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

Submitted To

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Submitted by

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Executive Summary

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

This report, Report #102, includes data collected from 1 April through 30 June 2018. The next quarterly report will be issued October 31, 2018.

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

PDOP availability is based on Position Dilution of Precision (PDOP). Utilizing the weekly almanac posted on the US Coast Guard navigation web site, the coverage for every 5º grid point between 180W to 180E and 80S and 80N was calculated for every minute over a 24-hour period for each of the weeks covered in the reporting period. For this reporting period, the global availability based on PDOP less than six for CONUS was 99.9985%.

NANU summary and evaluation was achieved by reviewing the “Notice: Advisory to Navstar Users” (NANU) reports issued between 1 April and 30 June 2018. Using this data, we compute a set of statistics that give a relative idea of constellation health for both the current and combined history of past quarters. A total of seven outages were reported in the NANU’s this quarter. Six outages were scheduled ahead of time, while one unscheduled NANU occurred.

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

Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error standard was verified for each satellite from 24-hour accuracy values computed using data collected at the following six sites: Boston, Honolulu, Los Angeles, Miami, San Juan and Juneau. This data was also collected in one-second samples. All sites achieved 100% reliability, meeting the SPS specification. The maximum range error recorded was 13.851 meters on Satellite PRN 20. The SPS specification states that the range error should never exceed 30 meters for less than 99.79% of the day for a worst-case point and 99.94% globally. The maximum RMS range error value of 2.296 meters was recorded on satellite PRN 21. The SPS specification states that RMS URE cannot exceed 6 meters in any 24-hour interval.

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

The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent GNSS station data to generate precise GNSS products. During the evaluation period, the maximum 95% horizontal and vertical SPS errors were 5.48 meters and 12.20 meters respectively at Kourou, French Guyana.

From the analysis performed on data collected between 1 April and 30 June 2018, 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 FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS and WAAS for IFR operations and is further developing WAAS as a GPS augmentation system. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Analysis report. This report contains data collected at the following twenty-eight WAAS reference station locations:

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

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

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

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

1.2 Report Overview

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

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

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

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

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

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

Section 8 provides a summary of GPS Test NOTAMs.

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

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

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

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

1.3 Summary of Performance Requirements and Metrics

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

Table 1-1 SPS SIS Performance Requirements Standards

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

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

Instantaneous UTCOE Integrity	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ $1x10^{-5}$ Probability over any hour of the SPS SIS Instantaneous UTCOE exceeding the NTE tolerance without a timely alert during normal operations.	• For any healthy SPS SIS • SPS SIS URE NTE tolerance defined	✓
Unscheduled Failure Interruption Continuity	**Conditions and Constraints**	
Unscheduled Failure Interruptions: • ≥ 0.9998 Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Given that the SPS SIS is available from the slot at the start of the hour	✓
Status and Problem Reporting	**Conditions and Constraints**	**Evaluated in This Report**
Scheduled event affecting service • Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	• For any SPS SIS	✓
Unscheduled outage or problem affecting service	• For any SPS SIS	✓

• Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event		
Per-Slot Availability	**Conditions and Constraints**	
• ≥ 0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS • ≥ 0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a healthy SPS SIS	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard.	✓
Constellation Availability	**Conditions and Constraints**	
• ≥ 0.98 Probability that at least 21 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration • ≥ 0.99999 Probability that at least 20 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration	• Calculated as an average over all slots in the 24-slot constellation, normalized annually. • Applies to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.	✓
Operational Satellite Count	**Conditions and Constraints**	
• ≥ 0.95 Probability that the constellation will have at least 24 operational satellites regardless of	• 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	✓

whether those operational satellites are located in slots or not	defined to be an operational satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not.	

PDOP Availability	**Conditions and Constraints**	**Evaluated in This Report**
• ≥ 98% global PDOP of 6 or less • ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval	✓
Service Availability	**Conditions and Constraints**	
• ≥ 99% Horizontal Service Availability, average location • ≥ 99% Vertical Service Availability, average location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	✓
• ≥ 90% Horizontal Service Availability, worst-case location • ≥ 90% Vertical Service Availability, worst-case location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	✓

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

2. PDOP AVAILABILITY STANDARD

PDOP Availability: The percentage of time over any 24-hour interval that the PDOP value is less than or equal to

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

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

Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). 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 2º point between longitudes of 180W to 180E and 75S and 75N at one-minute intervals. This gives a total of 1440 samples for each of the 13,500 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.27 or better 99.9% of the time for each of the 24-hour intervals.

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

Table 2-1 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value	Global Average Availability (Spec: ≥ 98%)	Worst-Case Point Availability (Spec: ≥ 88%)
1 Apr – 7 Apr	3.23	100	99.53
8 – 14 Apr	3.23	100	99.44
15 – 21 Apr	3.25	100	99.64
22 – 28 Apr	3.25	100	100.00
29 Apr – 5 May	3.27	100	99.98
6 – 12 May	3.26	100	99.55
13 – 19 May	3.26	100	99.25
20 – 26 May	3.22	100	99.27
27 May – 2 Jun	3.18	100	99.33
3 – 9 Jun	3.16	100	99.30
10 – 16 Jun	3.17	100	99.31
17 – 23 Jun	3.23	100	99.25
24 Mar – 30 Jun	3.22	100	99.18

Figure 2-1 World GPS Maximum PDOP

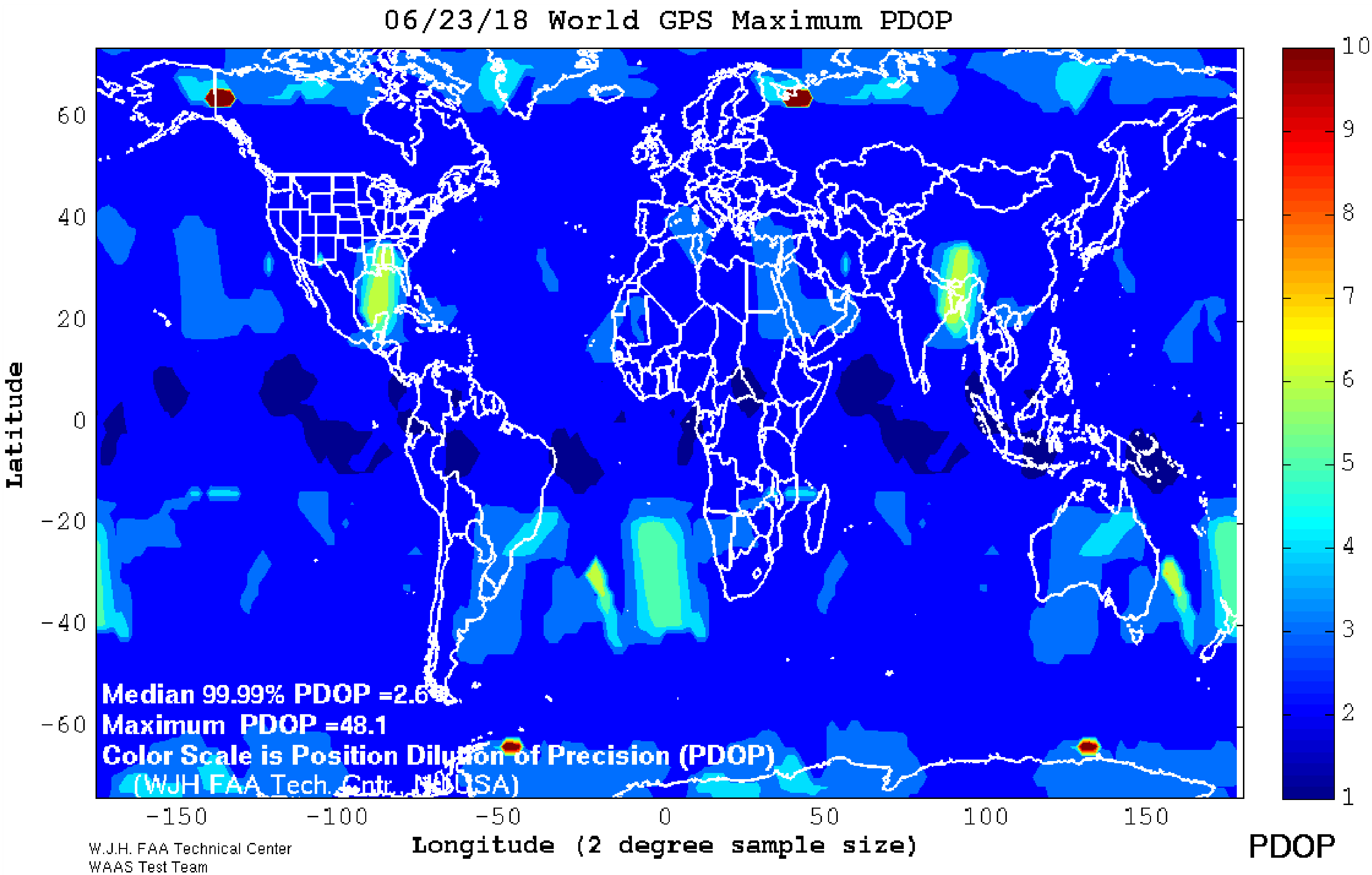
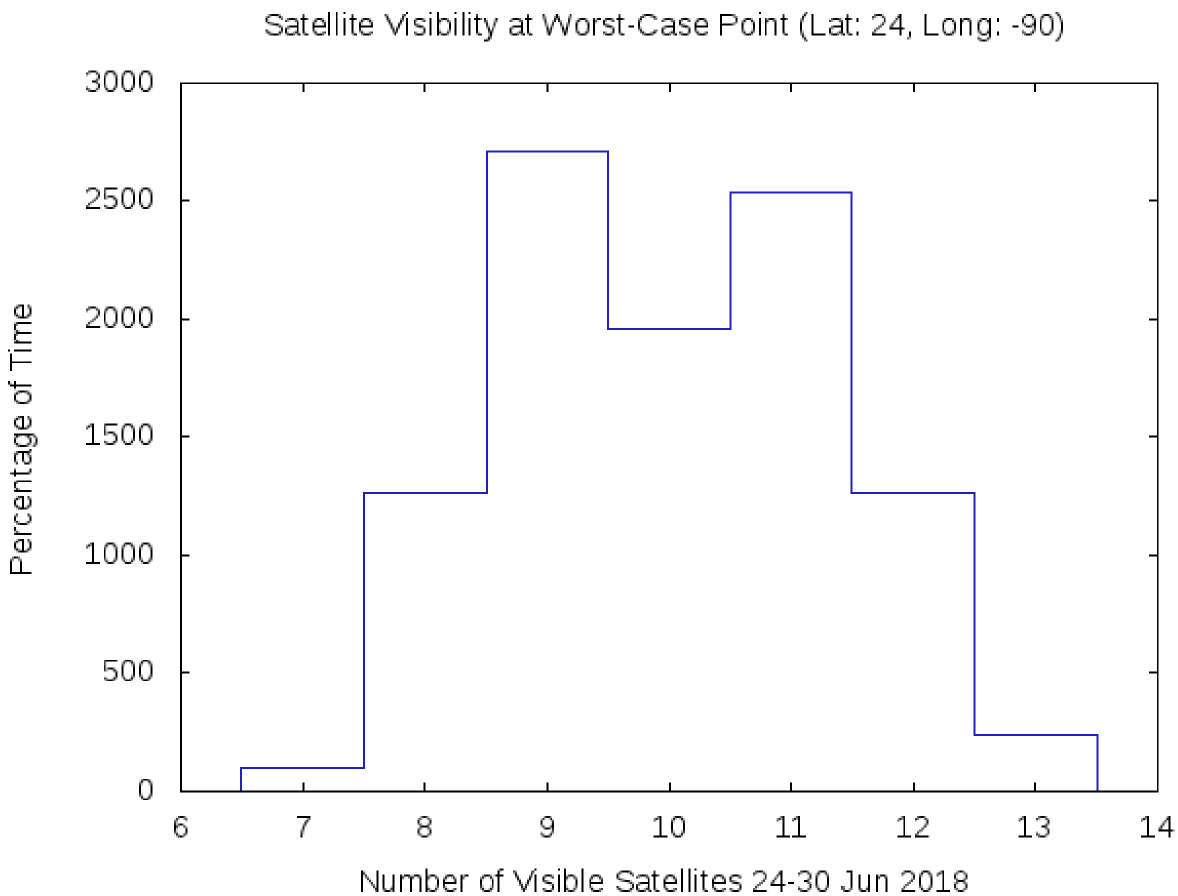


Figure 2-2 Satellite Visibility Profile for Worst-Case Point



3. NANU SUMMARY AND EVALUATION

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

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

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published “Notice: Advisory to Navstar Users” messages (NANU’s). During this reporting period, 1 April through 30 June 2018, there were a total of seven reported outages. Six outages were maintenance activities and were reported in advance, while one was an unscheduled outage. A complete listing of outage NANU’s for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU’s for the reporting period can be found in Table 3-2. Canceled outage NANU’s (if any) are provided in Table 3-3. The minimum duration a scheduled outage was forecasted ahead of time was 98.6 hours. The maximum response time following an unscheduled outage was 0.267 hours. Therefore the probability of continuity not being affected due to an unscheduled failure interruption was 100%, which met the specification requirement.

Table 3-1 NANUs Affecting Satellite Availability

NANU#	PRN	TYPE	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2018018	8	FCSTSUMM	5-Apr-18	19:27	6-Apr-18	0:49	0	5.37	5.37
2018022	17	FCSTSUMM	17-Apr-18	22:29	18-Apr-18	3:57	0	5.47	5.47
2018024	22	FCSTSUMM	27-Apr-18	8:27	27-Apr-18	13:40	0	5.22	5.22
2018025	23	FCSTSUMM	3-May-18	14:23	3-May-18	20:49	0	6.43	6.43
2018027	14	FCSTSUMM	18-May-18	8:17	18-May18	13:22	0	5.08	5.08
2018028	18	UNUNOREF	26-May-18	9:48	26-May-18	9:50	0.03	0	0.03
2018030	20	FCSTSUMM	22-Jun-18	2:02	22-Jun-18	8:15	0	6.22	6.22
Totals of Unscheduled, Scheduled & Total Downtime							0.03	33.79	33.82

GENERAL NANUs

None

Table 3-2 NANUs Forecasted to Affect Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2018016	8	FCSTDV	5-Apr	19:15	6-Apr	7:15	12	2018018
2018017	17	FCSTDV	12-Apr	22:15	13-Apr	10:15	0	2018019
2018020	17	FCSTDV	17-Apr	21:45	18-Apr	9:45	12	2018022
2018021	22	FCSTDV	27-Apr	7:45	27-Apr	19:45	12	2018024
2018023	23	FCSTDV	3-May	14:30	4-May	2:30	12	2018025
2018026	14	FCSTDV	18-May	8:00	18-May	20:00	12	2018027
2018029	20	FCSTDV	22-Jun	1:35	23-Jun	1:35	24	2018030
Total Forecasted Downtime							84	

Table 3-3 Cancelled NANUs

NANU#	PRN	Type	Start Date	Start Time	Comments
2018019	17	FCSTCANC	12-Apr-18	22:15:00	2018017

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published “Notice: Advisory to Navstar Users” messages (NANU’s). This data has been summarized in Table 3-4. The “Total Satellite Observed MTTR” was calculated by taking the average downtime of all satellite outage occurrences. Scheduled downtime was forecasted in advance via NANU’s. All other downtime reported via NANU was considered unscheduled. The “Percent Operational” was calculated based on the ratio of total actual operating hours to total available operating hours for every satellite.

Table 3-4 GPS Satellite Maintenance Statistics

Satellite Reliability/Maintainability/Availability (RMA) Parameter	**1-Apr-18 30-Jun-18**	**1-Jan-00 30-Jun-18**
Total Forecast Downtime (hrs):	84.00	12046.82
Total Actual Downtime (hrs):	33.82	39254.57
Total Actual Scheduled Downtime (hrs):	33.78	6708.49
Total Actual Unscheduled Downtime (hrs):	0.03	32546.08
Total Satellite Observed MTTR (hrs):	4.83	41.80
Scheduled Satellite Observed MTTR (hrs):	5.63	8.94
Unscheduled Satellite Observed MTTR (hrs):	0.03	172.20
# Total Satellite Outages:	7	939
# Scheduled Satellite Outages:	6	750
# Unscheduled Satellite Outages:	1	189
Percent Operational -- Scheduled Downtime:	99.95	99.87
Percent Operational -- All Downtime:	99.95	99.22

3.2 Service Availability Standard

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

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

• **Vertical Service Availability:** The percentage of time over any 24-hour interval that the predicted 95% vertical

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

To verify availability, the data collected from receivers at the twenty-eight WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-5. The data was collected at one-second intervals between 1 April and 30 June 2018.

Table 3-5 Accuracies Exceeding Threshold Statistics

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-hour Threshold Failures	Quarters Service Availability %
Albuquerque	7851292	0	100%
Anchorage	7849586	0	100%
Atlanta	6939646	0	100%
Barrow	7753189	0	100%
Bethel	7619525	0	100%
Billings	7853475	0	100%
Boston	7162345	0	100%
Cleveland	7849755	0	100%
Cold Bay	7603095	0	100%
Fairbanks	7832432	0	100%
Gander	7833166	0	100%
Honolulu	7852244	0	100%
Houston	7853123	0	100%
Iqaluit	6866601	0	100%
Juneau	7849898	0	100%

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-hour Threshold Failures	Quarters Service Availability %
Kansas City	7853374	0	100%
Kotzebue	5774109	0	100%
Los Angeles	7567883	0	100%
Merida	7824896	0	100%
Miami	7851758	0	100%
Minneapolis	7848154	0	100%
Oakland	7848648	0	100%
Salt Lake City	7848508	0	100%
San Jose Del Cabo	7131070	0	100%
San Juan	7850004	0	100%
Seattle	7846475	0	100%
Tapachula	7228964	0	100%
Washington, DC	7010910	0	100%
Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)			

4. SERVICE RELIABILITY STANDARD

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

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

Table 4-1 shows a comparison to the service reliability standard for range data collected at a set of six receivers across North America. Although the specification calls for yearly evaluations, we will be evaluating this SPS requirement at quarterly intervals. Additional range analysis results can be found in table 5-2. The maximum User Range Error recorded this quarter was 12.497 meters on satellite PRN 21.

Table 4-1 User Range Error Accuracy

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Percentage
1 Apr – 31 Jun 2018	**Boston**	61,984,072	0	100%
1 Apr – 31 Jun 2018	**Honolulu**	69,631,876	0	100%
1 Apr – 31 Jun 2018	**Los Angeles**	66,640,356	0	100%
1 Apr – 31 Jun 2018	**Miami**	68,662,199	0	100%
1 Apr – 31 Jun 2018	**Merida**	69,252,359	0	100%
1 Apr – 31 Jun 2018	**Juneau**	69,989,444	0	100%
1 Apr – 31 Jun 2018	**Global**	406,160,306	0	100%

5. ACCURACY STANDARD

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

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

• **Vertical Positioning Accuracy**: The statistical difference, at a 95% probability, between vertical position

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

User Range Accuracy	Conditions and Constraints
Single Frequency C/A-Code • ≤ 7.8m 95% Global Average URE during normal operations over All AODs • ≤ 6.0m 95% Global Average URE during operations at Zero AOD	• For any healthy SPS SIS • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1

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

5.1 Position Accuracy

The data used for this section was collected for every second from 1 April through 30 June 2018 at the selected WAAS locations. Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter. Every twenty-four hour analysis period this quarter passed both the worst-case and global average position accuracy requirements set forth by the SPS specification.

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

Site	95% Vertical (Meters)	95% Horizontal (Meters)	99.99% Vertical (Meters)	99.99% Horizontal (Meters)
Albuquerque	4.211	1.483	7.768	3.016
Anchorage	3.758	1.852	7.361	3.334
Atlanta	4.140	1.619	7.523	3.332
Barrow	3.645	1.458	8.686	2.722
Bethel	4.021	1.868	7.134	3.414
Billings	3.862	1.535	6.769	3.075
Boston	4.154	1.746	7.203	3.610
Cleveland	4.349	1.773	7.144	3.242
Cold Bay	4.183	1.667	7.487	3.527
Fairbanks	3.692	1.780	7.424	3.299
Gander	3.499	1.738	6.235	3.680
Honolulu	4.382	3.077	7.538	5.274
Houston	4.314	1.807	7.326	3.425
Iqaluit	3.264	1.347	5.942	2.926

Site	95% Vertical (Meters)	95% Horizontal (Meters)	99.99% Vertical (Meters)	99.99% Horizontal (Meters)
Juneau	3.389	1.743	6.834	3.284
Kansas City	4.135	1.593	7.610	2.868
Kotzebue	3.427	1.798	6.033	3.150
Los Angeles	4.549	1.715	7.165	3.125
Merida	4.156	2.379	8.845	4.727
Miami	4.084	1.894	7.268	3.870
Minneapolis	4.075	1.640	7.283	2.962
Oakland	4.706	1.652	7.863	3.059
Salt Lake City	4.181	1.466	7.997	2.807
San Jose Del Cabo	4.311	2.593	7.026	5.497
San Juan	3.594	1.918	7.084	4.062
Seattle	4.047	1.475	7.855	2.865
Tapachula	3.896	2.626	7.939	5.722
Washington, DC	4.119	1.680	6.997	3.417

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all twenty-eight WAAS sites from 1 April to 30 June 2018.

Figure 5-1 Global Vertical Error Histogram

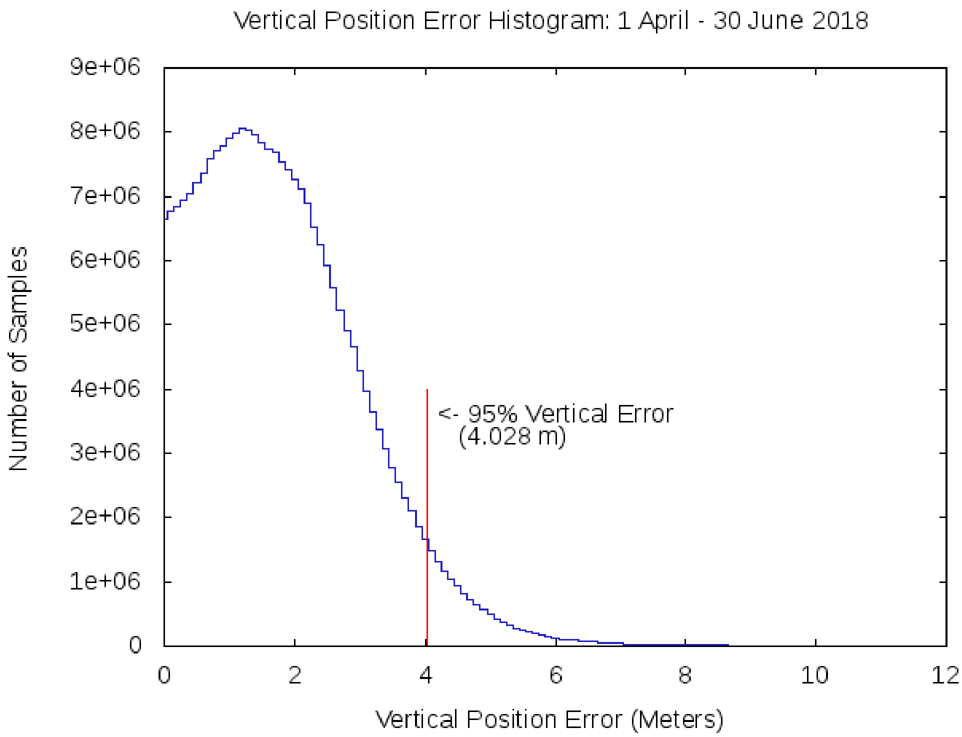
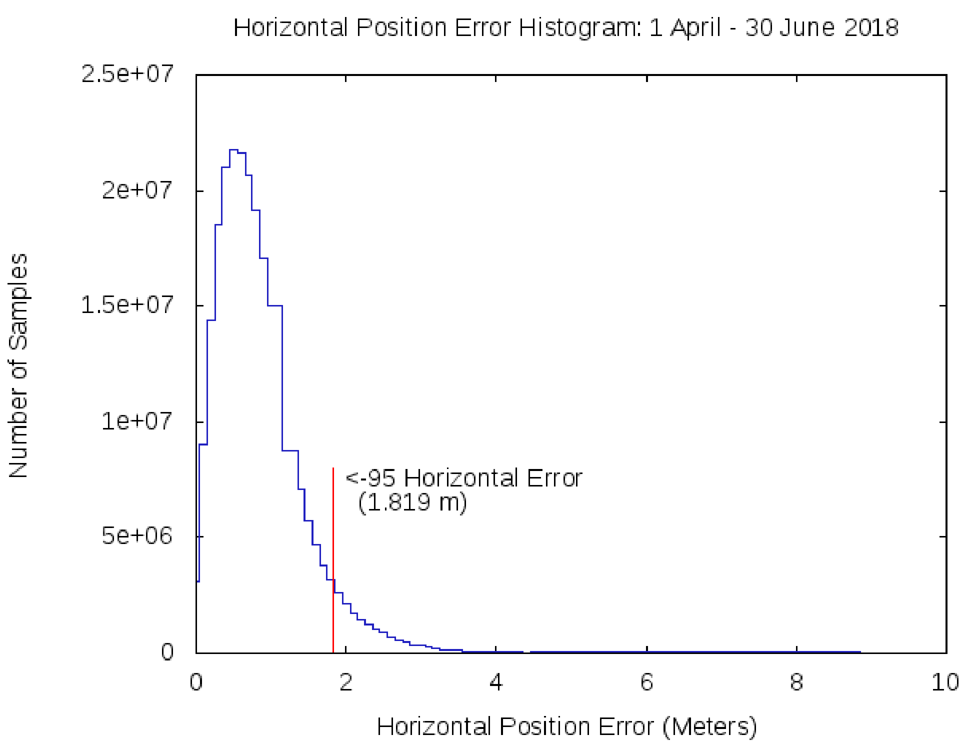


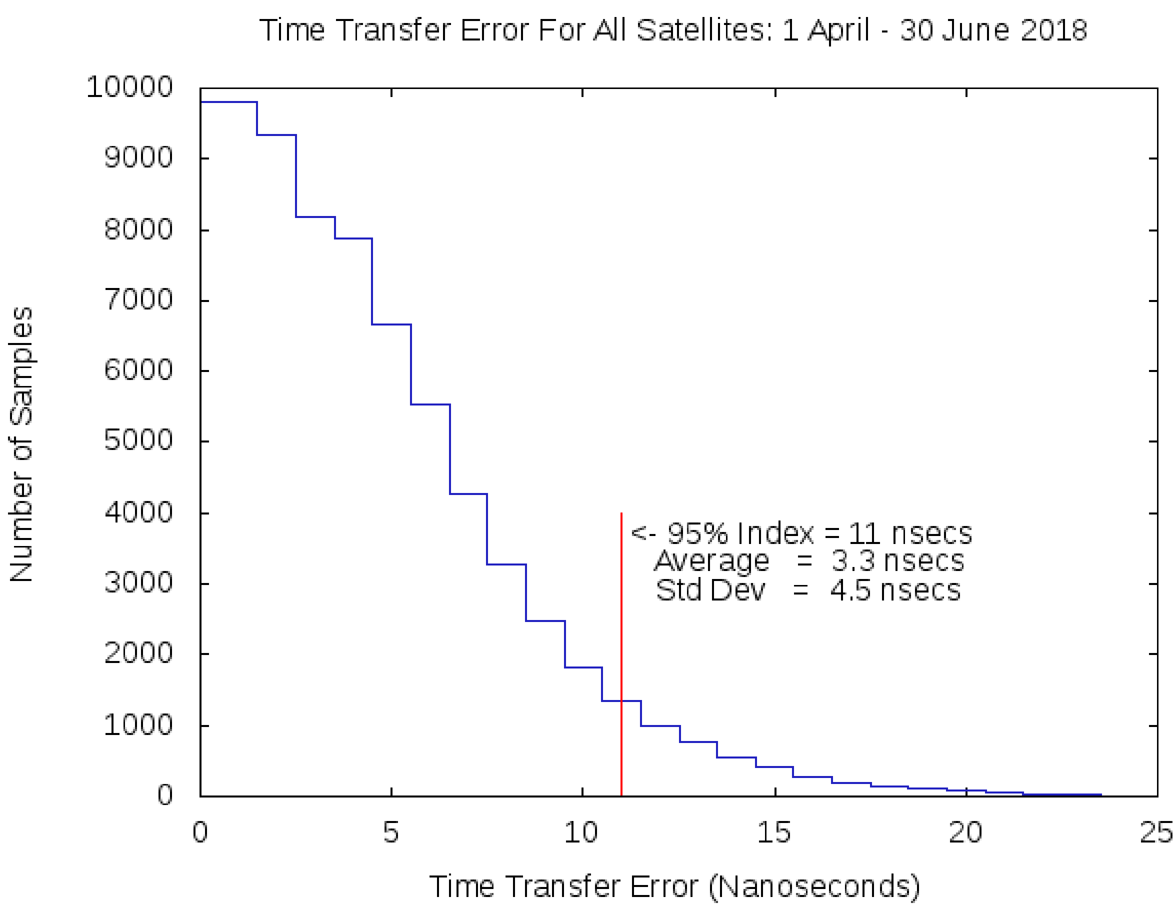
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 2018 was downloaded from USNO Internet site. The USNO data file contains the time difference between the USNO master clock and GPS system time for each GPS satellites during the time period. Over 10,000 samples of GPS time error are contained in the USNO data file. In order to evaluate the GPS time transfer error, the data file was used to create a histogram (Fig 5-3) to represent the distribution of GPS time error. The histogram was created by taking the absolute value of time difference between the USNO master clock and GPS system time, then creating data bins with one nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Fig 5-3. The maximum instantaneous UTC offset error (UTCOE) for the quarter was 28.4 nanoseconds. The mean, standard deviation and 95% index of Time Transfer Error, and the maximum UTCOE are all within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Error



5.3 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 April and 30 June 2018. A weighted average filter was used for the calculation of the range rate error and the range acceleration error. All Range Domain SPS specifications were met.

Table 5-2 Range Error Statistics

PRN	RMS Range Error (≤ 6 m) (Meters)	Range Error Mean (Meters)	1σ Range Error (Meters)	95% Range Error (Meters)	Max Range Error (SPS Spec. ≤ 30 m) (Meters)	Samples
1	1.673	1.059	1.157	2.931	8.041	13315305
2	1.786	1.354	1.042	3.005	9.715	14360091
3	1.093	0.408	0.876	1.968	6.917	13854438
5	1.306	0.574	1.009	2.442	7.752	13237790
6	1.211	0.374	1.020	2.280	9.280	13567794
7	1.500	0.928	0.931	2.498	7.761	12244138
8	1.639	0.763	1.106	2.766	7.352	12159742
9	1.607	1.287	0.898	2.781	7.401	12860263
10	1.348	0.863	0.856	2.335	9.788	12738478
11	1.681	1.158	1.032	2.812	7.035	11868371
12	1.366	0.641	1.038	2.623	11.435	13668683

PRN	RMS Range Error (< 6 m) (Meters)	Range Error Mean (Meters)	1σ Range Error (Meters)	95% Range Error (Meters)	Max Range Error (SPS Spec. < 30 m) (Meters)	Samples
13	1.270	0.477	0.986	2.394	8.943	12742949
14	1.661	1.418	0.788	2.668	6.263	13390203
15	1.478	0.966	1.008	2.624	9.235	12376714
16	1.636	1.210	0.965	2.698	6.005	12472292
17	1.370	0.673	1.017	2.427	8.999	14109483
18	1.441	0.682	1.134	2.603	6.047	13754825
19	2.013	1.667	1.032	3.295	9.573	13624537
20	2.264	1.862	1.207	3.714	13.851	13030889
21	2.296	1.811	1.301	3.892	10.662	12746184
22	2.096	1.891	0.856	3.198	7.075	12965132
23	1.504	1.246	0.768	2.479	6.243	12342955
24	1.773	0.556	1.485	3.200	10.927	13634697
25	1.413	0.937	0.962	2.533	7.901	14035766
26	1.258	0.671	0.914	2.221	6.218	12227180

PRN	RMS Range Error ($\leq$ 6 m) (Meters)	Range Error Mean (Meters)	1σ Range Error (Meters)	95% Range Error (Meters)	Max Range Error (SPS Spec. $\leq$ 30 m) (Meters)	Samples
27	1.348	0.811	0.925	2.291	6.442	12860213
28	1.762	1.220	1.054	2.983	8.029	13277636
29	1.726	1.129	1.112	2.992	9.256	12966302
30	1.568	1.094	0.993	2.614	7.432	12250987
31	1.172	0.613	0.907	2.071	7.200	13467736
32	1.225	0.674	0.874	2.234	6.469	14008533

Table 5-3 Range Rate Error Statistics

PRN	Range Rate Error RMS (mm/s)	95% Range Rate Error (mm/s)	Max Range Rate Error (mm/s)	Samples
1	1.318	2.490	139.650	13315305
2	1.451	2.743	176.530	14360091
3	1.249	2.428	65.380	13854438
5	1.483	2.878	170.920	13237790
6	1.281	2.497	53.530	13567794

PRN	Range Rate Error RMS (mm/s)	95% Range Rate Error (mm/s)	Max Range Rate Error (mm/s)	Samples
7	1.414	2.648	131.760	12244138
8	1.722	2.754	143.720	12159742
9	1.230	2.390	40.870	12860263
10	1.245	2.418	46.770	12738478
11	1.459	2.751	106.980	11868371
12	1.474	2.881	49.060	13668683
13	1.489	2.793	78.050	12742949
14	1.336	2.580	115.230	13390203
15	1.401	2.742	53.660	12376714
16	1.391	2.707	35.820	12472292
17	1.491	2.861	104.270	14109483
18	1.391	2.566	129.370	13754825
19	1.455	2.780	42.810	13624537
20	1.437	2.756	59.300	13030889
21	1.549	2.920	124.810	12746184

PRN	Range Rate Error RMS (mm/s)	95% Range Rate Error (mm/s)	Max Range Rate Error (mm/s)	Samples
22	1.357	2.624	38.290	12965132
23	1.325	2.544	37.760	12342955
24	1.849	3.196	148.860	13634697
25	1.280	2.493	80.320	14035766
26	1.264	2.450	73.370	12227180
27	1.280	2.476	40.150	12860213
28	1.427	2.705	137.470	13277636
29	1.442	2.787	118.120	12966302
30	1.247	2.424	26.420	12250987
31	1.364	2.607	99.330	13467736
32	1.255	2.423	88.560	14008533

Table 5-4 Range Acceleration Error Statistics

PRN	Range Acceleration Error RMS ($\mu m/s^2$)	95% Range Acceleration Error ($\mu m/s^2$)	Max Range Acceleration Error ($\mu m/s^2$)	Samples
1	10.285	18.473	1280	13315305
2	10.464	21.926	1700	14360091
3	10.016	18.223	660	13854438
5	10.190	25.523	1500	13237790
6	10.035	18.271	500	13567794
7	10.486	22.232	1320	12244138
8	13.669	22.828	1440	12159742
9	10.017	18.356	420	12860263
10	10.015	18.302	460	12738478
11	10.519	22.756	1080	11868371
12	10.122	24.870	480	13668683
13	10.806	23.843	790	12742949
14	10.133	21.085	1160	13390203
15	10.062	21.716	540	12376714

PRN	Range Acceleration Error RMS ($\mu m/s^2$)	95% Range Acceleration Error ($\mu m/s^2$)	Max Range Acceleration Error ($\mu m/s^2$)	Samples
16	10.039	21.956	350	12472292
17	10.502	24.911	1040	14109483
18	10.756	20.379	1290	13754825
19	10.112	22.980	430	13624537
20	10.183	22.325	610	13030889
21	11.012	24.766	1240	12746184
22	10.047	22.269	390	12965132
23	10.021	21.309	380	12342955
24	13.692	27.519	1490	13634697
25	10.067	18.264	800	14035766
26	10.023	18.476	730	12227180
27	10.039	18.674	340	12860213
28	10.423	22.165	1380	13277636
29	10.366	22.998	1170	12966302
30	10.000	18.730	270	12250987

PRN	Range Acceleration Error RMS ($\mu m/s^2$)	95% Range Acceleration Error ($\mu m/s^2$)	Max Range Acceleration Error ($\mu m/s^2$)	Samples
31	10.206	21.447	990	13467736
32	10.148	18.242	900	14008533

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the maximum range error, range rate error and range acceleration error for all satellites. The highest maximum range error occurred on satellite PRN 20 with an error of 13.851 meters. Satellite PRN 16 had the lowest maximum range error of 6.005 meters. Figure 5-7 is histogram of satellite range error for all satellites over the entire quarter. Figures 5-8, 5-9, and 5-10 show the individual maximums per satellite for range error, range rate error, and range acceleration error respectively.

Figure 5-4 Distribution of Daily Max Range Errors

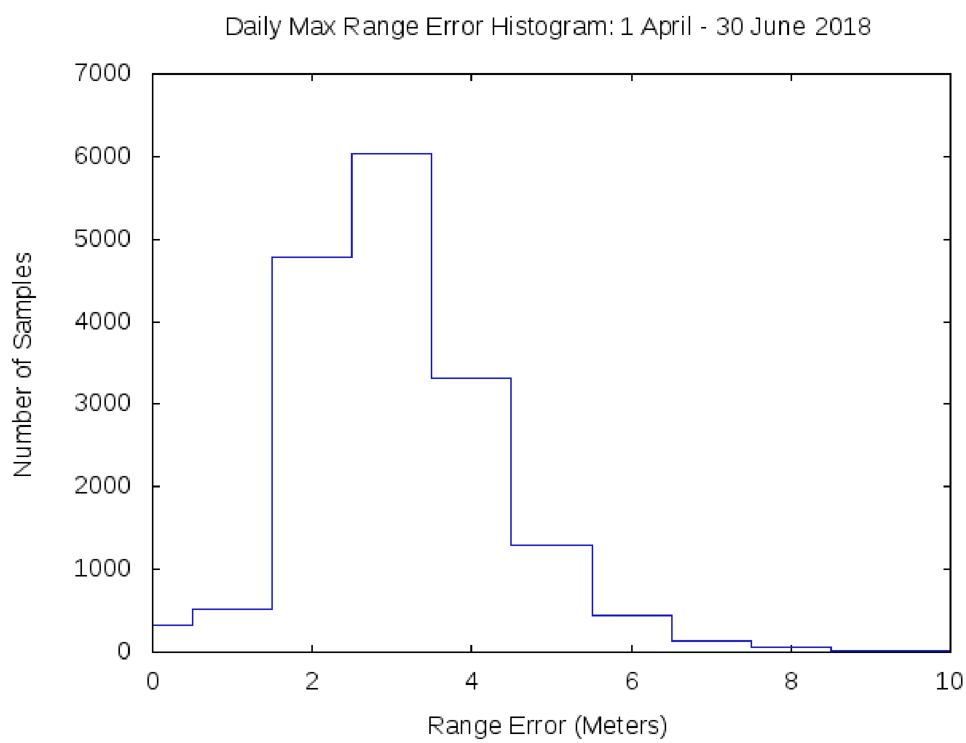


Figure 5-5 Distribution of Daily Max Range Rate Errors

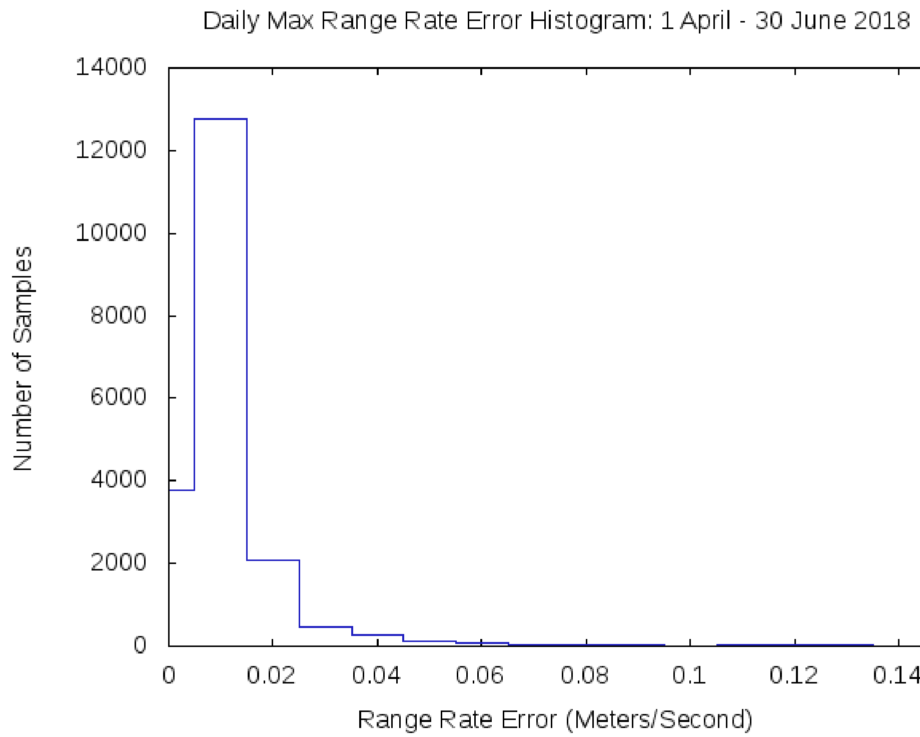


Figure 5-6 Distribution of Daily max Range Acceleration Errors

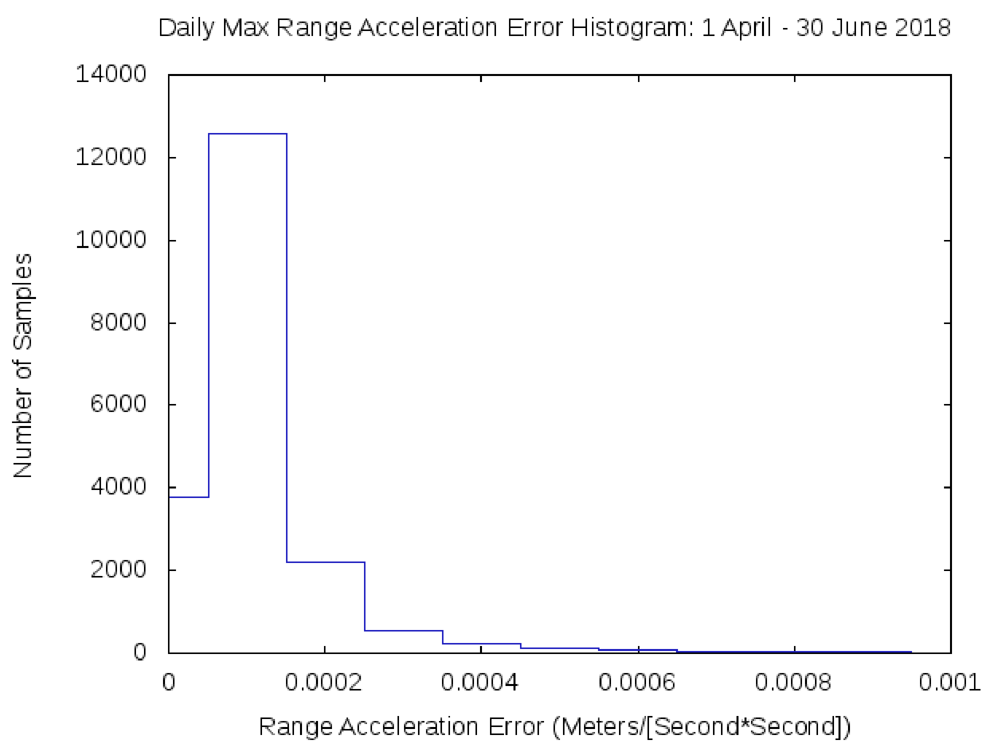


Figure 5-7 Range Error Histogram

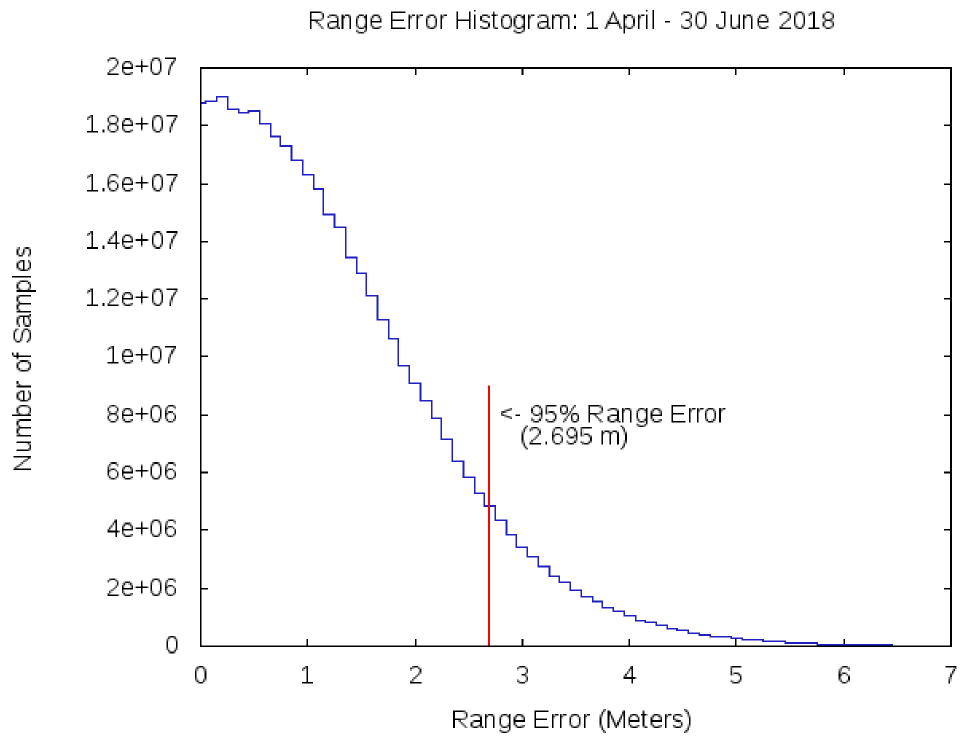


Figure 5-8 Maximum Range Error Per Satellite

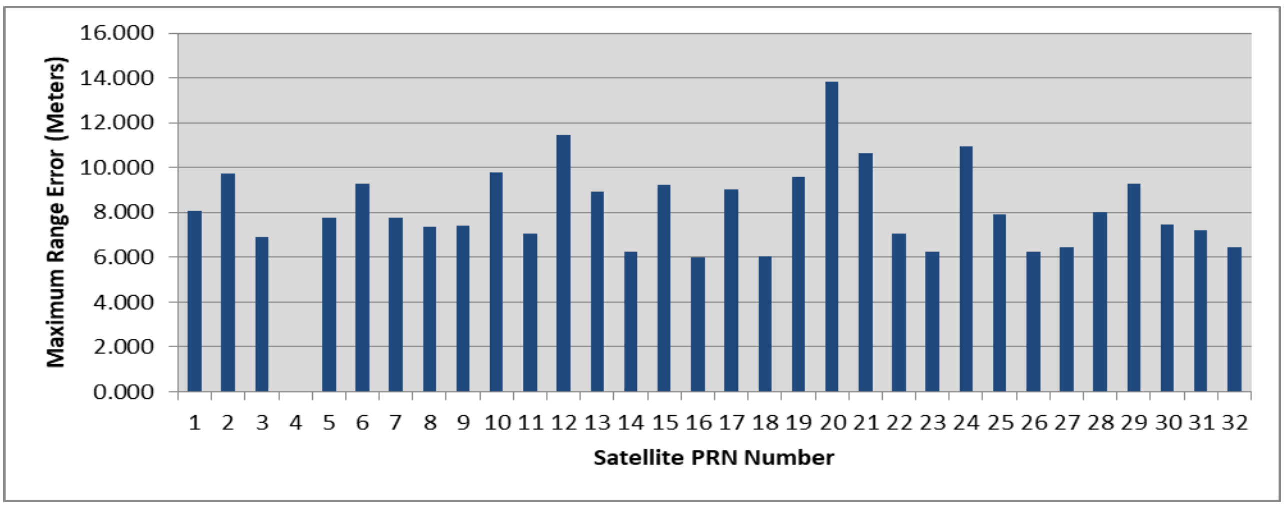


Figure 5-9 Maximum Range Rate Error Per Satellite

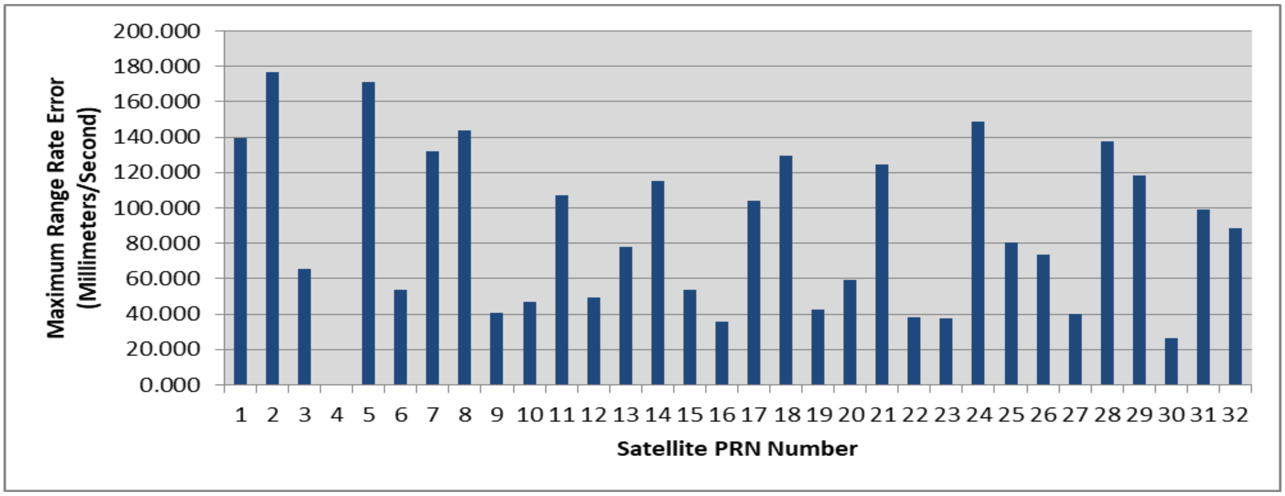
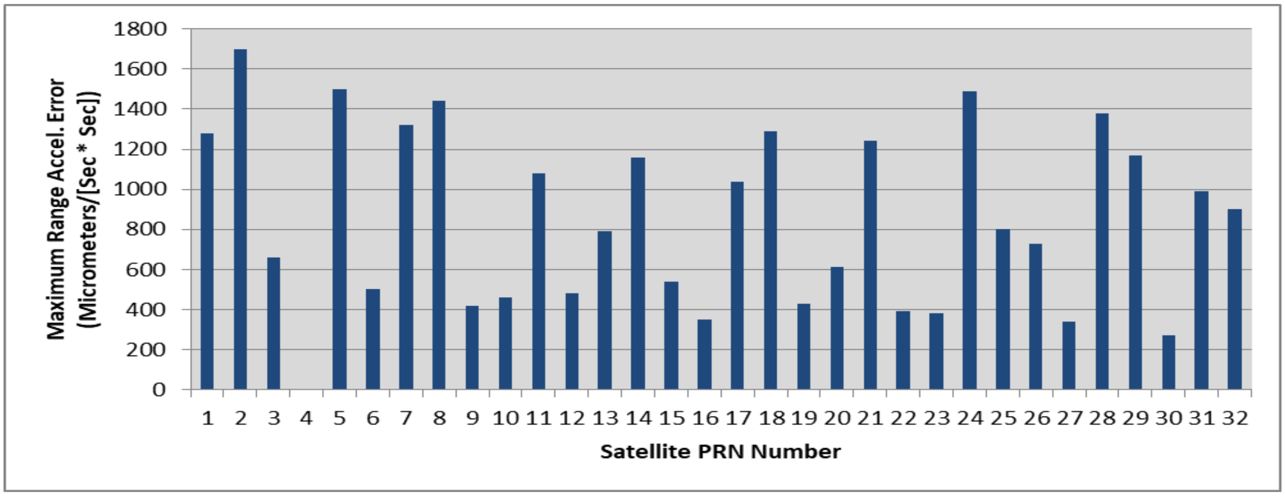


Figure 5-10 Maximum Range Acceleration Error Per Satellite



6. SOLAR STORMS

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

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

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

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

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

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

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

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

Figure 6-1 K-Index for 19-21 April 2018

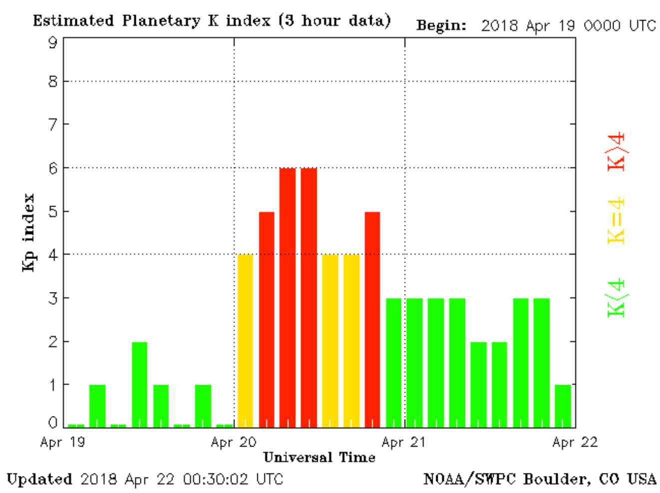


Figure 6-2 K-Index for 5-7 May 2018

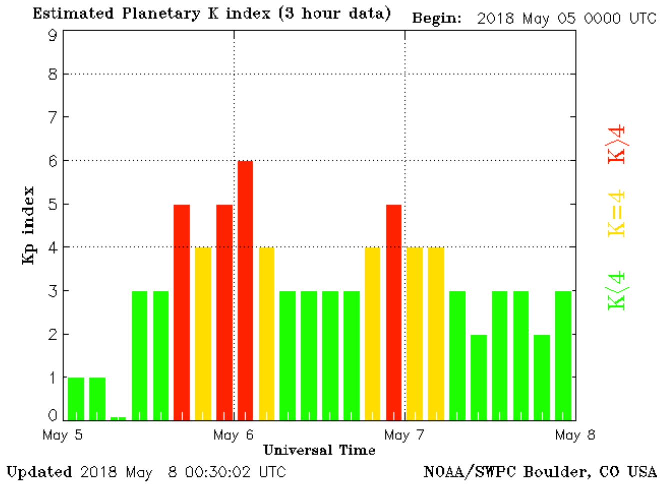


Figure 6-3 K-Index for 25-27 June 2018

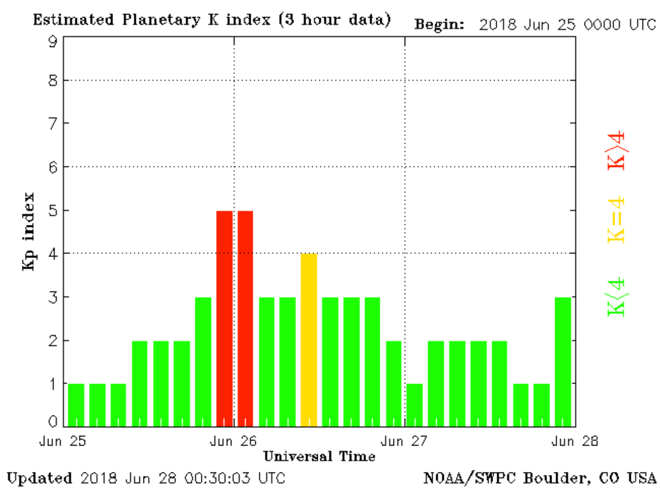


Table 6-1 shows the position accuracy information for the quarter's worst-case storm day, March 18, 2018 (see Figure 6-1). The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for April 20, 2018

Site	95% Horizontal (Meters)	95% Vertical (Meters)	Maximum Horizontal (Meters)	Maximum Vertical (Meters)
Albuquerque	1.984	5.869	2.634	6.308
Anchorage	2.464	4.179	3.371	5.097
Atlanta	1.994	6.298	2.992	6.973
Barrow	1.777	3.996	2.762	5.353
Bethel	2.339	4.177	3.344	4.996
Billings	2.132	4.766	3.250	5.713
Boston	1.714	5.260	2.815	6.103
Cleveland	1.874	5.655	2.484	7.239
Cold Bay	2.016	4.054	2.780	4.912
Fairbanks	2.237	4.099	2.841	5.749
Gander	2.039	3.947	2.786	5.006
Honolulu	3.380	5.117	4.712	5.784
Houston	2.373	5.840	3.084	7.881
Iqaluit	1.666	3.221	2.523	4.597

Site	95% Horizontal (Meters)	95% Vertical (Meters)	Maximum Horizontal (Meters)	Maximum Vertical (Meters)
Juneau	2.557	3.966	3.607	6.314
Kansas City	2.327	6.144	2.566	6.870
Kotzebue	2.080	6.102	2.616	6.785
Los Angeles	2.601	5.022	2.889	6.069
Merida	2.447	5.270	2.842	6.575
Miami	2.218	5.626	2.884	6.602
Minneapolis	1.960	6.042	2.645	6.755
Oakland	1.883	5.488	2.662	5.926
Salt Lake City	3.695	4.964	5.347	5.985
San Jose Del Cabo	2.668	3.980	4.172	4.937
San Juan	1.795	5.265	3.283	5.861
Seattle	2.676	4.457	3.698	5.819
Tapachula	1.927	5.623	2.592	6.883
Washington, DC	1.984	5.869	2.634	6.308

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 7-3 shows the 95% horizontal accuracy trends at these sites. Figure 7-4 shows the 95% vertical accuracy trends at these sites. A value of zero indicates no data. The ramping error in the trend plots for the equatorial sites is due to seasonal variations in the ionosphere that cannot be corrected by the Klobuchar thin shell model of the ionosphere utilized by single frequency GPS SPS receivers.

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

Table 7-1 Selected IGS Site Information

ID	City	Country
BOGT	Bogota	Colombia
GLPS	Puerto Ayora	Ecuador
GUAM	Dededo	Guam
IISC	Bangalore	India
KIRU	Kiruna	Sweden
KOUR	Kourou	French Guyana

ID	City	Country
MADR	Robledo	Spain
MAL2	Malindi	Kenya
MAS1	Maspalomas	Spain
MATE	Matera	Italy
MOBN*	Obninsk	Russian Federation
NNOR	New Norcia	Australia
NRIL*	Norilsk	Russian Federation
PETS*	Petropavlovsk-Kamchatka	Russian Federation
POL2	Bishkek	Kyrgyzstan
SUTM	Sutherland	South Africa
TIDB	Tidbinbilla	Australia
UNSA	Salta	Argentina
USUD	Usuda	Japan

Figure 7-1 Selected IGS Site Locations

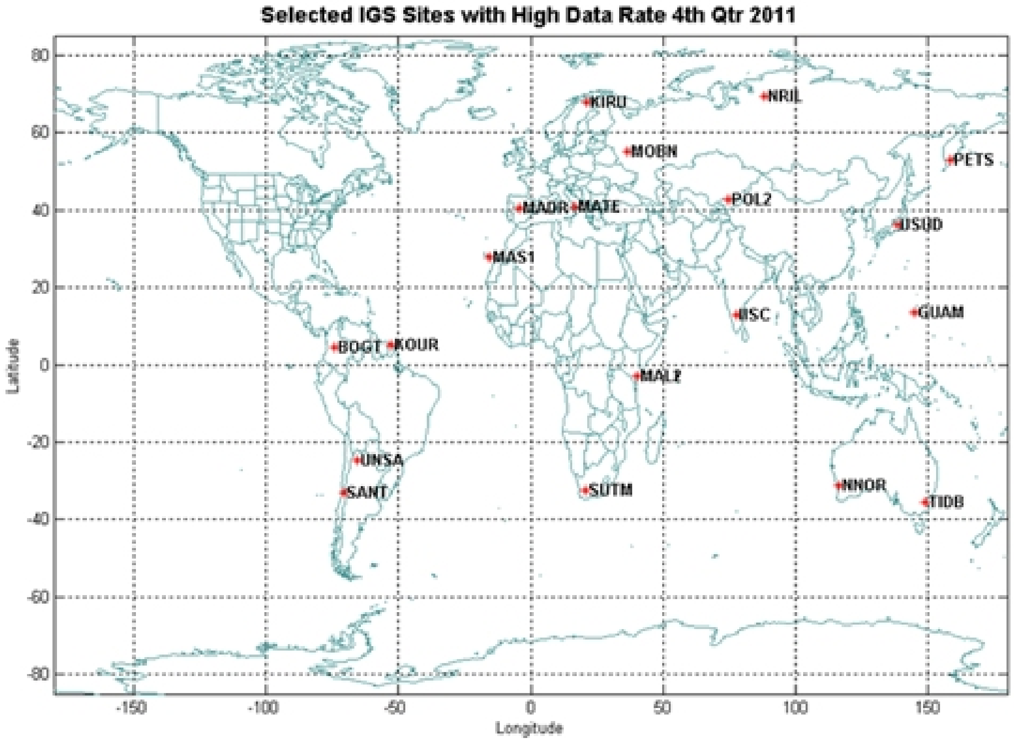


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

Site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
BOGT	2.02	4.09	50.01	50.01	54.62%
GLPS	2.31	3.80	50.01	50.01	74.07%
GUAM	1.64	3.31	4.31	20.02	99.02%
IISC	1.75	3.58	3.09	8.40	92.09%
KIRU	1.45	3.50	50.01	50.01	91.57%
KOUR	5.48	12.20	50.01	50.01	76.56%

Site	95% Horizontal Error (m)	95% Vertical Error (m)	99.99% Horizontal Error (m)	99.99% Vertical Error (m)	Percent Data Available
MADR	1.92	4.00	50.01	50.01	86.58%
MAL2	2.19	4.08	50.01	50.01	85.96%
MAS1	3.21	4.02	50.01	50.01	61.15%
MATE	1.90	4.71	50.01	50.01	89.90%
MOBN	0	0	0	0	0.00%
NNOR	1.58	3.81	3.90	9.03	99.34%
NRIL	0	0	0	0	0.00%
PETS	0	0	0	0	0.00%
POL2	2.46	4.98	50.01	50.01	83.87%
SANT	2.87	4.31	50.01	50.01	67.37%
SUTM	1.71	3.38	50.01	50.01	76.85%
TIDB	1.60	3.30	3.12	10.19	98.57%
UNSA	3.05	4.68	50.01	50.01	71.62%
USUD	2.40	4.66	5.84	11.84	99.92%

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

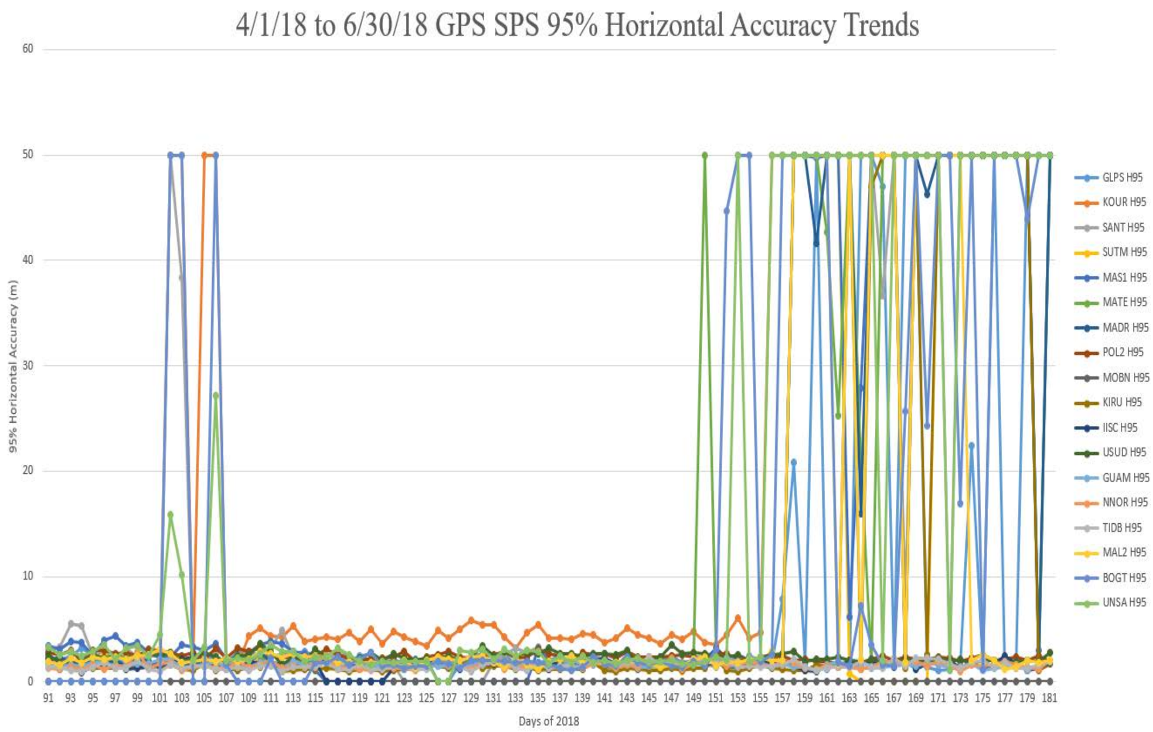
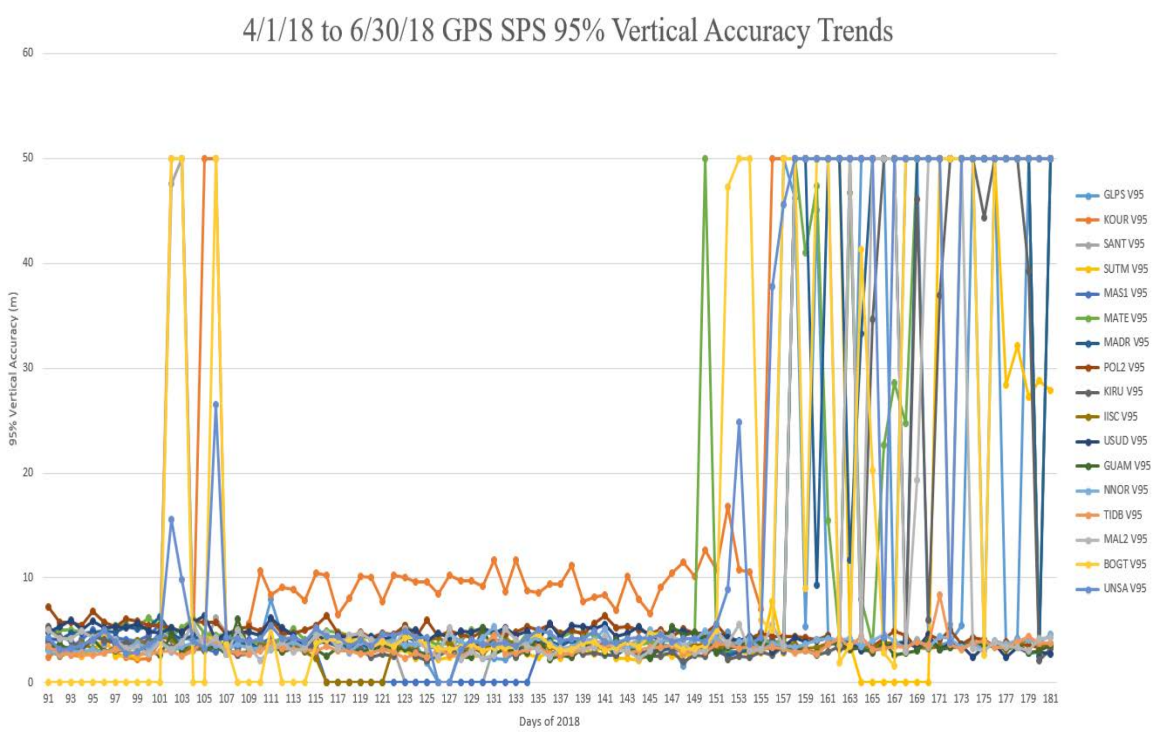


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites



8. RAIM PERFORMANCE

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

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

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

8.1 Site Performance

Table 8-1 shows the RAIM performance for the twenty-eight sites evaluated. For all sites collected, the minimum percent of time in RNP 0.1 mode was 99.447% at Cold Bay. The minimum percent of time spent in RNP 0.3 mode was 100% at all locations evaluated. The maximum 99% HPL value was 164.07 meters at Bethel.

Table 8-1 RAIM Site Statistics

CITY	99% HPL	Percent RNP 0.1	Percent RNP 0.3
Albuquerque	120.255	100	100
Anchorage	146.62	99.98	100
Atlanta	122.076	99.992	100
Barrow	113.279	99.995	100
Bethel	164.074	99.965	100
Billings	121.749	99.991	100
Boston	145.098	99.697	100
Cleveland	134.468	99.864	100
Cold Bay	159.985	99.447	100
Fairbanks	131.359	99.559	100
Gander	144.225	99.607	100
Honolulu	129.206	100	100
Houston	99.554	100	100
Iqaluit	138.631	99.994	100
Juneau	135.054	99.988	100
Kansas City	98.118	100	100
Kotzebue	135.28	100	100

CITY	99% HPL	Percent RNP 0.1	Percent RNP 0.3
Los Angeles	96.492	99.988	100
Merida	95.175	99.966	100
Miami	118.223	100	100
Minneapolis	117.399	99.986	100
Oakland	116.052	99.979	100
Salt Lake City	116.181	99.988	100
San Jose Del Cabo	91.596	100	100
San Juan	86.095	100	100
Seattle	122.959	99.993	100
Tapachula	105.872	100	100
Washington DC	130.648	99.844	100

8.2 RAIM Coverage

Figures 8-1 through 8-2 show the world wide RAIM coverage for both RNP 0.1 and RNP 0.3 respectively. Figures 8-3 through 8-4 show the daily RAIM coverage trends between 1 April and 30 June 2018.

Figure 8-1 RAIM RNP 0.1 Coverage

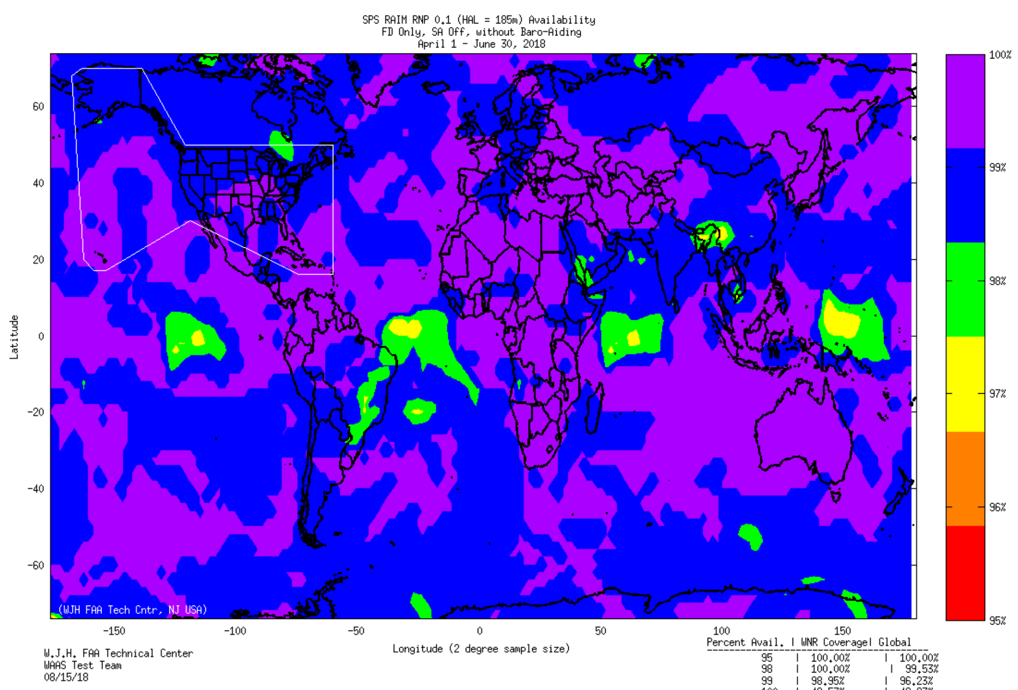


Figure 8-2 RAIM RNP 0.3 Coverage

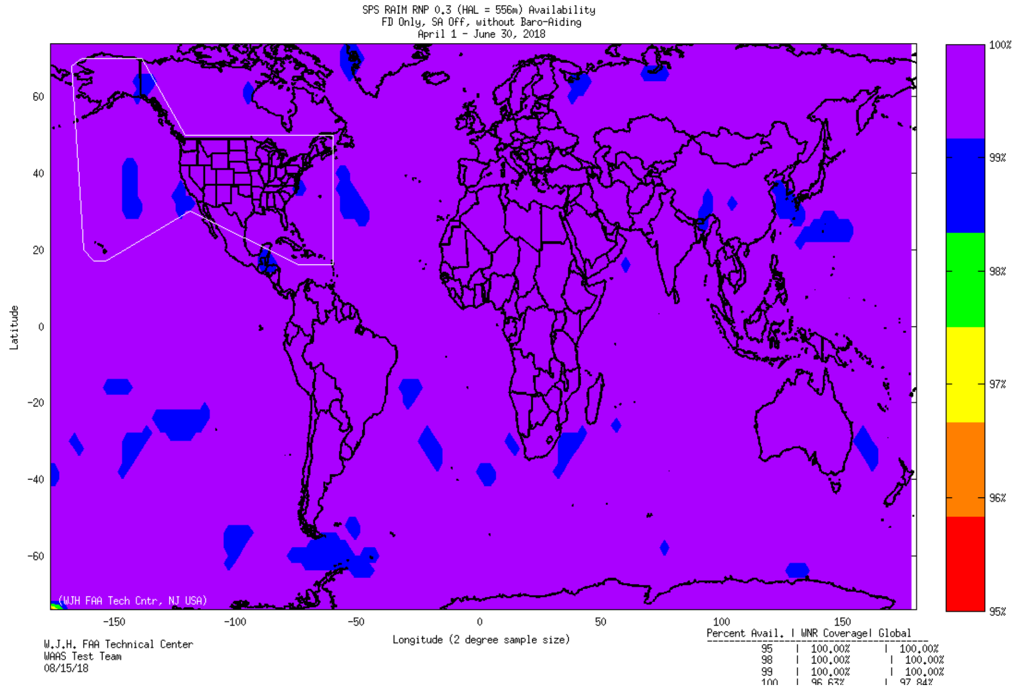


Figure 8-3 RAIM World Wide Coverage Trend

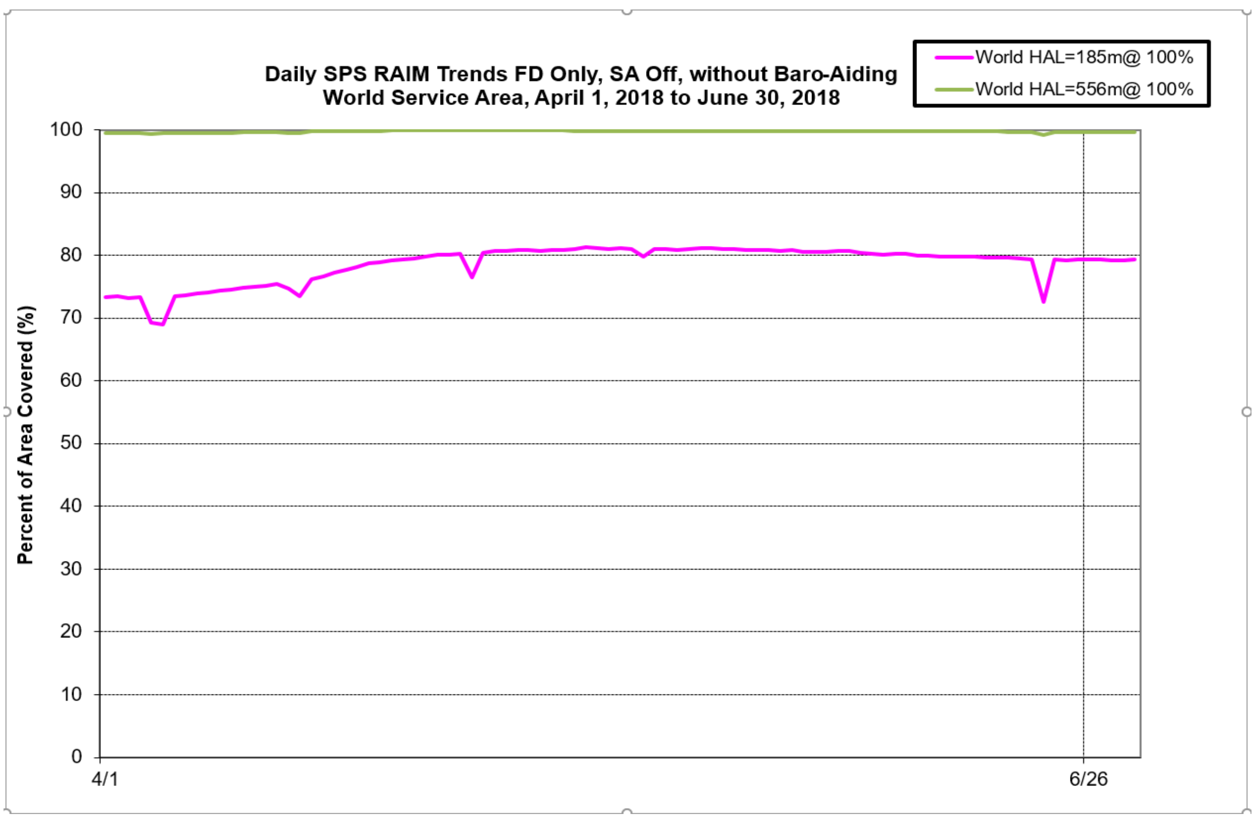
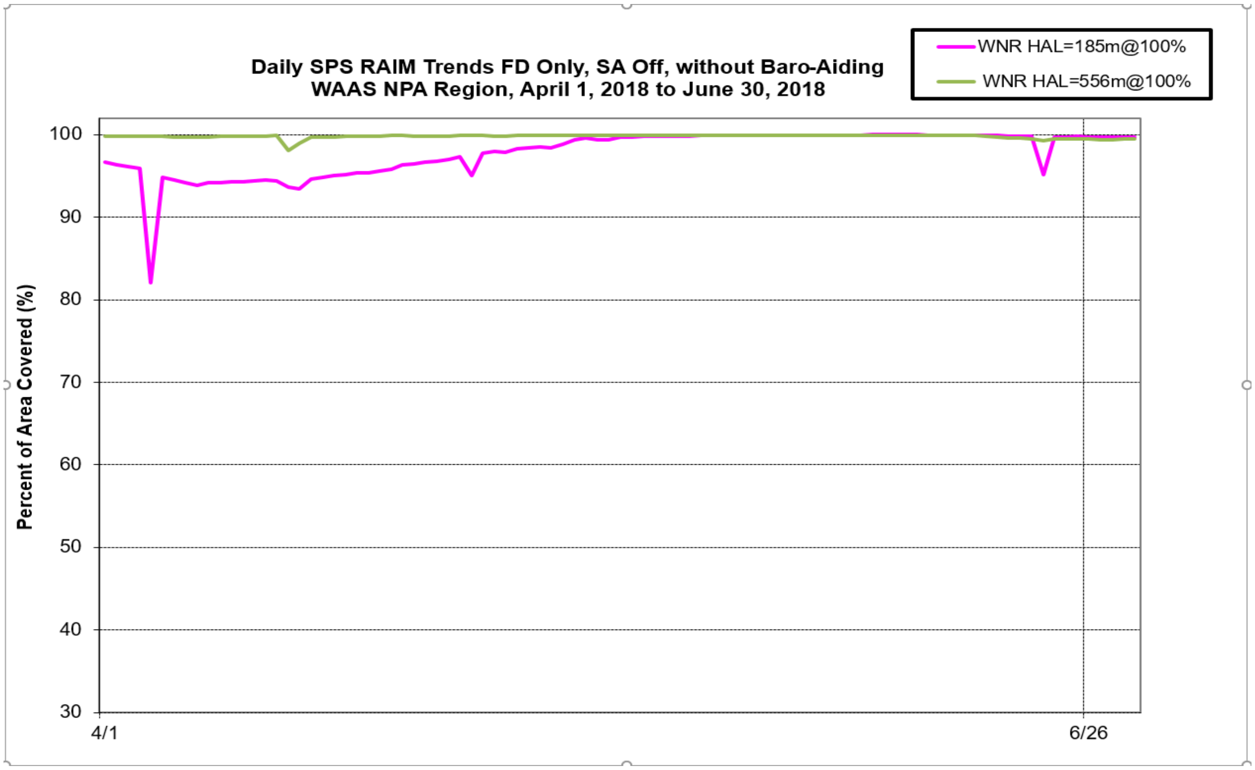


Figure 8-4 RAIM RNP Coverage Trend for WAAS NPA Service Area



8.3 RAIM Airport Analysis

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

Figure 8-5 RAIM RNP 0.1 Airport Availability

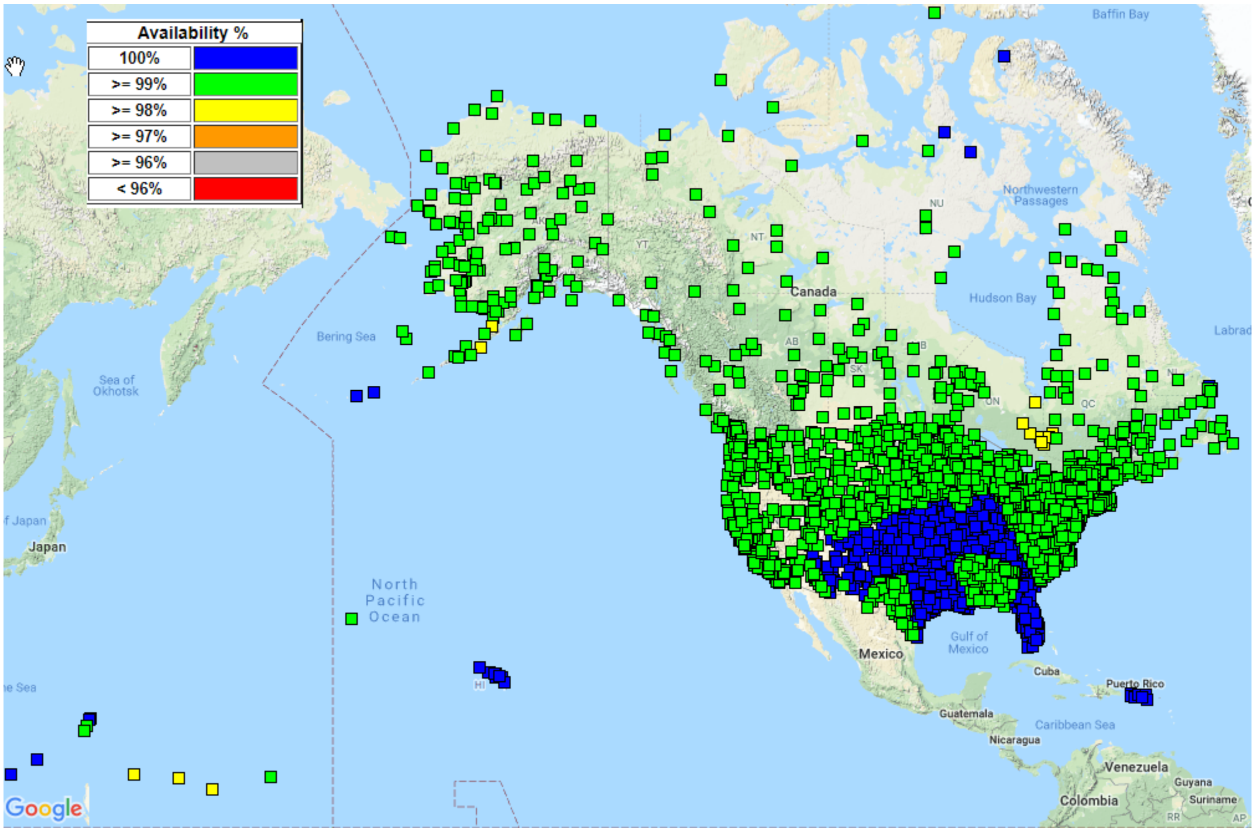
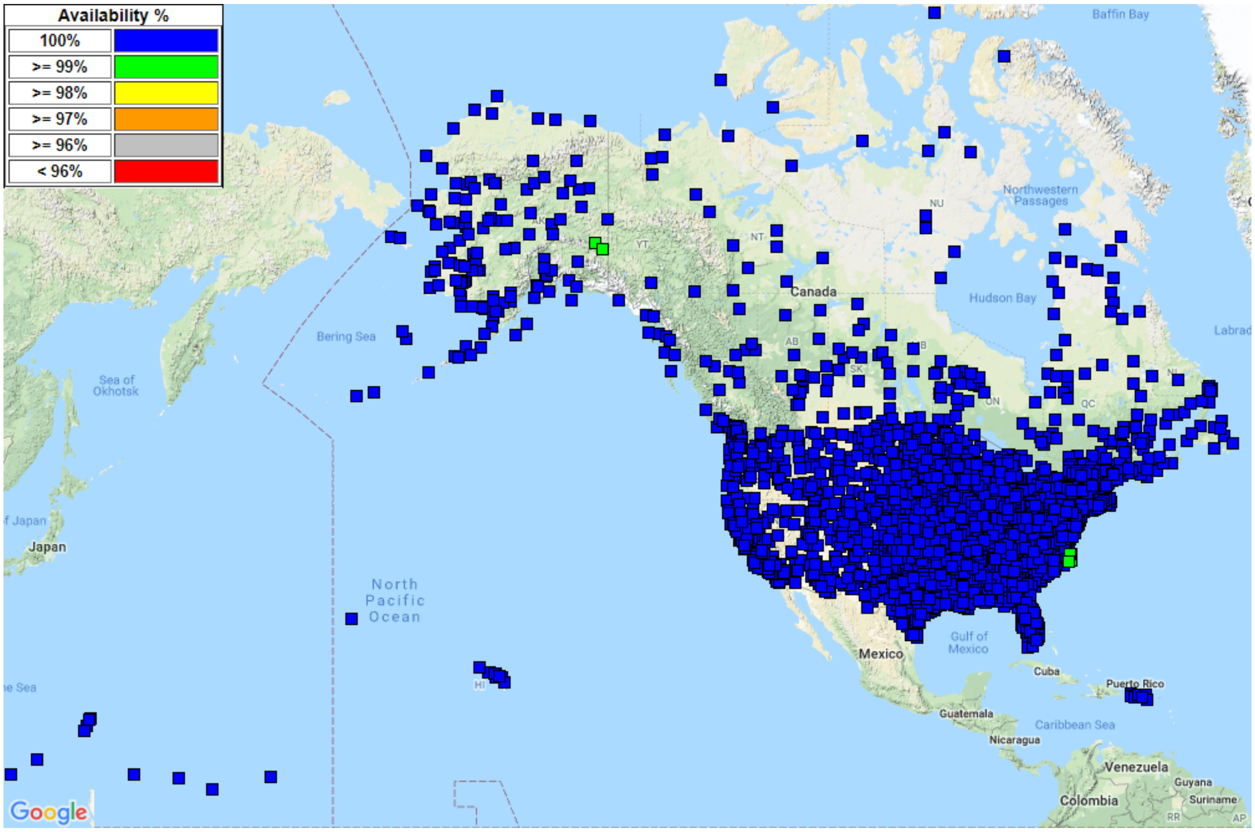


Figure 8-6 RAIM RNP 0.3 Airport Availability



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

Figure 8-7 RAIM RNP 0.1 Airport Outages

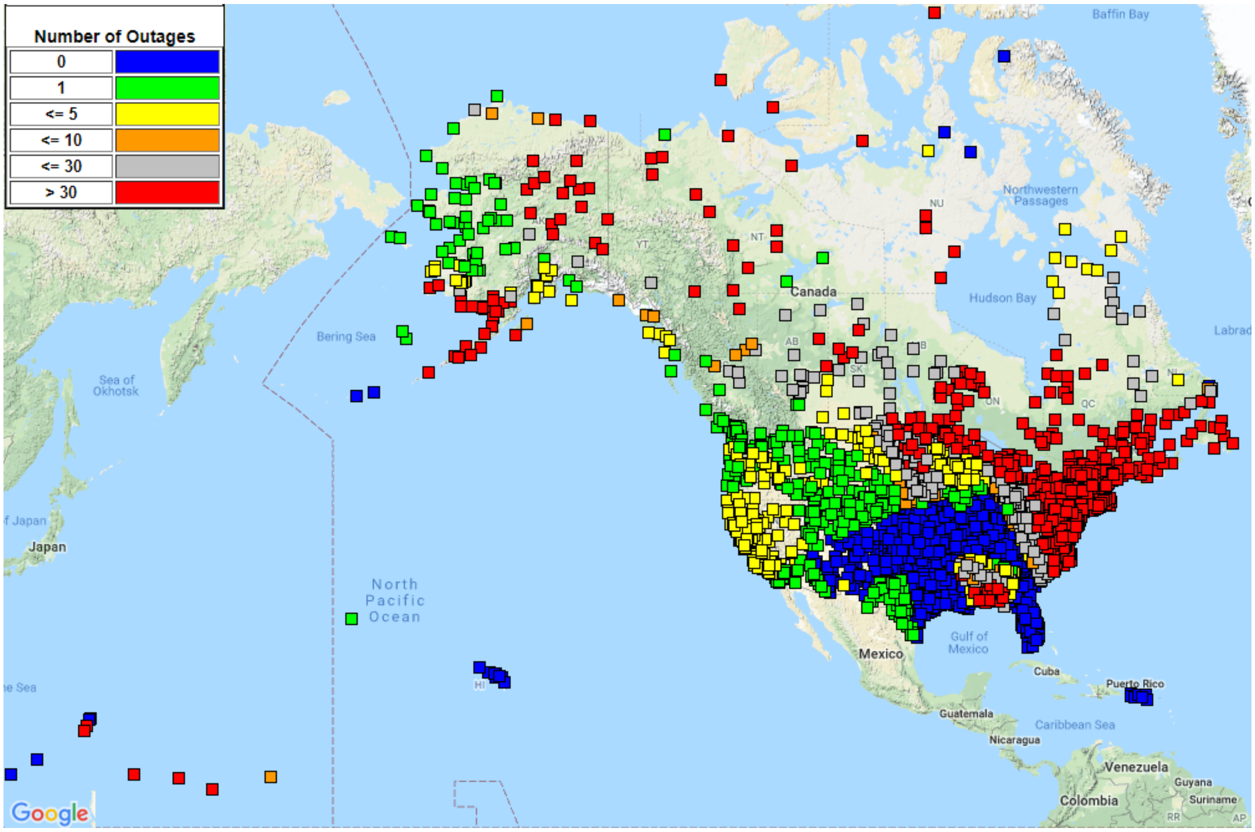
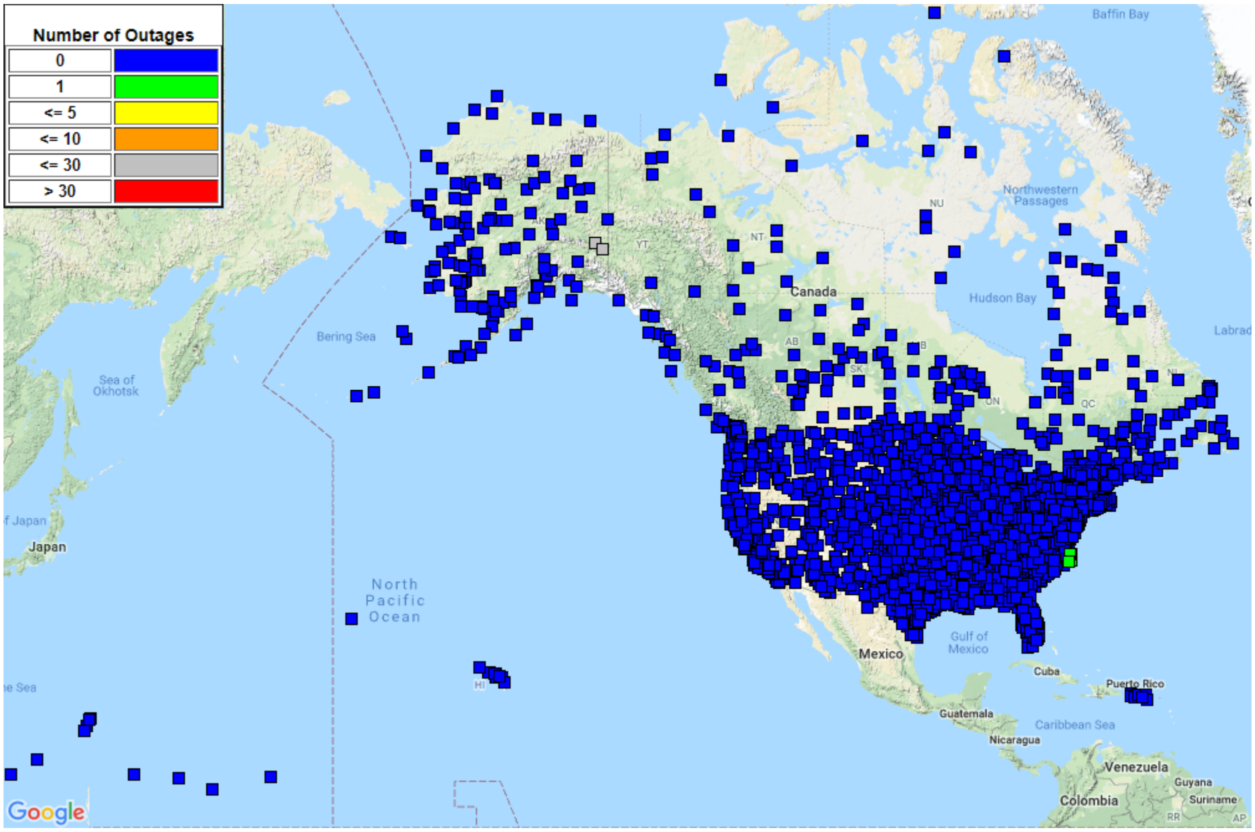


Figure 8-8 RAIM RNP 0.3 Airport Outages



9. GPS TEST NOTAMS SUMMARY

Due to software tool issues this section could not be completed on time for the report. This section will be updated as soon as possible.

10. APPENDICES

10.1 Appendix A: Performance Summary

Table 10-1 Performance Summary

User Range Error Accuracy	**Conditions and Constraints**	**Measured Performance**
Single Frequency C/A-Code • ≤ 7.8m 95% Global Average URE during normal operations over All AODs • ≤ 6.0m 95% Global Average URE during operations at Zero AOD • ≤ 12.8m 95% Global Average URE during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1	≤ 2.695 m N/A N/A
Single Frequency C/A-Code • ≤ 30m 99.94% Global Average URE during normal operations • ≤ 30m 99.79% Worst Case single point average during normal operations.	• For any healthy SPS SIS. • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1 • Including inter-signal bias (P(Y)-code to C/A-code) errors at L1 • Standard based on measurement interval of one year; average of daily values within service volume • Standard based on 3 service failures per year, lasting no more than 6 hours each	100% Global 100% WCP
User Range Rate	**Conditions and Constraints**	

Error Accuracy		
Single-Frequency C/A-Code: • ≤ 6 mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	≤ 2.655 mm/sec
User Range Acceleration Error Accuracy	**Conditions and Constraints**	
Single-Frequency C/A-Code: • ≤ 2 mm/sec^2 95% Global average URAE over any 3-second interval during normal operations at Any AOD	• For any healthy SPS SIS • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers • Neglecting single-frequency ionospheric delay model errors	≤ 21.478 mm/s^2

Per-Satellite Coverage	Conditions and Constraints	Measured Performance
Terrestrial Service Volume: • 100% Coverage	• For any health or marginal SPS SIS	100%
Constellation Coverage	**Conditions and Constraints**	
Terrestrial Service Volume: • 100% Coverage	• For any health or marginal SPS SIS	100%
Status and Problem Reporting	**Conditions and Constraints**	
Scheduled event affecting service		

• Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	• For any SPS SIS	≥ 98.6 hours Prior to event
Unscheduled outage or problem affecting service • Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	• For any SPS SIS	≤ 0.267 hours
Unscheduled Failure Interruption Continuity • ≥ 0.9998 Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption.	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Given that the SPS SIS is available from the slot at the start of the hour.	100%
Operational Satellite Count	**Conditions and Constraints**	
• ≥ 0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not	• Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operation satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not.	100%
PDOP Availability	**Conditions and Constraints**	
• ≥ 98% global PDOP of 6 or less • ≥ 88% worst site PDOP of 6 or less	• Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval	100 % 100 %
Service Availability	**Conditions and Constraints**	

• ≥ 99% Horizontal Service Availability, average location • ≥ 99% Vertical Service Availability, average location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	100% Horizontal 100% Vertical
• ≥ 90% Horizontal Service Availability, worst-case location • ≥ 90% Vertical Service Availability, worst-case location	• 17m Horizontal (SIS only) 95% threshold • 37m Vertical (SIS only) 95% threshold • Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.	100% Horizontal 100% Vertical

Position/Time Accuracy	**Conditions and Constraints**	
Global Average Position Domain Accuracy • ≤ 9m 95% Horizontal Error • ≤ 15m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 1.819 m Horizontal ≤ 4.028 m Vertical
Worst Site Position Domain Accuracy • ≤ 17m 95% Horizontal Error • ≤ 37m 95% Vertical Error	• Defined for a position/time solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours averaged over all points in the service volume.	≤ 3.077 m Horiz. ≤ 4.706 m Vert.
Time Transfer Domain Accuracy • ≤ 40 nanoseconds time transfer error 95% of time	• 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.	≤ 11 nanoseconds

(SIS only)		
Instantaneous UTCOE Integrity • NTE ±120 nanoseconds 99.999% of time without a timely alert (SIS only)	• For any healthy SPS SIS • Worst case for delayed alert is 6 hours	≤ 28.4 nanoseconds
Per-Slot Availability	**Conditions and Constraints**	
• ≥ 0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS • ≥ 0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a healthy SPS SIS	• Calculated as an average over all slots in the 24-slot constellation, normalized annually • Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard.	100% 100%
Constellation Availability	**Conditions and Constraints**	
• ≥ 0.98 Probability that at least 21 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration • ≥ 0.99999 Probability that at least 20 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration	• Calculated as an average over all slots in the 24-slot constellation, normalized annually. • Applies to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.	100% 100%

10.2 Appendix B: Geomagnetic Data

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

Current Quarter Daily Geomagnetic Data

	Middle Latitude - Fredericksburg -		High Latitude ---- College ----		Estimated --- Planetary ---	
Date	A	K-indices	A	K-indices	A	K-indices
2018 04 01	4	1 1 2 1 2 1 1 1	3	1 0 2 2 2 0 1 0	5	2 1 1 2 2 1 1 1
2018 04 02	4	1 1 1 0 2 2 1 1	2	1 1 0 2 1 1 0 0	5	2 1 1 1 2 2 1 1
2018 04 03	3	1 2 2 1 0 1 1 0	2	1 1 2 0 0 0 0 0	4	2 2 2 0 0 0 0 0
2018 04 04	4	0 0 1 2 2 2 1 2	6	0 0 0 4 3 1 0 0	5	0 1 1 2 2 2 1 2
2018 04 05	8	2 2 1 1 2 3 3 2	4	2 1 1 1 1 2 2 0	9	3 2 1 1 1 3 3 2
2018 04 06	3	1 1 0 1 1 2 1 1	2	1 0 0 1 1 1 0 0	4	1 1 1 1 1 2 1 1
2018 04 07	4	0 1 1 1 2 1 1 2	2	1 1 1 1 1 0 0 0	5	1 1 1 1 1 1 0 2
2018 04 08	5	1 2 1 1 1 1 2 2	2	1 1 0 1 0 1 0 1	5	1 2 0 1 1 2 2 2
2018 04 09	11	2 1 3 2 2 2 3 4	12	1 1 3 3 4 2 2 3	11	2 1 3 2 2 2 2 4
2018 04 10	14	2 4 4 2 3 2 2 3	34	3 4 5 4 6 5 3 3	18	2 4 4 3 3 3 2 3
2018 04 11	12	4 3 4 2 2 0 1 2	22	4 4 6 4 2 1 1 1	14	5 4 4 2 2 0 1 2
2018 04 12	8	2 2 3 1 2 2 2 2	11	2 1 3 4 3 2 1 2	9	2 2 3 2 2 2 2 3
2018 04 13	8	3 2 2 2 2 1 2 2	9	3 2 3 3 3 0 1 1	9	4 2 2 2 2 1 2 2
2018 04 14	6	1 1 0 1 3 2 2 2	2	1 1 0 0 1 1 1 0	6	2 2 0 1 2 2 2 2
2018 04 15	5	2 1 1 1 2 1 2 1	6	1 1 3 2 3 1 0 0	6	2 2 1 1 2 1 1 2
2018 04 16	3	1 1 0 1 2 1 1 0	1	0 0 0 2 0 0 0 0	3	1 1 0 1 1 0 0 1
2018 04 17	3	0 1 1 1 2 1 1 1	1	0 0 1 0 1 0 0 0	4	1 1 1 1 1 1 0 2
2018 04 18	6	1 2 1 2 2 2 2 1	8	1 1 2 3 4 2 1 0	6	1 2 1 2 2 2 1 1

2018	04	19	2	0	0	1	1	2	0	1	0	1	0	0	0	2	0	0	0	0	3	0	1	0	2	1	0	1	0
2018	04	20	29	3	4	6	4	4	3	4	3	56	1	5	7	7	4	5	4	3	47	4	5	6	6	4	4	5	3
2018	04	21	10	3	2	3	1	2	2	3	2	28	3	2	5	5	5	5	2	1	12	3	3	3	2	2	3	3	1
2018	04	22	5	2	2	1	1	2	1	1	2	5	2	1	2	1	2	1	1	1	5	2	2	2	1	2	1	1	2
2018	04	23	6	2	2	1	2	3	0	2	1	5	2	2	0	0	2	2	2	2	6	3	2	1	1	1	1	2	2
2018	04	24	4	1	0	2	1	2	1	1	2	3	0	0	2	0	2	1	1	1	5	1	0	2	1	2	1	2	2
2018	04	25	4	2	2	2	0	2	1	0	1	3	1	2	2	1	1	0	0	0	5	2	2	2	1	1	0	0	1
2018	04	26	4	2	1	1	1	2	0	1	1	4	1	0	0	3	2	0	1	1	4	2	1	1	1	1	0	1	2
2018	04	27	5	1	0	0	1	2	2	2	3	4	1	0	0	0	1	3	2	1	6	1	0	1	1	2	3	2	2
2018	04	28	5	2	1	1	1	2	1	2	1	2	2	1	1	1	0	0	0	0	4	2	1	1	1	1	1	1	1
2018	04	29	3	0	0	1	1	2	1	1	2	0	0	0	0	0	0	0	0	0	4	1	0	1	1	2	1	0	1
2018	04	30	10	2	2	1	2	3	2	4	1	3	3	1	0	1	0	1	0	0	6	3	2	1	1	2	2	2	1
2018	05	01	3	0	1	1	1	2	0	1	1	1	1	1	0	0	0	0	0	1	3	0	1	1	0	1	0	1	1
2018	05	02	5	1	2	1	2	2	1	2	0	2	1	1	1	2	0	0	0	0	4	1	2	1	1	1	1	1	0
2018	05	03	3	0	0	0	1	2	1	1	2	0	0	0	0	0	0	0	0	1	4	1	1	1	1	1	1	1	2
2018	05	04	4	0	1	1	1	2	2	2	1	1	0	1	0	1	0	0	0	0	4	1	1	1	1	1	1	1	1
2018	05	05	12	1	1	1	3	3	3	3	4	27	1	1	0	2	5	6	5	4	20	1	1	0	3	3	5	4	5
2018	05	06	24	5	4	3	3	3	3	4	4	29	4	5	4	5	5	3	2	3	31	6	4	3	3	3	3	4	5
2018	05	07	14	3	4	3	2	3	2	2	3	31	3	5	5	4	5	5	1	2	17	4	4	3	2	3	3	2	3
2018	05	08	12	2	3	3	3	2	3	3	2	27	3	5	4	5	3	5	2	2	14	3	3	3	3	2	4	4	2
2018	05	09	13	3	3	3	2	3	2	3	3	29	3	3	6	4	5	3	3	3	16	3	3	3	2	3	2	4	4
2018	05	10	11	3	2	4	3	2	2	1	2	21	3	2	4	5	4	4	2	2	12	3	3	3	3	2	3	1	2
2018	05	11	19	2	4	3	2	4	2	5	3	28	2	3	6	4	5	4	2	3	16	2	4	4	2	3	2	4	4
2018	05	12	10	3	4	2	2	2	1	2	2	9	3	3	2	4	1	0	1	1	10	3	4	2	2	1	1	2	2
2018	05	13	10	1	2	3	3	3	2	2	2	12	1	1	3	5	3	2	1	1	8	2	2	2	2	2	2	2	2
2018	05	14	5	1	1	1	1	2	1	2	2	5	2	1	1	1	3	1	0	1	5	2	1	2	1	1	1	1	2
2018	05	15	5	1	1	1	1	2	2	1	2	2	1	1	1	0	0	1	0	1	4	1	1	1	1	1	1	1	2
2018	05	16	3	0	0	0	1	2	1	2	1	1	0	0	0	0	0	0	1	1	4	0	0	1	1	1	1	2	2
2018	05	17	9	2	2	2	2	3	2	3	2	15	2	2	1	3	5	4	2	2	10	3	2	2	3	3	2	2	2

```
2018 05 18   3 1 1 1 1 2 0 1 1   7 2 2 1 3 3 1 1 0   4 2 1 1 1 1 1 1 1
2018 05 19   3 0 0 0 1 2 2 1 1   0 0 0 0 0 0 1 0 0   3 0 1 0 1 1 1 1 1
2018 05 20   3 0 1 1 1 1 2 1 0   2 1 1 1 1 2 0 0 0   3 1 1 2 1 1 1 0 0
2018 05 21   3 0 1 0 2 1 1 1 1   1 0 1 0 2 0 0 0 0   3 0 1 1 1 0 1 0 1
2018 05 22   6 0 1 3 1 1 2 2 2   6 0 1 4 1 1 1 2 1   5 1 1 2 1 1 1 2 2
2018 05 23  10 2 3 3 2 3 2 2 2  18 2 3 4 5 4 3 0 1   9 2 2 3 3 3 2 1 2
2018 05 24   5 2 2 1 1 2 2 1 1   1 1 1 0 1 0 0 0 0   4 2 2 1 1 1 1 1 1
2018 05 25   4 1 0 0 1 2 1 3 0   2 2 1 1 1 1 0 0 0   3 2 1 0 1 1 0 1 0
2018 05 26   5 0 1 1 1 3 1 2 2   2 0 1 0 0 1 0 1 1   4 0 1 1 1 2 1 1 2
2018 05 27   5 2 2 1 2 2 1 1 1   5 2 2 0 3 2 0 1 1   4 2 2 1 1 1 1 1 1
2018 05 28   4 1 1 1 2 2 1 1 1   2 0 1 1 1 1 0 1 0   4 1 1 1 1 2 1 1 1
2018 05 29   5 2 2 1 2 2 1 1 1   2 1 2 1 0 0 0 1 0   4 1 2 1 1 1 1 1 1
2018 05 30   5 1 1 1 1 2 2 2 2   2 0 1 1 0 0 0 2 1   4 1 1 1 1 1 1 2 2
2018 05 31  11 2 2 1 2 3 3 3 3   9 2 2 0 3 1 3 3 2  12 2 2 1 2 2 4 4 3
2018 06 01  19 3 3 4 3 4 4 3 2  46 3 5 6 5 6 6 2 2  26 3 4 4 4 5 4 3 3
2018 06 02  14 3 3 3 2 3 3 3 3  25 3 4 4 5 5 2 3 3  17 3 4 3 2 3 2 4 4
2018 06 03   9 3 2 1 2 2 3 2 2  15 3 2 1 5 4 2 2 2   9 3 2 1 2 3 3 2 2
2018 06 04   5 1 2 1 1 2 1 2 1   4 2 2 1 2 1 1 1 0   5 1 2 2 1 1 1 2 1
2018 06 05   6 2 2 1 2 2 2 2 1   7 2 2 1 3 3 1 1 1   6 2 2 2 2 2 2 2 1
2018 06 06   9 1 2 0 2 2 3 4 2   5 1 1 0 0 2 2 3 1   7 1 1 0 1 1 2 4 2
2018 06 07   6 2 2 1 1 2 2 1 2   3 1 2 1 1 1 1 0 0   6 3 2 1 1 1 1 1 2
2018 06 08   5 1 3 1 2 2 1 0 0   6 2 2 0 3 3 0 0 0   4 1 2 1 2 2 0 0 0
2018 06 09   5 1 1 1 2 2 1 2 1   3 0 1 1 3 0 1 1 0   4 1 1 1 2 1 1 1 1
2018 06 10   4 1 2 1 1 2 1 2 0   0 0 1 0 0 0 0 0 0   4 1 2 1 0 1 1 1 1
2018 06 11   4 1 0 0 1 2 2 1 2   1 1 1 0 0 0 1 0 0   4 1 1 1 0 1 1 0 2
2018 06 12   5 2 2 1 1 2 1 1 1   2 1 1 1 0 0 0 0 1   4 2 2 1 0 1 0 1 1
2018 06 13   7 0 2 1 2 2 2 2 3   1 1 1 1 0 0 0 0 0   5 1 1 2 1 1 1 1 2
2018 06 14   7 3 2 2 2 2 1 1 1   3 2 1 1 1 2 0 0 1   5 2 1 2 1 1 1 1 1
2018 06 15   6 2 1 1 1 2 2 3 1   2 1 2 0 0 0 1 0 0   4 1 1 1 1 1 1 1 1
```

2018 06 16	4	1	1	1	1	2	2	1	1	1	1	1	0	0	0	0	0	0	3	1	1	1	1	1	1	0	1
2018 06 17	7	2	1	1	2	3	2	2	2	2	1	1	1	1	0	0	1	1	5	1	1	1	1	1	1	2	2
2018 06 18	20	5	4	4	4	2	3	1	2	33	4	3	5	6	6	2	1	2	19	5	4	4	4	3	2	2	2
2018 06 19	6	2	2	2	2	2	1	2	1	11	2	2	3	4	4	0	1	1	6	2	2	3	2	2	1	1	1
2018 06 20	7	1	2	3	3	2	1	1	1	6	1	2	3	3	1	1	0	1	5	1	2	2	2	1	1	1	1
2018 06 21	4	1	1	1	1	2	1	1	1	2	1	1	1	1	0	0	1	0	3	1	1	1	1	1	0	1	0
2018 06 22	4	0	1	1	2	2	1	1	1	1	0	1	1	0	0	0	1	0	4	0	1	1	1	1	1	1	1
2018 06 23	15	2	3	2	4	3	2	3	4	24	1	4	2	5	5	4	3	3	16	2	3	2	4	4	3	2	4
2018 06 24	8	2	2	3	2	2	1	2	2	11	3	2	3	3	4	1	1	1	7	2	2	3	2	2	1	1	2
2018 06 25	10	2	1	1	2	2	2	3	4	15	1	1	1	2	5	4	3	3	12	1	1	1	2	2	2	3	5
2018 06 26	17	5	3	3	3	3	2	3	2	33	5	4	4	5	5	4	4	3	20	5	3	3	4	3	3	3	2
2018 06 27	7	1	3	2	1	2	1	2	2	11	2	3	2	4	3	1	2	2	7	1	2	2	2	2	1	1	3
2018 06 28	5	1	1	1	1	2	2	2	1	5	2	1	1	1	2	1	1	2	5	2	1	1	1	2	1	2	1
2018 06 29	3	1	2	0	1	1	1	1	1	2	2	1	1	1	0	1	0	0	4	1	2	1	1	1	1	0	0
2018 06 30	3	0	0	1	2	2	1	1	1	2	0	1	0	1	1	1	1	1	6	0	1	1	1	1	1	0	1

10.3 Appendix C: Performance Analysis (PAN) Problem Report

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

Problem Description:

There were no problems this quarter.

10.4 Appendix D: Glossary

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

General Terms and Definitions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SPS SIS User Range Error (URE) Statistic:

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

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

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

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

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

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

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

11. GPS BROADCAST ORBIT VERSUS NGA PRECISE ORBITS AND URA (IAURA) BOUNDING ANALYSES

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

The assumption being validated is:

Height Error: +/- 15 meters (standard deviation < 2.8 m),

Along Track Error: +/- 65 meters (standard deviation < 12.2 m)

Cross Track Error: +/- 30 meters (standard deviation < 5.6 m)

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

For C/A Nav data, all IGS high rate 15-minute broadcast navigation data RINEX format files are downloaded and merged into 24 hour broadcast navigation data files which are then added to RINEX nav data files from all WAAS peripheral reference stations. A majority voting algorithm is used to screen the navigation data after a LSB recovery algorithm is applied. NGA APC precise ephemeris referenced to the GPS satellite antenna phase center is downloaded from the NGA site. GPS satellite positions are computed every 15 minutes and differenced with the precise orbits. The resulting error information is then segregated into the Height, Along Track, and Cross Track (HAC) error data. The standard deviation of those errors is then computed for each dimension for each satellite. Figures 11-1 through 11-4 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 April 01 to June 30, 2018 is presented. Only data points where GPS is healthy and valid precise data is available are considered. There was maintenance on PRN-8 on 04/05/18, PRN-17 on 04/17/18, PRN-22 on 04/22/18, PRN-23 on 05/03/18, PRN-14 on 05/18/18, and PRN-20 on 06/22/18. Figure 11-5 shows the availability of C/A Nav data. There were no points where GPS was healthy and the NGA data was missing. There are no points where GPS C/A GPS Nav data is unavailable other than during NANUs.

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

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

Figures 11-7 and 11-8 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)

Figures 11-9 thru 11-58 are plots of the height, along track, and cross track error relative to NGA precise orbits by PRN number. These plots do not include clock error.

Figures 11-59 thru 11-70 are QQ plots of the URA (IAURA) normalized total range error (height, along track, cross track, and clock) projected onto the surface of the earth. +/- 13.9° from the bore sight of the satellite is used to approximate the surface of the earth. The max URA of the broadcast URA index range is used for the C/A Nav data, IAURA is used for the CNAV data. The range of the QQ plot axis has been fixed at +/- 5. Annotations are provided for any instances beyond that range.

Errors larger than 3 times URA (IAURA) for C/A and 4 times URA (IURA) for CNAV were investigated.

Figures 11-71 thru 11-116 are histograms of the height error, along track error, cross track error, and URA (IAURA) normalized range error.

Figures 11-117 thru 11-162 are the timelines of the URA (IAURA) normalized range error. Missing data point are in red and are NANUs for the C/A data. The large number of red points in the CNAV data is the points where the satellites are out of view of ACY.

GPS Broadcast Orbit Accuracy Standard Deviation Plots

Figure 11-1 GPS Broadcast Orbit Accuracy Standard Deviations Using C/A Nav Data

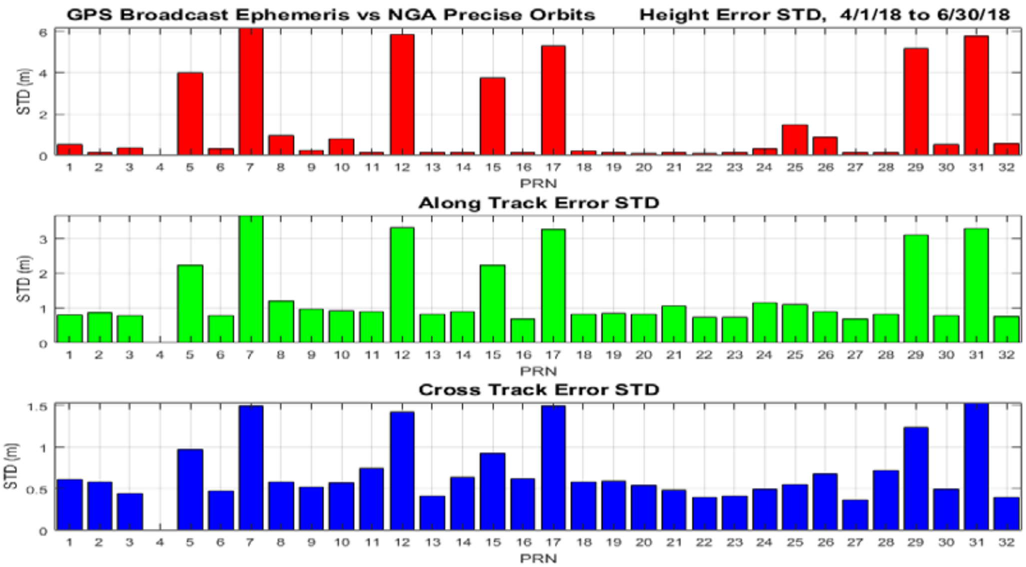


Figure 11-2 GPS Broadcast Orbit Accuracy Standard Deviations Using L2C CNAV Data

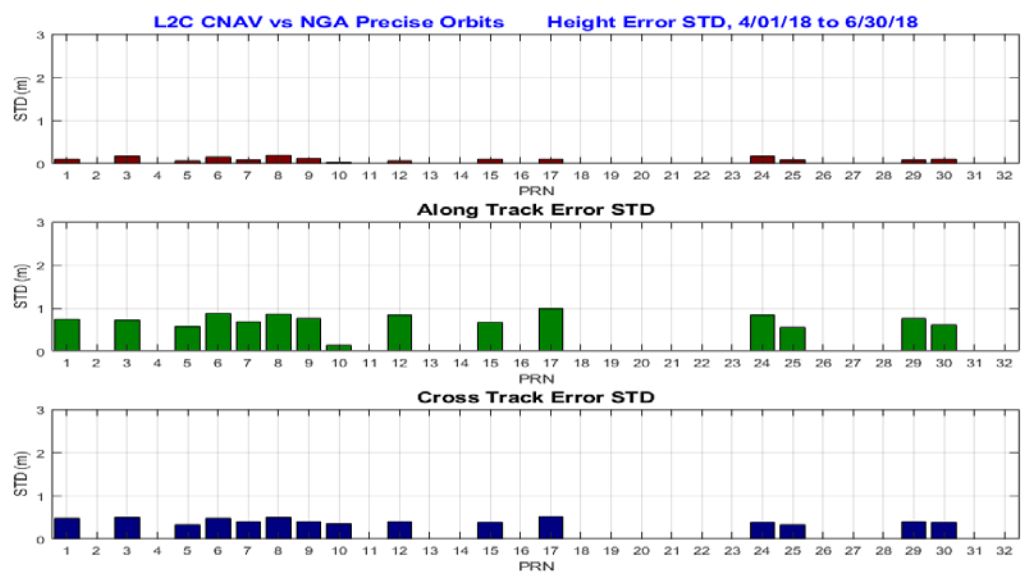


Figure 11-3 GPS Broadcast Orbit Error Means Using C/A Nav Data

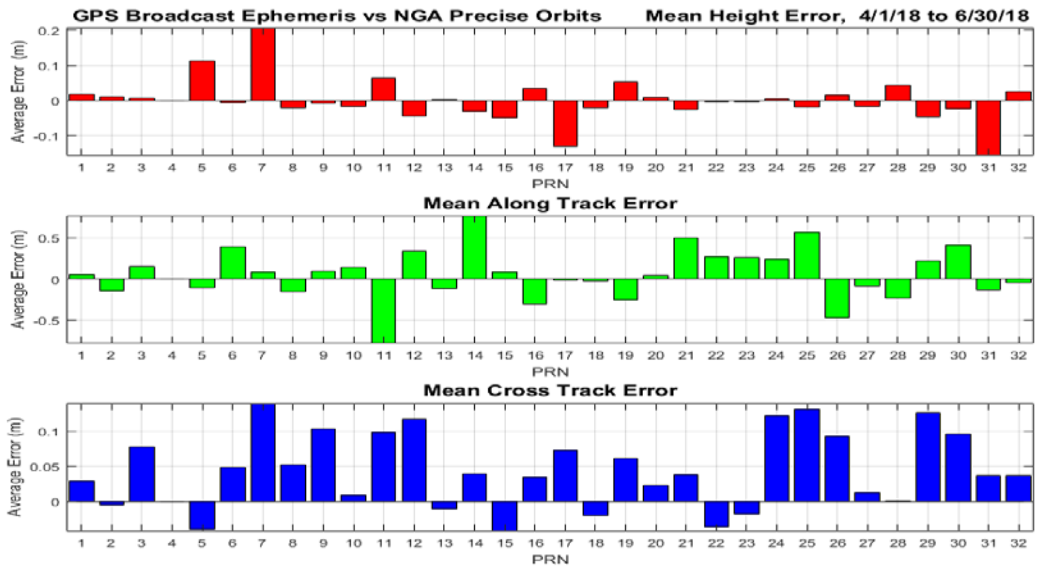
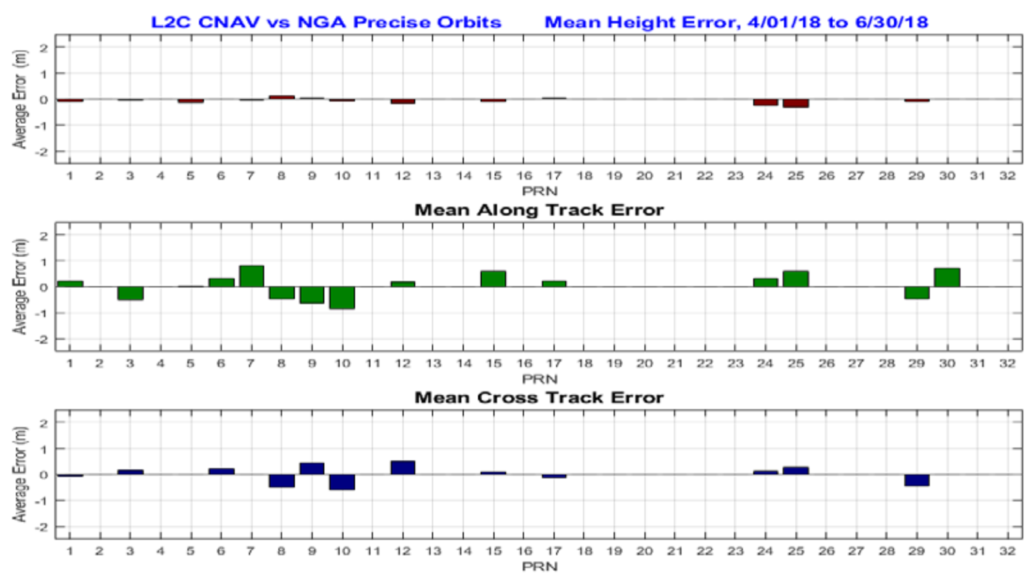
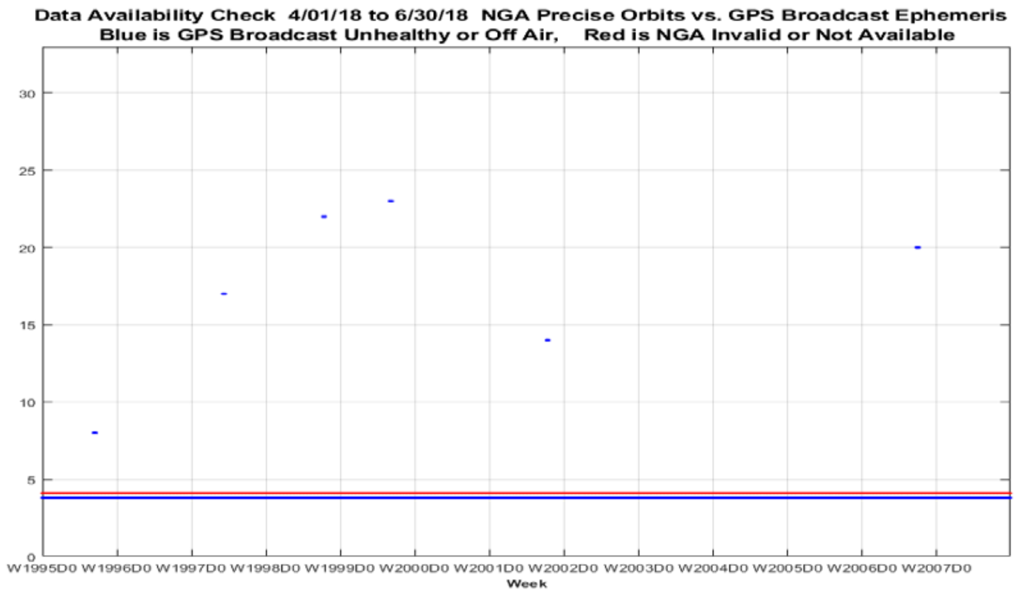


Figure 11-4 GPS Broadcast Orbit Error Means Using L2C CNAV Data



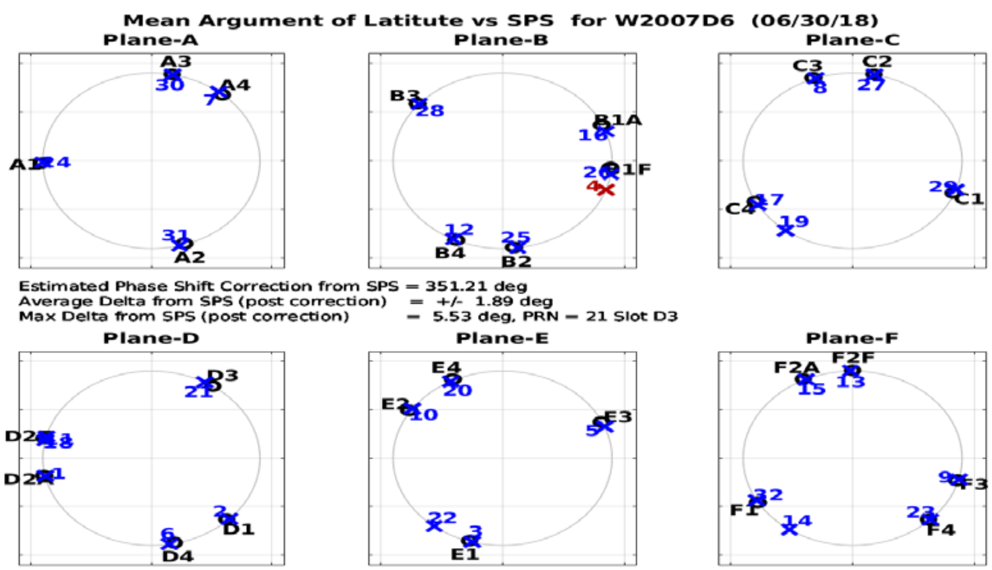
Broadcast Ephemeris vs. NGA Precise Data Availability Plots

Figure 11-5 Broadcast Ephemeris vs. NGA Precise Data Availability Plots



Current GPS Constellation

Figure 11-6 Current GPS Constellation



URA Over-bounding Plots

Figure 11-7 URA Over-bounding Using C/A Nav Data

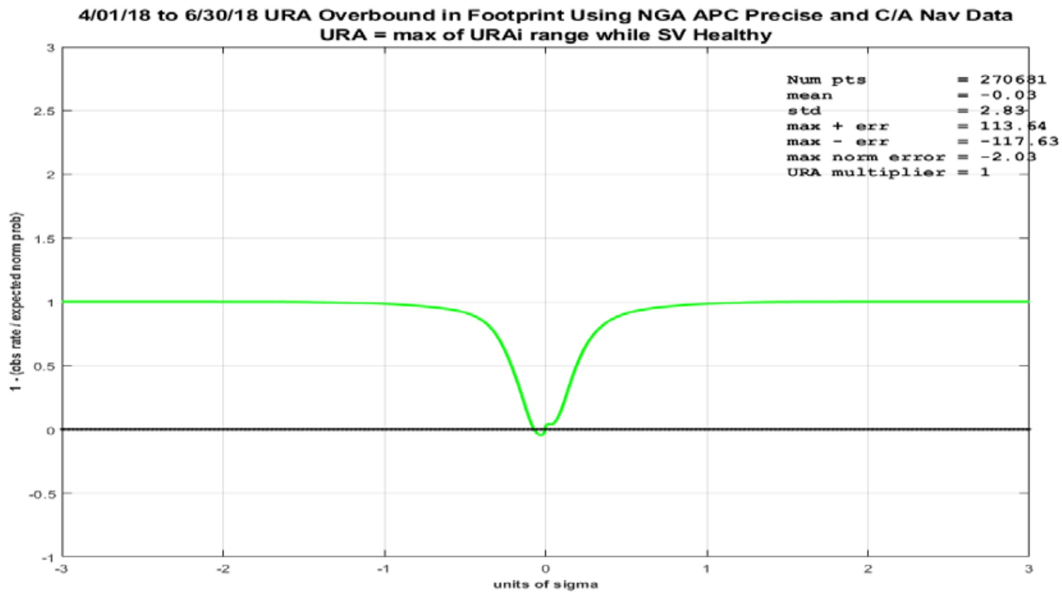
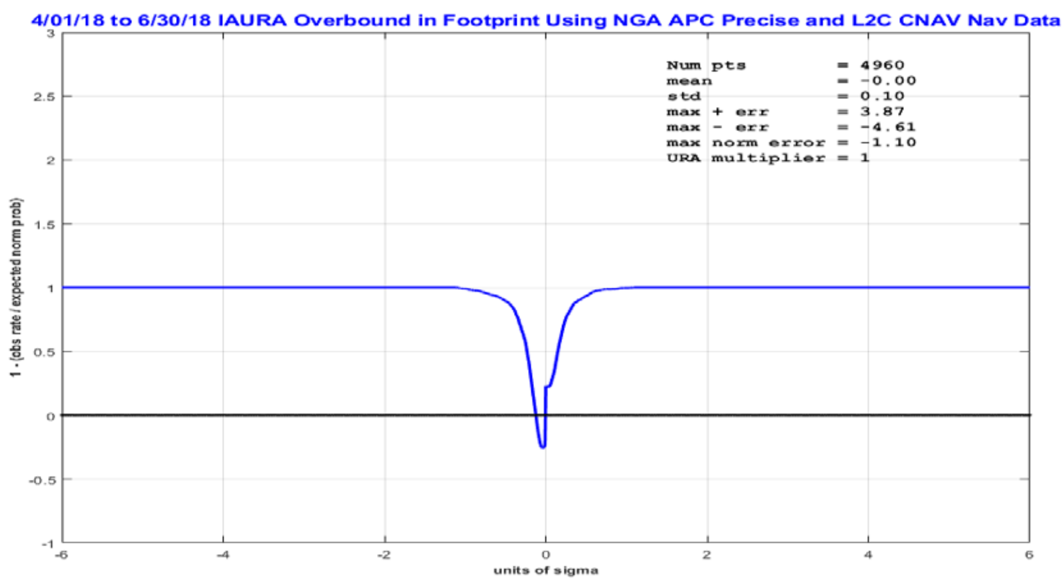


Figure 11-8 IAURA Over-bounding Using L2C CNAV Data



Orbit Error Plots for All Satellites

Figure 11-9 Orbit Error PRN-1 (SVN-63) Using C/A Nav Data

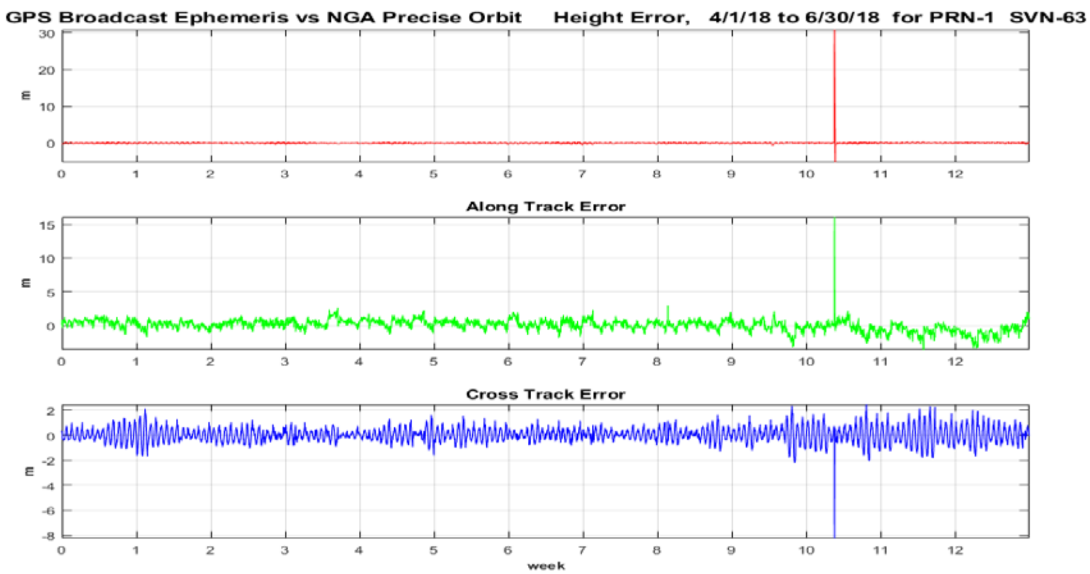


Figure 11-10 Orbit Error PRN-1 (SVN-63) Using L2C CNAV Data

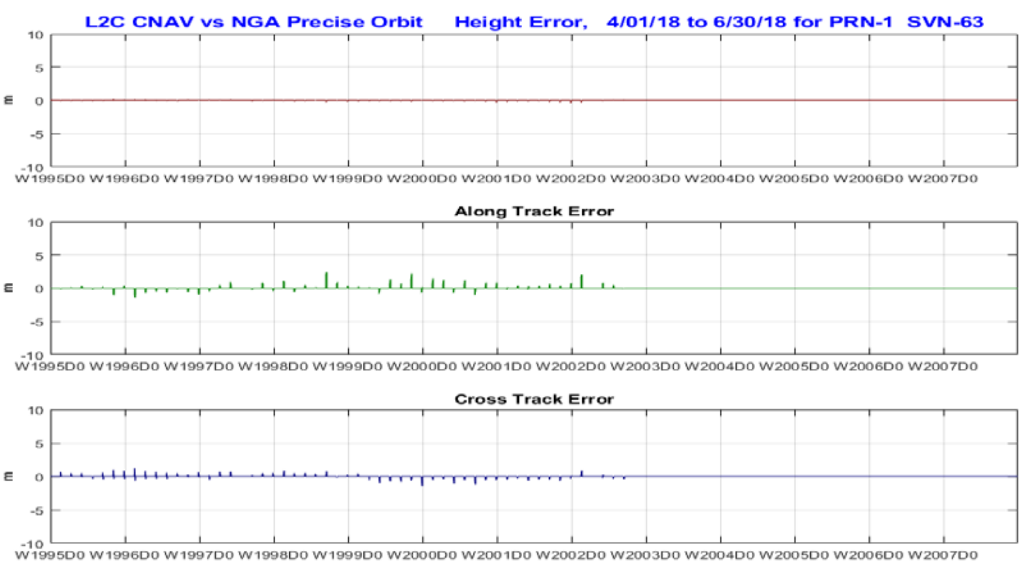


Figure 11-11 Orbit Error PRN-2 (SVN-61) Using C/A Nav Data

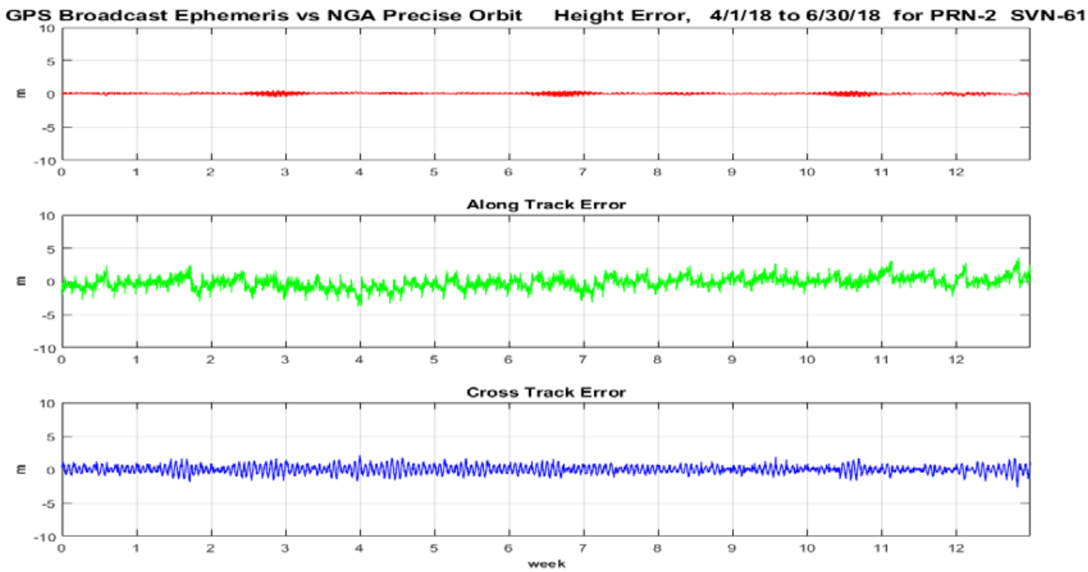


Figure 11-12 Orbit Error PRN-3 (SVN-69) Using C/A Nav Data

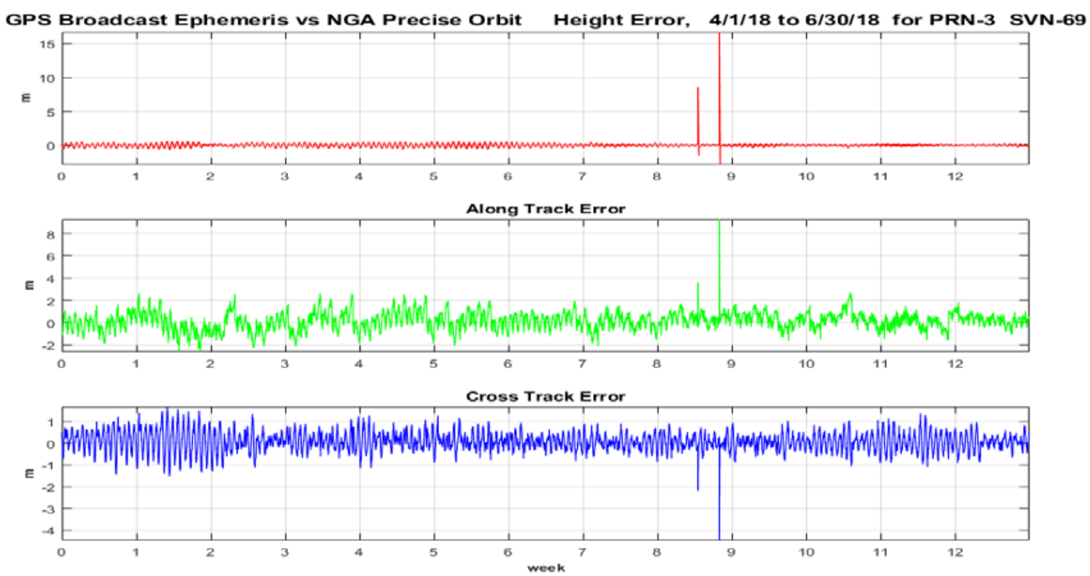


Figure 11-13 Orbit Error PRN-3 (SVN-69) Using L2C CNAV Data

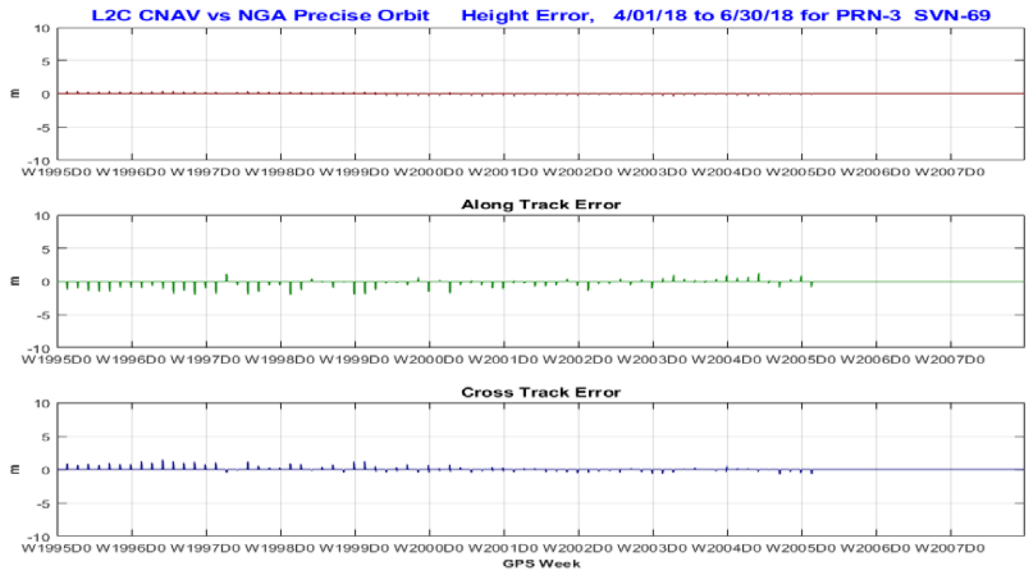


Figure 11-14 Orbit Error PRN-5 (SVN-50) Using C/A Nav Data

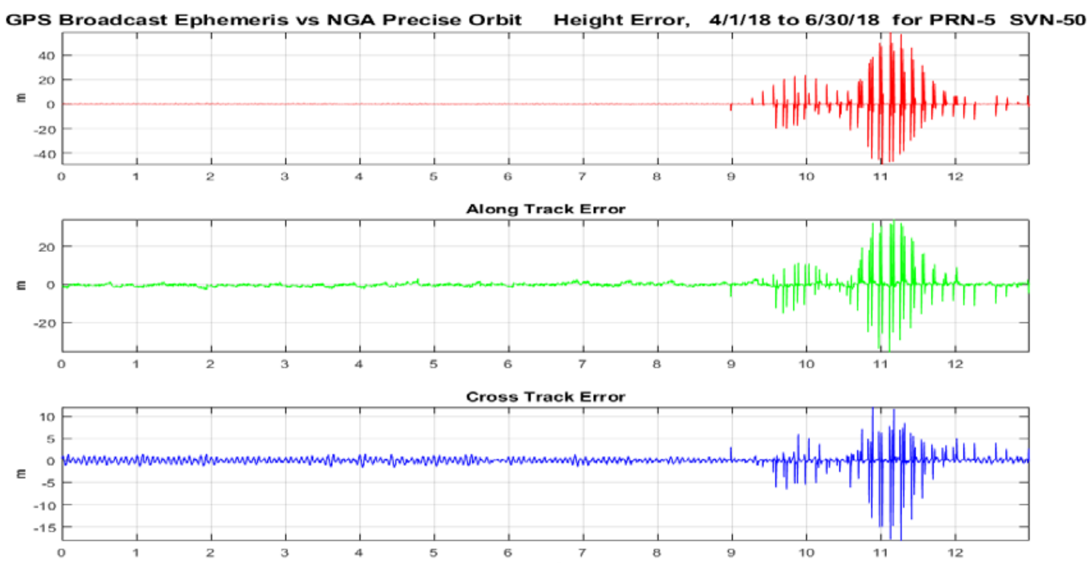


Figure 11-15 Orbit Error PRN-5 (SVN-50) Using L2C CNAV Data

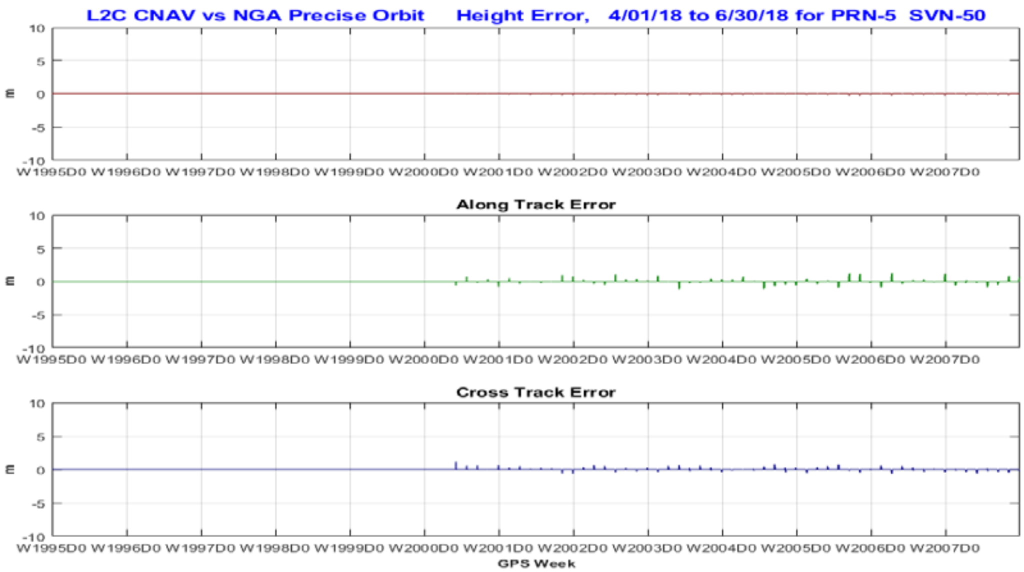


Figure 11-16 Orbit Error PRN-6 (SVN-67) Using C/A Nav Data

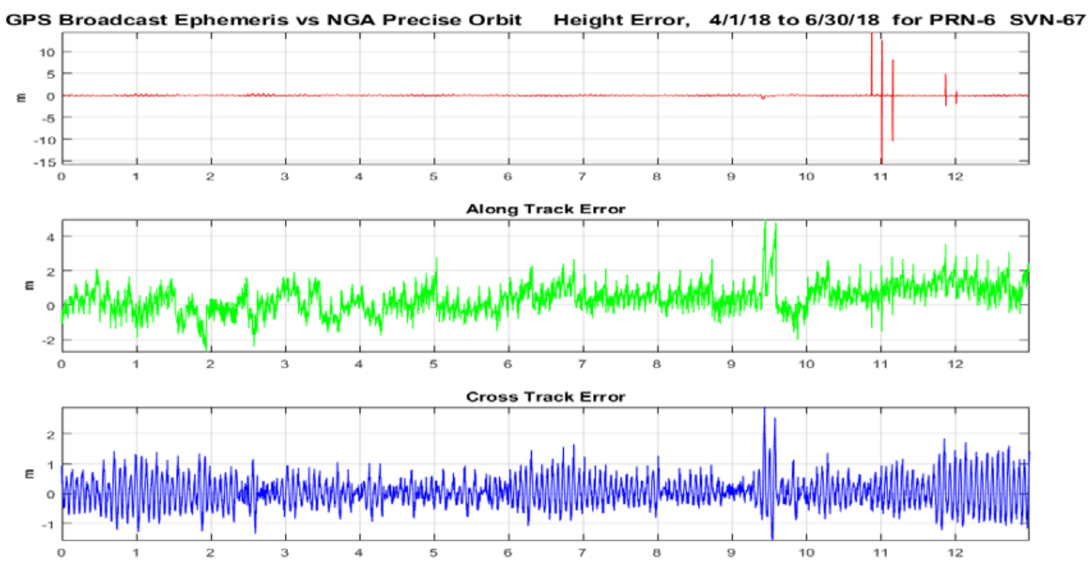


Figure 11-17 Orbit Error PRN-6 (SVN-67) Using L2C CNAV Data

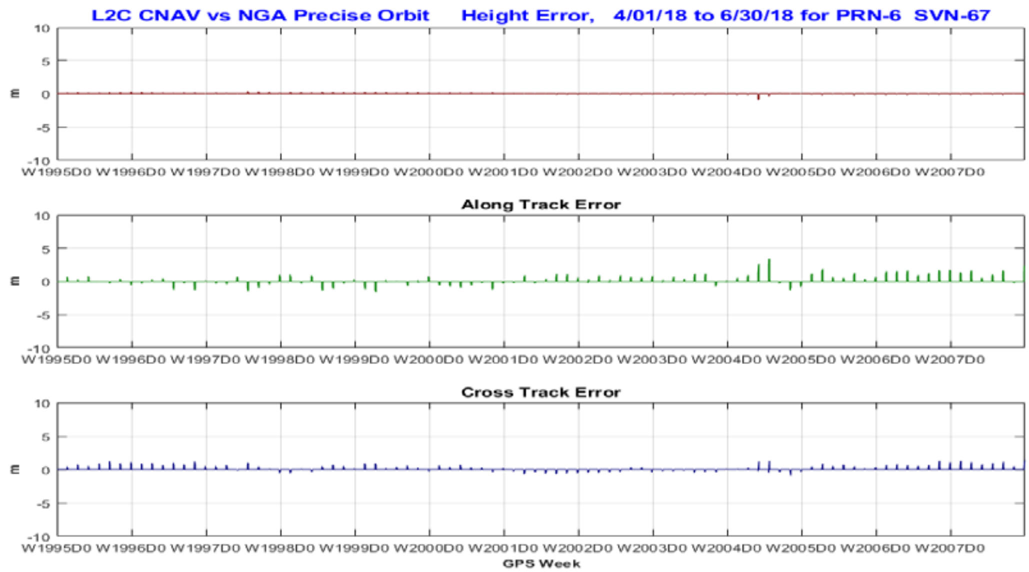


Figure 11-18 Orbit Error PRN-7 (SVN-48) Using C/A Nav Data

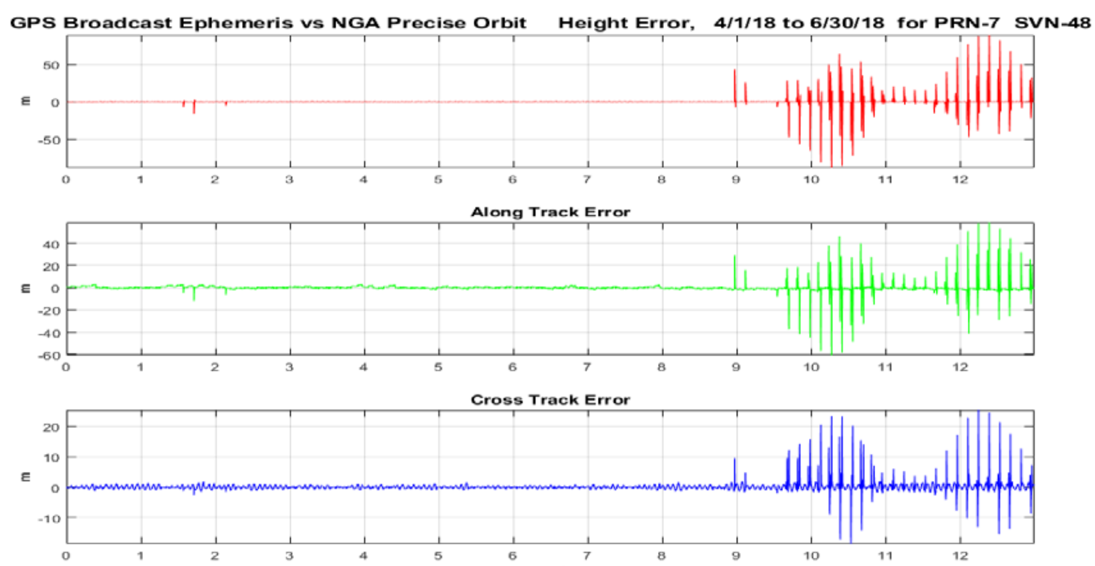


Figure 11-19 Orbit Error PRN-7 (SVN-48) Using L2C CNAV Data

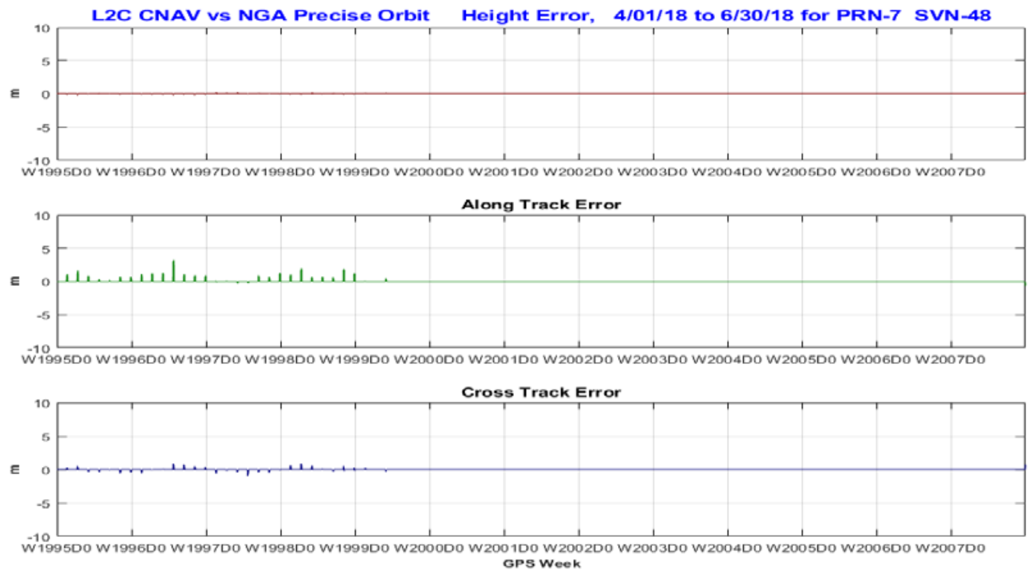


Figure 11-20 Orbit Error PRN-8 (SVN-72) Using C/A Nav Data

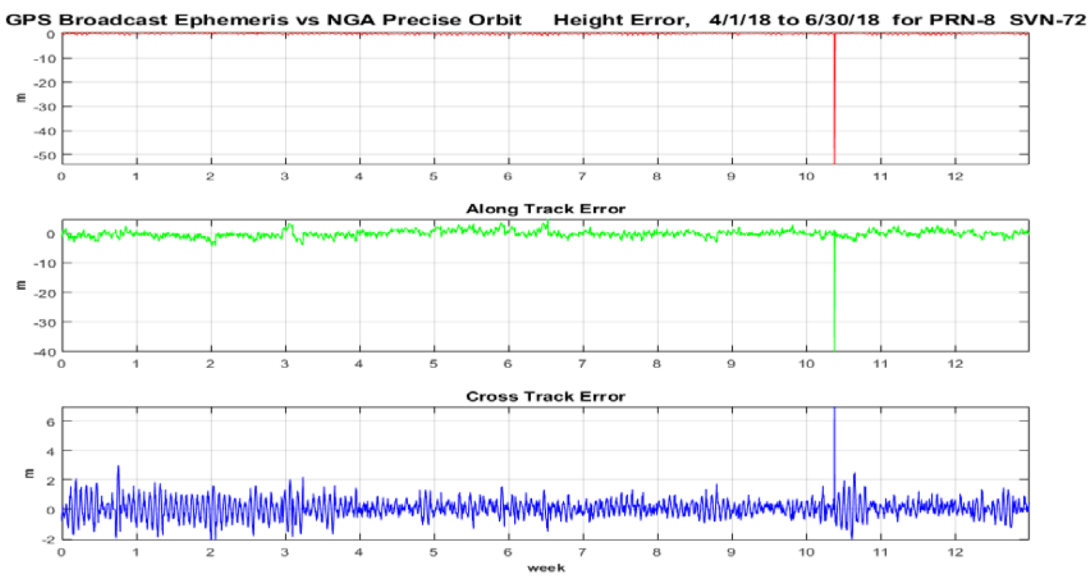


Figure 11-21 Orbit Error PRN-8 (SVN-72) Using L2C CNAV Data

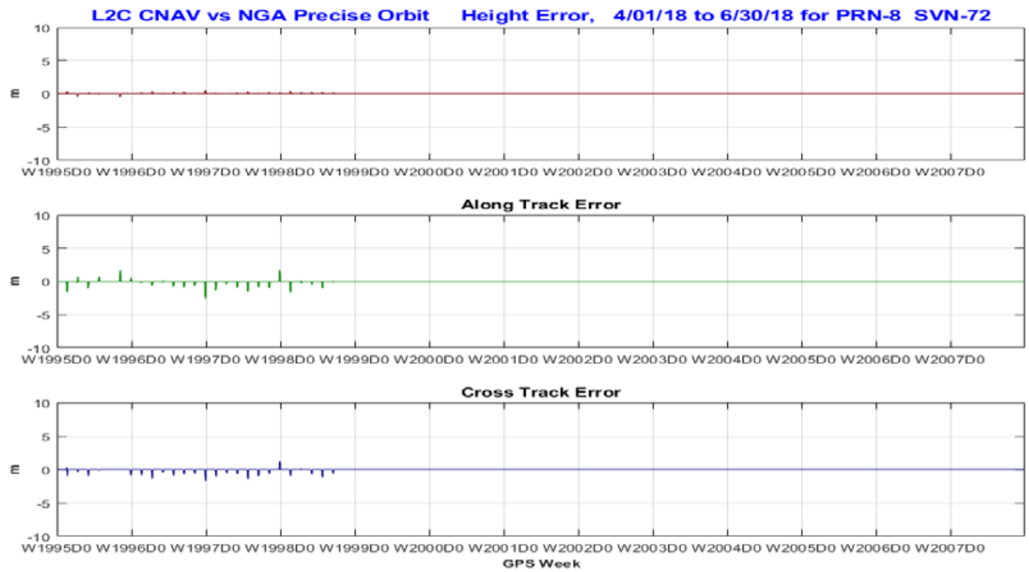


Figure 11-22 Orbit Error PRN-9 (SVN-68) Using C/A Nav Data

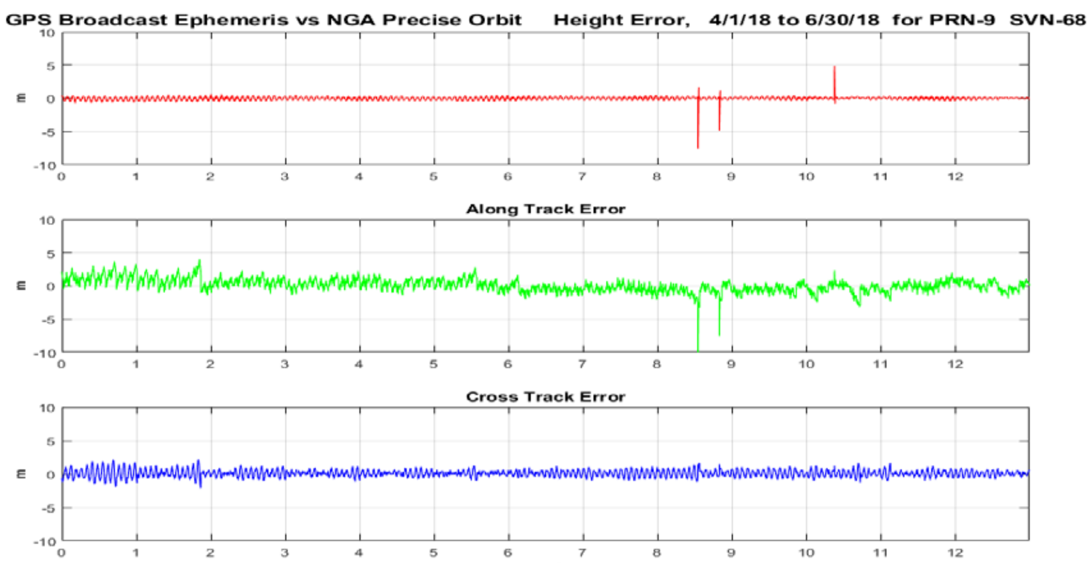


Figure 11-23 Orbit Error PRN-9 (SVN-68) Using L2C CNAV Data

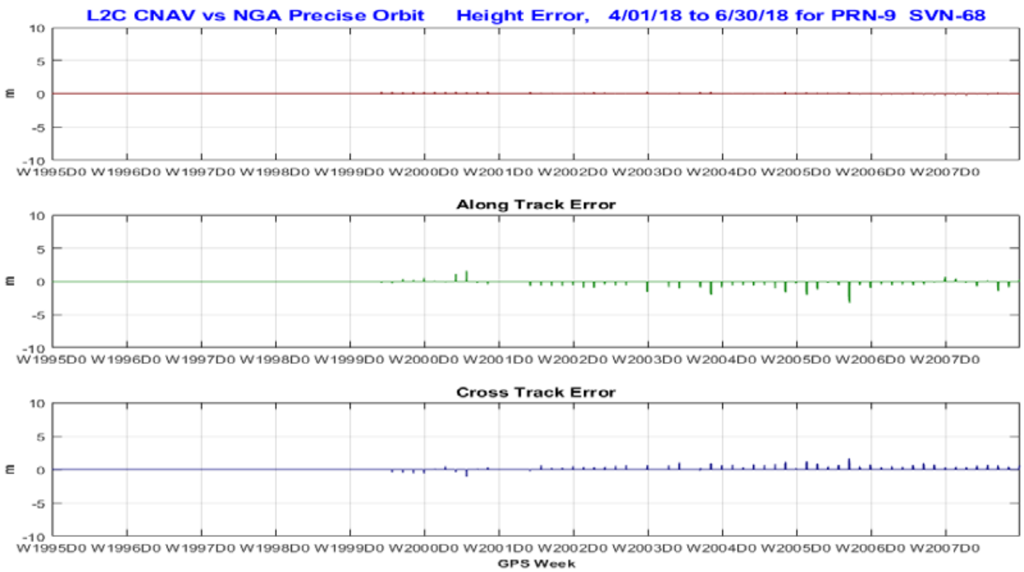


Figure 11-24 Orbit Error PRN-10 (SVN-73) Using C/A Nav Data

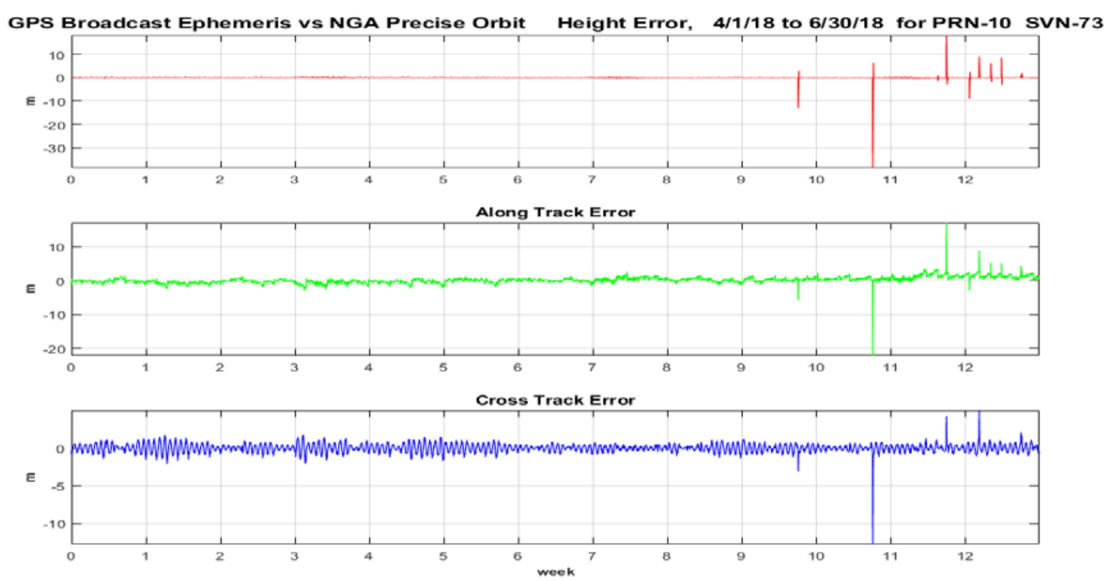


Figure 11-25 Orbit Error PRN-10 (SVN-73) Using L2C CNAV Data

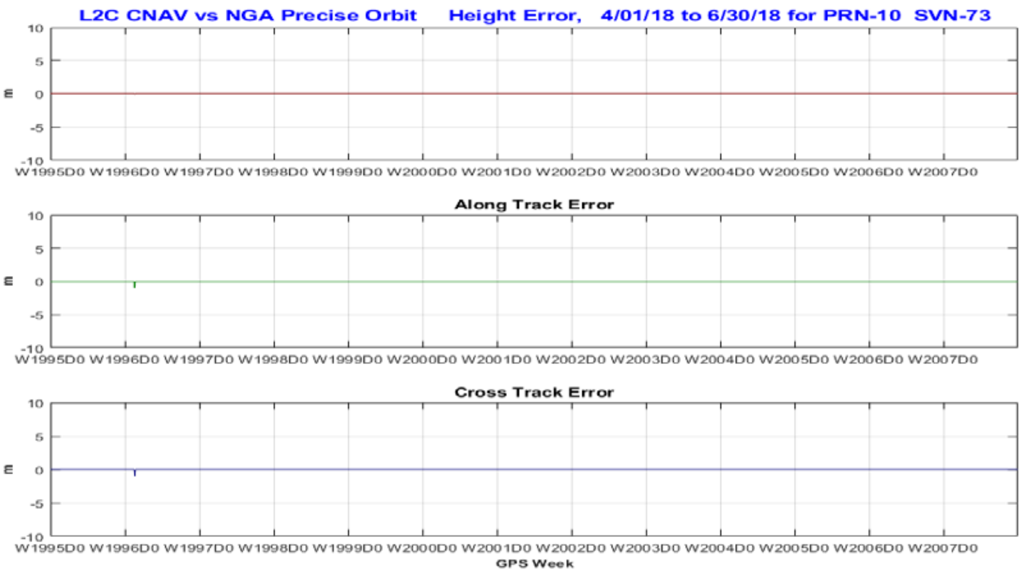


Figure 11-26 Orbit Error PRN-11 (SVN-46) Using C/A Nav Data

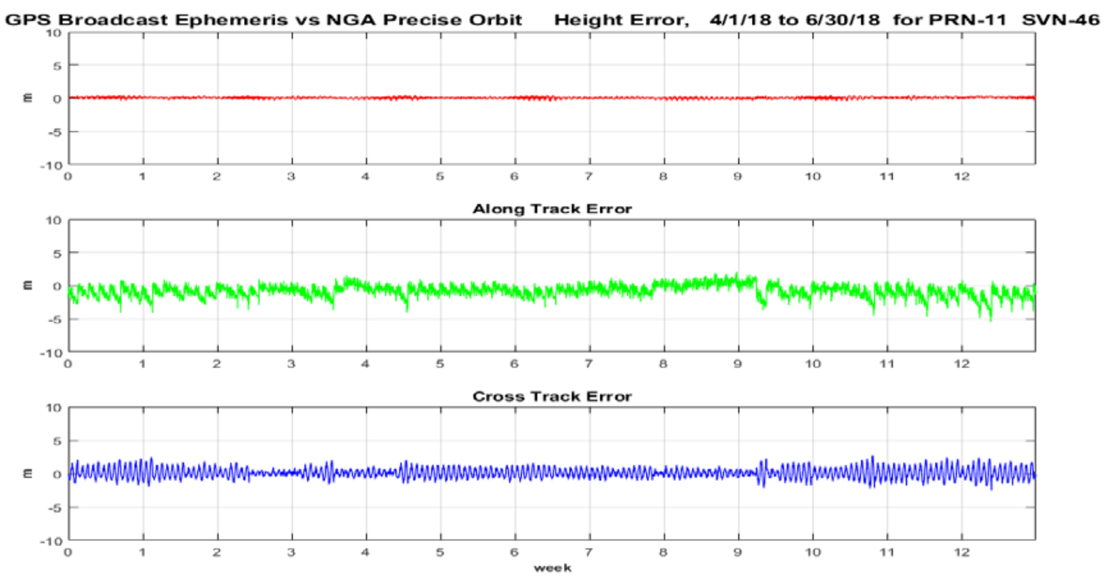


Figure 11-27 Orbit Error PRN-12 (SVN-58) Using C/A Nav Data

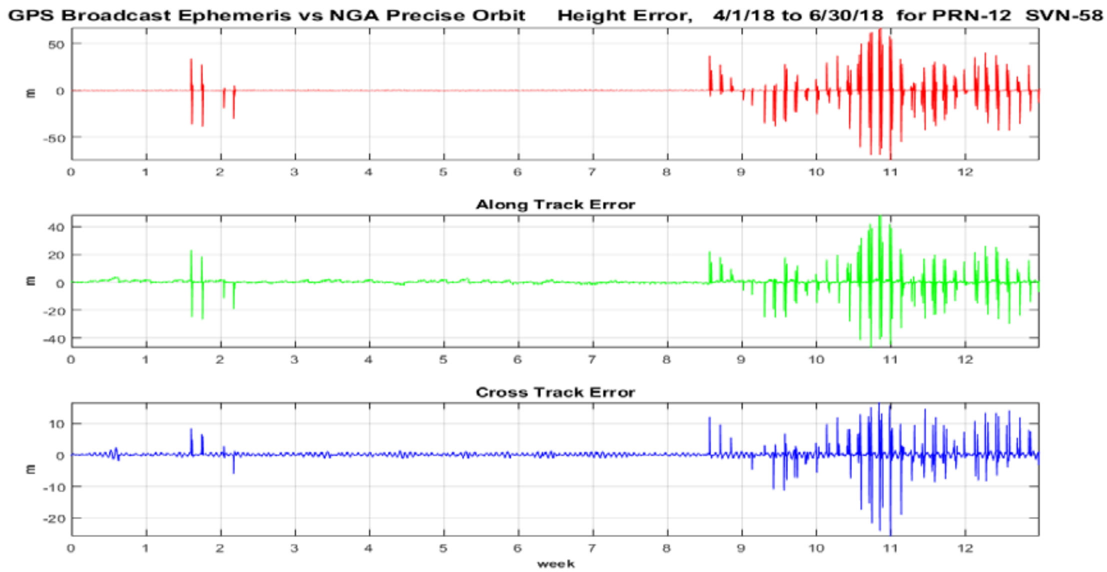


Figure 11-28 Orbit Error PRN-12 (SVN-58) Using L2C CNAV Data

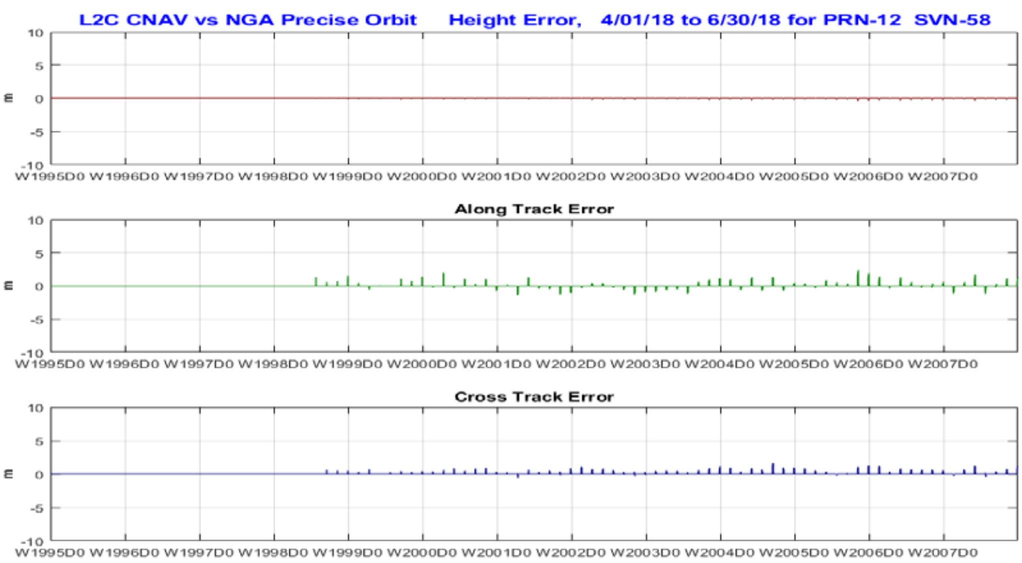


Figure 11-29 Orbit Error PRN-13 (SVN-43) Using C/A Nav Data

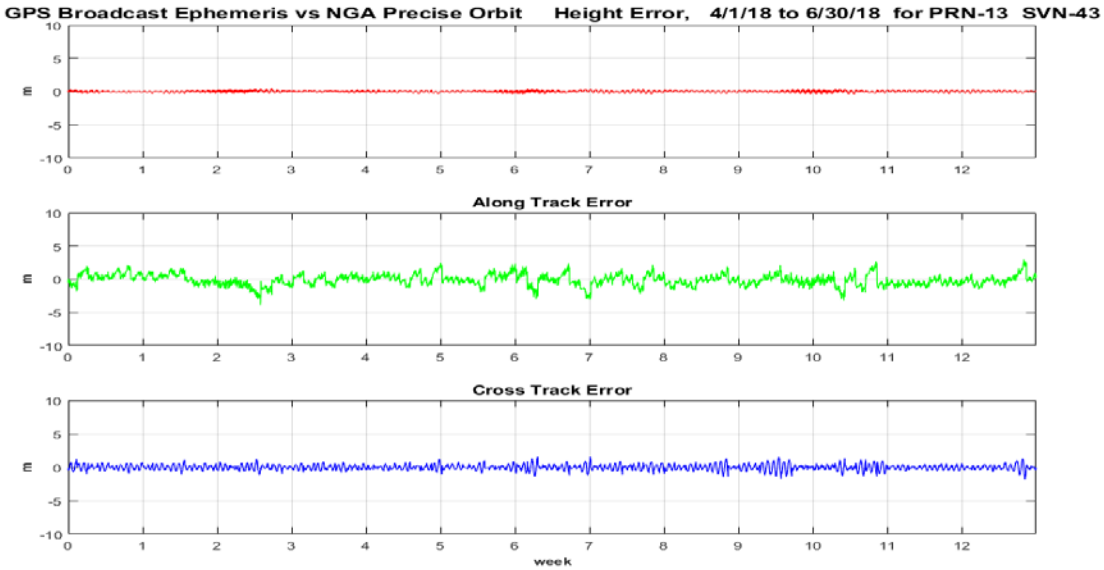


Figure 11-30 Orbit Error PRN-14 (SVN-41) Using C/A Nav Data

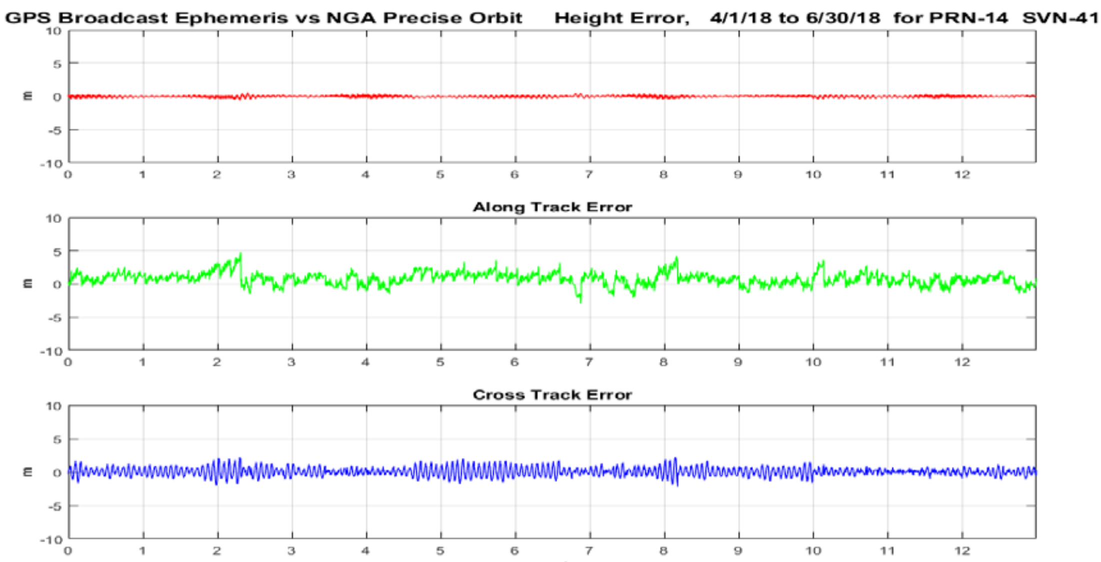


Figure 11-31 Orbit Error PRN-15 (SVN-55) Using C/A Nav Data

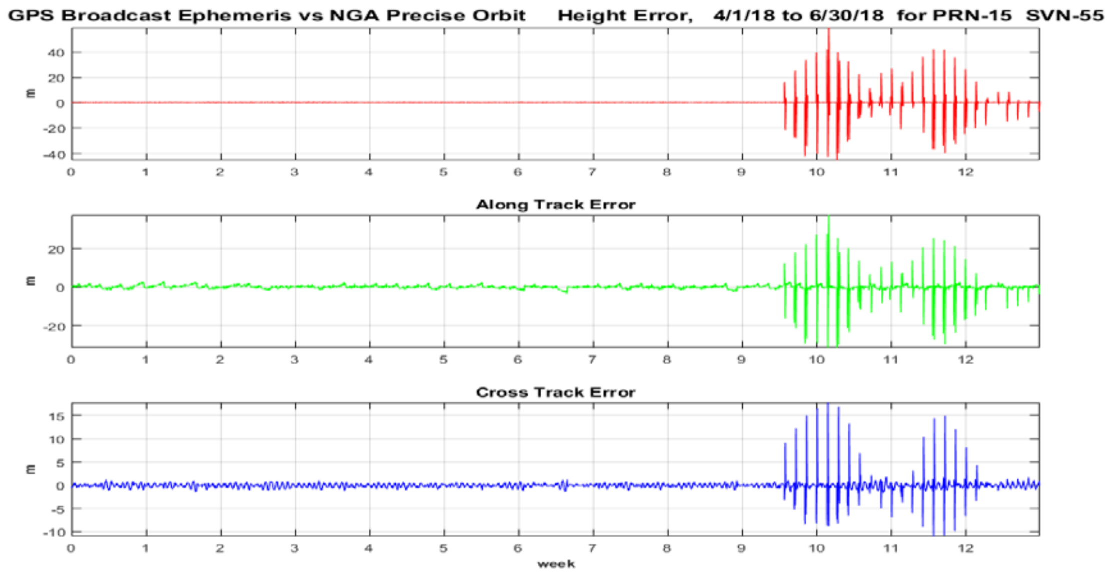


Figure 11-32 Orbit Error PRN-15 (SVN-55) Using L2C CNAV Data

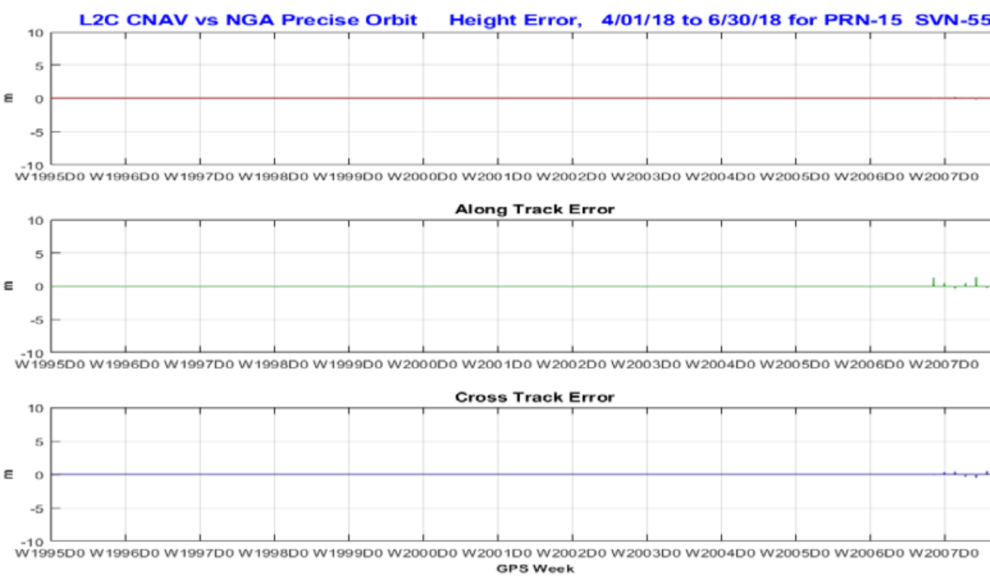


Figure 11-33 Orbit Error PRN-16 (SVN-56) Using C/A Nav Data

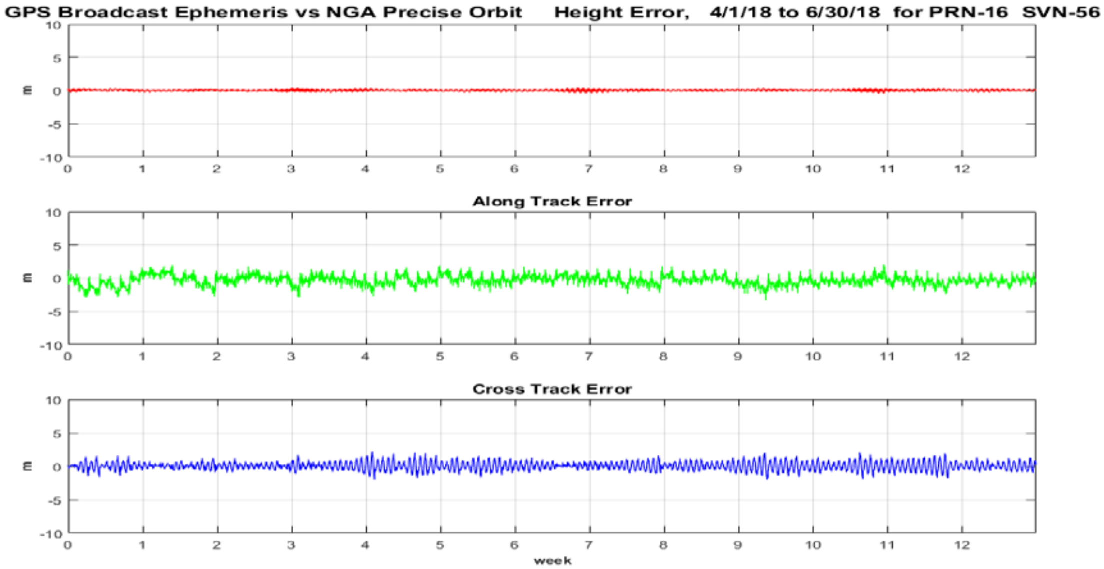


Figure 11-34 Orbit Error PRN-17 (SVN-53) Using C/A Nav Data

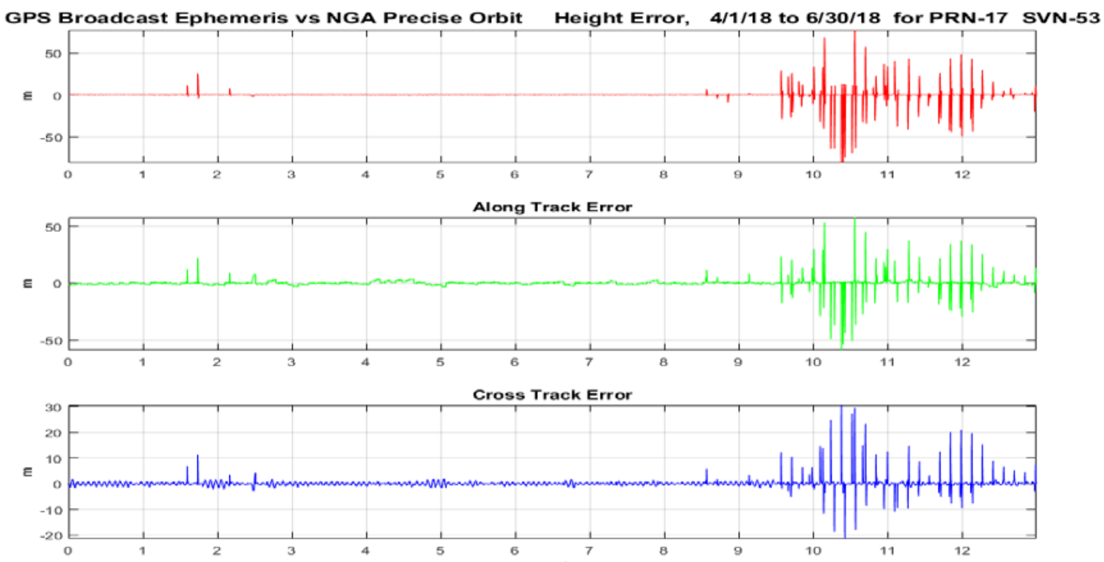


Figure 11-35 Orbit Error PRN-17 (SVN-53) Using L2C CNAV Data

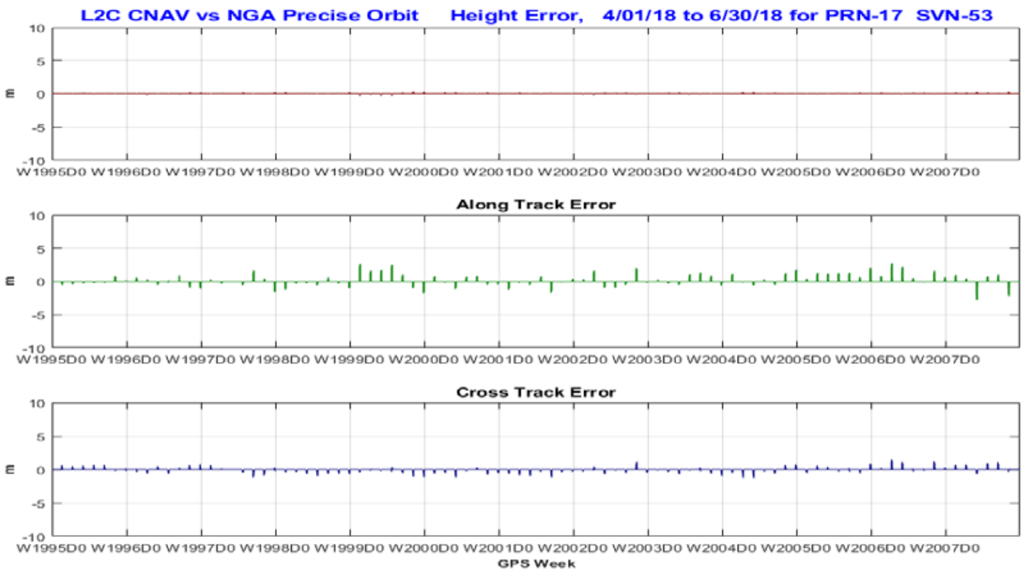


Figure 11-36 Orbit Error PRN-18 (SVN-34) Using C/A Nav Data

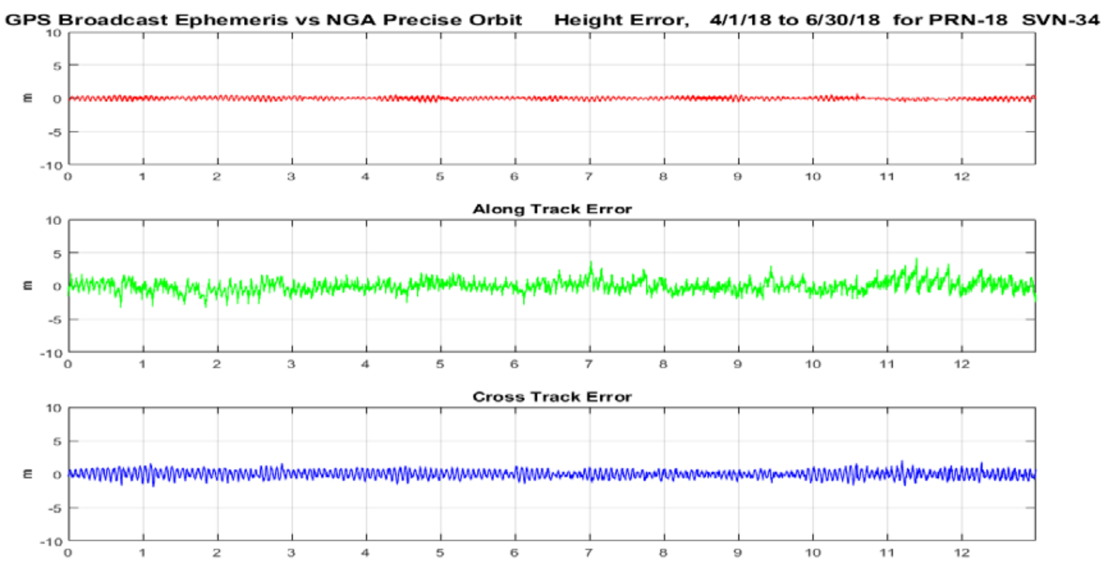


Figure 11-37 Orbit Error PRN-19 (SVN-59) Using C/A Nav Data

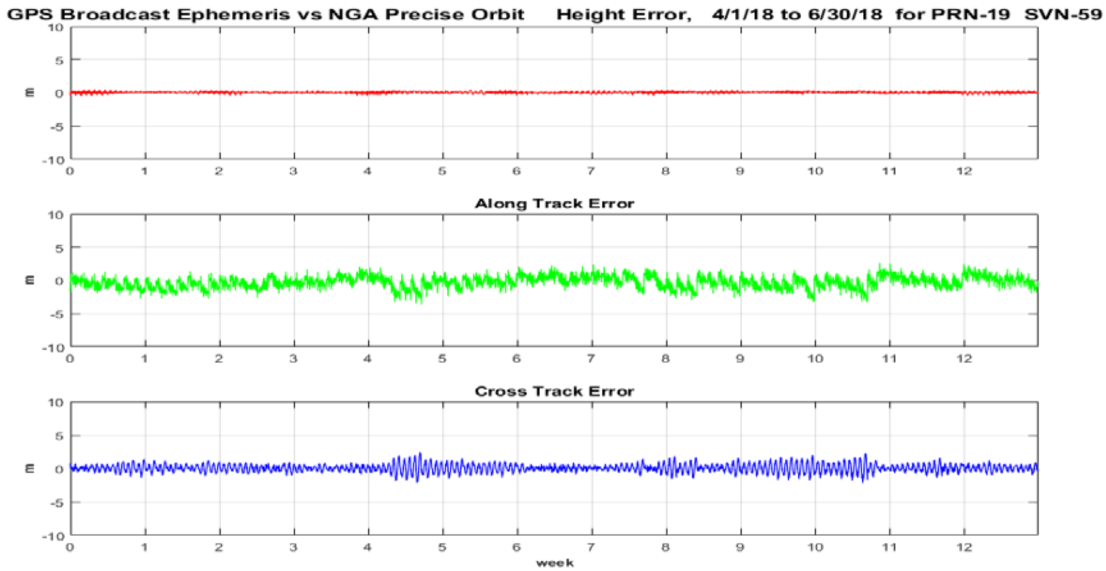


Figure 11-38 Orbit Error PRN-20 (SVN-51) Using C/A Nav Data

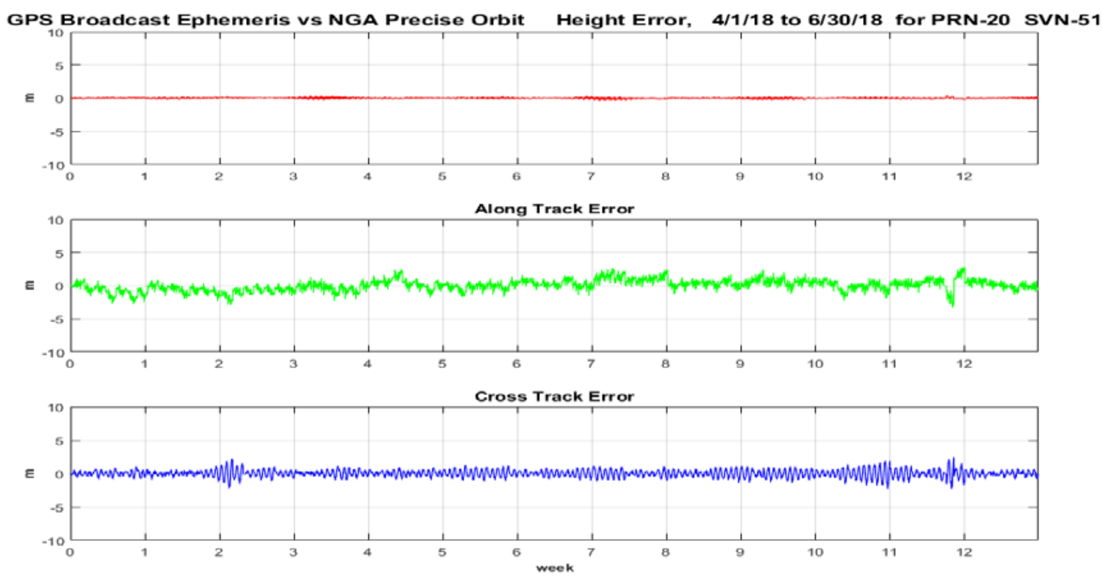


Figure 11-39 Orbit Error PRN-21 (SVN-45) Using C/A Nav Data

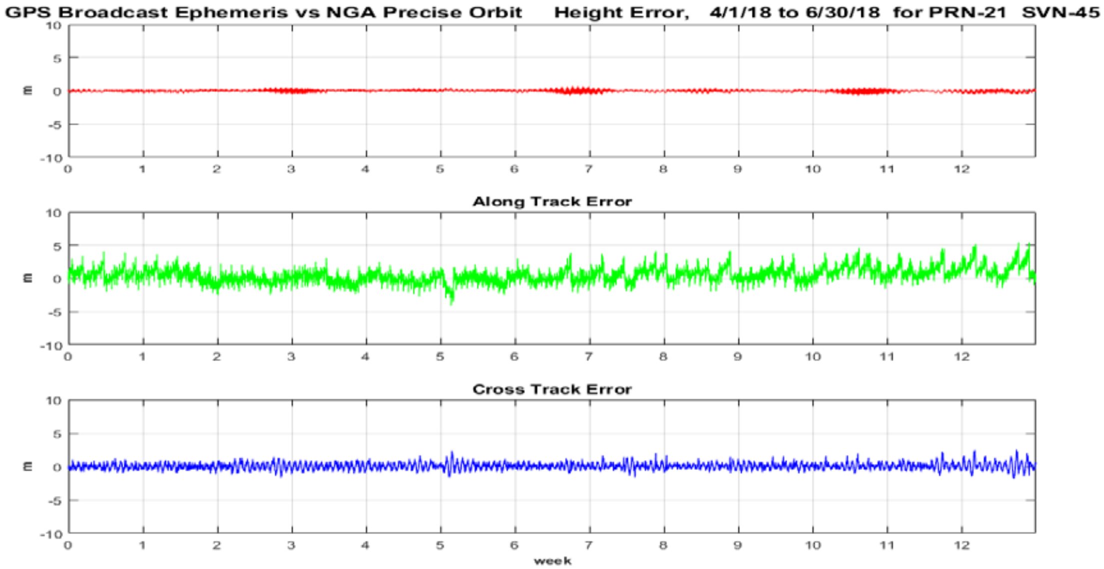


Figure 11-40 Orbit Error PRN-22 (SVN-47) Using C/A Nav Data

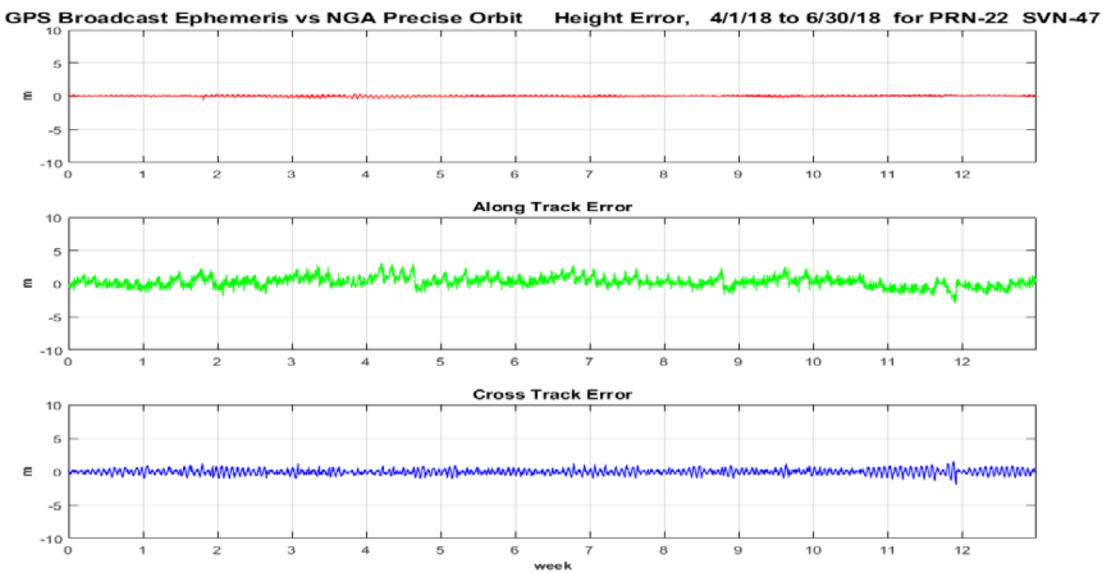


Figure 11-41 Orbit Error PRN-23 (SVN-60) Using C/A Nav Data

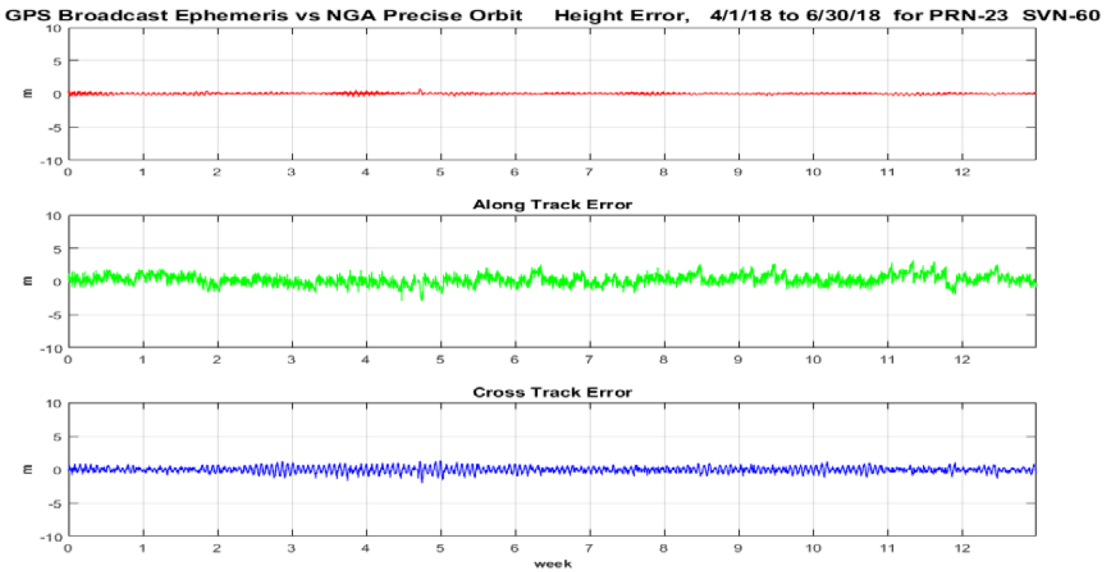


Figure 11-42 Orbit Error PRN-24 (SVN-65) Using C/A Nav Data

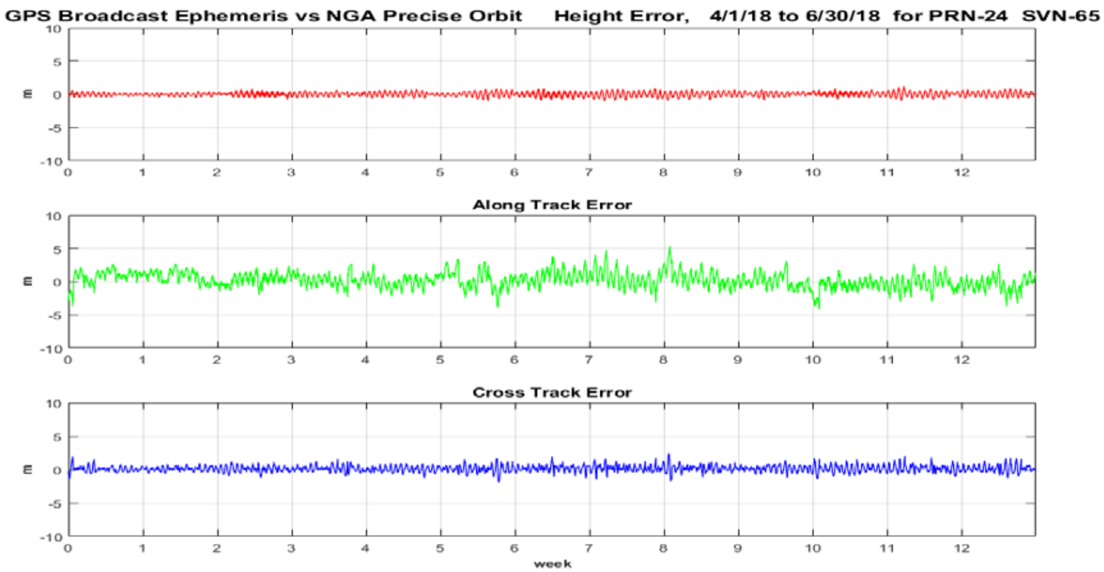


Figure 11-43 Orbit Error PRN-24 (SVN-65) Using L2C CNAV Data

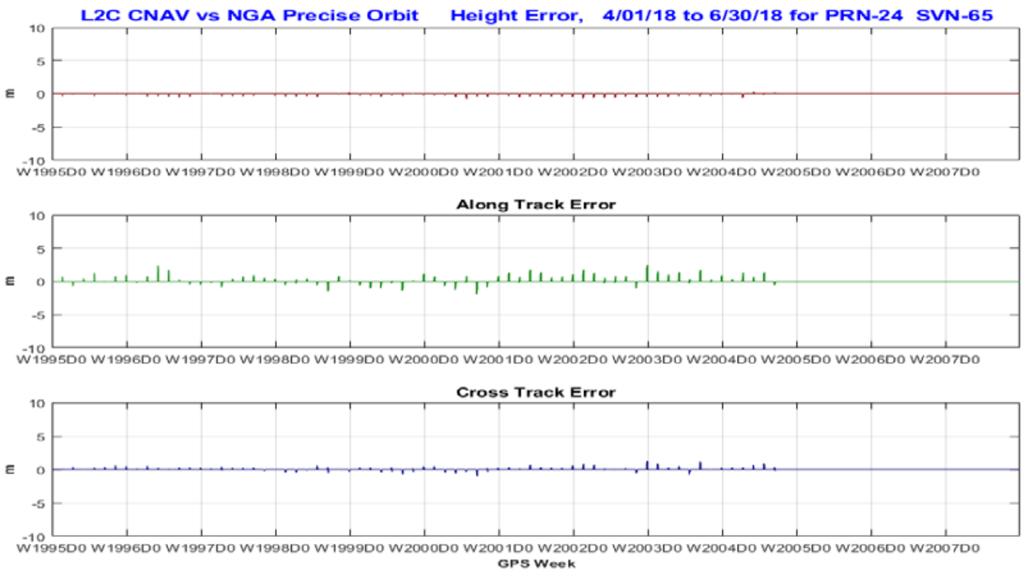


Figure 11-44 Orbit Error PRN-25 (SVN-62) Using C/A Nav Data

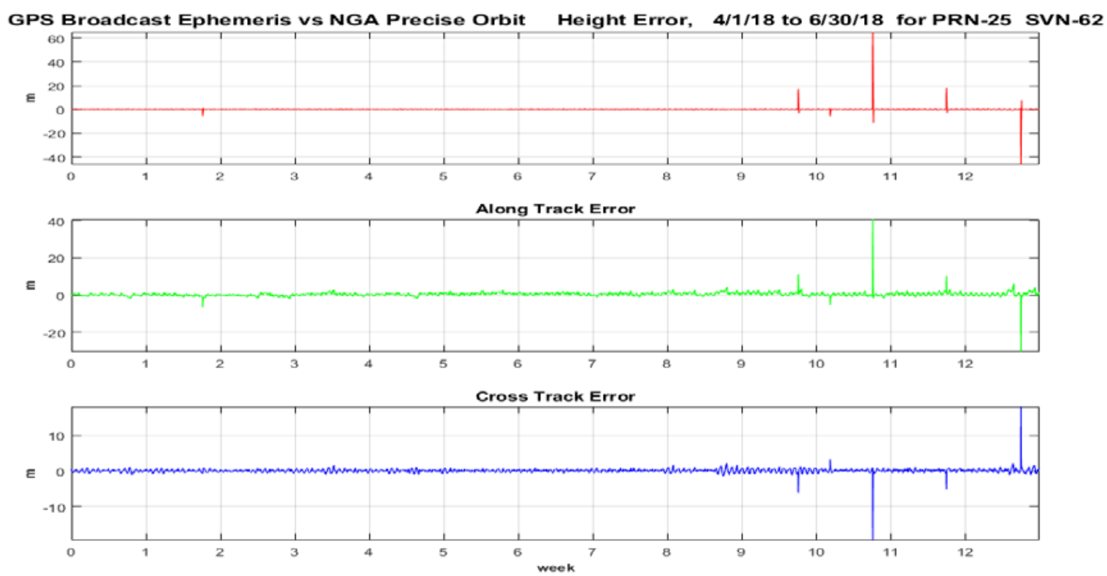


Figure 11-45 Orbit Error PRN-25 (SVN-62) Using L2C CNAV Data

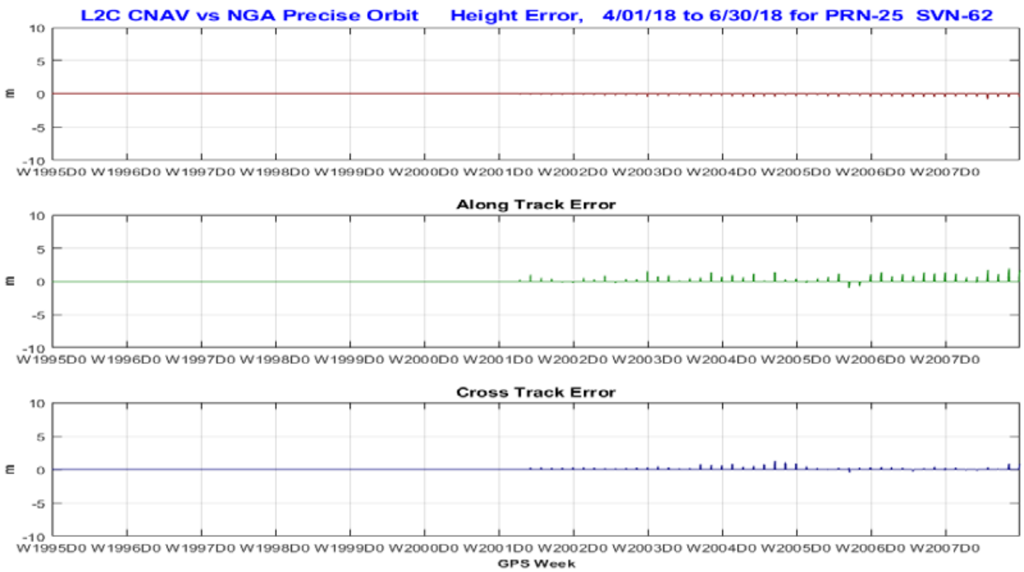


Figure 11-46 Orbit Error PRN-26 (SVN-71) Using C/A Nav Data

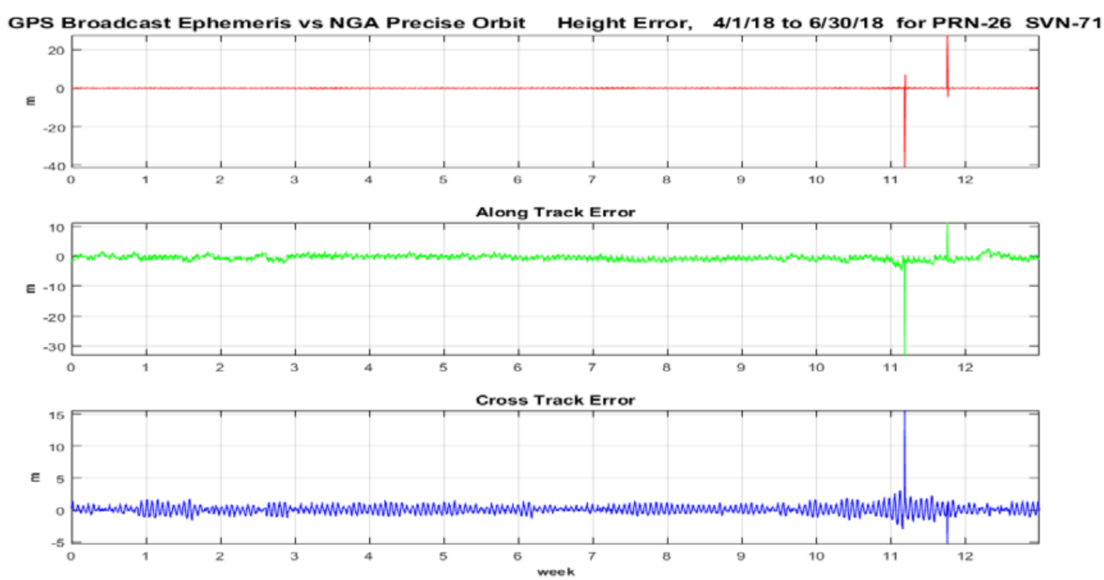


Figure 11-47 Orbit Error PRN-26 (SVN-71) Using L2C CNAV Data

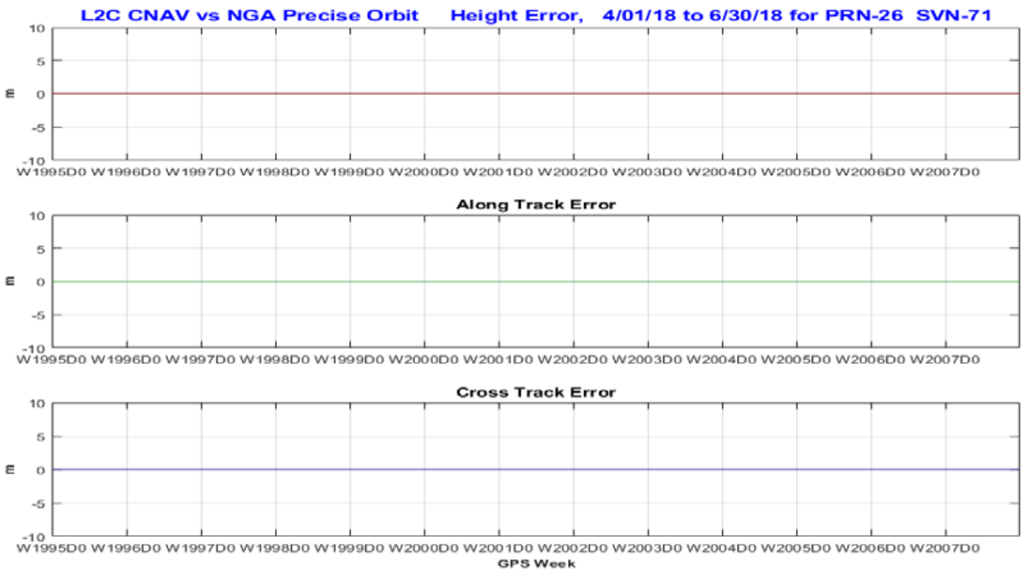


Figure 11-48 Orbit Error PRN-27 (SVN-66) Using C/A Nav Data

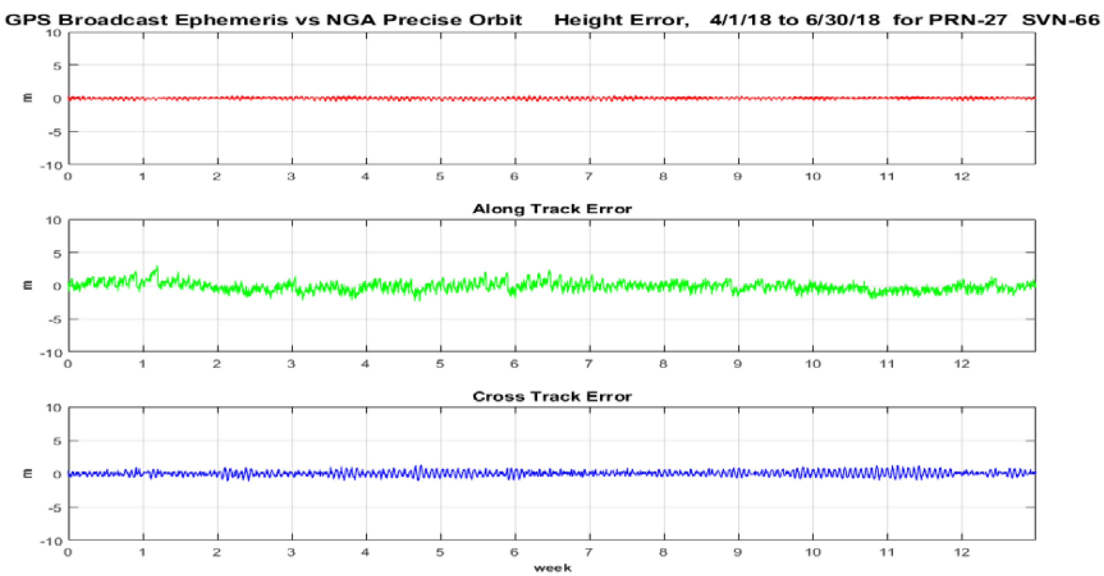


Figure 11-49 Orbit Error PRN-27 (SVN-66) Using L2C CNAV Data

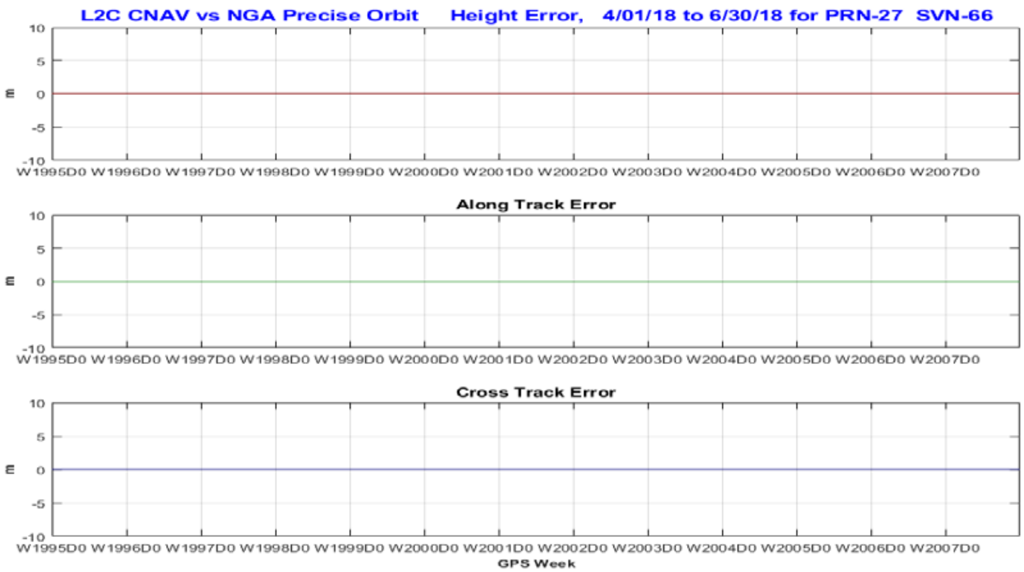


Figure 11-50 Orbit Error PRN-28 (SVN-44) Using C/A Nav Data

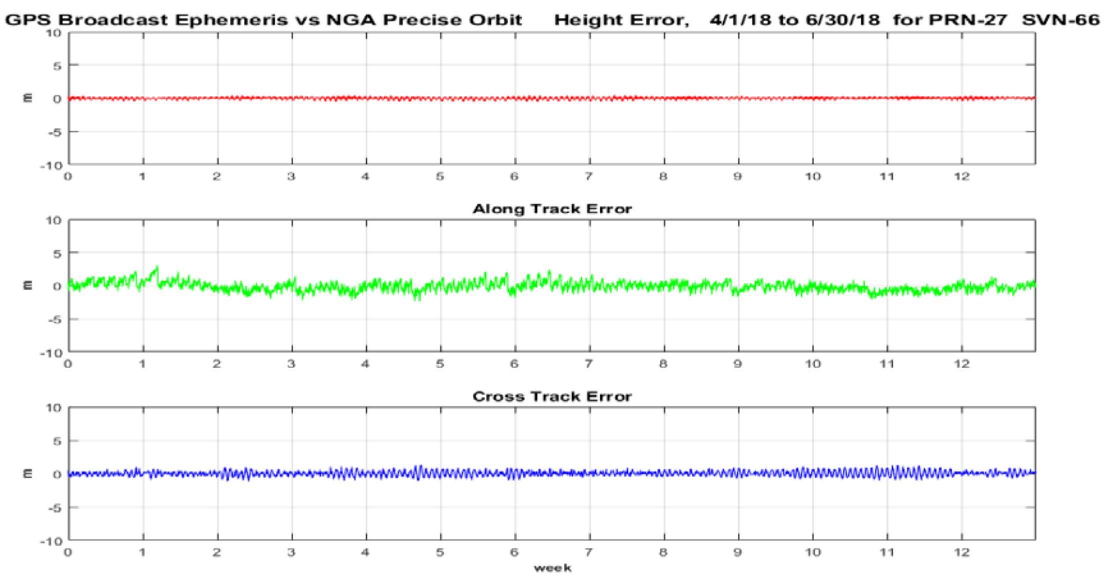


Figure 11-51 Orbit Error PRN-29 (SVN-57) Using C/A Nav Data

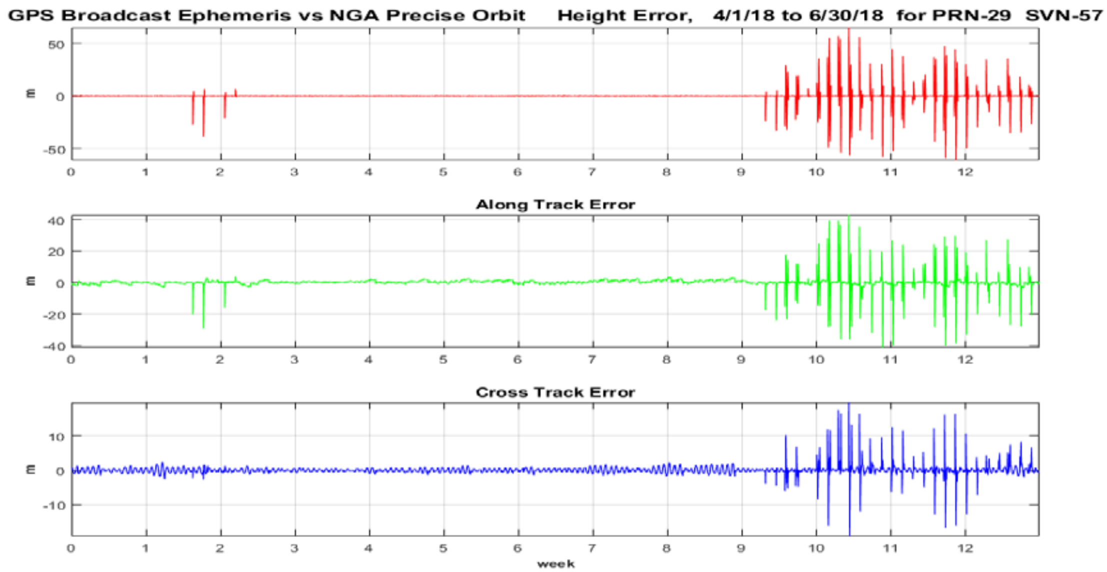


Figure 11-52 Orbit Error PRN-29 (SVN-57) Using L2C CNAV Data

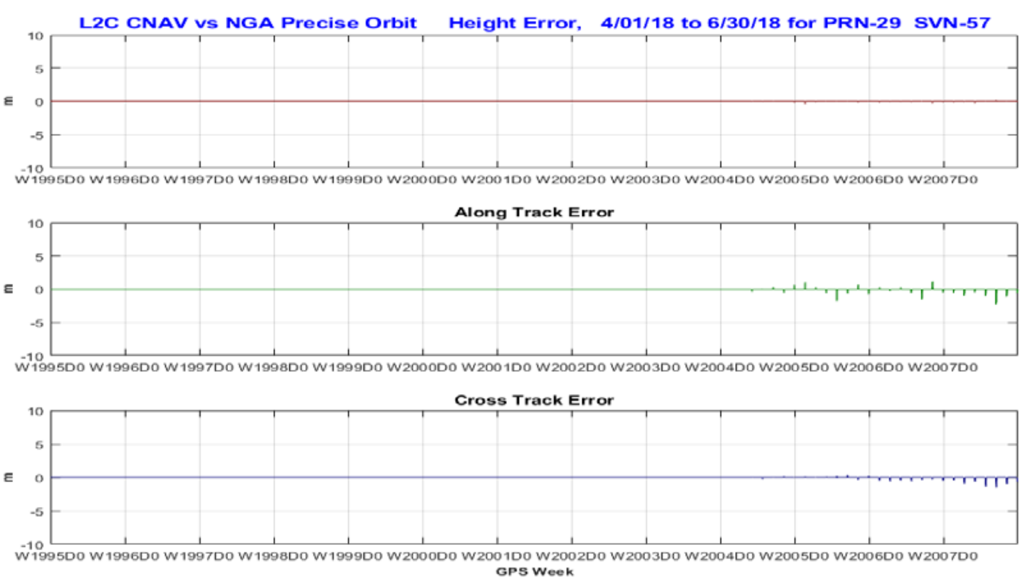


Figure 11-53 Orbit Error PRN-30 (SVN-64) Using C/A Nav Data

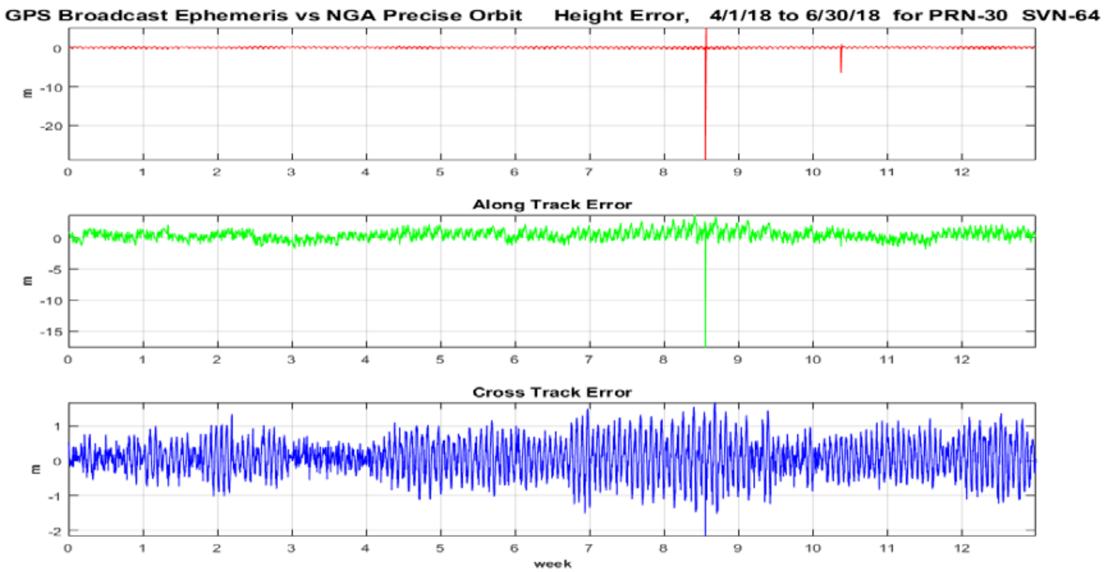


Figure 11-54 Orbit Error PRN-30 (SVN-64) Using L2C CNAV Data

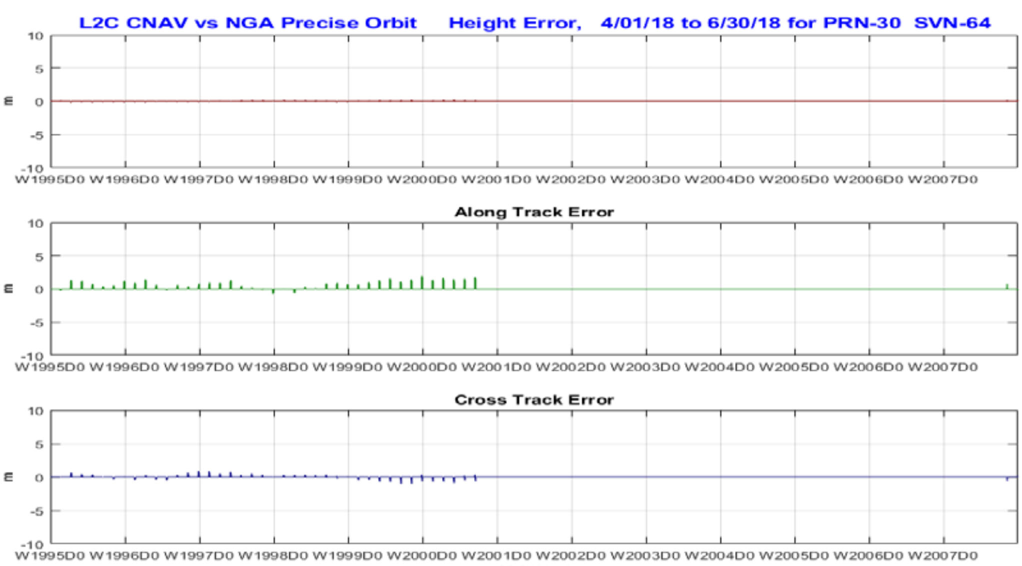


Figure 11-55 Orbit Error PRN-31 (SVN-52) Using C/A Nav Data

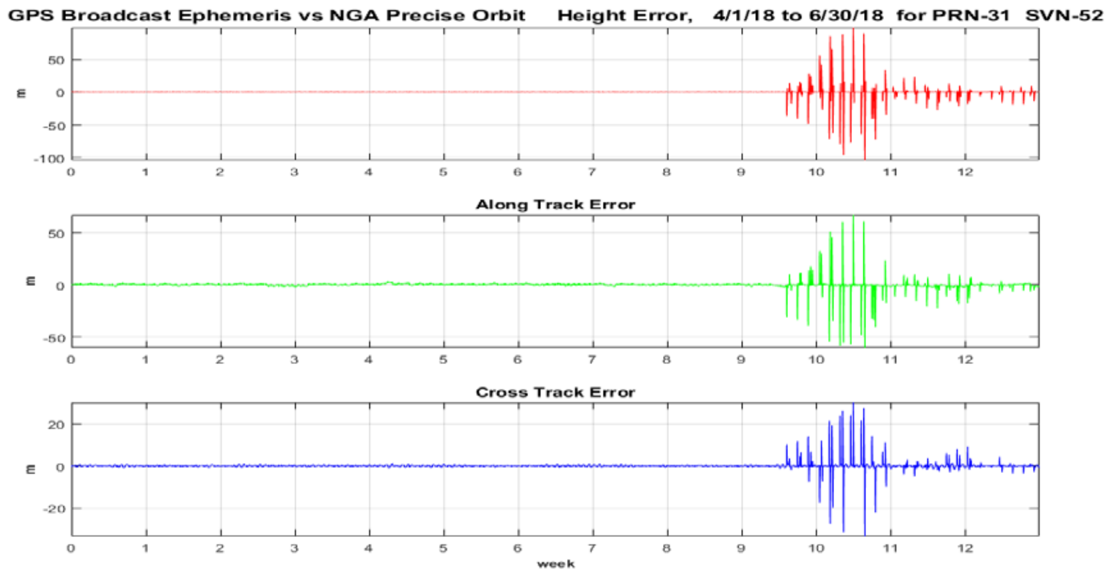


Figure 11-56 Orbit Error PRN-31 (SVN-52) Using L2C CNAV Data

Figure 11-57 Orbit Error PRN-32 (SVN-70) Using C/A Nav Data

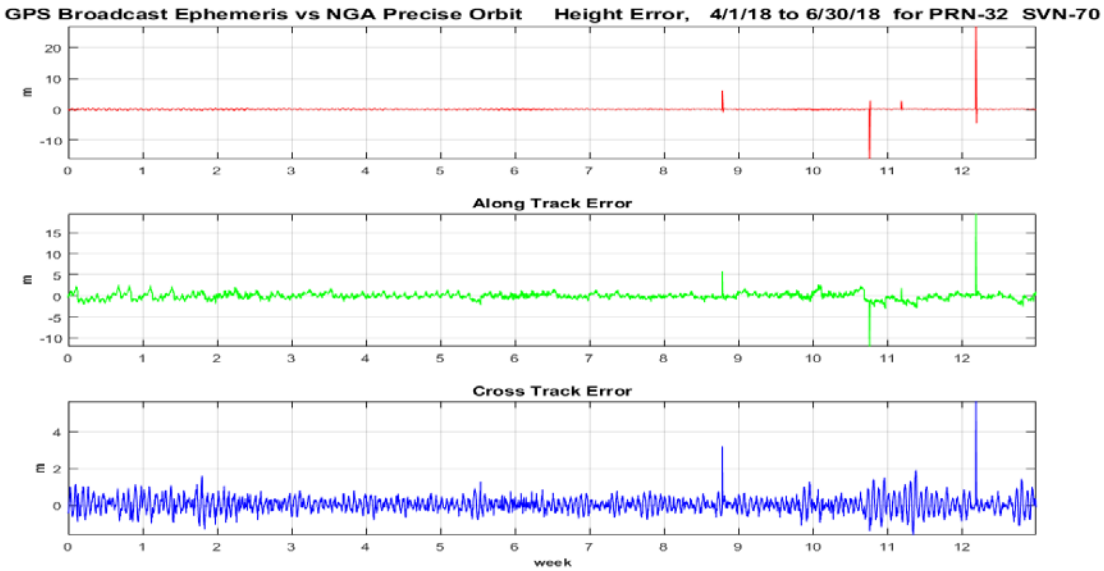
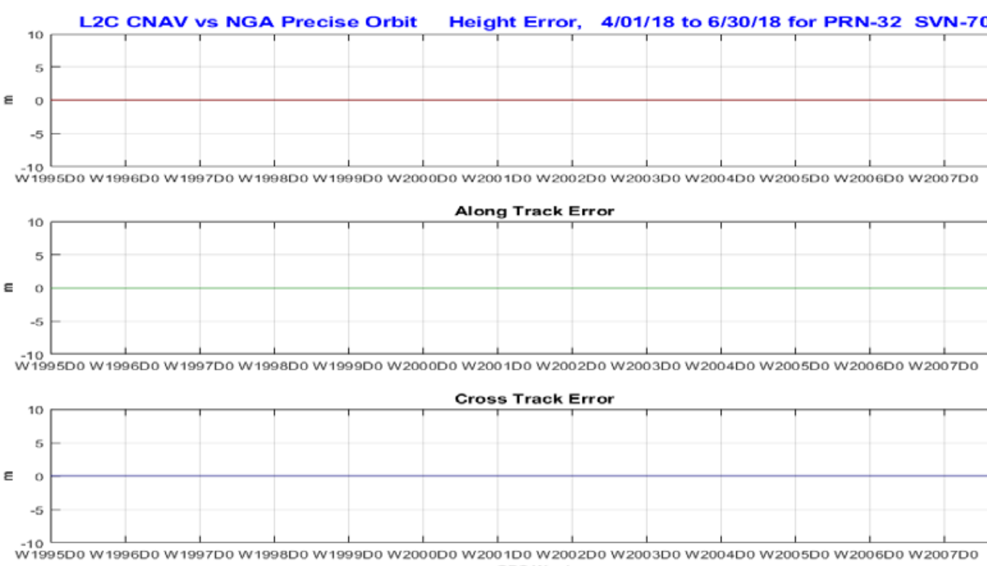


Figure 11-58 Orbit Error PRN-32 (SVN-70) Using L2C CNAV Data



QQ Plots of URA Normalized Error for All Satellites

Figure 11-59 QQ Plots of Range Error PRNs 1 to 5 Using C/A Nav Data

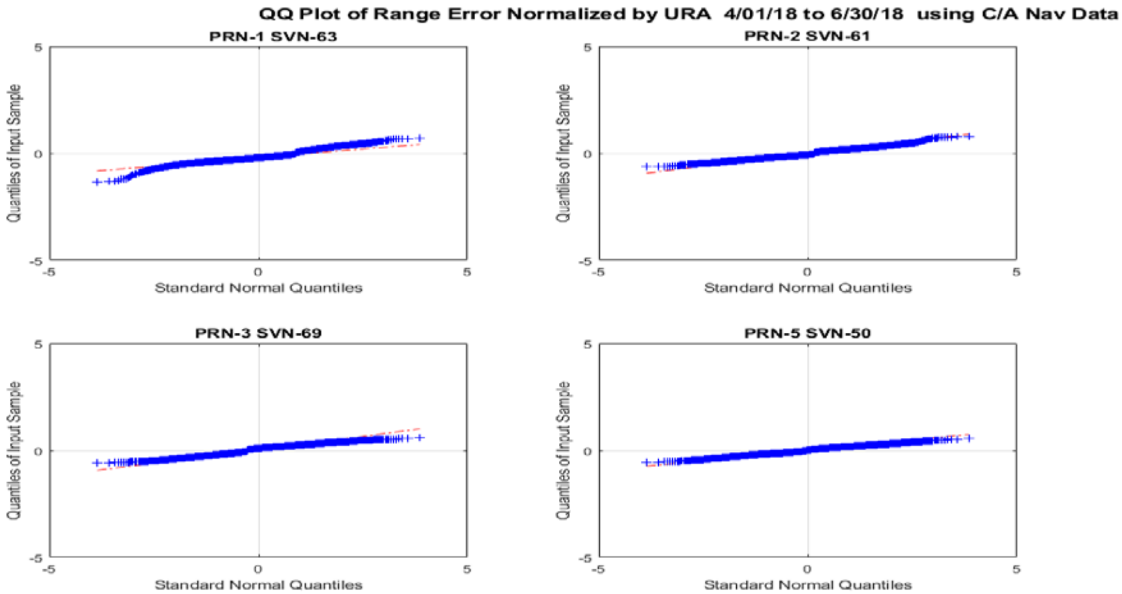


Figure 11-60 QQ Plots of Range Error PRNs 6 to 9 Using C/A Nav Data

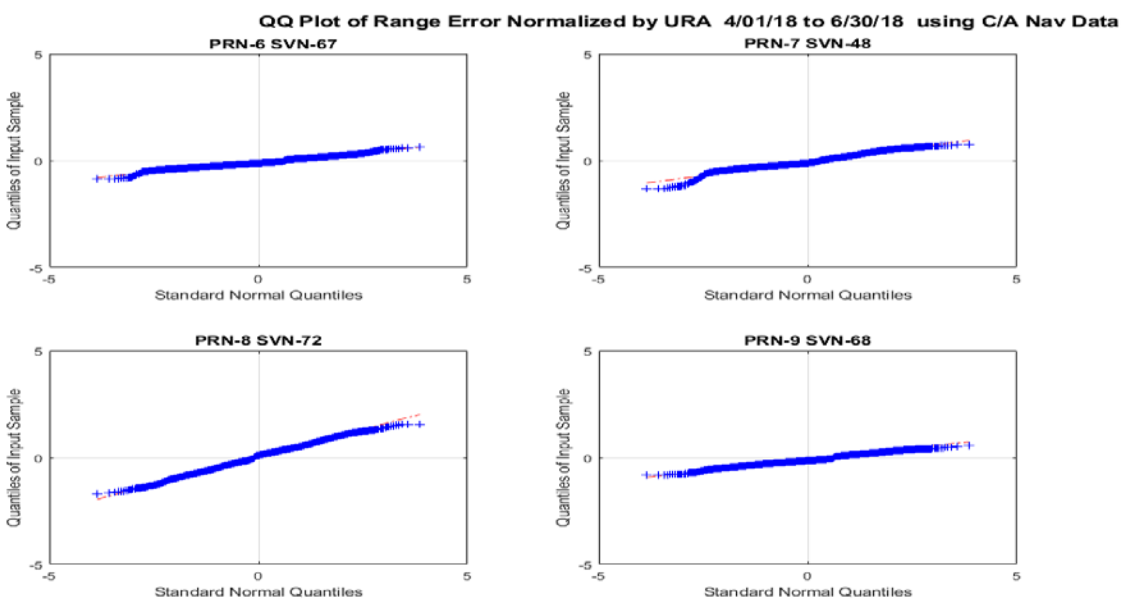


Figure 11-61 QQ Plots of Range Error PRNs 10 to 13 Using C/A Nav Data

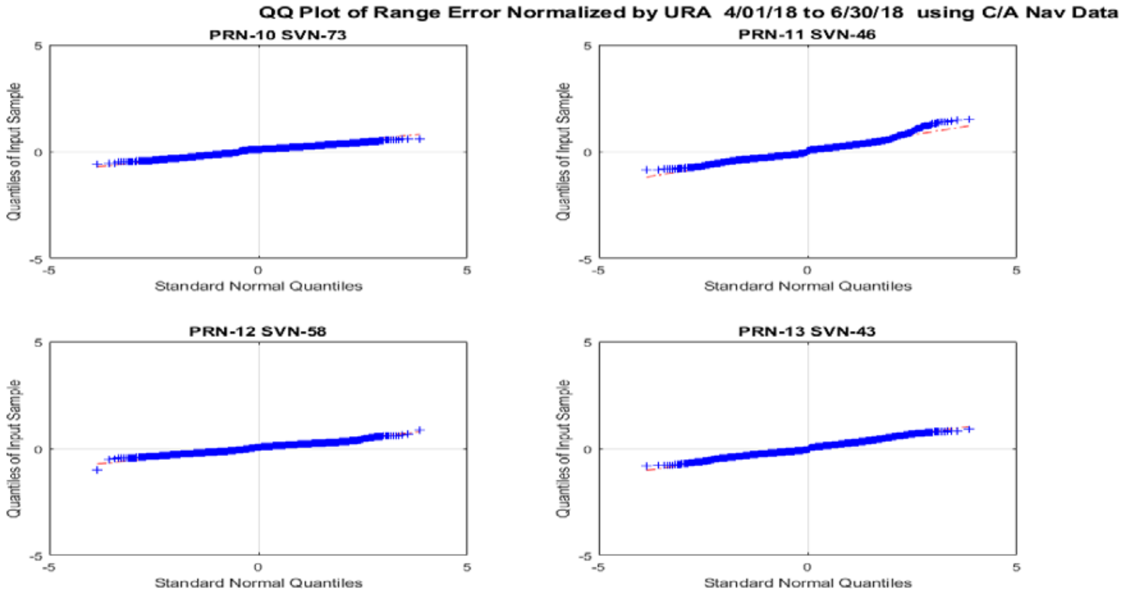


Figure 11-62 QQ Plots of Range Error PRNs 14 to 17 Using C/A Nav Data

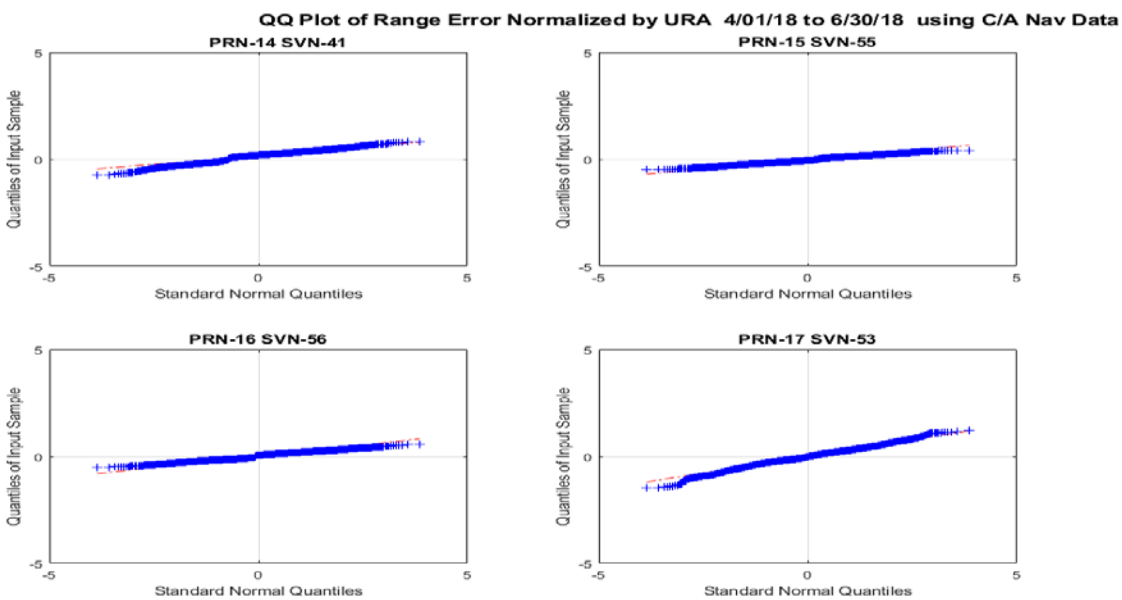


Figure 11-63 QQ Plots of Range Error PRNs 18 to 21 Using C/A Nav Data

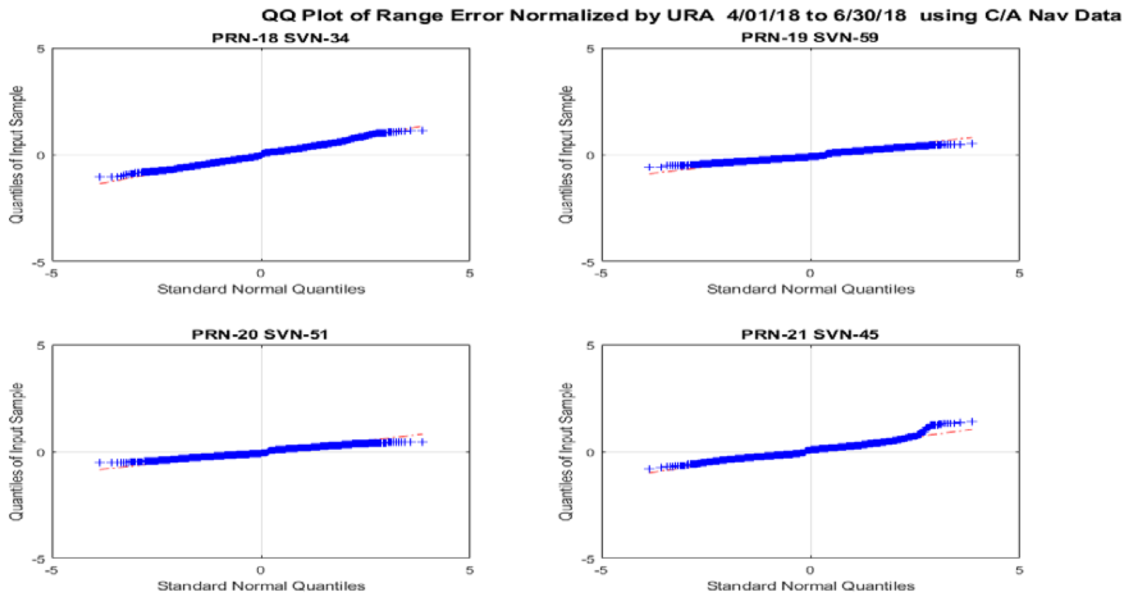


Figure 11-64 QQ Plots of Range Error PRNs 22 to 25 Using C/A Nav Data

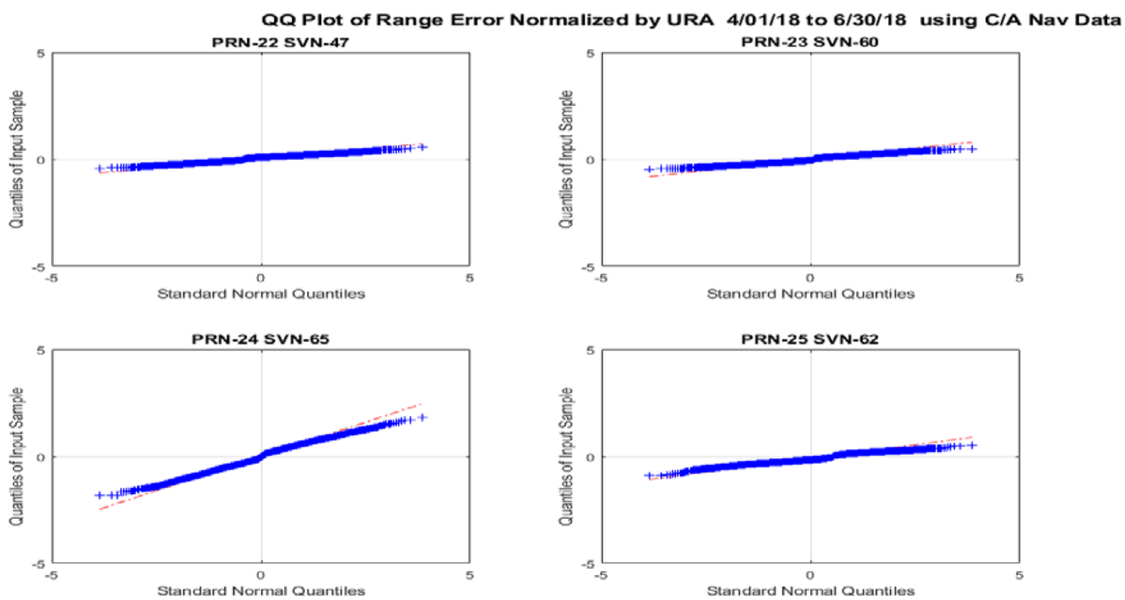


Figure 11-65 QQ Plots of Range Error PRNs 26 to 29 Using C/A Nav Data

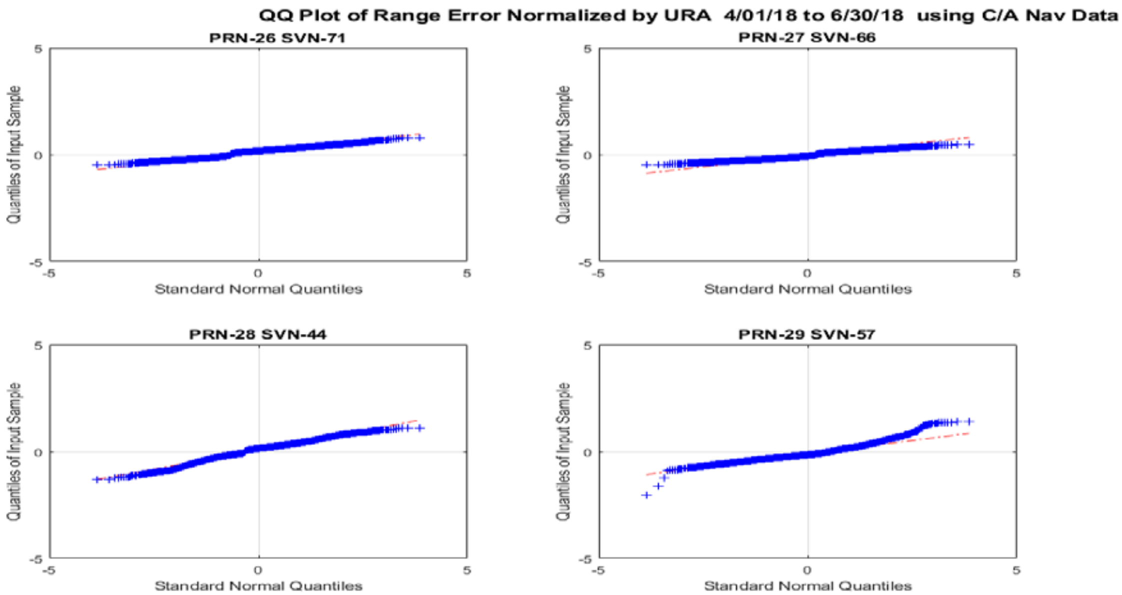


Figure 11-66 QQ Plots of Range Error PRNs 30 to 32 Using C/A Nav Data

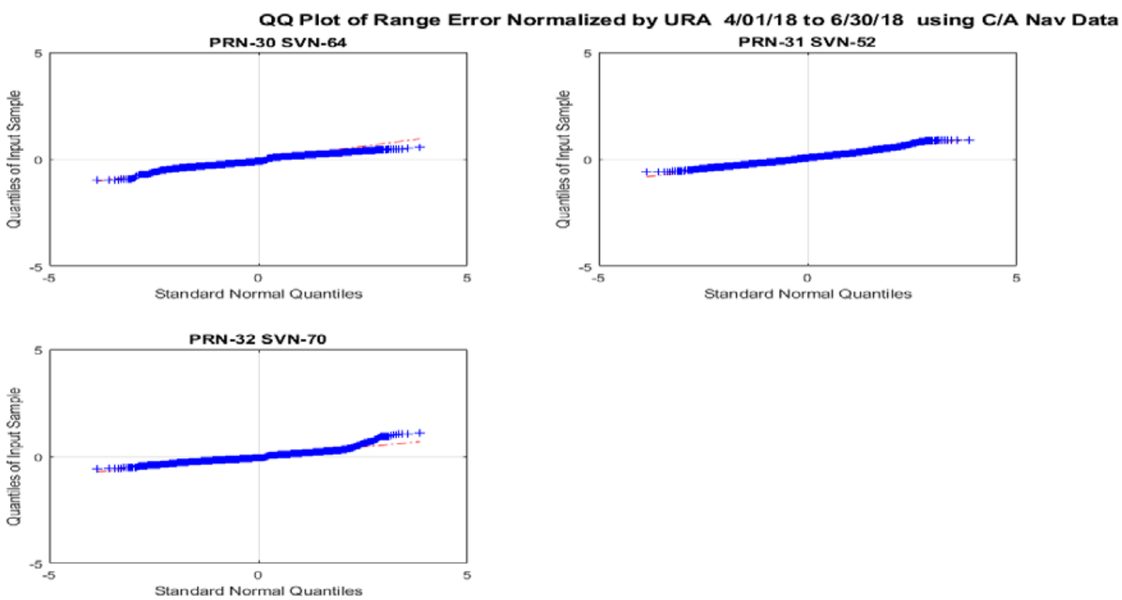


Figure 11-67 QQ Plots of Range Error PRNs 1, 3, 5, and 6 Using L2C CNAV Data

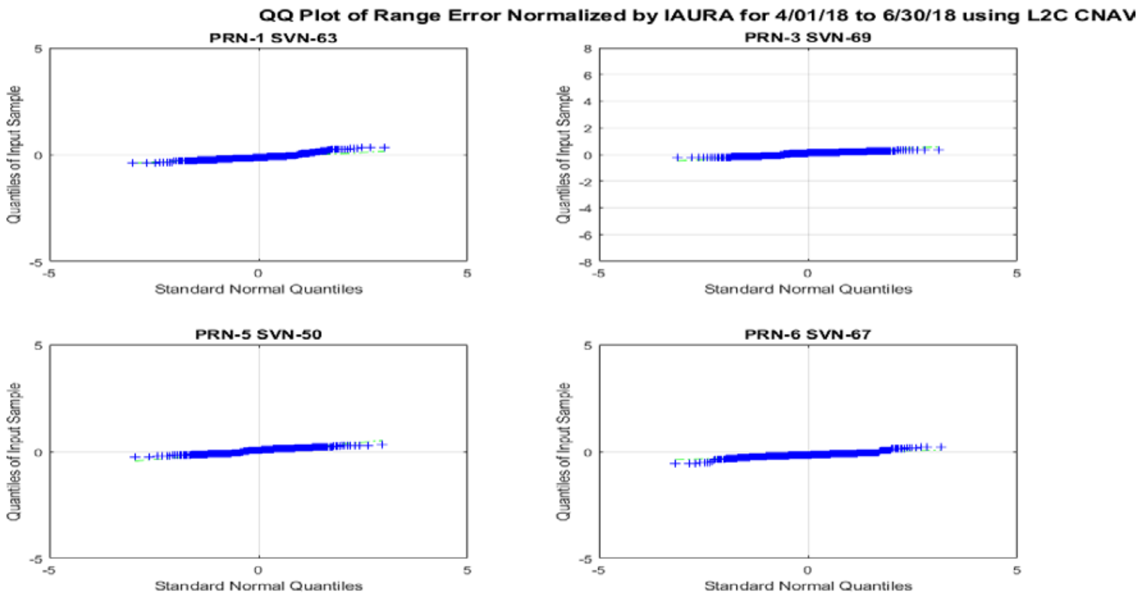


Figure 11-68 QQ Plots of Range Error PRNs 7, 8, 9, and 10 Using L2C CNAV Data

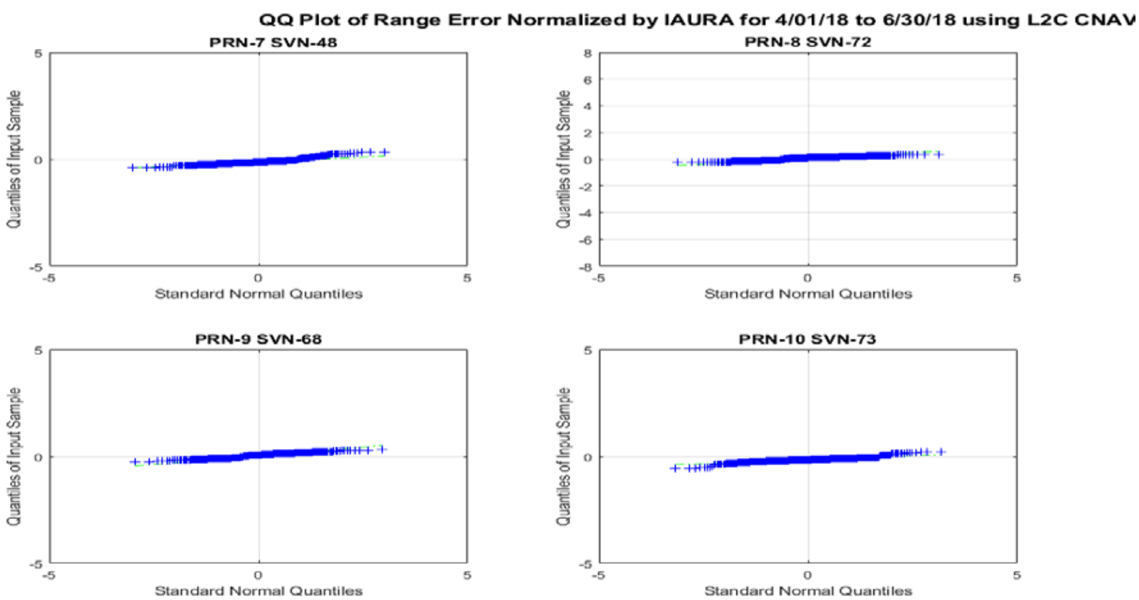


Figure 11-69 QQ Plots of Range Error PRNs 12, 15, 17, and 24 Using L2C CNAV Data

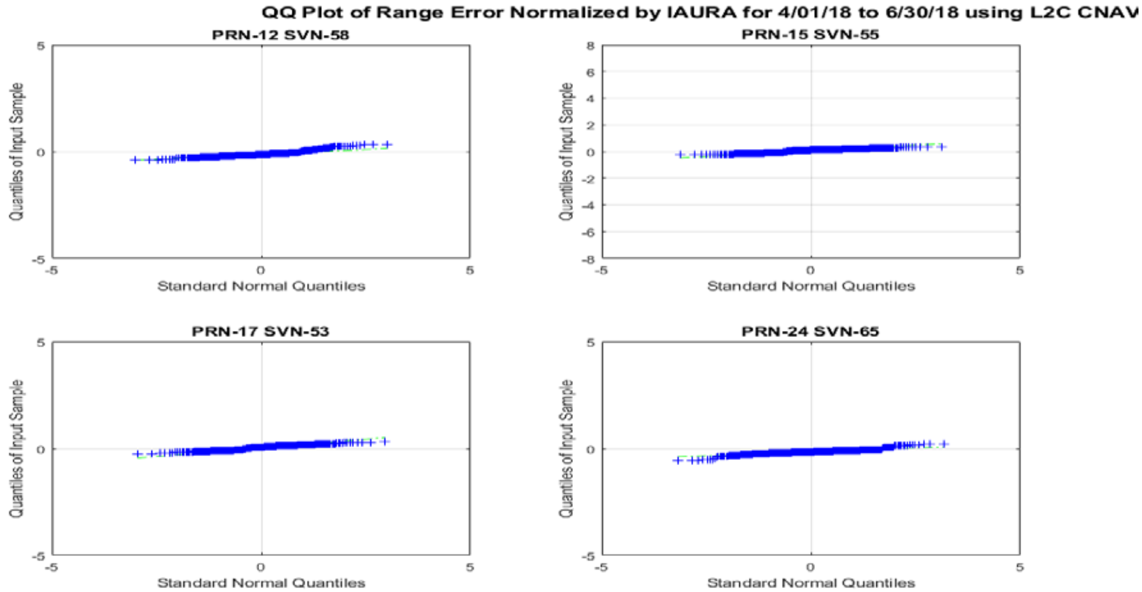
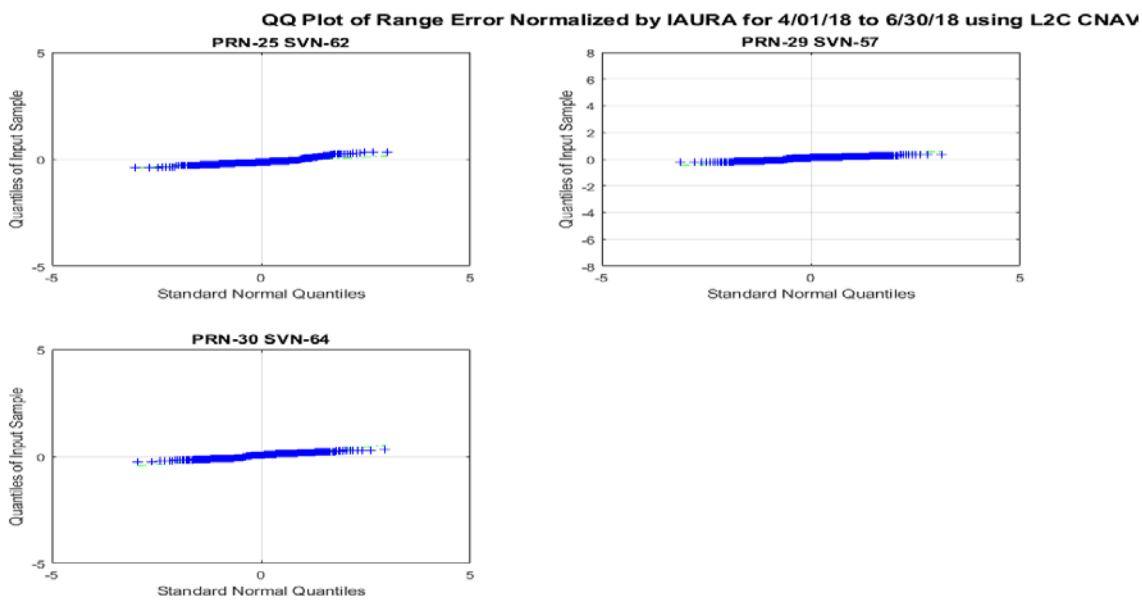


Figure 11-70 QQ Plots of Range Error PRNs 25, 29, and 30 Using L2C CNAV Data



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

Figure 11-71 Histograms of H, A, C, and Range Error PRN-1 (SVN-63) Using C/A Nav Data

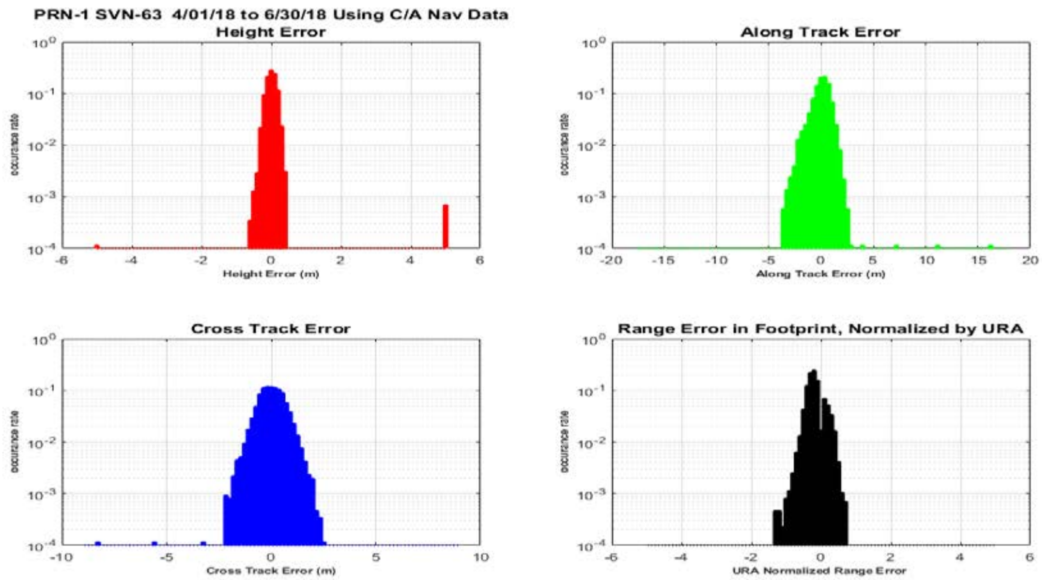


Figure 11-72 Histograms of H, A, C, and Range Error PRN-1 (SVN-63) Using L2C CNAV Data

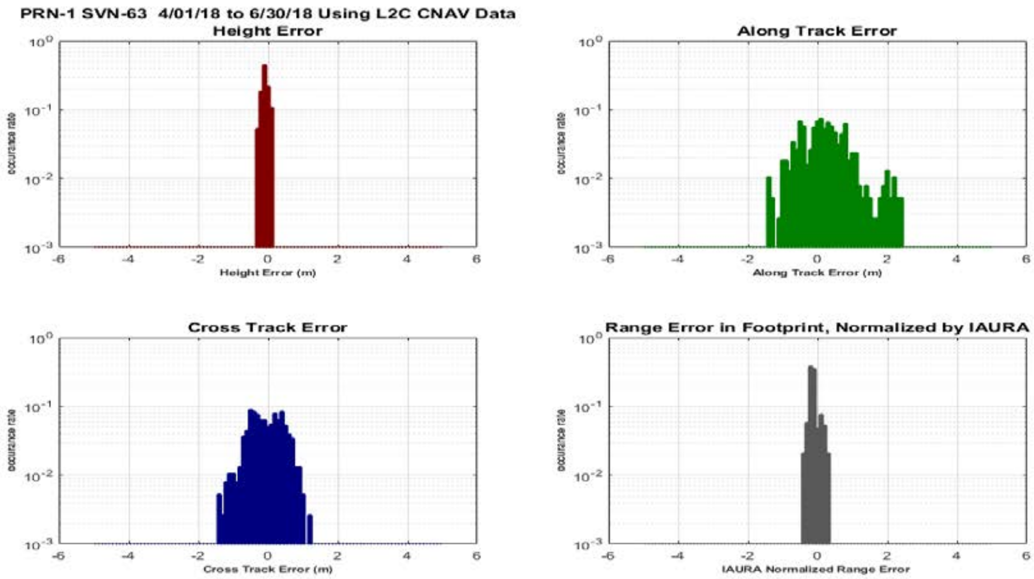


Figure 11-73 Histograms of H, A, C, and Range Error PRN-2 (SVN-61) Using C/A Nav Data

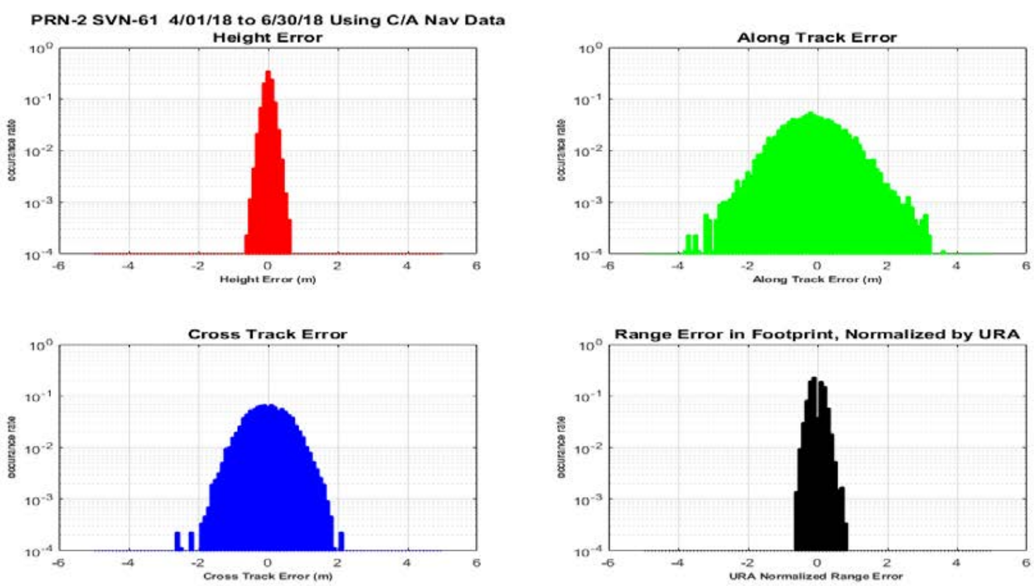


Figure 11-74 Histograms of H, A, C, and Range Error PRN-3 (SVN-69) Using C/A Nav Data

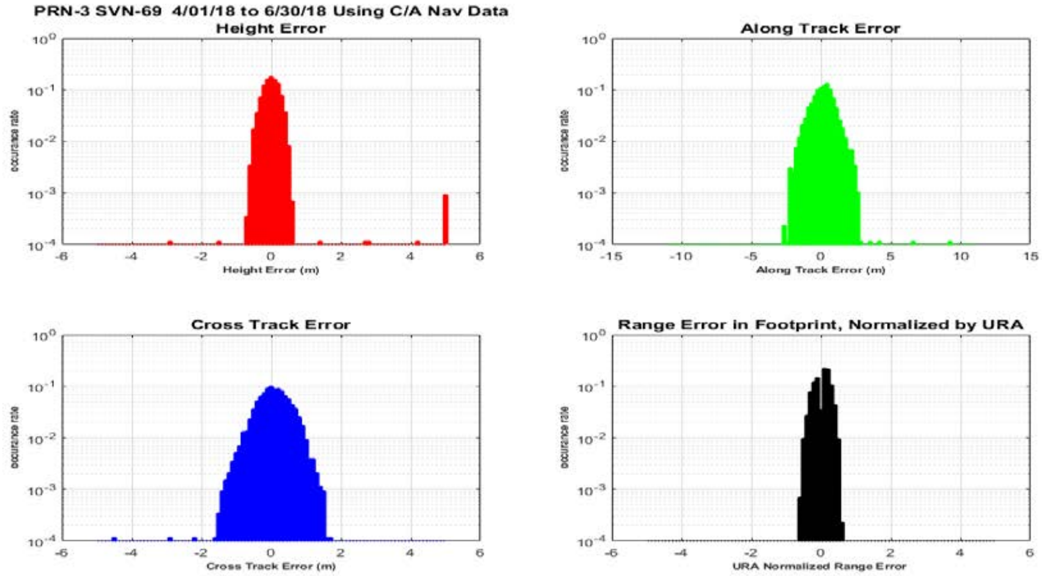


Figure 11-75 Histograms of H, A, C, and Range Error PRN-3 (SVN-69) Using L2C CNAV Data

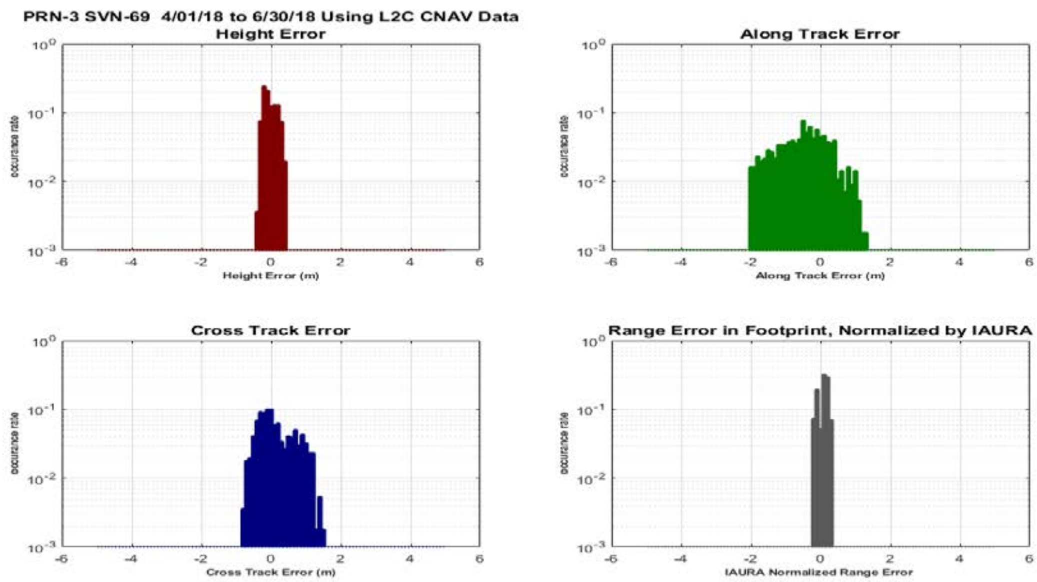


Figure 11-76 Histograms of H, A, C, and Range Error PRN-5 (SVN-50) Using C/A Nav Data

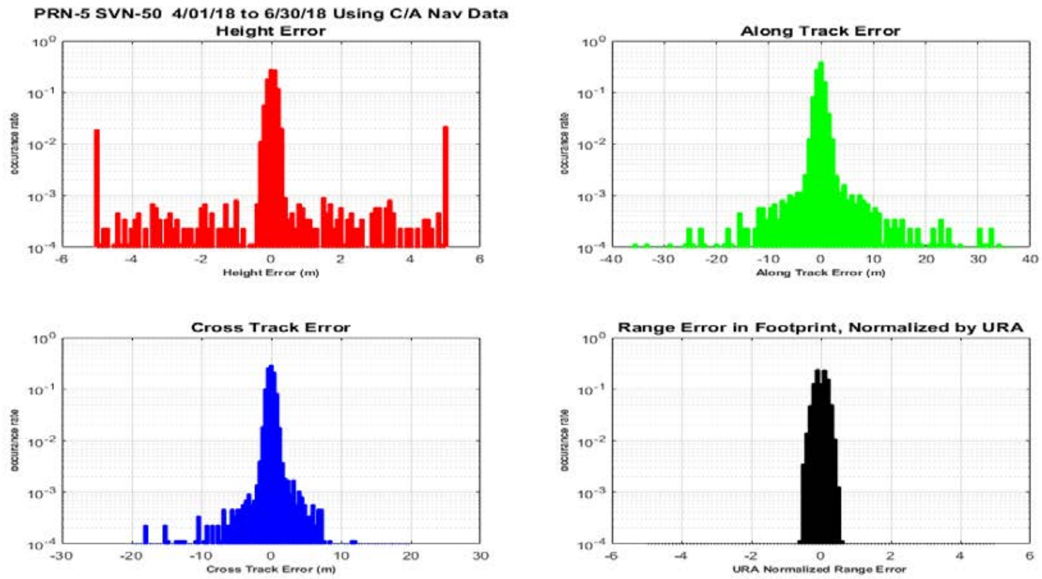


Figure 11-77 Histograms of H, A, C, and Range Error PRN-5 (SVN-50) Using L2C CNAV Data

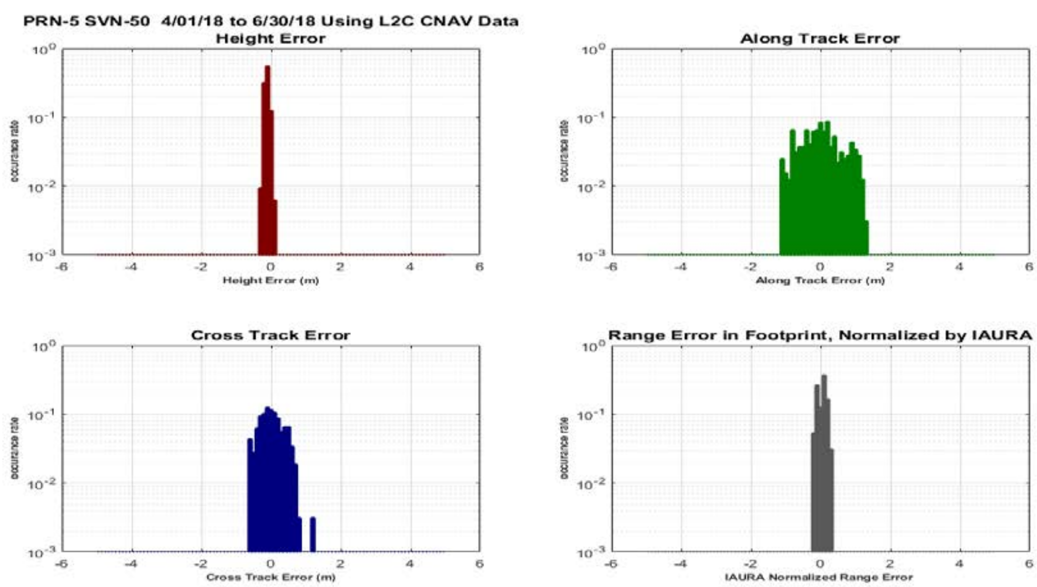


Figure 11-78 Histograms of H, A, C, and Range Error PRN-6 (SVN-67) Using C/A Nav Data

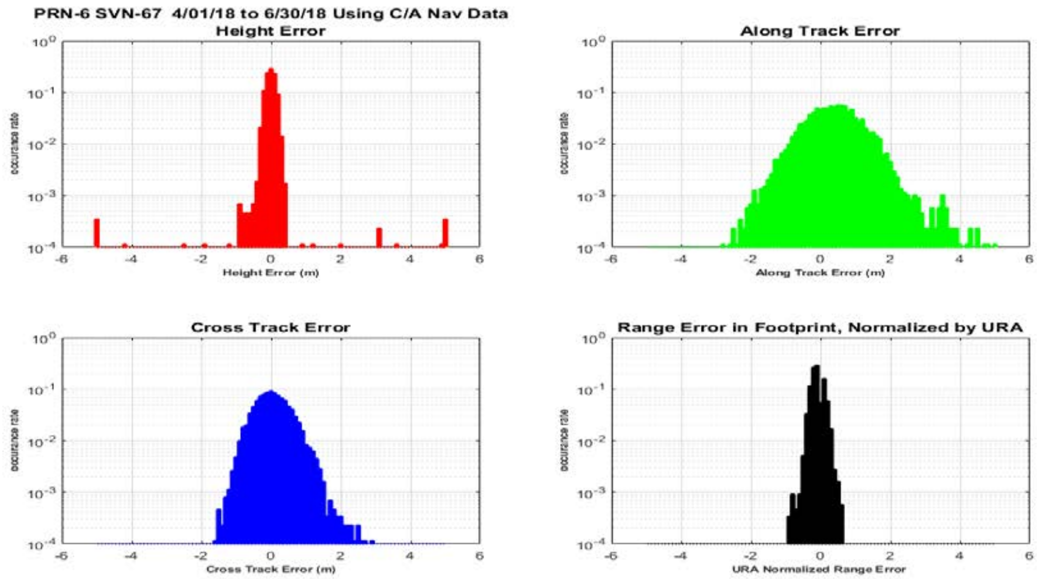


Figure 11-79 Histograms of H, A, C, and Range Error PRN-6 (SVN-67) Using L2C CNAV Data

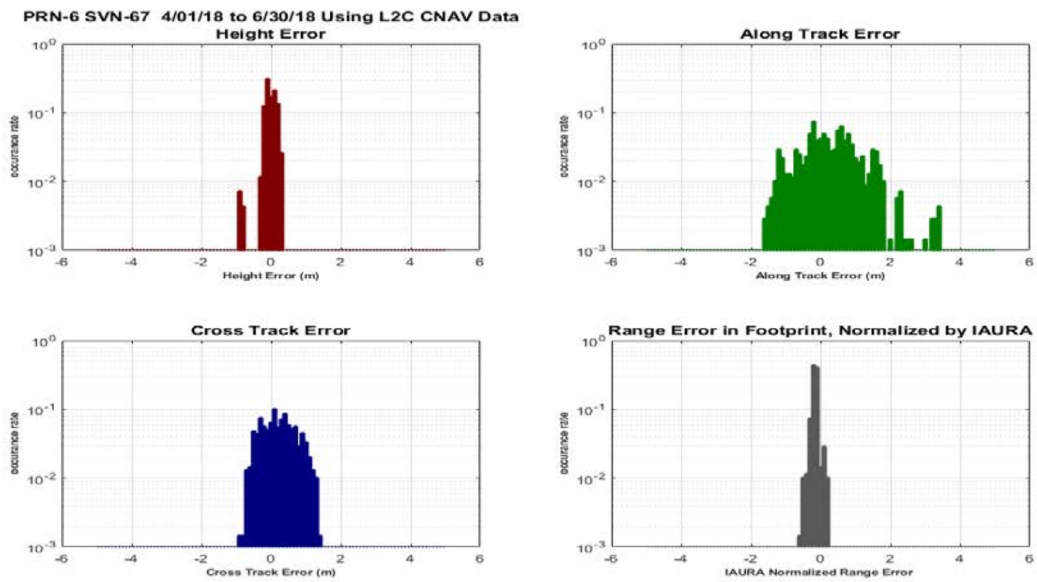


Figure 11-80 Histograms of H, A, C, and Range Error PRN-7 (SVN-48) Using C/A Nav Data

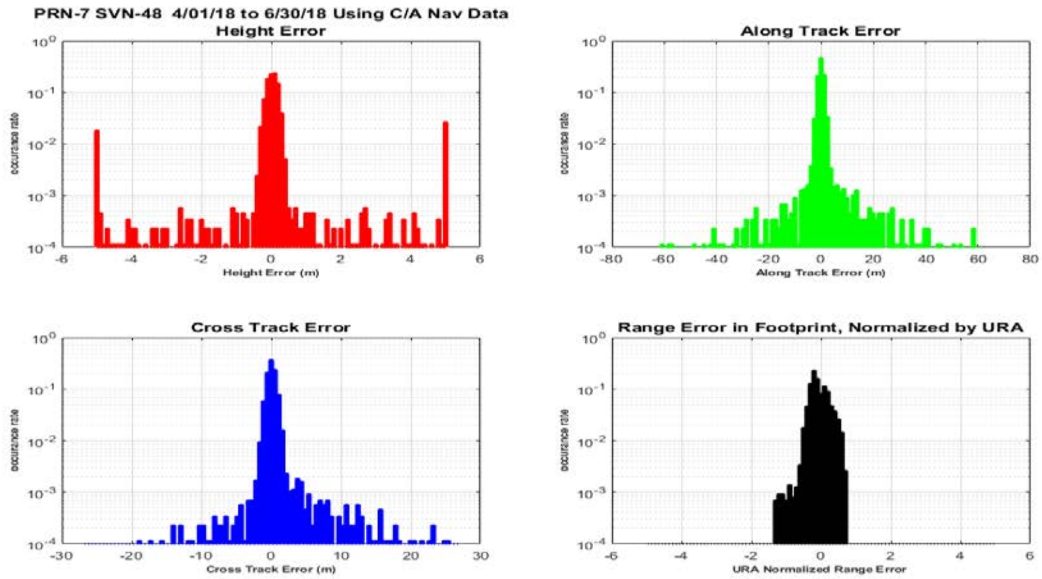


Figure 11-81 Histograms of H, A, C, and Range Error PRN-7 (SVN-48) Using L2C CNAV Data

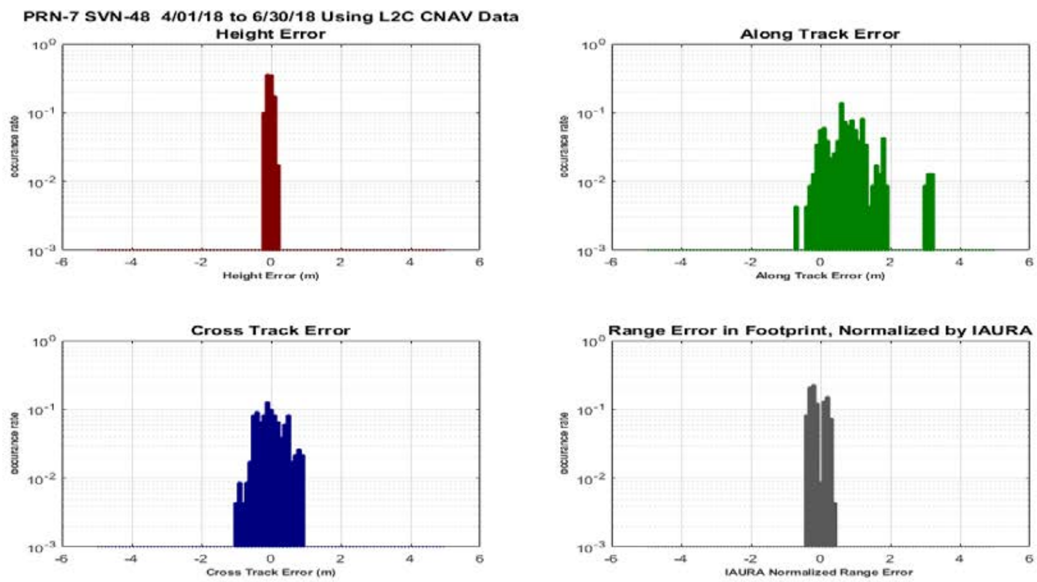


Figure 11-82 Histograms of H, A, C, and Range Error PRN-8 (SVN-72) Using C/A Nav Data

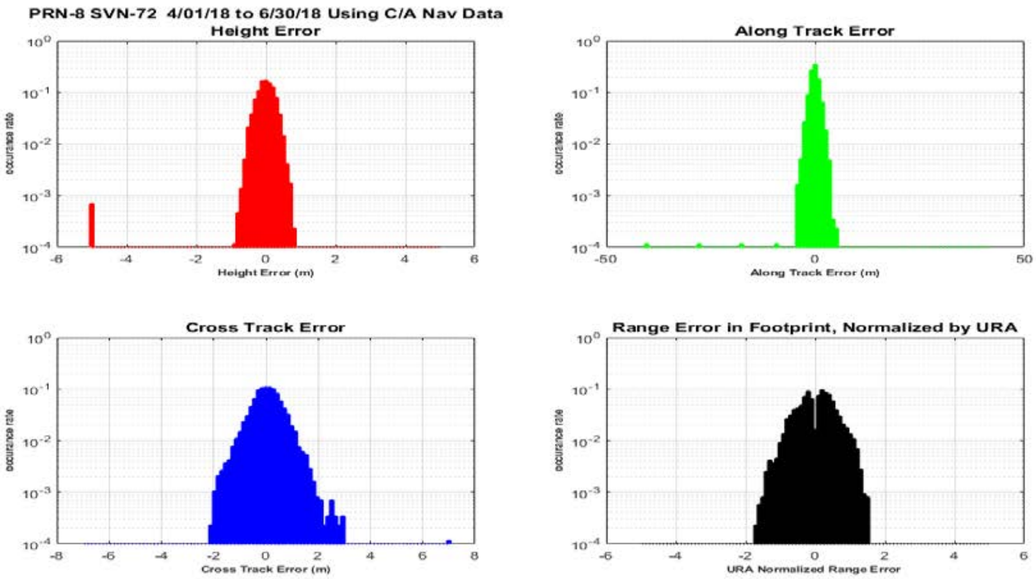


Figure 11-83 Histograms of H, A, C, and Range Error PRN-8 (SVN-72) Using L2C CNAV Data

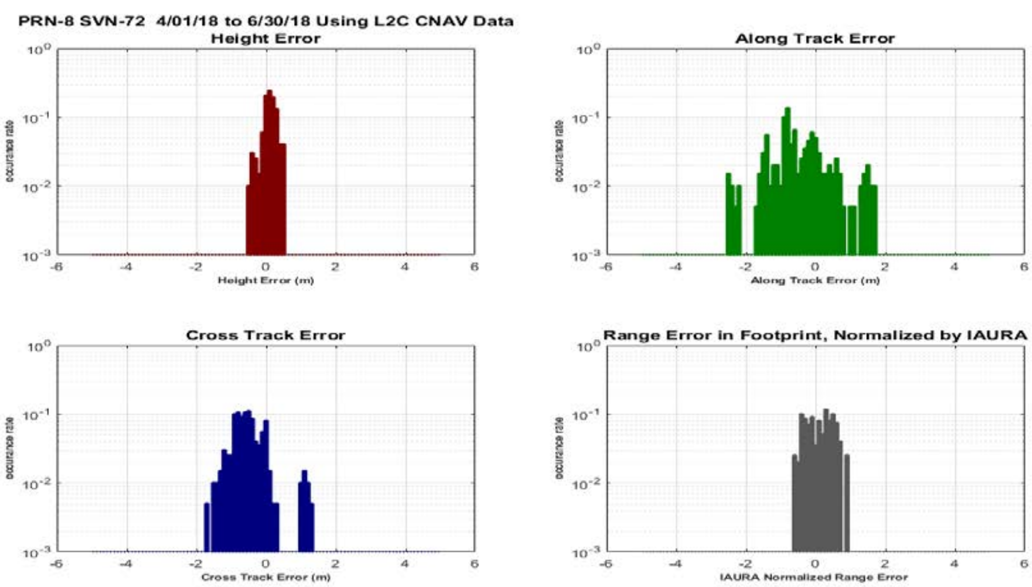


Figure 11-84 Histograms of H, A, C, and Range Error PRN-9 (SVN-68) Using C/A Nav Data

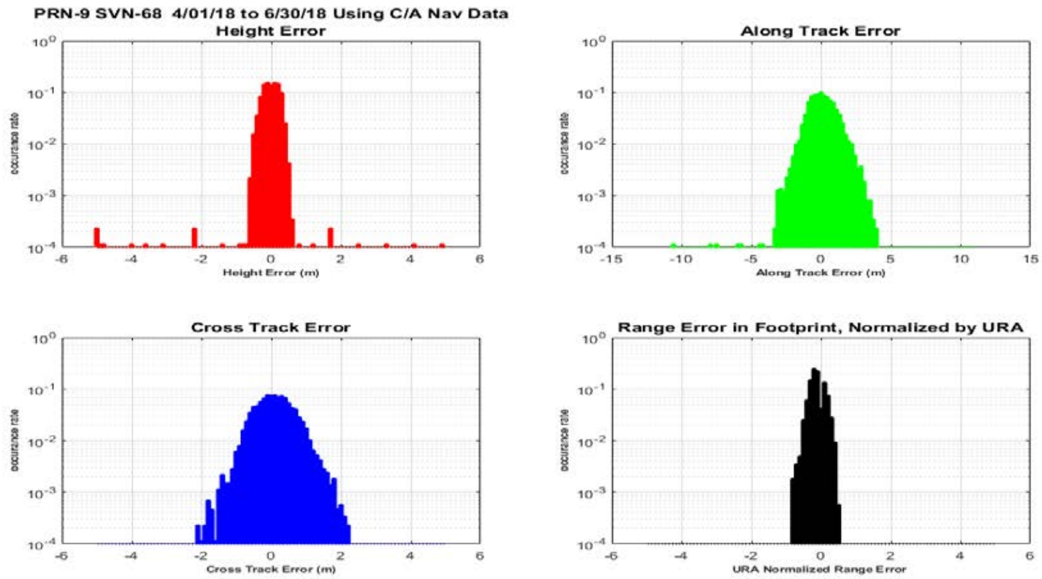


Figure 11-85 Histograms of H, A, C, and Range Error PRN-9 (SVN-68) Using L2C CNAV Data

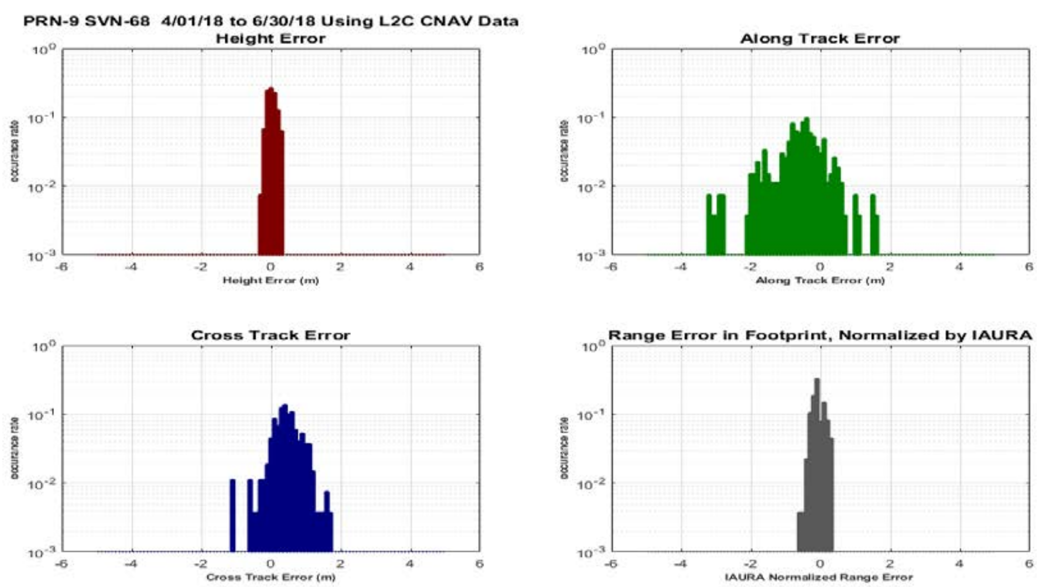


Figure 11-86 Histograms of H, A, C, and Range Error PRN-10 (SVN-73) Using C/A Nav Data

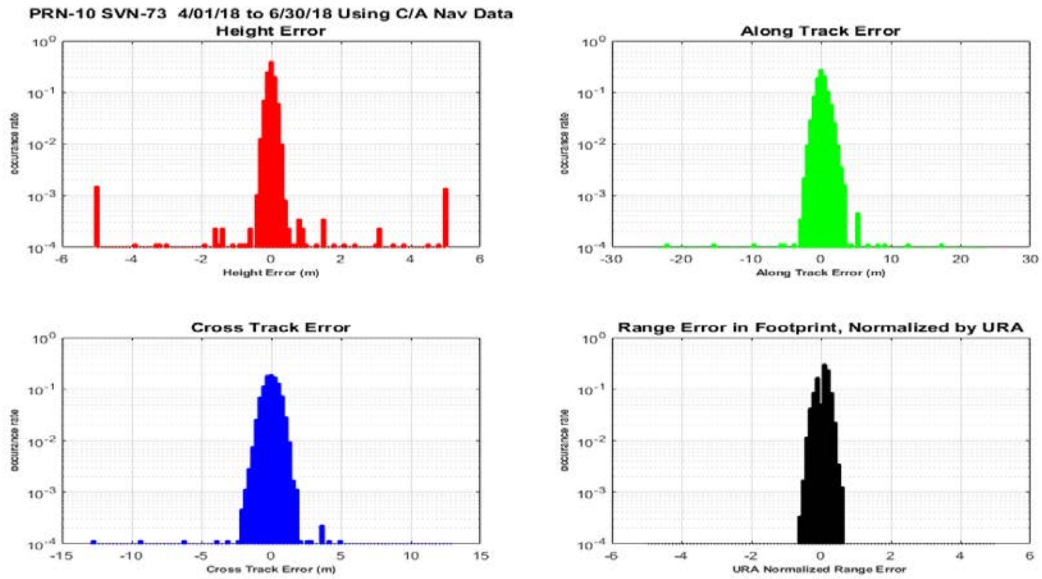


Figure 11-87 Histograms of H, A, C, and Range Error PRN-10 (SVN-73) Using L2C CNAV Data

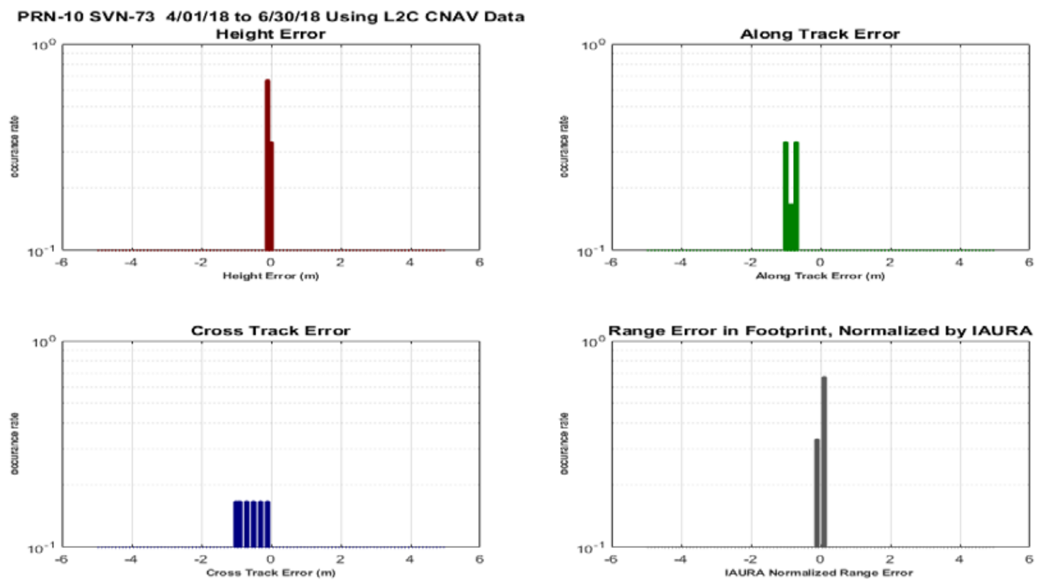


Figure 11-88 Histograms of H, A, C, and Range Error PRN-11 (SVN-46) Using C/A Nav Data

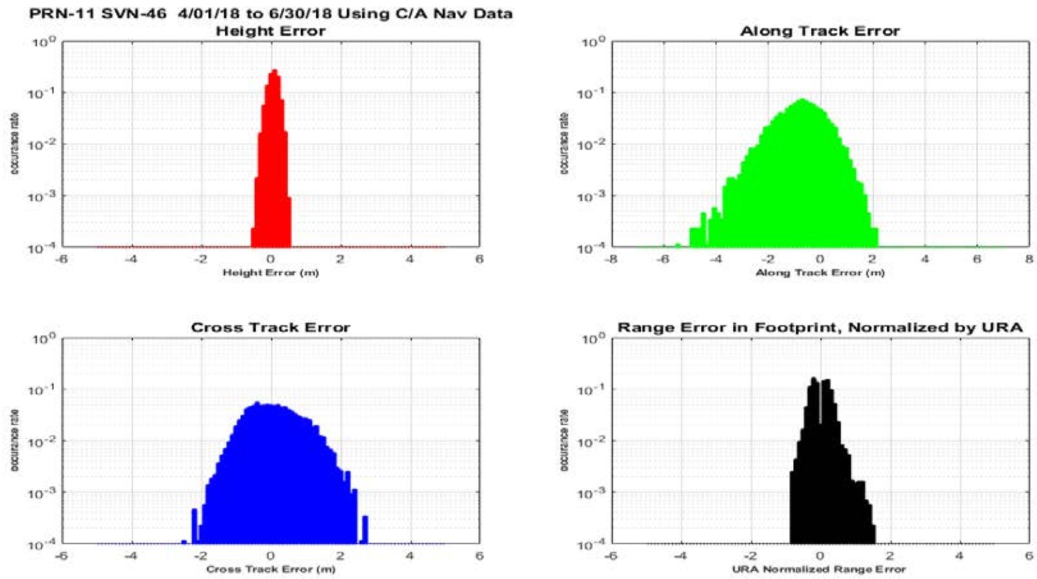


Figure 11-89 Histograms of H, A, C, and Range Error PRN-12 (SVN-58) Using C/A Nav Data

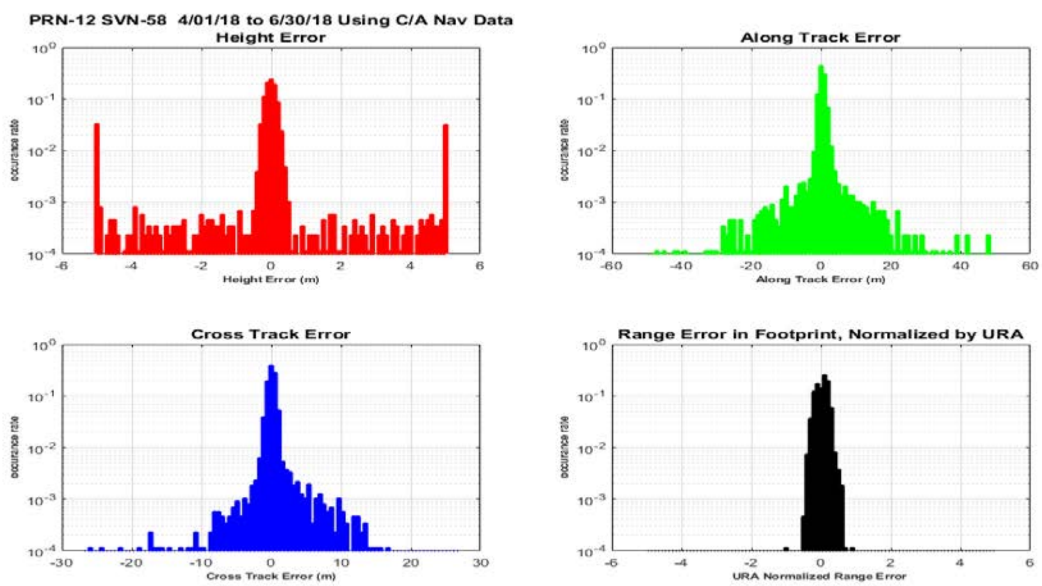


Figure 11-90 Histograms of H, A, C, and Range Error PRN-12 (SVN-58) Using L2C CNAV Data

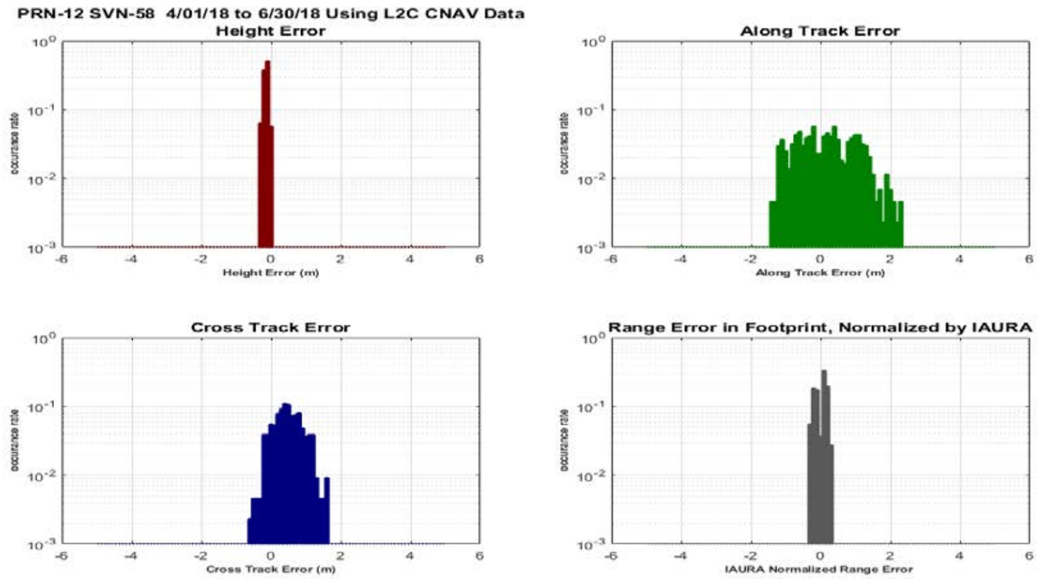


Figure 11-91 Histograms of H, A, C, and Range Error PRN-13 (SVN-43) Using C/A Nav Data

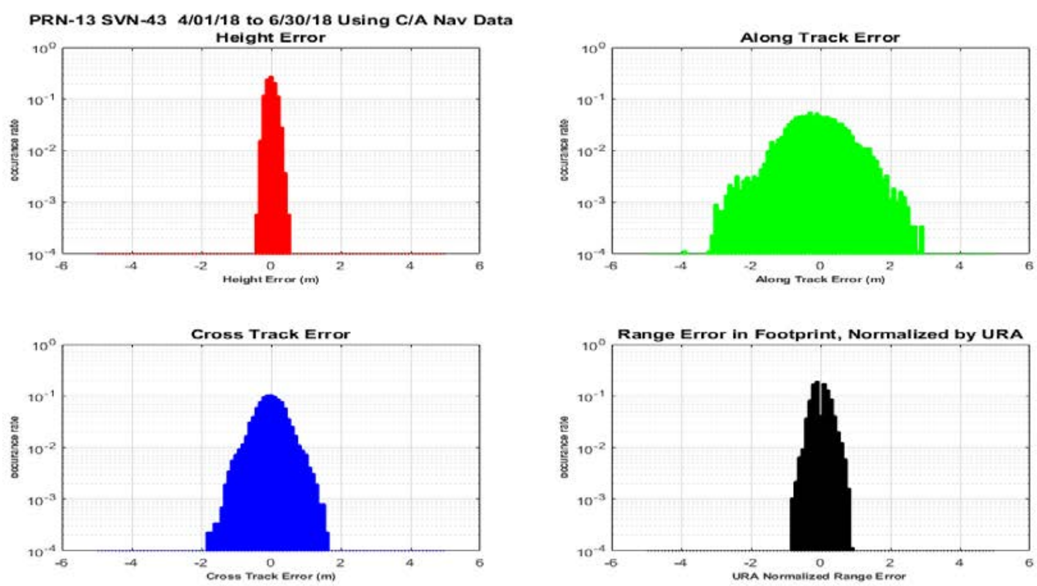


Figure 11-92 Histograms of H, A, C, and Range Error PRN-14 (SVN-41) Using C/A Nav Data

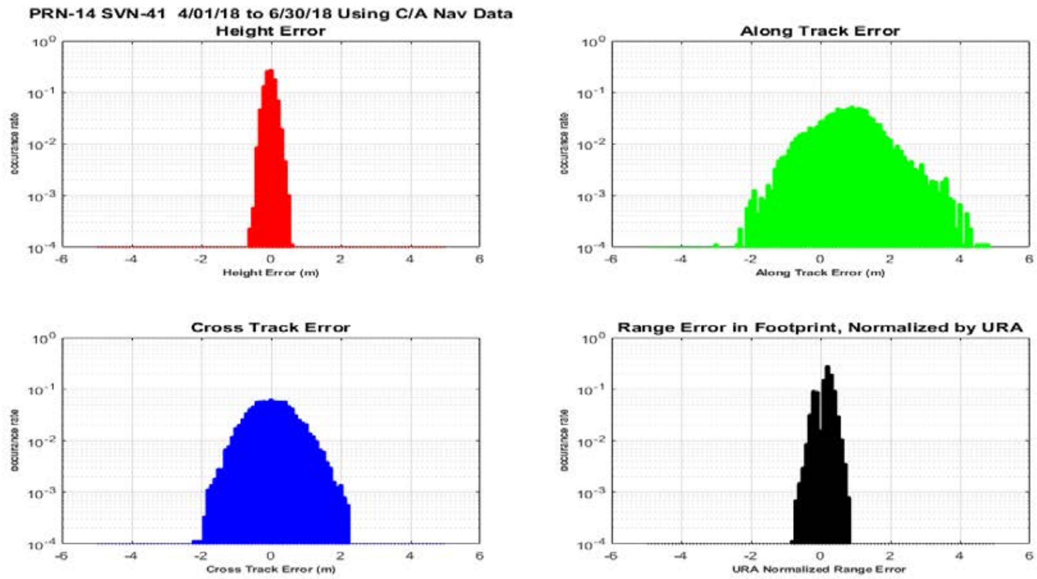


Figure 11-93 Histograms of H, A, C, and Range Error PRN-15 (SVN-55) Using C/A Nav Data

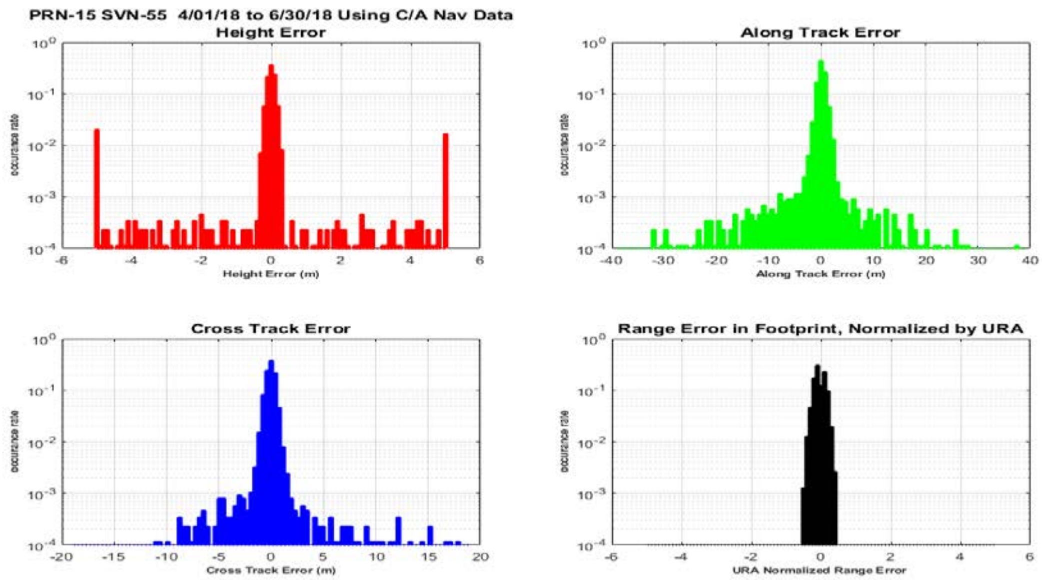


Figure 11-94 Histograms of H, A, C, and Range Error PRN-15 (SVN-55) Using L2C CNAV Data

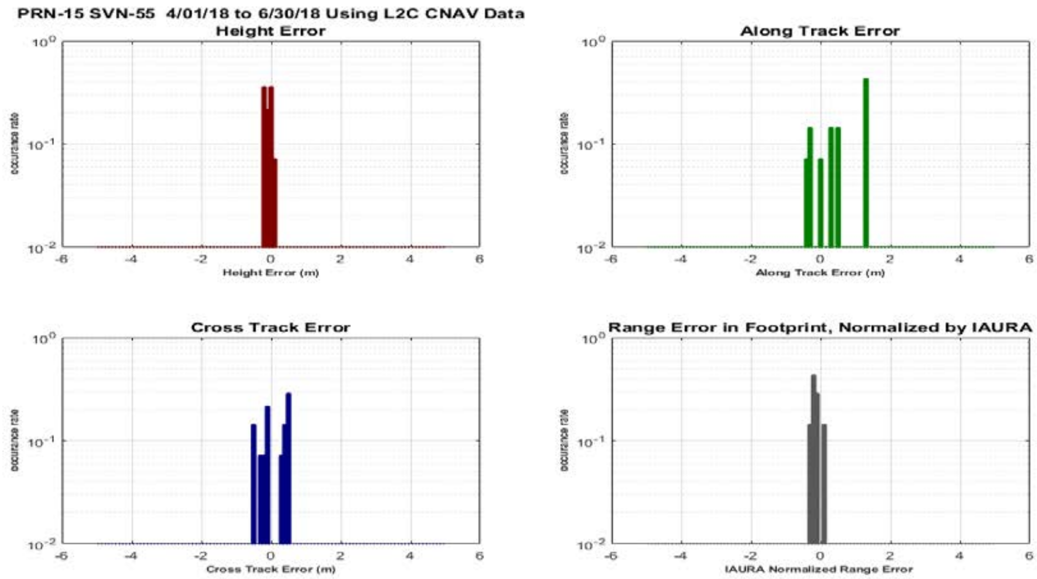


Figure 11-95 Histograms of H, A, C, and Range Error PRN-16 (SVN-56) Using C/A Nav Data

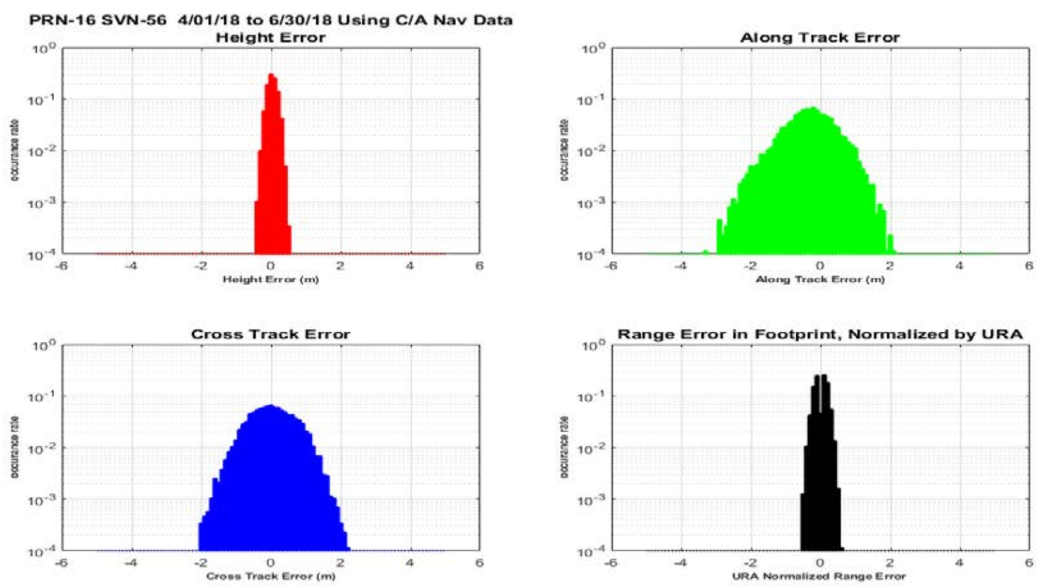


Figure 11-96 Histograms of H, A, C, and Range Error PRN-17 (SVN-53) Using C/A Nav Data

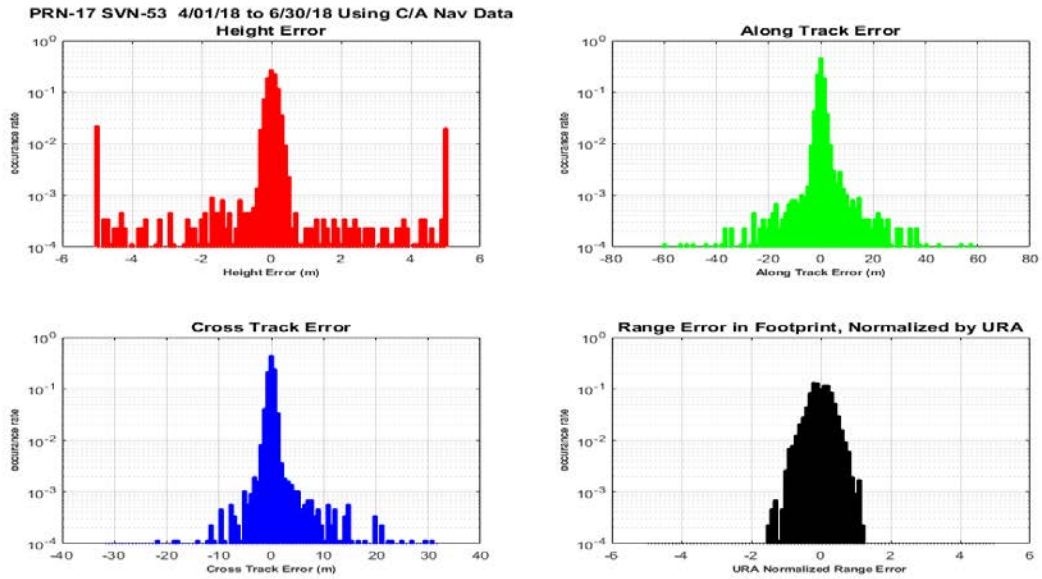


Figure 11-97 Histograms of H, A, C, and Range Error PRN-17 (SVN-53) Using L2C CNAV Data

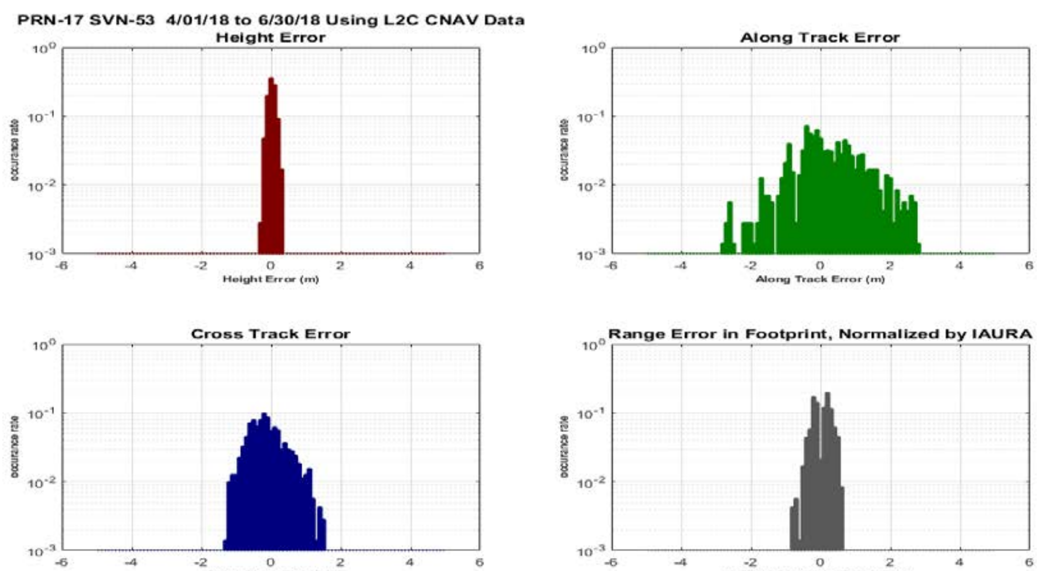


Figure 11-98 Histograms of H, A, C, and Range Error PRN-18 (SVN-34) Using C/A Nav Data

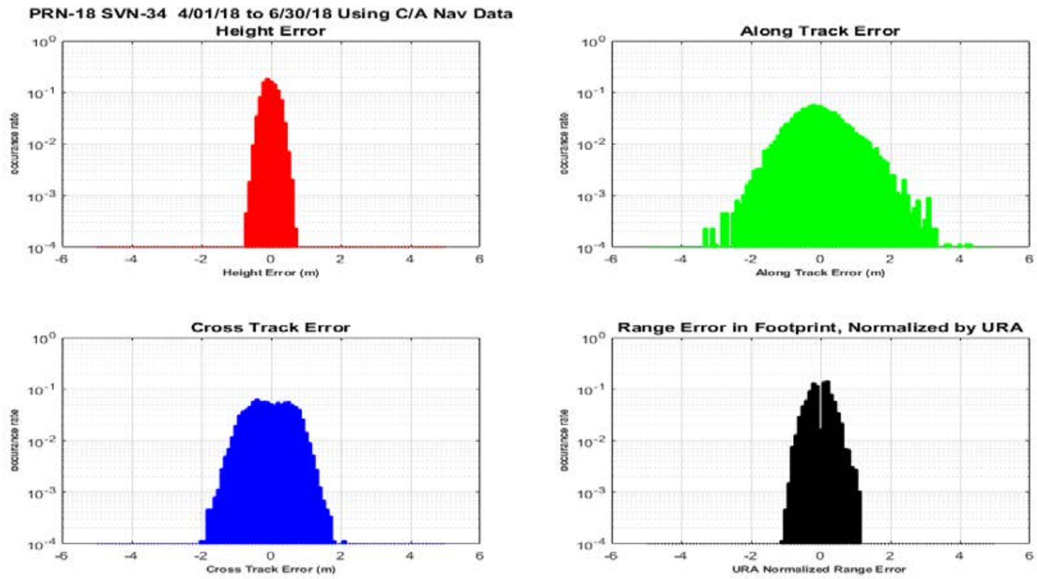


Figure 11-99 Histograms of H, A, C, and Range Error PRN-19 (SVN-59) Using C/A Nav Data

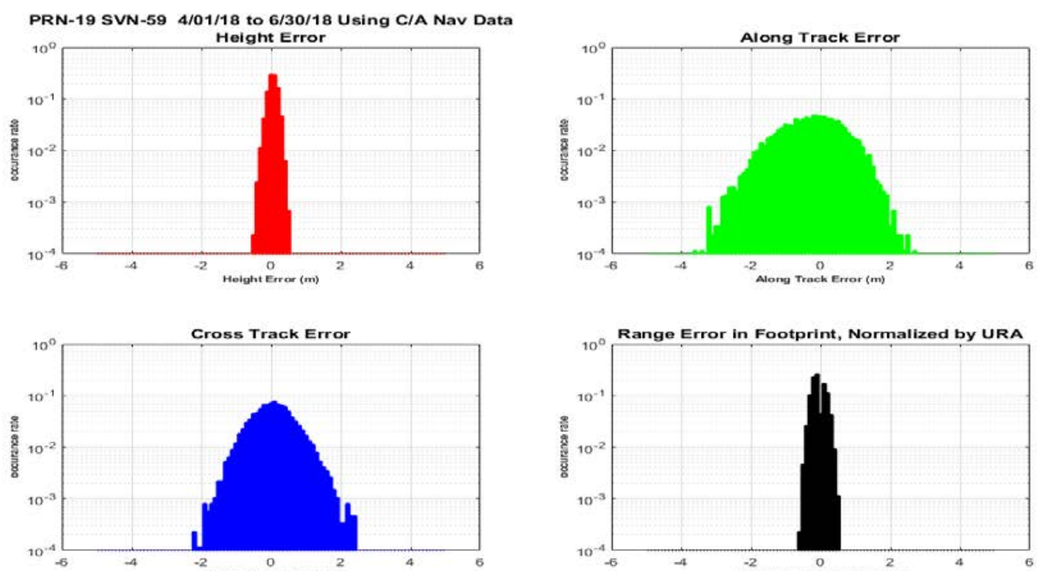


Figure 11-100 Histograms of H, A, C, and Range Error PRN-20 (SVN-51) Using C/A Nav Data

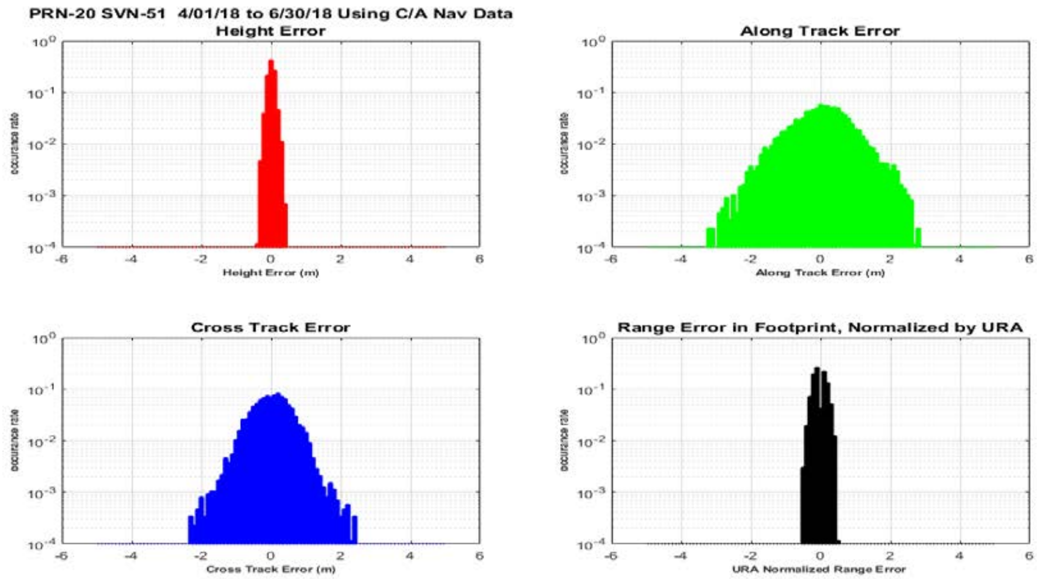


Figure 11-101 Histograms of H, A, C, and Range Error PRN-21 (SVN-45) Using C/A Nav Data

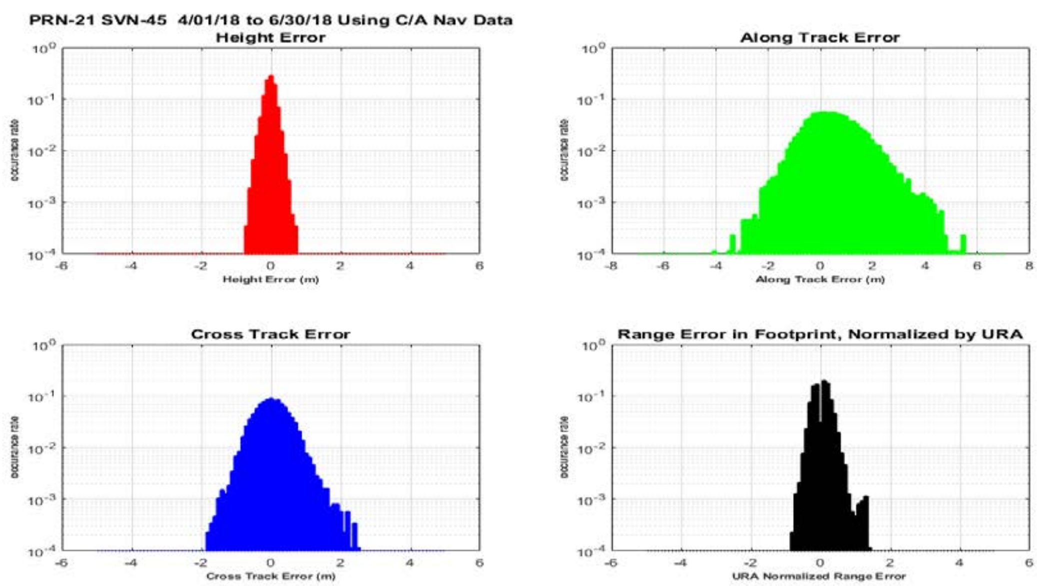


Figure 11-102 Histograms of H, A, C, and Range Error PRN-22 (SVN-47) Using C/A Nav Data

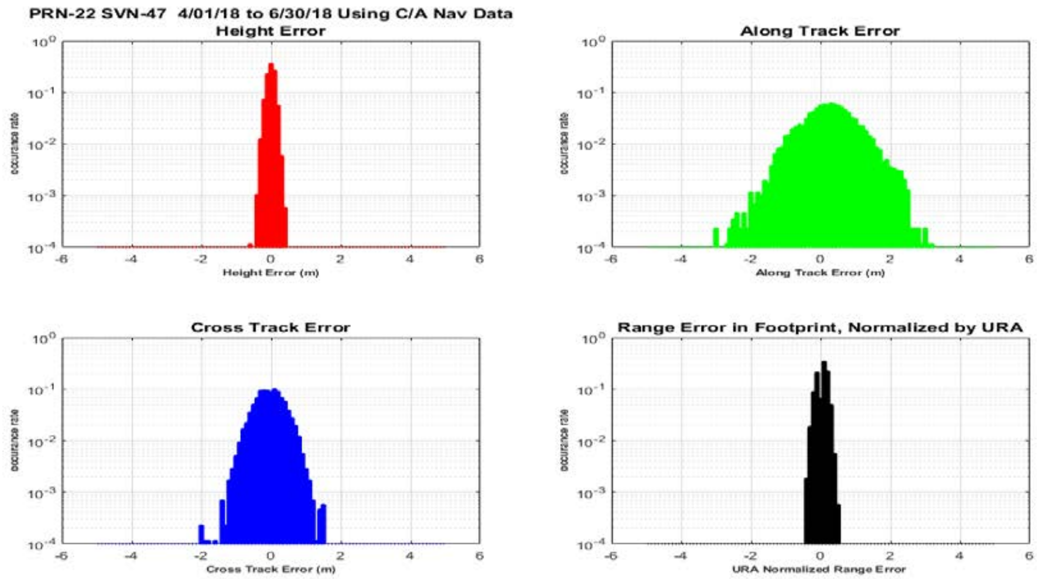


Figure 11-103 Histograms of H, A, C, and Range Error PRN-23 (SVN-60) Using C/A Nav Data

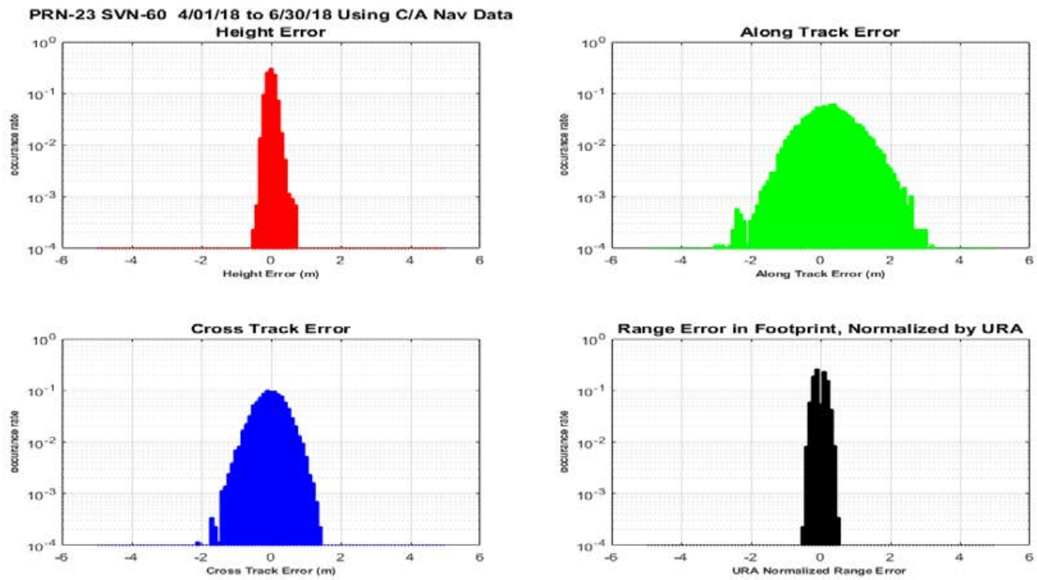


Figure 11-104 Histograms of H, A, C, and Range Error PRN-24 (SVN-65) Using C/A Nav Data

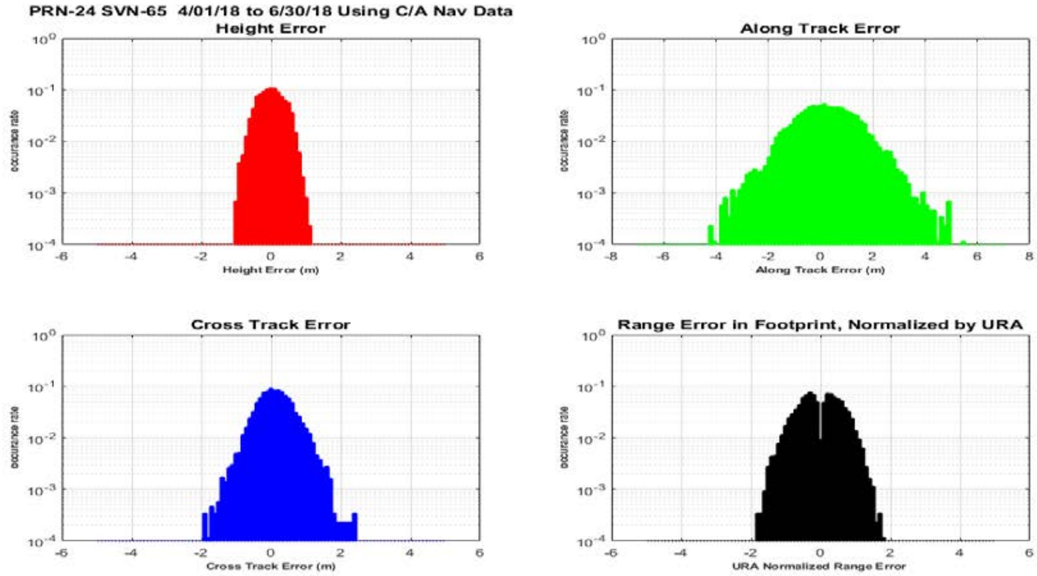


Figure 11-105 Histograms of H, A, C, and Range Error PRN-24 (SVN-65) Using L2C CNAV Data

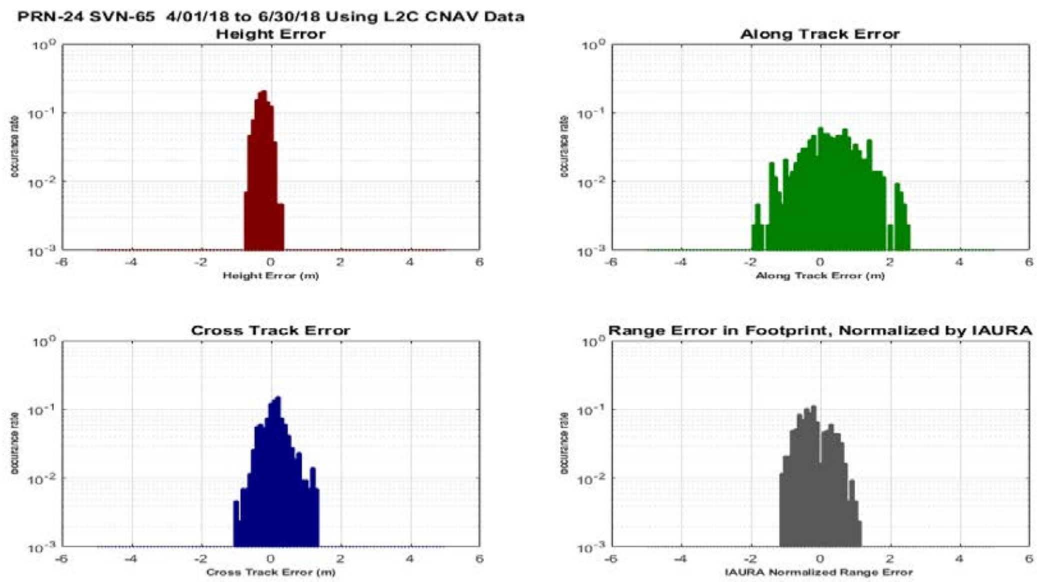


Figure 11-106 Histograms of H, A, C, and Range Error PRN-25 (SVN-62) Using C/A Nav Data

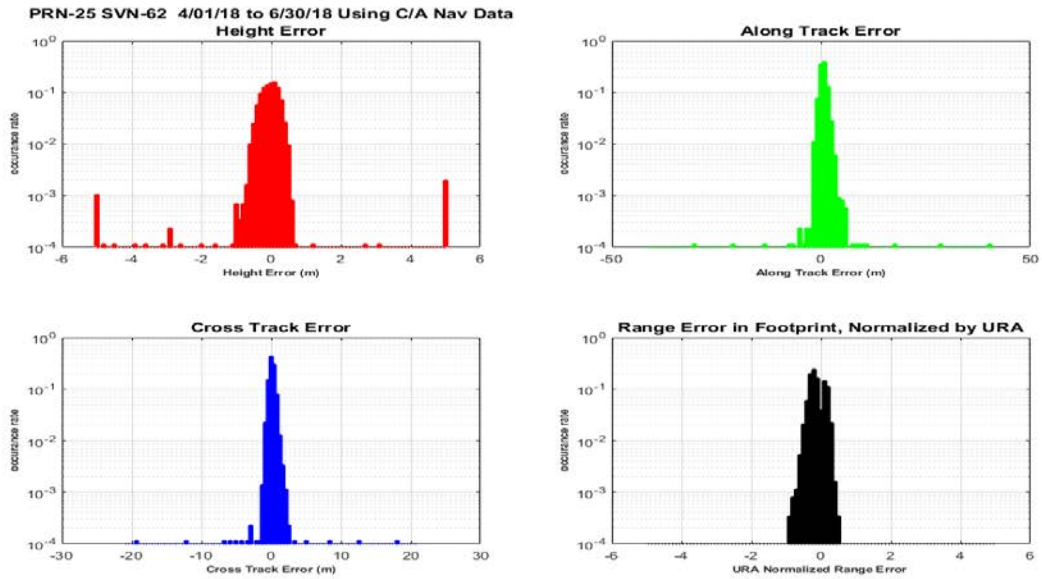


Figure 11-107 Histograms of H, A, C, and Range Error PRN-25 (SVN-62) Using L2C CNAV Data

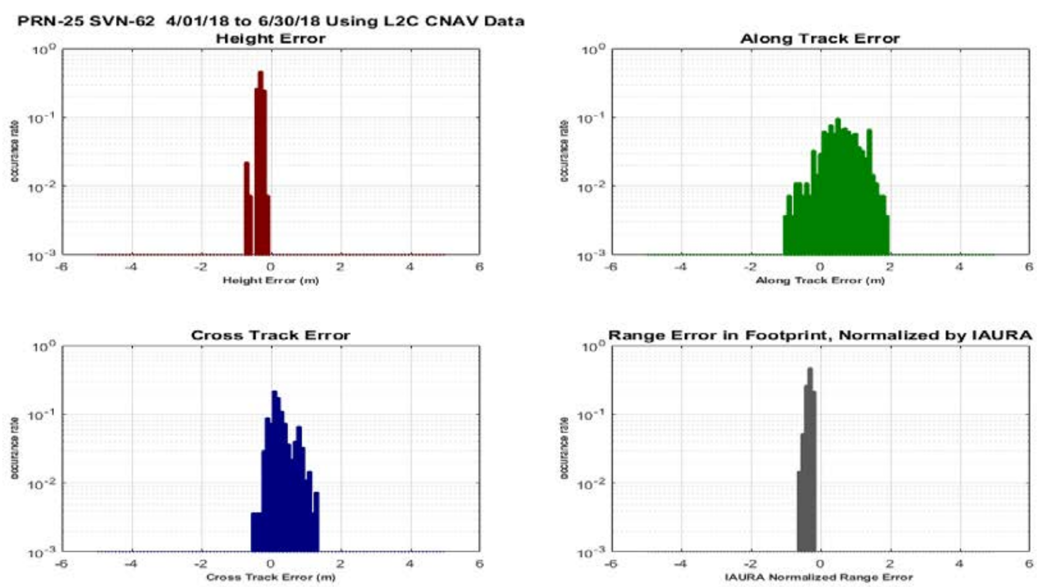


Figure 11-108 Histograms of H, A, C, and Range Error PRN-26 (SVN-71) Using C/A Nav Data

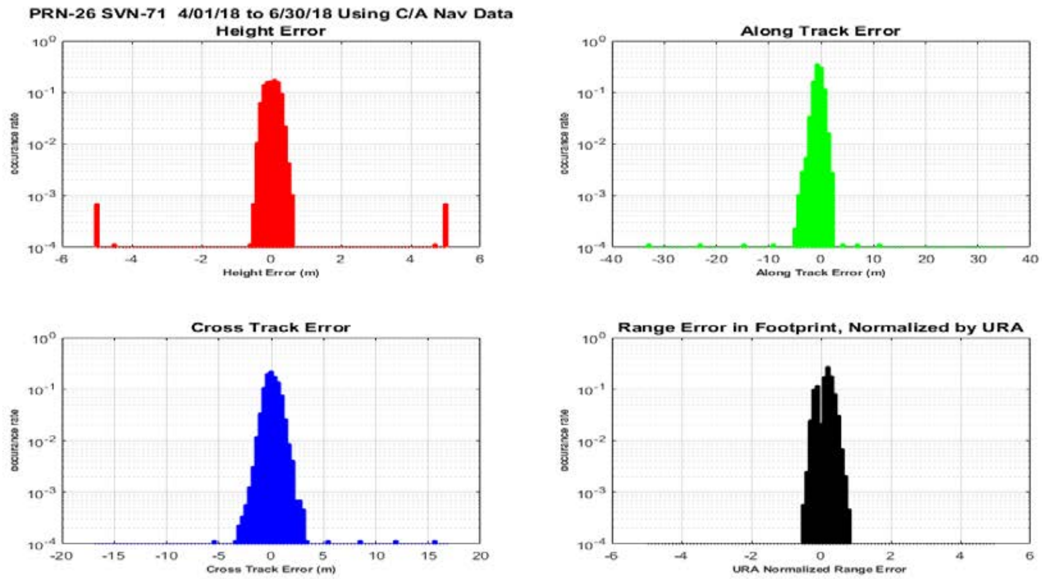


Figure 11-109 Histograms of H, A, C, and Range Error PRN-27 (SVN-66) Using C/A Nav Data

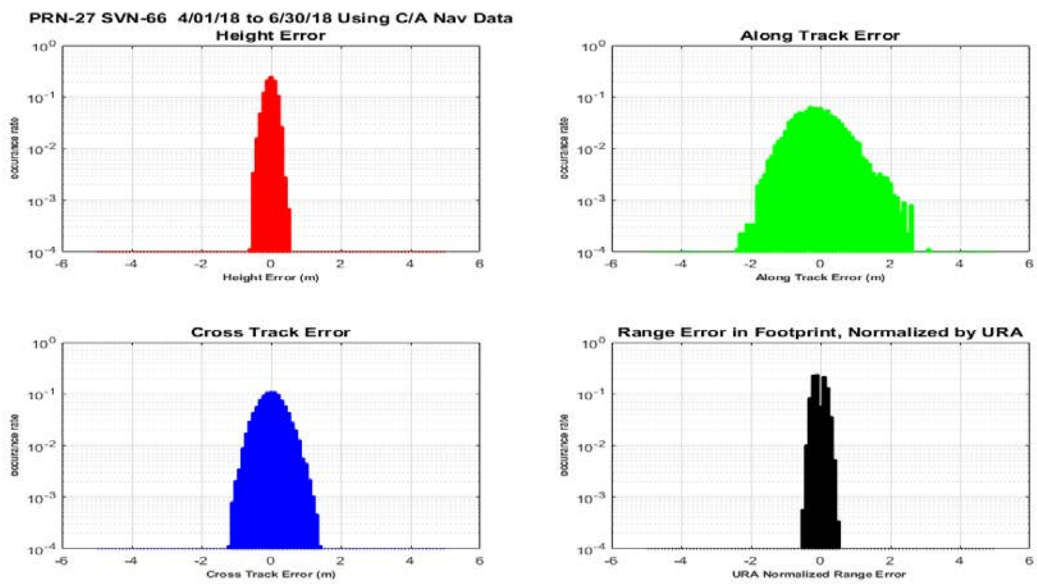


Figure 11-110 Histograms of H, A, C, and Range Error PRN-28 (SVN-44) Using C/A Nav Data

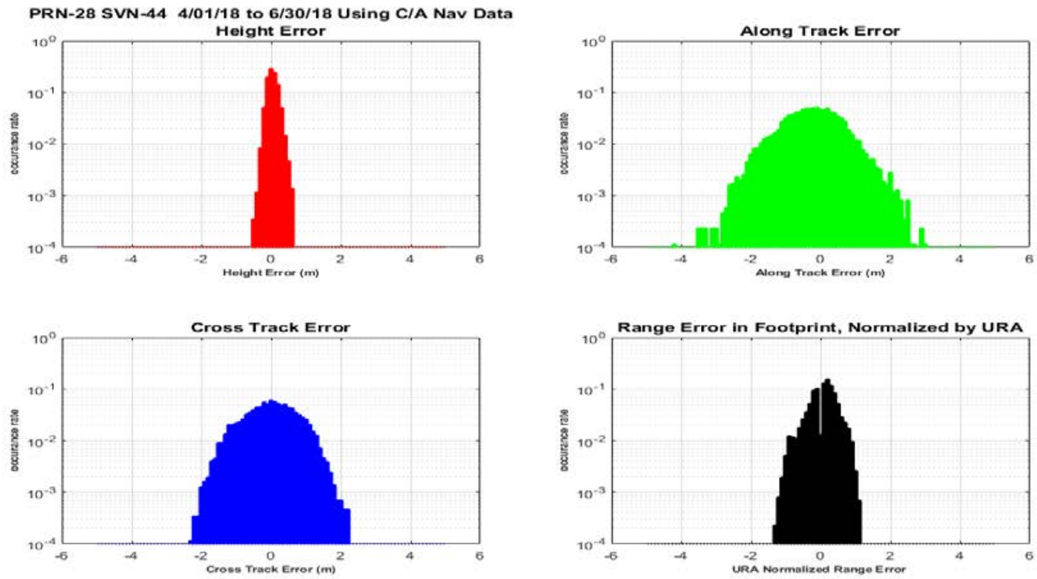


Figure 11-111 Histograms of H, A, C, and Range Error PRN-29 (SVN-57) Using C/A Nav Data

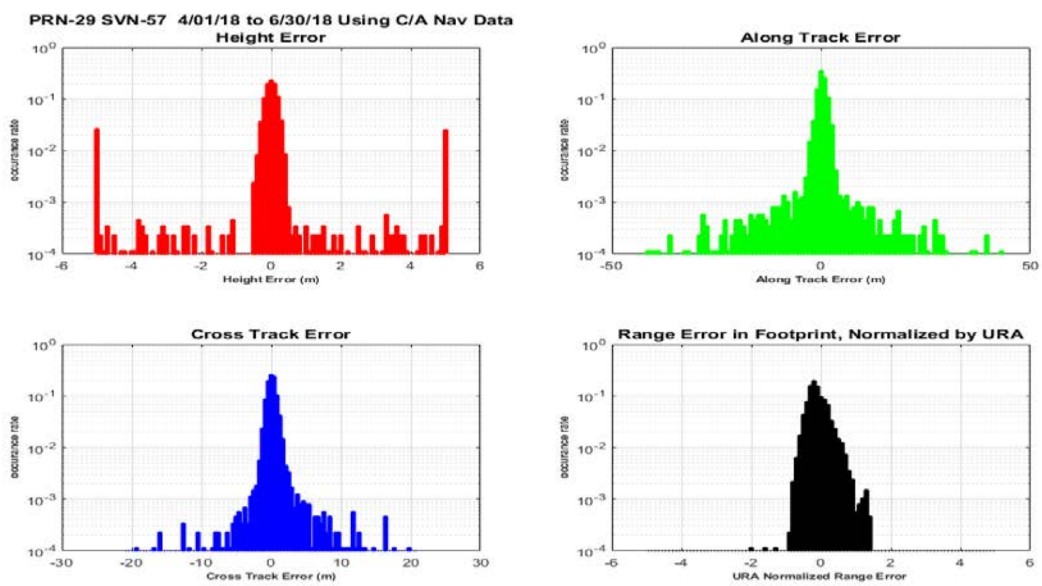


Figure 11-112 Histograms of H, A, C, and Range Error PRN-29 (SVN-57) Using L2C CNAV Data

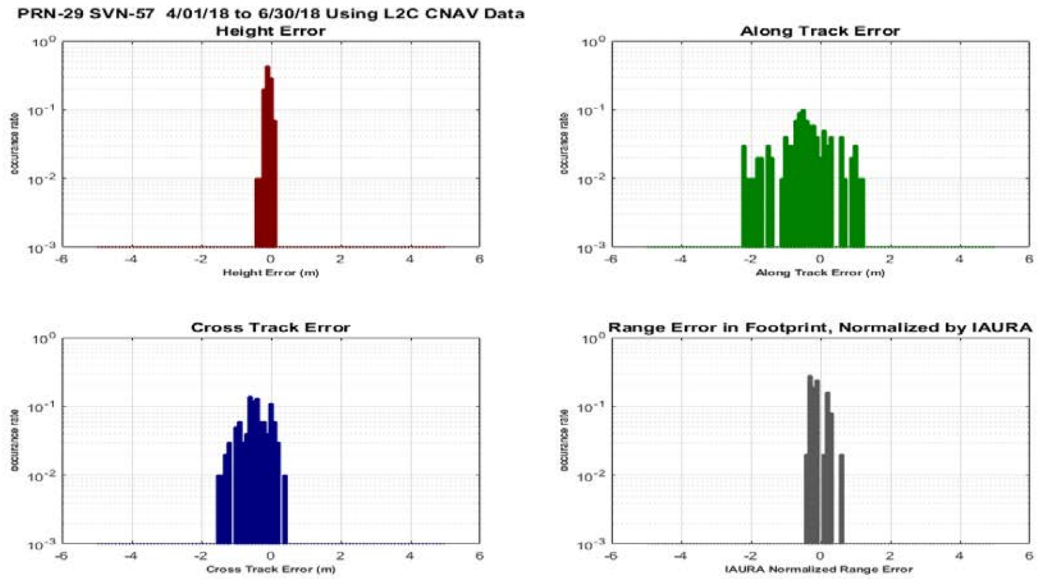


Figure 11-113 Histograms of H, A, C, and Range Error PRN-30 (SVN-64) Using C/A Nav Data

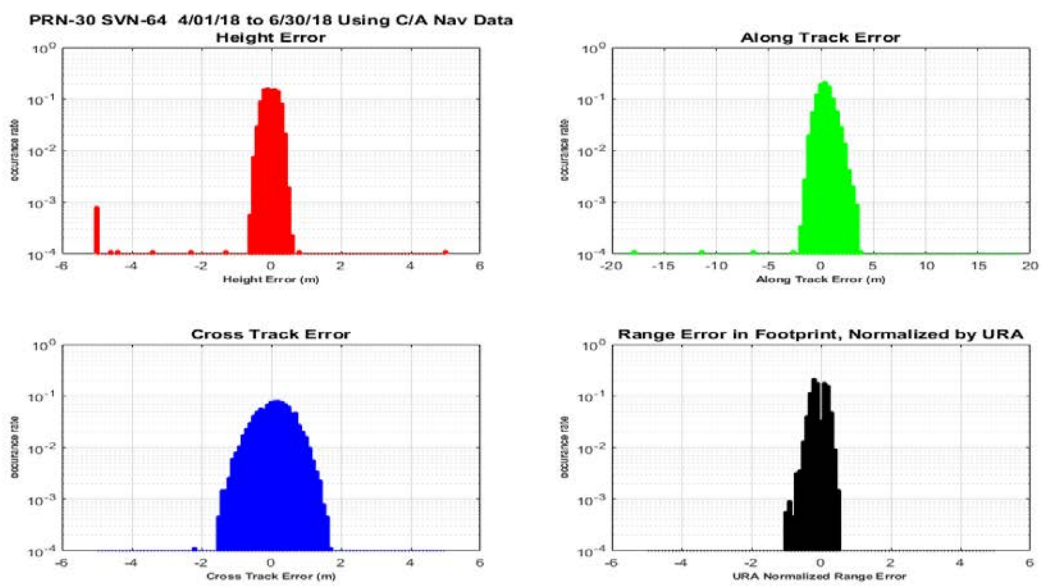


Figure 11-114 Histograms of H, A, C, and Range Error PRN-30 (SVN-64) Using L2C CNAV Data

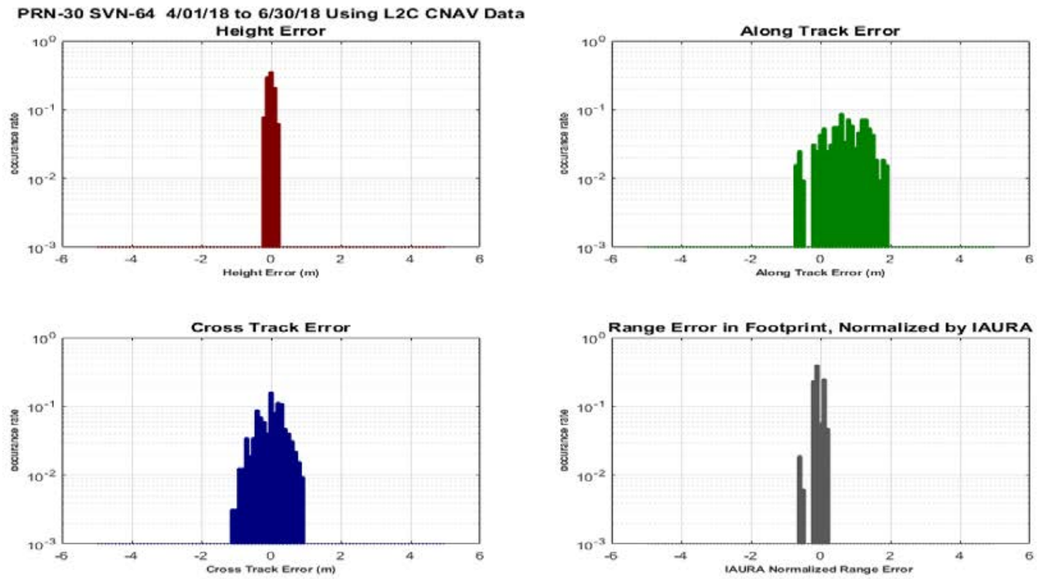


Figure 11-115 Histograms of H, A, C, and Range Error PRN-31 (SVN-52) Using C/A Nav Data

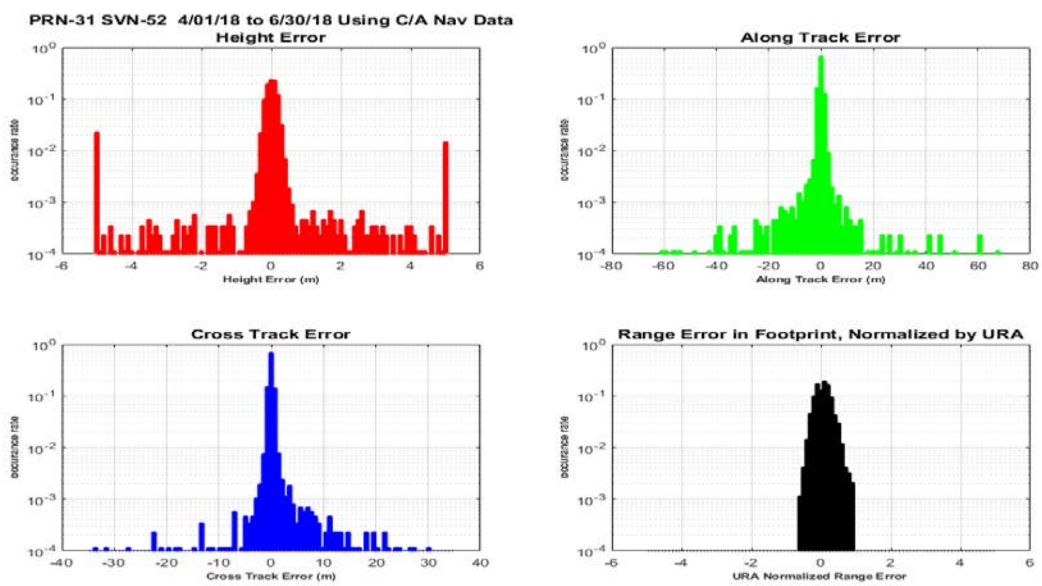
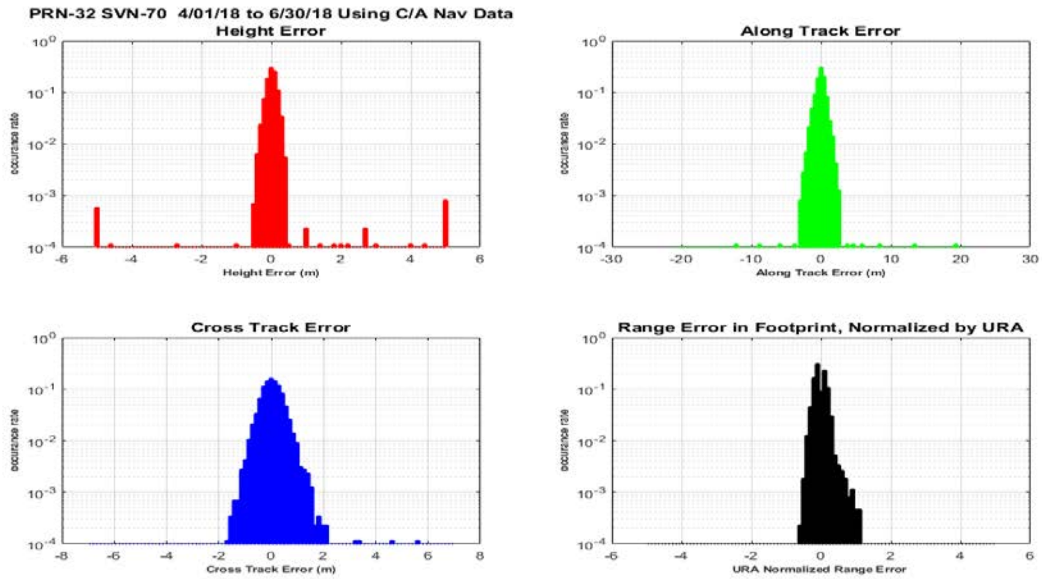


Figure 11-116 Histograms of H, A, C, and Range Error PRN-32 (SVN-70) Using C/A Nav Data



Timeline of URA Normalized Range Error for All Satellites

Figure 11-117 Timeline of URA Normalized Range Error PRN-1 (SVN-63) Using C/A Nav Data

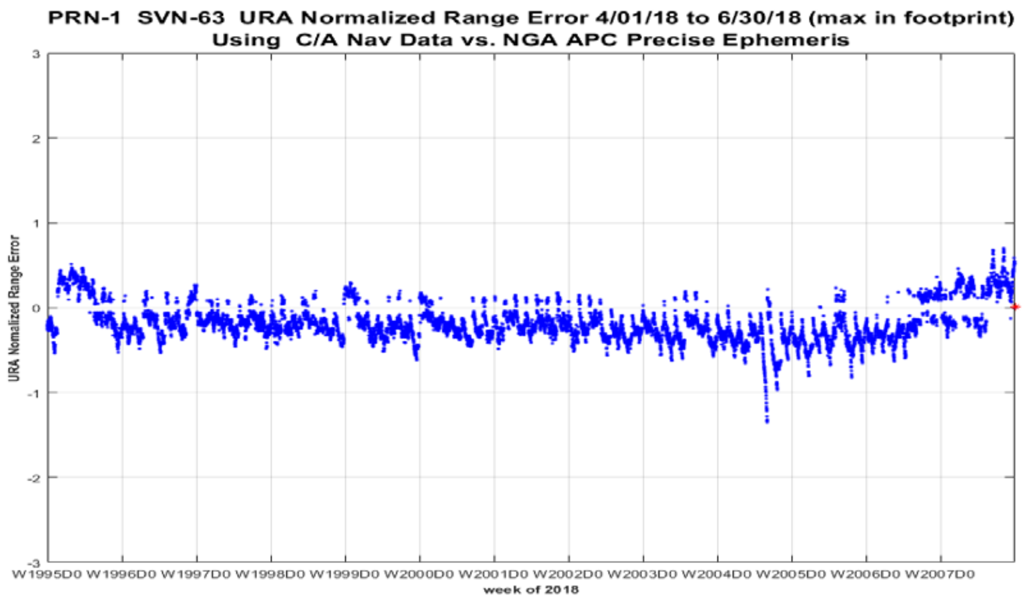


Figure 11-118 Timeline of IAURA Normalized Range Error PRN-1 (SVN-63) Using L2C CNAV Data

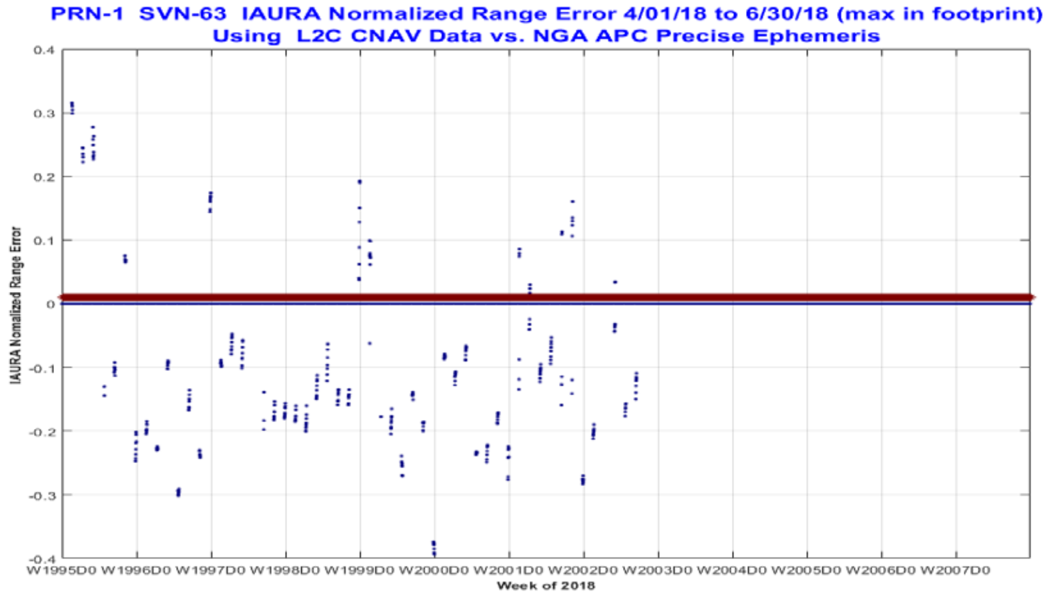


Figure 11-119 Timeline of URA Normalized Range Error PRN-2 (SVN-61) Using C/A Nav Data

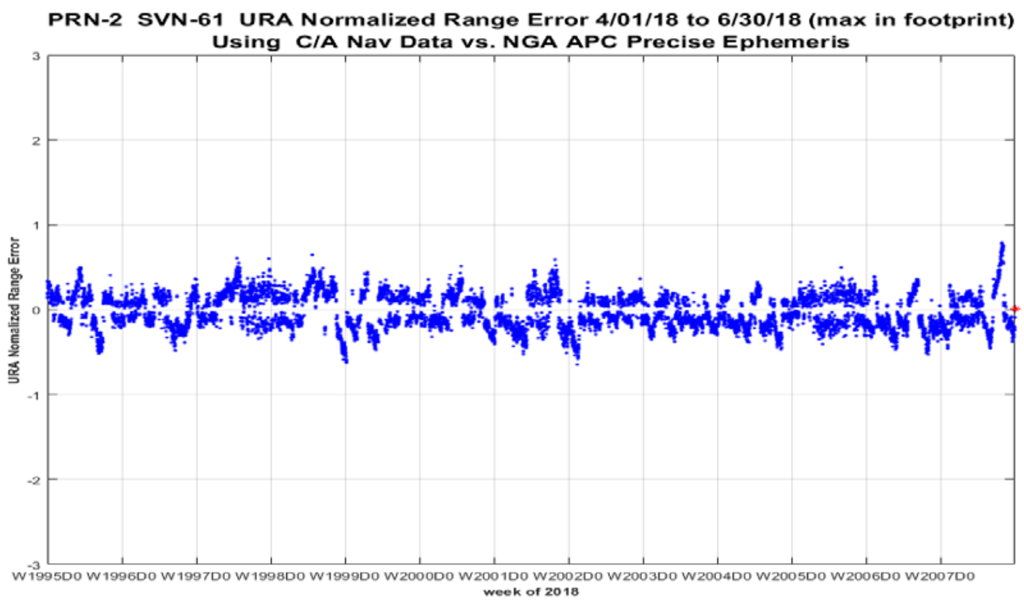


Figure 11-120 Timeline of URA Normalized Range Error PRN-3 (SVN-69) Using C/A Nav Data

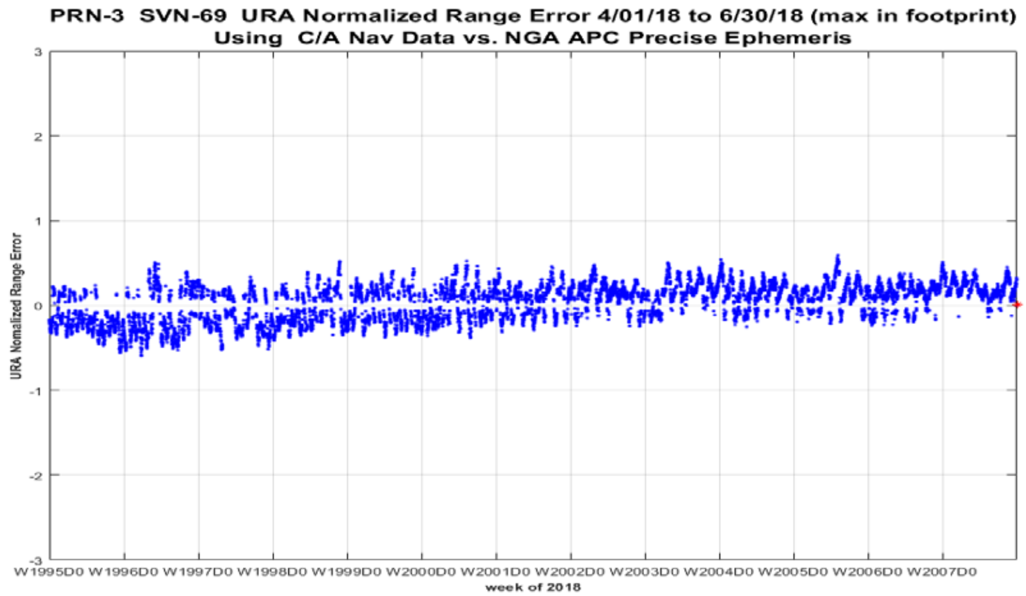


Figure 11-121 Timeline of IAURA Normalized Range Error PRN-3 (SVN-69) Using L2C CNAV Data

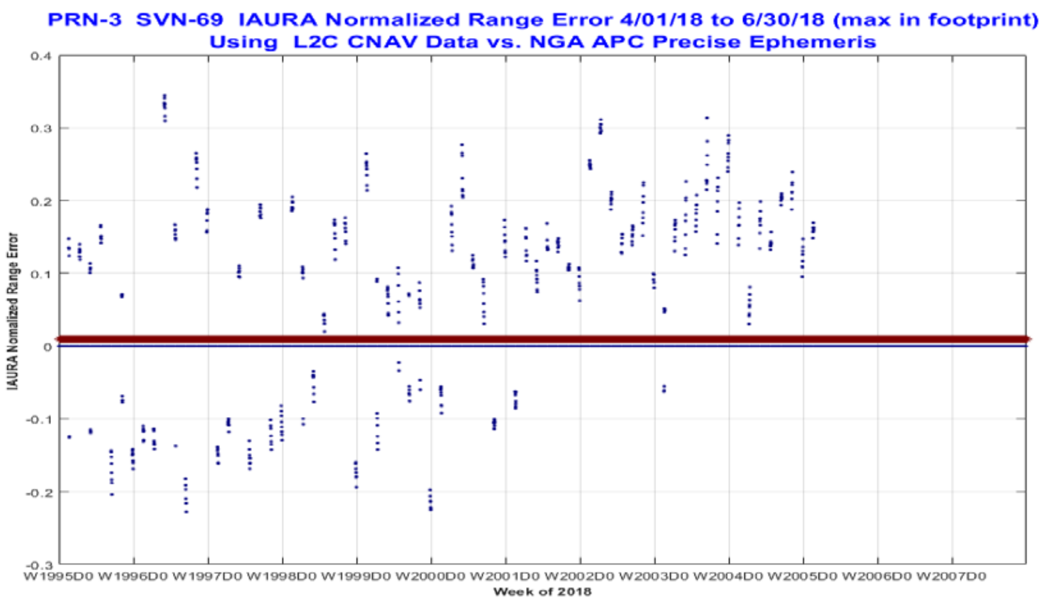


Figure 11-122 Timeline of URA Normalized Range Error PRN-5 (SVN-50) Using C/A Nav Data

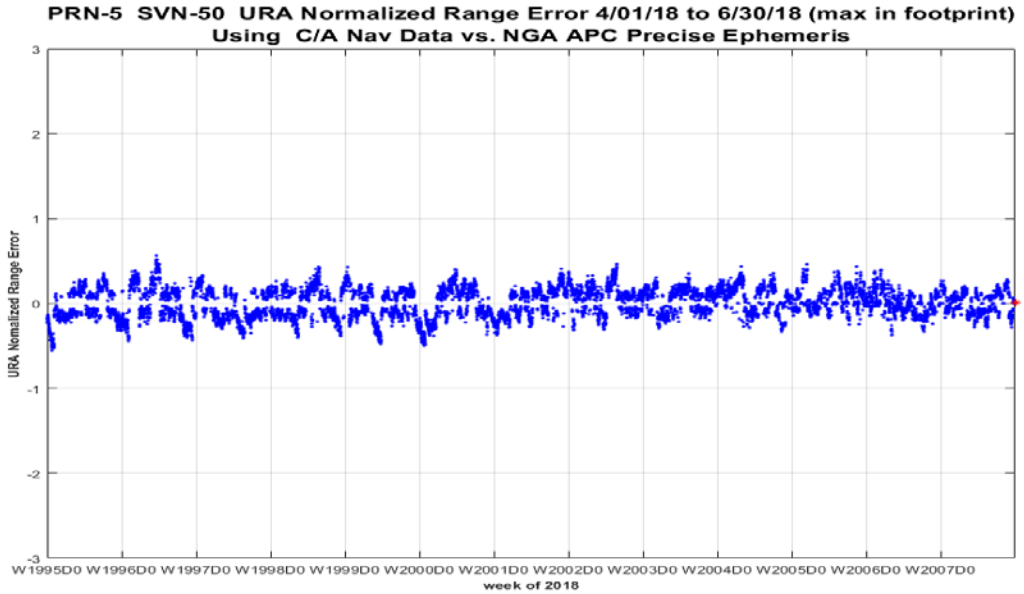


Figure 11-123 Timeline of IAURA Normalized Range Error PRN-5 (SVN-50) Using L2C CNAV Data

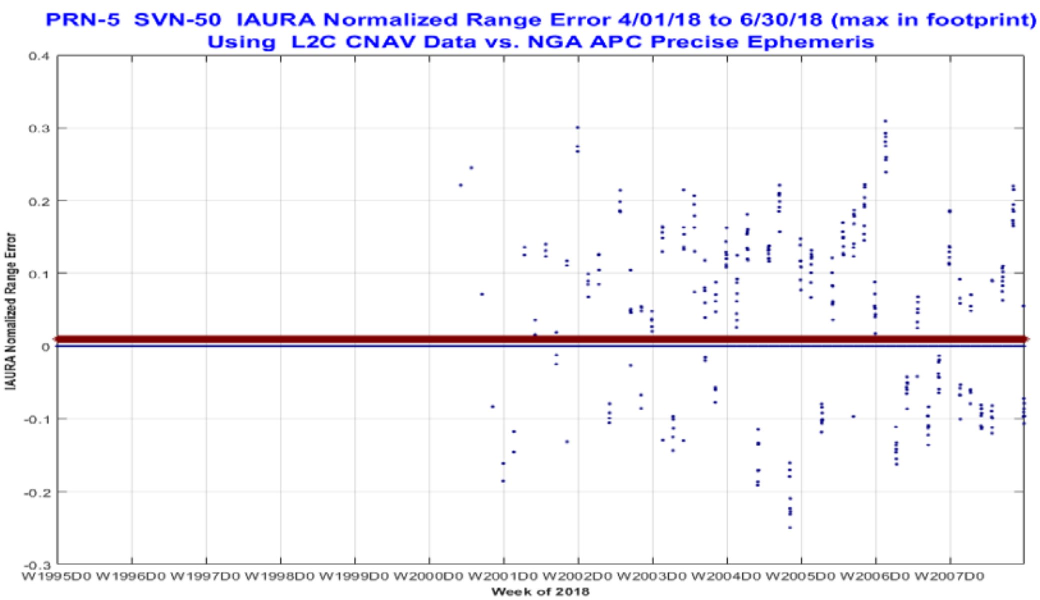


Figure 11-124 Timeline of URA Normalized Range Error PRN-6 (SVN-67) Using C/A Nav Data

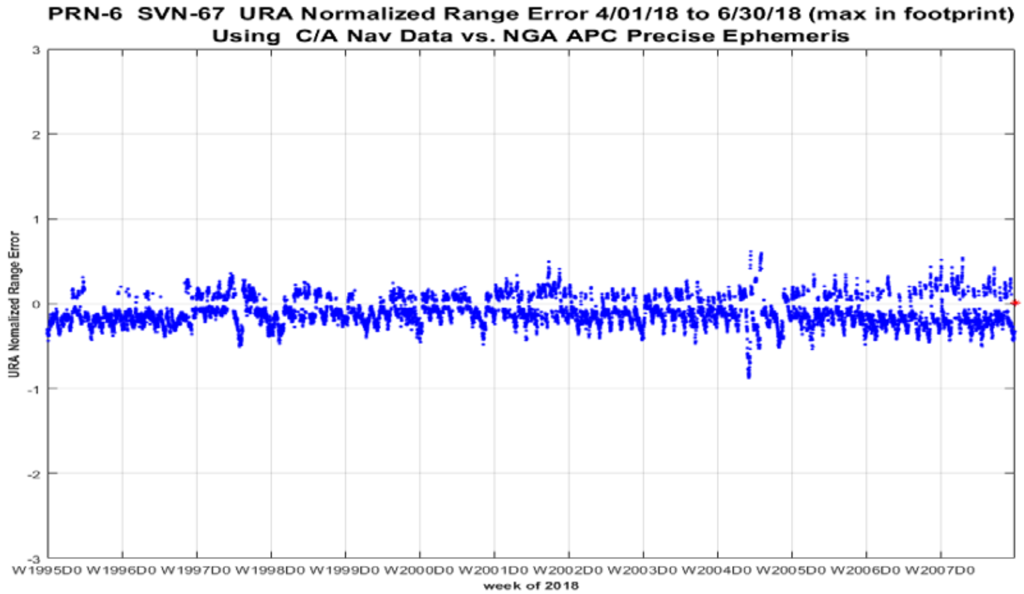


Figure 11-125 Timeline of IAURA Normalized Range Error PRN-6 (SVN-67) Using L2C CNAV Data

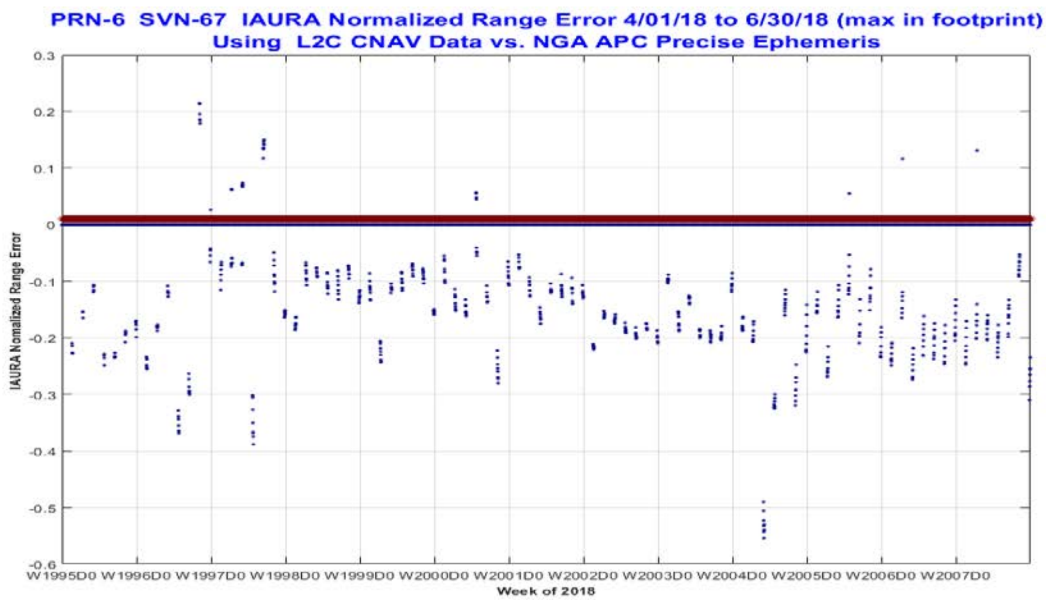


Figure 11-126 Timeline of URA Normalized Range Error PRN-7 (SVN-48) Using C/A Nav Data

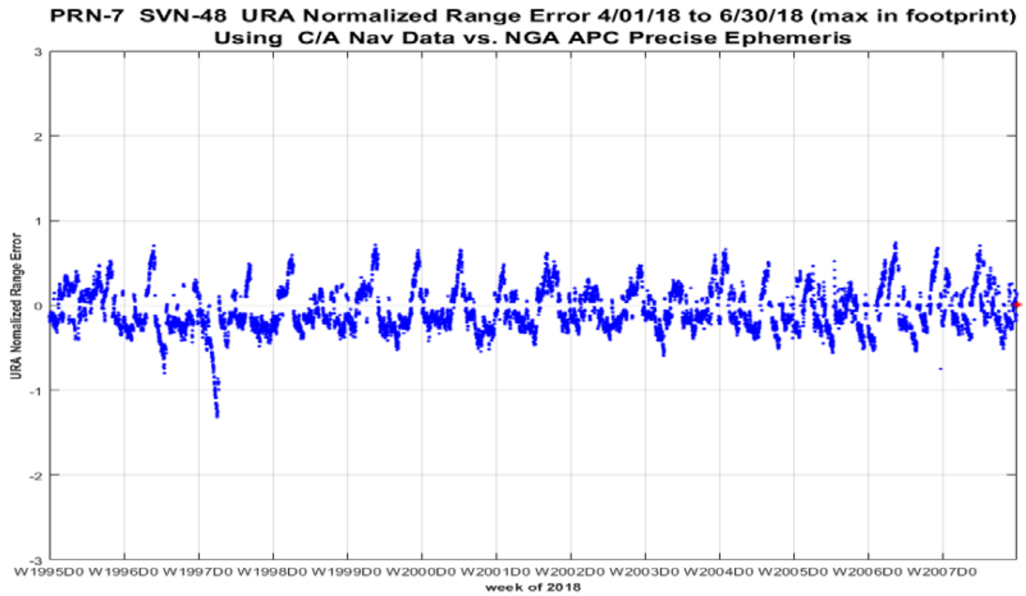


Figure 11-127 Timeline of IAURA Normalized Range Error PRN-7 (SVN-48) Using L2C CNAV Data

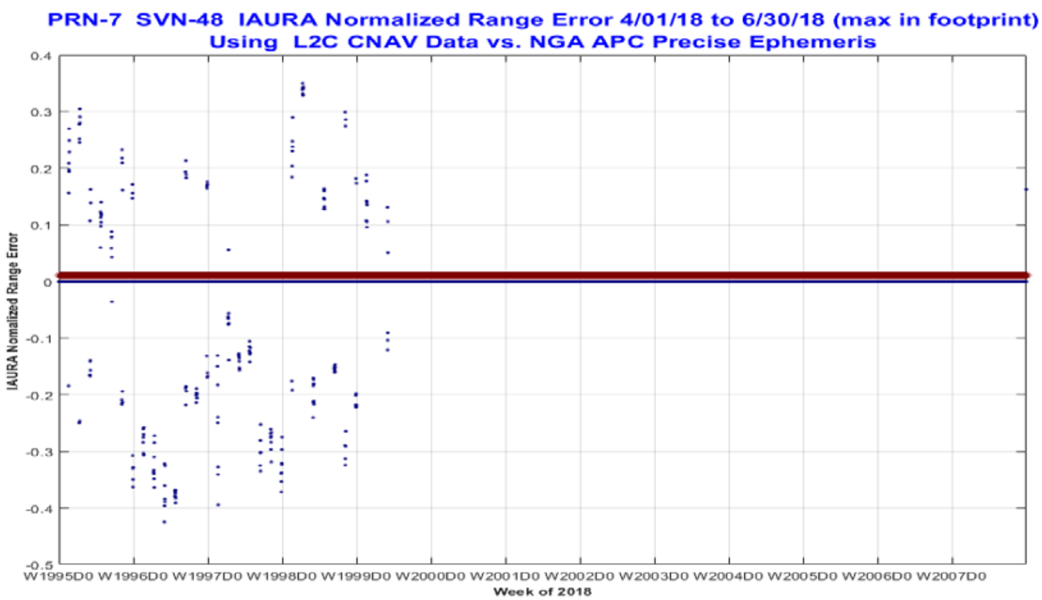


Figure 11-128 Timeline of URA Normalized Range Error PRN-8 (SVN-72) Using C/A Nav Data

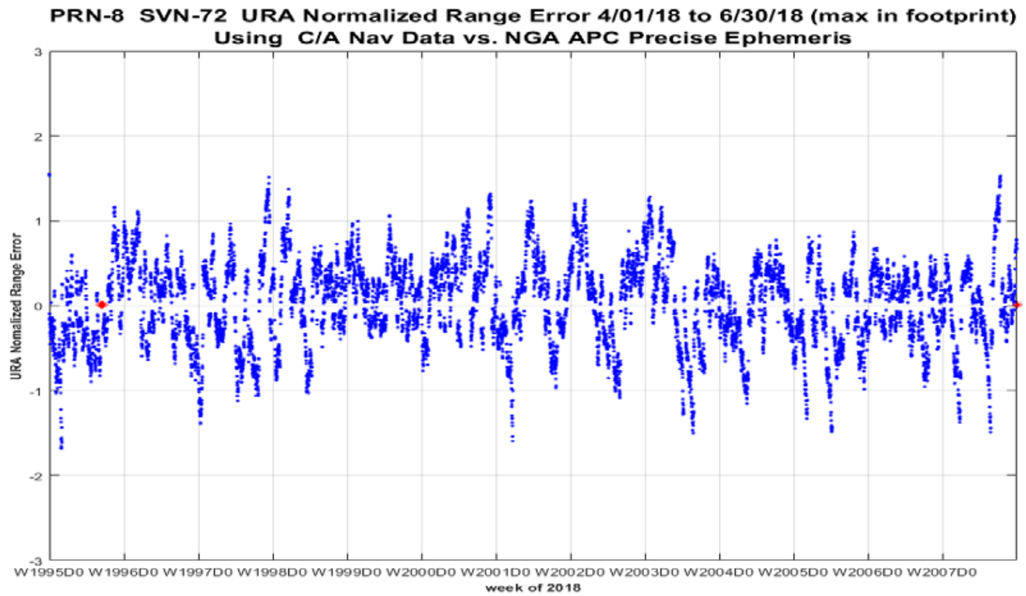


Figure 11-129 Timeline of IAURA Normalized Range Error PRN-8 (SVN-72) Using L2C CNAV Data

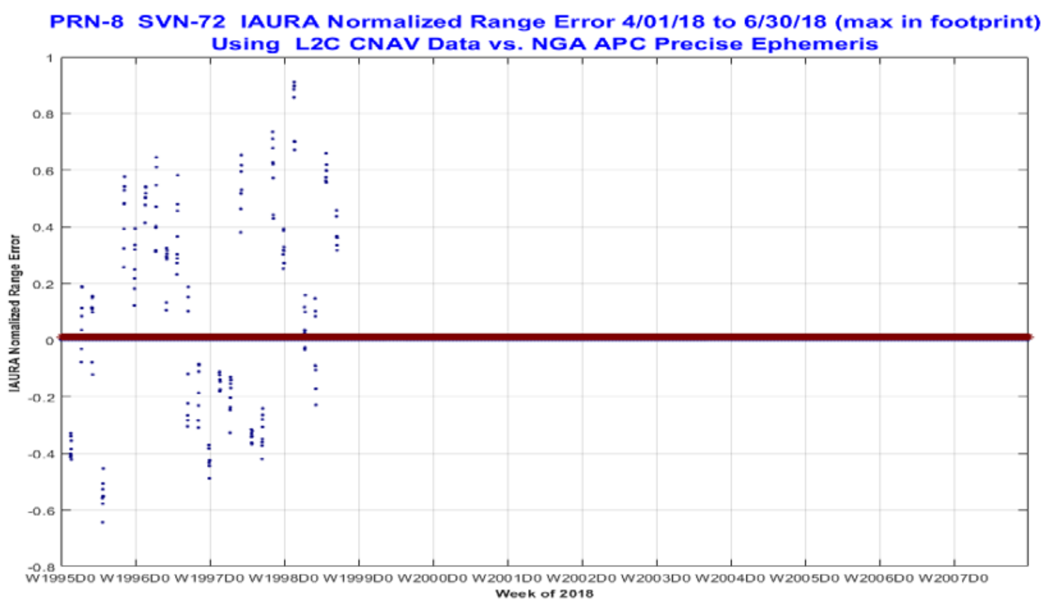


Figure 11-130 Timeline of URA Normalized Range Error PRN-9 (SVN-68) Using C/A Nav Data

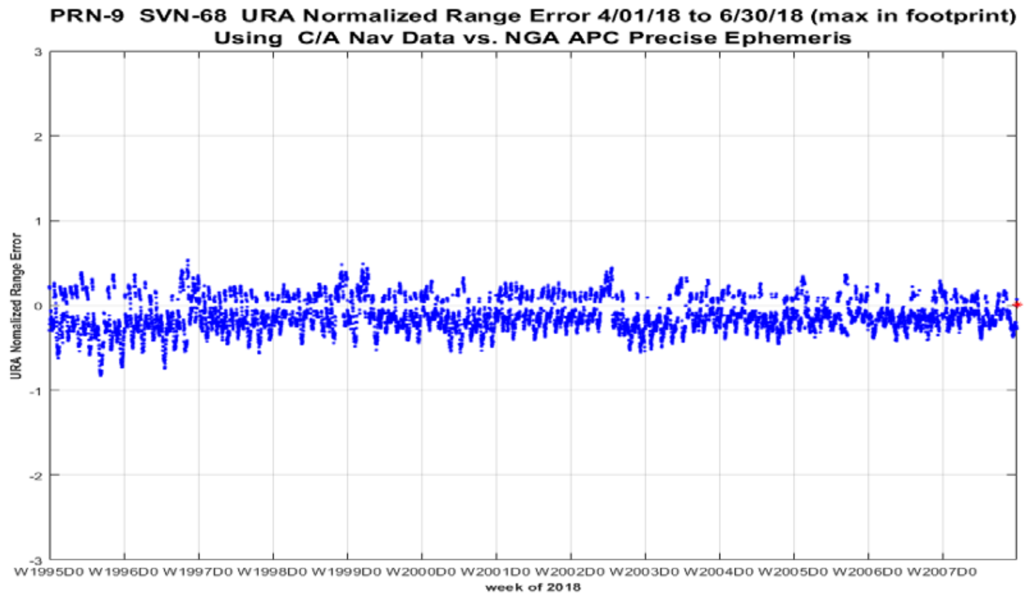


Figure 11-131 Timeline of IAURA Normalized Range Error PRN-9 (SVN-68) Using L2C CNAV Data

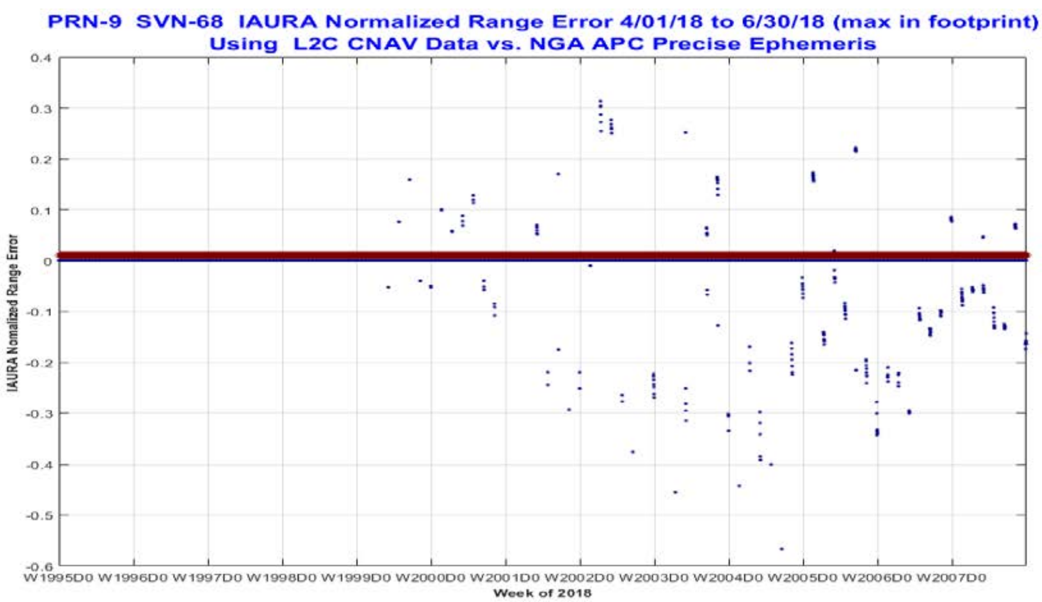


Figure 11-132 Timeline of URA Normalized Range Error PRN-10 (SVN-73) Using C/A Nav Data

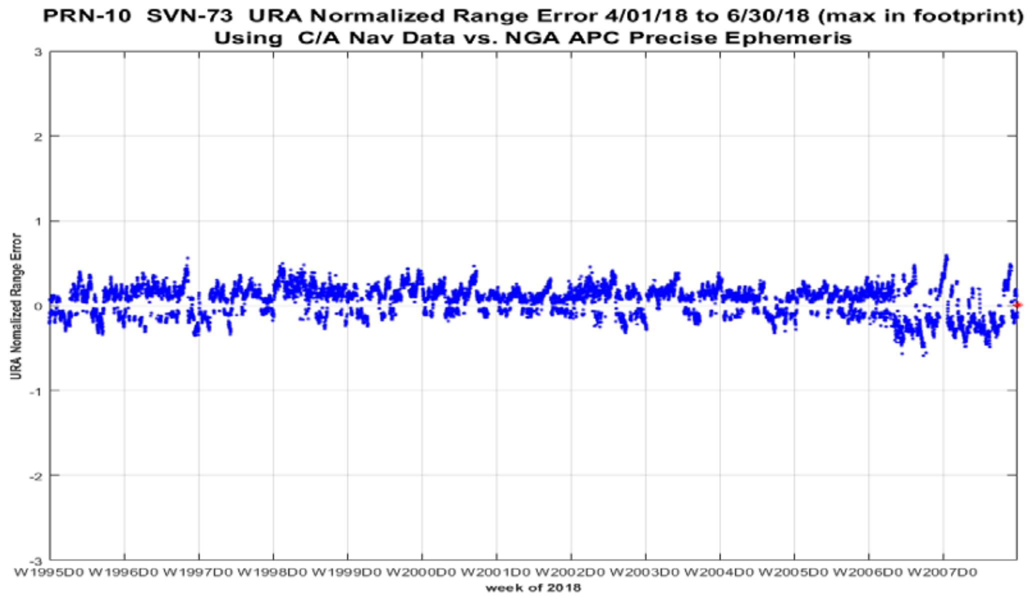


Figure 11-133 Timeline of IAURA Normalized Range Error PRN-10 (SVN-73) Using L2C CNAV Data

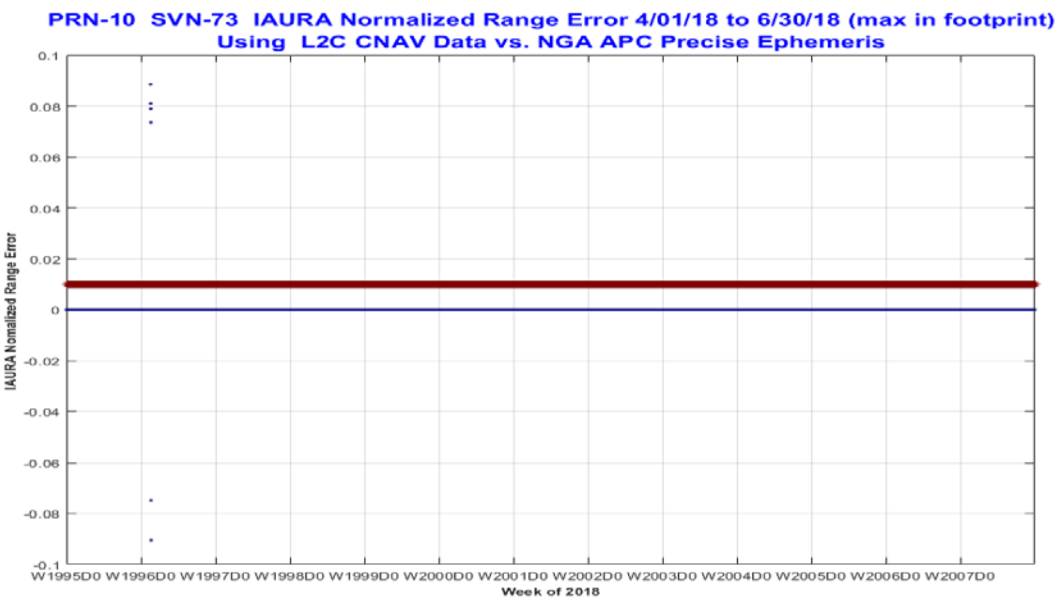


Figure 11-134 Timeline of URA Normalized Range Error PRN-11 (SVN-46) Using C/A Nav Data

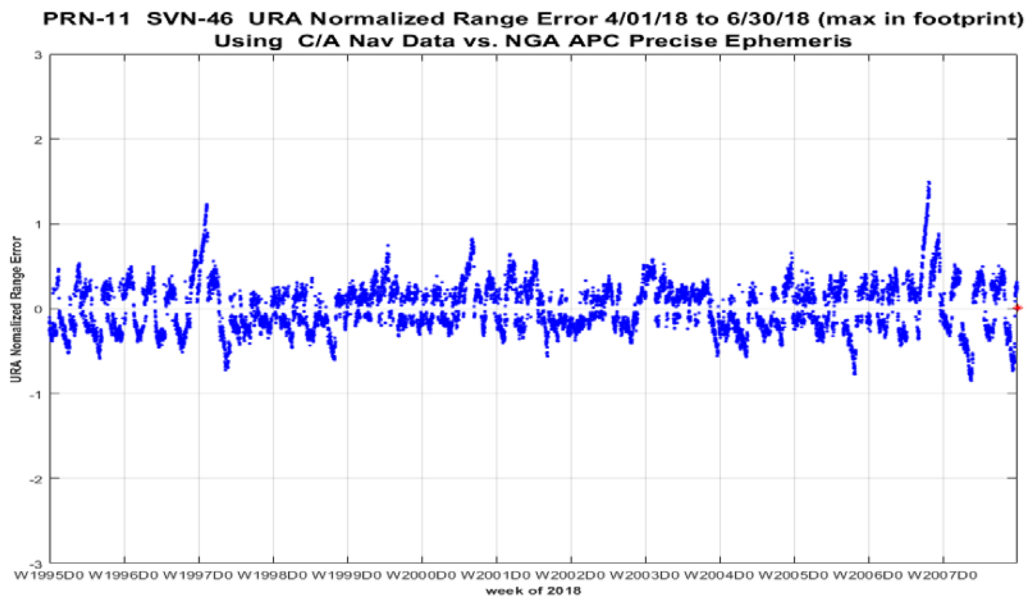


Figure 11-135 Timeline of URA Normalized Range Error PRN-12 (SVN-58) Using C/A Nav Data

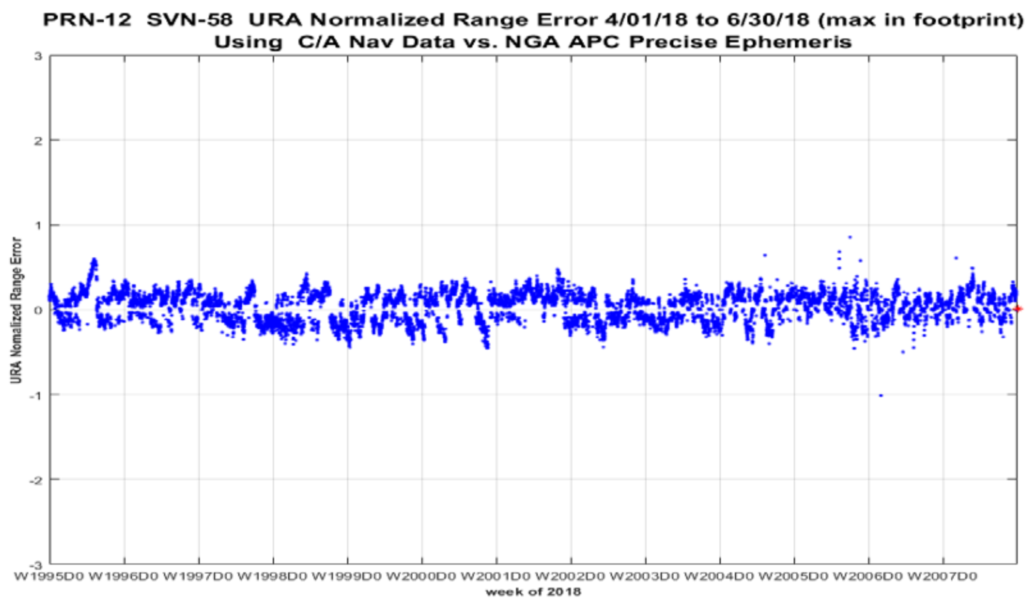


Figure 11-136 Timeline of IAURA Normalized Range Error PRN-12 (SVN-58) Using L2C CNAV Data

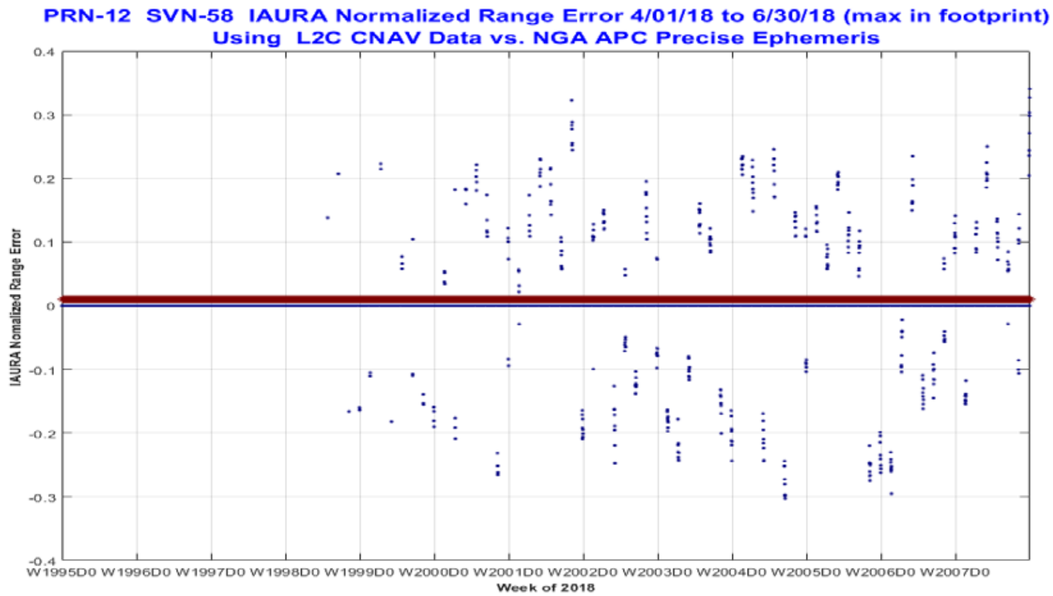


Figure 11-137 Timeline of URA Normalized Range Error PRN-13 (SVN-43) Using C/A Nav Data

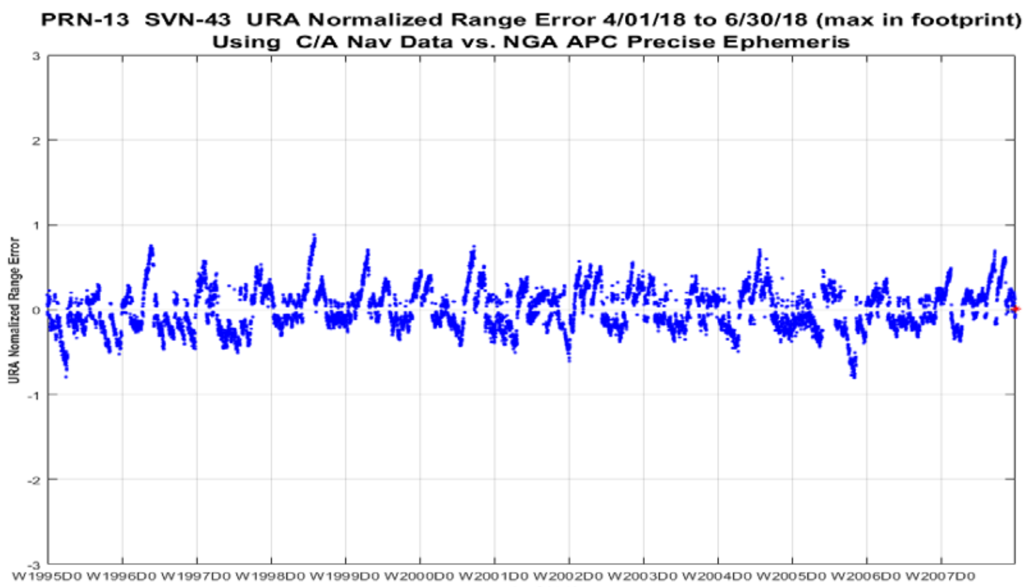


Figure 11-138 Timeline of URA Normalized Range Error PRN-14 (SVN-41) Using C/A Nav Data

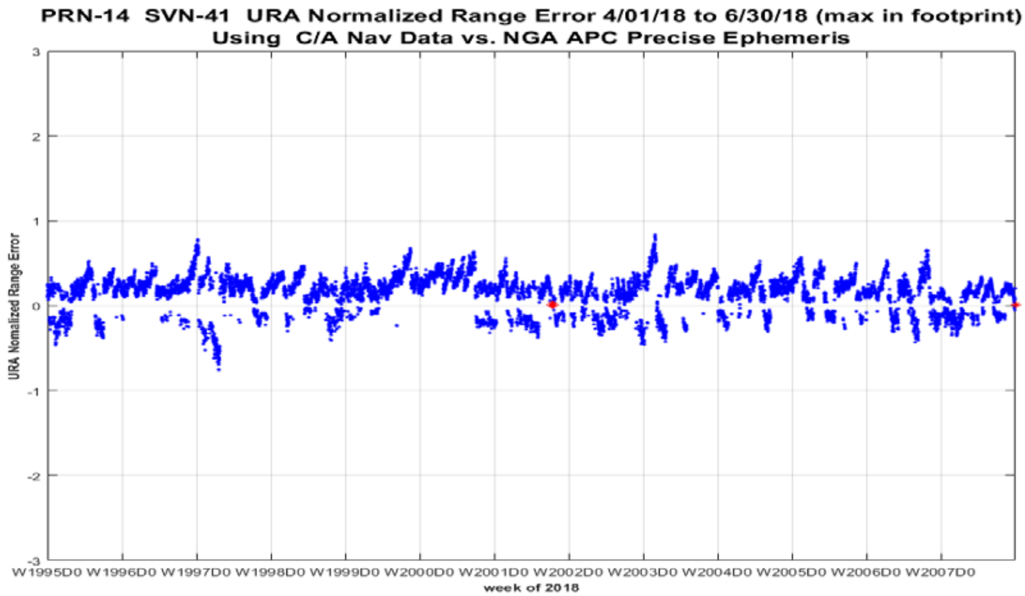


Figure 11-139 Timeline of URA Normalized Range Error PRN-15 (SVN-55) Using C/A Nav Data

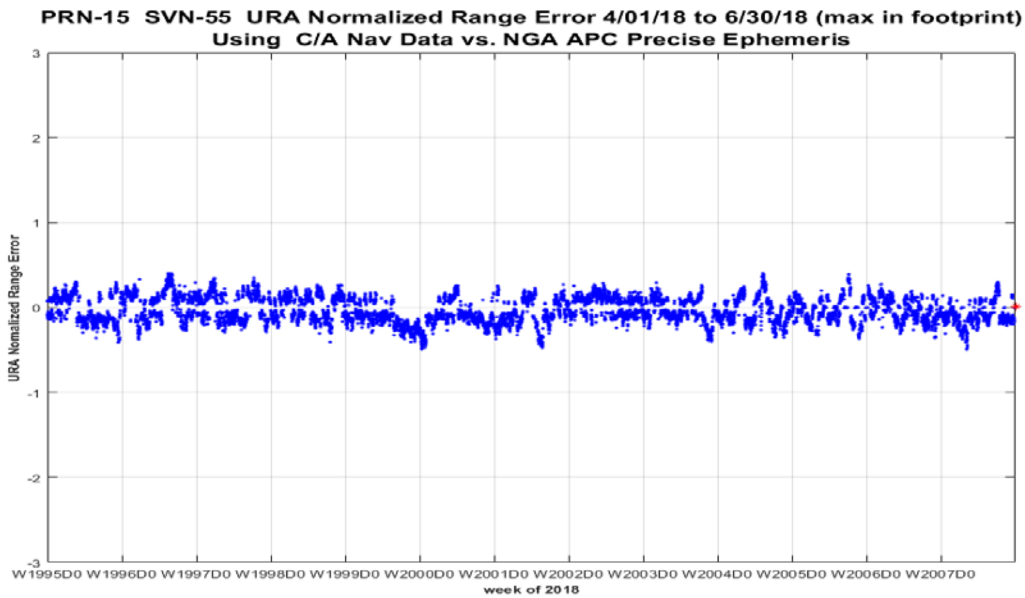


Figure 11-140 Timeline of IAURA Normalized Range Error PRN-15 (SVN-55) Using L2C CNAV Data

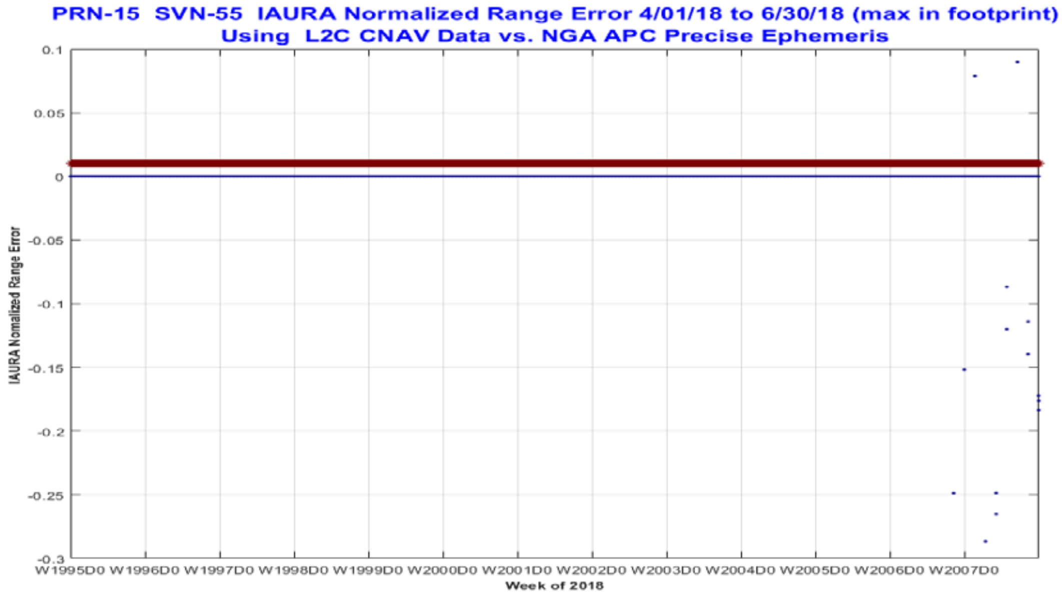


Figure 11-141 Timeline of URA Normalized Range Error PRN-16 (SVN-56) Using C/A Nav Data

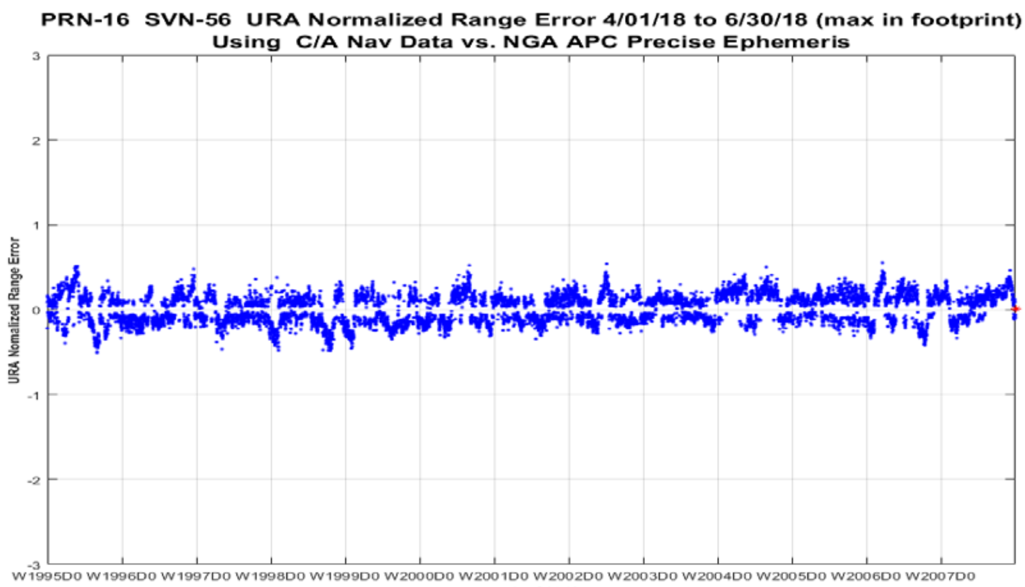


Figure 11-142 Timeline of URA Normalized Range Error PRN-17 (SVN-53) Using C/A Nav Data

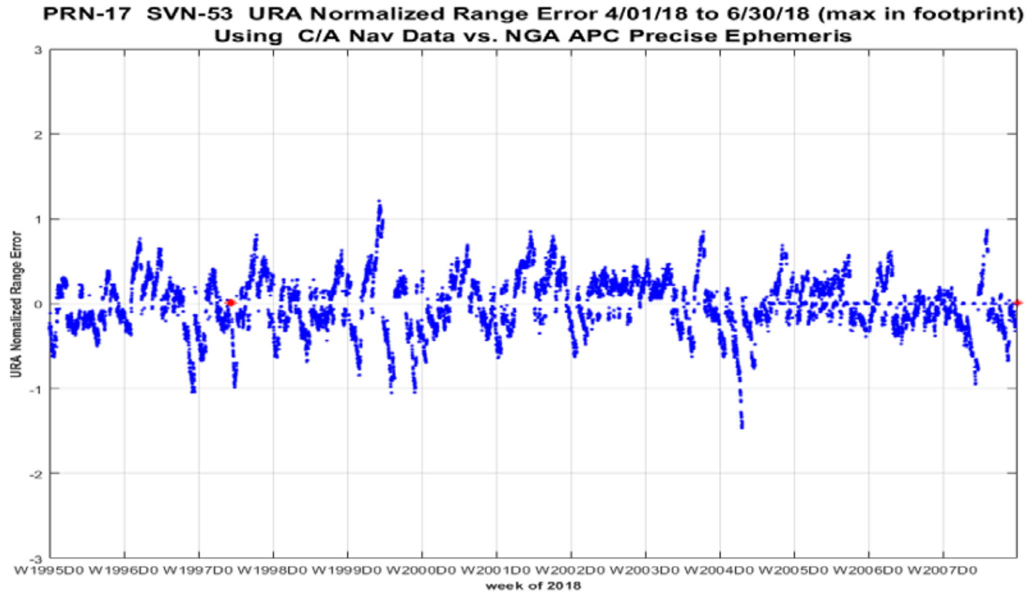


Figure 11-143 Timeline of IAURA Normalized Range Error PRN-17 (SVN-53) Using L2C CNAV Data

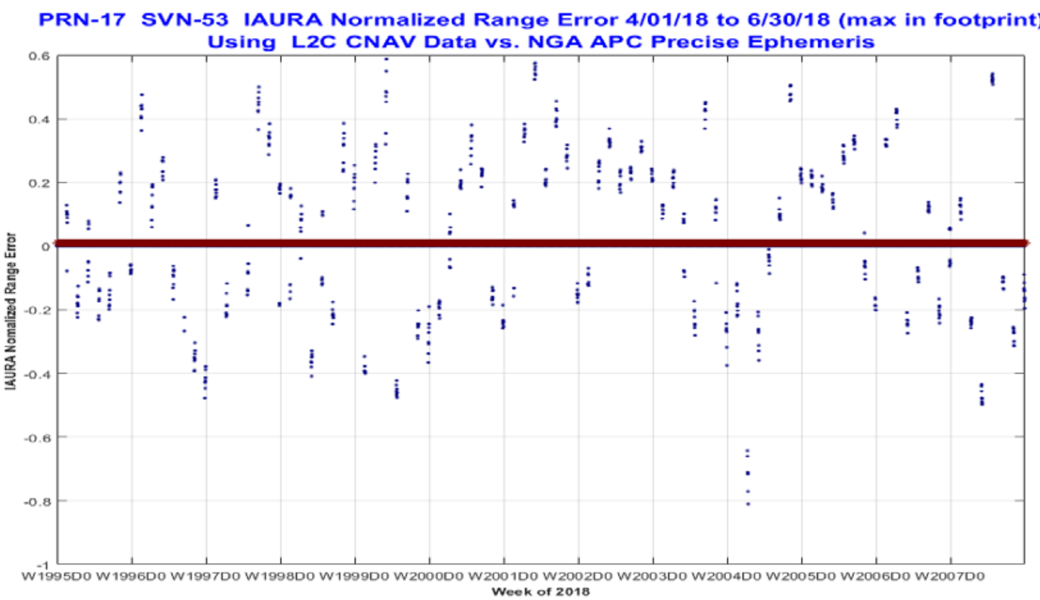


Figure 11-144 Timeline of URA Normalized Range Error PRN-18 (SVN-34) Using C/A Nav Data

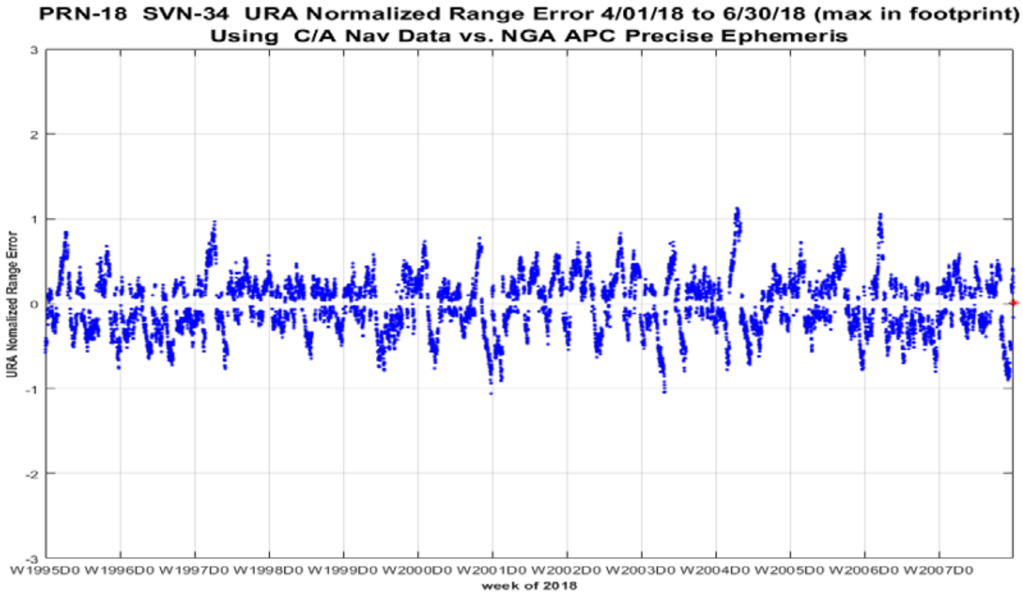


Figure 11-145 Timeline of URA Normalized Range Error PRN-19 (SVN-59) Using C/A Nav Data

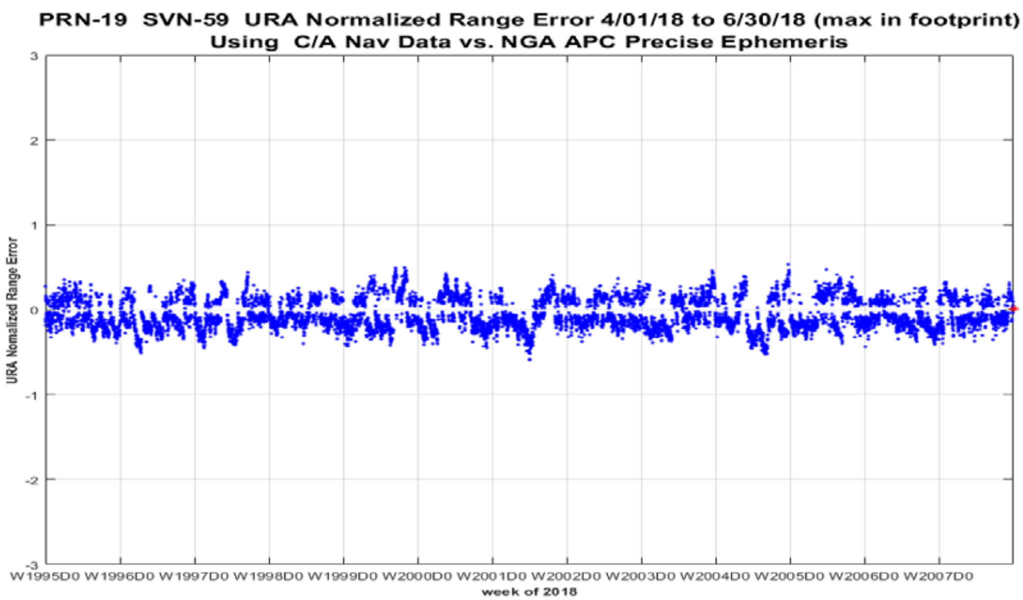


Figure 11-146 Timeline of URA Normalized Range Error PRN-20 (SVN-51) Using C/A Nav Data

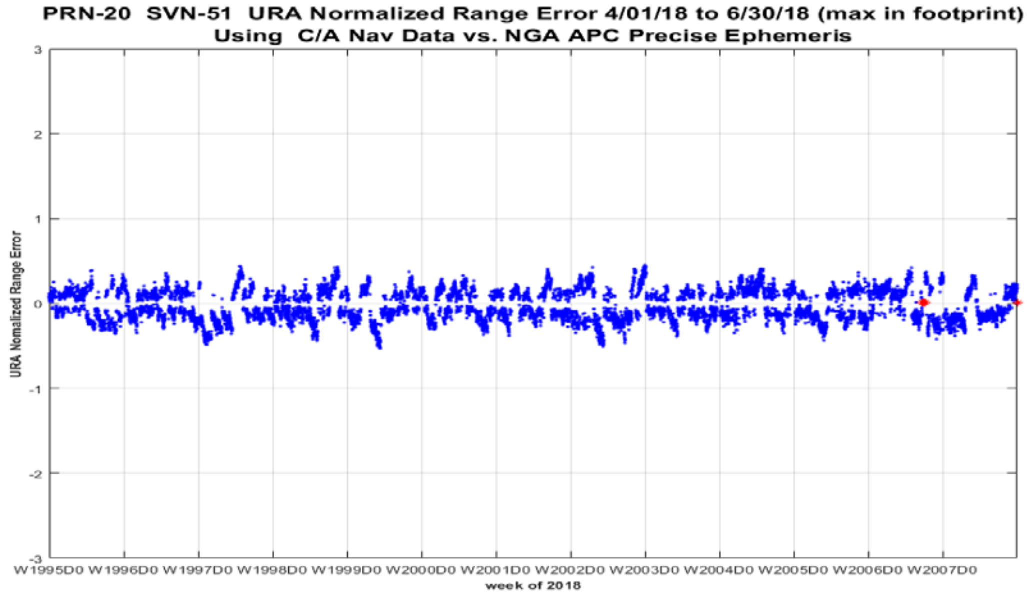


Figure 11-147 Timeline of URA Normalized Range Error PRN-21 (SVN-45) Using C/A Nav Data

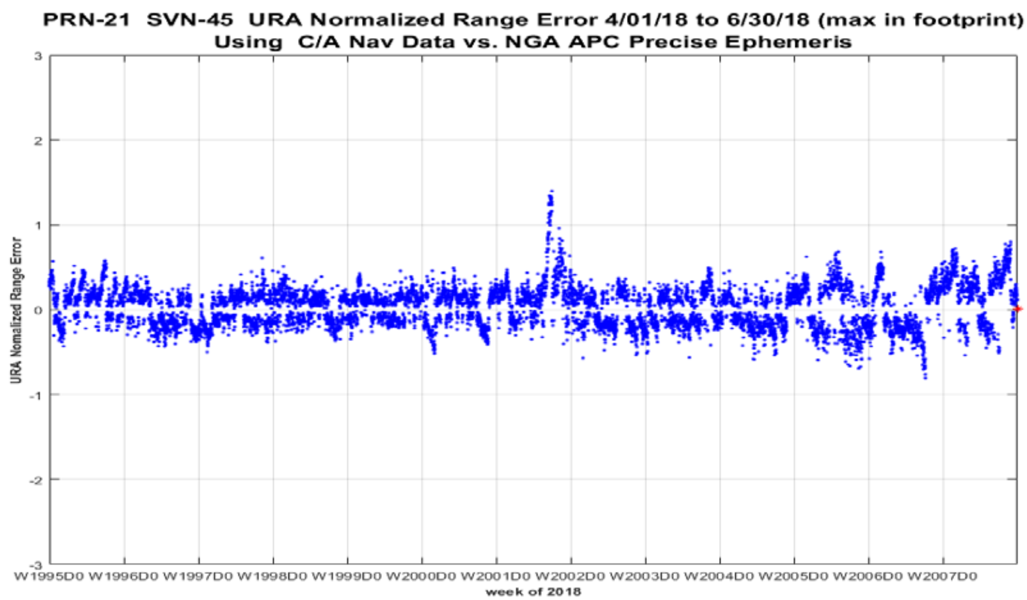


Figure 11-148 Timeline of URA Normalized Range Error PRN-22 (SVN-47) Using C/A Nav Data

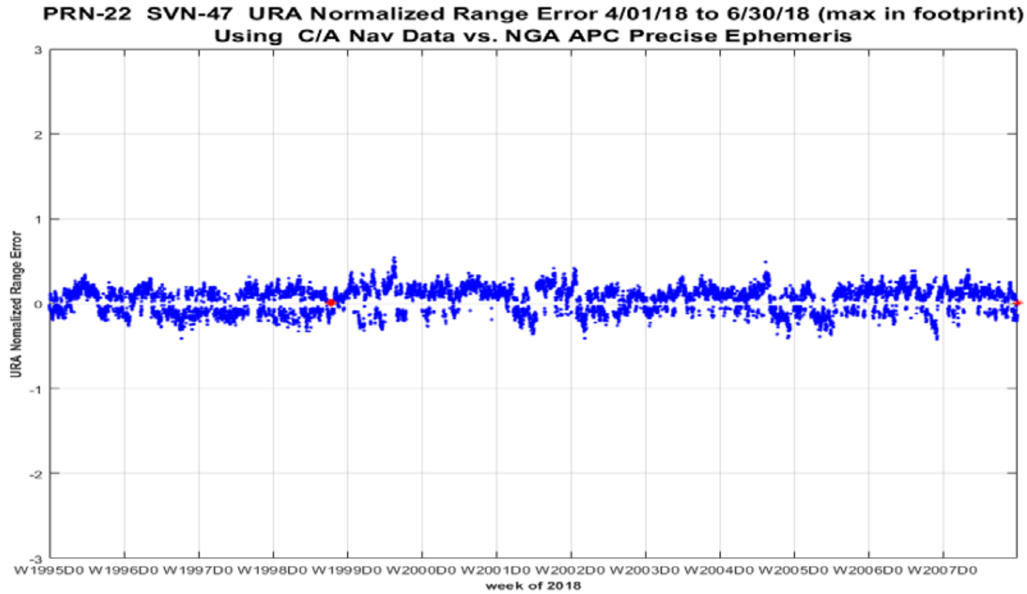


Figure 11-149 Timeline of URA Normalized Range Error PRN-23 (SVN-60) Using C/A Nav Data

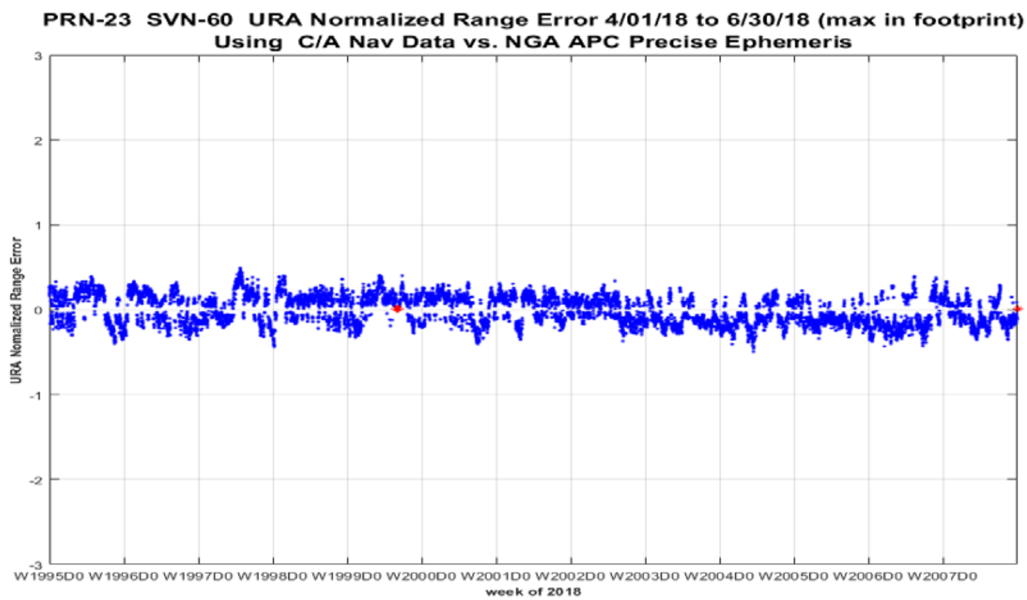


Figure 11-150 Timeline of URA Normalized Range Error PRN-24 (SVN-65) Using C/A Nav Data

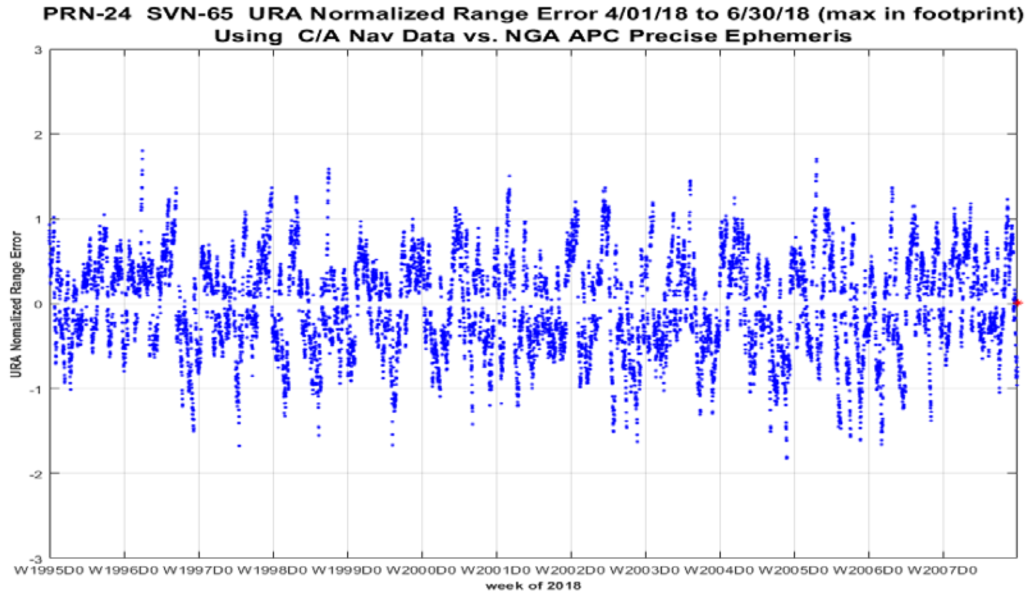


Figure 11-151 Timeline of IAURA Normalized Range Error PRN-24 (SVN-65) Using L2C CNAV Data

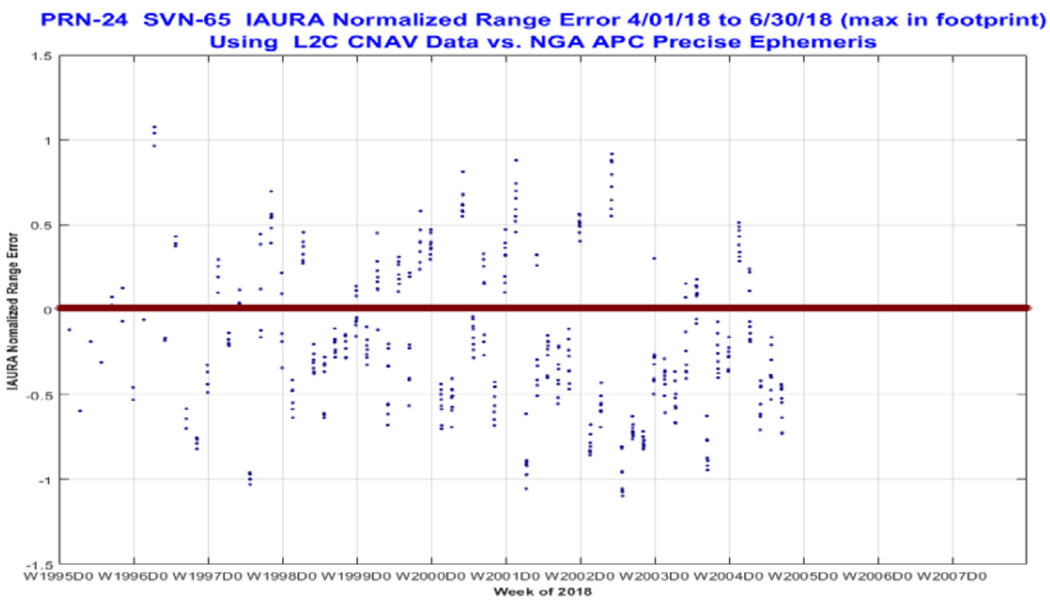


Figure 11-152 Timeline of URA Normalized Range Error PRN-25 (SVN-62) Using C/A Nav Data

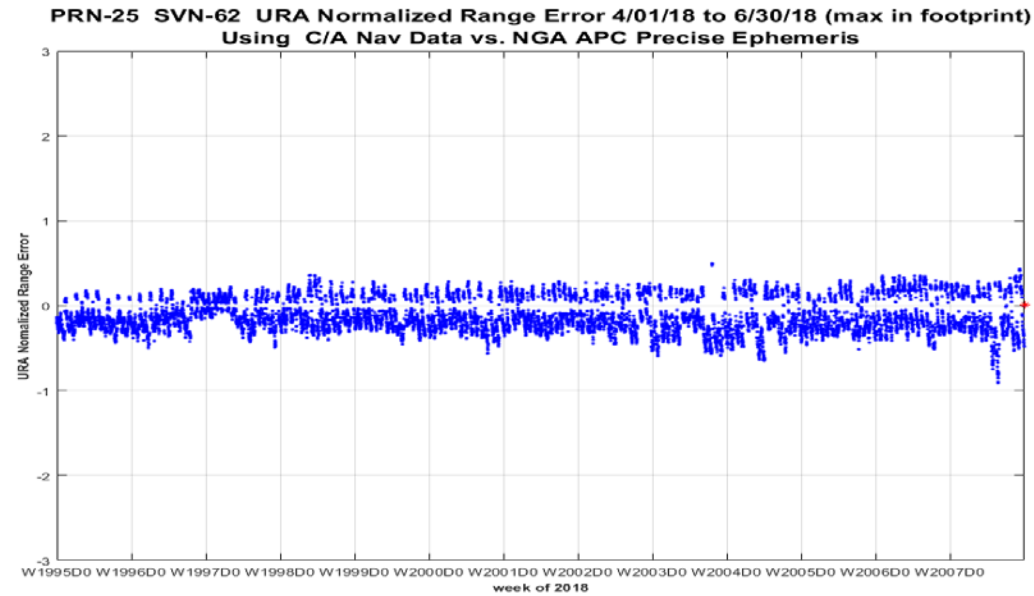


Figure 11-153 Timeline of IAURA Normalized Range Error PRN-25 (SVN-62) Using L2C CNAV Data

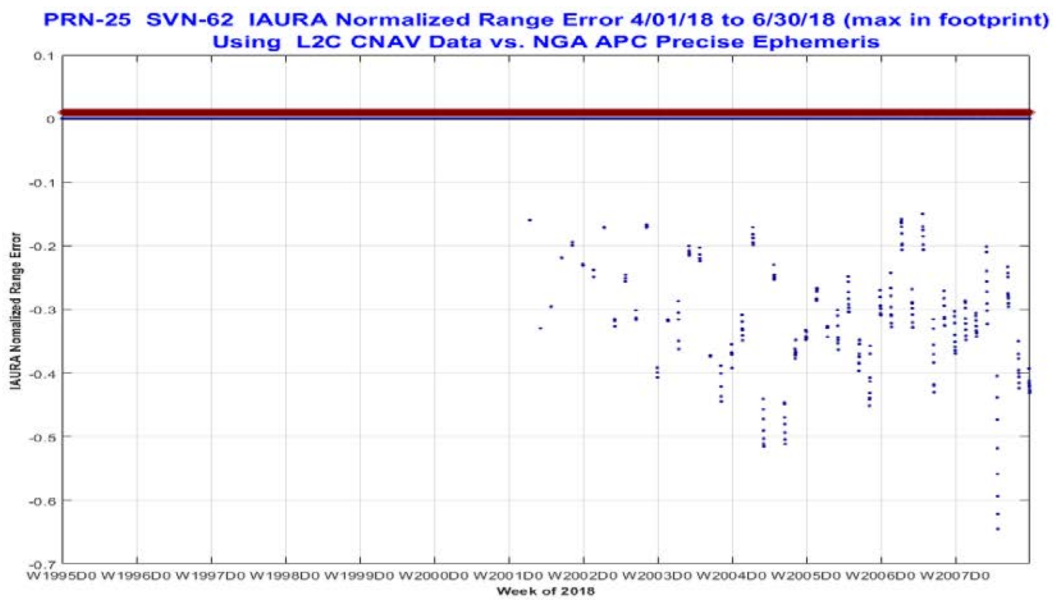


Figure 11-154 Timeline of URA Normalized Range Error PRN-26 (SVN-71) Using C/A Nav Data

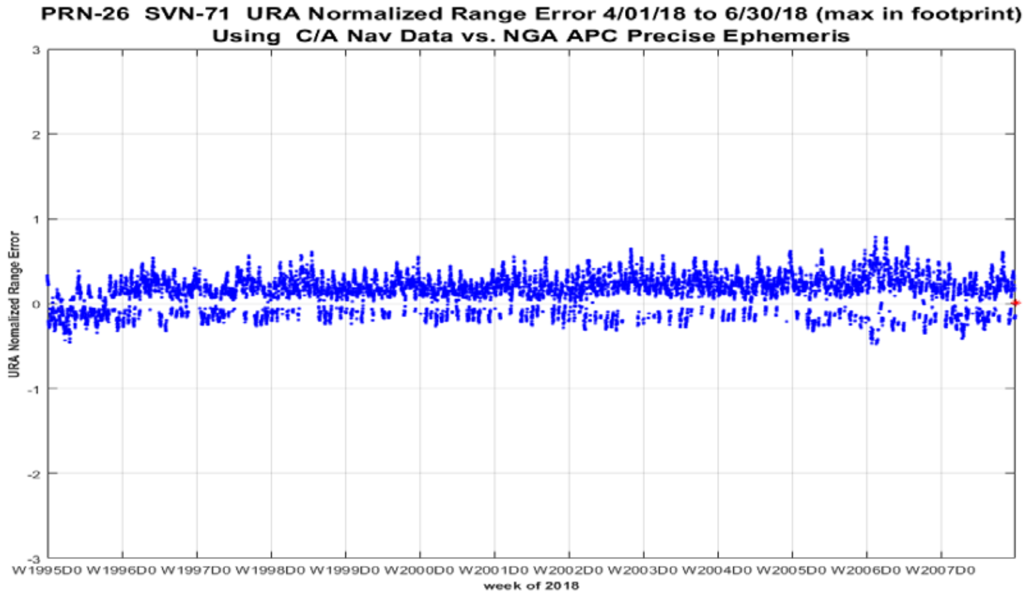


Figure 11-155 Timeline of URA Normalized Range Error PRN-27 (SVN-66) Using C/A Nav Data

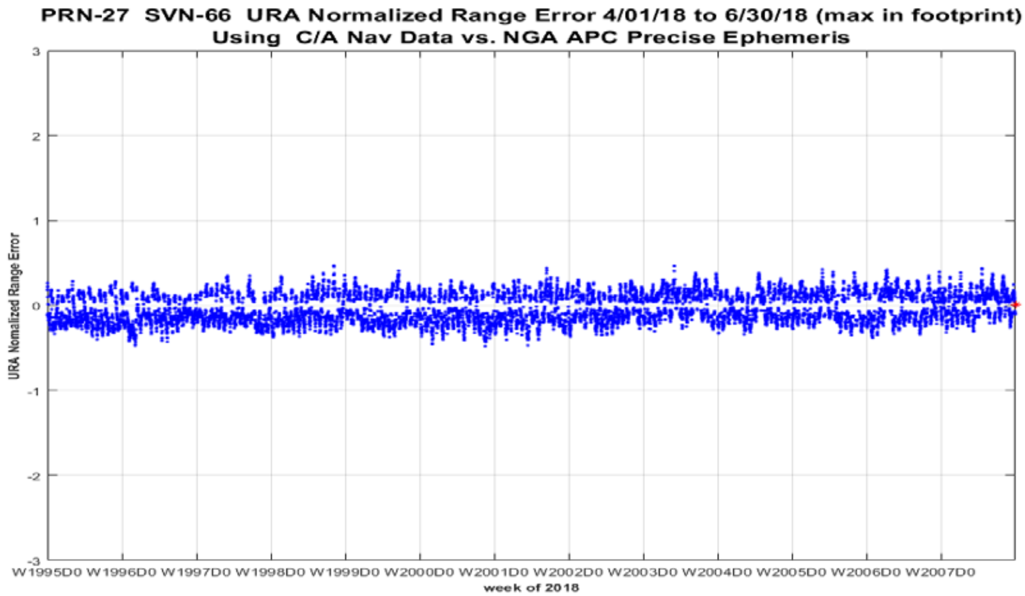


Figure 11-156 Timeline of URA Normalized Range Error PRN-28 (SVN-44) Using C/A Nav Data

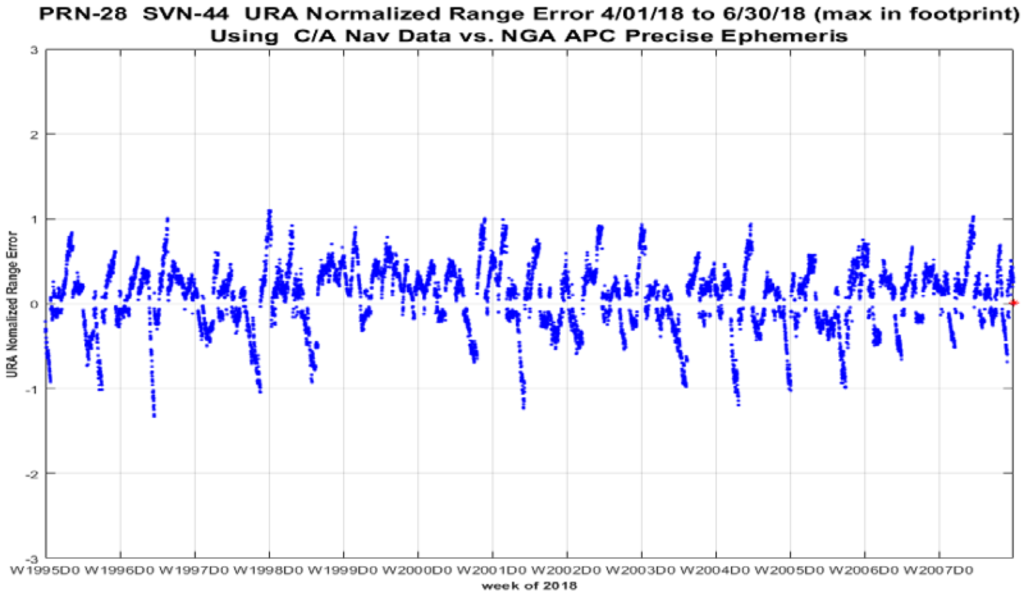


Figure 11-157 Timeline of URA Normalized Range Error PRN-29 (SVN-57) Using C/A Nav Data

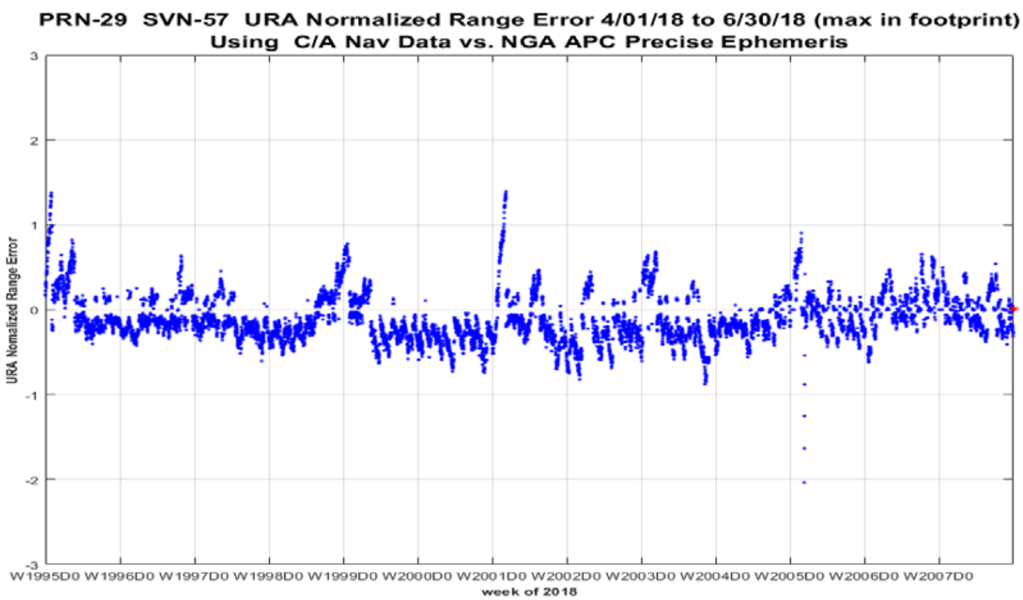


Figure 11-158 Timeline of IAURA Normalized Range Error PRN-29 (SVN-57) Using L2C CNAV Data

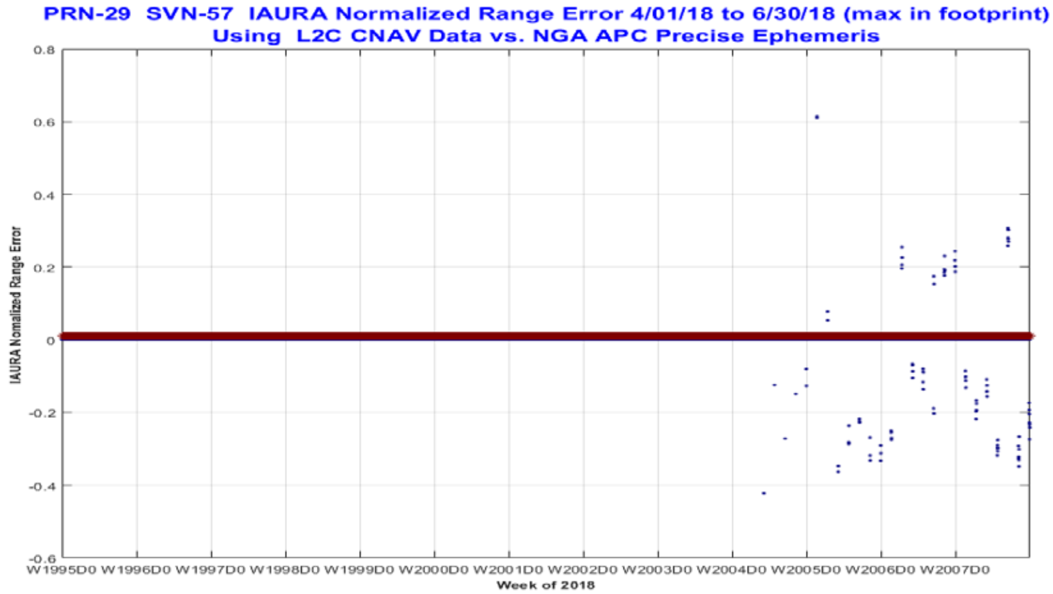


Figure 11-159 Timeline of URA Normalized Range Error PRN-30 (SVN-64) Using C/A Nav Data

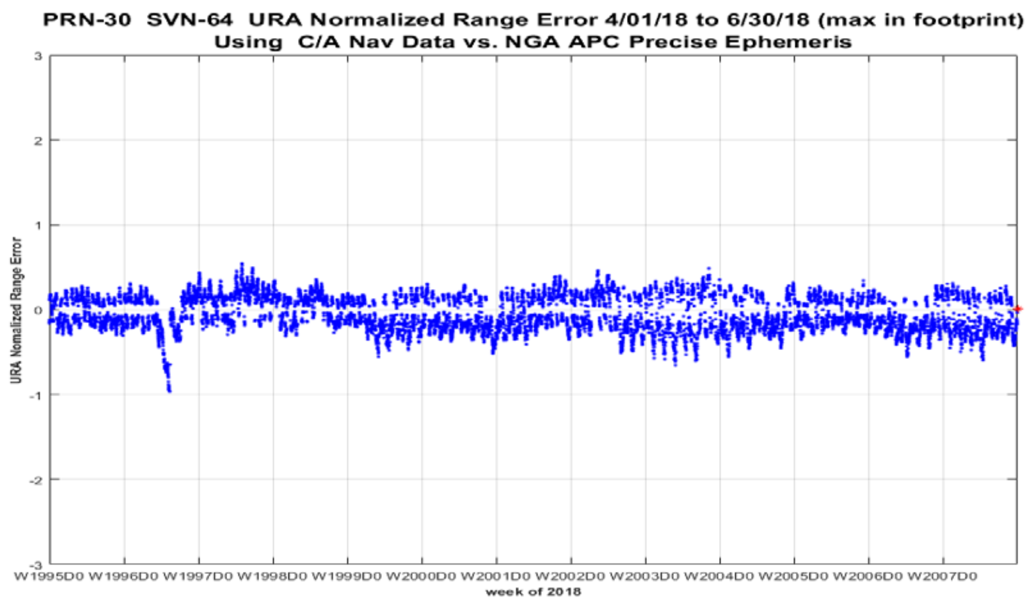


Figure 11-160 Timeline of IAURA Normalized Range Error PRN-30 (SVN-64) Using L2C CNAV Data

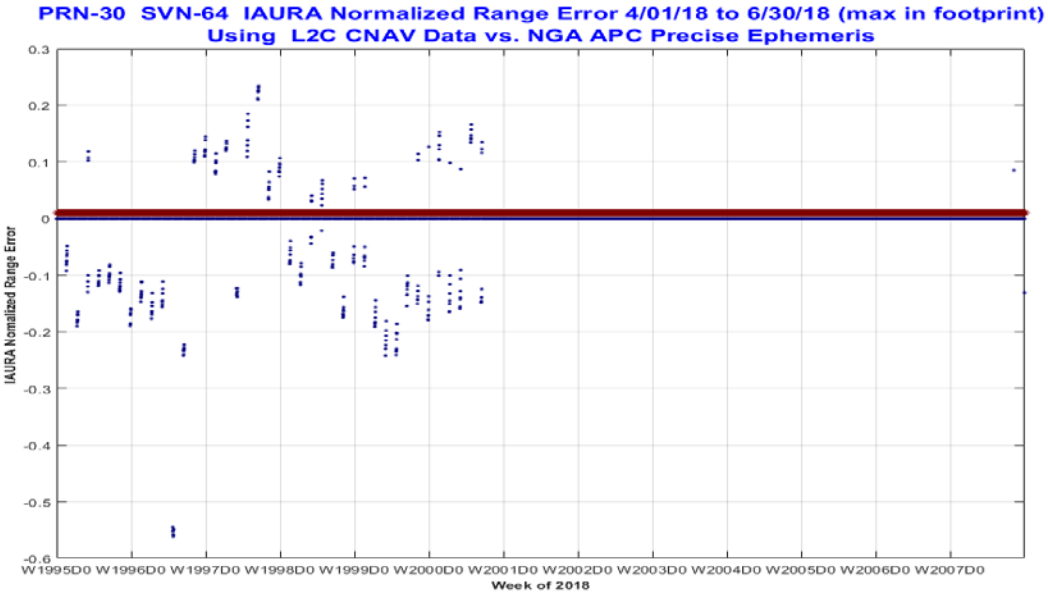


Figure 11-161 Timeline of URA Normalized Range Error PRN-31 (SVN-52) Using C/A Nav Data

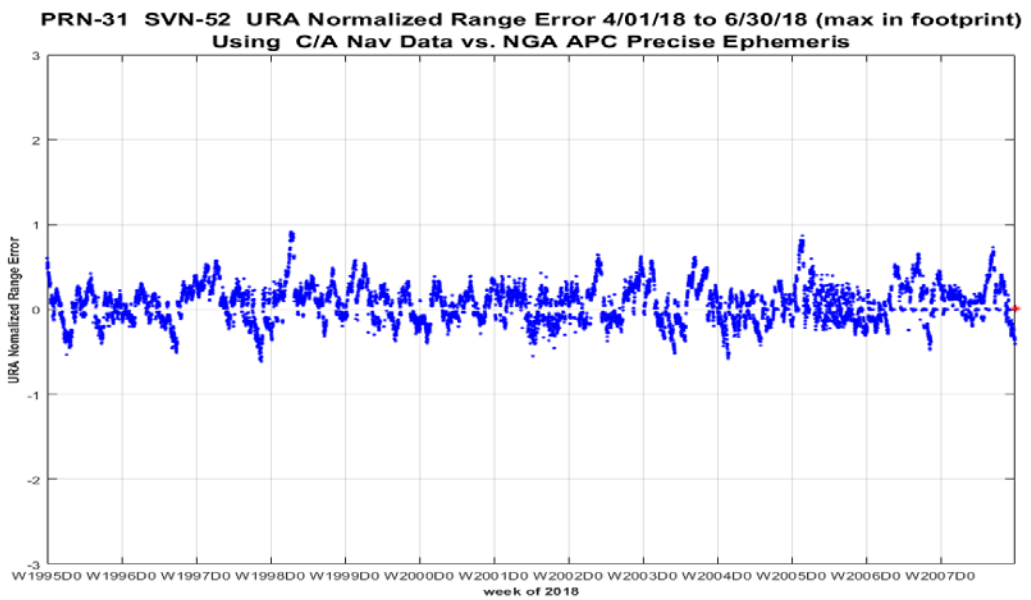


Figure 11-162 Timeline of URA Normalized Range Error PRN-32 (SVN-70) Using C/A Nav Data