GLOBAL POSITIONING SYSTEM (GPS) STANDARD POSITIONING SERVICE (SPS) PERFORMANCE ANALYSIS REPORT

Report #106

Reporting Period: April 01 to June 30, 2019

July 2019

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The Satellite Navigation Programs Branch (AJM-321) has tasked the Satellite Navigation Branch (ANG-E66) at the William J. Hughes Technical Center to document the GPS Standard Positioning Service (SPS) performance in quarterly GPS SPS Performance Analysis (PAN) Reports. The reports contain the analysis performed on data collected at 28 Wide Area Augmentation System (WAAS) Reference Stations. This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the GPS SPS Performance Standard (4^{th} Edition, dated September 2008).

This GPS SPS Performance Analysis Report #106 includes data collected from April 1 through June 30, 2019 reporting period. The next quarterly report will be issued October 31, 2019.

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

PDOP Availability Standard. This global availability is based on PDOP. Using the weekly almanac posted on the US Coast Guard navigation website, real-time broadcast satellite ephemeris, and summary NANUs, the coverage data for every 2° 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 was 99.9979%.

NANU Summary and Evaluation. This evaluation was achieved by reviewing the NANU reports issued between 1 April and 30 June 2019. Using this data, a set of statistics were computed that give a relative idea of constellation health for both the current and combined history of past quarters. For this quarter, 45 outages were reported in the NANU's. Seven outages were scheduled ahead of time, and 38 unscheduled NANUs occurred.

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

Accuracy Standard. Calculating the 24-hour 95% horizontal and vertical position error values verified the accuracy standards. The User Range Error standard was verified for each satellite from 24-hour accuracy values computed using data collected at the following six sites: Boston, Honolulu, Los Angeles, Miami, Merida, and Juneau. This data was also collected in 1-second samples. All sites achieved 100% reliability, meeting the SPS Standard. The maximum range error recorded was 13.040 meters on Satellite PRN 24. The SPS Standard states that the range error should never exceed 30 meters for less than 99.79% of the day for a worst-case point and 99.94%

globally. The maximum Root Mean Square (RMS) range error value of 2.470 meters was recorded on satellite PRN 21. The SPS Standard states that RMS User Range Error (URE) cannot exceed 6 meters in any 24-hour interval.

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

IGS Data Performance. The IGS is a voluntary federation of many worldwide agencies that pool resources and permanent Global Navigation Satellite System (GNSS) station data to generate precise GNSS products. During the evaluation period, the maximum 95% horizontal and vertical SPS errors were 50.1 meters and 50.1 meters, respectively, for most IGS sites.

RAIM Performance. RAIM is a technology developed to assess the integrity of GPS signals in a GPS receiver system. During the evaluation period, the minimum percentage of time in RNP 0.1 mode was 99.71% at Fairbanks. The minimum percent of time spent in RNP 0.3 mode was 100% at all sites. The maximum 99% HPL value was 141.54 meters at Cleveland.

The analysis performed on data collected between 01 April and 30 June 2019 showed that GPS performance met all SPS requirements that were evaluated.

TABLE OF CONTENTS

1. INTRODUCTION 1
1.1 Objective of GPS SPS Performance Analysis Report 1
1.2 Report Overview 2
1.3 Summary of Performance Requirements and Metrics 3
2. PDOP AVAILABILITY STANDARD 8
3. NANU SUMMARY AND ELEVATION 11
3.1 Satellite Outages from NANU Reports 12
3.2 Service Availability Standard 16
4. SERVICE RELIABILITY STANDARD 17
5. ACCURACY STANDARD 18
5.1 Position Accuracy 20
5.2 Time Transfer Accuracy 22
5.3 Range Domain Accuracy 23
6. SOLAR STORMS 29
7. IGS DATA 33
8. RAIM PERFORMANCE 37
8.1 Site Performance 38
8.2 RAIM Coverage 39
8.3 RAIM Airport Analysis 44
9. GPS TEST NOTAMs SUMMARY 50
9.1 GPS Test NOTAMs Issued 50
10. GPS BROADCAST ORBIT VERSUS NGA PRECISE ORBITS AND URA (IAURA) BOUNDING ANALYSIS 51
10.1 GPS Broadcast Orbit Accuracy Standard Deviation Plots 53
10.2 Broadcast Ephemeris vs. NGA Precise Data Availability Plots 55
10.3 Current GPS Constellation 55
10.4 URA Over-bounding Plots 56
10.5 Orbit Error Plots for All Satellites 57
10.6 QQ Plots of URA Normalized Error for All Satellites 82
10.7 Histogram Plots of H, A, C, and Range Error for All Satellites 88
10.8 Timeline of URA Normalized Range Error for All Satellites 111
Appendix A: Performance Summary 135
Appendix B: Geomagnetic Data 141
Appendix C:Glossary 143

LIST OF FIGURES

Figure 2-1 World GPS Maximum PDOP 10
Figure 2-2 Satellite Visibility Profile for Worst-Case Point....11
Figure 5-1 Global Vertical Error Histogram....21
Figure 5-2 Global Horizontal Error Histogram 22
Figure 5-3 Time Transfer Error 23
Figure 5-4 Distribution of Daily Max Range Errors....26
Figure 5-5 Distribution of Daily Max Range Rate Errors 27
Figure 5-6 Distribution of Daily Max Range Acceleration Errors 27
Figure 5-7 Range Error Histogram 28
Figure 5-8 Maximum Range Error per Satellite 28
Figure 5-9 Maximum Range Rate Error per Satellite 29
Figure 5-10 Maximum Range Acceleration Error per Satellite 29
Figure 6-1 K-Index for May 11, 2019 31
Figure 6-2 K-Index for May 14, 2019 31
Figure 6-3 K-Index for June 9, 2019 32
Figure 7-1 Selected IGS Site Locations....35
Figure 7-2 GPS SPS 95% Horizontal Accuracy Trends at Selected IGS Sites....36
Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites....37
Figure 8-1 RAIM RNP 0.1 Coverage 40
Figure 8-2 RAIM RNP 0.3 Coverage 41
Figure 8-3 RAIM World Wide Coverage Trend....42
Figure 8-4 RAIM RNP Coverage Trend for WAAS NPA Service Area....43
Figure 8-5 RAIM RNP 0.1 Airport Availability....45
Figure 8-6 RAIM RNP 0.3 Airport Availability....46
Figure 8-7 RAIM RNP 0.1 Airport Outages....48
Figure 8-8 RAIM RNP 0.3 Airport Outages....49
Figure 10-1 GPS Broadcast Orbit Accuracy Standard Deviations Using C/A Nav Data 53
Figure 10-2 GPS Broadcast Orbit Accuracy Standard Deviations Using L2C CNAV Data 53
Figure 10-3 GPS Broadcast Orbit Error Means Using C/A Nav Data....54
Figure 10-4 GPS Broadcast Orbit Error Means Using L2C CNAV Data....54
Figure 10-5 Broadcast Ephemeris vs. NGA Precise Data Availability Plots....55
Figure 10-6 Current GPS Constellation....55
Figure 10-7 URA Over-bounding Using C/A Nav Data....56
Figure 10-8 IAURA Over-bounding Using L2C CNAV Data 57
Figure 10-9 Orbit Error PRN-1 (SVN-63) Using C/A Nav Data....57
Figure 10-10 Orbit Error PRN-1 (SVN-63) Using L2C CNAV Data....58
Figure 10-11 Orbit Error PRN-2 (SVN-61) Using C/A Nav Data....58
Figure 10-12 Orbit Error PRN-3 (SVN-69) Using C/A Nav Data....59
Figure 10-13 Orbit Error PRN-3 (SVN-69) Using L2C CNAV Data....59
Figure 10-14 Orbit Error PRN-5 (SVN-50) Using C/A Nav Data....60
Figure 10-15 Orbit Error PRN-5 (SVN-50) Using L2C CNAV Data....60
Figure 10-16 Orbit Error PRN-6 (SVN-67) Using C/A Nav Data....61
Figure 10-17 Orbit Error PRN-6 (SVN-67) Using L2C CNAV Data....61
Figure 10-18 Orbit Error PRN-7 (SVN-48) Using C/A Nav Data....62
Figure 10-19 Orbit Error PRN-7 (SVN-48) Using L2C CNAV Data....62
Figure 10-20 Orbit Error PRN-8 (SVN-72) Using C/A Nav Data....63
Figure 10-21 Orbit Error PRN-8 (SVN-72) Using L2C CNAV Data....63
Figure 10-22 Orbit Error PRN-9 (SVN-68) Using C/A Nav Data....64
Figure 10-23 Orbit Error PRN-9 (SVN-68) Using L2C CNAV Data....64
Figure 10-24 Orbit Error PRN-10 (SVN-73) Using C/A Nav Data....65
Figure 10-25 Orbit Error PRN-10 (SVN-73) Using L2C CNAV Data 65
Figure 10-26 Orbit Error PRN-11 (SVN-46) Using C/A Nav Data....66
Figure 10-27 Orbit Error PRN-12 (SVN-58) Using C/A Nav Data....66

Figure 10-28 Orbit Error PRN-12 (SVN-58) Using L2C CNAV Data 67
Figure 10-29 Orbit Error PRN-13 (SVN-43) Using C/A Nav Data.....67
Figure 10-30 Orbit Error PRN-14 (SVN-41) Using C/A Nav Data.....68
Figure 10-31 Orbit Error PRN-15 (SVN-55) Using C/A Nav Data.....68
Figure 10-32 Orbit Error PRN-15 (SVN-55) Using L2C CNAV Data 69
Figure 10-33 Orbit Error PRN-16 (SVN-56) Using C/A Nav Data.....69
Figure 10-34 Orbit Error PRN-17 (SVN-53) Using C/A Nav Data.....70
Figure 10-35 Orbit Error PRN-17 (SVN-53) Using L2C CNAV Data 70
Figure 10-36 Orbit Error PRN-18 (SVN-34) Using C/A Nav Data.....71
Figure 10-37 Orbit Error PRN-19 (SVN-59) Using C/A Nav Data.....71
Figure 10-38 Orbit Error PRN-20 (SVN-51) Using C/A Nav Data.....72
Figure 10-39 Orbit Error PRN-21 (SVN-45) Using C/A Nav Data.....72
Figure 10-40 Orbit Error PRN-22 (SVN-47) Using C/A Nav Data.....73
Figure 10-41 Orbit Error PRN-23 (SVN-60) Using C/A Nav Data.....73
Figure 10-42 Orbit Error PRN-24 (SVN-65) Using C/A Nav Data.....74
Figure 10-43 Orbit Error PRN-24 (SVN-65) Using L2C CNAV Data 74
Figure 10-44 Orbit Error PRN-25 (SVN-62) Using C/A Nav Data.....75
Figure 10-45 Orbit Error PRN-25 (SVN-62) Using L2C CNAV Data 75
Figure 10-46 Orbit Error PRN-26 (SVN-71) Using C/A Nav Data.....76
Figure 10-47 Orbit Error PRN-26 (SVN-71) Using L2C CNAV Data 76
Figure 10-48 Orbit Error PRN-27 (SVN-66) Using C/A Nav Data.....77
Figure 10-49 Orbit Error PRN-27 (SVN-66) Using L2C CNAV Data 77
Figure 10-50 Orbit Error PRN-28 (SVN-44) Using C/A Nav Data.....78
Figure 10-51 Orbit Error PRN-29 (SVN-57) Using C/A Nav Data.....78
Figure 10-52 Orbit Error PRN-29 (SVN-57) Using L2C CNAV Data 79
Figure 10-53 Orbit Error PRN-30 (SVN-64) Using C/A Nav Data.....79
Figure 10-54 Orbit Error PRN-30 (SVN-64) Using L2C CNAV Data 80
Figure 10-55 Orbit Error PRN-31 (SVN-52) Using C/A Nav Data.....80
Figure 10-56 Orbit Error PRN-31 (SVN-52) Using L2C CNAV Data 81
Figure 10-57 Orbit Error PRN-32 (SVN-70) Using C/A Nav Data.....81
Figure 10-58 Orbit Error PRN-32 (SVN-70) Using L2C CNAV Data 82
Figure 10-59 QQ Plots of Range Error PRNs 1 to 5 Using C/A Nav Data 82
Figure 10-60 QQ Plots of Range Error PRNs 6 to 9 Using C/A Nav Data 83
Figure 10-61 QQ Plots of Range Error PRNs 10 to 13 Using C/A Nav Data 83
Figure 10-62 QQ Plots of Range Error PRNs 14 to 17 Using C/A Nav Data 84
Figure 10-63 QQ Plots of Range Error PRNs 18 to 21 Using C/A Nav Data 84
Figure 10-64 QQ Plots of Range Error PRNs 22 to 25 Using C/A Nav Data 85
Figure 10-65 QQ Plots of Range Error PRNs 26 to 29 Using C/A Nav Data 85
Figure 10-66 QQ Plots of Range Error PRNs 30 to 32 Using C/A Nav Data 86
Figure 10-67 QQ Plots of Range Error PRNs 1, 3, 5, and 6 Using L2C CNAV Data.....86
Figure 10-68 QQ Plots of Range Error PRNs 7, 8, 9, and 12 Using L2C CNAV Data.....87
Figure 10-69 QQ Plots of Range Error PRNs 15, 17, 24 and 25 Using L2C CNAV Data.....87
Figure 10-70 QQ Plots of Range Error PRNs 26, 29, and 30 Using L2C CNAV Data.....88
Figure 10-71 Histograms of H, A, C, and Range Error PRN-1 (SVN-63) Using C/A Nav Data 88
Figure 10-72 Histograms of H, A, C, and Range Error PRN-1 (SVN-63) Using L2C CNAV Data 89
Figure 10-73 Histograms of H, A, C, and Range Error PRN-2 (SVN-61) Using C/A Nav Data 89
Figure 10-74 Histograms of H, A, C, and Range Error PRN-3 (SVN-69) Using C/A Nav Data 90
Figure 10-75 Histograms of H, A, C, and Range Error PRN-3 (SVN-69) Using L2C CNAV Data 90
Figure 10-76 Histograms of H, A, C, and Range Error PRN-5 (SVN-50) Using C/A Nav Data 91
Figure 10-77 Histograms of H, A, C, and Range Error PRN-5 (SVN-50) Using L2C CNAV Data 91
Figure 10-78 Histograms of H, A, C, and Range Error PRN-6 (SVN-67) Using C/A Nav Data 92
Figure 10-79 Histograms of H, A, C, and Range Error PRN-6 (SVN-67) Using L2C CNAV Data 92
Figure 10-80 Histograms of H, A, C, and Range Error PRN-7 (SVN-48) Using C/A Nav Data 93
Figure 10-81 Histograms of H, A, C, and Range Error PRN-7 (SVN-48) Using L2C CNAV Data 93
Figure 10-82 Histograms of H, A, C, and Range Error PRN-8 (SVN-72) Using C/A Nav Data 94
Figure 10-83 Histograms of H, A, C, and Range Error PRN-8 (SVN-72) Using L2C CNAV Data 94

Figure 10-84 Histograms of H, A, C, and Range Error PRN-9 (SVN-68) Using C/A Nav Data 95
Figure 10-85 Histograms of H, A, C, and Range Error PRN-9 (SVN-68) Using L2C CNAV Data 95
Figure 10-86 Histograms of H, A, C, and Range Error PRN-10 (SVN-73) Using C/A Nav Data 96
Figure 10-87 Histograms of H, A, C, and Range Error PRN-11 (SVN-46) Using C/A Nav Data 96
Figure 10-88 Histograms of H, A, C, and Range Error PRN-12 (SVN-58) Using C/A Nav Data 97
Figure 10-89 Histograms of H, A, C, and Range Error PRN-12 (SVN-58) Using L2C CNAV Data 97
Figure 10-90 Histograms of H, A, C, and Range Error PRN-13 (SVN-43) Using C/A Nav Data 98
Figure 10-91 Histograms of H, A, C, and Range Error PRN-14 (SVN-41) Using C/A Nav Data 98
Figure 10-92 Histograms of H, A, C, and Range Error PRN-15 (SVN-55) Using C/A Nav Data 99
Figure 10-93 Histograms of H, A, C, and Range Error PRN-15 (SVN-55) Using L2C CNAV Data 99
Figure 10-94 Histograms of H, A, C, and Range Error PRN-16 (SVN-56) Using C/A Nav Data 100
Figure 10-95 Histograms of H, A, C, and Range Error PRN-17 (SVN-53) Using C/A Nav Data 100
Figure 10-96 Histograms of H, A, C, and Range Error PRN-17 (SVN-53) Using L2C CNAV Data 101
Figure 10-97 Histograms of H, A, C, and Range Error PRN-18 (SVN-34) Using C/A Nav Data 101
Figure 10-98 Histograms of H, A, C, and Range Error PRN-19 (SVN-59) Using C/A Nav Data 102
Figure 10-99 Histograms of H, A, C, and Range Error PRN-20 (SVN-51) Using C/A Nav Data 102
Figure 10-100 Histograms of H, A, C, and Range Error PRN-21 (SVN-45) Using C/A Nav Data 103
Figure 10-101 Histograms of H, A, C, and Range Error PRN-22 (SVN-47) Using C/A Nav Data 103
Figure 10-102 Histograms of H, A, C, and Range Error PRN-23 (SVN-60) Using C/A Nav Data 104
Figure 10-103 Histograms of H, A, C, and Range Error PRN-24 (SVN-65) Using C/A Nav Data 104
Figure 10-104 Histograms of H, A, C, and Range Error PRN-24 (SVN-65) Using L2C CNAV Data 105
Figure 10-105 Histograms of H, A, C, and Range Error PRN-25 (SVN-62) Using C/A Nav Data 105
Figure 10-106 Histograms of H, A, C, and Range Error PRN-25 (SVN-62) Using L2C CNAV Data 106
Figure 10-107 Histograms of H, A, C, and Range Error PRN-26 (SVN-71) Using C/A Nav Data 106
Figure 10-108 Histograms of H, A, C, and Range Error PRN-26 (SVN-71) Using L2C CNAV Data 107
Figure 10-109 Histograms of H, A, C, and Range Error PRN-27 (SVN-66) Using C/A Nav Data 107
Figure 10-110 Histograms of H, A, C, and Range Error PRN-28 (SVN-44) Using C/A Nav Data 108
Figure 10-111 Histograms of H, A, C, and Range Error PRN-29 (SVN-57) Using C/A Nav Data 108
Figure 10-112 Histograms of H, A, C, and Range Error PRN-29 (SVN-57) Using L2C CNAV Data 109
Figure 10-113 Histograms of H, A, C, and Range Error PRN-30 (SVN-64) Using C/A Nav Data 109
Figure 10-114 Histograms of H, A, C, and Range Error PRN-30 (SVN-64) Using L2C CNAV Data 110
Figure 10-115 Histograms of H, A, C, and Range Error PRN-31 (SVN-52) Using C/A Nav Data 110
Figure 10-116 Histograms of H, A, C, and Range Error PRN-32 (SVN-70) Using C/A Nav Data 111
Figure 10-117 Timeline of URA Normalized Range Error PRN-1 (SVN-63) Using C/A Nav Data 111
Figure 10-118 Timeline of IAURA Normalized Range Error PRN-1 (SVN-63) Using L2C CNAV Data 112
Figure 10-119 Timeline of URA Normalized Range Error PRN-2 (SVN-61) Using C/A Nav Data 112
Figure 10-120 Timeline of URA Normalized Range Error PRN-3 (SVN-69) Using C/A Nav Data 113
Figure 10-121 Timeline of IAURA Normalized Range Error PRN-3 (SVN-69) Using L2C CNAV Data 113
Figure 10-122 Timeline of URA Normalized Range Error PRN-5 (SVN-50) Using C/A Nav Data 114
Figure 10-123 Timeline of IAURA Normalized Range Error PRN-5 (SVN-50) Using L2C CNAV Data 114
Figure 10-124 Timeline of URA Normalized Range Error PRN-6 (SVN-67) Using C/A Nav Data 115
Figure 10-125 Timeline of IAURA Normalized Range Error PRN-6 (SVN-67) Using L2C CNAV Data 115
Figure 10-126 Timeline of URA Normalized Range Error PRN-7 (SVN-48) Using C/A Nav Data 116
Figure 10-127 Timeline of IAURA Normalized Range Error PRN-7 (SVN-48) Using L2C CNAV Data 116
Figure 10-128 Timeline of URA Normalized Range Error PRN-8 (SVN-72) Using C/A Nav Data 117
Figure 10-129 Timeline of IAURA Normalized Range Error PRN-8 (SVN-72) Using L2C CNAV Data 117
Figure 10-130 Timeline of URA Normalized Range Error PRN-9 (SVN-68) Using C/A Nav Data 118
Figure 10-131 Timeline of IAURA Normalized Range Error PRN-9 (SVN-68) Using L2C CNAV Data 118
Figure 10-132 Timeline of URA Normalized Range Error PRN-10 (SVN-73) Using C/A Nav Data 119
Figure 10-133 Timeline of URA Normalized Range Error PRN-11 (SVN-46) Using C/A Nav Data 119
Figure 10-134 Timeline of URA Normalized Range Error PRN-12 (SVN-58) Using C/A Nav Data 120
Figure 10-135 Timeline of IAURA Normalized Range Error PRN-12 (SVN-58) Using L2C CNAV Data 120
Figure 10-136 Timeline of URA Normalized Range Error PRN-13 (SVN-43) Using C/A Nav Data 121
Figure 10-137 Timeline of URA Normalized Range Error PRN-14 (SVN-41) Using C/A Nav Data 121
Figure 10-138 Timeline of URA Normalized Range Error PRN-15 (SVN-55) Using C/A Nav Data 122
Figure 10-139 Timeline of IAURA Normalized Range Error PRN-15 (SVN-55) Using L2C CNAV Data 122

Figure 10-140 Timeline of URA Normalized Range Error PRN-16 (SVN-56) Using C/A Nav Data 123
Figure 10-141 Timeline of URA Normalized Range Error PRN-17 (SVN-53) Using C/A Nav Data 123
Figure 10-142 Timeline of IAURA Normalized Range Error PRN-17 (SVN-53) Using L2C CNAV Data.............124
Figure 10-143 Timeline of URA Normalized Range Error PRN-18 (SVN-34) Using C/A Nav Data 124
Figure 10-144 Timeline of URA Normalized Range Error PRN-19 (SVN-59) Using C/A Nav Data 125
Figure 10-145 Timeline of URA Normalized Range Error PRN-20 (SVN-51) Using C/A Nav Data 125
Figure 10-146 Timeline of URA Normalized Range Error PRN-21 (SVN-45) Using C/A Nav Data 126
Figure 10-147 Timeline of URA Normalized Range Error PRN-22 (SVN-47) Using C/A Nav Data 126
Figure 10-148 Timeline of URA Normalized Range Error PRN-23 (SVN-60) Using C/A Nav Data 127
Figure 10-149 Timeline of URA Normalized Range Error PRN-24 (SVN-65) Using C/A Nav Data 127
Figure 10-150 Timeline of IAURA Normalized Range Error PRN-24 (SVN-65) Using L2C CNAV Data.............128
Figure 10-151 Timeline of URA Normalized Range Error PRN-25 (SVN-62) Using C/A Nav Data 128
Figure 10-152 Timeline of IAURA Normalized Range Error PRN-25 (SVN-62) Using L2C CNAV Data.............129
Figure 10-153 Timeline of URA Normalized Range Error PRN-26 (SVN-71) Using C/A Nav Data 129
Figure 10-154 Timeline of IAURA Normalized Range Error PRN-26 (SVN-71) Using L2C CNAV Data.............130
Figure 10-155 Timeline of URA Normalized Range Error PRN-27 (SVN-66) Using C/A Nav Data 130
Figure 10-156 Timeline of URA Normalized Range Error PRN-28 (SVN-44) Using C/A Nav Data 131
Figure 10-157 Timeline of URA Normalized Range Error PRN-29 (SVN-57) Using C/A Nav Data 131
Figure 10-158 Timeline of IAURA Normalized Range Error PRN-29 (SVN-57) Using L2C CNAV Data.............132
Figure 10-159 Timeline of URA Normalized Range Error PRN-30 (SVN-64) Using C/A Nav Data 132
Figure 10-160 Timeline of IAURA Normalized Range Error PRN-30 (SVN-64) Using L2C CNAV Data.............133
Figure 10-161 Timeline of URA Normalized Range Error PRN-31 (SVN-52) Using C/A Nav Data 133
Figure 10-162 Timeline of URA Normalized Range Error PRN-32 (SVN-70) Using C/A Nav Data 134

LIST OF TABLES

Table 1-1. SPS SIS Performance Requirements Standards Evaluated in This Report....3
Table 2-1. PDOP Availability Standard Parameters....8
Table 2-2 PDOP Availability Statistics....9
Table 3-1. Parameters for Issuing NANUs....11
Table 3-2 NANUs Affecting Satellite Availability....13
Table 3-3 NANUs Forecasted to Affect Satellite Availability....15
Table 3-4 Cancelled NANUs....15
Table 3-5 GPS Satellite Maintenance Statistics....15
Table 3-6. Service Availability Standard....16
Table 3-7 Accuracies Exceeding Threshold Statistics....16
Table 4-1. User Range Error Accuracy Parameters....18
Table 4-2 User Range Error Accuracy....18
Table 5-1. Accuracy Standard Parameters....19
Table 5-2 Horizontal & Vertical Accuracy Statistics for the Quarter....20
Table 5-3 Range Error Statistics....23
Table 5-4 Range Rate Error Statistics....24
Table 5-5 Range Acceleration Error Statistics....25
Table 6-1 Horizontal & Vertical Accuracy Statistics for May 14, 2019....32
Table 7-1. Selected IGS Sites Information....34
Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites....35
Table 8-1 RAIM Site Statistics....38
Table A-1 Performance Summary....135

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. 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 28 WAAS reference station locations:

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

The analysis of the data is divided to include the performance categories stated in the SPS Performance Standard (4th Edition, September 2008) as well as additional performance categories and are laid out as follows:

1. PDOP Availability Standard

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

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

1.2 Report Overview

Section 2. Summarizes the results obtained from the coverage calculation program developed by the WAAS test team at the William J. Hughes Technical Center. The SPS coverage area program uses the GPS satellite almanacs to compute each satellite position as a function of time for a selected day of the week. This program establishes a 2-degree grid between 180-degrees east and 180-degrees west, and from 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 Standard calls for yearly evaluations, this SPS requirement is reported at quarterly intervals.

Section 5. Provides the position accuracies based on data collected on a daily basis at 1-second intervals. This section also provides the statistics on the range error, range error rate, and range acceleration error for each satellite. The overall average, maximum, minimum and standard deviations of the range rates and accelerations are tabulated for each satellite.

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

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

Section 8. Provides a summary of RAIM performance.

Section 9. Provides a summary of GPS Test NOTAMs.

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

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

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

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

1.3 Summary of Performance Requirements and Metrics

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

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

Parameter	Conditions and Constraints
Per-Satellite Coverage Terrestrial Service Volume: 100% Coverage Space Service Volume: No Coverage Performance Specified	For any healthy or marginal SPS SIS.
Constellation Coverage Terrestrial Service Volume: 100% Coverage Space Service Volume: No Performance Specified	For any healthy or marginal SPS SIS.
User Range Error Accuracy 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 or marginal SPS SIS. Neglecting single-frequency ionospheric delay model errors. Including group delay time correction (T_{GD}) errors at L1. Including inter-signal bias (P(Y)-code to C/A-code) errors at L1.

Parameter	Conditions and Constraints
User Range Error Accuracy Single-Frequency C/A-Code • ≤30m 99.94% Global Average URE during normal operations • ≤30m 99.79% Worst Case single point average during normal operations	For any healthy or marginal SPS SIS. Neglecting single-frequency ionospheric delay model errors. Including group delay time correction (T_{GD}) errors at L1. Standard based on measurement interval of one year; average of daily values within service volume Standard based on 3 service failures per year, lasting no more than 6 hours each
User Range Rate Error Accuracy Single-Frequency C/A Code: ≤6mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	For any healthy SPS SIS. Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers. Neglecting single-frequency ionospheric delay model errors.
User Range Acceleration Error Accuracy Single-Frequency C/A Code: ≤2mm/sec^2 95% Global Average URAE over any 3-second interval during normal operations at Any AOD	For any healthy SPS SIS. Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers. Neglecting single-frequency ionospheric delay model errors.
Coordinated Universal Time Offset Error Accuracy ≤40 nanoseconds 95% Global average UTCOE during normal operations at Any AOD.	For any healthy SPS SIS.

Parameter	Conditions and Constraints
Instantaneous URE Integrity Single-Frequency C/A-Code: $\leq 1x10^{-5}$ Probability over any hour of the SPS SIS Instantaneous URE exceeding the NTE tolerance without a timely alert during normal operations. **Note:** Please see results in the WAAS PAN Report located at http://www.nstb.tc.faa.gov/DisplayArchive.htm	For any healthy SPS SIS. SPS SIS URE NTE tolerance defined to be ±4.42 times the upper bound on the URA value corresponding to the URA index "N" currently broadcast by the satellite. Given 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 single-frequency ionospheric delay model errors.
Instantaneous UTCOE Integrity Single-Frequency C/A-Code: $\leq 1x10^{-5}$ Probability over any hour of the sPS SIS Instantaneous UTCOE exceeding the NTE tolerance without a timely alert during normal operations.	For any healthy SPS SIS. SPS SIS URE NTE tolerance defined.
Unscheduled Failure Interruption Continuity Unscheduled Failure Interruptions: ≥0.9998 Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption.	Calculated as an average over all slots in the 24-slot constellation, normalized annually. Given that the SPS SIS is available from the slot at the start of the hour.
Status and Problem Reporting Scheduled event affecting service Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	For any SPS SIS.

Parameter	Conditions and Constraints
Status and Problem Reporting Unscheduled outage or problem affecting service Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	For any SPS SIS.
Per-Slot Availability ≥ 0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS ≥ 0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a healthy SPS SIS	Calculated as an average over all slots in the 24-slot constellation, normalized annually Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard.
Constellation Availability ≥0.98 Probability that at least 21 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration. ≥0.99999 Probability that at least 20 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration.	Calculated as an average over all slots in the 24-slot constellation, normalized annually. Applied to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.

Parameter	Conditions and Constraints
Operational Satellite Count ≥0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not.	Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operational satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not.
PDOP Availability ≥98% global PDOP of 6 or less ≥88% worst site PDOP of 6 or less	Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.
Service Availability ≥99% Horizontal Service Availability, average location ≥99% Vertical Service Availability, average location	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.
Service Availability ≥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.

Parameter	Conditions and Constraints
Position/Time Accuracy 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.
Position/Time Accuracy 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.
Position/Time Accuracy Time Transfer Domain Accuracy: ≤40 nanoseconds time transfer error 95% of time (SIS only)	Defined for a position/time solution meeting the representative user conditions. Standard based on a measurement interval of 24 hours averaged over all points in the service volume.

2. PDOP AVAILABILITY STANDARD

PDOP Availability is defined as the percentage of time over any 24-hour interval that the PDOP value is less than or equal to its threshold for any point within the service volume. Dilution of Precision (DOP) is defined as the magnifying effect on GPS position error induced by mapping GPS range errors into position within the specified coordinate system through the geometry of the position solution. The DOP varies as a function of satellite positions relative to user position. The DOP may be represented in any user local coordinate desired. Examples are HDOP for local horizontal, VDOP for local vertical, PDOP for all three coordinates, and TDOP for time.

Table 2-1 shows the PDOP Availability Standard parameters.

Table 2-1. PDOP Availability Standard Parameters

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

Almanacs for GPS weeks used for this coverage portion of the report were obtained from the Coast Guard web site (https://www.navcen.uscg.gov/). In addition, real-time broadcast satellite ephemeris and summary NANUs were utilized to incorporate satellite maintenance start and stop times. Using this data, an SPS coverage area program developed by the WAAS test team was used to calculate the PDOP at every 2-degree point between longitudes of 180W to 180E and 75S and 75N at 1-minute intervals. This gives 1440 samples for each of the 13,500 grid points in the coverage area. Table 2-2 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-2 also gives the global 99.9% PDOP value for each of the 13 GPS Weeks. The PDOP was 3.197 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. There were no "DOP holes", where the PDOP value is greater than six, evaluated for satellite visibility for any 24-hour intervals during the evaluation period. The histogram in Figure 2-2 shows satellite visibility at the worst-case point for the 24 hour interval with the highest PDOP. The GPS coverage performance evaluated met the specifications stated in the SPS.

Table 2-2 PDOP Availability Statistics

Date Range of Week	Global 99.9% PDOP Value (Meters)	Global Average Availability (Spec: ≥ 98%)	Worst-Case Point Availability (Spec: ≥ 88%)
04/01/2019 - 04/07/2019	3.0043	99.9999	99.9404
04/08/2019 - 04/14/2019	3.0309	99.9999	99.8214
04/15/2019 - 04/21/2019	3.0562	99.9998	99.7123
04/22/2019 - 04/28/2019	3.1485	99.9997	99.613
04/29/2019 - 05/05/2019	3.0686	99.9995	99.5138
05/06/2019 - 05/12/2019	3.0448	99.9993	99.4444
05/13/2019 - 05/19/2019	3.0576	99.9991	99.3849
05/20/2019 - 05/26/2019	3.0828	99.999	99.3055
05/27/2019 - 06/02/2019	3.0938	99.9988	99.2162
06/03/2019 - 06/09/2019	3.1938	99.9986	99.2261
06/10/2019 - 06/16/2019	3.1253	99.9983	98.998
06/17/2019 - 06/23/2019	3.1669	99.9981	99.0377
06/24/2019 - 06/30/2019	3.1969	99.9979	99.0079

Figure 2-1 World GPS Maximum PDOP

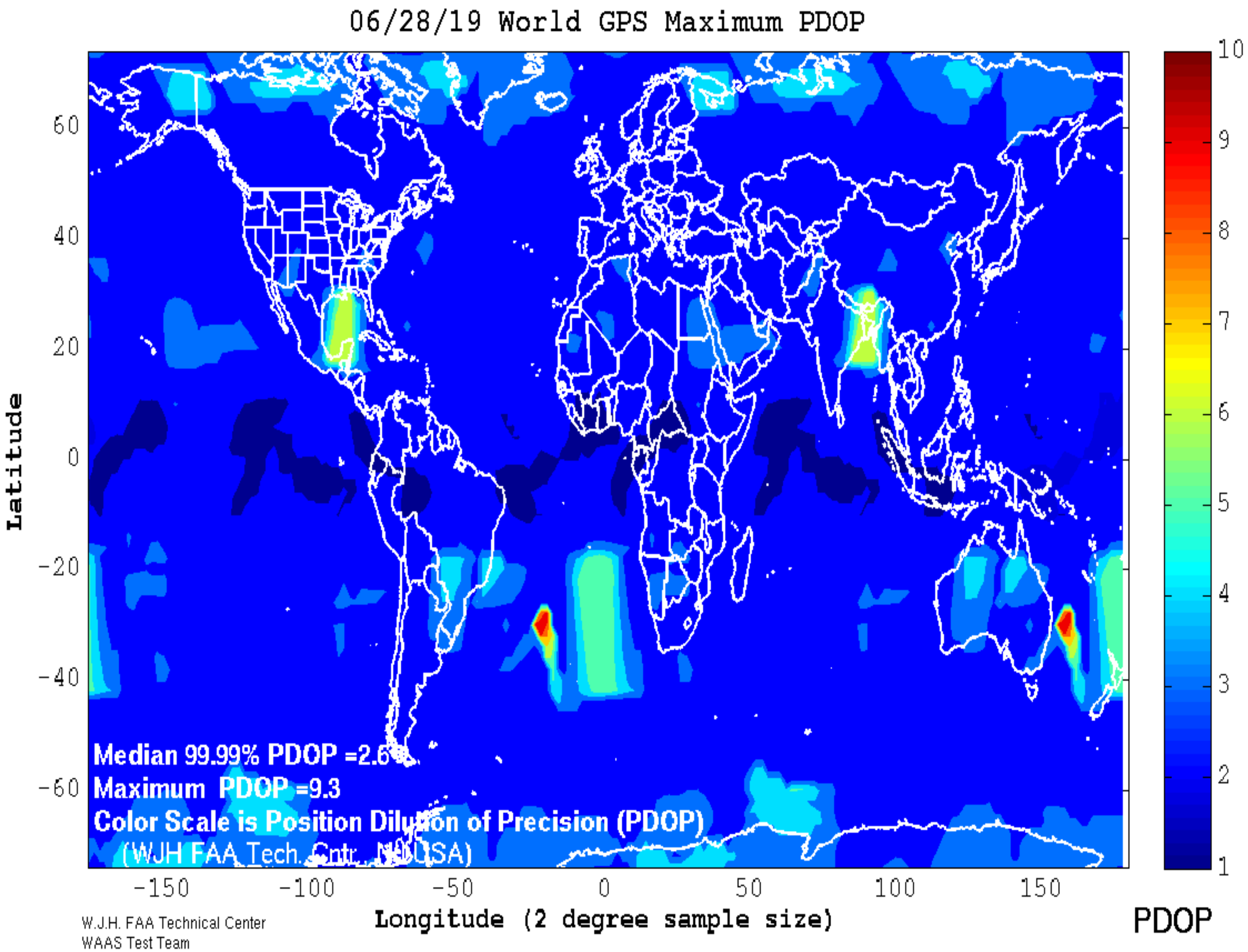
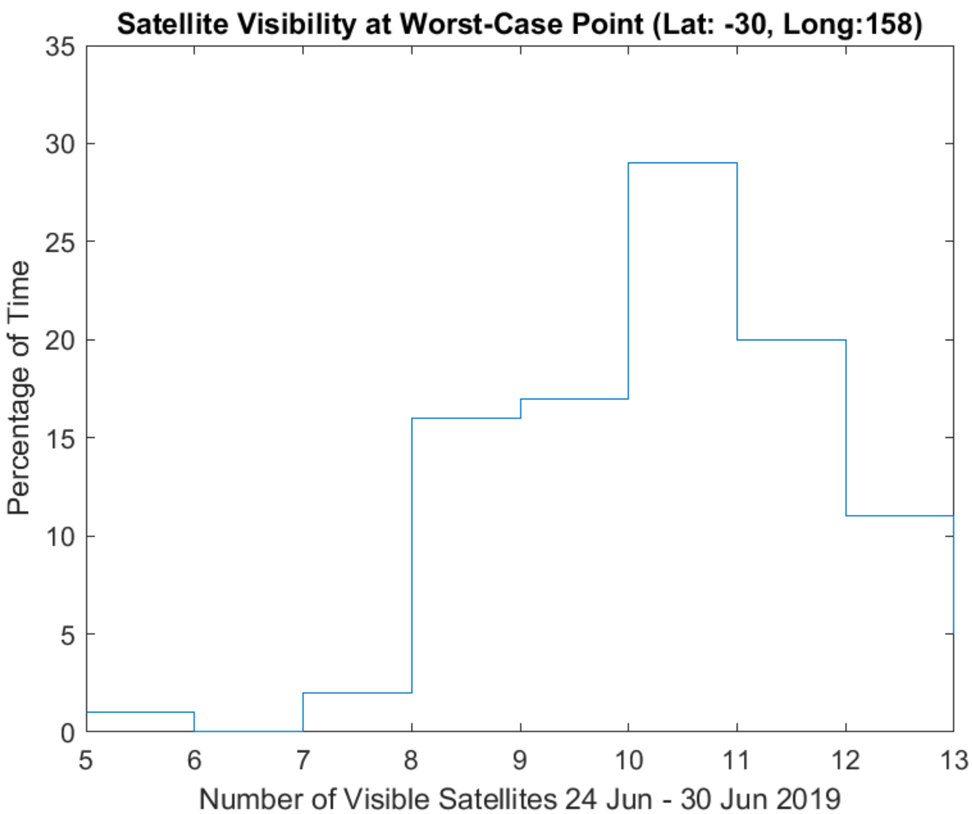


Figure 2-2 Satellite Visibility Profile for Worst-Case Point



3. NANU SUMMARY AND ELEVATION

A Notice Advisory to NAVSTAR Users (NANU) is a periodic bulletin alerting users to changes in the satellite system performance. Table 3-1 shows the parameters for issuing NANUs.

Table 3-1. Parameters for Issuing NANUs

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 NANUs. During this reporting period, 1 April through 30 June 2019, there were 45 reported outages. Seven outages were maintenance activities and were reported in advance, and 38 were unscheduled outages, 33 of which were short 1–2 minute outages for PRN18, the last operational GPS IIA satellite in the WAAS constellation. A complete listing of outage NANU's for the reporting period is provided in Table 3-2. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-3. Canceled outage NANU's (if any) are provided in Table 3-4. The minimum duration a scheduled outage was forecasted ahead of time was 72.0 hours. The maximum response time following an unscheduled outage was 0.400 hours. Therefore, the probability of continuity not being affected due to an unscheduled failure interruption was 100%, which met the specification requirement.

Table 3-2 NANUs Affecting Satellite Availability

NANU	PRN	TYPE	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2019046	18	UNUNOREF	01-Apr-19	14:02	01-Apr-19	14:04	0.03	0	0.03
2019047	32	FCSTSUMM	04-Apr-19	10:16	04-Apr-19	11:42	0	1.43	1.43
2019048	18	UNUNOREF	04-Apr-19	13:52	04-Apr-19	13:53	0.02	0	0.02
2019051	18	UNUNOREF	07-Apr-19	13:48	07-Apr-19	13:50	0.03	0	0.03
2019052	18	UNUNOREF	07-Apr-19	13:53	07-Apr-19	13:55	0.03	0	0.03
2019053	18	UNUNOREF	09-Apr-19	13:29	09-Apr-19	13:31	0.03	0	0.03
2019054	32	FCSTSUMM	09-Apr-19	09:41	09-Apr-19	14:04	0	4.38	4.38
2019055	18	UNUNOREF	10-Apr-19	13:18	10-Apr-19	13:19	0.02	0	0.02
2019056	18	UNUNOREF	10-Apr-19	13:21	10-Apr-19	13:22	0.02	0	0.02
2019058	18	UNUNOREF	11-Apr-19	13:26	11-Apr-19	13:27	0.02	0	0.02
2019059	22	FCSTSUMM	12-Apr-19	08:29	12-Apr-19	14:32	0	6.05	6.05
2019060	18	UNUNOREF	17-Apr-19	13:13	17-Apr-19	13:14	0.02	0	0.02
2019061	3	FCSTSUMM	19-Apr-19	09:12	19-Apr-19	14:30	0	5.3	5.3
2019063	18	UNUNOREF	25-Apr-19	16:36	25-Apr-19	16:37	0.02	0	0.02
2019064	1	FCSTSUMM	24-Apr-19	18:56	25-Apr-19	17:27	0	22.52	22.52
2019065	18	UNUNOREF	27-Apr-19	15:26	27-Apr-19	15:27	0.02	0	0.02
2019067	7	FCSTSUMM	02-May-19	16:04	02-May-19	23:05	0	7.02	7.02
2019068	18	UNUNOREF	03-May-19	14:55	03-May-19	14:58	0.05	0	0.05
2019069	18	UNUNOREF	05-May-19	15:03	05-May-19	15:06	0.05	0	0.05
2019070	18	UNUNOREF	07-May-19	15:34	07-May-19	15:36	0.03	0	0.03
2019071	18	UNUNOREF	08-May-19	15:19	08-May-19	15:21	0.03	0	0.03
2019072	18	UNUNOREF	08-May-19	15:22	08-May-19	15:24	0.03	0	0.03
2019073	18	UNUNOREF	09-May-19	15:30	09-May-19	15:33	0.05	0	0.05
2019074	18	UNUNOREF	12-May-19	15:22	12-May-19	15:24	0.03	0	0.03
2019075	18	UNUNOREF	16-May-19	17:50	16-May-19	17:51	0.02	0	0.02
2019076	18	UNUNOREF	17-May-19	14:44	17-May-19	14:46	0.03	0	0.03
2019077	18	UNUNOREF	28-May-19	15:47	28-May-19	15:50	0.05	0	0.05
2019078	18	UNUNOREF	29-May-19	14:56	29-May-19	14:59	0.05	0	0.05
2019079	18	UNUNOREF	31-May-19	14:11	31-May-19	14:13	0.03	0	0.03
2019081	18	UNUNOREF	01-Jun-19	14:09	01-Jun-19	14:10	0.02	0	0.02

NANU	PRN	TYPE	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2019082	18	UNUNOREF	02-Jun-19	14:04	02-Jun-19	14:05	0.02	0	0.02
2019083	30	FCSTSUMM	06-Jun-19	12:22	06-Jun-19	17:23	0	5.02	5.02
2019084	18	UNUNOREF	07-Jun-19	15:31	07-Jun-19	15:32	0.02	0	0.02
2019085	3	UNUNOREF	07-Jun-19	16:00	07-Jun-19	16:01	0.02	0	0.02
2019086	3	UNUNOREF	08-Jun-19	16:00	08-Jun-19	16:01	0.02	0	0.02
2019087	18	UNUNOREF	11-Jun-19	15:23	11-Jun-19	15:24	0.02	0	0.02
2019088	18	UNUNOREF	13-Jun-19	15:08	13-Jun-19	15:09	0.02	0	0.02
2019089	18	UNUNOREF	15-Jun-19	14:33	15-Jun-19	14:34	0.02	0	0.02
2019091	2	UNUSABLE	23-Jun-19	13:50	23-Jun-19	15:03	1.22	0	1.22
2019092	18	UNUNOREF	23-Jun-19	19:48	23-Jun-19	19:49	0.02	0	0.02
2019093	29	UNUNOREF	24-Jun-19	16:28	24-Jun-19	16:34	0.1	0	0.1
2019095	13	UNUSABLE	24-Jun-19	18:18	24-Jun-19	18:38	0.33	0	0.33
2019096	18	UNUNOREF	25-Jun-19	20:09	25-Jun-19	20:10	0.02	0	0.02
2019097	18	UNUNOREF	25-Jun-19	20:12	25-Jun-19	20:13	0.02	0	0.02
2019098	18	UNUNOREF	27-Jun-19	19:41	27-Jun-19	19:42	0.02	0	0.02
Totals of Unscheduled, Scheduled, and Total Downtime							2.6	51.72	54.32

Table 3-3 NANUs Forecasted to Affect Satellite Availability

NANU	PRN	TYPE	Start Date	Start Time	End Date	End Time	Total	Comments
2019043	32	FCSTDV	04-Apr	09:45	04-Apr	21:45	12	2019047
2019049	32	FCSTDV	09-Apr	09:30	09-Apr	21:30	12	2019054
2019050	22	FCSTDV	12-Apr	08:10	12-Apr	20:10	12	2019059
2019057	3	FCSTDV	19-Apr	08:45	19-Apr	20:45	12	2019061
2019062	1	FCSTMX	24-Apr	17:30	26-Apr	17:30	48	2019064
2019066	7	FCSTDV	02-May	15:45	03-May	03:45	12	2019067
2019080	30	FCSTDV	06-Jun	12:20	07-Jun	00:20	12	2019083
2019090	2	UNUSUFN	23-Jun	13:50				2019091
Total Forecasted Downtime							120	

Table 3-4 Cancelled NANUs

NANU	PRN	TYPE	Start Date	Start Time	Comments
N/A	N/A	N/A	N/A	N/A	N/A

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published NANUs. This data has been summarized in Table 3-5. The "Total Satellite Observed MTTR" was calculated by taking the average downtime of all satellite outage occurrences. Scheduled downtime was forecasted in advance via 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 3-5 GPS Satellite Maintenance Statistics

Satellite Reliability/Maintainability/Availability (RMA) Paramenter	04/01/2019 to 06/30/2019	01/01/2000 to 06/30/2019
Total Forecasted Downtime (hrs)	120	12358.82
Total Actual Downtime (hrs)	54.32	39971.67
Total Actual Scheduled Downtime (hrs)	51.72	6855.28
Total Actual Unscheduled Downtime(hrs)	2.6	33116.39
Total Satellite Observed MTTR (hrs)	1.21	38.43
Scheduled Satellite Observed (hrs)	7.39	8.87
Unscheduled Satellite Observed (hrs)	0.07	124.03
Total Satellite Outages (number)	45	1040
Scheduled Satellite Outages (number)	7	773
Unscheduled Satellite Outages (number)	38	267
Percent Operational -- Scheduled downtime (%)	99.92	99.87
Percent Operational -- All downtime (%)	99.92	99.25

3.2 Service Availability Standard

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

Table 3-6. Service Availability Standard

Service Availability Standard	Conditions and Constraints
≥99% Horizontal Service Availability, average location ≥99% Vertical Service Availability, average location	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 28 WAAS sites was used to calculate 24-hour accuracy information and reported in Table 3-7. The data was collected at 1-second intervals between 1 April and 30 June 2019.

Table 3-7 Accuracies Exceeding Threshold Statistics

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-Hour Threshold Failures	April 2019 – June 2019 Service Availability (%)
Albuquerque	7861869	0	100
Anchorage	7861877	0	100
Atlanta	7861889	0	100
Barrow	7856979	0	100
Bethel	7861784	0	100
Billings	7861699	0	100
Boston	7855986	0	100
Cleveland	7861888	0	100
Cold Bay	7861614	0	100

Site	Total Number of Seconds of SPS Monitoring	Instances of 24-Hour Threshold Failures	April 2019 – June 2019 Service Availability (%)
Fairbanks	7800663	0	100
Gander	7861791	0	100
Honolulu	7861886	0	100
Houston	7861890	0	100
Iqaluit	6014948	0	100
Juneau	7861807	0	100
Kansas City	7861878	0	100
Kotzebue	7860680	0	100
Los Angeles	7857074	0	100
Merida	7856694	0	100
Miami	7861890	0	100
Minneapolis	7861888	0	100
Oakland	7861887	0	100
Salt Lake City	7861889	0	100
San Jose Del Cabo	7455490	0	100
San Juan	7861889	0	100
Seattle	7861889	0	100
Tapachula	7788015	0	100
Washington DC	7861889	0	100
Global Average over Reporting Period = 100% (SPS Spec. > 95.87%)			

4. SERVICE RELIABILITY STANDARD

Service Reliability is the percentage of time over a specific time interval that the instantaneous SIS SPS URE is maintained within a specified reliability threshold at any given point within the service volume, for all healthy GPS satellites. Table 4-1 shows the User Range Error Accuracy parameters.

Table 4-1. User Range Error Accuracy Parameters

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 4-2 shows a comparison to the service reliability standard for range data collected at a set of six receivers across North America. Although the specification calls for yearly evaluations, we will be evaluating this SPS requirement at quarterly intervals. Additional range analysis results can be found in Table 5-3. The maximum User Range Error recorded this quarter was 13.040 meters on satellite PRN24.

Table 4-2 User Range Error Accuracy

Date Range of Data Collection	Site	Number of Samples This Quarter	Number of Samples where SPS URE > 30m NTE	Percentage (%)
01 APRIL - 30 JUNE 2019	Boston	68021449	0	100
01 APRIL - 30 JUNE 2019	Honolulu	70361298	0	100
01 APRIL - 30 JUNE 2019	Juneau	70043876	0	100
01 APRIL - 30 JUNE 2019	Los Angeles	69085798	0	100
01 APRIL - 30 JUNE 2019	Merida	70304794	0	100
01 APRIL - 30 JUNE 2019	Miami	68874116	0	100
01 APRIL - 30 JUNE 2019	Global	416691331	0	100

5. ACCURACY STANDARD

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

Table 5-1 shows the Accuracy Standard parameters.

Table 5-1. Accuracy Standard Parameters

Position/Time Accuracy	Conditions and Constraints
Position/Time Accuracy Global Average Position Domain Accuracy: • ≤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.
Position/Time Accuracy 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.
Position/Time Accuracy 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 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.
User Range 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.
User Range Accuracy 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.

Position/Time Accuracy	Conditions and Constraints
Coordinated Universal Time Offset Error Accuracy ≤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 01 April through 30 June 2019 at the selected WAAS locations. Table 5-2 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter. Every 24-hour analysis period this quarter passed both the worst-case and global average position accuracy requirements set forth by the SPS specification.

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

Site	95% Vertical (Meters)	95% Horizontal (Meters)	99.99% Vertical (Meters)	99.99% Horizontal (Meters)
Albuquerque	4.56	1.46	8.33	2.66
Anchorage	3.85	1.77	8.53	2.88
Atlanta	4.71	1.62	9.42	3.49
Barrow	3.68	1.43	7.65	2.75
Bethel	4.16	1.75	8.65	2.95
Billings	3.84	1.50	8.04	2.60
Boston	4.34	1.79	8.88	3.54
Cleveland	4.50	1.81	8.97	3.41
Cold Bay	4.27	1.55	8.47	2.66
Fairbanks	3.74	1.73	7.75	3.53
Gander	3.50	1.69	6.87	3.50
Honolulu	4.89	3.24	7.87	7.15
Houston	4.87	1.68	7.91	3.61
Juneau	3.41	1.68	7.20	3.44
Kansas City	4.48	1.58	8.02	2.89
Kotzebue	3.90	1.82	7.55	2.89
Los Angeles	4.81	1.67	8.48	2.95
Merida	4.72	2.12	9.36	4.21
Miami	4.58	1.72	9.21	3.83
Minneapolis	4.17	1.63	8.08	2.87
Oakland	4.89	1.61	8.59	3.04
Salt Lake City	4.34	1.42	8.29	2.71
San Jose Del Cabo	4.87	2.44	8.18	4.87
San Juan	3.80	1.75	7.70	4.80
Seattle	3.96	1.43	7.91	2.90

Site	95% Vertical (Meters)	95% Horizontal (Meters)	99.99% Vertical (Meters)	99.99% Horizontal (Meters)
Tapachula	4.50	2.49	8.01	5.24
Washington, DC	4.38	1.72	8.93	3.27

Figure 5-1 and Figure 5-2 are the combined histograms of the vertical and horizontal errors for all 28 WAAS sites from 01 April to 30 June 2019.

Figure 5-1 Global Vertical Error Histogram

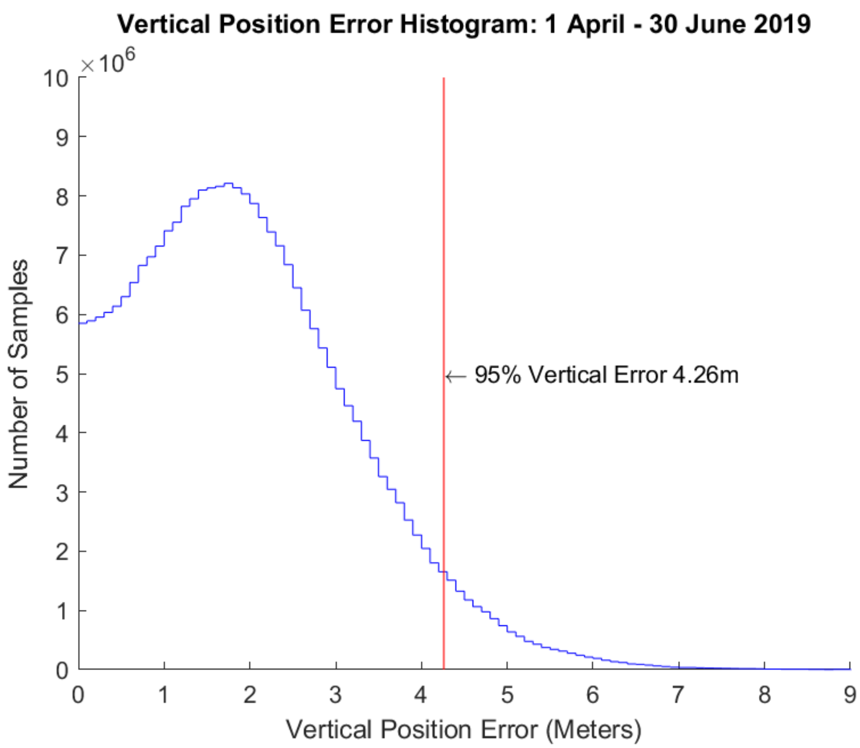
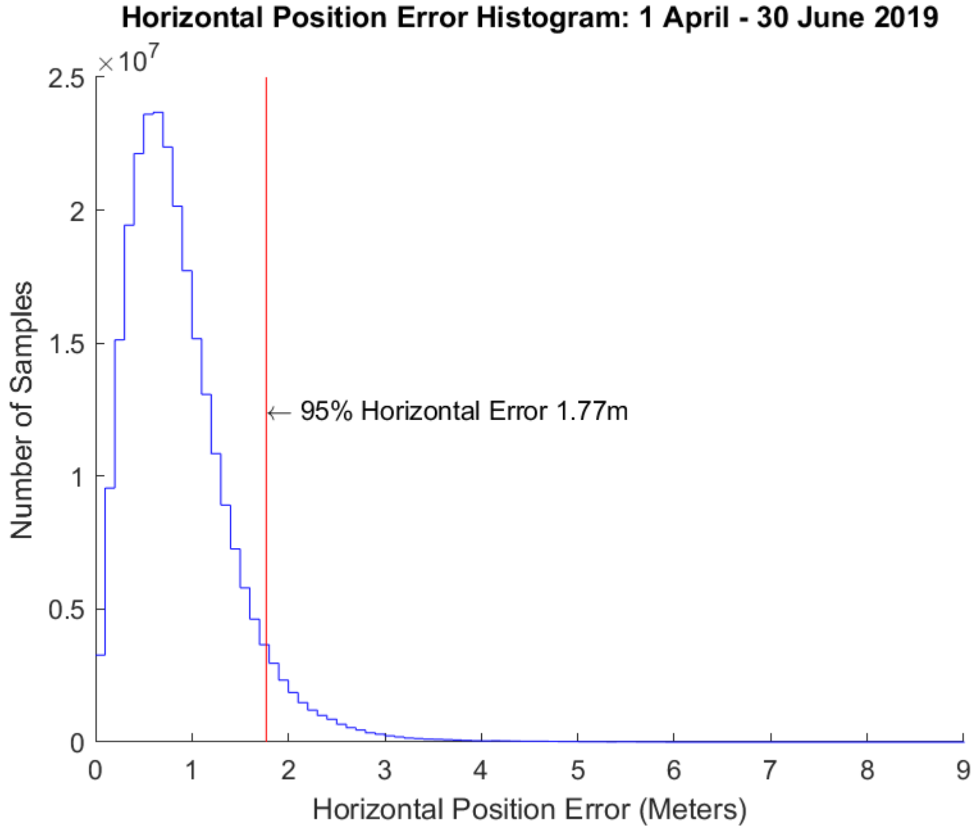


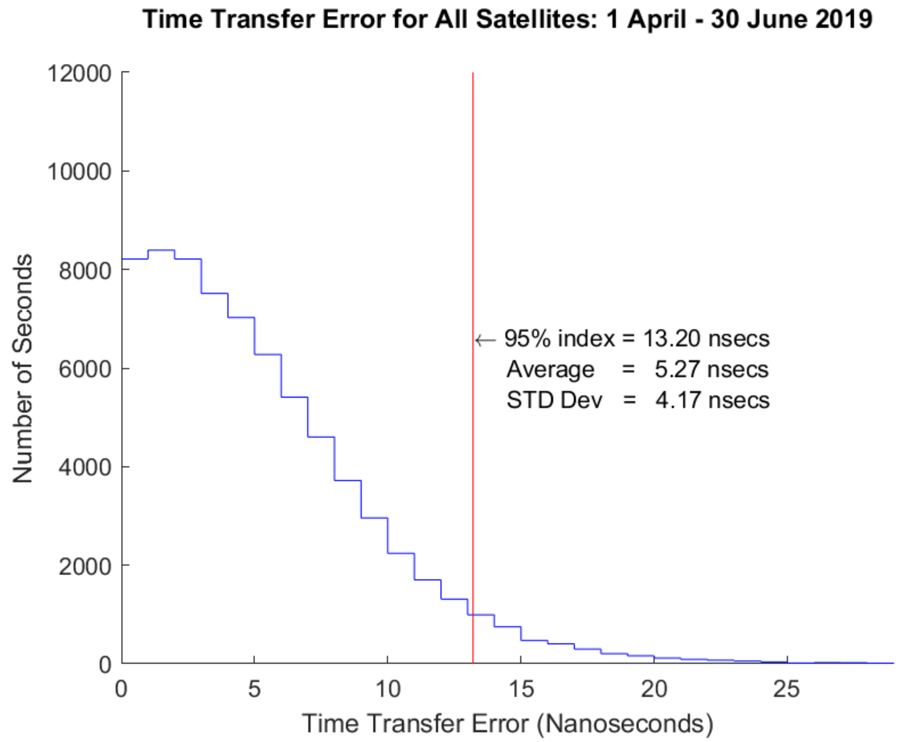
Figure 5-2 Global Horizontal Error Histogram



5.2 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 2019 was downloaded from the USNO website. The USNO data file contains the time difference between the USNO master clock and GPS system time for each GPS satellites during the time period. Over 10,000 samples of GPS time error are contained in the USNO data file. In order to evaluate the GPS time transfer error, the data file was used to create a histogram (Figure 5-3) to represent the distribution of GPS time error. The histogram was created by taking the absolute value of time difference between the USNO master clock and GPS system time, then creating data bins with 1 nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Figure 5-3. The maximum instantaneous UTC offset error (UTCOE) for the quarter was 17.7 nanoseconds. The mean, standard deviation, and 95% index of Time Transfer Error, and the maximum UTCOE are all within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Error



5.3 Range Domain Accuracy

Table 5-3 through Table 5-5 provide the statistical data for the range error, range rate error, and the range acceleration error for each satellite. This data was collected between 01 April and 30 June 2019. A weighted average filter was used for the calculation of the range rate error and the range acceleration error. All Range Domain SPS specifications were met.

Table 5-3 Range Error Statistics

PRN	RMS Range Error (<6m) (Meters)	Range Error Mean (Meters)	1σ Range Error (Meters)	95% Range Error (Meters)	Max Range Error (SPS Spec. < 30m) (Meters)	Samples
1	1.42	0.71	1.16	2.55	7.22	13609245
2	1.98	1.6	1.1	3.33	9.42	14722613
3	1.07	0.42	0.89	1.93	5.2	14099779
5	1.39	0.88	1.0	2.6	9.12	13597010
6	1.44	0.9	1.03	2.62	6.95	13867546
7	1.5	1.07	0.87	2.49	9.1	12549359
8	1.81	1.07	1.1	3.0	10.51	12539796
9	1.54	1.26	0.84	2.66	11.19	13352399
10	1.61	1.15	0.97	2.71	12.34	12998484
11	1.79	1.36	1.04	2.97	7.76	12223652

PRN	RMS Range Error (<6m) (Meters)	Range Error Mean (Meters)	1σ Range Error (Meters)	95% Range Error (Meters)	Max Range Error (SPS Spec. < 30m) (Meters)	Samples
12	1.44	0.87	1.04	2.69	12.58	14026150
13	1.38	0.87	0.96	2.46	8.09	13482581
14	2.01	1.75	0.87	3.17	9.87	14071019
15	1.5	1.13	0.88	2.58	10.35	12684651
16	1.7	1.35	0.95	2.81	6.91	12978927
17	1.56	1.04	0.97	2.68	10.0	14557592
18	1.54	0.75	1.17	2.75	7.04	13947569
19	2.15	1.87	1.0	3.41	7.9	14034570
20	2.44	2.1	1.17	3.78	12.54	12947235
21	2.47	2.08	1.26	3.96	10.25	13110018
22	2.33	2.12	0.93	3.56	10.47	13455466
23	1.7	1.45	0.82	2.74	8.61	12863439
24	1.86	0.87	1.45	3.28	13.04	13902734
25	1.41	0.91	1.0	2.57	8.16	14305303
26	1.56	1.12	0.97	2.63	6.82	12565269
27	1.53	1.05	0.96	2.54	7.02	13134678
28	2.1	1.59	1.12	3.42	8.84	13584894
29	1.53	1.04	0.95	2.6	6.84	13067616
30	1.77	1.35	1.03	2.9	7.23	12618775
31	1.34	0.8	0.97	2.34	8.48	13684106
32	1.28	0.79	0.85	2.26	7.59	14108856

Table 5-4 Range Rate Error Statistics

PRN	Range Rate Error RMS (mm/s)	95% Range Rate Error (mm/s)	Max Range Rate Error (mm/s)	Samples
1	1.33	2.55	100.27	13609245
2	1.43	2.76	78.53	14722613
3	1.32	2.51	71.0	14099779
5	1.52	2.93	49.35	13597010
6	1.32	2.55	83.17	13867546
7	1.4	2.7	73.72	12549359
8	1.62	2.85	137.06	12539796
9	1.27	2.46	36.25	13352399
10	1.28	2.47	40.38	12998484
11	1.5	2.82	109.94	12223652
12	1.49	2.91	58.68	14026150
13	1.5	2.78	99.17	13482581
14	1.43	2.71	103.46	14071019
15	1.42	2.76	56.99	12684651
16	1.44	2.8	52.37	12978927

PRN	Range Rate Error RMS (mm/s)	95% Range Rate Error (mm/s)	Max Range Rate Error (mm/s)	Samples
17	1.59	2.89	150.1	14557592
18	1.47	2.63	111.83	13947569
19	1.46	2.83	61.84	14034570
20	1.44	2.74	83.71	12947235
21	1.54	2.94	37.44	13110018
22	1.41	2.72	87.32	13455466
23	1.35	2.62	52.31	12863439
24	1.82	3.24	140.84	13902734
25	1.34	2.58	52.17	14305303
26	1.29	2.51	49.62	12565269
27	1.31	2.54	77.42	13134678
28	1.81	2.8	133.75	13584894
29	1.44	2.81	88.24	13067616
30	1.3	2.49	84.38	12618775
31	1.4	2.68	88.08	13684106
32	1.3	2.51	108.43	14108856

Table 5-5 Range Acceleration Error Statistics

PRN	Rate Acceleration Error RMS (um/s^2)	95% Range Acceleration Error (um/s^2)	Max Range Acceleration Error (um/s^2)	Samples
1	10.13	18.96	1000	13609245
2	10.21	22.86	750	14722613
3	10.12	19.1	700	14099779
5	10.49	26.54	490	13597010
6	10.11	18.51	840	13867546
7	10.17	23.11	730	12549359
8	12.08	24.69	1390	12539796
9	10.02	19.49	370	13352399
10	10.04	18.43	400	12998484
11	10.73	24.66	1100	12223652
12	10.15	25.68	570	14026150
13	10.93	24.59	990	13482581
14	10.31	22.93	1030	14071019
15	10.09	23.47	580	12684651
16	10.04	24.63	520	12978927
17	11.85	25.2	1490	14557592
18	11.22	21.31	1130	13947569
19	10.19	23.91	620	14034570
20	10.26	23.14	840	12947235
21	10.86	25.74	380	13110018
22	10.13	23.45	870	13455466
23	10.06	22.21	490	12863439

PRN	Rate Acceleration Error RMS (um/s^2)	95% Range Acceleration Error (um/s^2)	Max Range Acceleration Error (um/s^2)	Samples
24	13.83	27.9	1420	13902734
25	10.1	19.07	520	14305303
26	10.04	18.55	490	12565269
27	10.06	18.86	770	13134678
28	14.68	24.55	1350	13584894
29	10.07	23.68	880	13067616
30	10.17	19.49	840	12618775
31	10.27	22.94	800	13684106
32	10.07	18.46	1080	14108856

Figure 5-4 through Figure 5-6 are graphical representations of the distributions of the maximum range error, range rate error, and range acceleration error for all satellites. The highest maximum range error occurred on satellite PRN24 with an error of 13.040 meters. Satellite PRN had the lowest maximum range error of 5.200 meters. Figure 5-7 is histogram of satellite range error for all satellites over the entire quarter. Figure 5-8 through Figure 5-10 show the individual maximums per satellite for range error, range rate error, and range acceleration error, respectively.

Figure 5-4 Distribution of Daily Max Range Errors

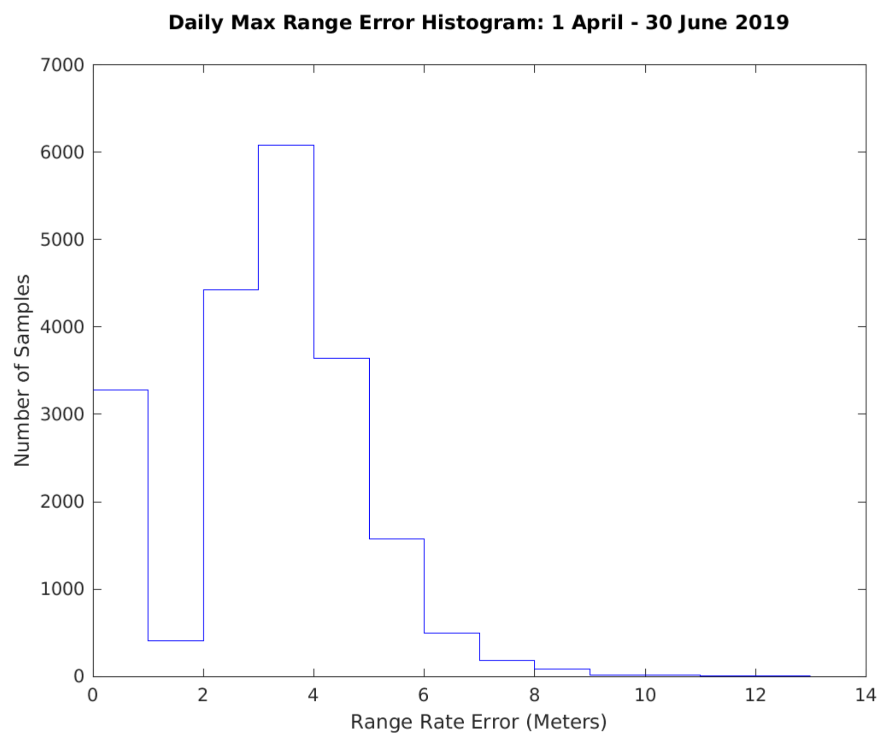


Figure 5-5 Distribution of Daily Max Range Rate Errors

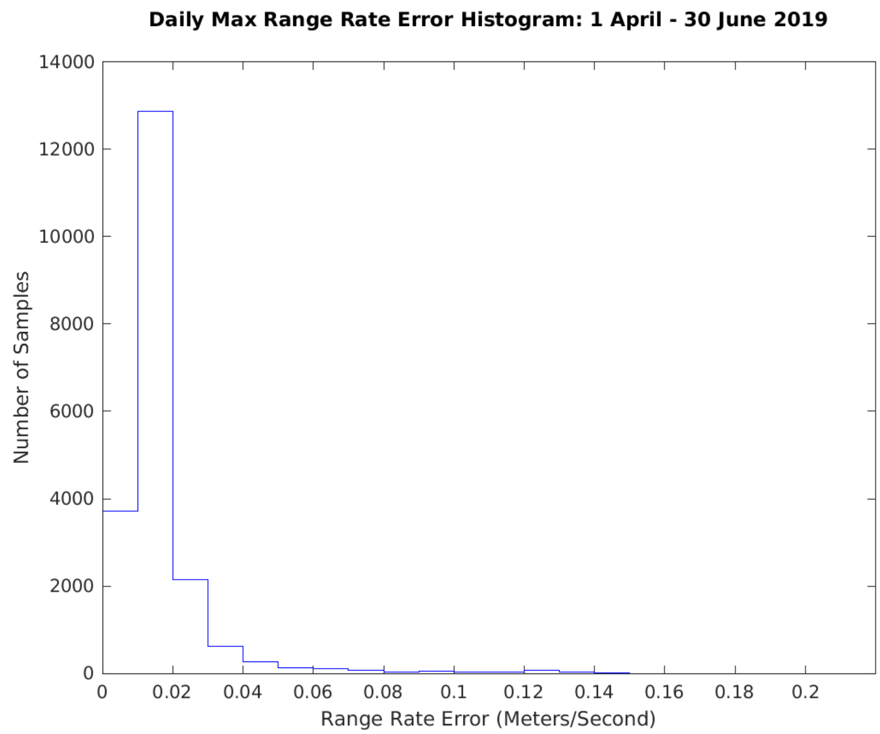


Figure 5-6 Distribution of Daily Max Range Acceleration Errors

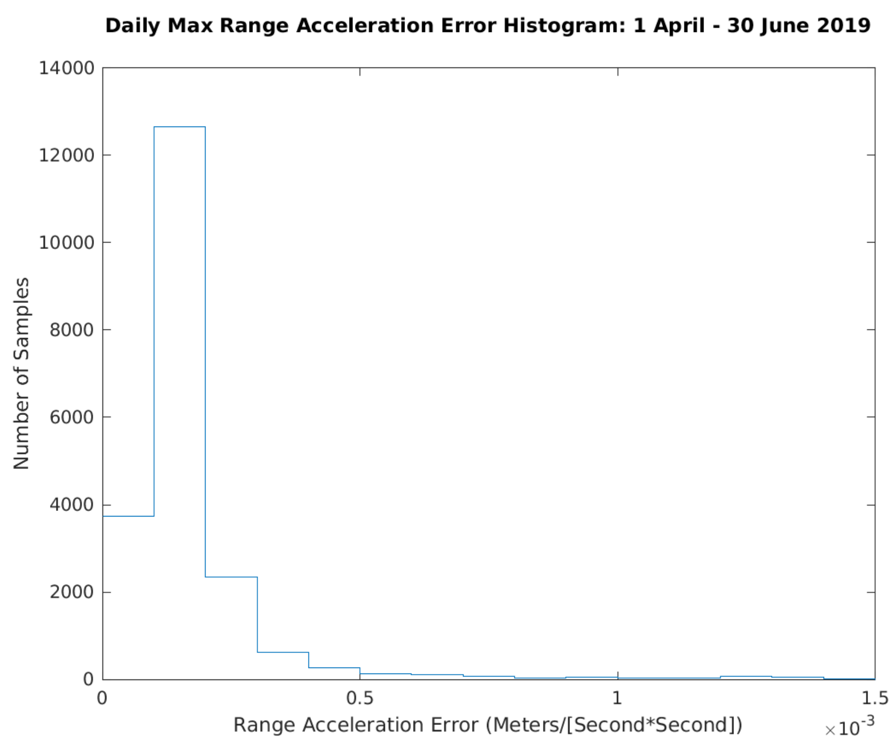


Figure 5-7 Range Error Histogram

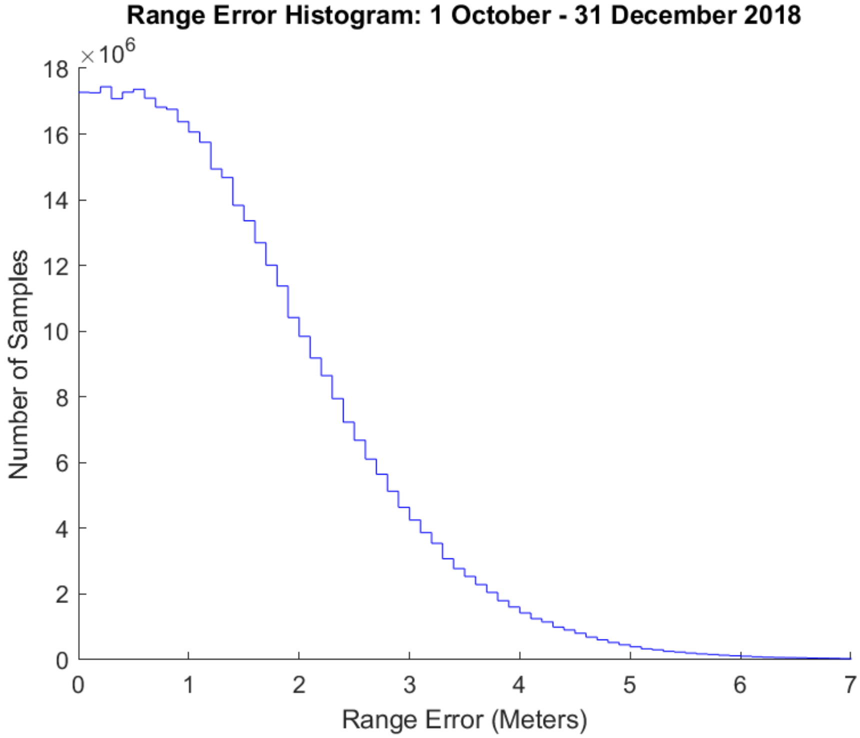


Figure 5-8 Maximum Range Error per Satellite

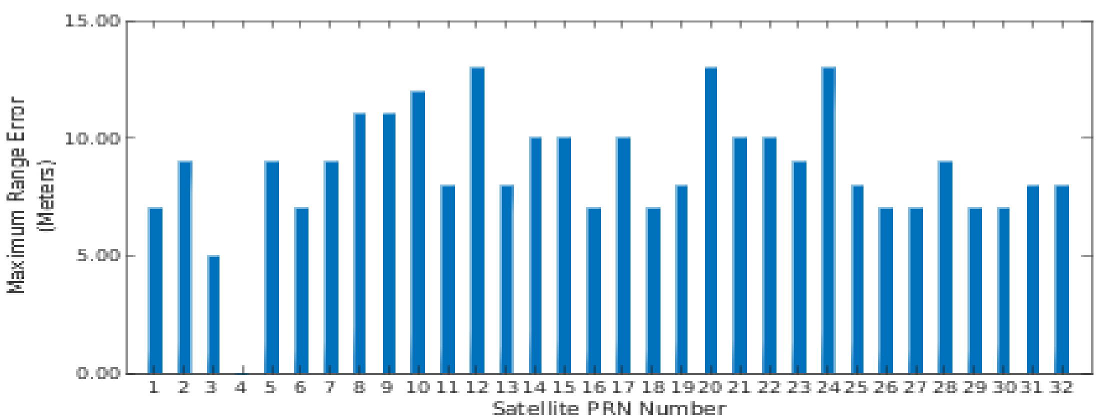


Figure 5-9 Maximum Range Rate Error per Satellite

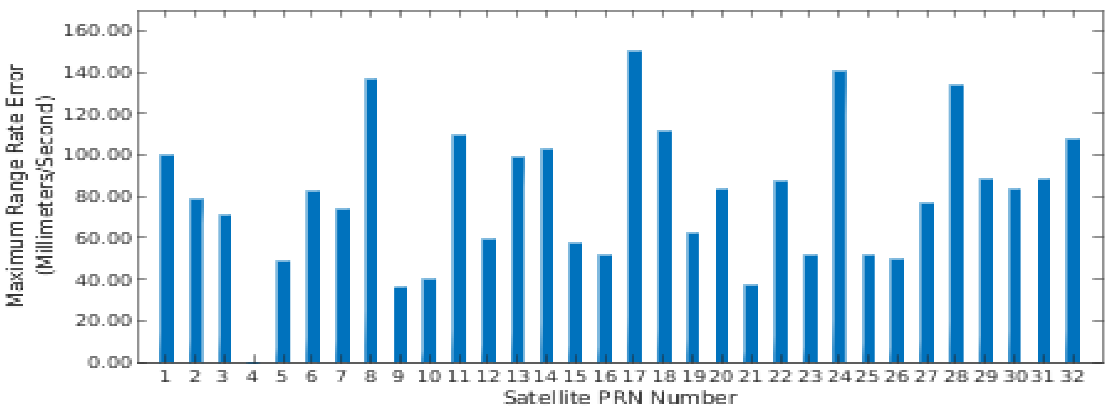
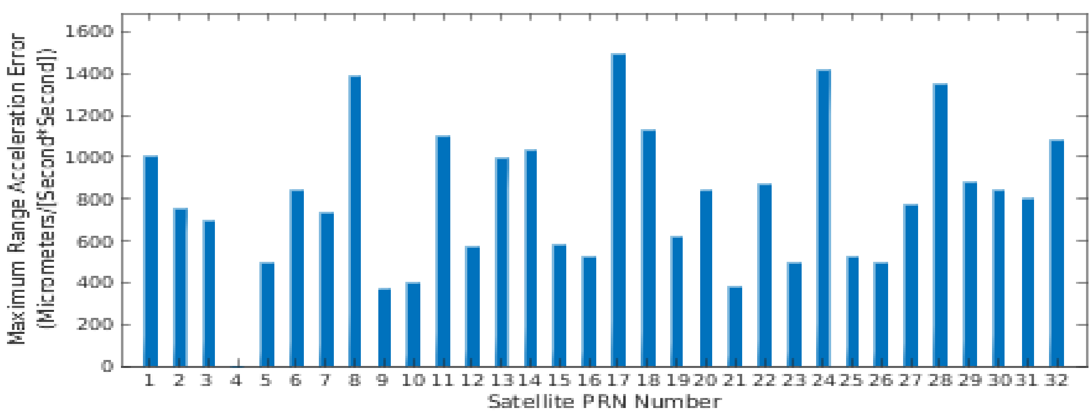


Figure 5-10 Maximum Range Acceleration Error per Satellite



6. SOLAR STORMS

Solar storm activity is being monitored 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.

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

Figure 6-1 K-Index for May 11, 2019

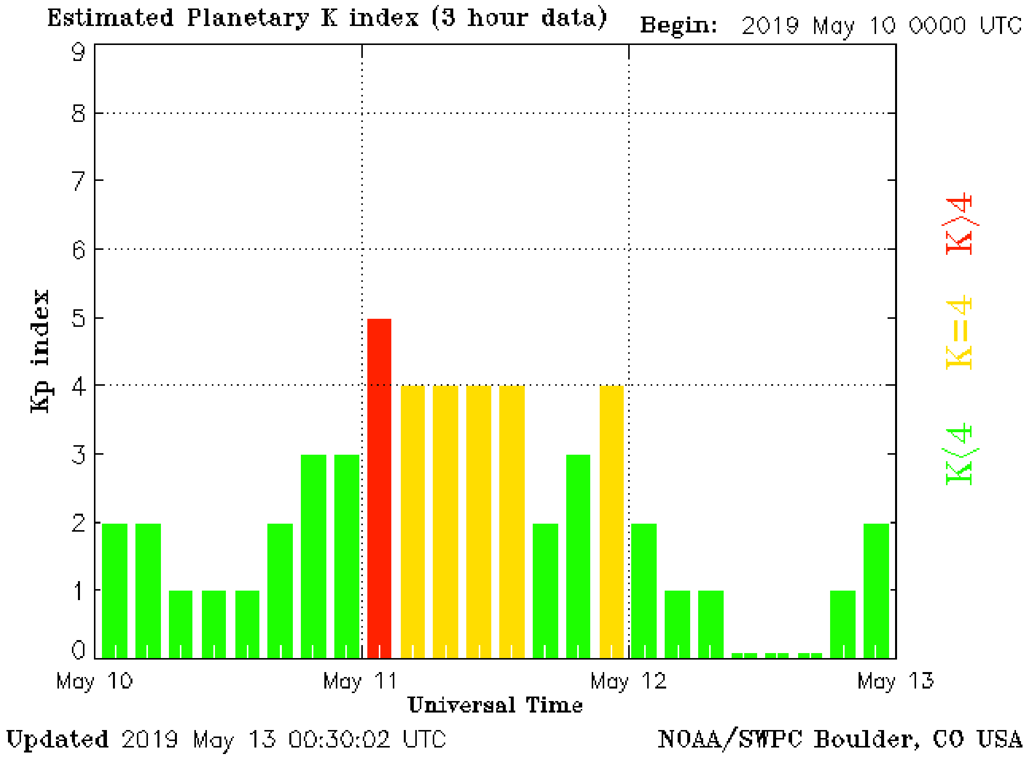


Figure 6-2 K-Index for May 14, 2019

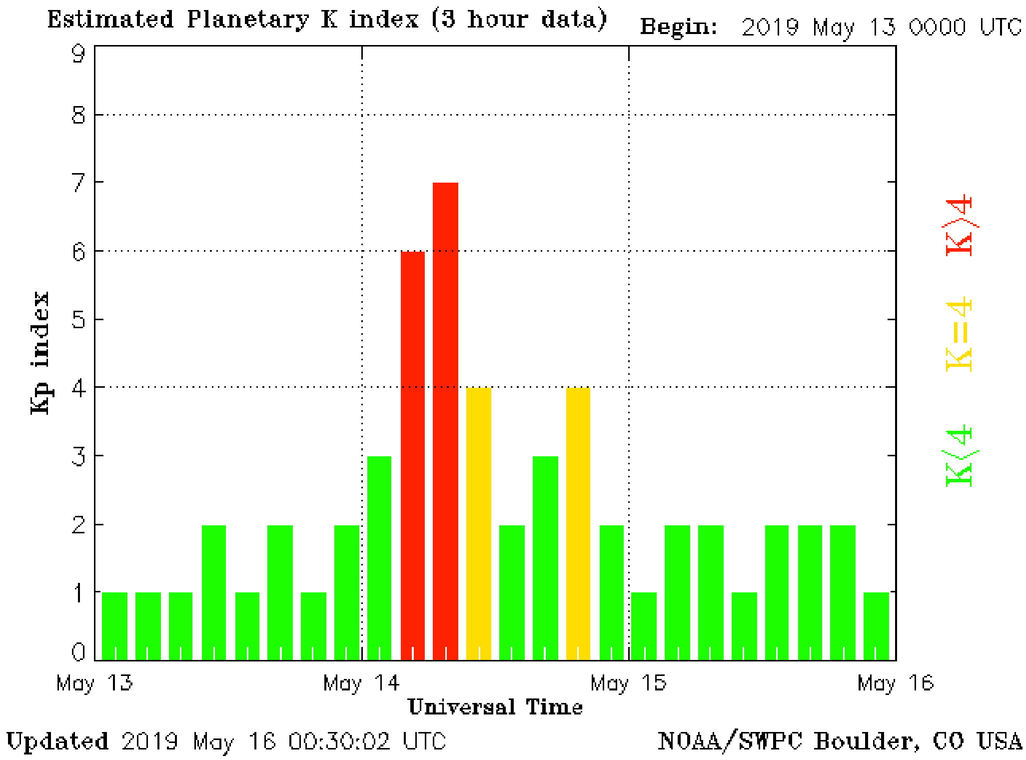


Figure 6-3 K-Index for June 9, 2019

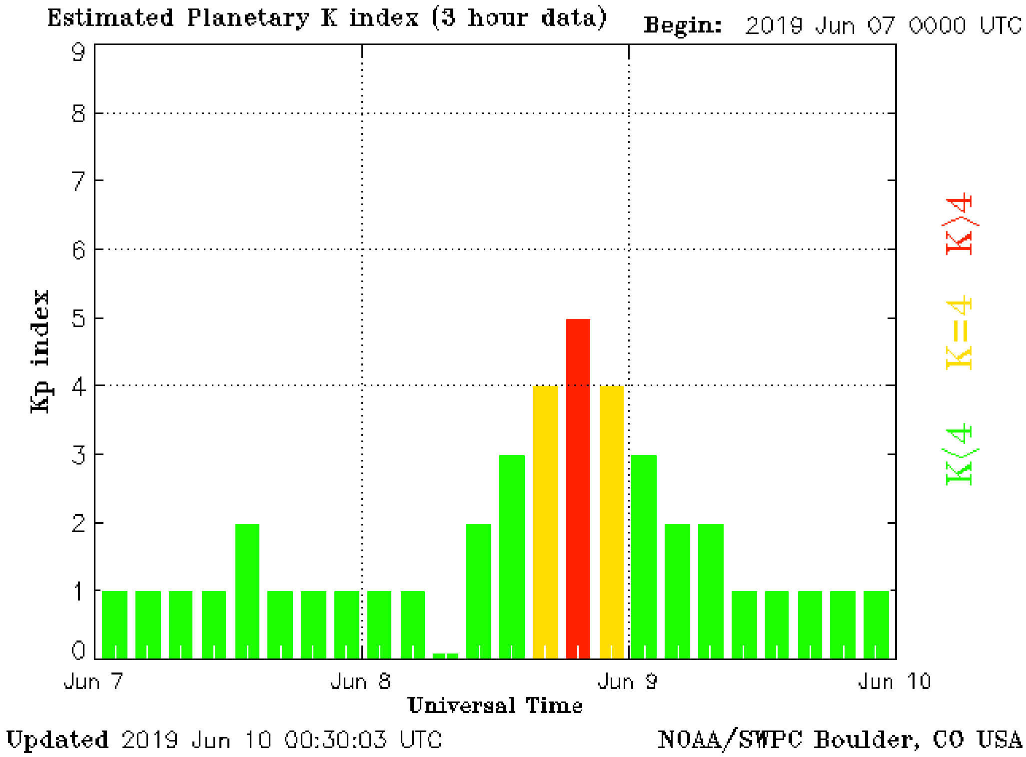


Table 6-1 shows the position accuracy information for the quarter's worst-case storm day, May 14, 2019 (see Figure 6-1 through Figure 6-3). The GPS SPS performance met all requirements during all storms that occurred during this quarter.

Table 6-1 Horizontal & Vertical Accuracy Statistics for May 14, 2019

Site	95% Horizontal (Meters)	95% Vertical (Meters)	MAX Horizontal (Meters)	MAX Vertical (Meters)
Albuquerque	1.582	4.678	2.124	5.826
Anchorage	1.843	3.795	2.674	5.642
Atlanta	2.181	5.797	2.901	6.393
Barrow	1.235	3.41	2.224	5.878
Bethel	1.802	4.196	2.433	5.23
Billings	1.351	3.95	1.708	4.836
Boston	2.104	4.694	3.422	5.761
Cleveland	2.001	5.295	2.959	6.71
Cold Bay	1.717	4.289	1.988	5.486
Fairbanks	1.625	3.549	3.218	6.223
Gander	1.784	3.528	3.197	4.196
Honolulu	2.614	4.785	3.362	7.923
Houston	1.791	5.632	2.514	6.448
Iqaluit	1.363	3.77	2.934	5.164

Site	95% Horizontal (Meters)	95% Vertical (Meters)	MAX Horizontal (Meters)	MAX Vertical (Meters)
Juneau	1.617	3.484	2.645	5.119
Kansas City	1.659	4.749	2.678	5.078
Kotzebue	1.731	3.549	2.223	5.417
Los Angeles	1.442	4.915	1.99	5.593
Merida	1.669	5.037	2.268	5.91
Miami	1.877	5.297	2.437	6.084
Minneapolis	1.256	4.497	1.785	5.372
Oakland	1.55	4.737	1.872	5.608
Salt Lake City	1.32	4.656	1.878	5.348
San Jose Del Cabo	2.798	5.08	3.303	6.045
San Juan	1.935	4.763	2.237	6.48
Seattle	1.24	3.711	1.917	4.403
Tapachula	2.492	4.224	2.754	4.789
Washington DC	2.259	5.069	2.986	6.653

7. IGS DATA

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

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

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

Table 7-1 and Figure 7-1 show the IGS site information and locations. The Russian Federation sites were unavailable for this reporting period. Table 7-2 shows the GPS SPS accuracy performance observed at a selection of high-rate IGS sites. Figure 7-2 shows the 95% horizontal accuracy trends at these sites.

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[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

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

Table 7-1. Selected IGS Sites Information

ID	City	Country
BOGT	Bogota	Colombia
GLPS	Puerto Ayora	Ecuador
GUAM	Dededo	Guam
IISC	Bangalore	India
KIRU	Kiruna	Sweden
KOUR	Kourou	French Guyana
MADR	Robledo	Spain
MAL2	Malindi	Kenya
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	Kyrghyzstan
SUTM	Sutherland	South Africa
TIDB	Tidbinbilla	Australia
UNSA	Salta	Argentina
USUD	Usuda	Japan

Figure 7-1 Selected IGS Site Locations

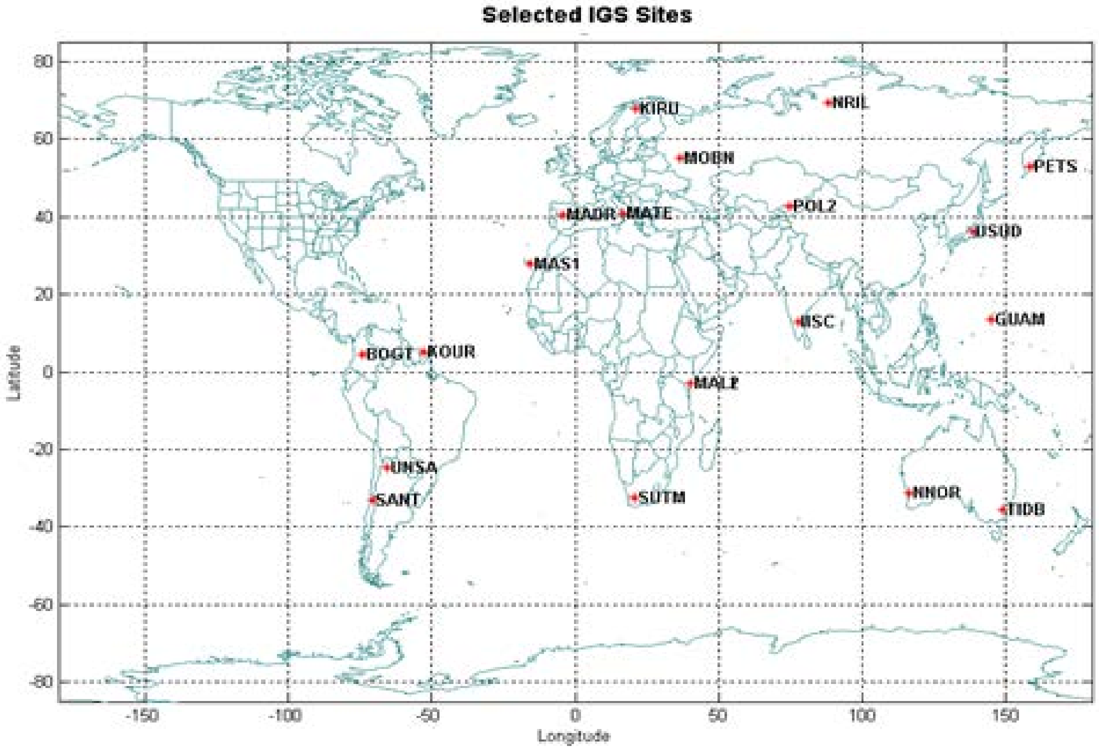


Table 7-2 GPS SPS Performance at Selected High Rate IGS Sites

Site	95% Horizontal Error (M)	95% Vertical Error (M)	99.99% Horizontal Error (M)	99.99% Vertical Error (M)	Percent Data Available
BOGT	50.01	50.01	50.01	50.01	35.32%
GLPS	50.01	40.63	50.01	50.01	44.23%
GUAM	0	0	0	0	0.00%
IISC	50.01	50.01	50.01	50.01	9.75%
KIRU	50.01	50.01	50.01	50.01	14.54%
KOUR	50.01	50.01	50.01	50.01	22.07%
MADR	50.01	50.01	50.01	50.01	19.92%
MAL2	50.01	50.01	50.01	50.01	4.63%
MALI	0	0	0	0	0.00%
MAS1	50.01	50.01	50.01	50.01	16.61%
MATE	50.01	50.01	50.01	50.01	23.20%
MOBN	0	0	0	0	0.00%
NNOR	50.01	50.01	50.01	50.01	24.31%
NRIL	0	0	0	0	0.00%
PETS	0	0	0	0	0.00%

Site	95% Horizontal Error (M)	95% Vertical Error (M)	99.99% Horizontal Error (M)	99.99% Vertical Error (M)	Percent Data Available
POL2	50.01	50.01	50.01	50.01	11.66%
SANT	50.01	50.01	50.01	50.01	41.50%
SUTM	50.01	50.01	50.01	50.01	13.84%
TIDB	50.01	50.01	50.01	50.01	28.41%
UNSA	50.01	50.01	50.01	50.01	41.71%
USUD	50.01	50.01	50.01	50.01	11.22%

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

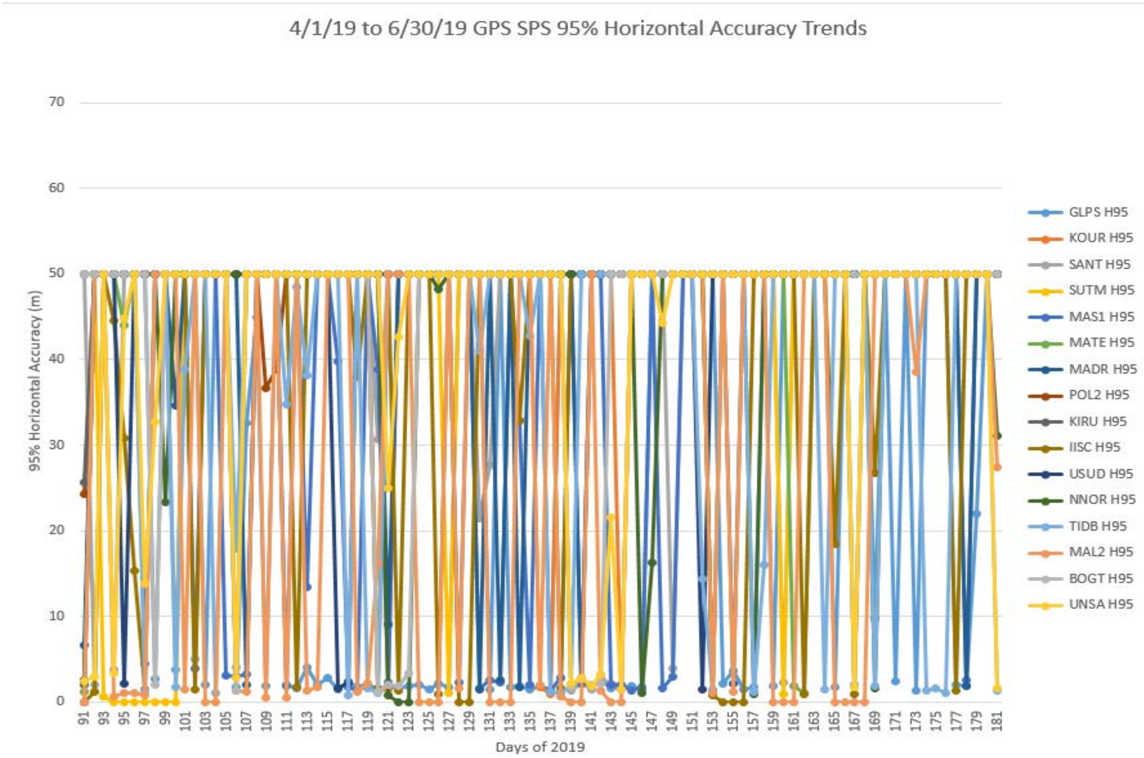
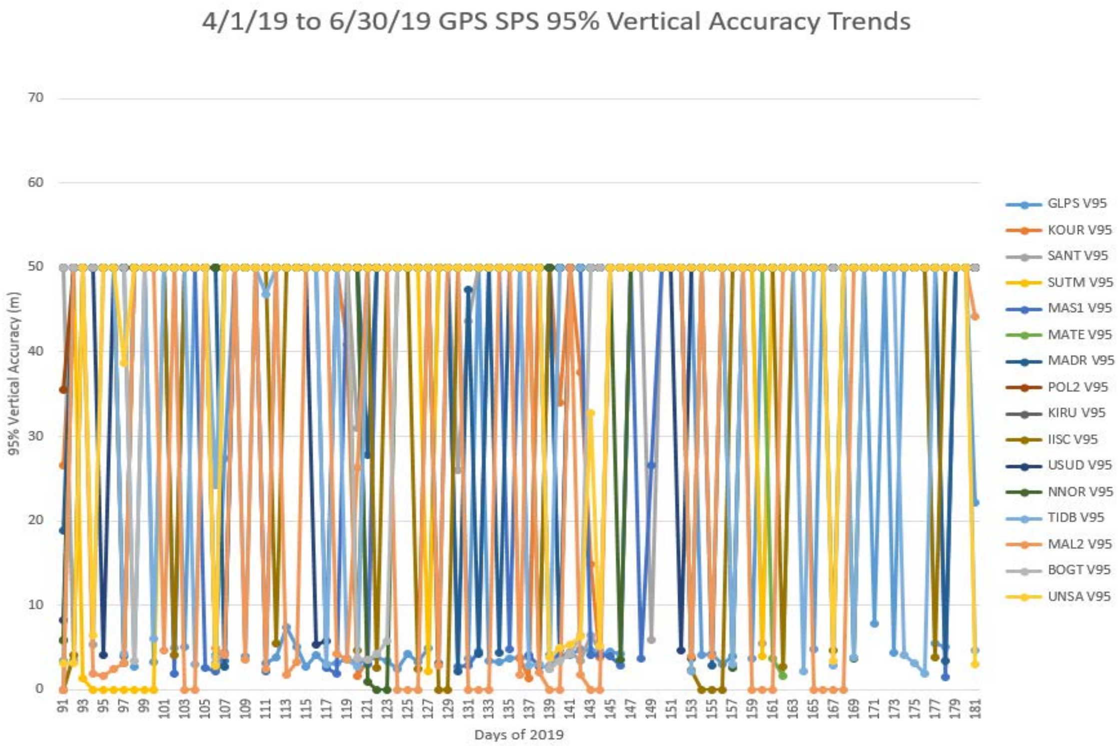


Figure 7-3 GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites



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 1/15,000.

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 28 sites evaluated. For all sites collected, the minimum percent of time in RNP 0.1 mode was 99.707% at Fairbanks. The minimum percent of time spent in RNP 0.3 mode was 100 at all locations evaluated. The maximum 99% HPL value was 141.544 meters at Cleveland.

Table 8-1 RAIM Site Statistics

City	99% HPL (Meters)	Percentage RNP 0.1 (%)	Percentage RNP 0.3 (%)
Albuquerque	124.571	100	100
Anchorage	139.339	99.99387	100
Atlanta	108.284	100	100
Barrow	121.095	100	100
Bethel	138.453	99.99348	100
Billings	113.795	100	100
Boston	120.739	100	100
Cleveland	141.544	100	100
Cold Bay	133.331	99.81293	100
Fairbanks	135.882	99.70662	100
Gander	125.436	99.83242	100
Honolulu	127.258	99.99686	100
Houston	97.483	100	100
Iqaluit	131.166	99.98941	100
Juneau	135.816	99.98154	100
Kansas City	112.765	100	100
Kotzebue	134.183	99.95466	100
Los Angeles	94.416	100	100
Merida	89.585	99.77007	100
Miami	123.759	100	100
Minneapolis	114.343	99.95459	100
Oakland	107.703	100	100
Salt Lake City	113.3	100	100
San Jose Del Cabo	89.824	100	100
San Juan	80.734	100	100
Seattle	125.795	100	100
Tapachula	97.726	100	100
Washington DC	131.707	100	100

8.2 RAIM Coverage

Figure 8-1 and Figure 8-2 show the worldwide RAIM coverage for both RNP 0.1 and RNP 0.3, respectively. Figure 8-3 and Figure 8-4 show the daily RAIM coverage trends between 01 April and 30 June 2019.

Figure 8-1 RAIM RNP 0.1 Coverage

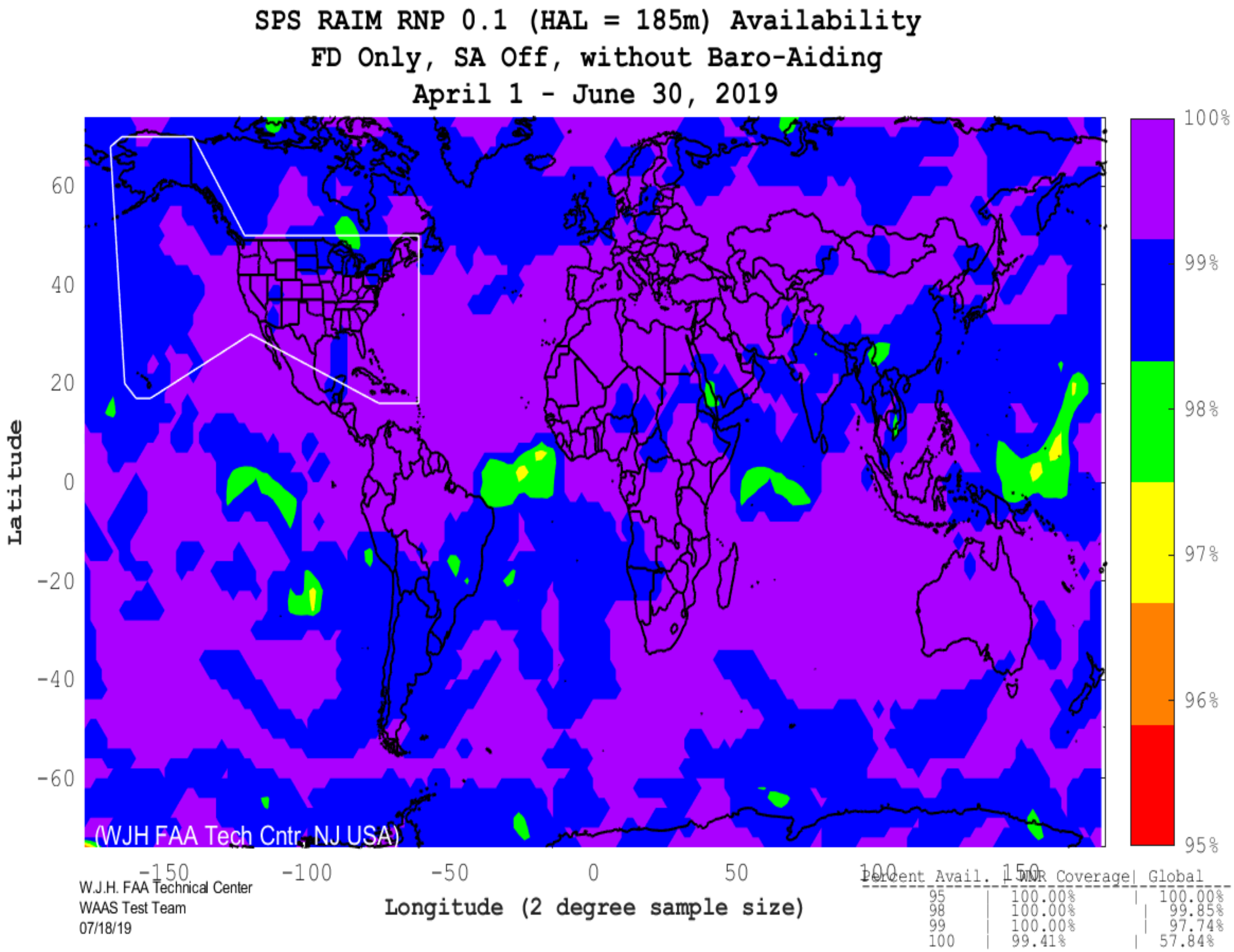


Figure 8-2 RAIM RNP 0.3 Coverage

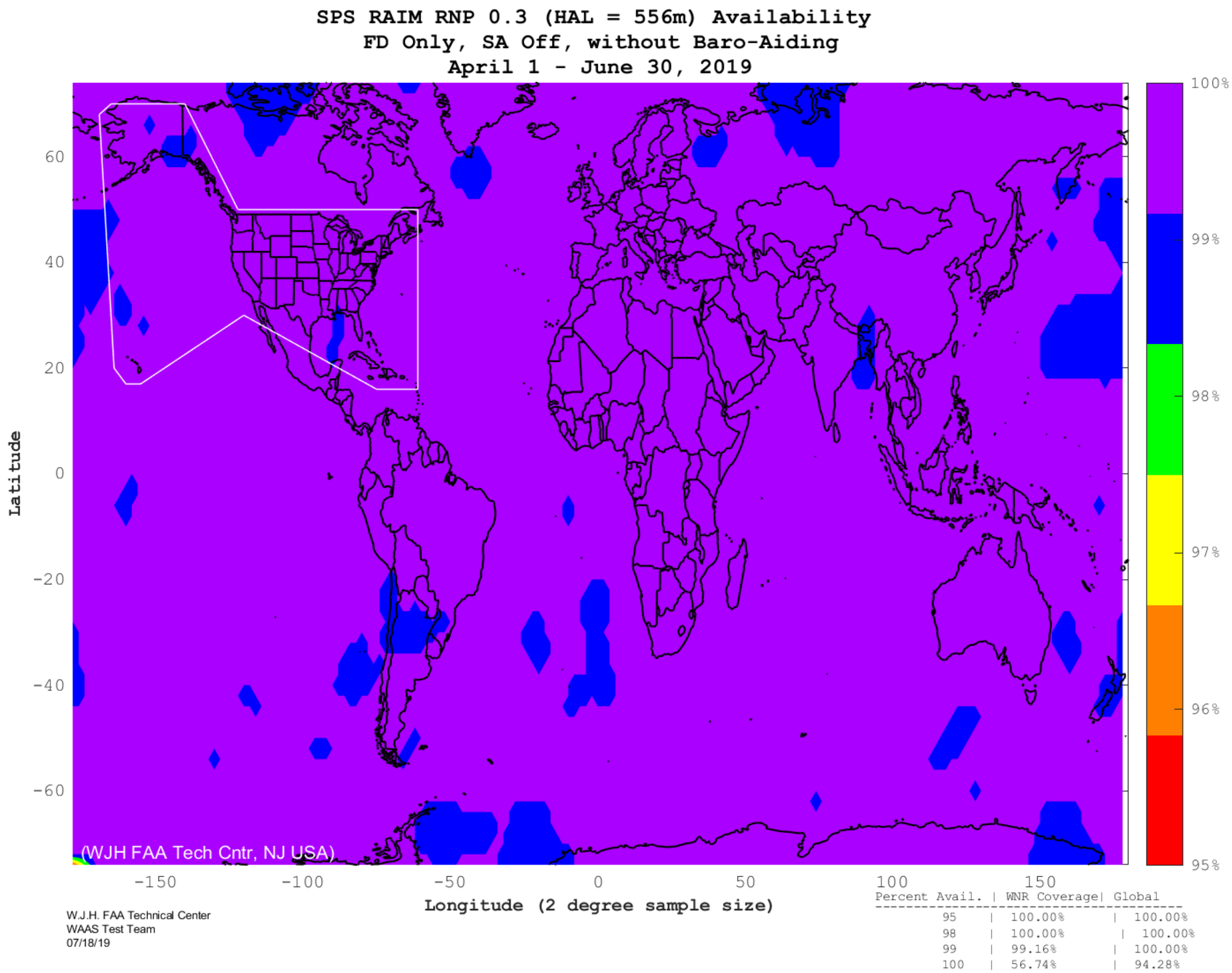


Figure 8-3 RAIM World Wide Coverage Trend

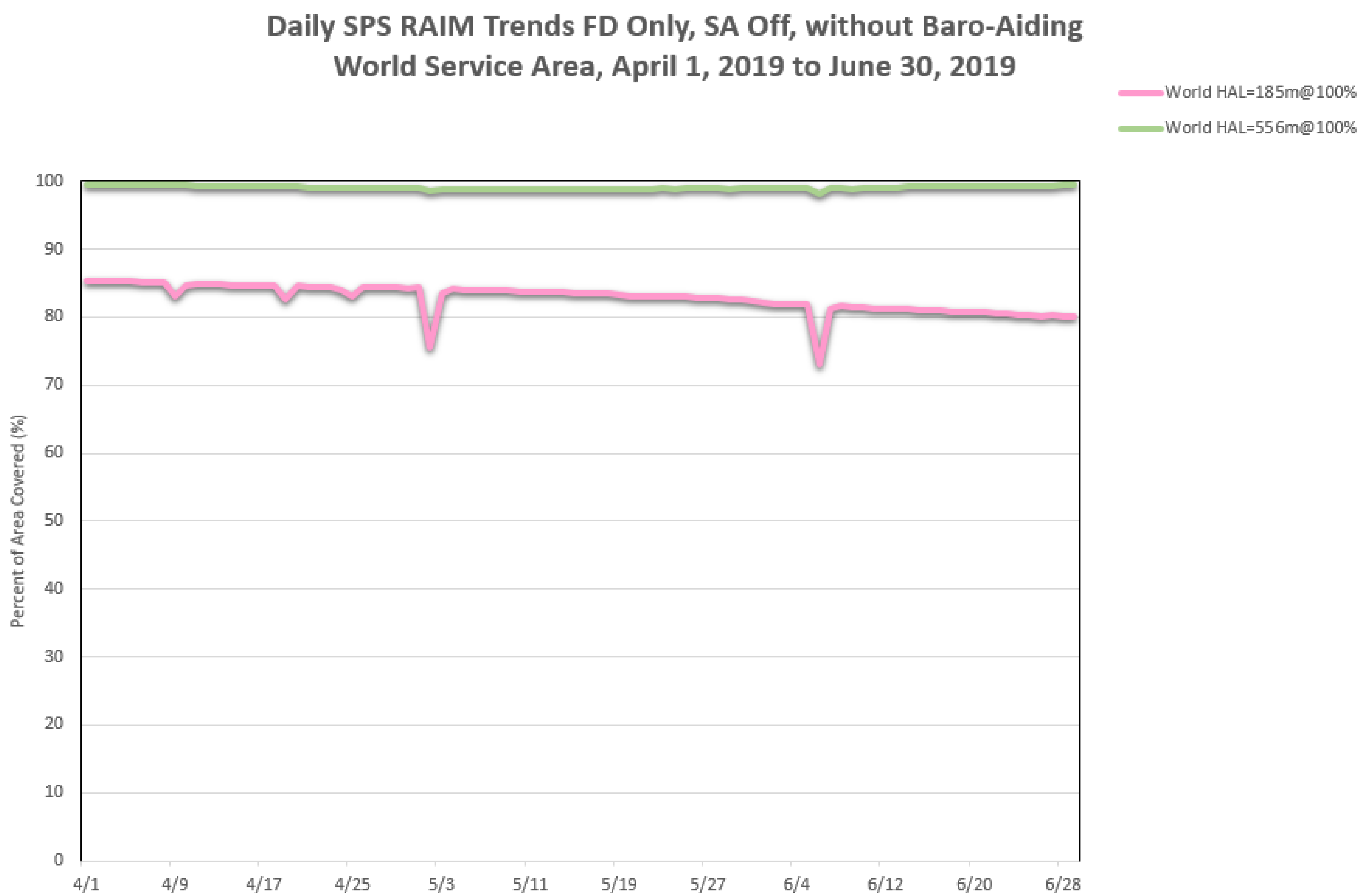
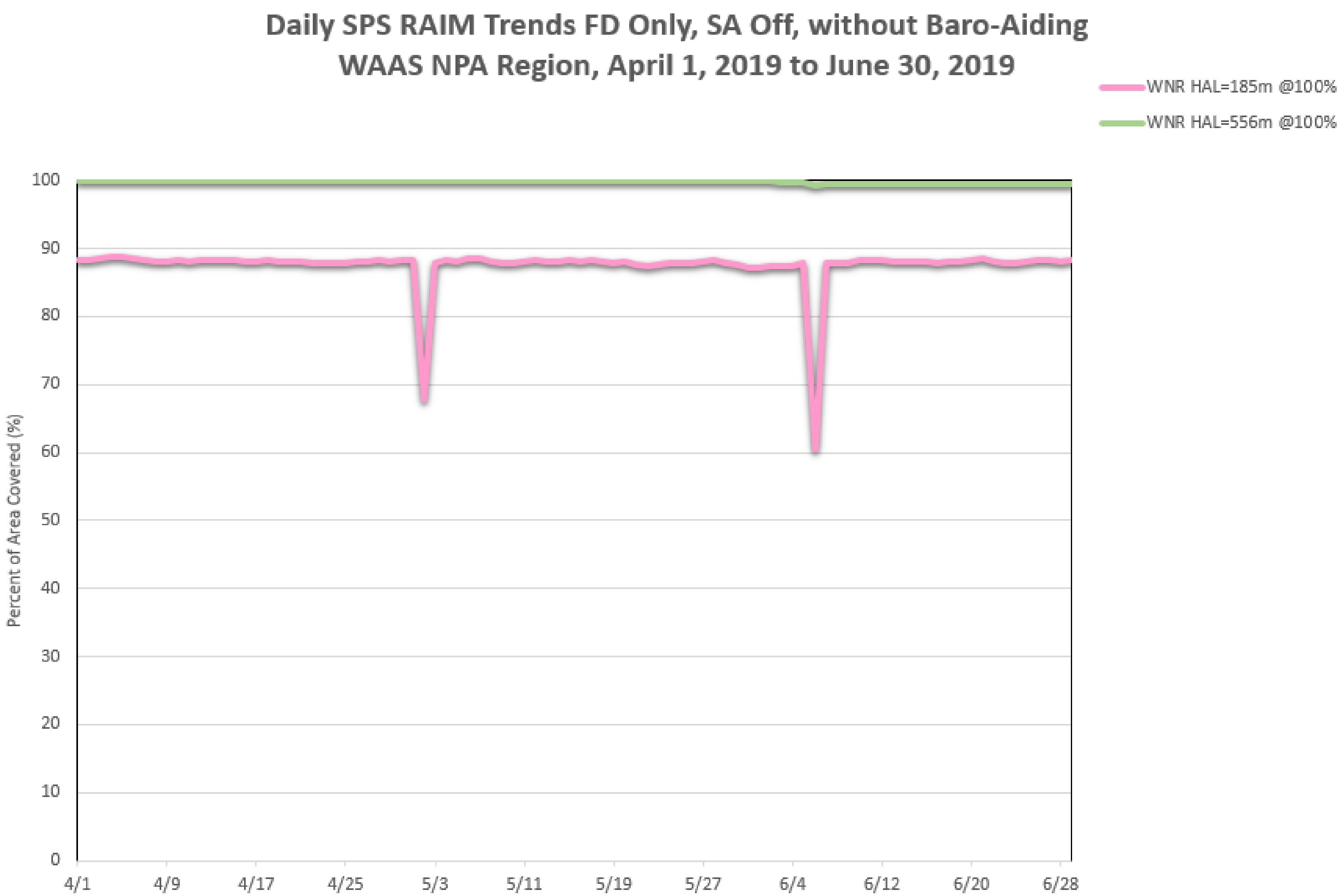


Figure 8-4 RAIM RNP Coverage Trend for WAAS NPA Service Area



8.3 RAIM Airport Analysis

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

Figure 8-5 RAIM RNP 0.1 Airport Availability

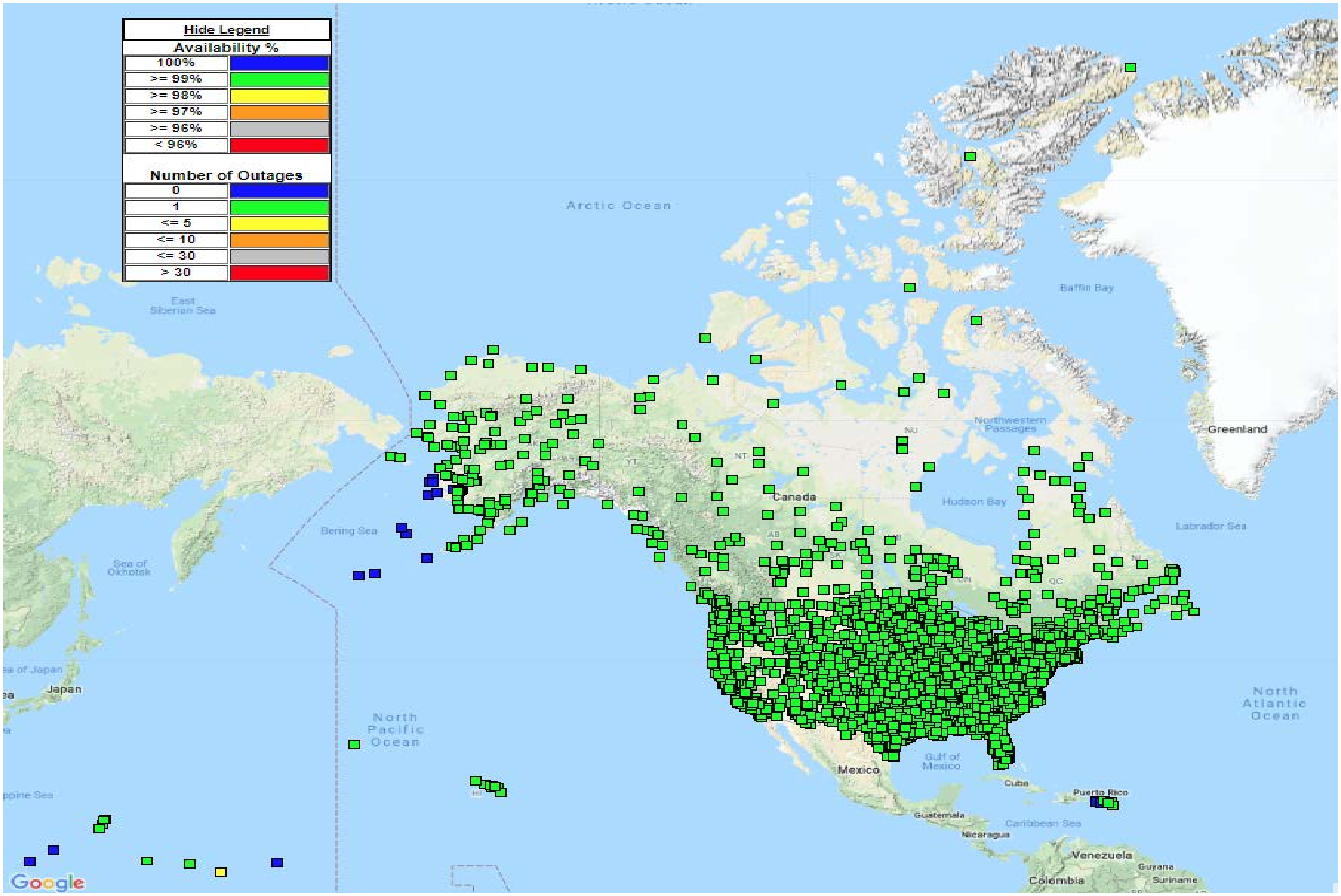


Figure 8-6 RAIM RNP 0.3 Airport Availability

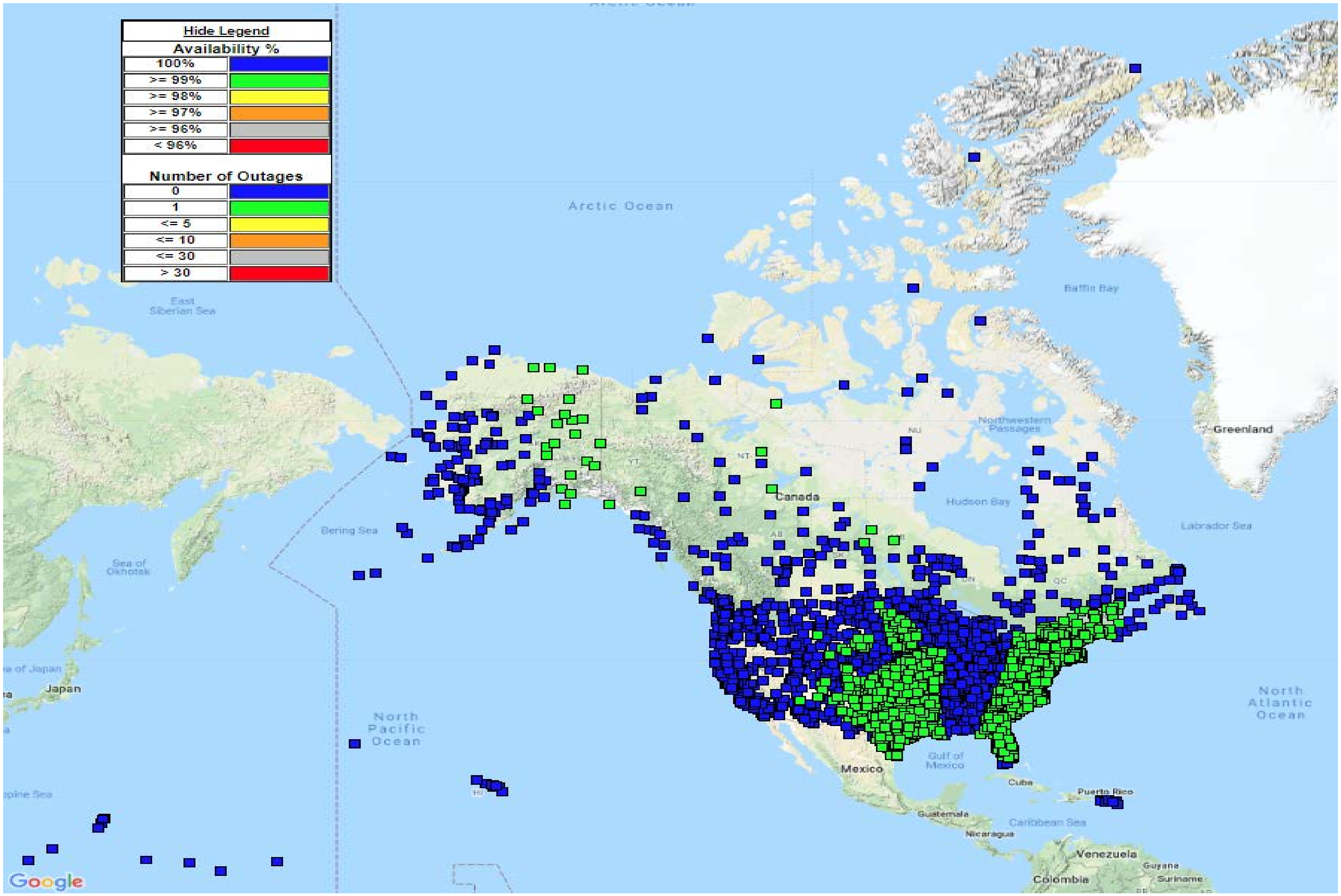


Figure 8-7 and Figure 8-8 respectively show the number of RAIM RNP 0.1 and RAIM RNP 0.3 outages for every airport in the U.S. and Canada that have a RNAV (GPS) published approach or better.

Figure 8-7 RAIM RNP 0.1 Airport Outages

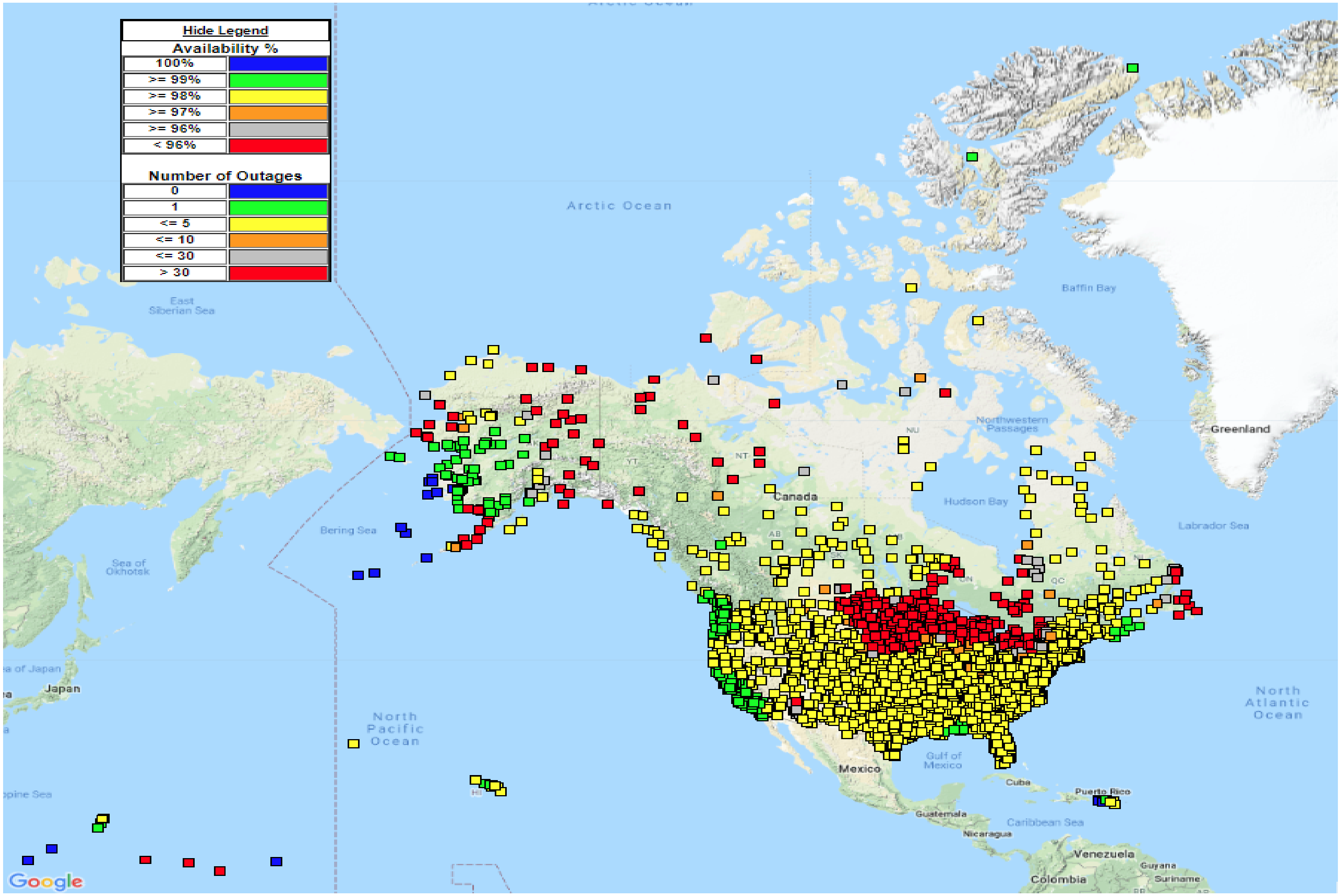
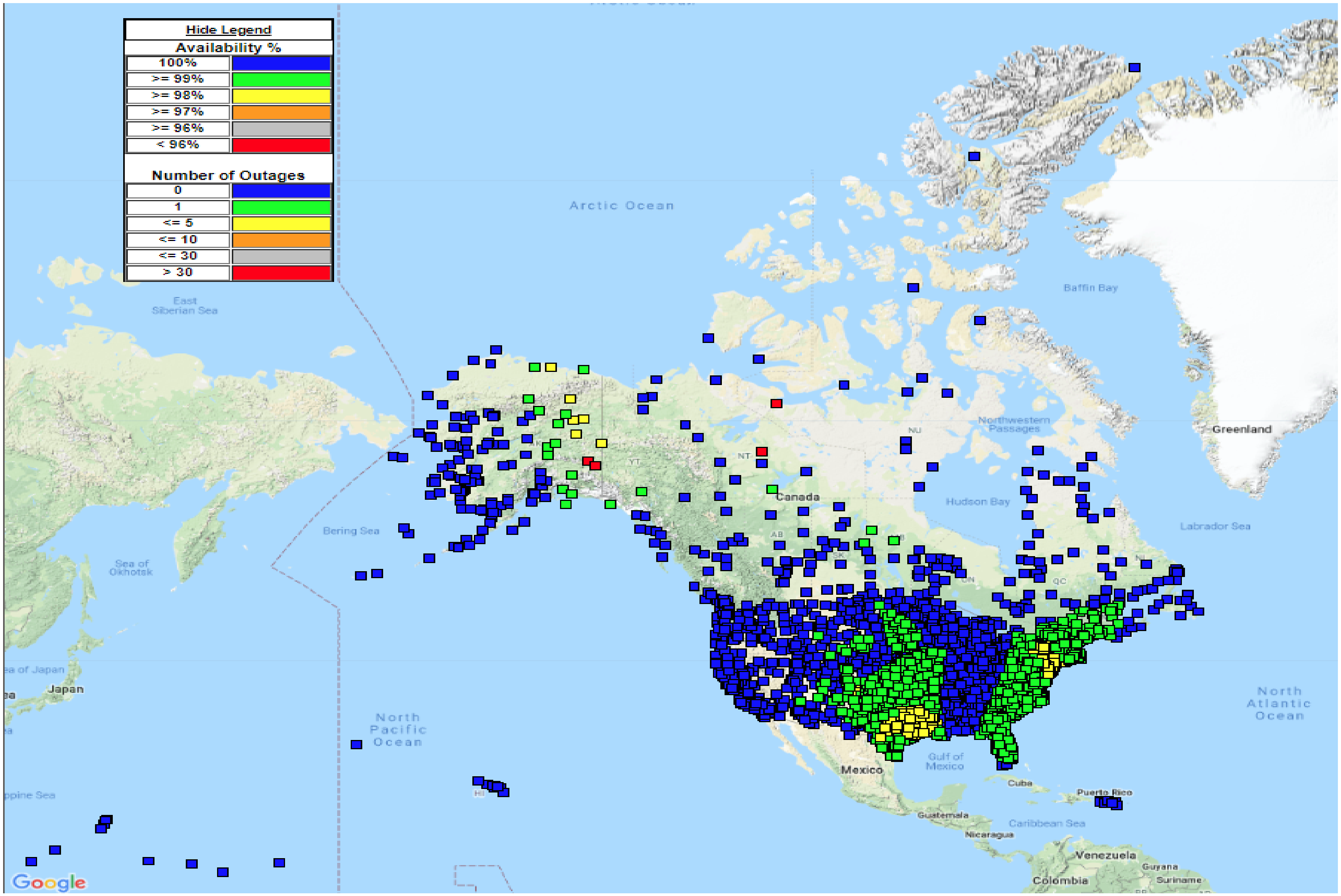


Figure 8-8 RAIM RNP 0.3 Airport Outages



9. GPS TEST NOTAMS SUMMARY

9.1 GPS Test NOTAMs Issued

Section 9 will be completed after publication of this report. It will be added upon completion.

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

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

The assumptions being validated are:

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

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

For C/A Nav data, all IGS high-rate 15-minute broadcast navigation data RINEX format files are downloaded and merged into 24-hour broadcast navigation data files which are then added to RINEX nav data files from all WAAS peripheral reference stations. A majority voting algorithm is used to screen the navigation data after a LSB recovery algorithm is applied. NGA APC precise ephemeris referenced to the GPS satellite antenna phase center is downloaded from the NGA site. GPS satellite positions are computed every 15 minutes and differenced with the precise orbits. The resulting error information is then segregated into the Height, Along Track, and Cross Track (HAC) error data. The standard deviation of those errors is then computed for each dimension for each satellite. Figure 10-1 through Figure 10-4 show the standard deviation results.

The assumption is valid if a 5.33 scaling of the standard deviation across all satellites is within the a priori. Three months of data from April 1 to June 30, 2019 is presented. Only data points in which GPS is healthy and valid precise data is available are considered. There was maintenance on PRN32 on 04/04/19 and 04/09/19, PRN22 on 04/12/19, PRN3 on 04/19/19, PRN1 on 04/24/19, PRN7 on 05/02/19, PRN20 on 06/06/19, and PRN2 on 06/23/19. Figure 10-5 shows the availability of C/A Nav data. There were no points where GPS was healthy and the NGA data was missing. 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 ACY NSTB 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.

Figure 10-7 and Figure 10-8 are URA (IAURA) over bounding plots. URA bounding using C/A Nav data used the maximum of the range indicated by the broadcast URA index. IAURA bounding using CNAV data used the algorithm from IS-GPS-200/IS-GPS-705. The error used in the analysis is at the location of maximum error in the footprint (usually edge of coverage). Review of the bounding plots, the QQ plots, and the histograms indicates that CNAV data is not as conservative as using the max URA from the C/A Nav data. The CNAV over bounding plot does not pass. Sparseness of data may have contributed to the failure to over bound. (i.e., using the full 3-hour fit interval at the beginning and end of tracks).

Figure 10-9 through Figure 10-58 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.

Figure 10-59 through Figure 10-70 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. The surface of the Earth Is approximated using +/-13.9-degrees from the bore sight of the satellite. The max URA of the broadcast URA index range is used for the C/A Nav data, and IAURA is used for the CNAV data. The range of the QQ plot axis has been fixed at +/-5. Annotations are provided for any instances beyond that range.

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

Figure 10-71 through 10-116 are histograms of the height error, along track error, cross track error, and URA (IAURA) normalized range error.

Figures 10-117 through Figure 10-162 are the timelines of the URA (IAURA) normalized range error. Missing data points are in red and are NANUs for the C/A data. The large number of red points in the CNAV data are the points where the satellites are out of view of ACY.

10.1 GPS Broadcast Orbit Accuracy Standard Deviation Plots

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

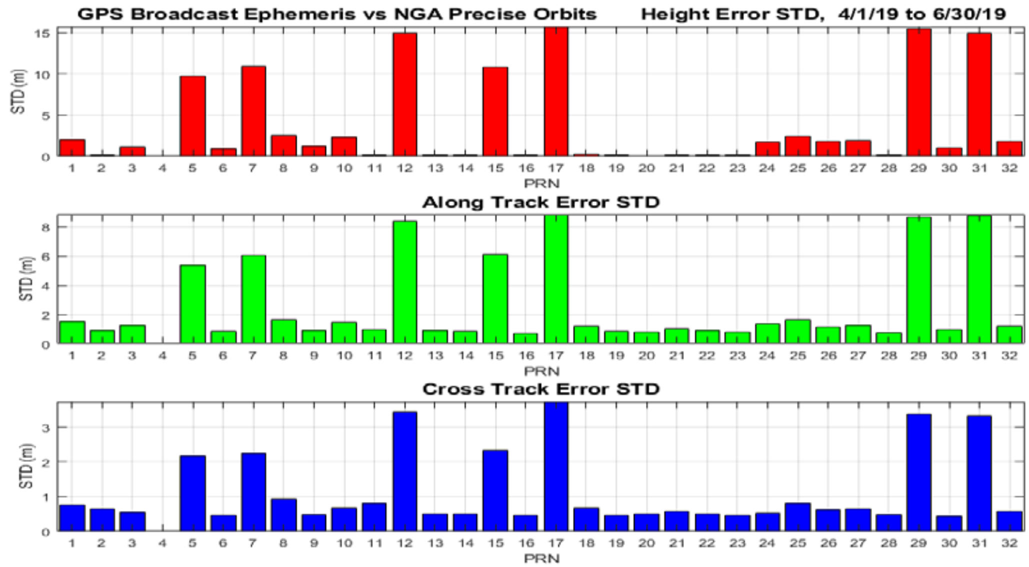


Figure 10-2 GPS Broadcast Orbit Accuracy Standard Deviations Using L2C CNAV Data

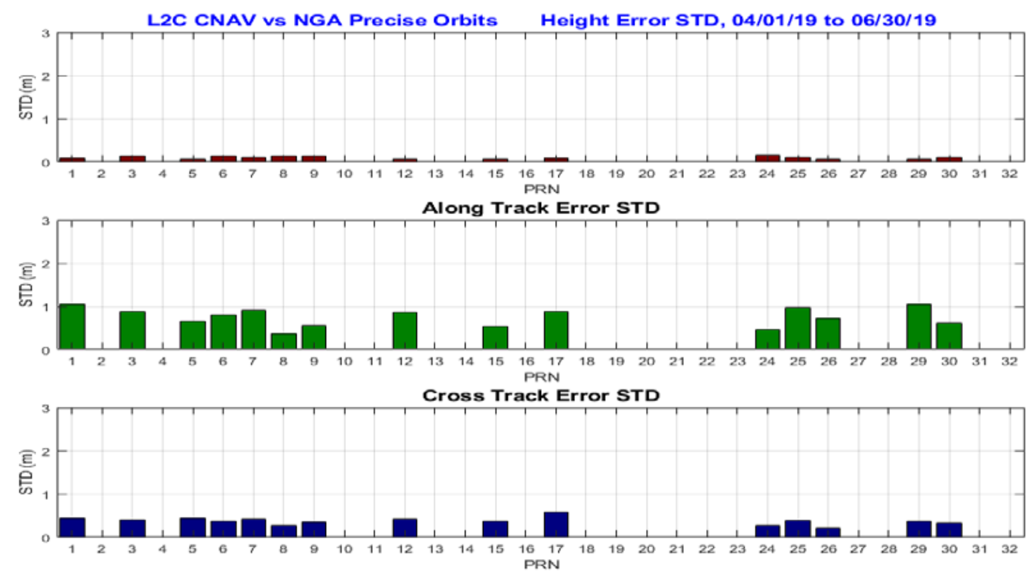


Figure 10-3 GPS Broadcast Orbit Error Means Using C/A Nav Data

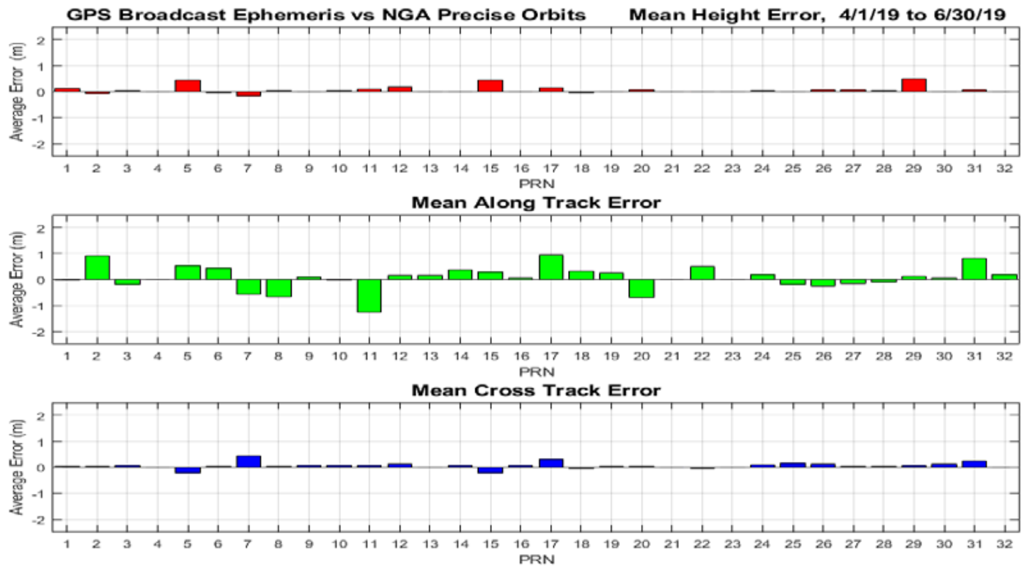
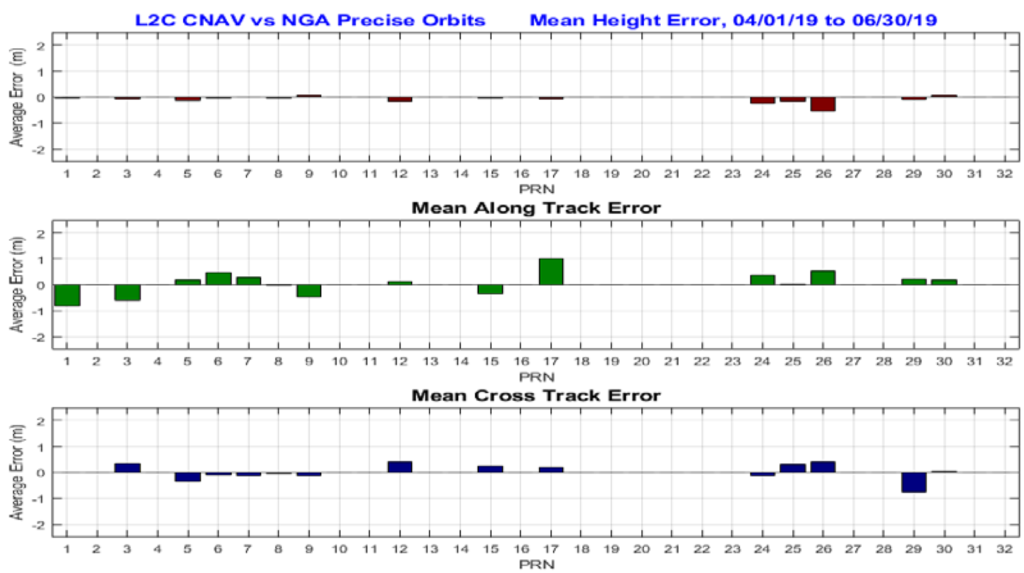
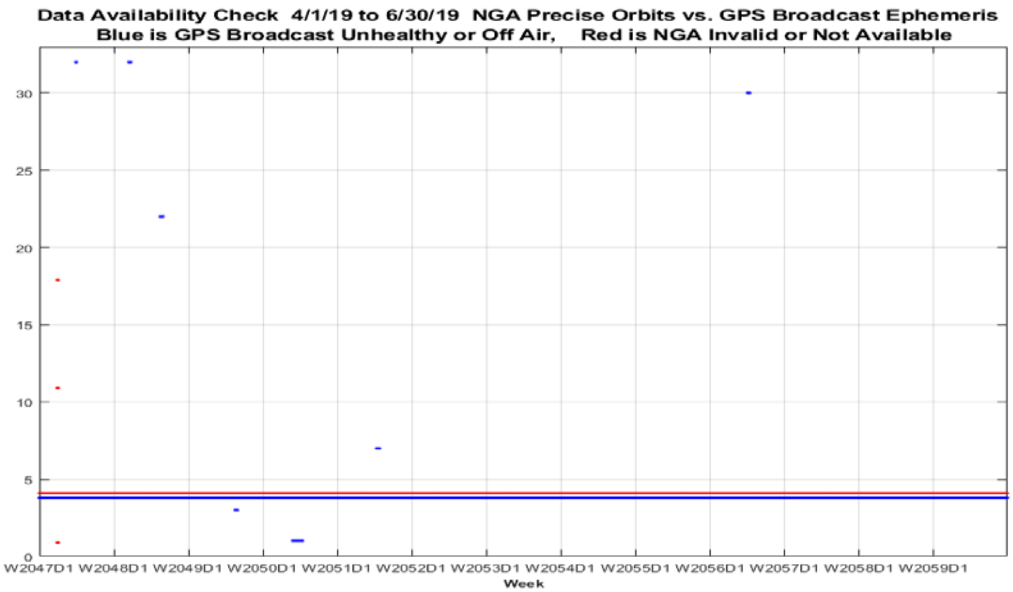


Figure 10-4 GPS Broadcast Orbit Error Means Using L2C CNAV Data



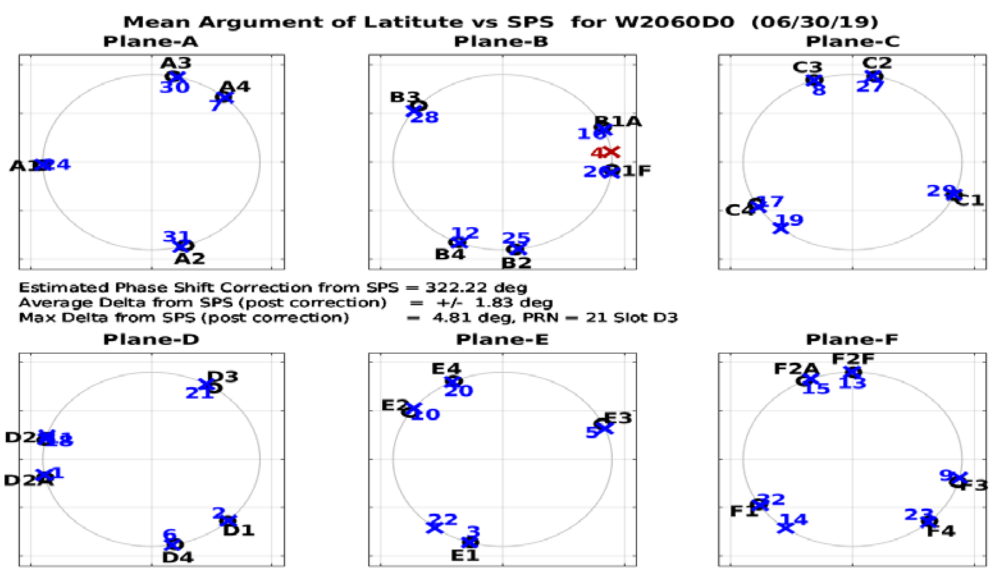
10.2 Broadcast Ephemeris vs. NGA Precise Data Availability Plots

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



10.3 Current GPS Constellation

Figure 10-6 Current GPS Constellation



10.4 URA Over-bounding Plots

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

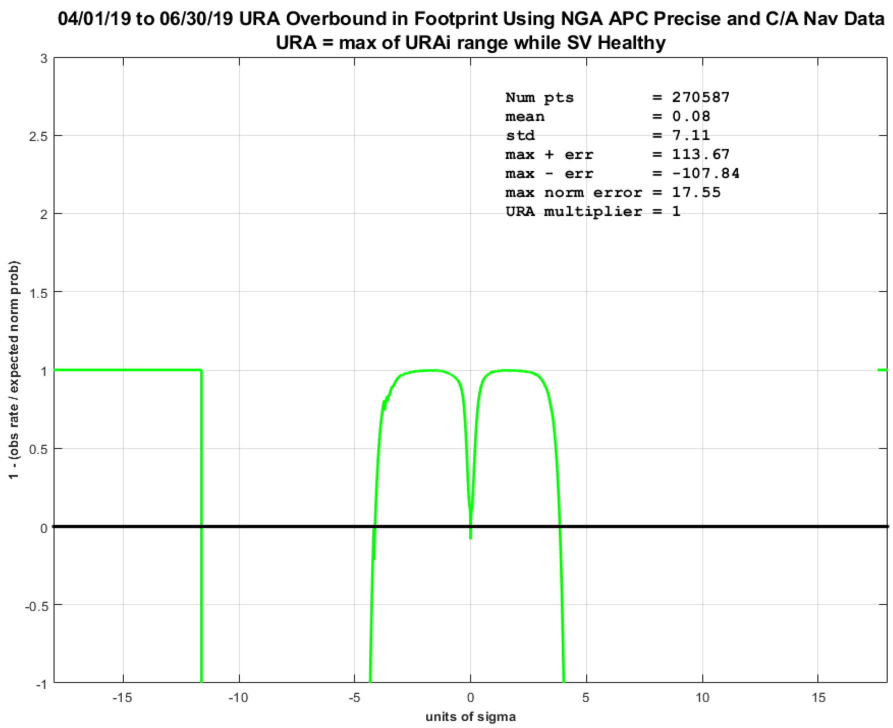
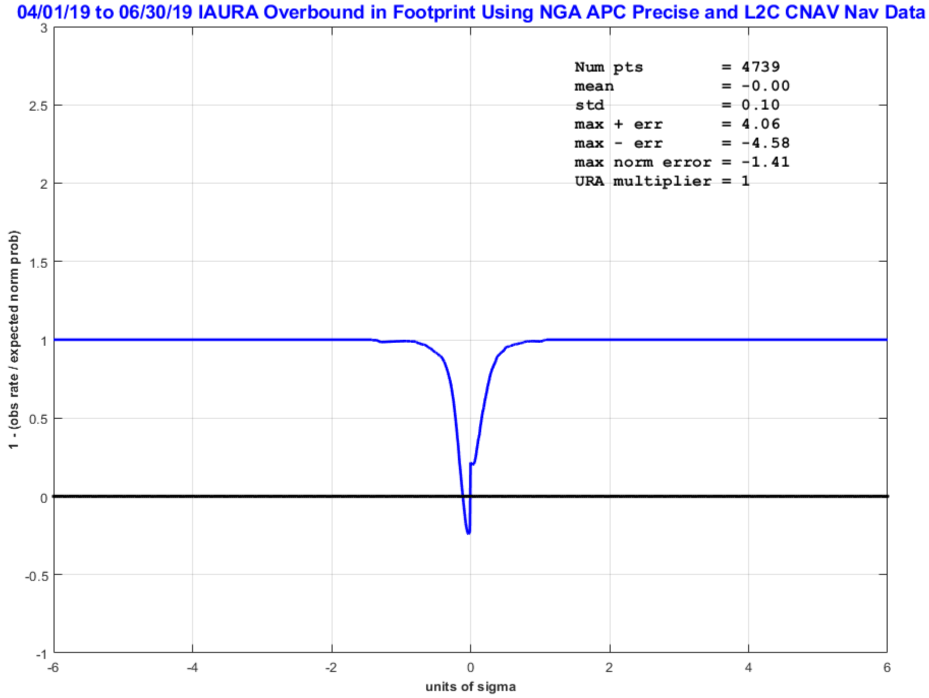


Figure 10-8 IAURA Over-bounding Using L2C CNAV Data



10.5 Orbit Error Plots for All Satellites

Figure 10-9 Orbit Error PRN-1 (SVN-63) Using C/A Nav Data

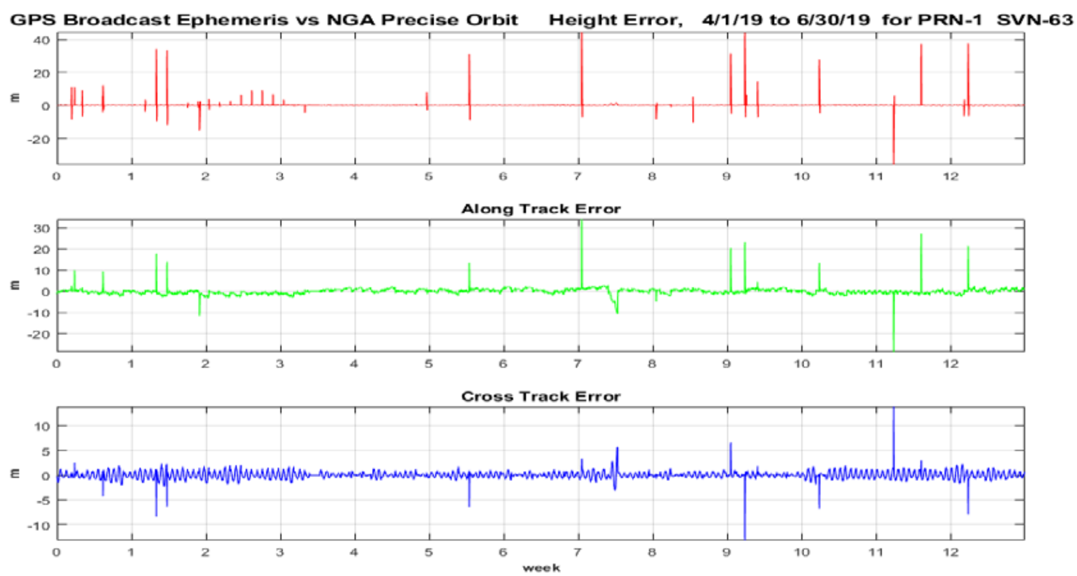


Figure 10-10 Orbit Error PRN-1 (SVN-63) Using L2C CNAV Data

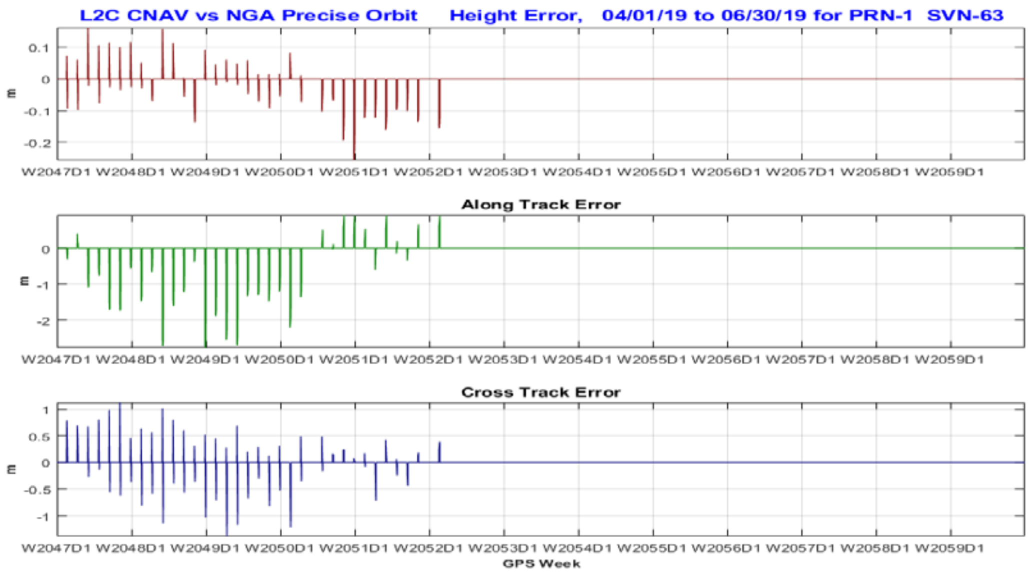


Figure 10-11 Orbit Error PRN-2 (SVN-61) Using C/A Nav Data

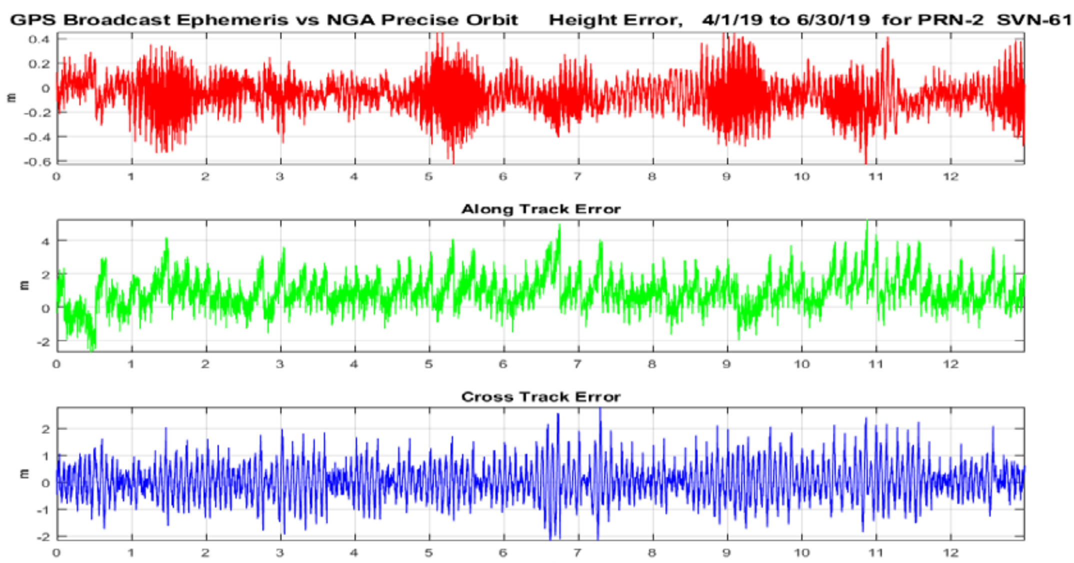


Figure 10-12 Orbit Error PRN-3 (SVN-69) Using C/A Nav Data

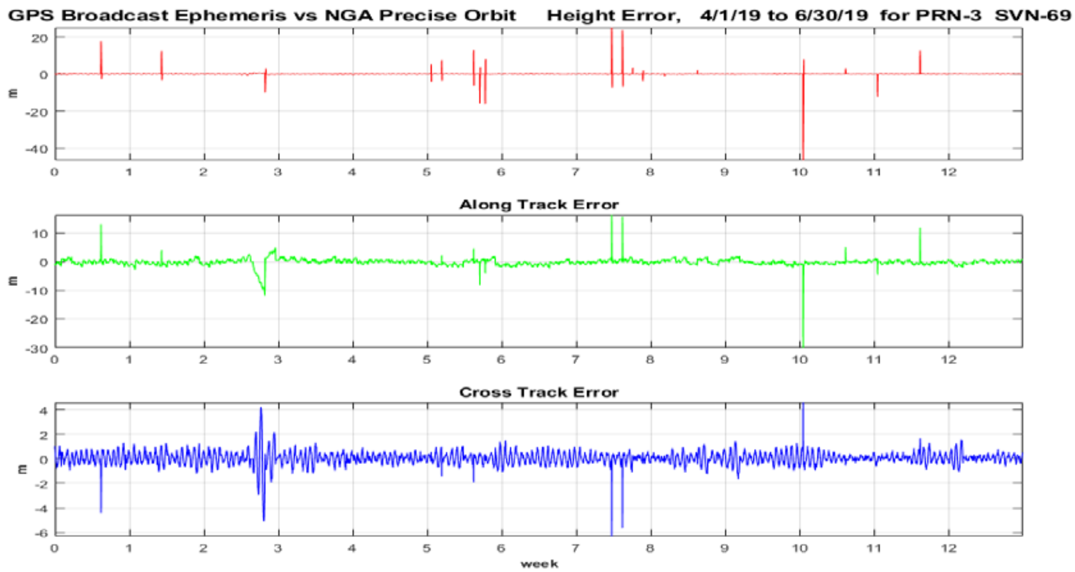


Figure 10-13 Orbit Error PRN-3 (SVN-69) Using L2C CNAV Data

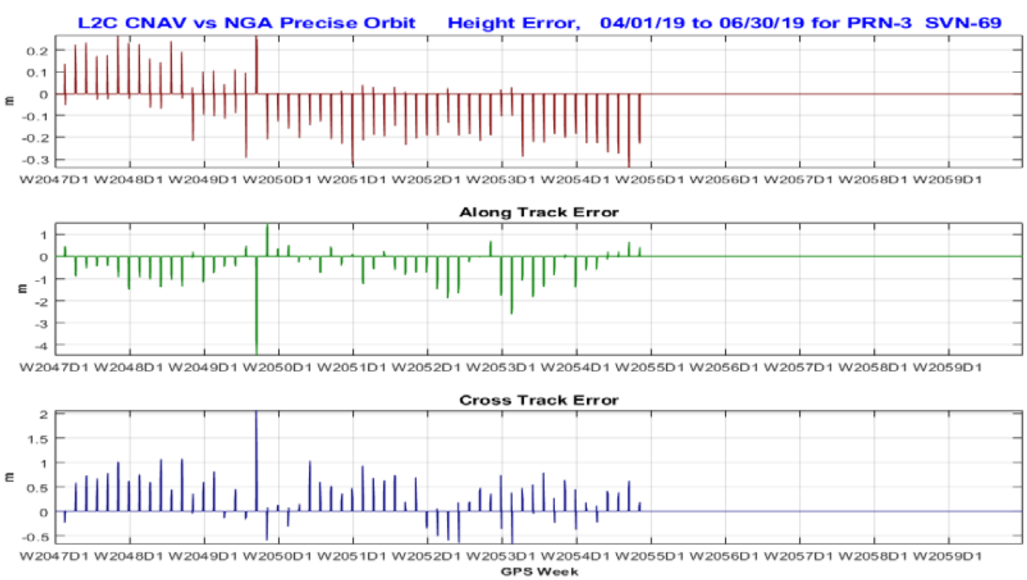


Figure 10-14 Orbit Error PRN-5 (SVN-50) Using C/A Nav Data

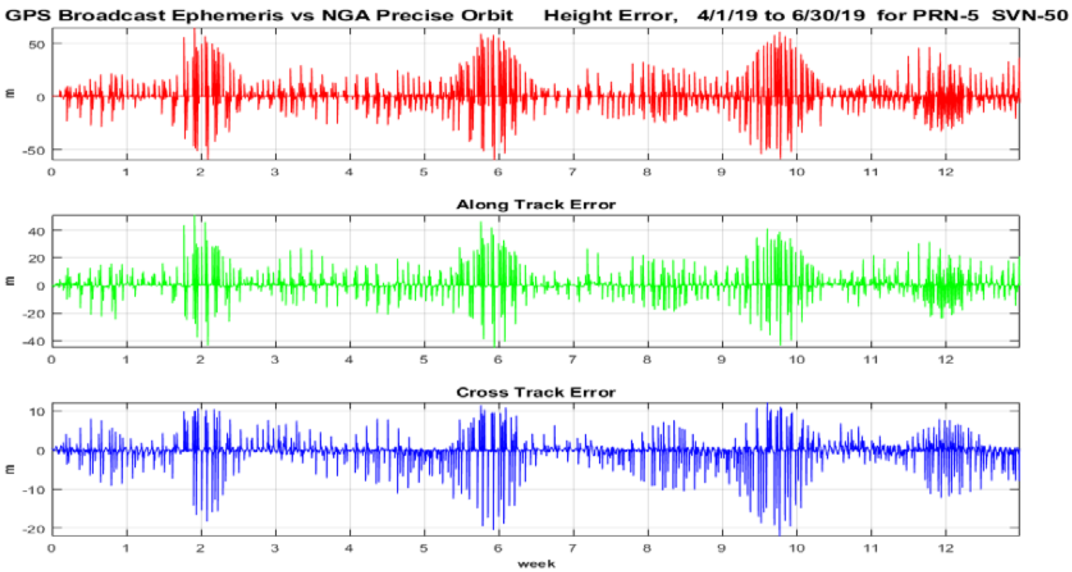


Figure 10-15 Orbit Error PRN-5 (SVN-50) Using L2C CNAV Data

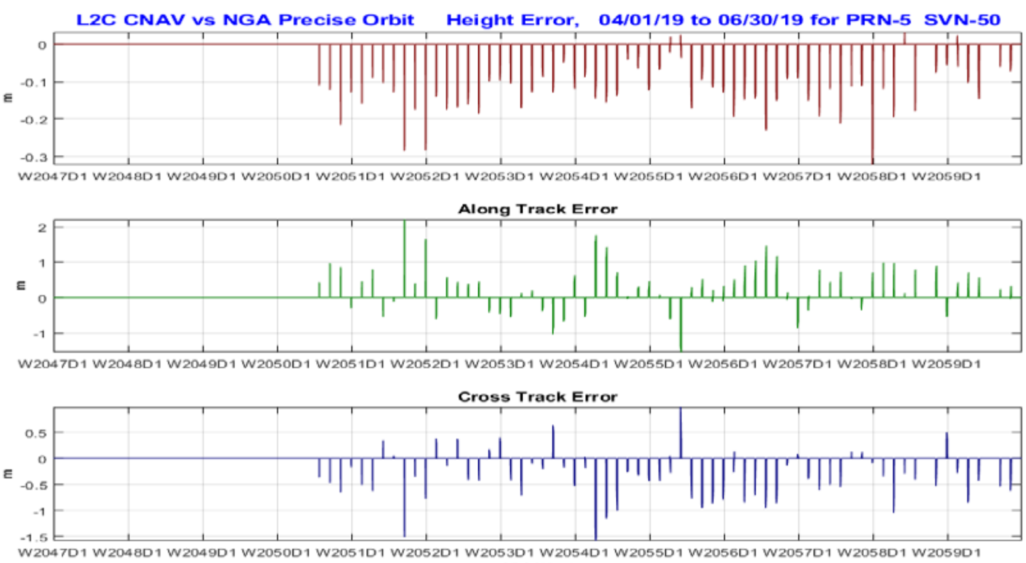


Figure 10-16 Orbit Error PRN-6 (SVN-67) Using C/A Nav Data

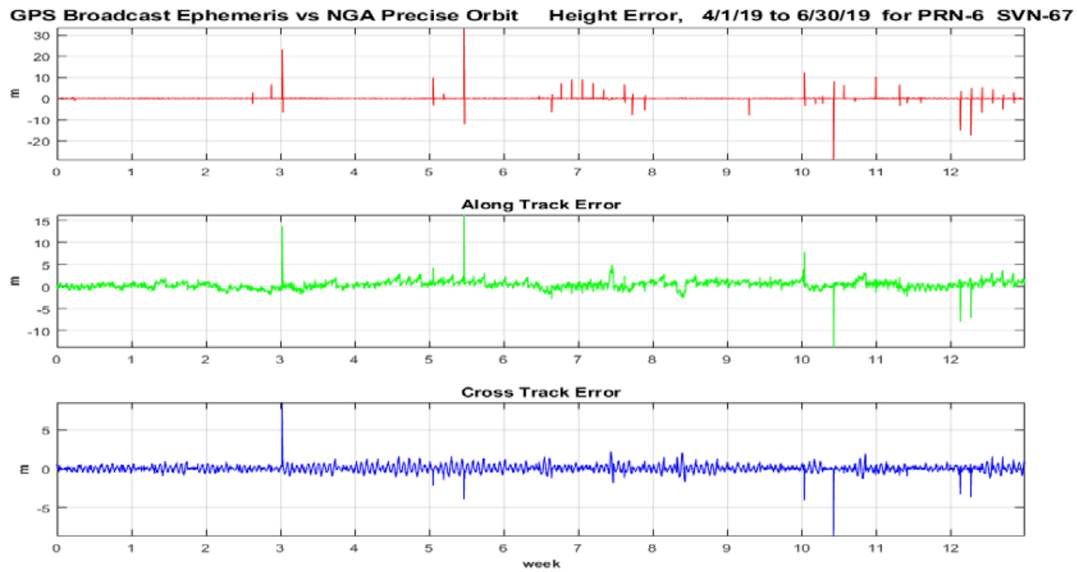


Figure 10-17 Orbit Error PRN-6 (SVN-67) Using L2C CNAV Data

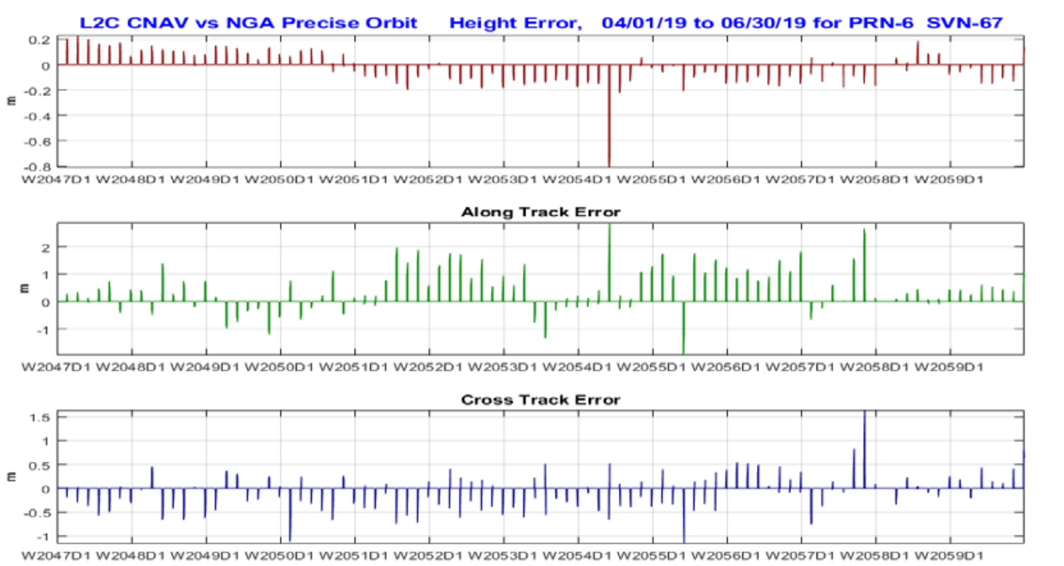


Figure 10-18 Orbit Error PRN-7 (SVN-48) Using C/A Nav Data

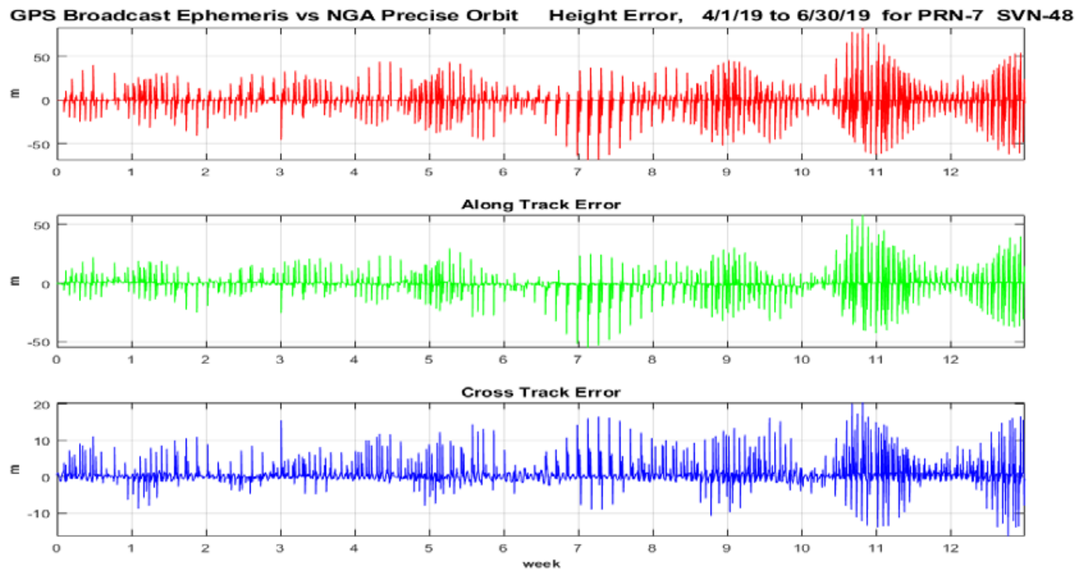


Figure 10-19 Orbit Error PRN-7 (SVN-48) Using L2C CNAV Data

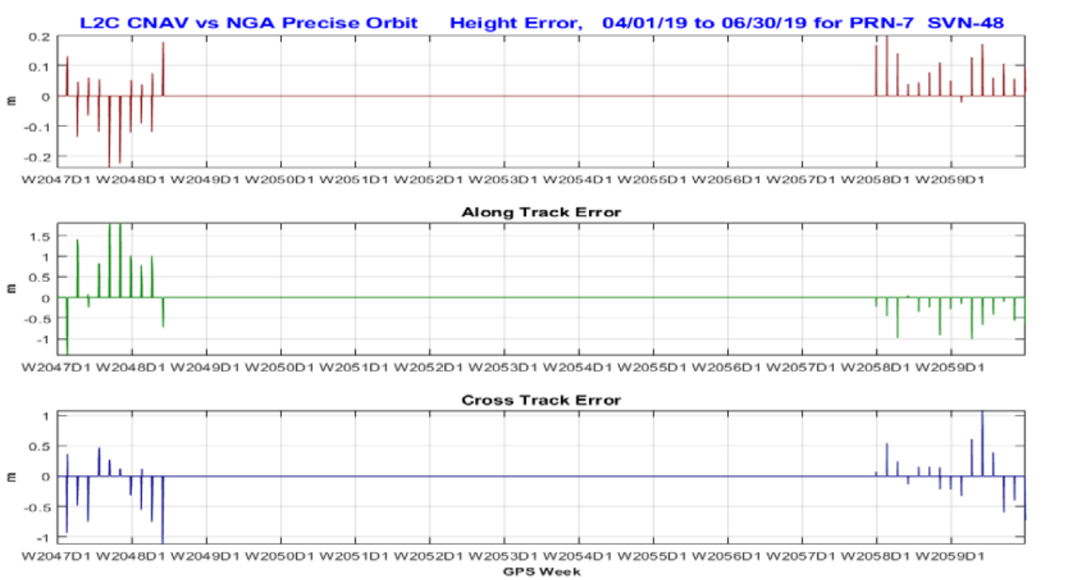


Figure 10-20 Orbit Error PRN-8 (SVN-72) Using C/A Nav Data

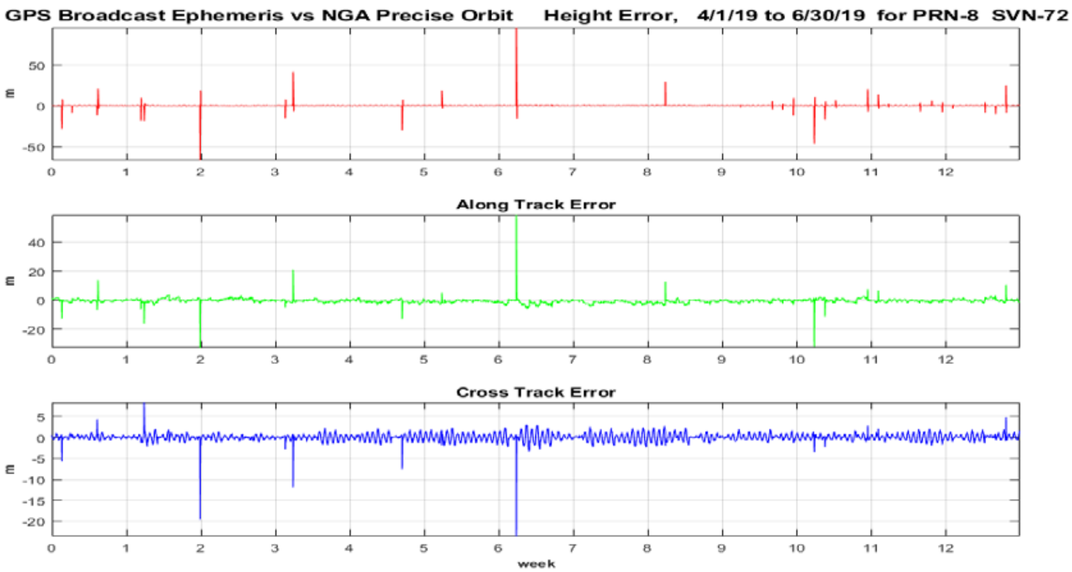


Figure 10-21 Orbit Error PRN-8 (SVN-72) Using L2C CNAV Data

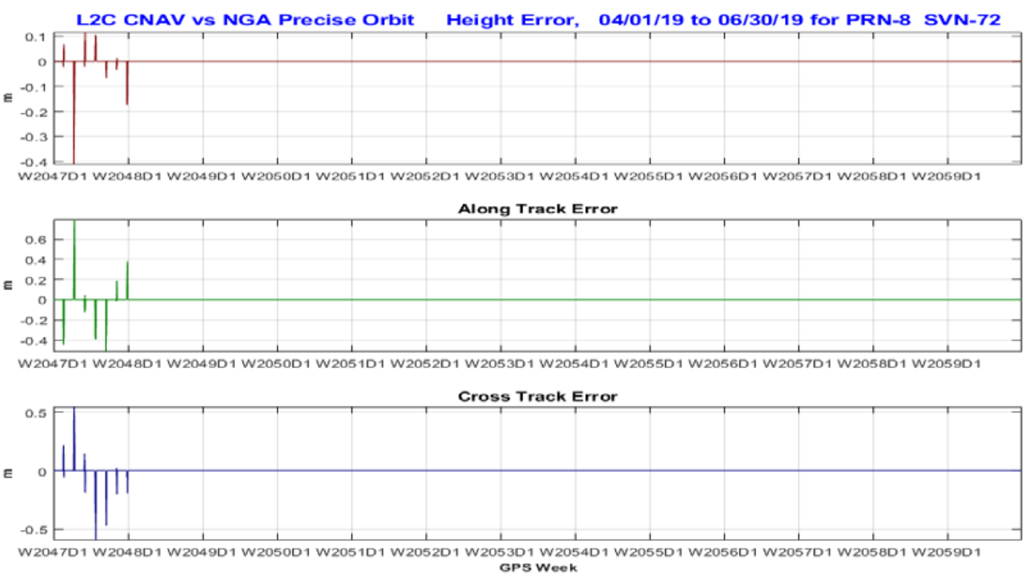


Figure 10-22 Orbit Error PRN-9 (SVN-68) Using C/A Nav Data

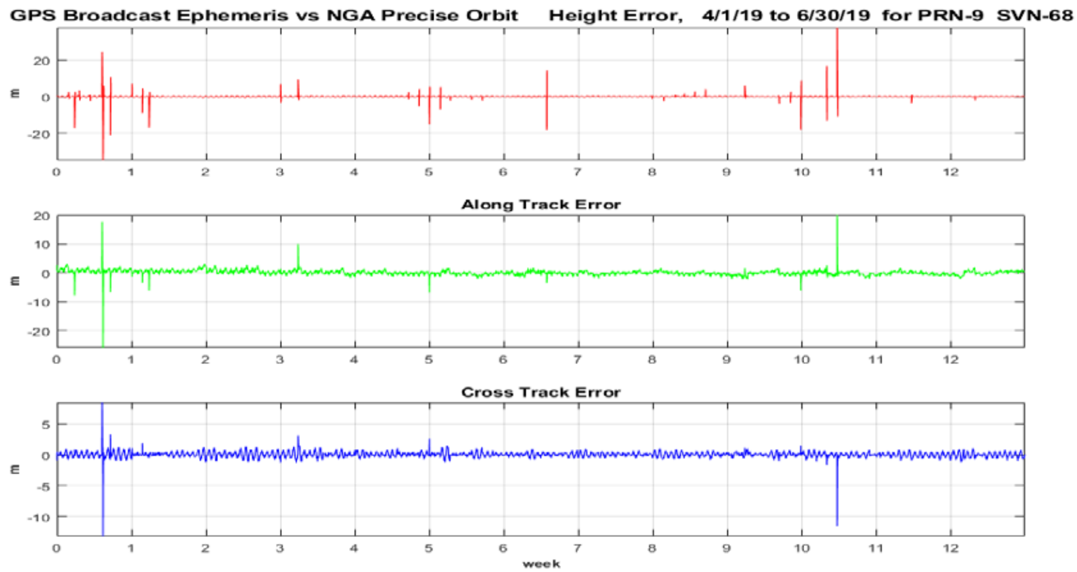


Figure 10-23 Orbit Error PRN-9 (SVN-68) Using L2C CNAV Data

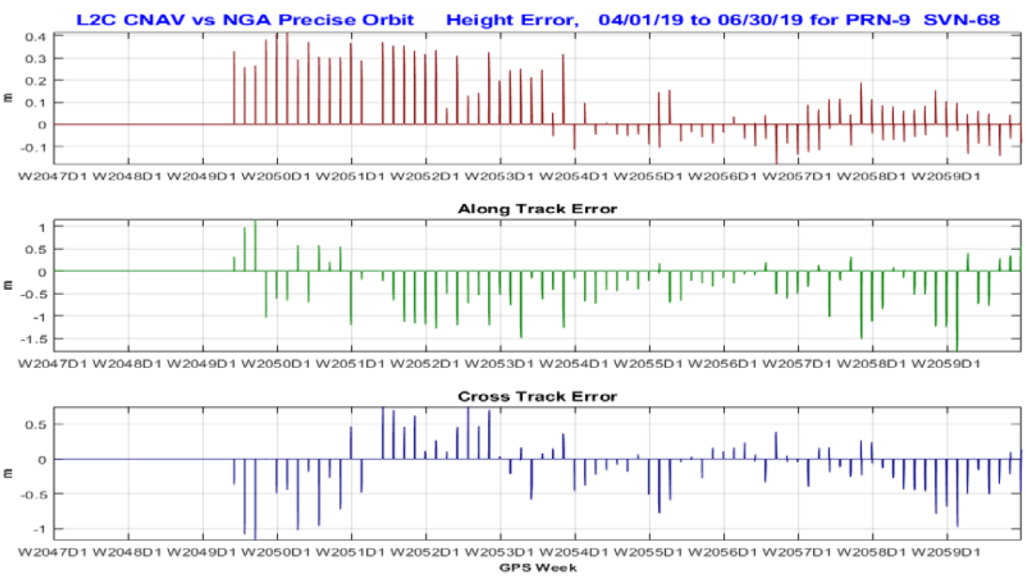


Figure 10-24 Orbit Error PRN-10 (SVN-73) Using C/A Nav Data

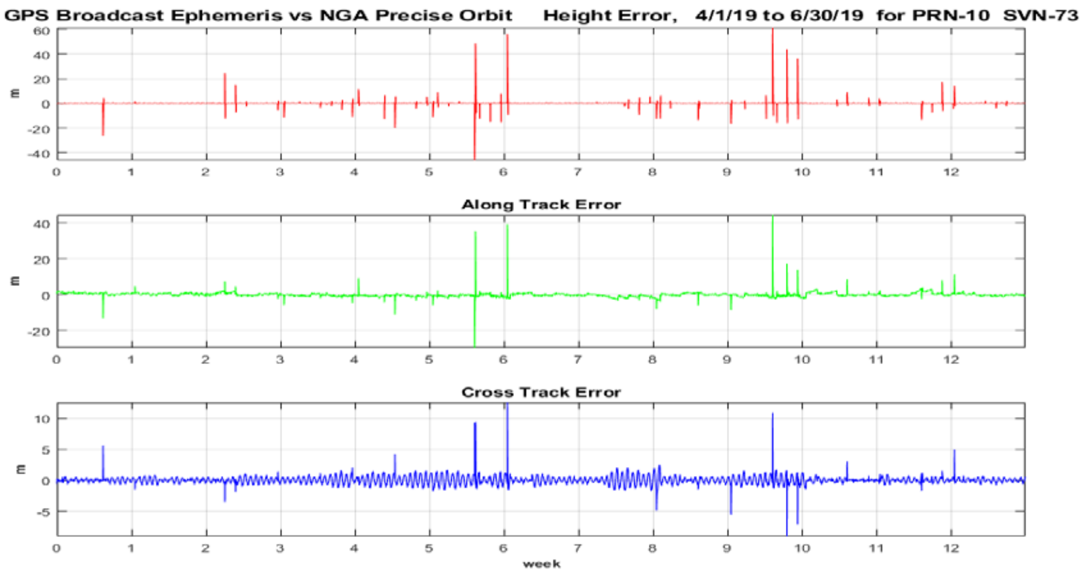


Figure 10-25 Orbit Error PRN-10 (SVN-73) Using L2C CNAV Data

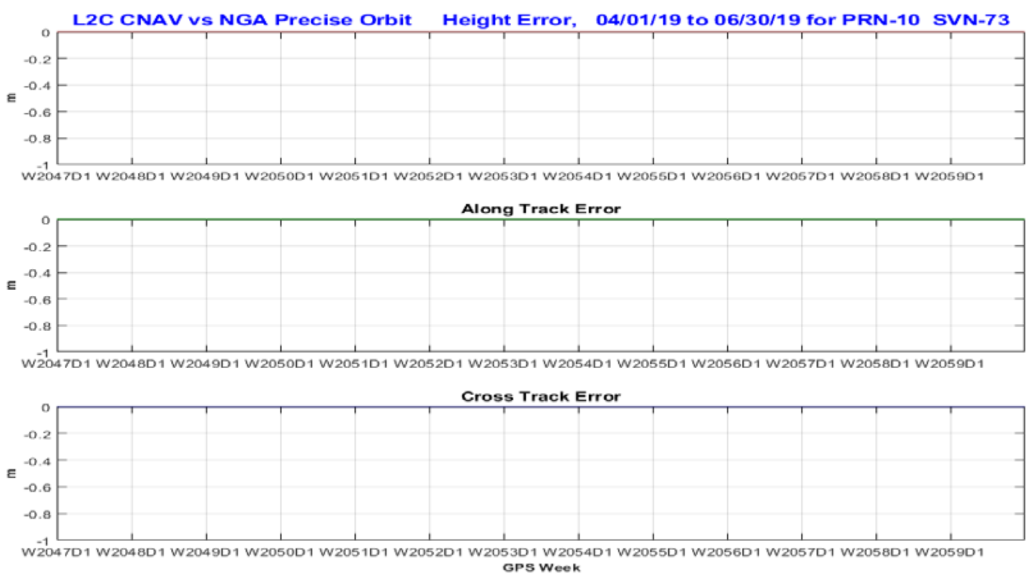


Figure 10-26 Orbit Error PRN-11 (SVN-46) Using C/A Nav Data

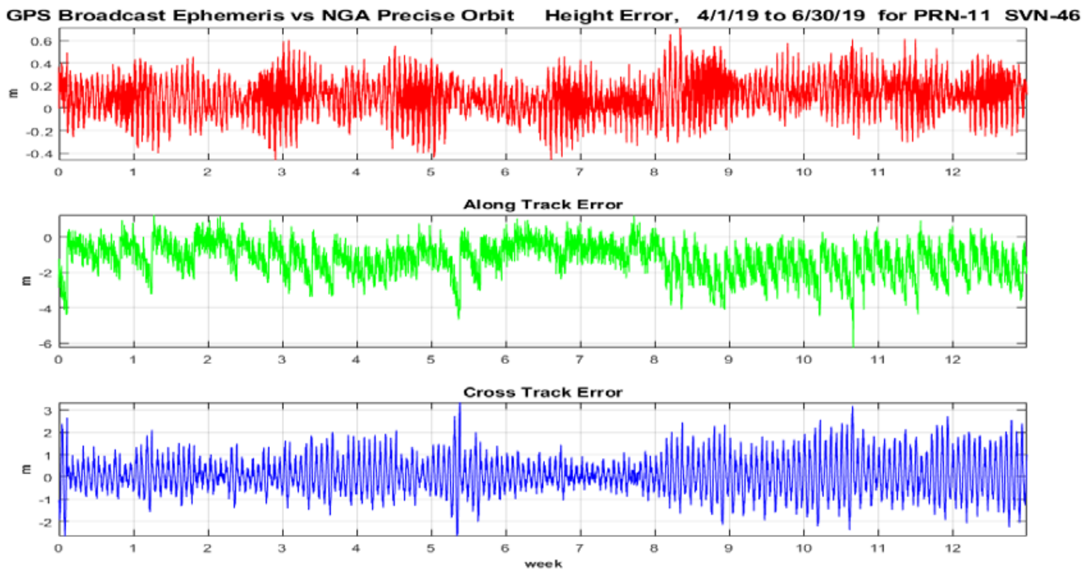


Figure 10-27 Orbit Error PRN-12 (SVN-58) Using C/A Nav Data

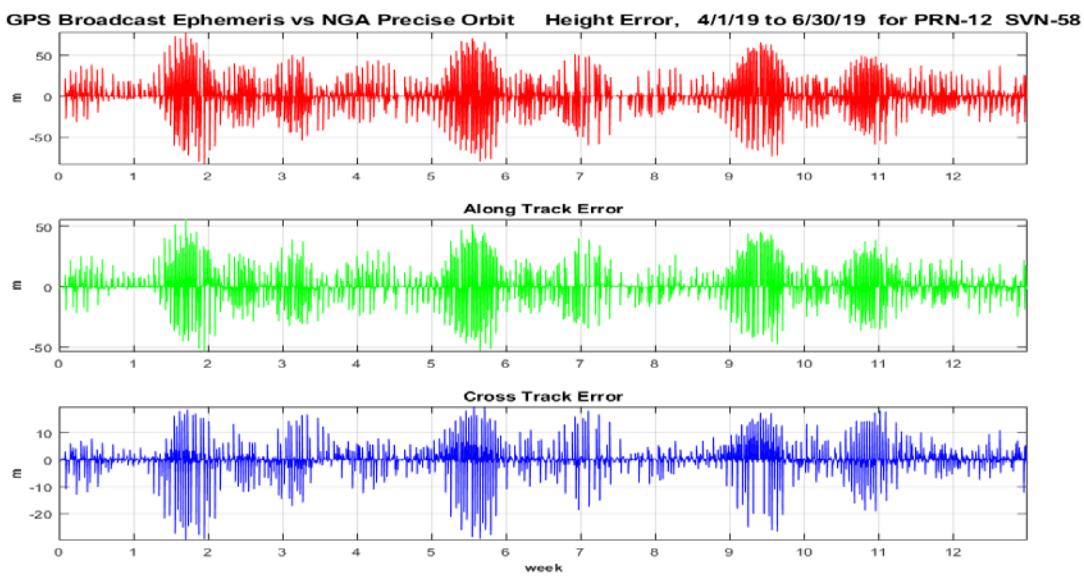


Figure 10-28 Orbit Error PRN-12 (SVN-58) Using L2C CNAV Data

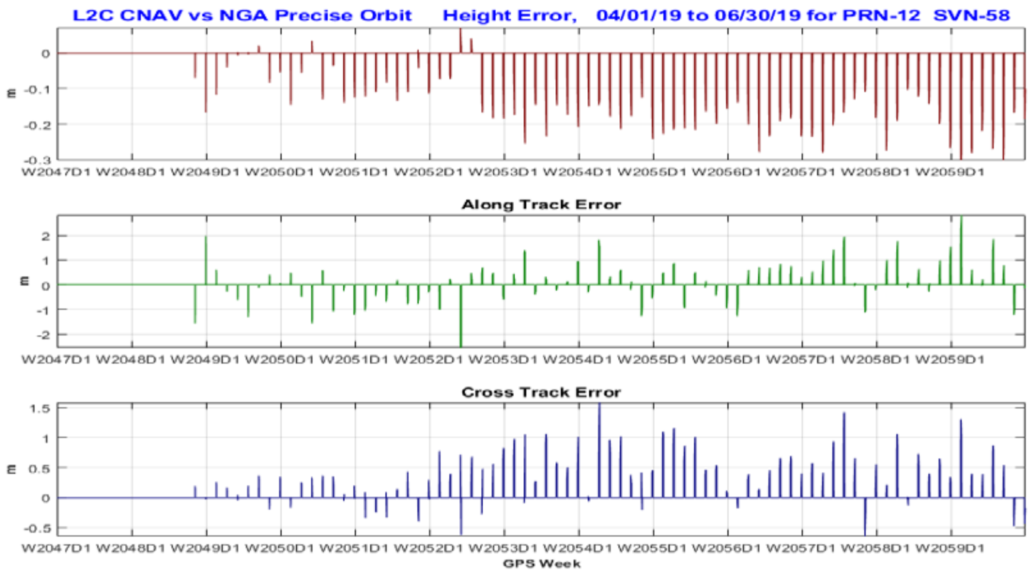


Figure 10-29 Orbit Error PRN-13 (SVN-43) Using C/A Nav Data

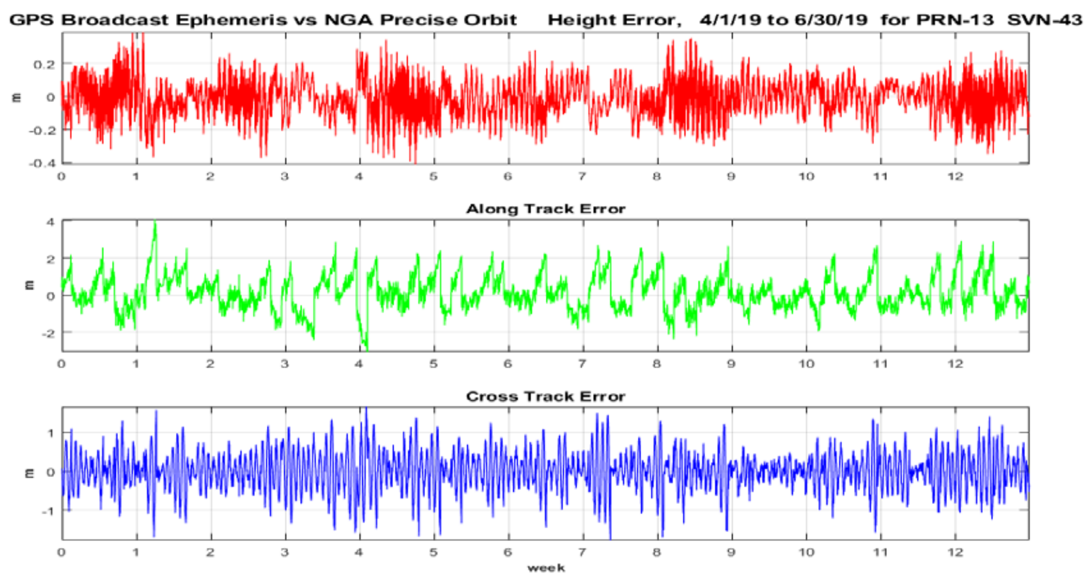


Figure 10-30 Orbit Error PRN-14 (SVN-41) Using C/A Nav Data

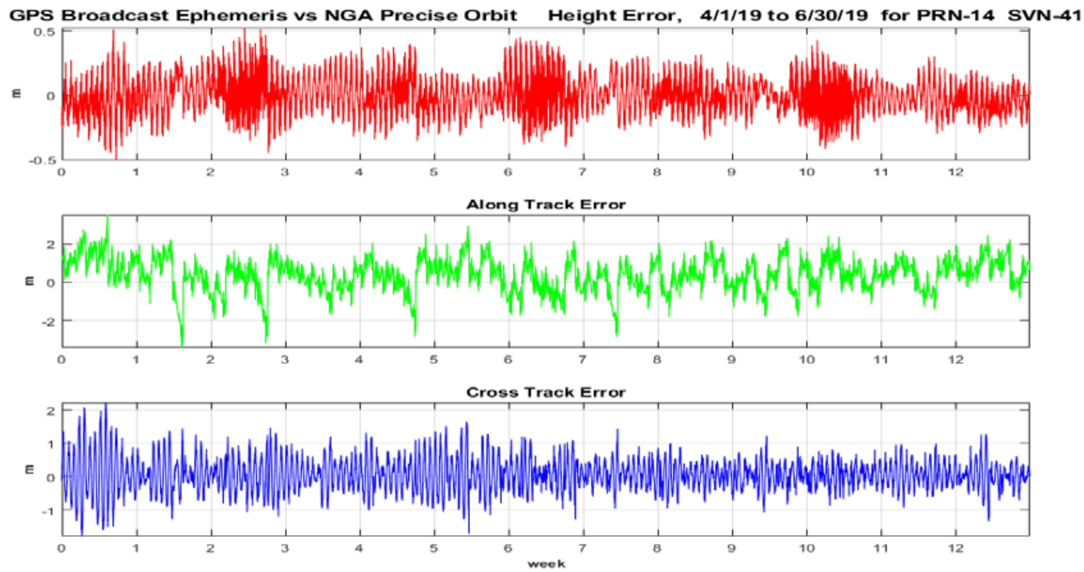


Figure 10-31 Orbit Error PRN-15 (SVN-55) Using C/A Nav Data

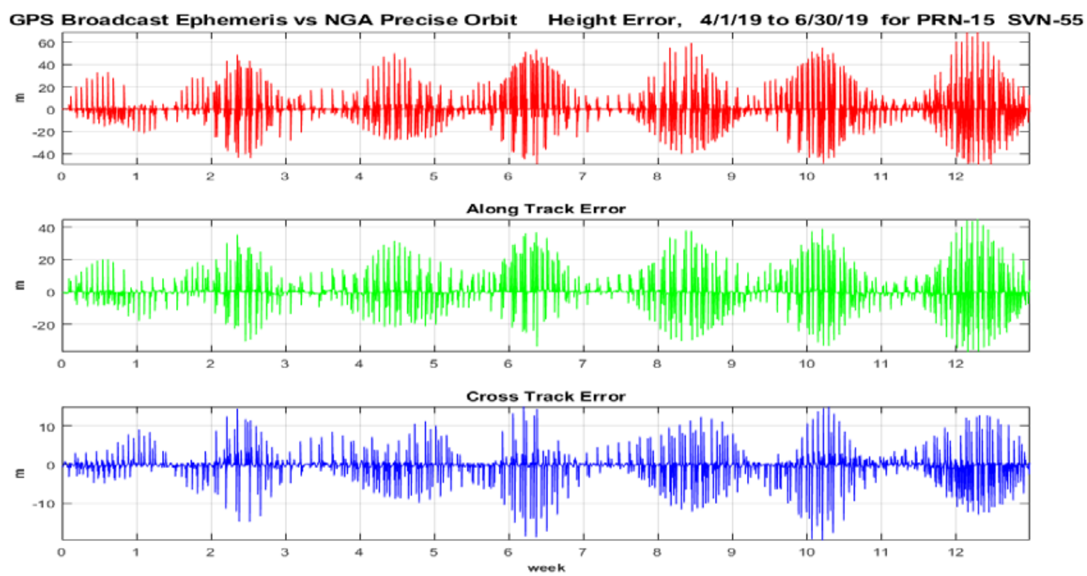


Figure 10-32 Orbit Error PRN-15 (SVN-55) Using L2C CNAV Data

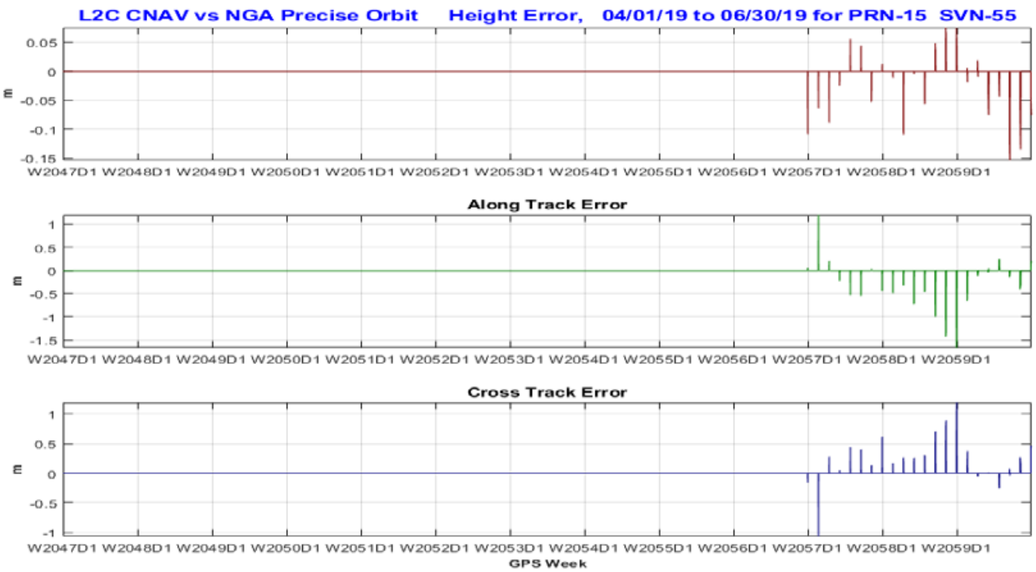


Figure 10-33 Orbit Error PRN-16 (SVN-56) Using C/A Nav Data

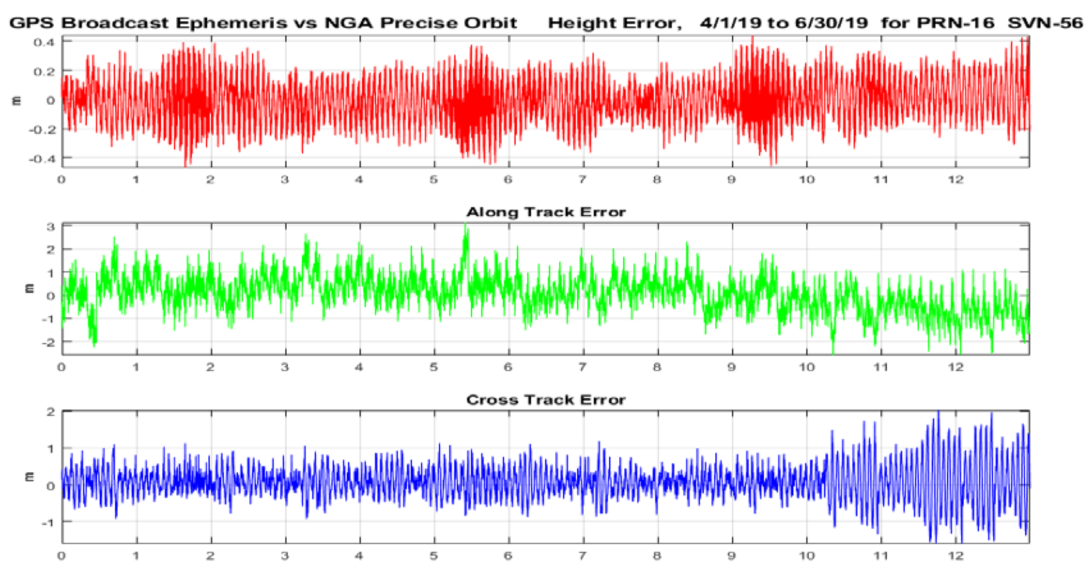


Figure 10-34 Orbit Error PRN-17 (SVN-53) Using C/A Nav Data

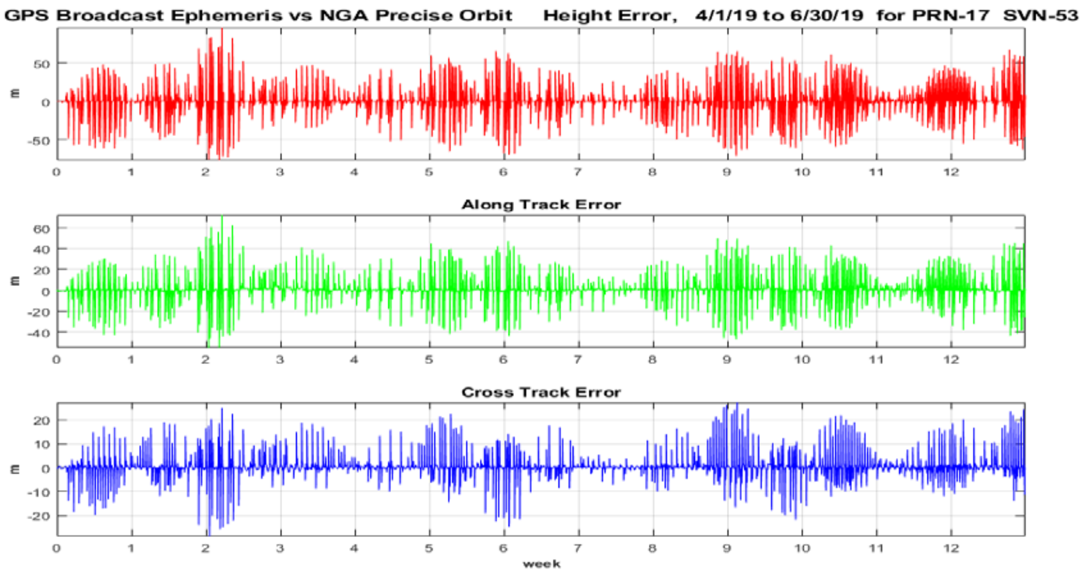


Figure 10-35 Orbit Error PRN-17 (SVN-53) Using L2C CNAV Data

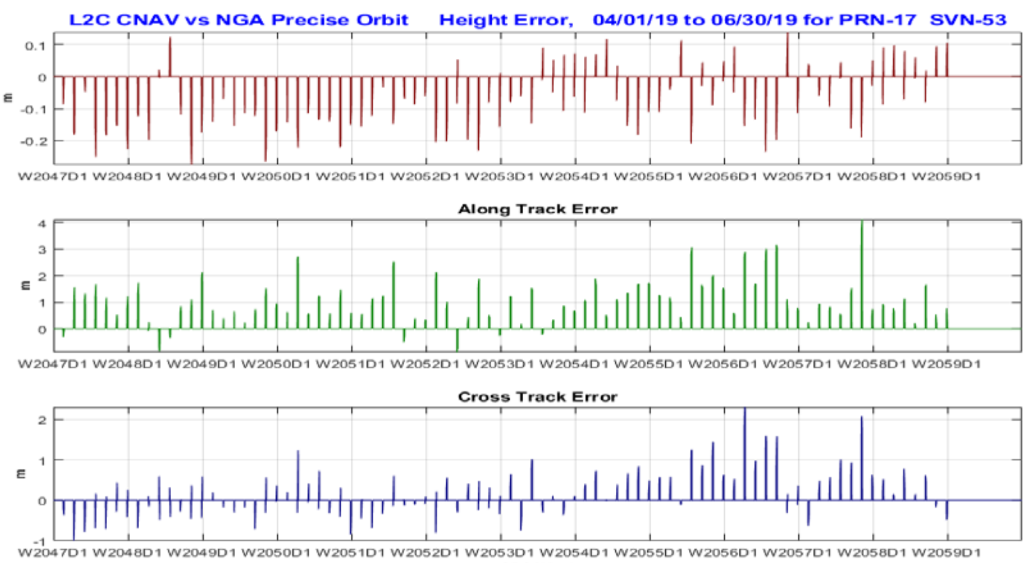


Figure 10-36 Orbit Error PRN-18 (SVN-34) Using C/A Nav Data

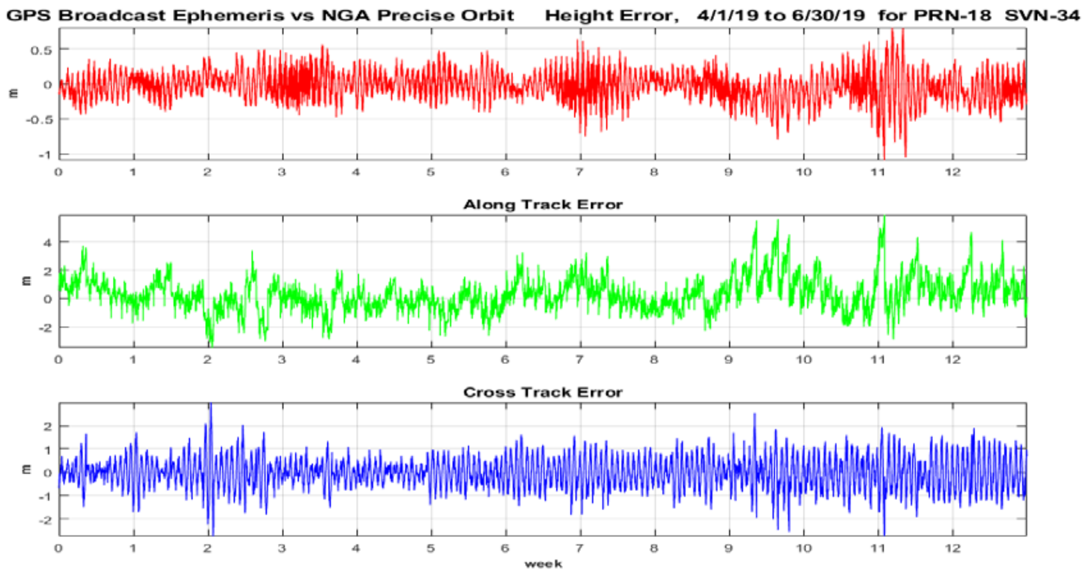


Figure 10-37 Orbit Error PRN-19 (SVN-59) Using C/A Nav Data

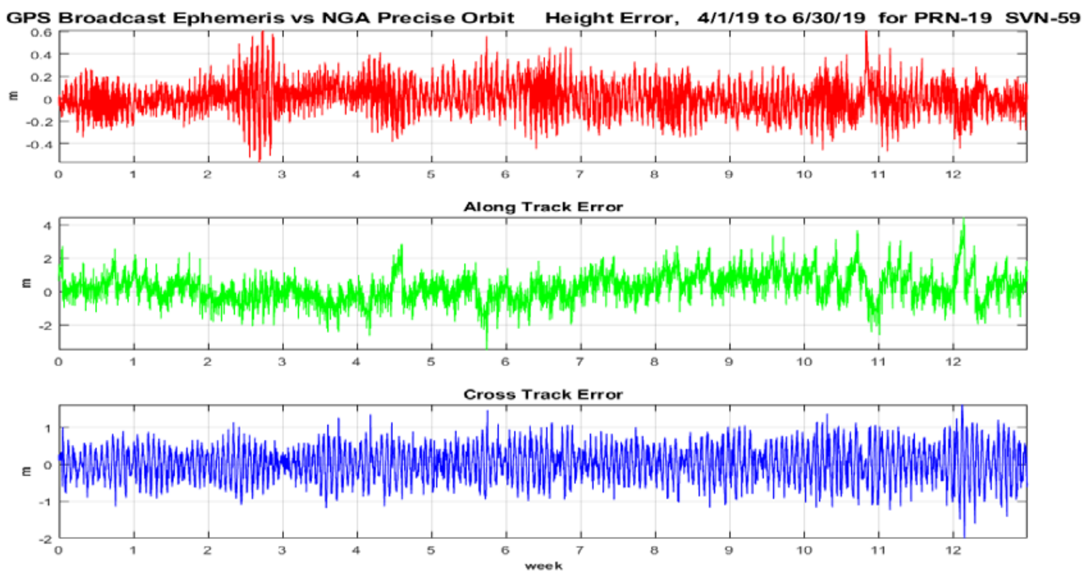


Figure 10-38 Orbit Error PRN-20 (SVN-51) Using C/A Nav Data

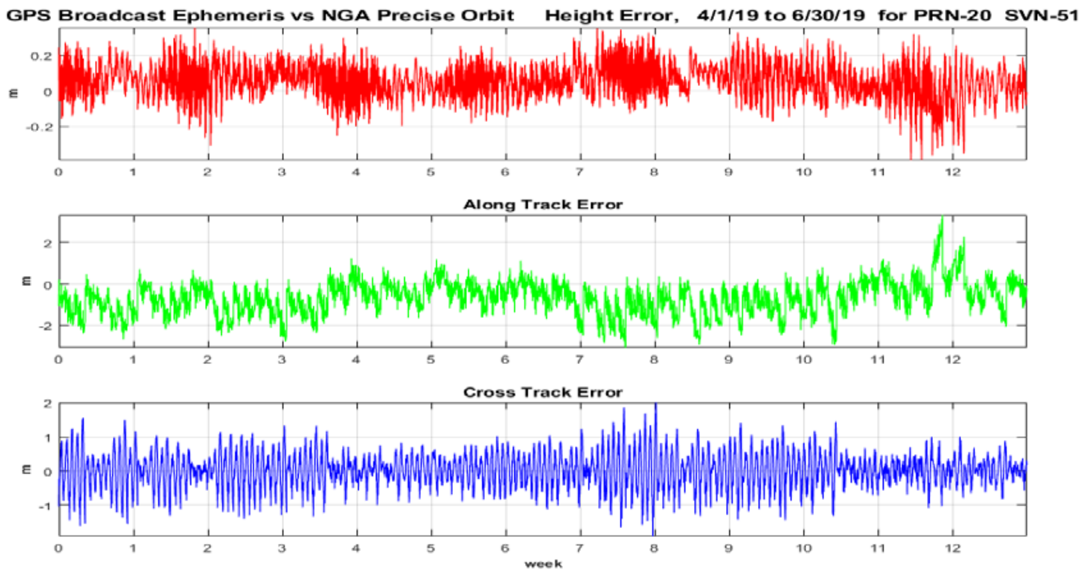


Figure 10-39 Orbit Error PRN-21 (SVN-45) Using C/A Nav Data

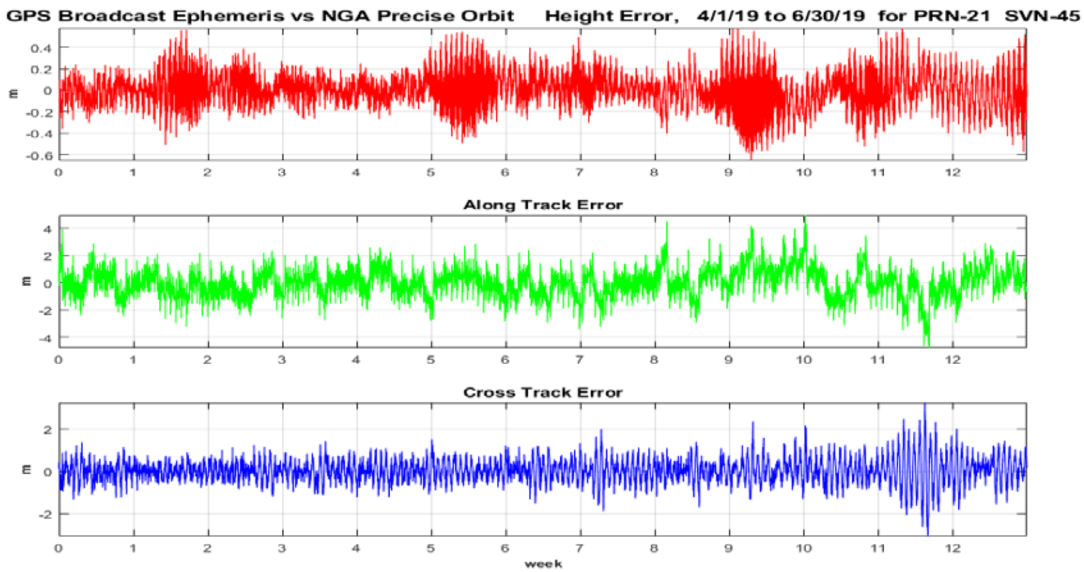


Figure 10-40 Orbit Error PRN-22 (SVN-47) Using C/A Nav Data

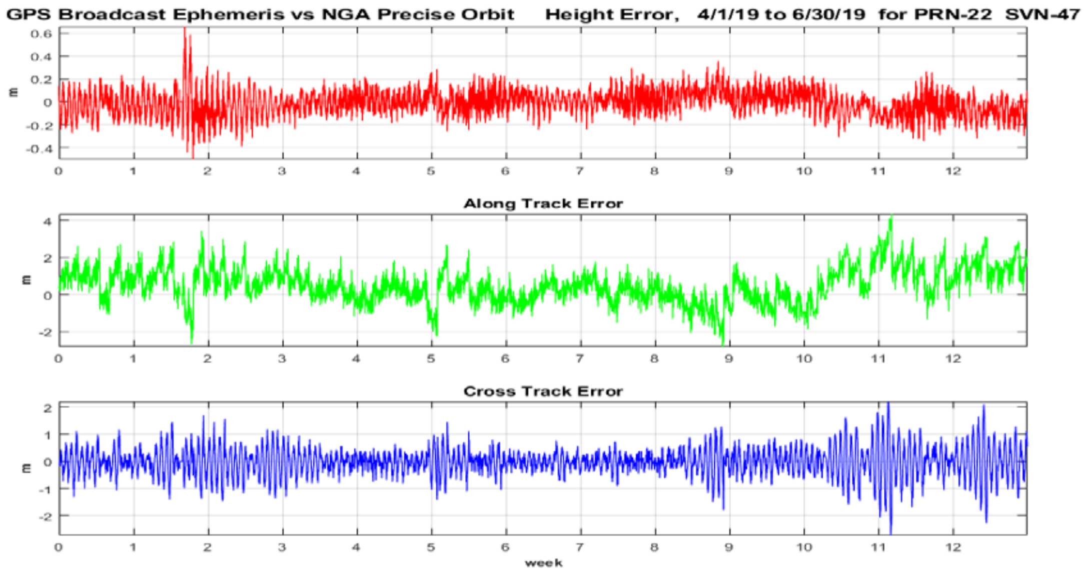


Figure 10-41 Orbit Error PRN-23 (SVN-60) Using C/A Nav Data

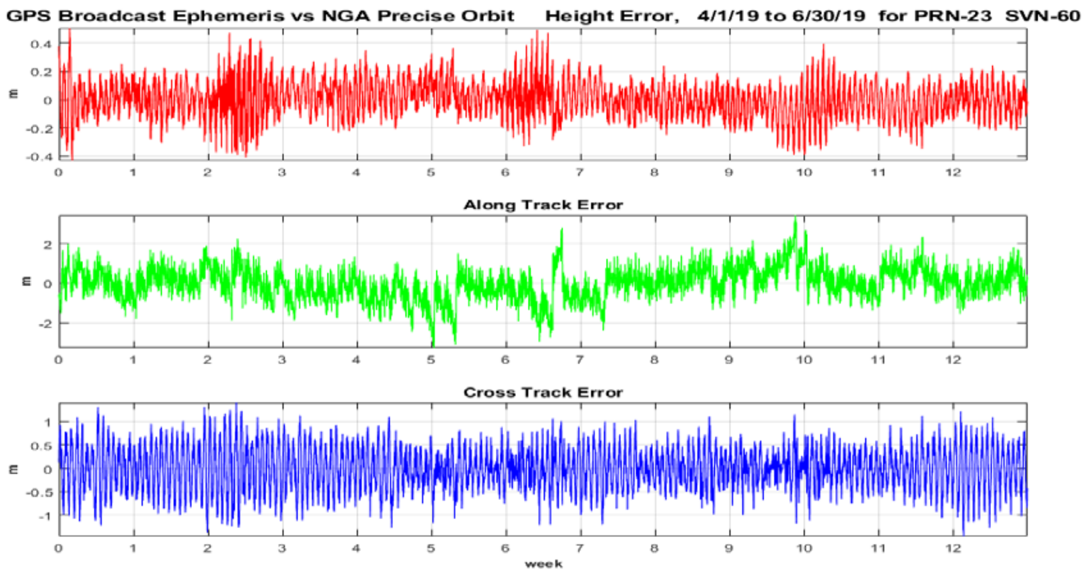


Figure 10-42 Orbit Error PRN-24 (SVN-65) Using C/A Nav Data

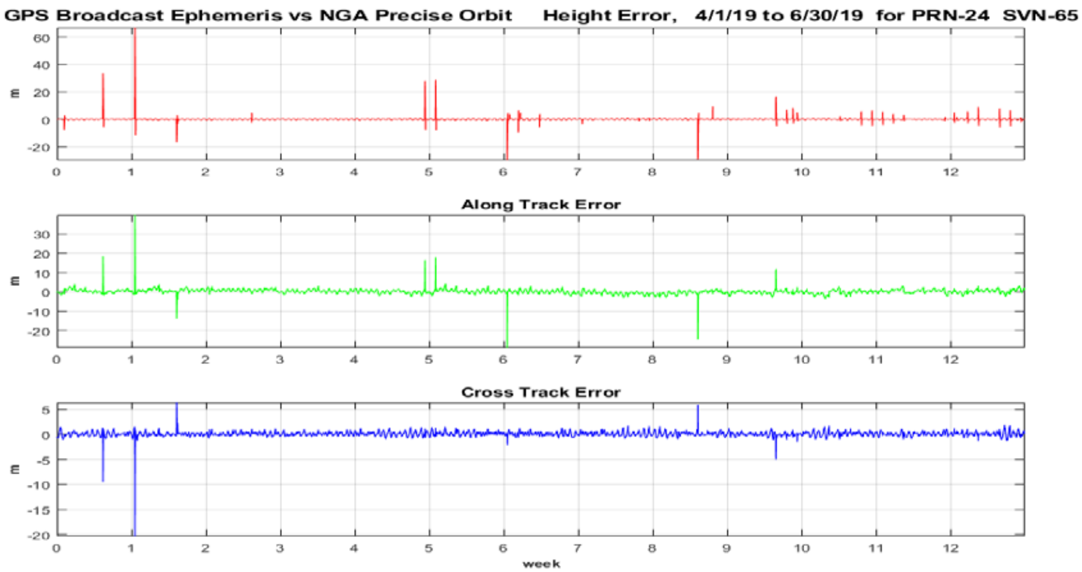


Figure 10-43 Orbit Error PRN-24 (SVN-65) Using L2C CNAV Data

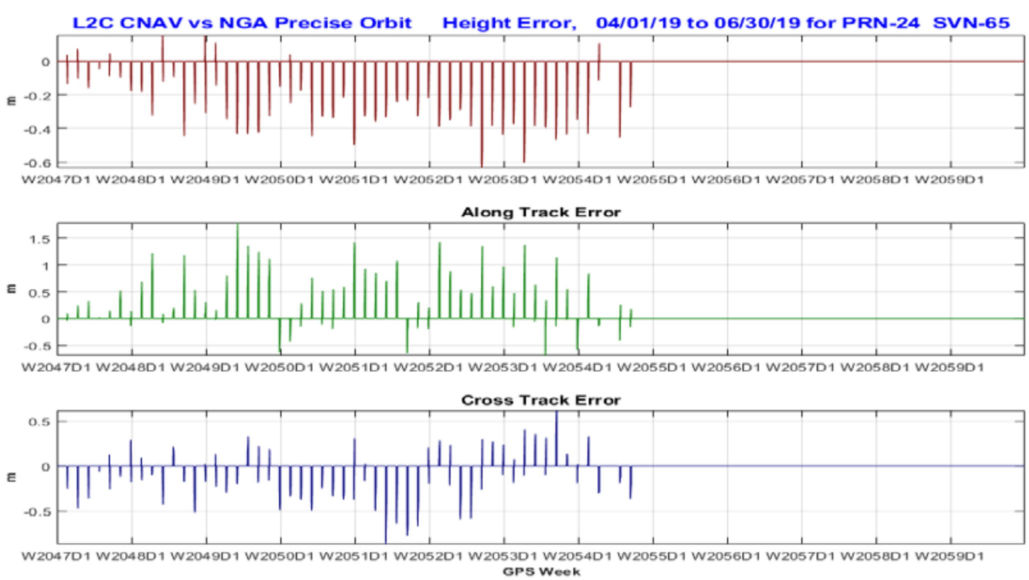


Figure 10-44 Orbit Error PRN-25 (SVN-62) Using C/A Nav Data

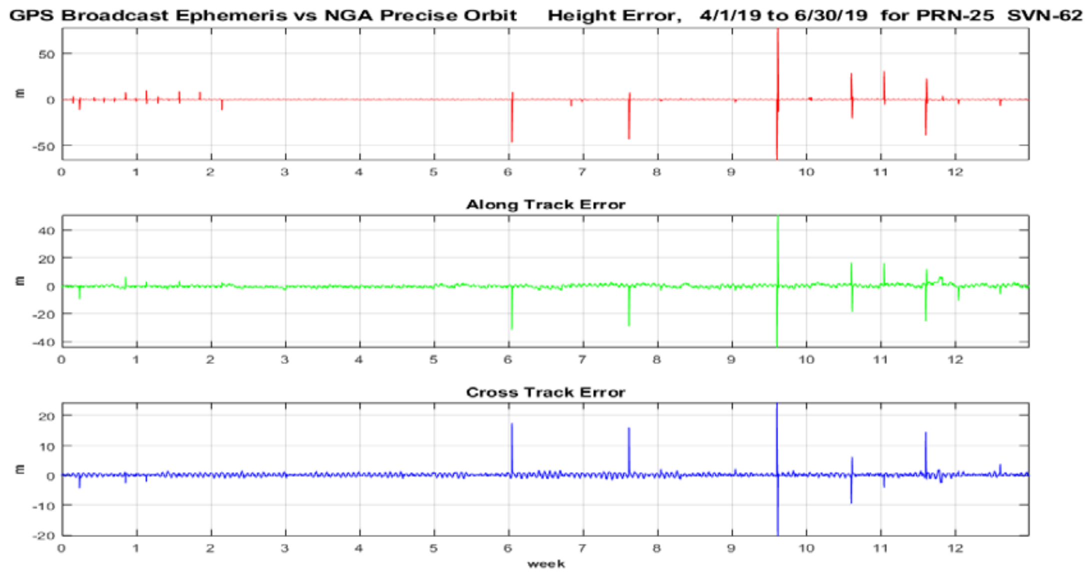


Figure 10-45 Orbit Error PRN-25 (SVN-62) Using L2C CNAV Data

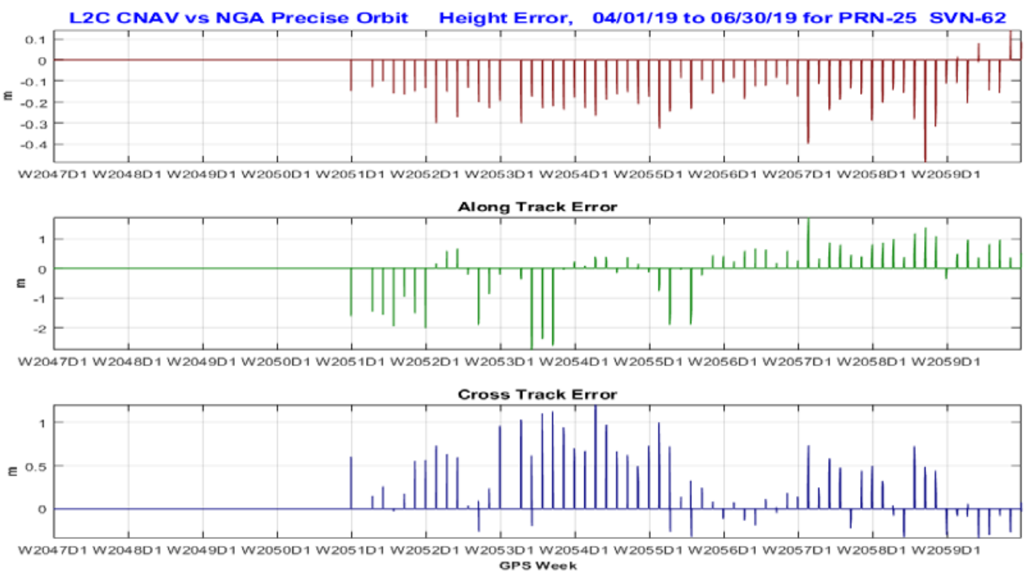


Figure 10-46 Orbit Error PRN-26 (SVN-71) Using C/A Nav Data

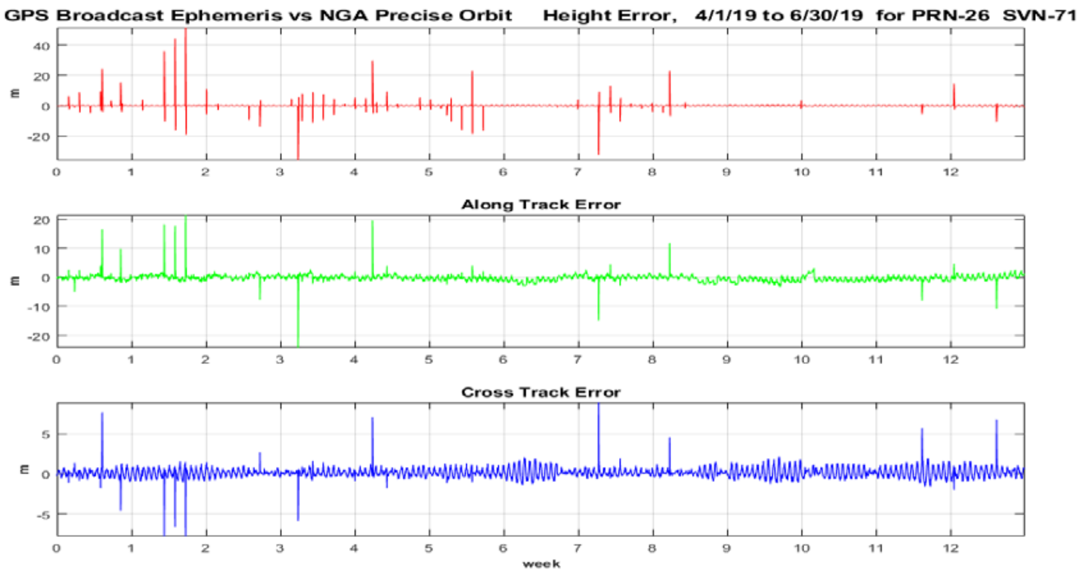


Figure 10-47 Orbit Error PRN-26 (SVN-71) Using L2C CNAV Data

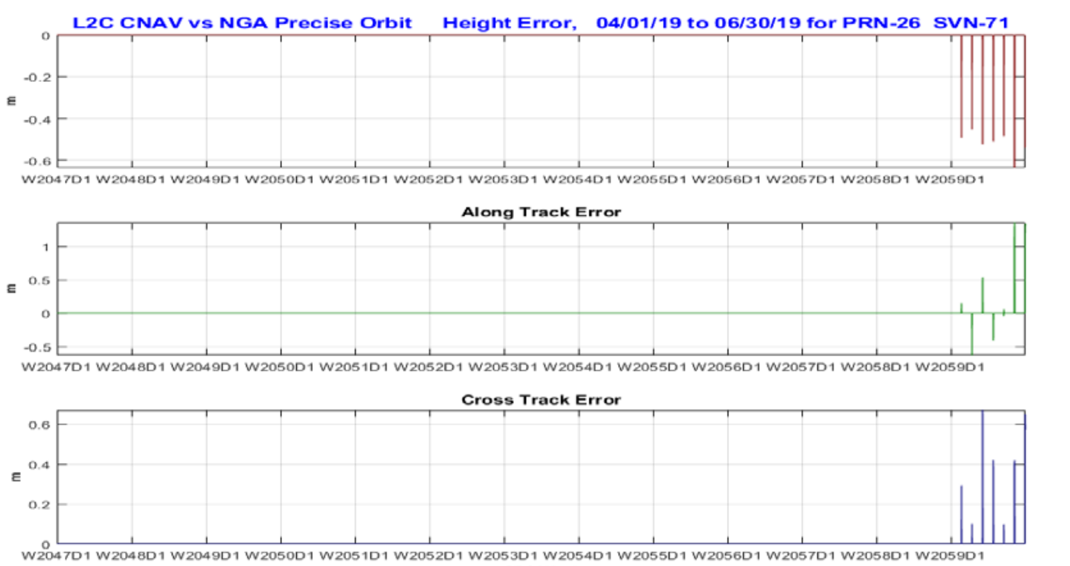


Figure 10-48 Orbit Error PRN-27 (SVN-66) Using C/A Nav Data

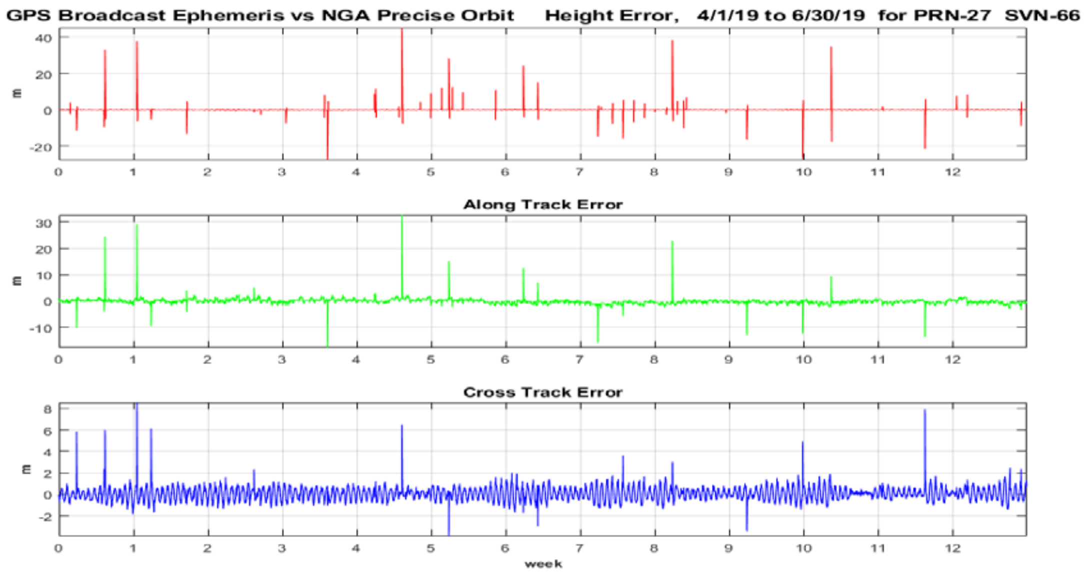


Figure 10-49 Orbit Error PRN-27 (SVN-66) Using L2C CNAV Data

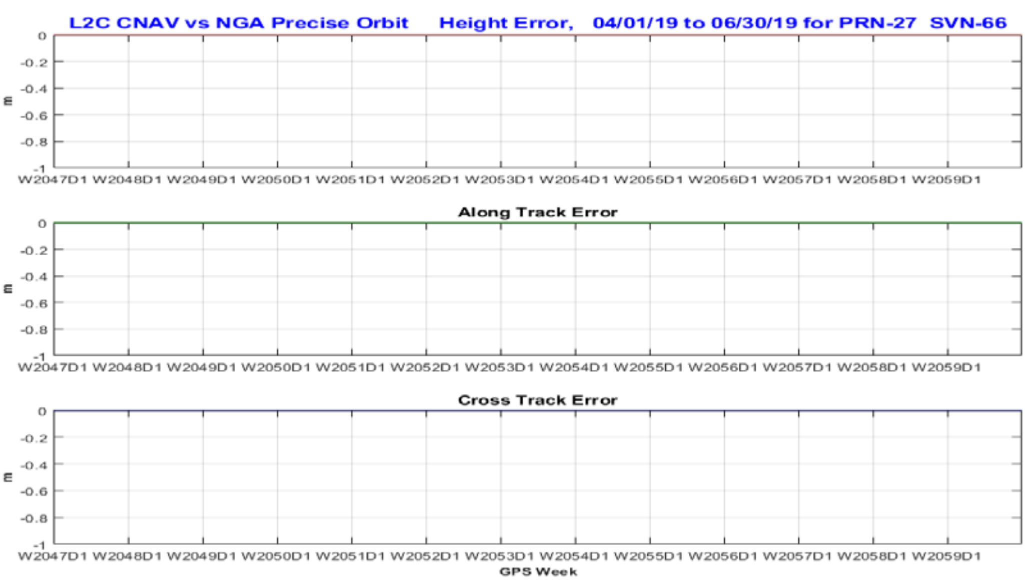


Figure 10-50 Orbit Error PRN-28 (SVN-44) Using C/A Nav Data

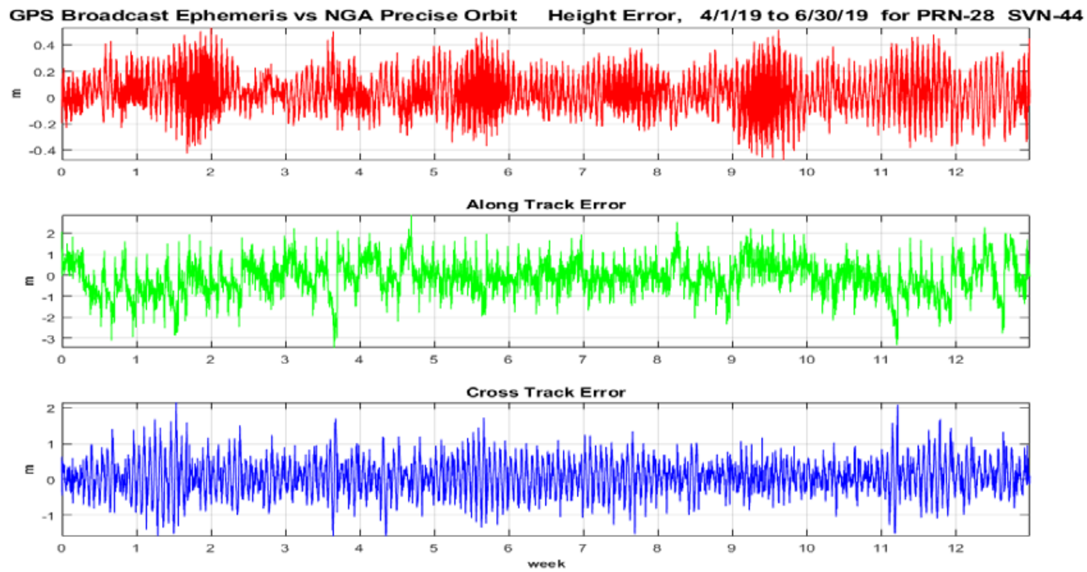


Figure 10-51 Orbit Error PRN-29 (SVN-57) Using C/A Nav Data

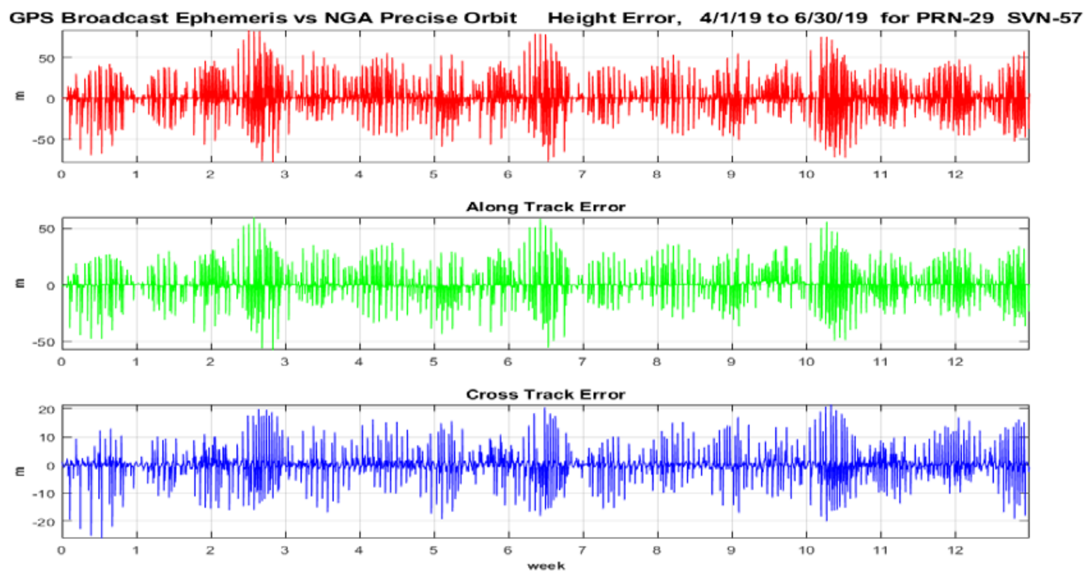


Figure 10-52 Orbit Error PRN-29 (SVN-57) Using L2C CNAV Data

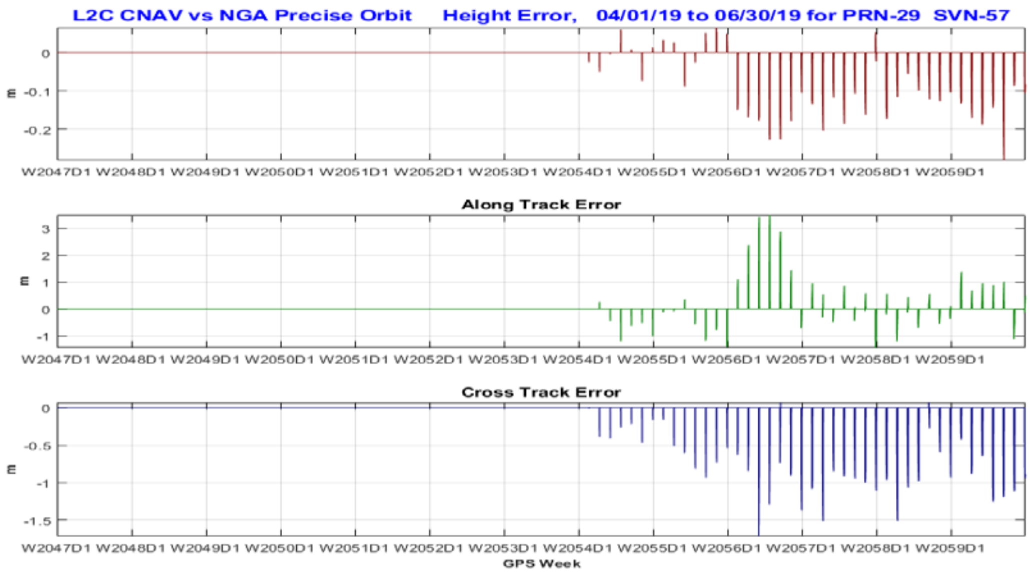


Figure 10-53 Orbit Error PRN-30 (SVN-64) Using C/A Nav Data

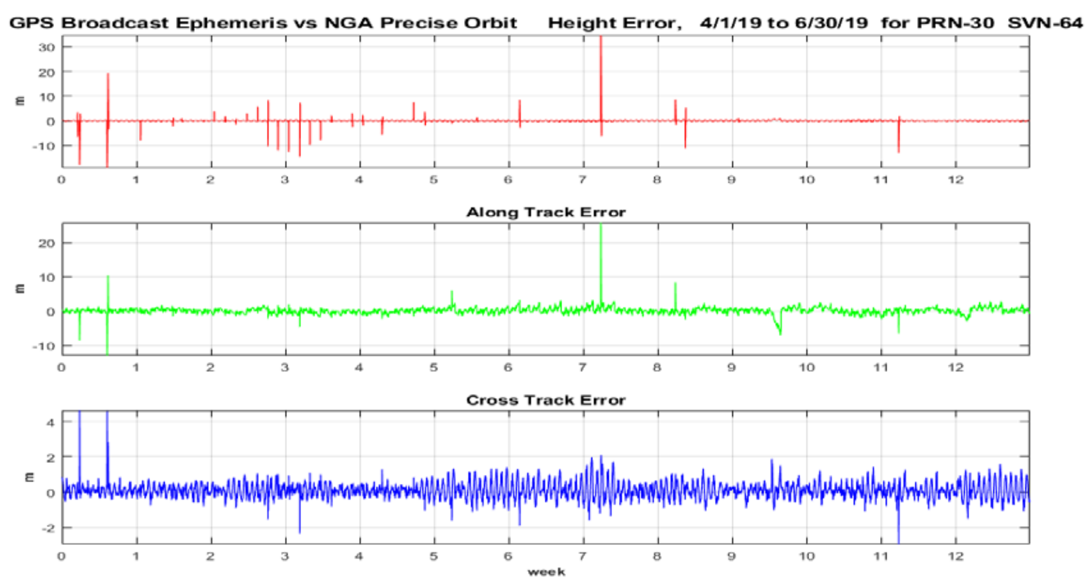


Figure 10-54 Orbit Error PRN-30 (SVN-64) Using L2C CNAV Data

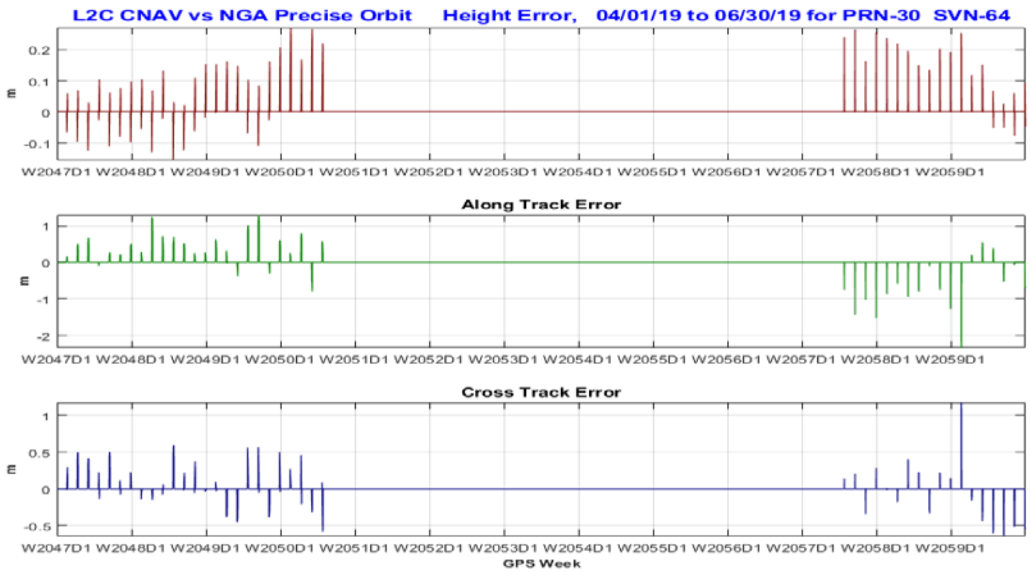


Figure 10-55 Orbit Error PRN-31 (SVN-52) Using C/A Nav Data

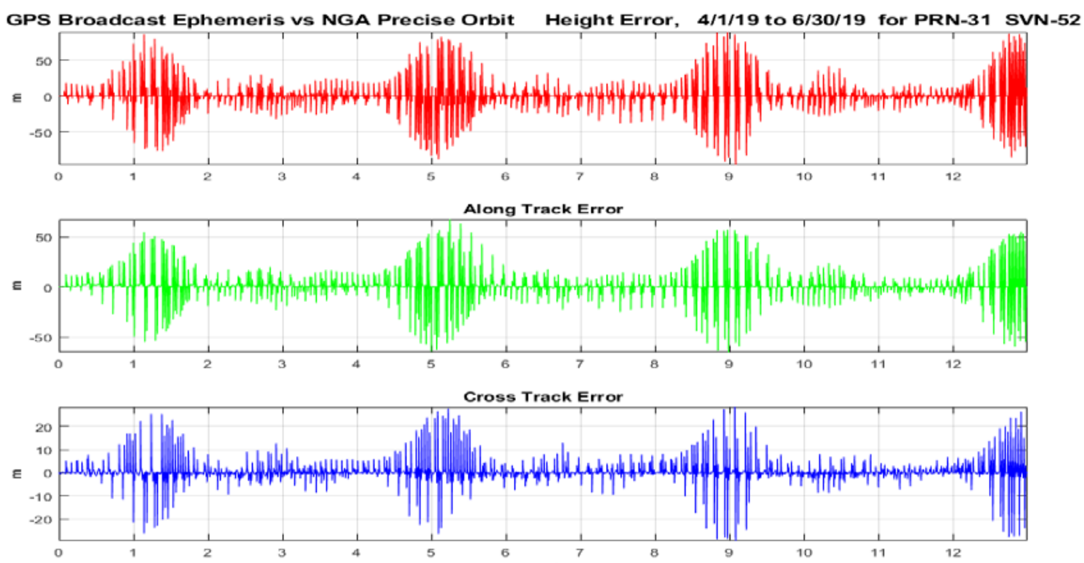


Figure 10-56 Orbit Error PRN-31 (SVN-52) Using L2C CNAV Data

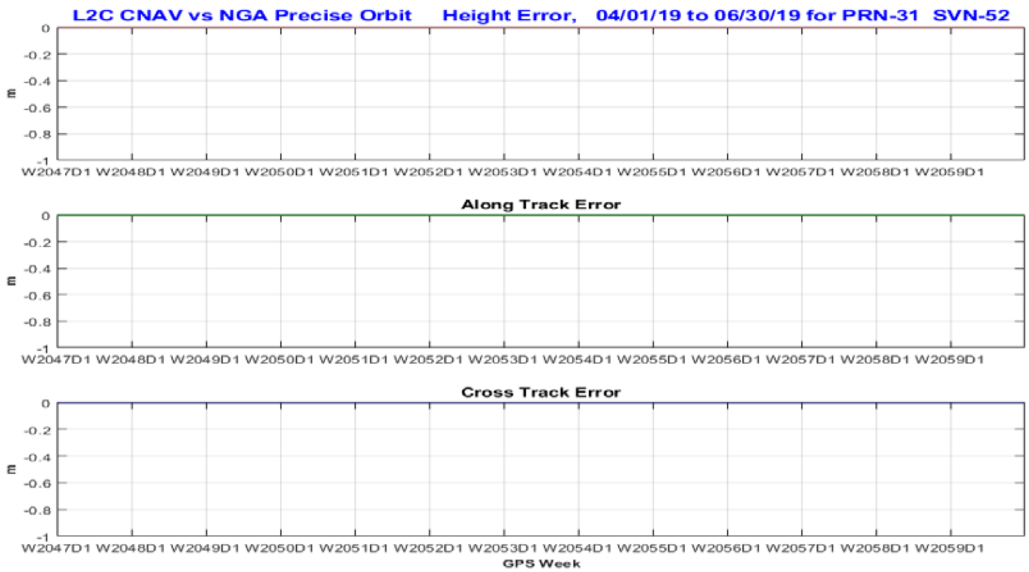


Figure 10-57 Orbit Error PRN-32 (SVN-70) Using C/A Nav Data

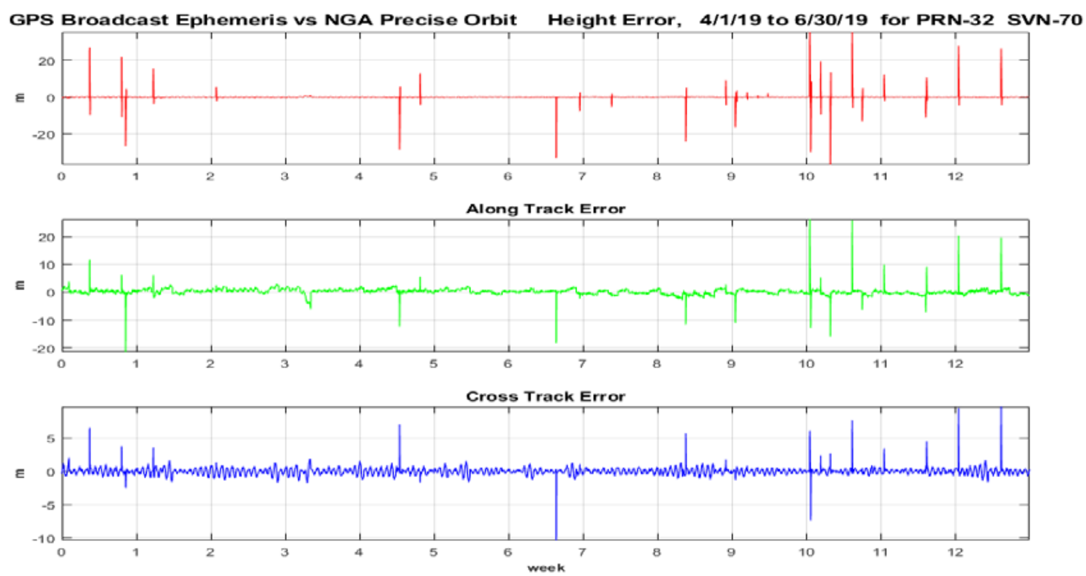
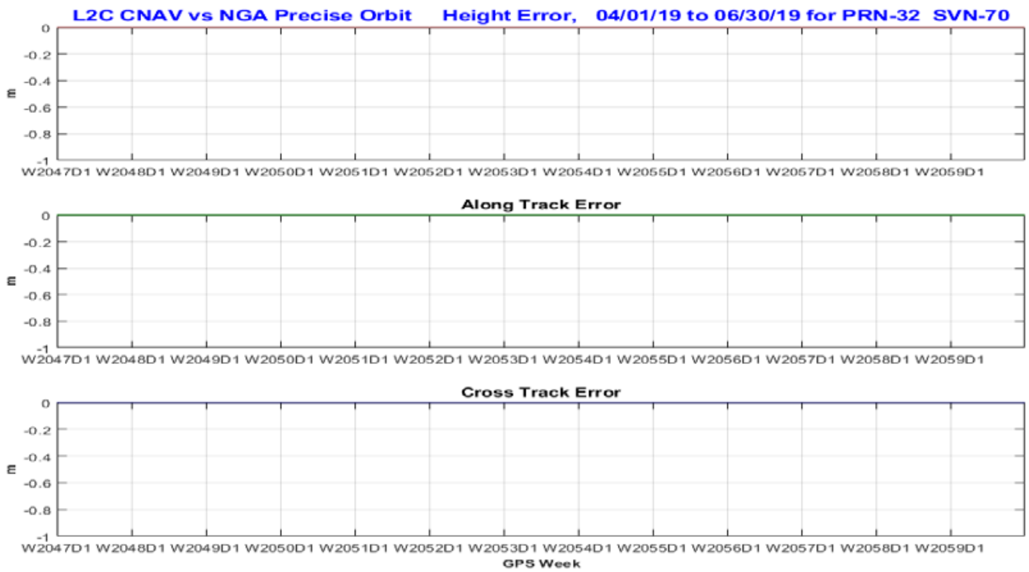


Figure 10-58 Orbit Error PRN-32 (SVN-70) Using L2C CNAV Data



10.6 QQ Plots of URA Normalized Error for All Satellites

Figure 10-59 QQ Plots of Range Error PRNs 1 to 5 Using C/A Nav Data

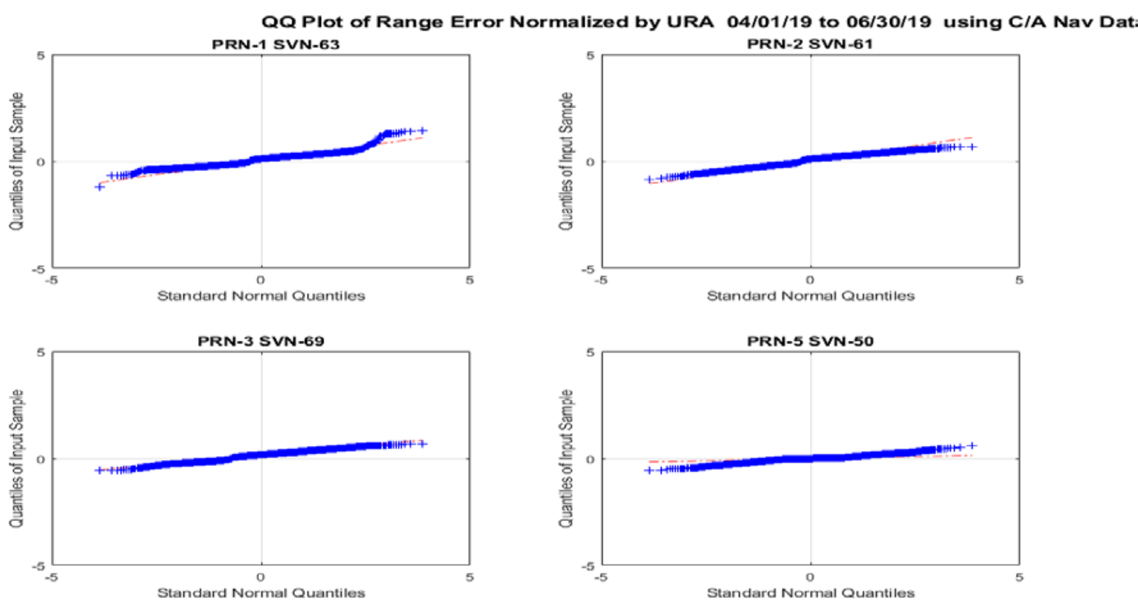


Figure 10-60 QQ Plots of Range Error PRNs 6 to 9 Using C/A Nav Data

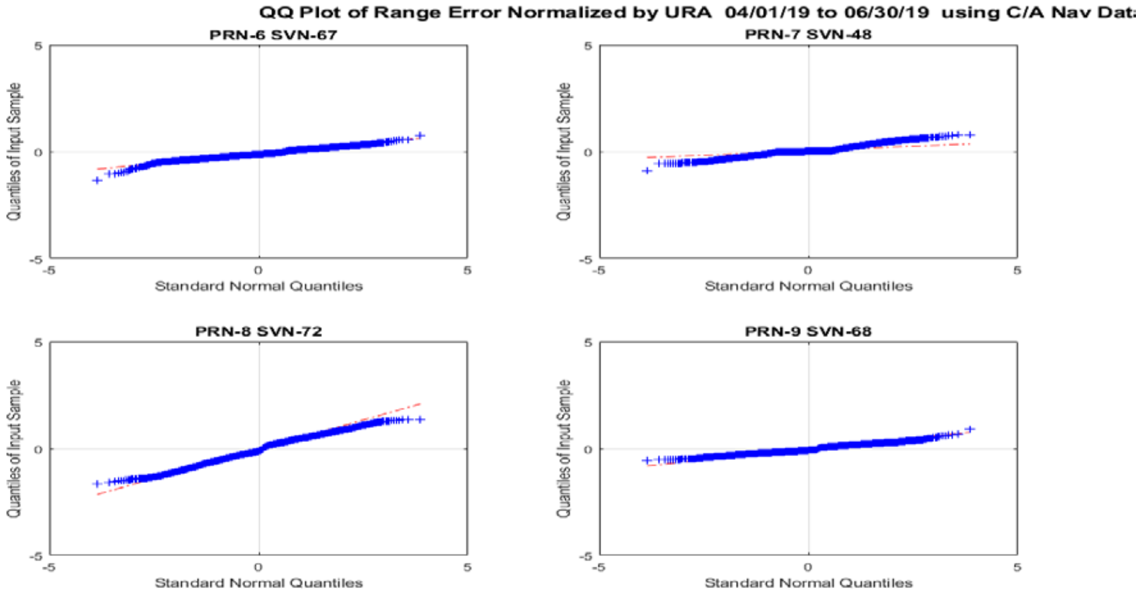


Figure 10-61 QQ Plots of Range Error PRNs 10 to 13 Using C/A Nav Data

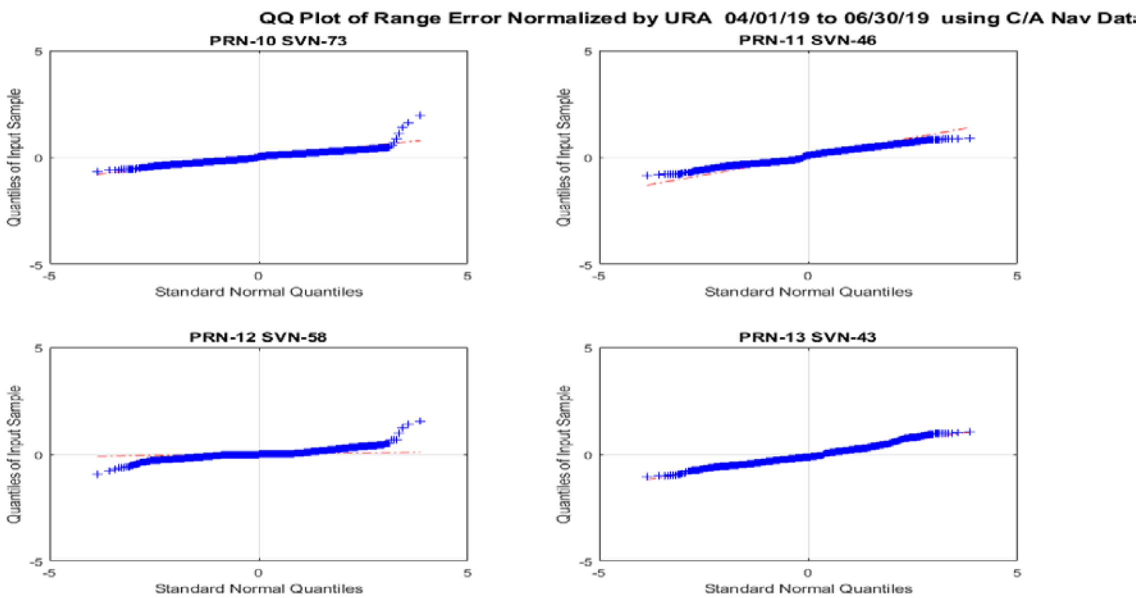


Figure 10-62 QQ Plots of Range Error PRNs 14 to 17 Using C/A Nav Data

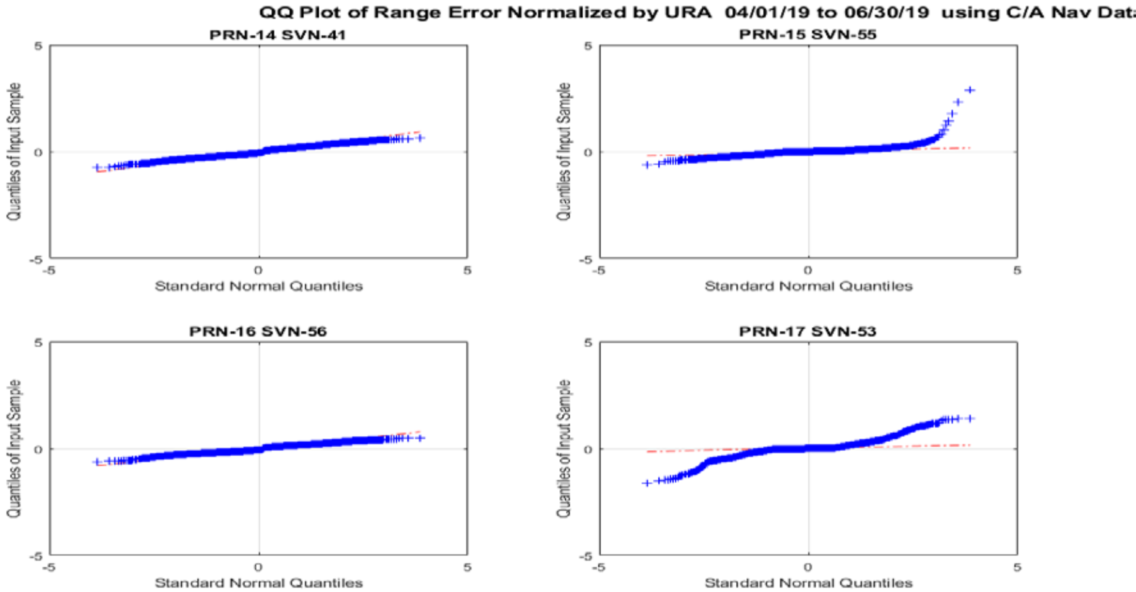


Figure 10-63 QQ Plots of Range Error PRNs 18 to 21 Using C/A Nav Data

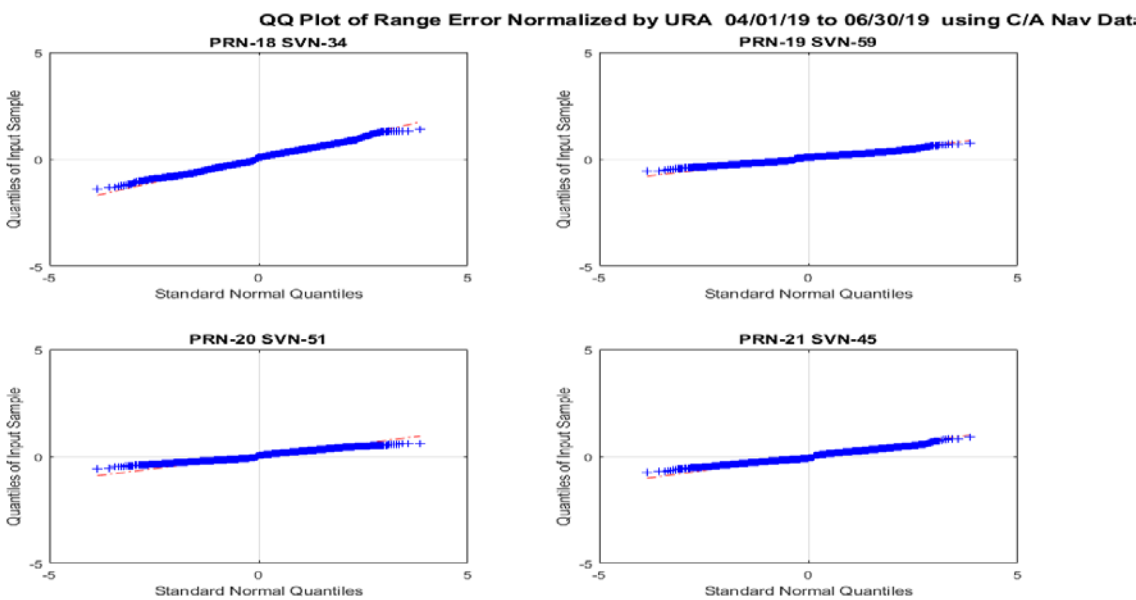


Figure 10-64 QQ Plots of Range Error PRNs 22 to 25 Using C/A Nav Data

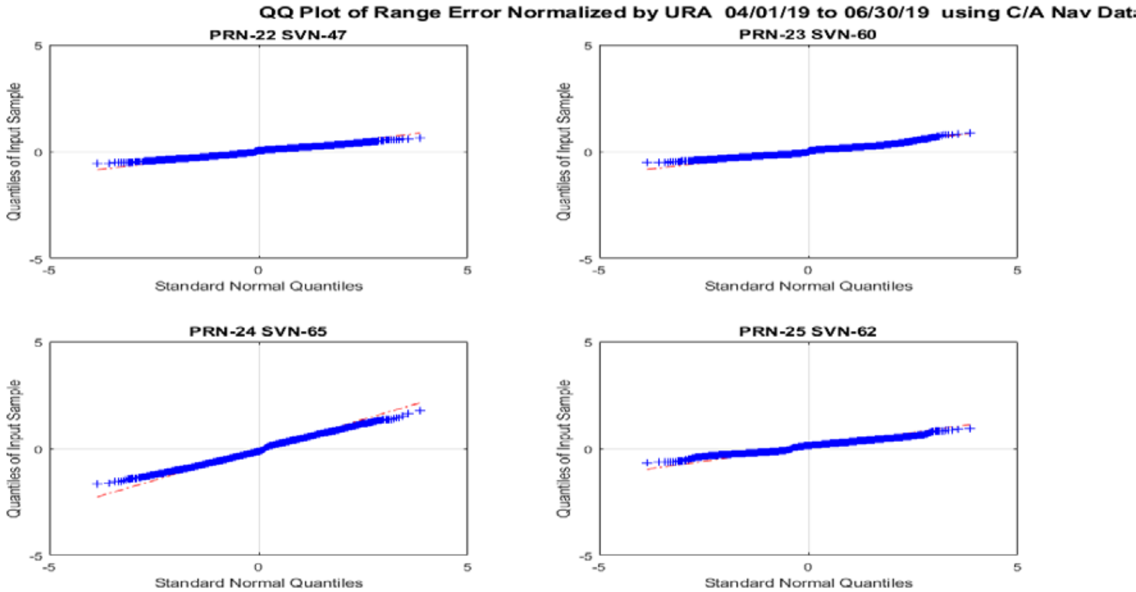


Figure 10-65 QQ Plots of Range Error PRNs 26 to 29 Using C/A Nav Data

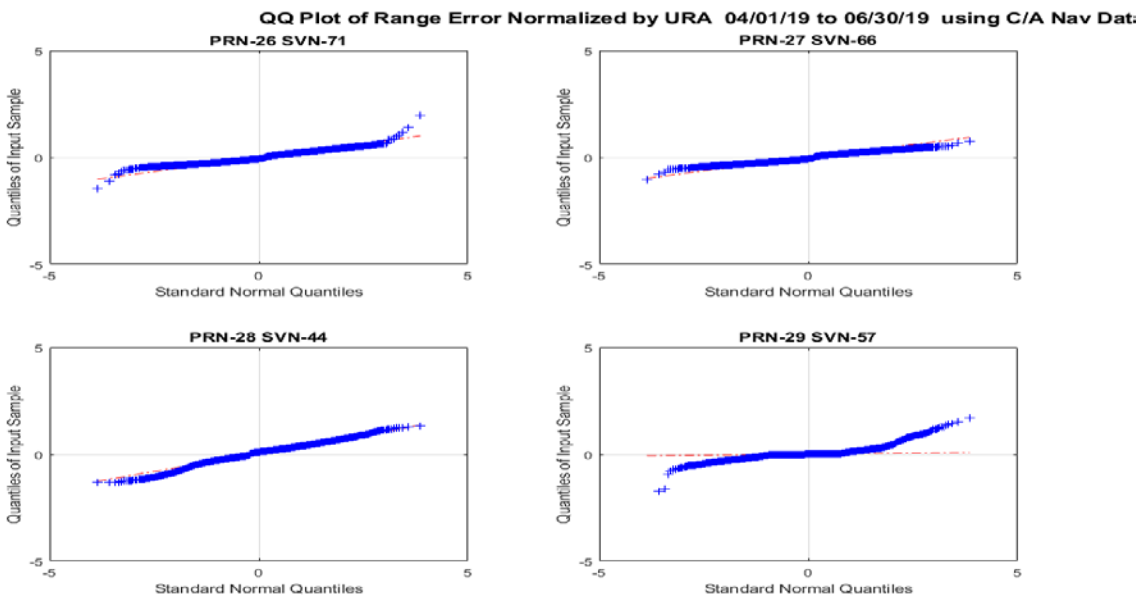


Figure 10-66 QQ Plots of Range Error PRNs 30 to 32 Using C/A Nav Data

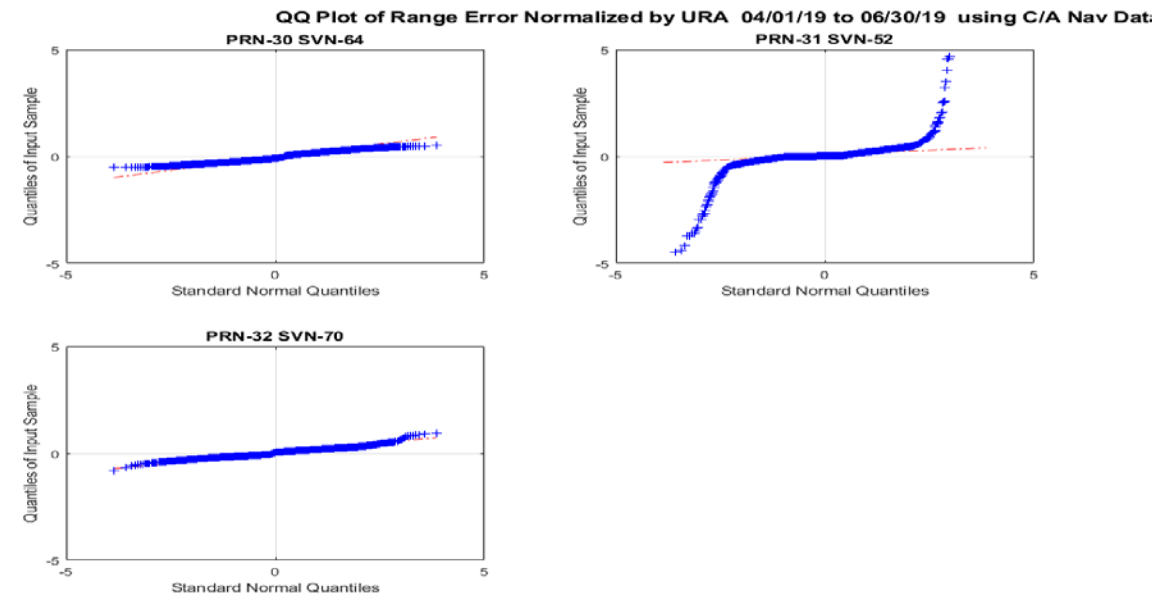


Figure 10-67 QQ Plots of Range Error PRNs 1, 3, 5, and 6 Using L2C CNAV Data

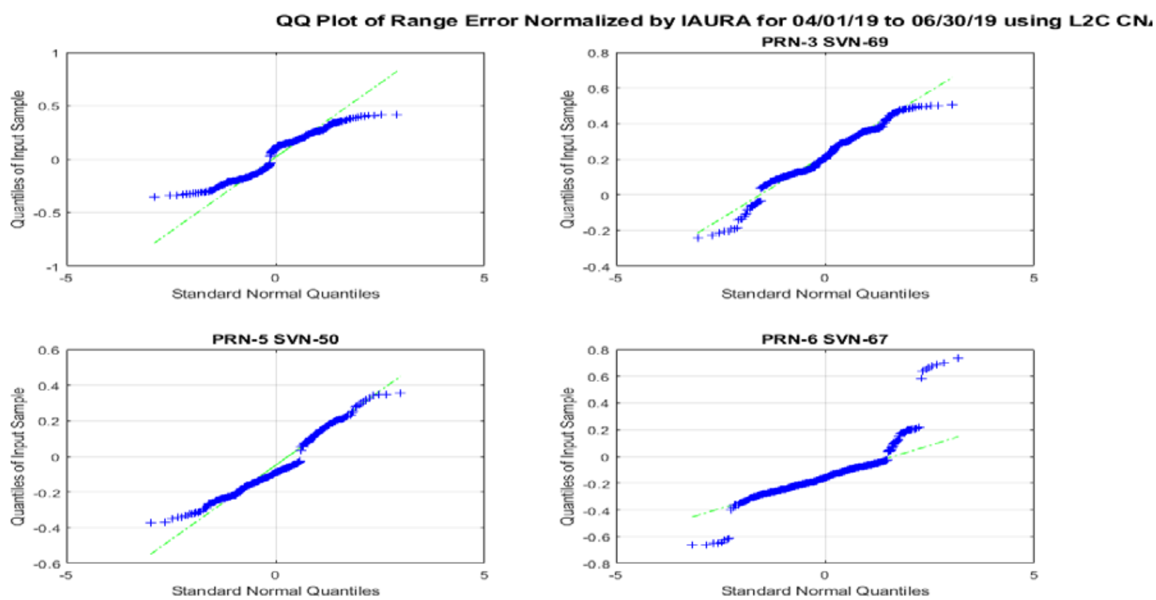


Figure 10-68 QQ Plots of Range Error PRNs 7, 8, 9, and 12 Using L2C CNAV Data

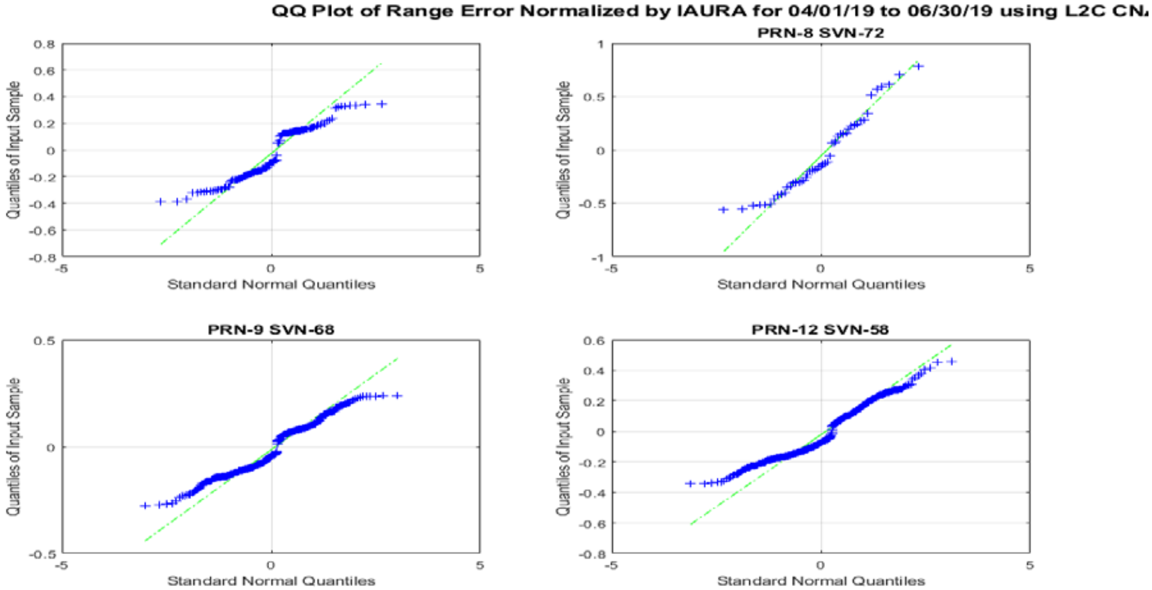


Figure 10-69 QQ Plots of Range Error PRNs 15, 17, 24 and 25 Using L2C CNAV Data

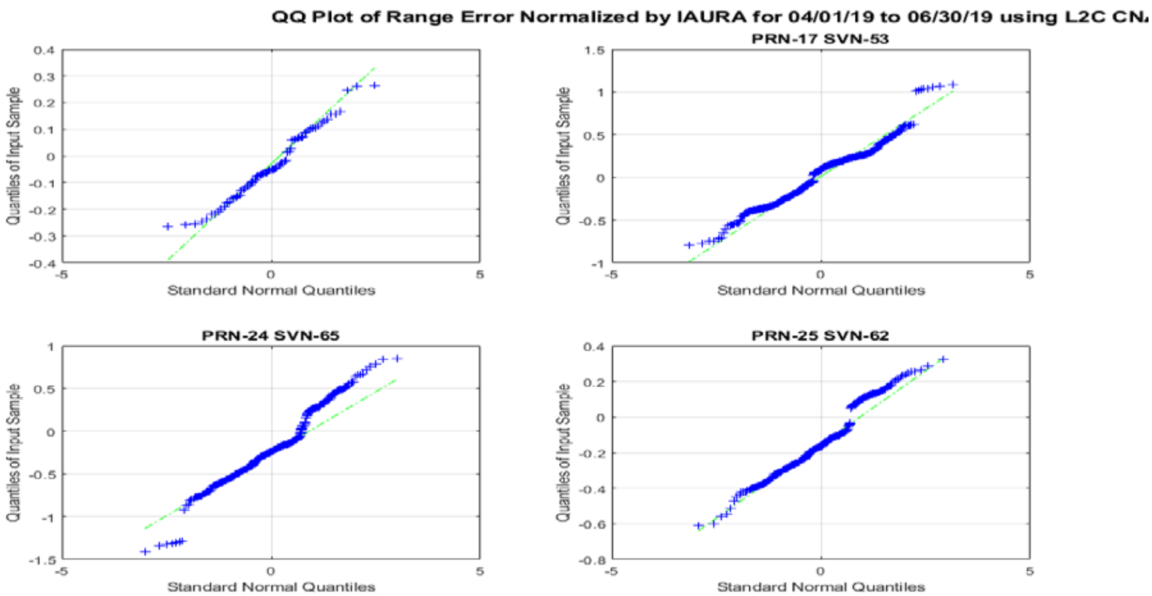
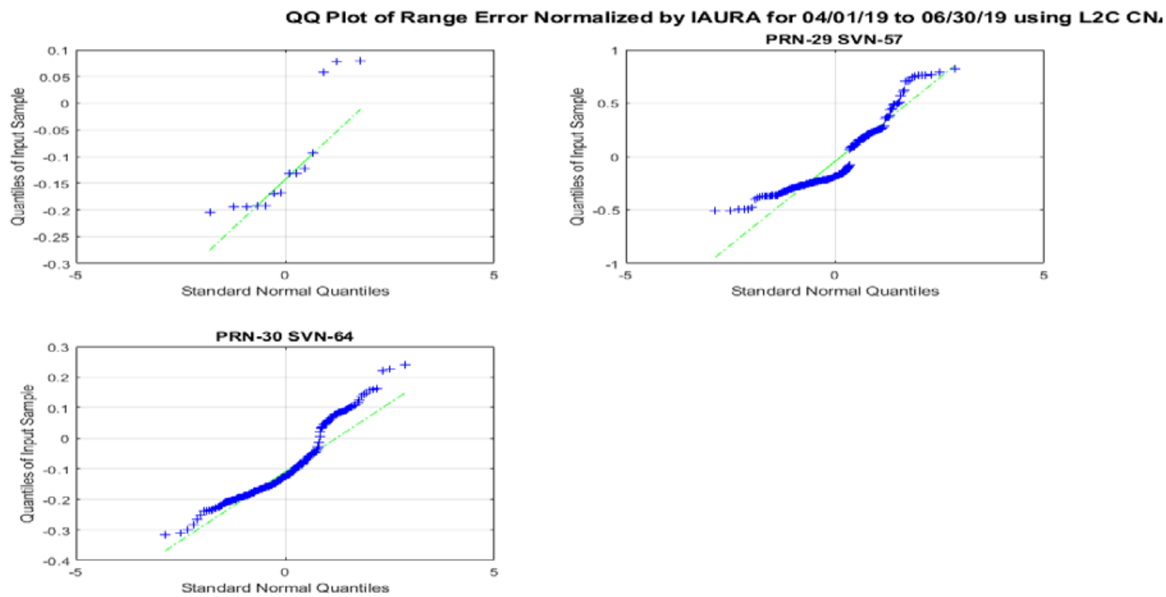


Figure 10-70 QQ Plots of Range Error PRNs 26, 29, and 30 Using L2C CNAV Data



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

Figure 10-71 Histograms of H, A, C, and Range Error PRN-1 (SVN-63) Using C/A Nav Data

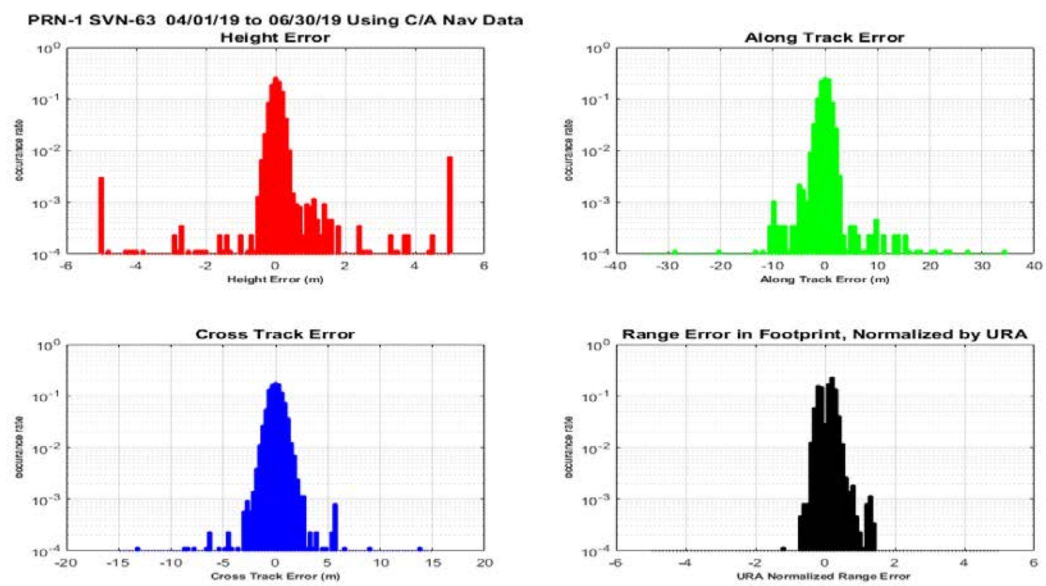


Figure 10-72 Histograms of H, A, C, and Range Error PRN-1 (SVN-63) Using L2C CNAV Data

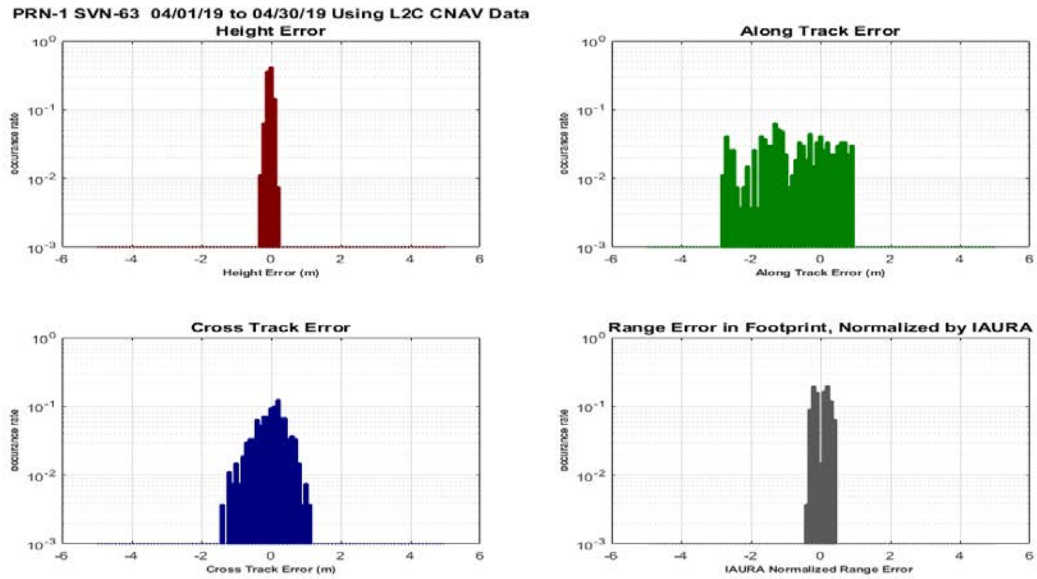


Figure 10-73 Histograms of H, A, C, and Range Error PRN-2 (SVN-61) Using C/A Nav Data

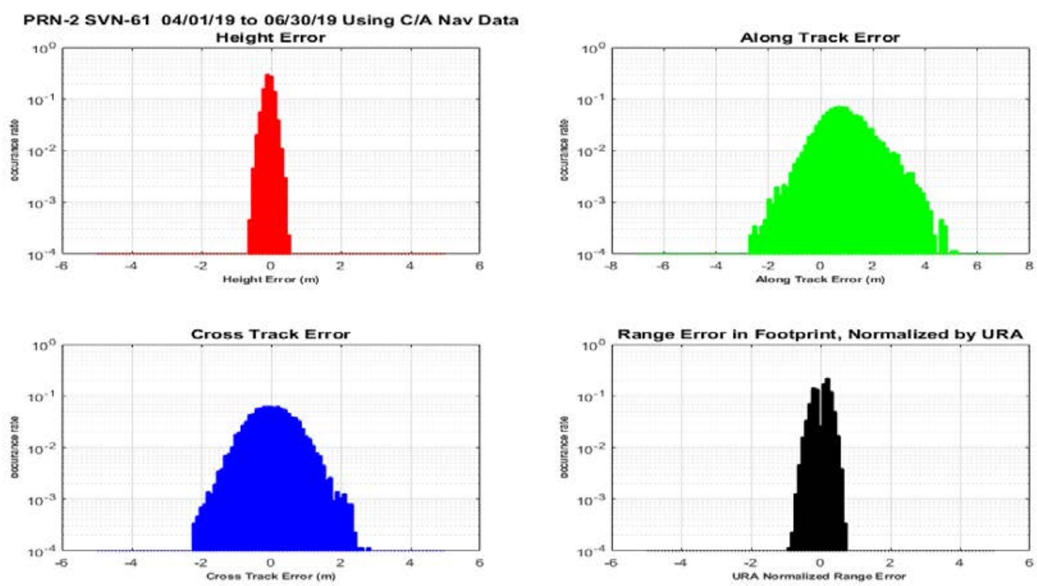


Figure 10-74 Histograms of H, A, C, and Range Error PRN-3 (SVN-69) Using C/A Nav Data

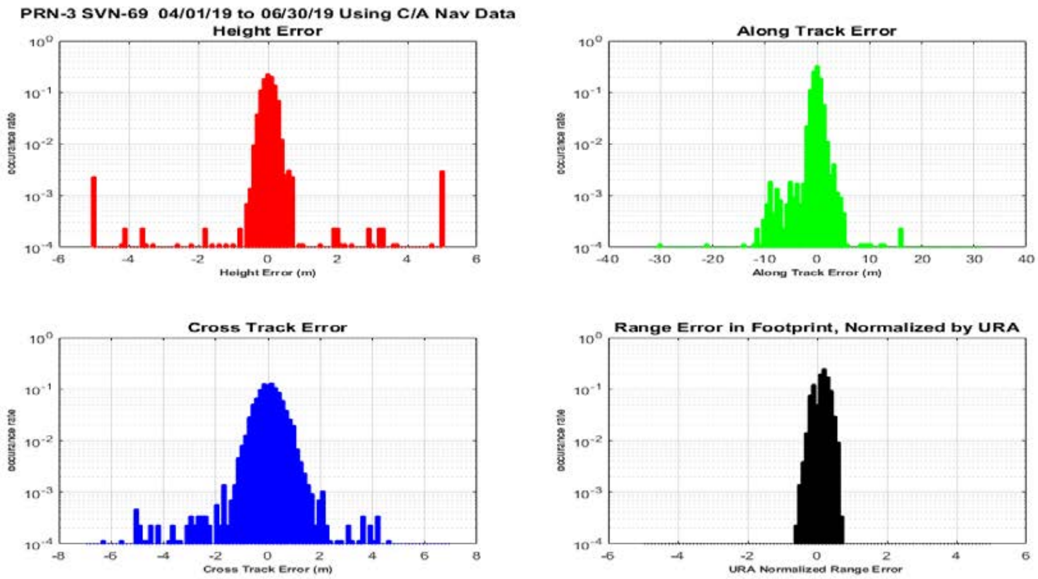


Figure 10-75 Histograms of H, A, C, and Range Error PRN-3 (SVN-69) Using L2C CNAV Data

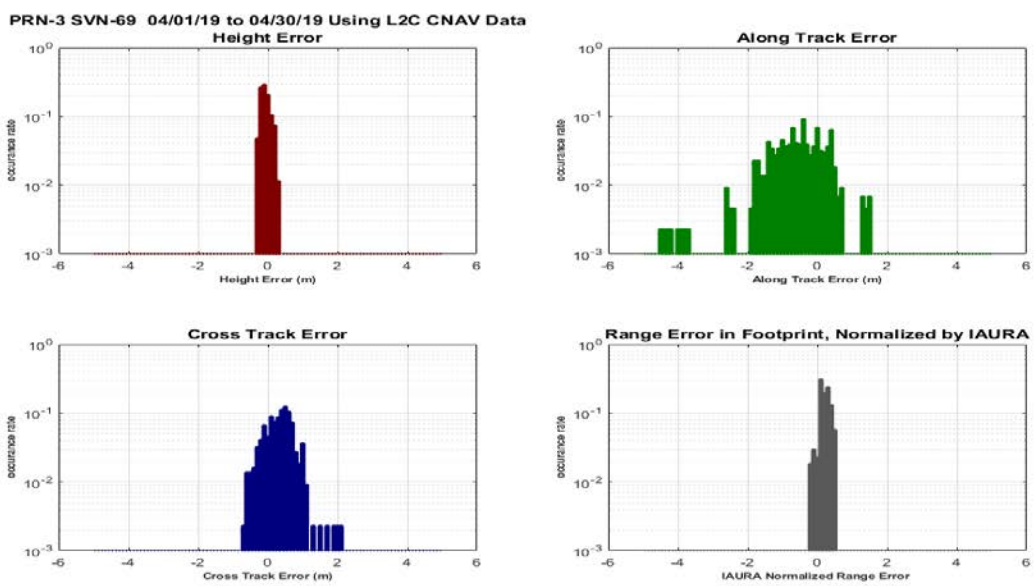


Figure 10-76 Histograms of H, A, C, and Range Error PRN-5 (SVN-50) Using C/A Nav Data

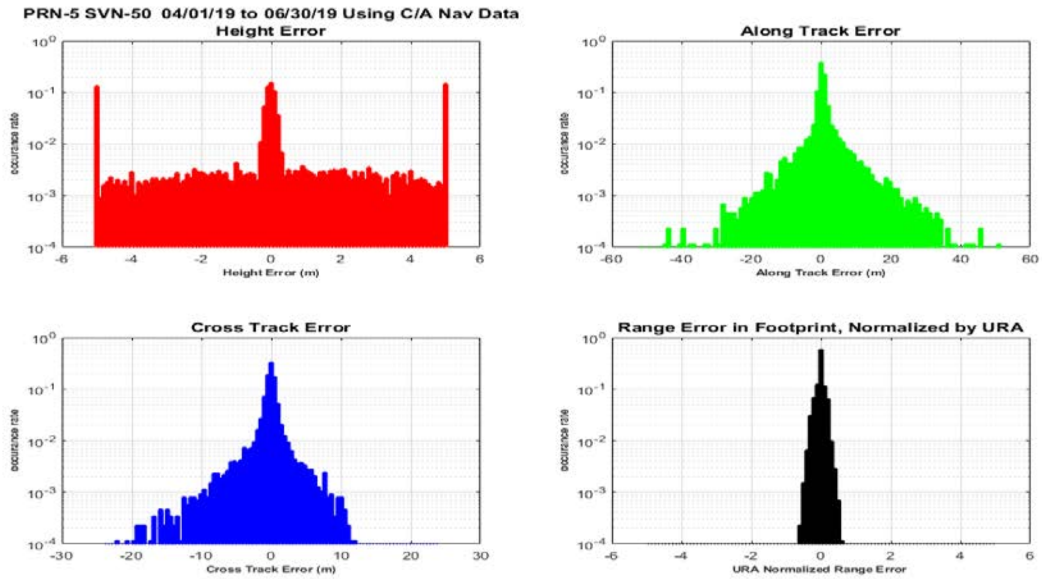


Figure 10-77 Histograms of H, A, C, and Range Error PRN-5 (SVN-50) Using L2C CNAV Data

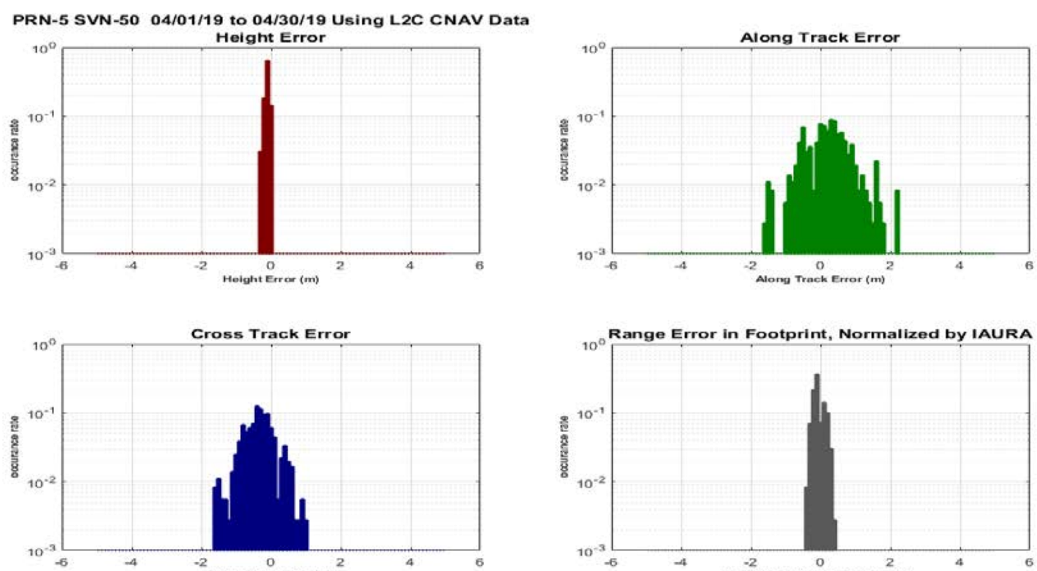


Figure 10-78 Histograms of H, A, C, and Range Error PRN-6 (SVN-67) Using C/A Nav Data

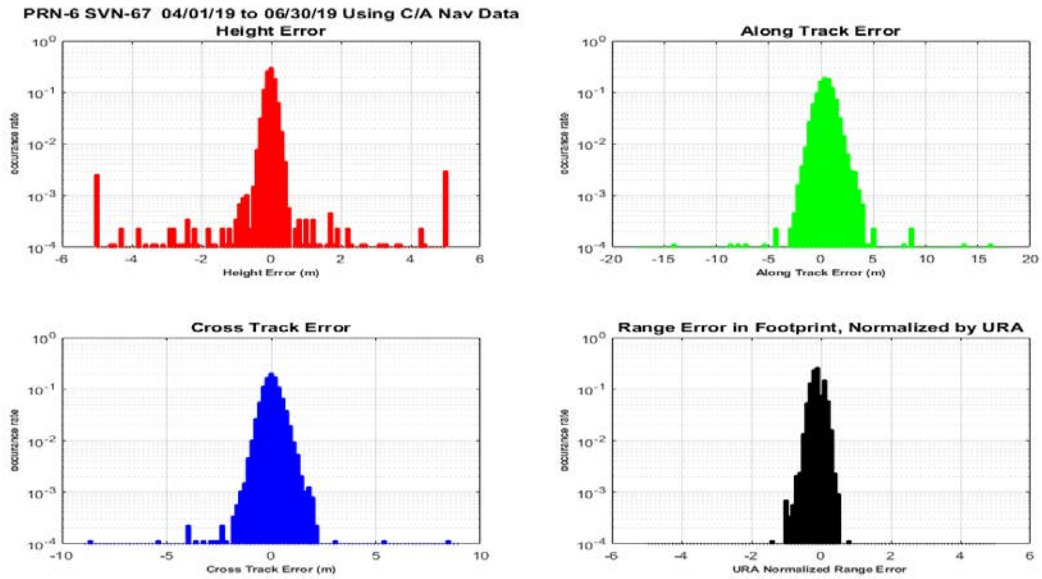


Figure 10-79 Histograms of H, A, C, and Range Error PRN-6 (SVN-67) Using L2C CNAV Data

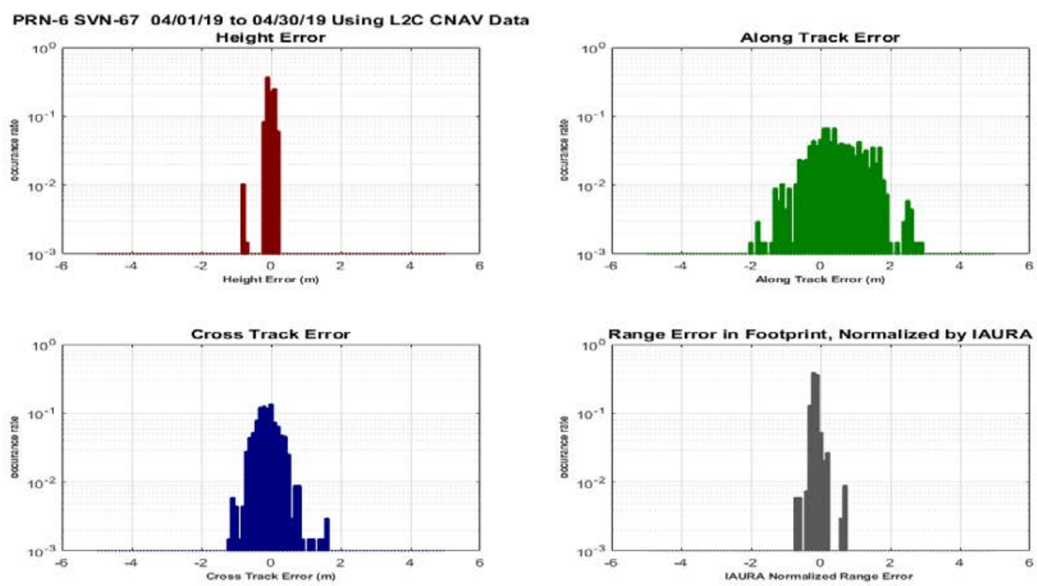


Figure 10-80 Histograms of H, A, C, and Range Error PRN-7 (SVN-48) Using C/A Nav Data

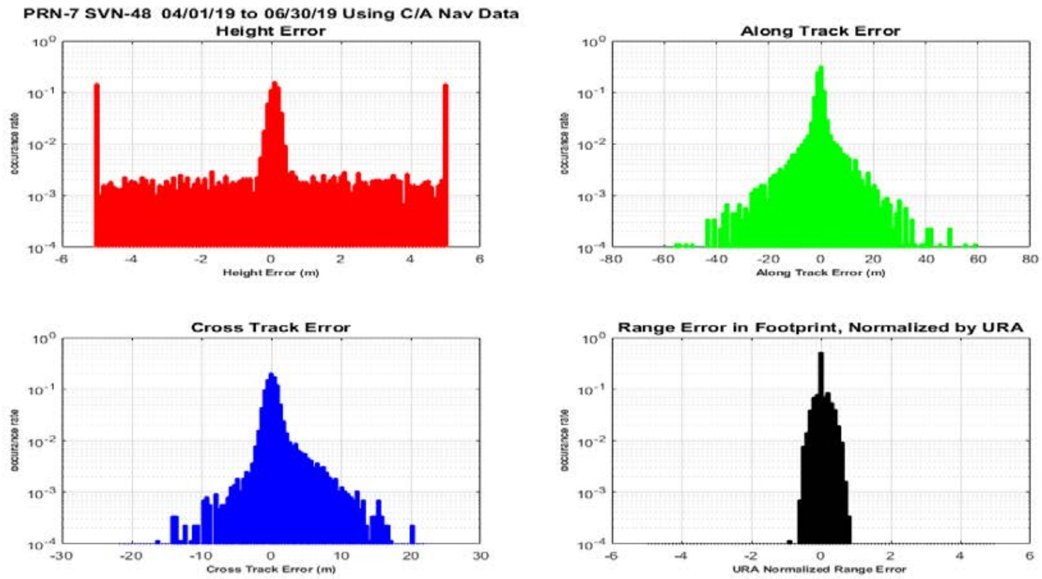


Figure 10-81 Histograms of H, A, C, and Range Error PRN-7 (SVN-48) Using L2C CNAV Data

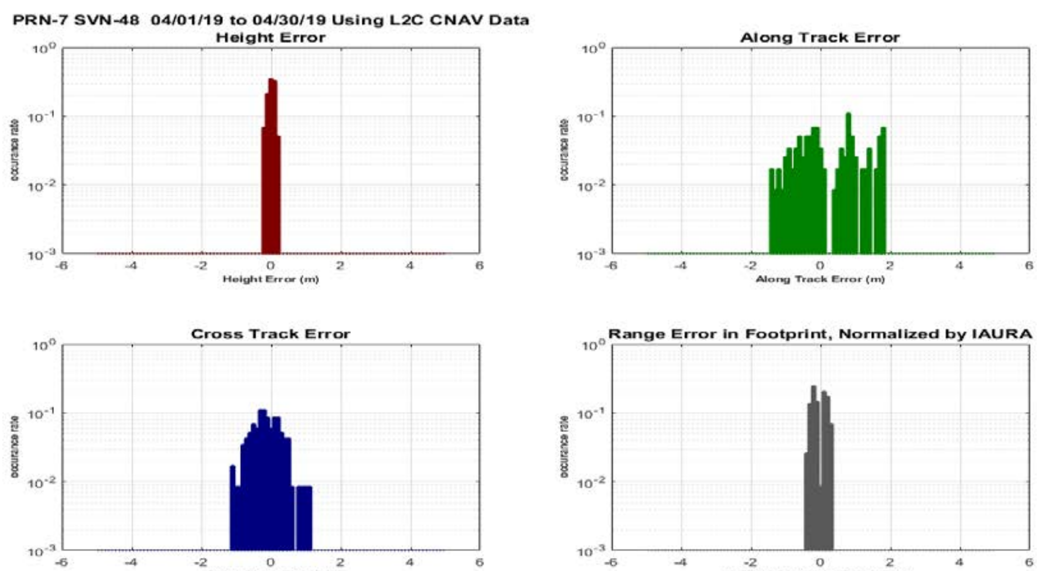


Figure 10-82 Histograms of H, A, C, and Range Error PRN-8 (SVN-72) Using C/A Nav Data

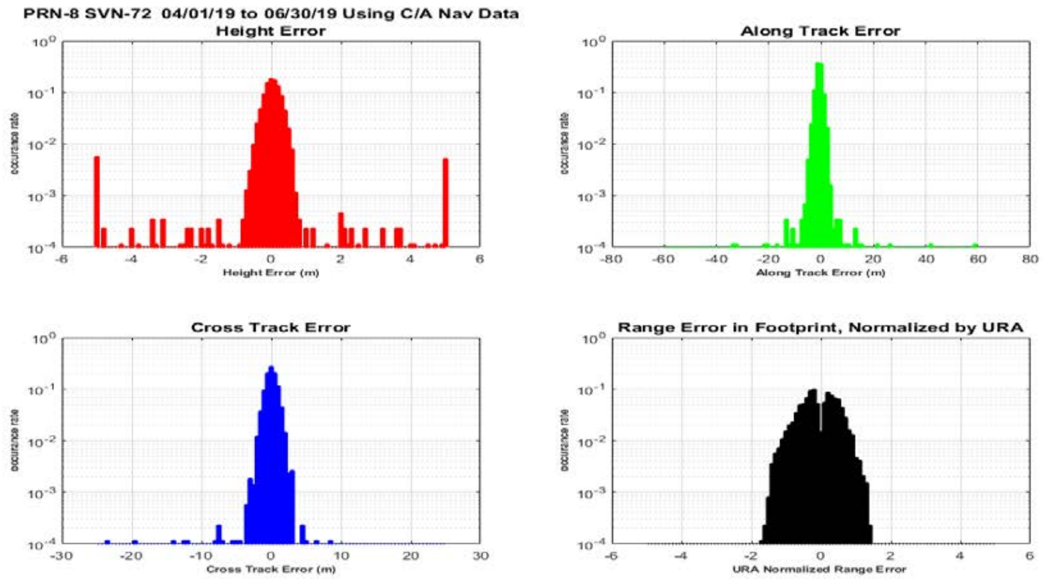


Figure 10-83 Histograms of H, A, C, and Range Error PRN-8 (SVN-72) Using L2C CNAV Data

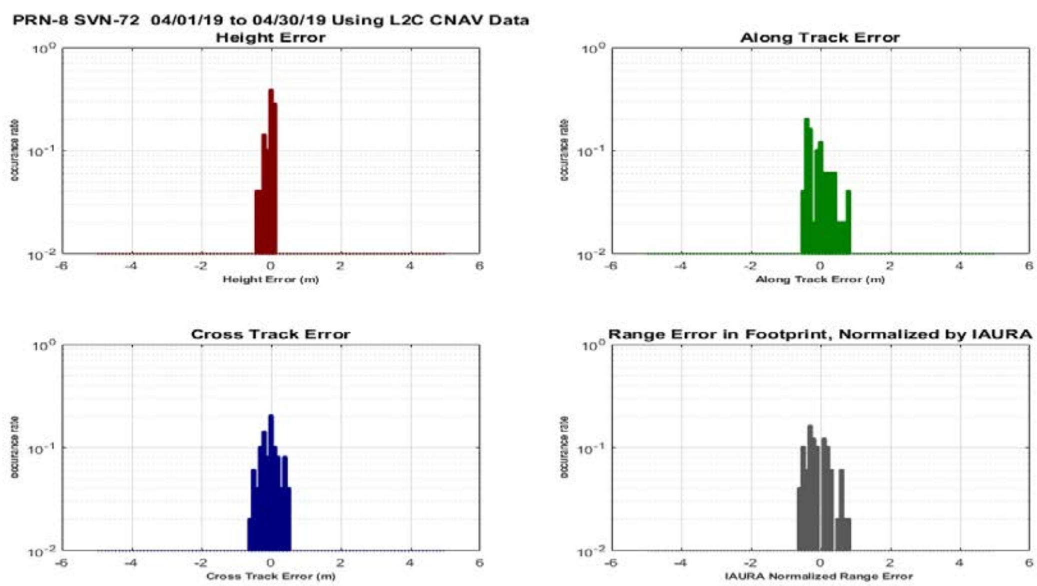


Figure 10-84 Histograms of H, A, C, and Range Error PRN-9 (SVN-68) Using C/A Nav Data

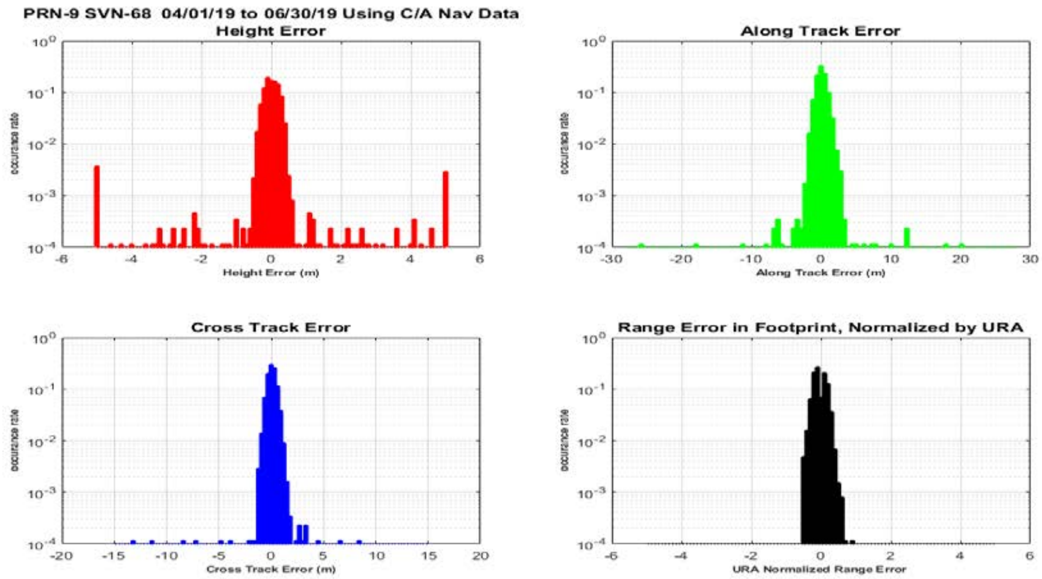


Figure 10-85 Histograms of H, A, C, and Range Error PRN-9 (SVN-68) Using L2C CNAV Data

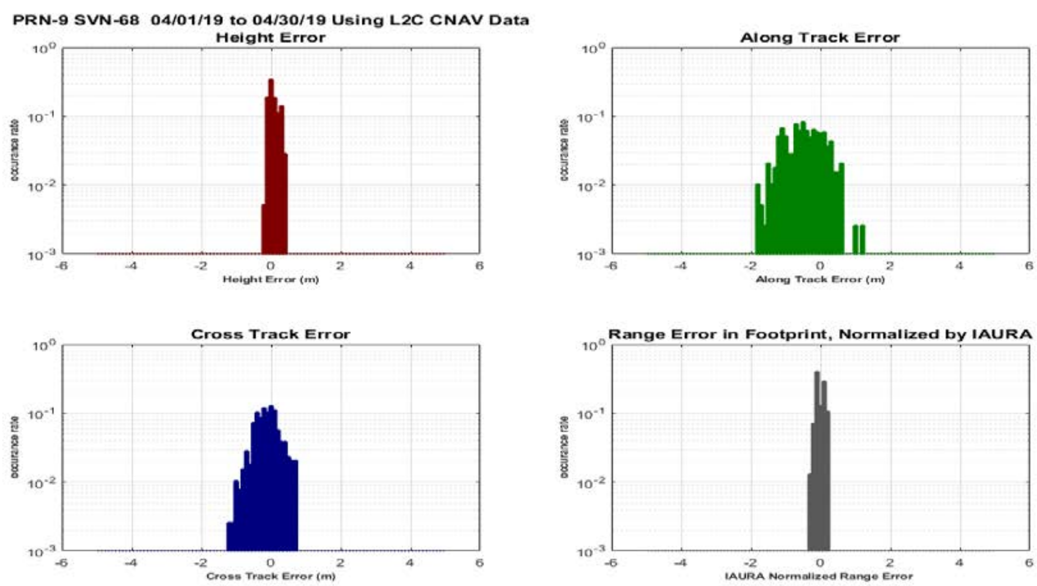


Figure 10-86 Histograms of H, A, C, and Range Error PRN-10 (SVN-73) Using C/A Nav Data

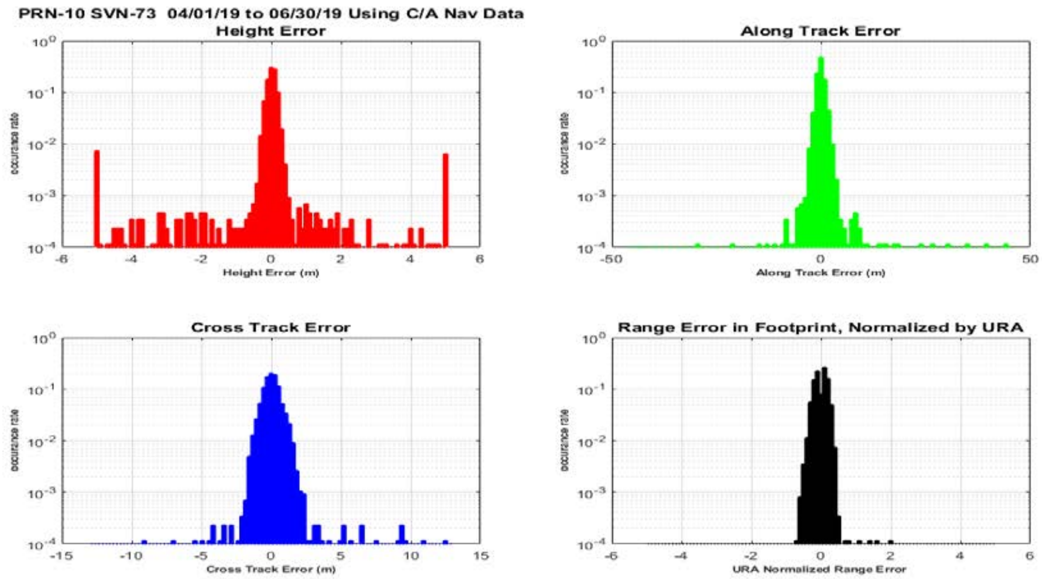


Figure 10-87 Histograms of H, A, C, and Range Error PRN-11 (SVN-46) Using C/A Nav Data

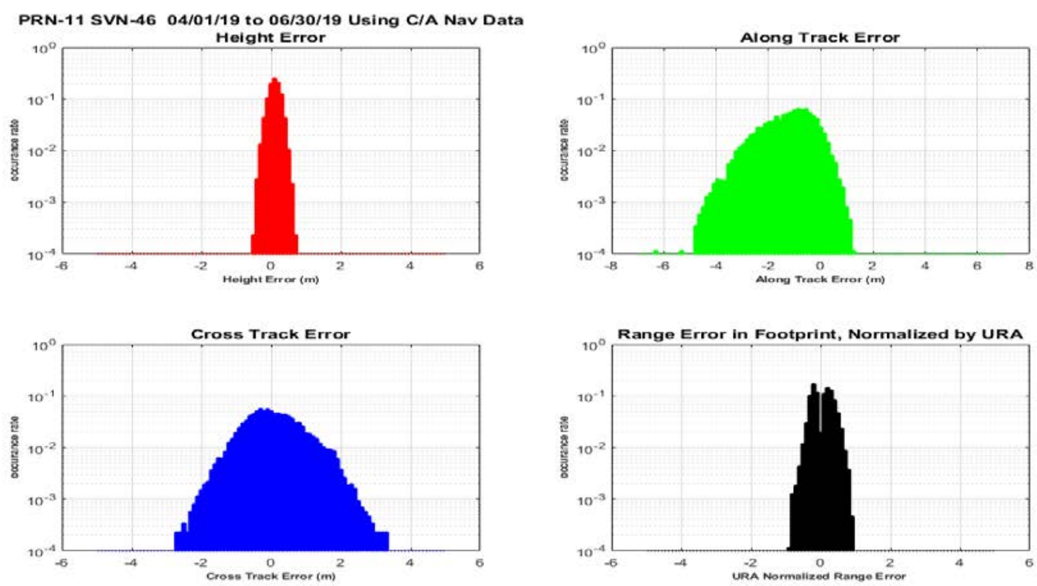


Figure 10-88 Histograms of H, A, C, and Range Error PRN-12 (SVN-58) Using C/A Nav Data

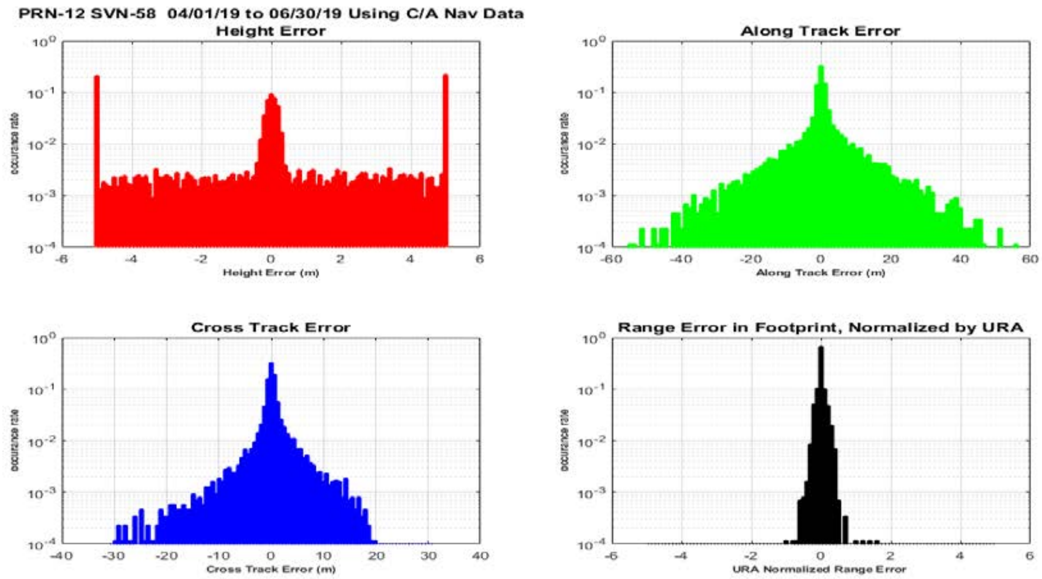


Figure 10-89 Histograms of H, A, C, and Range Error PRN-12 (SVN-58) Using L2C CNAV Data

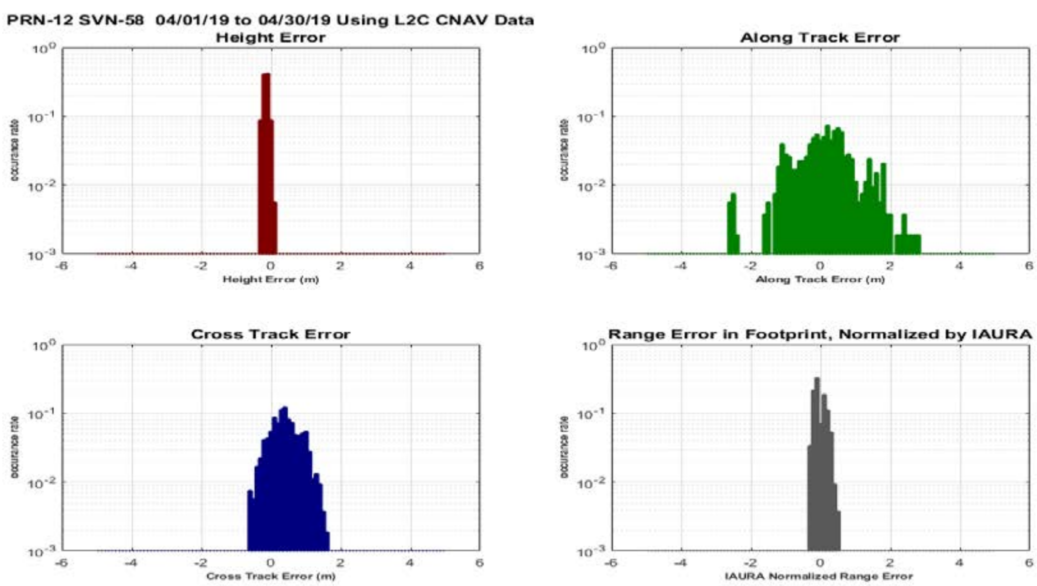


Figure 10-90 Histograms of H, A, C, and Range Error PRN-13 (SVN-43) Using C/A Nav Data

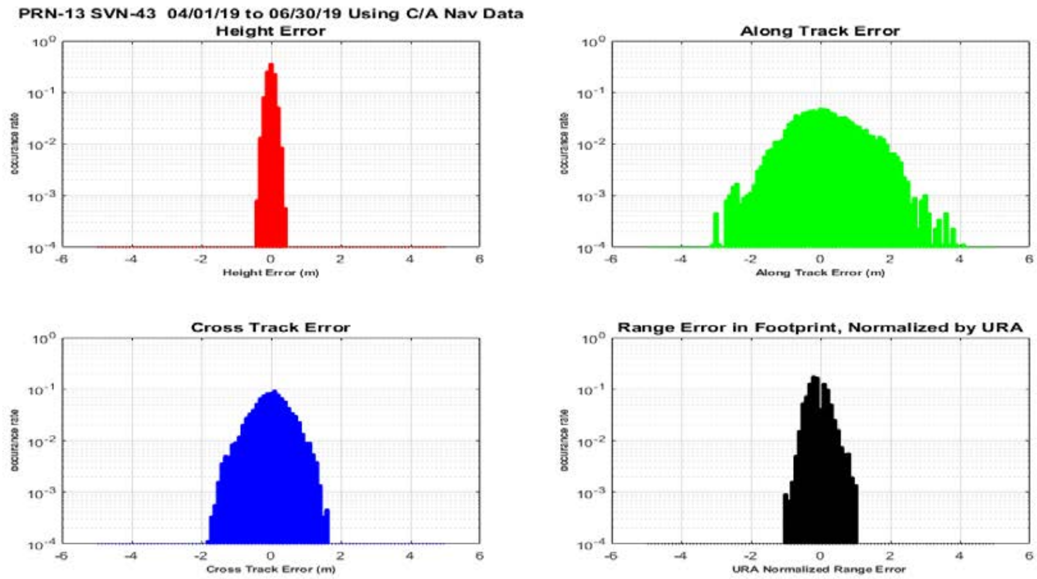


Figure 10-91 Histograms of H, A, C, and Range Error PRN-14 (SVN-41) Using C/A Nav Data

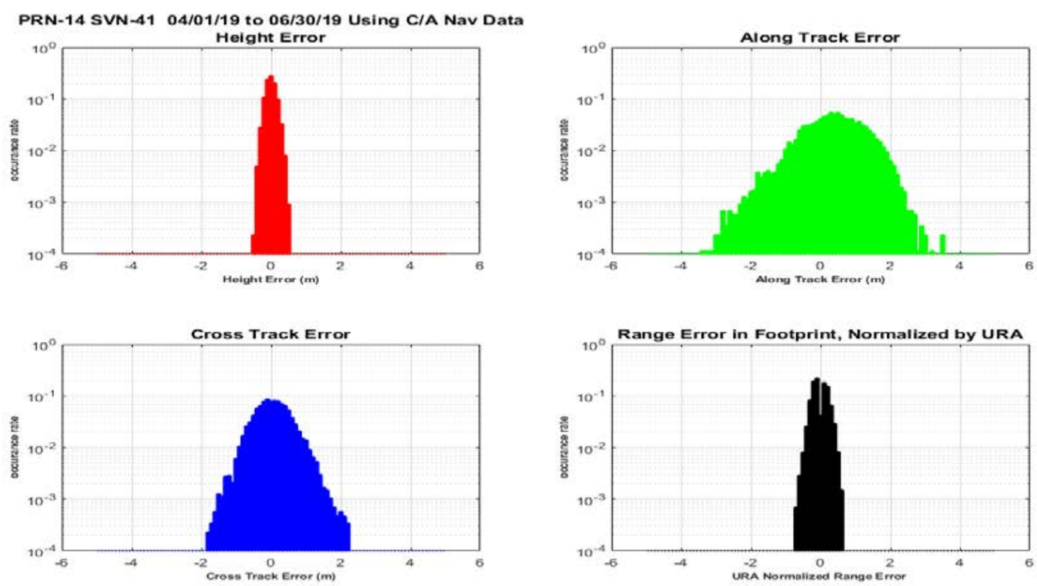


Figure 10-92 Histograms of H, A, C, and Range Error PRN-15 (SVN-55) Using C/A Nav Data

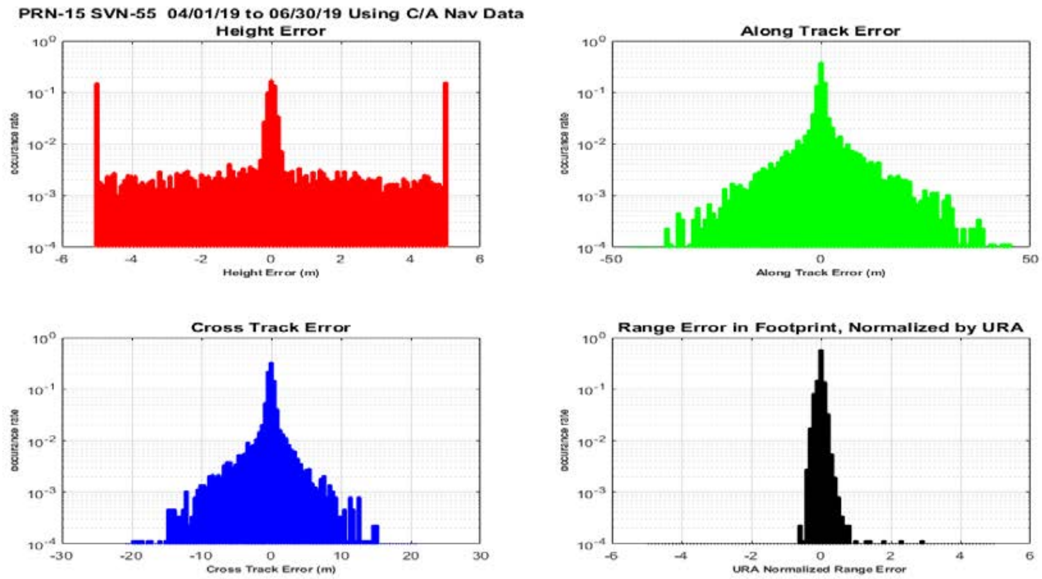


Figure 10-93 Histograms of H, A, C, and Range Error PRN-15 (SVN-55) Using L2C CNAV Data

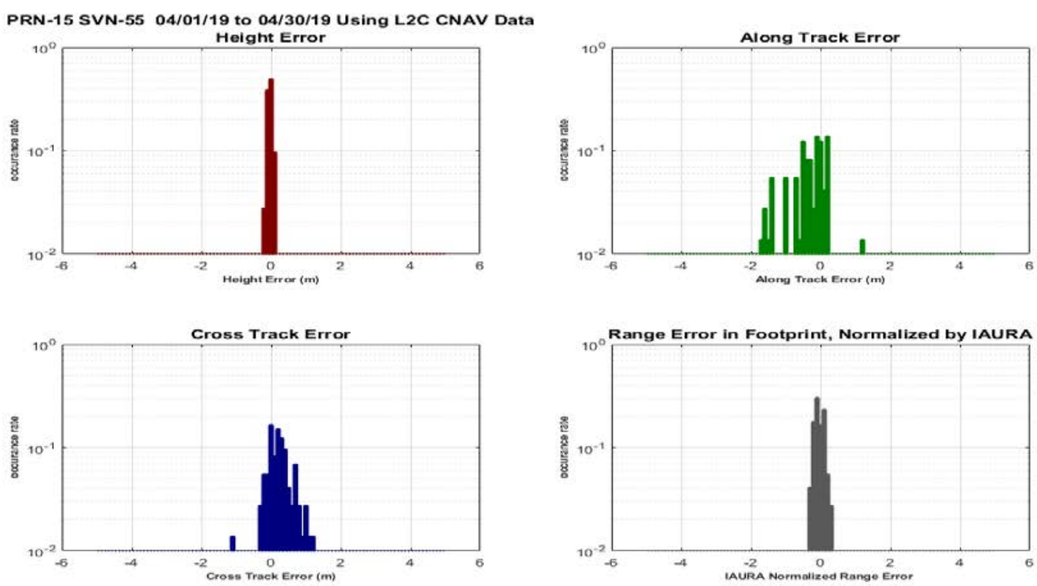


Figure 10-94 Histograms of H, A, C, and Range Error PRN-16 (SVN-56) Using C/A Nav Data

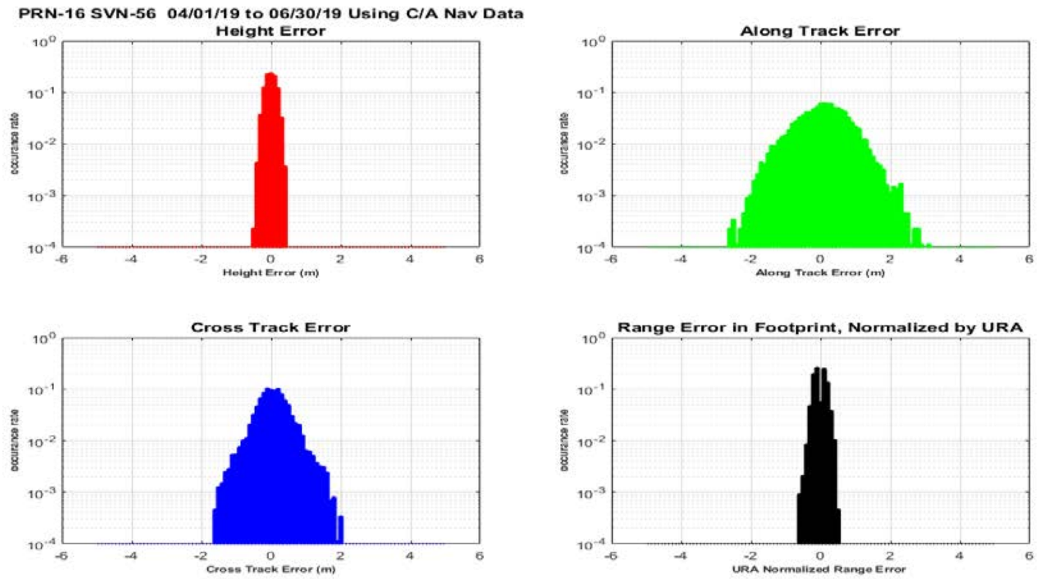


Figure 10-95 Histograms of H, A, C, and Range Error PRN-17 (SVN-53) Using C/A Nav Data

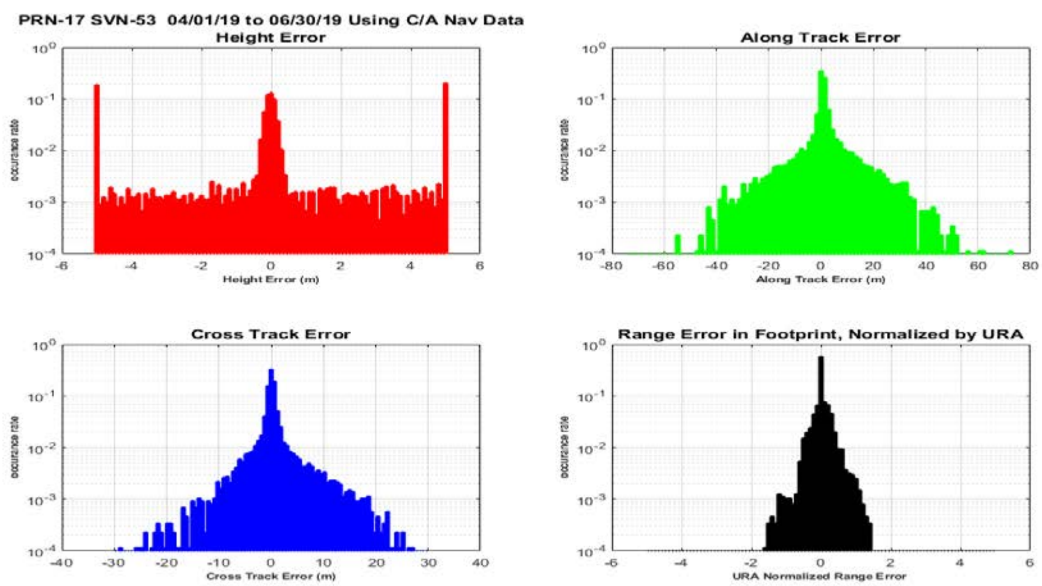


Figure 10-96 Histograms of H, A, C, and Range Error PRN-17 (SVN-53) Using L2C CNAV Data

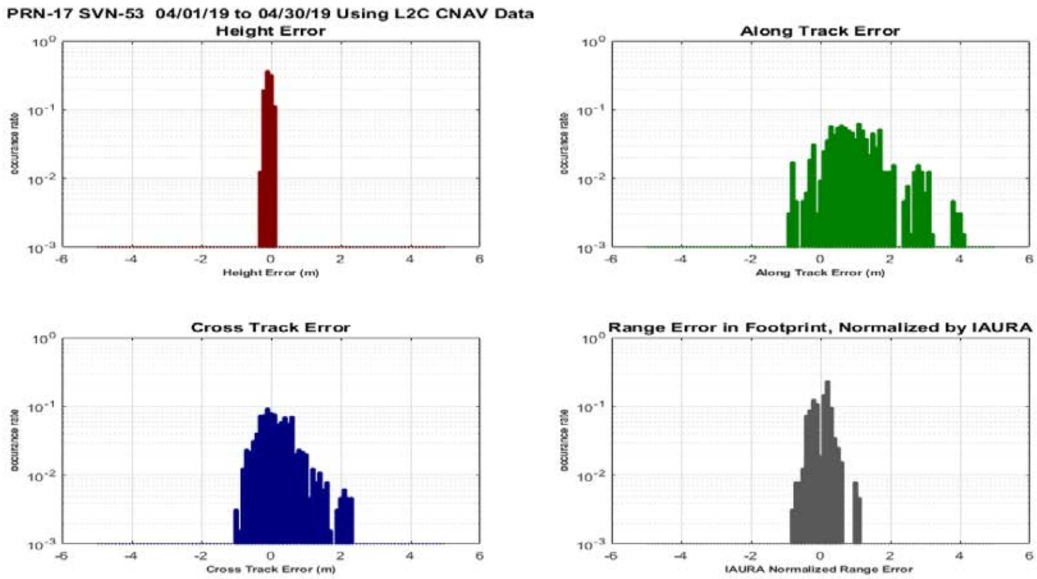


Figure 10-97 Histograms of H, A, C, and Range Error PRN-18 (SVN-34) Using C/A Nav Data

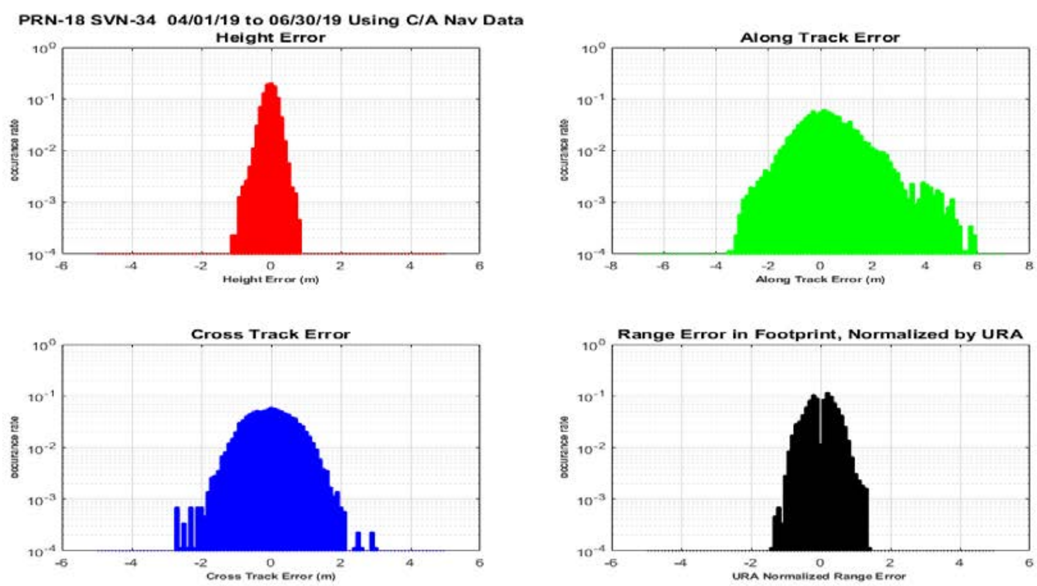


Figure 10-98 Histograms of H, A, C, and Range Error PRN-19 (SVN-59) Using C/A Nav Data

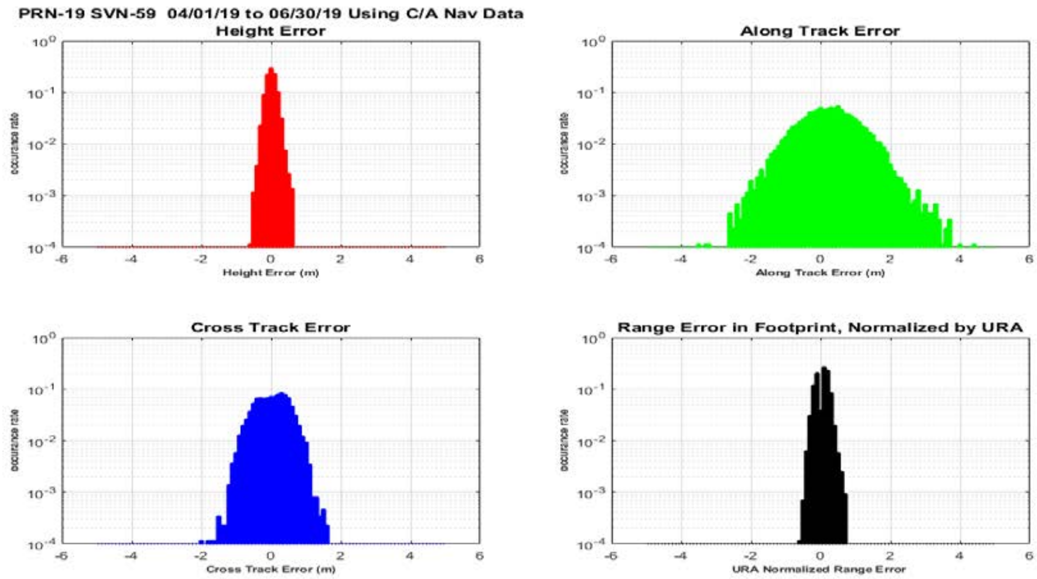


Figure 10-99 Histograms of H, A, C, and Range Error PRN-20 (SVN-51) Using C/A Nav Data

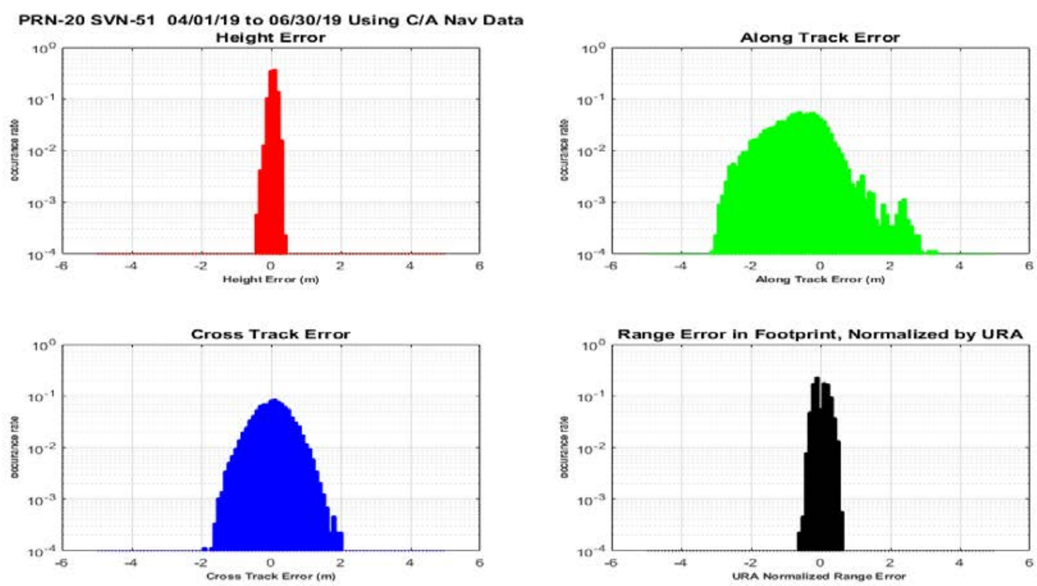


Figure 10-100 Histograms of H, A, C, and Range Error PRN-21 (SVN-45) Using C/A Nav Data

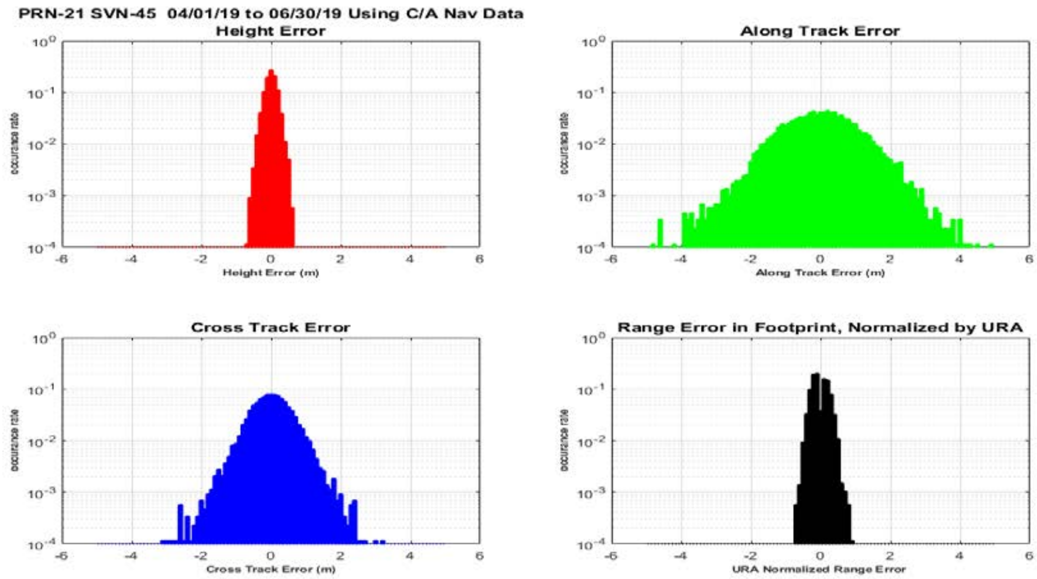


Figure 10-101 Histograms of H, A, C, and Range Error PRN-22 (SVN-47) Using C/A Nav Data

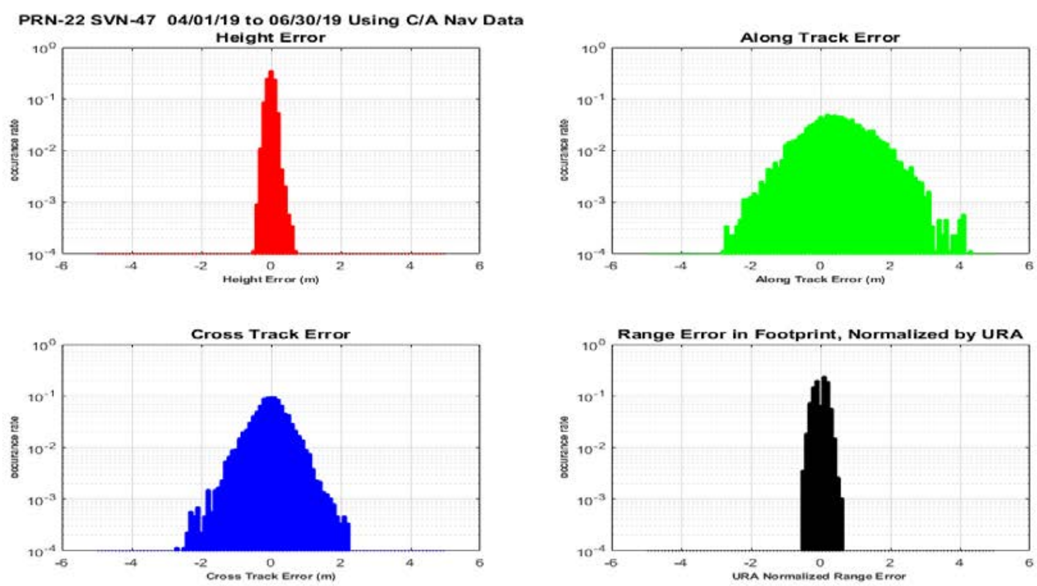


Figure 10-102 Histograms of H, A, C, and Range Error PRN-23 (SVN-60) Using C/A Nav Data

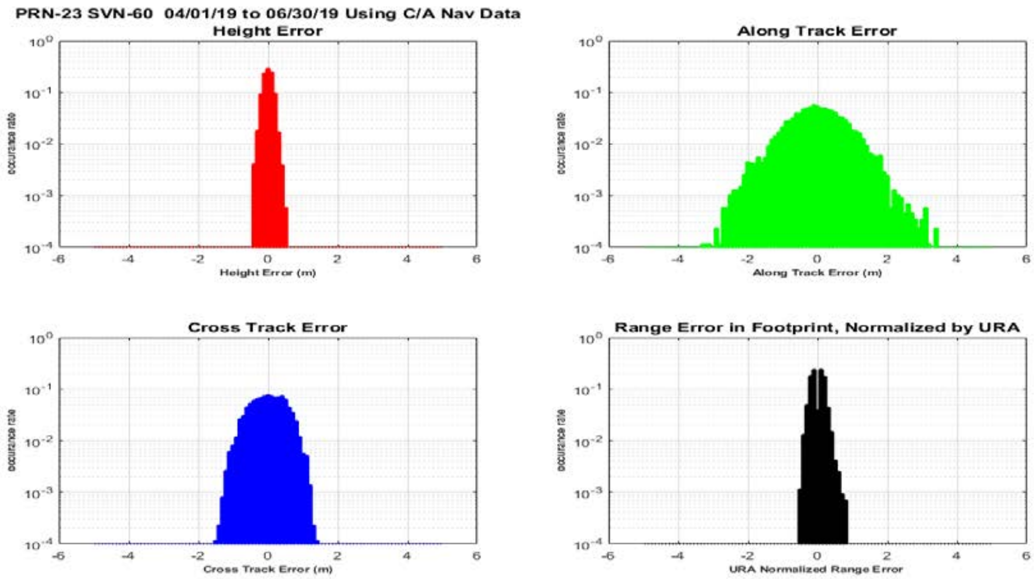


Figure 10-103 Histograms of H, A, C, and Range Error PRN-24 (SVN-65) Using C/A Nav Data

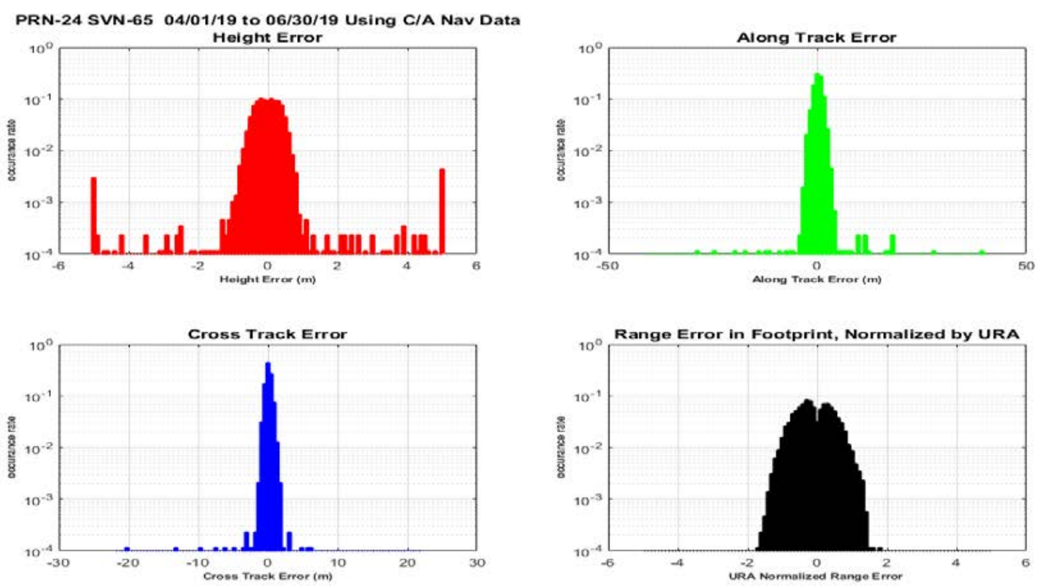


Figure 10-104 Histograms of H, A, C, and Range Error PRN-24 (SVN-65) Using L2C CNAV Data

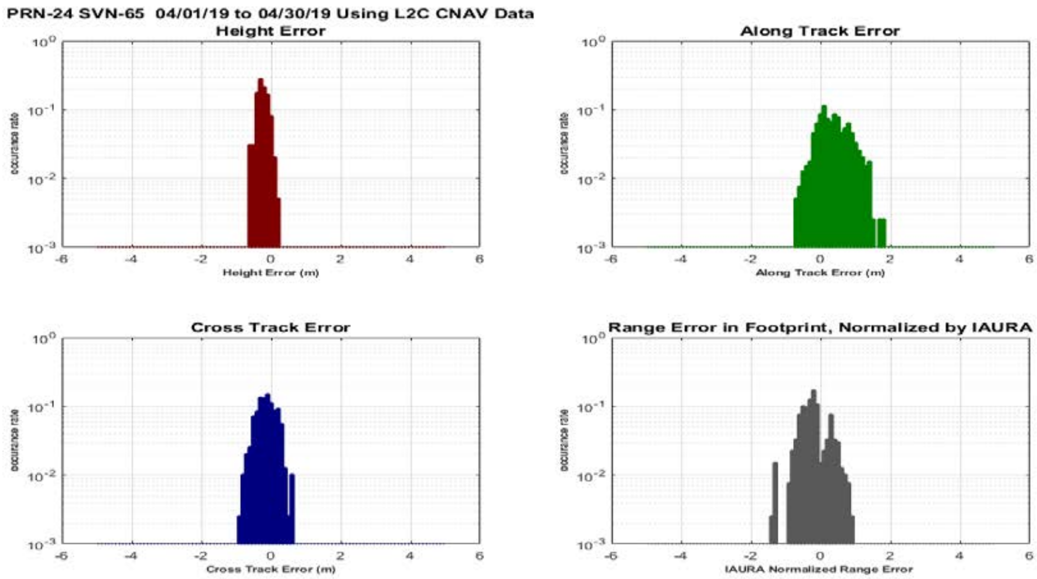


Figure 10-105 Histograms of H, A, C, and Range Error PRN-25 (SVN-62) Using C/A Nav Data

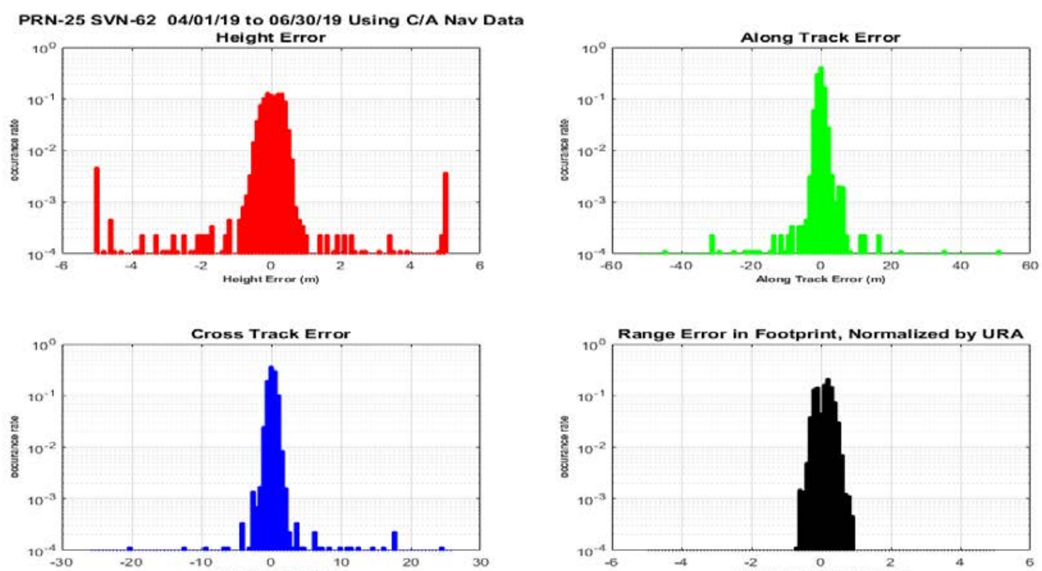


Figure 10-106 Histograms of H, A, C, and Range Error PRN-25 (SVN-62) Using L2C CNAV Data

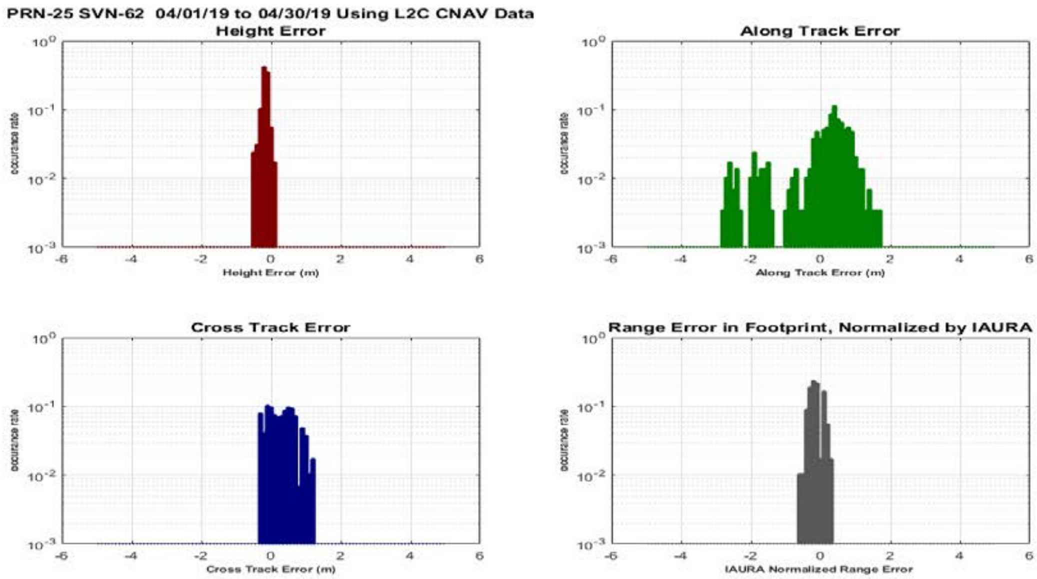


Figure 10-107 Histograms of H, A, C, and Range Error PRN-26 (SVN-71) Using C/A Nav Data

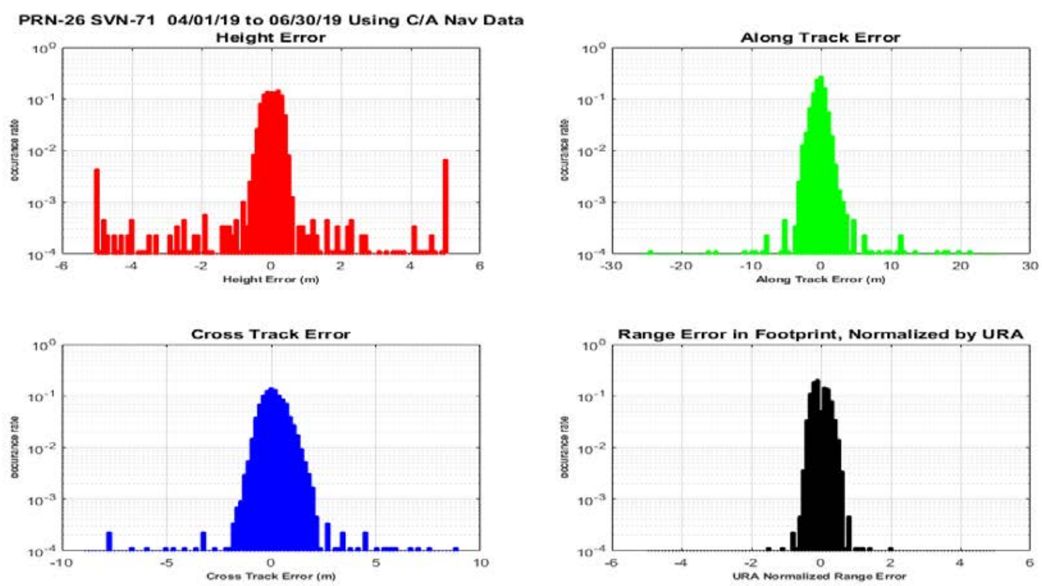


Figure 10-108 Histograms of H, A, C, and Range Error PRN-26 (SVN-71) Using L2C CNAV Data

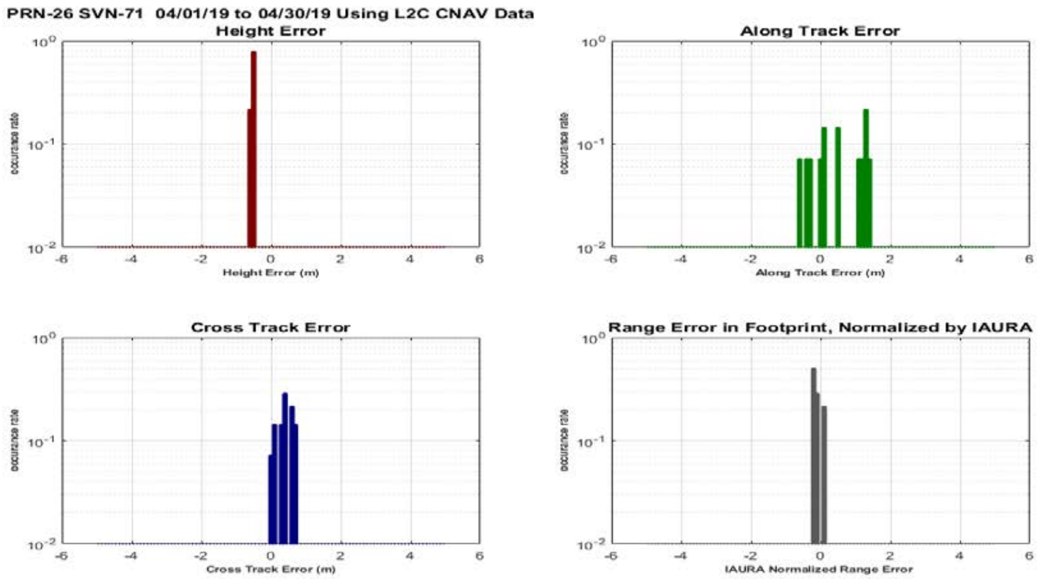


Figure 10-109 Histograms of H, A, C, and Range Error PRN-27 (SVN-66) Using C/A Nav Data

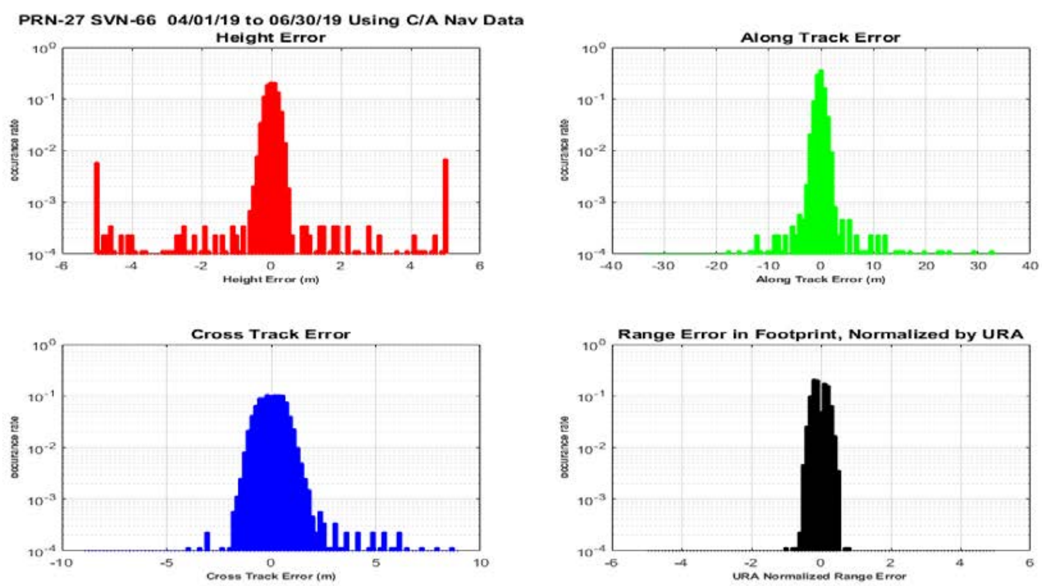


Figure 10-110 Histograms of H, A, C, and Range Error PRN-28 (SVN-44) Using C/A Nav Data

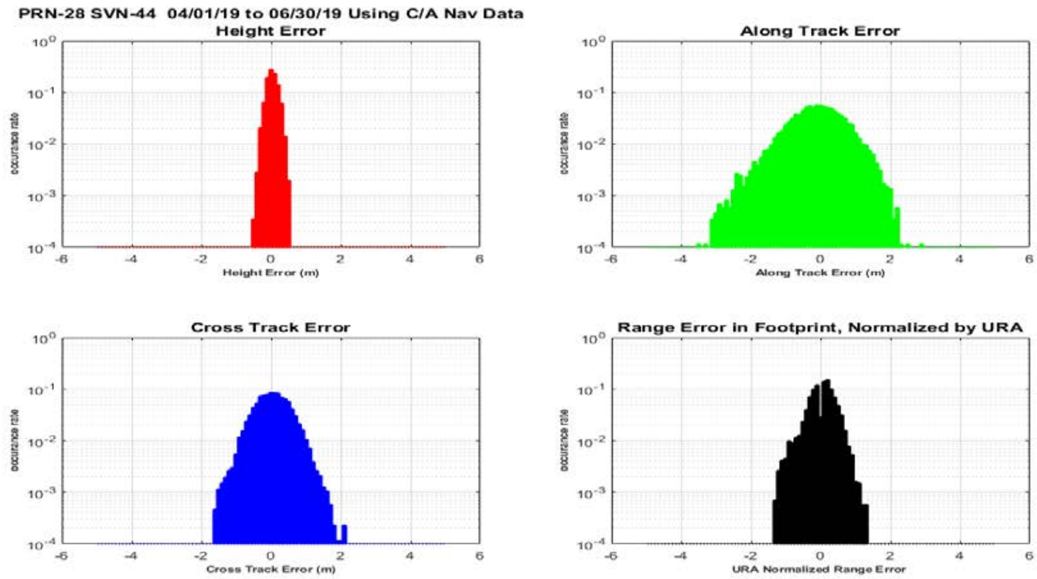


Figure 10-111 Histograms of H, A, C, and Range Error PRN-29 (SVN-57) Using C/A Nav Data

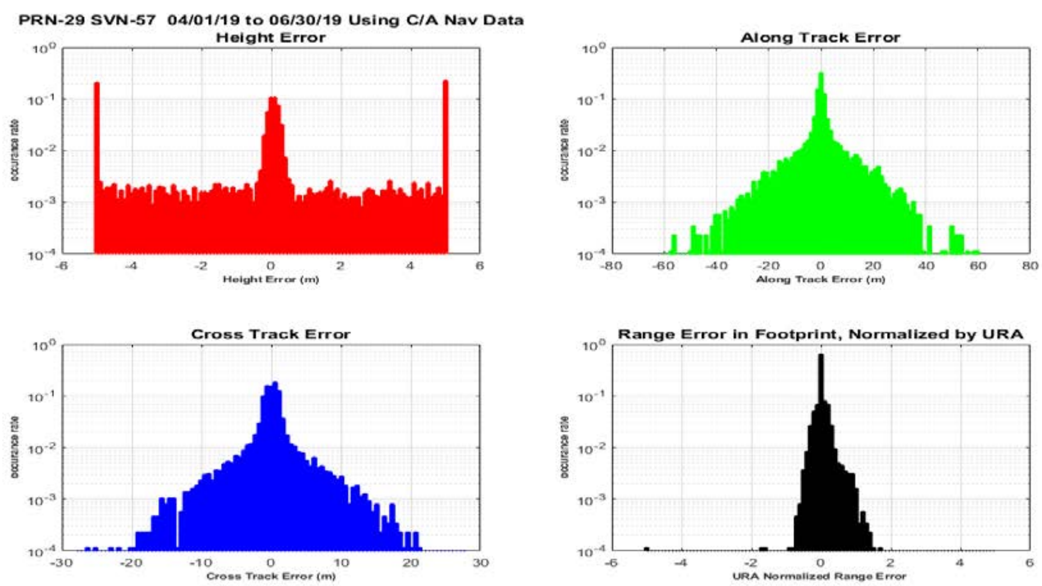


Figure 10-112 Histograms of H, A, C, and Range Error PRN-29 (SVN-57) Using L2C CNAV Data

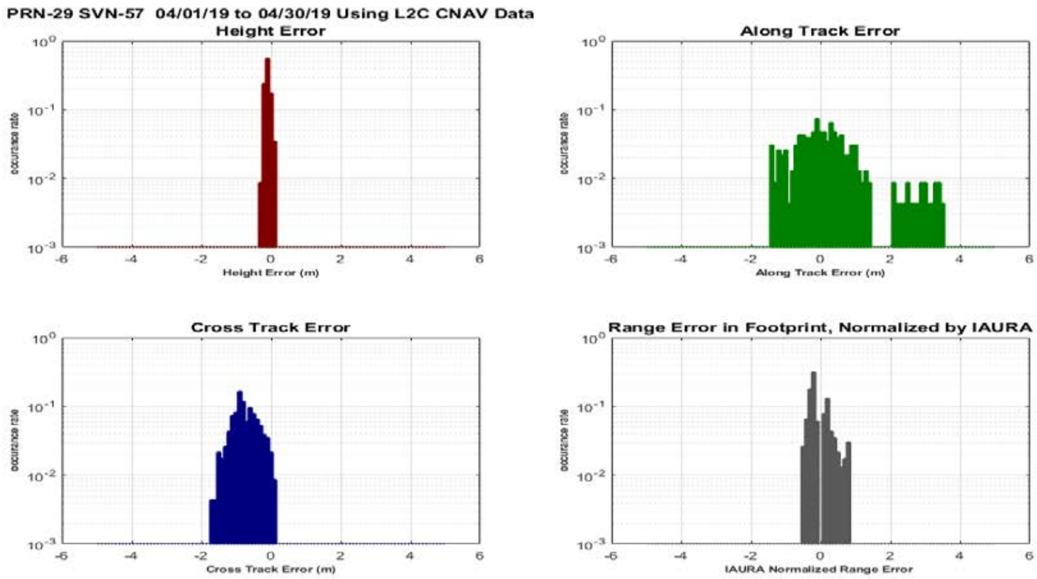


Figure 10-113 Histograms of H, A, C, and Range Error PRN-30 (SVN-64) Using C/A Nav Data

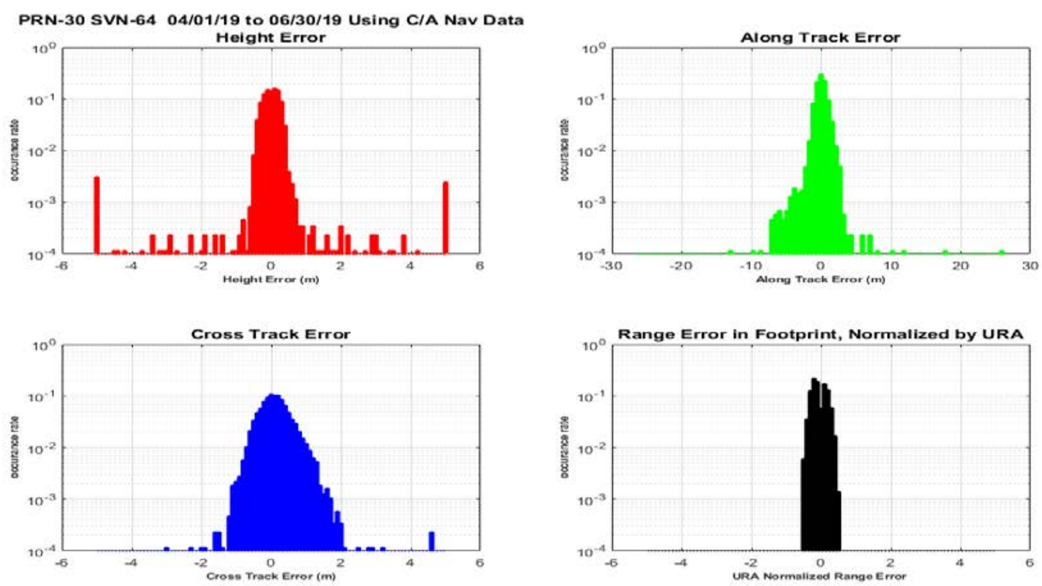


Figure 10-114 Histograms of H, A, C, and Range Error PRN-30 (SVN-64) Using L2C CNAV Data

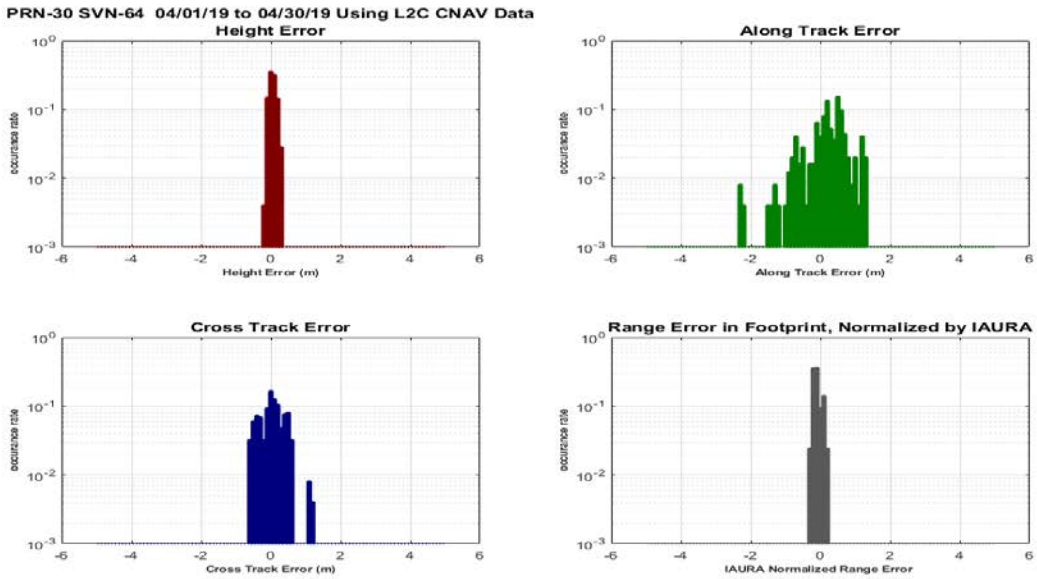


Figure 10-115 Histograms of H, A, C, and Range Error PRN-31 (SVN-52) Using C/A Nav Data

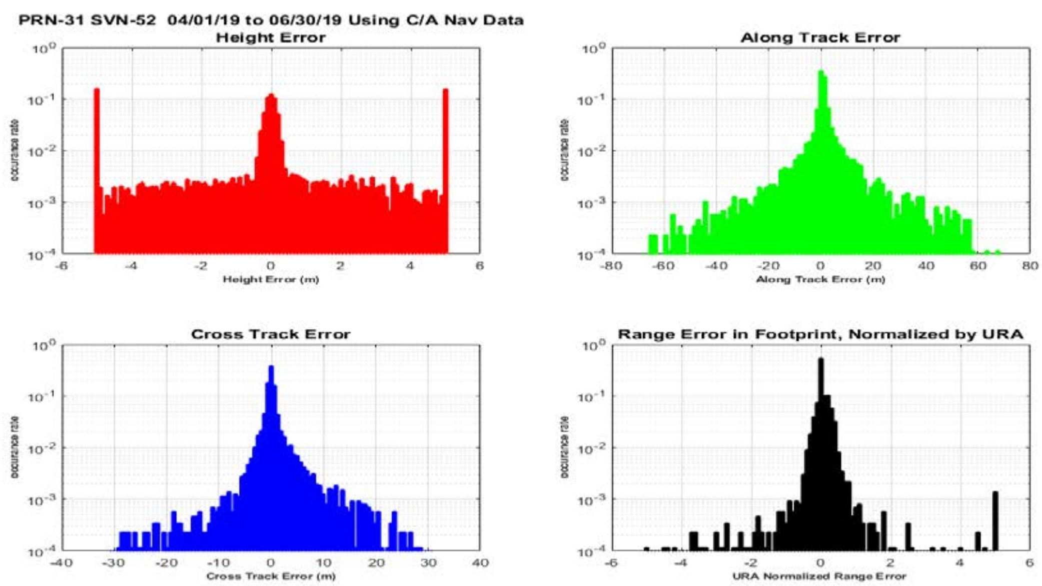
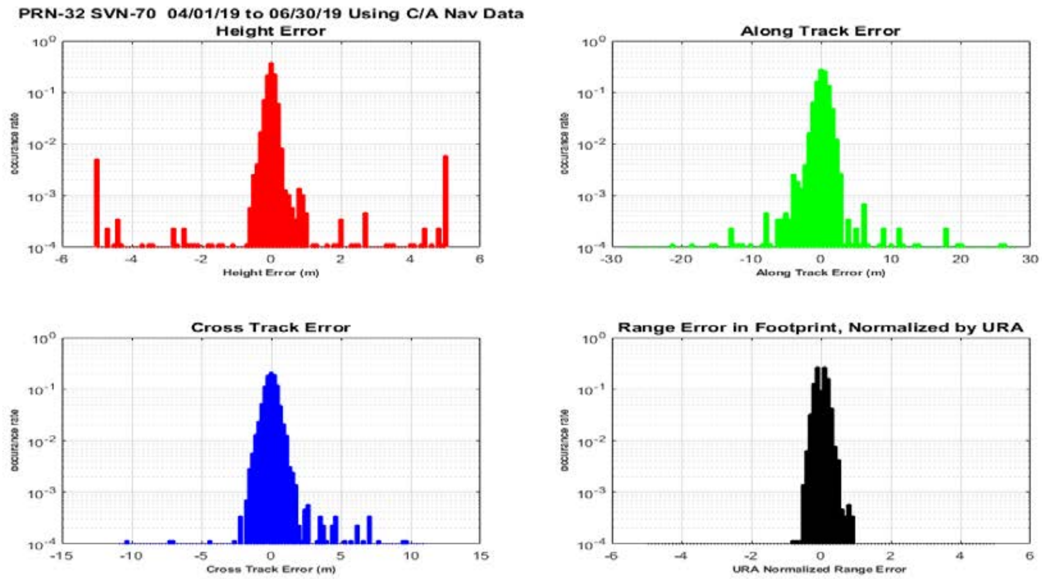


Figure 10-116 Histograms of H, A, C, and Range Error PRN-32 (SVN-70) Using C/A Nav Data



10.8 Timeline of URA Normalized Range Error for All Satellites

Figure 10-117 Timeline of URA Normalized Range Error PRN-1 (SVN-63) Using C/A Nav Data

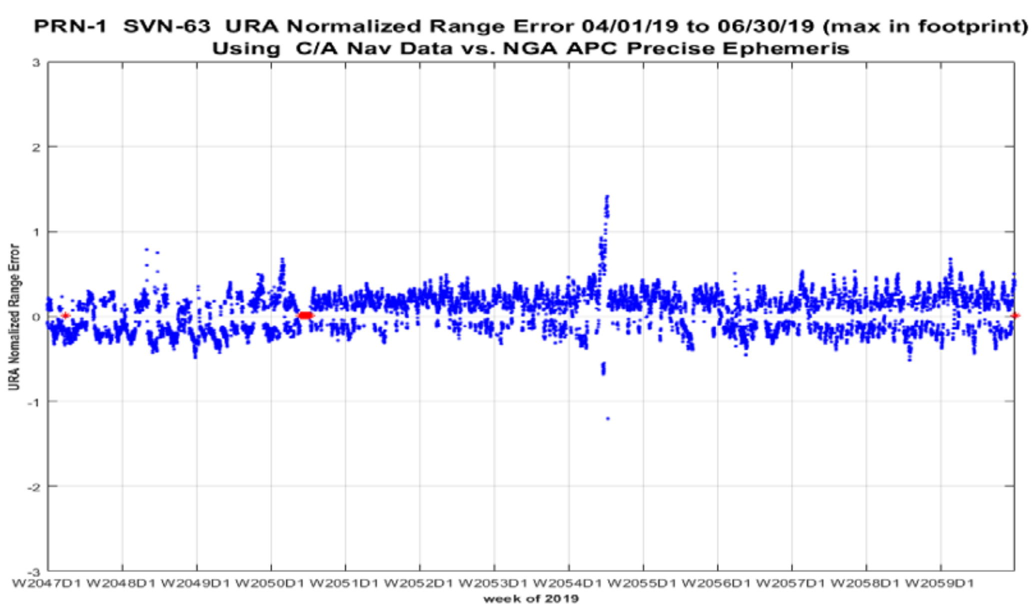


Figure 10-118 Timeline of IAURA Normalized Range Error PRN-1 (SVN-63) Using L2C CNAV Data

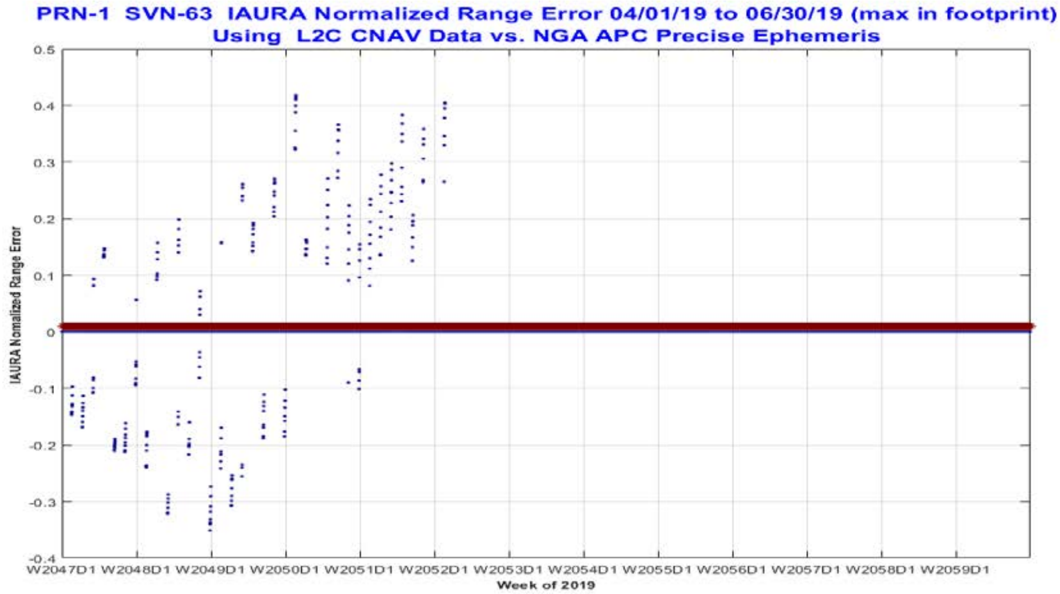


Figure 10-119 Timeline of URA Normalized Range Error PRN-2 (SVN-61) Using C/A Nav Data

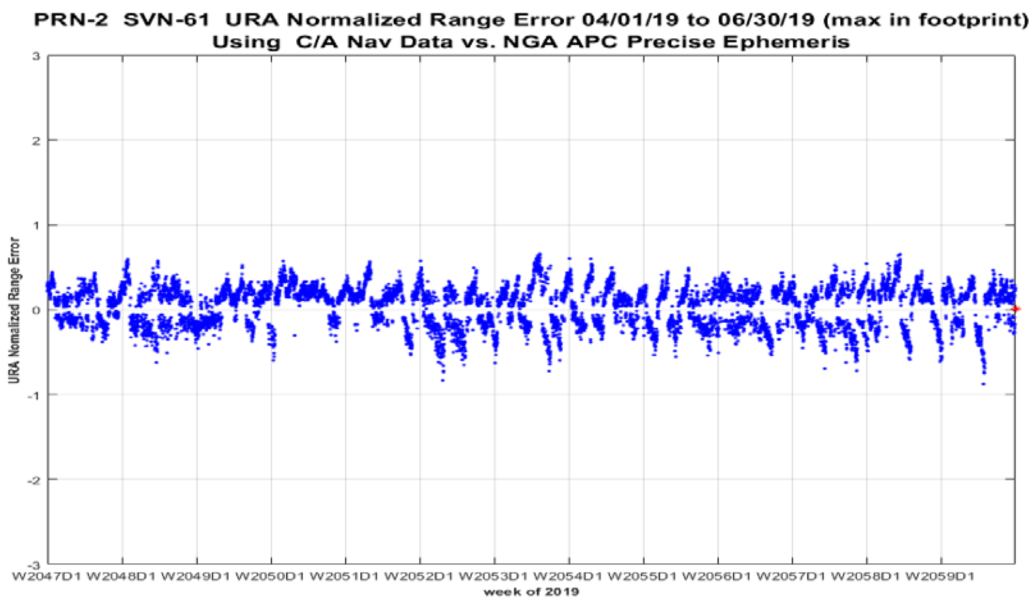


Figure 10-120 Timeline of URA Normalized Range Error PRN-3 (SVN-69) Using C/A Nav Data

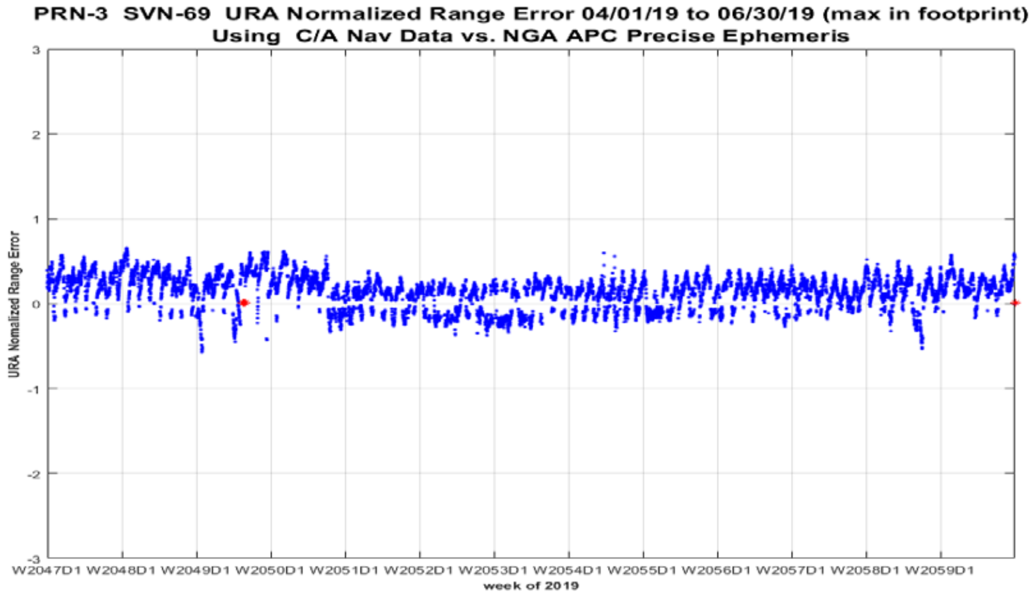


Figure 10-121 Timeline of IAURA Normalized Range Error PRN-3 (SVN-69) Using L2C CNAV Data

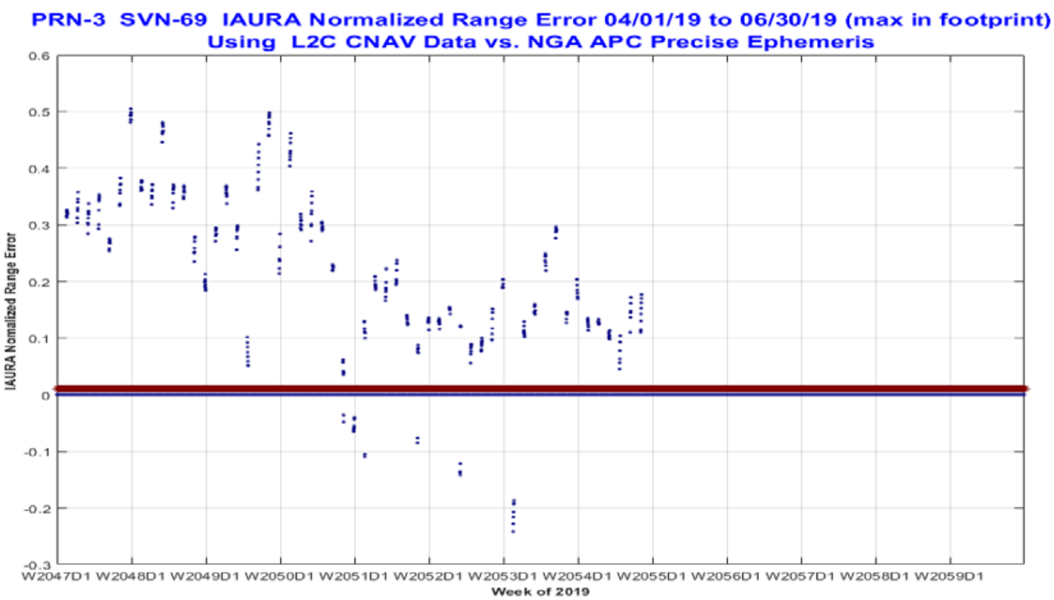


Figure 10-122 Timeline of URA Normalized Range Error PRN-5 (SVN-50) Using C/A Nav Data

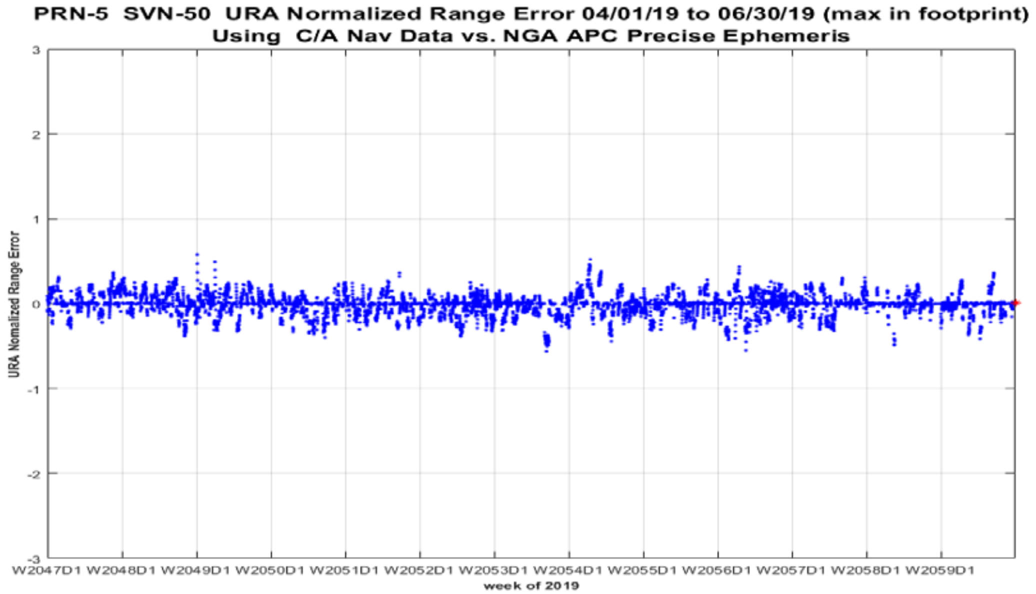


Figure 10-123 Timeline of IAURA Normalized Range Error PRN-5 (SVN-50) Using L2C CNAV Data

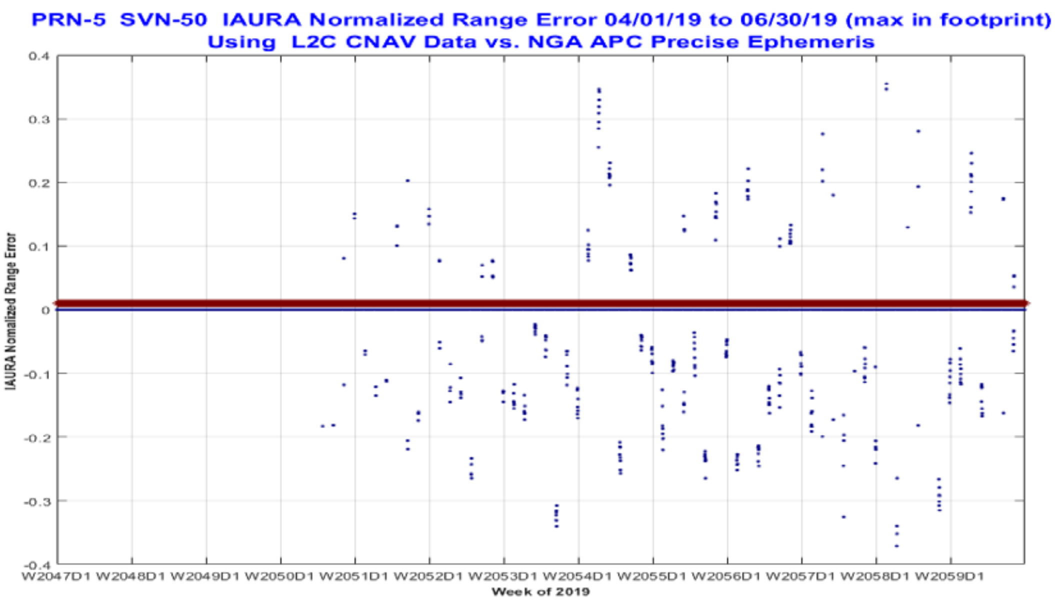


Figure 10-124 Timeline of URA Normalized Range Error PRN-6 (SVN-67) Using C/A Nav Data

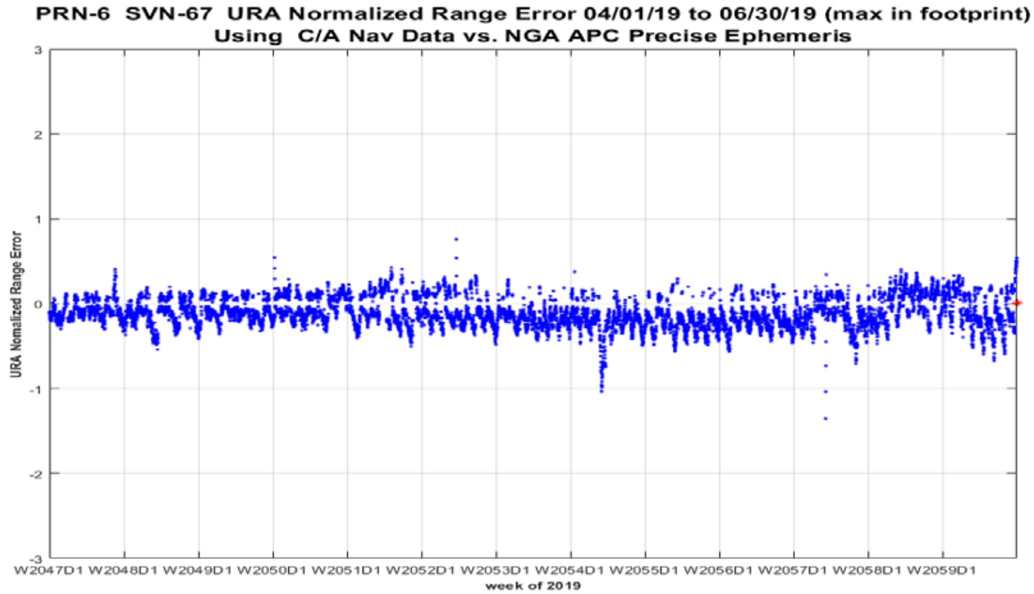


Figure 10-125 Timeline of IAURA Normalized Range Error PRN-6 (SVN-67) Using L2C CNAV Data

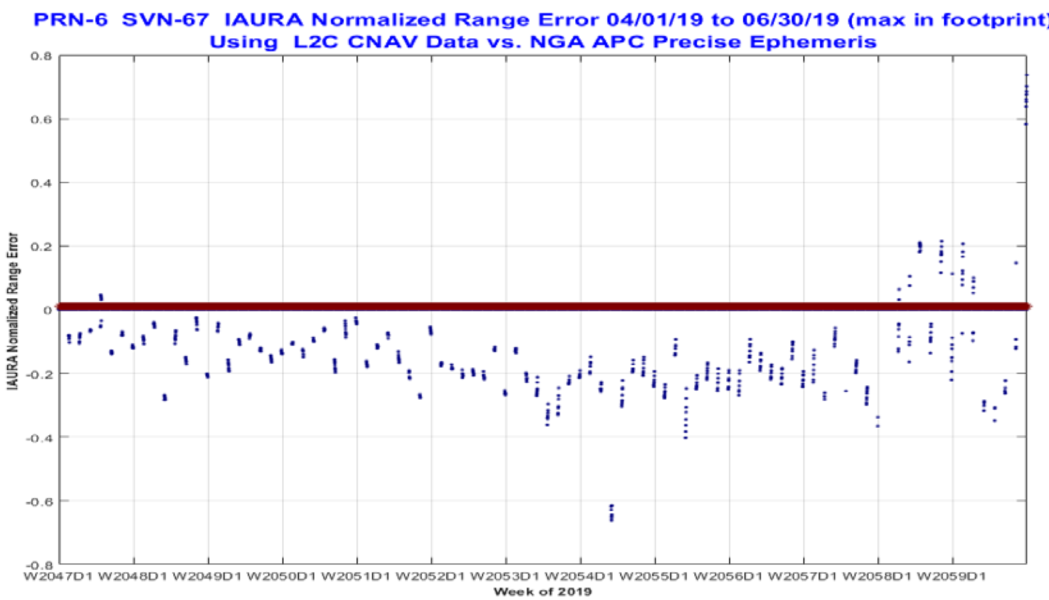


Figure 10-126 Timeline of URA Normalized Range Error PRN-7 (SVN-48) Using C/A Nav Data

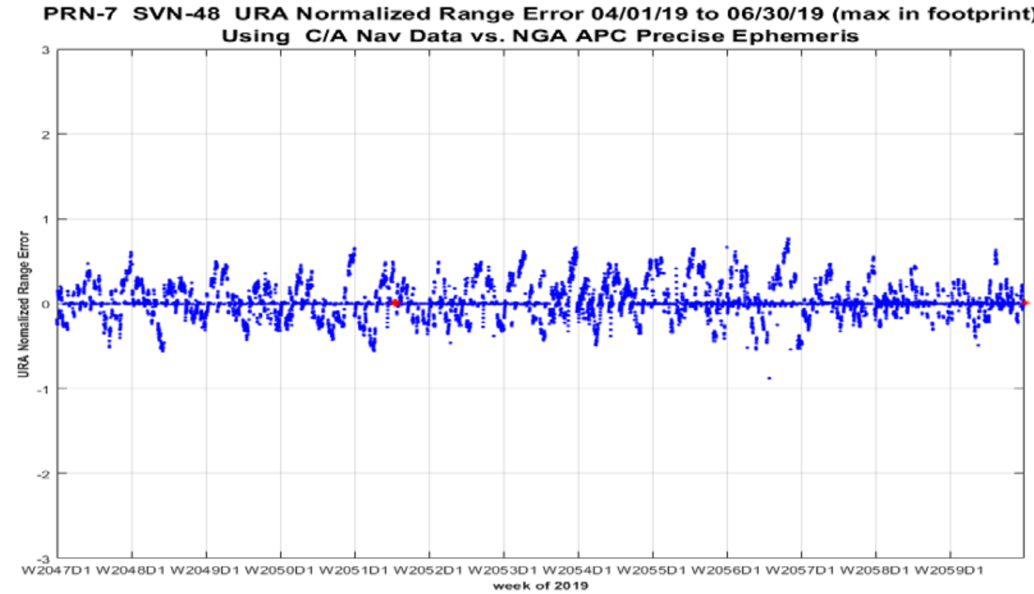


Figure 10-127 Timeline of IAURA Normalized Range Error PRN-7 (SVN-48) Using L2C CNAV Data

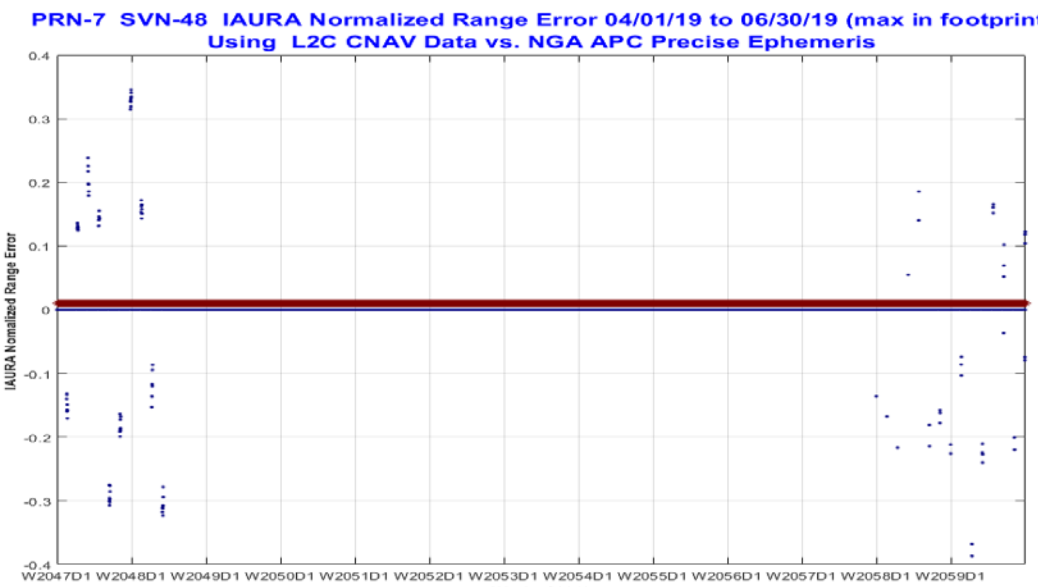


Figure 10-128 Timeline of URA Normalized Range Error PRN-8 (SVN-72) Using C/A Nav Data

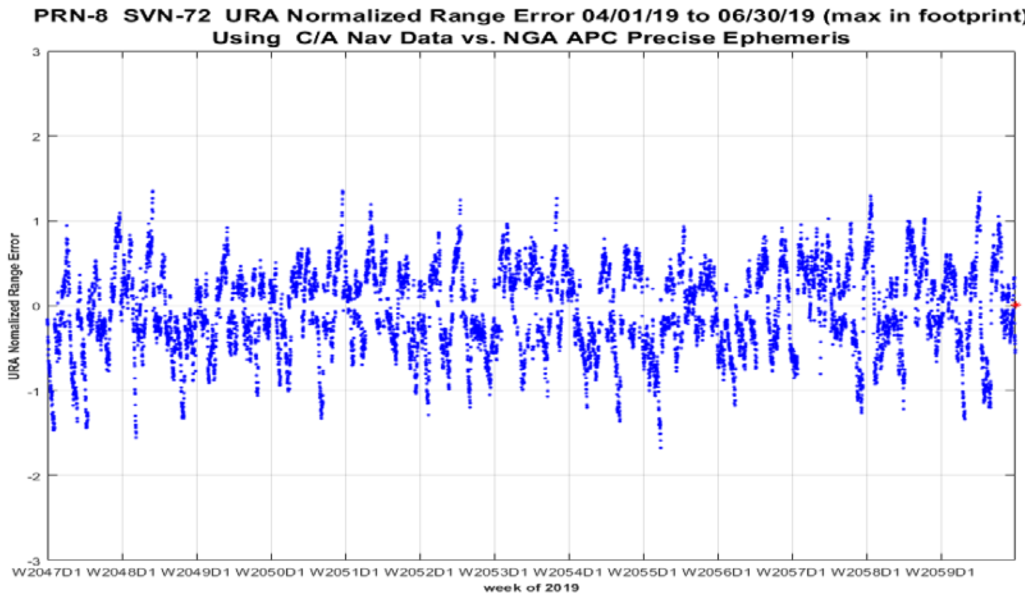


Figure 10-129 Timeline of IAURA Normalized Range Error PRN-8 (SVN-72) Using L2C CNAV Data

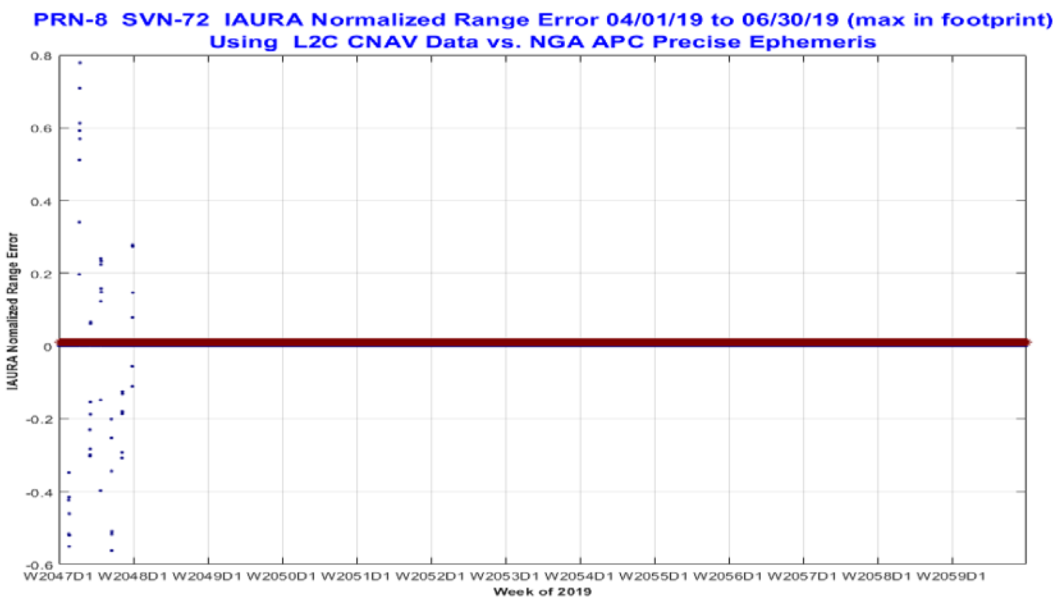


Figure 10-130 Timeline of URA Normalized Range Error PRN-9 (SVN-68) Using C/A Nav Data

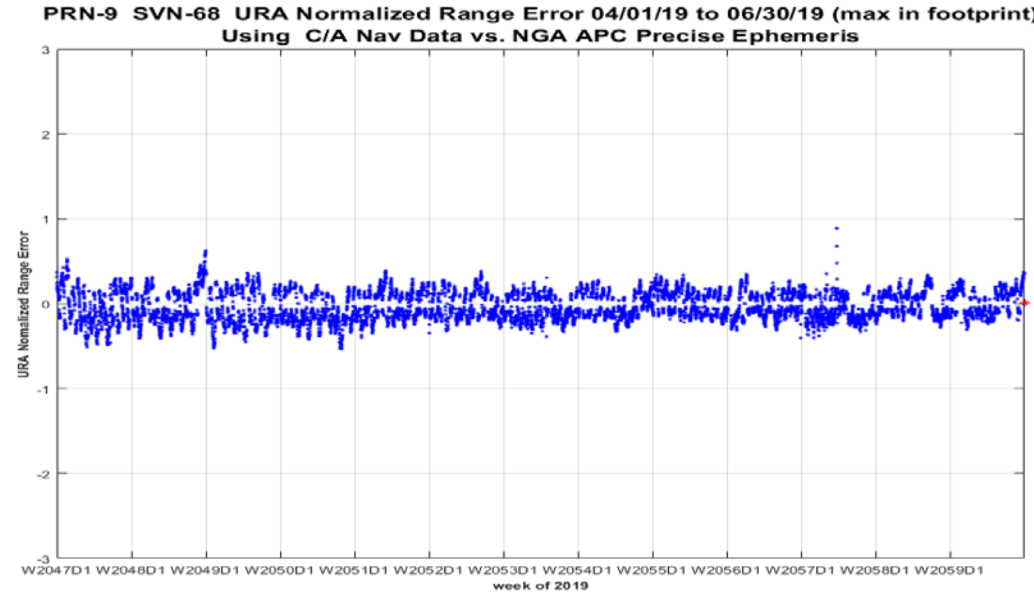


Figure 10-131 Timeline of IAURA Normalized Range Error PRN-9 (SVN-68) Using L2C CNAV Data

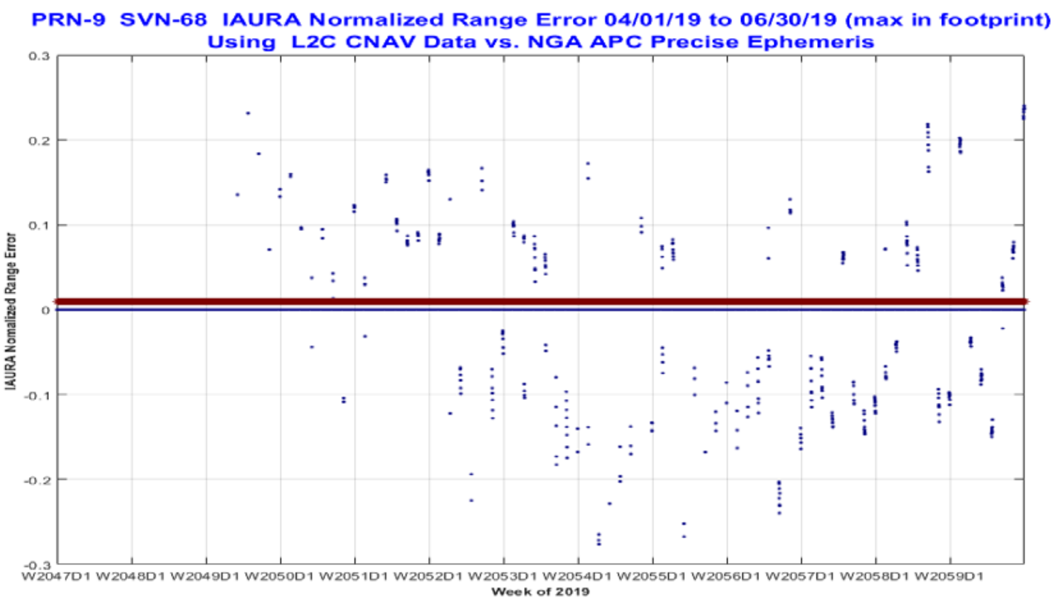


Figure 10-132 Timeline of URA Normalized Range Error PRN-10 (SVN-73) Using C/A Nav Data

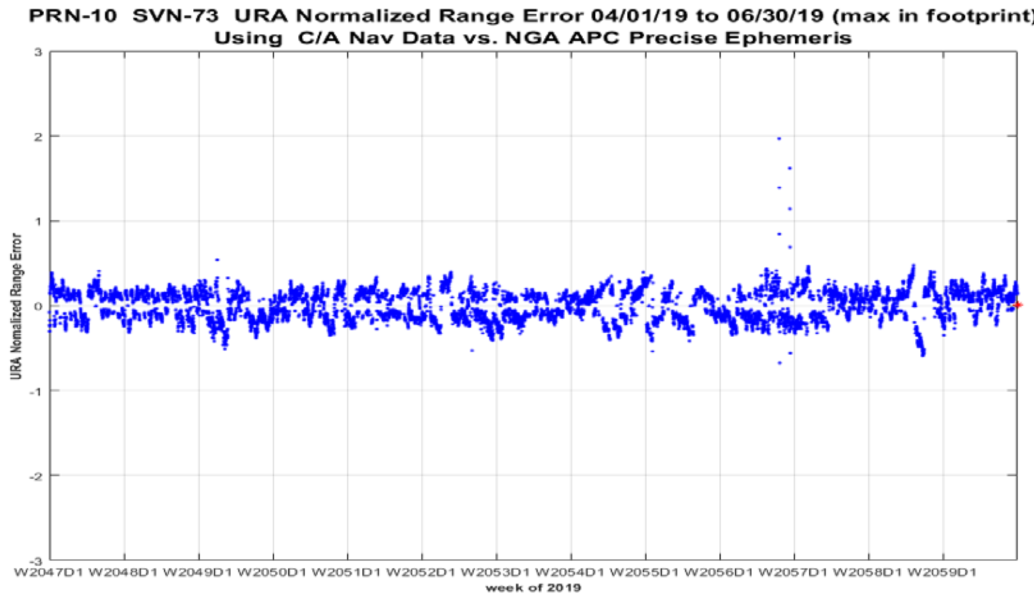


Figure 10-133 Timeline of URA Normalized Range Error PRN-11 (SVN-46) Using C/A Nav Data

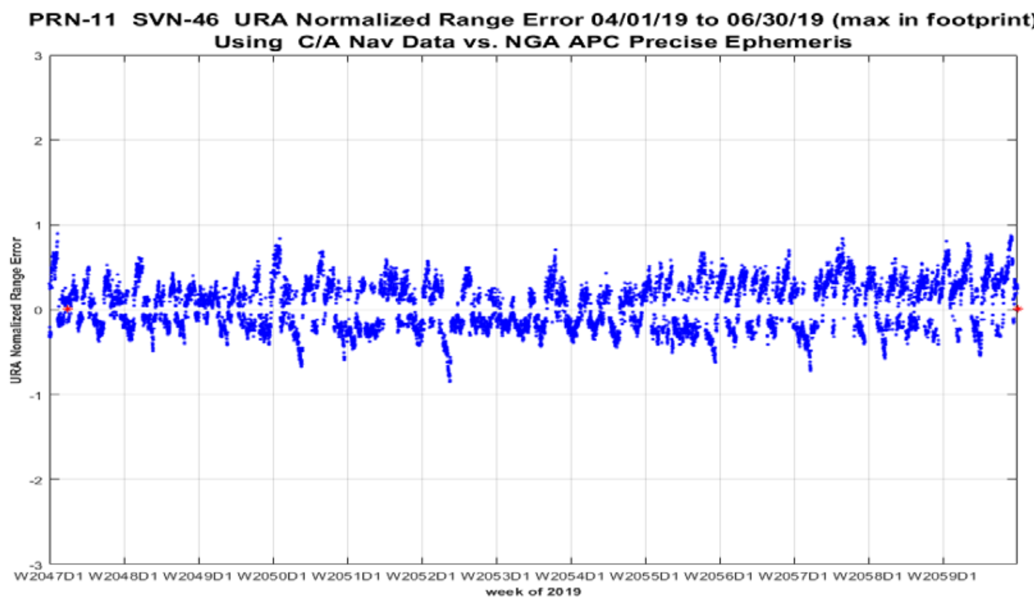


Figure 10-134 Timeline of URA Normalized Range Error PRN-12 (SVN-58) Using C/A Nav Data

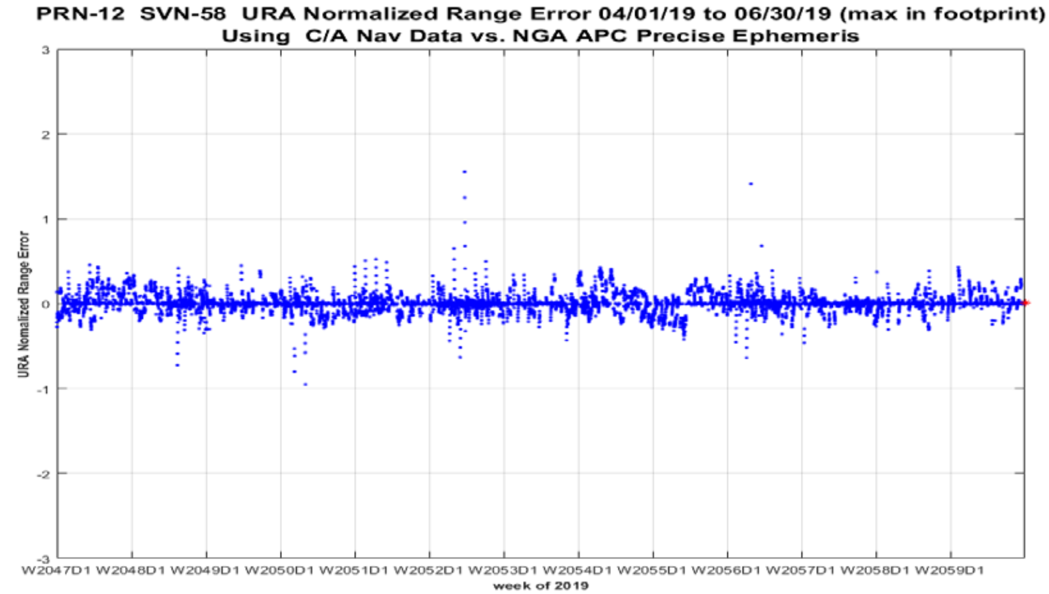


Figure 10-135 Timeline of IAURA Normalized Range Error PRN-12 (SVN-58) Using L2C CNAV Data

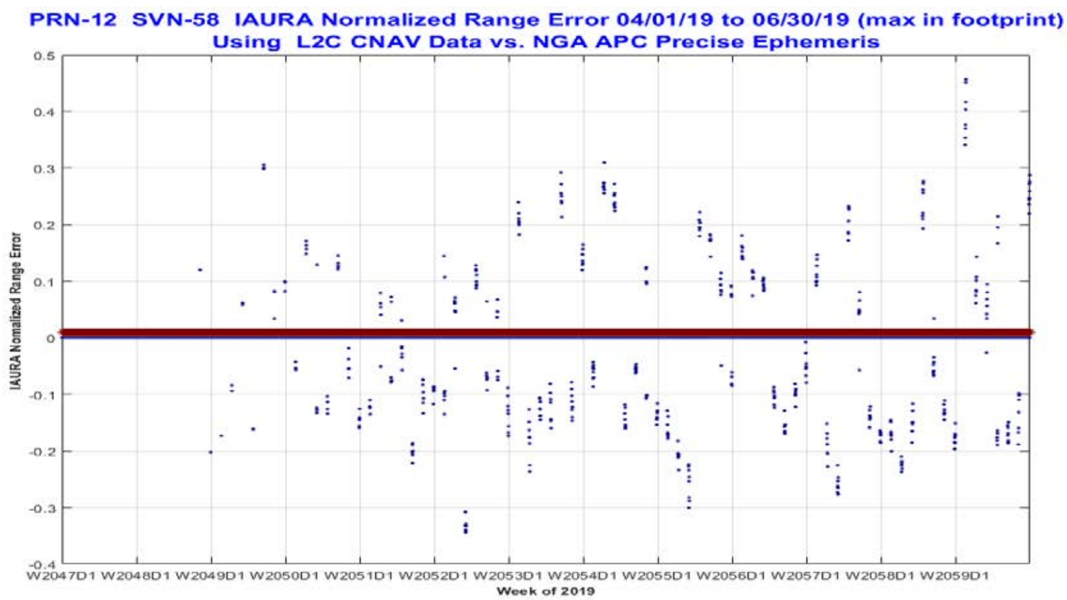


Figure 10-136 Timeline of URA Normalized Range Error PRN-13 (SVN-43) Using C/A Nav Data

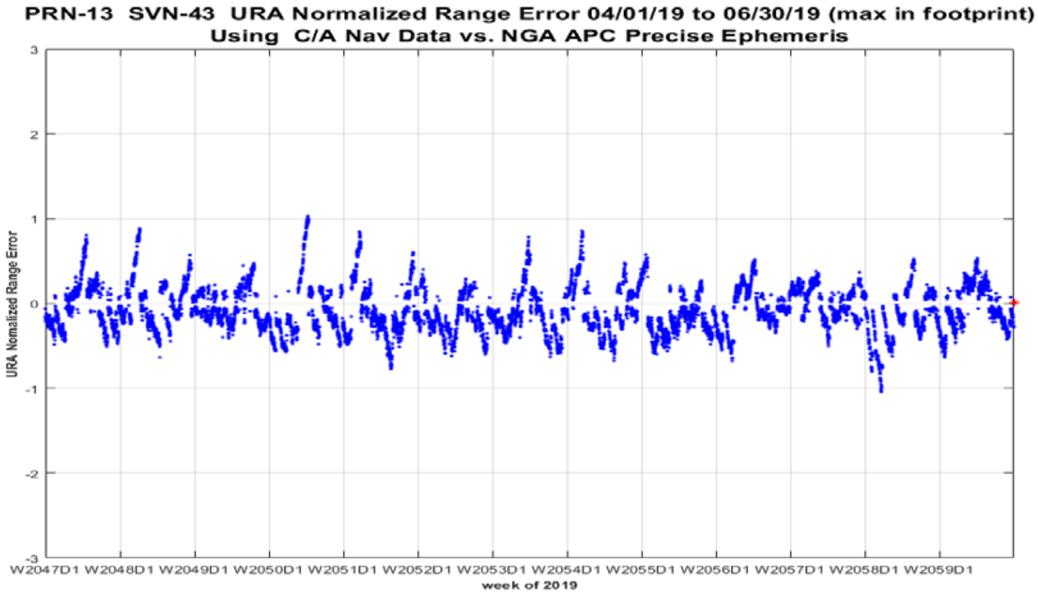


Figure 10-137 Timeline of URA Normalized Range Error PRN-14 (SVN-41) Using C/A Nav Data

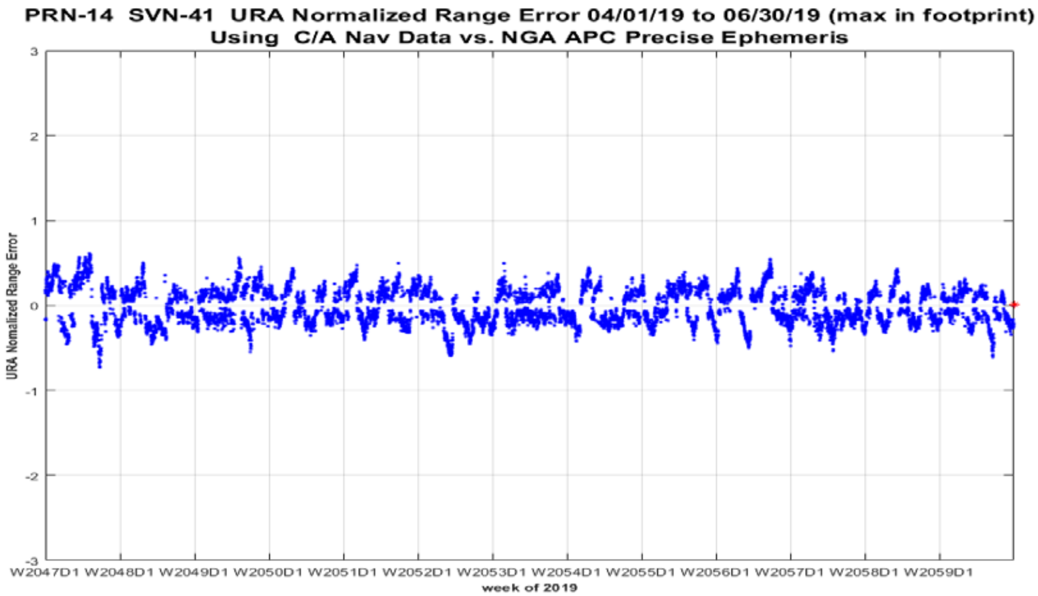


Figure 10-138 Timeline of URA Normalized Range Error PRN-15 (SVN-55) Using C/A Nav Data

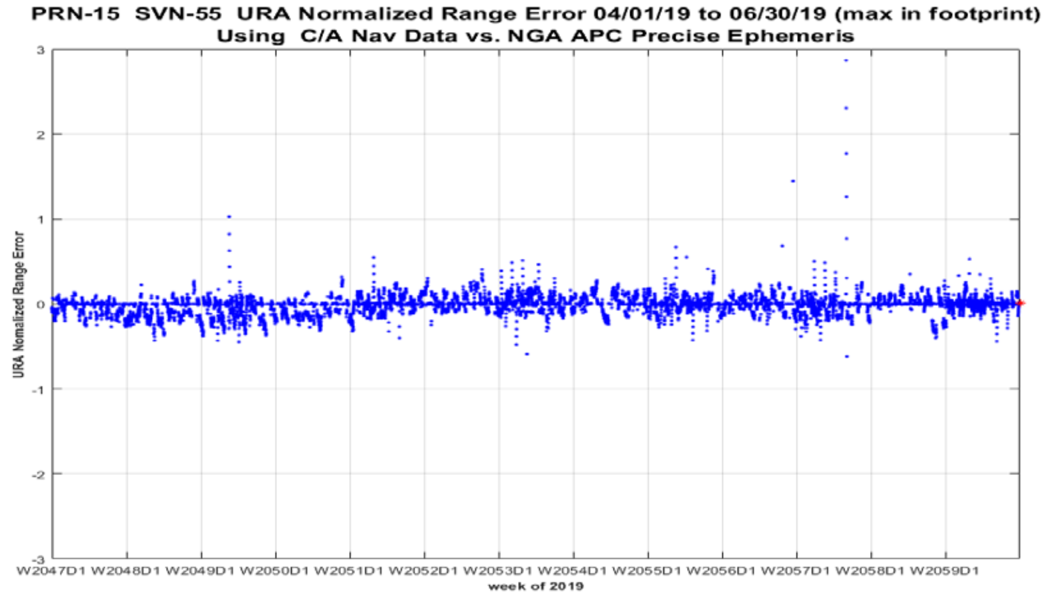


Figure 10-139 Timeline of IAURA Normalized Range Error PRN-15 (SVN-55) Using L2C CNAV Data

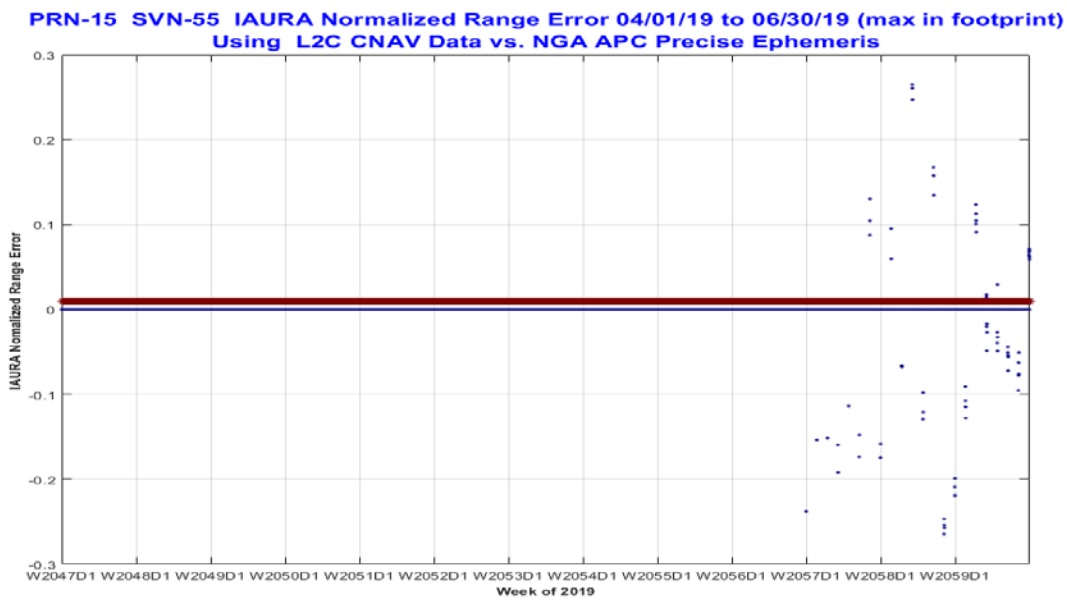


Figure 10-140 Timeline of URA Normalized Range Error PRN-16 (SVN-56) Using C/A Nav Data

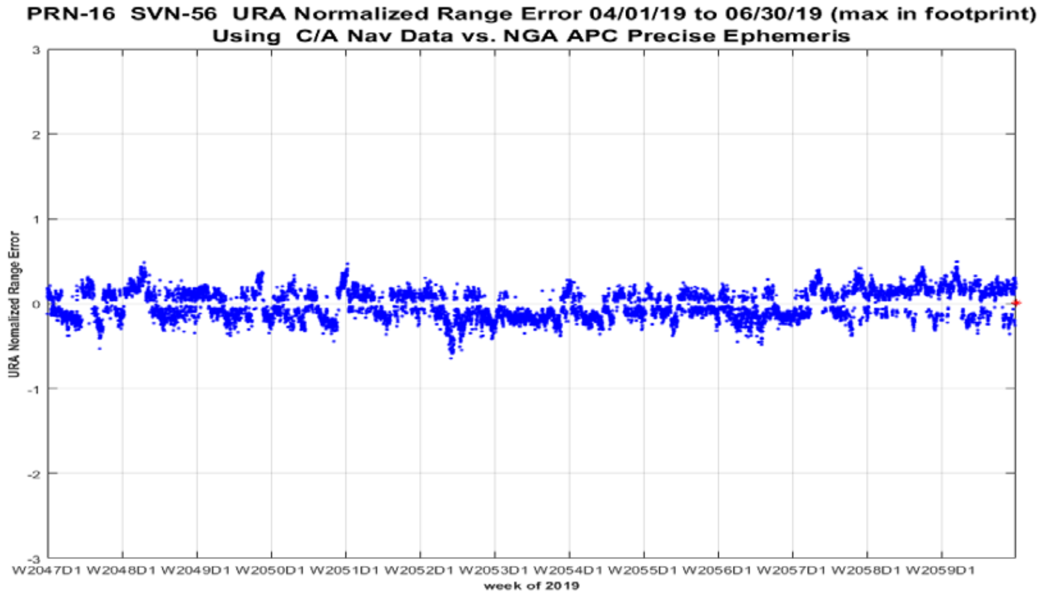


Figure 10-141 Timeline of URA Normalized Range Error PRN-17 (SVN-53) Using C/A Nav Data

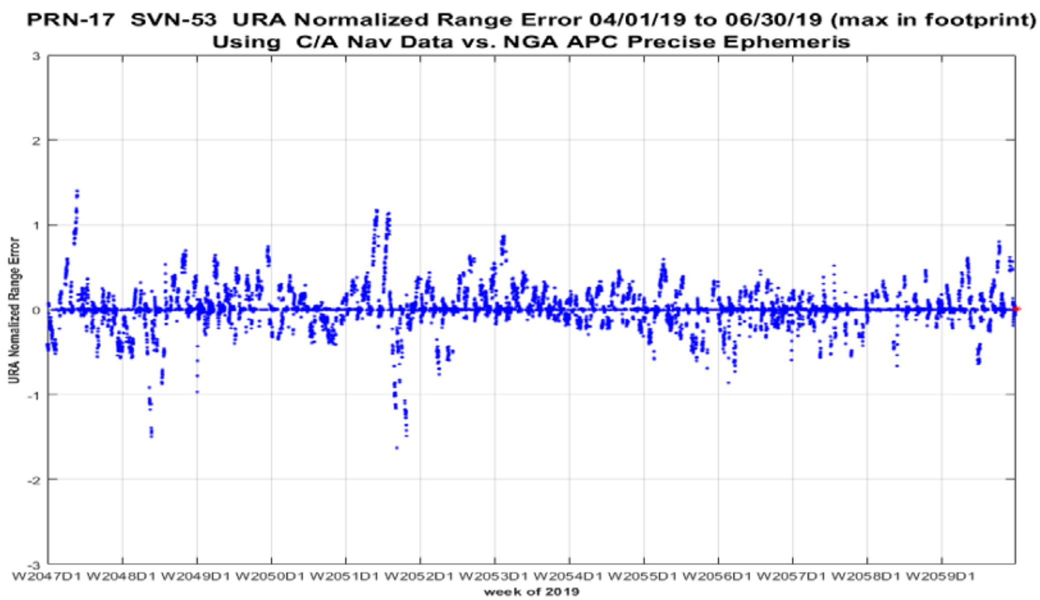


Figure 10-142 Timeline of IAURA Normalized Range Error PRN-17 (SVN-53) Using L2C CNAV Data

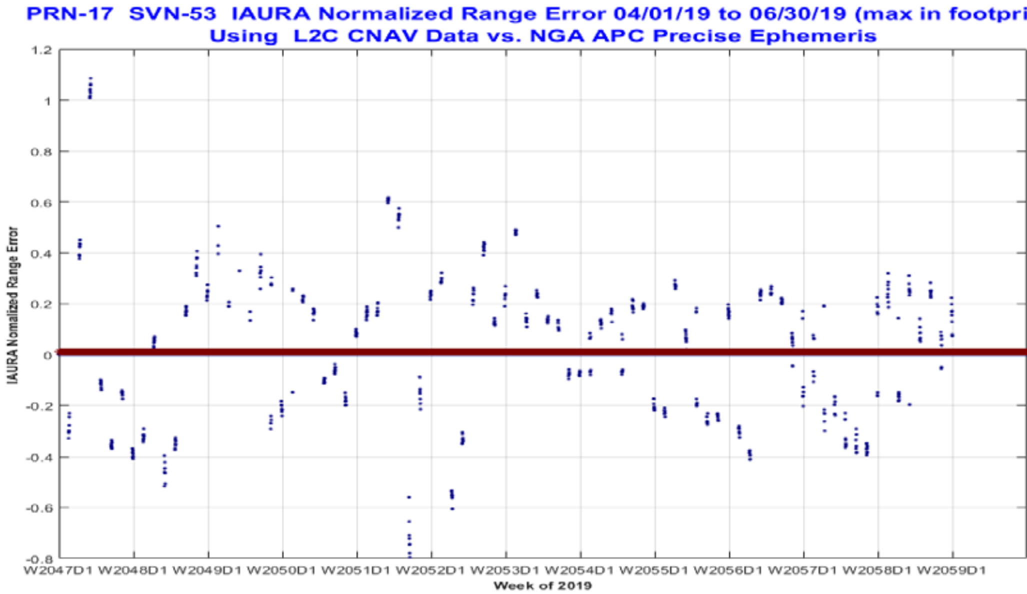


Figure 10-143 Timeline of URA Normalized Range Error PRN-18 (SVN-34) Using C/A Nav Data

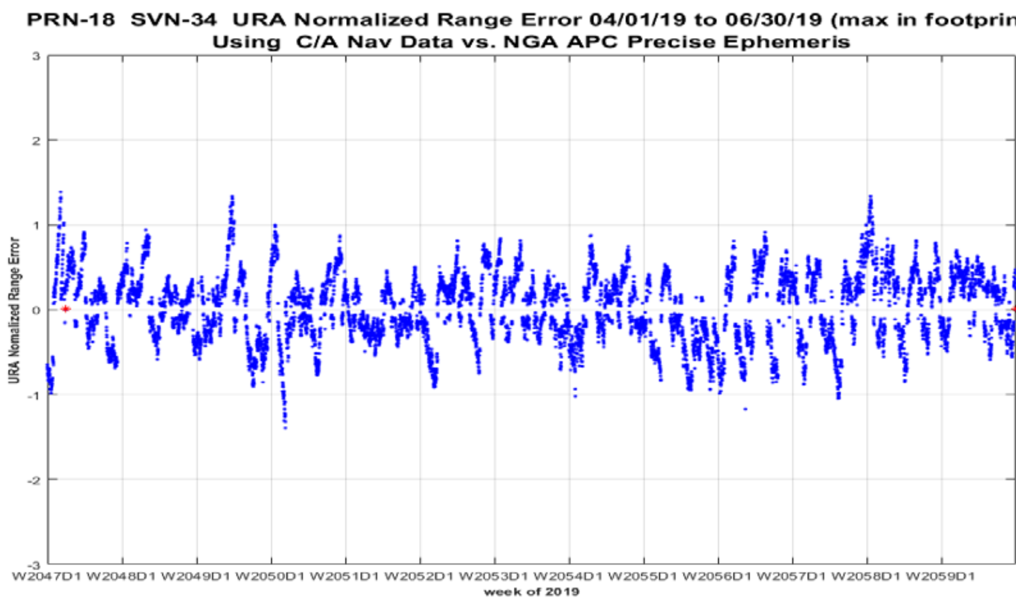


Figure 10-144 Timeline of URA Normalized Range Error PRN-19 (SVN-59) Using C/A Nav Data

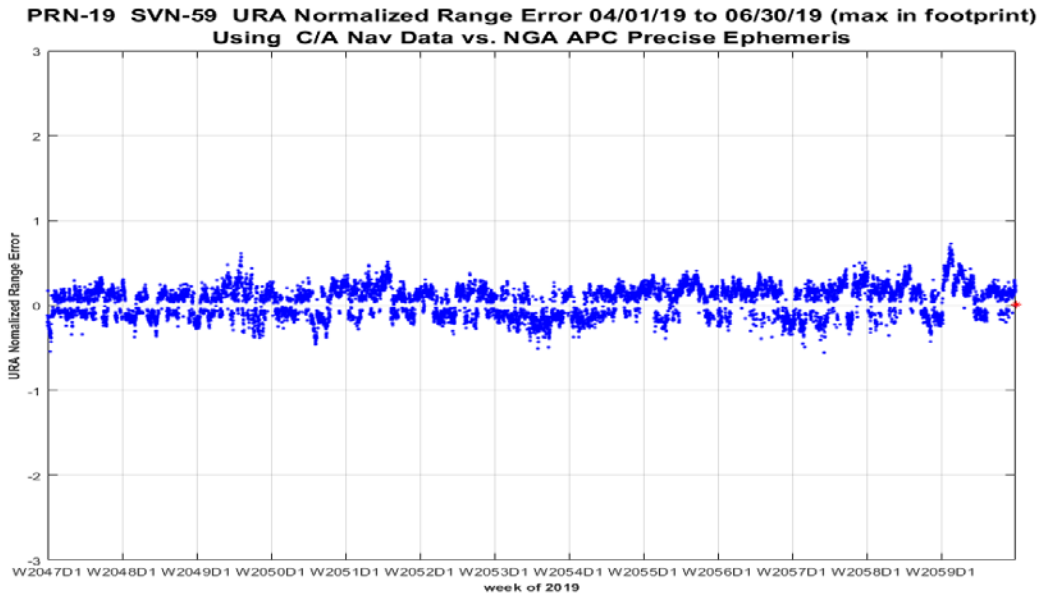


Figure 10-145 Timeline of URA Normalized Range Error PRN-20 (SVN-51) Using C/A Nav Data

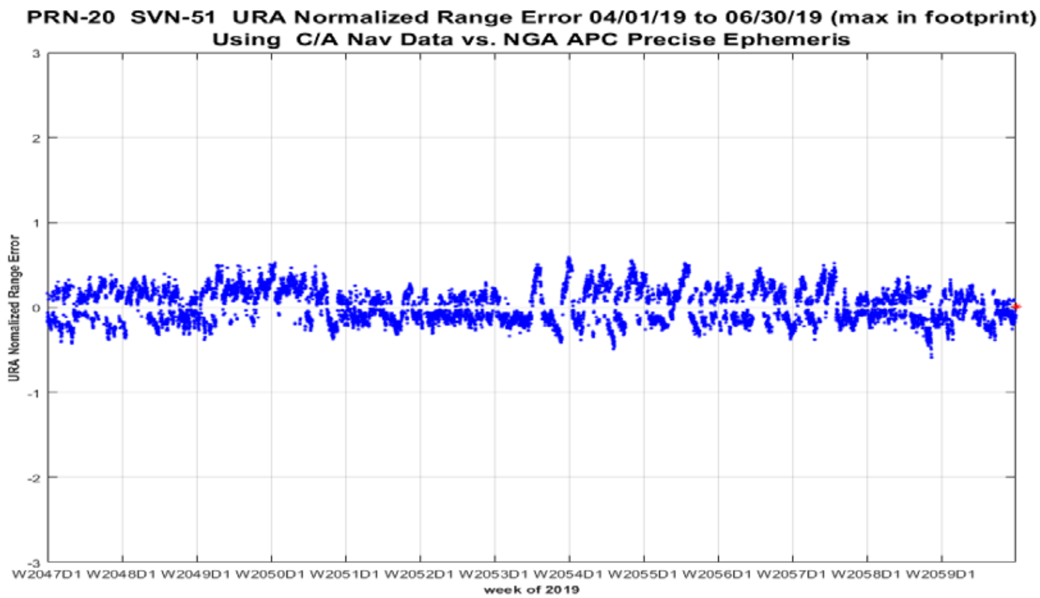


Figure 10-146 Timeline of URA Normalized Range Error PRN-21 (SVN-45) Using C/A Nav Data

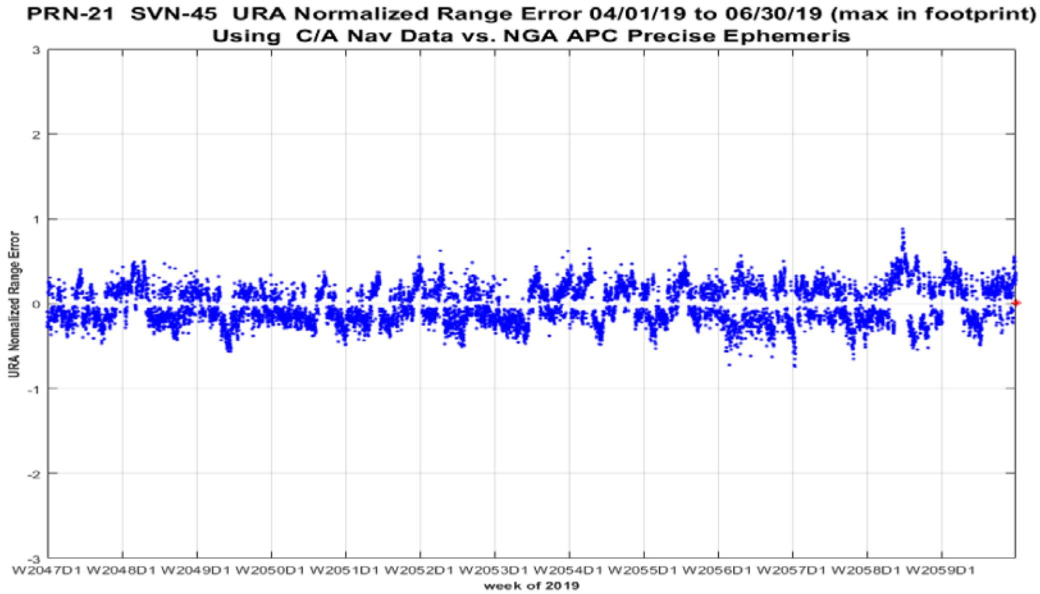


Figure 10-147 Timeline of URA Normalized Range Error PRN-22 (SVN-47) Using C/A Nav Data

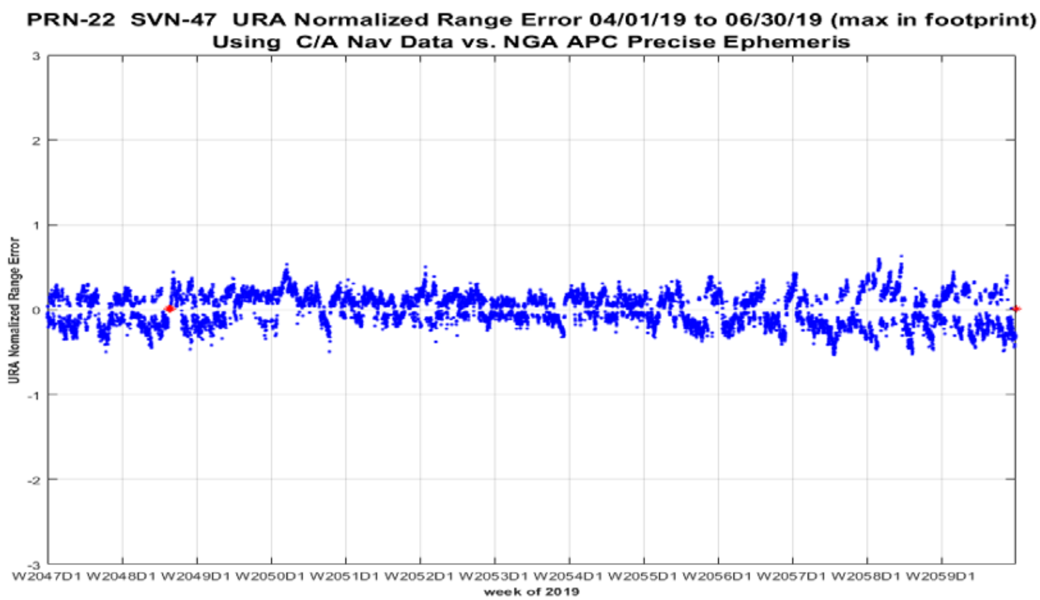


Figure 10-148 Timeline of URA Normalized Range Error PRN-23 (SVN-60) Using C/A Nav Data

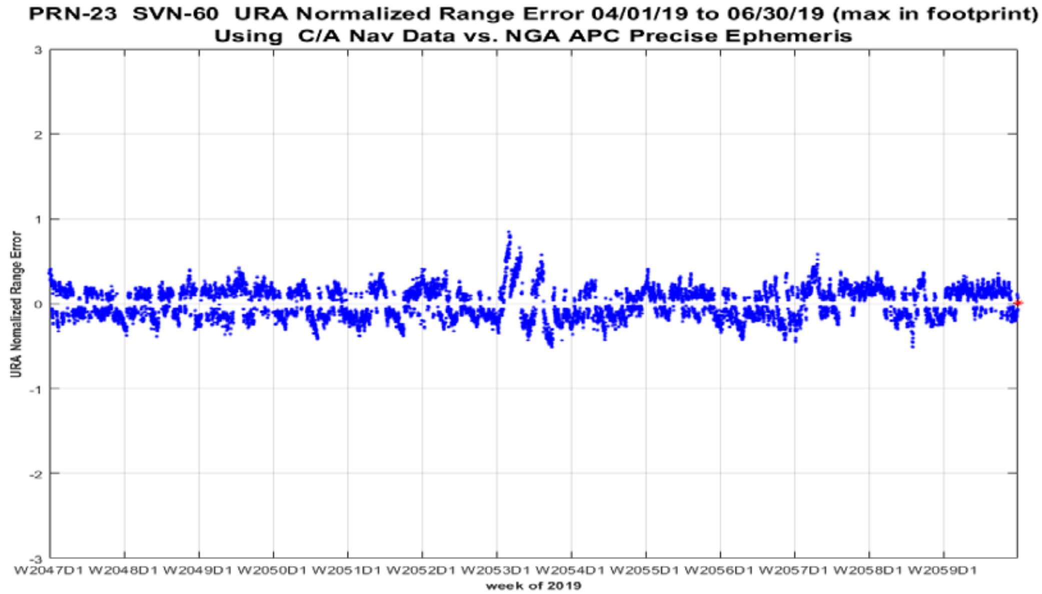


Figure 10-149 Timeline of URA Normalized Range Error PRN-24 (SVN-65) Using C/A Nav Data

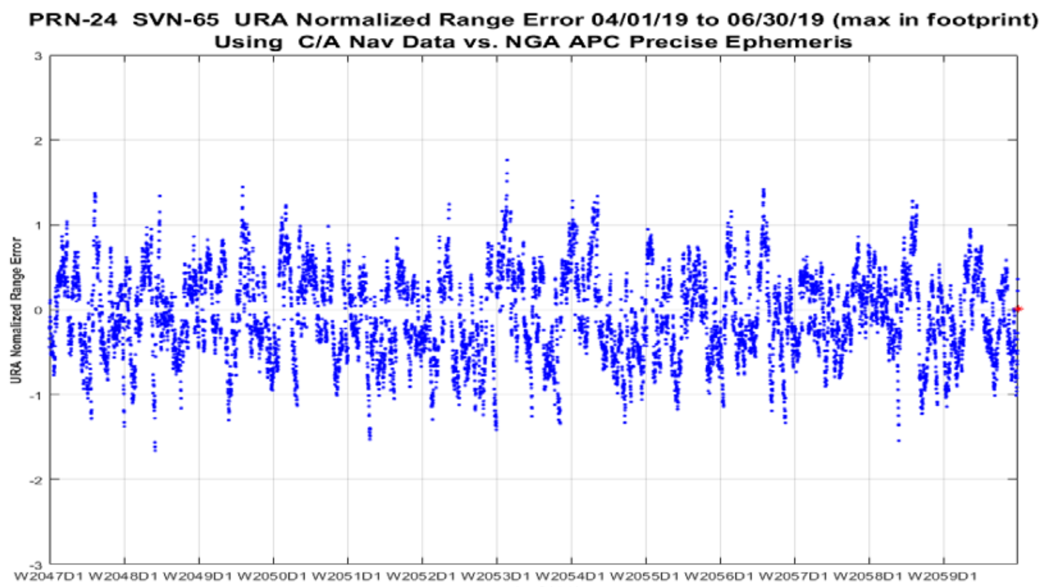


Figure 10-150 Timeline of IAURA Normalized Range Error PRN-24 (SVN-65) Using L2C CNAV Data

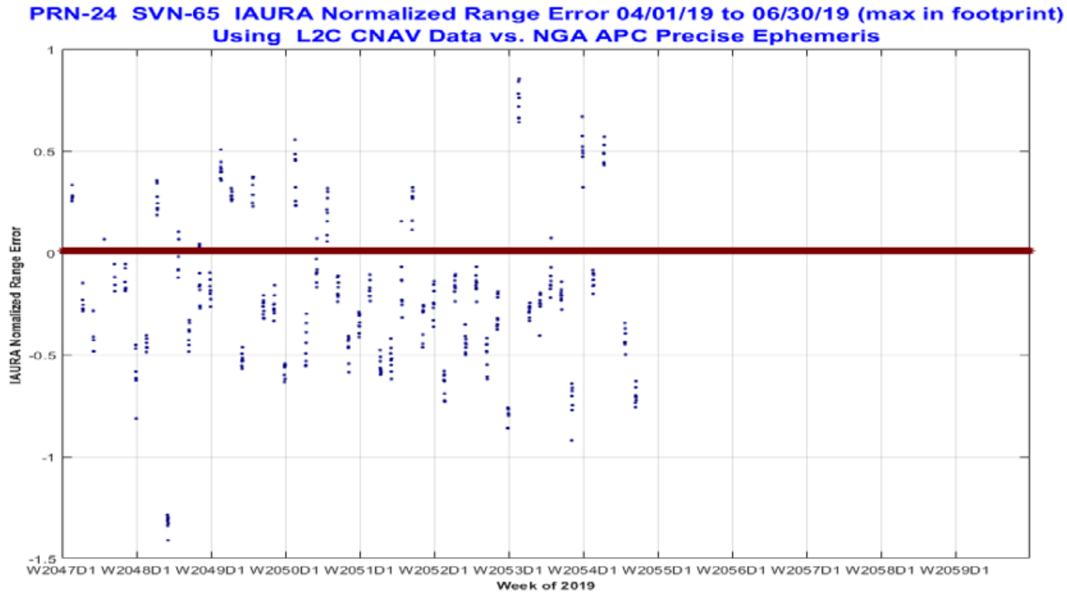


Figure 10-151 Timeline of URA Normalized Range Error PRN-25 (SVN-62) Using C/A Nav Data

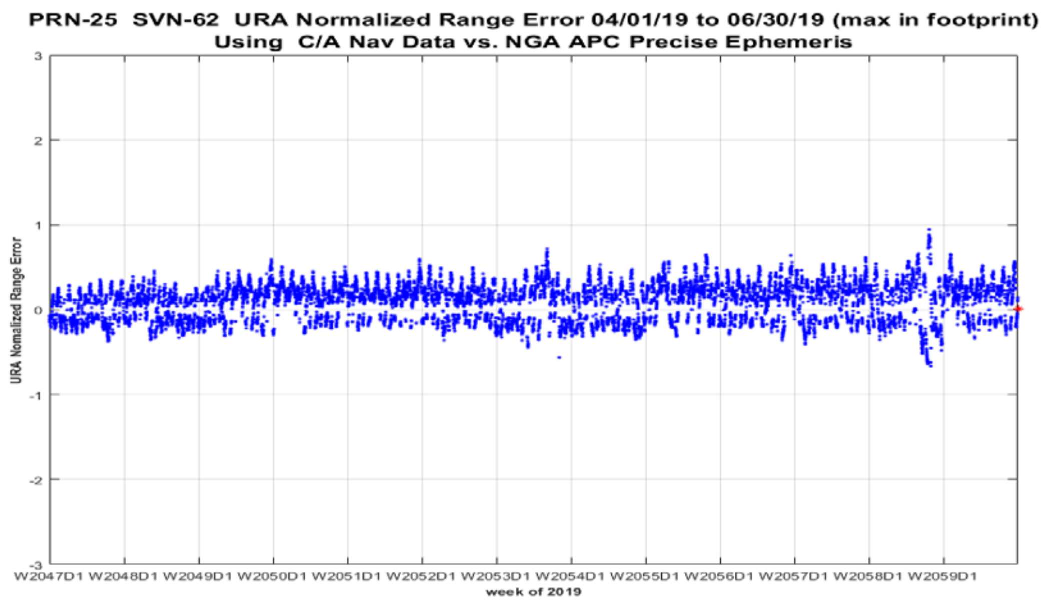


Figure 10-152 Timeline of IAURA Normalized Range Error PRN-25 (SVN-62) Using L2C CNAV Data

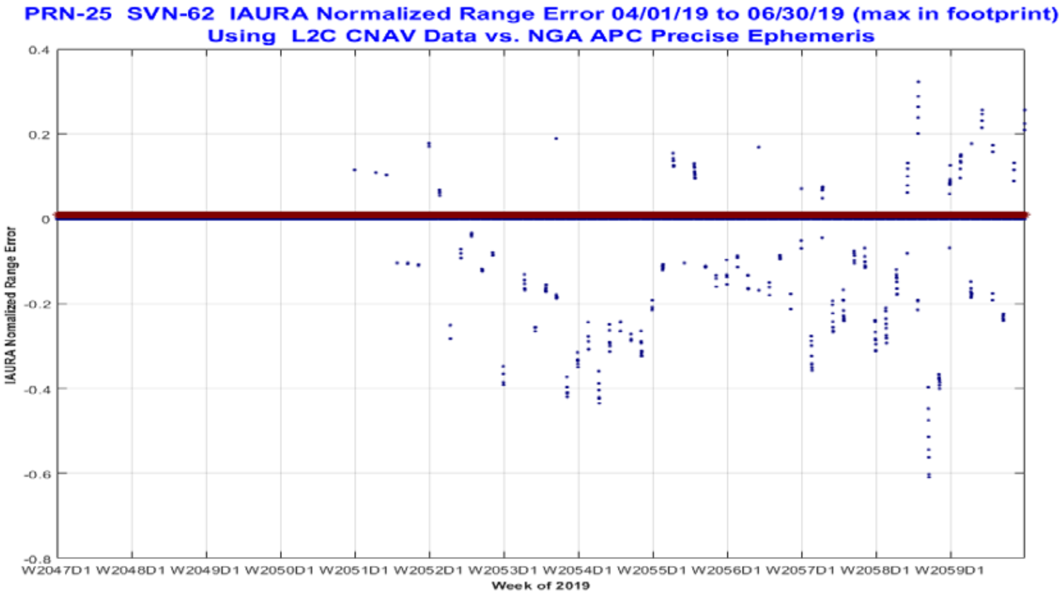


Figure 10-153 Timeline of URA Normalized Range Error PRN-26 (SVN-71) Using C/A Nav Data

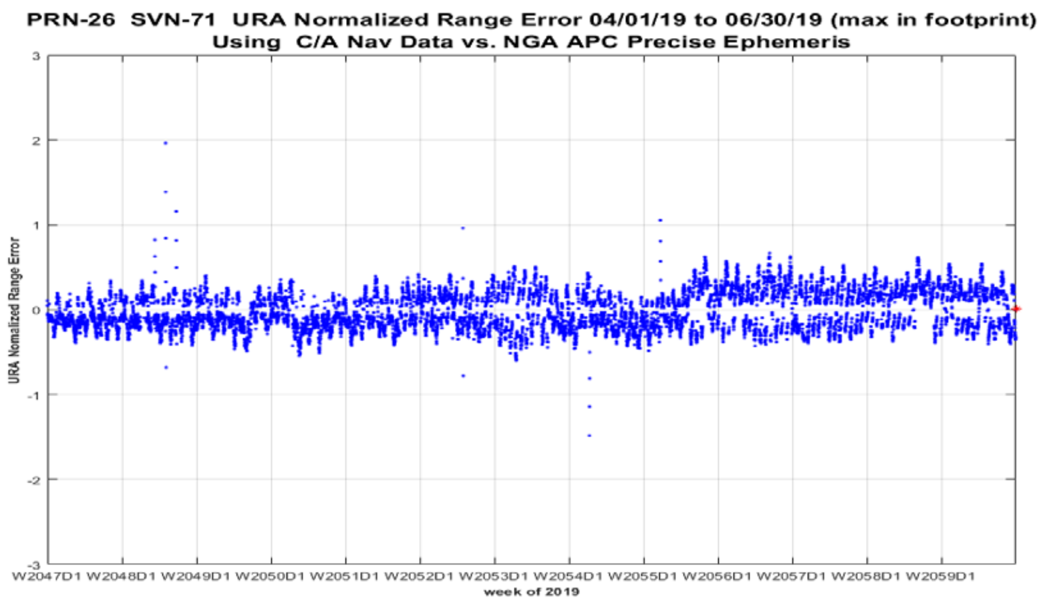


Figure 10-154 Timeline of IAURA Normalized Range Error PRN-26 (SVN-71) Using L2C CNAV Data

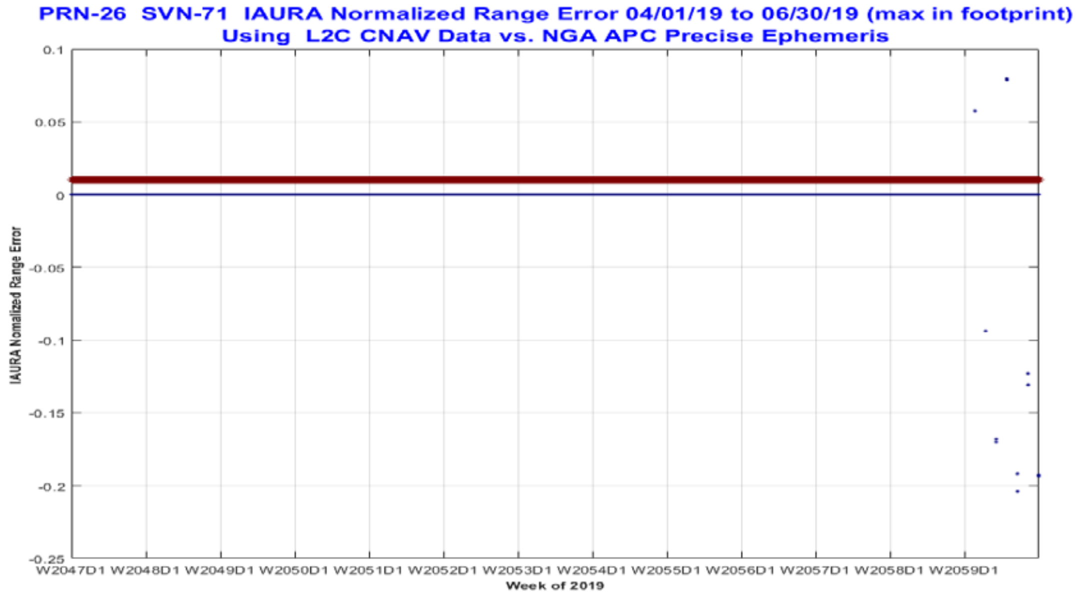


Figure 10-155 Timeline of URA Normalized Range Error PRN-27 (SVN-66) Using C/A Nav Data

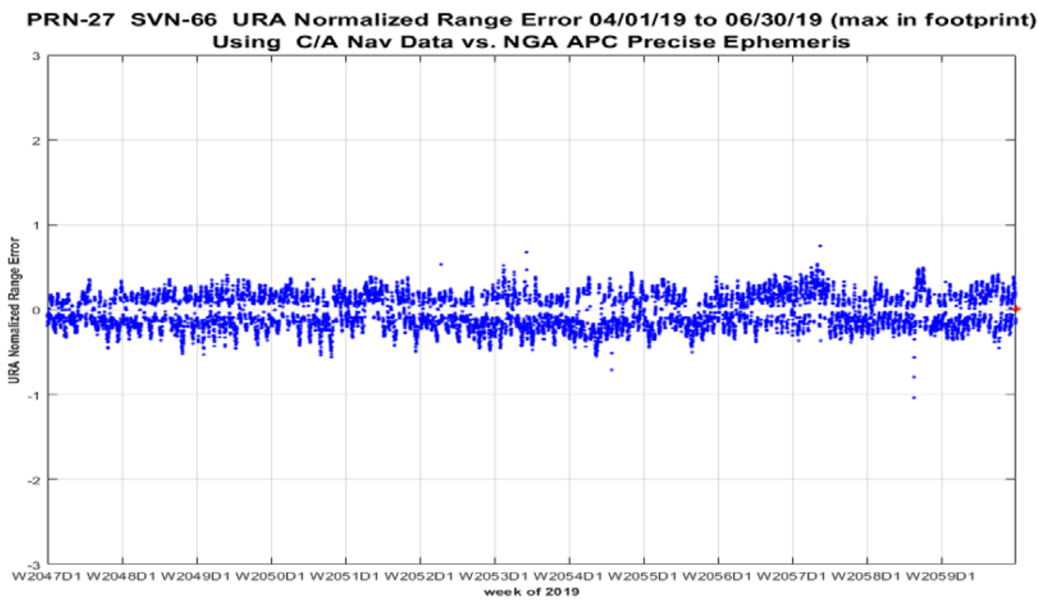


Figure 10-156 Timeline of URA Normalized Range Error PRN-28 (SVN-44) Using C/A Nav Data

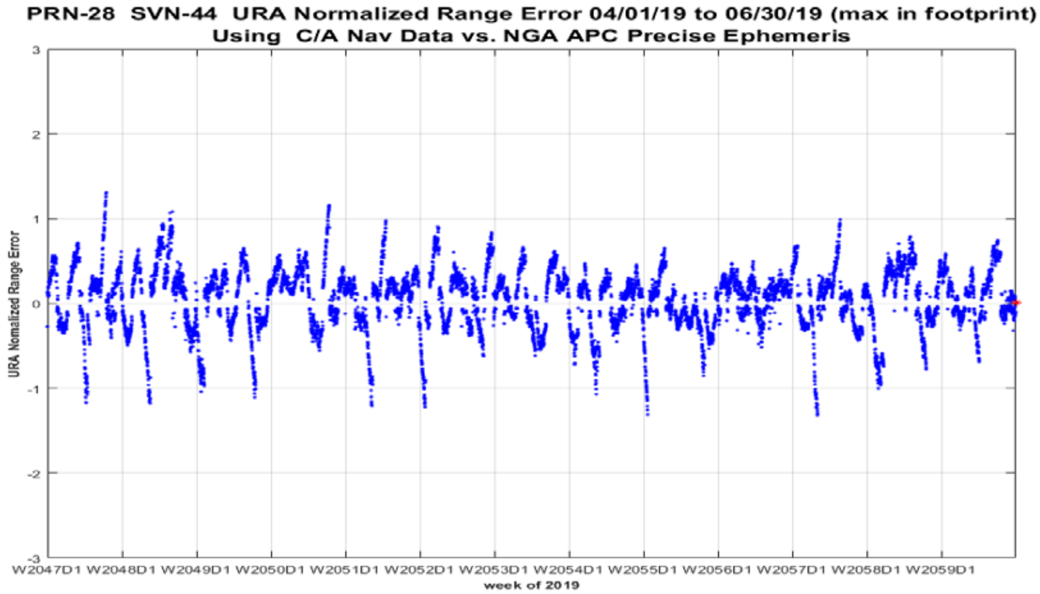


Figure 10-157 Timeline of URA Normalized Range Error PRN-29 (SVN-57) Using C/A Nav Data

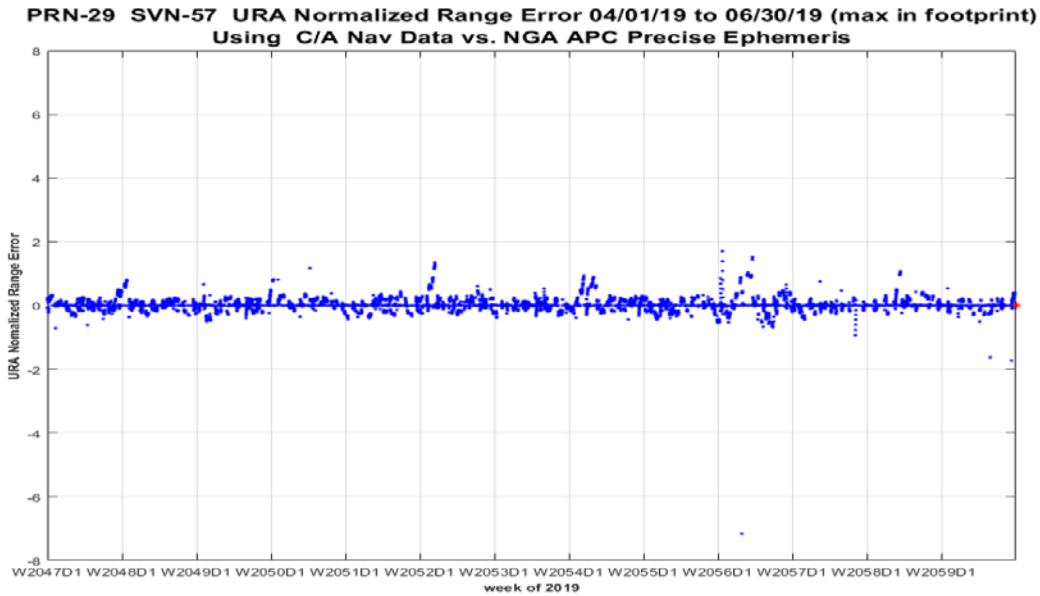


Figure 10-158 Timeline of IAURA Normalized Range Error PRN-29 (SVN-57) Using L2C CNAV Data

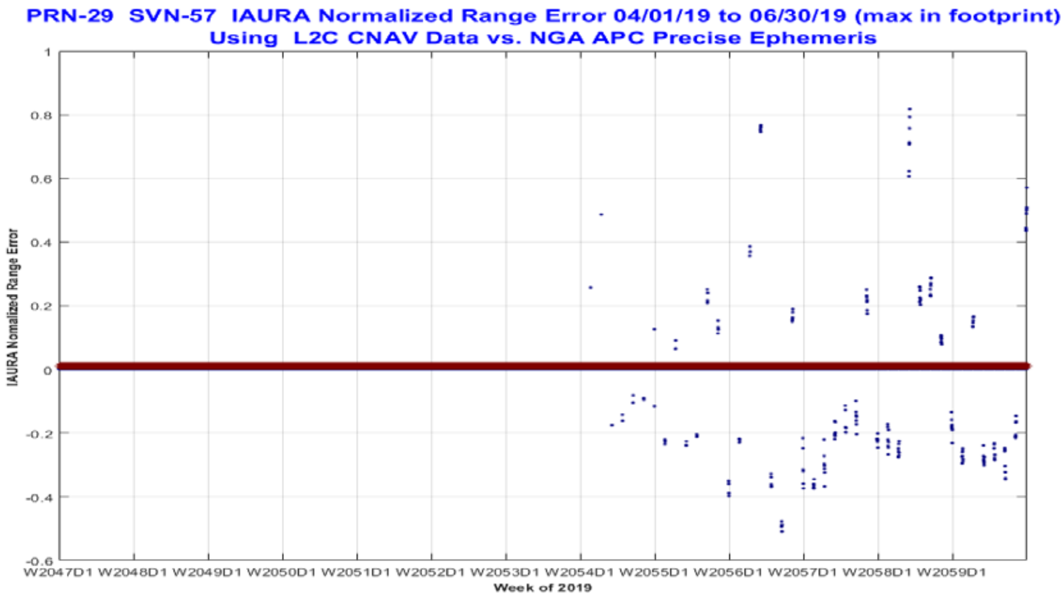


Figure 10-159 Timeline of URA Normalized Range Error PRN-30 (SVN-64) Using C/A Nav Data

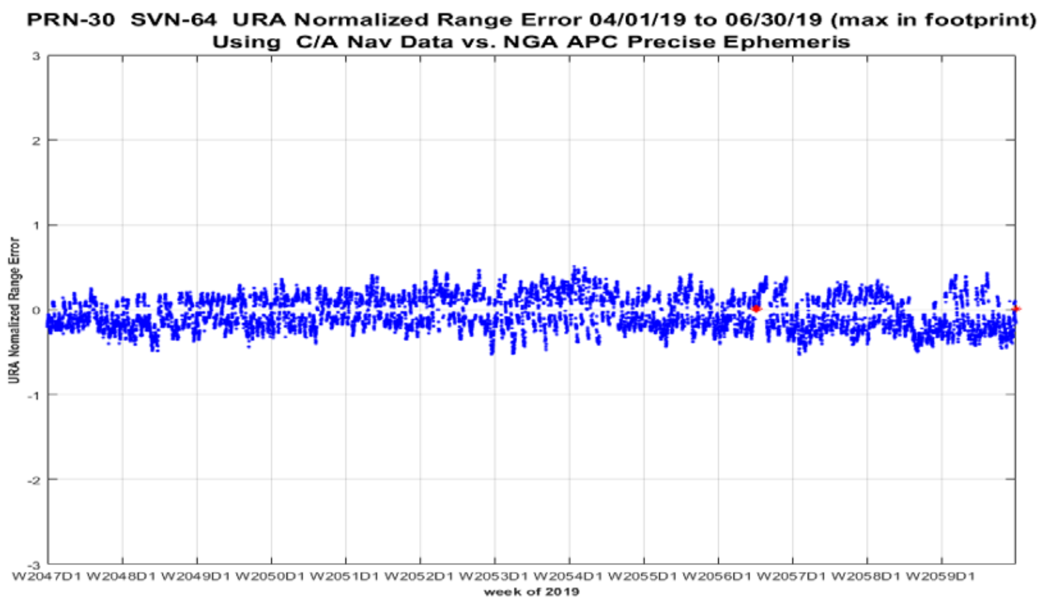


Figure 10-160 Timeline of IAURA Normalized Range Error PRN-30 (SVN-64) Using L2C CNAV Data

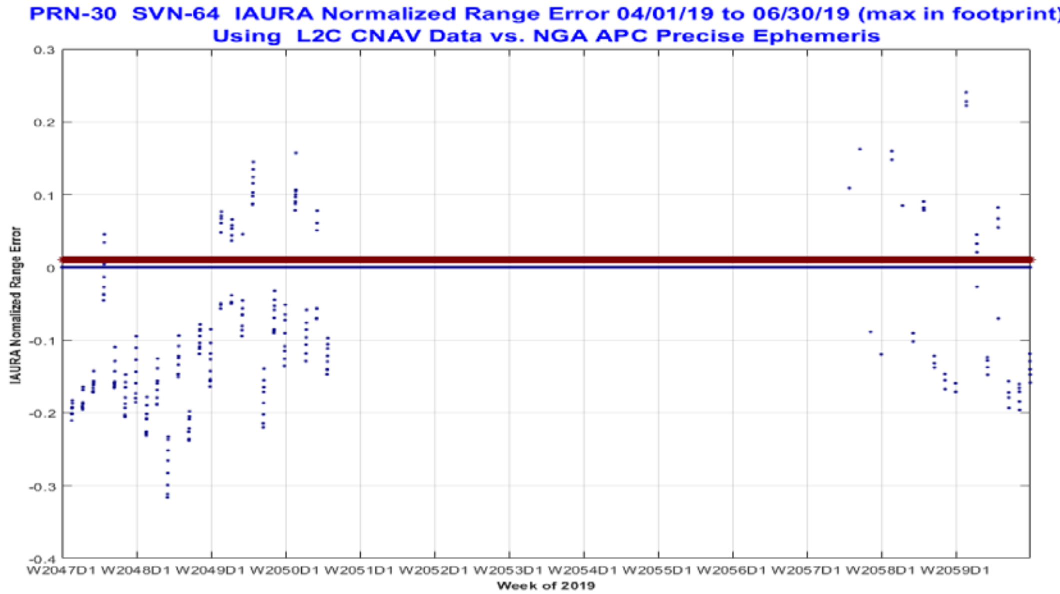


Figure 10-161 Timeline of URA Normalized Range Error PRN-31 (SVN-52) Using C/A Nav Data

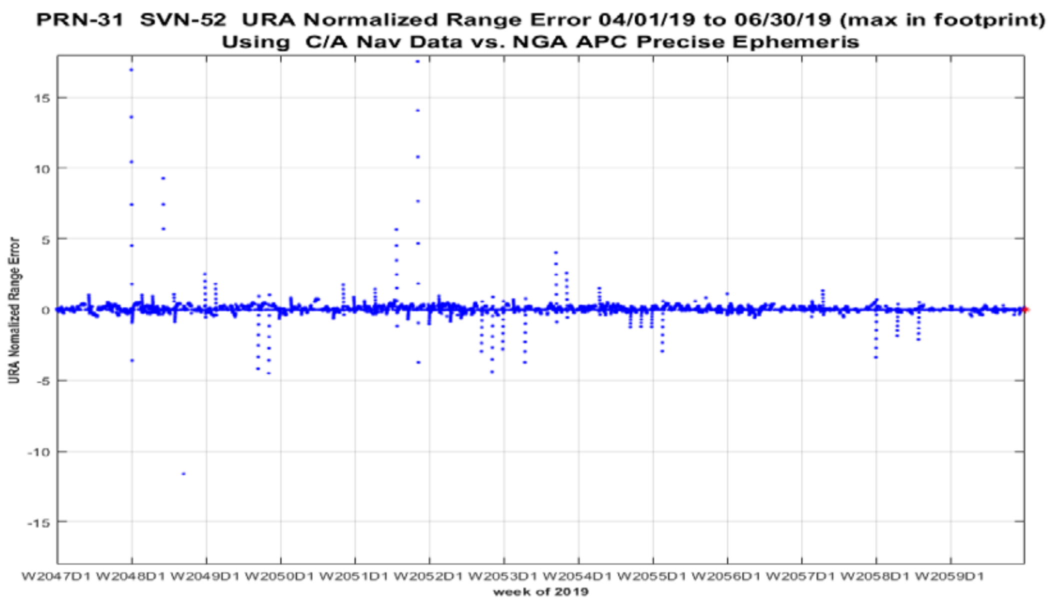
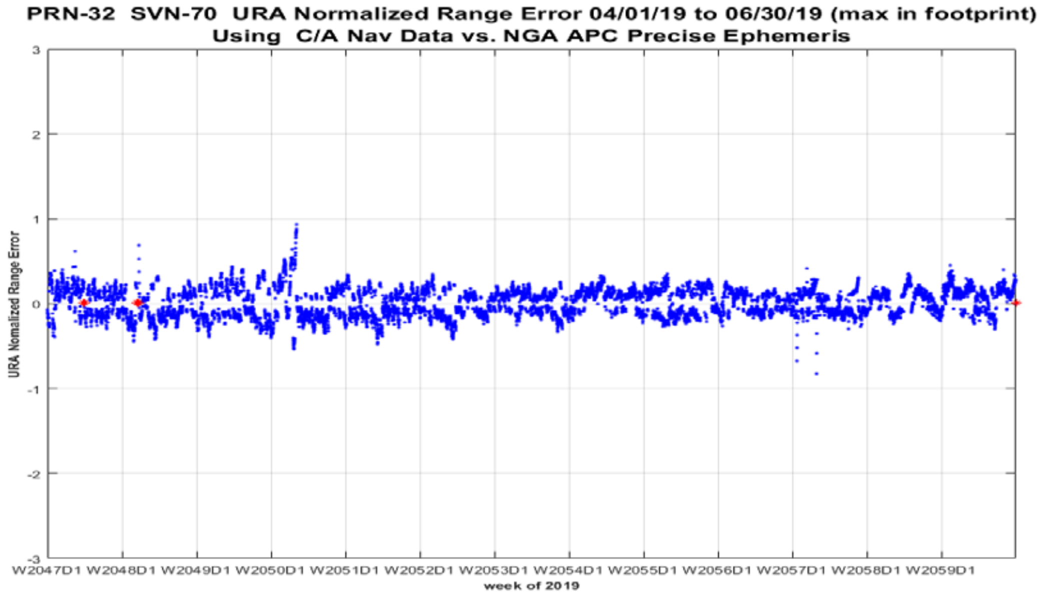


Figure 10-162 Timeline of URA Normalized Range Error PRN-32 (SVN-70) Using C/A Nav Data



APPENDIX A: PERFORMANCE SUMMARY

Table A-1 Performance Summary

Parameter	Measured Performance	Conditions and Constraints
User Range Error Accuracy Single-Frequency C/A-Code 1. ≤7.8m 95% Global Average URE during normal operations over All AODs 2. ≤6.0m 95% Global Average URE during operations at Zero AOD 3. ≤12.8m 95% Global Average URE during normal operations at Any AOD	1. ≤2.838 m 2. N/A 3. N/A	For any healthy SPS SIS. Neglecting single-frequency ionospheric delay model errors. Including group delay time correction (T_{GD}) errors at L1. Including inter-signal bias (P(Y)-code to C/A-code) errors at L1.
User Range Error Accuracy Single-Frequency C/A-Code 1. ≤30m 99.94% Global Average URE during normal operations 2. ≤30m 99.79% Worst Case single point average during normal operations	1. 100% Global 2. 100% WCP	For any healthy SPS SIS. Neglecting single-frequency ionospheric delay model errors. Including group delay time correction (T_{GD}) errors at L1. Standard based on measurement interval of one year; average of daily values within service volume Standard based on 3 service failures per year, lasting no more than 6 hours each

Parameter	Measured Performance	Conditions and Constraints
User Range Rate Error Accuracy Single-Frequency C/A Code: ≤6mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD	≤2.713 mm/sec	For any healthy SPS SIS. Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers. Neglecting single-frequency ionospheric delay model errors.
User Range Acceleration Error Accuracy Single-Frequency C/A Code: ≤2mm/sec^2 95% Global Average URAE over any 3-second interval during normal operations at Any AOD	≤0.022 mm/s^2	For any healthy SPS SIS. Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers. Neglecting single-frequency ionospheric delay model errors.
Per-Satellite Coverage Terrestrial Service Volume: 100% Coverage	100%	For any healthy or marginal SPS SIS.
Constellation Coverage Terrestrial Service Volume: 100% Coverage	100%	For any healthy or marginal SPS SIS.

Parameter	Measured Performance	Conditions and Constraints
Status and Problem Reporting Scheduled event affecting service Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event	≥72.0 hours Prior to event	For any SPS SIS.
Status and Problem Reporting Unscheduled outage or problem affecting service Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event	≤0.400 hours	For any SPS SIS.
Status and Problem Reporting Unscheduled Failure Interruption Continuity: ≥0.9998 Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption.	100%	Calculated as an average over all slots in the 24-slot constellation, normalized annually. Given that the SPS SIS is available from the slot at the start of the hour.
Operational Satellite Count ≥0.95 Probability that the constellation will have at least 24 operational satellites regardless of whether those operational satellites are located in slots or not.	100%	Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operational satellite regardless of whether that satellite is currently broadcasting a healthy SPS SIS or not and regardless of whether the broadcast SPS SIS also satisfies the other performance standards in the SPS performance standard or not.

Parameter	Measured Performance	Conditions and Constraints
PDOP Availability 1. ≥98% global PDOP of 6 or less 2. ≥88% worst site PDOP of 6 or less	1. 100% 2. 100%	Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.
Service Availability 1. ≥99% Horizontal Service Availability, average location 2. ≥99% Vertical Service Availability, average location	1. 100% Horizontal 2. 100% Vertical	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.
Service Availability 1. ≥90% Horizontal Service Availability, worst-case location 2. ≥90% Vertical Service Availability, worst-case location	1. 100% Horizontal 2. 100% Vertical	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 Global Average Position Domain Accuracy: 1. ≤9m 95% Horizontal Error 2. ≤15m 95 % Vertical Error	1. ≤1.766 m Horizontal 2. ≤4.257 m Vertical	Defined for a position/time solution meeting the representative user conditions. Standard based on a measurement interval of 24 hours averaged over all points in the service volume.

Parameter	Measured Performance	Conditions and Constraints
Position/Time Accuracy Worst Site Position Domain Accuracy: 1. ≤17m 95% Horizontal Error 2. ≤37m 95% Vertical Error	1. ≤3.241 m Horizontal 2. ≤4.893 m Vertical	Defined for a position/time solution meeting the representative user conditions. Standard based on a measurement interval of 24 hours averaged over all points in the service volume.
Position/Time Accuracy Time Transfer Domain Accuracy: ≤40 nanoseconds time transfer error 95% of time (SIS only)	≤13.2 nanoseconds	Defined for a time transfer solution meeting the representative user conditions. Standard based on a measurement interval of 24 hours averaged over all points in the service volume.
Position/Time Accuracy Instantaneous UTCOE Integrity: NTE ±120 nanoseconds 99.999% of time without a timely alert. (SIS only)	≤77.1 nanoseconds	For any healthy SPS SIS. Worst case for delayed alert is 6 hours.

Parameter	Measured Performance	Conditions and Constraints
Per-Slot Availability 1. ≥0.957 Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS 2. ≥0.957 Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a healthy SPS SIS	1. 100% 2. 100%	Calculated as an average over all slots in the 24-slot constellation, normalized annually Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard.
Constellation Availability 1. ≥0.98 Probability that at least 21 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration. 2. ≥0.99999 Probability that at least 20 slots out of the 24 will be occupied either by a satellite broadcasting a healthy SPS SIS in the baseline 24-slot configuration or by a pair of satellites each broadcasting a healthy SPS SIS in the expanded slot configuration.	1. 100% 2. 100%	Calculated as an average over all slots in the 24-slot constellation, normalized annually. Applied to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.

APPENDIX B: GEOMAGNETIC DATA

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
2019 04 01	6	2 1 2 3 2 1 1 0	22	1 1 5 6 4 3 1 0	8	2 2 2 4 2 2 1 0
2019 04 02	5	1 0 0 1 1 1 3 3	2	1 0 0 0 2 1 1 1	6	1 1 1 1 1 1 3 3
2019 04 03	12	2 4 3 2 2 2 2 3	24	2 3 4 5 6 2 1 2	12	3 4 3 2 3 2 2 3
2019 04 04	8	2 2 2 2 2 3 2 1	15	2 2 2 5 3 4 2 1	10	3 2 2 3 2 3 2 1
2019 04 05	10	3 3 2 2 2 3 2 2	20	2 3 3 5 5 3 2 2	14	3 3 3 2 3 3 2 3
2019 04 06	7	2 3 2 2 2 1 1 1	5	2 2 2 3 1 1 0 0	7	2 3 2 2 1 1 2 1
2019 04 07	5	0 2 2 1 2 2 1 2	4	1 1 1 2 3 1 0 0	5	1 2 1 1 2 1 1 2
2019 04 08	12	2 4 3 2 3 2 2 2	24	2 4 4 4 6 3 2 1	13	3 4 3 2 3 3 2 2
2019 04 09	11	4 2 3 3 2 1 1 2	14	2 2 4 4 3 3 2 2	11	4 2 3 3 2 2 2 2
2019 04 10	10	3 3 3 1 3 2 2 1	19	4 4 4 2 4 4 2 1	14	4 4 3 1 2 3 3 2
2019 04 11	6	1 2 3 2 2 2 1 0	11	2 2 2 4 3 3 1 1	7	2 3 2 2 2 2 1 1
2019 04 12	7	3 2 1 1 2 2 2 2	14	2 2 3 3 5 2 2 2	9	3 2 2 1 2 1 2 3
2019 04 13	7	3 3 1 1 2 1 1 1	4	1 3 2 0 1 0 1 1	8	3 3 2 1 1 1 2 1
2019 04 14	3	0 2 2 0 1 1 0 1	3	1 1 3 1 0 0 0 0	4	0 2 2 1 0 1 0 1
2019 04 15	8	1 1 3 2 2 1 3 2	8	1 1 3 4 2 0 2 1	8	2 2 3 2 2 1 2 2
2019 04 16	6	2 1 3 2 2 0 1 1	12	2 1 5 2 4 0 0 0	6	2 2 3 2 2 1 1 1
2019 04 17	3	1 1 0 1 1 1 1 1	1	1 0 0 0 0 0 1 1	3	1 0 1 0 0 1 2 1
2019 04 18	2	0 0 0 1 2 0 1 1	0	0 0 0 0 0 0 0 0	2	0 0 0 0 1 0 1 0
2019 04 19	4	0 1 2 1 1 1 2 1	3	0 0 0 2 2 1 1 0	4	0 0 1 2 1 1 2 1
2019 04 20	4	1 1 1 1 2 1 1 1	1	0 1 0 1 0 0 1 0	4	1 1 1 1 1 1 1 1
2019 04 21	4	1 1 1 1 2 1 1 1	2	1 0 1 2 0 0 0 0	4	2 1 1 1 1 0 0 1
2019 04 22	4	0 1 2 2 2 1 1 1	2	0 0 2 0 0 1 1 0	4	1 1 1 1 1 1 1 1
2019 04 23	8	1 2 1 1 2 2 3 3	4	0 0 0 2 2 2 2 2	8	1 1 0 1 1 2 3 3
2019 04 24	6	3 1 0 2 2 2 1 2	10	2 1 0 4 4 3 1 0	7	3 1 0 2 2 2 1 2
2019 04 25	4	1 2 2 1 1 0 1 1	9	1 2 2 4 4 1 0 0	5	1 2 2 2 2 0 1 0
2019 04 26	2	0 0 0 1 2 1 1 1	3	0 0 0 2 2 2 1 1	4	1 0 1 1 1 1 1 2
2019 04 27	5	1 0 2 2 2 1 2 2	8	1 0 3 4 3 0 0 1	6	1 0 2 2 2 1 2 2
2019 04 28	4	1 1 1 1 1 1 2 1	6	1 1 3 2 1 2 1 1	5	1 1 2 1 1 1 2 2
2019 04 29	6	2 2 0 1 3 2 1 1	3	1 1 0 1 2 2 0 0	5	2 2 0 1 1 2 1 1
2019 04 30	4	1 1 0 1 3 1 1 1	5	1 1 0 1 3 2 1 1	5	2 1 0 1 2 1 2 1
2019 05 01	8	0 2 2 1 3 1 3 3	10	1 2 2 3 3 2 2 3	11	1 2 2 2 2 2 3 4
2019 05 02	13	4 3 3 2 3 2 3 1	19	3 4 4 4 4 2 3 1	12	4 4 3 2 2 2 2 2
2019 05 03	8	2 2 2 1 3 1 2 3	9	2 2 3 3 2 1 2 2	7	2 2 2 1 2 1 2 3
2019 05 04	9	1 2 3 3 3 2 2 1	22	1 3 4 5 5 4 1 1	10	1 2 3 3 3 2 2 2
2019 05 05	4	2 1 0 1 2 1 1 1	2	1 1 0 0 1 1 0 0	4	2 1 0 0 1 1 0 1
2019 05 06	5	1 0 0 2 3 2 2 1	5	1 1 0 3 2 2 1 1	5	1 1 0 2 2 1 2 2
2019 05 07	5	1 2 1 1 2 2 2 1	4	2 2 1 0 2 1 1 1	5	2 2 1 1 1 1 2 1
2019 05 08	2	0 1 0 0 2 1 1 1	1	1 1 0 0 0 0 0 1	3	0 1 0 0 1 0 0 1
2019 05 09	8	1 2 3 2 2 2 2 2	7	2 2 3 3 1 0 1 1	7	1 2 3 2 1 1 2 2
2019 05 10	7	1 2 1 1 1 2 3 3	5	2 1 2 2 0 2 2 1	7	2 2 1 1 1 2 3 3
2019 05 11	19	4 4 4 4 3 2 2 3	63	5 4 6 7 7 5 3 2	25	5 4 4 4 4 2 3 4
2019 05 12	5	2 1 2 1 1 1 1 2	4	2 1 2 2 0 0 1 1	4	2 1 1 0 0 0 1 2
2019 05 13	5	0 0 1 2 2 2 1 3	9	1 1 1 3 2 4 2 2	6	1 1 1 2 1 2 1 2

2019 05 14	23	3	5	5	4	3	3	3	1	45	3	7	6	5	4	4	3	2	36	3	6	7	4	2	3	4	2
2019 05 15	8	1	2	2	1	3	2	3	1	4	0	2	1	0	1	2	2	1	6	1	2	2	1	2	2	2	1
2019 05 16	9	2	2	2	1	3	2	2	3	5	1	2	1	2	1	1	2	2	8	2	2	2	1	2	1	3	3
2019 05 17	7	3	2	2	1	3	1	1	1	5	3	2	1	1	2	1	0	0	5	3	2	1	1	2	1	0	1
2019 05 18	8	1	1	2	4	2	2	2	1	10	1	1	4	5	0	0	0	0	5	1	1	2	2	1	0	1	0
2019 05 19	3	0	0	1	1	2	1	1	2	1	0	0	1	0	0	0	0	1	3	0	0	1	1	1	1	0	2
2019 05 20	7	3	2	2	1	2	1	2	2	3	2	2	2	1	0	1	0	0	6	3	2	1	1	1	1	1	1
2019 05 21	4	1	2	1	1	2	1	1	1	2	1	0	0	0	2	0	0	1	4	1	2	1	1	2	0	0	1
2019 05 22	5	0	1	2	2	2	2	1	1	2	0	1	1	2	1	0	0	1	4	0	1	2	1	1	1	1	1
2019 05 23	5	1	1	1	2	2	2	1	2	4	2	1	0	3	1	1	0	1	5	1	1	1	2	1	1	1	2
2019 05 24	6	1	2	1	2	2	2	2	2	3	1	2	1	0	1	1	1	1	5	1	2	1	1	1	1	2	2
2019 05 25	3	1	0	1	1	1	1	2	1	1	0	0	0	0	1	0	1	1	4	1	1	0	1	1	1	2	2
2019 05 26	6	1	1	1	1	2	2	2	3	1	1	0	0	0	0	0	0	1	5	1	1	1	0	1	1	1	3
2019 05 27	12	2	3	4	2	3	3	2	1	14	3	3	4	4	3	2	1	0	10	3	3	3	2	1	3	2	1
2019 05 28	9	1	0	2	2	3	2	3	3	4	1	1	1	1	1	1	2	2	8	1	1	2	2	2	2	3	3
2019 05 29	16	3	4	4	3	2	2	3	3	28	4	4	6	5	4	2	1	2	14	3	4	3	3	2	2	3	3
2019 05 30	8	3	2	2	2	2	2	2	2	13	3	3	2	5	2	2	1	1	8	3	2	2	2	2	1	2	2
2019 05 31	5	2	2	2	1	2	1	1	1	5	2	2	3	2	2	0	0	0	5	2	2	2	1	1	1	0	1
2019 06 01	4	1	0	1	1	2	2	1	2	1	1	1	1	0	0	0	0	0	3	1	0	1	0	1	1	1	1
2019 06 02	4	2	0	0	1	2	2	2	1	1	1	1	0	0	0	0	0	0	4	2	1	0	0	1	1	1	1
2019 06 03	5	1	0	1	2	2	2	2	2	3	1	0	0	2	2	1	0	1	4	1	1	0	2	1	1	1	1
2019 06 04	8	2	1	2	2	2	2	3	2	11	2	2	4	3	2	3	2	1	7	2	2	2	2	2	2	2	2
2019 06 05	5	2	1	1	1	2	1	2	1	2	2	1	1	1	0	0	0	0	4	2	1	1	0	1	1	1	1
2019 06 06	4	0	1	1	1	2	1	2	1	1	1	0	1	0	0	0	0	0	3	1	1	1	1	1	0	1	0
2019 06 07	6	1	0	1	1	3	2	2	2	2	0	0	2	1	0	1	0	0	4	1	1	1	1	2	1	1	1
2019 06 08	14	1	1	0	2	3	4	4	4	10	1	1	0	1	2	4	4	2	18	1	1	0	2	3	4	5	4
2019 06 09	8	4	2	1	2	2	1	1	1	5	2	3	2	1	2	0	1	0	6	3	2	2	1	1	1	1	1
2019 06 10	4	0	0	0	1	3	2	2	1	1	1	1	0	0	0	0	0	1	3	1	1	0	1	1	1	1	1
2019 06 11	3	1	1	0	1	2	1	1	1	1	2	1	0	0	0	0	0	0	3	1	1	1	1	1	0	1	1
2019 06 12	5	1	1	2	2	2	2	1	1	-1	1	1	1	0	2	0	0	-1	4	1	2	1	1	1	1	1	0
2019 06 13	12	1	2	2	2	4	2	2	4	13	1	1	2	3	5	3	2	2	10	1	2	2	2	3	2	2	4
2019 06 14	13	4	2	3	2	4	2	2	1	15	3	2	5	3	4	1	1	1	8	3	2	3	2	2	1	1	1
2019 06 15	6	1	1	2	2	2	2	1	2	4	1	2	2	3	1	0	0	0	4	1	2	2	2	1	1	0	1
2019 06 16	6	1	2	1	1	2	3	1	1	2	1	2	1	0	0	0	1	0	4	1	2	1	1	1	1	0	1
2019 06 17	5	1	1	1	2	2	2	1	1	2	0	0	0	3	1	0	0	0	3	0	1	1	1	1	1	0	1
2019 06 18	3	0	0	0	1	2	2	2	1	1	0	0	0	0	0	1	1	1	4	1	1	0	1	1	1	1	1
2019 06 19	4	1	1	1	1	2	2	1	1	2	1	0	1	1	0	1	0	1	4	1	1	1	1	1	1	1	1
2019 06 20	8	1	2	3	2	3	1	2	2	12	0	2	4	5	1	1	2	1	7	1	2	3	2	1	1	2	2
2019 06 21	8	1	2	2	2	2	2	2	3	6	1	2	2	3	3	0	0	1	6	1	2	2	2	2	1	2	2
2019 06 22	5	1	2	2	1	1	2	1	1	2	1	1	2	1	0	0	0	0	4	1	2	2	1	0	1	1	0
2019 06 23	4	0	0	1	1	2	2	2	1	2	0	0	0	2	2	0	1	0	3	0	1	1	1	1	1	1	1
2019 06 24	5	2	2	0	1	2	1	2	1	4	2	2	0	1	2	0	1	1	5	2	2	1	1	2	1	2	1
2019 06 25	5	1	0	1	2	2	1	2	2	2	1	1	1	1	1	0	0	0	4	1	0	1	1	1	0	1	1
2019 06 26	5	2	2	2	2	1	2	1	0	6	1	1	3	4	1	0	0	0	6	2	2	2	2	1	1	0	1
2019 06 27	4	1	1	0	1	1	2	2	1	1	1	1	0	0	1	0	0	0	4	1	1	0	1	1	1	1	1
2019 06 28	5	2	2	1	1	2	1	1	1	1	2	1	0	0	0	0	0	0	4	2	2	1	1	1	1	1	1
2019 06 29	3	0	0	1	1	1	2	1	1	2	0	1	1	0	0	0	1	1	3	1	1	1	0	1	1	1	1
2019 06 30	3	2	0	0	1	2	0	0	1	1	1	0	0	0	1	0	0	1	4	3	1	0	1	1	1	0	1

APPENDIX C: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.