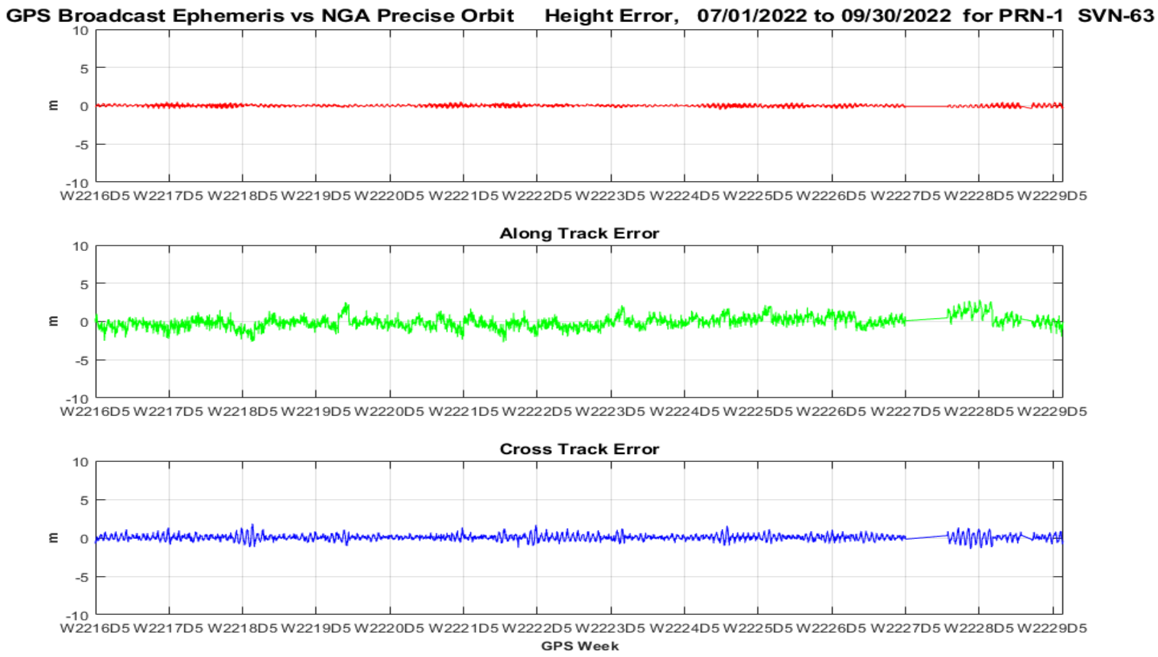


Figure 10-9. Orbit Error PRN1 (SVN63) Using C/A Nav Data

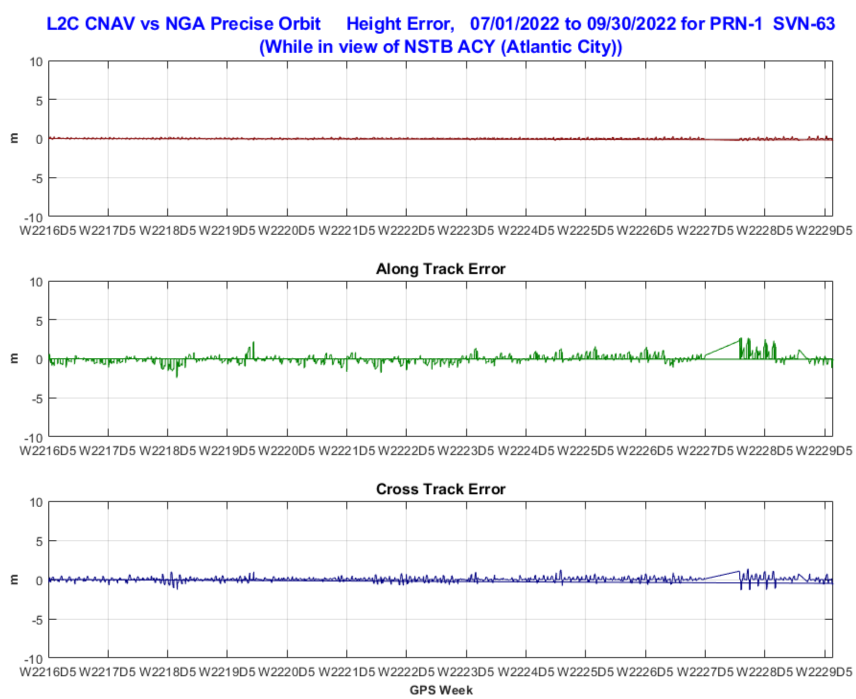


Figure 10-10. Orbit Error PRN1 (SVN63) Using L2C CNAV Data

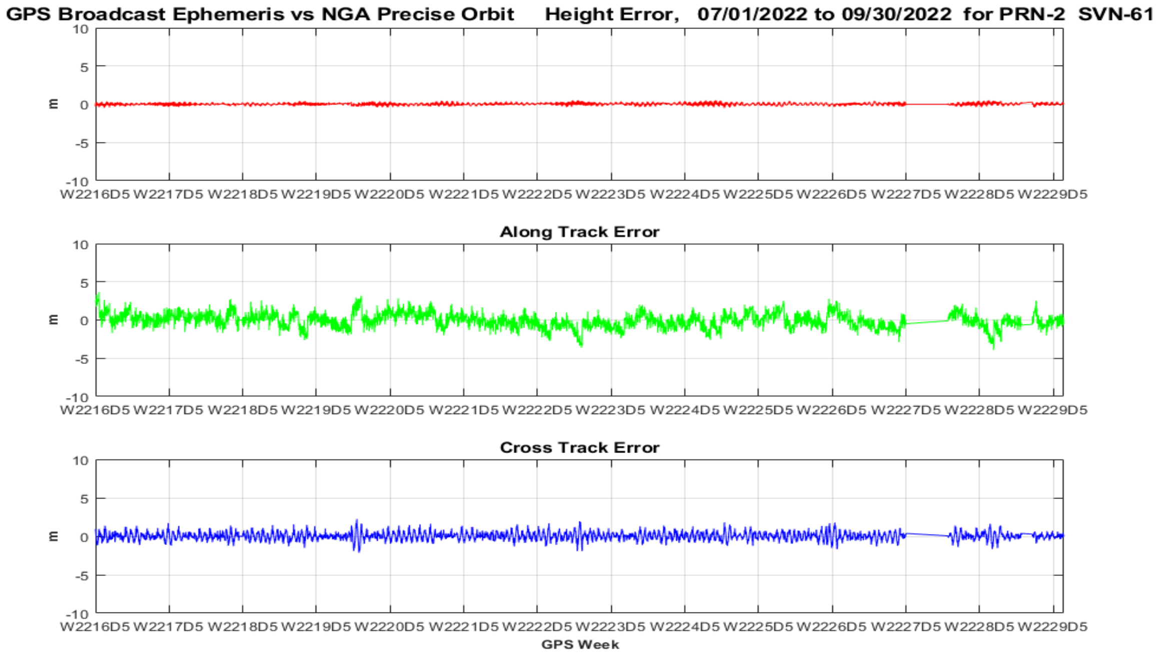


Figure 10-11. Orbit Error PRN2 (SVN61) Using C/A Nav Data

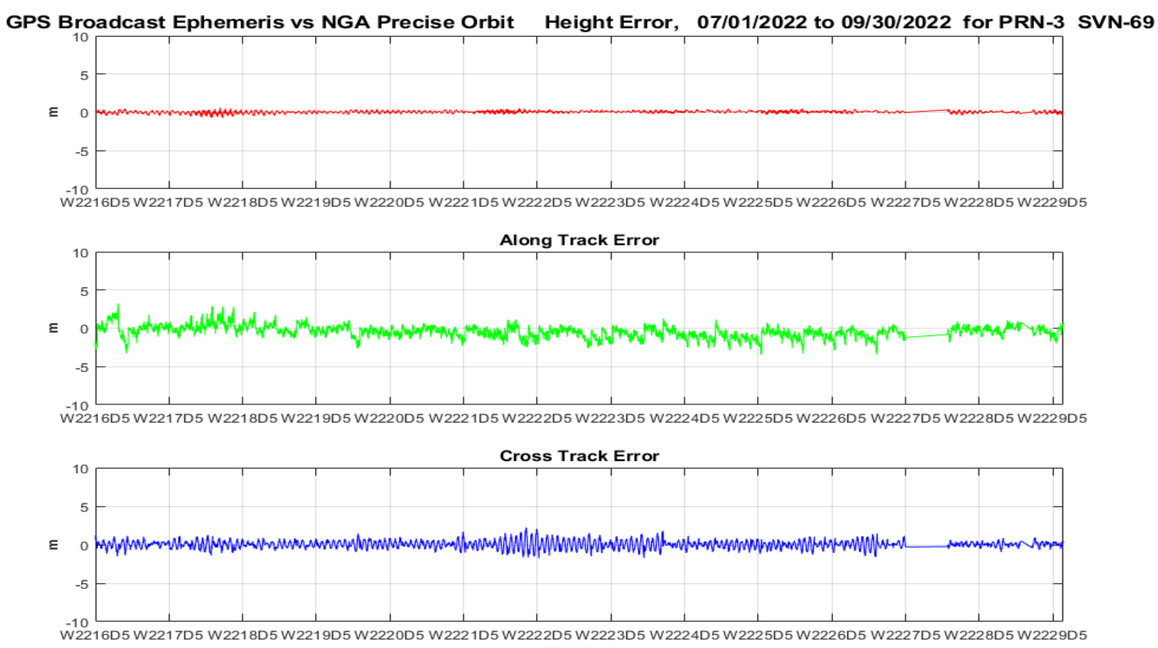


Figure 10-12. Orbit Error PRN3 (SVN69) Using C/A Nav Data

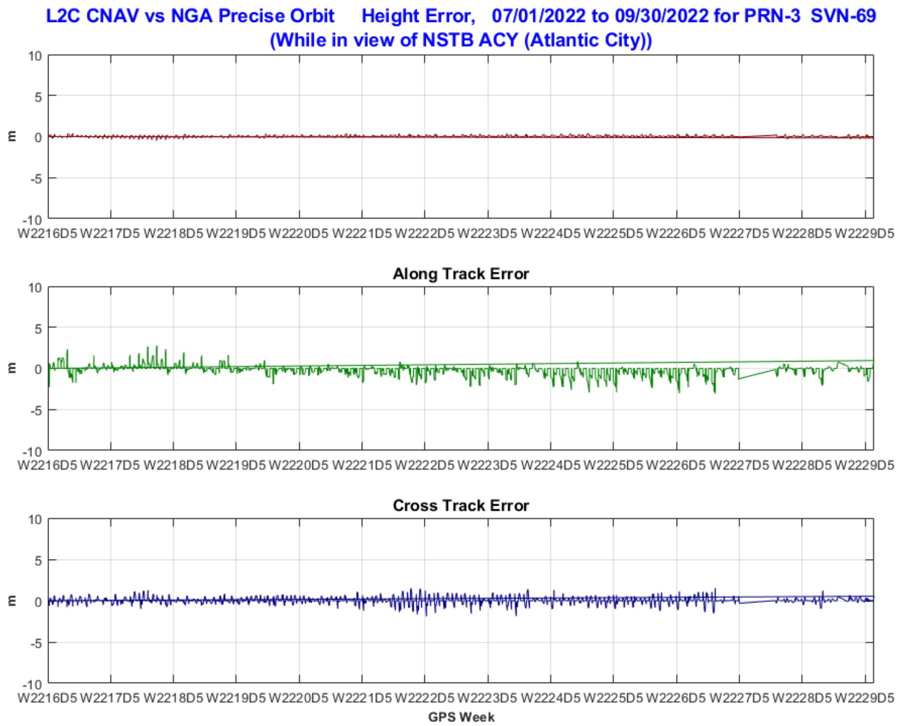


Figure 10-13. Orbit Error PRN3 (SVN69) Using L2C CNAV Data

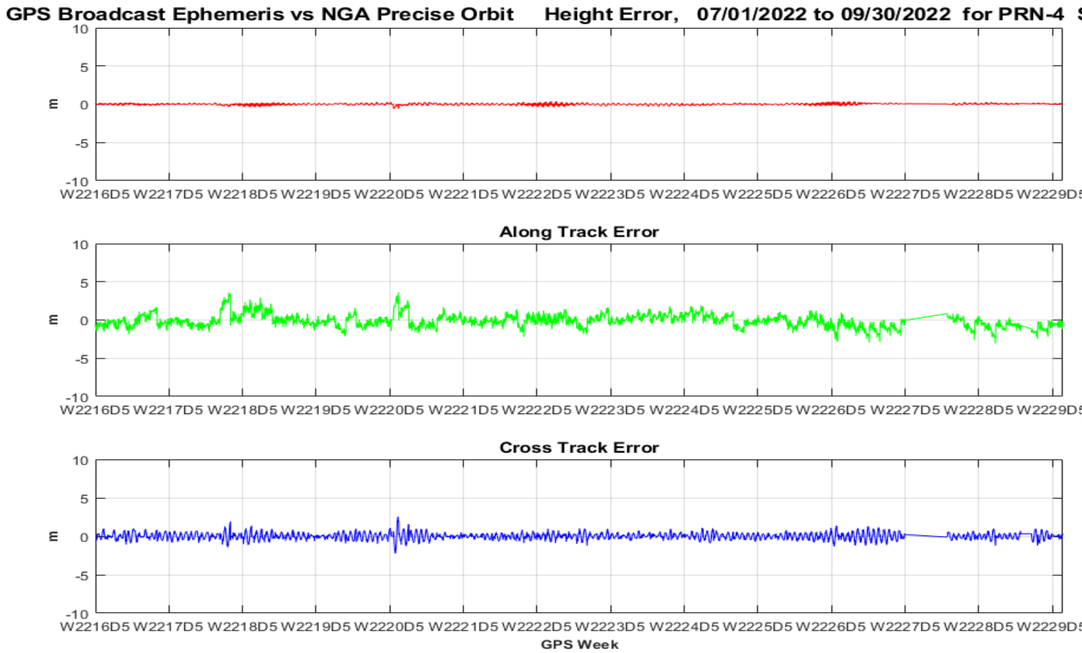


Figure 10-14. Orbit Error PRN4 (SVN74) Using C/A Nav Data

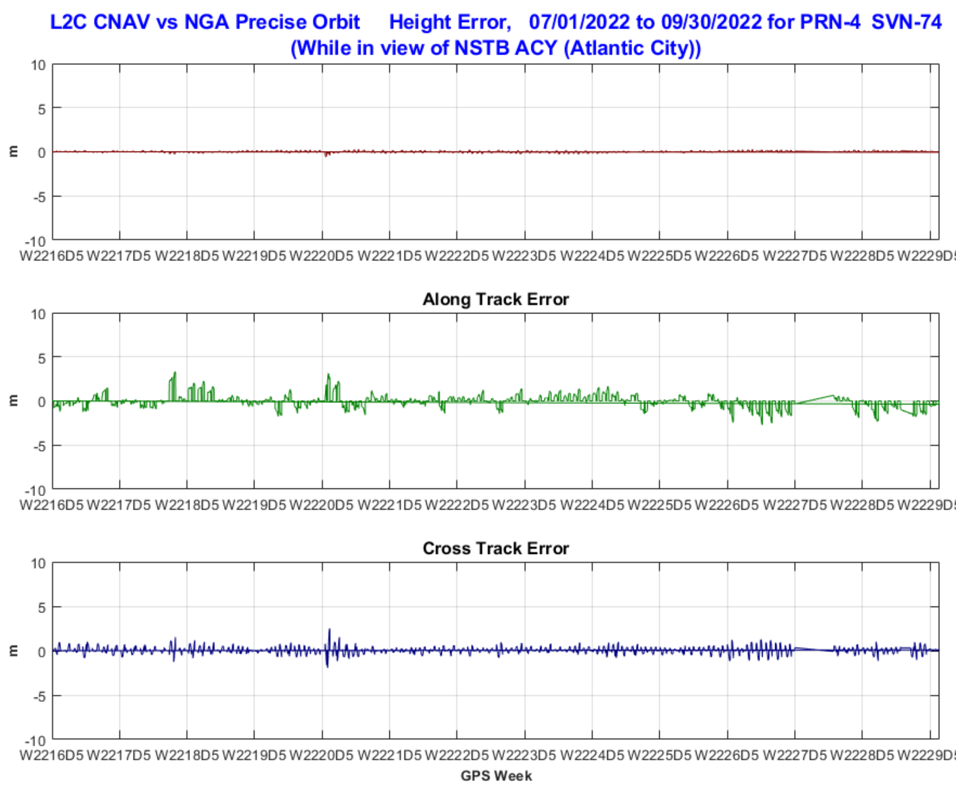


Figure 10-15. Orbit Error PRN4 (SVN74) Using L2C CNAV Data

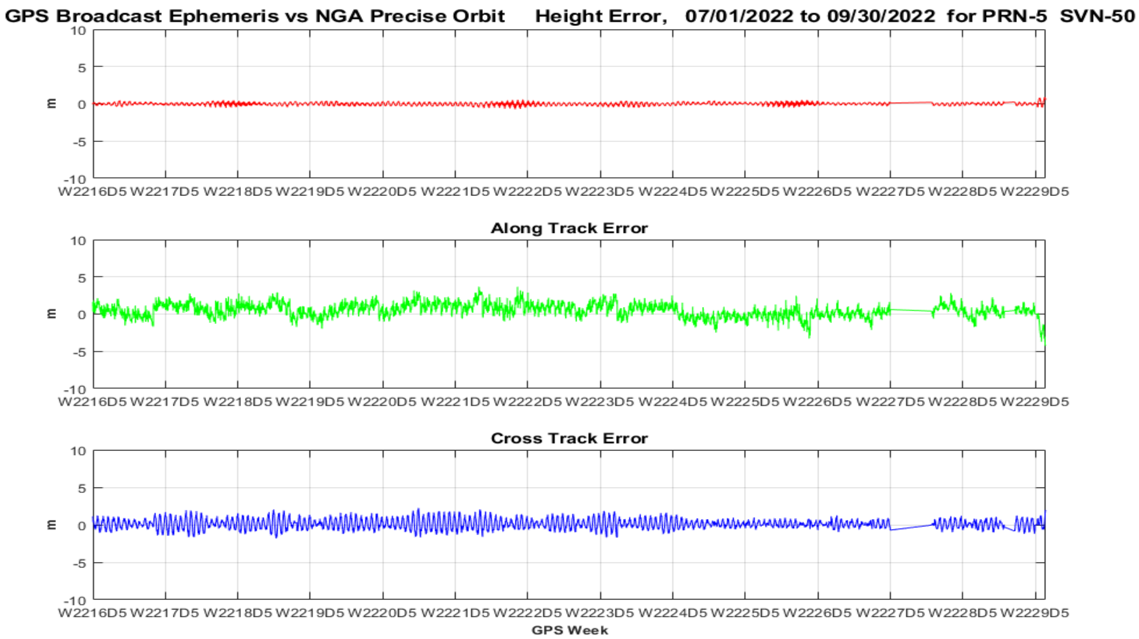


Figure 10-16. Orbit Error PRN5 (SVN50) Using C/A Nav Data

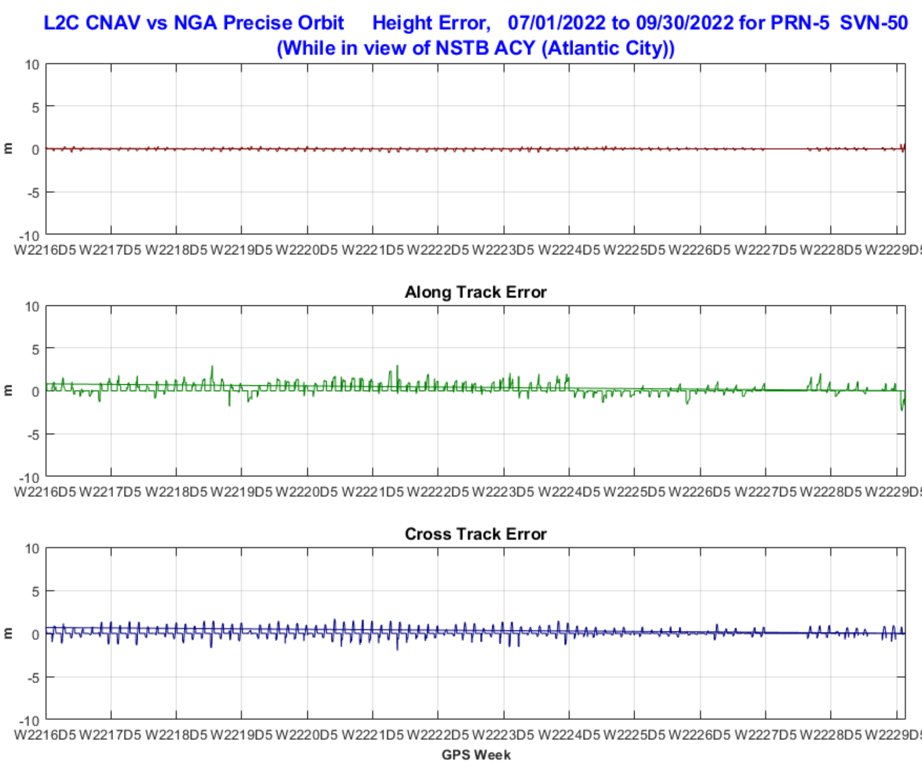


Figure 10-17. Orbit Error PRN5 (SVN50) Using L2C CNAV Data

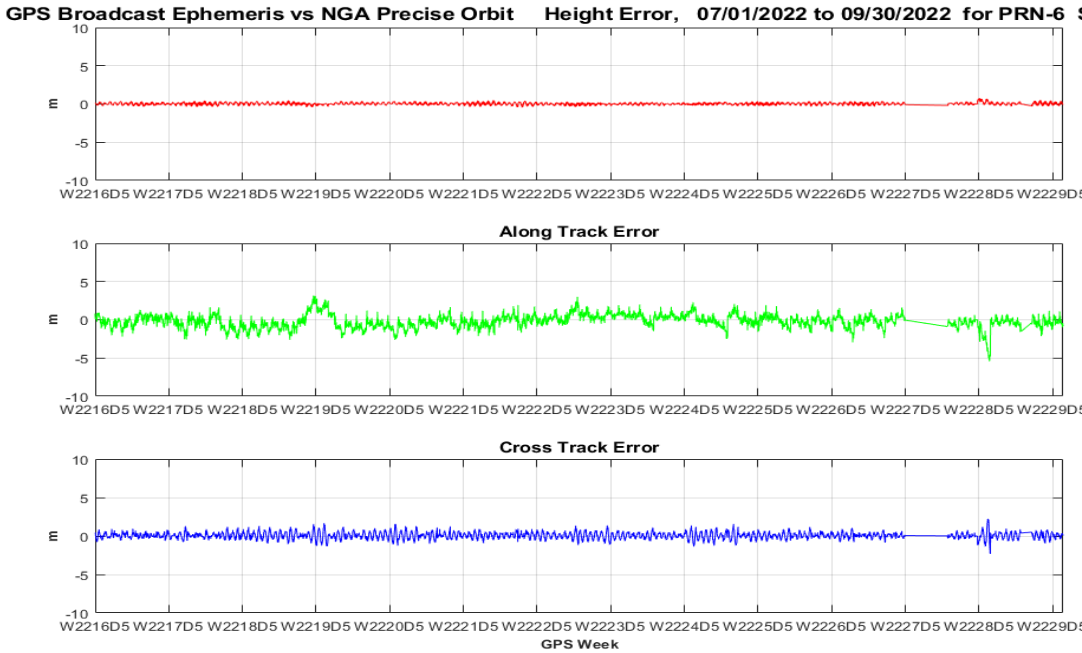


Figure 10-18. Orbit Error PRN6 (SVN67) Using C/A Nav Data

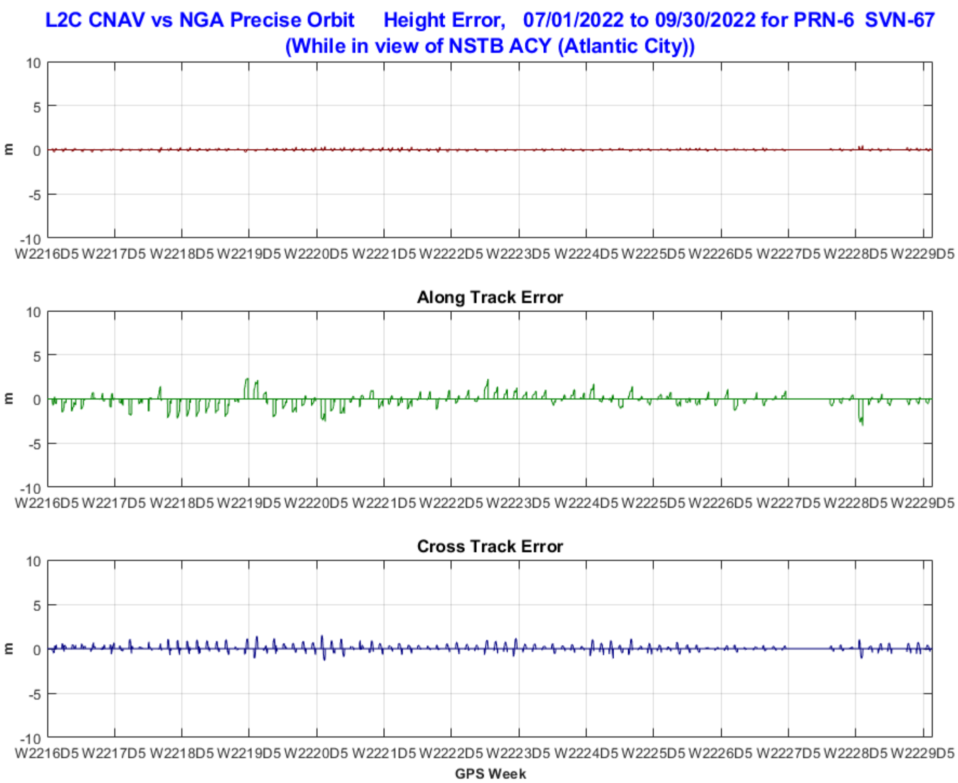


Figure 10-19. Orbit Error PRN6 (SVN67) Using L2C CNAV Data

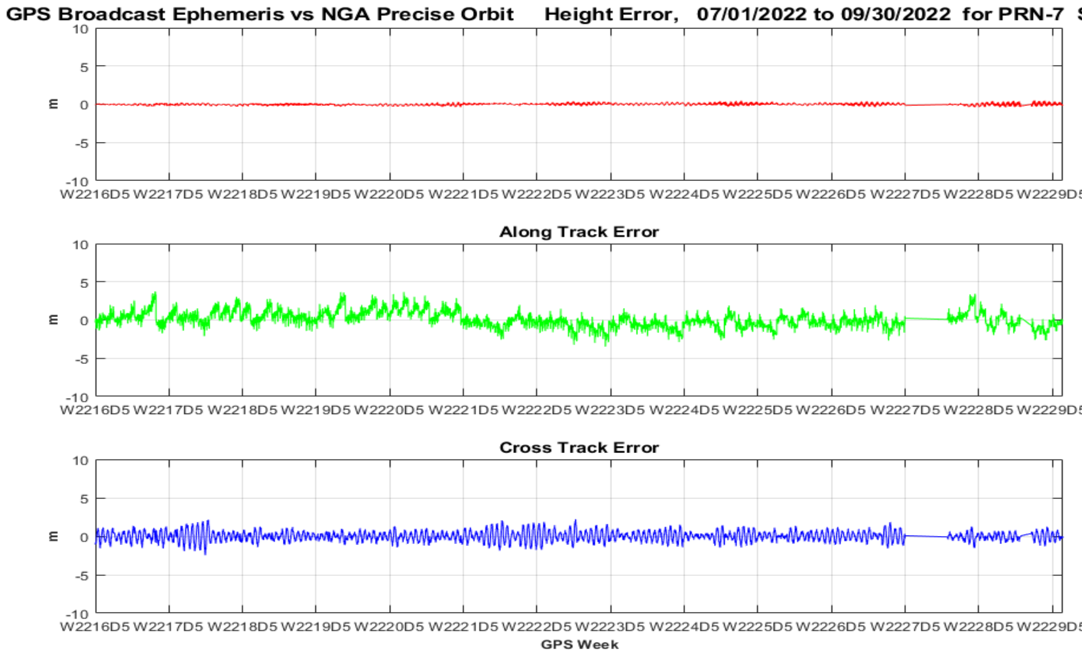


Figure 10-20. Orbit Error PRN7 (SVN48) Using C/A Nav Data

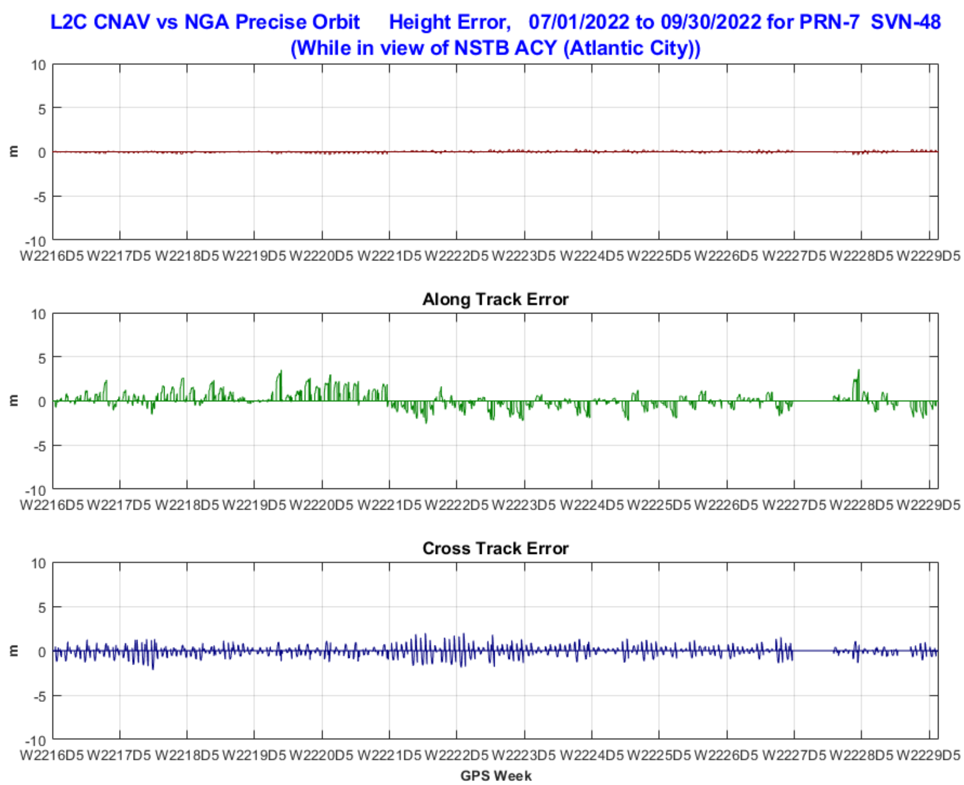


Figure 10-21. Orbit Error PRN7 (SVN48) Using L2C CNAV Data

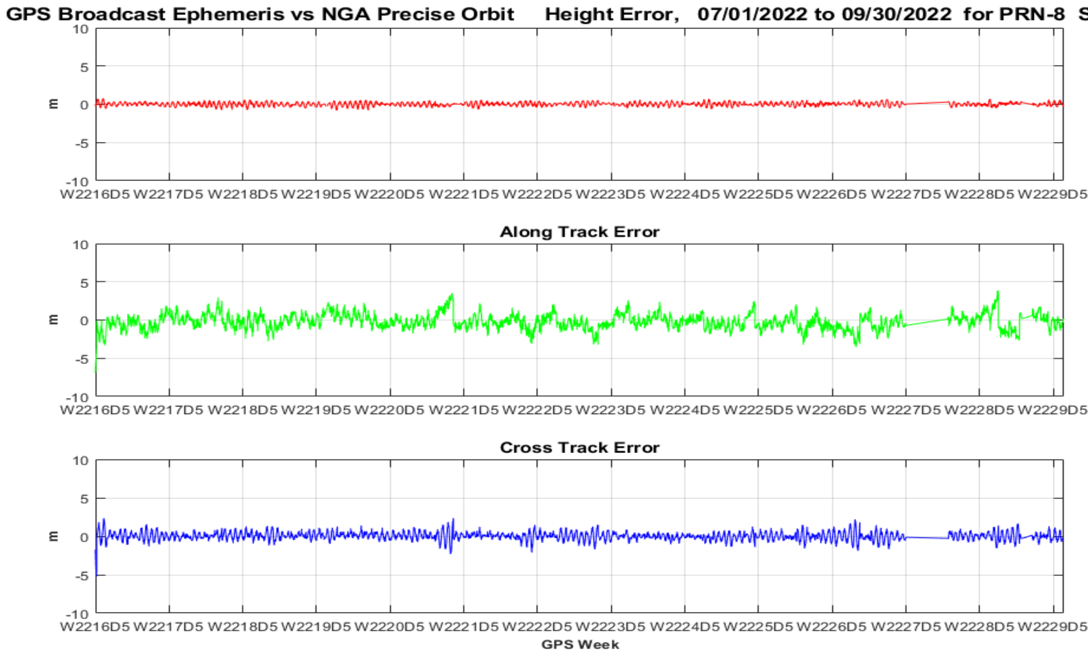


Figure 10-22. Orbit Error PRN8 (SVN72) Using C/A Nav Data

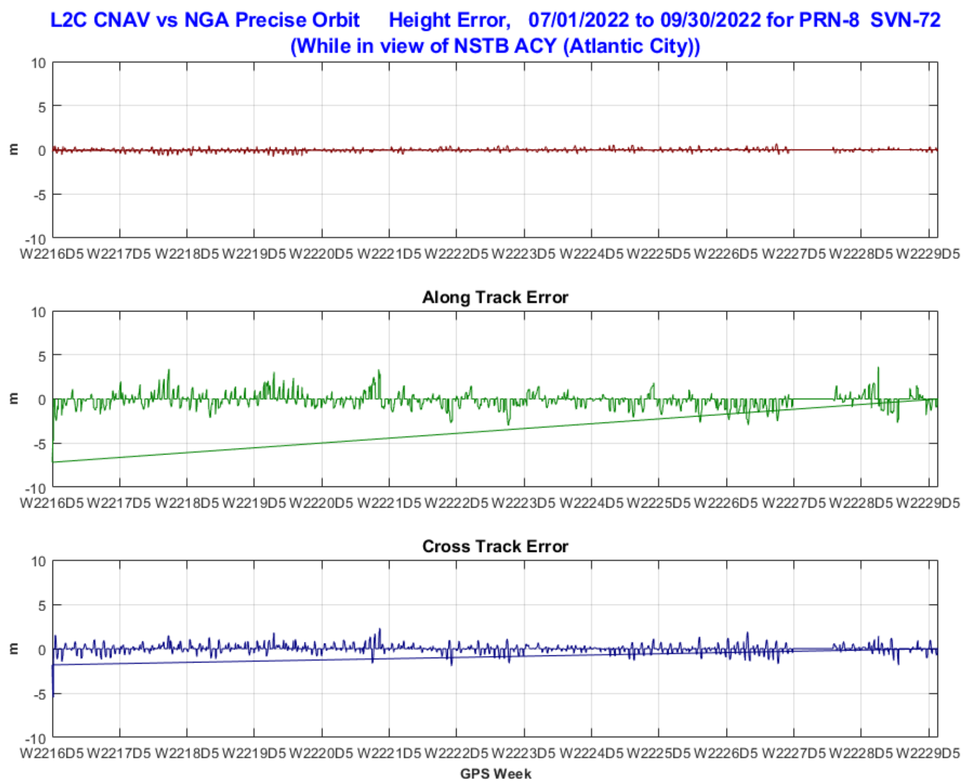


Figure 10-23. Orbit Error PRN8 (SVN72) Using L2C CNAV Data

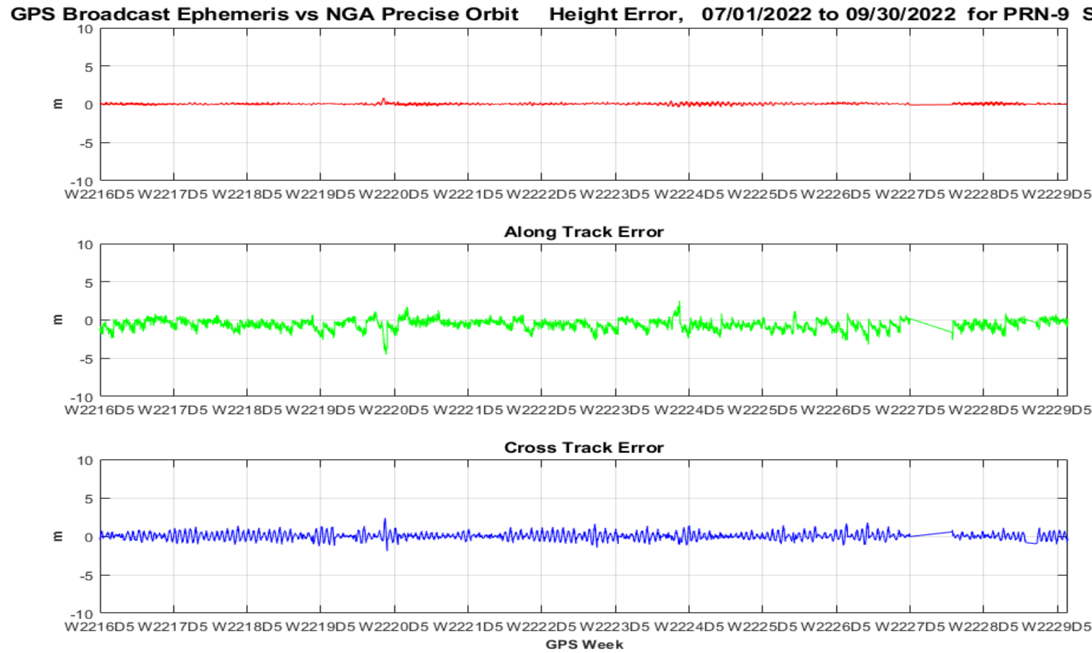


Figure 10-24. Orbit Error PRN9 (SVN68) Using C/A Nav Data

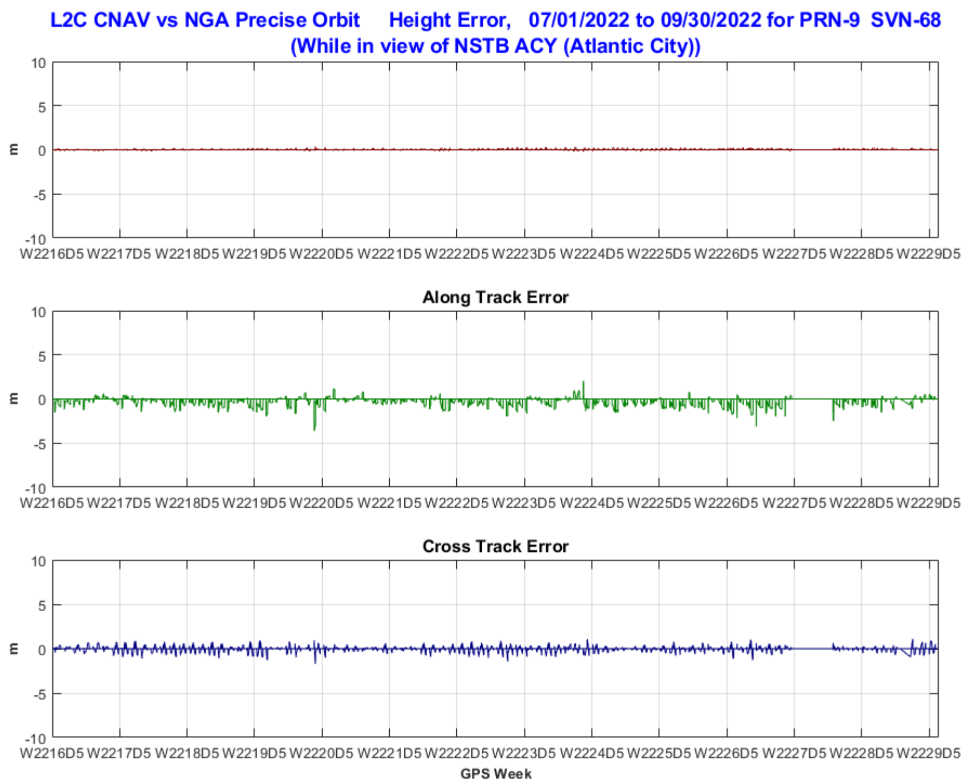


Figure 10-25. Orbit Error PRN9 (SVN68) Using L2C CNAV Data

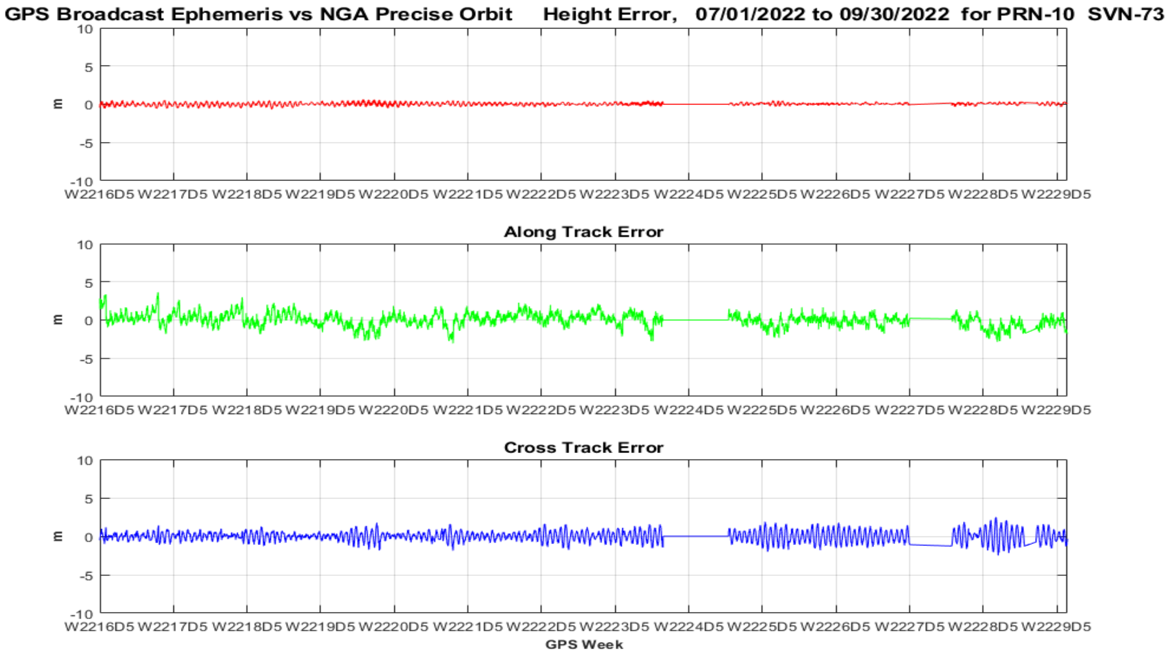


Figure 10-26. Orbit Error PRN10 (SVN73) Using C/A Nav Data

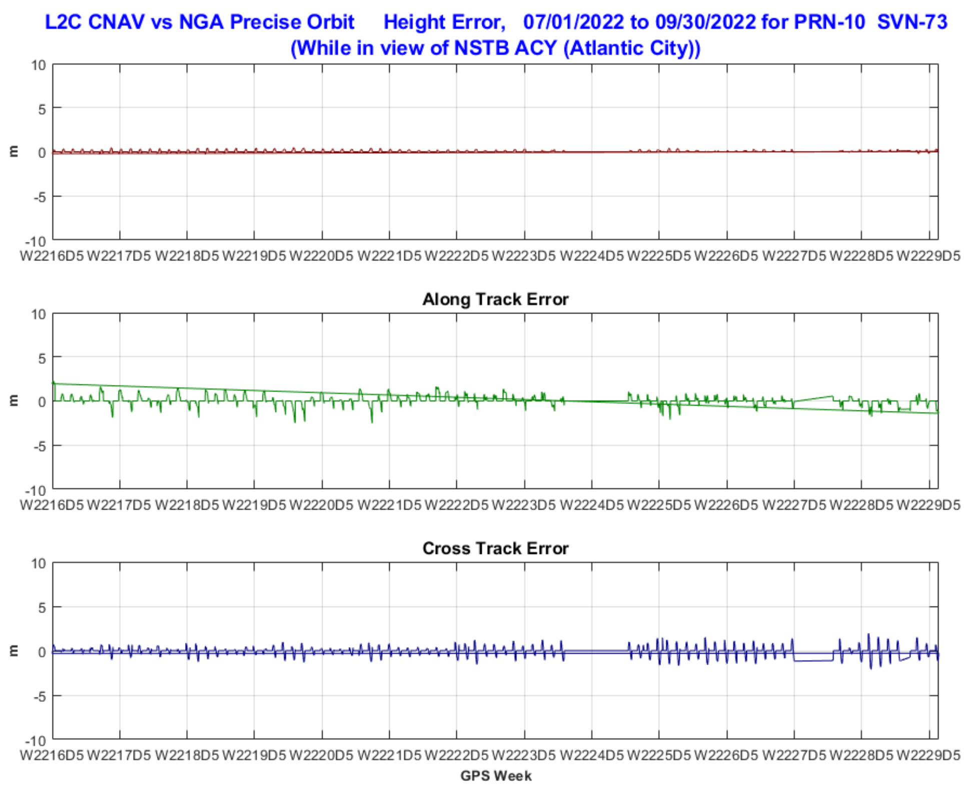


Figure 10-27. Orbit Error PRN10 (SVN73) Using L2C CNAV Data

Figure 10-28. Orbit Error PRN11 (SVN78) Using C/A Nav Data

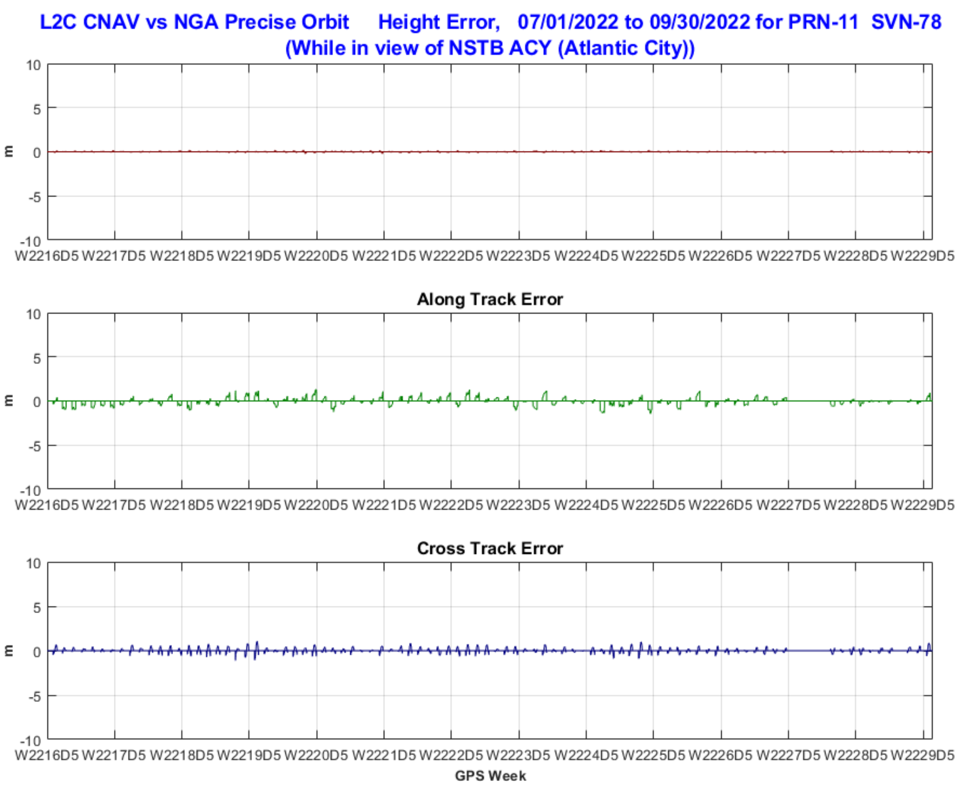


Figure 10-29. Orbit Error PRN11 (SVN78) Using L2C CNAV Data

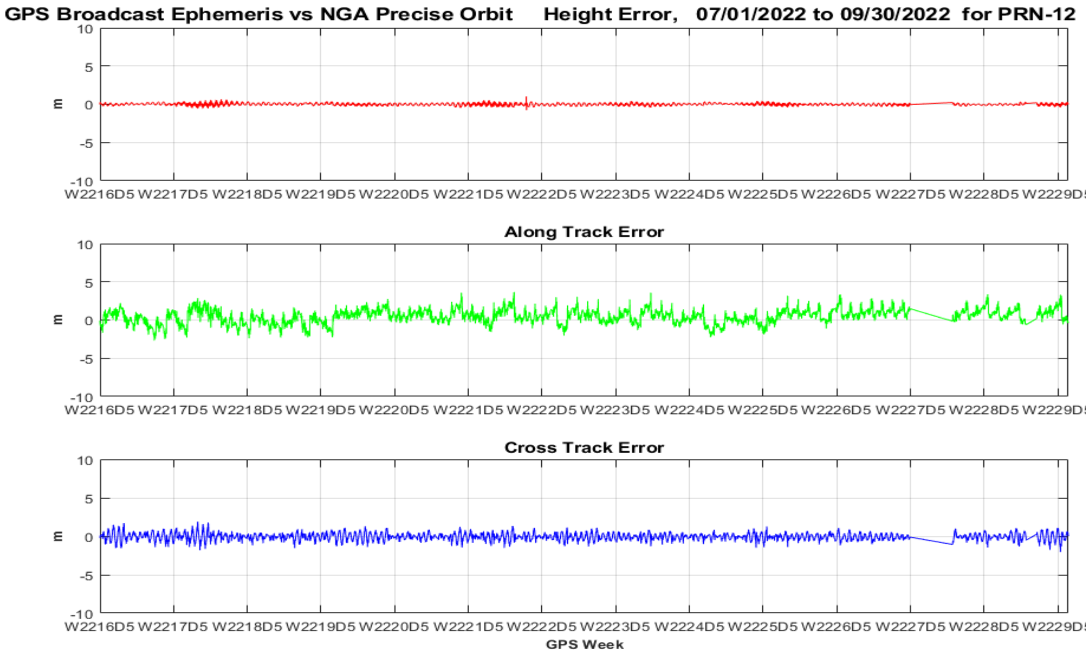


Figure 10-30. Orbit Error PRN12 (SVN58) Using C/A Nav Data

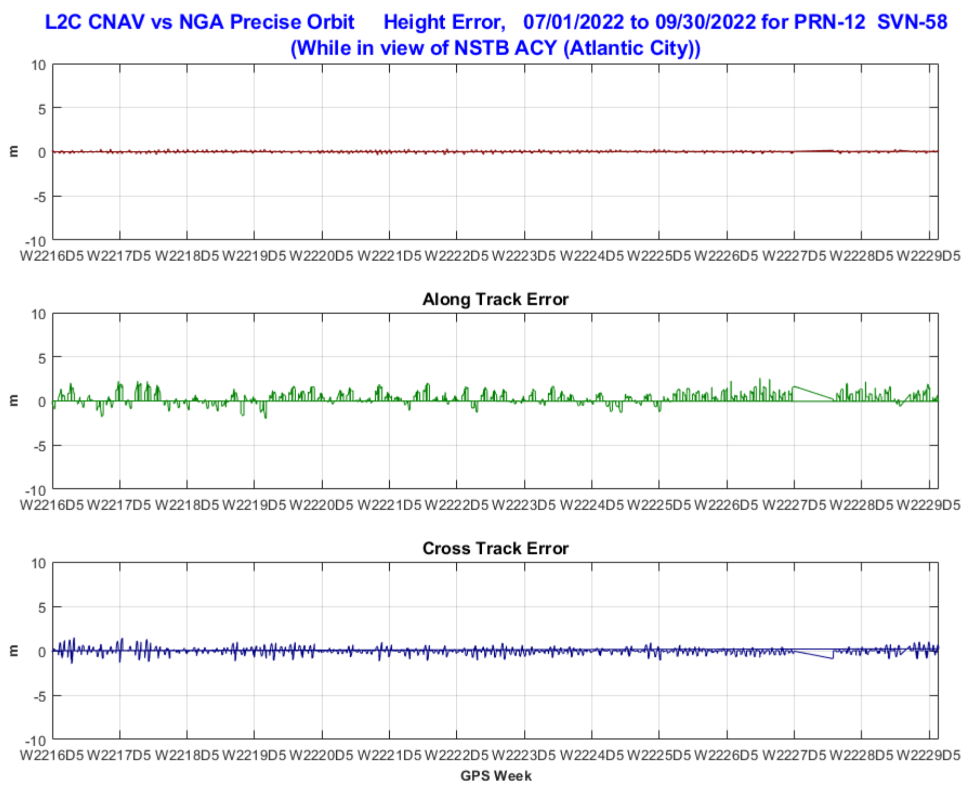


Figure 10-31. Orbit Error PRN12 (SVN58) Using L2C CNAV Data

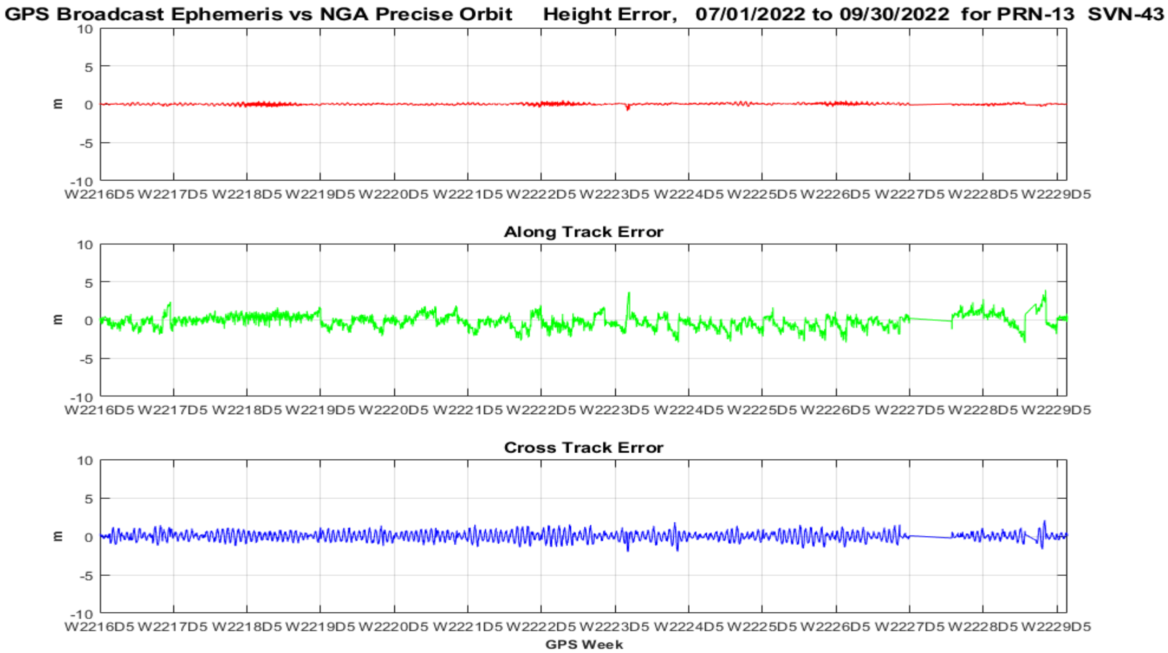


Figure 10-32. Orbit Error PRN13 (SVN43) Using C/A Nav Data

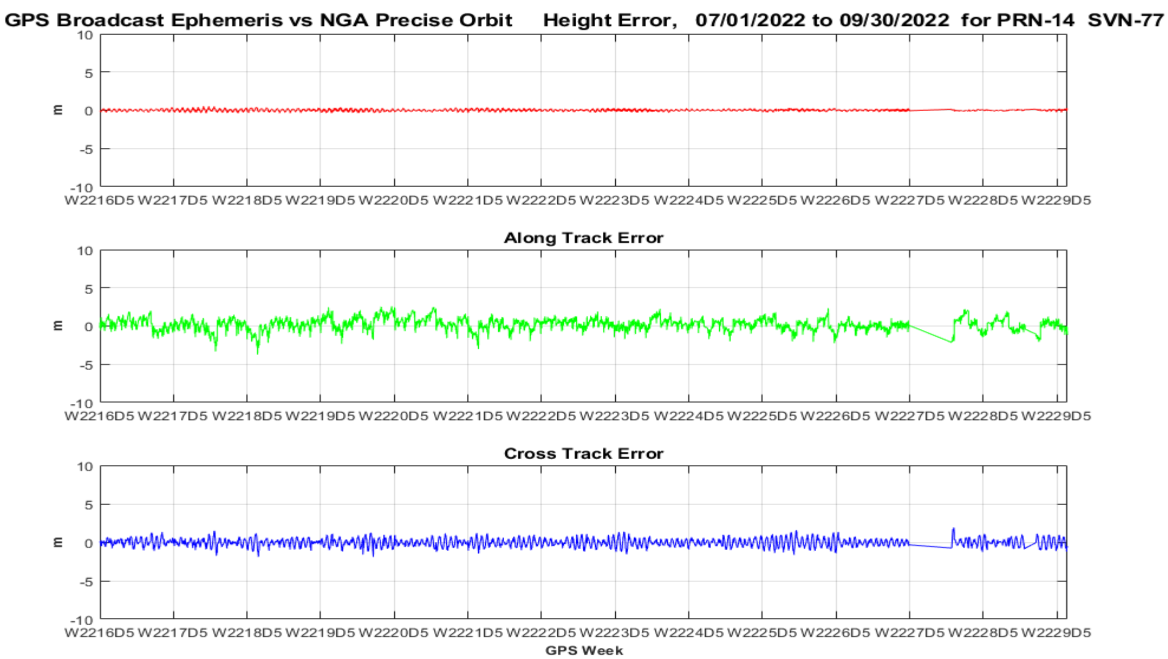


Figure 10-33. Orbit Error PRN14 (SVN77) Using C/A Nav Data

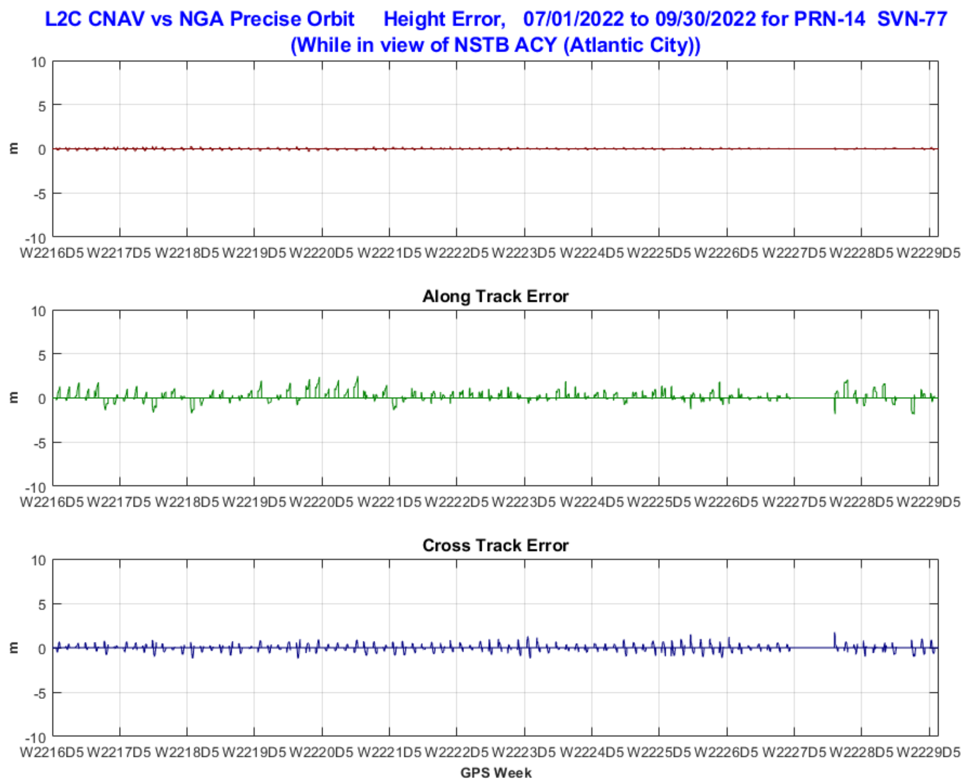


Figure 10-34. Orbit Error PRN14 (SVN77) Using L2C CNAV Data

Figure 10-35. Orbit Error PRN15 (SVN55) Using C/A Nav Data

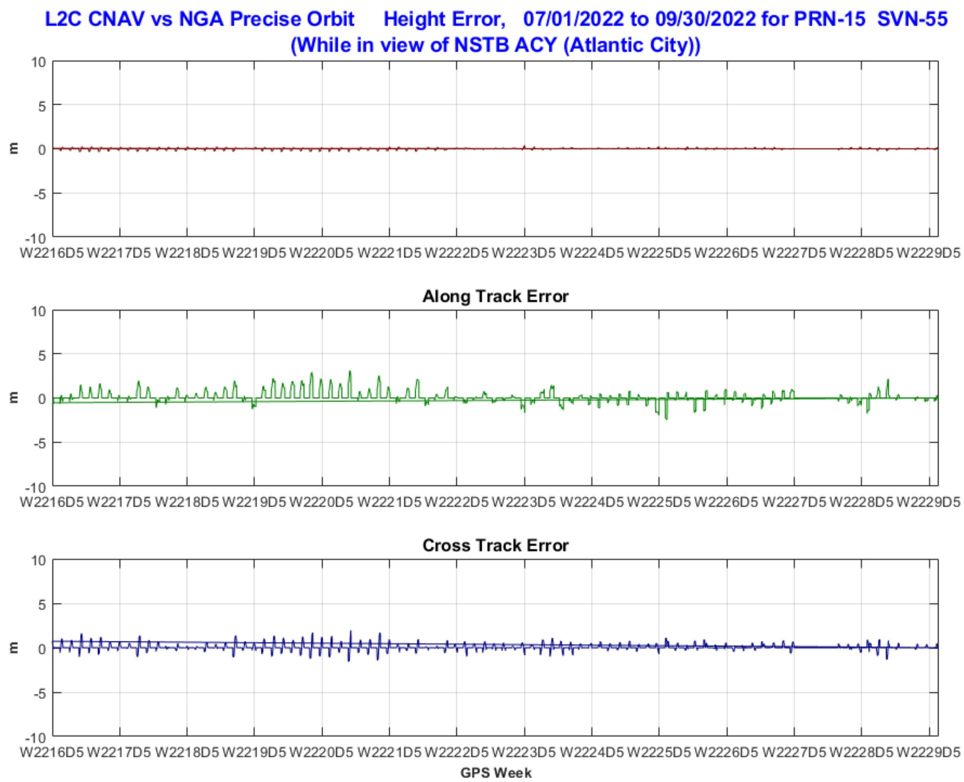


Figure 10-36. Orbit Error PRN15 (SVN55) Using L2C CNAV Data

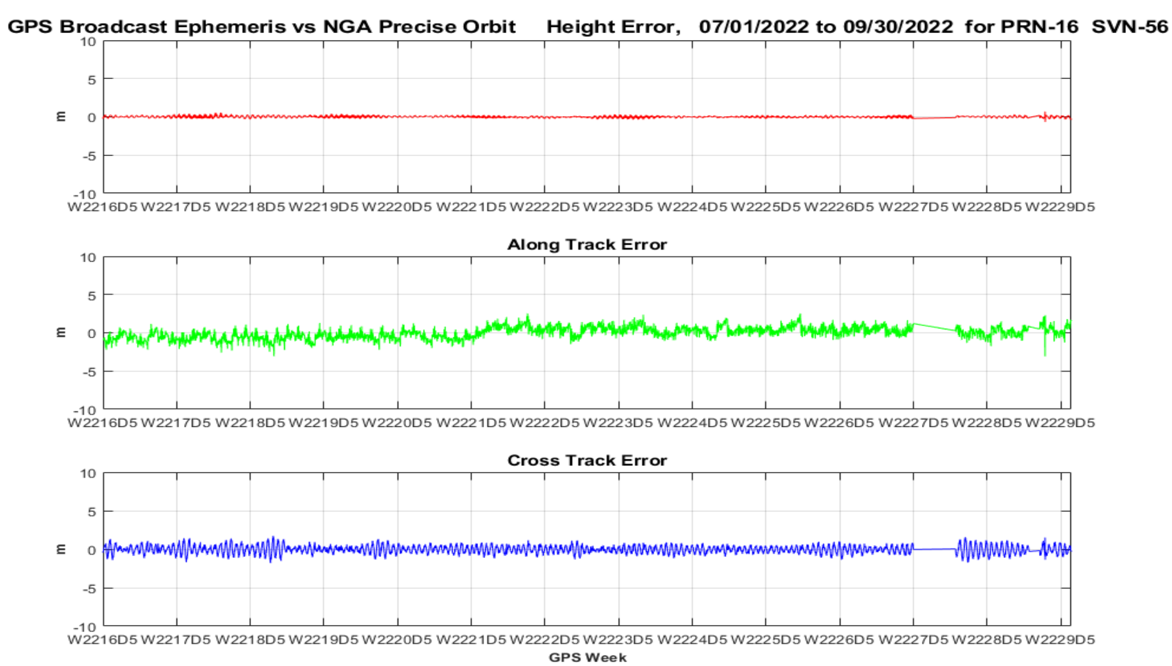


Figure 10-37. Orbit Error PRN16 (SVN56) Using C/A Nav Data

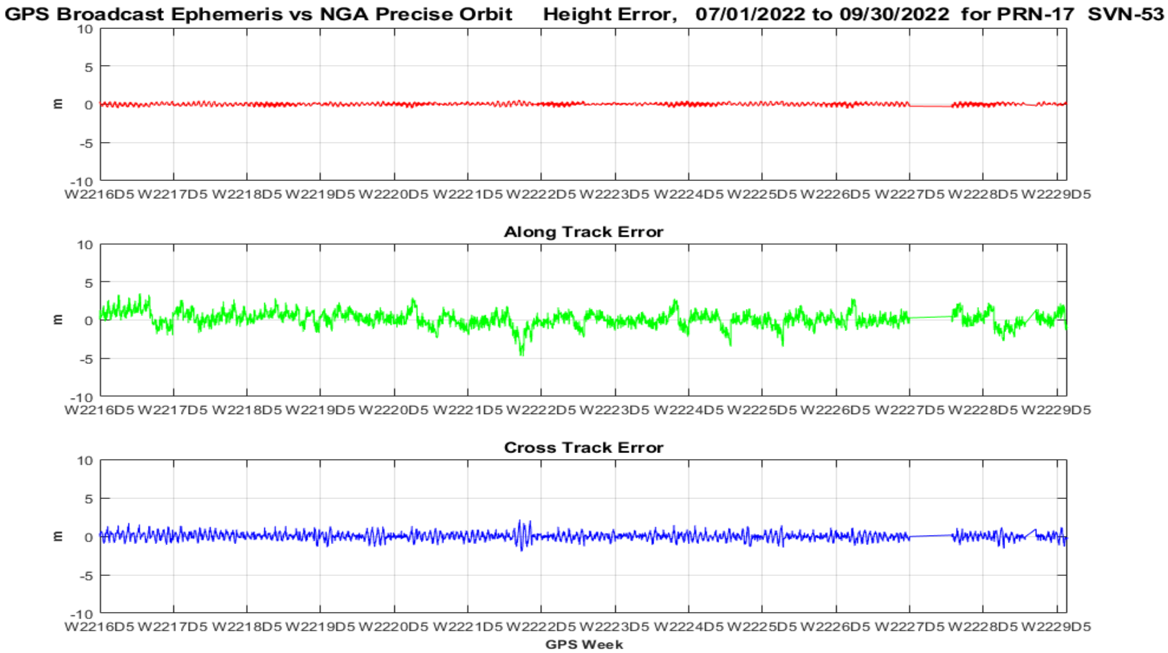


Figure 10-38. Orbit Error PRN17 (SVN53) Using C/A Nav Data

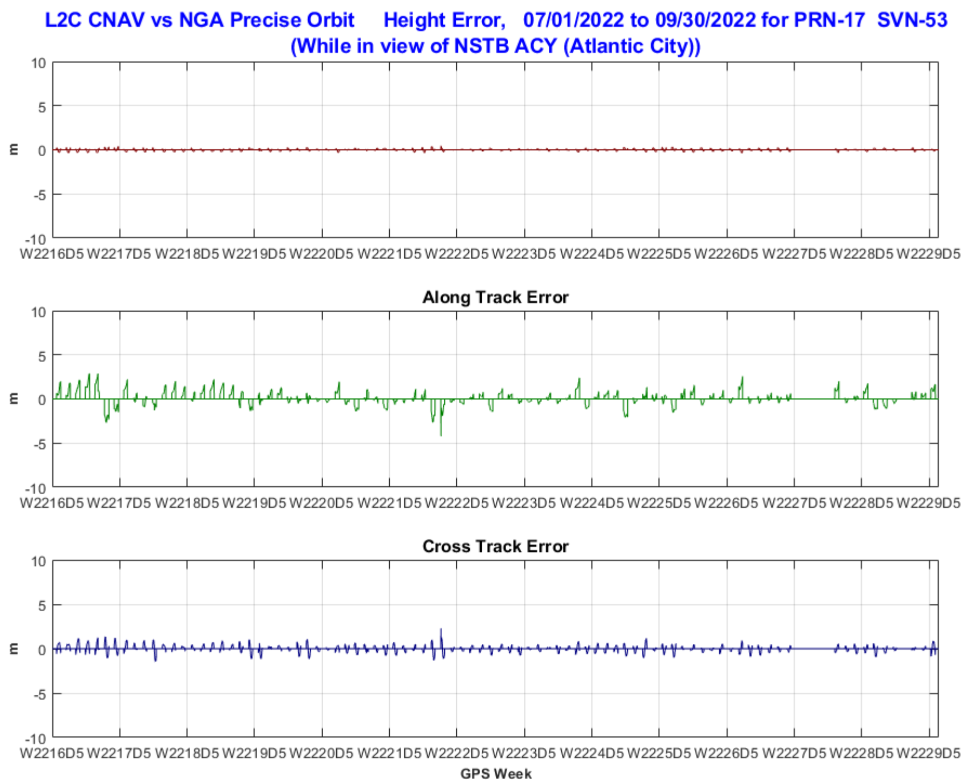


Figure 10-39. Orbit Error PRN17 (SVN53) Using L2C CNAV Data

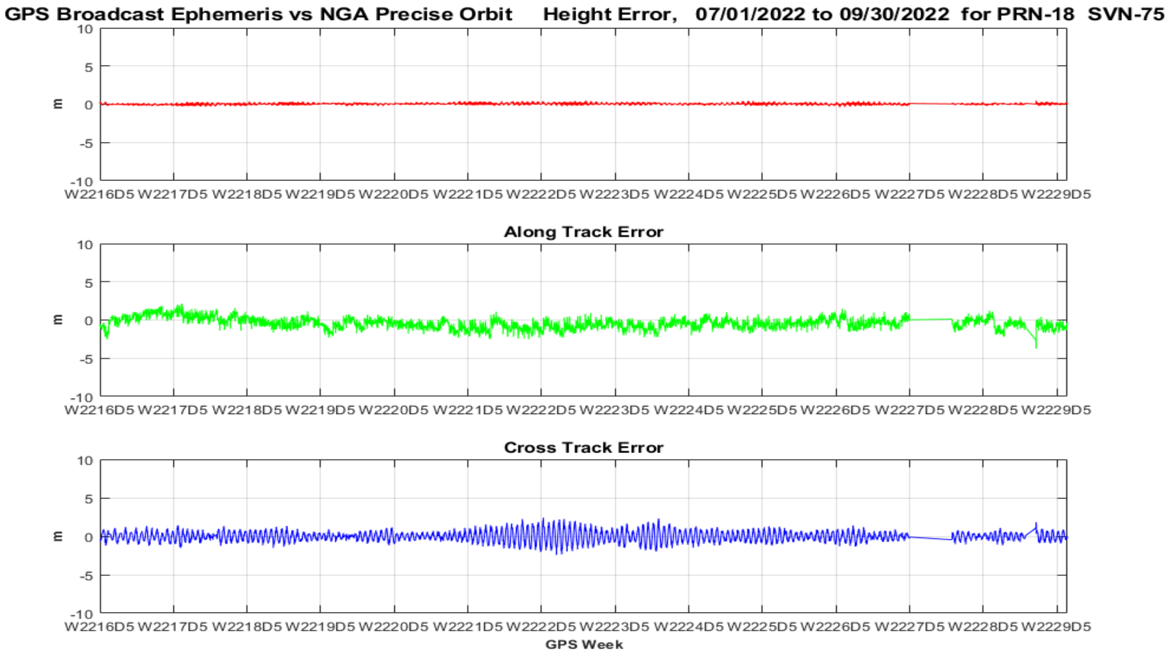


Figure 10-40. Orbit Error PRN18 (SVN75) Using C/A Nav Data

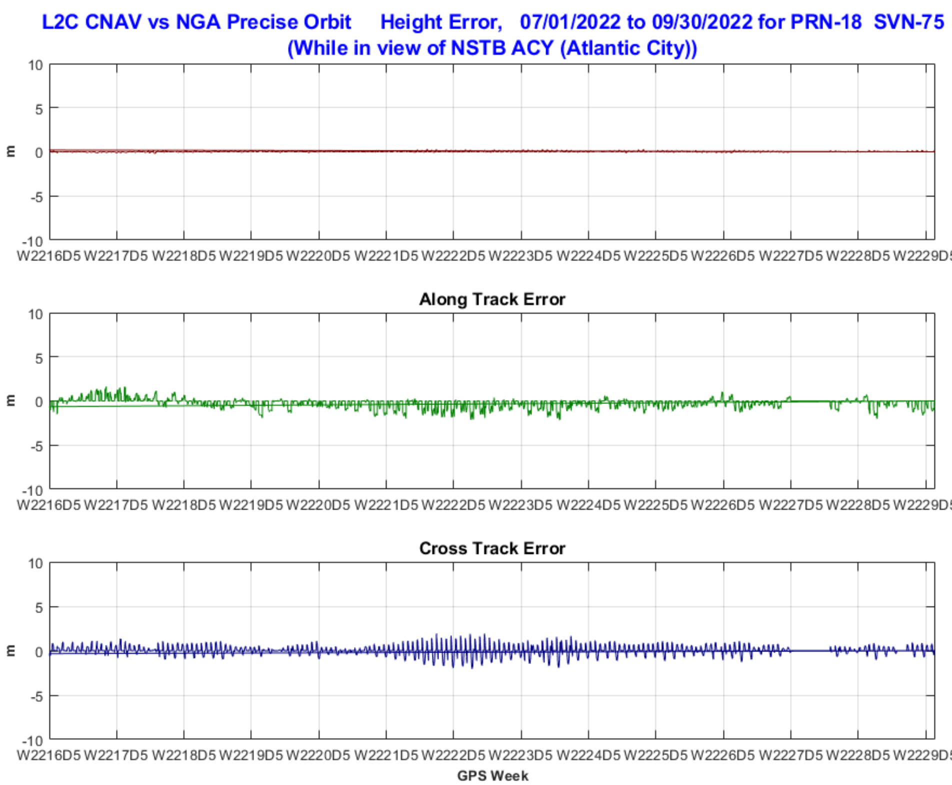


Figure 10-41. Orbit Error PRN18 (SVN75) Using L2C CNAV Data

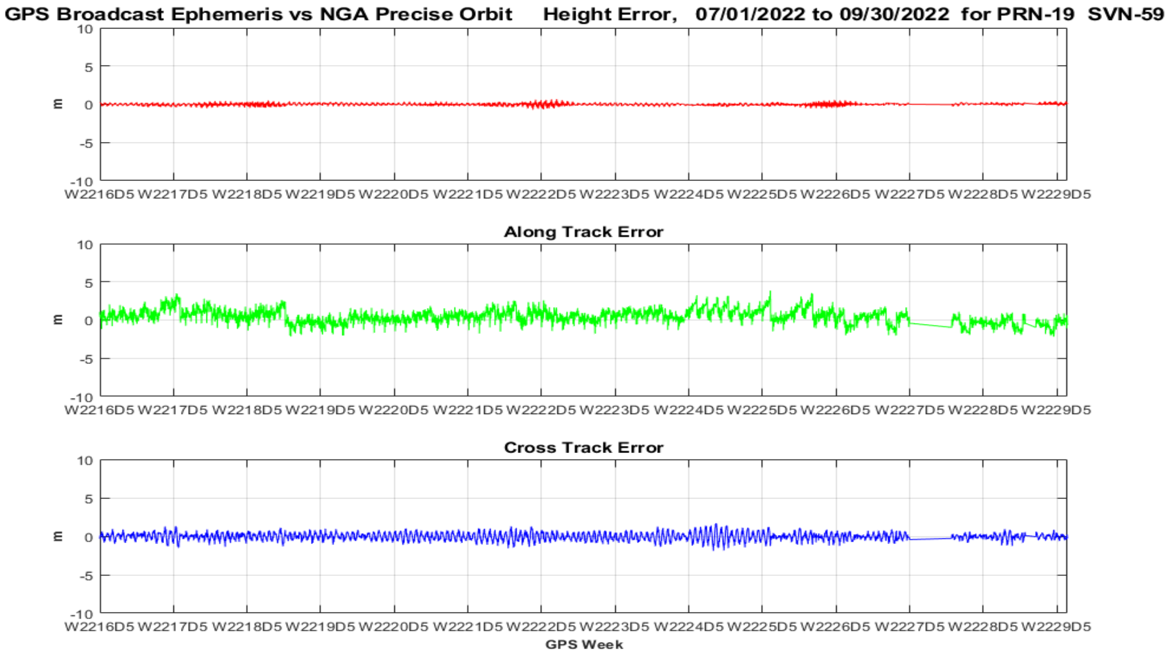


Figure 10-42. Orbit Error PRN19 (SVN59) Using C/A Nav Data

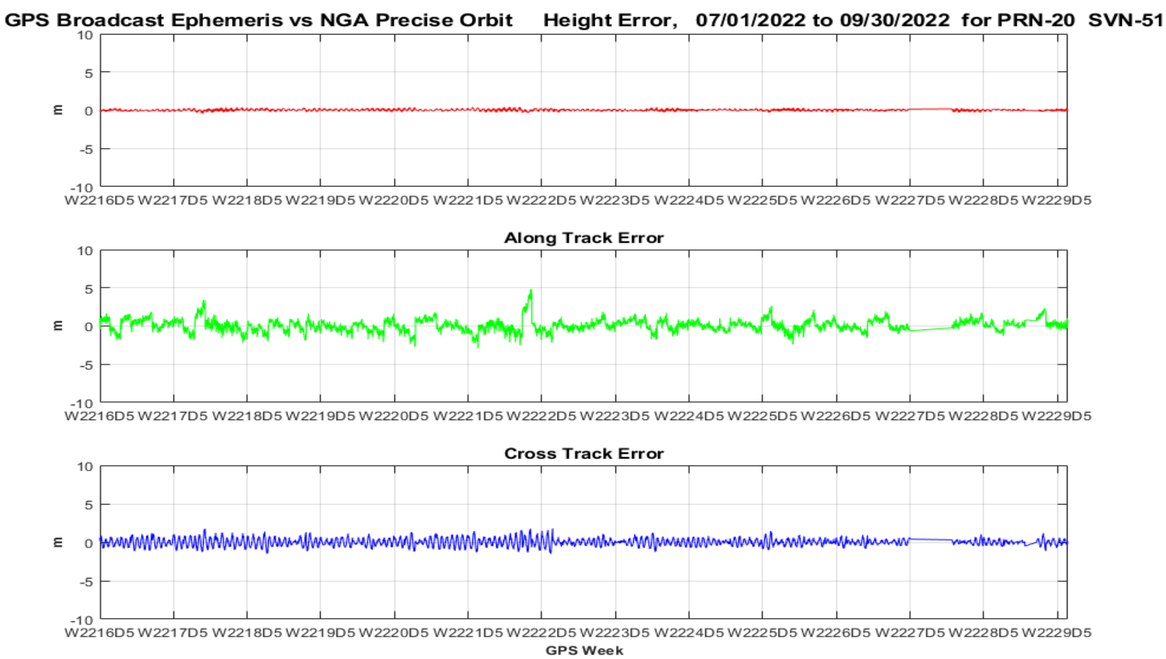


Figure 10-43. Orbit Error PRN20 (SVN51) Using C/A Nav Data

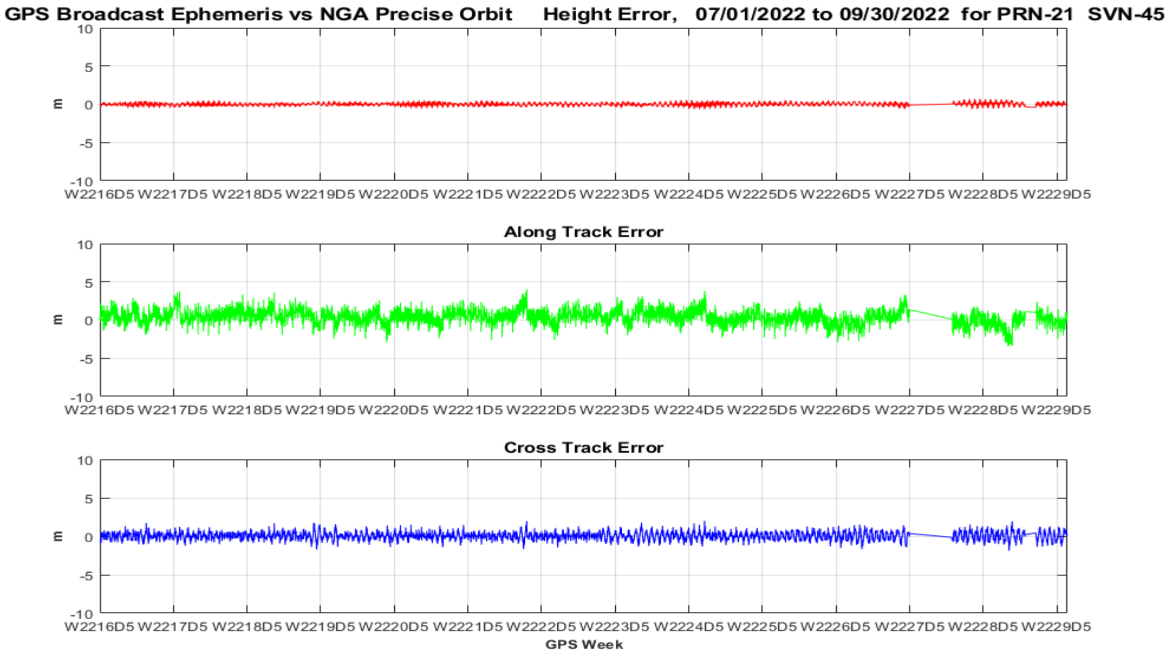


Figure 10-44. Orbit Error PRN21 (SVN45) Using C/A Nav Data

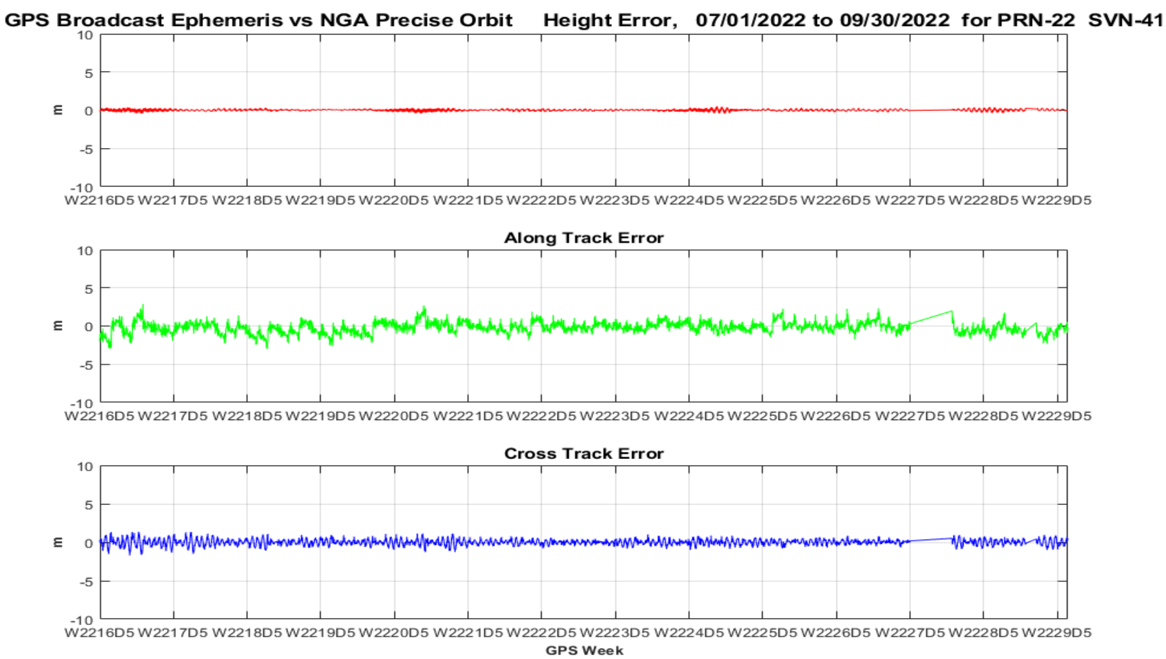


Figure 10-45. Orbit Error PRN22 (SVN41) Using C/A Nav Data

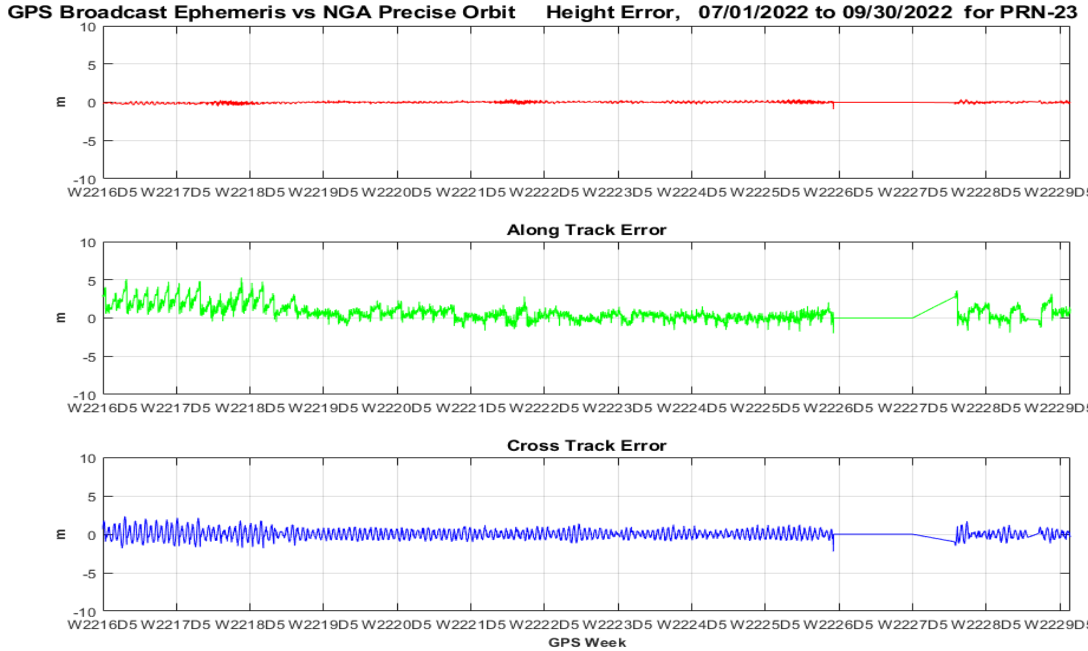


Figure 10-46. Orbit Error PRN23 (SVN76) Using C/A Nav Data

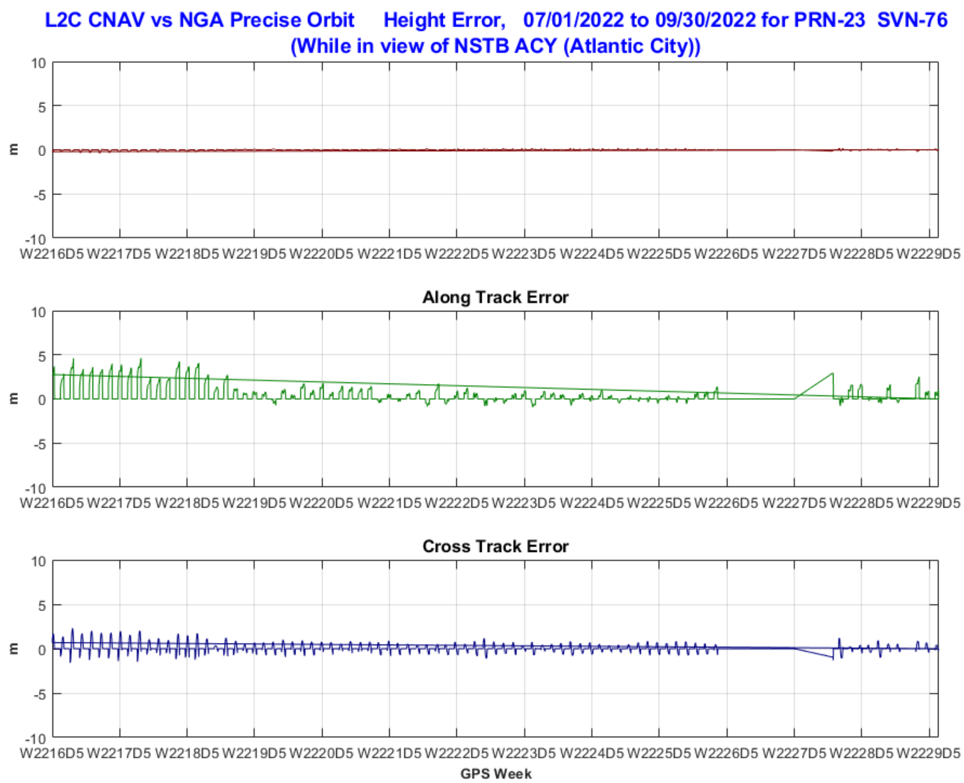


Figure 10-47. Orbit Error PRN23 (SVN76) Using L2C CNAV Data

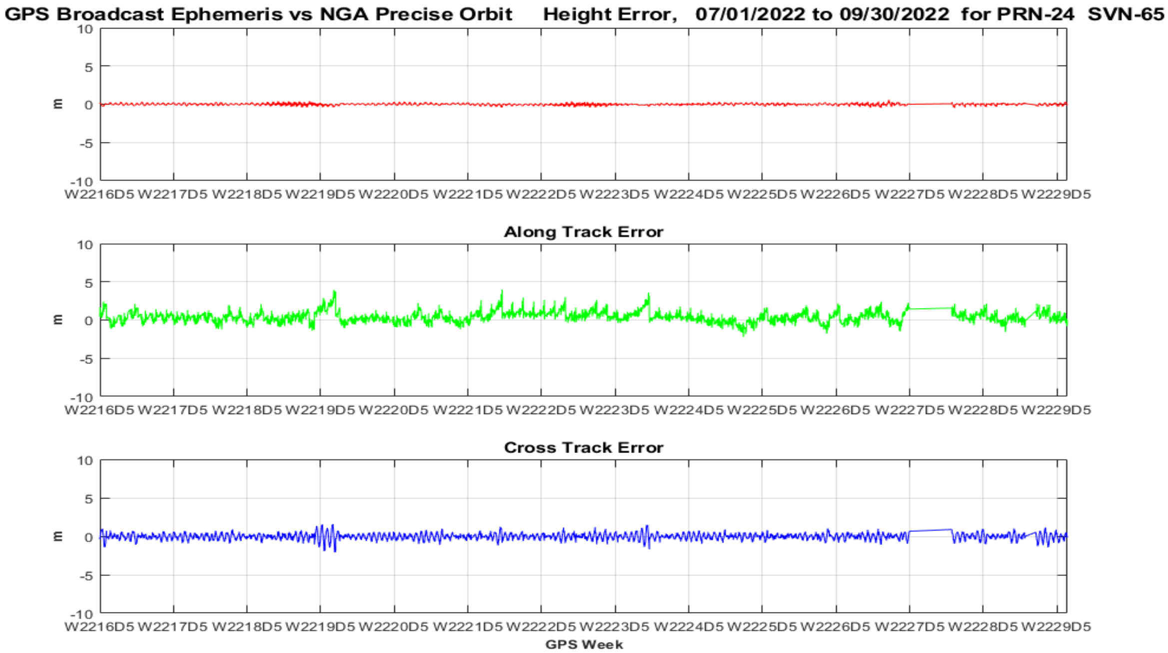


Figure 10-48. Orbit Error PRN24 (SVN65) Using C/A Nav Data

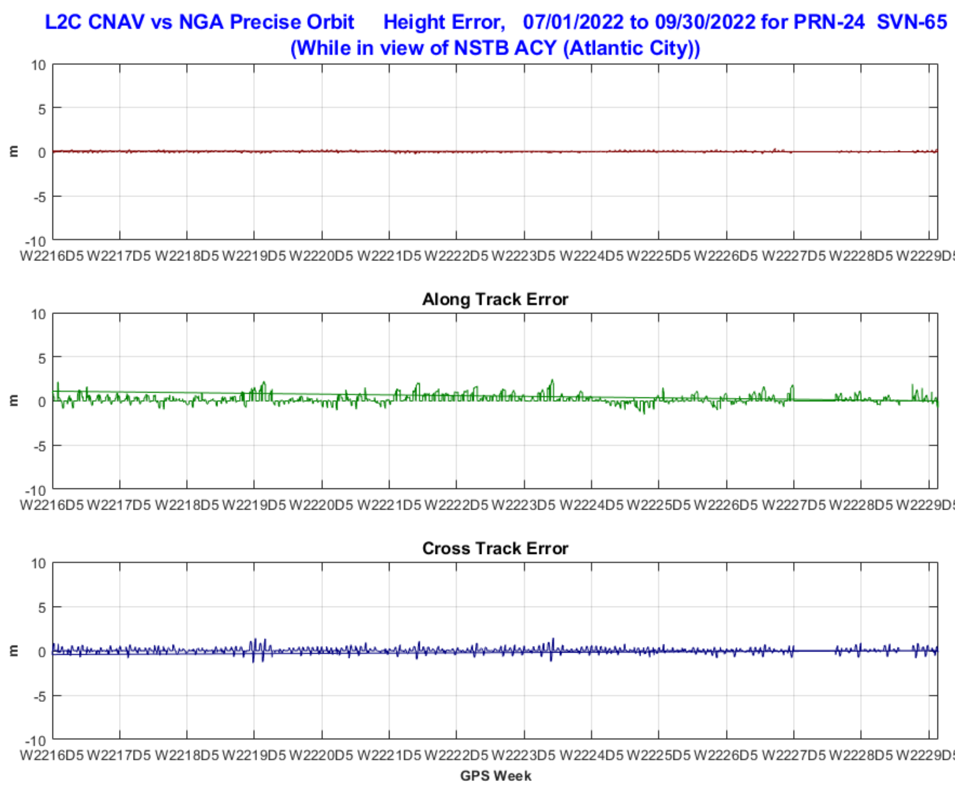


Figure 10-49. Orbit Error PRN24 (SVN65) Using L2C CNAV Data

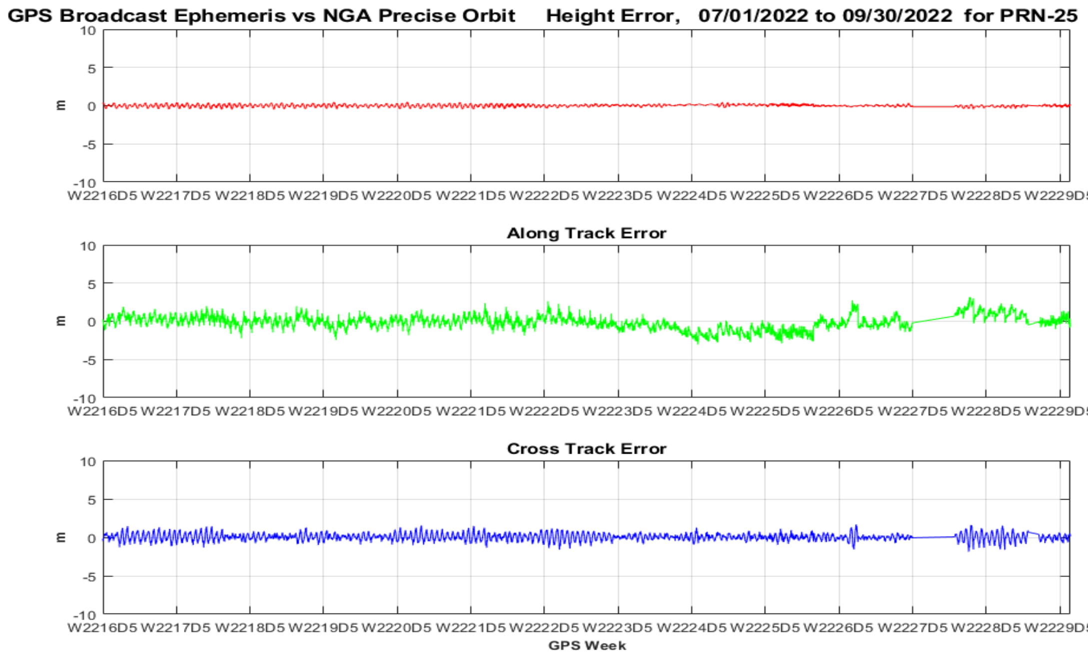


Figure 10-50. Orbit Error PRN25 (SVN62) Using C/A Nav Data

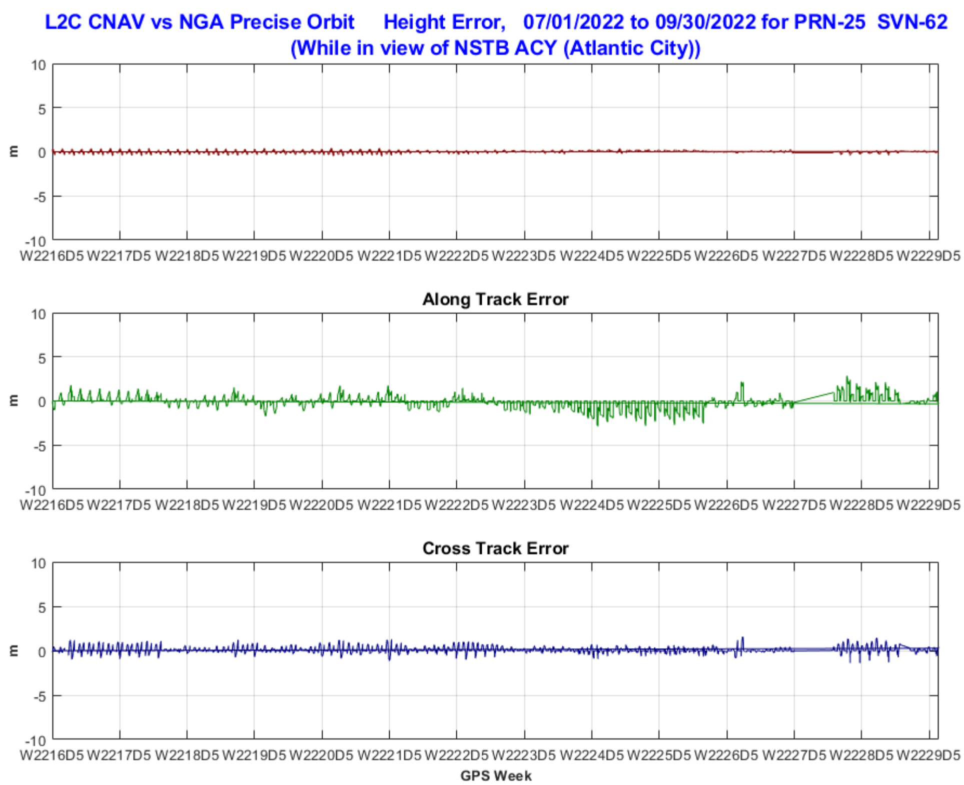


Figure 10-51. Orbit Error PRN25 (SVN62) Using L2C CNAV Data

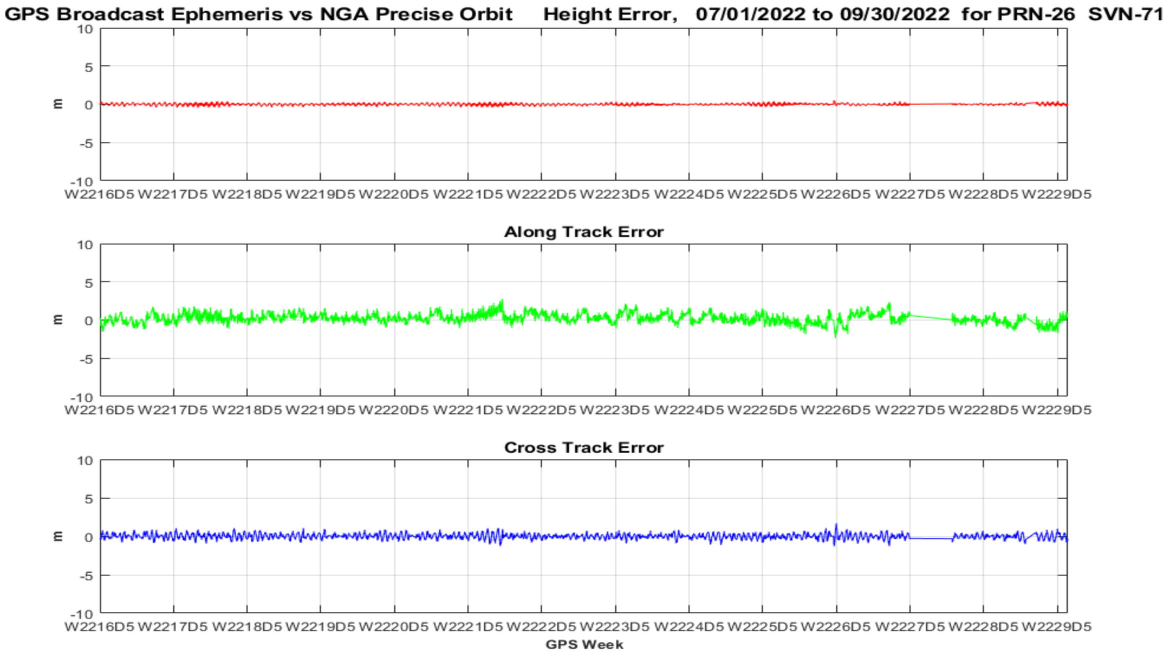


Figure 10-52. Orbit Error PRN26 (SVN71) Using C/A Nav Data

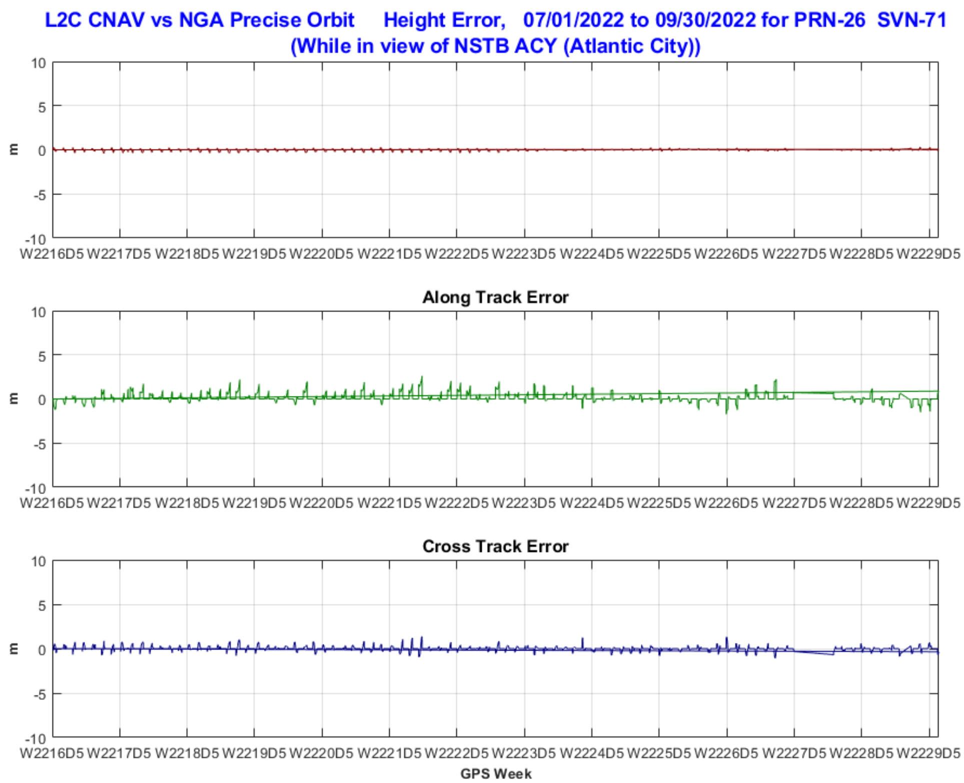


Figure 10-53. Orbit Error PRN26 (SVN71) Using L2C CNAV Data

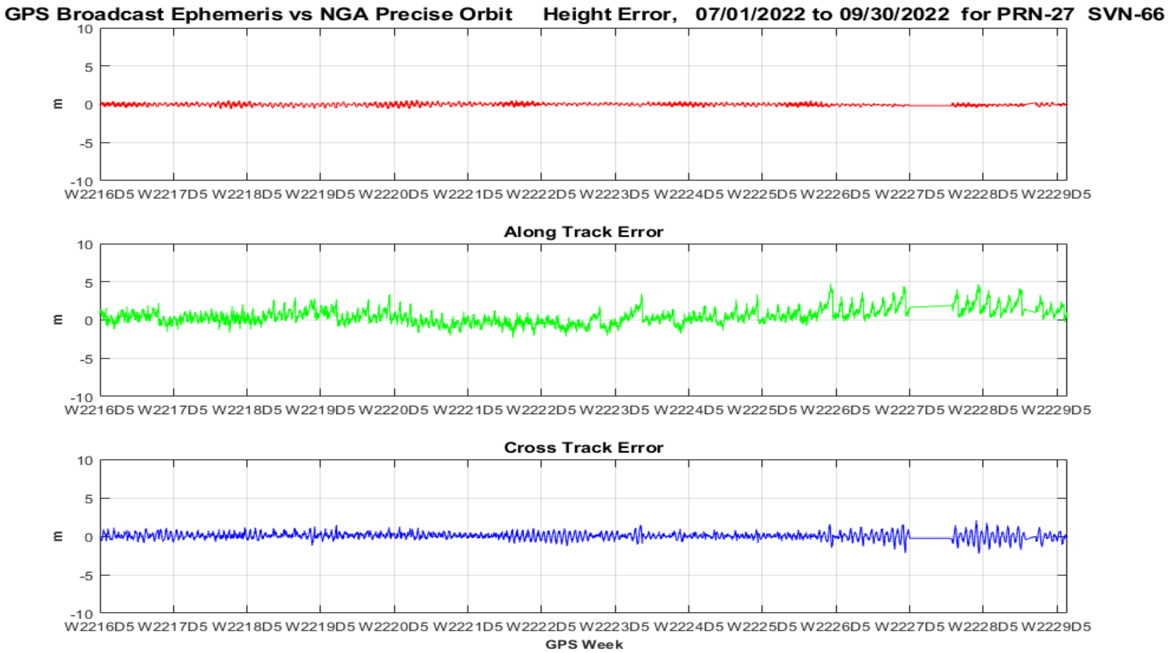


Figure 10-54. Orbit Error PRN27 (SVN66) Using C/A Nav Data

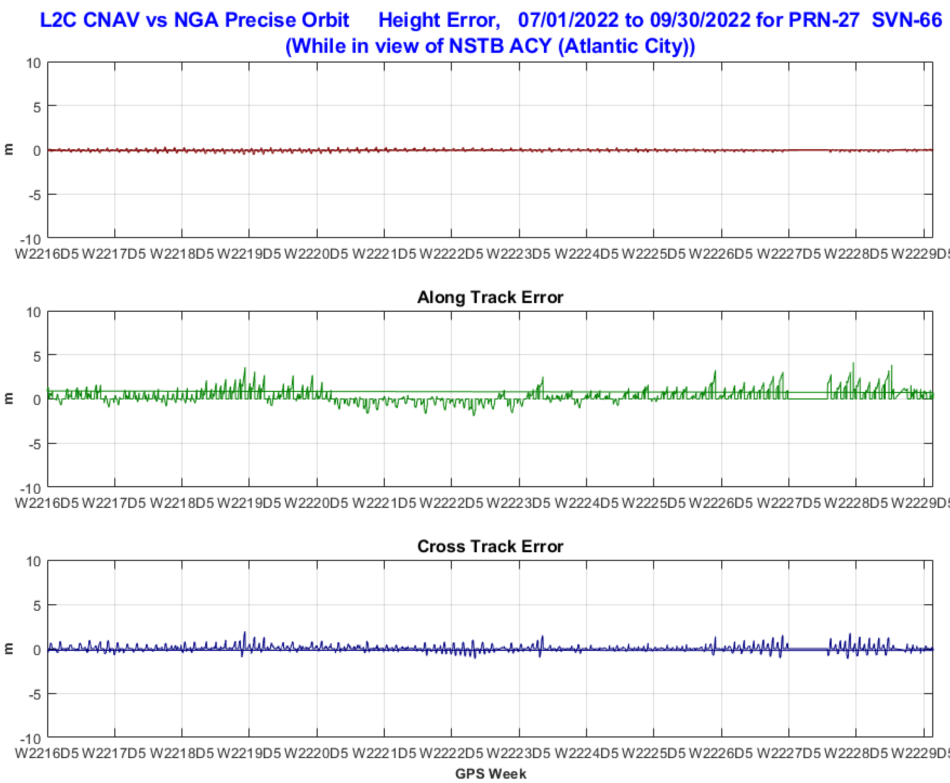


Figure 10-55. Orbit Error PRN27 (SVN66) Using L2C CNAV Data

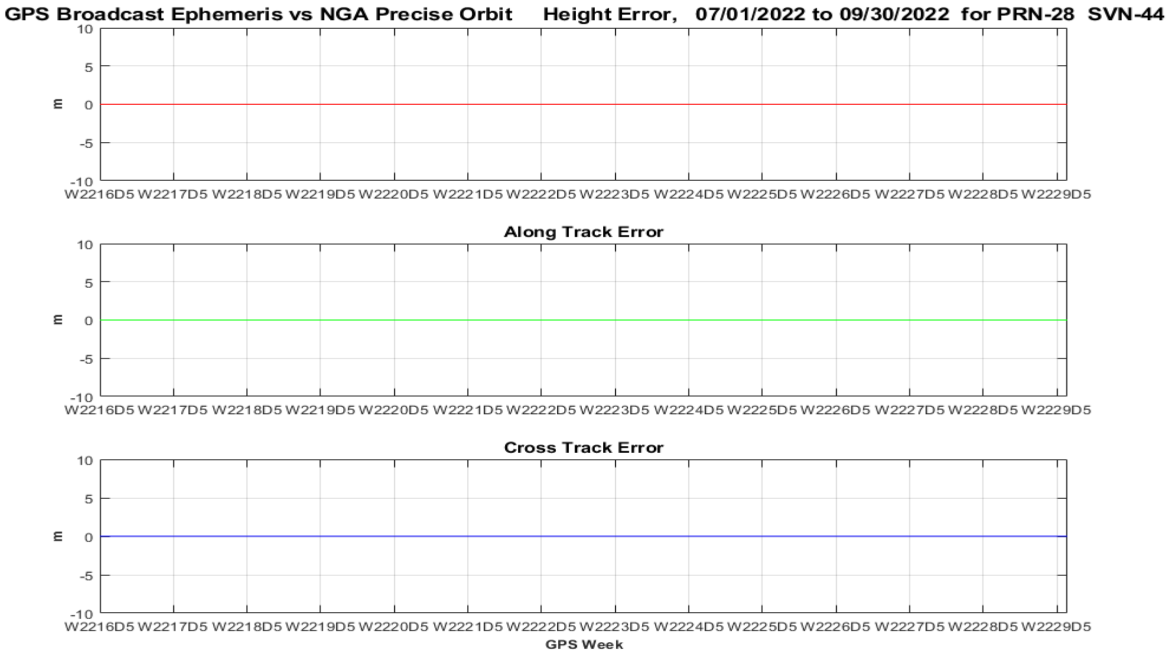


Figure 10-56. Orbit Error PRN28 (SVN44) Using C/A Nav Data

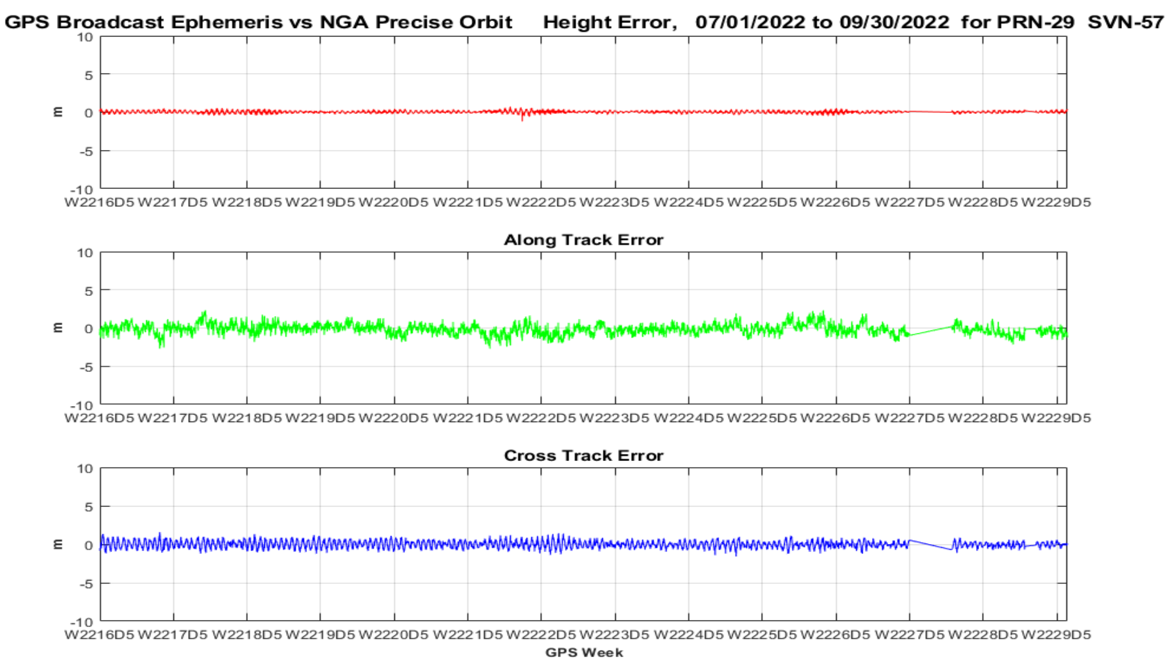


Figure 10-57. Orbit Error PRN29 (SVN57) Using C/A Nav Data

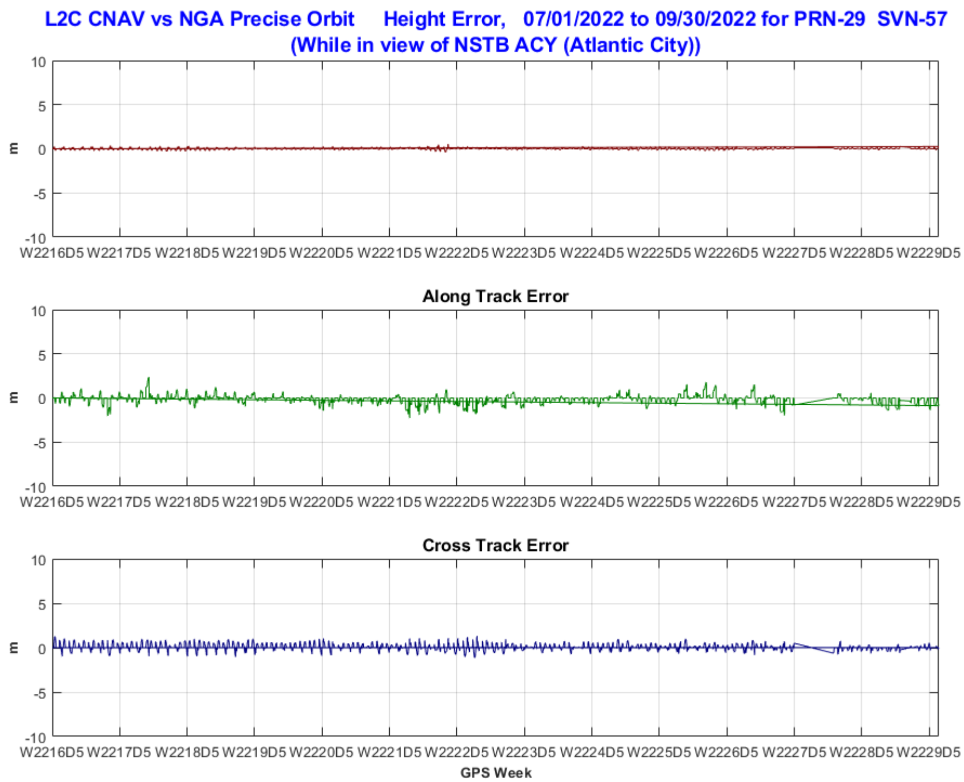


Figure 10-58. Orbit Error PRN29 (SVN57) Using L2C CNAV Data

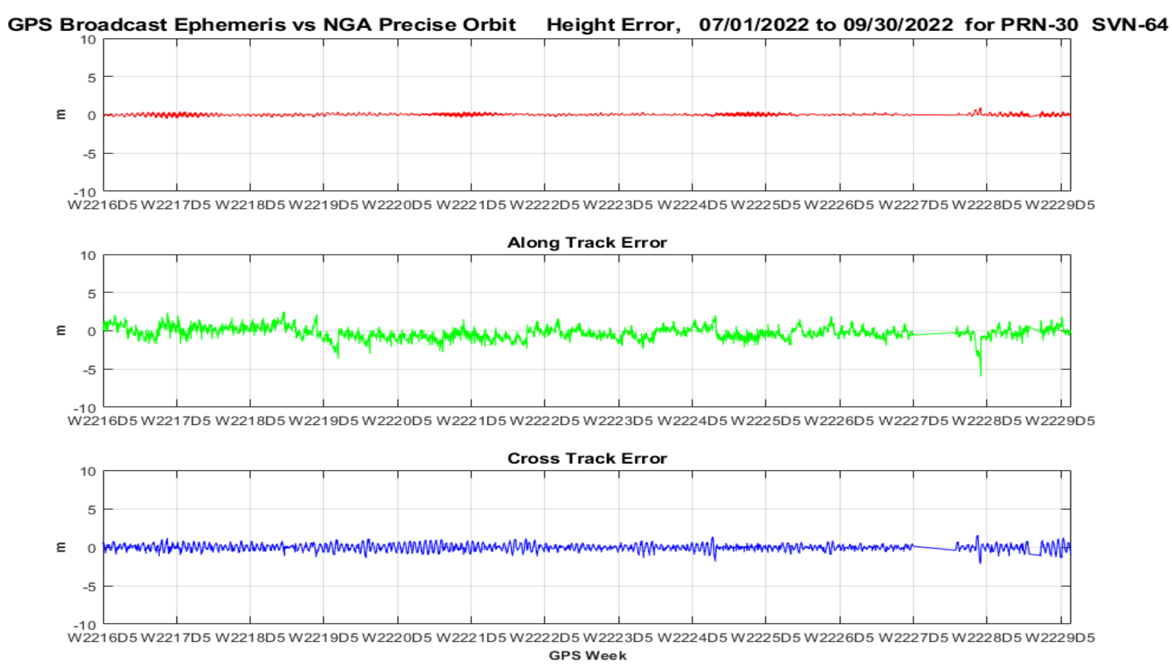


Figure 10-59. Orbit Error PRN30 (SVN64) Using C/A Nav Data

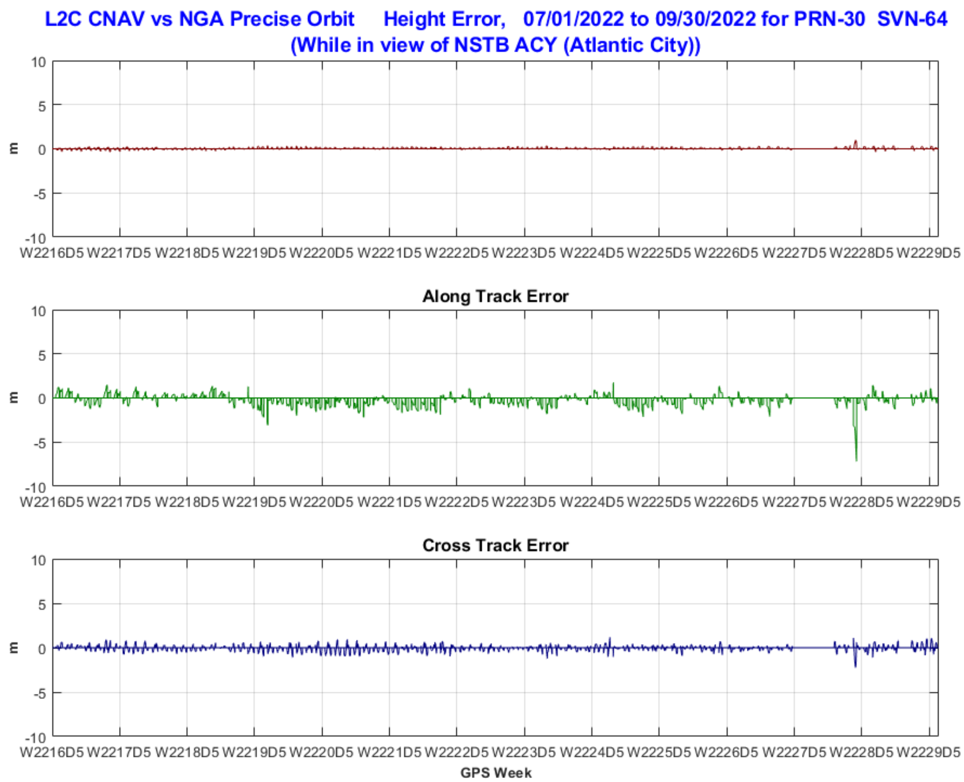


Figure 10-60. Orbit Error PRN30 (SVN64) Using L2C CNAV Data

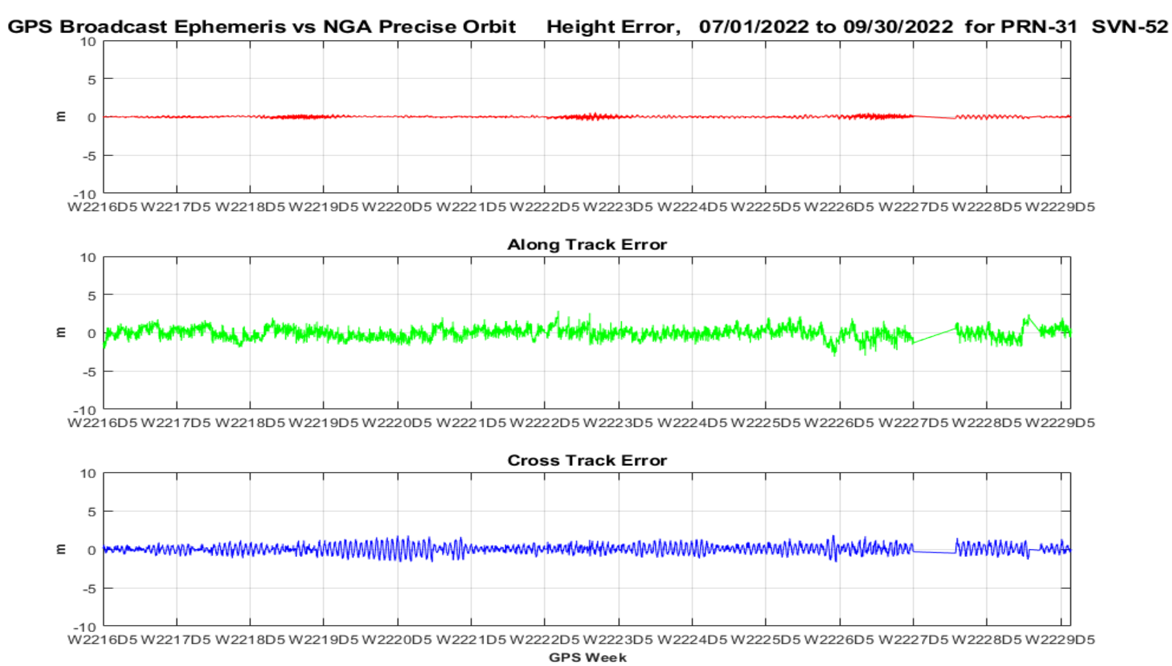


Figure 10-61. Orbit Error PRN31 (SVN52) Using C/A Nav Data

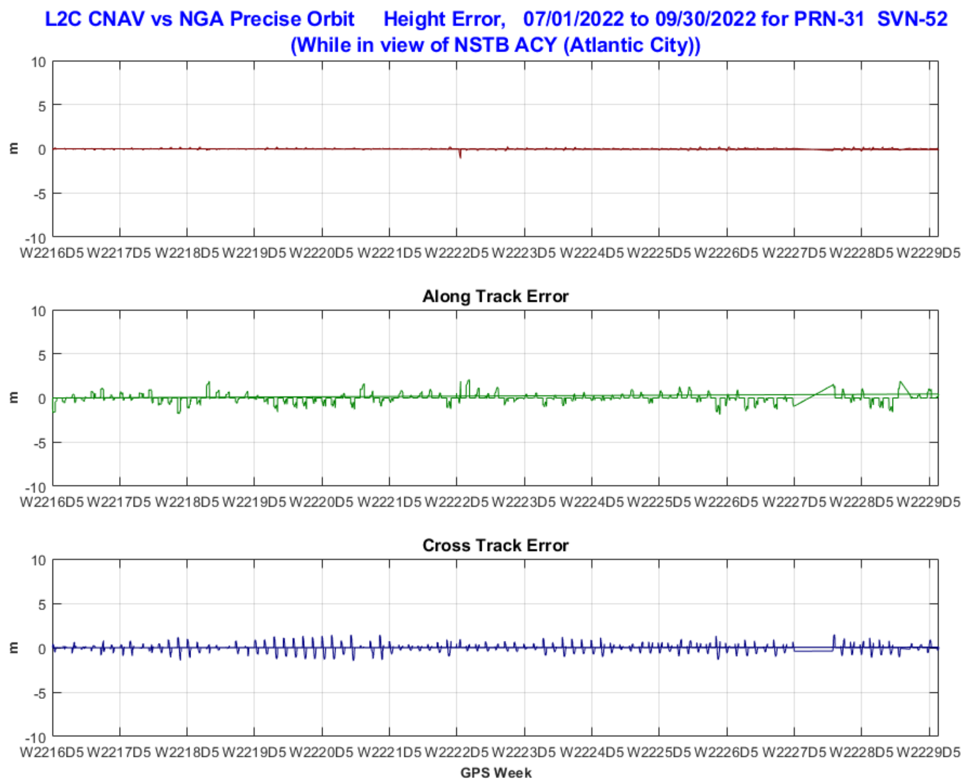


Figure 10-62. Orbit Error PRN31 (SVN52) Using L2C CNAV Data

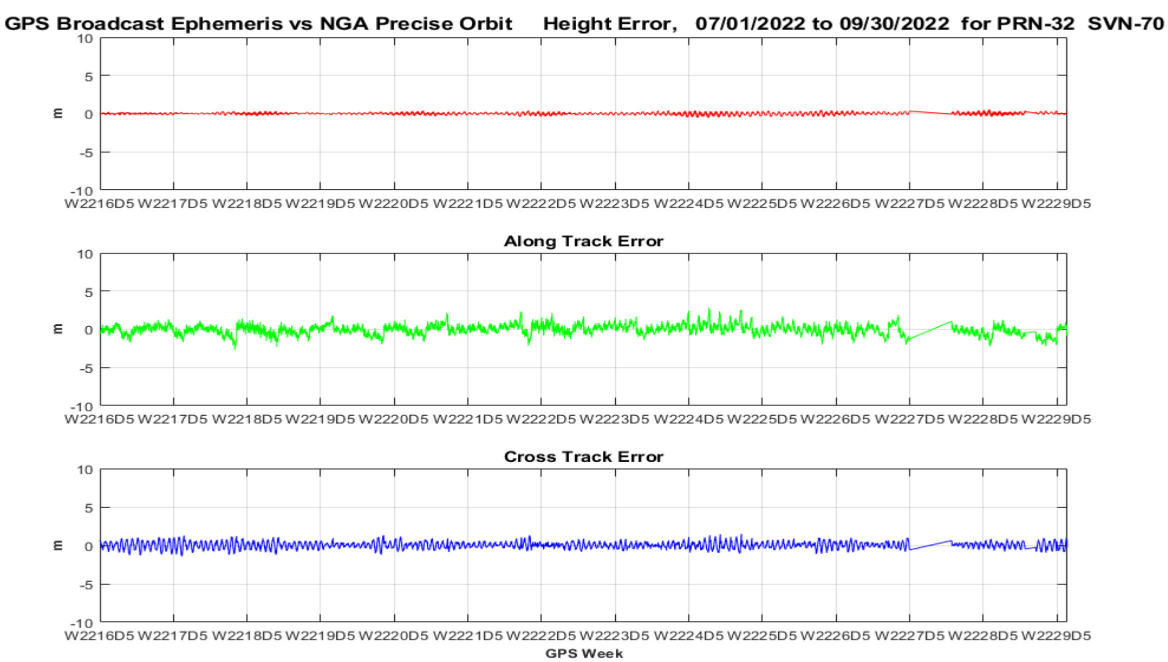


Figure 10-63. Orbit Error PRN32 (SVN70) Using C/A Nav Data

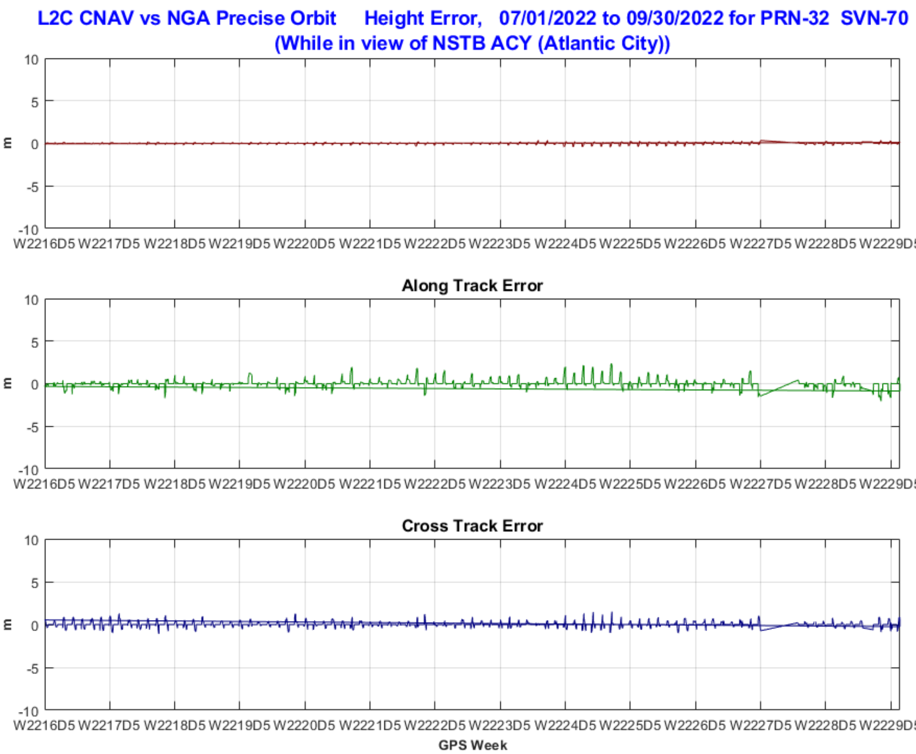


Figure 10-64. Orbit Error PRN32 (SVN70) Using L2C CNAV Data

10.6 QQ Plots of URA Normalized Error for All Satellites

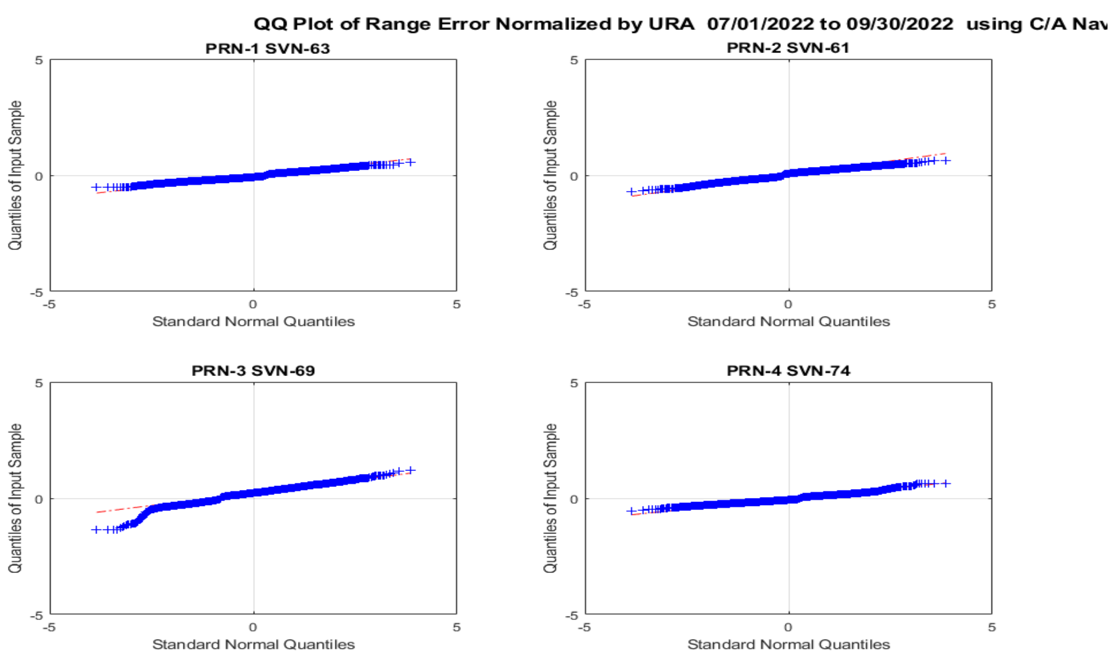


Figure 10-65. QQ Plots of Range Error PRNs 1 to 4 Using C/A Nav Data

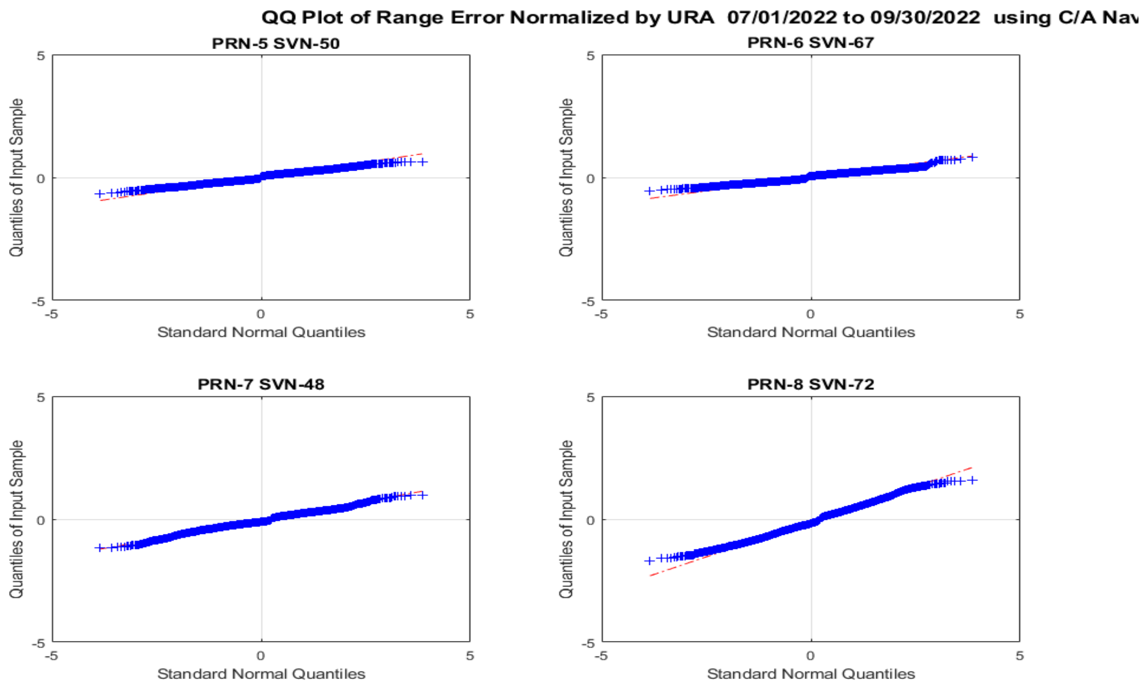


Figure 10-66. QQ Plots of Range Error PRNs 5 to 8 Using C/A Nav Data

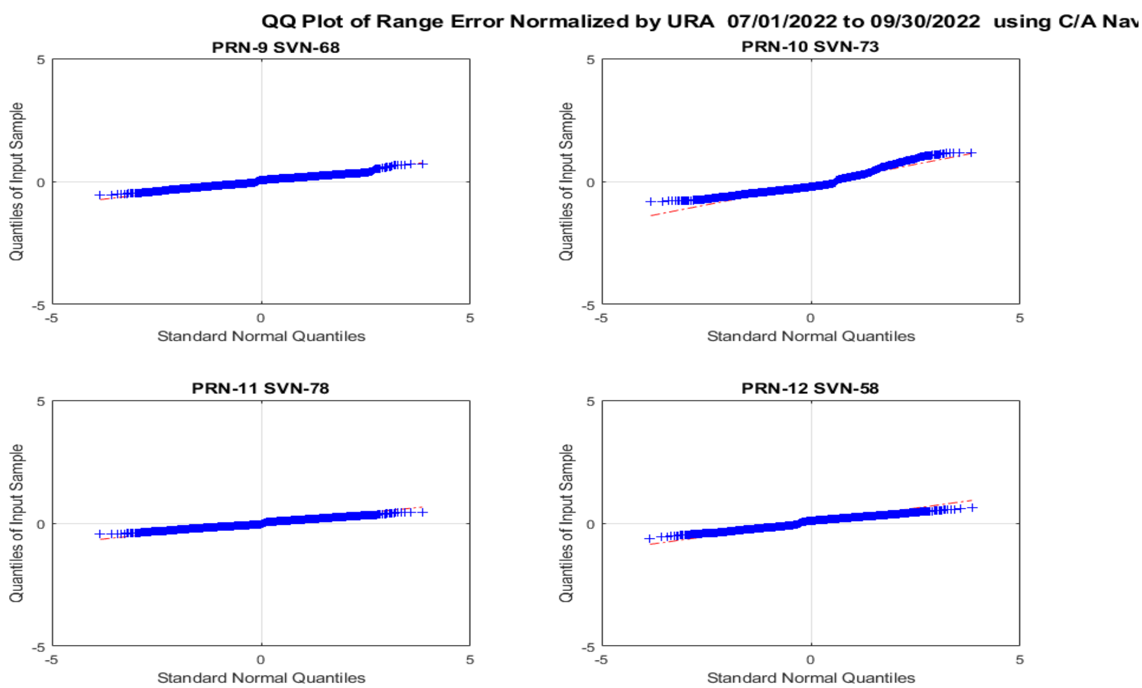


Figure 10-67. QQ Plots of Range Error PRNs 9 to 12 Using C/A Nav Data

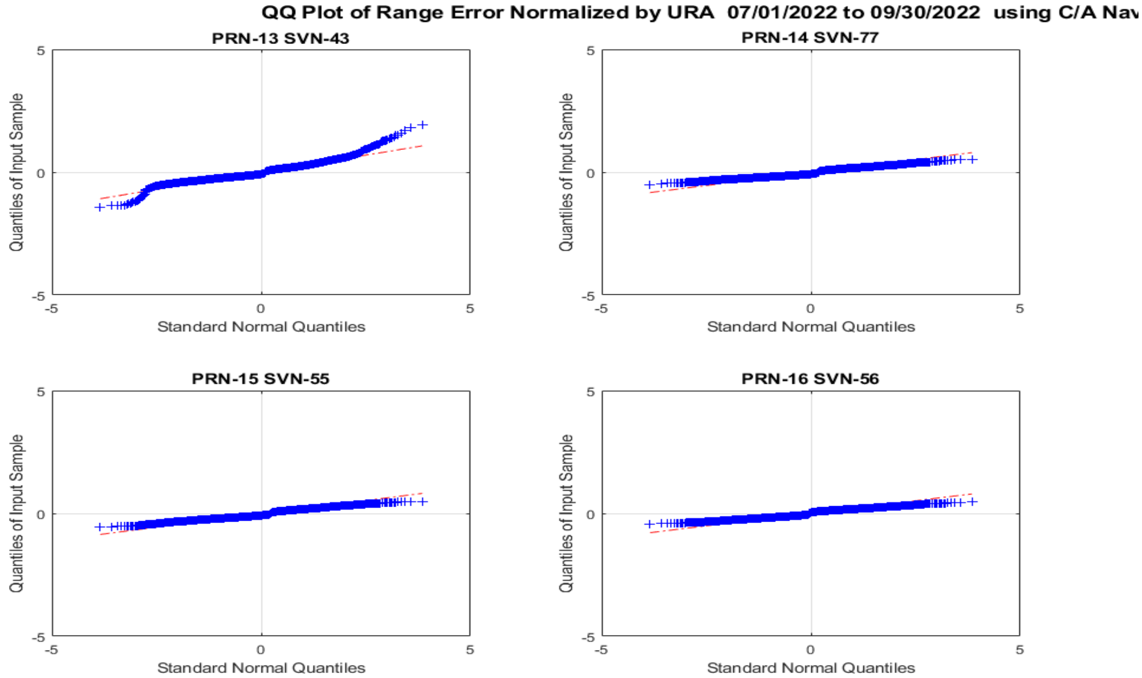


Figure 10-68. QQ Plots of Range Error PRNs 13 to 16 Using C/A Nav Data

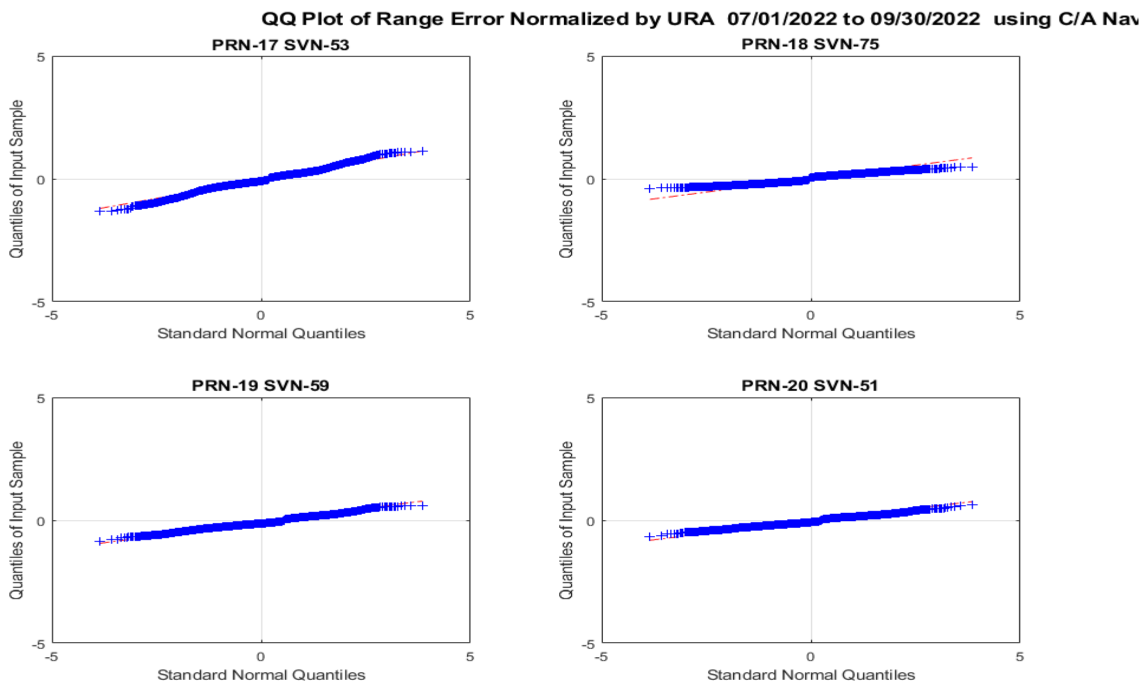


Figure 10-69. QQ Plots of Range Error PRNs 17 to 20 Using C/A Nav Data

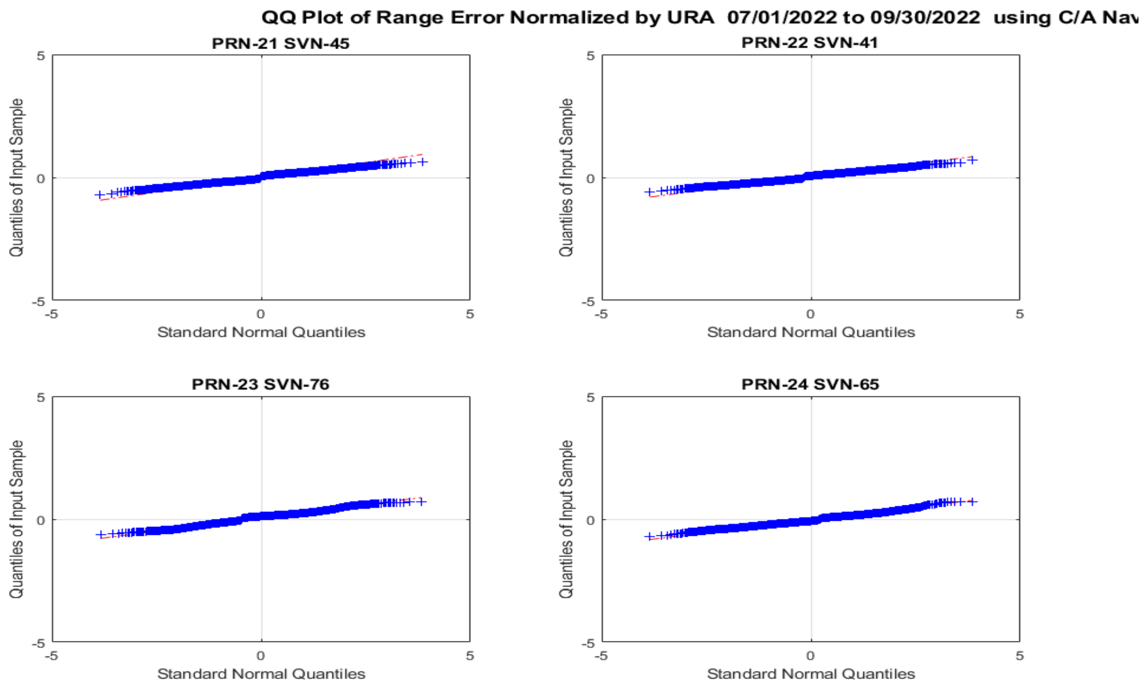


Figure 10-70. QQ Plots of Range Error PRNs 21 to 24 Using C/A Nav Data

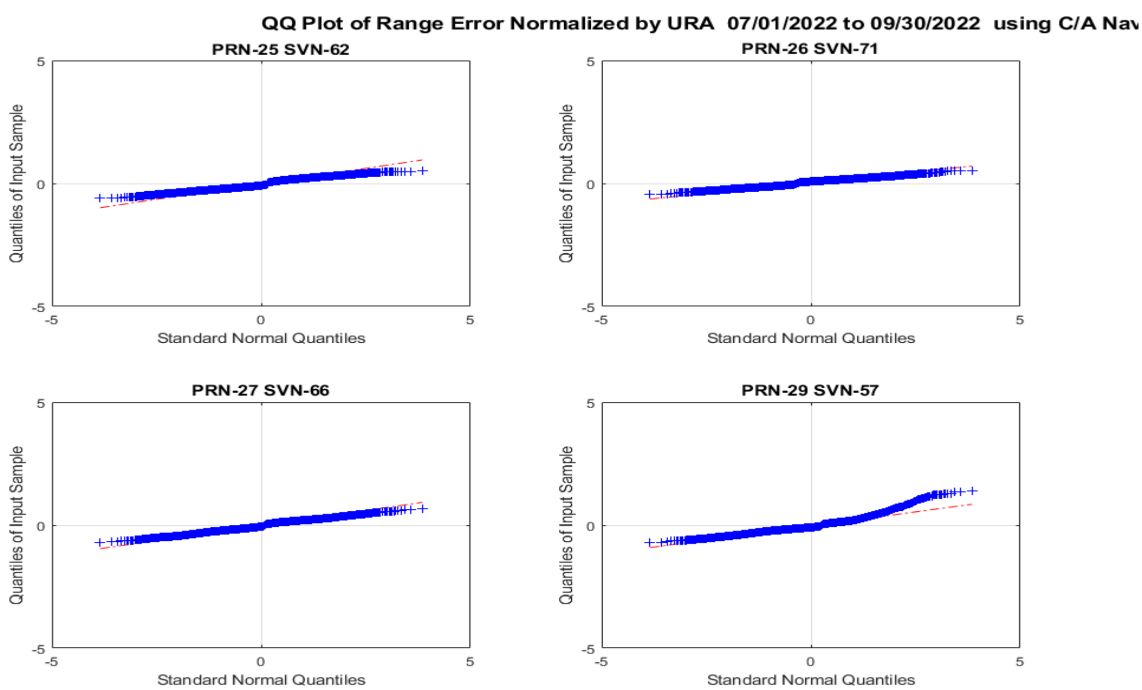


Figure 10-71. QQ Plots of Range Error PRNs 25 to 29 Using C/A Nav Data

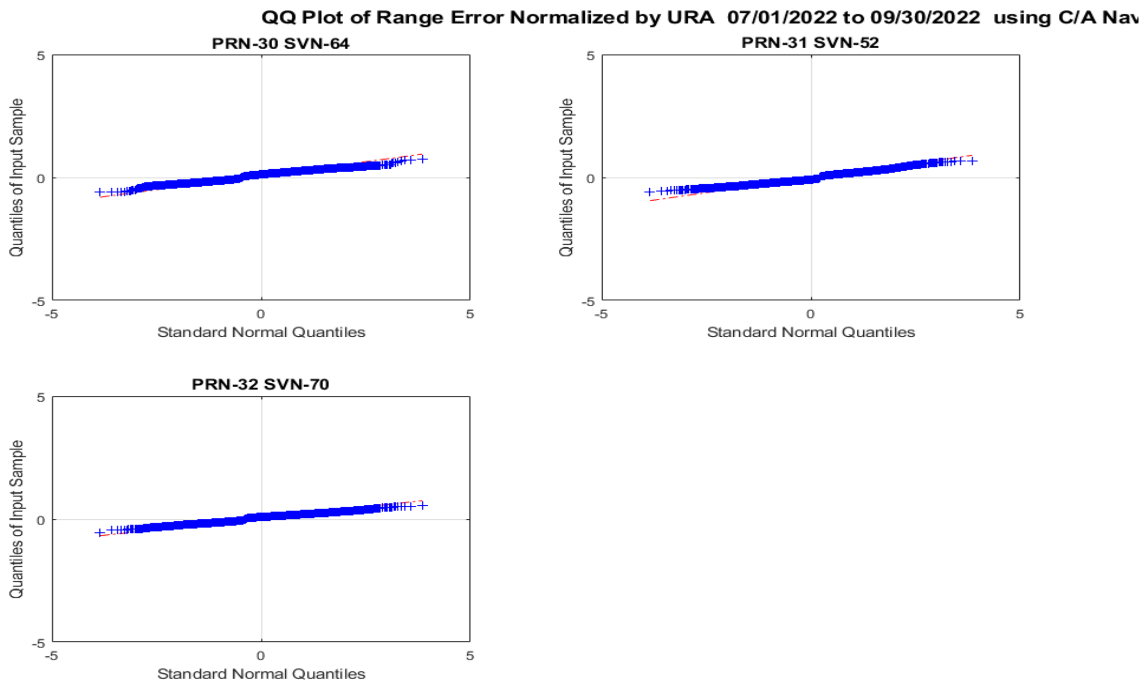


Figure 10-72. QQ Plots of Range Error PRNs 30 to 32 Using C/A Nav Data

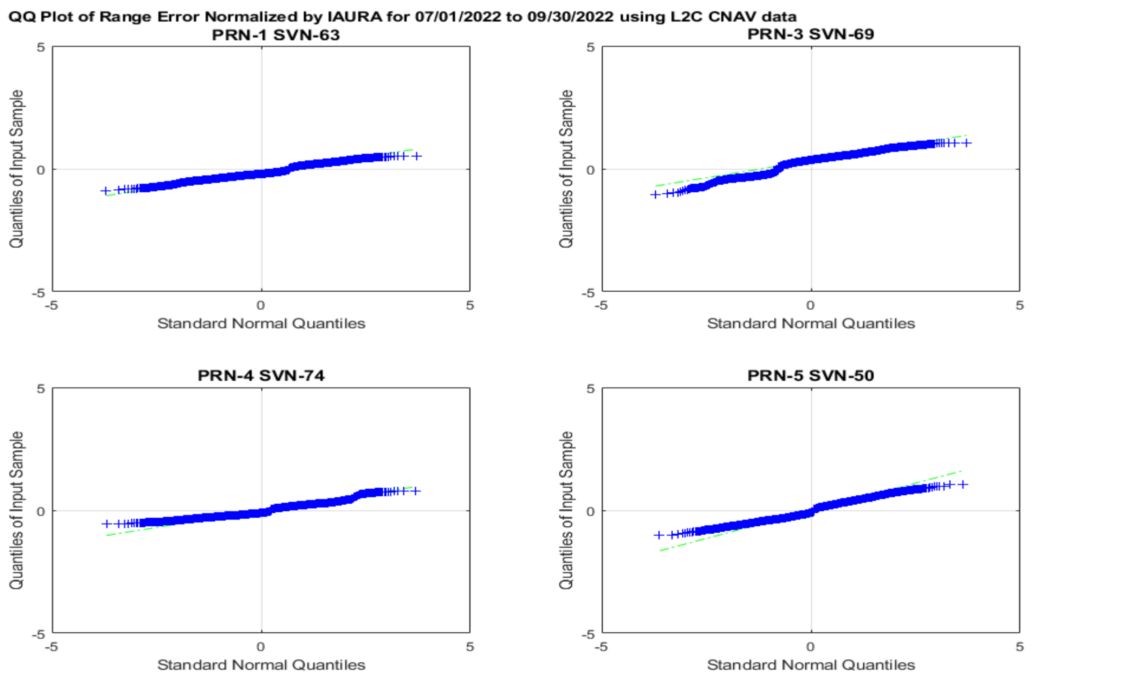


Figure 10-73. QQ Plots of Range Error PRNs 1, 3, 4, and 5 Using L2C CNAV Data

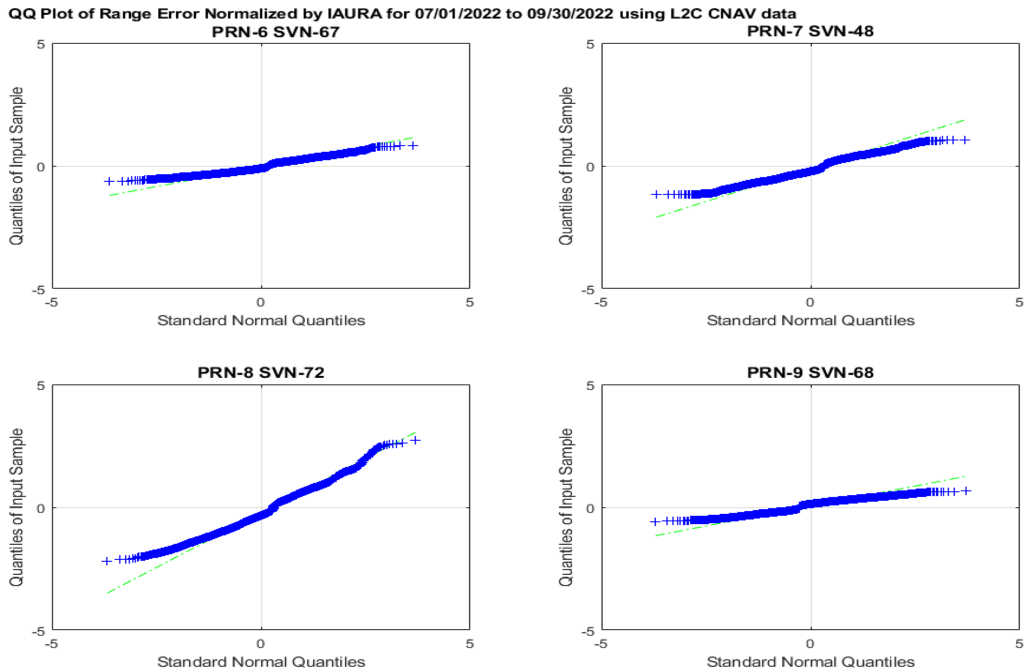


Figure 10-74. QQ Plots of Range Error PRNs 6, 7, 8, and 9 Using L2C CNAV Data

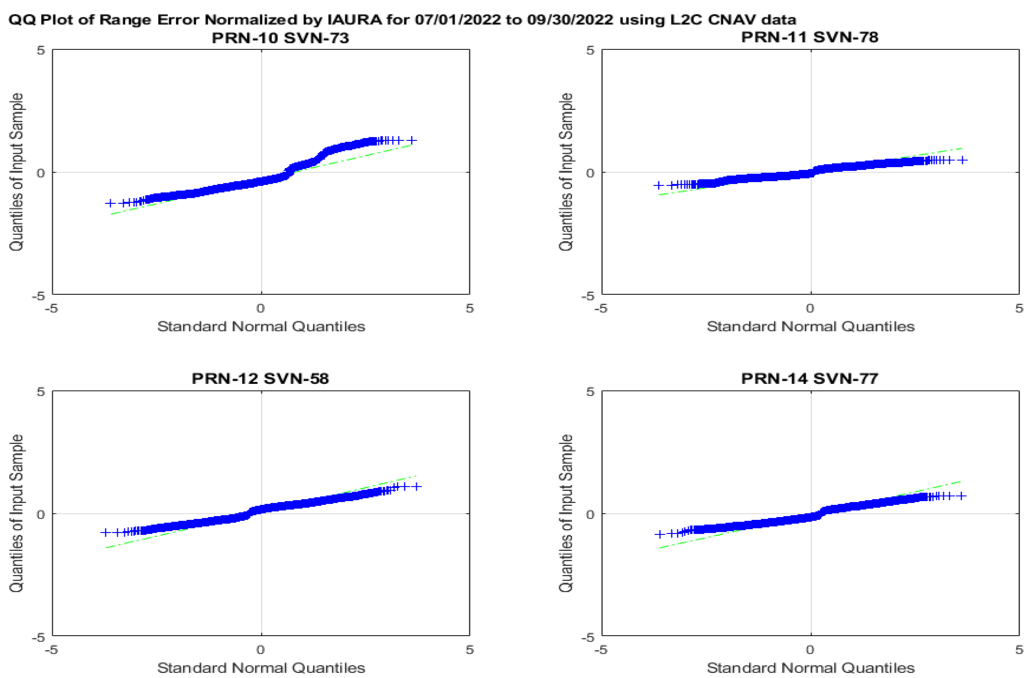


Figure 10-75. QQ Plots of Range Error PRNs 10, 11, 12, and 14 Using L2C CNAV Data

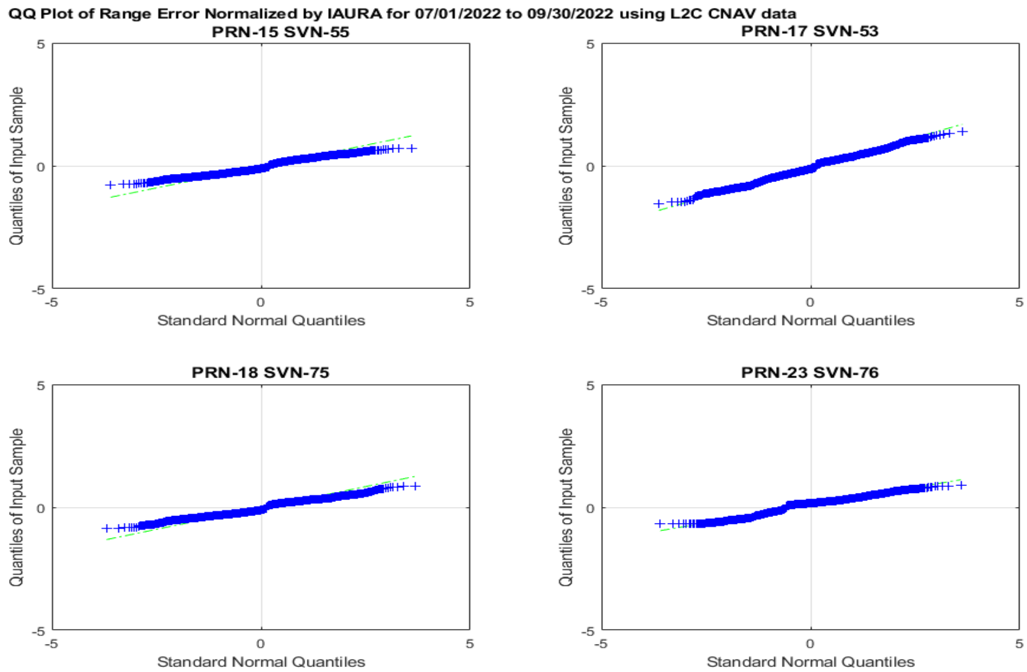


Figure 10-76. QQ Plots of Range Error PRNs 15, 17, 18, and 23 Using L2C CNAV Data

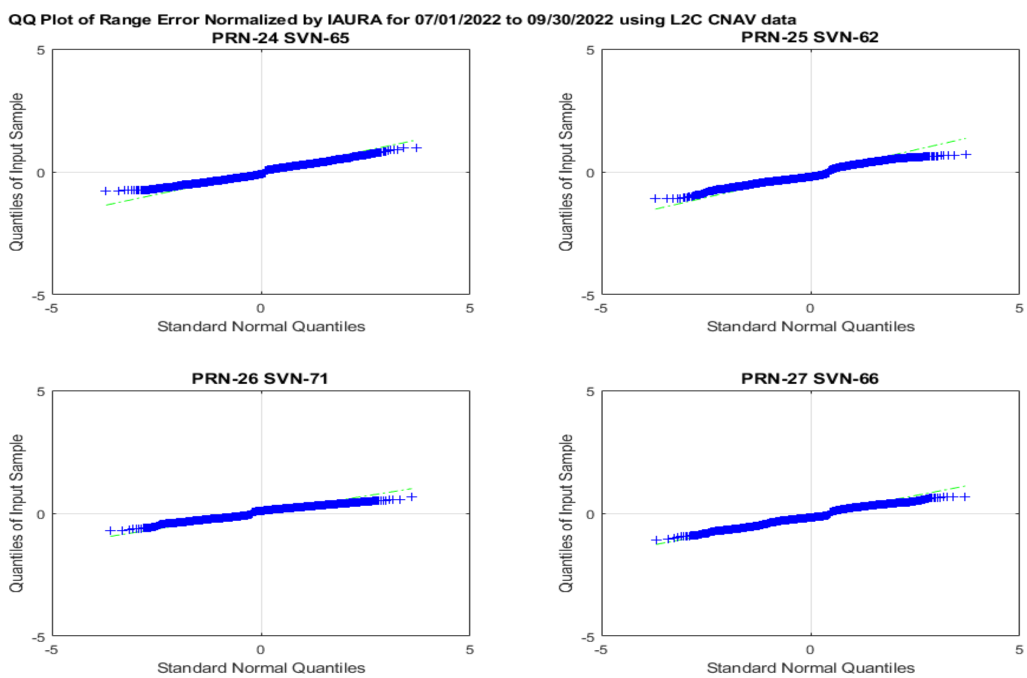


Figure 10-77. QQ Plots of Range Error PRNs 24, 25, 26, and 27 Using L2C CNAV Data

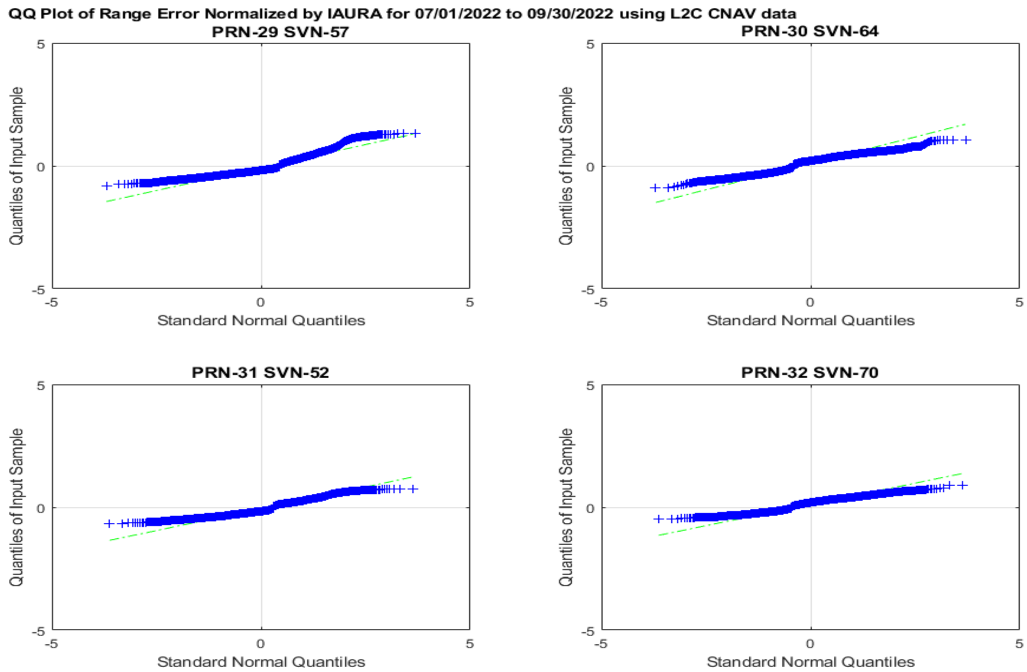


Figure 10-78. QQ Plots of Range Error PRNs 29, 30, 31, and 32 Using L2C CNAV Data

10.7 Histogram Plots of H, A, C, and Range Error for All Satellites

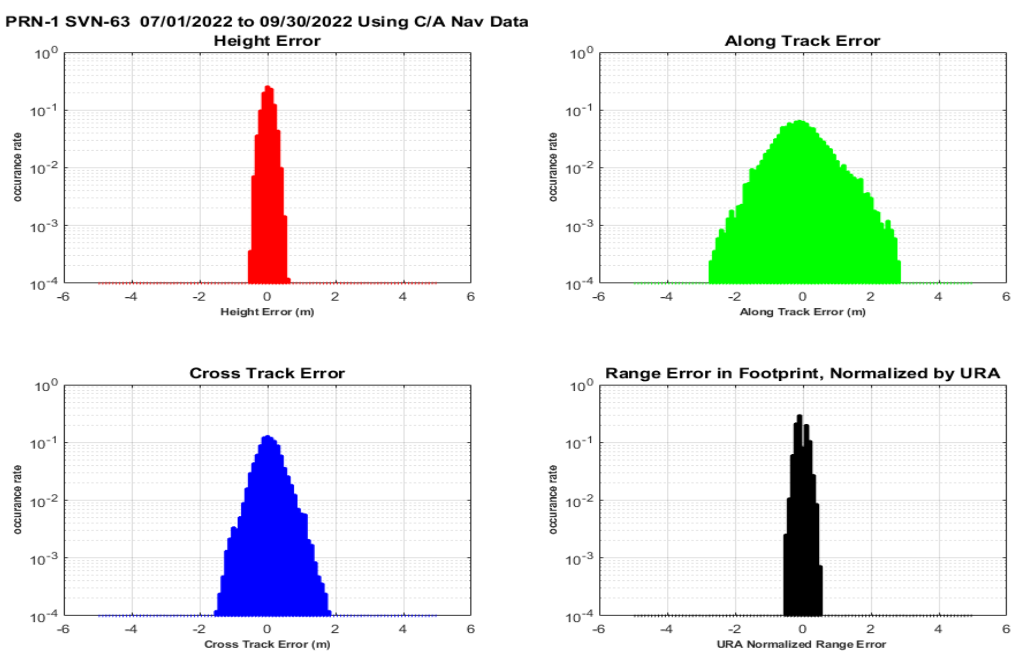


Figure 10-79. Histograms of H, A, C, and Range Error PRN1 (SVN63) Using C/A Nav Data

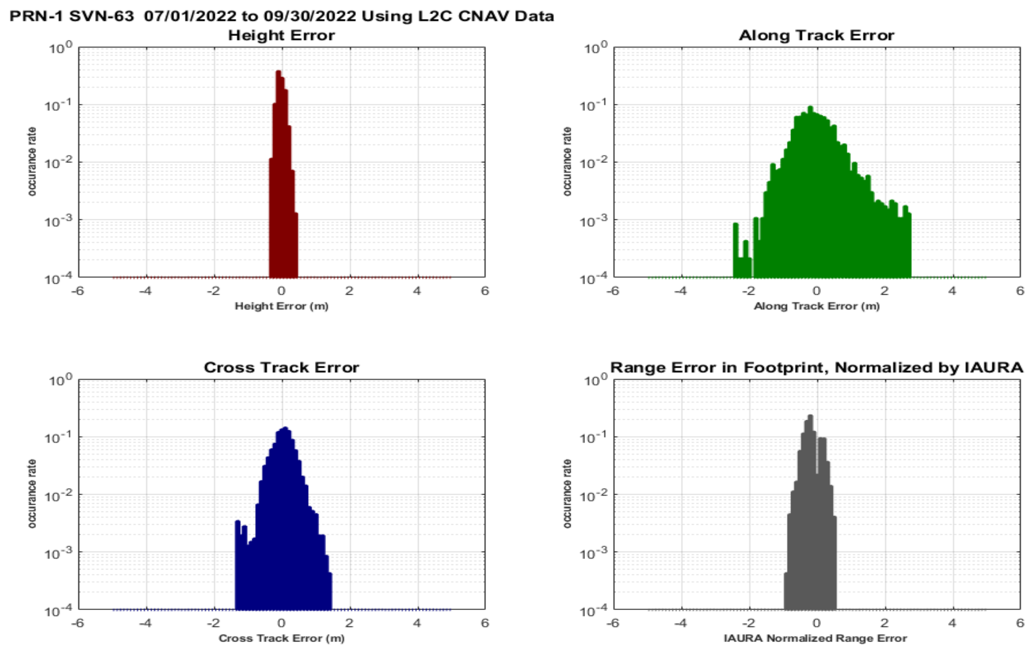


Figure 10-80. Histograms of H, A, C, and Range Error PRN1 (SVN63) Using L2C CNAV Data

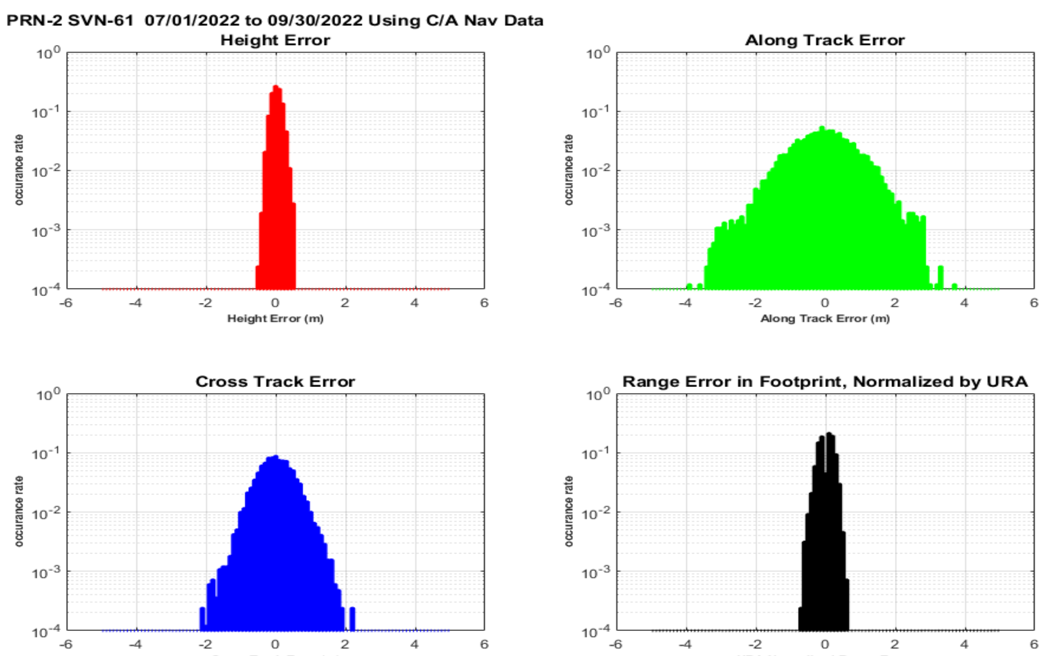


Figure 10-81. Histograms of H, A, C, and Range Error PRN2 (SVN61) Using C/A Nav Data

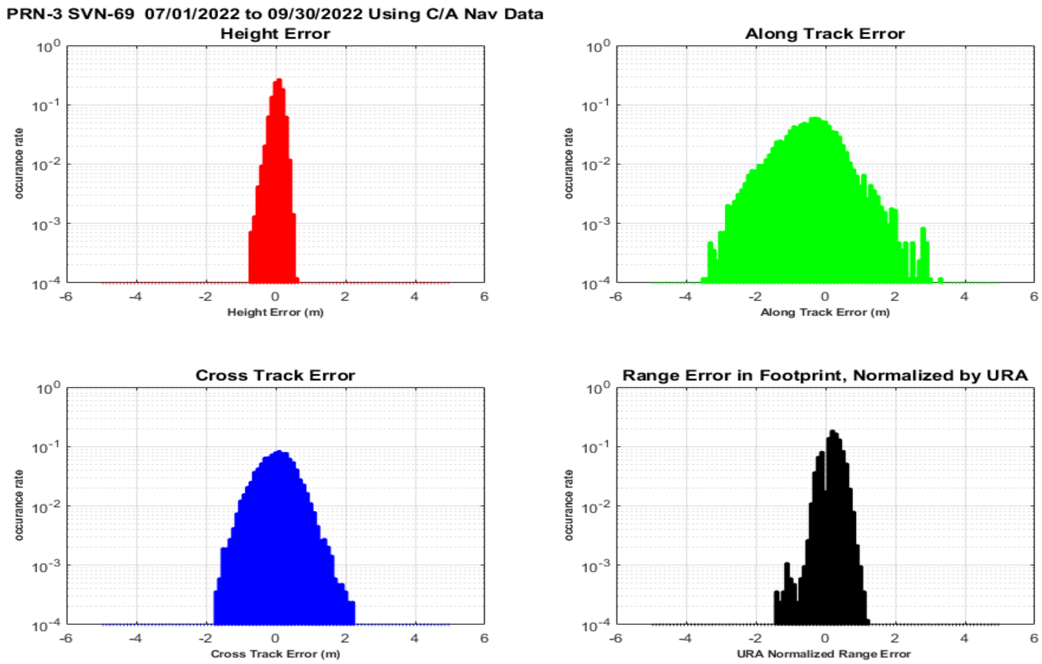


Figure 10-82. Histograms of H, A, C, and Range Error PRN3 (SVN69) Using C/A Nav Data

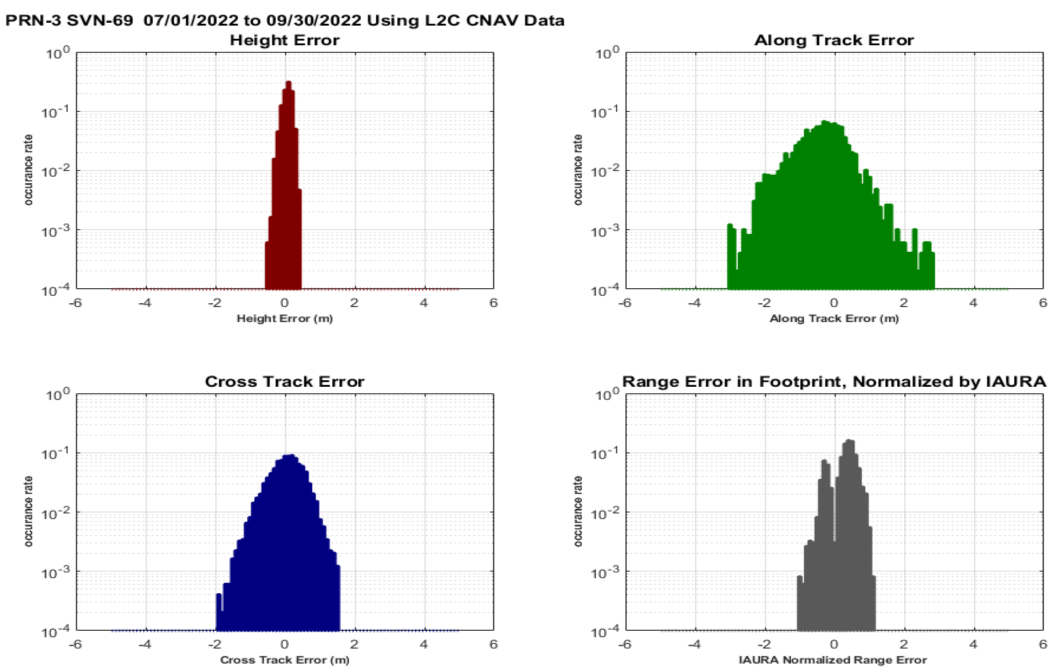


Figure 10-83. Histograms of H, A, C, and Range Error PRN3 (SVN69) Using L2C CNAV Data

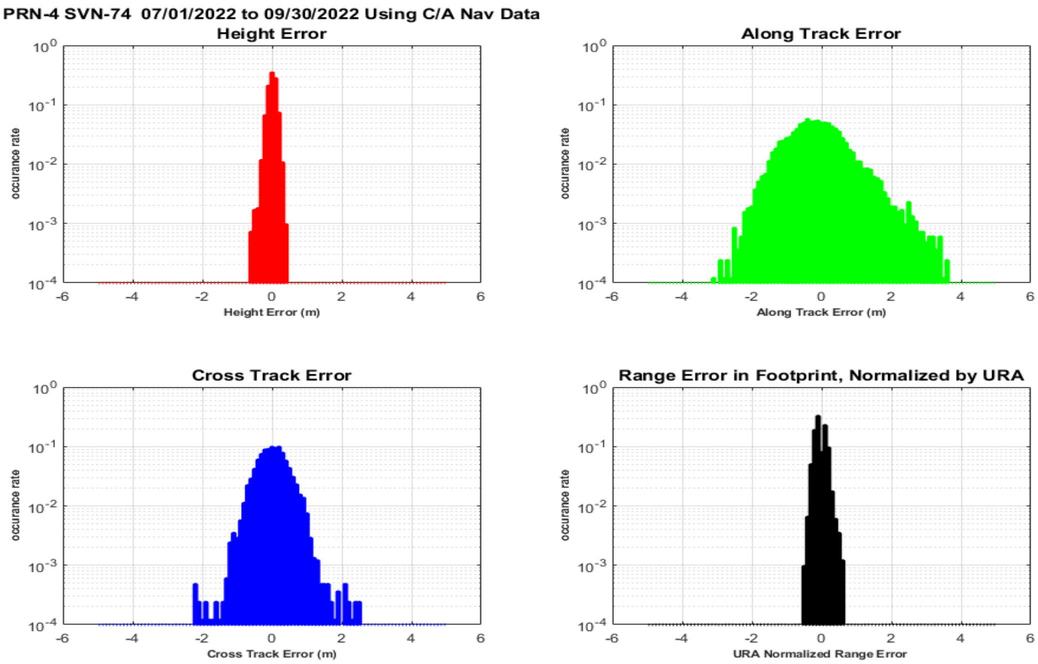


Figure 10-84. Histograms of H, A, C, and Range Error PRN4 (SVN74) Using C/A Nav Data

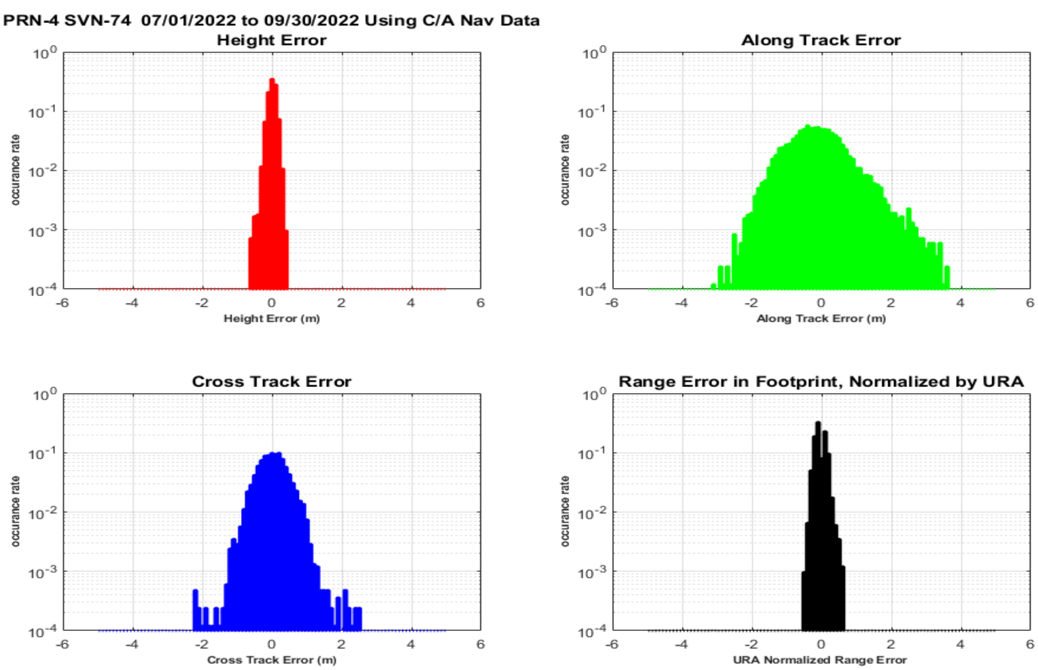


Figure 10-85. Histograms of H, A, C, and Range Error PRN4 (SVN74) Using L2C CNAV Data

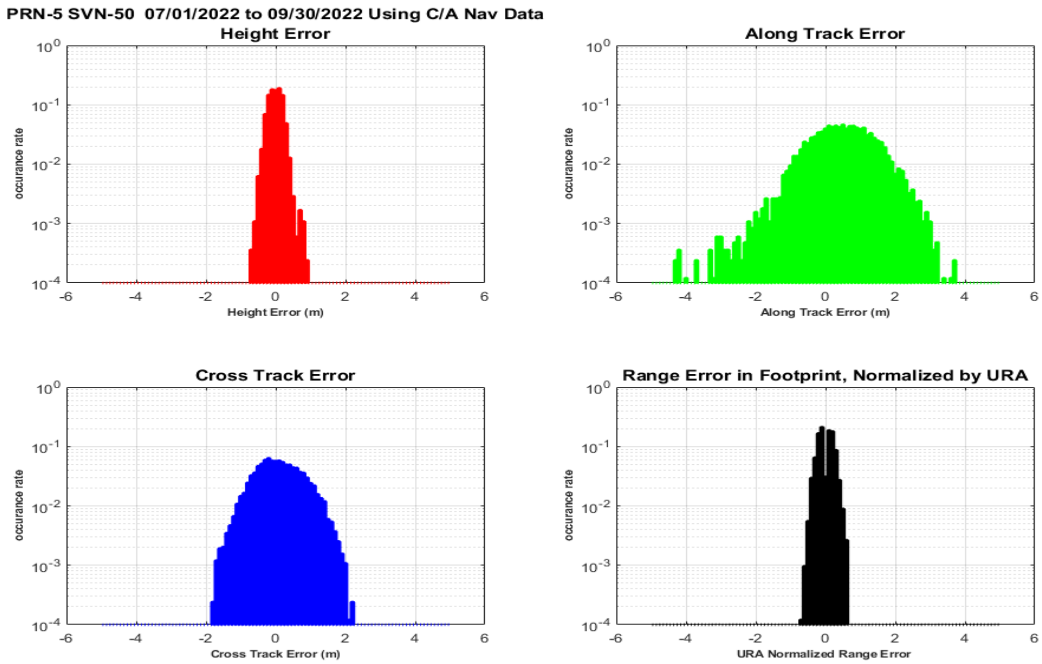


Figure 10-86. Histograms of H, A, C, and Range Error PRN5 (SVN50) Using C/A Nav Data

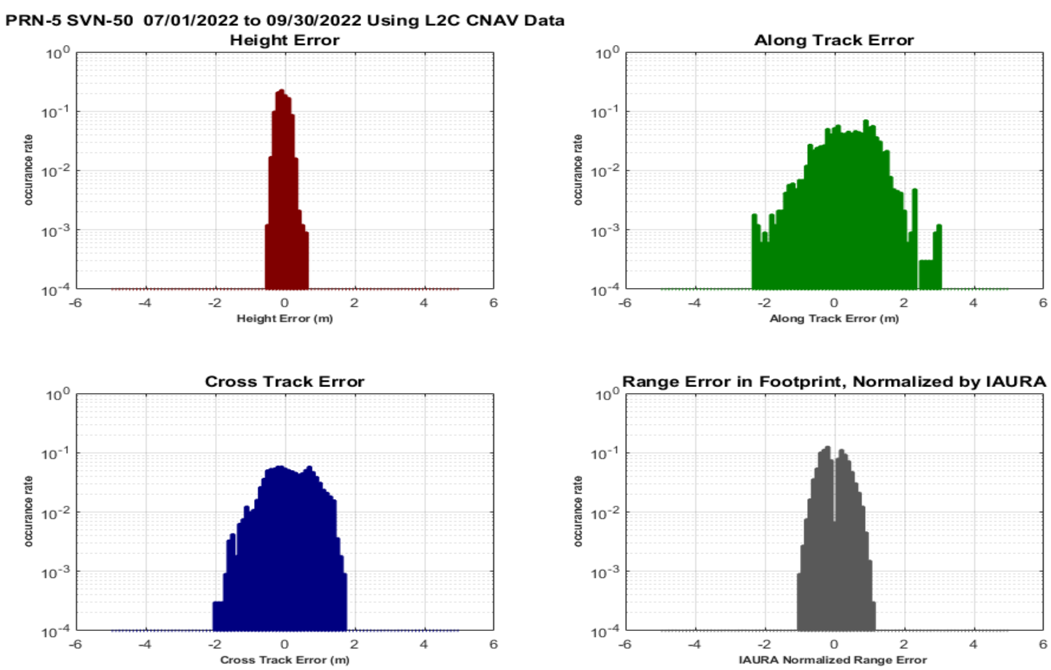


Figure 10-87. Histograms of H, A, C, and Range Error PRN5 (SVN50) Using L2C CNAV Data

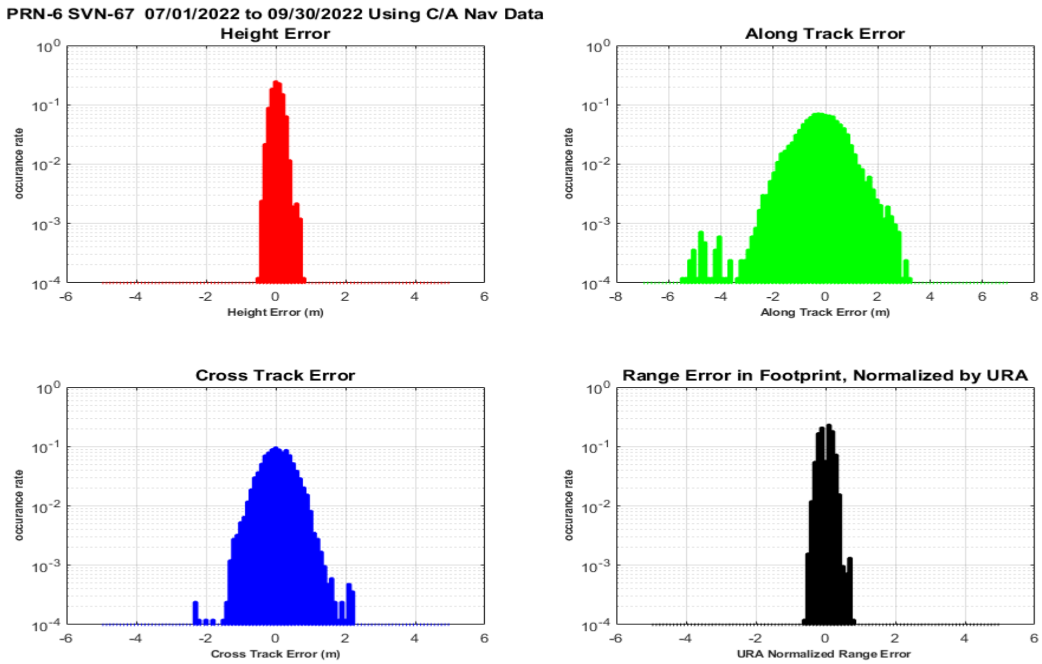


Figure 10-88. Histograms of H, A, C, and Range Error PRN6 (SVN67) Using C/A Nav Data

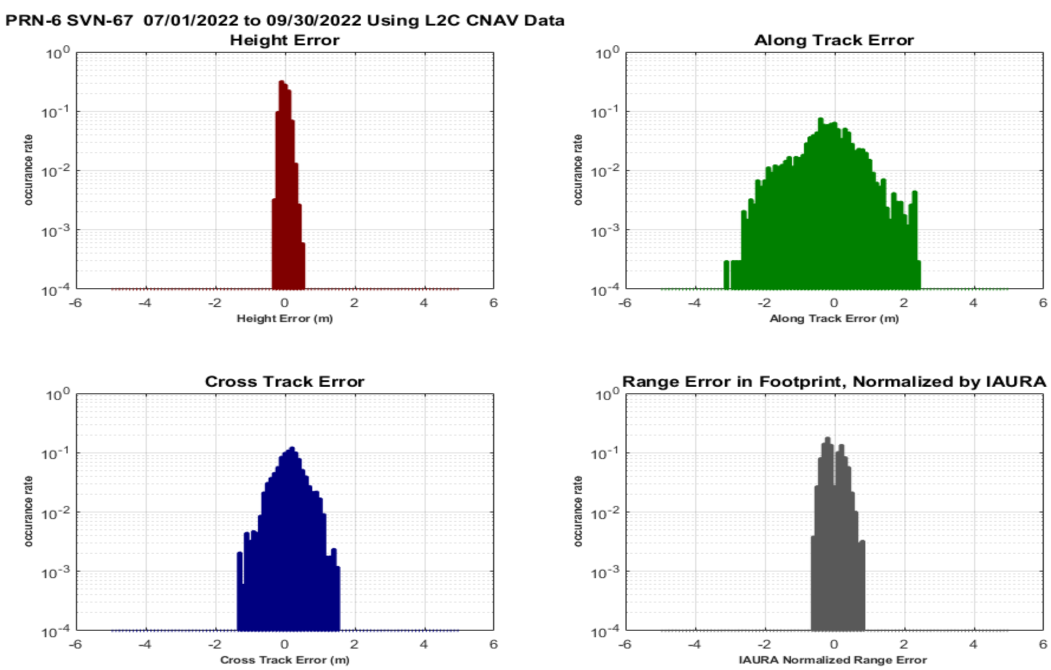


Figure 10-89. Histograms of H, A, C, and Range Error PRN6 (SVN67) Using L2C CNAV Data

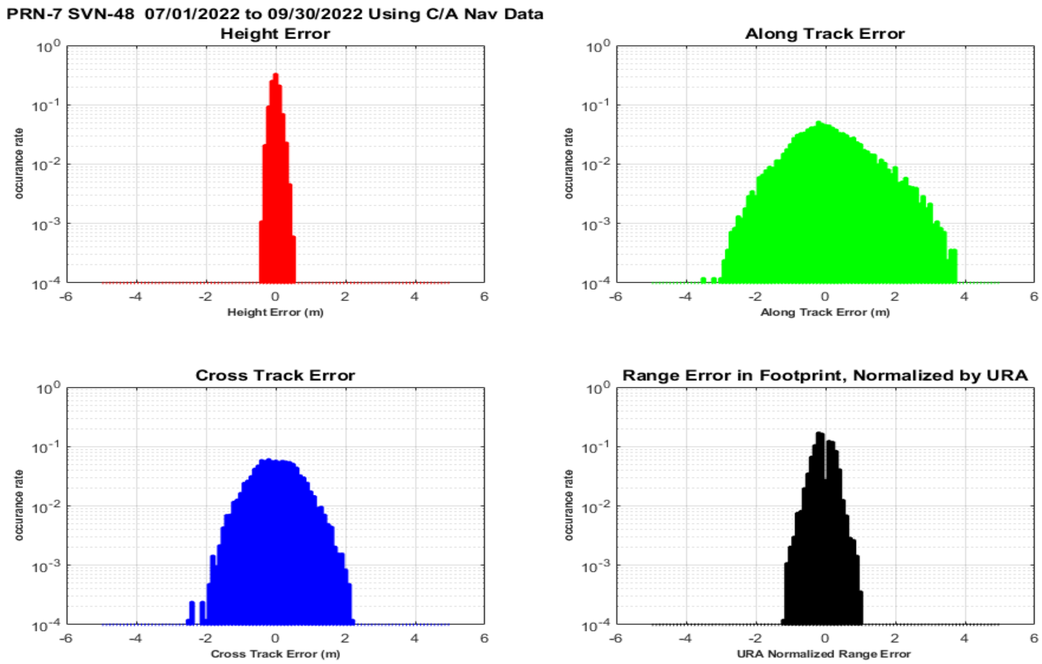


Figure 10-90. Histograms of H, A, C, and Range Error PRN7 (SVN48) Using C/A Nav Data

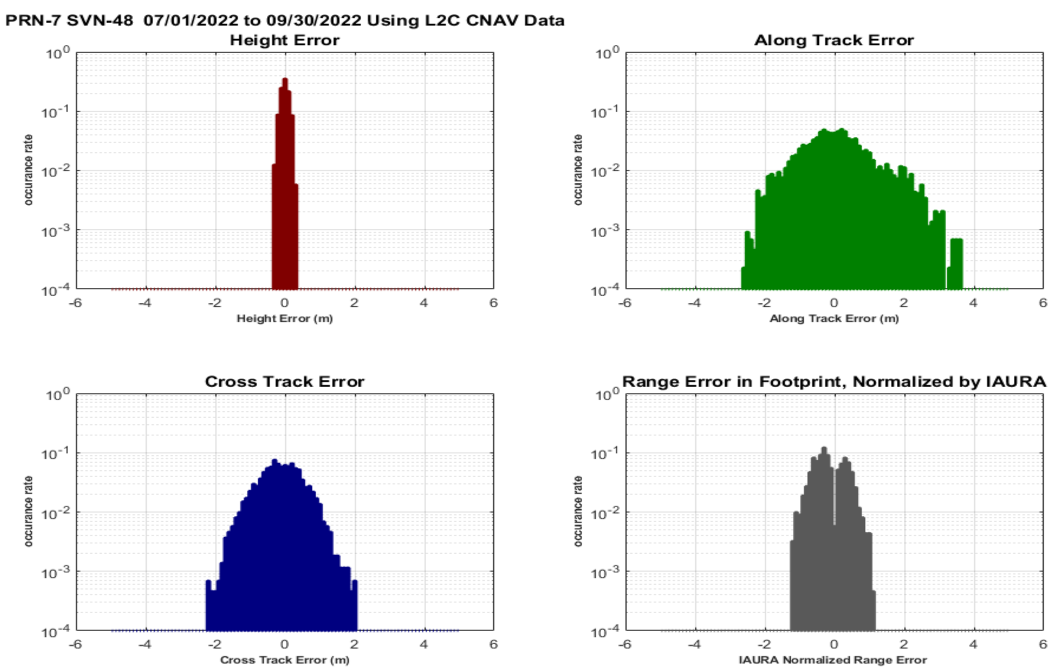


Figure 10-91. Histograms of H, A, C, and Range Error PRN7 (SVN48) Using L2C CNAV Data

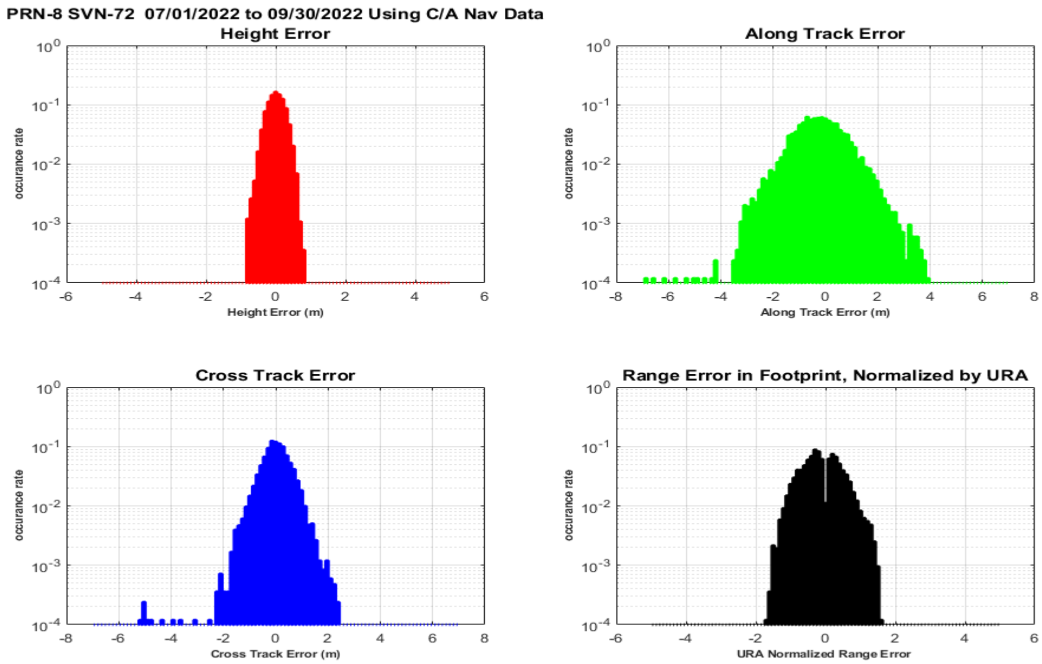


Figure 10-92. Histograms of H, A, C, and Range Error PRN8 (SVN72) Using C/A Nav Data

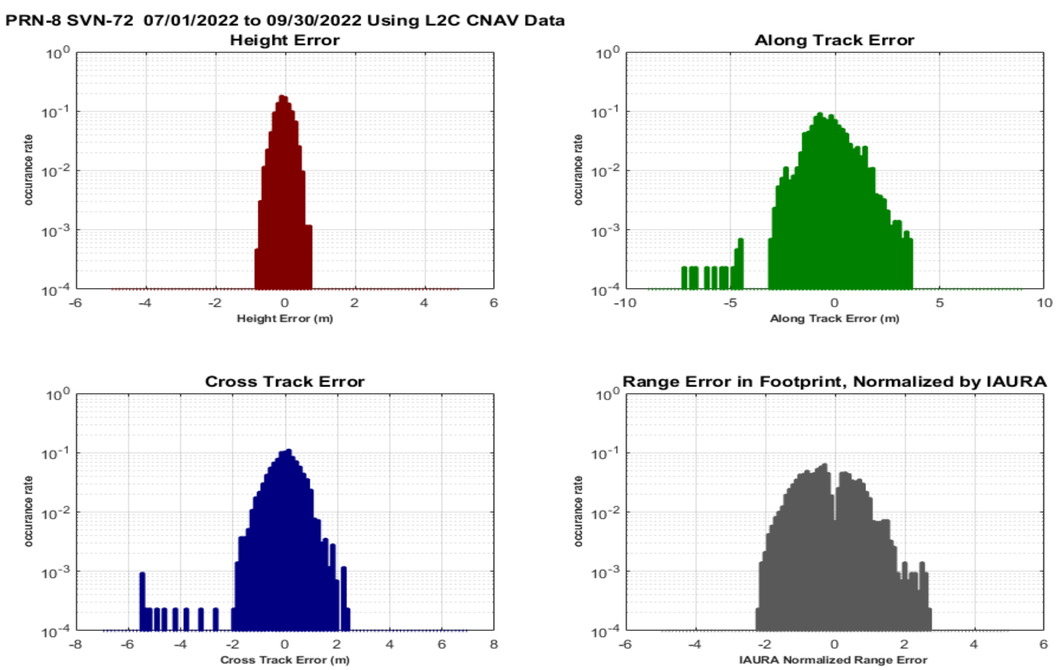


Figure 10-93. Histograms of H, A, C, and Range Error PRN8 (SVN72) Using L2C CNAV Data

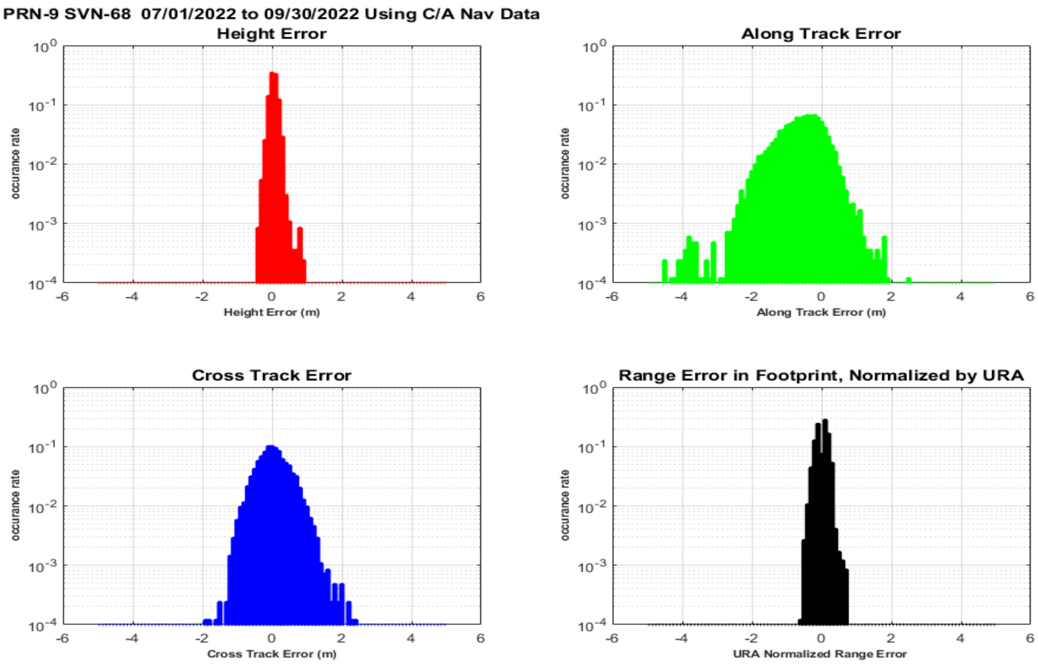


Figure 10-94. Histograms of H, A, C, and Range Error PRN9 (SVN68) Using C/A Nav Data

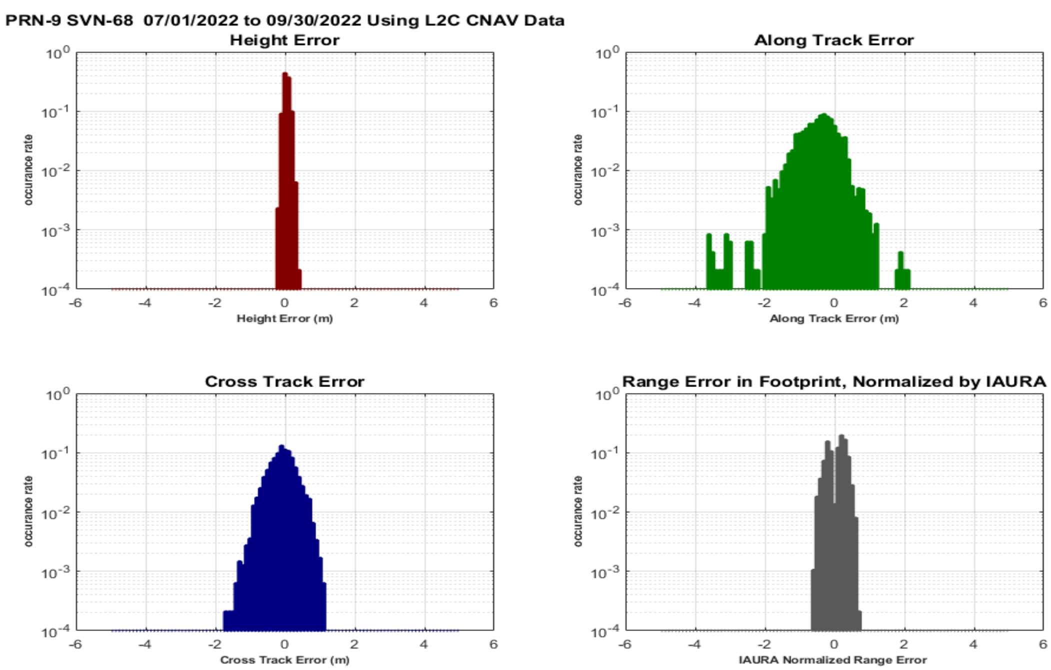


Figure 10-95. Histograms of H, A, C, and Range Error PRN9 (SVN68) Using L2C CNAV Data

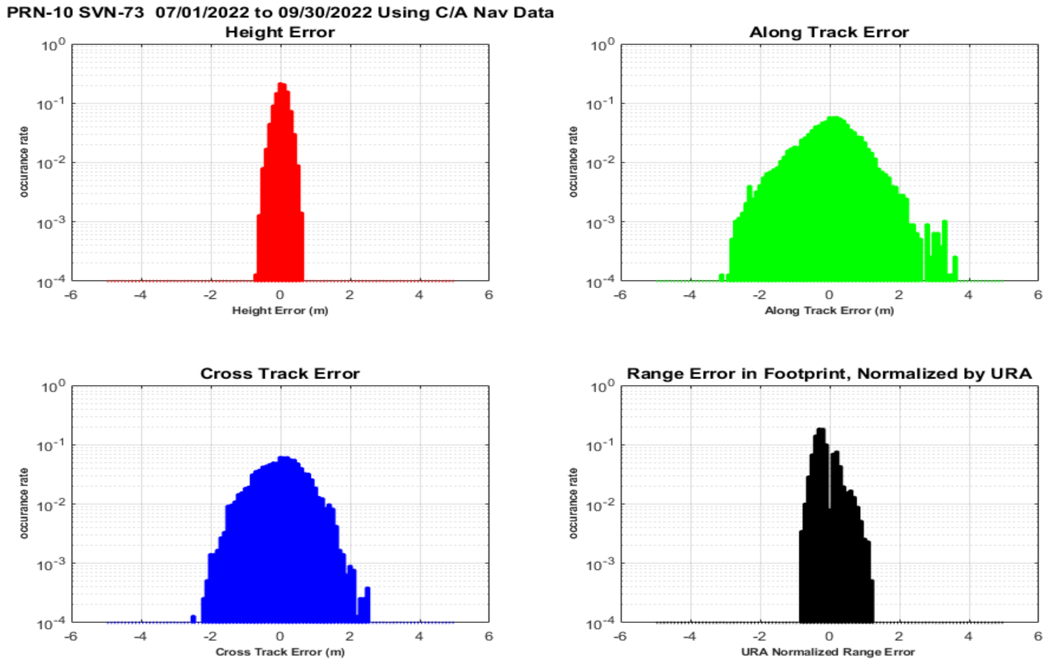


Figure 10-96. Histograms of H, A, C, and Range Error PRN10 (SVN73) Using C/A Nav Data

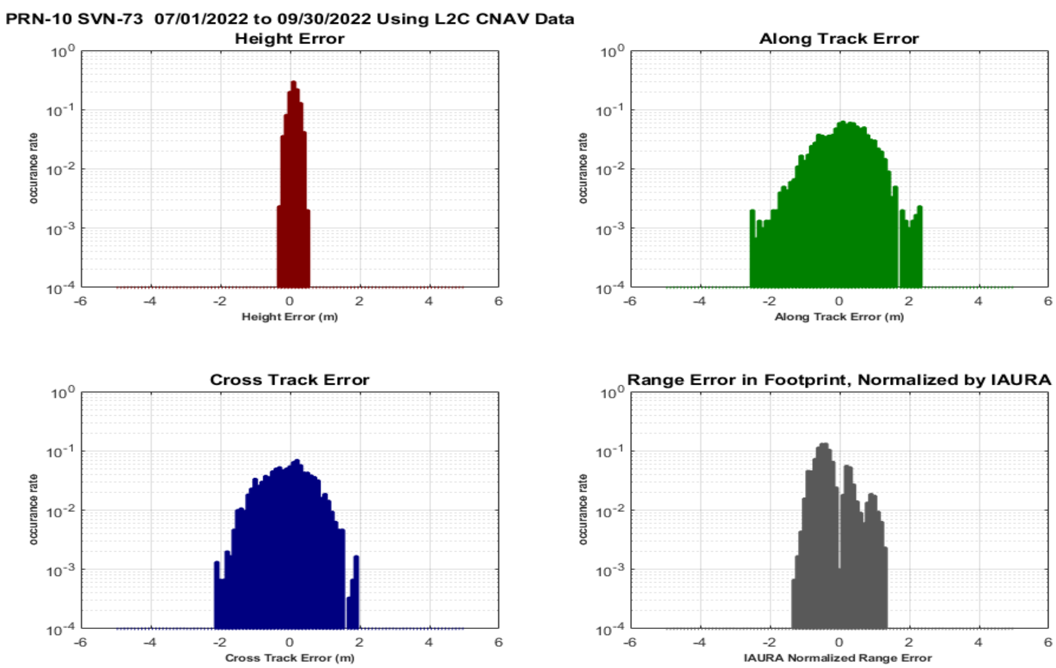


Figure 10-97. Histograms of H, A, C, and Range Error PRN10 (SVN73) Using L2C CNAV Data

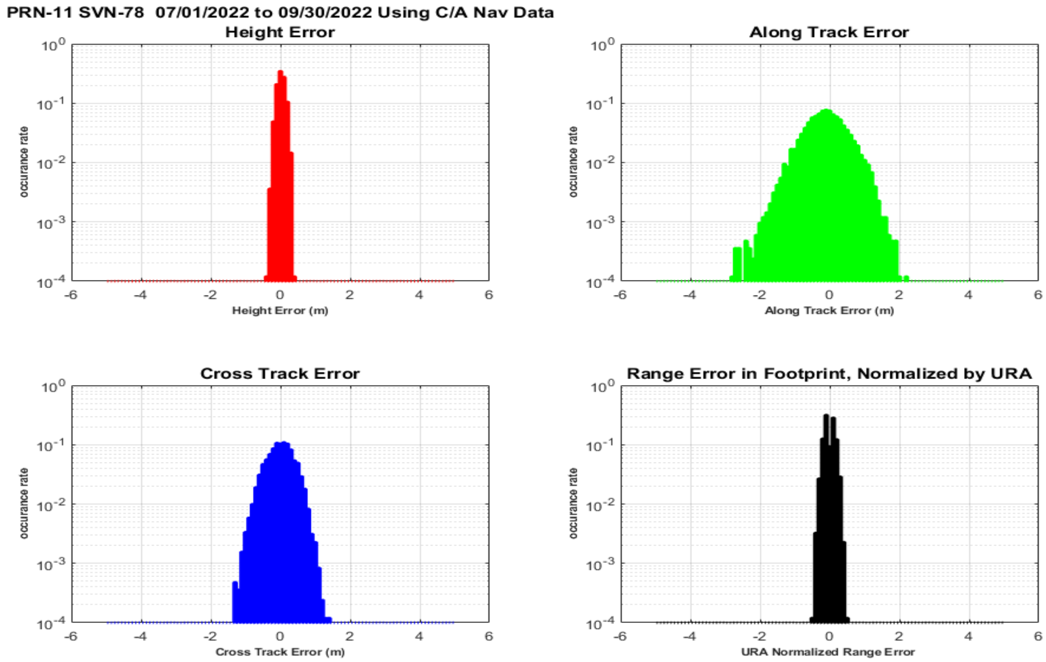


Figure 10-98. Histograms of H, A, C, and Range Error PRN11 (SVN78) Using C/A Nav Data

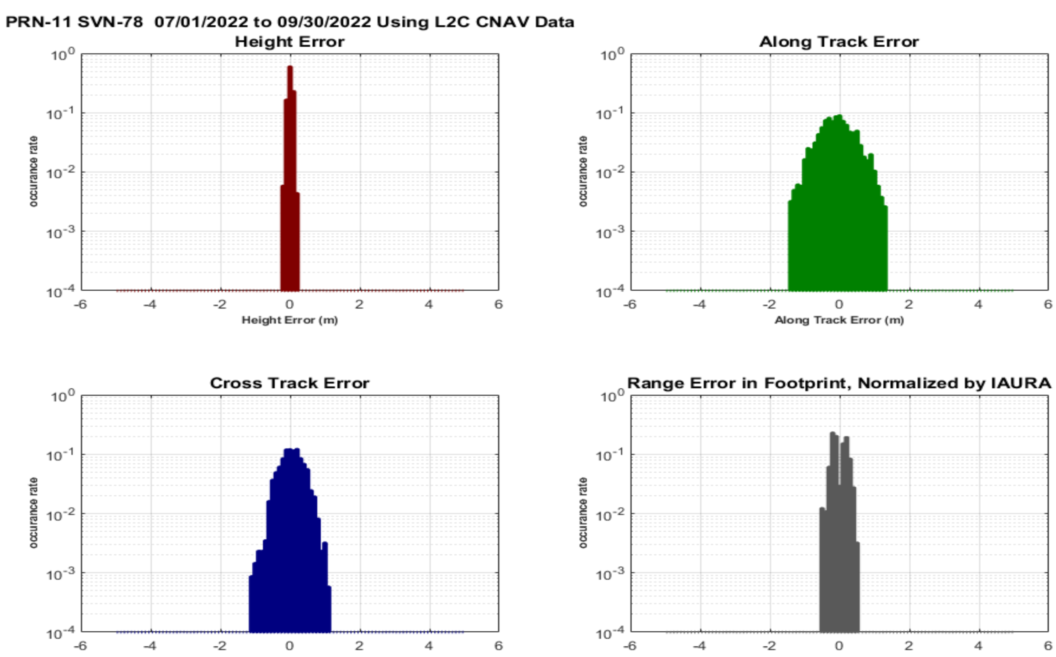


Figure 10-99. Histograms of H, A, C, and Range Error PRN11 (SVN78) Using L2C CNAV Data

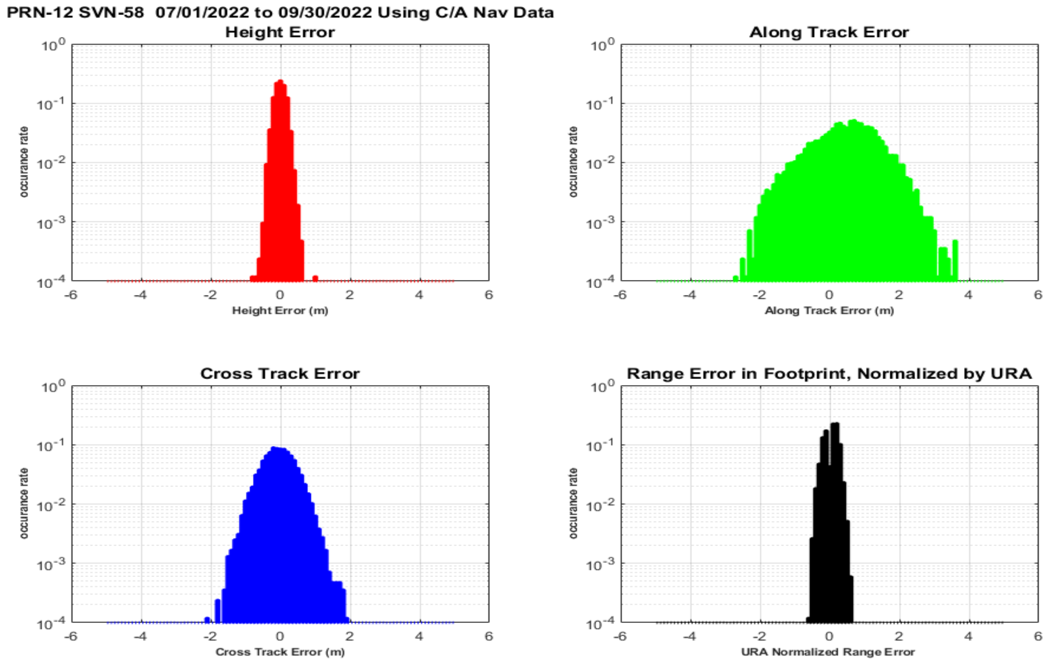


Figure 10-100. Histograms of H, A, C, and Range Error PRN12 (SVN58) Using C/A Nav Data

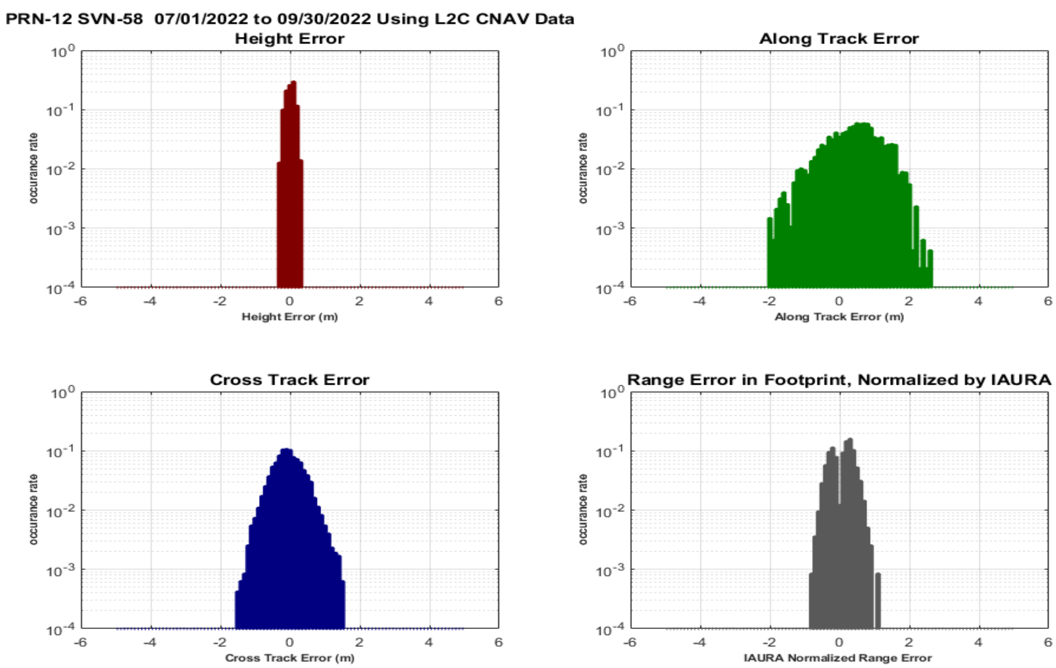


Figure 10-101. Histograms of H, A, C, and Range Error PRN12 (SVN58) Using L2C CNAV Data

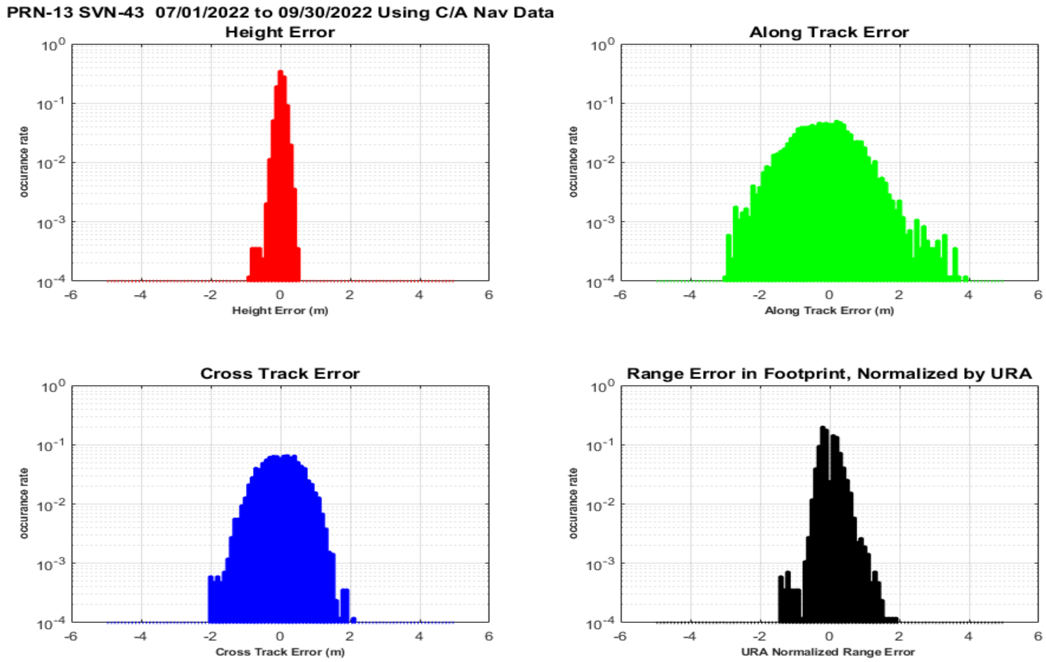


Figure 10-102. Histograms of H, A, C, and Range Error PRN13 (SVN43) Using C/A Nav Data

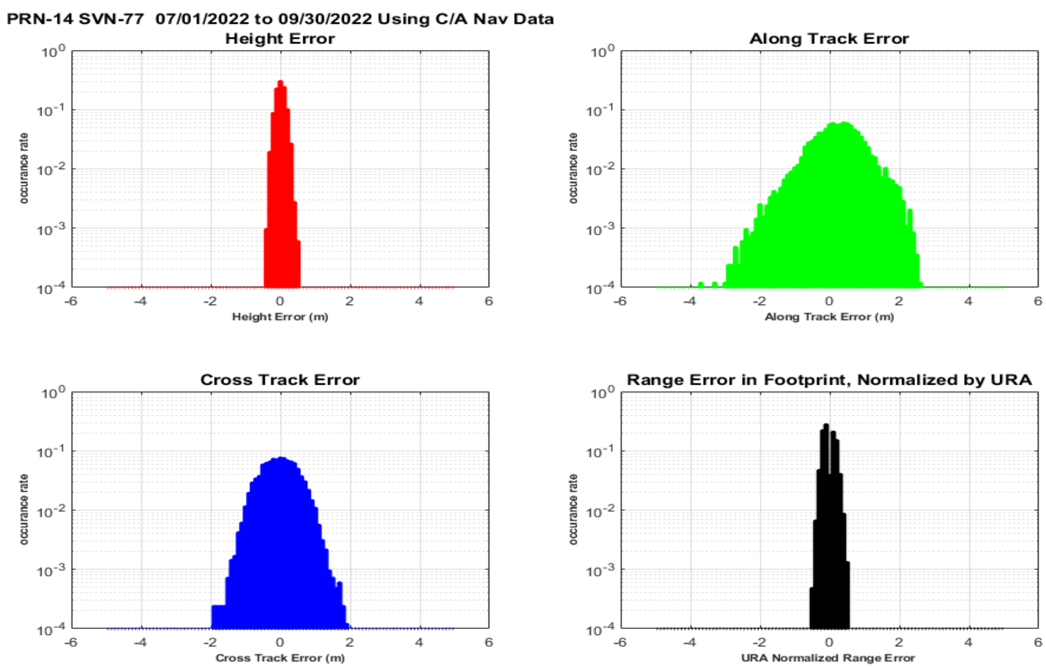


Figure 10-103. Histograms of H, A, C, and Range Error PRN14 (SVN77) Using C/A Nav Data

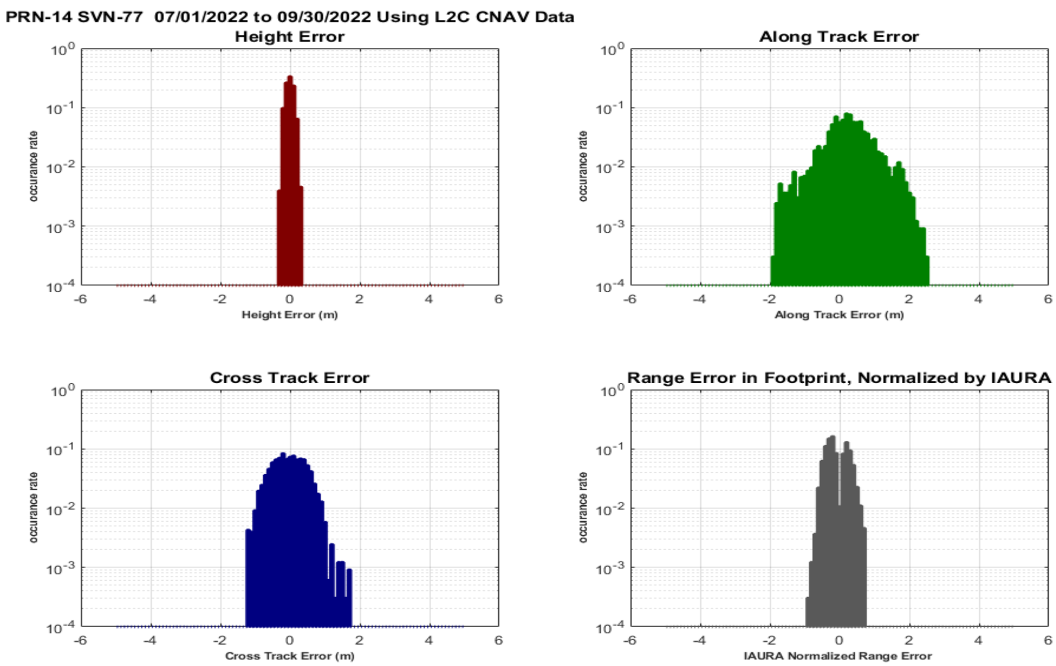


Figure 10-104. Histograms of H, A, C, and Range Error PRN14 (SVN77) Using L2C CNAV Data

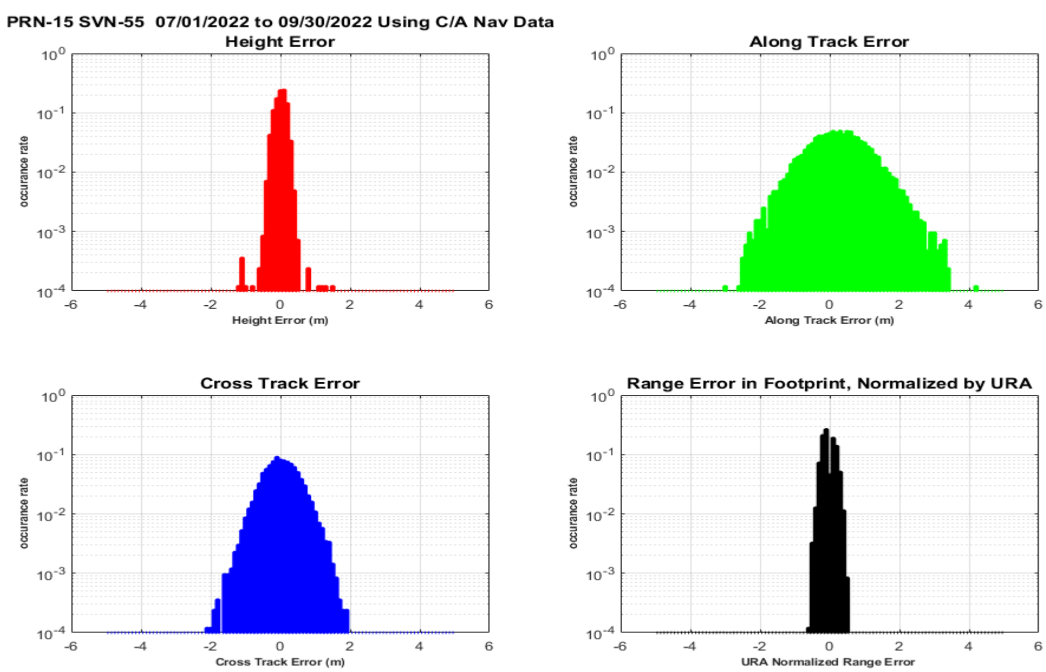


Figure 10-105. Histograms of H, A, C, and Range Error PRN15 (SVN55) Using C/A Nav Data

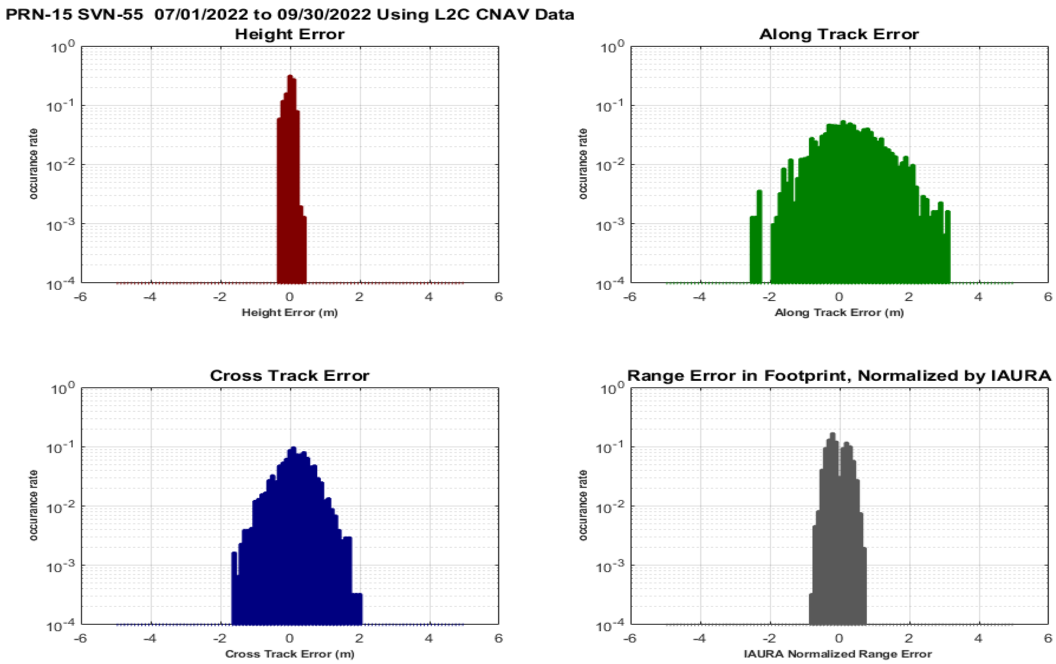


Figure 10-106. Histograms of H, A, C, and Range Error PRN15 (SVN55) Using L2C CNAV Data

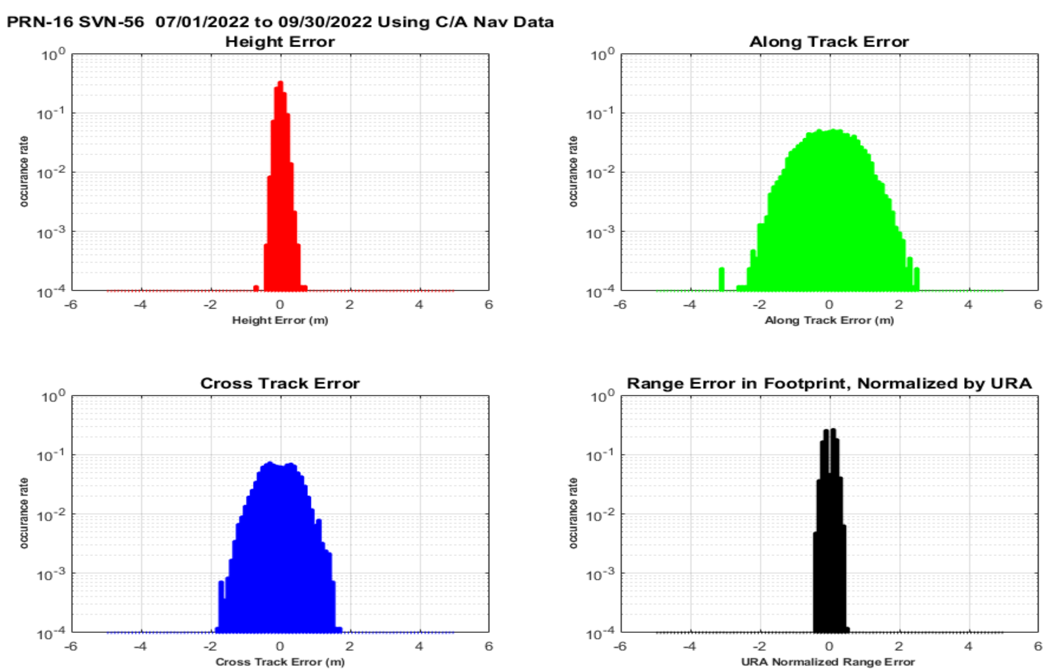


Figure 10-107. Histograms of H, A, C, and Range Error PRN16 (SVN56) Using C/A Nav Data

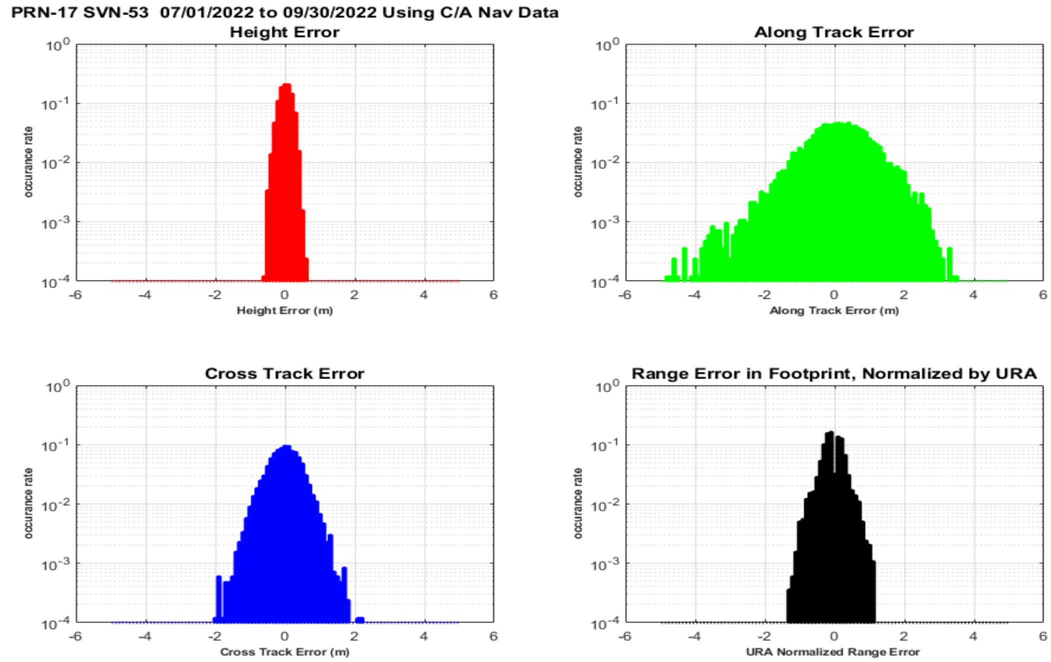


Figure 10-108. Histograms of H, A, C, and Range Error PRN17 (SVN53) Using C/A Nav Data

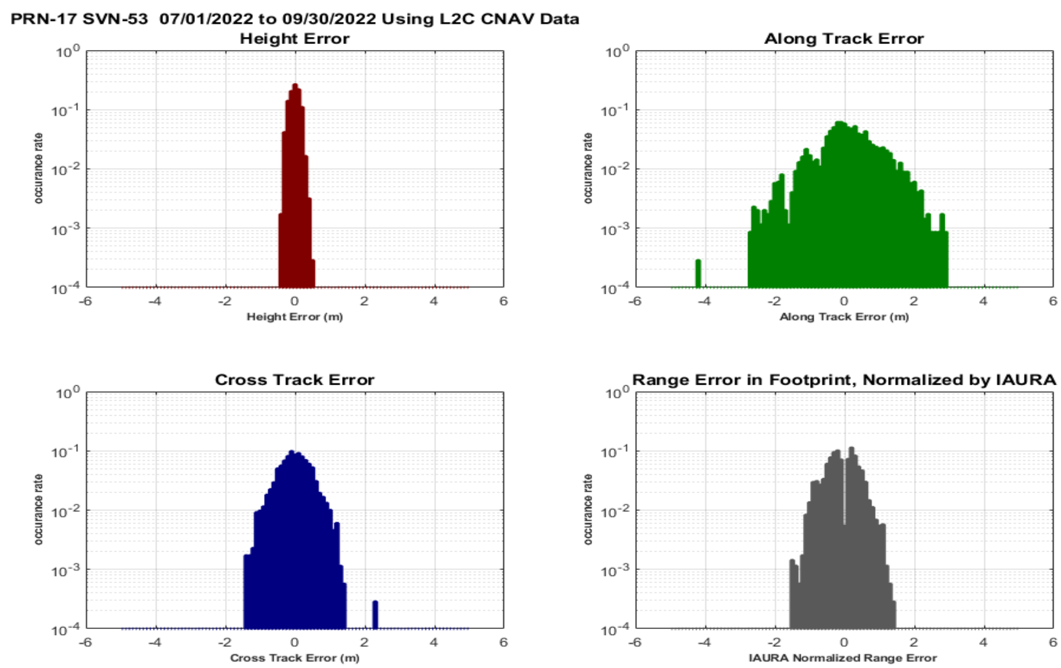


Figure 10-109. Histograms of H, A, C, and Range Error PRN17 (SVN53) Using L2C CNAV Data

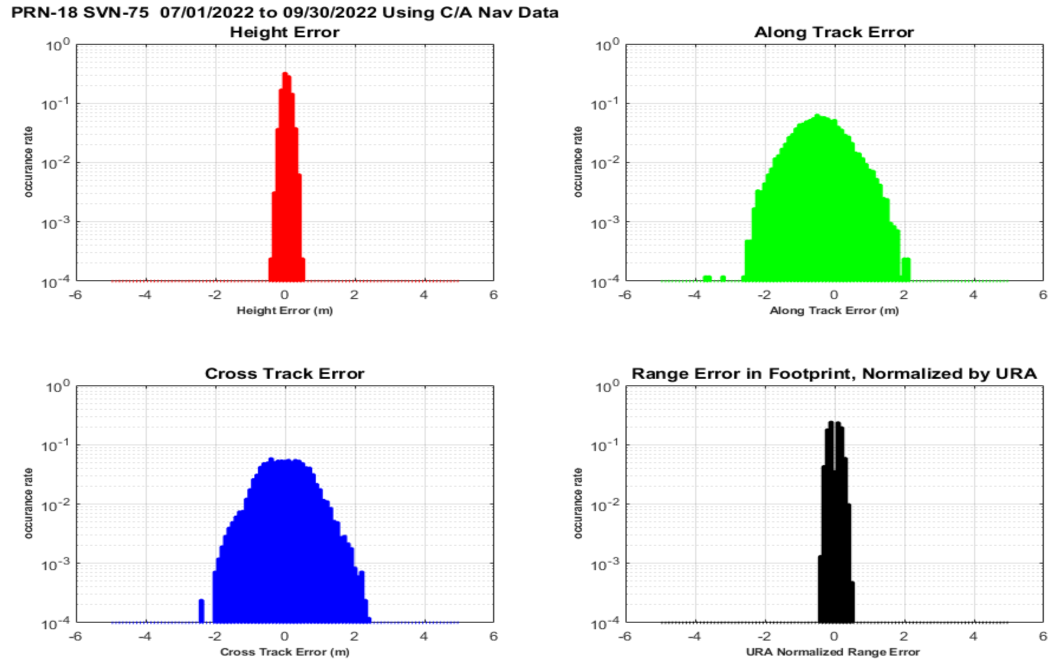


Figure 10-110. Histograms of H, A, C, and Range Error PRN18 (SVN75) Using C/A Nav Data

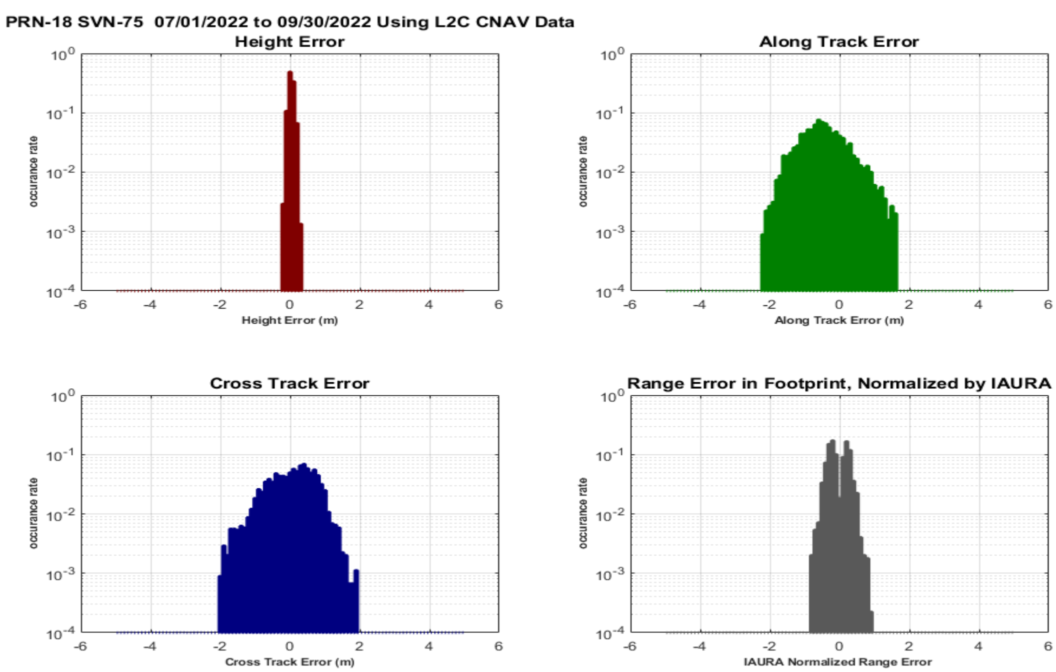


Figure 10-111. Histograms of H, A, C, and Range Error PRN18 (SVN75) Using L2C CNAV Data

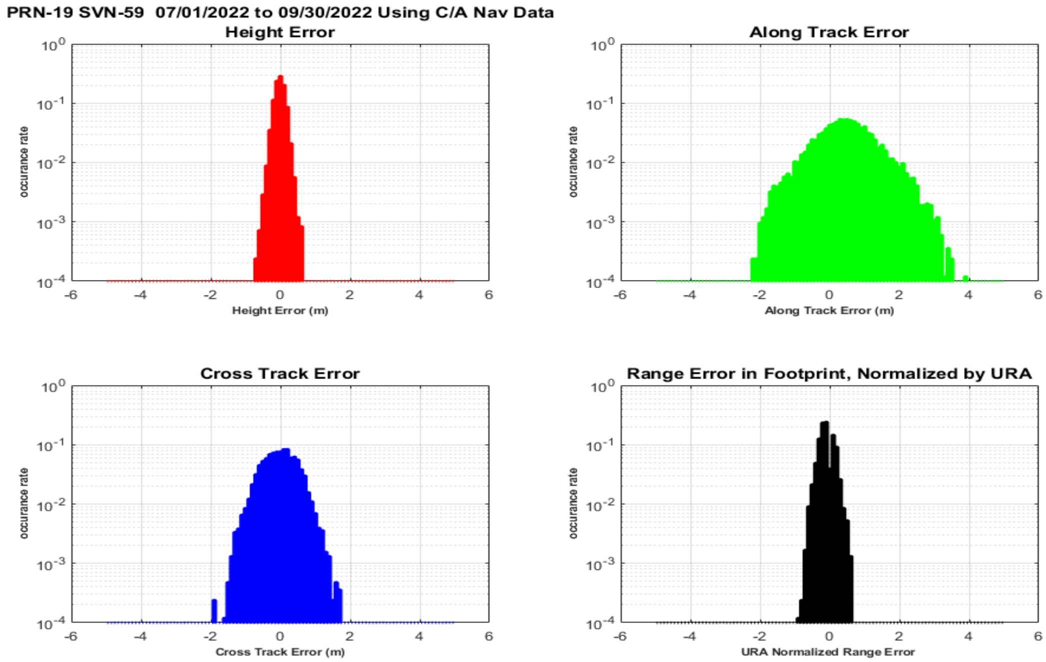


Figure 10-112. Histograms of H, A, C, and Range Error PRN19 (SVN59) Using C/A Nav Data

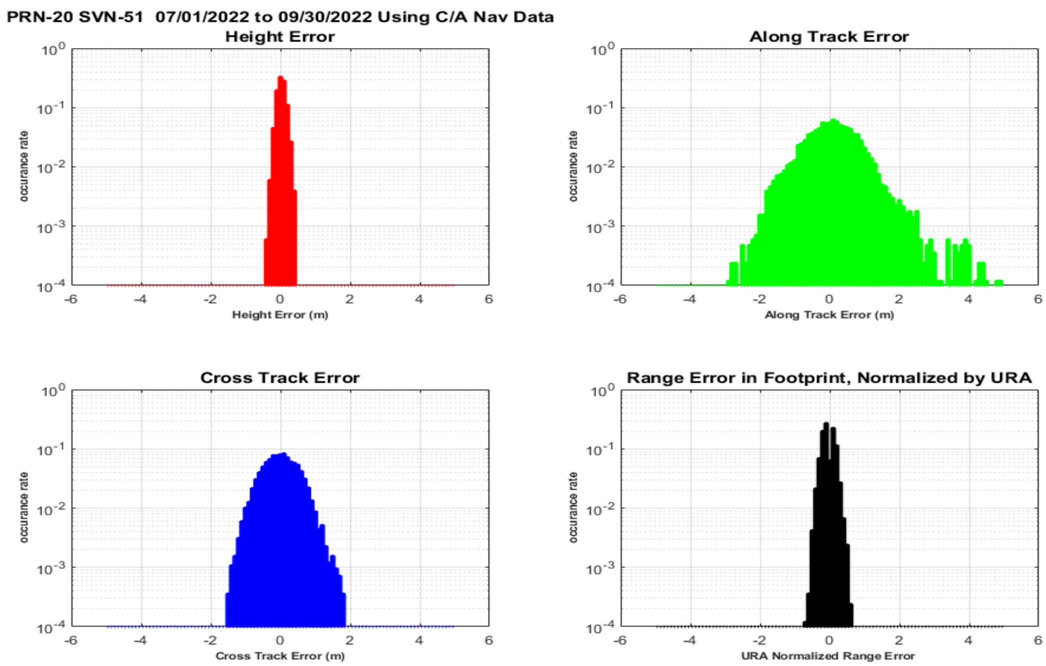


Figure 10-113. Histograms of H, A, C, and Range Error PRN20 (SVN51) Using C/A Nav Data

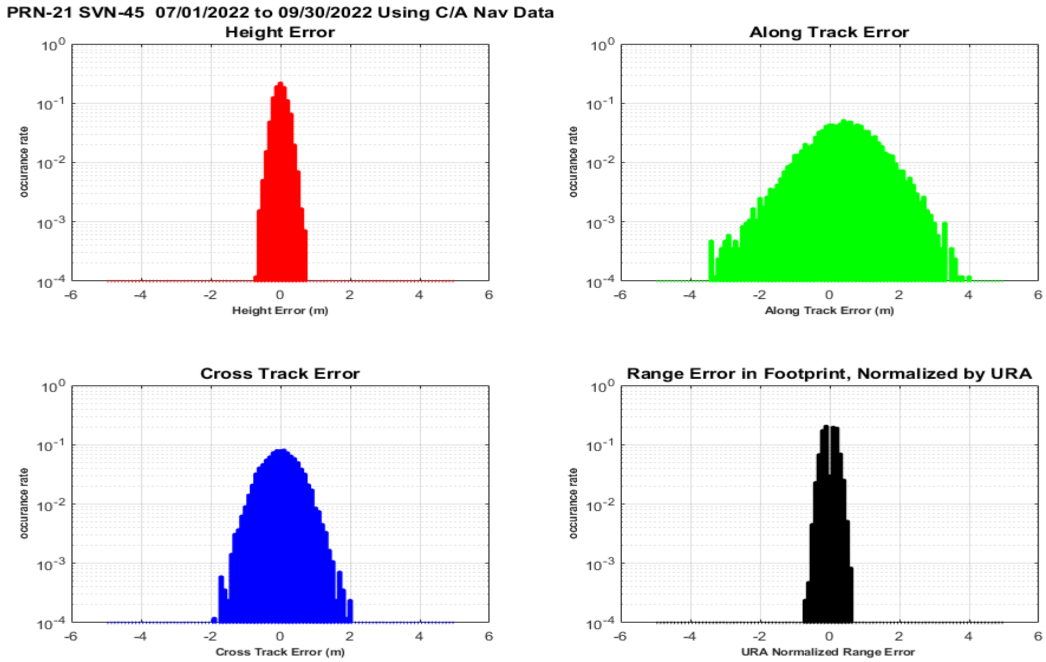


Figure 10-114. Histograms of H, A, C, and Range Error PRN21 (SVN45) Using C/A Nav Data

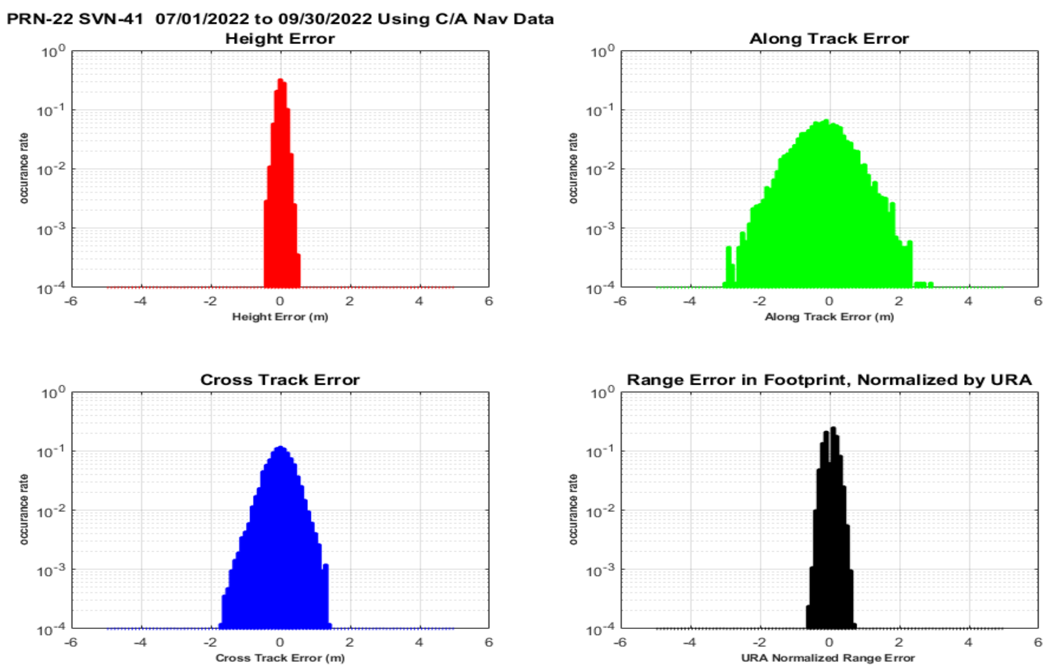


Figure 10-115. Histograms of H, A, C, and Range Error PRN22 (SVN41) Using C/A Nav Data

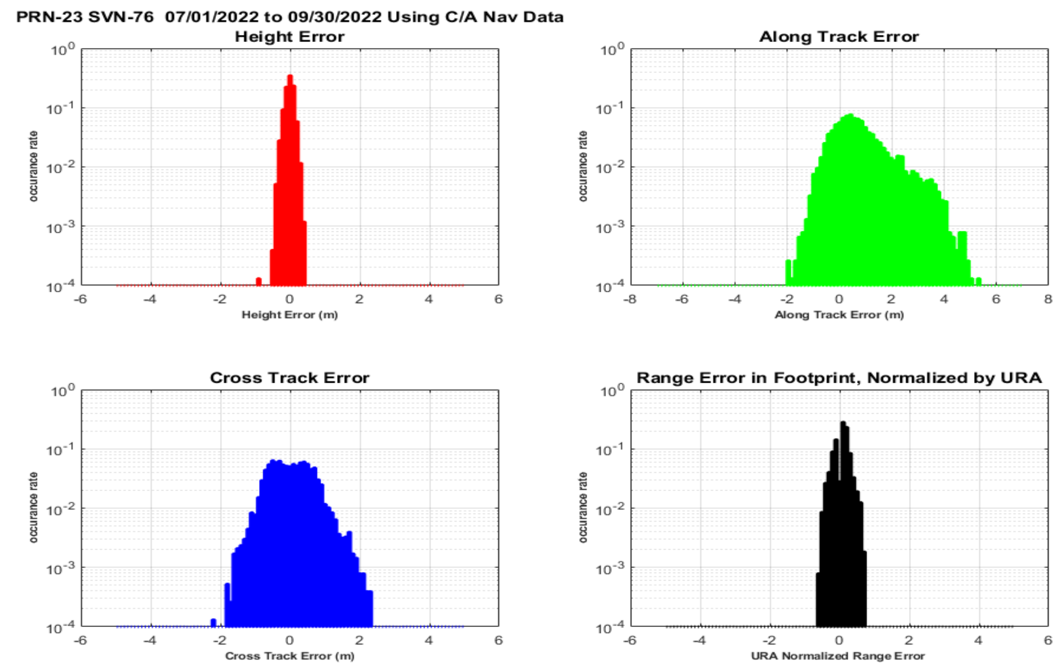


Figure 10-116. Histograms of H, A, C, and Range Error PRN23 (SVN76) Using C/A Nav Data

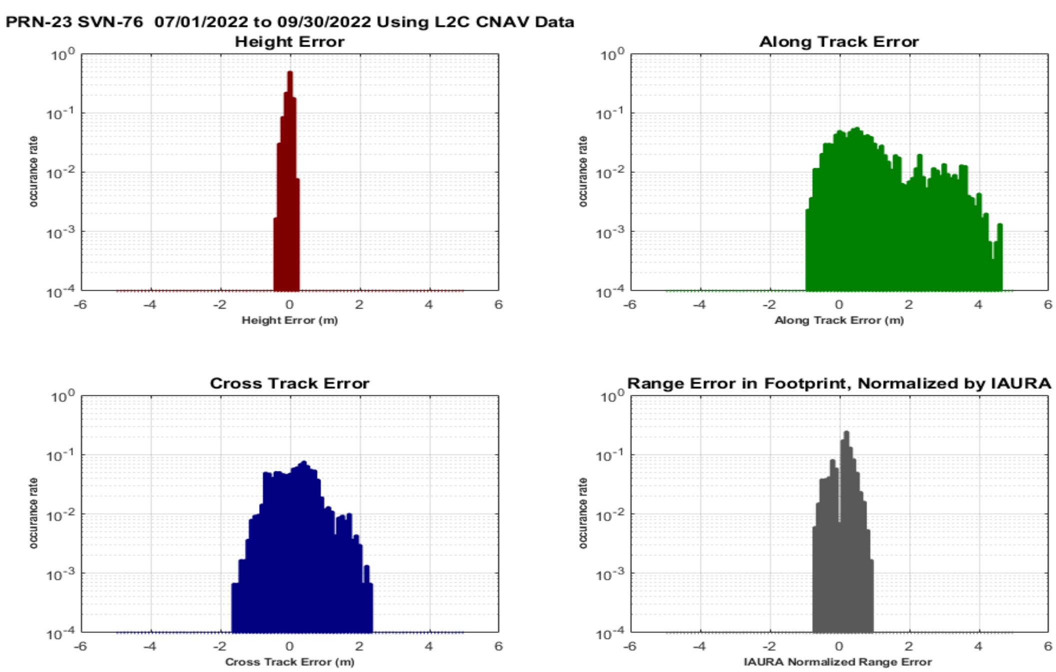


Figure 10-117. Histograms of H, A, C, and Range Error PRN23 (SVN76) Using L2C CNAV Data

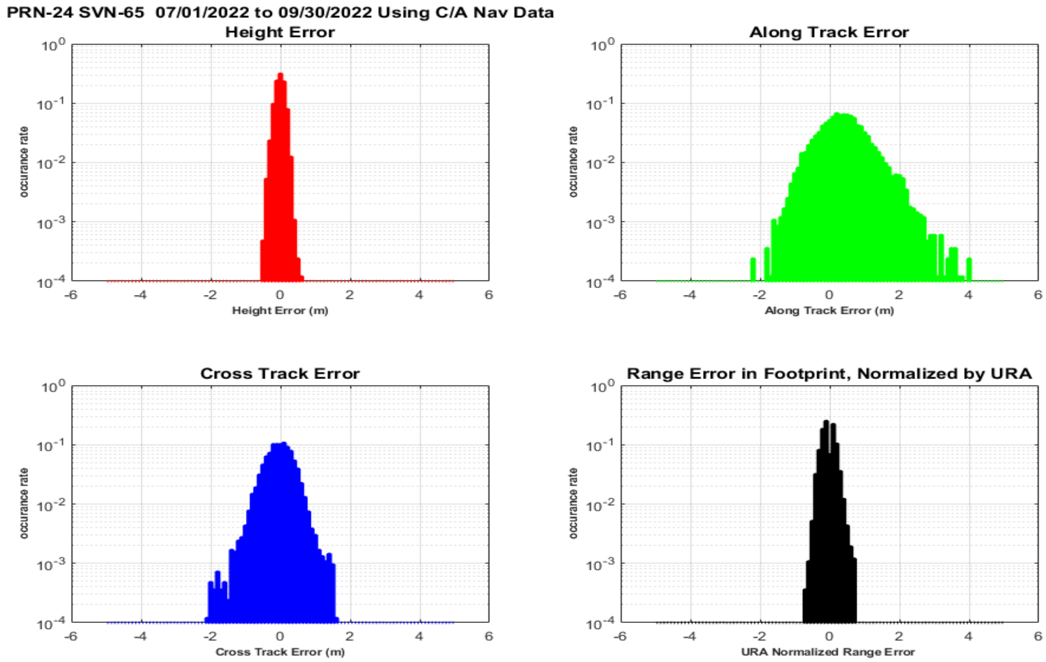


Figure 10-118. Histograms of H, A, C, and Range Error PRN24 (SVN65) Using C/A Nav Data

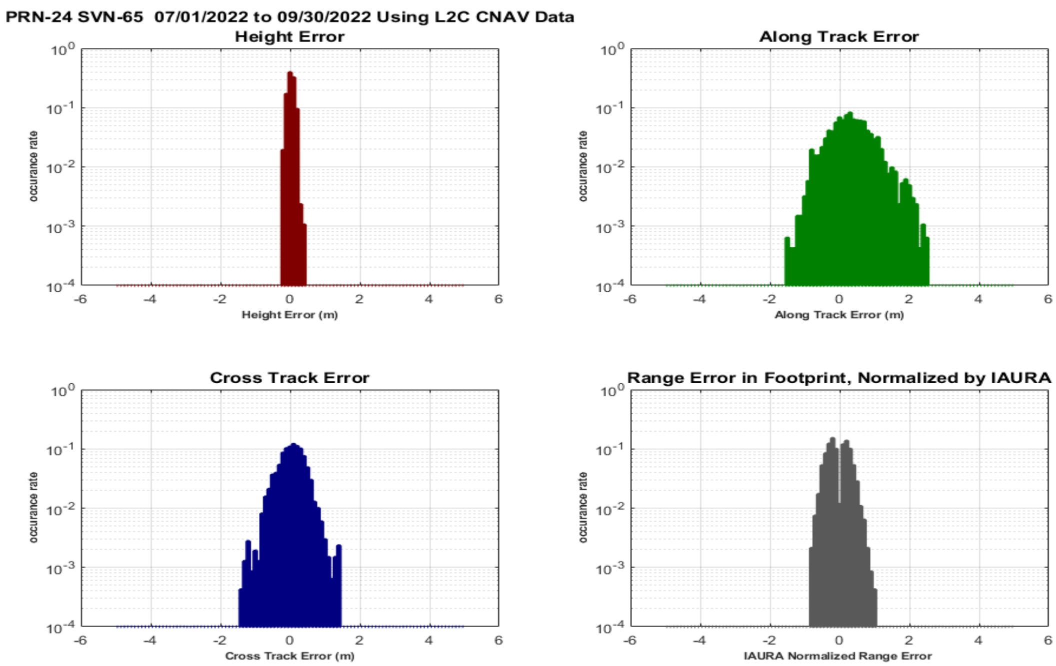


Figure 10-119. Histograms of H, A, C, and Range Error PRN24 (SVN65) Using L2C CNAV Data

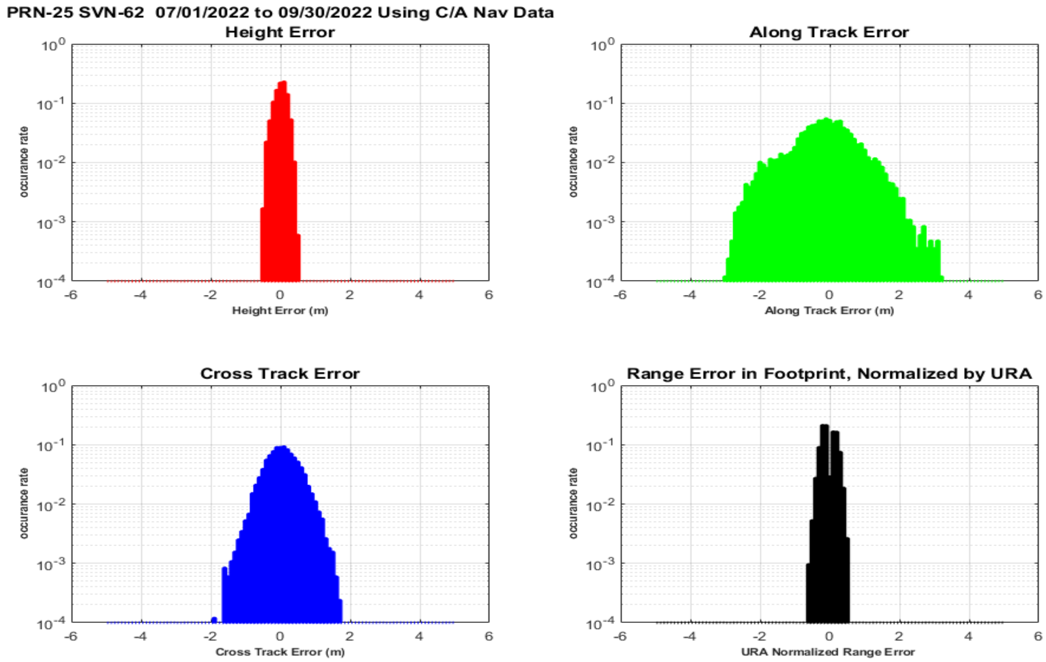


Figure 10-120. Histograms of H, A, C, and Range Error PRN25 (SVN62) Using C/A Nav Data

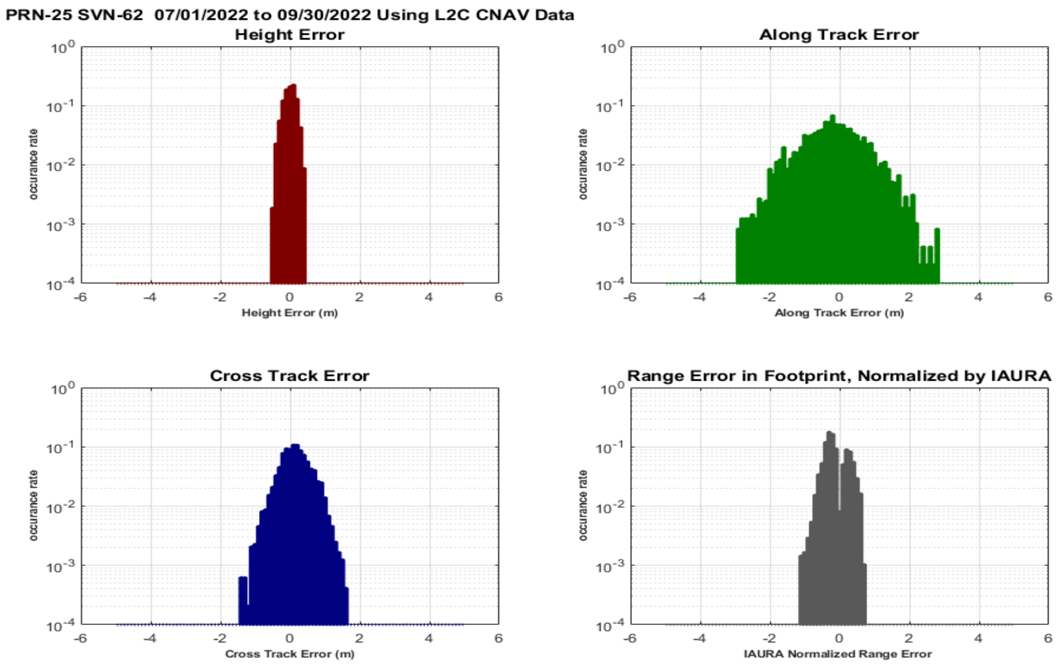


Figure 10-121. Histograms of H, A, C, and Range Error PRN25 (SVN62) Using L2C CNAV Data

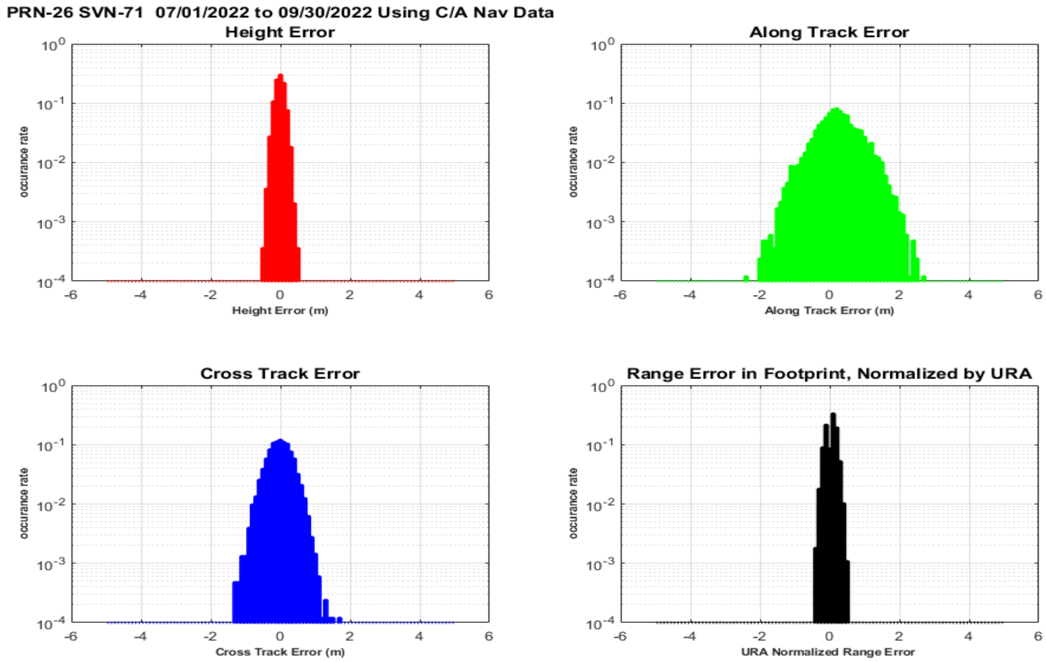


Figure 10-122. Histograms of H, A, C, and Range Error PRN26 (SVN71) Using C/A Nav Data

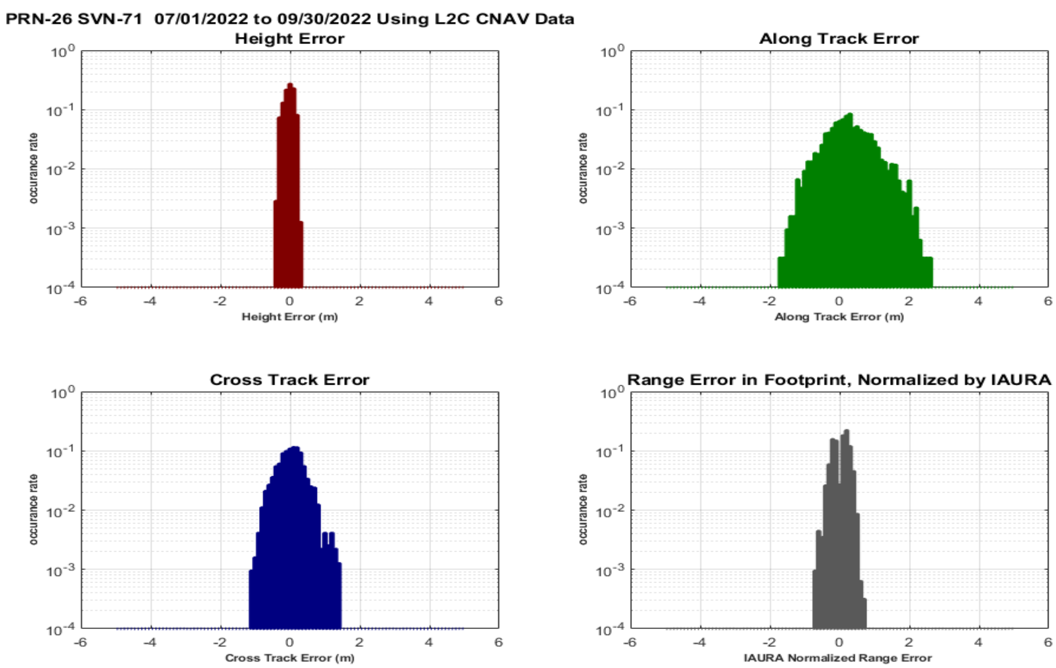


Figure 10-123. Histograms of H, A, C, and Range Error PRN26 (SVN71) Using L2C CNAV Data

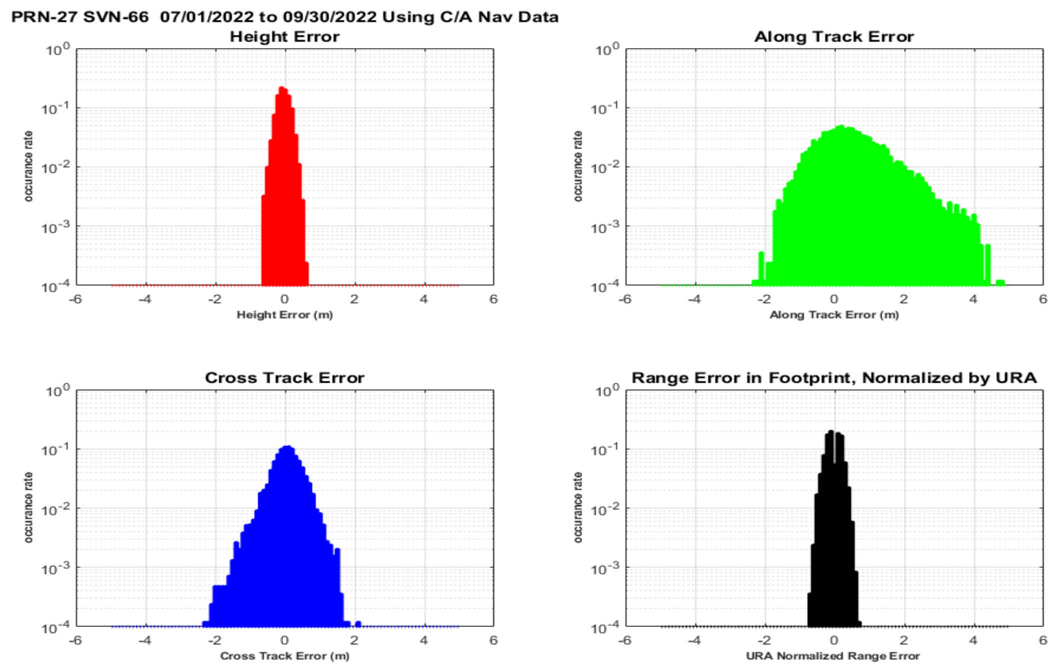


Figure 10-124. Histograms of H, A, C, and Range Error PRN27 (SVN66) Using C/A Nav Data

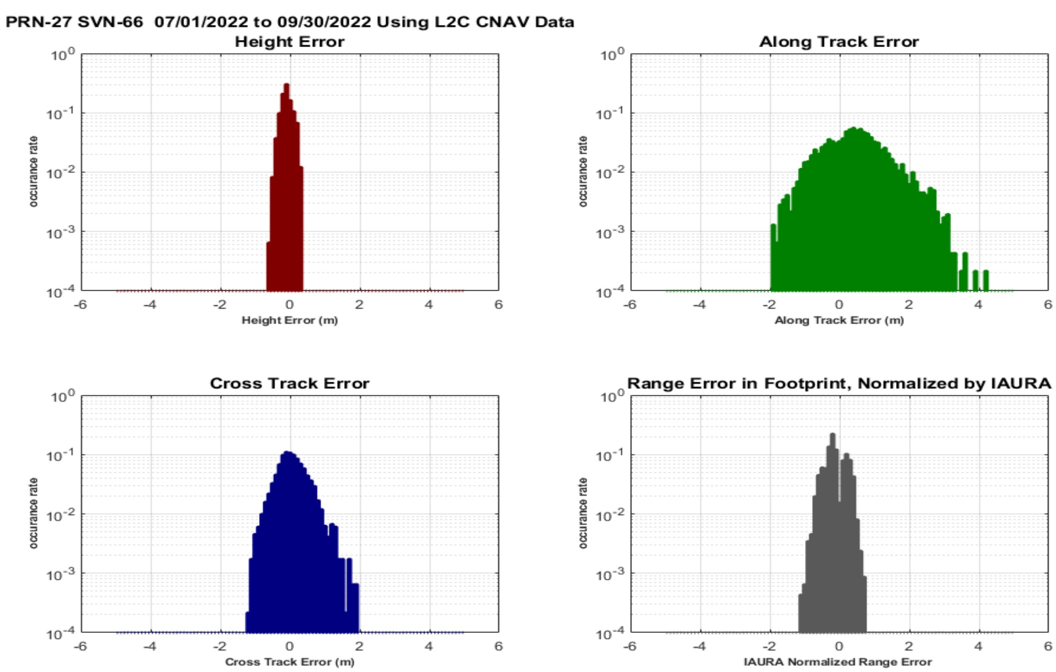


Figure 10-125. Histograms of H, A, C, and Range Error PRN27 (SVN66) Using L2C CNAV Data

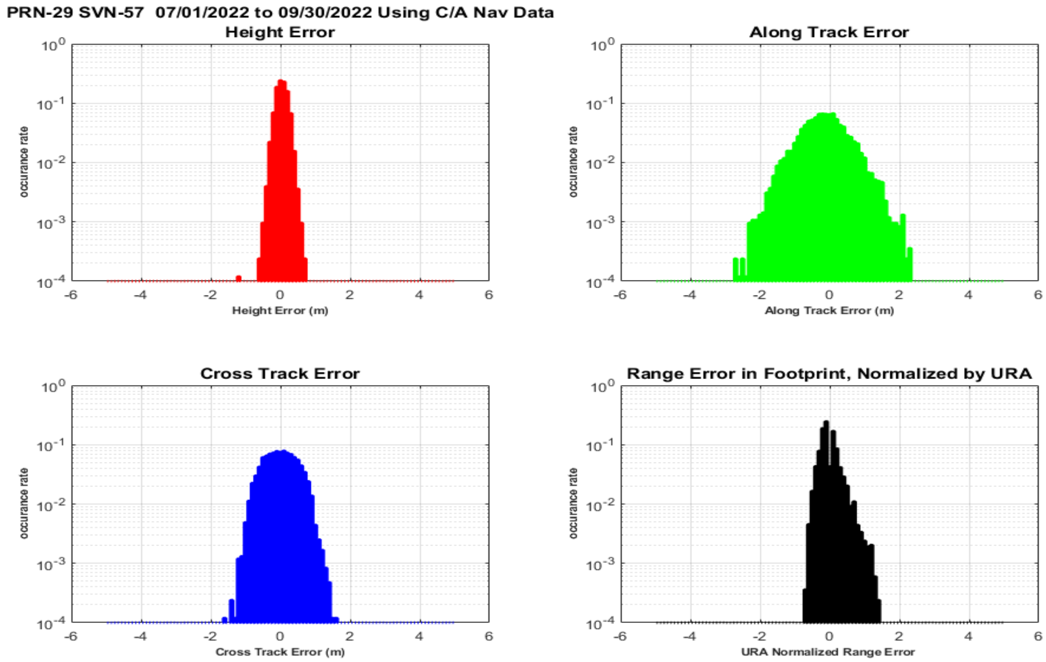


Figure 10-126. Histograms of H, A, C, and Range Error PRN29 (SVN57) Using C/A Nav Data

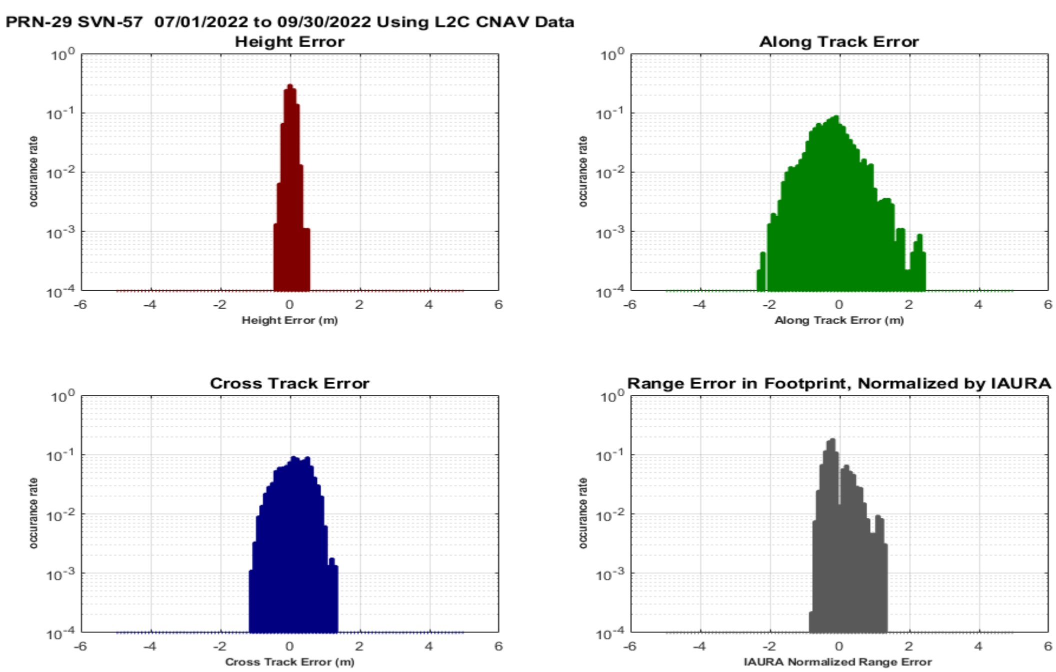


Figure 10-127. Histograms of H, A, C, and Range Error PRN29 (SVN57) Using L2C CNAV Data

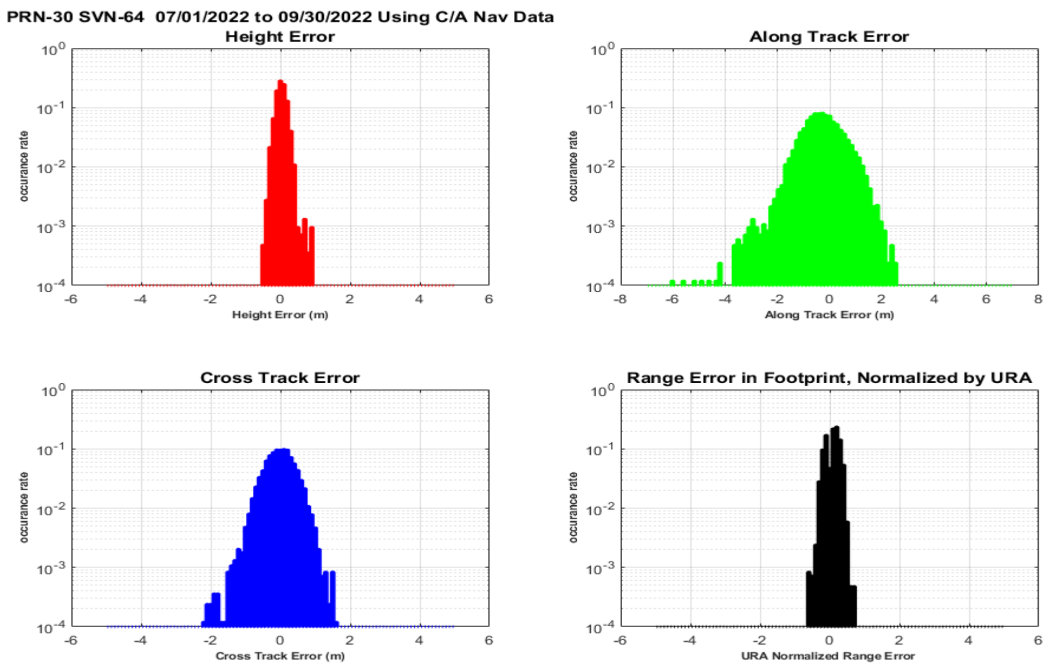


Figure 10-128. Histograms of H, A, C, and Range Error PRN30 (SVN64) Using C/A Nav Data

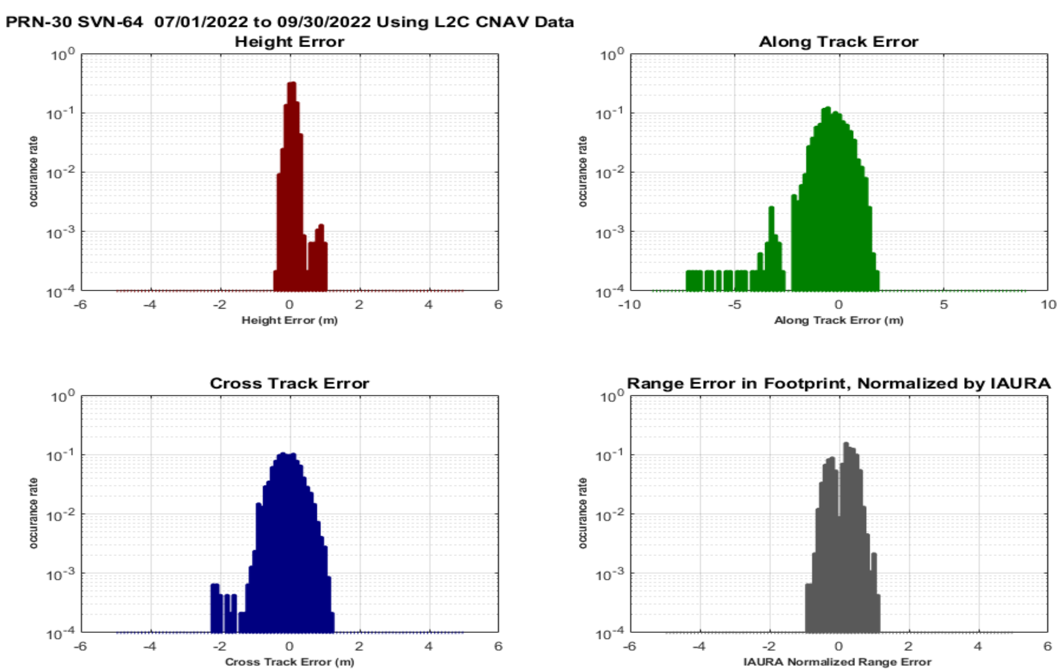


Figure 10-129. Histograms of H, A, C, and Range Error PRN30 (SVN64) Using L2C CNAV Data

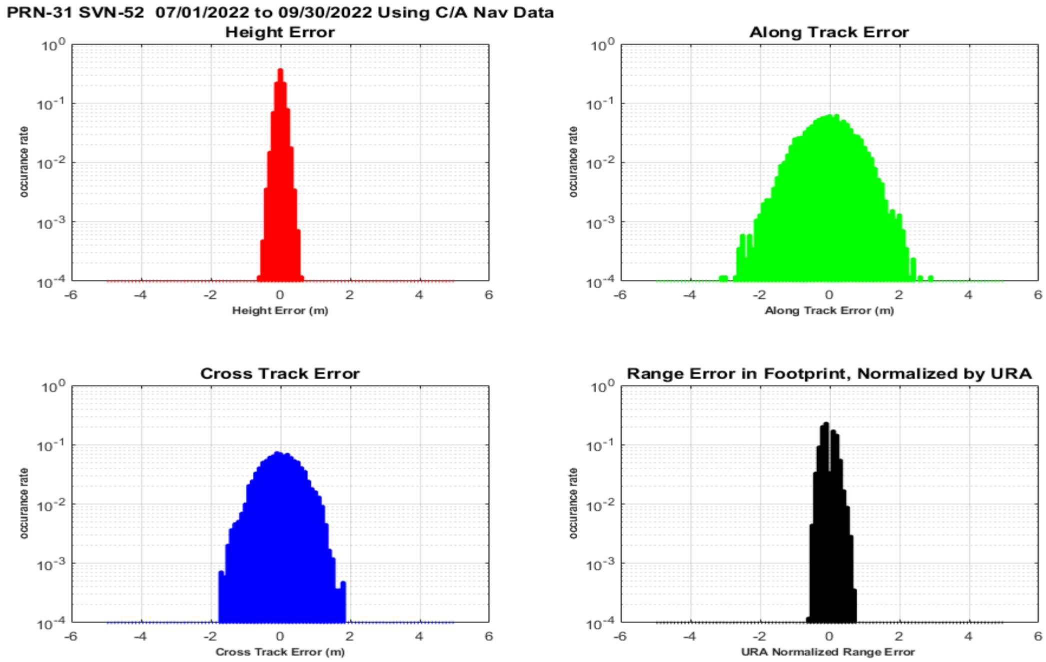


Figure 10-130. Histograms of H, A, C, and Range Error PRN31 (SVN52) Using C/A Nav Data

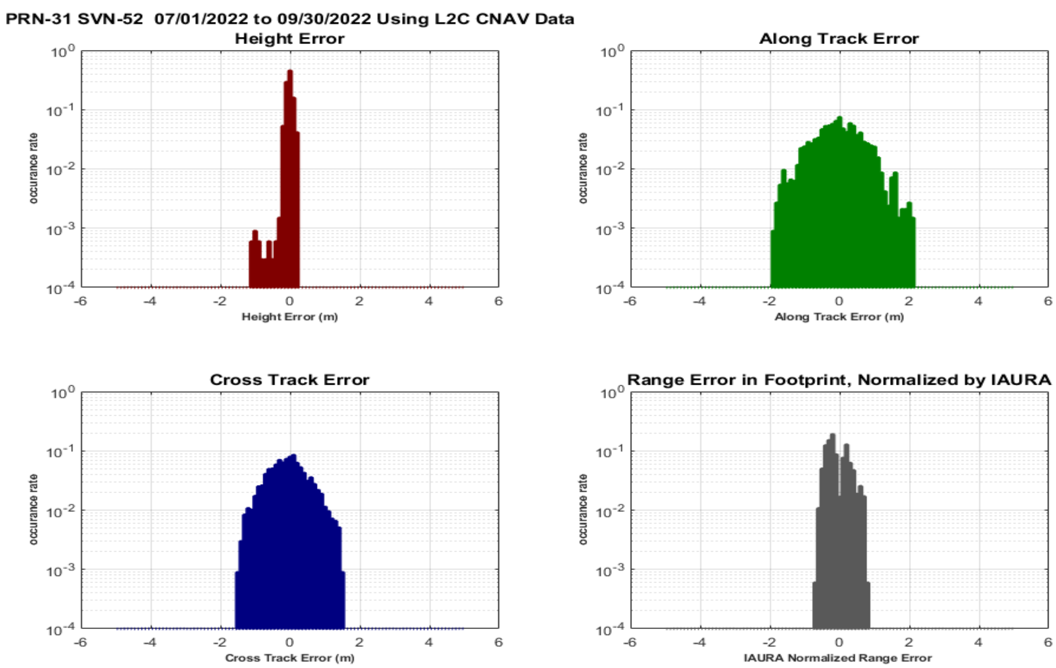


Figure 10-131. Histograms of H, A, C, and Range Error PRN31 (SVN52) Using L2C CNAV Data

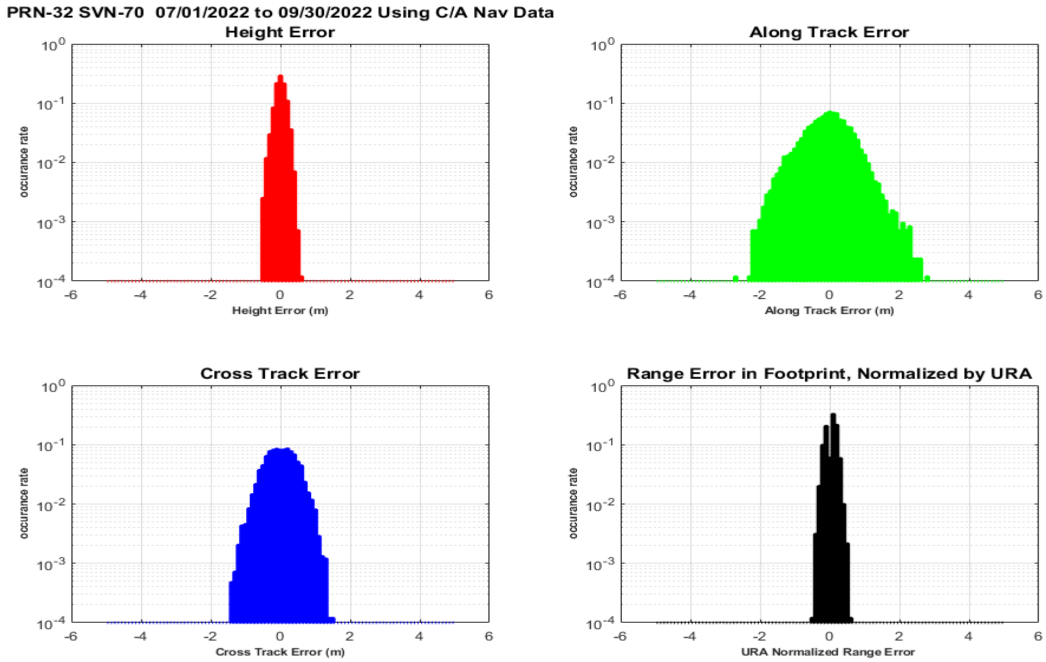


Figure 10-132. Histograms of H, A, C, and Range Error PRN32 (SVN70) Using C/A Nav Data

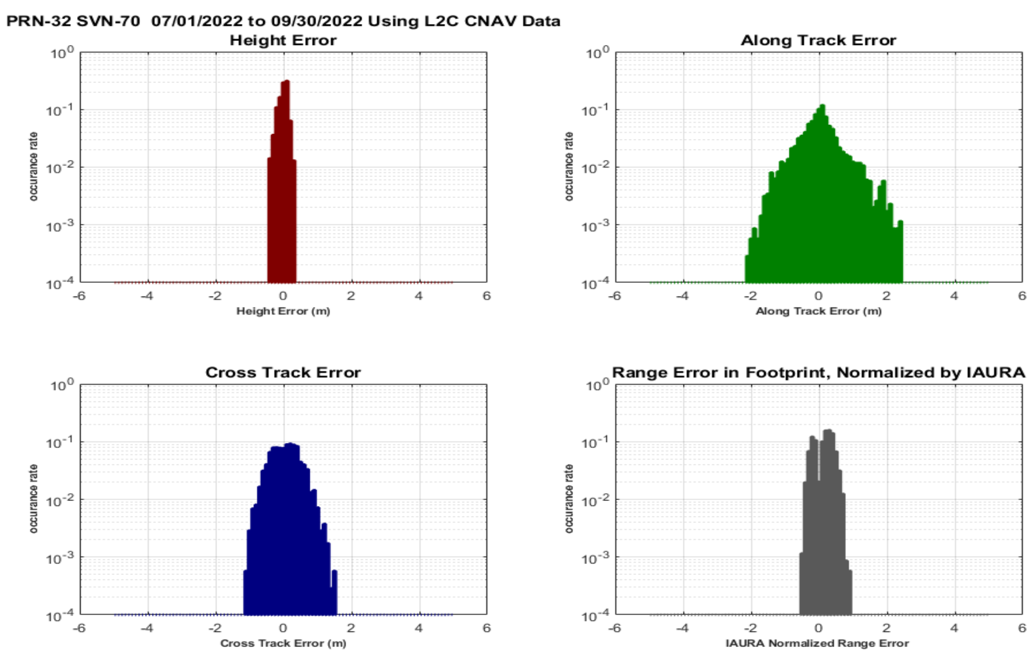


Figure 10-133. Histograms of H, A, C, and Range Error PRN32 (SVN70) Using L2C CNAV Data

10.8 Timeline of URA Normalized Range Error for All Satellites

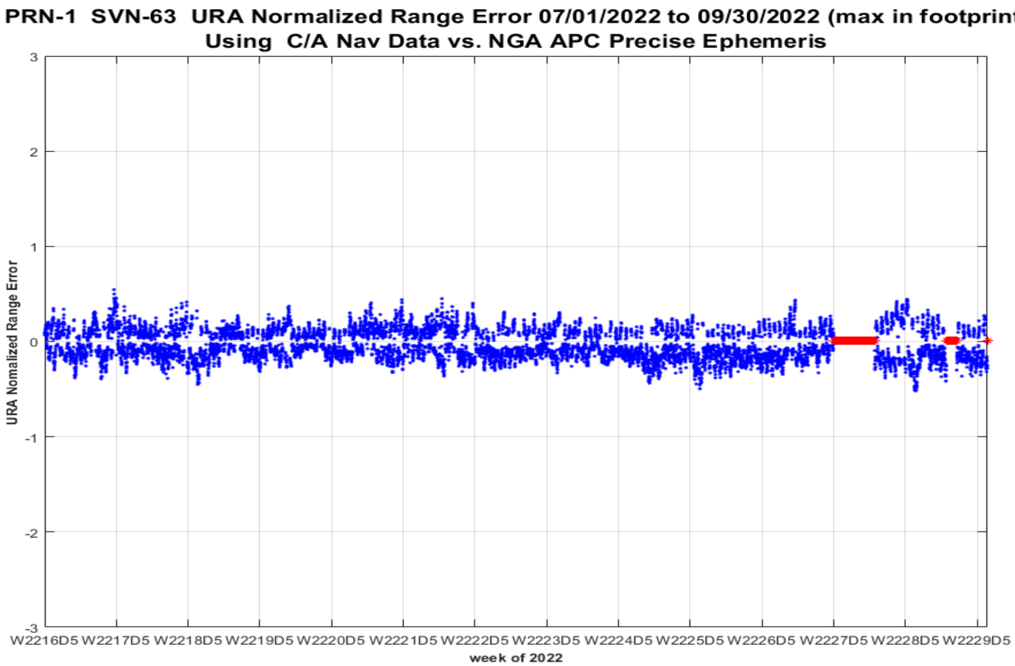


Figure 10-134. Timeline of URA Normalized Range Error PRN1 (SVN63) Using C/A Nav Data

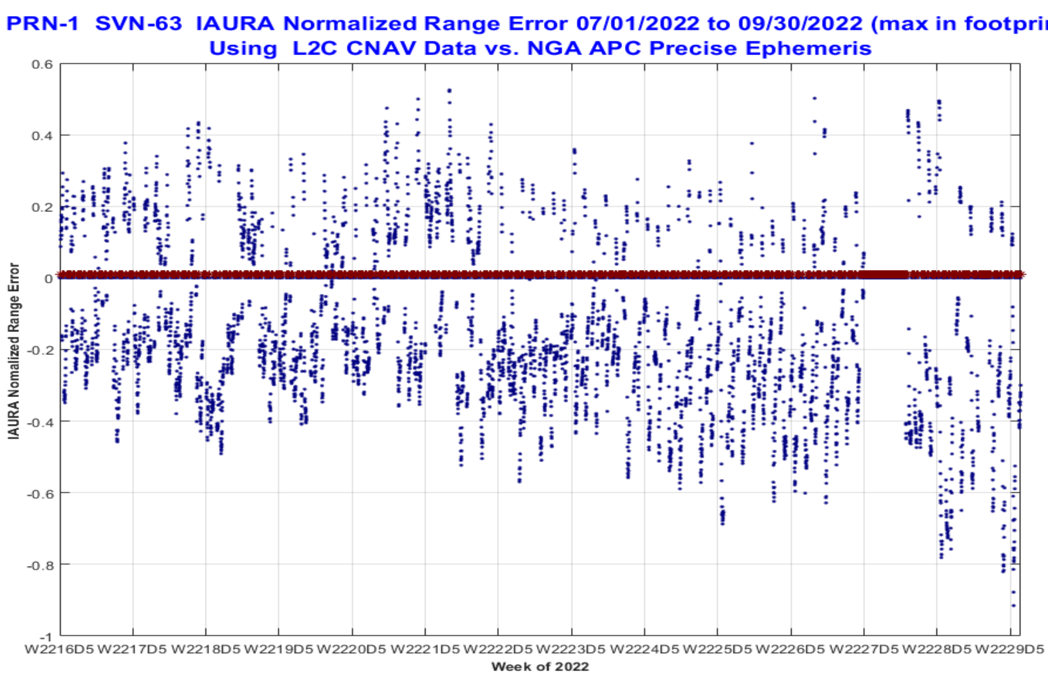


Figure 10-135. Timeline of IAURA Normalized Range Error PRN1 (SVN63) Using L2C CNAV Data

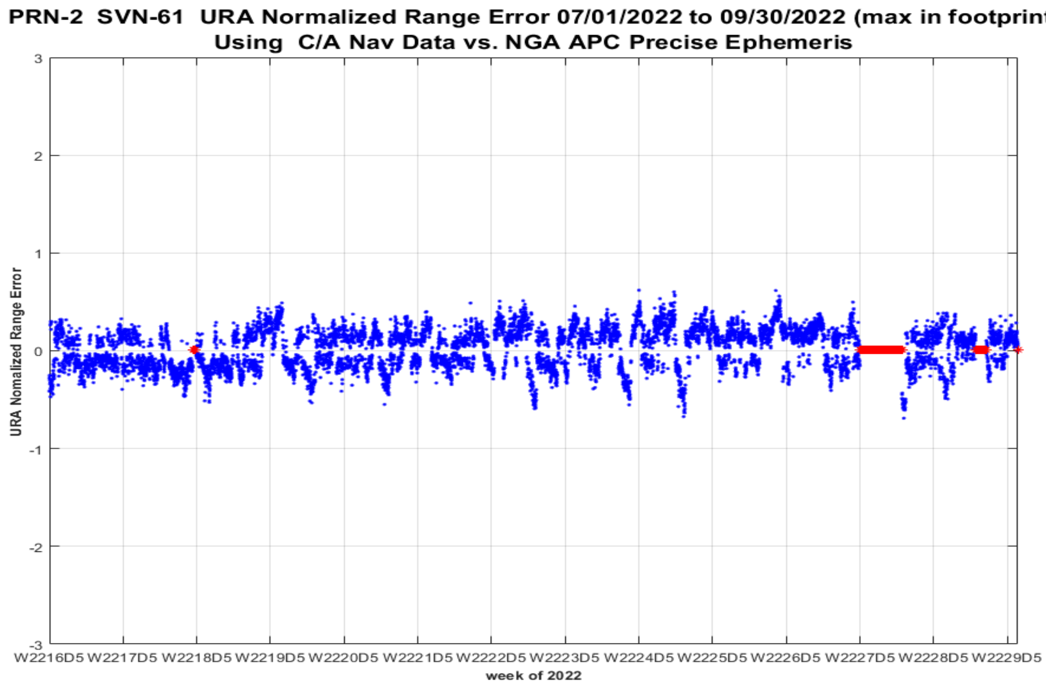


Figure 10-136. Timeline of URA Normalized Range Error PRN2 (SVN61) Using C/A Nav Data

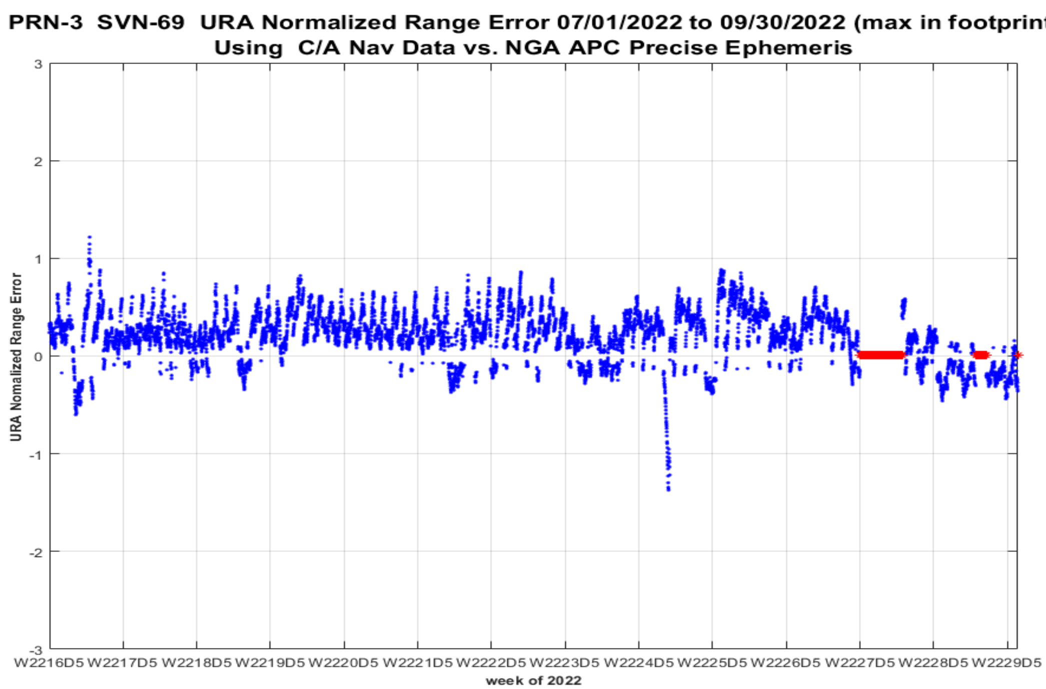


Figure 10-137. Timeline of URA Normalized Range Error PRN3 (SVN69) Using C/A Nav Data

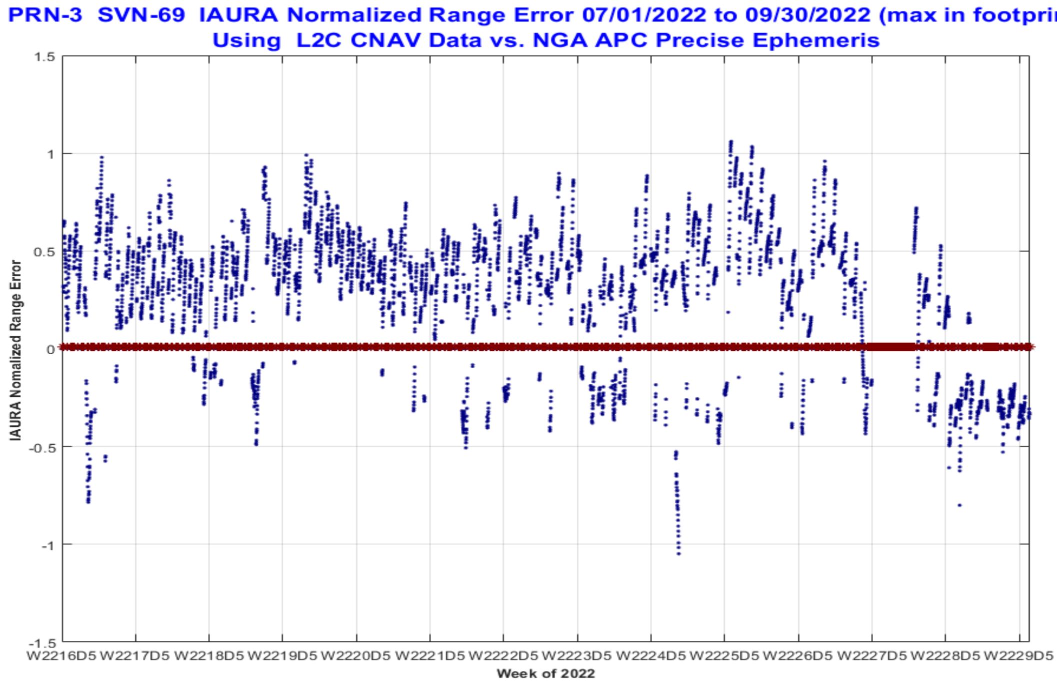


Figure 10-138. Timeline of IAURA Normalized Range Error PRN3 (SVN69) Using L2C CNAV Data

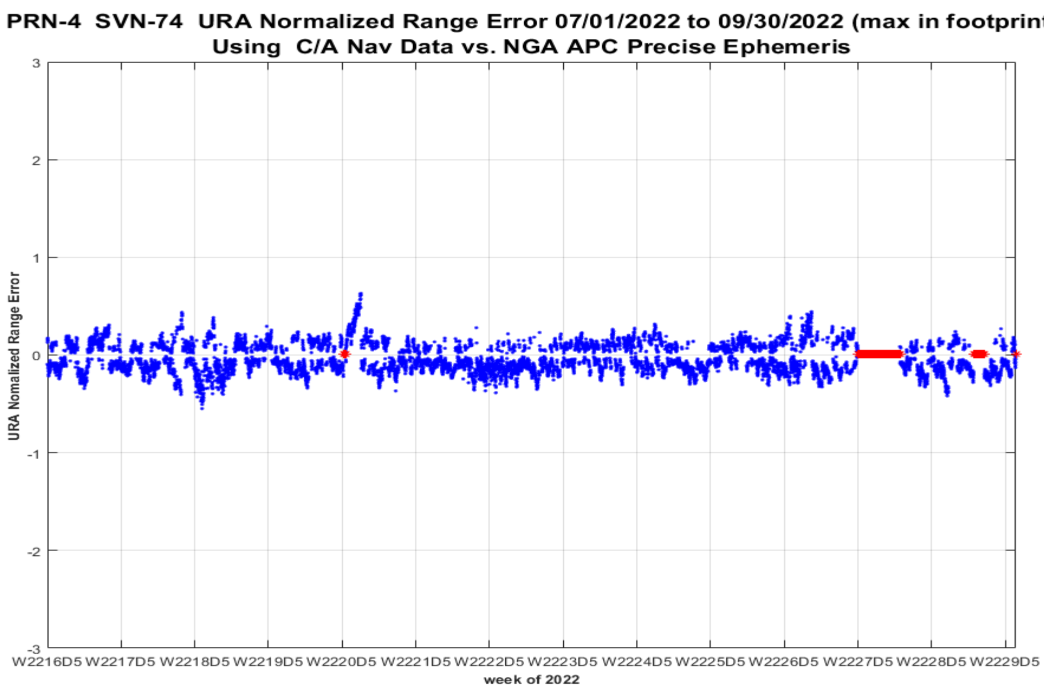


Figure 10-139. Timeline of URA Normalized Range Error PRN4 (SVN74) Using C/A Nav Data

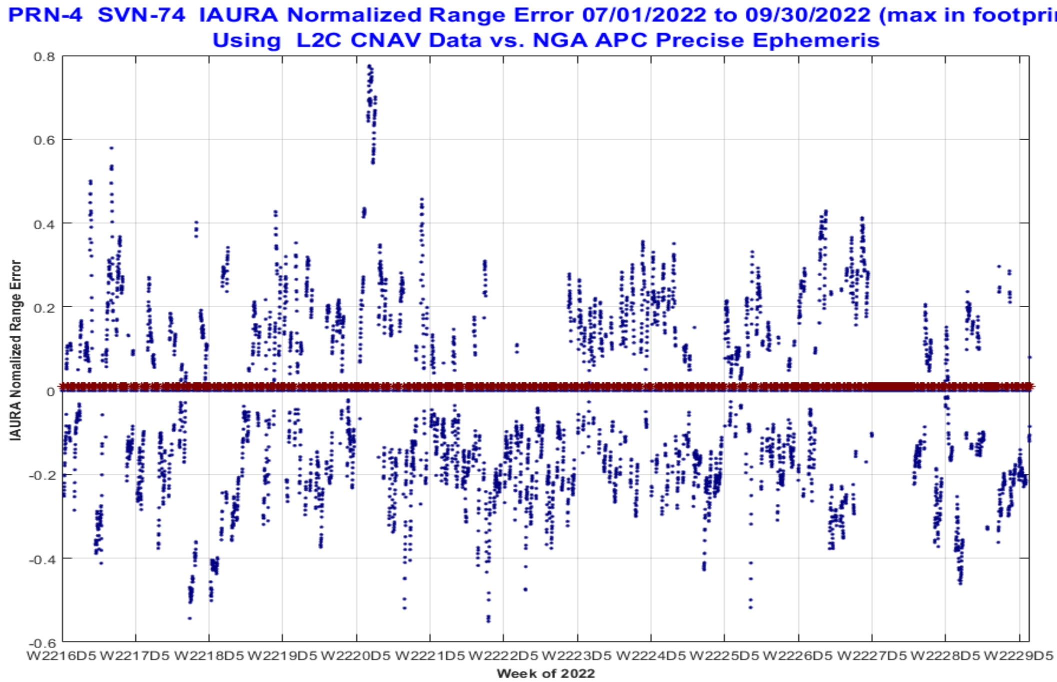


Figure 10-140. Timeline of IAURA Normalized Range Error PRN4 (SVN74) Using L2C CNAV Data

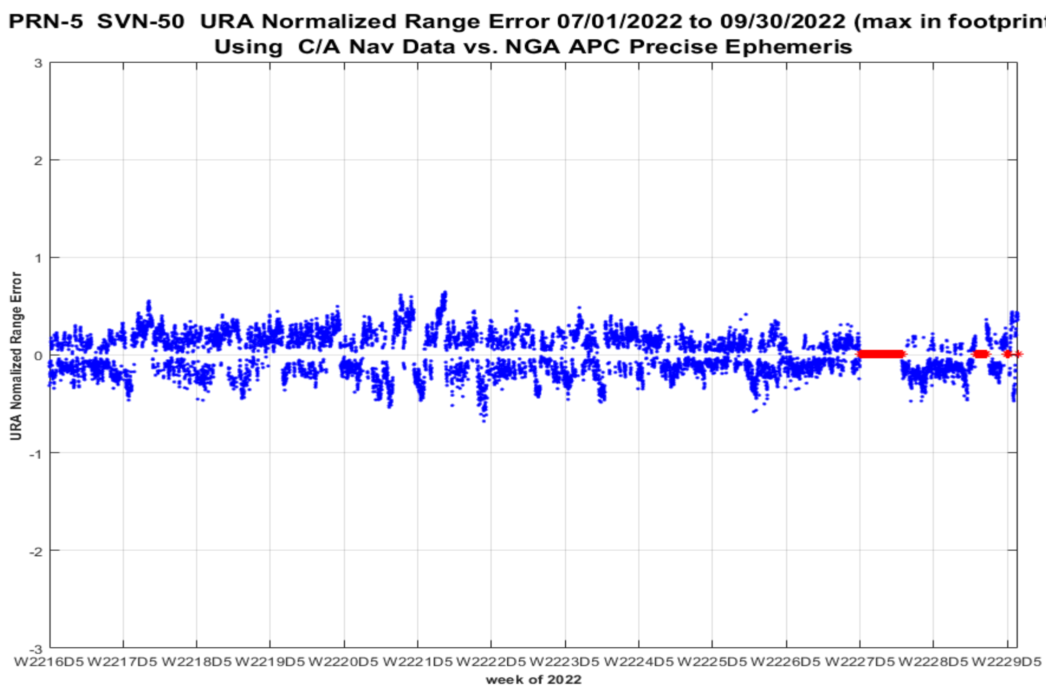


Figure 10-141. Timeline of URA Normalized Range Error PRN5 (SVN50) Using C/A Nav Data

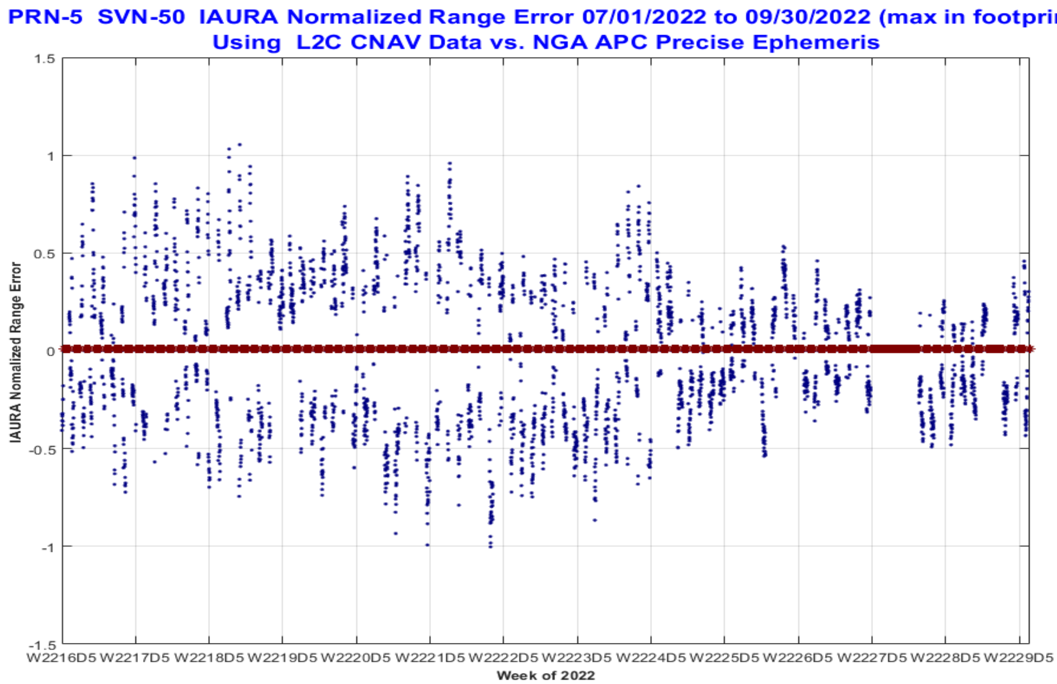


Figure 10-142. Timeline of IAURA Normalized Range Error PRN5 (SVN50) Using L2C CNAV Data

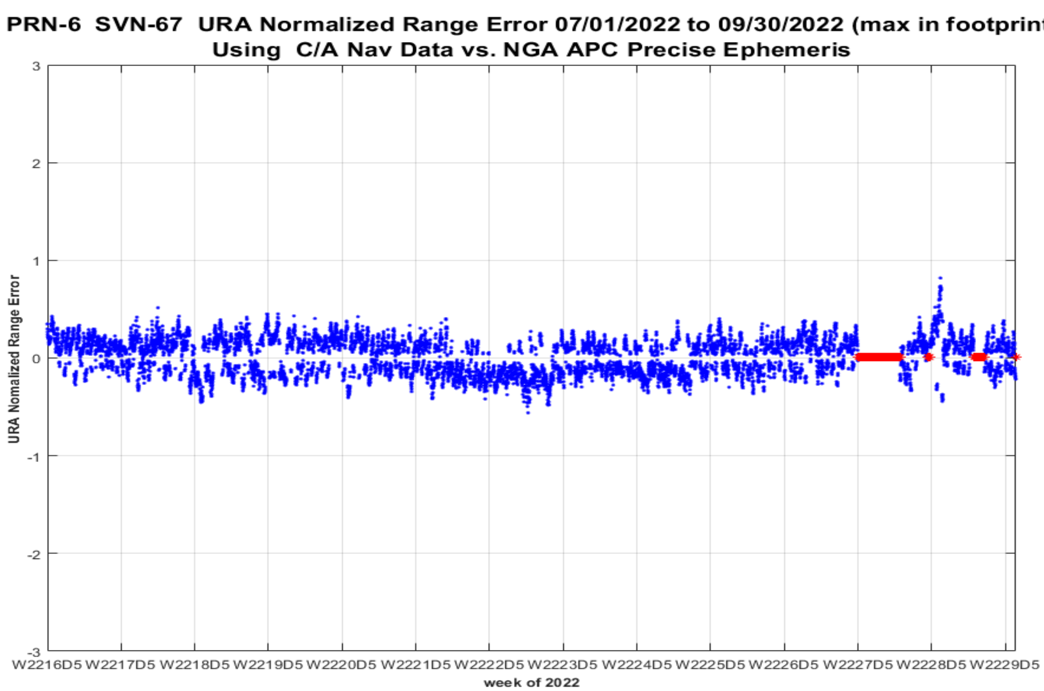


Figure 10-143. Timeline of URA Normalized Range Error PRN6 (SVN67) Using C/A Nav Data

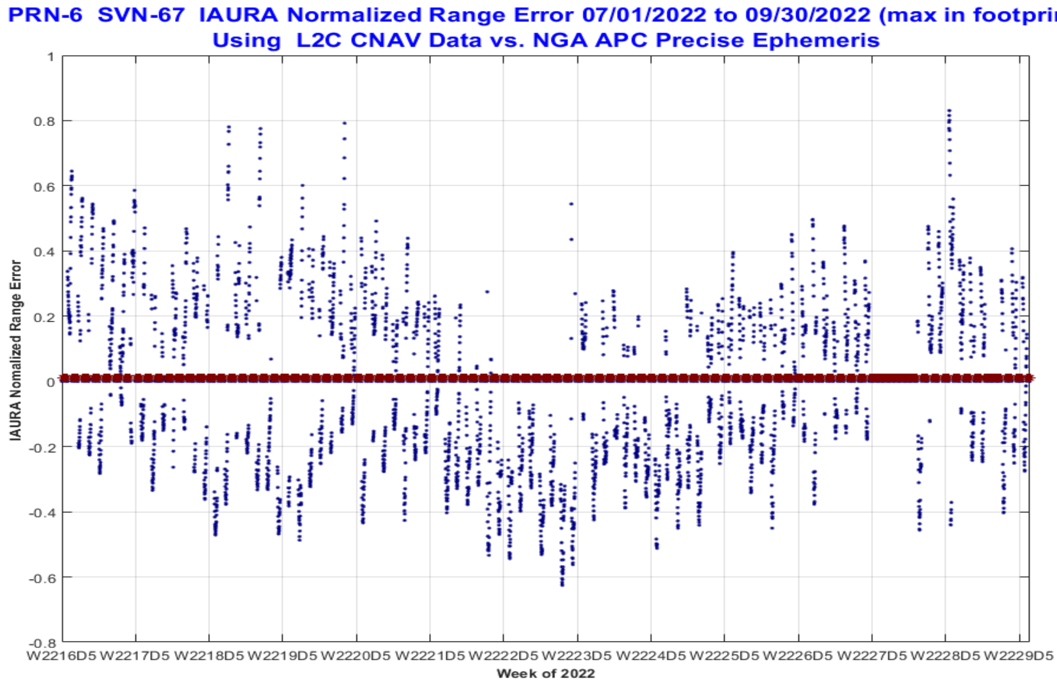


Figure 10-144. Timeline of IAURA Normalized Range Error PRN6 (SVN67) Using L2C CNAV Data

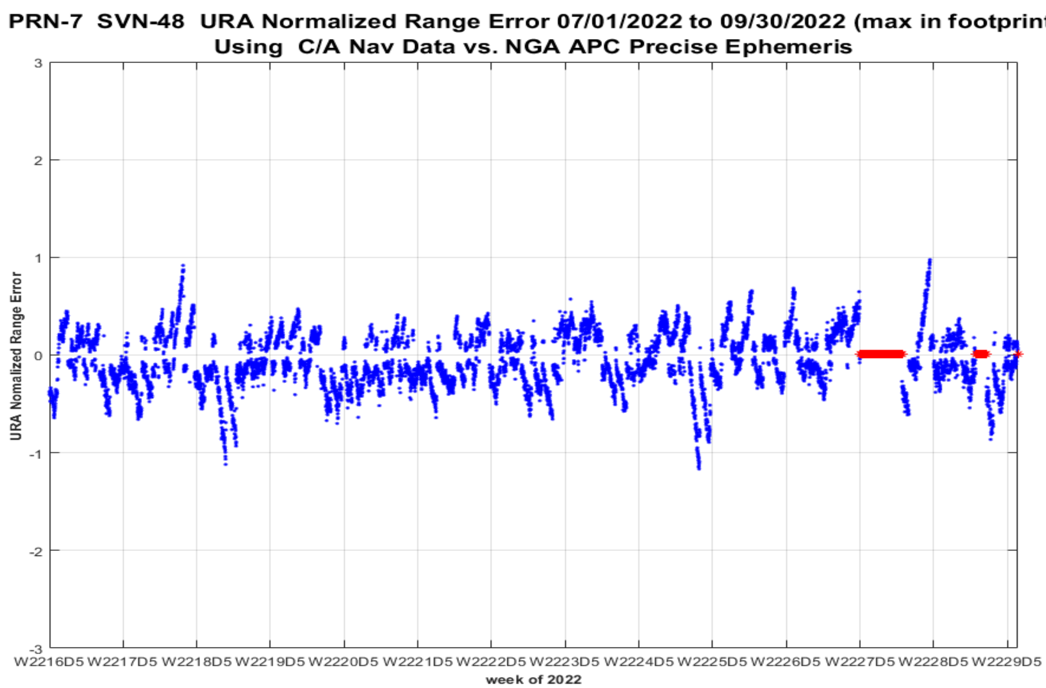


Figure 10-145. Timeline of URA Normalized Range Error PRN7 (SVN48) Using C/A Nav Data

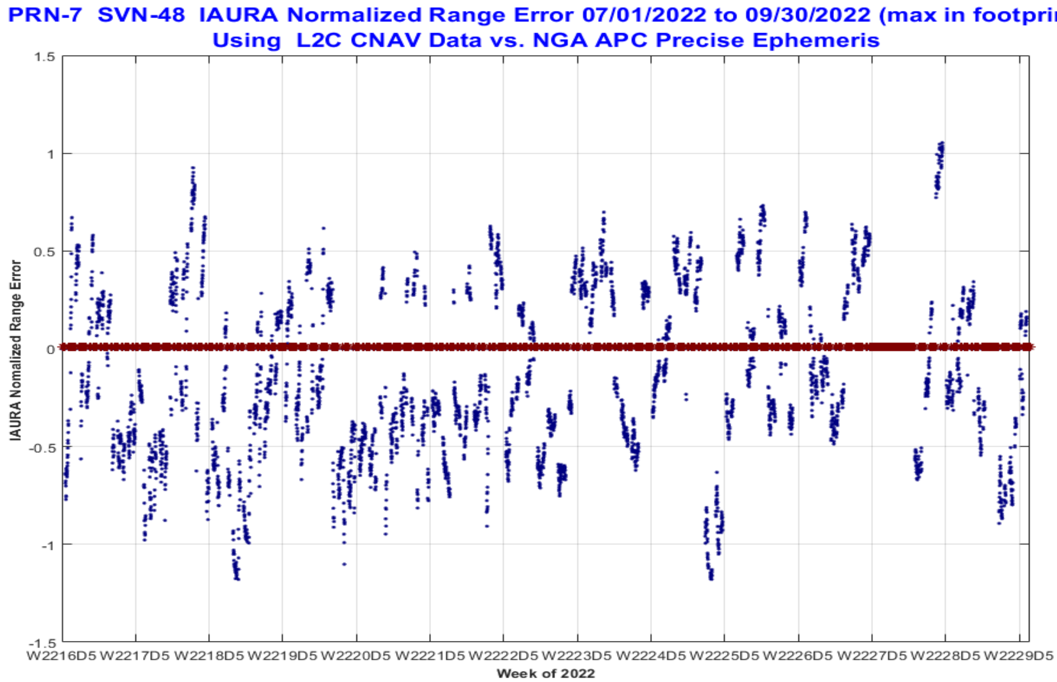


Figure 10-146. Timeline of IAURA Normalized Range Error PRN7 (SVN48) Using L2C CNAV Data

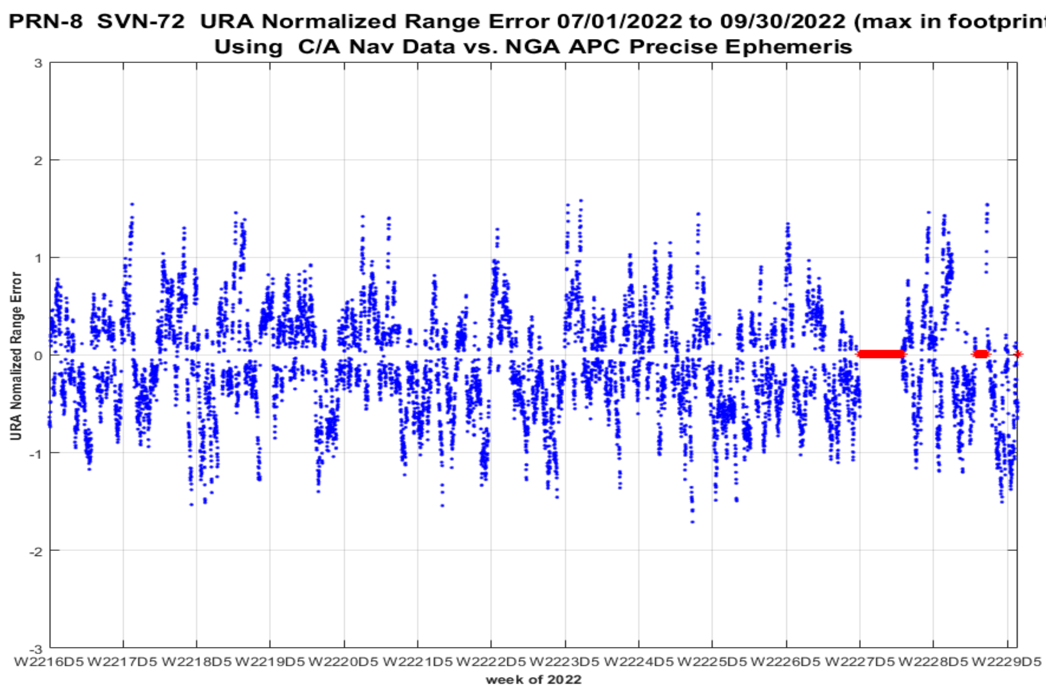


Figure 10-147. Timeline of URA Normalized Range Error PRN8 (SVN72) Using C/A Nav Data

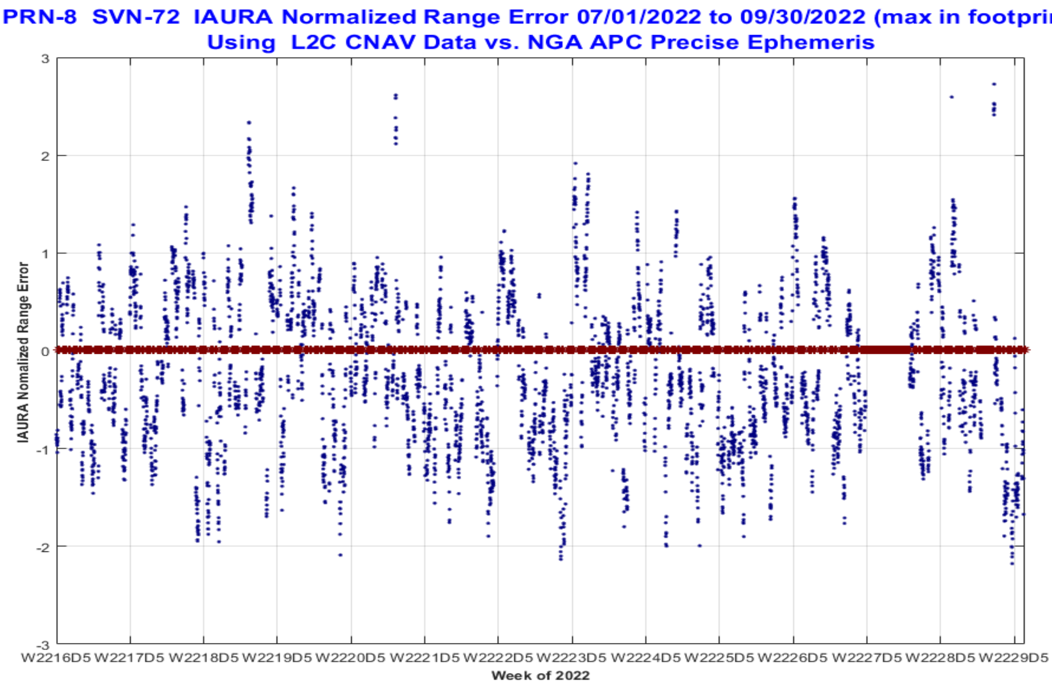


Figure 10-148. Timeline of IAURA Normalized Range Error PRN8 (SVN72) Using L2C CNAV Data

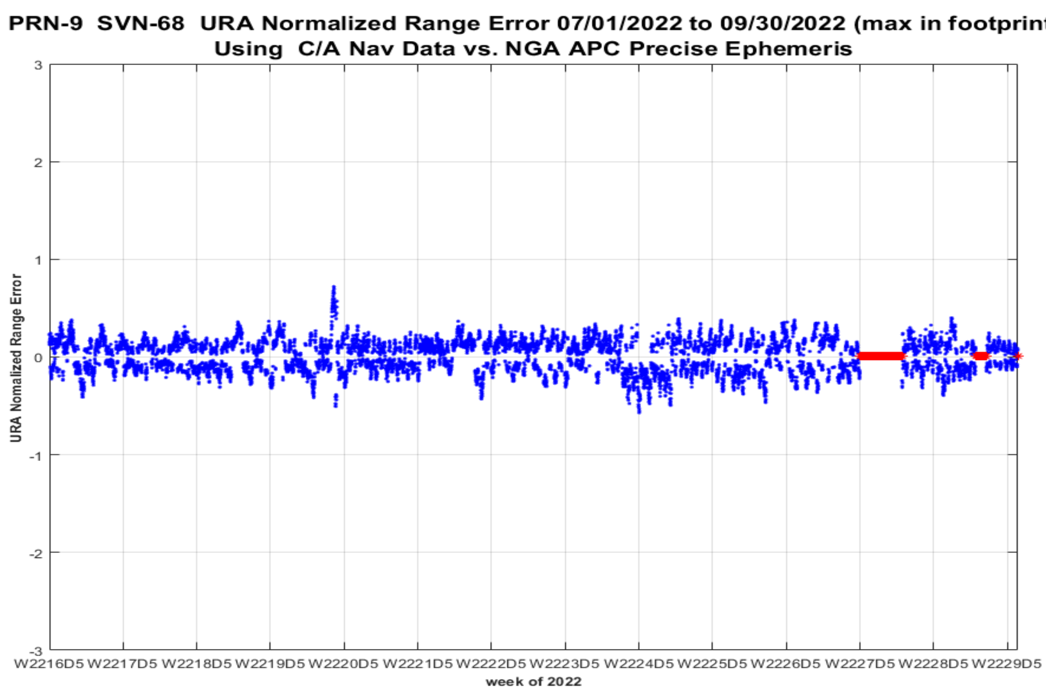


Figure 10-149. Timeline of URA Normalized Range Error PRN9 (SVN68) Using C/A Nav Data

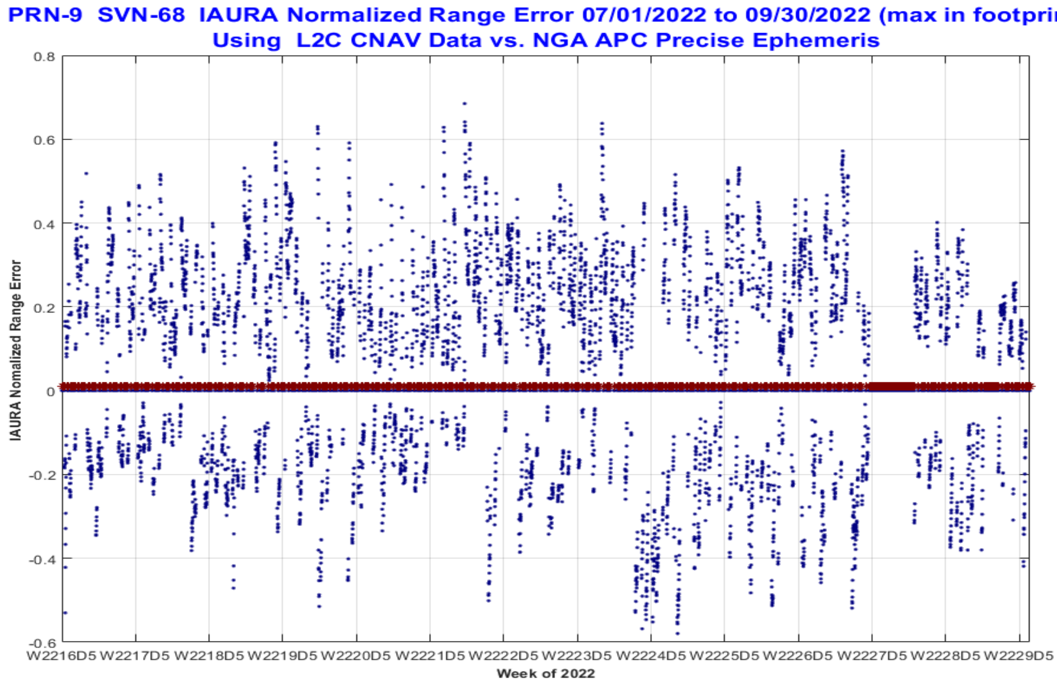


Figure 10-150. Timeline of IAURA Normalized Range Error PRN9 (SVN68) Using L2C CNAV Data

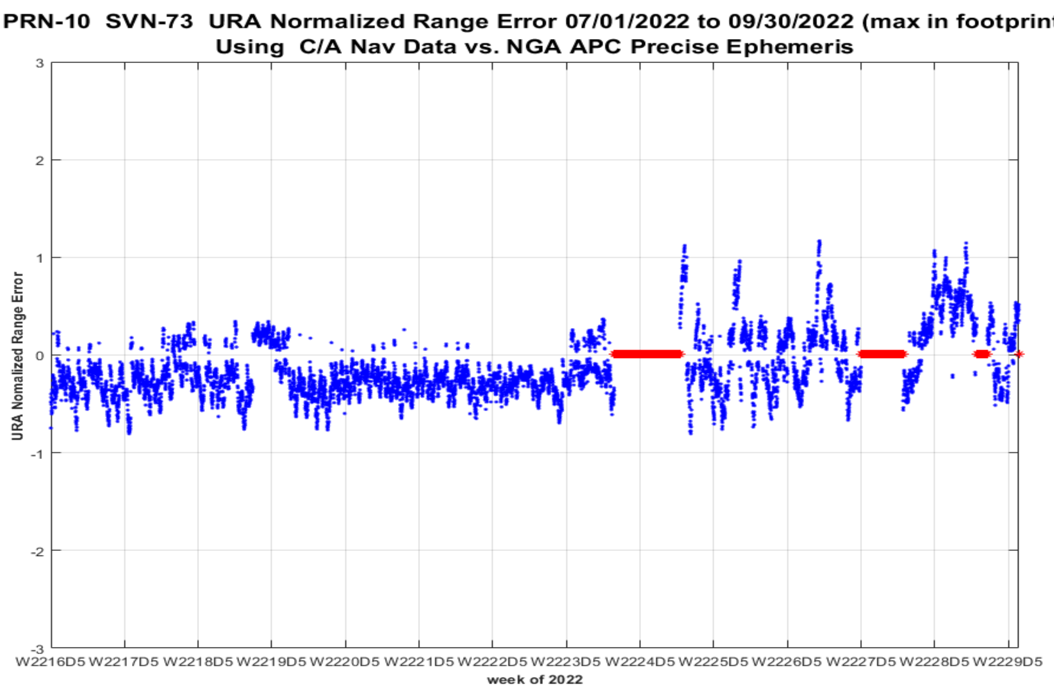


Figure 10-151. Timeline of URA Normalized Range Error PRN10 (SVN73) Using C/A Nav Data

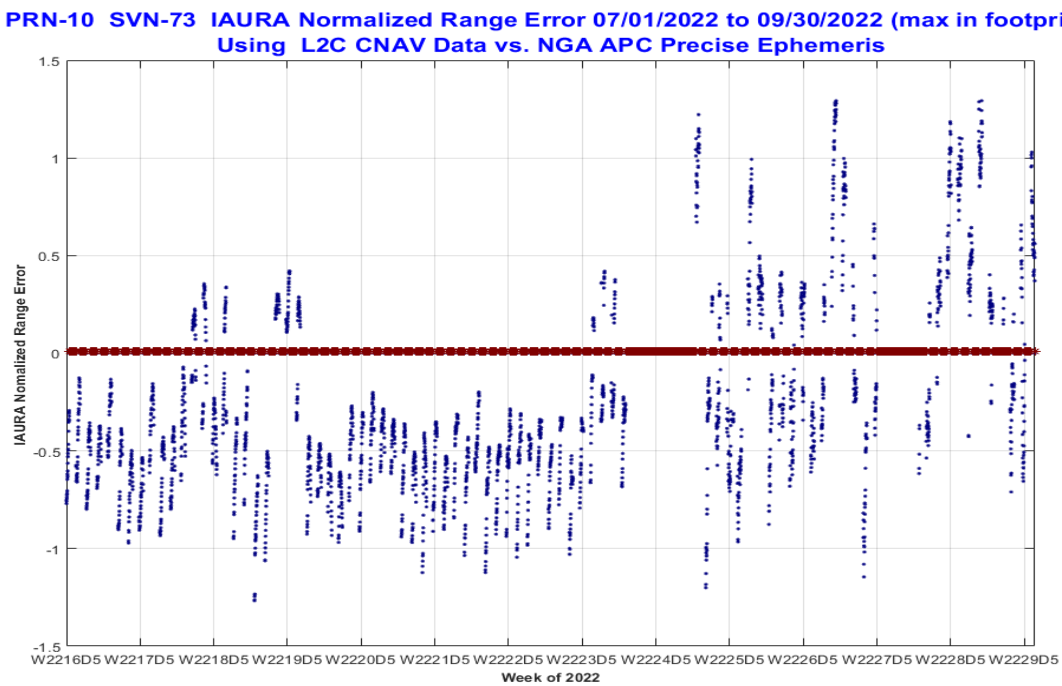


Figure 10-152. Timeline of IAURA Normalized Range Error PRN10 (SVN73) Using L2C CNAV Data

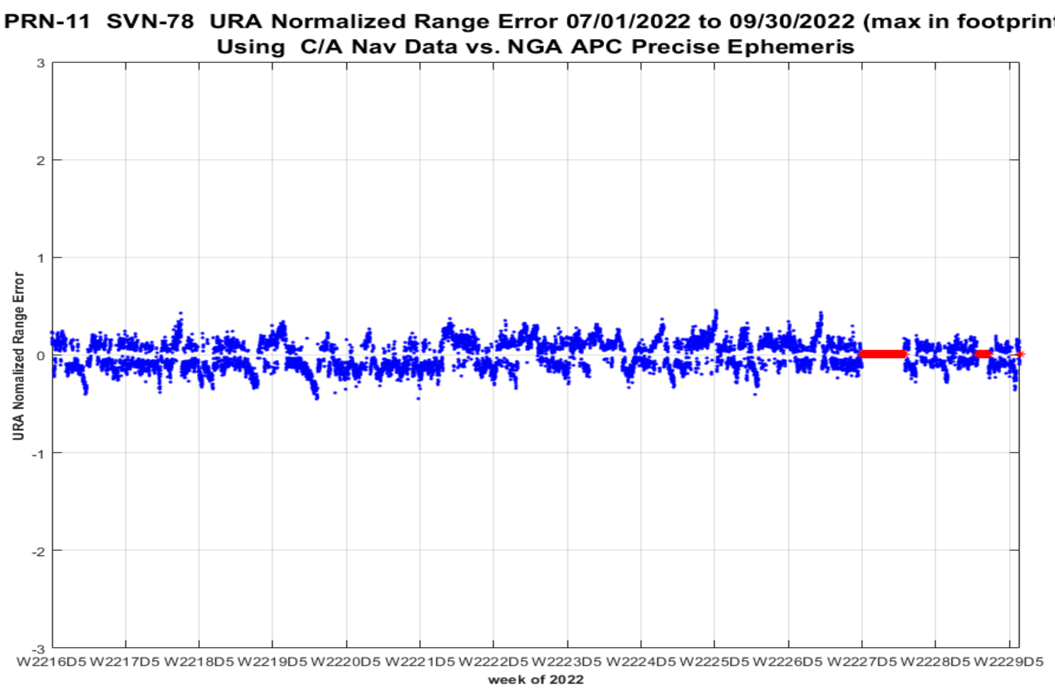


Figure 10-153. Timeline of URA Normalized Range Error PRN11 (SVN78) Using C/A Nav Data

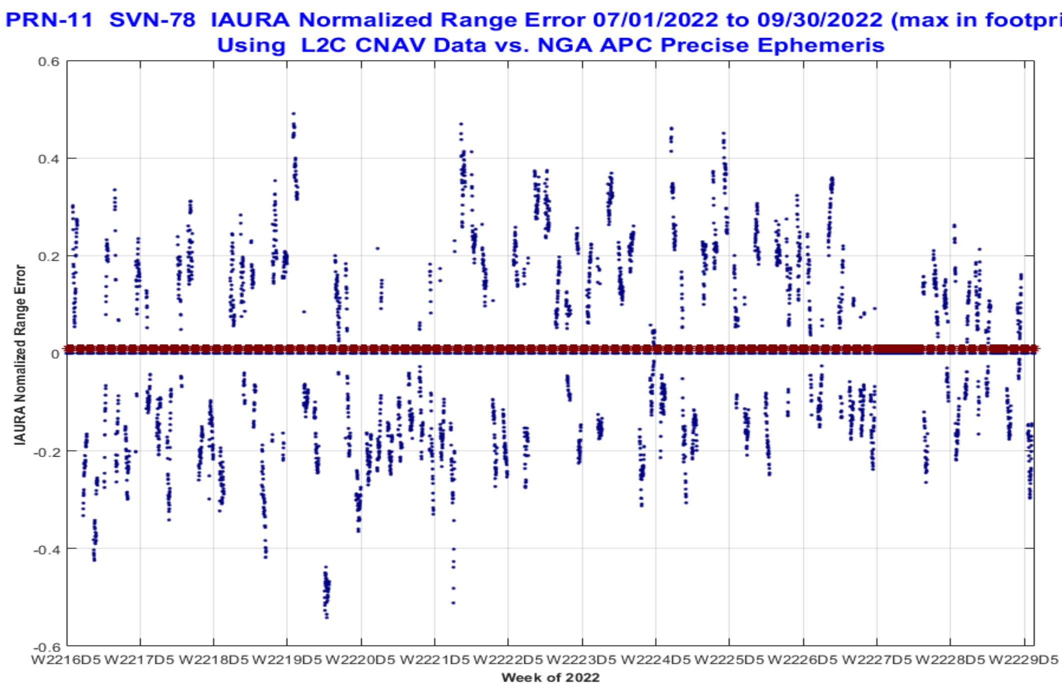


Figure 10-154. Timeline of IAURA Normalized Range Error PRN11 (SVN78) Using L2C CNAV Data

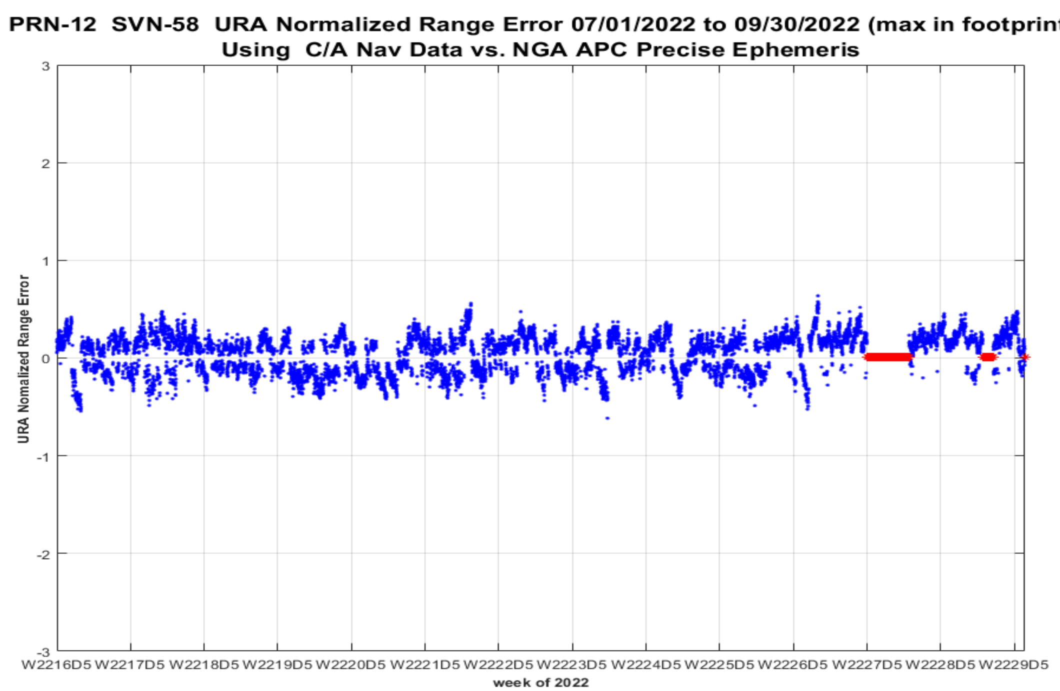


Figure 10-155. Timeline of URA Normalized Range Error PRN12 (SVN58) Using C/A Nav Data

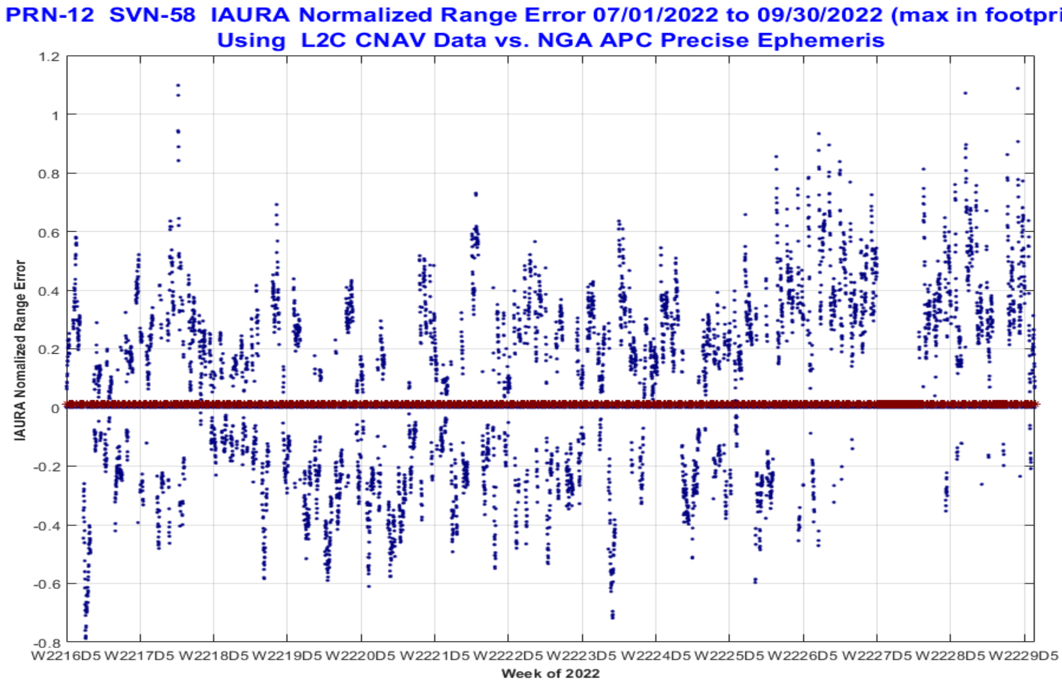


Figure 10-156. Timeline of IAURA Normalized Range Error PRN12 (SVN58) Using L2C CNAV Data

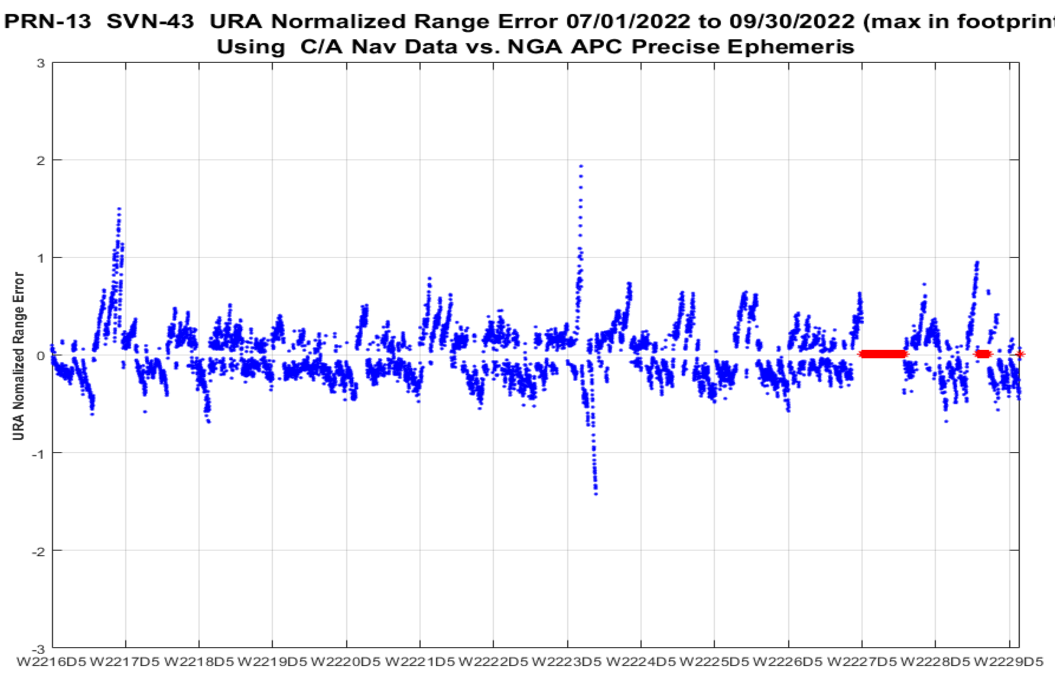


Figure 10-157. Timeline of URA Normalized Range Error PRN13 (SVN43) Using C/A Nav Data

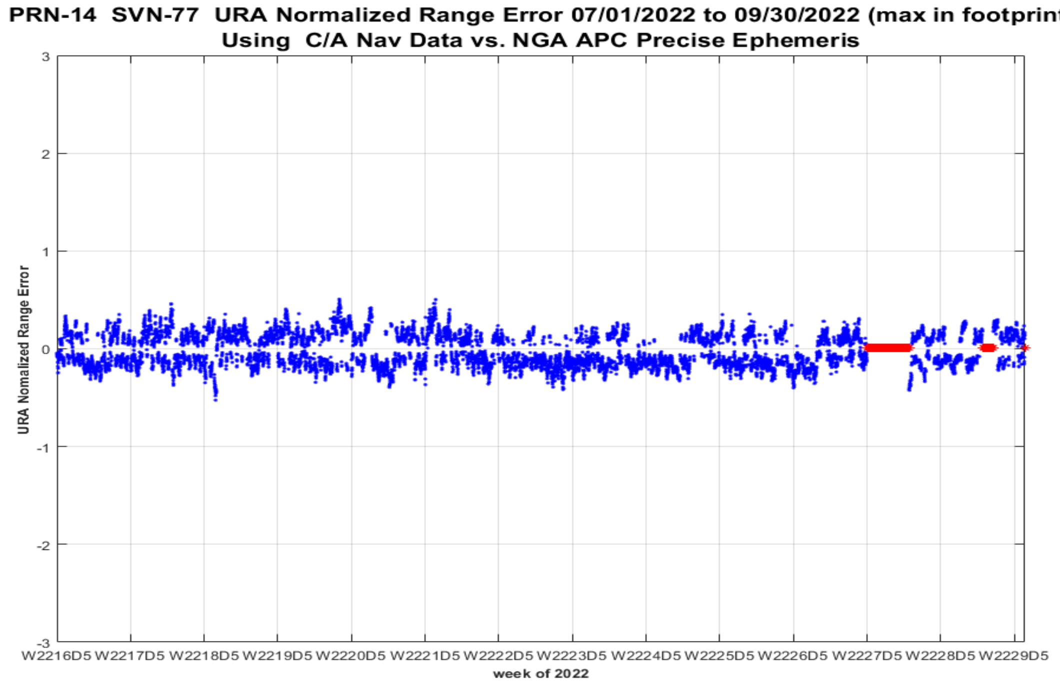


Figure 10-158. Timeline of URA Normalized Range Error PRN14 (SVN77) Using C/A Nav Data

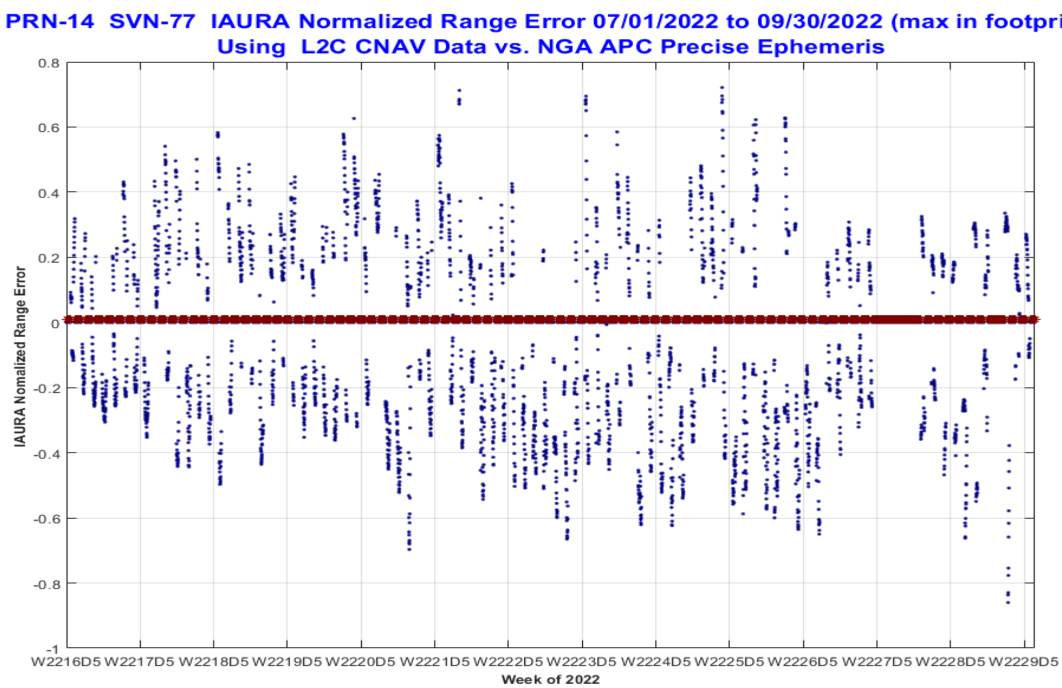


Figure 10-159. Timeline of IAURA Normalized Range Error PRN14 (SVN77) Using L2C CNAV Data

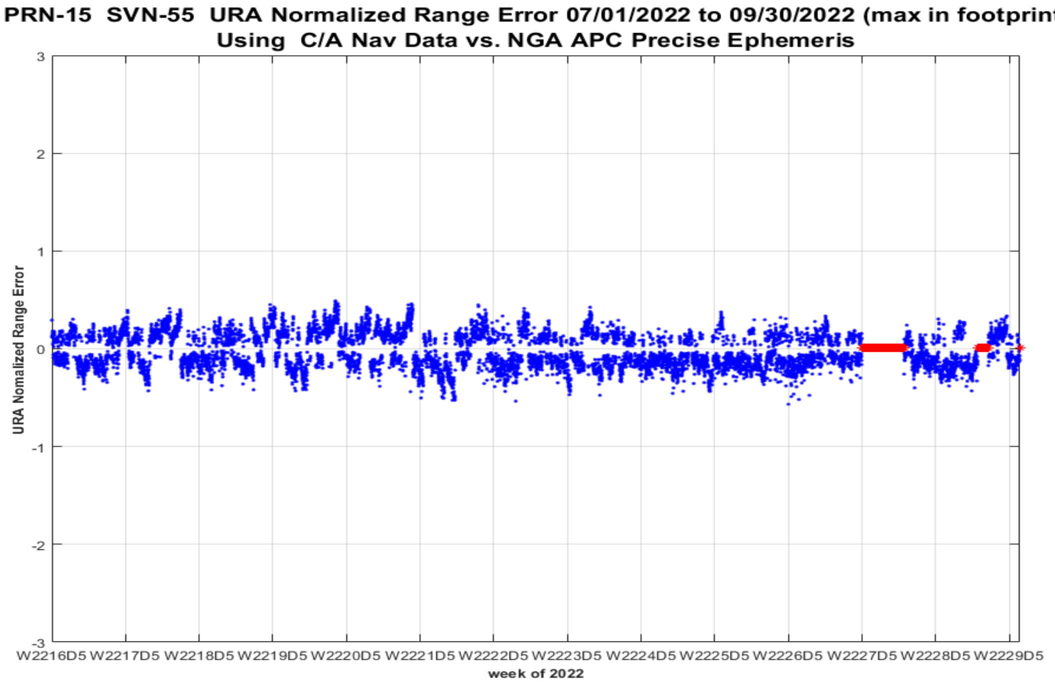


Figure 10-160. Timeline of URA Normalized Range Error PRN15 (SVN55) Using C/A Nav Data

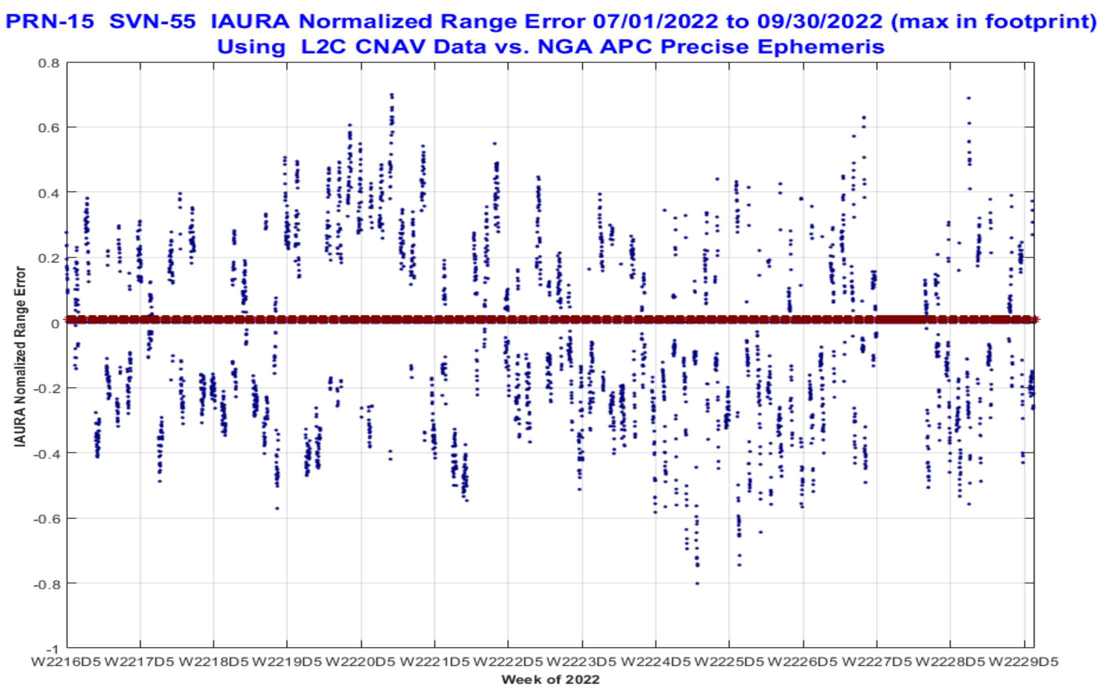


Figure 10-161. Timeline of IAURA Normalized Range Error PRN15 (SVN55) Using L2C CNAV Data

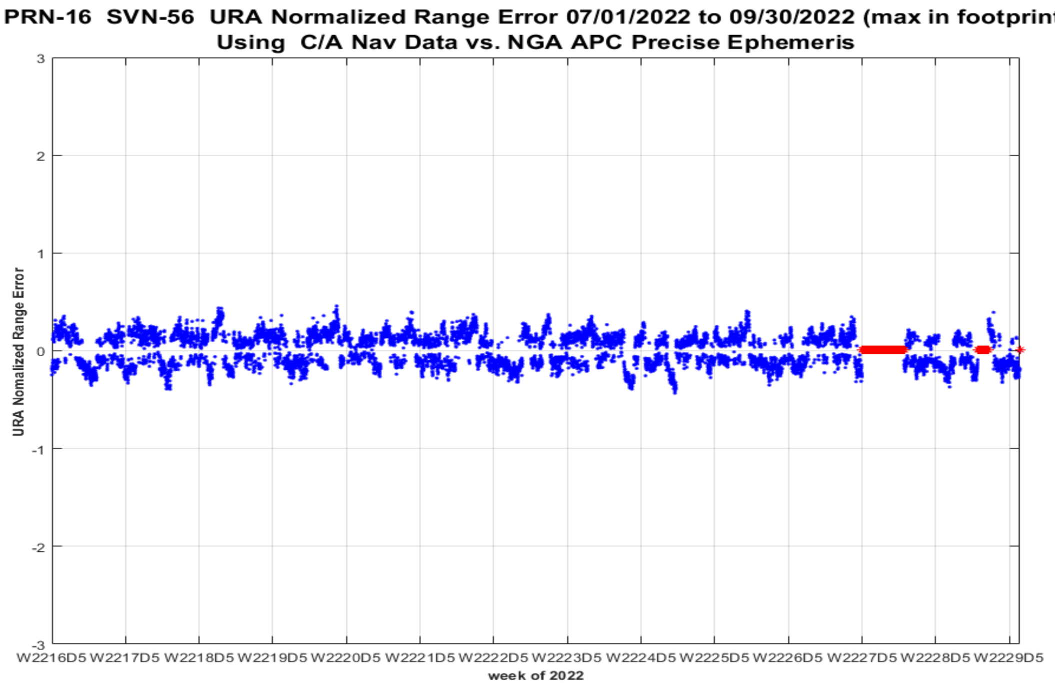


Figure 10-162. Timeline of URA Normalized Range Error PRN16 (SVN56) Using C/A Nav Data

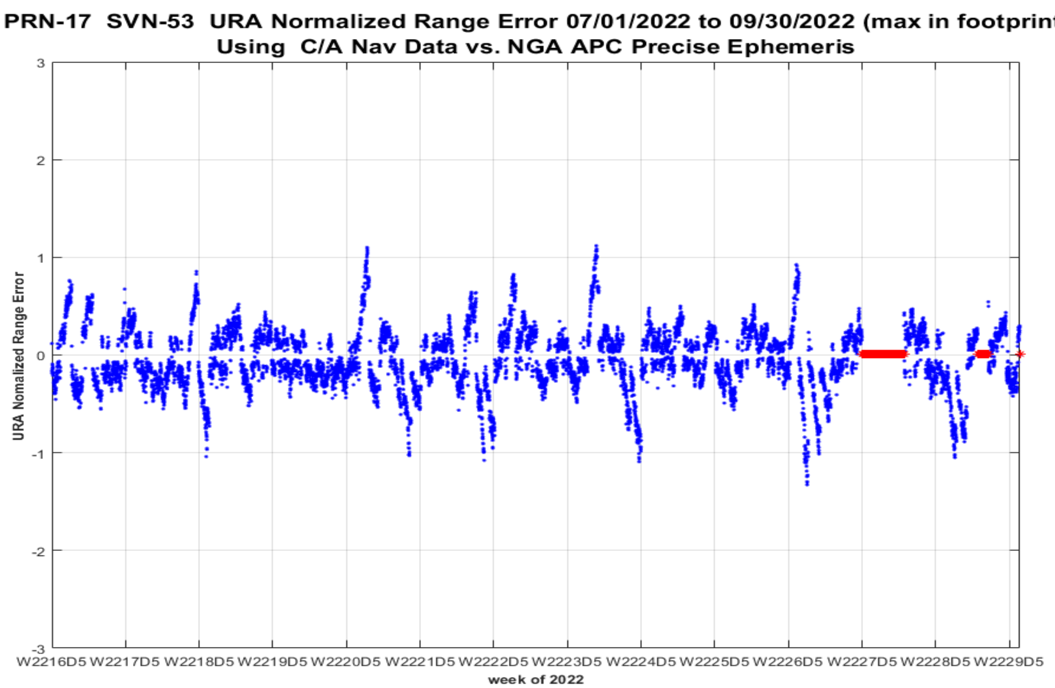


Figure 10-163. Timeline of URA Normalized Range Error PRN17 (SVN53) Using C/A Nav Data

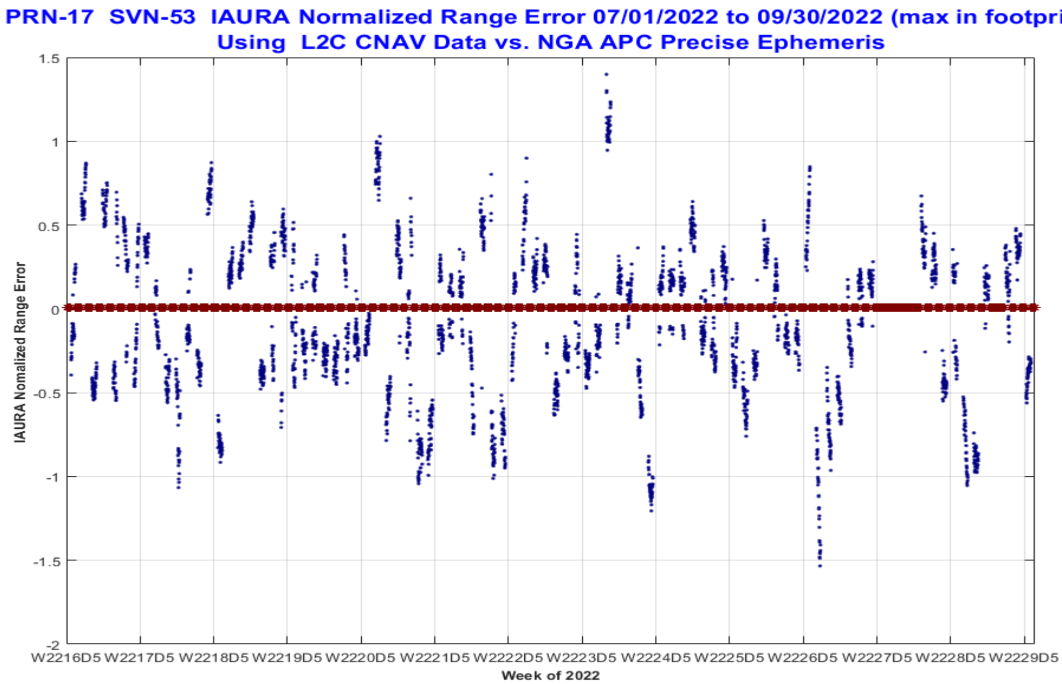


Figure 10-164. Timeline of IAURA Normalized Range Error PRN17 (SVN53) Using L2C CNAV Data

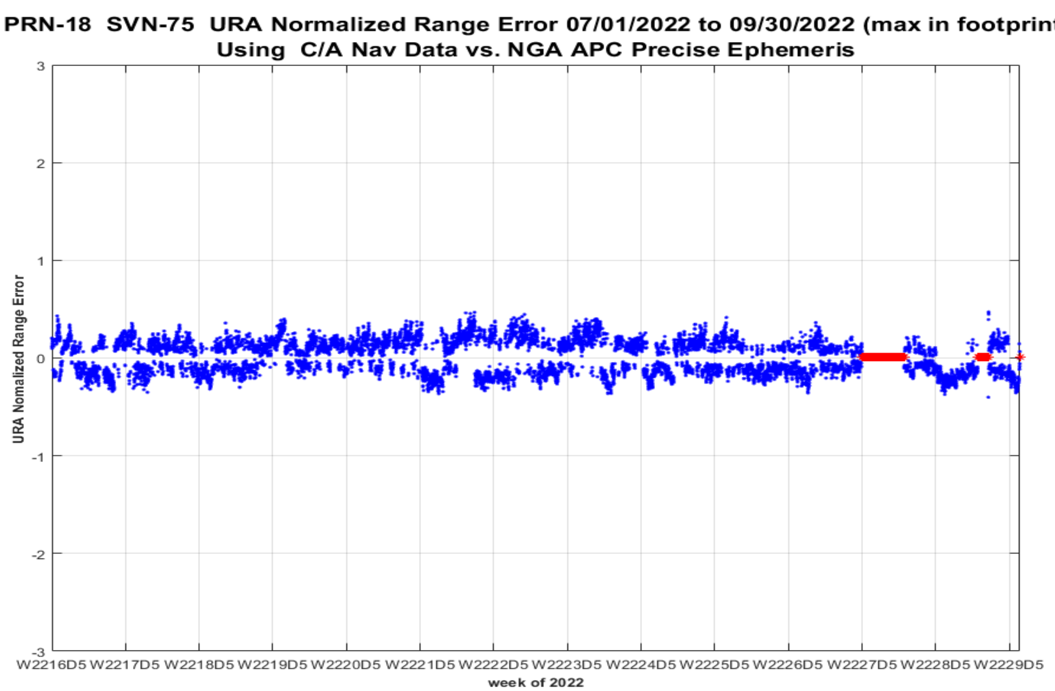


Figure 10-165. Timeline of URA Normalized Range Error PRN18 (SVN75) Using C/A Nav Data

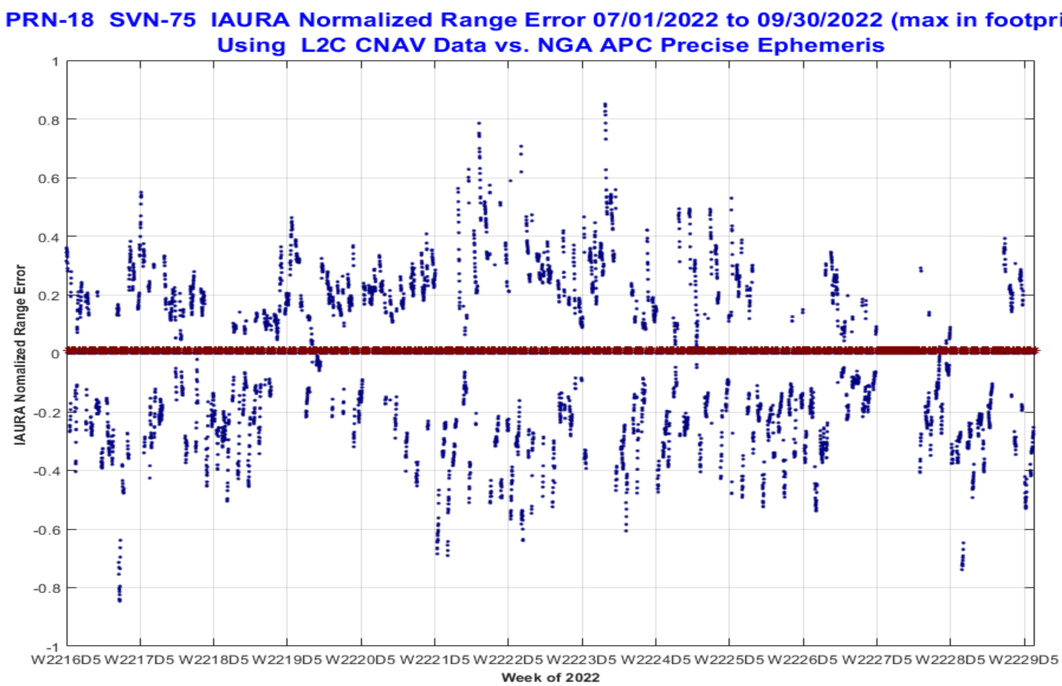


Figure 10-166. Timeline of IAURA Normalized Range Error PRN18 (SVN75) Using L2C CNAV Data

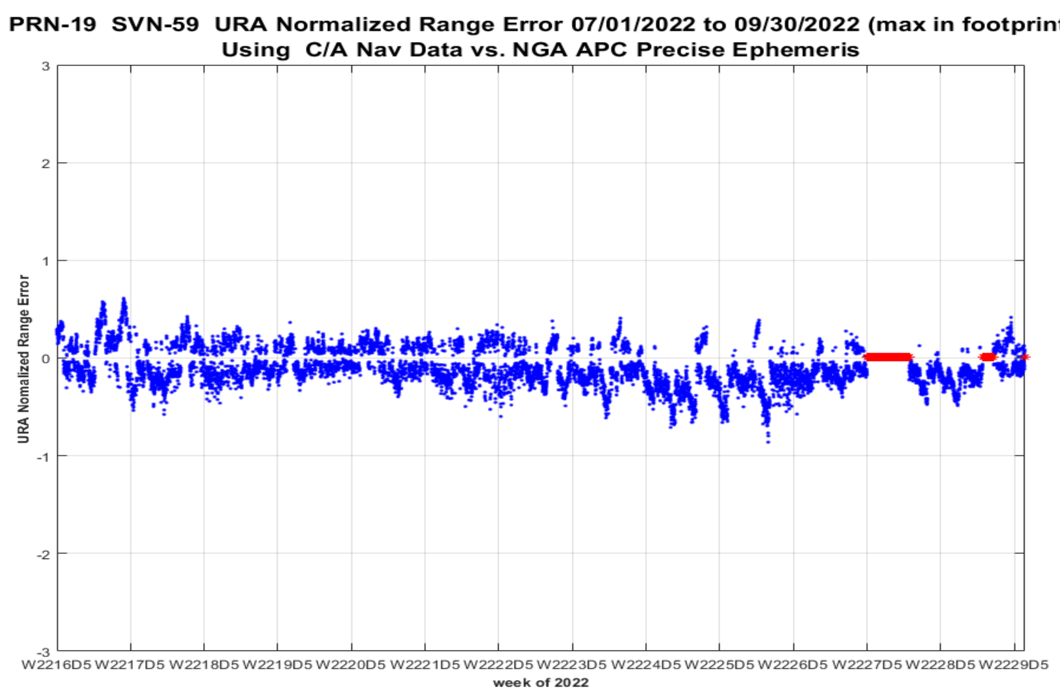


Figure 10-167. Timeline of URA Normalized Range Error PRN19 (SVN59) Using C/A Nav Data

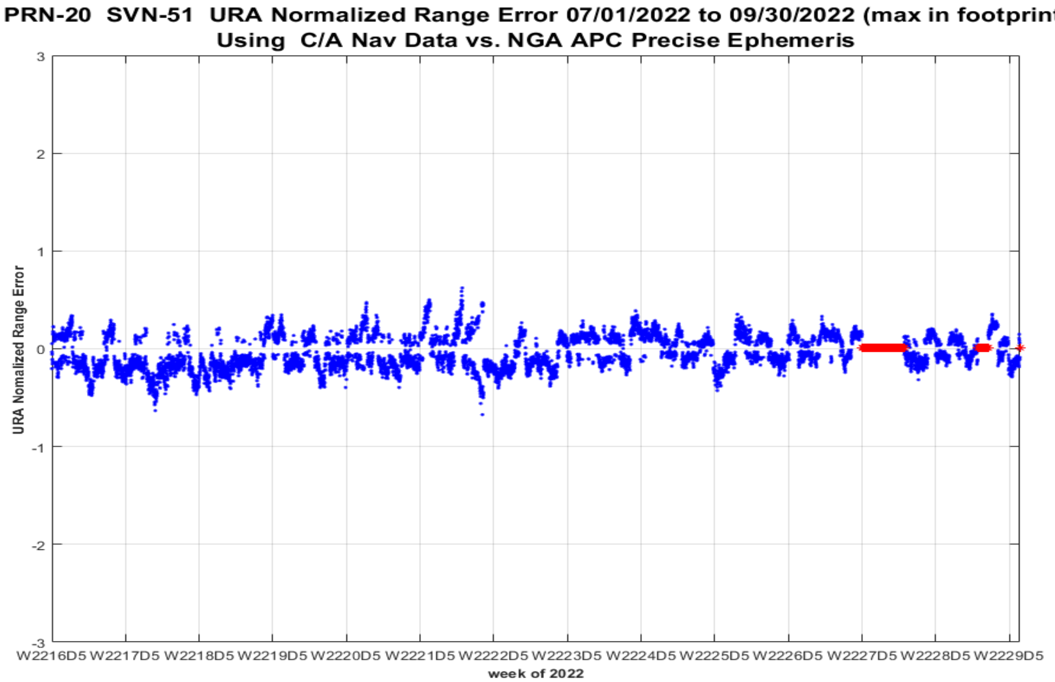


Figure 10-168. Timeline of URA Normalized Range Error PRN20 (SVN51) Using C/A Nav Data

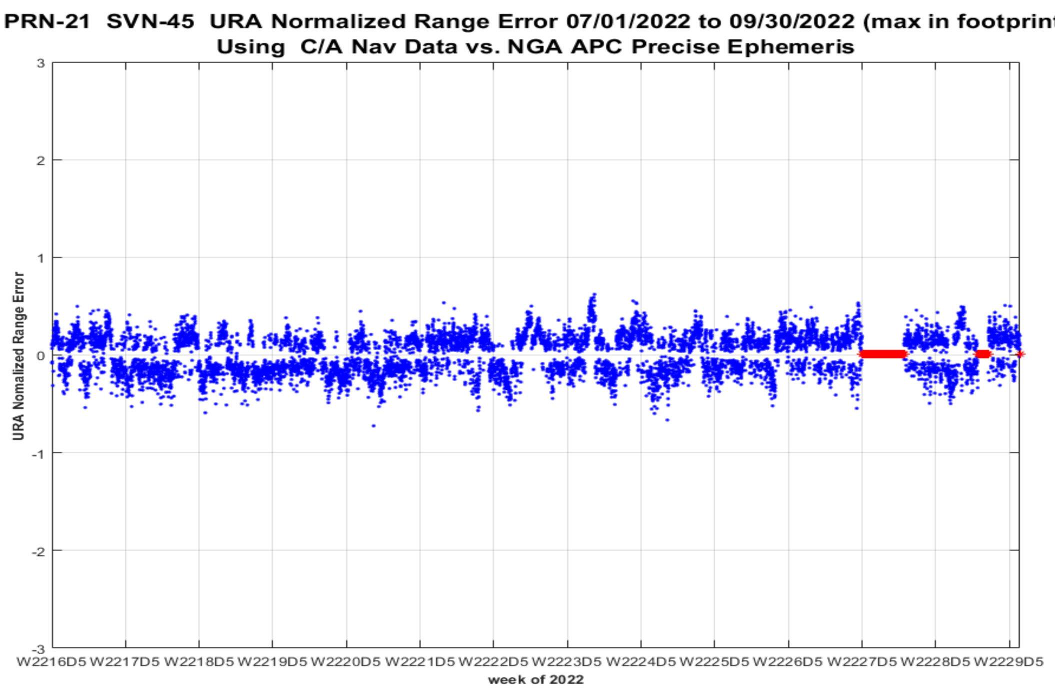


Figure 10-169. Timeline of URA Normalized Range Error PRN21 (SVN45) Using C/A Nav Data

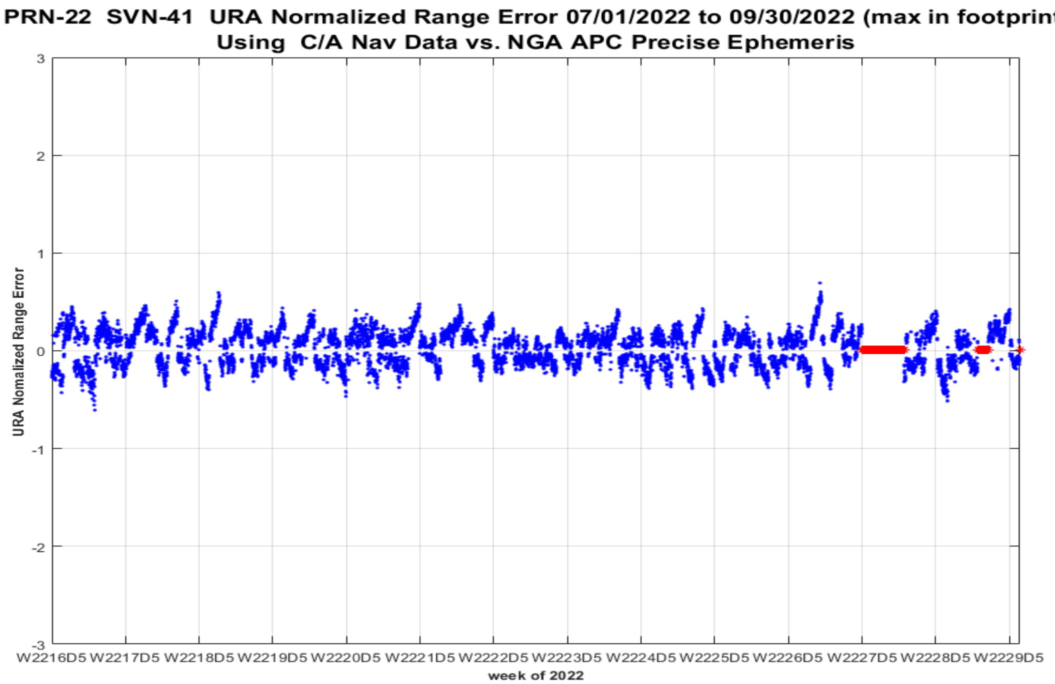


Figure 10-170. Timeline of URA Normalized Range Error PRN22 (SVN41) Using C/A Nav Data

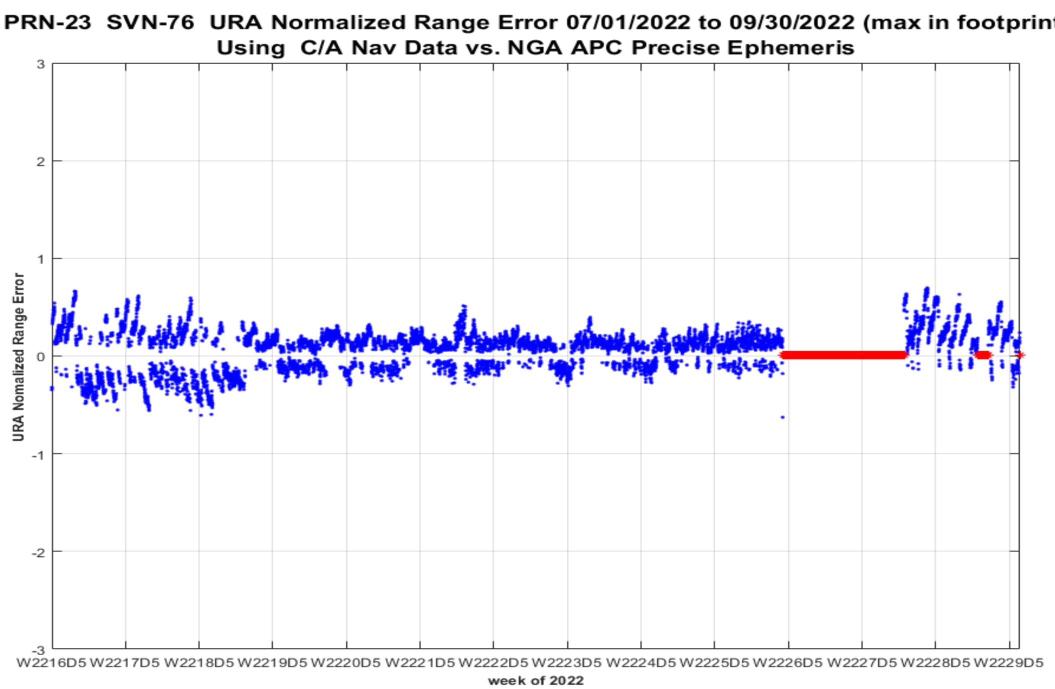


Figure 10-171. Timeline of URA Normalized Range Error PRN23 (SVN76) Using C/A Nav Data

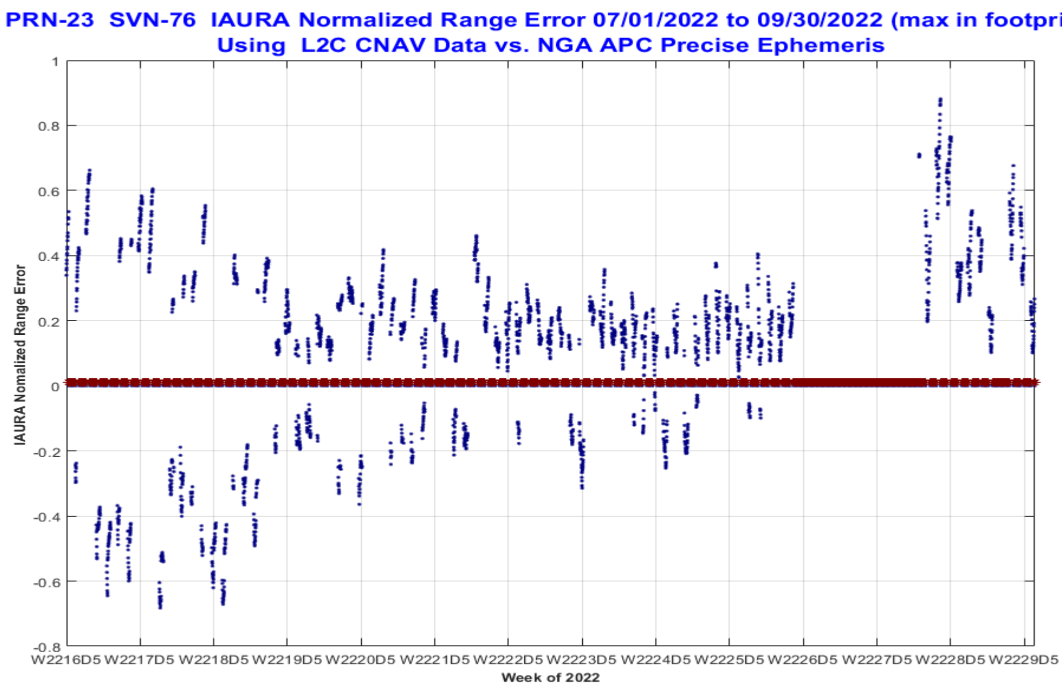


Figure 10-172. Timeline of IAURA Normalized Range Error PRN23 (SVN76) Using L2C CNAV Data

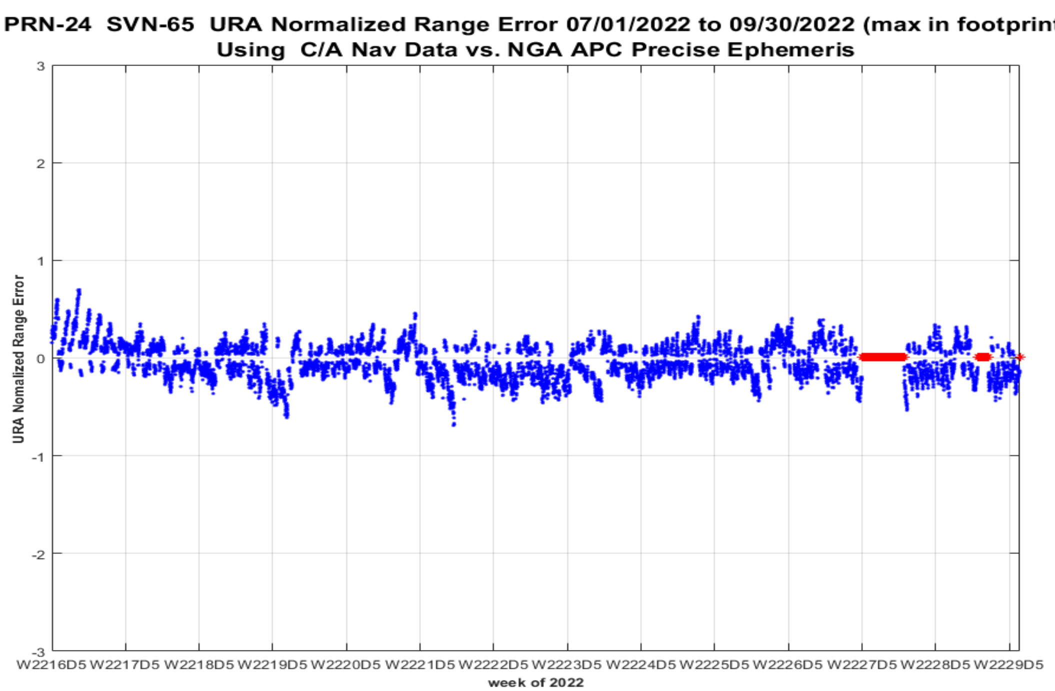


Figure 10-173. Timeline of URA Normalized Range Error PRN24 (SVN65) Using C/A Nav Data

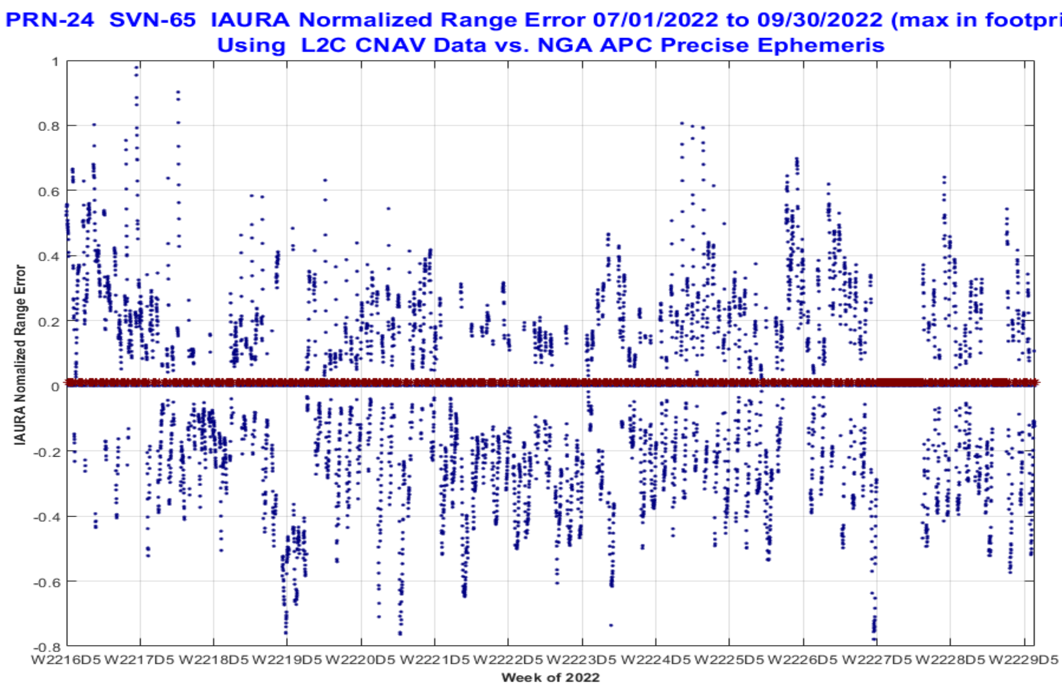


Figure 10-174. Timeline of IAURA Normalized Range Error PRN24 (SVN65) Using L2C CNAV Data

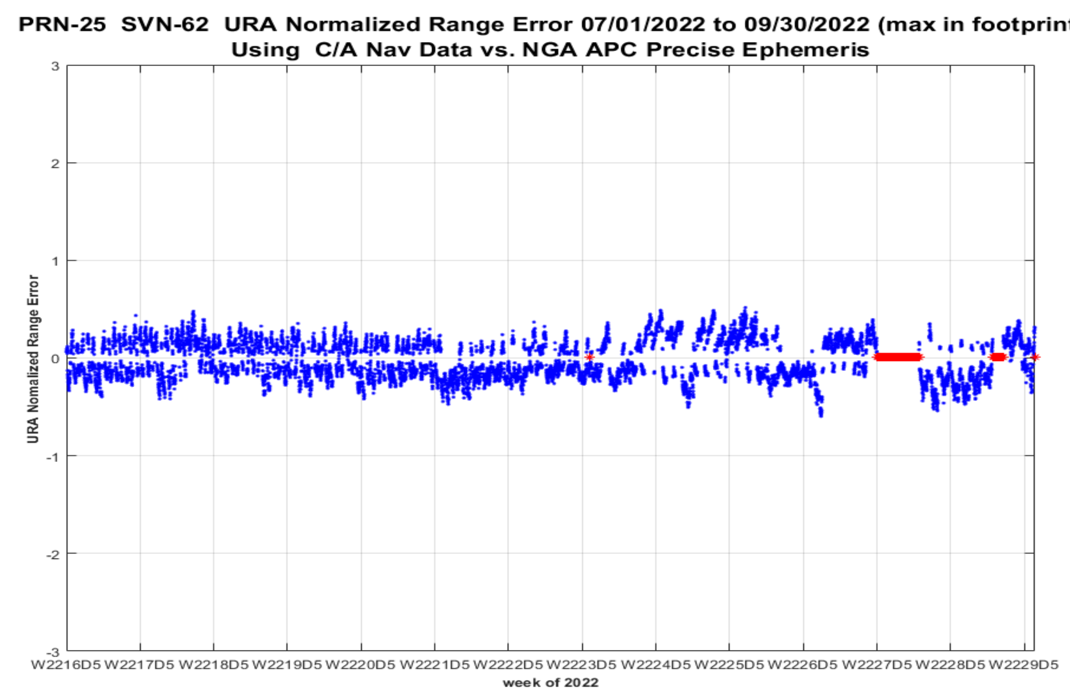


Figure 10-175. Timeline of URA Normalized Range Error PRN25 (SVN62) Using C/A Nav Data

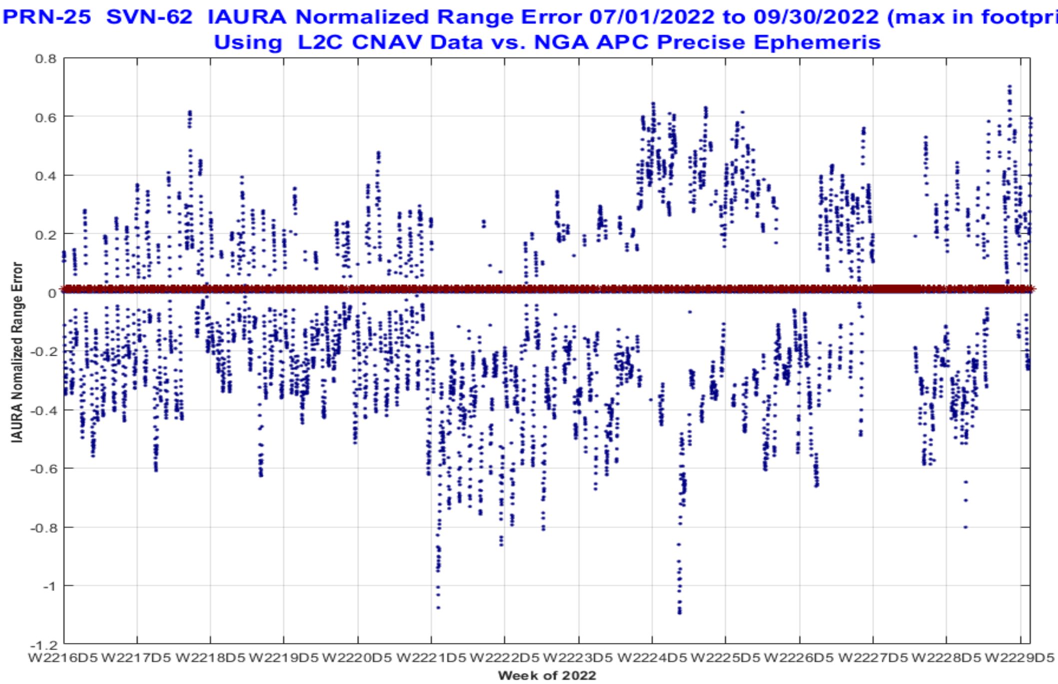


Figure 10-176. Timeline of IAURA Normalized Range Error PRN25 (SVN62) Using L2C CNAV Data

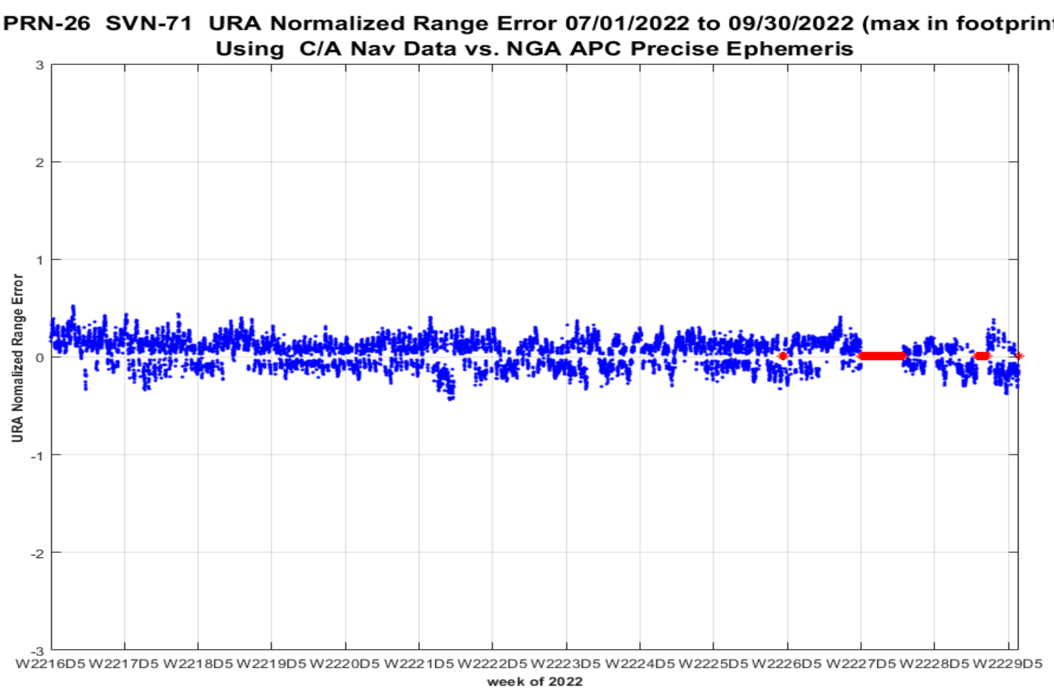


Figure 10-177. Timeline of URA Normalized Range Error PRN26 (SVN71) Using C/A Nav Data

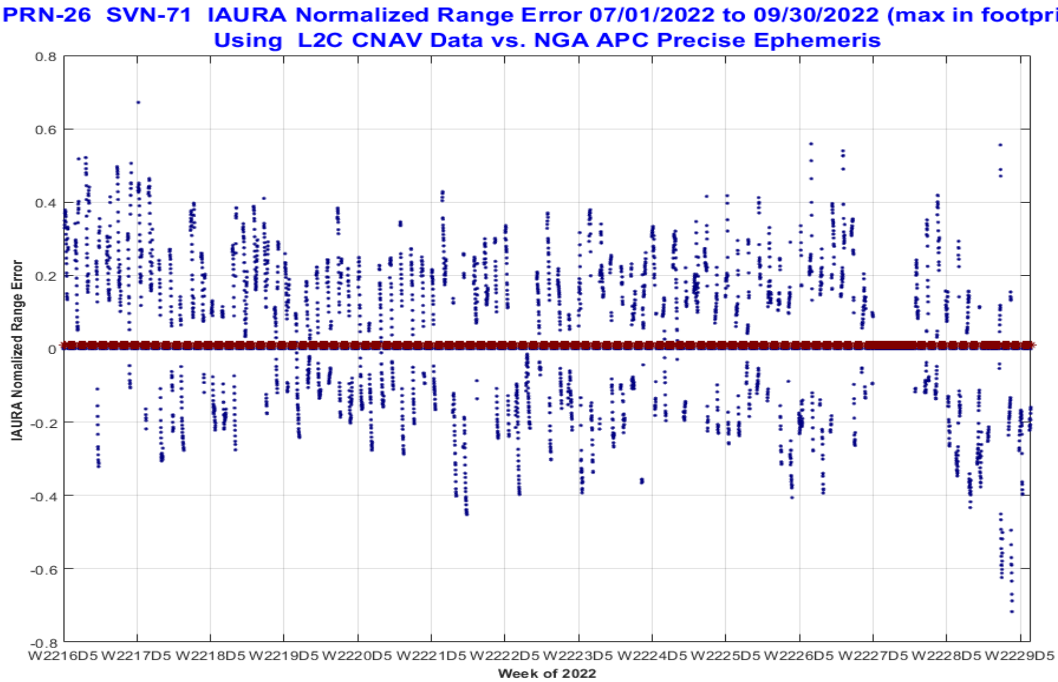


Figure 10-178. Timeline of IAURA Normalized Range Error PRN26 (SVN71) Using L2C CNAV Data

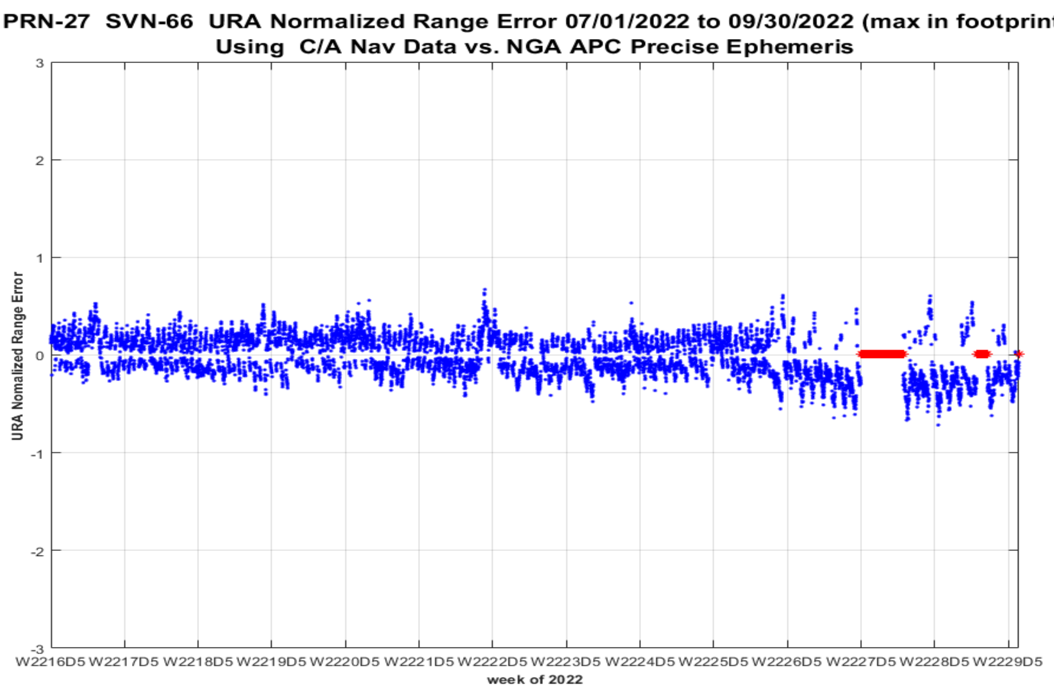


Figure 10-179. Timeline of URA Normalized Range Error PRN27 (SVN66) Using C/A Nav Data

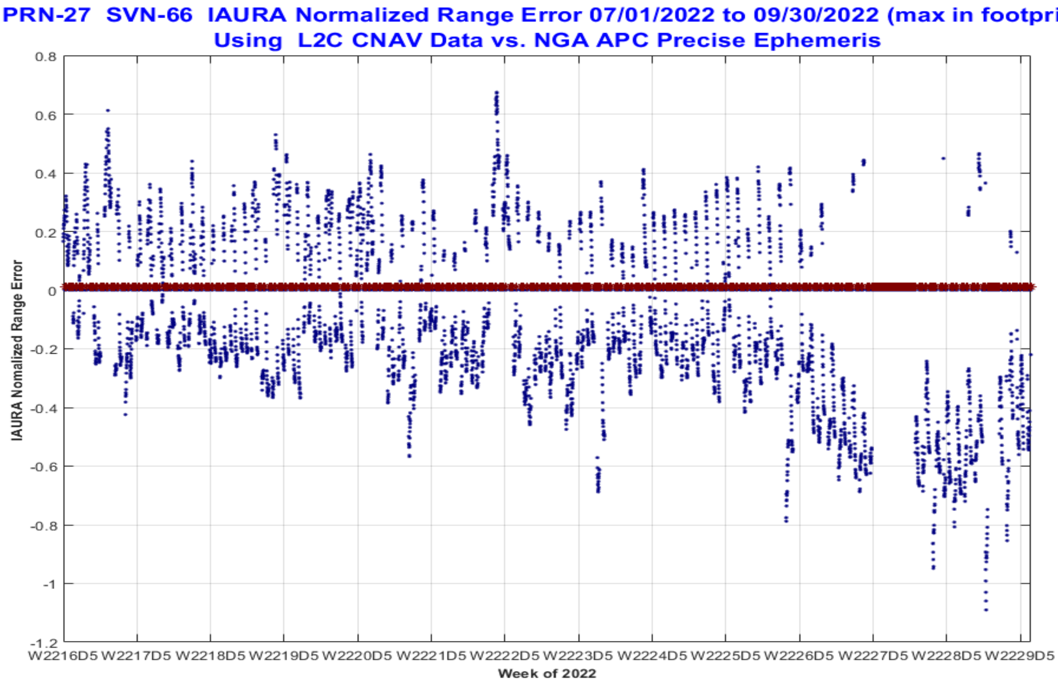


Figure 10-180. Timeline of IAURA Normalized Range Error PRN27 (SVN66) Using L2C CNAV Data

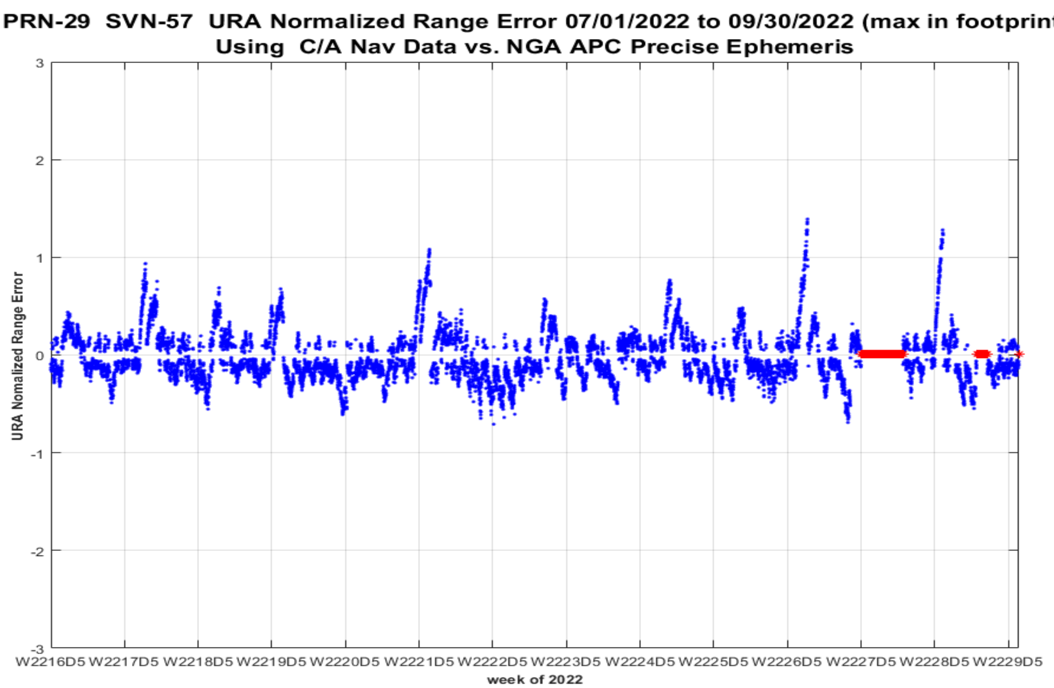


Figure 10-181. Timeline of URA Normalized Range Error PRN29 (SVN57) Using C/A Nav Data

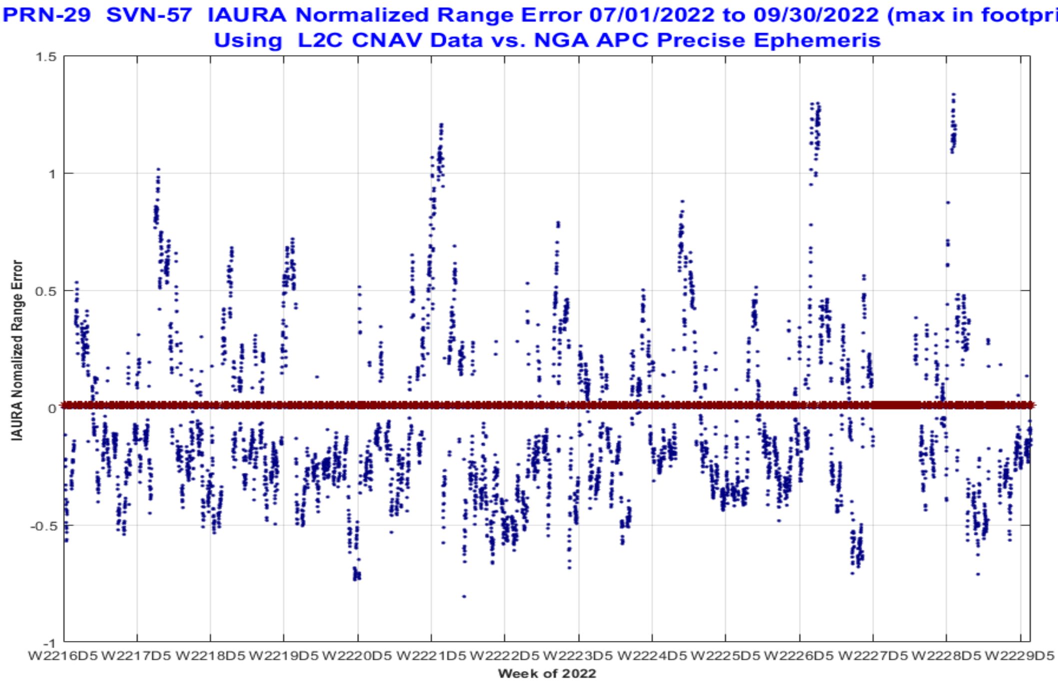


Figure 10-182. Timeline of IAURA Normalized Range Error PRN29 (SVN57) Using L2C CNAV Data

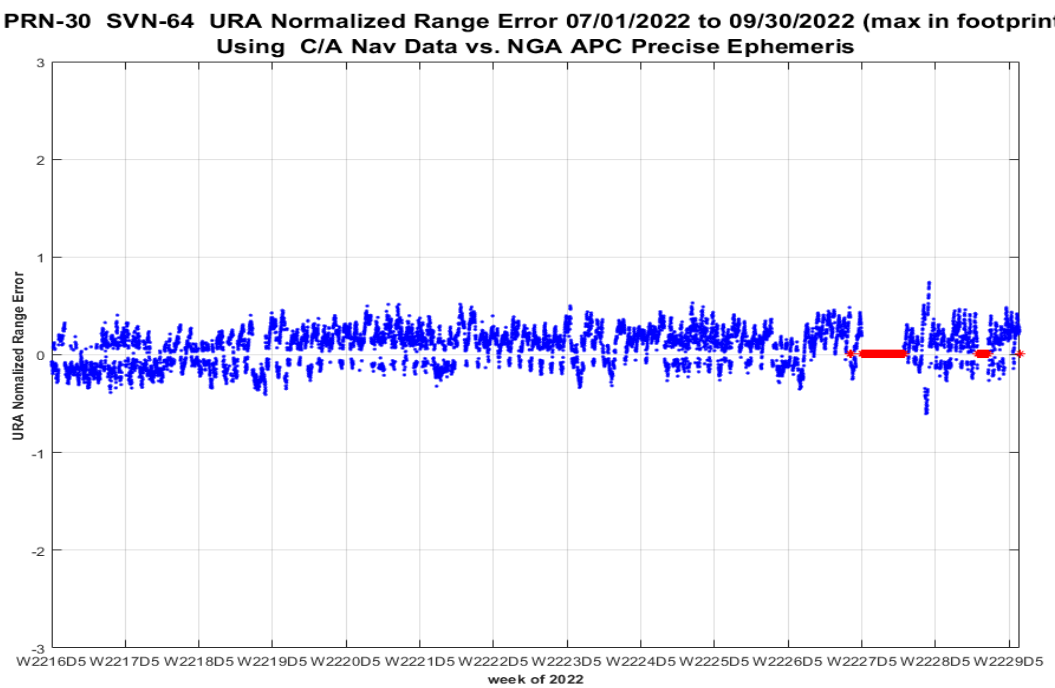


Figure 10-183. Timeline of URA Normalized Range Error PRN30 (SVN64) Using C/A Nav Data

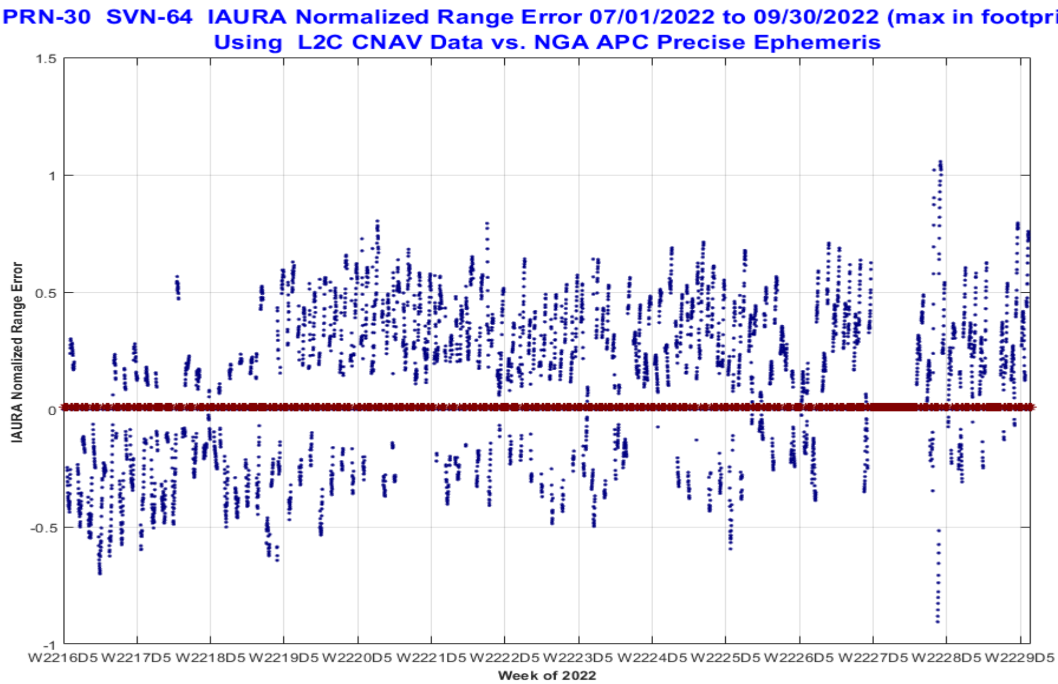


Figure 10-184. Timeline of IAURA Normalized Range Error PRN30 (SVN64) Using L2C CNAV Data

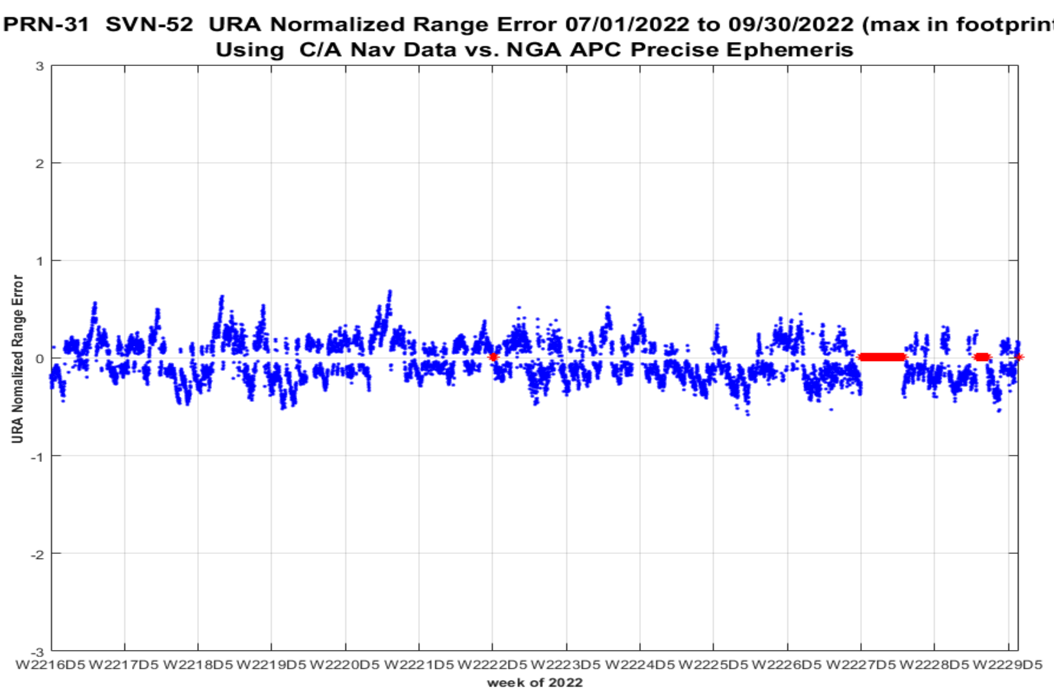


Figure 10-185. Timeline of URA Normalized Range Error PRN31 (SVN52) Using C/A Nav Data

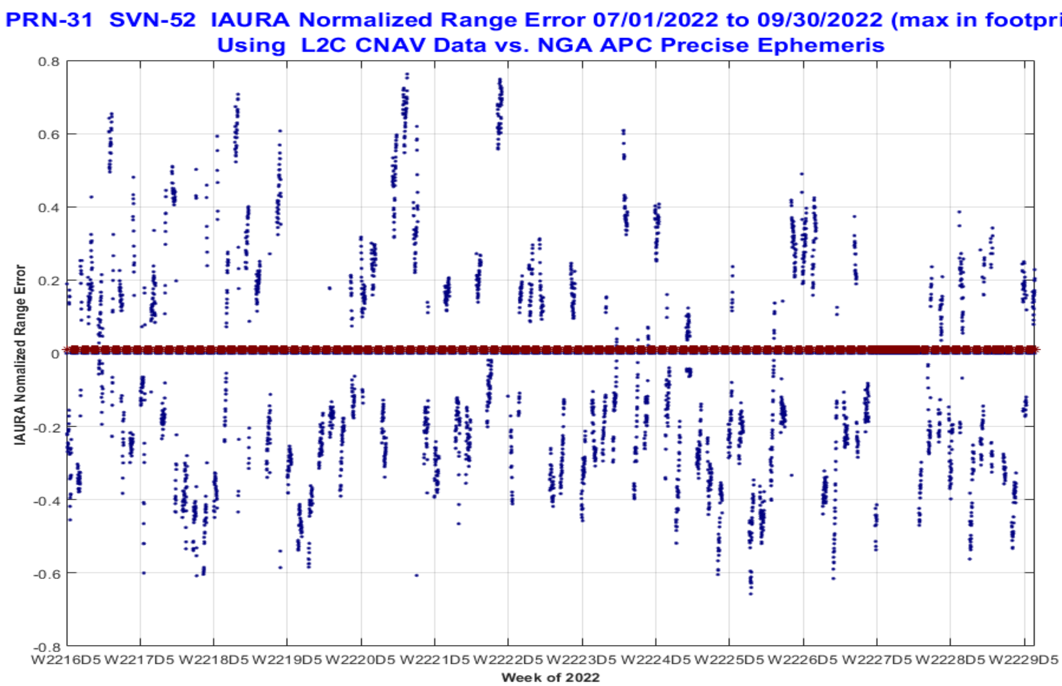


Figure 10-186. Timeline of IAURA Normalized Range Error PRN31 (SVN52) Using L2C CNAV Data

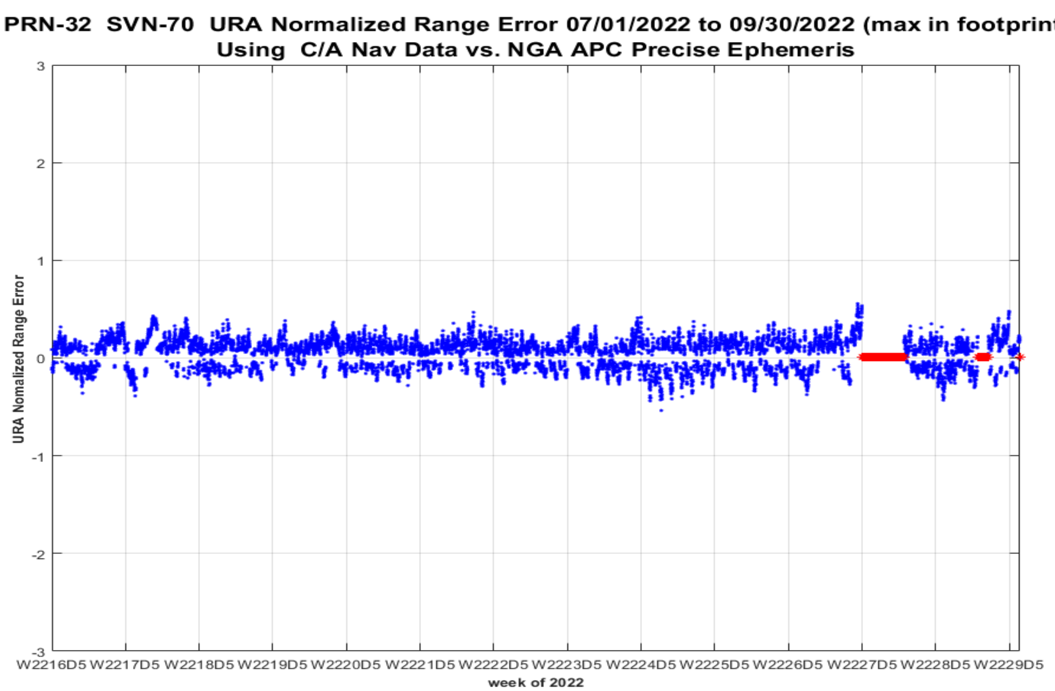


Figure 10-187. Timeline of URA Normalized Range Error PRN32 (SVN70) Using C/A Nav Data

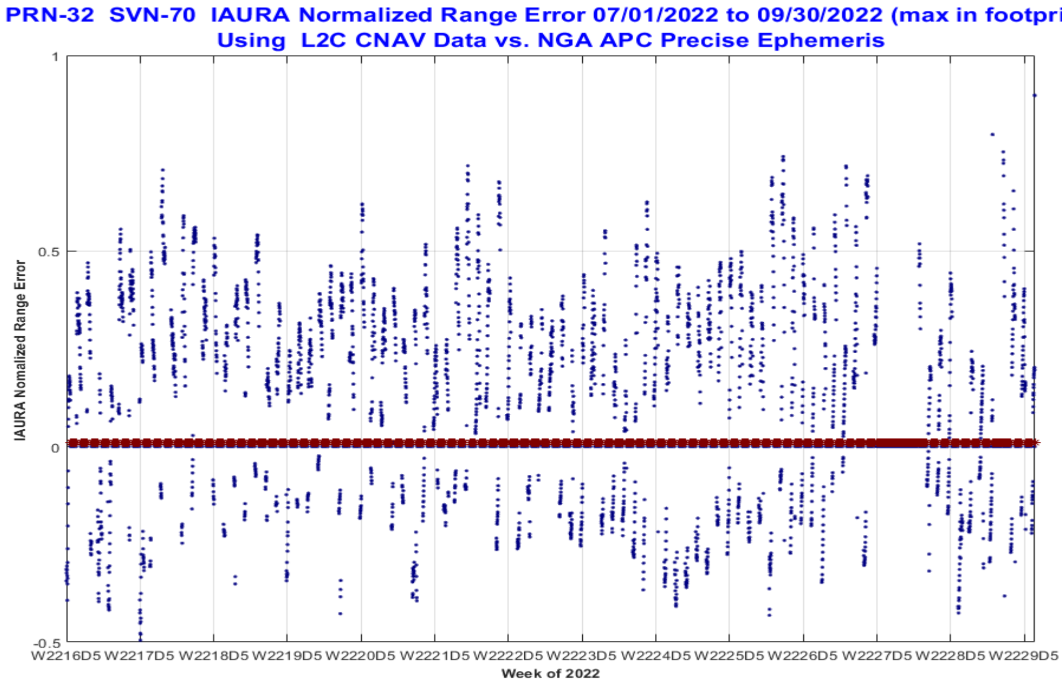


Figure 10-188. Timeline of IAURA Normalized Range Error PRN32 (SVN70) Using L2C CNAV Data

APPENDIX A: PERFORMANCE SUMMARY

Table A-1. Performance Summary

Parameter	Measured Performance	Conditions and Constraints
User Range Error Accuracy Single-Frequency C/A-Code 1. ≤7.8m 95% Global Average URE during normal operations over All AODs 2. ≤6.0m 95% Global Average URE during operations at Zero AOD 3. ≤12.8m 95% Global Average URE during normal operations at Any AOD	1. ≤3.145m 2. N/A 3. N/A	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.
User Range Error Accuracy Single-Frequency C/A-Code 1. ≤30m 99.94% Global Average URE during normal operations 2. ≤30m 99.79% Worst Case single point average during normal operations	1. 100% Global 2. 100% WCP	For any healthy SPS SIS. Neglecting single-frequency ionospheric delay model errors. Including group delay time correction (T_{GD}) 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 Single-Frequency C/A Code: ≤6mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	≤3.186mm/sec	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.

Parameter	Measured Performance	Conditions and Constraints
User Range Acceleration Error Accuracy Single-Frequency C/A Code: ≤2mm/sec^2 95% Global Average URAE over any 3-second interval during normal operations at Any AOD	≤25.491mm/s^2	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.
Per-Satellite Coverage Terrestrial Service Volume: 100% Coverage	100%	For any healthy or marginal SPS SIS.
Constellation Coverage Terrestrial Service Volume: 100% Coverage	100%	For any healthy or marginal SPS SIS.
Status and Problem Reporting Scheduled event affecting service Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	≥64.9 hours Prior to event	For any SPS SIS.
Status and Problem Reporting Unscheduled outage or problem affecting service Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	≤0.617 hours	For any SPS SIS.
Status and Problem Reporting Unscheduled Failure Interruption Continuity: ≥0.9998 Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption.	100%	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.

Parameter	Measured Performance	Conditions and Constraints
Operational Satellite Count ≥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.	100%	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 1. ≥98% global PDOP of 6 or less 2. ≥88% worst site PDOP of 6 or less	1. 100% 2. 100%	Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.
Service Availability 1. ≥99% Horizontal Service Availability, average location 2. ≥99% Vertical Service Availability, average location	1. 100% Horizontal 2. 100% Vertical	15m Horizontal (SIS only) 95% threshold. 33m 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.
Service Availability 1. ≥90% Horizontal Service Availability, worst-case location 2. ≥90% Vertical Service Availability, worst-case location	1. 100% Horizontal 2. 100% Vertical	15m Horizontal (SIS only) 95% threshold. 33m 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.

Parameter	Measured Performance	Conditions and Constraints
Position/Time Accuracy Global Average Position Domain Accuracy: 1. ≤8m 95% Horizontal Error 2. ≤13m 95% Vertical Error	1. ≤2. 654m Horizontal 2. ≤3.979m Vertical	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.
Position/Time Accuracy Worst Site Position Domain Accuracy: 1. ≤15m 95% Horizontal Error 2. ≤33m 95% Vertical Error	1. ≤5.910m Horizontal 2. ≤5.110m Vertical	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.
Position/Time Accuracy Time Transfer Domain Accuracy: ≤30 nanoseconds time transfer error 95% of time (SIS only)	≤8.6 nanoseconds	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.
Position/Time Accuracy Instantaneous UTCOE Integrity: NTE ±120 nanoseconds 99.999% of time without a timely alert. (SIS only)	≤2.8 nanoseconds	For any healthy SPS SIS. Worst case for delayed alert is 6 hours.

Parameter	Measured Performance	Conditions and Constraints
Per-Slot Availability 1. ≥0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS 2. ≥0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a healthy SPS SIS	1. 100% 2. 100%	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 1. ≥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. 2. ≥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.	1. 100% 2. 100%	Calculated as an average over all slots in the 24-slot constellation, normalized annually. Applied to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.

APPENDIX B: GEOMAGNETIC DATA

```
Product: Daily Geomagnetic Data     quar_DGD.txt
Issued: 2130 UT 07 Oct 2022
  Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
  Please send comment and suggestions to SWPC.Webmaster@noaa.gov
#              Current Quarter Daily Geomagnetic Data

#

#                 Middle Latitude        High Latitude          Estimated
#               - Fredericksburg -     ---- College ----      --- Planetary ---
#  Date          A     K-indices        A     K-indices        A     K-indices
2022 07 01      8  1 0 0 2 2 3 3 3     3  1 1 0 0 0 0 2 2     7  2 1 1 1 1 2 3 3
2022 07 02     17  4 4 4 3 2 3 1 3    25  4 5 5 4 3 4 2 1    19  4 5 4 3 2 3 1 3
2022 07 03     11  3 0 2 2 3 2 2 4     4  2 0 1 1 1 1 1 2     8  2 0 1 2 2 1 2 4
2022 07 04     18  3 4 4 3 3 3 3 3    30  3 6 4 2 5 4 4 2    21  3 5 4 3 3 4 4 3
2022 07 05      4  1 0 0 2 2 2 1 1     3  1 1 1 1 0 1 1 1     4  1 1 1 1 1 1 1 1
2022 07 06      5  1 2 1 2 2 2 1 1     4  1 0 2 3 0 1 0 0     5  1 1 2 2 1 1 1 0
2022 07 07     15  1 0 3 3 5 3 2 3    46  0 0 2 3 6 6 7 5    20  0 1 2 2 5 4 4 5
2022 07 08     14  3 4 3 3 2 2 3 2    26  5 5 3 5 4 2 3 1    19  5 5 3 3 3 2 3 2
2022 07 09      6  2 1 0 1 3 2 1 2     6  1 2 0 0 3 3 1 1     6  1 1 0 1 3 2 1 2
2022 07 10      8  0 1 3 2 3 2 2 2    14  1 2 3 4 5 1 2 1     7  1 1 3 2 3 1 2 1
2022 07 11     10  1 0 1 3 3 3 3 3    10  1 0 1 1 4 2 4 2    12  1 1 1 2 2 3 4 3
2022 07 12     16  3 3 3 4 4 2 3 2    36  2 4 5 5 6 4 5 1    18  3 3 3 4 5 3 3 3
2022 07 13      5  2 1 1 2 2 2 0 1     9  1 1 1 3 4 3 1 0     5  2 2 2 1 2 1 1 1
2022 07 14      5  0 1 0 1 2 3 2 2     2  0 0 0 1 1 2 1 1     5  1 1 1 1 1 2 1 2
2022 07 15      7  0 2 0 2 2 3 3 2     9  1 3 1 1 3 3 2 2     8  2 2 0 2 2 2 3 3
2022 07 16      9  2 3 3 3 2 1 1 1     6  2 2 2 3 1 0 1 1     7  2 2 3 2 1 1 1 1
2022 07 17      6  1 1 2 2 2 2 2 1     2  0 0 1 0 1 1 2 0     5  1 1 1 2 1 1 2 1
2022 07 18     10  1 2 1 3 2 2 2 4    18  0 1 3 5 5 1 4 0     8  1 1 2 3 2 1 2 3
2022 07 19     19  3 4 4 3 4 3 2 3    43  1 4 6 5 5 6 5 2    26  3 4 5 4 4 4 4 4
2022 07 20      7  2 3 1 2 2 2 1 2    12  3 2 1 4 4 2 1 2     7  2 3 1 2 2 1 1 2
2022 07 21     14  2 1 1 3 3 4 4 3    25  1 1 2 5 4 6 3 3    22  2 1 2 3 3 5 5 4
2022 07 22     11  3 2 3 3 2 2 2 3    20  4 3 5 5 2 2 1 2    11  3 3 3 3 1 2 2 3
2022 07 23     15  3 5 3 3 2 2 2 2    26  3 5 5 4 5 2 2 2    17  3 5 4 2 2 1 1 3
2022 07 24      9  2 3 2 2 3 2 2 2    15  3 3 3 4 3 3 2 2     9  3 2 2 2 2 2 3 2
2022 07 25      8  3 2 0 2 3 2 1 2     4  2 2 1 0 1 1 1 1     6  3 2 1 1 1 1 1 2
2022 07 26      7  3 2 0 2 2 2 2 2     6  2 3 0 2 2 1 1 2     8  4 2 1 2 2 1 1 2
2022 07 27      9  2 2 2 2 3 2 2 3    10  2 3 2 3 3 2 1 2     9  3 2 2 2 2 2 2 3
2022 07 28      9  2 2 3 2 3 2 2 1    10  1 3 3 1 4 2 1 1     7  2 2 3 1 2 2 2 1
2022 07 29      6  1 1 1 1 3 2 1 2     2  1 1 0 0 1 1 1 0     4  1 1 1 1 1 1 1 2
2022 07 30      8  1 1 2 2 2 3 1 3     6  1 2 1 2 3 1 1 1     7  2 2 1 1 2 2 1 3
2022 07 31     12  2 2 3 3 3 3 2 3    11  2 2 2 0 4 4 1 2    11  2 2 2 2 3 4 2 3
2022 08 01      8  2 2 2 2 3 1 2 2    12  2 3 2 4 4 2 1 1     8  3 2 2 2 2 1 1 2
2022 08 02     10  3 2 3 2 2 2 2 3    11  2 2 2 4 3 2 2 2     9  2 2 3 2 1 2 3 3
2022 08 03      7  3 2 1 2 2 1 2 2     9  2 3 3 3 2 2 1 1     8  3 3 2 2 1 2 2 2
2022 08 04      7  2 1 1 2 3 2 2 1     4  2 1 1 1 2 1 1 1     6  2 1 1 2 2 2 2 2
2022 08 05      7  3 2 1 2 2 2 1 1     3  2 2 0 0 1 1 0 1     6  3 2 1 1 1 1 0 2
2022 08 06      5  1 0 0 2 2 2 2 2     1  1 0 0 0 0 0 1 0     4  1 1 1 1 1 1 1 2
2022 08 07     20  1 2 3 4 4 3 3 5    42  0 2 4 6 6 6 3 5    24  1 2 3 4 4 4 4 6
2022 08 08     21  4 4 4 4 3 3 3 3    48  5 5 6 6 5 5 3 3    31  5 5 5 4 3 3 4 4
2022 08 09     15  2 4 3 3 3 3 3 2    45  3 4 6 6 6 5 3 3    19  3 4 3 4 4 4 3 2
2022 08 10     10  2 3 1 2 3 2 3 2    23  3 3 2 5 5 3 4 2    11  2 3 2 2 3 3 3 3
```

2022 08 11	12	2 2 3 3 3 3 2 3	57	2 3 3 7 7 6 5 2	16	2 2 2 3 3 4 4 3
2022 08 12	6	2 1 2 2 2 2 1 1	18	2 1 3 6 4 2 0 1	7	3 1 2 3 2 1 1 1
2022 08 13	10	2 2 3 3 3 2 2 2	18	1 2 2 4 4 5 3 2	10	2 2 3 3 3 2 2 2
2022 08 14	9	3 3 2 3 2 2 2 0	6	3 3 2 1 1 0 1 0	7	3 2 2 2 2 1 1 1
2022 08 15	6	1 1 2 2 3 2 1 1	8	1 1 1 0 2 5 1 0	6	1 2 2 2 2 2 1 1
2022 08 16	5	1 2 0 2 2 2 1 2	4	1 1 1 3 2 0 0 1	5	1 2 1 2 1 1 0 2
2022 08 17	22	2 3 1 3 3 4 5 5	17	1 3 1 3 3 4 4 4	31	2 3 2 3 2 4 6 6
2022 08 18	19	3 2 3 3 4 4 3 4	30	2 3 3 3 6 6 3 3	26	3 2 3 3 5 5 4 5
2022 08 19	15	3 3 1 2 2 4 4 3	25	3 4 3 4 5 3 5 2	20	3 3 2 2 2 4 5 4
2022 08 20	16	3 4 3 2 1 4 3 3	15	4 4 5 2 0 0 2 2	14	4 3 3 2 1 1 3 4
2022 08 21	13	2 2 2 3 3 4 3 2	18	3 3 1 4 3 5 3 2	14	3 2 2 3 3 4 3 2
2022 08 22	7	3 2 2 2 2 1 2 1	9	3 4 2 3 1 1 1 0	7	3 3 2 2 2 1 2 1
2022 08 23	3	0 1 0 1 2 0 1 2	2	1 1 0 1 1 0 1 1	4	1 1 1 1 1 0 0 2
2022 08 24	4	1 0 1 2 2 1 1 1	1	1 1 0 0 0 0 0 1	3	1 0 1 1 1 1 0 1
2022 08 25	5	1 1 1 2 2 1 1 2	2	1 1 0 0 2 0 0 1	5	1 1 2 2 2 1 1 2
2022 08 26	5	1 1 1 1 2 2 2 1	1	1 1 0 0 0 0 0 0	5	1 2 1 1 1 1 1 2
2022 08 27	11	1 1 1 3 4 2 3 3	15	1 1 1 4 5 3 3 2	14	2 1 2 4 4 3 3 3
2022 08 28	7	1 1 1 2 3 3 2 1	17	2 2 2 6 3 2 2 1	7	2 1 2 3 2 2 2 1
2022 08 29	13	2 4 3 3 3 2 3 1	21	2 4 5 4 5 1 2 0	14	2 4 3 3 3 2 3 1
2022 08 30	13	2 4 2 3 3 2 2 3	17	2 4 3 5 3 2 2 2	13	2 4 2 3 2 2 2 3
2022 08 31	12	3 3 1 2 3 2 2 4	13	2 2 2 4 4 2 2 3	13	3 3 2 3 2 2 2 4
2022 09 01	9	2 3 2 2 3 2 2 1	9	3 3 2 3 2 1 1 1	9	2 4 2 2 2 2 1 1
2022 09 02	10	2 1 2 3 2 2 1 4	7	1 0 2 2 4 1 1 1	8	2 1 2 2 2 1 1 4
2022 09 03	23	5 3 3 4 4 3 2 4	33	4 3 5 5 6 3 3 3	25	5 3 4 4 4 3 3 4
2022 09 04	33	4 4 5 5 4 4 3 5	91	5 6 7 7 6 7 5 5	64	5 6 6 6 5 6 4 5
2022 09 05	21	4 4 4 4 3 3 3 3	49	5 4 5 7 5 5 3 3	32	5 5 4 5 3 4 4 4
2022 09 06	14	3 3 3 3 3 2 3 3	31	5 4 5 4 5 4 3 2	20	4 4 3 3 3 3 4 4
2022 09 07	12	2 2 4 3 3 3 2 1	27	3 2 3 5 5 5 4 2	14	3 2 3 3 3 4 3 1
2022 09 08	17	2 4 4 3 3 2 2 4	36	2 3 6 6 5 4 3 3	19	3 4 4 3 3 3 3 4
2022 09 09	14	3 2 3 4 4 2 1 2	30	2 1 4 7 5 2 1 1	13	4 2 3 4 3 2 1 2
2022 09 10	10	2 1 3 2 3 2 3 2	31	2 2 4 4 6 6 3 1	12	3 2 3 2 3 3 3 2
2022 09 11	9	2 1 1 3 3 3 2 1	15	2 1 1 5 4 4 1 1	9	3 2 1 2 2 3 2 1
2022 09 12	9	2 2 3 3 3 1 2 1	23	1 3 6 5 4 2 0 1	9	3 3 3 2 2 1 2 1
2022 09 13	5	0 1 3 1 2 2 1 1	5	0 0 3 3 1 1 0 0	4	0 0 2 1 1 1 0 1
2022 09 14	10	1 0 3 2 2 2 3 4	6	0 0 1 2 3 1 2 3	9	1 0 2 2 2 2 3 4
2022 09 15	8	4 1 1 2 2 2 1 1	4	2 1 0 1 1 2 1 1	6	4 1 1 1 1 2 1 1
2022 09 16	5	0 2 1 1 2 3 1 1	2	0 1 0 1 0 1 0 1	4	1 2 1 2 1 1 0 1
2022 09 17	5	1 1 1 1 3 2 1 1	4	1 1 1 2 3 0 0 1	5	1 1 1 1 2 1 0 2
2022 09 18	9	2 2 3 2 3 2 2 2	22	2 2 5 5 5 2 2 2	11	2 2 3 3 3 2 2 2
2022 09 19	7	2 1 0 2 3 3 1 2	18	2 0 1 4 5 5 2 2	11	3 1 1 3 3 3 2 3
2022 09 20	6	2 2 1 2 2 2 2 1	6	2 2 1 2 2 2 1 1	8	2 2 1 2 2 2 3 2
2022 09 21	4	1 0 1 2 2 2 0 1	8	1 1 2 5 1 0 0 1	5	2 1 2 2 1 1 0 2
2022 09 22	5	0 1 1 1 2 2 1 3	3	0 0 0 0 2 1 1 2	6	0 1 1 1 2 2 1 3
2022 09 23	12	3 2 3 3 3 3 2 2	27	1 1 6 5 4 5 1 2	12	3 1 3 3 3 3 2 3
2022 09 24	10	2 3 2 2 3 3 2 2	22	2 3 3 6 4 3 2 2	13	2 4 2 3 3 3 3 3
2022 09 25	5	2 2 2 2 2 1 0 1	11	1 1 1 5 4 2 0 0	7	2 2 2 2 2 1 0 2
2022 09 26	5	1 1 0 1 1 2 1 3	4	1 0 0 2 3 0 0 1	6	2 1 0 1 1 1 1 3
2022 09 27	33	5 3 2 3 3 7 3 2	25	5 3 2 6 4 2 2 2	24	6 4 2 4 3 3 3 3
2022 09 28	3	1 1 0 1 1 2 1 1	3	2 1 0 0 0 1 2 0	5	2 1 1 1 1 1 2 1
2022 09 29	7	1 0 3 3 2 2 1 1	8	1 0 3 3 3 2 1 2	7	1 1 3 2 2 2 1 1
2022 09 30	12	2 4 4 2 3 2 1 0	27	1 3 5 5 6 3 1 0	17	3 4 4 3 3 2 1 1

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. 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 SPS Signal Specification.

Problem Description:

There were no problems this quarter.

APPENDIX D: KEY TERMS

The terms and definitions discussed below were taken from the Standard Positioning Service Performance Specification (April 2020). An understanding of these terms and definitions is a necessary prerequisite to the full understanding of the Signal Specification.

General Terms and Definitions

Alarm: An indication requiring an immediate response (e.g., to preserve integrity).

Alert: Generic term encompassing both alarm and warning.

Alerted Misleading Signal-in-Space Information (AMSI): The pseudorange data set (e.g., pseudorange measurement and NAV data) provided by a SPS SIS provides alerted MSI (AMSI) when the instantaneous URE exceeds the SIS URE NTE tolerance but a timely alert (alarm or warning) is provided.

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.

Auxiliary Satellite: An operational satellite that is not occupying a defined orbital slot in the baseline 24-slot constellation or the expandable 24-slot constellation. Auxiliary satellites are typically either newly launched satellites waiting to take their place in the baseline/expandable 24-slot constellation, or are older satellites that are nearing the end of their useful lives and have been shifted out of the baseline/expandable 24-slot constellation. The SPS SIS broadcast by an auxiliary satellite is not required to meet all of the standards in Section 3.

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 pseudorange measured at a given location and the expected pseudorange, 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 where 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 that 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 *pseudorange*.

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 as 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 an 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.