



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

**GLOBAL POSITIONING SYSTEM  
STANDARD POSITIONING SERVICE  
PERFORMANCE ANALYSIS REPORT**

**January 2020**

**Report #108**

**Reporting Period: October 01 to December 31, 2019**

**<http://www.nstb.tc.faa.gov/>**

**FAA William J. Hughes Technical Center  
Atlantic City International Airport, New Jersey 08405**

The Global Positioning System (GPS) Product Team 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<sup>th</sup> Edition, dated September 2008).

This GPS SPS Performance Analysis Report #108 includes data collected from October 1 through December 31, 2019 reporting period. The next quarterly report will be issued April 30, 2020.

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, the coverage data for every 5° grid point between 180W to 180E and 80S and 80N was calculated for every minute over a 24-hour period for each of the weeks covered in the reporting period. For this reporting period, the global availability based on PDOP less than six for CONUS was 99.9986%.

**NANU Summary and Evaluation.** This evaluation was achieved by reviewing the NANU reports issued between 1 October and 31 December 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, 10 outages were reported in the NANU’s. Five outages were scheduled ahead of time, and Five 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 12.680 meters on satellite PRN18. 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 2.410 meters was recorded

on satellite PRN22. 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 International GNSS Service (IGS) generates precise, high-quality Global Navigation Satellite System (GNSS) products through a partnership of worldwide agencies that share GPS, GLONASS, and other GNSS station data. During the evaluation period, the maximum 95% horizontal and vertical SPS errors were 2.23 meters and 4.79 meters, respectively, at Puerto Ayora, Ecuador.

**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 99.772% at Honolulu. The minimum percent of time spent in RNP 0.3 mode was 99.996 at Kansas City. The maximum 99% HPL value was 152.24 meters at Gander.

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

The analysis performed on data collected between 1 October and 31 December 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 .....   | 15  |
| 4.   | SERVICE RELIABILITY STANDARD .....  | 16  |
| 5.   | ACCURACY STANDARD .....   | 18  |
| 5.1  | Position Accuracy.....  | 19  |
| 5.2  | Time Transfer Accuracy.....   | 22  |
| 5.3  | Range Domain Accuracy.....  | 23  |
| 6.   | SOLAR STORMS.....   | 30  |
| 7.   | IGS DATA .....  | 34  |
| 8.   | RAIM PERFORMANCE .....  | 38  |
| 8.1  | Site Performance .....  | 39  |
| 8.2  | RAIM Coverage .....   | 40  |
| 8.3  | RAIM Airport Analysis .....   | 45  |
| 9.   | GPS TEST NOTAMs SUMMARY .....   | 51  |
| 9.1  | GPS Test NOTAMs Issued.....   | 51  |
| 10.  | GPS BROADCAST ORBIT VERSUS NGA PRECISE ORBITS AND URA (IAURA)<br>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 .....                               | 81  |
| 10.7 | Histogram Plots of H, A, C, and Range Error for All Satellites .....                    | 87  |
| 10.8 | Timeline of URA Normalized Range Error for All Satellites .....                         | 110 |
|      | Appendix A: Performance Summary.....  | 134 |
|      | Appendix B: Geomagnetic Data.....   | 140 |
|      | Appendix C: Performance Analysis (PAN) Problem Report.....                              | 142 |
|      | Appendix D: 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.....                                 | 27 |
| Figure 5-5. Distribution of Daily Max Range Rate Errors .....                           | 27 |
| Figure 5-6. Distribution of Daily Max Range Acceleration Errors .....                   | 28 |
| Figure 5-7. Range Error Histogram .....   | 28 |
| Figure 5-8. Maximum Range Error Per Satellite .....                                     | 29 |
| 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 October 25, 2019.....   | 31 |
| Figure 6-2. K-Index for November 22, 2019.....  | 32 |
| Figure 6-3. K-Index for December 19, 2019 .....   | 32 |
| Figure 7-1. Selected IGS Site Locations.....  | 36 |
| Figure 7-2. GPS SPS 95% Horizontal Accuracy Trends at Selected IGS Sites.....           | 37 |
| Figure 7-3. GPS SPS 95% Vertical Accuracy Trends at Selected IGS Sites.....             | 38 |
| Figure 8-1. RAIM RNP 0.1 Coverage .....   | 41 |
| Figure 8-2. RAIM RNP 0.3 Coverage .....   | 42 |
| Figure 8-3. RAIM World Wide Coverage Trend.....   | 43 |
| Figure 8-4. RAIM RNP Coverage Trend for WAAS NPA Service Area.....                      | 44 |
| Figure 8-5. RAIM RNP 0.1 Airport Availability.....                                      | 46 |
| Figure 8-6. RAIM RNP 0.3 Airport Availability.....                                      | 47 |
| Figure 8-7. RAIM RNP 0.1 Airport Outages.....   | 49 |
| Figure 8-8. RAIM RNP 0.3 Airport Outages.....   | 50 |
| 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 .....                              | 56 |
| Figure 10-9. Orbit Error PRN1 (SVN-63) Using C/A Nav Data.....                          | 57 |

|   |    |
|---|----|
| Figure 10-10. Orbit Error PRN1 (SVN-63) Using L2C CNAV Data.....  | 57 |
| Figure 10-11. Orbit Error PRN2 (SVN-61) Using C/A Nav Data.....   | 58 |
| Figure 10-12. Orbit Error PRN3 (SVN-69) Using C/A Nav Data.....   | 58 |
| Figure 10-13. Orbit Error PRN3 (SVN-69) Using L2C CNAV Data.....  | 59 |
| Figure 10-14. Orbit Error PRN5 (SVN-50) Using C/A Nav Data.....   | 59 |
| Figure 10-15. Orbit Error PRN5 (SVN-50) Using L2C CNAV Data.....  | 60 |
| Figure 10-16. Orbit Error PRN6 (SVN-67) Using C/A Nav Data.....   | 60 |
| Figure 10-17. Orbit Error PRN6 (SVN-67) Using L2C CNAV Data.....  | 61 |
| Figure 10-18. Orbit Error PRN7 (SVN-48) Using C/A Nav Data.....   | 61 |
| Figure 10-19. Orbit Error PRN7 (SVN-48) Using L2C CNAV Data.....  | 62 |
| Figure 10-20. Orbit Error PRN8 (SVN-72) Using C/A Nav Data.....   | 62 |
| Figure 10-21. Orbit Error PRN8 (SVN-72) Using L2C CNAV Data.....  | 63 |
| Figure 10-22. Orbit Error PRN9 (SVN-68) Using C/A Nav Data.....   | 63 |
| Figure 10-23. Orbit Error PRN9 (SVN-68) Using L2C CNAV Data.....  | 64 |
| Figure 10-24. Orbit Error PRN10 (SVN-73) Using C/A Nav Data.....  | 64 |
| Figure 10-25. Orbit Error PRN10 (SVN-73) Using L2C CNAV Data..... | 65 |
| Figure 10-26. Orbit Error PRN11 (SVN-46) Using C/A Nav Data.....  | 65 |
| Figure 10-27. Orbit Error PRN12 (SVN-58) Using C/A Nav Data.....  | 66 |
| Figure 10-28. Orbit Error PRN12 (SVN-58) Using L2C CNAV Data..... | 66 |
| Figure 10-29. Orbit Error PRN13 (SVN-43) Using C/A Nav Data.....  | 67 |
| Figure 10-30. Orbit Error PRN15 (SVN-55) Using C/A Nav Data.....  | 67 |
| Figure 10-31. Orbit Error PRN15 (SVN-55) Using L2C CNAV Data..... | 68 |
| Figure 10-32. Orbit Error PRN16 (SVN-56) Using C/A Nav Data.....  | 68 |
| Figure 10-33. Orbit Error PRN17 (SVN-53) Using C/A Nav Data.....  | 69 |
| Figure 10-34. Orbit Error PRN17 (SVN-53) Using L2C CNAV Data..... | 69 |
| Figure 10-35. Orbit Error PRN18 (SVN-34) Using C/A Nav Data.....  | 70 |
| Figure 10-36. Orbit Error PRN19 (SVN-59) Using C/A Nav Data.....  | 70 |
| Figure 10-37. Orbit Error PRN21 (SVN-45) Using C/A Nav Data.....  | 71 |
| Figure 10-38. Orbit Error PRN22 (SVN-47) Using C/A Nav Data.....  | 71 |
| Figure 10-39. Orbit Error PRN23 (SVN-60) Using C/A Nav Data.....  | 72 |
| Figure 10-40. Orbit Error PRN24 (SVN-65) Using C/A Nav Data.....  | 72 |
| Figure 10-41. Orbit Error PRN24 (SVN-65) Using L2C CNAV Data..... | 73 |
| Figure 10-42. Orbit Error PRN25 (SVN-62) Using C/A Nav Data.....  | 73 |
| Figure 10-43. Orbit Error PRN25 (SVN-62) Using L2C CNAV Data..... | 74 |
| Figure 10-44. Orbit Error PRN26 (SVN-71) Using C/A Nav Data.....  | 74 |
| Figure 10-45. Orbit Error PRN26 (SVN-71) Using L2C CNAV Data..... | 75 |
| Figure 10-46. Orbit Error PRN27 (SVN-66) Using C/A Nav Data.....  | 75 |

|   |    |
|---|----|
| Figure 10-47. Orbit Error PRN27 (SVN-66) Using L2C CNAV Data.....                             | 76 |
| Figure 10-48. Orbit Error PRN28 (SVN-44) Using C/A Nav Data.....                              | 76 |
| Figure 10-49. Orbit Error PRN29 (SVN-57) Using C/A Nav Data.....                              | 77 |
| Figure 10-50. Orbit Error PRN29 (SVN-57) Using L2C CNAV Data.....                             | 77 |
| Figure 10-51. Orbit Error PRN30 (SVN-64) Using C/A Nav Data.....                              | 78 |
| Figure 10-52. Orbit Error PRN30 (SVN-64) Using L2C CNAV Data.....                             | 78 |
| Figure 10-53. Orbit Error PRN31 (SVN-52) Using C/A Nav Data.....                              | 79 |
| Figure 10-54. Orbit Error PRN31 (SVN-52) Using L2C CNAV Data.....                             | 79 |
| Figure 10-55. Orbit Error PRN32 (SVN-70) Using C/A Nav Data.....                              | 80 |
| Figure 10-56. Orbit Error PRN32 (SVN-70) Using L2C CNAV Data.....                             | 80 |
| Figure 10-57. QQ Plots of Range Error PRNs 1 to 5 Using C/A Nav Data .....                    | 81 |
| Figure 10-58. QQ Plots of Range Error PRNs 6 to 9 Using C/A Nav Data .....                    | 81 |
| Figure 10-59. QQ Plots of Range Error PRNs 10 to 13 Using C/A Nav Data .....                  | 82 |
| Figure 10-60. QQ Plots of Range Error PRNs 14 to 17 Using C/A Nav Data .....                  | 82 |
| Figure 10-61. QQ Plots of Range Error PRNs 18 to 21 Using C/A Nav Data .....                  | 83 |
| Figure 10-62. QQ Plots of Range Error PRNs 22 to 25 Using C/A Nav Data .....                  | 83 |
| Figure 10-63. QQ Plots of Range Error PRNs 26 to 29 Using C/A Nav Data .....                  | 84 |
| Figure 10-64. QQ Plots of Range Error PRNs 30 to 32 Using C/A Nav Data .....                  | 84 |
| Figure 10-65. QQ Plots of Range Error PRNs 1, 3, 7, and 8 Using L2C CNAV Data.....            | 85 |
| Figure 10-66. QQ Plots of Range Error PRNs 9, 10, 12, and 15 Using L2C CNAV Data.....         | 85 |
| Figure 10-67. QQ Plots of Range Error PRNs 24, 25, 26 and 27 Using L2C CNAV Data.....         | 86 |
| Figure 10-68. QQ Plots of Range Error PRNs 29, 30, 31, and 32 Using L2C CNAV Data.....        | 86 |
| Figure 10-69. Histograms of H, A, C, and Range Error PRN1 (SVN-63) Using C/A Nav Data.....    | 87 |
| Figure 10-70. Histograms of H, A, C, and Range Error PRN1 (SVN-63) Using L2C CNAV Data .....  | 87 |
| Figure 10-71. Histograms of H, A, C, and Range Error PRN2 (SVN-61) Using C/A Nav Data.....    | 88 |
| Figure 10-72. Histograms of H, A, C, and Range Error PRN3 (SVN-69) Using C/A Nav Data.....    | 88 |
| Figure 10-73. Histograms of H, A, C, and Range Error PRN3 (SVN-69) Using L2C CNAV Data .....  | 89 |
| Figure 10-74. Histograms of H, A, C, and Range Error PRN5 (SVN-50) Using C/A Nav Data.....    | 89 |
| Figure 10-75. Histograms of H, A, C, and Range Error PRN6 (SVN-67) Using C/A Nav Data.....    | 90 |
| Figure 10-76. Histograms of H, A, C, and Range Error PRN7 (SVN-48) Using C/A Nav Data.....    | 90 |
| Figure 10-77. Histograms of H, A, C, and Range Error PRN7 (SVN-48) Using L2C CNAV Data .....  | 91 |
| Figure 10-78. Histograms of H, A, C, and Range Error PRN8 (SVN-72) Using C/A Nav Data.....    | 91 |
| Figure 10-79. Histograms of H, A, C, and Range Error PRN8 (SVN-72) Using L2C CNAV Data .....  | 92 |
| Figure 10-80. Histograms of H, A, C, and Range Error PRN9 (SVN-68) Using C/A Nav Data.....    | 92 |
| Figure 10-81. Histograms of H, A, C, and Range Error PRN9 (SVN-68) Using L2C CNAV Data .....  | 93 |
| Figure 10-82. Histograms of H, A, C, and Range Error PRN10 (SVN-73) Using C/A Nav Data.....   | 93 |
| Figure 10-83. Histograms of H, A, C, and Range Error PRN10 (SVN-73) Using L2C CNAV Data ..... | 94 |

|   |     |
|---|-----|
| Figure 10-84. Histograms of H, A, C, and Range Error PRN11 (SVN-46) Using C/A Nav Data.....     | 94  |
| Figure 10-85. Histograms of H, A, C, and Range Error PRN12 (SVN-58) Using C/A Nav Data.....     | 95  |
| Figure 10-86. Histograms of H, A, C, and Range Error PRN12 (SVN-58) Using L2C CNAV Data .....   | 95  |
| Figure 10-87. Histograms of H, A, C, and Range Error PRN13 (SVN-43) Using C/A Nav Data.....     | 96  |
| Figure 10-88. Histograms of H, A, C, and Range Error PRN14 (SVN-41) Using C/A Nav Data.....     | 96  |
| Figure 10-89. Histograms of H, A, C, and Range Error PRN15 (SVN-55) Using C/A Nav Data.....     | 97  |
| Figure 10-90. Histograms of H, A, C, and Range Error PRN15 (SVN-55) Using L2C CNAV Data .....   | 97  |
| Figure 10-91. Histograms of H, A, C, and Range Error PRN16 (SVN-56) Using C/A Nav Data.....     | 98  |
| Figure 10-92. Histograms of H, A, C, and Range Error PRN17 (SVN-53) Using C/A Nav Data.....     | 98  |
| Figure 10-93. Histograms of H, A, C, and Range Error PRN18 (SVN-34) Using C/A Nav Data.....     | 99  |
| Figure 10-94. Histograms of H, A, C, and Range Error PRN19 (SVN-59) Using C/A Nav Data.....     | 99  |
| Figure 10-95. Histograms of H, A, C, and Range Error PRN20 (SVN-51) Using C/A Nav Data.....     | 100 |
| Figure 10-96. Histograms of H, A, C, and Range Error PRN21 (SVN-45) Using C/A Nav Data.....     | 100 |
| Figure 10-97. Histograms of H, A, C, and Range Error PRN22 (SVN-47) Using C/A Nav Data.....     | 101 |
| Figure 10-98. Histograms of H, A, C, and Range Error PRN23 (SVN-60) Using C/A Nav Data.....     | 101 |
| Figure 10-99. Histograms of H, A, C, and Range Error PRN24 (SVN-65) Using C/A Nav Data.....     | 102 |
| Figure 10-100. Histograms of H, A, C, and Range Error PRN24 (SVN-65) Using L2C CNAV Data .....  | 102 |
| Figure 10-101. Histograms of H, A, C, and Range Error PRN25 (SVN-62) Using C/A Nav Data.....    | 103 |
| Figure 10-102. Histograms of H, A, C, and Range Error PRN25 (SVN-62) Using L2C CNAV Data .....  | 103 |
| Figure 10-103. Histograms of H, A, C, and Range Error PRN26 (SVN-71) Using C/A Nav Data.....    | 104 |
| Figure 10-104. Histograms of H, A, C, and Range Error PRN26 (SVN-71) Using L2C CNAV Data .....  | 104 |
| Figure 10-105. Histograms of H, A, C, and Range Error PRN27 (SVN-66) Using C/A Nav Data.....    | 105 |
| Figure 10-106. Histograms of H, A, C, and Range Error PRN27 (SVN-66) Using L2C CNAV Data .....  | 105 |
| Figure 10-107. Histograms of H, A, C, and Range Error PRN28 (SVN-44) Using C/A Nav Data.....    | 106 |
| Figure 10-108. Histograms of H, A, C, and Range Error PRN29 (SVN-57) Using C/A Nav Data.....    | 106 |
| Figure 10-109. Histograms of H, A, C, and Range Error PRN29 (SVN-57) Using L2C CNAV Data .....  | 107 |
| Figure 10-110. Histograms of H, A, C, and Range Error PRN30 (SVN-64) Using C/A Nav Data.....    | 107 |
| Figure 10-111. Histograms of H, A, C, and Range Error PRN30 (SVN-64) Using L2C CNAV Data .....  | 108 |
| Figure 10-112. Histograms of H, A, C, and Range Error PRN31 (SVN-52) Using C/A Nav Data.....    | 108 |
| Figure 10-113. Histograms of H, A, C, and Range Error PRN31 (SVN-52) Using L2C CNAV Data .....  | 109 |
| Figure 10-114. Histograms of H, A, C, and Range Error PRN32 (SVN-70) Using C/A Nav Data.....    | 109 |
| Figure 10-115. Histograms of H, A, C, and Range Error PRN32 (SVN-70) Using L2C CNAV Data .....  | 110 |
| Figure 10-116. Timeline of URA Normalized Range Error PRN1 (SVN-63) Using C/A Nav Data .....    | 110 |
| Figure 10-117. Timeline of IAURA Normalized Range Error PRN1 (SVN-63) Using L2C CNAV Data ..... | 111 |
| Figure 10-118. Timeline of URA Normalized Range Error PRN2 (SVN-61) Using C/A Nav Data .....    | 111 |
| Figure 10-119. Timeline of URA Normalized Range Error PRN3 (SVN-69) Using C/A Nav Data .....    | 112 |
| Figure 10-120. Timeline of IAURA Normalized Range Error PRN3 (SVN-69) Using L2C CNAV Data ..... | 112 |

|  |     |
|--|-----|
| Figure 10-121. Timeline of URA Normalized Range Error PRN5 (SVN-50) Using C/A Nav Data .....     | 113 |
| Figure 10-122. Timeline of URA Normalized Range Error PRN6 (SVN-67) Using C/A Nav Data .....     | 113 |
| Figure 10-123. Timeline of URA Normalized Range Error PRN7 (SVN-48) Using C/A Nav Data .....     | 114 |
| Figure 10-124. Timeline of IAURA Normalized Range Error PRN7 (SVN-48) Using L2C CNAV Data .....  | 114 |
| Figure 10-125. Timeline of URA Normalized Range Error PRN8 (SVN-72) Using C/A Nav Data .....     | 115 |
| Figure 10-126. Timeline of IAURA Normalized Range Error PRN8 (SVN-72) Using L2C CNAV Data .....  | 115 |
| Figure 10-127. Timeline of URA Normalized Range Error PRN9 (SVN-68) Using C/A Nav Data .....     | 116 |
| Figure 10-128. Timeline of IAURA Normalized Range Error PRN9 (SVN-68) Using L2C CNAV Data .....  | 116 |
| Figure 10-129. Timeline of URA Normalized Range Error PRN10 (SVN-73) Using C/A Nav Data .....    | 117 |
| Figure 10-130. Timeline of IAURA Normalized Range Error PRN10 (SVN-73) Using L2C CNAV Data ..... | 117 |
| Figure 10-131. Timeline of URA Normalized Range Error PRN11 (SVN-46) Using C/A Nav Data .....    | 118 |
| Figure 10-132. Timeline of URA Normalized Range Error PRN12 (SVN-58) Using C/A Nav Data .....    | 118 |
| Figure 10-133. Timeline of IAURA Normalized Range Error PRN12 (SVN-58) Using L2C CNAV Data ..... | 119 |
| Figure 10-134. Timeline of URA Normalized Range Error PRN13 (SVN-43) Using C/A Nav Data .....    | 119 |
| Figure 10-135. Timeline of URA Normalized Range Error PRN14 (SVN-41) Using C/A Nav Data .....    | 120 |
| Figure 10-136. Timeline of URA Normalized Range Error PRN15 (SVN-55) Using C/A Nav Data .....    | 120 |
| Figure 10-137. Timeline of IAURA Normalized Range Error PRN15 (SVN-55) Using L2C CNAV Data ..... | 121 |
| Figure 10-138. Timeline of URA Normalized Range Error PRN16 (SVN-56) Using C/A Nav Data .....    | 121 |
| Figure 10-139. Timeline of URA Normalized Range Error PRN17 (SVN-53) Using C/A Nav Data .....    | 122 |
| Figure 10-140. Timeline of URA Normalized Range Error PRN18 (SVN-34) Using C/A Nav Data .....    | 122 |
| Figure 10-141. Timeline of URA Normalized Range Error PRN19 (SVN-59) Using C/A Nav Data .....    | 123 |
| Figure 10-142. Timeline of URA Normalized Range Error PRN20 (SVN-51) Using C/A Nav Data .....    | 123 |
| Figure 10-143. Timeline of URA Normalized Range Error PRN21 (SVN-45) Using C/A Nav Data .....    | 124 |
| Figure 10-144. Timeline of URA Normalized Range Error PRN22 (SVN-47) Using C/A Nav Data .....    | 124 |
| Figure 10-145. Timeline of URA Normalized Range Error PRN23 (SVN-60) Using C/A Nav Data .....    | 125 |
| Figure 10-146. Timeline of URA Normalized Range Error PRN24 (SVN-65) Using C/A Nav Data .....    | 125 |
| Figure 10-147. Timeline of IAURA Normalized Range Error PRN24 (SVN-65) Using L2C CNAV Data ..... | 126 |
| Figure 10-148. Timeline of URA Normalized Range Error PRN25 (SVN-62) Using C/A Nav Data .....    | 126 |
| Figure 10-149. Timeline of IAURA Normalized Range Error PRN25 (SVN-62) Using L2C CNAV Data ..... | 127 |
| Figure 10-150. Timeline of URA Normalized Range Error PRN26 (SVN-71) Using C/A Nav Data .....    | 127 |
| Figure 10-151. Timeline of IAURA Normalized Range Error PRN26 (SVN-71) Using L2C CNAV Data ..... | 128 |
| Figure 10-152. Timeline of URA Normalized Range Error PRN27 (SVN-66) Using C/A Nav Data .....    | 128 |
| Figure 10-153. Timeline of IAURA Normalized Range Error PRN27 (SVN-66) Using L2C CNAV Data ..... | 129 |
| Figure 10-154. Timeline of URA Normalized Range Error PRN28 (SVN-44) Using C/A Nav Data .....    | 129 |
| Figure 10-155. Timeline of URA Normalized Range Error PRN29 (SVN-57) Using C/A Nav Data .....    | 130 |
| Figure 10-156. Timeline of IAURA Normalized Range Error PRN29 (SVN-57) Using L2C CNAV Data ..... | 130 |
| Figure 10-157. Timeline of URA Normalized Range Error PRN30 (SVN-64) Using C/A Nav Data .....    | 131 |

|  |     |
|--|-----|
| Figure 10-158. Timeline of IAURA Normalized Range Error PRN30 (SVN-64) Using L2C CNAV Data ..... | 131 |
| Figure 10-159. Timeline of URA Normalized Range Error PRN31 (SVN-52) Using C/A Nav Data .....    | 132 |
| Figure 10-160. Timeline of IAURA Normalized Range Error PRN31 (SVN-52) Using L2C CNAV Data ..... | 132 |
| Figure 10-161. Timeline of URA Normalized Range Error PRN32 (SVN-70) Using C/A Nav Data .....    | 133 |
| Figure 10-162. Timeline of IAURA Normalized Range Error PRN32 (SVN-70) Using L2C CNAV Data ..... | 133 |

**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 .....                  | 14  |
| Table 3-4. Cancelled NANUs.....   | 14  |
| Table 3-5. GPS Satellite Maintenance Statistics.....                                | 14  |
| Table 3-6. Service Availability Standard.....                                       | 15  |
| Table 3-7. Accuracies Exceeding Threshold Statistics .....                          | 15  |
| Table 4-1. User Range Error Accuracy Parameters.....                                | 17  |
| Table 4-2. User Range Error Accuracy .....  | 17  |
| Table 5-1. Accuracy Standard Parameters.....  | 18  |
| Table 5-2. Horizontal & Vertical Accuracy Statistics for the Quarter.....           | 19  |
| 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.....                       | 33  |
| Table 7-1. Selected IGS Sites Information .....                                     | 34  |
| Table 7-2. GPS SPS Performance at Selected High Rate IGS Sites .....                | 36  |
| Table 8-1. RAIM Site Statistics.....  | 39  |
| Table A-1. Performance Summary .....  | 134 |

## 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 (4<sup>th</sup> 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 5-degree grid between 180-degrees east and 180-degrees west, and from 80-degrees north and 80-degrees south. The program then computes the PDOP at each grid point (1485 total grid points) every minute for the entire day and stores the results. After the PDOP's have been saved, the 99.99% index of 1-minute PDOP at each grid point is determined and plotted as contour lines (see Figure 2-1). The program also saves the number of satellites used in PDOP calculation at each grid point for analysis.

**Section 3.** Summarizes the GPS constellation performance by providing the "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 will be reported at quarterly intervals.

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

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

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

**Section 8.** Provides a summary of RAIM performance.

**Section 9.** Provides a summary of GPS Test NOTAMs. Note that this section is not available for this reporting period.

**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   |
|--|--|
| <b>Per-Satellite Coverage</b><br>Terrestrial Service Volume:<br>100% Coverage<br><br>Space Service Volume:<br>No Coverage Performance Specified  | For any healthy or marginal SPS SIS.   |
| <b>Constellation Coverage</b><br>Terrestrial Service Volume:<br>100% Coverage<br><br>Space Service Volume:<br>No Performance Specified   | For any healthy or marginal SPS SIS.   |
| <b>User Range Error Accuracy</b><br>Single-Frequency C/A-Code <ul style="list-style-type: none"> <li>• <math>\leq 7.8\text{m}</math> 95% Global Average URE during normal operations over All AODs</li> <li>• <math>\leq 6.0\text{m}</math> 95% Global Average URE during operations at Zero AOD</li> <li>• <math>\leq 12.8\text{m}</math> 95% Global Average URE during normal operations at Any AOD</li> </ul> | For any healthy or marginal SPS SIS.<br><br>Neglecting single-frequency ionospheric delay model errors.<br><br>Including group delay time correction ( $T_{GD}$ ) errors at L1.<br><br>Including inter-signal bias (P(Y)-code to C/A-code) errors at L1. |

| Parameter   | Conditions and Constraints   |
|---|--|
| <p><b>User Range Error Accuracy</b><br/>Single-Frequency C/A-Code</p> <ul style="list-style-type: none"> <li>• <math>\leq 30\text{m}</math> 99.94% Global Average URE during normal operations</li> <li>• <math>\leq 30\text{m}</math> 99.79% Worst Case single point average during normal operations</li> </ul> | <p>For any healthy or marginal SPS SIS.</p> <p>Neglecting single-frequency ionospheric delay model errors.</p> <p>Including group delay time correction (<math>T_{GD}</math>) errors at L1.</p> <p>Standard based on measurement interval of one year; average of daily values within service volume</p> <p>Standard based on 3 service failures per year, lasting no more than 6 hours each</p> |
| <p><b>User Range Rate Error Accuracy</b><br/>Single-Frequency C/A Code:</p> <p><math>\leq 6\text{mm/sec}</math> 95% Global Average URRE over any 3-second interval during normal operations at Any AOD</p>  | <p>For any healthy SPS SIS.</p> <p>Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers.</p> <p>Neglecting single-frequency ionospheric delay model errors.</p>   |
| <p><b>User Range Acceleration Error Accuracy</b><br/>Single-Frequency C/A Code:</p> <p><math>\leq 2\text{mm/sec}^2</math> 95% Global Average URAE over any 3-second interval during normal operations at Any AOD</p>  | <p>For any healthy SPS SIS.</p> <p>Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers.</p> <p>Neglecting single-frequency ionospheric delay model errors.</p>   |
| <p><b>Coordinated Universal Time Offset Error Accuracy</b></p> <p><math>\leq 40</math> nanoseconds 95% Global average UTCOE during normal operations at Any AOD.</p>  | <p>For any healthy SPS SIS.</p>  |

| Parameter   | Conditions and Constraints   |
|---|--|
| <p><b>Instantaneous URE Integrity</b><br/>Single-Frequency C/A-Code:</p> <p><math>\leq 1 \times 10^{-5}</math> Probability over any hour of the SPS SIS Instantaneous URE exceeding the NTE tolerance without a timely alert during normal operations.</p> <p><b>Note:</b> Please see results in the WAAS PAN Report located at <a href="http://www.nstb.tc.faa.gov/DisplayArchive.htm">http://www.nstb.tc.faa.gov/DisplayArchive.htm</a></p> | <p>For any healthy SPS SIS.</p> <p>SPS SIS URE NTE tolerance defined to be <math>\pm 4.42</math> times the upper bound on the URA value corresponding to the URA index “N” currently broadcast by the satellite.</p> <p>Given that the maximum SPS SIS instantaneous URE did not exceed the NTE tolerance at the start of the hour.</p> <p>Worst case for delayed alert is 6 hours.</p> <p>Neglecting single-frequency ionospheric delay model errors.</p> |
| <p><b>Instantaneous UTCOE Integrity</b><br/>Single-Frequency C/A-Code:</p> <p><math>\leq 1 \times 10^{-5}</math> Probability over any hour of the sPS SIS Instantaneous UTCOE exceeding the NTE tolerance without a timely alert during normal operations.</p>  | <p>For any healthy SPS SIS.</p> <p>SPS SIS URE NTE tolerance defined.</p>  |
| <p><b>Unscheduled Failure Interruption Continuity</b><br/>Unscheduled Failure Interruptions:</p> <p><math>\geq 0.9998</math> Probability over any hour of not losing the SPS SIS availability from a slot due to unscheduled interruption.</p>  | <p>Calculated as an average over all slots in the 24-slot constellation, normalized annually.</p> <p>Given that the SPS SIS is available from the slot at the start of the hour.</p>   |
| <p><b>Status and Problem Reporting</b><br/>Scheduled event affecting service<br/>Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event</p>  | <p>For any SPS SIS.</p>  |

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

| Parameter   | Conditions and Constraints   |
|---|--|
| <b>Operational Satellite Count</b><br>$\geq 0.95$ 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. |
| <b>PDOP Availability</b><br>$\geq 98\%$ global PDOP of 6 or less<br><br>$\geq 88\%$ 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.   |
| <b>Service Availability</b><br>$\geq 99\%$ Horizontal Service Availability, average location<br><br>$\geq 99\%$ Vertical Service Availability, average location   | 17m Horizontal (SIS only) 95% threshold.<br><br>37m Vertical (SIS only) 95% threshold.<br><br>Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.   |
| <b>Service Availability</b><br>$\geq 90\%$ Horizontal Service Availability, worst-case location<br><br>$\geq 90\%$ Vertical Service Availability, worst-case location   | 17m Horizontal (SIS only) 95% threshold.<br><br>37m Vertical (SIS only) 95% threshold.<br><br>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   |
|--|--|
| <b>Position/Time Accuracy</b><br>Global Average Position Domain Accuracy: <ul style="list-style-type: none"> <li>• <math>\leq 9\text{m}</math> 95% Horizontal Error</li> <li>• <math>\leq 15\text{m}</math> 95 % Vertical Error</li> </ul> | Defined for a position/time solution meeting the representative user conditions.<br><br>Standard based on a measurement interval of 24 hours averaged over all points in the service volume. |
| <b>Position/Time Accuracy</b><br>Worst Site Position Domain Accuracy: <ul style="list-style-type: none"> <li>• <math>\leq 17\text{m}</math> 95% Horizontal Error</li> <li>• <math>\leq 37\text{m}</math> 95% Vertical Error</li> </ul>     | Defined for a position/time solution meeting the representative user conditions.<br><br>Standard based on a measurement interval of 24 hours averaged over all points in the service volume. |
| <b>Position/Time Accuracy</b><br>Time Transfer Domain Accuracy:<br><br>$\leq 40$ nanoseconds time transfer error<br>95% of time<br><br>(SIS only)  | Defined for a position/time solution meeting the representative user conditions.<br><br>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  |
|--|---|
| $\geq 98\%$ global PDOP of 6 or less<br><br>$\geq 88\%$ 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 3.354 or better 99.9% of the time for each of the 24-hour intervals.

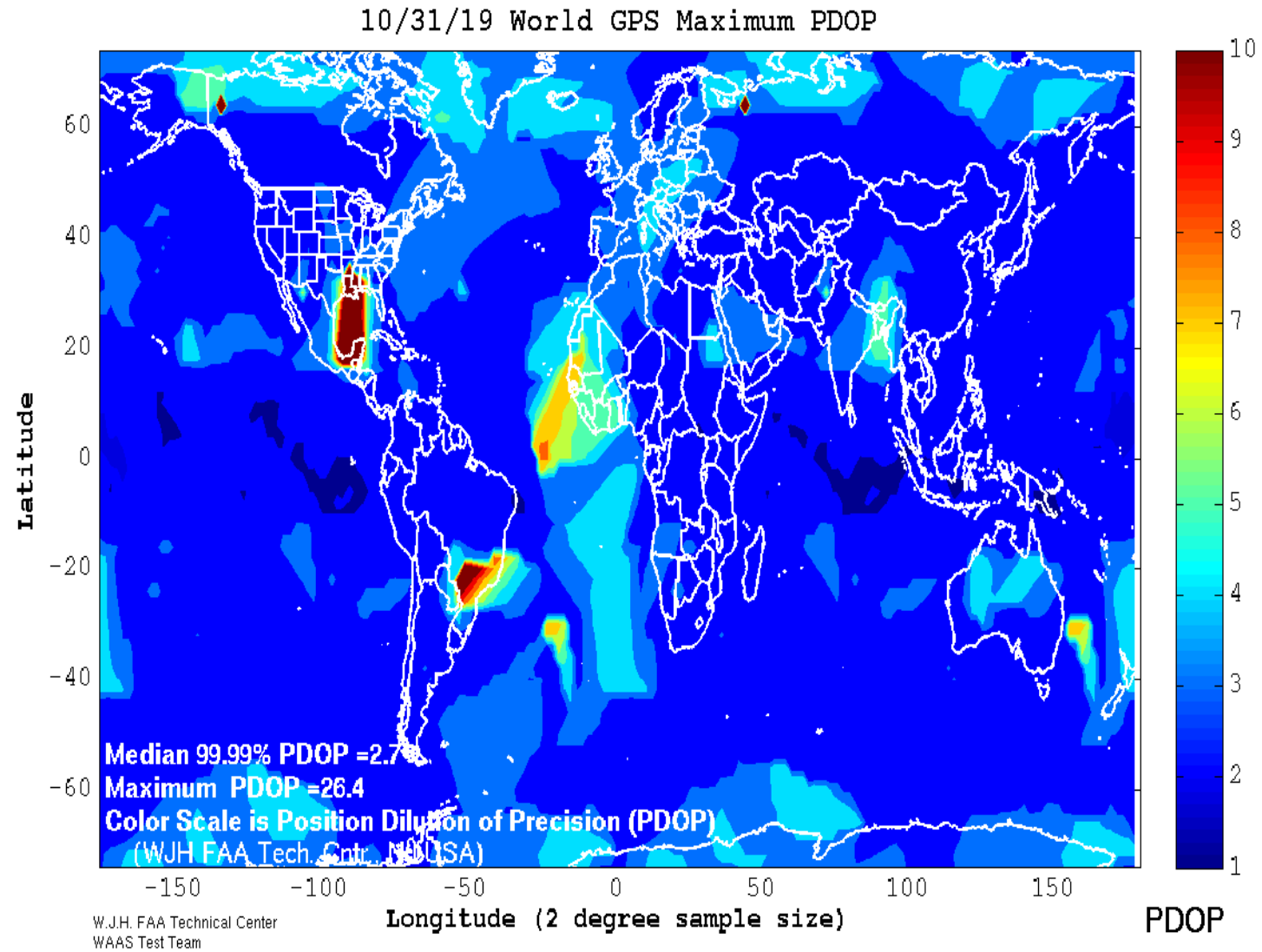
Figure 2-1 is a contour plot of PDOP values over the entire globe. Inside each contour area, the PDOP value is greater than or equal to the contour value shown in the legend for that color line. That areas' value is also less than the next higher contour value, unless another contour line lies within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

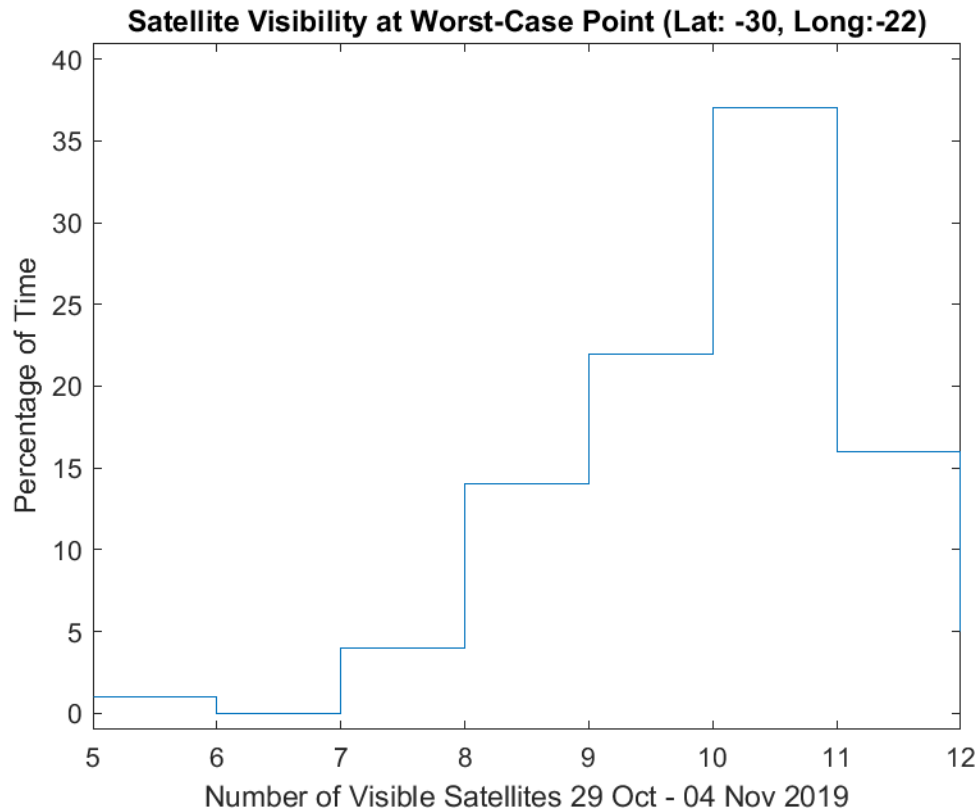
**Table 2-2. PDOP Availability Statistics**

| <b>Date Range of Week</b> | <b>Global<br/>99.9% PDOP<br/>Value<br/>(Meters)</b> | <b>Global<br/>Average<br/>Availability<br/>(Spec: <math>\geq 98\%</math>)</b> | <b>Worst-Case<br/>Point<br/>Availability<br/>(Spec: <math>\geq 88\%</math>)</b> |
|---------------------------|---|---|---|
| 10/01/2019 - 10/07/2019   | 3.2788  | 99.9991   | 98.9285   |
| 10/08/2019 - 10/14/2019   | 3.3283  | 99.9991   | 98.9583   |
| 10/15/2019 - 10/21/2019   | 3.2833  | 99.9992   | 99.0476   |
| 10/22/2019 - 10/28/2019   | 3.2781  | 99.9993   | 99.0674   |
| 10/29/2019 - 11/04/2019   | 3.3541  | 99.9986   | 99.1269   |
| 11/05/2019 - 11/11/2019   | 3.2757  | 99.9994   | 99.1765   |
| 11/12/2019 - 11/18/2019   | 3.2731  | 99.9993   | 99.1865   |
| 11/19/2019 - 11/25/2019   | 3.2451  | 99.9994   | 99.2559   |
| 11/26/2019 - 12/02/2019   | 3.2289  | 99.9994   | 99.2361   |
| 12/03/2019 - 12/09/2019   | 3.2169  | 99.9994   | 99.1666   |
| 12/10/2019 - 12/16/2019   | 3.2   | 99.9995   | 99.1865   |
| 12/17/2019 - 12/23/2019   | 3.1853  | 99.9995   | 99.2162   |
| 12/24/2019 - 12/30/2019   | 3.1645  | 99.9995   | 99.3253   |
| 12/31/2019 - 01/06/2020   | 3.1486  | 99.9996   | 99.3912   |



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**

| <b>Status and Problem Reporting</b>  | <b>Conditions and Constraints</b> |
|--|-----------------------------------|
| Scheduled event affecting service:<br>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:<br>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 October through 31 December 2019, there were 10 reported outages. Five outages were maintenance activities and were reported in advance, and five were unscheduled outages. 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 136.0 hours. The maximum response time following an unscheduled outage was 0.750 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**

| <b>NANU</b>                                       | <b>PRN</b> | <b>TYPE</b> | <b>Start Date</b> | <b>Start Time</b> | <b>End Date</b> | <b>End Time</b> | <b>Total<br/>Unscheduled<br/>Hours</b> | <b>Total<br/>Scheduled<br/>Hours</b> | <b>Total<br/>Hours</b> |
|---|------------|-------------|-------------------|-------------------|-----------------|-----------------|--|--------------------------------------|------------------------|
| <a href="#">2019152</a>                           | 18         | UNUNOREF    | 02-Oct-19         | 14:46             | 02-Oct-19       | 14:47           | 0.02                                   | 0                                    | 0.02                   |
| <a href="#">2019155</a>                           | 2          | UNUSABLE    | 03-Oct-19         | 15:46             | 03-Oct-19       | 20:55           | 5.15                                   | 0                                    | 5.15                   |
| <a href="#">2019157</a>                           | 18         | UNUNOREF    | 04-Oct-19         | 14:12             | 04-Oct-19       | 14:14           | 0.03                                   | 0                                    | 0.03                   |
| <a href="#">2019160</a>                           | 24         | FCSTSUMM    | 10-Oct-19         | 07:00             | 10-Oct-19       | 12:00           | 0                                      | 5                                    | 5                      |
| <a href="#">2019164</a>                           | 3          | UNUSABLE    | 28-Oct-19         | 05:59             | 28-Oct-19       | 06:40           | 0.68                                   | 0                                    | 0.68                   |
| <a href="#">2019165</a>                           | 5          | FCSTSUMM    | 31-Oct-19         | 13:29             | 31-Oct-19       | 18:55           | 0                                      | 5.43                                 | 5.43                   |
| <a href="#">2019167</a>                           | 29         | UNUSABLE    | 04-Nov-19         | 21:28             | 05-Nov-19       | 19:01           | 21.55                                  | 0                                    | 21.55                  |
| <a href="#">2019170</a>                           | 12         | FCSTSUMM    | 15-Nov-19         | 05:06             | 15-Nov-19       | 10:23           | 0                                      | 5.28                                 | 5.28                   |
| <a href="#">2019171</a>                           | 14         | FCSTSUMM    | 21-Nov-19         | 09:46             | 21-Nov-19       | 15:52           | 0                                      | 6.1                                  | 6.1                    |
| <a href="#">2019173</a>                           | 11         | FCSTSUMM    | 19-Dec-19         | 15:49             | 19-Dec-19       | 23:55           | 0                                      | 8.1                                  | 8.1                    |
| Totals of Unschedule Scheduled and Total Downtime |            |             |                   |                   |                 |                 | 27.43                                  | 29.91                                | 57.34                  |

**Table 3-3. NANUs Forecasted to Affect Satellite Availability**

| NANU                      | PRN | TYPE      | Start Date | Start Time | End Date | End Time | Total Number | Comments                |
|---------------------------|-----|-----------|------------|------------|----------|----------|--------------|-------------------------|
| <a href="#">2019153</a>   | 24  | FCSTDV    | 10-Oct     | 06:15      | 10-Oct   | 18:15    | 12           | <a href="#">2019160</a> |
| <a href="#">2019154</a>   | 2   | UNUSUFN   | 03-Oct     | 15:46      |          |          |              | <a href="#">2019155</a> |
| <a href="#">2019161</a>   | 5   | FCSTDV    | 31-Oct     | 10:00      | 31-Oct   | 22:00    | 0            | <a href="#">2019162</a> |
| <a href="#">2019162</a>   | 5   | FCSTRESCD | 31-Oct     | 12:30      | 01-Nov   | 00:30    | 12           | <a href="#">2019165</a> |
| <a href="#">2019163</a>   | 3   | UNUSUFN   | 28-Oct     | 05:59      |          |          |              | <a href="#">2019164</a> |
| <a href="#">2019166</a>   | 29  | UNUSUFN   | 04-Nov     | 21:28      |          |          |              | <a href="#">2019167</a> |
| <a href="#">2019168</a>   | 12  | FCSTDV    | 15-Nov     | 04:30      | 15-Nov   | 16:30    | 12           | <a href="#">2019170</a> |
| <a href="#">2019169</a>   | 14  | FCSTDV    | 21-Nov     | 09:40      | 21-Nov   | 21:40    | 12           | <a href="#">2019171</a> |
| <a href="#">2019172</a>   | 11  | FCSTDV    | 19-Dec     | 15:45      | 20-Dec   | 03:45    | 12           | <a href="#">2019173</a> |
| Total Forecasted Downtime |     |           |            |            |          |          | 60           |                         |

**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      |

**Table 3-5. GPS Satellite Maintenance Statistics**

| Satellite Reliability/Maintainability/Availability (RMA) Paramenter | 10/01/2019 to 12/31/2019 | 01/01/2000 to 12/31/2019 |
|---|--------------------------|--------------------------|
| Total Forecasted Downtime (hrs)                                     | 60                       | 12622.82                 |
| Total Actual Downtime (hrs)   | 57.34                    | 40209.02                 |
| Total Actual Scheduled Downtime (hrs)                               | 29.91                    | 6966.39                  |
| Total Actual Unscheduled Downtime(hrs)                              | 27.43                    | 33242.63                 |
| Total Satellite Observed MTTR (hrs)                                 | 5.73                     | 37.02                    |
| Scheduled Satellite Observed (hrs)                                  | 5.98                     | 8.76                     |
| Unscheduled Satellite Observed (hrs)                                | 5.49                     | 114.24                   |
| Total Satellite Outages (number)                                    | 10                       | 1086                     |
| Scheduled Satellite Outages (number)                                | 5                        | 795                      |
| Unscheduled Satellite Outages (number)                              | 5                        | 291                      |
| Percent Operational -- Scheduled downtime (%)                       | 99.96                    | 99.87                    |
| Percent Operational -- All downtime (%)                             | 99.92                    | 99.26                    |

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.

### 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**

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

To verify availability, the data collected from receivers at the 28 WAAS sites was reduced to calculate 24-hour accuracy information and reported in Table 3-7. The data was collected at 1-second intervals between 1 October and 31 December 2019.

**Table 3-7. Accuracies Exceeding Threshold Statistics**

| <b>Site</b> | <b>Total Number or Seconds of SPS Monitoring</b> | <b>Instances of 24-Hour Threshold Failures</b> | <b>October 2019 - December 2019 Service Availability (%)</b> |
|-------------|--|--|--|
| Albuquerque | 7946533  | 0  | 100  |
| Anchorage   | 7948750  | 0  | 100  |
| Atlanta     | 7948773  | 0  | 100  |
| Barrow      | 7926735  | 0  | 100  |
| Bethel      | 7943193  | 0  | 100  |

| Site   | Total Number<br>or Seconds of<br>SPS Monitoring | Instances of<br>24-Hour<br>Threshold<br>Failures | October 2019 - December<br>2019 Service Availability<br>(%) |
|--|---|--|---|
| Billings   | 7948744   | 0  | 100   |
| Boston   | 7946109   | 0  | 100   |
| Cleveland  | 7943404   | 0  | 100   |
| Cold Bay   | 7763711   | 0  | 100   |
| Fairbanks  | 7947020   | 0  | 100   |
| Gander   | 7948629   | 0  | 100   |
| Honolulu   | 7948798   | 0  | 100   |
| Houston  | 7948800   | 0  | 100   |
| Iqaluit  | 6834334   | 0  | 100   |
| Juneau   | 7948441   | 0  | 100   |
| Kansas City  | 7948793   | 0  | 100   |
| Kotzebue   | 7684020   | 0  | 100   |
| Los Angeles  | 7940701   | 0  | 100   |
| Merida   | 7943126   | 0  | 100   |
| Miami  | 7948800   | 0  | 100   |
| Minneapolis  | 7948798   | 0  | 100   |
| Oakland  | 7948800   | 0  | 100   |
| Salt Lake City   | 7948800   | 0  | 100   |
| San Jose Del Cabo  | 7810900   | 0  | 100   |
| San Juan   | 7948791   | 0  | 100   |
| Seattle  | 7948608   | 0  | 100   |
| Tapachula  | 7841630   | 0  | 100   |
| Washington, D.C.   | 7948739   | 0  | 100   |
| <b>Global Average over Reporting Period = 100% (SPS Spec. &gt; 95.87%)</b> |   |  |   |

#### 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**

| <b>User Range Error Accuracy</b>  | <b>Conditions and Constraints</b>   |
|---|---|
| Single Frequency C/A-Code: <ul style="list-style-type: none"> <li>• <math>\leq 30\text{m}</math> 99.94% Global Average URE during normal operations</li> <li>• <math>\leq 30\text{m}</math> 99.79% Worst Case single point average during normal operations.</li> </ul> | For any healthy SPS SIS.<br>Neglecting single-frequency ionospheric delay model errors.<br>Including group delay time correction ( $T_{GD}$ ) errors at L1.<br>Including inter-signal bias (P(Y)-code to C/A-code) errors at L1.<br>Standard based on measurement interval of one year; average of daily values within service volume.<br>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 12.680 meters on satellite PRN18.

**Table 4-2. User Range Error Accuracy**

| <b>Date Range of Data Collection</b> | <b>Site</b> | <b>Number of Samples This Quarter</b> | <b>Number of Samples where SPS URE &gt; 30m NTE</b> | <b>Percentage (%)</b> |
|--------------------------------------|-------------|---------------------------------------|---|-----------------------|
| 01 OCTOBER - 31 DECEMBER 2019        | Boston      | 66858087                              | 0   | 100                   |
| 01 OCTOBER - 31 DECEMBER 2019        | Honolulu    | 68822170                              | 0   | 100                   |
| 01 OCTOBER - 31 DECEMBER 2019        | Juneau      | 68874107                              | 0   | 100                   |
| 01 OCTOBER - 31 DECEMBER 2019        | Los Angeles | 67918965                              | 0   | 100                   |
| 01 OCTOBER - 31 DECEMBER 2019        | Merida      | 68625189                              | 0   | 100                   |
| 01 OCTOBER - 31 DECEMBER 2019        | Miami       | 67815317                              | 0   | 100                   |
| 01 OCTOBER - 31 DECEMBER 2019        | Global      | 408913835                             | 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**

| <b>Position/Time Accuracy</b>   | <b>Conditions and Constraints</b>  |
|---|--|
| <b>Position/Time Accuracy</b><br>Global Average Position Domain Accuracy: <ul style="list-style-type: none"> <li>• <math>\leq 9\text{m}</math> 95% Horizontal Error</li> <li>• <math>\leq 15\text{m}</math> 95% Vertical Error</li> </ul>   | Defined for a position/time solution meeting the representative user conditions.<br>Standard based on a measurement interval of 24 hours averaged over all points in the service volume.   |
| <b>Position/Time Accuracy</b><br>Worst Site Position Domain Accuracy: <ul style="list-style-type: none"> <li>• <math>\leq 17\text{m}</math> 95% Horizontal Error</li> <li>• <math>\leq 37\text{m}</math> 95% Vertical Error</li> </ul>  | Defined for a position/time solution meeting the representative user conditions.<br>Standard based on a measurement interval of 24 hours averaged over all points in the service volume.   |
| <b>Position/Time Accuracy</b><br>Time Transfer Domain Accuracy:<br>$\leq 40$ nanoseconds time transfer error 95% of time (SIS only)   | Defined for a time transfer solution meeting the representative user conditions.<br>Standard based on a measurement interval of 24 hours averaged over all points in the service volume.   |
| <b>User Range Accuracy</b><br>Single Frequency C/A-Code: <ul style="list-style-type: none"> <li>• <math>\leq 7.8\text{m}</math> 95% Global Average URE during normal operations over All AODs</li> <li>• <math>\leq 6.0\text{m}</math> 95% Global Average URE during operations at Zero AOD</li> <li>• <math>\leq 12.8\text{m}</math> 95% Global Average URE during normal operations at Any AOD</li> </ul> | For any healthy SPS SIS.<br>Neglecting single-frequency ionospheric delay model errors.<br>Including group delay time correction ( $T_{GD}$ ) errors at L1.<br>Including inter-signal bias (P(Y)-code to C/A-code) errors at L1. |

| <b>Position/Time Accuracy</b>   | <b>Conditions and Constraints</b>   |
|---|---|
| <b>User Range Accuracy</b><br>Single-Frequency C/A-Code:<br>$\leq 6$ mm/sec 95% Global Average URRE over any 3-second interval during normal operations at Any AOD              | For any healthy SPS SIS.<br>Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers.<br>Neglecting single-frequency ionospheric delay model errors. |
| <b>User Range Accuracy</b><br>Single-Frequency C/A-Code:<br>$\leq 2$ mm/sec <sup>2</sup> 95% Global average URAE over any 3-second interval during normal operations at Any AOD | For any healthy SPS SIS.<br>Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers.<br>Neglecting single-frequency ionospheric delay model errors. |
| <b>Coordinated Universal Time Offset Error Accuracy</b><br>$\leq 40$ nanoseconds 95% Global average UTCOE during normal operations at Any AOD.                                  | For any healthy SPS SIS.  |

## 5.1 Position Accuracy

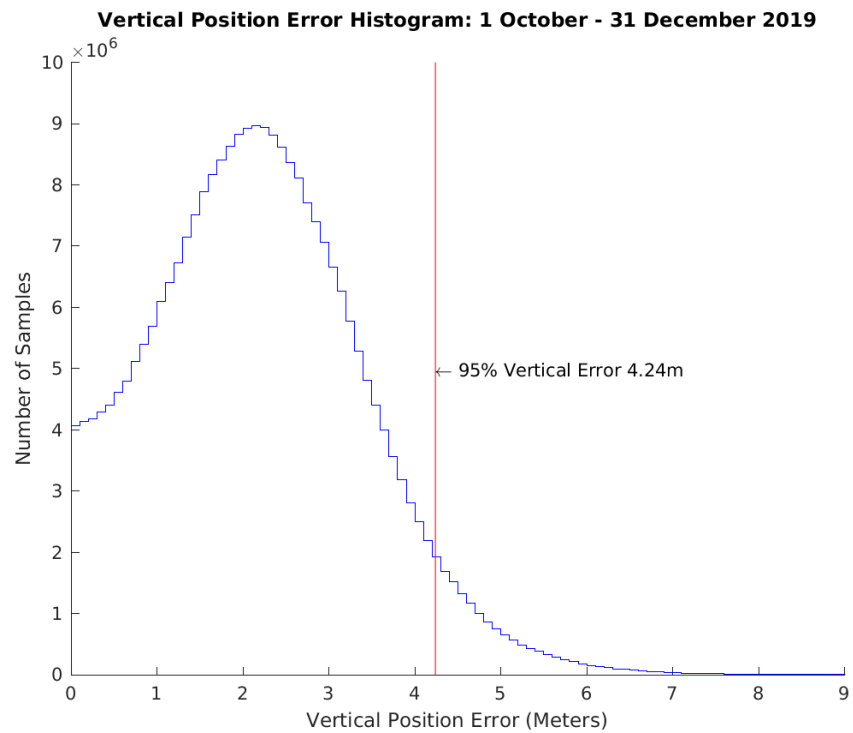
The data used for this section was collected for every second from 1 October through 31 December 2019 at the selected WAAS locations. Table 5-2 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter. Every 24-hour analysis period this quarter passed both the worst-case and global average position accuracy requirements set forth by the SPS specification.

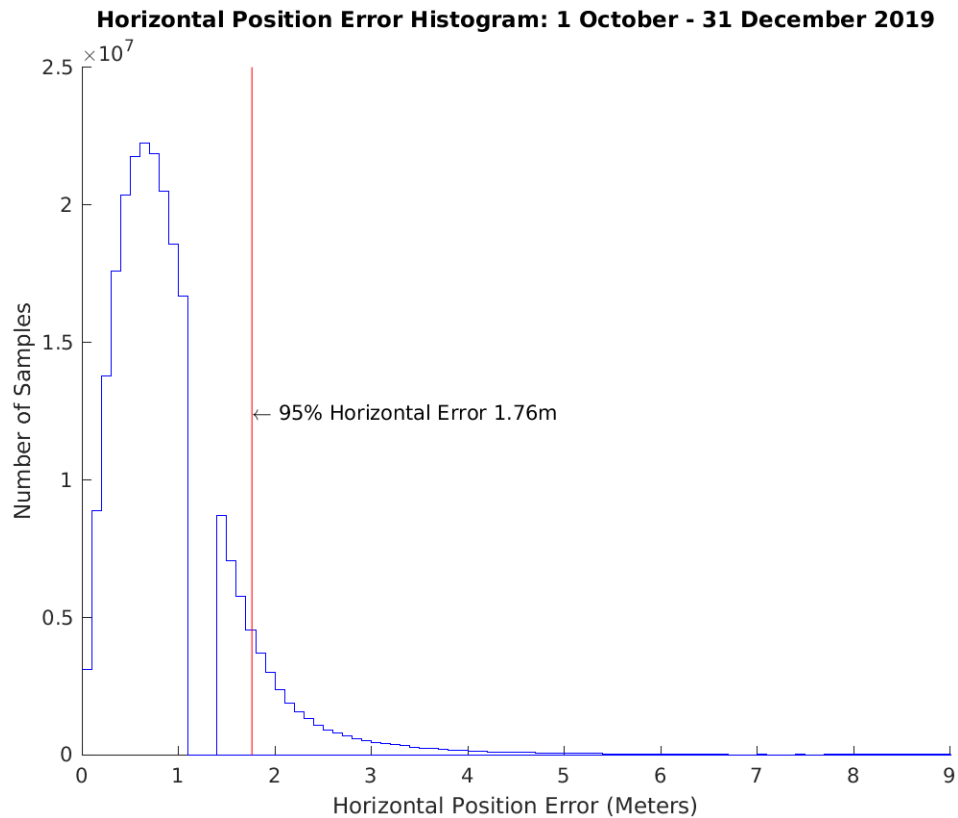
**Table 5-2. Horizontal & Vertical Accuracy Statistics for the Quarter**

| <b>Site</b> | <b>95%<br/>Vertical<br/>(Meters)</b> | <b>95%<br/>Horizontal<br/>(Meters)</b> | <b>99.99%<br/>Vertical<br/>(Meters)</b> | <b>99.99%<br/>Horizontal<br/>(Meters)</b> |
|-------------|--------------------------------------|--|---|---|
| Albuquerque | 4.20                                 | 1.55                                   | 6.52                                    | 3.45                                      |
| Anchorage   | 4.14                                 | 1.48                                   | 6.73                                    | 2.83                                      |
| Atlanta     | 4.19                                 | 1.85                                   | 7.22                                    | 3.34                                      |
| Barrow      | 4.61                                 | 1.33                                   | 9.30                                    | 2.89                                      |
| Bethel      | 4.42                                 | 1.45                                   | 7.16                                    | 2.93                                      |
| Billings    | 3.92                                 | 1.75                                   | 6.20                                    | 3.29                                      |
| Boston      | 3.54                                 | 2.17                                   | 7.04                                    | 4.03                                      |
| Cleveland   | 3.89                                 | 2.15                                   | 6.99                                    | 4.55                                      |
| Cold Bay    | 4.17                                 | 1.59                                   | 6.27                                    | 3.16                                      |

| <b>Site</b>       | <b>95%<br/>Vertical<br/>(Meters)</b> | <b>95%<br/>Horizontal<br/>(Meters)</b> | <b>99.99%<br/>Vertical<br/>(Meters)</b> | <b>99.99%<br/>Horizontal<br/>(Meters)</b> |
|-------------------|--------------------------------------|--|---|---|
| Fairbanks         | 4.13                                 | 1.39                                   | 7.74                                    | 2.64                                      |
| Gander            | 3.40                                 | 2.27                                   | 6.98                                    | 3.92                                      |
| Honolulu          | 5.12                                 | 2.91                                   | 9.21                                    | 5.19                                      |
| Honolulu          | 5.12                                 | 2.91                                   | 9.21                                    | 5.19                                      |
| Houston           | 4.63                                 | 1.65                                   | 8.33                                    | 3.29                                      |
| Juneau            | 3.67                                 | 1.47                                   | 6.37                                    | 2.84                                      |
| Kansas City       | 4.03                                 | 1.88                                   | 6.56                                    | 3.66                                      |
| Kotzebue          | 4.42                                 | 1.46                                   | 8.15                                    | 3.07                                      |
| Los Angeles       | 4.69                                 | 1.67                                   | 6.72                                    | 3.03                                      |
| Merida            | 4.77                                 | 1.56                                   | 9.56                                    | 4.39                                      |
| Miami             | 4.49                                 | 1.59                                   | 6.74                                    | 3.33                                      |
| Minneapolis       | 3.92                                 | 1.89                                   | 6.60                                    | 3.66                                      |
| Oakland           | 4.74                                 | 1.73                                   | 6.83                                    | 2.77                                      |
| Salt Lake City    | 4.17                                 | 1.63                                   | 6.69                                    | 2.93                                      |
| San Jose Del Cabo | 5                                    | 1.87                                   | 8.23                                    | 3.76                                      |
| San Juan          | 3.92                                 | 1.62                                   | 6.68                                    | 5.35                                      |
| Seattle           | 4.01                                 | 1.65                                   | 6.40                                    | 3   |
| Tapachula         | 4.91                                 | 2                                      | 10.1                                    | 5.18                                      |
| Washington D.C.   | 3.79                                 | 2.11                                   | 7.13                                    | 3.77                                      |

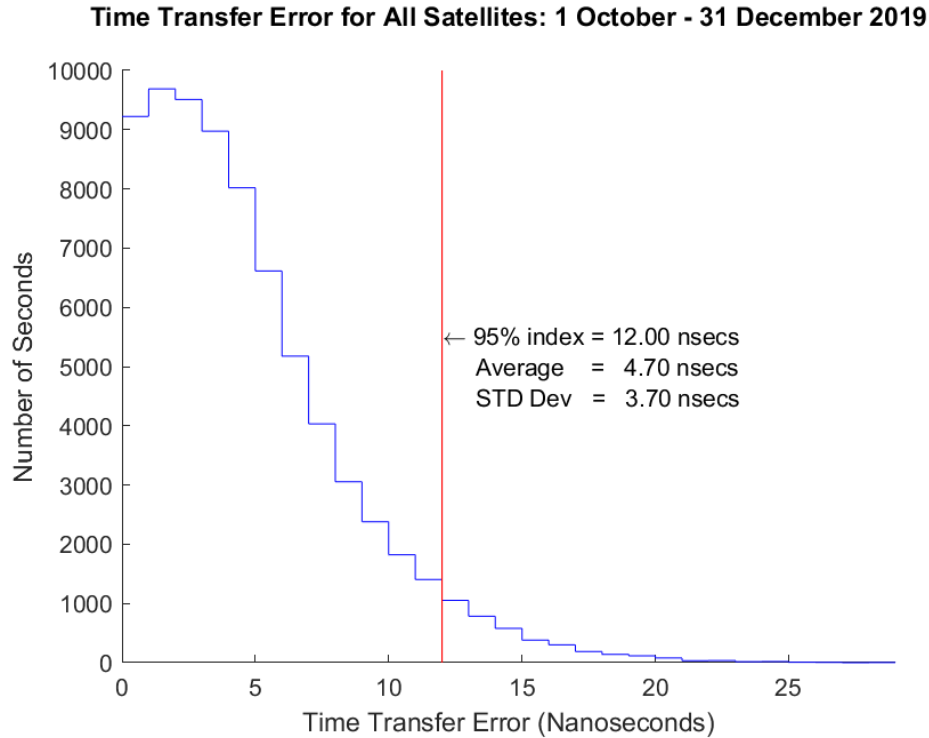
Figure 5-1 and Figure 5-2 are the combined histograms of the vertical and horizontal errors for all 28 WAAS sites from 1 October to 31 December 2019.

**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 October and 31 December 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 (UTC OE) for the quarter was 19.2 nanoseconds. The mean, standard deviation, and 95% index of Time Transfer Error, and the maximum UTC OE 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 1 October and 31 December 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) | 1 $\sigma$ Range Error (Meters) | 95% Range Error (Meters) | Max Range Error (SPS Spec. < 30m) (Meters) | Samples (Number) |
|-----|--------------------------------|---------------------------|---------------------------------|--------------------------|--|------------------|
| 1   | 1.56                           | 0.97                      | 1.15                            | 2.75                     | 9.02                                       | 14052187         |
| 2   | 2.13                           | 1.82                      | 1.05                            | 3.43                     | 8.04                                       | 14746530         |
| 3   | 1.36                           | 0.89                      | 0.94                            | 2.32                     | 7.09                                       | 14492670         |
| 5   | 1.4                            | 0.81                      | 1.03                            | 2.61                     | 7.98                                       | 13705483         |
| 6   | 1.35                           | 0.81                      | 0.96                            | 2.46                     | 8.73                                       | 13992689         |
| 7   | 1.64                           | 1.29                      | 0.92                            | 2.78                     | 10.63                                      | 12785499         |
| 8   | 1.66                           | 1.04                      | 1.15                            | 2.98                     | 12.19                                      | 12745806         |
| 9   | 1.66                           | 1.36                      | 0.89                            | 2.7                      | 11.28                                      | 13420474         |
| 10  | 1.52                           | 1.1                       | 0.92                            | 2.52                     | 6.01                                       | 13119335         |
| 11  | 1.79                           | 1.33                      | 1.12                            | 3.1                      | 10.13                                      | 12400095         |

| PRN | RMS Range Error (<6m) (Meters) | Range Error Mean (Meters) | 1 $\sigma$ Range Error (Meters) | 95% Range Error (Meters) | Max Range Error (SPS Spec. < 30m) (Meters) | Samples (Number) |
|-----|--------------------------------|---------------------------|---------------------------------|--------------------------|--|------------------|
| 12  | 1.54                           | 1.07                      | 1.03                            | 2.64                     | 7.15                                       | 13853621         |
| 13  | 1.25                           | 0.56                      | 0.96                            | 2.22                     | 5.48                                       | 13680614         |
| 14  | 2.14                           | 1.87                      | 0.91                            | 3.28                     | 5.79                                       | 14068130         |
| 15  | 1.48                           | 1.09                      | 0.91                            | 2.51                     | 5.27                                       | 12774922         |
| 16  | 1.91                           | 1.61                      | 1.01                            | 3.1                      | 7.5  | 12821898         |
| 17  | 1.62                           | 1.13                      | 1.01                            | 2.84                     | 9.33                                       | 14680566         |
| 18  | 1.83                           | 1.1                       | 1.29                            | 3.31                     | 12.68                                      | 1035992          |
| 19  | 2.37                           | 2.12                      | 1.02                            | 3.7                      | 9.23                                       | 14173046         |
| 20  | 2.37                           | 2.04                      | 1.16                            | 3.7                      | 6.72                                       | 13245653         |
| 21  | 2.34                           | 1.94                      | 1.21                            | 3.66                     | 7.17                                       | 13205506         |
| 22  | 2.41                           | 2.16                      | 1.02                            | 3.77                     | 8.17                                       | 14190661         |
| 23  | 1.94                           | 1.65                      | 0.93                            | 3.06                     | 9.0  | 13126629         |
| 24  | 1.64                           | 0.51                      | 1.34                            | 2.98                     | 7.7  | 13868021         |
| 25  | 1.69                           | 1.31                      | 1.03                            | 2.93                     | 5.41                                       | 14354151         |
| 26  | 1.74                           | 1.41                      | 0.98                            | 2.9                      | 8.7  | 12795063         |
| 27  | 1.67                           | 1.26                      | 1.02                            | 2.87                     | 8.01                                       | 13534499         |
| 28  | 2.28                           | 1.84                      | 1.2                             | 3.65                     | 10.99                                      | 13608186         |
| 29  | 1.54                           | 1.04                      | 0.94                            | 2.58                     | 8.62                                       | 13198681         |
| 30  | 1.68                           | 1.3                       | 0.97                            | 2.82                     | 10.53                                      | 12890218         |
| 31  | 1.49                           | 1.07                      | 0.92                            | 2.44                     | 6.79                                       | 13869775         |
| 32  | 1.4                            | 0.9                       | 0.86                            | 2.39                     | 7.04                                       | 14477235         |

Table 5-4. Range Rate Error Statistics

| PRN | Range Rate Error RMS (mm/s) | 95% Range Rate Error (mm/s) | Max Range Rate Error (mm/s) | Samples Number |
|-----|-----------------------------|-----------------------------|-----------------------------|----------------|
| 1   | 1.26                        | 2.44                        | 80.63                       | 14052187       |
| 2   | 1.38                        | 2.67                        | 91.22                       | 14746530       |
| 3   | 1.24                        | 2.4                         | 42.03                       | 14492670       |
| 5   | 1.49                        | 2.87                        | 138.01                      | 13705483       |
| 6   | 1.27                        | 2.45                        | 127.42                      | 13992689       |
| 7   | 1.43                        | 2.71                        | 56.99                       | 12785499       |
| 8   | 1.68                        | 2.82                        | 137.5                       | 12745806       |
| 9   | 1.22                        | 2.37                        | 81.2                        | 13420474       |
| 10  | 1.21                        | 2.34                        | 50.9                        | 13119335       |
| 11  | 1.48                        | 2.76                        | 64.88                       | 12400095       |
| 12  | 1.46                        | 2.84                        | 48.5                        | 13853621       |
| 13  | 1.44                        | 2.78                        | 73.08                       | 13680614       |
| 14  | 1.32                        | 2.58                        | 71.14                       | 14068130       |
| 15  | 1.38                        | 2.68                        | 38.45                       | 12774922       |
| 16  | 1.42                        | 2.78                        | 42.67                       | 12821898       |

| PRN | Range Rate Error RMS (mm/s) | 95% Range Rate Error (mm/s) | Max Range Rate Error (mm/s) | Samples Number |
|-----|-----------------------------|-----------------------------|-----------------------------|----------------|
| 17  | 1.6                         | 2.88                        | 108.71                      | 14680566       |
| 18  | 1.31                        | 2.54                        | 20.09                       | 1035992        |
| 19  | 1.41                        | 2.73                        | 62.47                       | 14173046       |
| 20  | 1.36                        | 2.64                        | 35.3                        | 13245653       |
| 21  | 1.45                        | 2.8                         | 37.04                       | 13205506       |
| 22  | 1.38                        | 2.65                        | 54.91                       | 14190661       |
| 23  | 1.36                        | 2.57                        | 46.92                       | 13126629       |
| 24  | 2.03                        | 3.17                        | 138.62                      | 13868021       |
| 25  | 1.24                        | 2.41                        | 51.58                       | 14354151       |
| 26  | 1.24                        | 2.39                        | 57.04                       | 12795063       |
| 27  | 1.26                        | 2.43                        | 36.39                       | 13534499       |
| 28  | 1.63                        | 2.7                         | 133.37                      | 13608186       |
| 29  | 1.4                         | 2.68                        | 127.28                      | 13198681       |
| 30  | 1.27                        | 2.43                        | 115.89                      | 12890218       |
| 31  | 1.37                        | 2.58                        | 62.37                       | 13869775       |
| 32  | 1.22                        | 2.36                        | 52.84                       | 14477235       |

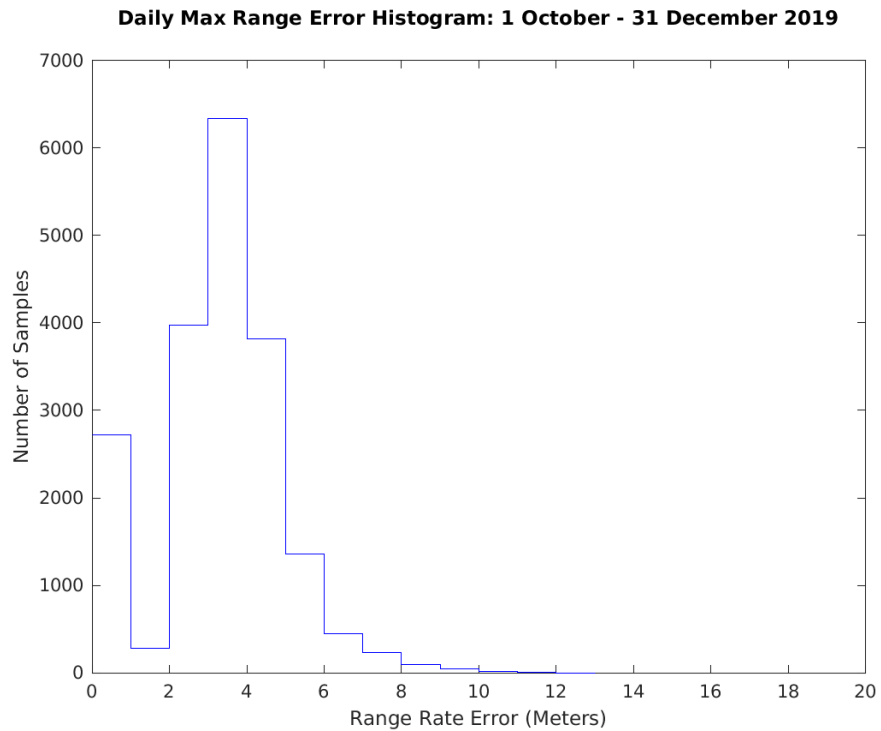
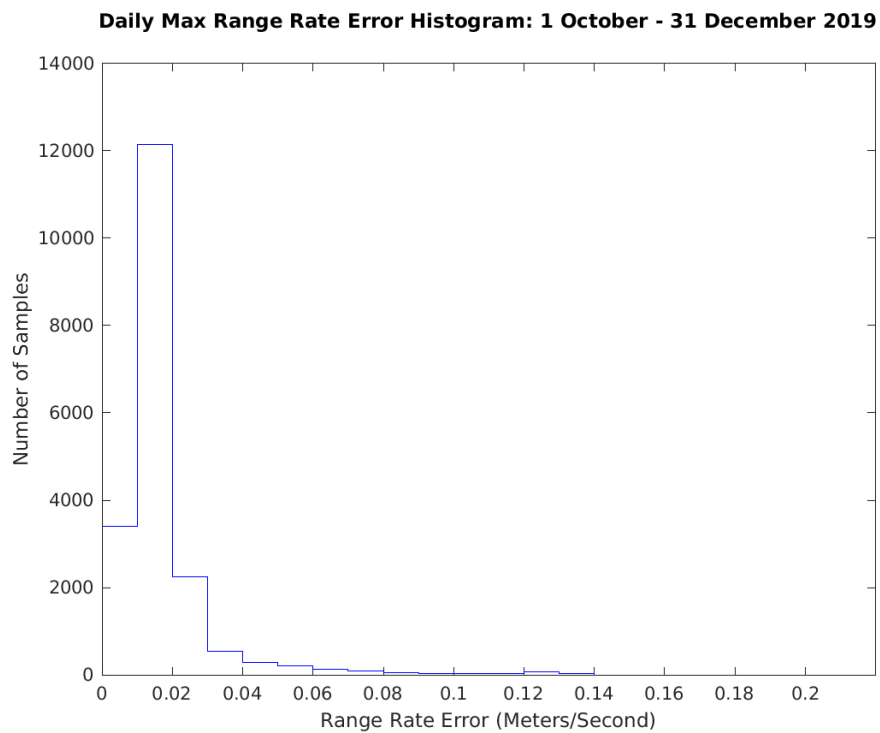
**Table 5-5. Range Acceleration Error Statistics**

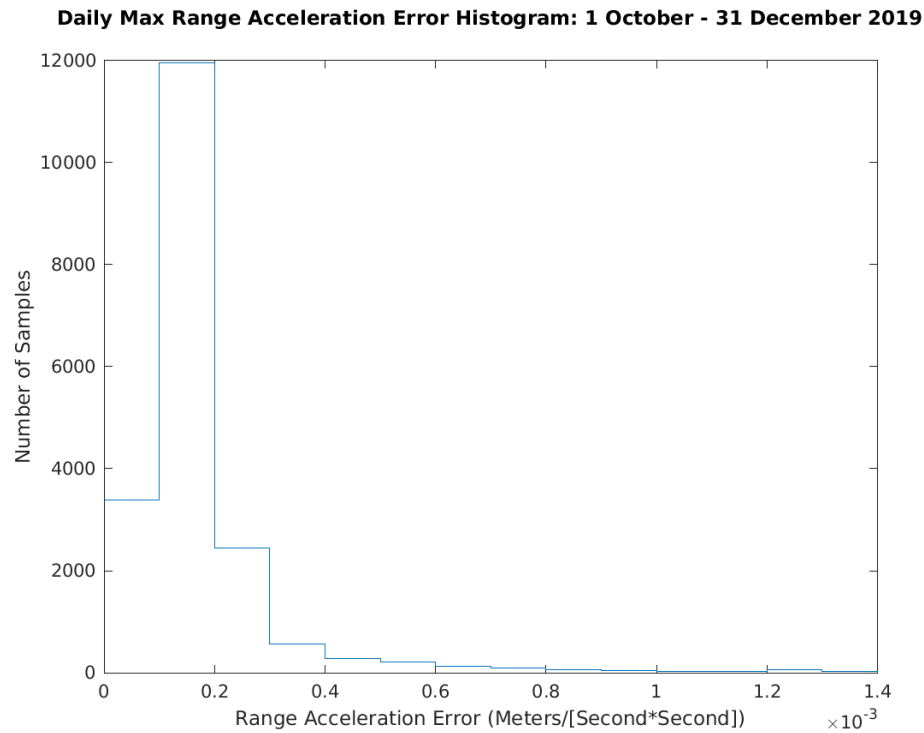
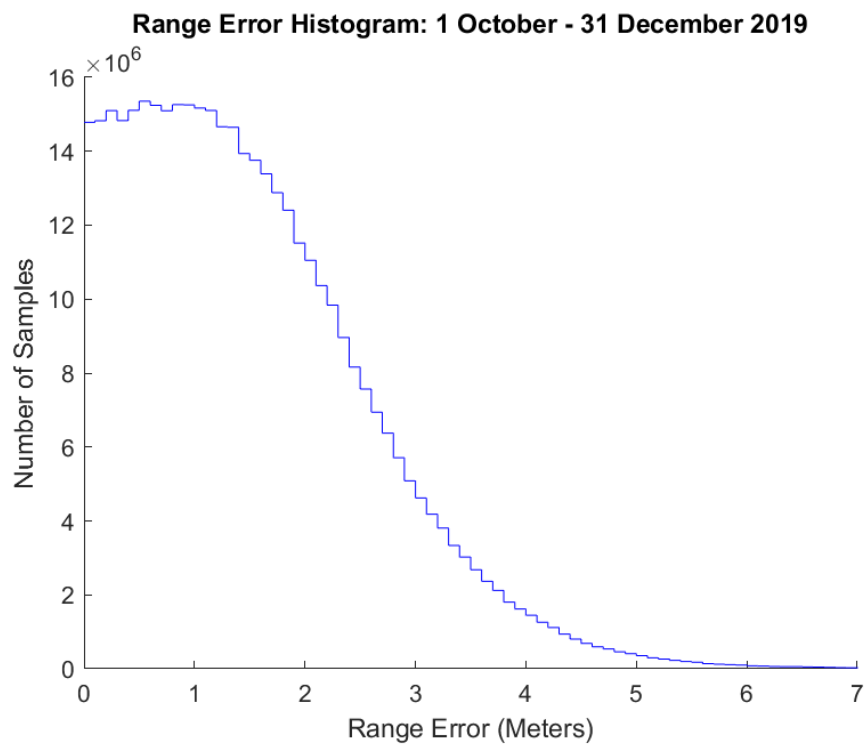
| PRN | Rate Acceleration Error RMS (um/s^2) | 95% Range Acceleration Error (um/s^2) | Max Range Acceleration Error (um/s^2) | Samples (Number) |
|-----|--------------------------------------|---------------------------------------|---------------------------------------|------------------|
| 1   | 10.09                                | 17.76                                 | 760                                   | 14052187         |
| 2   | 10.22                                | 21.86                                 | 920                                   | 14746530         |
| 3   | 10.06                                | 18.18                                 | 420                                   | 14492670         |
| 5   | 10.64                                | 25.03                                 | 1110                                  | 13705483         |
| 6   | 10.14                                | 17.13                                 | 1280                                  | 13992689         |
| 7   | 10.33                                | 23.09                                 | 570                                   | 12785499         |
| 8   | 13.11                                | 24.87                                 | 1360                                  | 12745806         |
| 9   | 10.05                                | 18.46                                 | 800                                   | 13420474         |
| 10  | 10.11                                | 16.98                                 | 470                                   | 13119335         |
| 11  | 10.63                                | 23.94                                 | 640                                   | 12400095         |
| 12  | 10.08                                | 24.37                                 | 470                                   | 13853621         |
| 13  | 10.68                                | 24.23                                 | 740                                   | 13680614         |
| 14  | 10.13                                | 21.97                                 | 710                                   | 14068130         |
| 15  | 10.0                                 | 23.23                                 | 360                                   | 12774922         |
| 16  | 10.04                                | 24.6                                  | 430                                   | 12821898         |
| 17  | 11.85                                | 24.82                                 | 1090                                  | 14680566         |
| 18  | 10.0                                 | 20.22                                 | 200                                   | 1035992          |
| 19  | 10.17                                | 23.09                                 | 610                                   | 14173046         |
| 20  | 10.03                                | 22.16                                 | 360                                   | 13245653         |
| 21  | 10.05                                | 24.34                                 | 370                                   | 13205506         |
| 22  | 10.03                                | 23.2                                  | 550                                   | 14190661         |

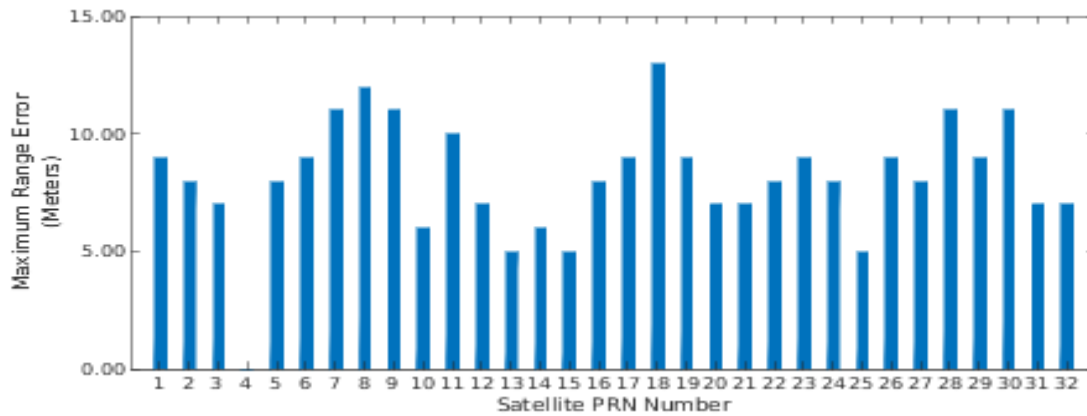
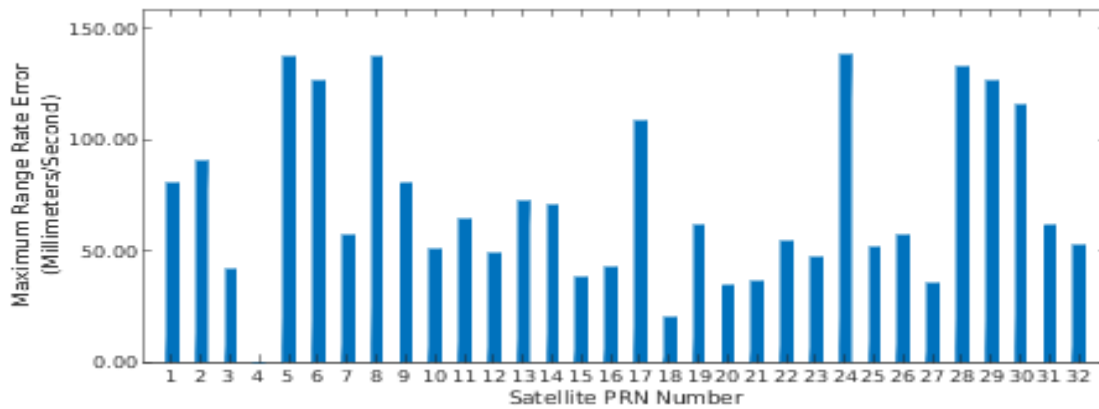
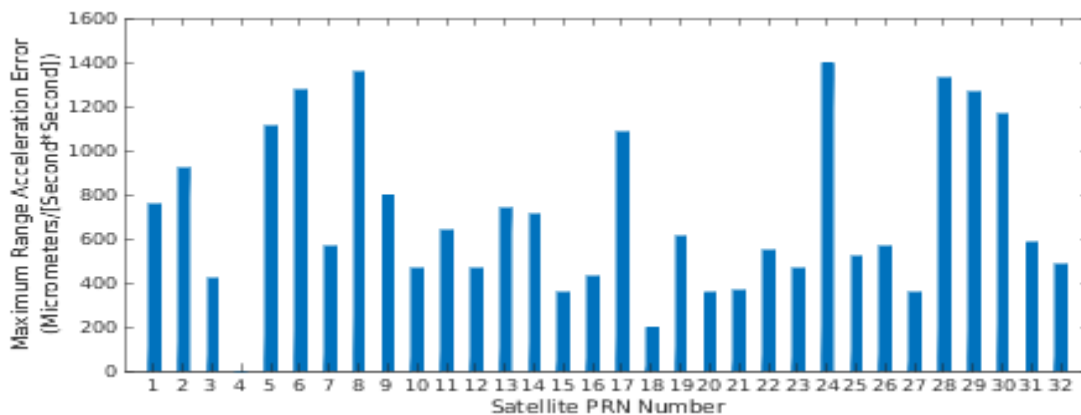


| <b>PRN</b> | <b>Rate<br/>Acceleration<br/>Error RMS<br/>(um/s^2)</b> | <b>95% Range<br/>Acceleration Error<br/>(um/s^2)</b> | <b>Max Range<br/>Acceleration<br/>Error<br/>(um/s^2)</b> | <b>Samples<br/>(Number)</b> |
|------------|---|--|--|-----------------------------|
| 23         | 10.11   | 21.27  | 470  | 13126629                    |
| 24         | 17.2  | 26.57  | 1400   | 13868021                    |
| 25         | 10.0  | 18.13  | 520  | 14354151                    |
| 26         | 10.08   | 17.52  | 570  | 12795063                    |
| 27         | 10.0  | 17.46  | 360  | 13534499                    |
| 28         | 12.95   | 22.74  | 1330   | 13608186                    |
| 29         | 10.26   | 22.96  | 1270   | 13198681                    |
| 30         | 10.05   | 18.54  | 1170   | 12890218                    |
| 31         | 10.29   | 22.48  | 590  | 13869775                    |
| 32         | 10.02   | 17.38  | 490  | 14477235                    |

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 PRN18 with an error of 12.680 meters. Satellite PRN15 had the lowest maximum range error of 5.270 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.*

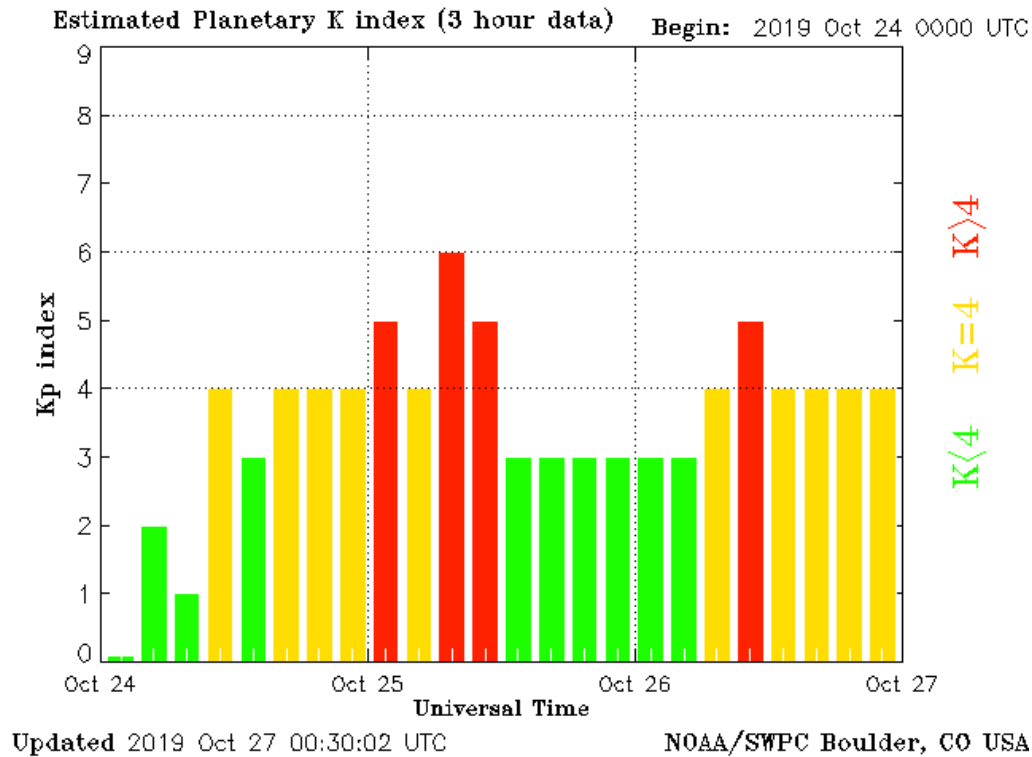
*An instrument called a magnetometer may also measure the disturbance of the geomagnetic field. At NOAA's operations center magnetometer data is received from dozens of observatories in one-minute intervals. The data is received at or near to 'real-time' and allows NOAA to keep track of the current state 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 for the actual geomagnetic data for this reporting period).

**Figure 6-1. K-Index for October 25, 2019**



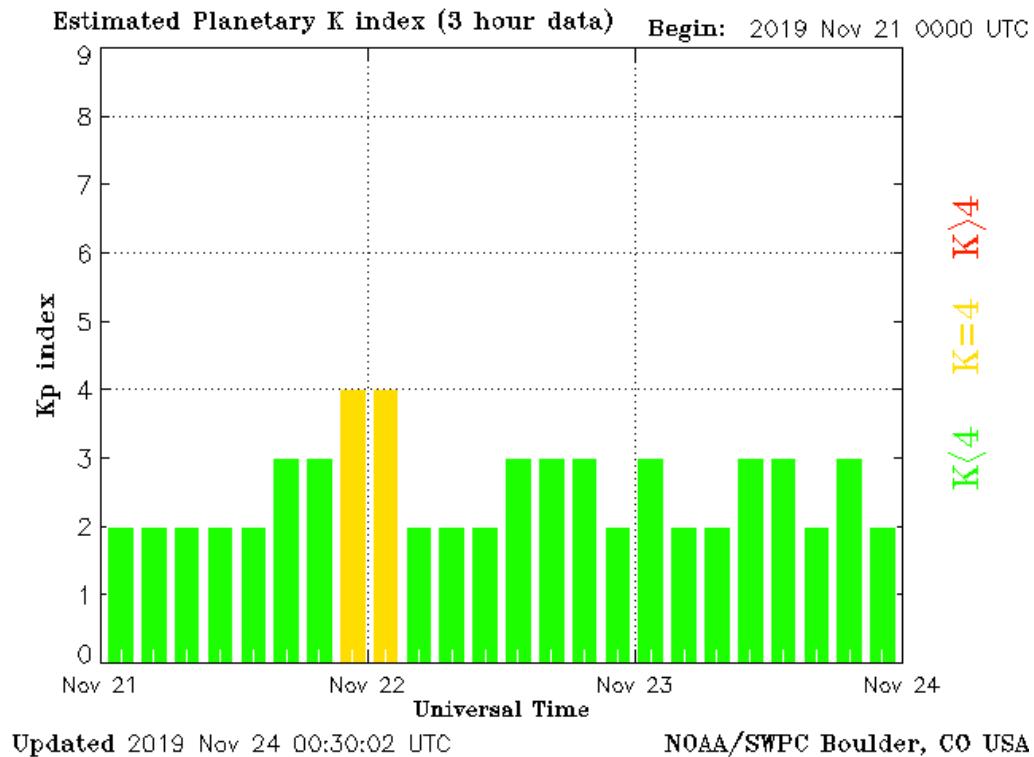
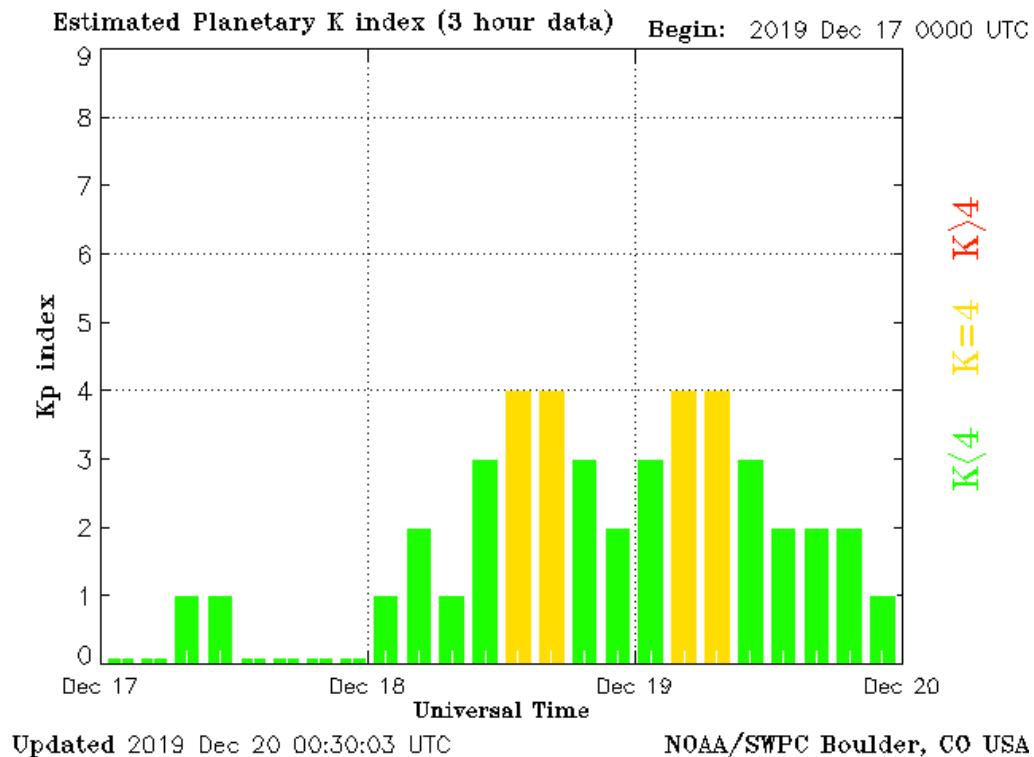
**Figure 6-2. K-Index for November 22, 2019****Figure 6-3. K-Index for December 19, 2019**

Table 6-1 shows the position accuracy information for the quarter's worst-case storm day, October 25, 2019 (see Figure 6-1). The GPS SPS performance met all requirements during all storms that occurred during this quarter.

**Table 6-1. Horizontal & Vertical Accuracy Statistics for**

| <b>Site</b>       | <b>95%<br/>Horizontal<br/>(Meters)</b> | <b>95%<br/>Vertical<br/>(Meters)</b> | <b>MAX<br/>Horizontal<br/>(Meters)</b> | <b>MAX<br/>Vertical<br/>(Meters)</b> |
|-------------------|--|--------------------------------------|--|--------------------------------------|
| Albuquerque       | 1.206                                  | 3.668                                | 1.463                                  | 5.612                                |
| Anchorage         | 1.18                                   | 3.148                                | 2.258                                  | 3.98                                 |
| Atlanta           | 1.661                                  | 2.865                                | 2.261                                  | 3.899                                |
| Barrow            | 0.991                                  | 3.702                                | 1.772                                  | 5.678                                |
| Bethel            | 1.101                                  | 3.19                                 | 1.504                                  | 3.709                                |
| Billings          | 1.474                                  | 3.197                                | 1.853                                  | 4.143                                |
| Boston            | 1.913                                  | 2.859                                | 2.609                                  | 3.833                                |
| Cleveland         | 1.965                                  | 3.14                                 | 2.431                                  | 3.99                                 |
| Cold Bay          | 1.471                                  | 2.877                                | 2.173                                  | 3.579                                |
| Fairbanks         | 0.997                                  | 3.222                                | 1.658                                  | 4.056                                |
| Gander            | 1.96                                   | 2.915                                | 2.26                                   | 4.298                                |
| Honolulu          | 3.176                                  | 5.139                                | 3.973                                  | 6.817                                |
| Houston           | 1.627                                  | 3.641                                | 2.189                                  | 5.341                                |
| Iqaluit           | 1.498                                  | 3.628                                | 4.457                                  | 6.63                                 |
| Juneau            | 1.05                                   | 2.957                                | 1.91                                   | 3.732                                |
| Kansas City       | 1.738                                  | 3.05                                 | 2.169                                  | 3.876                                |
| Los Angeles       | 1.494                                  | 4.661                                | 3.247                                  | 6.583                                |
| Merida            | 2.264                                  | 3.782                                | 2.813                                  | 4.799                                |
| Miami             | 1.734                                  | 3.231                                | 2.042                                  | 4.1                                  |
| Minneapolis       | 1.506                                  | 3.109                                | 1.729                                  | 3.609                                |
| Oakland           | 1.55                                   | 4.399                                | 2.037                                  | 6.645                                |
| Salt Lake City    | 1.41                                   | 3.719                                | 1.636                                  | 5.539                                |
| San Jose Del Cabo | 2.005                                  | 4.541                                | 2.607                                  | 7.898                                |
| San Juan          | 1.772                                  | 3.119                                | 2.589                                  | 4.144                                |
| Seattle           | 1.5                                    | 3.304                                | 1.921                                  | 4.281                                |
| Tapachula         | 2.277                                  | 4.349                                | 2.794                                  | 5.143                                |
| Washington DC     | 1.776                                  | 3.223                                | 2.153                                  | 3.695                                |



## 7. IGS DATA

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

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

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

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

**Table 7-1. Selected IGS Sites Information**

| <b>ID</b> | <b>City</b>  | <b>Country</b> |
|-----------|--------------|----------------|
| BOGT      | Bogota       | Colombia       |
| GLPS      | Puerto Ayora | Ecuador        |
| GUAM      | Dededo       | Guam           |
| IISC      | Bangalore    | India          |
| KIRU      | Kiruna       | Sweden         |
| KOUR      | Kourou       | French Guyana  |

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<sup>1</sup> 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

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

Figure 7-1. Selected IGS Site Locations

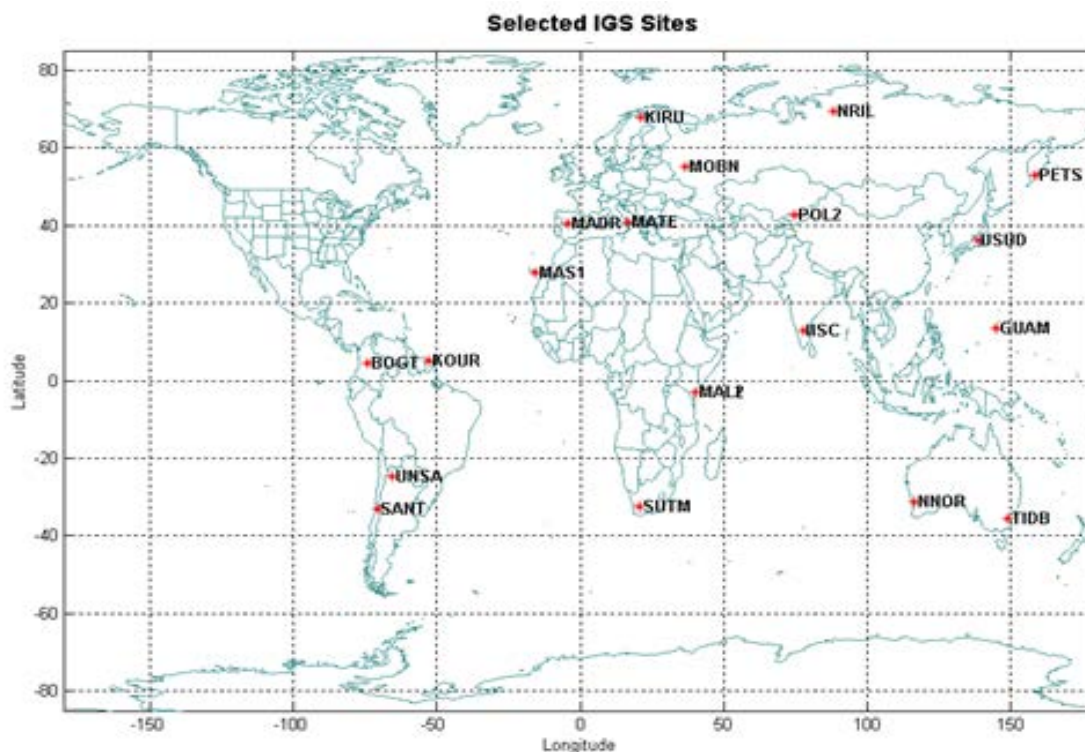
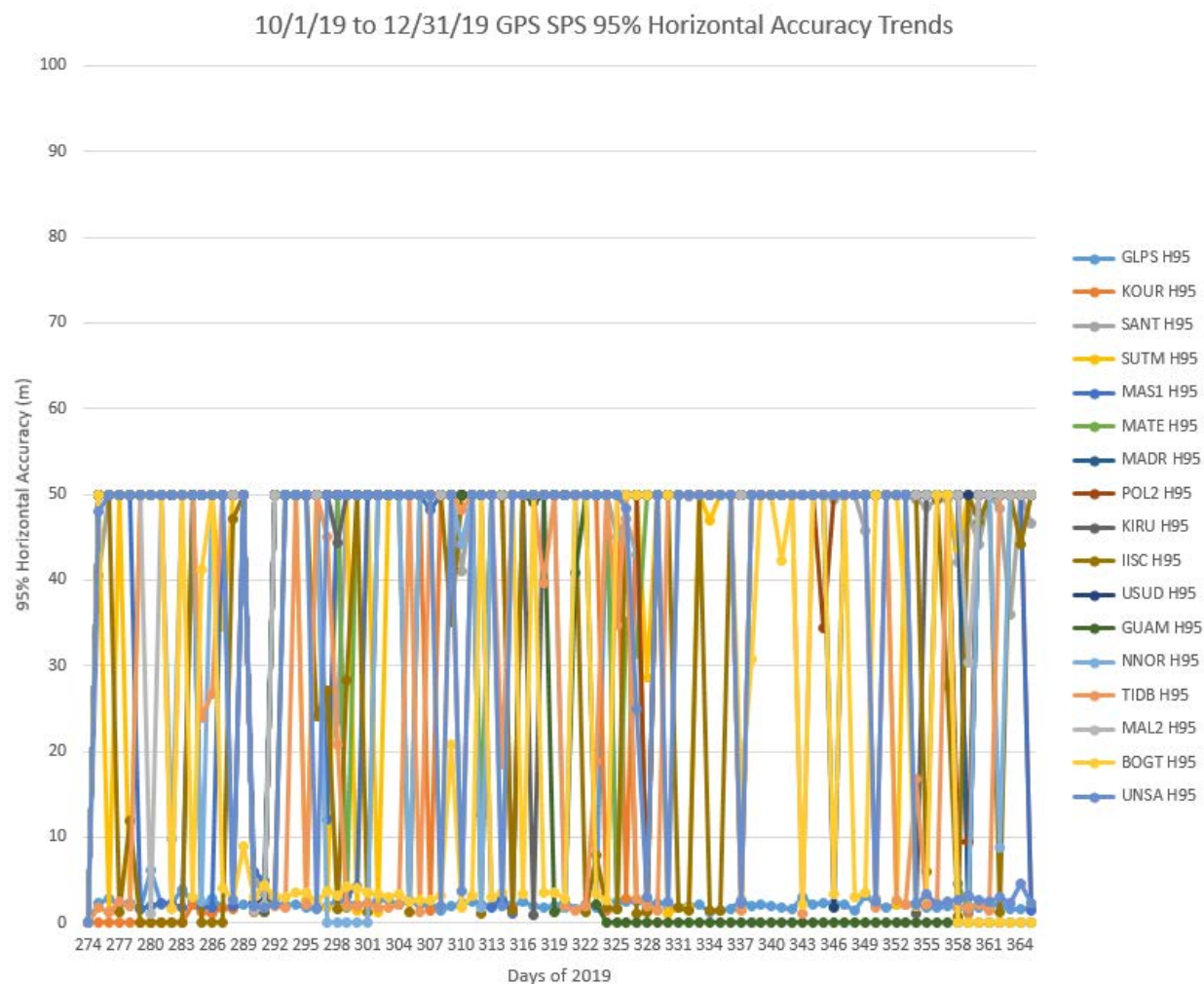


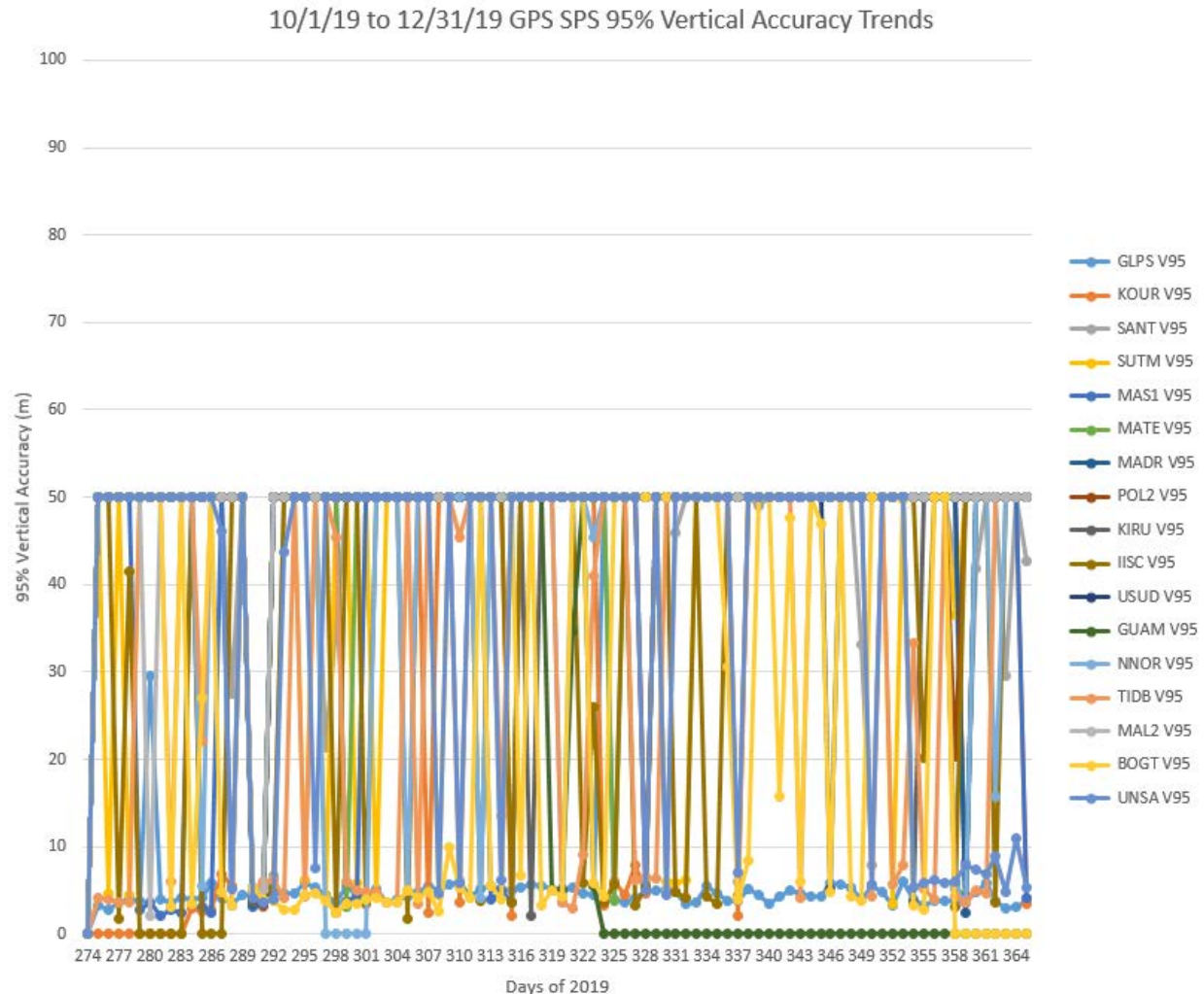
Table 7-2. GPS SPS Performance at Selected High Rate IGS Sites

| Site | 95%<br>Horizontal<br>Error<br>(Meters) | 95%<br>Vertical<br>Error<br>(Meters) | 99.99%<br>Horizontal<br>Error<br>(Meters) | 99.99%<br>Vertical<br>Error<br>(Meters) | Percent Data<br>Available<br>(%) |
|------|--|--------------------------------------|---|---|----------------------------------|
| BOGT | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 39.84                            |
| GLPS | 2.23                                   | 4.79                                 | 50.01                                     | 50.01                                   | 54.61                            |
| GUAM | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 20.28                            |
| IISC | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 11.44                            |
| KIRU | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 18.55                            |
| KOUR | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 24.70                            |
| MADR | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 26.38                            |
| MAL2 | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 18.74                            |
| MAS1 | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 22.51                            |
| MATE | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 17.52                            |
| MOBN | 0                                      | 0                                    | 0   | 0                                       | 0.00                             |
| NNOR | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 37.99                            |
| NRIL | 0                                      | 0                                    | 0   | 0                                       | 0.00                             |
| PETS | 0                                      | 0                                    | 0   | 0                                       | 0.00                             |
| POL2 | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 14.70                            |
| SANT | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 56.36                            |
| SUTM | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 16.46                            |

| Site | 95%<br>Horizontal<br>Error<br>(Meters) | 95%<br>Vertical<br>Error<br>(Meters) | 99.99%<br>Horizontal<br>Error<br>(Meters) | 99.99%<br>Vertical<br>Error<br>(Meters) | Percent Data<br>Available<br>(%) |
|------|--|--------------------------------------|---|---|----------------------------------|
| TIDB | 46.97                                  | 50.01                                | 50.01                                     | 50.01                                   | 58.28                            |
| UNSA | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 52.67                            |
| USUD | 50.01                                  | 50.01                                | 50.01                                     | 50.01                                   | 28.12                            |

**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 99.772% at Honolulu. The minimum percent of time spent in RNP 0.3 mode was 99.996% at Kansas City. The maximum 99% HPL value was 152.241 meters at Gander.

**Table 8-1. RAIM Site Statistics**

| <b>City</b>     | <b>99% HPL<br/>(Meters)</b> | <b>Percentage<br/>RNP 0.1<br/>(%)</b> | <b>Percentage<br/>RNP 0.3<br/>(%)</b> |
|-----------------|-----------------------------|---------------------------------------|---------------------------------------|
| Arcata          | 112.227                     | 99.98352                              | 100                                   |
| Atlantic City-a | 113.315                     | 100                                   | 100                                   |
| Oklahoma City   | 111.683                     | 99.96713                              | 100                                   |
| Albuquerque     | 120.184                     | 99.97808                              | 100                                   |
| Anchorage       | 129.503                     | 99.9694                               | 100                                   |
| Atlanta         | 106.667                     | 99.9887                               | 100                                   |
| Barrow          | 111.692                     | 99.99263                              | 100                                   |
| Bethel          | 136.333                     | 99.97672                              | 100                                   |
| Billings        | 113.518                     | 99.97011                              | 99.99969                              |
| Boston          | 111.003                     | 99.97961                              | 100                                   |
| Cleveland       | 112.464                     | 99.98537                              | 100                                   |
| Cold Bay        | 139.066                     | 99.86471                              | 100                                   |
| Fairbanks       | 131.015                     | 99.87887                              | 99.99684                              |
| Gander          | 152.241                     | 99.96688                              | 100                                   |
| Honolulu        | 148.666                     | 99.77233                              | 100                                   |
| Houston         | 99.73                       | 99.98695                              | 100                                   |
| Iqaluit         | 133.91                      | 99.97934                              | 100                                   |
| Juneau          | 139.215                     | 99.98979                              | 100                                   |
| Kansas City     | 107.249                     | 99.965                                | 99.9963                               |
| Kotzebue        | 122.5                       | 99.99599                              | 100                                   |
| Los Angeles     | 96.65                       | 99.97967                              | 100                                   |
| Merida          | 89.137                      | 99.9791                               | 100                                   |
| Miami           | 120.722                     | 99.99287                              | 100                                   |

| <b>City</b>       | <b>99% HPL<br/>(Meters)</b> | <b>Percentage<br/>RNP 0.1<br/>(%)</b> | <b>Percentage<br/>RNP 0.3<br/>(%)</b> |
|-------------------|-----------------------------|---------------------------------------|---------------------------------------|
| Minneapolis       | 124.874                     | 99.79324                              | 100                                   |
| Oakland           | 117.021                     | 99.96466                              | 100                                   |
| Salt Lake City    | 117.374                     | 99.98319                              | 100                                   |
| San Jose Del Cabo | 87.153                      | 99.98841                              | 100                                   |
| San Juan          | 83.829                      | 100                                   | 100                                   |
| Seattle           | 120.217                     | 99.9746                               | 100                                   |
| Tapachula         | 96.912                      | 99.98155                              | 100                                   |
| Washington DC     | 111.355                     | 99.97379                              | 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 1 October and 31 December 2019.

Figure 8-1. RAIM RNP 0.1 Coverage

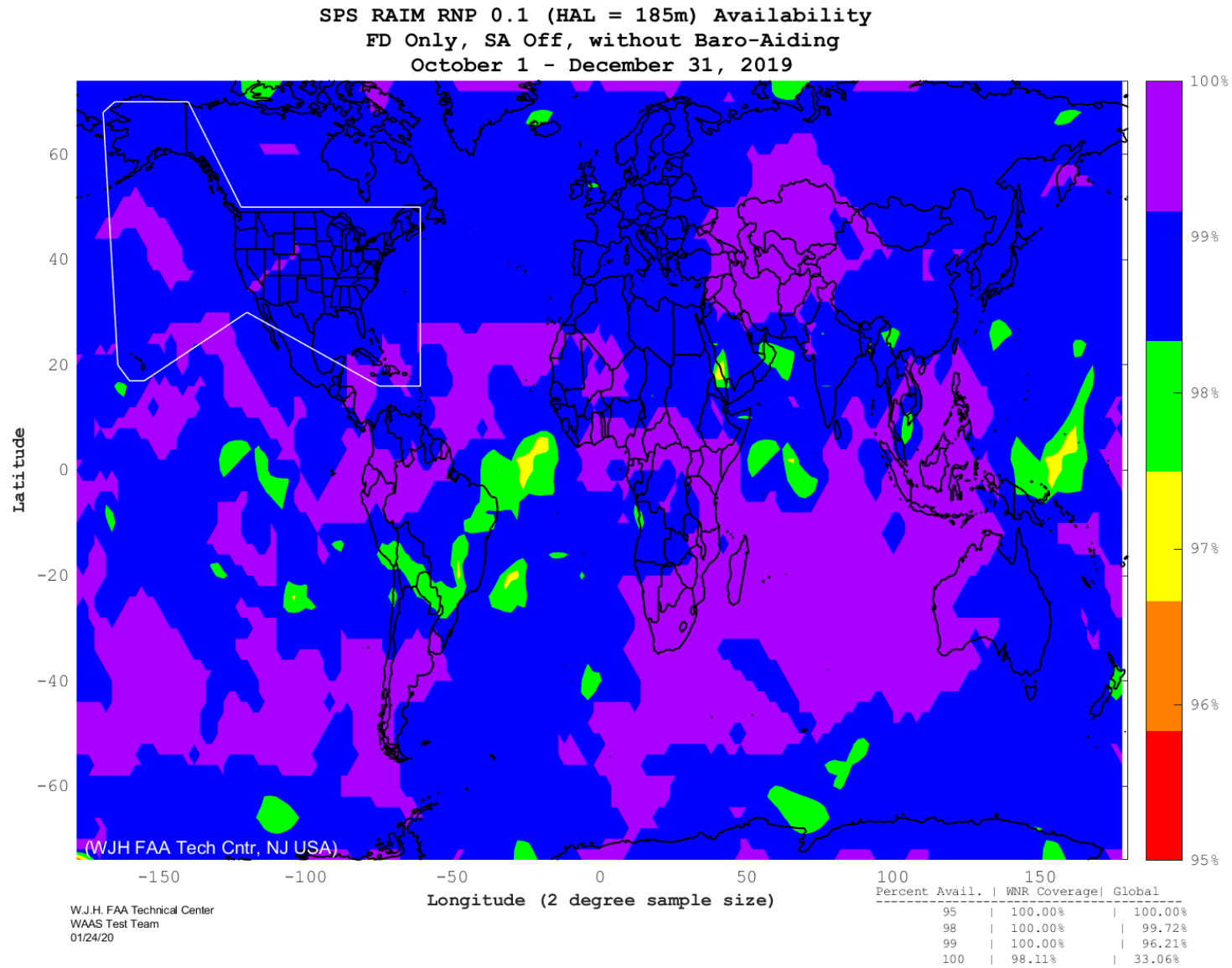




Figure 8-2. RAIM RNP 0.3 Coverage

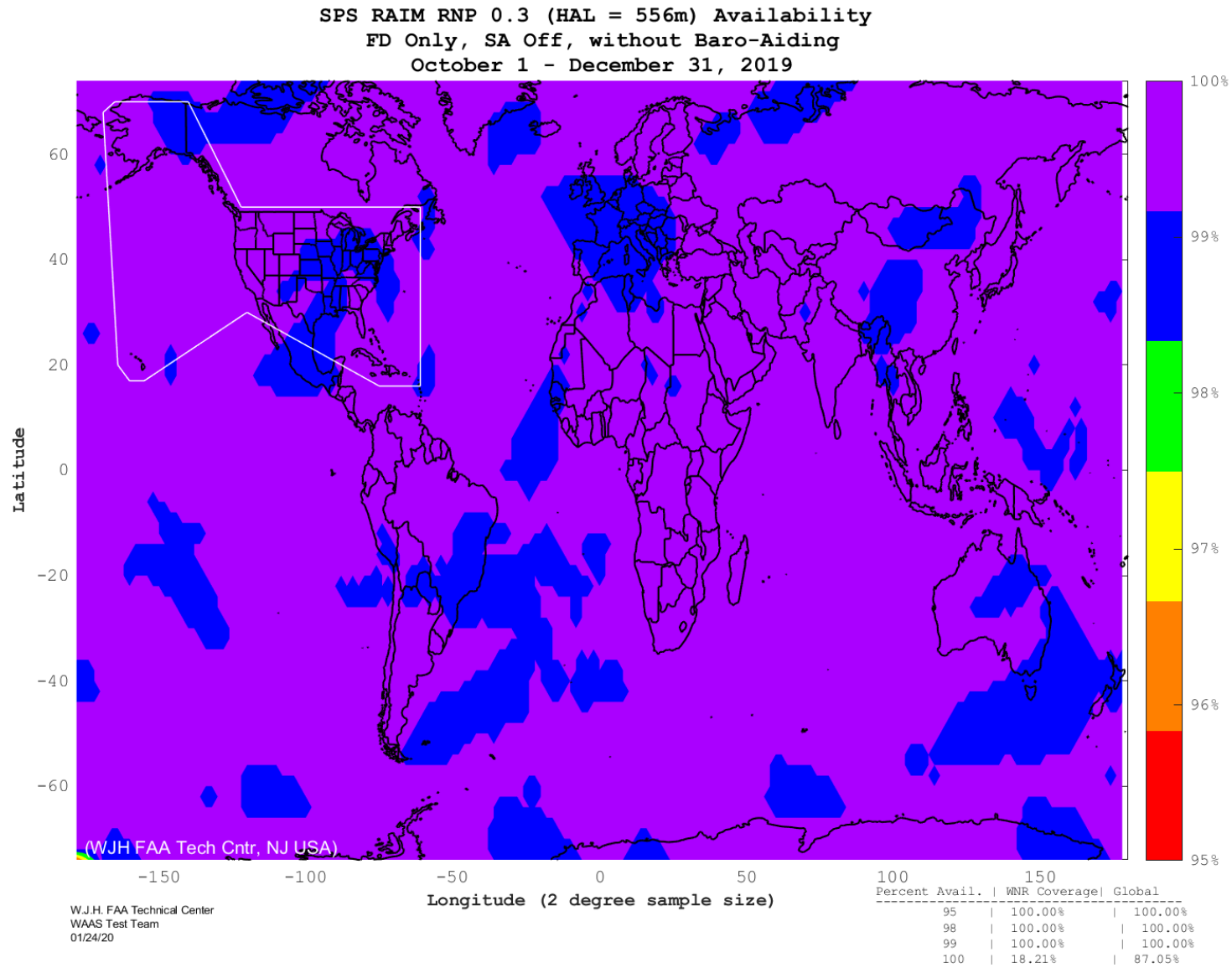
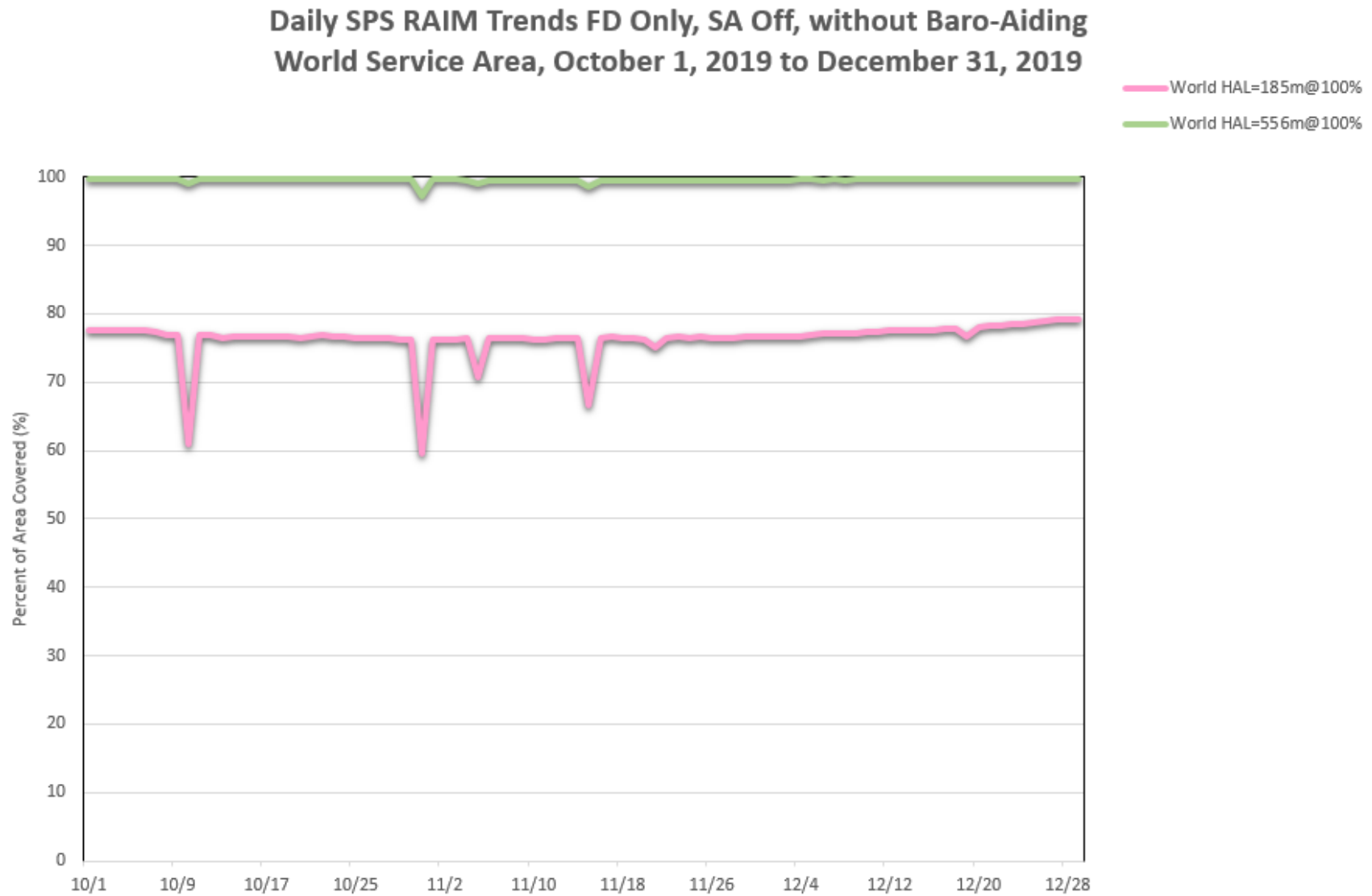


Figure 8-3. RAIM World Wide Coverage Trend



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

**Daily SPS RAIM Trends FD Only, SA Off, without Baro-Aiding  
World Service Area, October 1, 2019 to December 31, 2019**



### **8.3 RAIM Airport Analysis**

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

Figure 8-5. RAIM RNP 0.1 Airport Availability

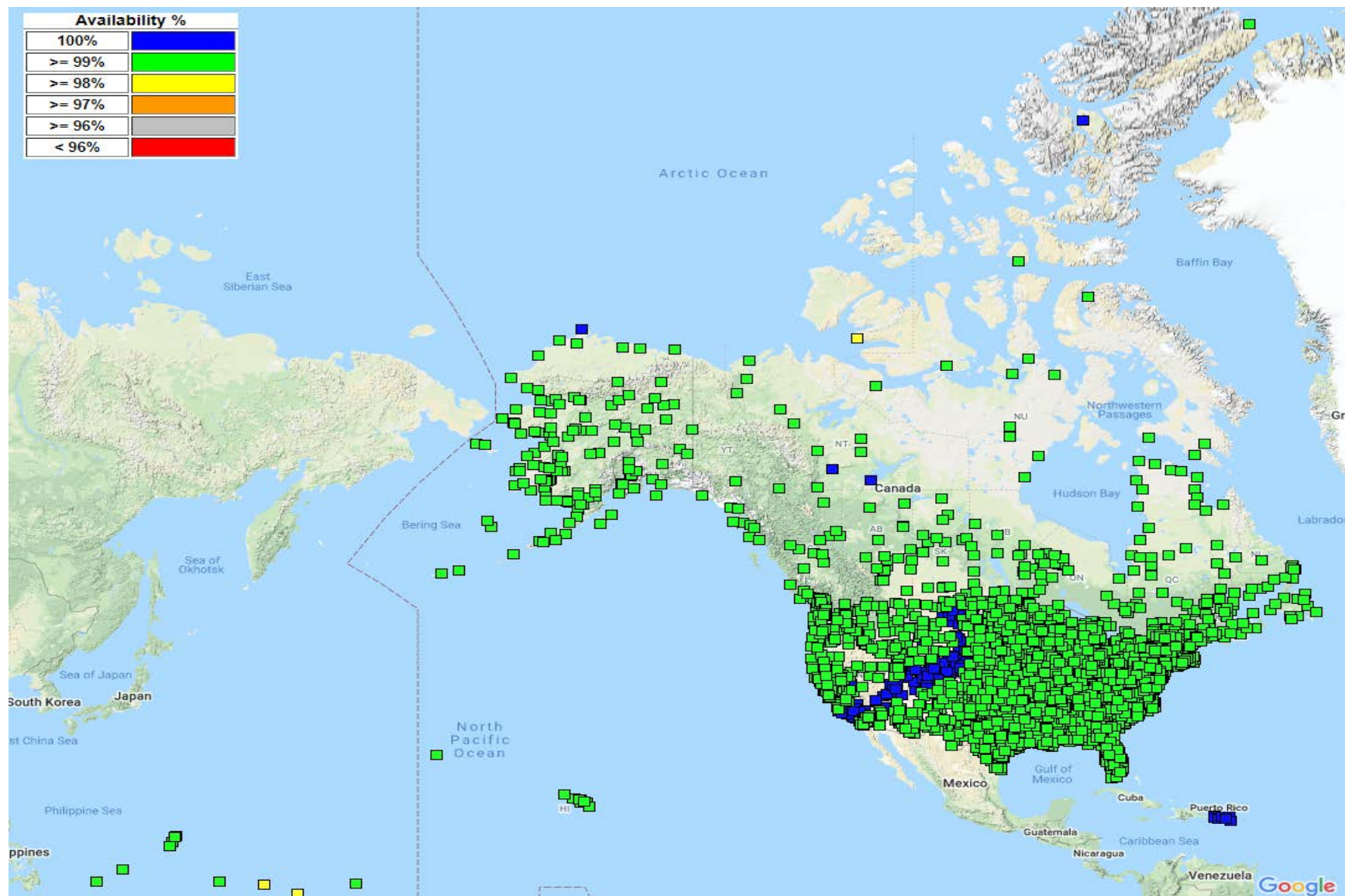




Figure 8-6. RAIM RNP 0.3 Airport Availability

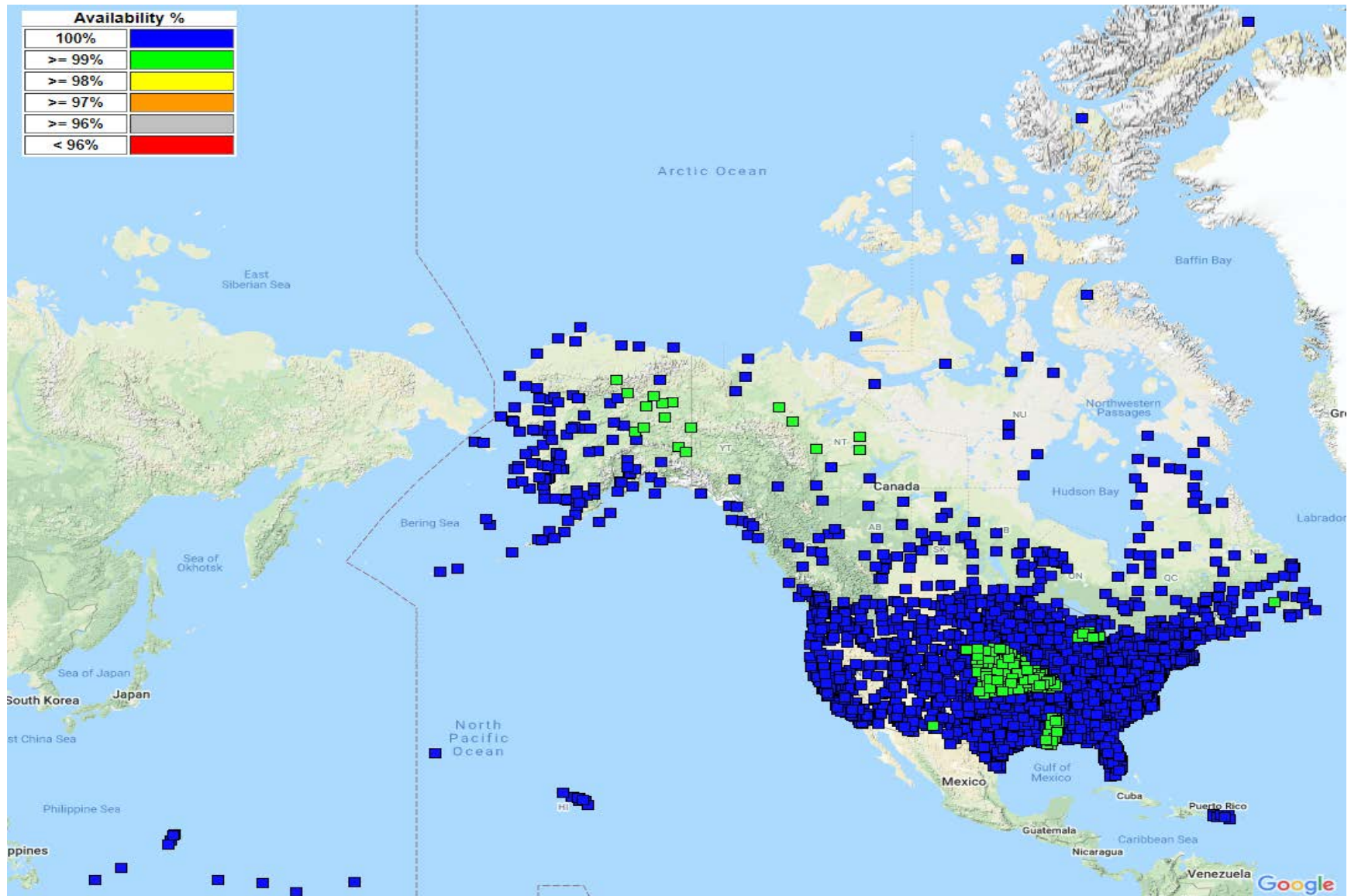


Figure 8-7 and Figure 8-8 respectively show the number of RAIM RNP 0.1 and RAIM RNP 0.3 outages for every airport in the U.S. and Canada that have a RNAV (GPS) published approach or better.

Figure 8-7. RAIM RNP 0.1 Airport Outages

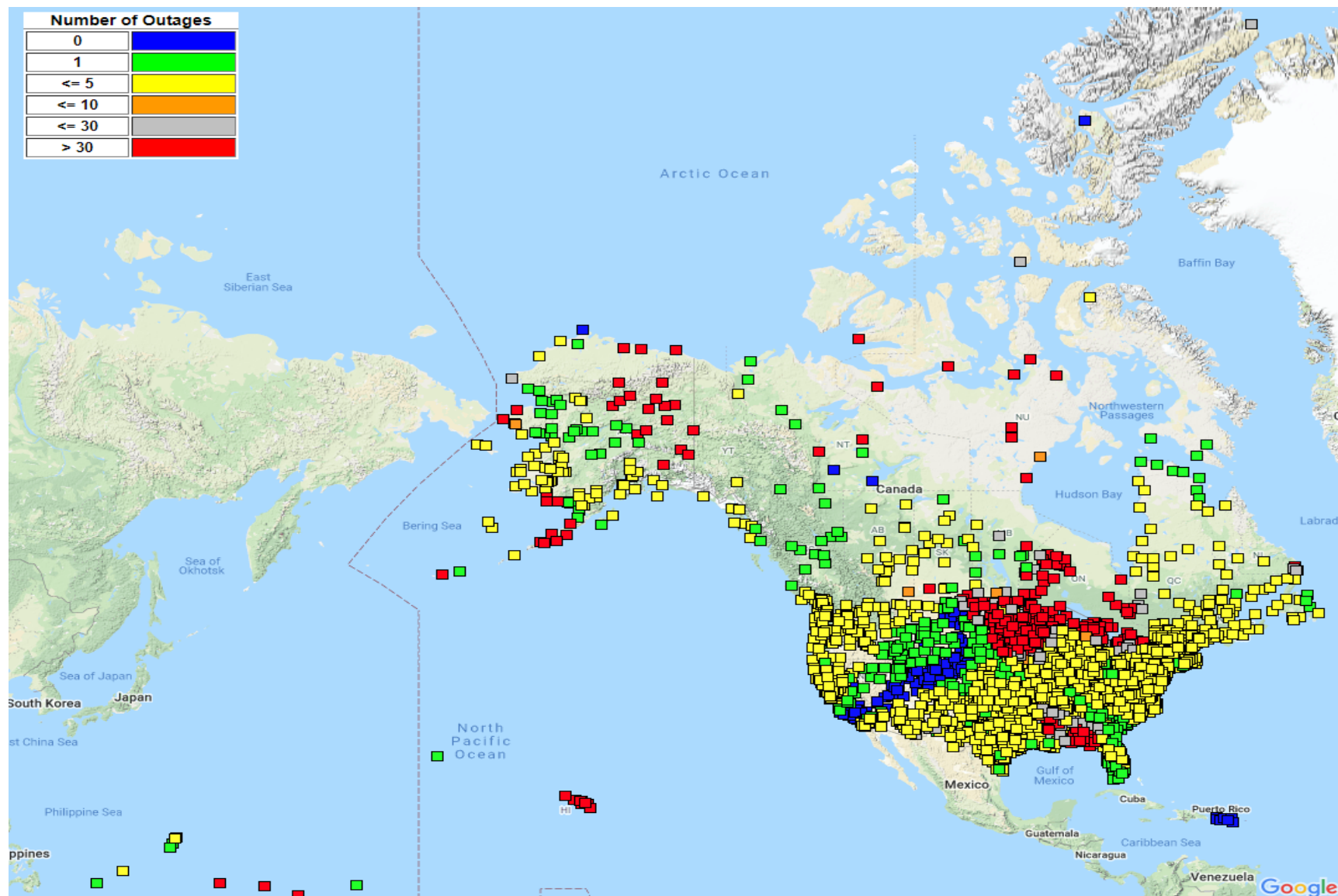
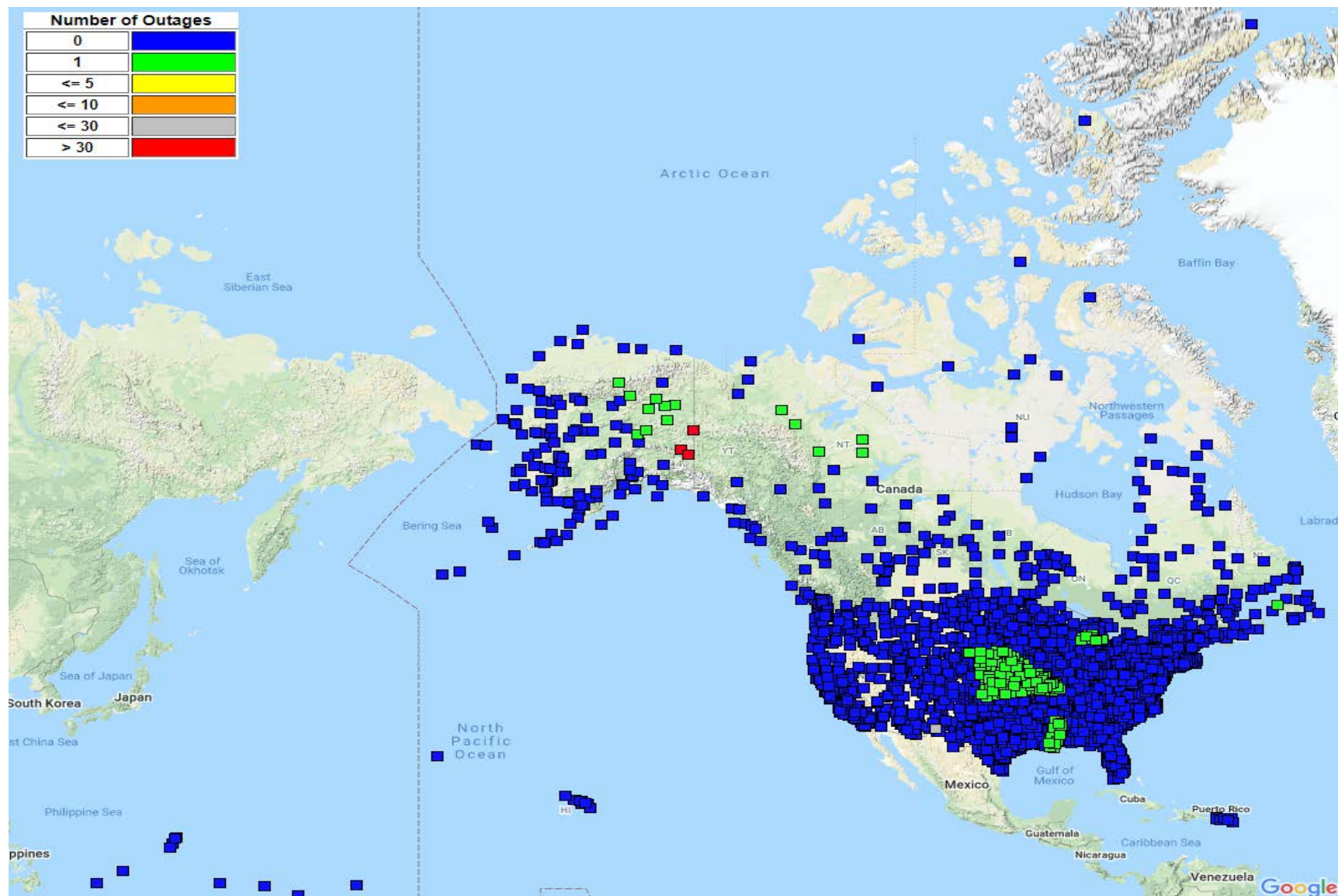




Figure 8-8. RAIM RNP 0.3 Airport Outages



## 9. GPS TEST NOTAMS SUMMARY

### 9.1 GPS Test NOTAMs Issued

GPS test NOTAMs were not evaluated for this quarter.

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

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

The assumptions being validated are:

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

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

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

The assumption is valid if a 5.33 scaling of the standard deviation across all satellites is within the a priori. Three months of data from October 1 to December 31, 2019 is presented. Only data points in which GPS is healthy and valid precise data is available are considered. There was maintenance on PRN24 on 10/10/19, PRN5 on 10/31/19, PRN12 on 11/15/19, PRN14 on 11/21/19, and PRN11 on 12/19/19. PRN2, PRN3, and PRN29 were set unusable with reference on 10/03/19, 10/28/19, and 11/04/19 respectively. In addition, PRN18 was set unusable with no reference on 10/02/19 and 10/04/19 and later decommissioned on 10/07/19. 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 NSTB ACY 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  $\text{error} = \text{broadcast ECEF} - \text{precise ECEF}$ . 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  $\pm 13.9$ -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  $\pm 5$ . Annotations are provided for any instances beyond that range.

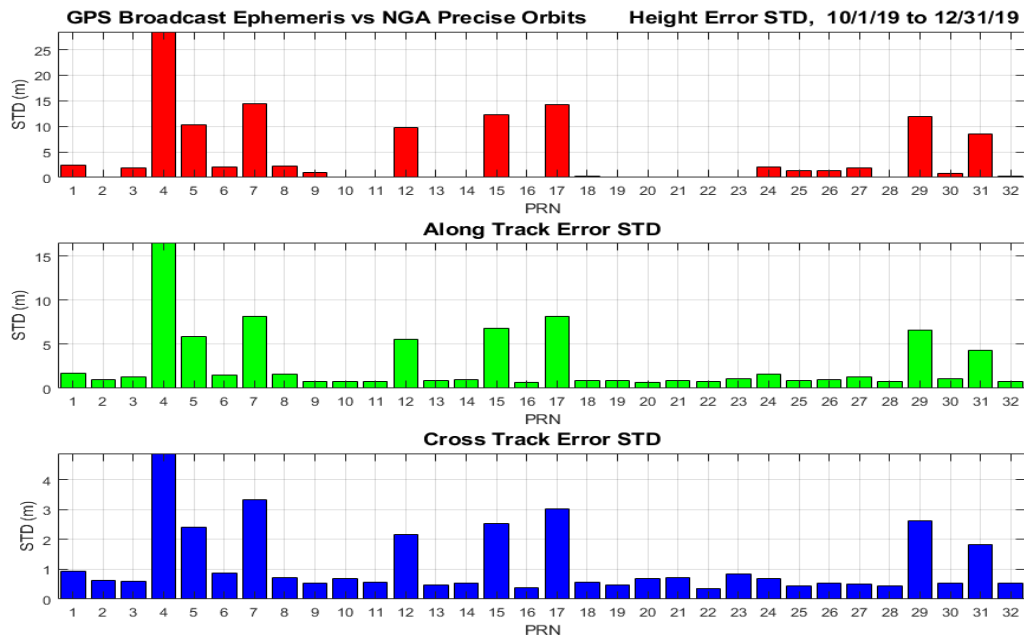
Errors larger than 3 times URA (IAURA) for C/A and 4 times URA (IURA) for CNAV were investigated.

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

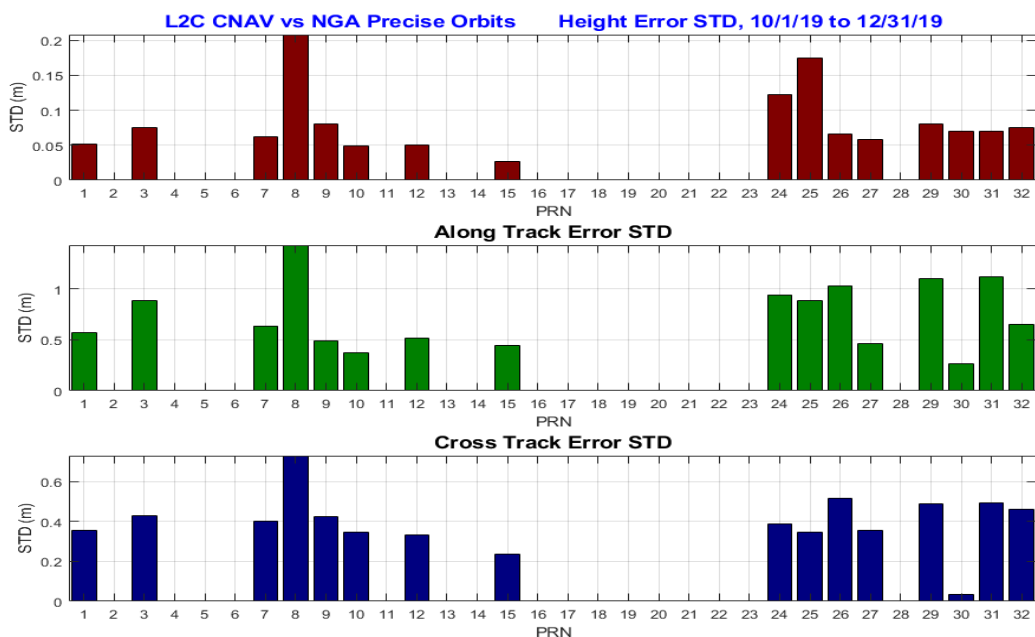
Figure 10-117 through Figure 10-162 are the timelines of the URA (IAURA) normalized range error. Missing data points are in red and are NANUs for the C/A data. The large number of red points in the CNAV data are the points where the satellites are out of view of ACY.

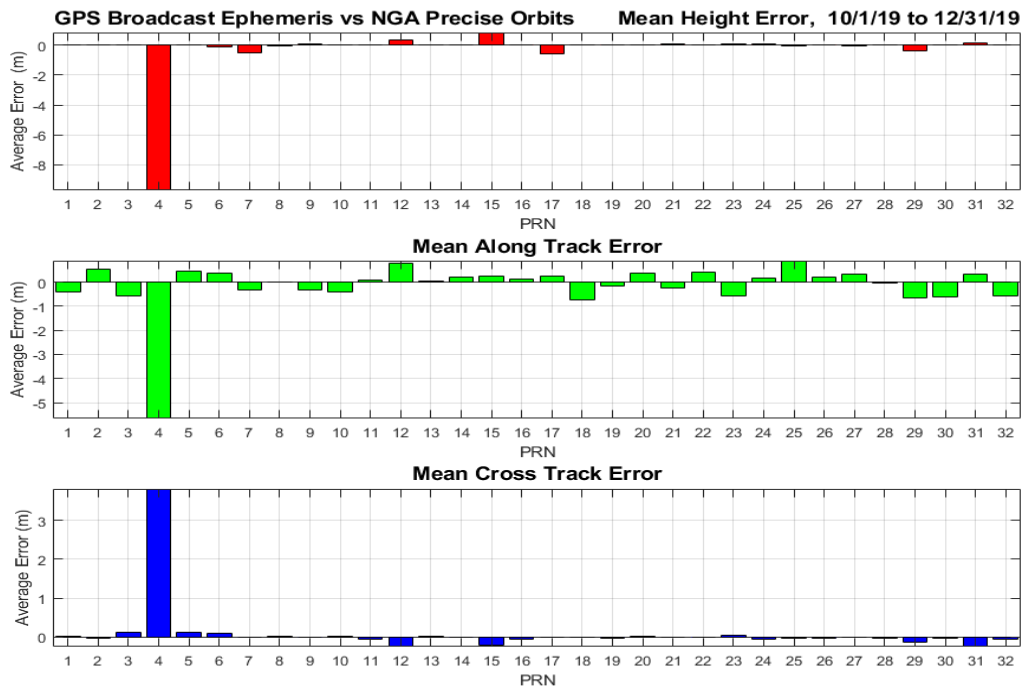
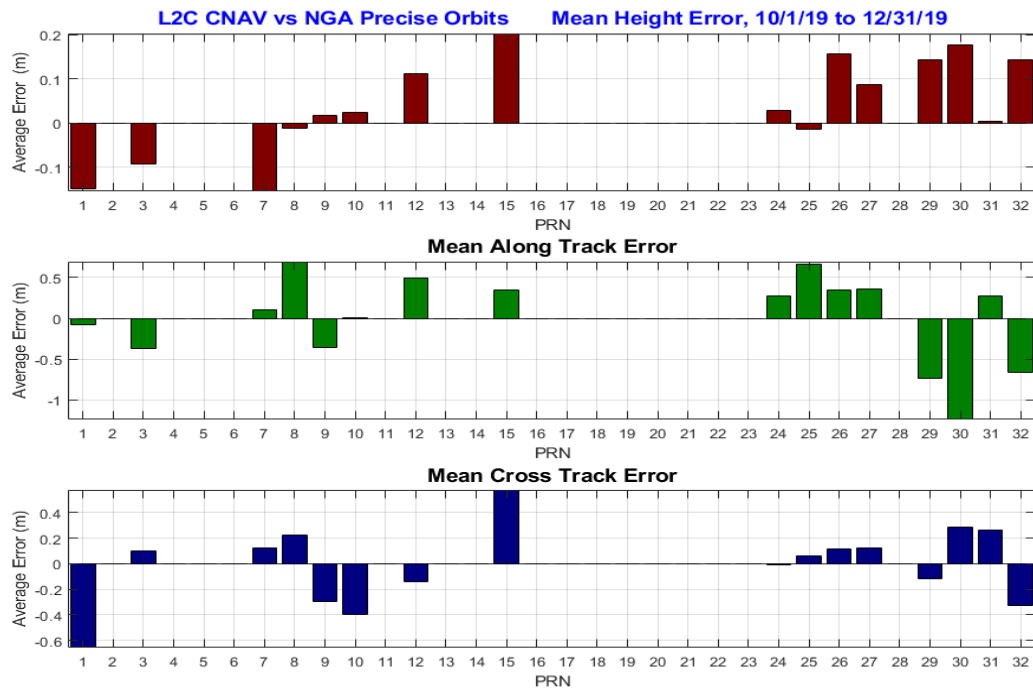
## 10.1 GPS Broadcast Orbit Accuracy Standard Deviation Plots

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



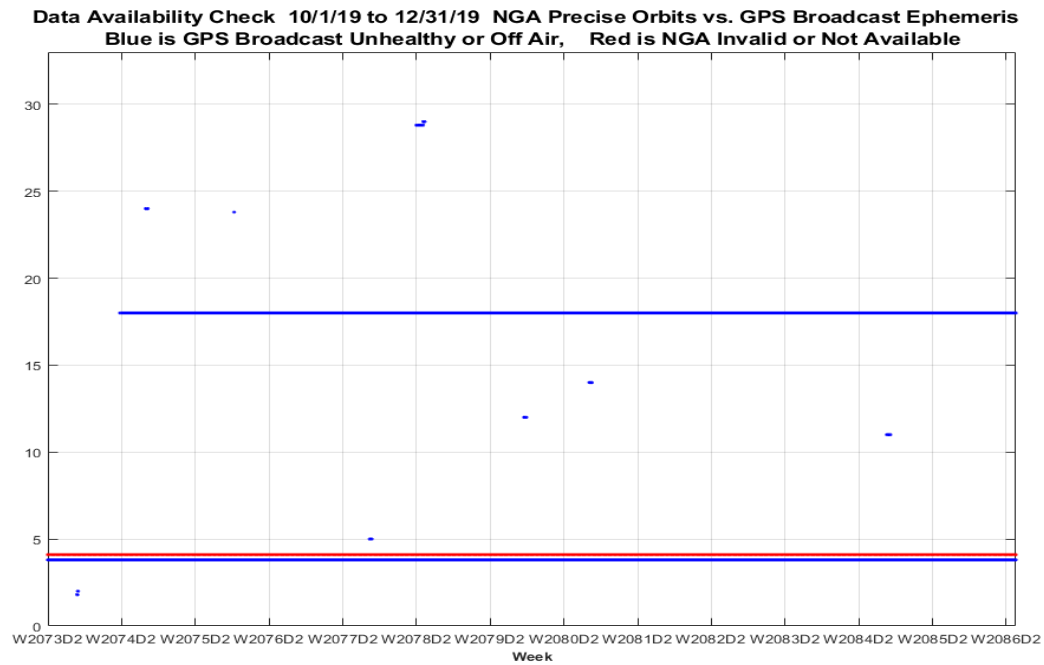
**Figure 10-2. GPS Broadcast Orbit Accuracy Standard Deviations Using L2C CNAV Data**



**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**

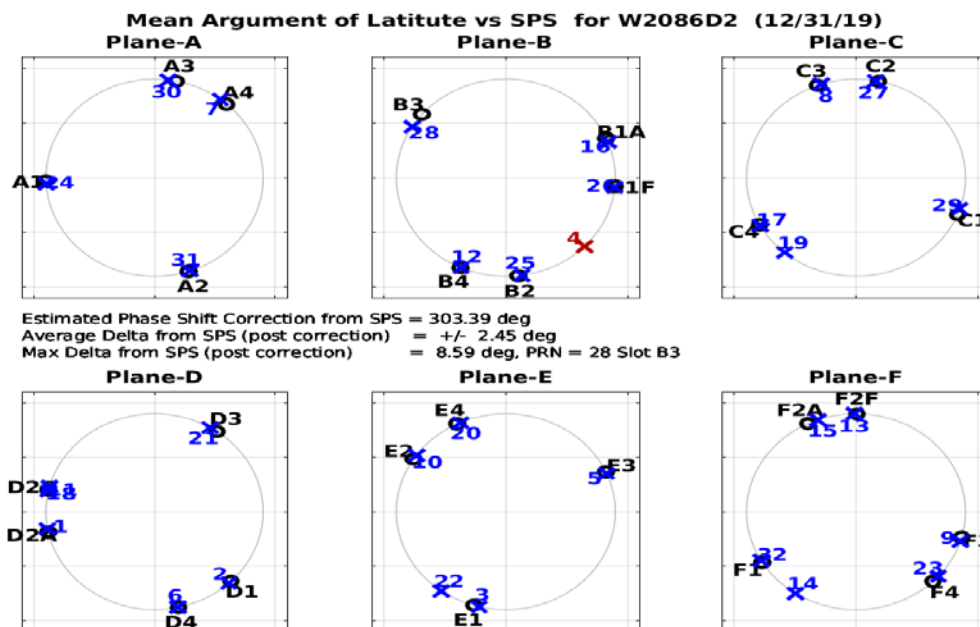
## 10.2 Broadcast Ephemeris vs. NGA Precise Data Availability Plots

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



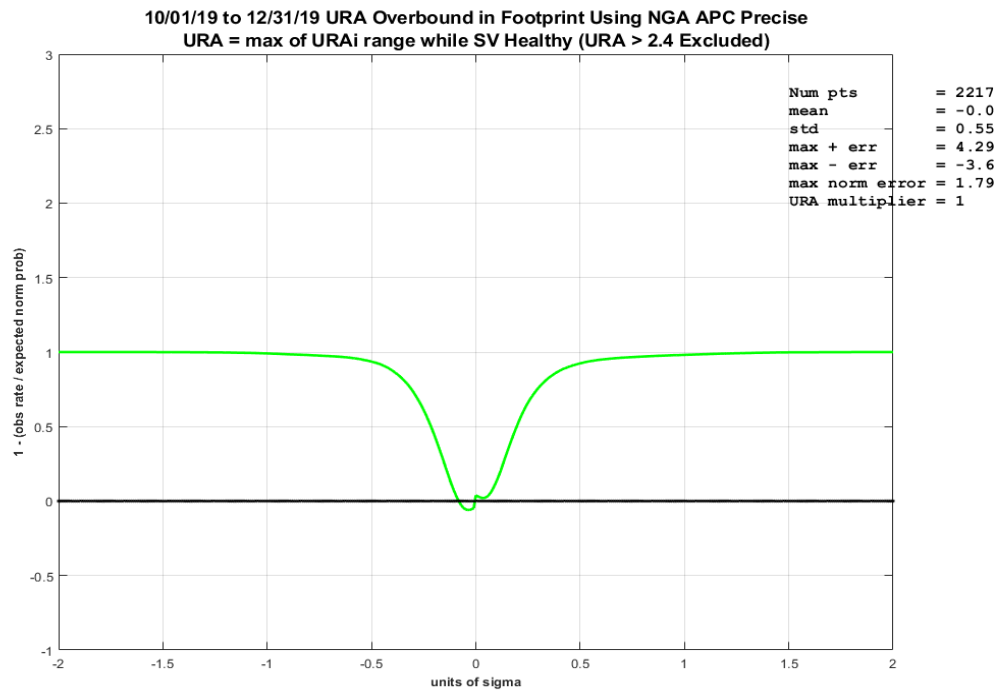
## 10.3 Current GPS Constellation

**Figure 10-6. Current GPS Constellation**

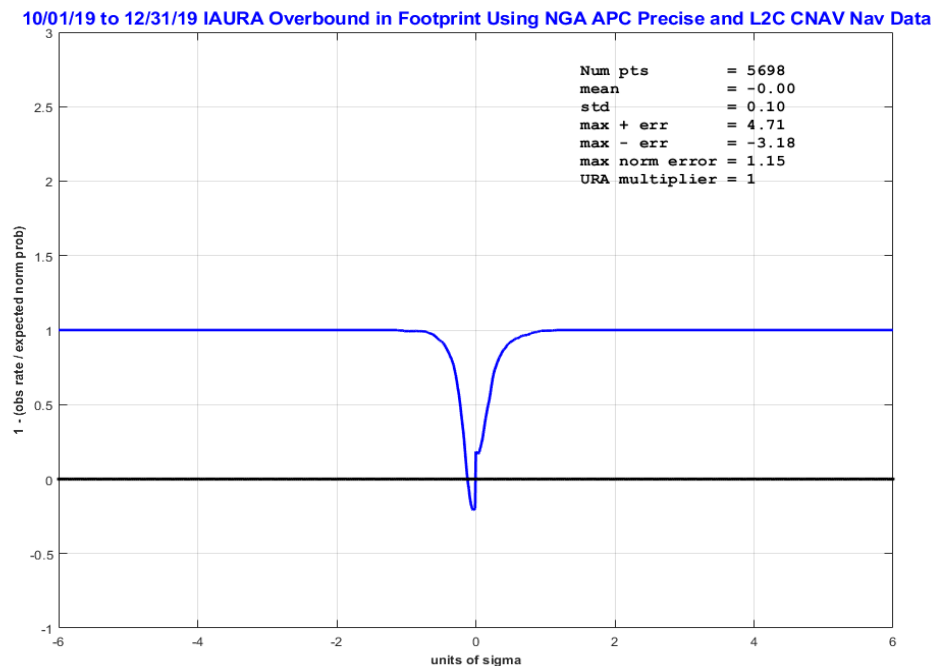


## 10.4 URA Over-bounding Plots

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

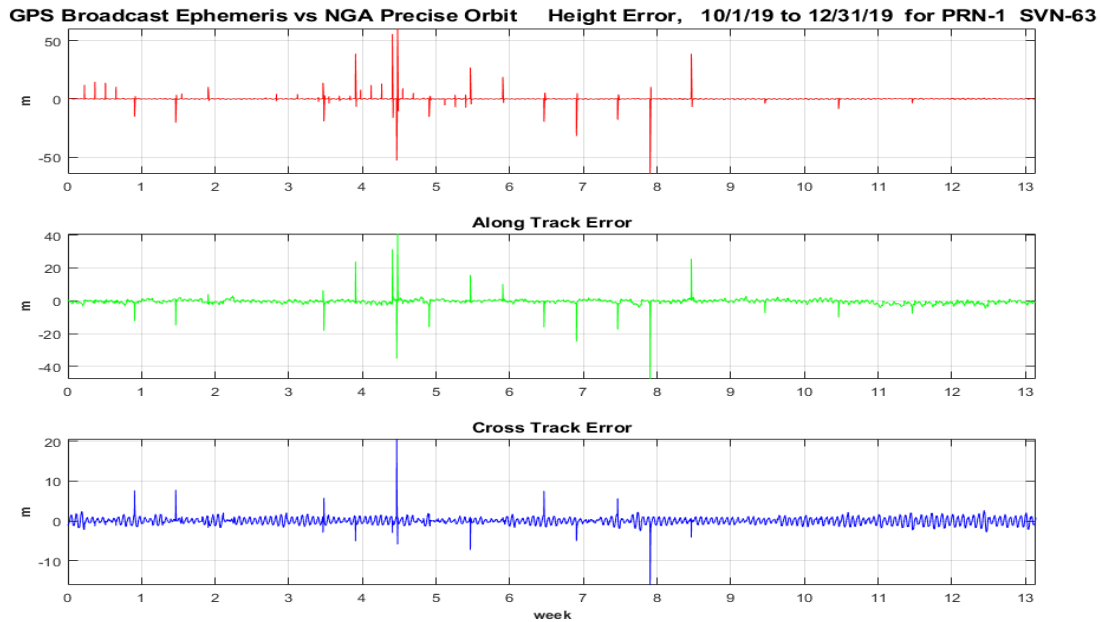


**Figure 10-8. IAURA Over-bounding Using L2C CNAV Data**

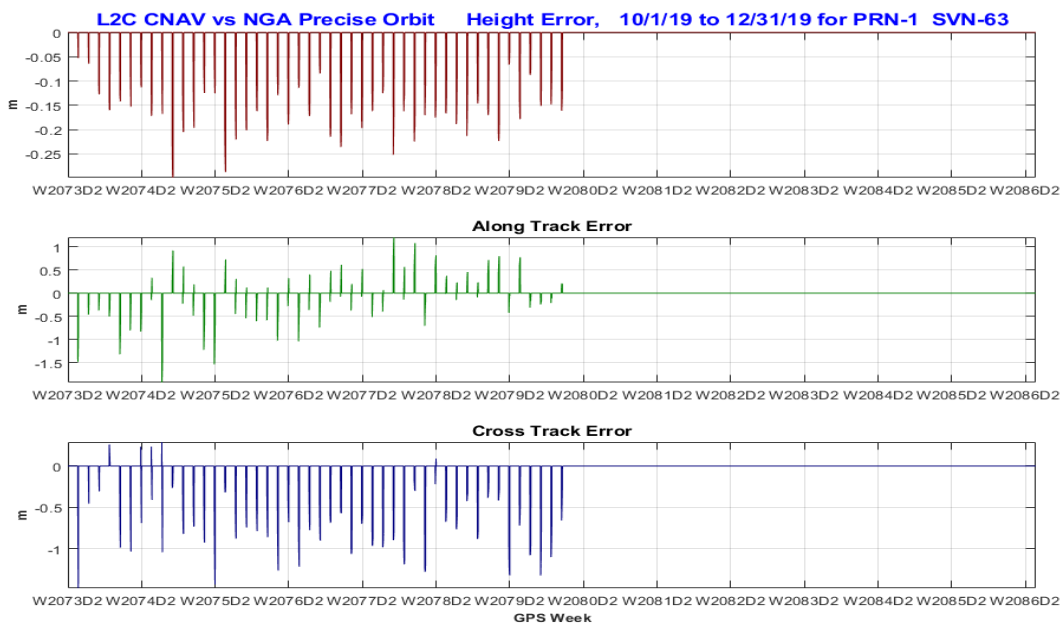


## 10.5 Orbit Error Plots for All Satellites

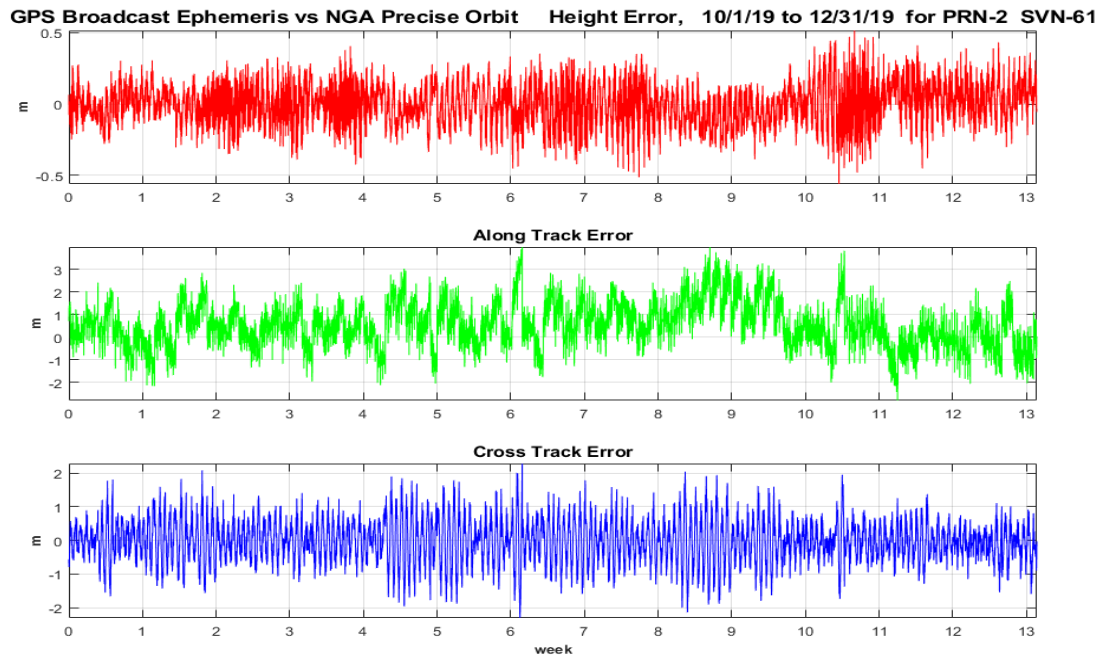
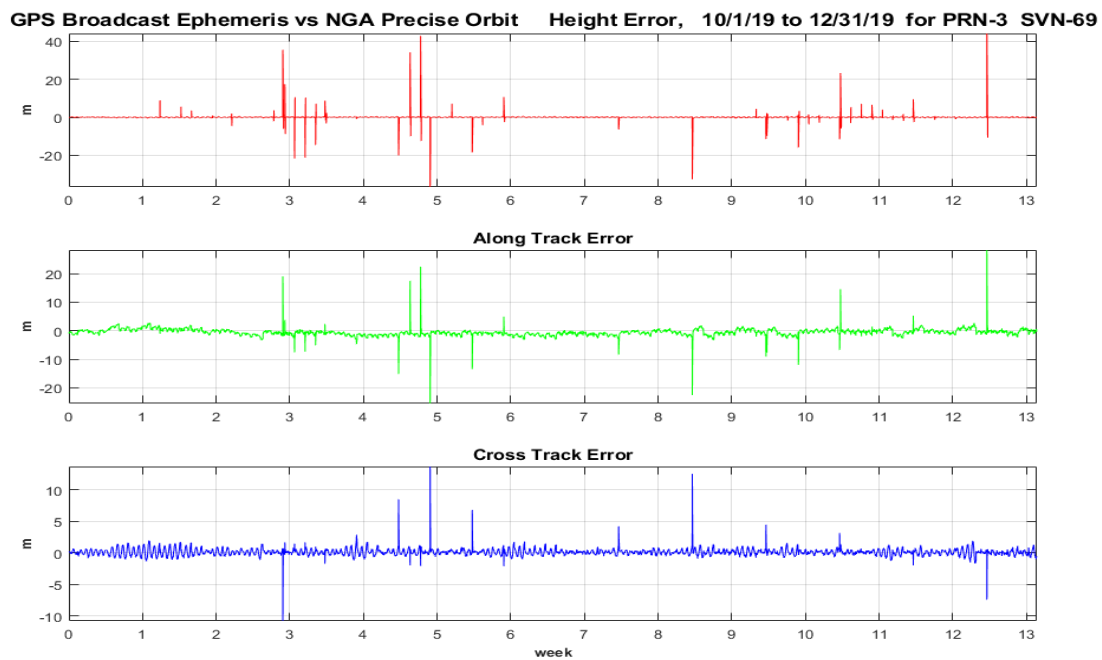
**Figure 10-9. Orbit Error PRN1 (SVN-63) Using C/A Nav Data**

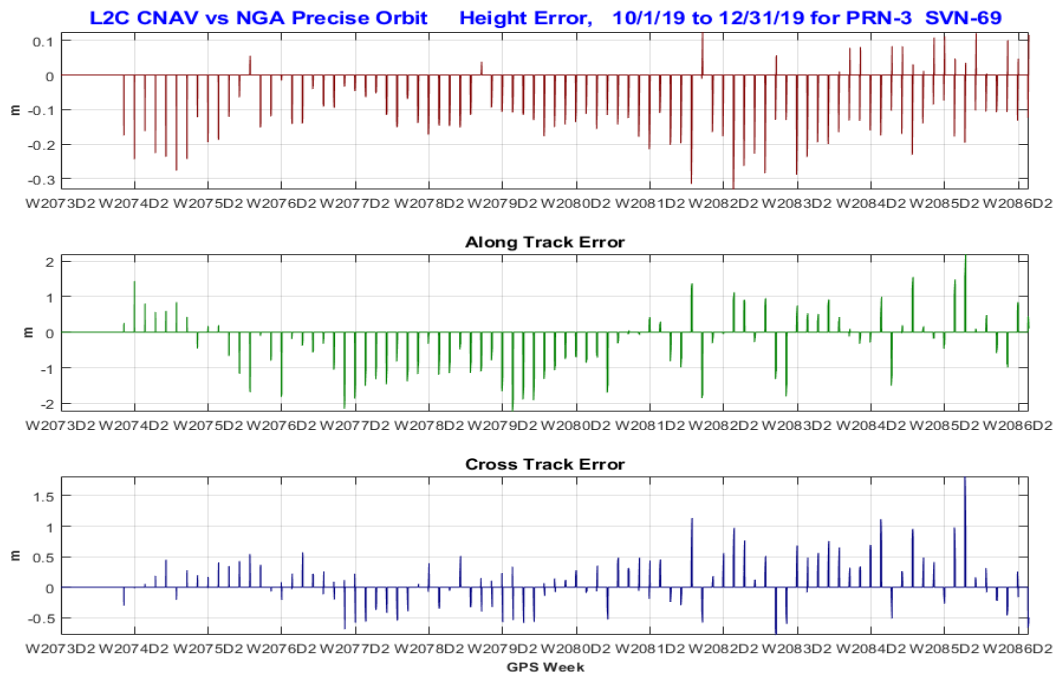
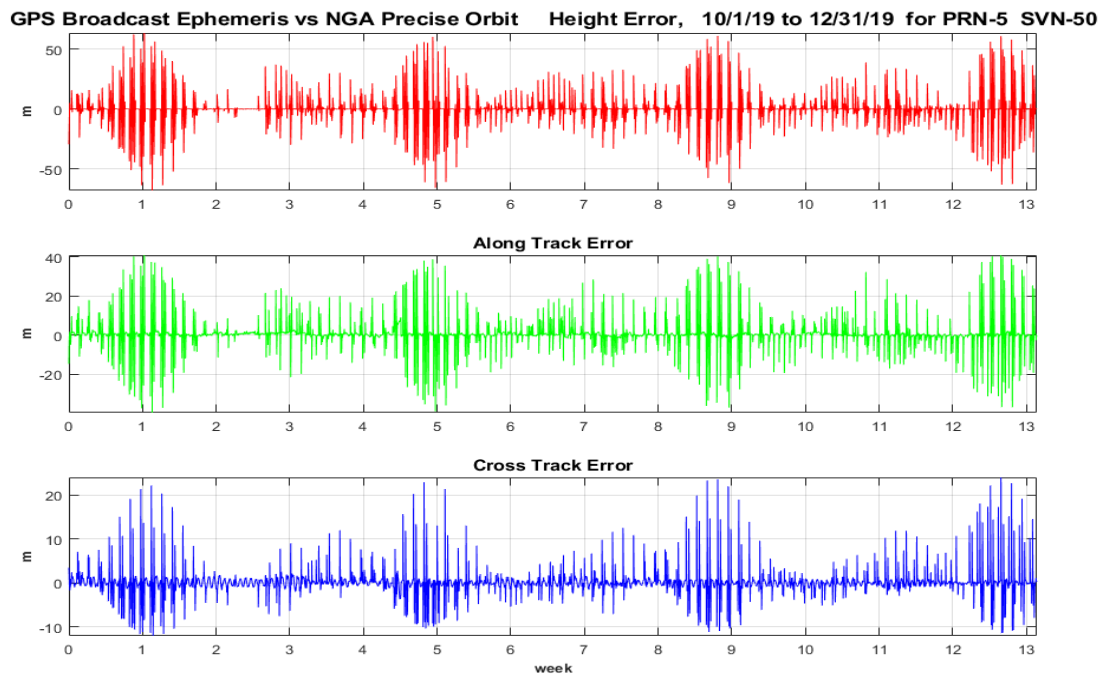


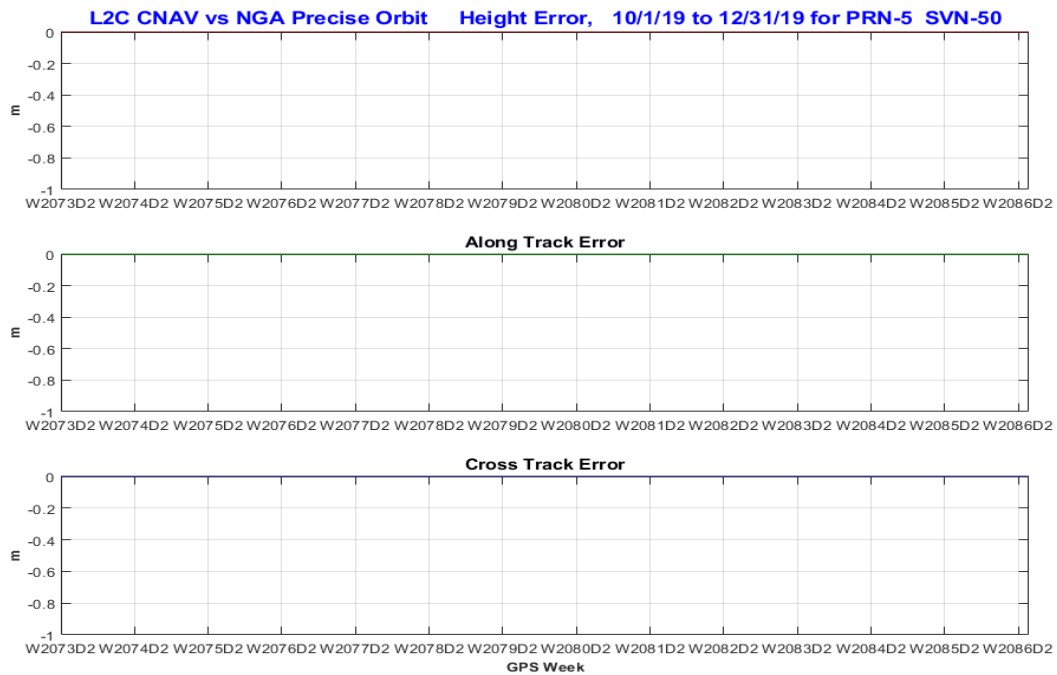
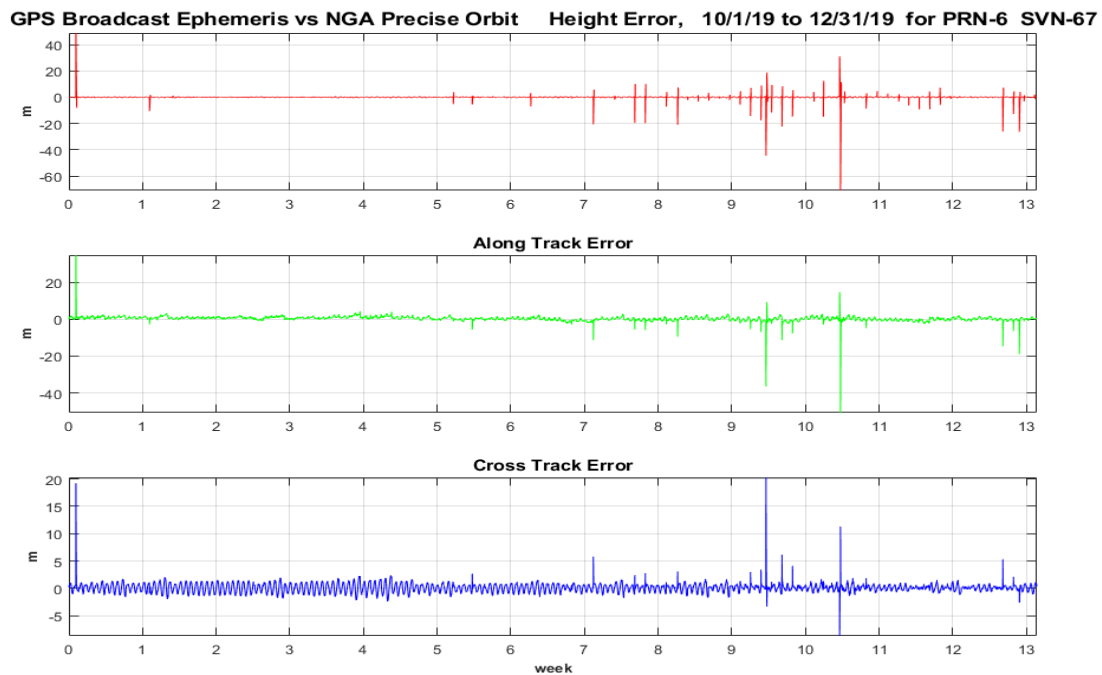
**Figure 10-10. Orbit Error PRN1 (SVN-63) Using L2C CNAV Data**

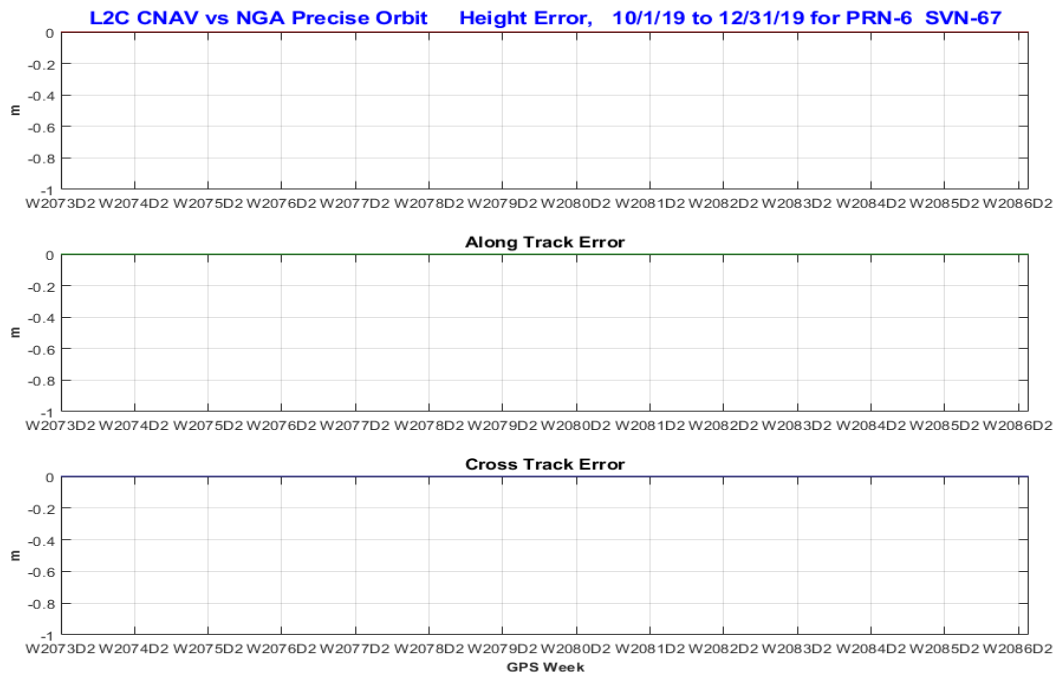
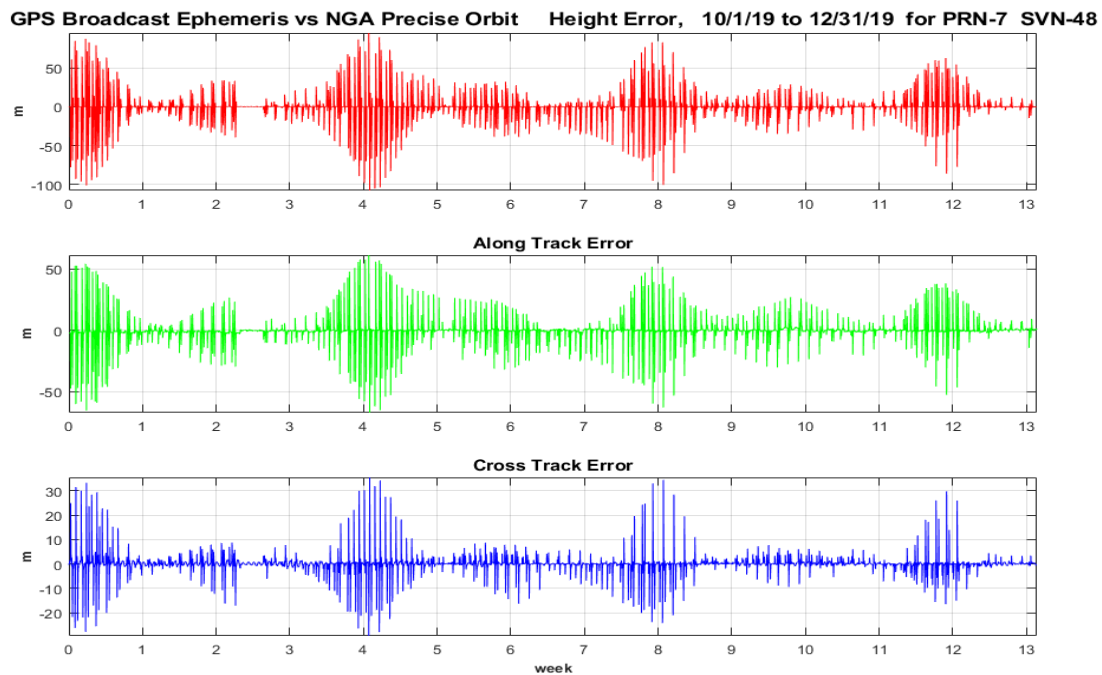


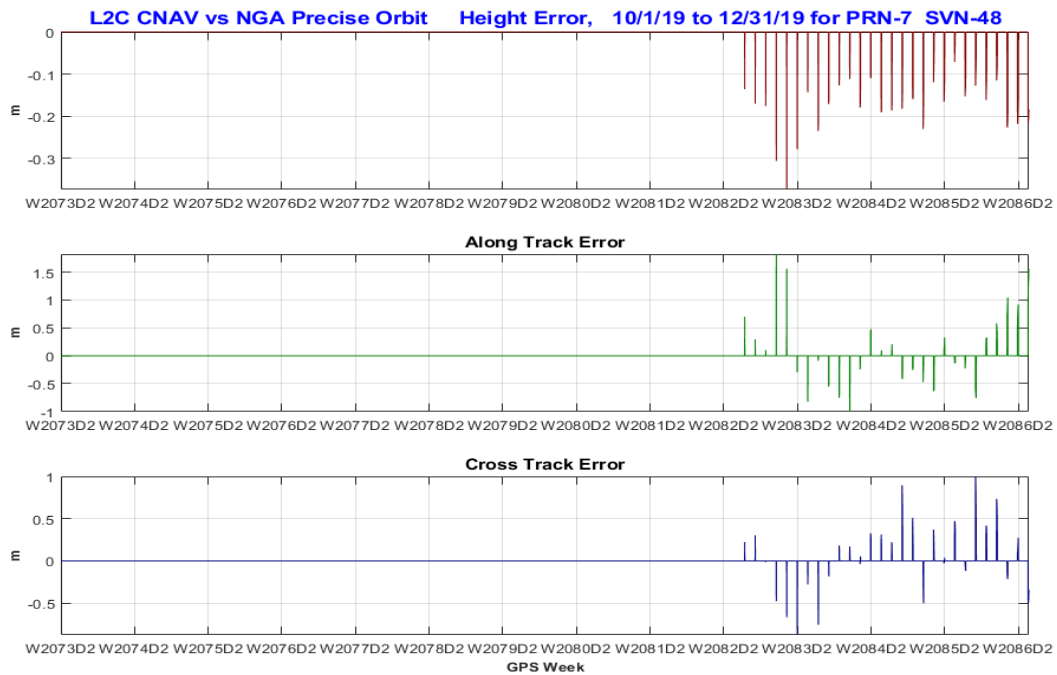
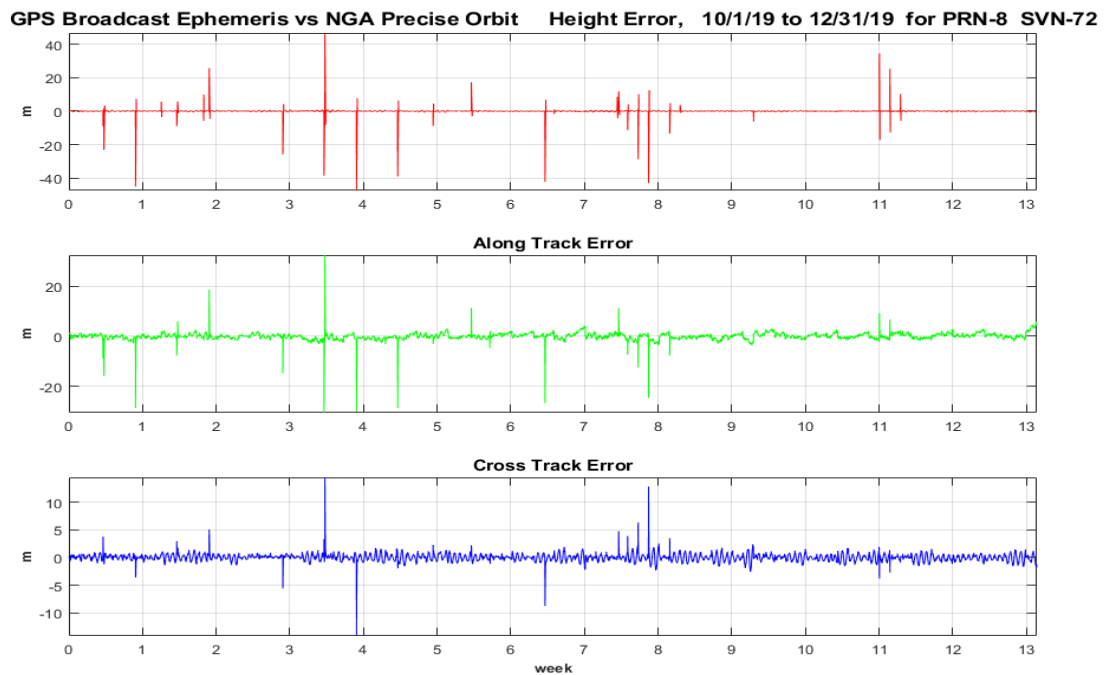


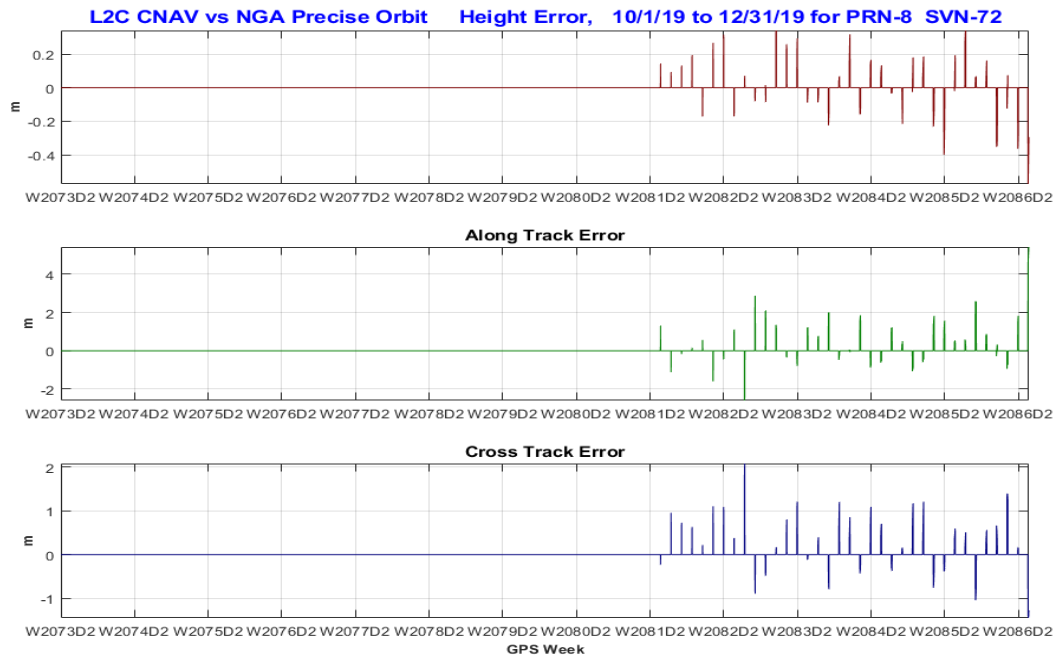
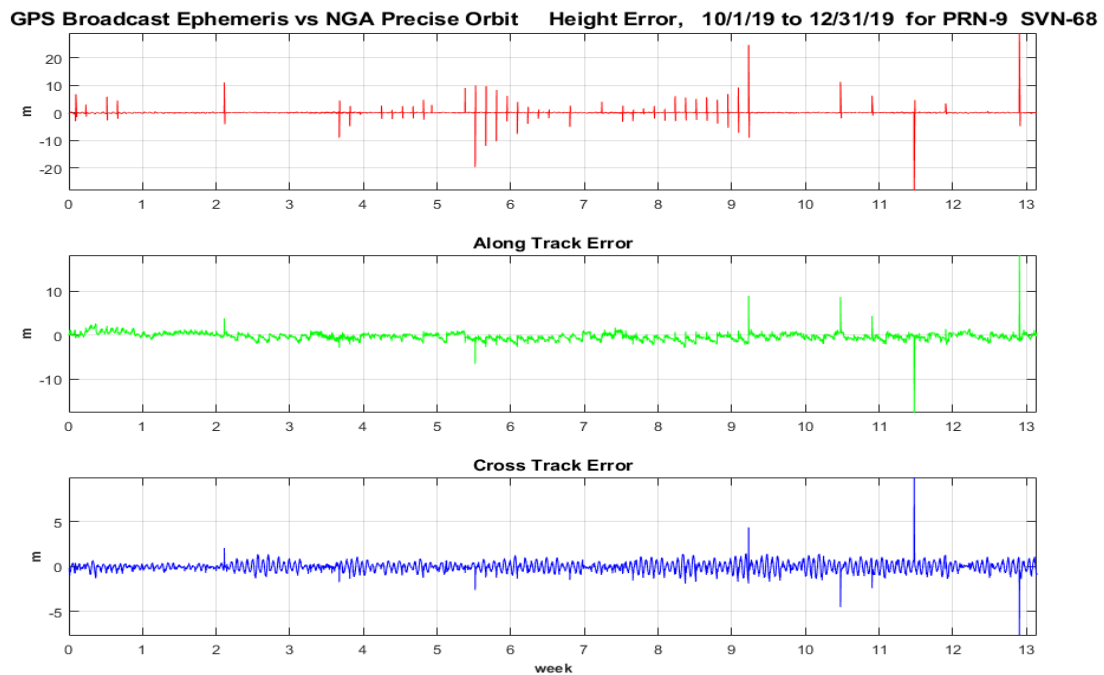
**Figure 10-11. Orbit Error PRN2 (SVN-61) Using C/A Nav Data****Figure 10-12. Orbit Error PRN3 (SVN-69) Using C/A Nav Data**

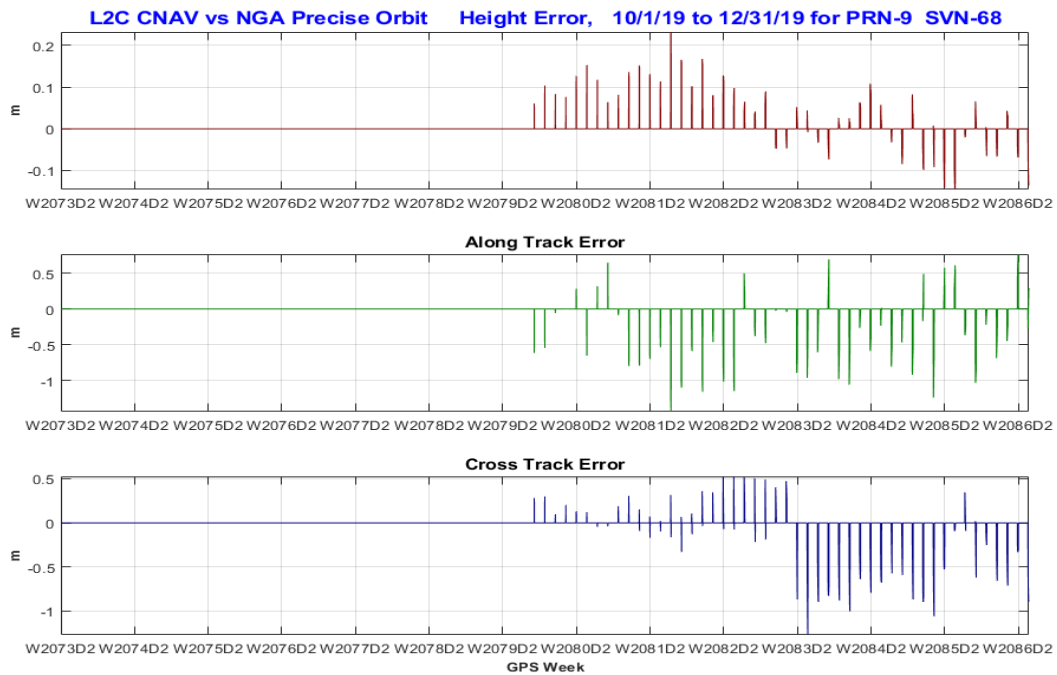
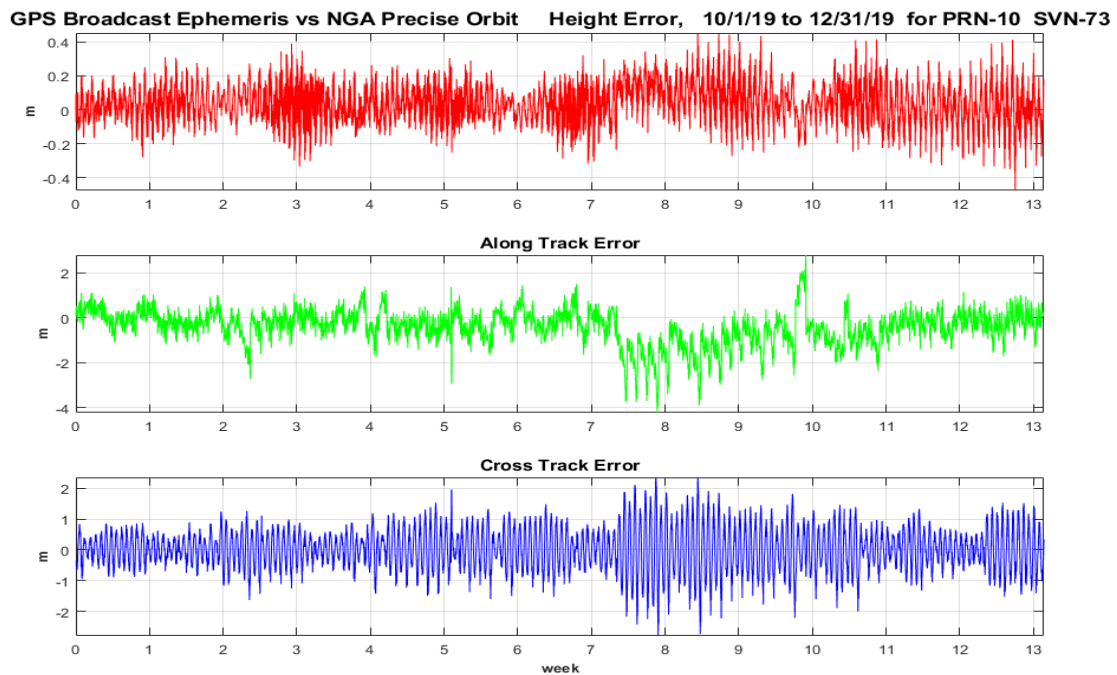
**Figure 10-13. Orbit Error PRN3 (SVN-69) Using L2C CNAV Data****Figure 10-14. Orbit Error PRN5 (SVN-50) Using C/A Nav Data**

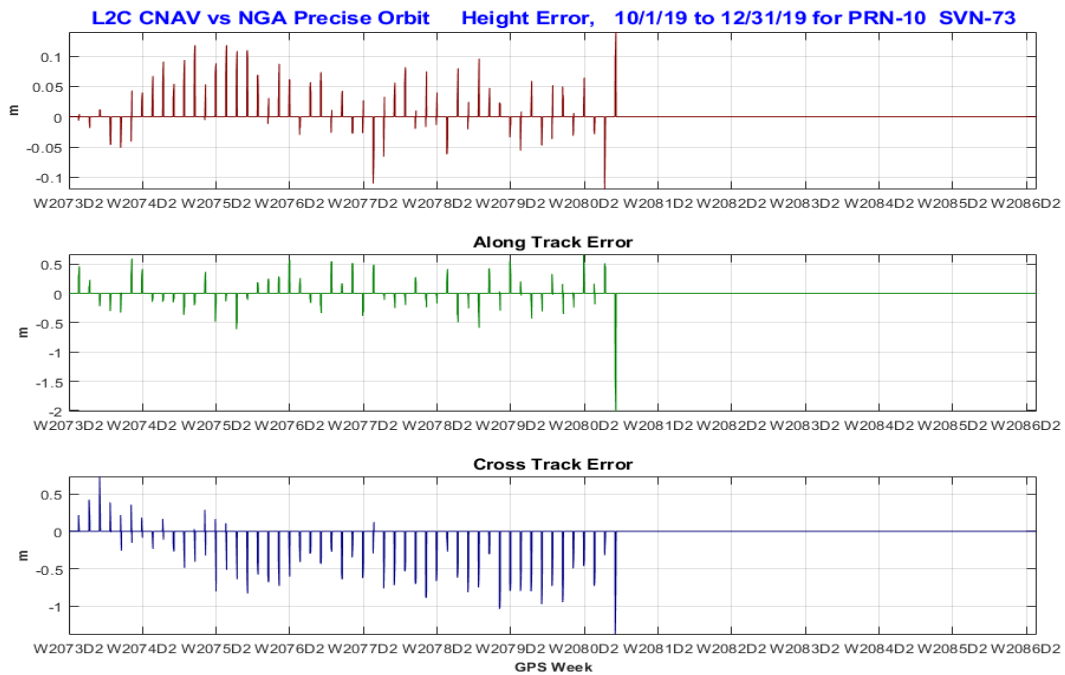
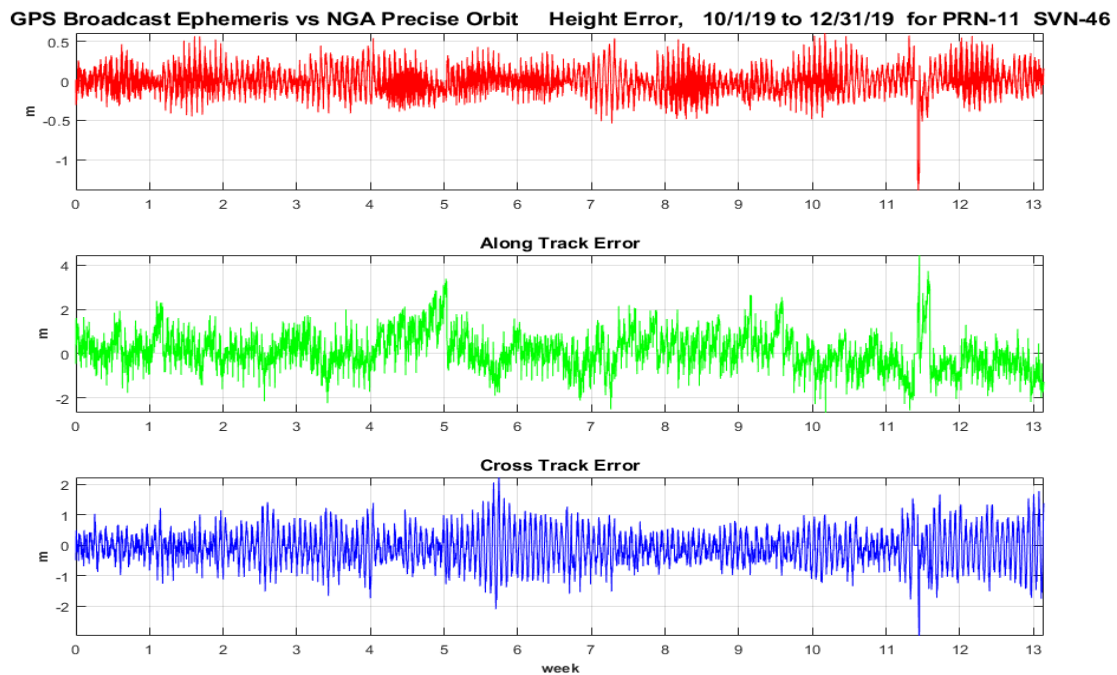
**Figure 10-15. Orbit Error PRN5 (SVN-50) Using L2C CNAV Data****Figure 10-16. Orbit Error PRN6 (SVN-67) Using C/A Nav Data**

**Figure 10-17. Orbit Error PRN6 (SVN-67) Using L2C CNAV Data****Figure 10-18. Orbit Error PRN7 (SVN-48) Using C/A Nav Data**

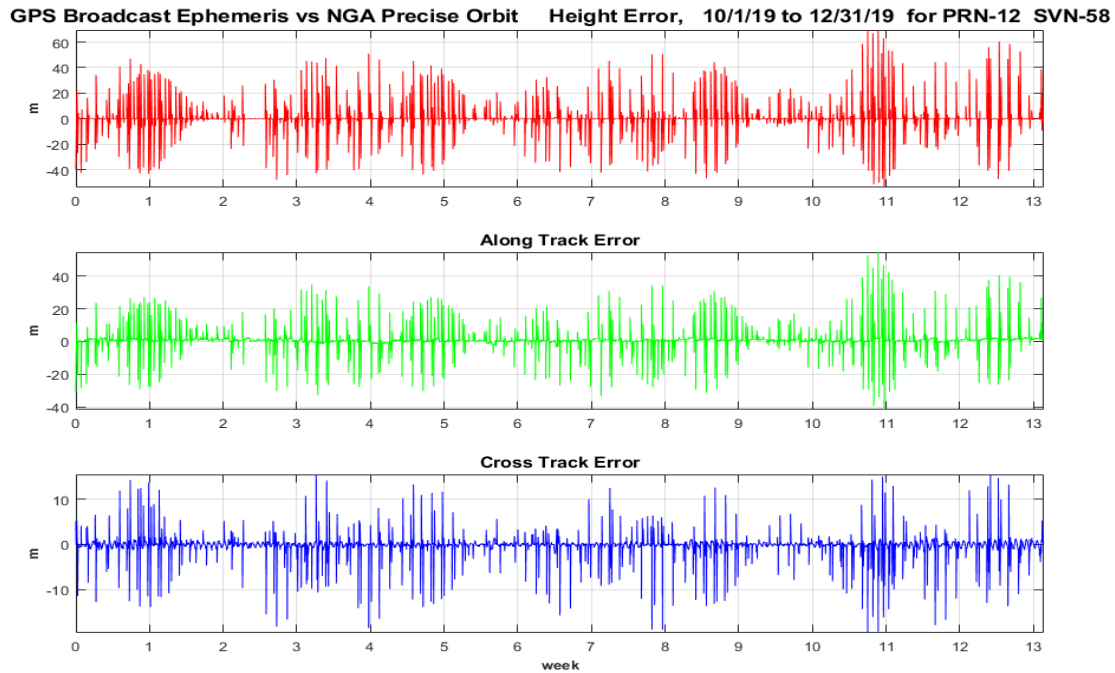
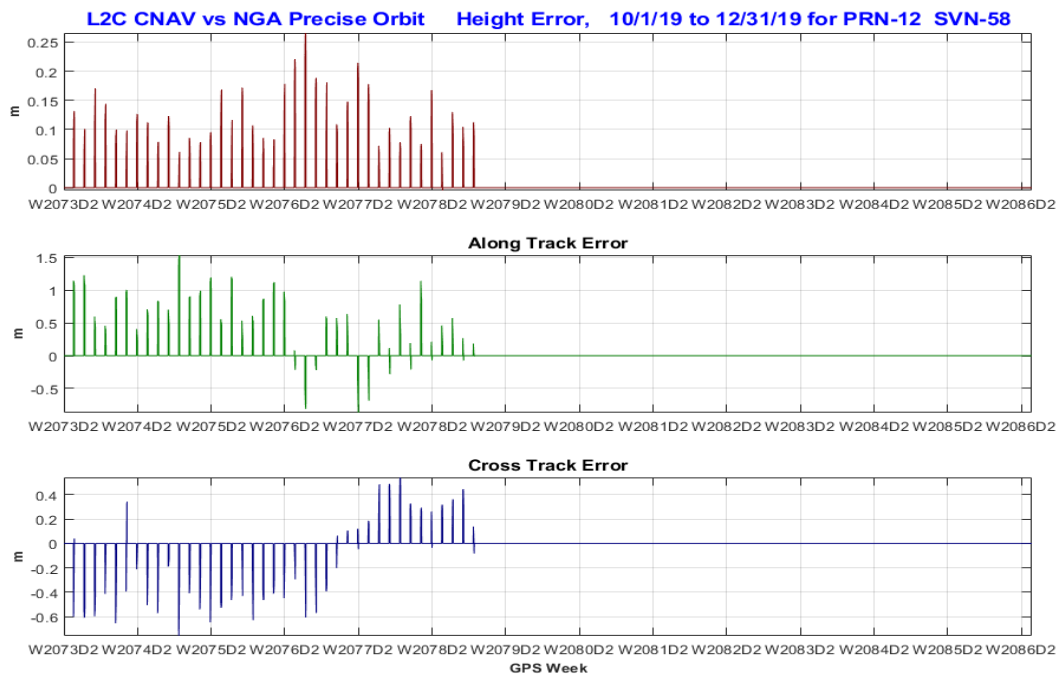
**Figure 10-19. Orbit Error PRN7 (SVN-48) Using L2C CNAV Data****Figure 10-20. Orbit Error PRN8 (SVN-72) Using C/A Nav Data**

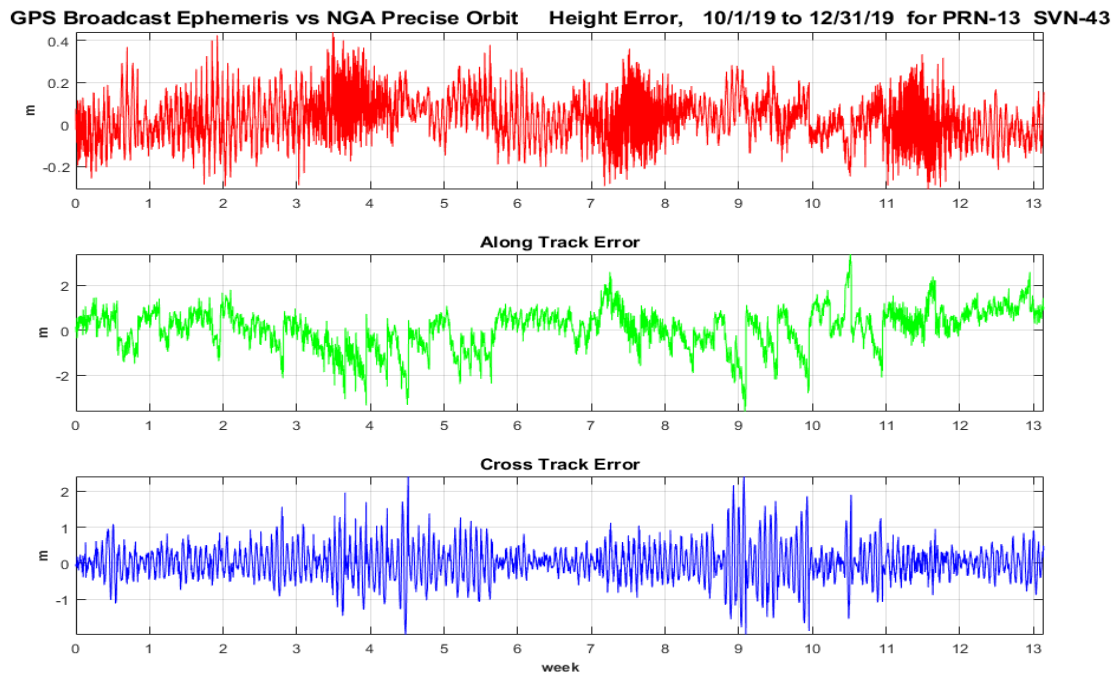
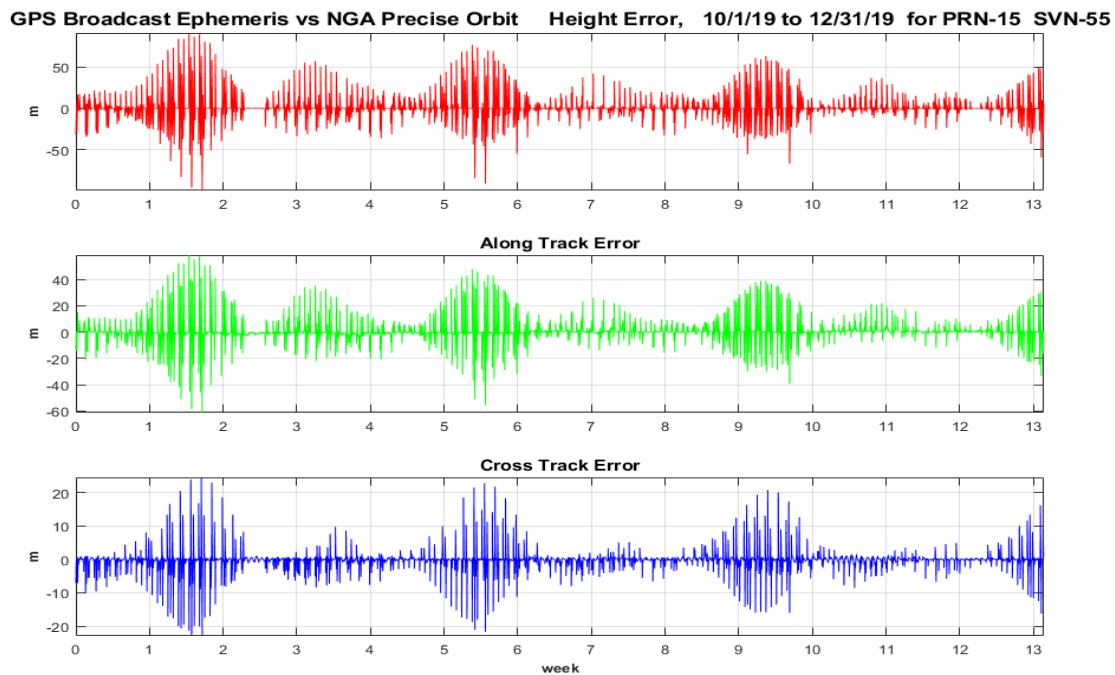
**Figure 10-21. Orbit Error PRN8 (SVN-72) Using L2C CNAV Data****Figure 10-22. Orbit Error PRN9 (SVN-68) Using C/A Nav Data**

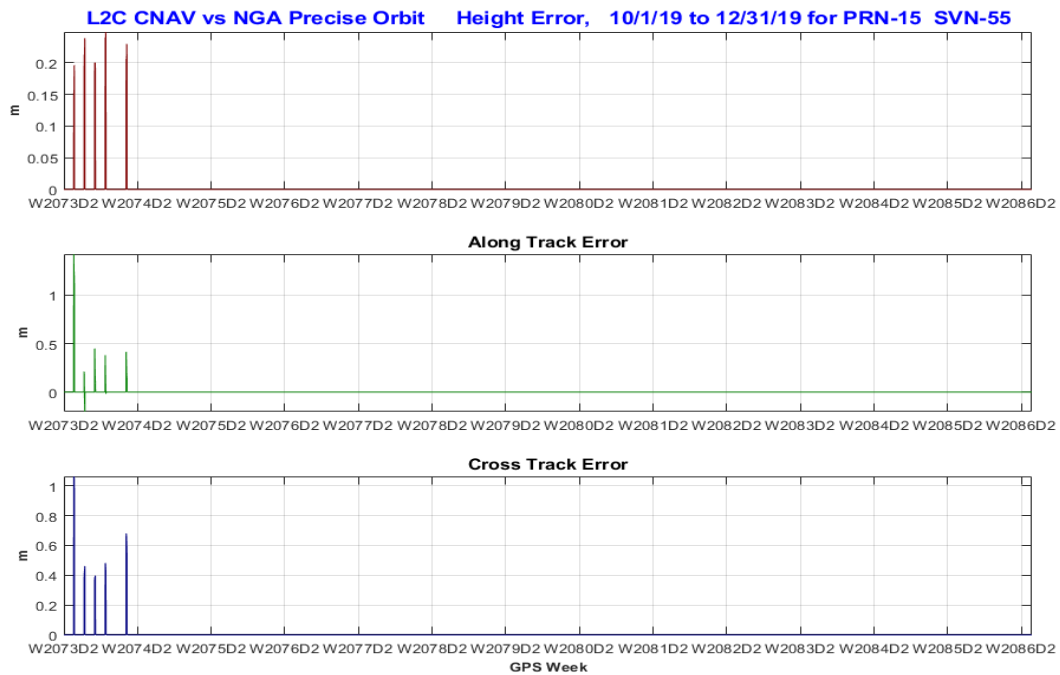
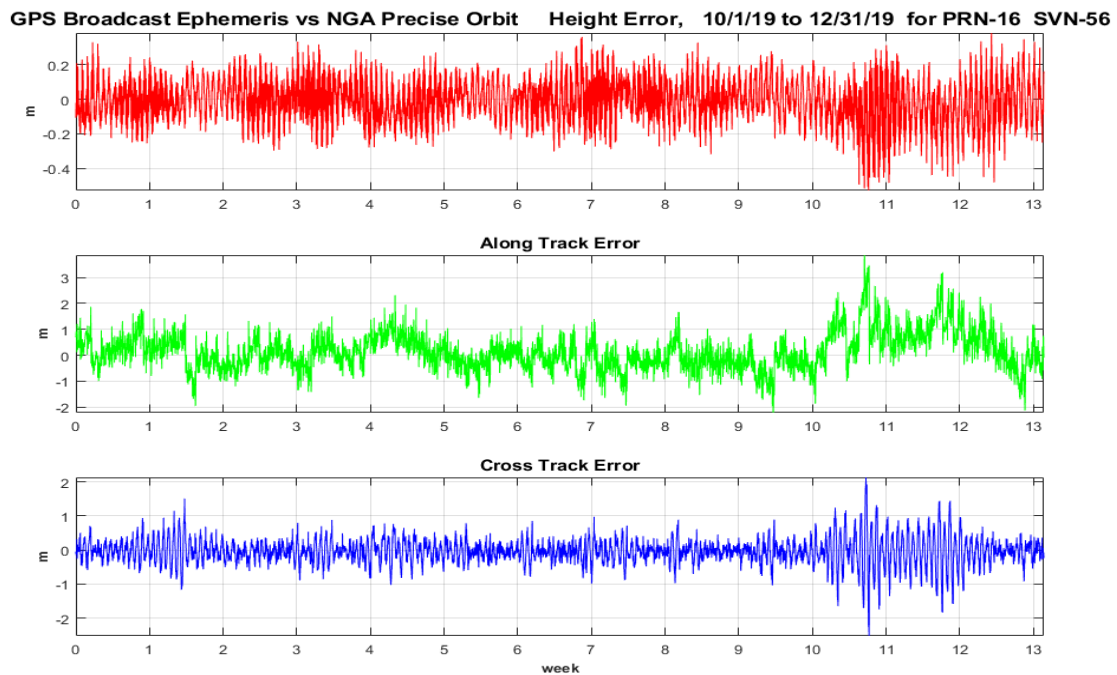
**Figure 10-23. Orbit Error PRN9 (SVN-68) Using L2C CNAV Data****Figure 10-24. Orbit Error PRN10 (SVN-73) Using C/A Nav Data**

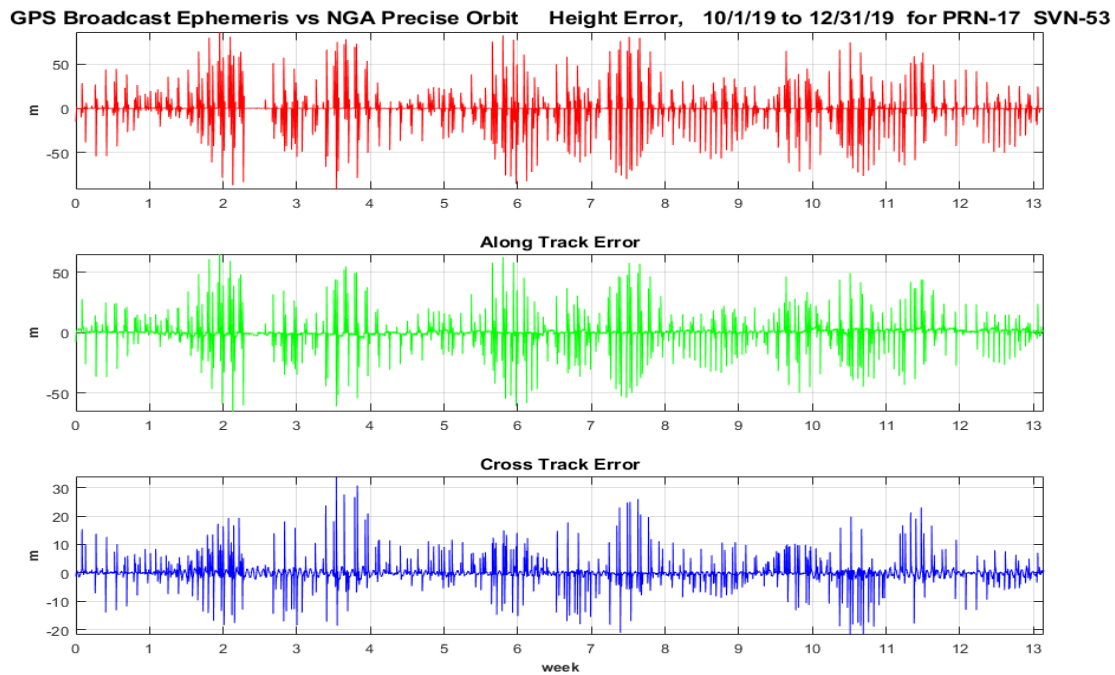
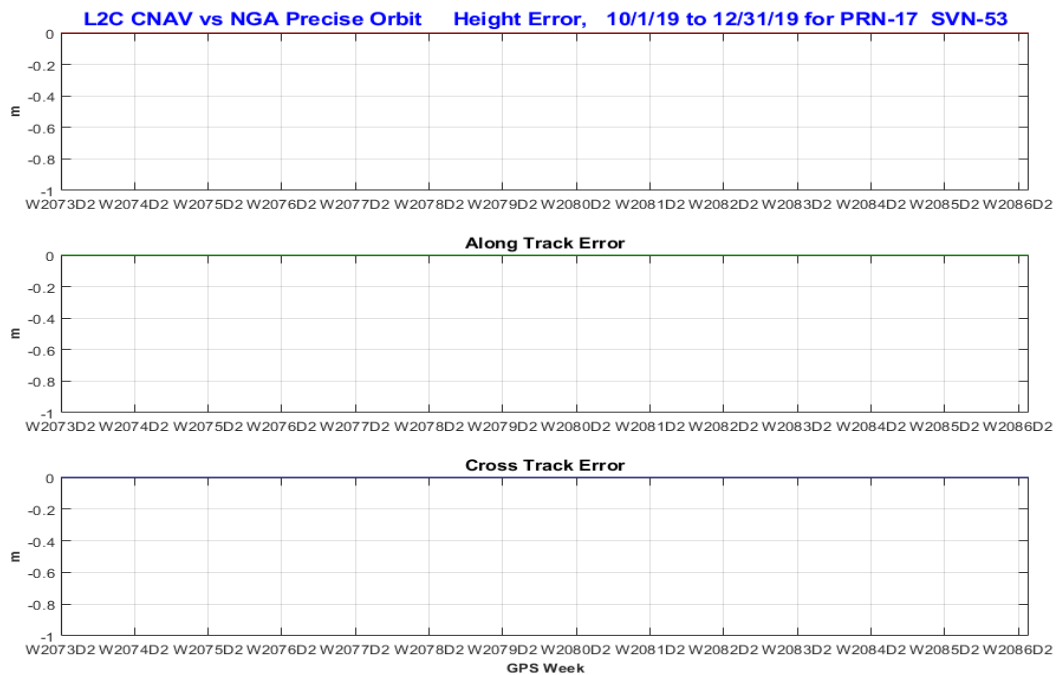
**Figure 10-25. Orbit Error PRN10 (SVN-73) Using L2C CNAV Data****Figure 10-26. Orbit Error PRN11 (SVN-46) Using C/A Nav Data**

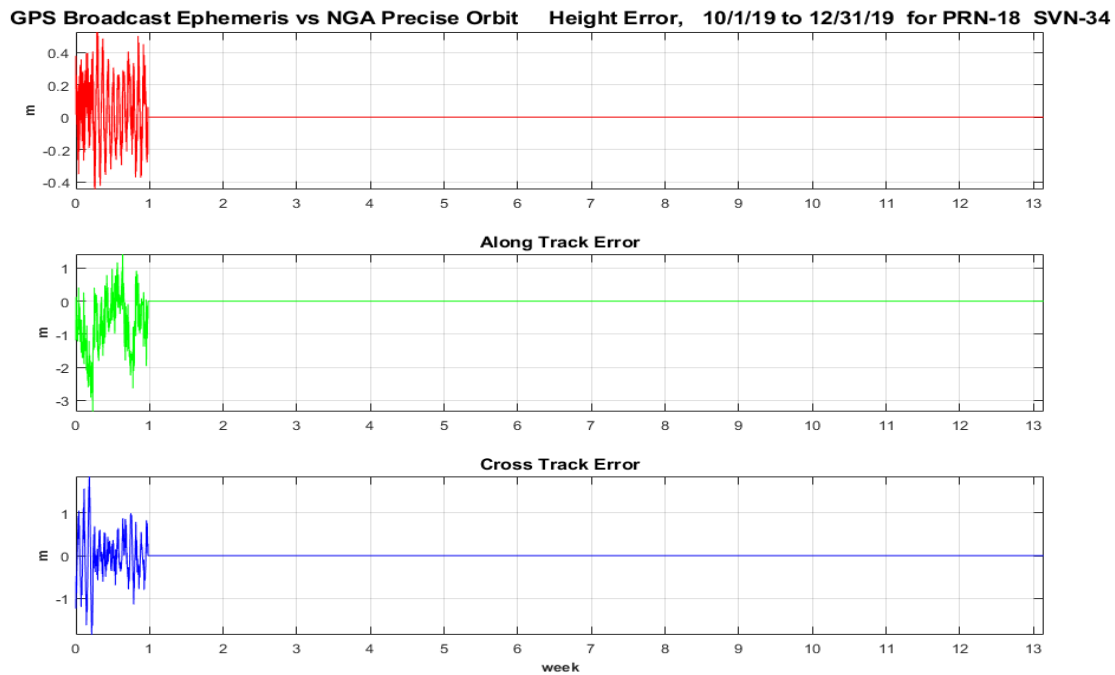
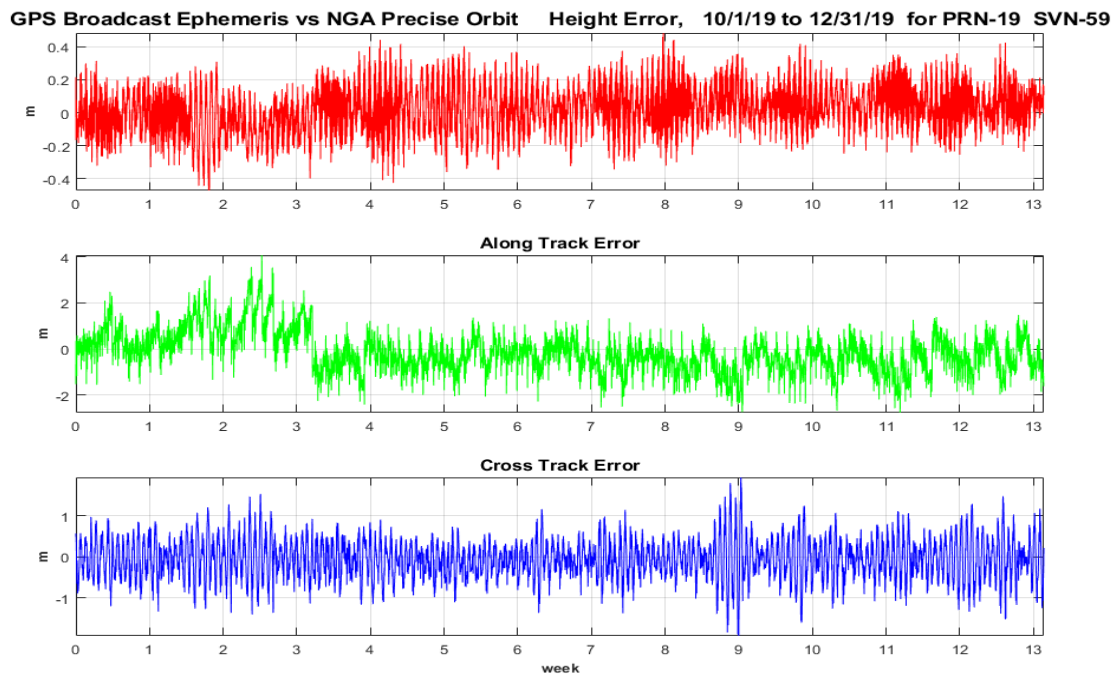


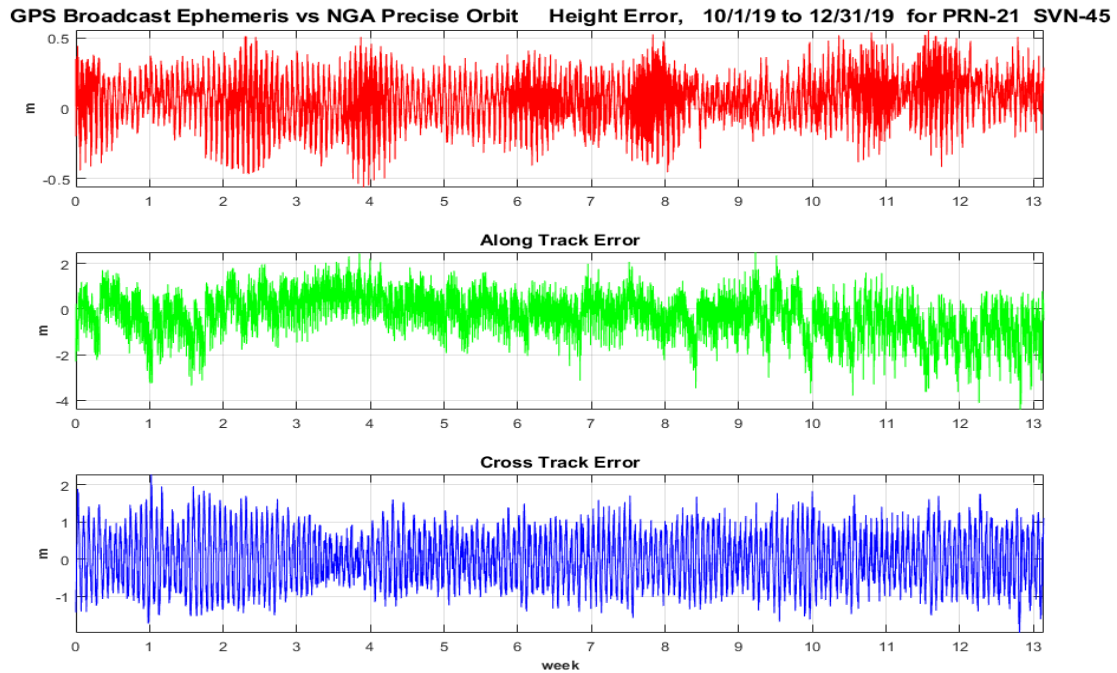
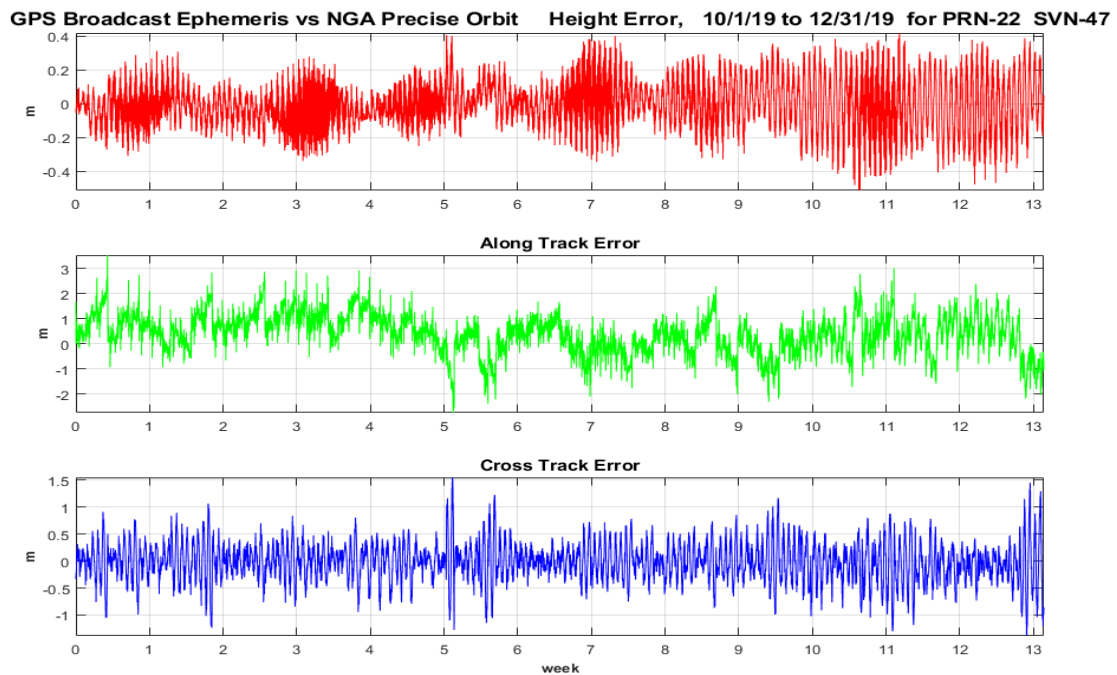
**Figure 10-27. Orbit Error PRN12 (SVN-58) Using C/A Nav Data****Figure 10-28. Orbit Error PRN12 (SVN-58) Using L2C CNAV Data**

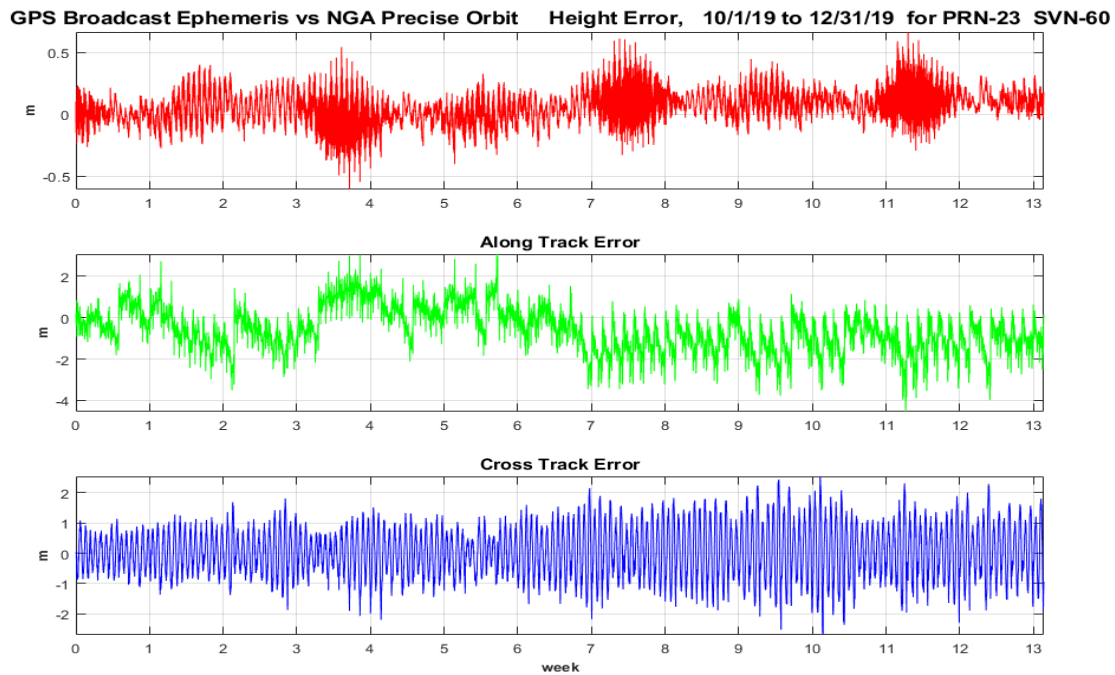
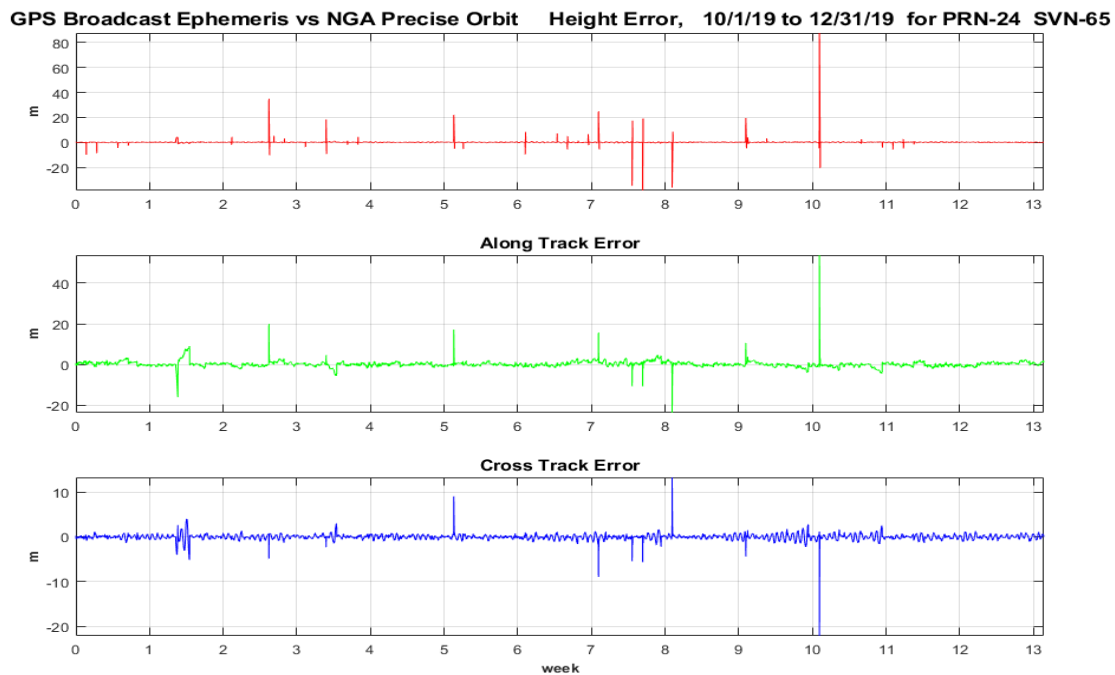
**Figure 10-29. Orbit Error PRN13 (SVN-43) Using C/A Nav Data****Figure 10-30. Orbit Error PRN15 (SVN-55) Using C/A Nav Data**

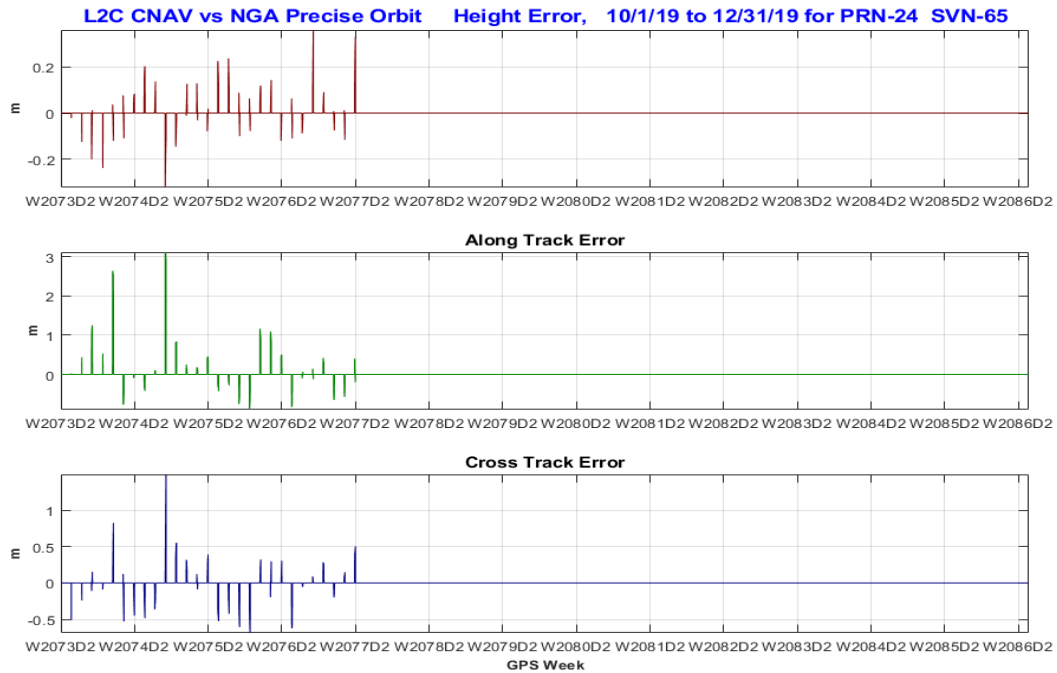
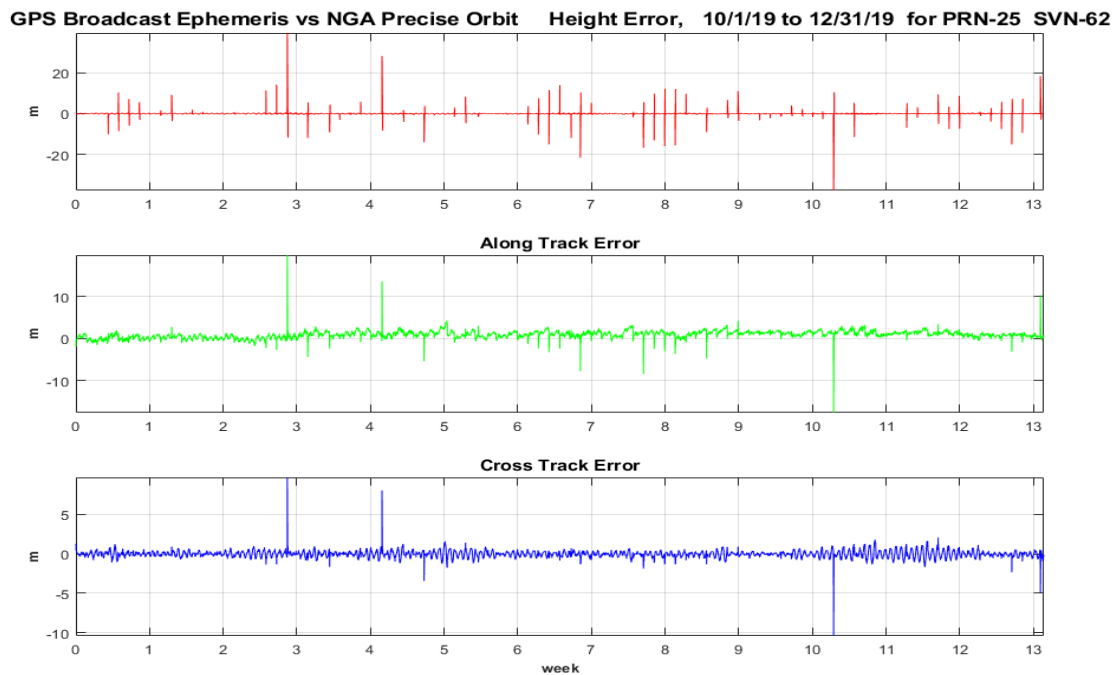
**Figure 10-31. Orbit Error PRN15 (SVN-55) Using L2C CNAV Data****Figure 10-32. Orbit Error PRN16 (SVN-56) Using C/A Nav Data**

**Figure 10-33. Orbit Error PRN17 (SVN-53) Using C/A Nav Data****Figure 10-34. Orbit Error PRN17 (SVN-53) Using L2C CNAV Data**

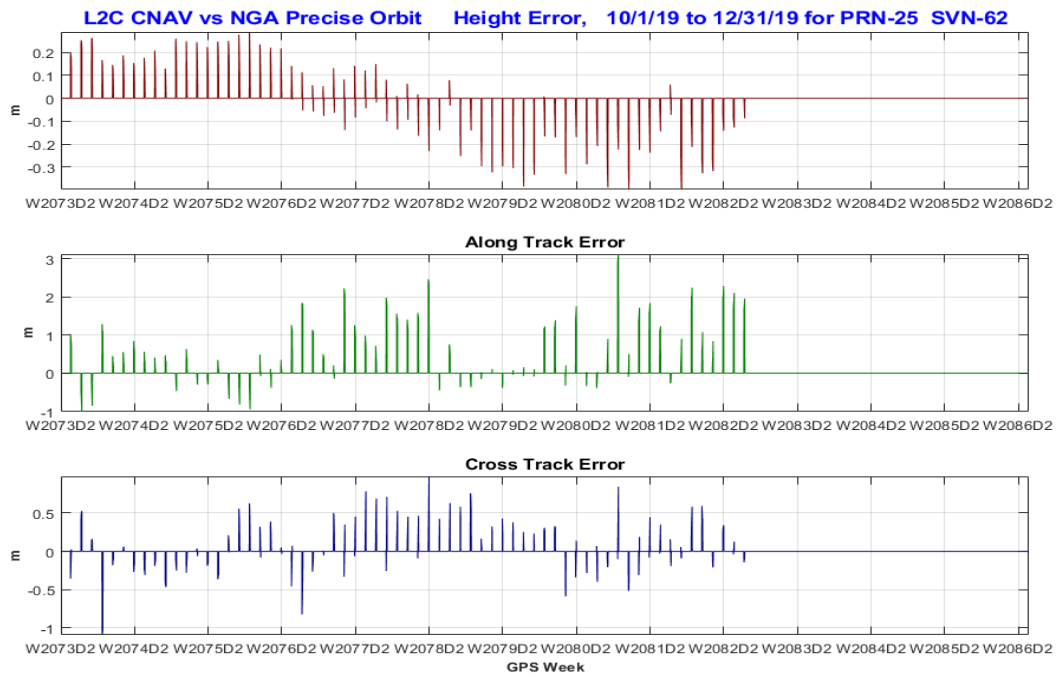
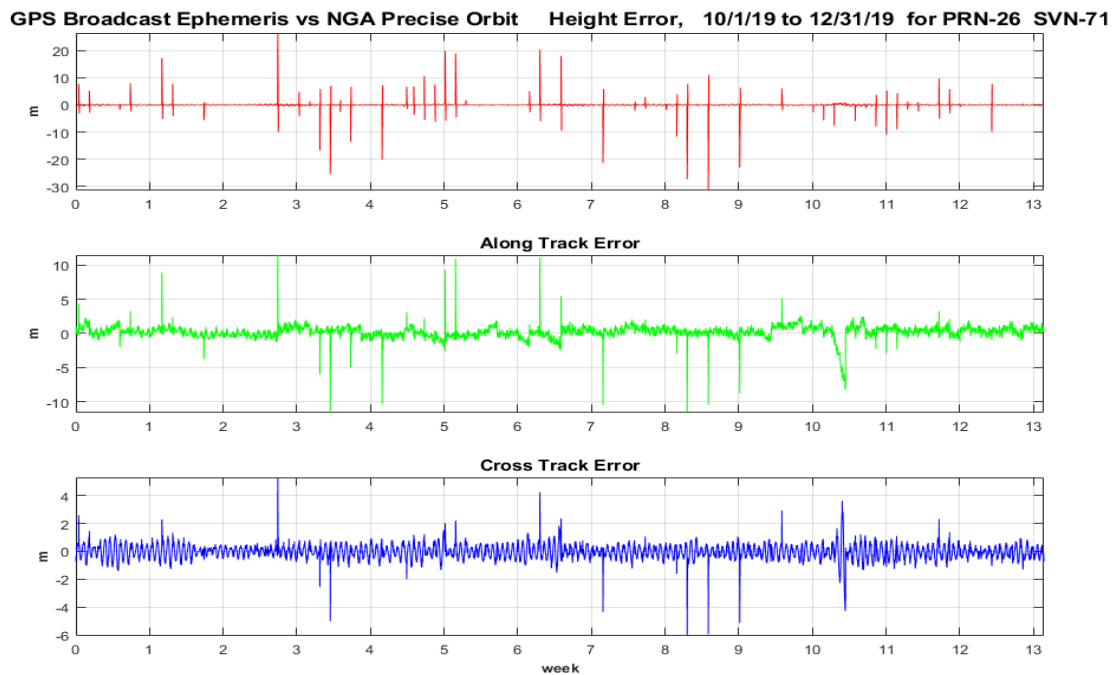
**Figure 10-35. Orbit Error PRN18 (SVN-34) Using C/A Nav Data****Figure 10-36. Orbit Error PRN19 (SVN-59) Using C/A Nav Data**

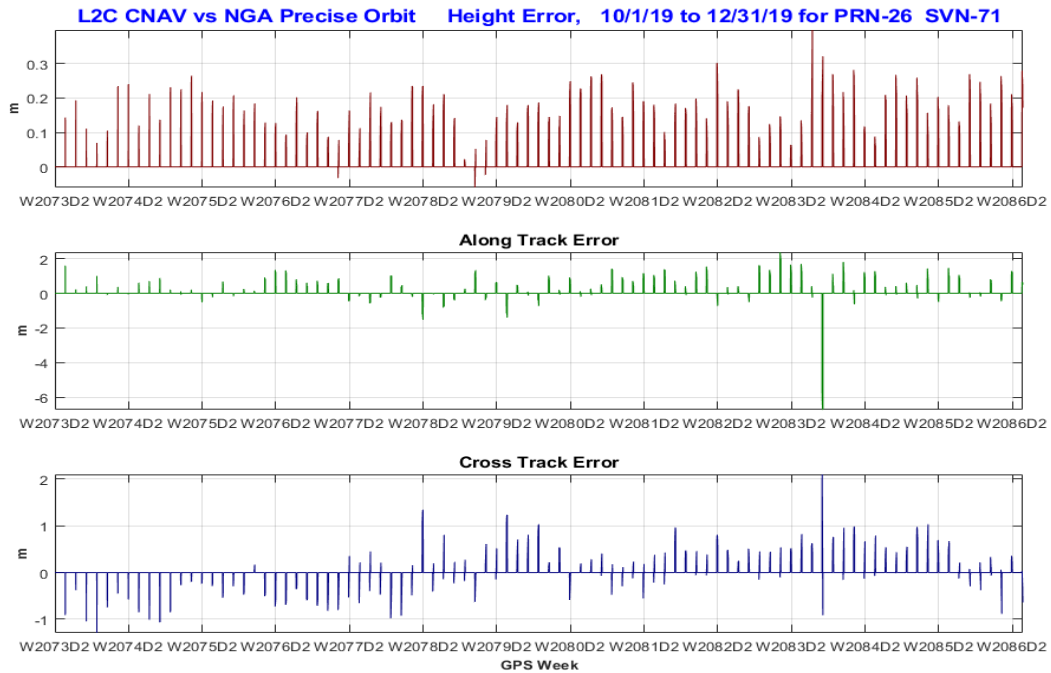
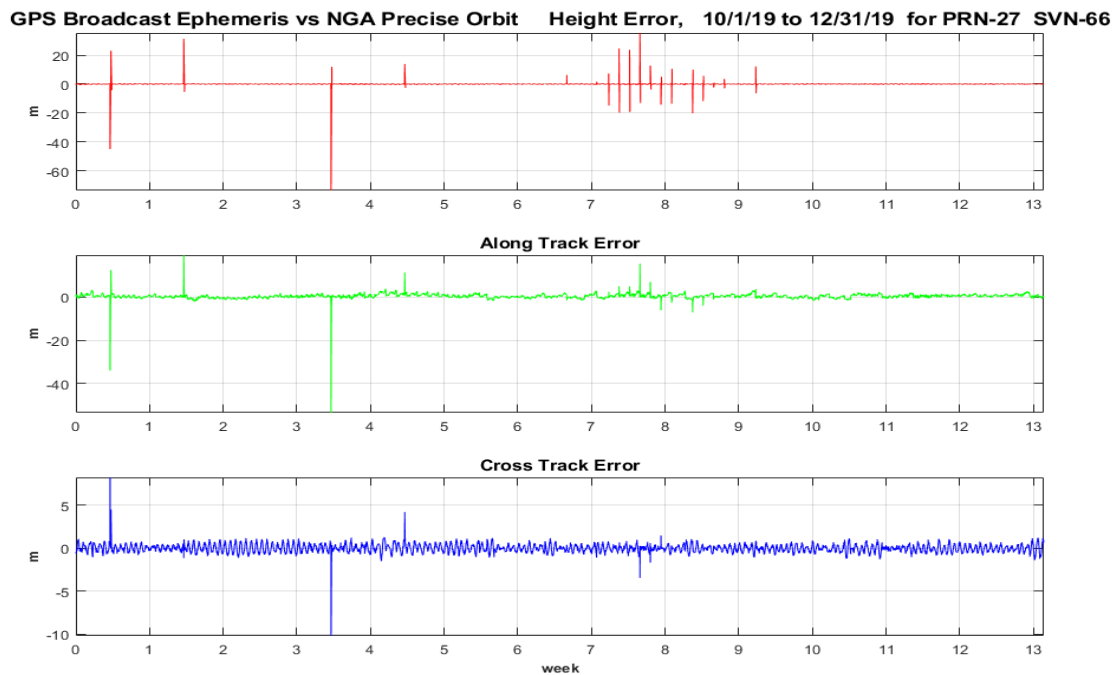
**Figure 10-37. Orbit Error PRN21 (SVN-45) Using C/A Nav Data****Figure 10-38. Orbit Error PRN22 (SVN-47) Using C/A Nav Data**

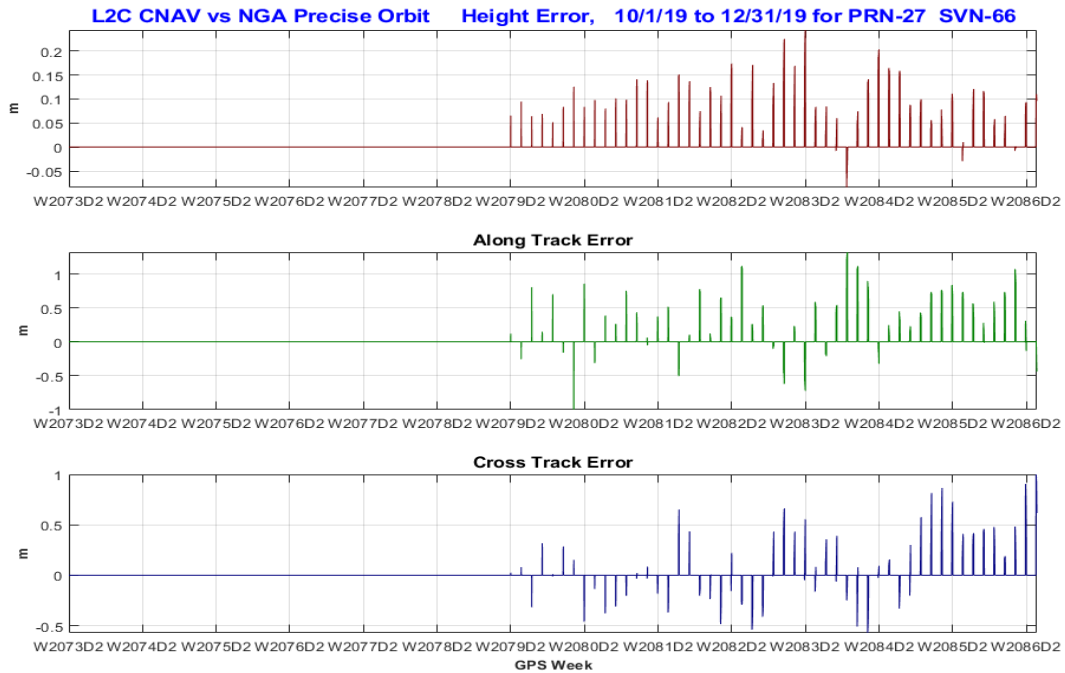
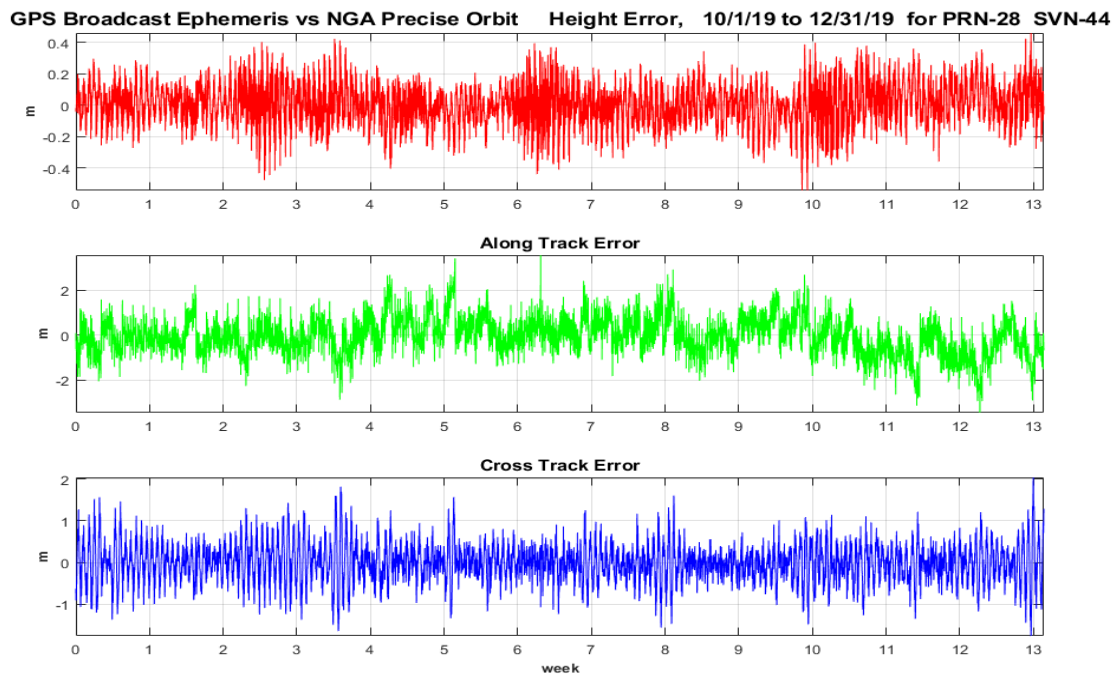
**Figure 10-39. Orbit Error PRN23 (SVN-60) Using C/A Nav Data****Figure 10-40. Orbit Error PRN24 (SVN-65) Using C/A Nav Data**

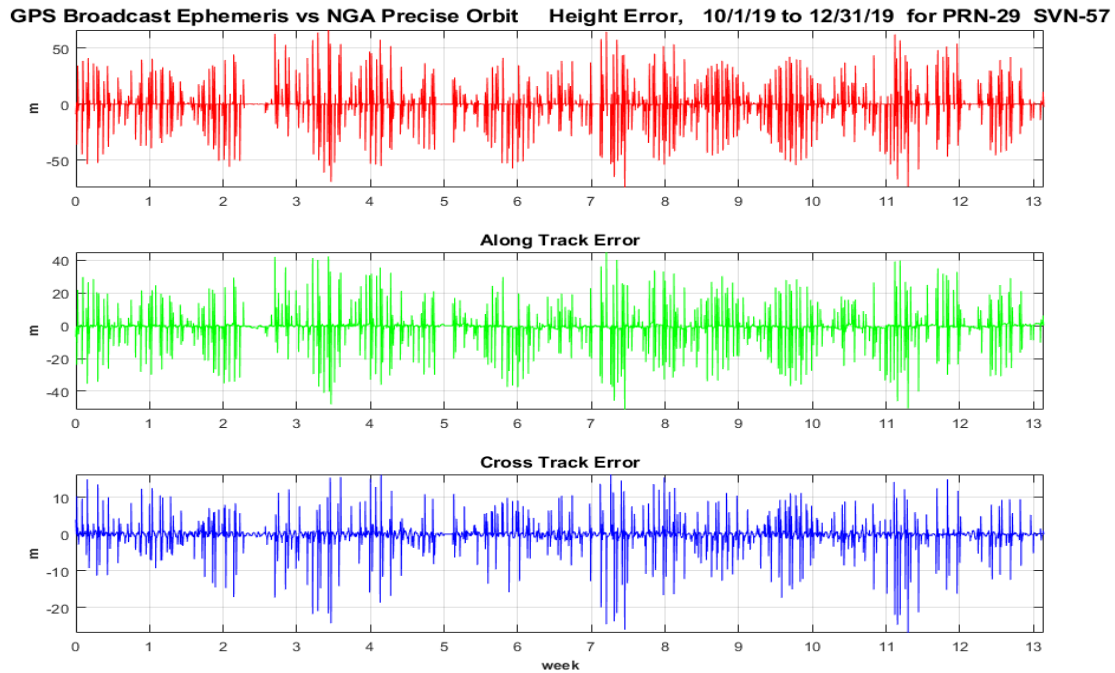
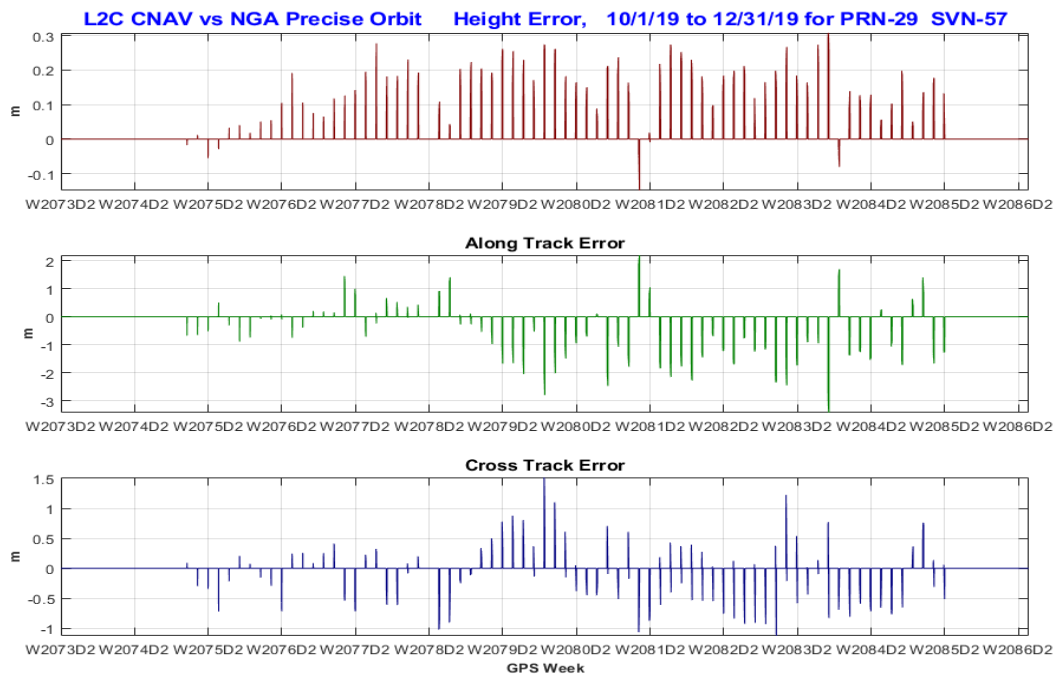
**Figure 10-41. Orbit Error PRN24 (SVN-65) Using L2C CNAV Data****Figure 10-42. Orbit Error PRN25 (SVN-62) Using C/A Nav Data**

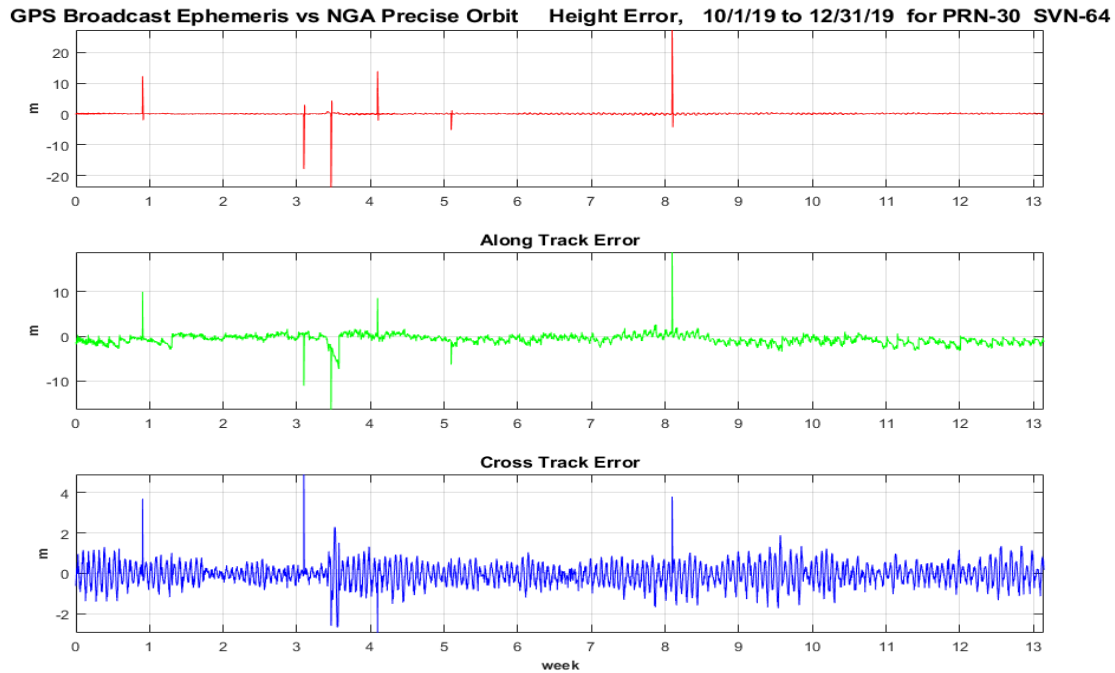
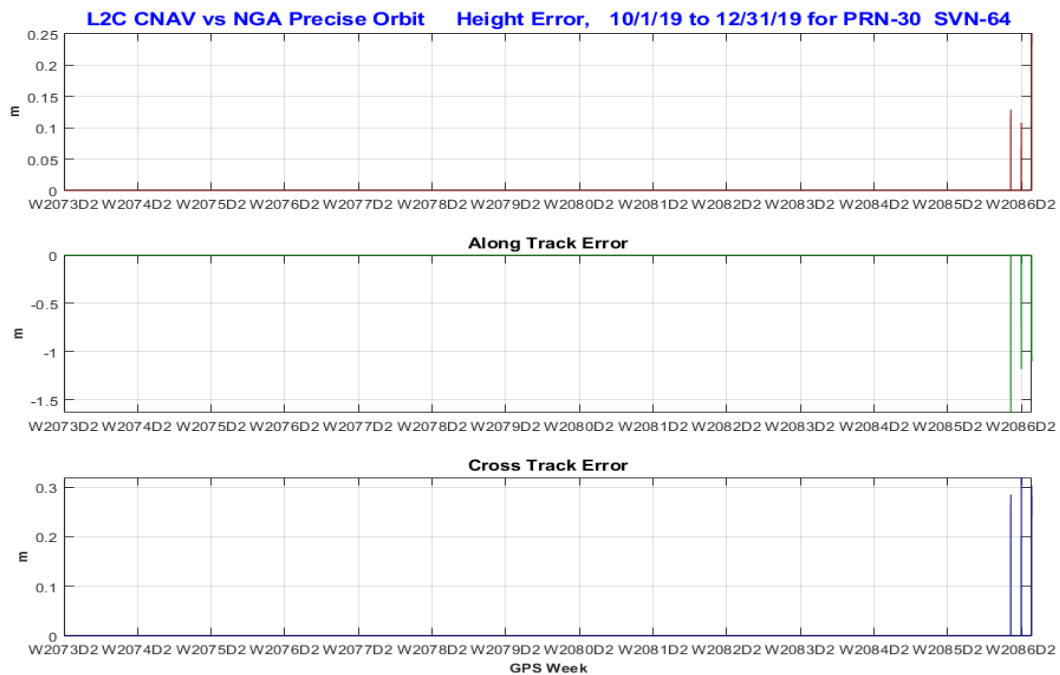


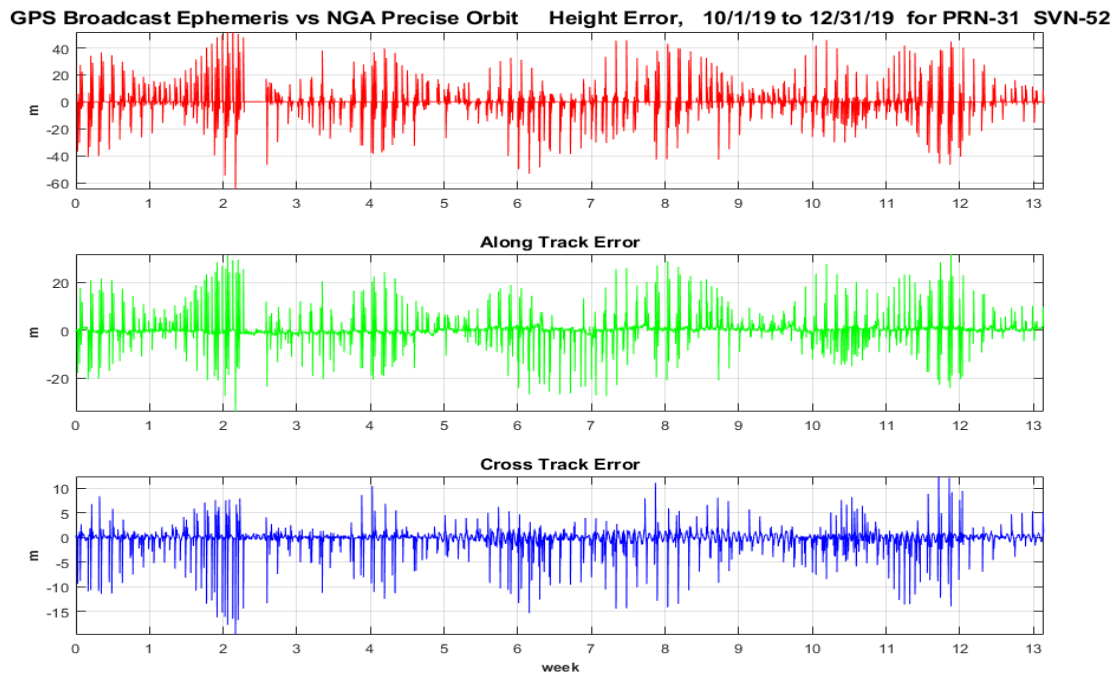
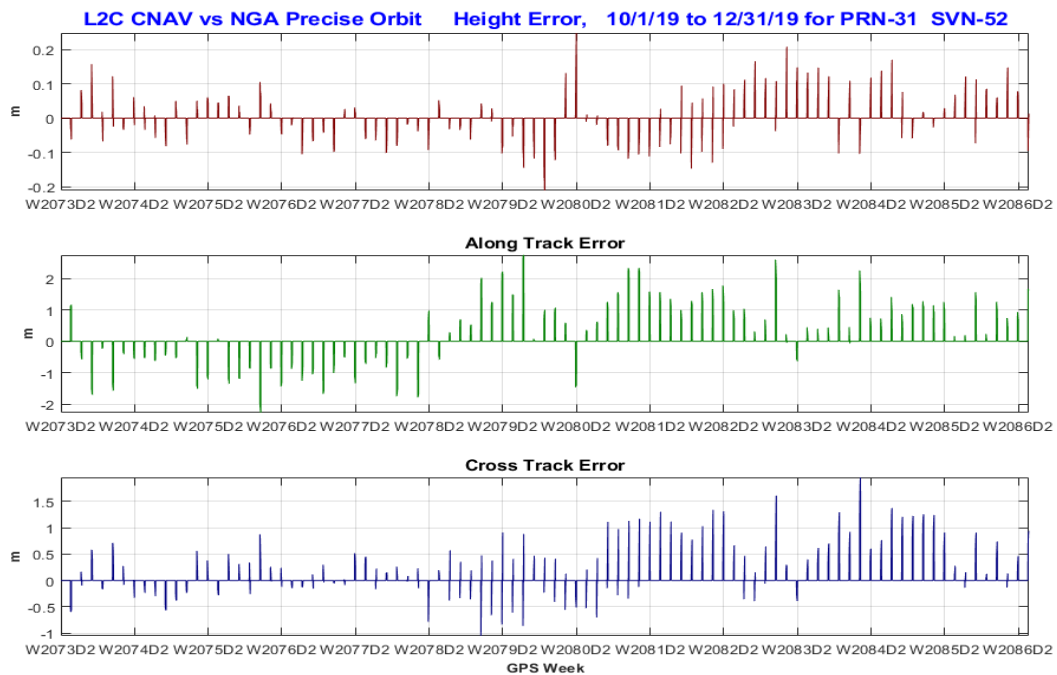
**Figure 10-43. Orbit Error PRN25 (SVN-62) Using L2C CNAV Data****Figure 10-44. Orbit Error PRN26 (SVN-71) Using C/A Nav Data**

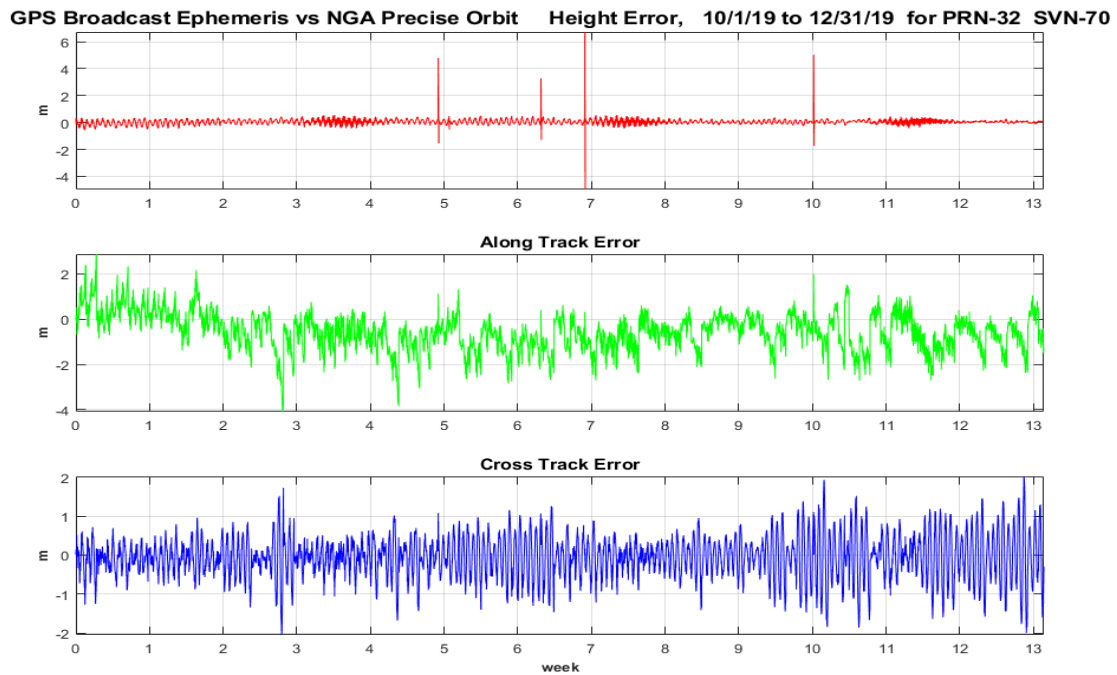
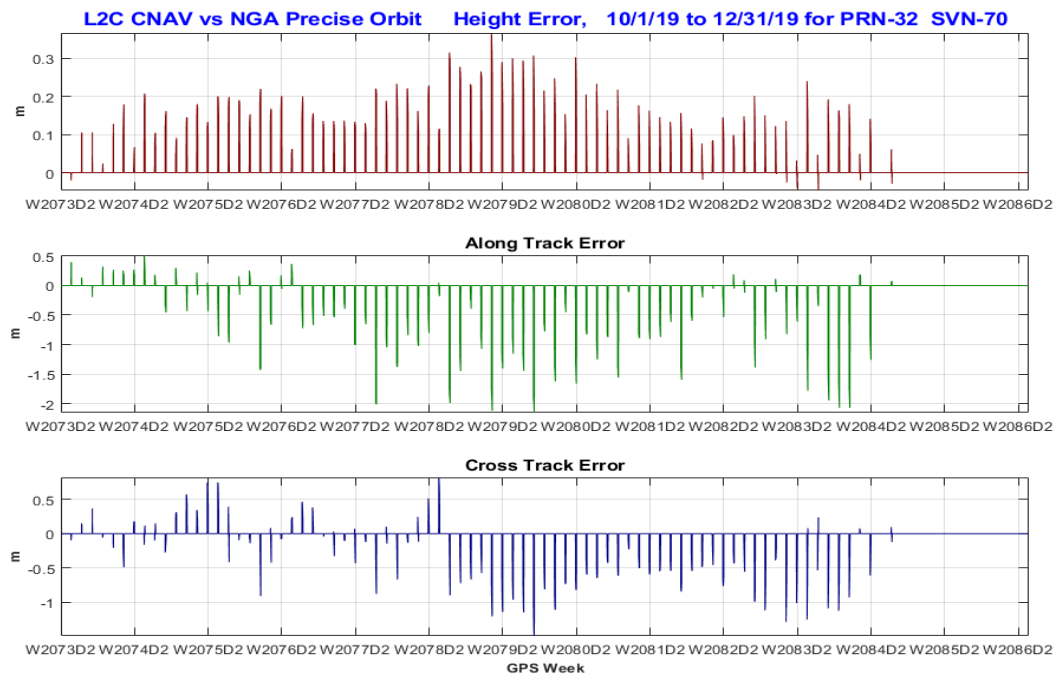
**Figure 10-45. Orbit Error PRN26 (SVN-71) Using L2C CNAV Data****Figure 10-46. Orbit Error PRN27 (SVN-66) Using C/A Nav Data**

**Figure 10-47. Orbit Error PRN27 (SVN-66) Using L2C CNAV Data****Figure 10-48. Orbit Error PRN28 (SVN-44) Using C/A Nav Data**

**Figure 10-49. Orbit Error PRN29 (SVN-57) Using C/A Nav Data****Figure 10-50. Orbit Error PRN29 (SVN-57) Using L2C CNAV Data**

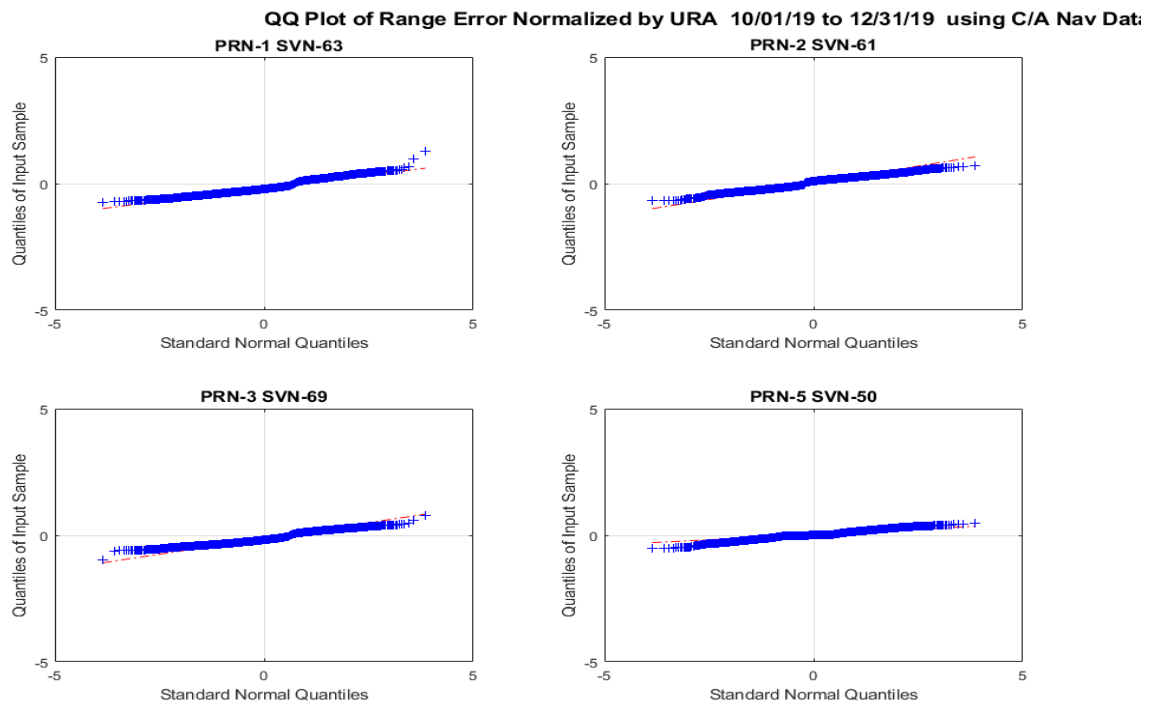
**Figure 10-51. Orbit Error PRN30 (SVN-64) Using C/A Nav Data****Figure 10-52. Orbit Error PRN30 (SVN-64) Using L2C CNAV Data**

**Figure 10-53. Orbit Error PRN31 (SVN-52) Using C/A Nav Data****Figure 10-54. Orbit Error PRN31 (SVN-52) Using L2C CNAV Data**

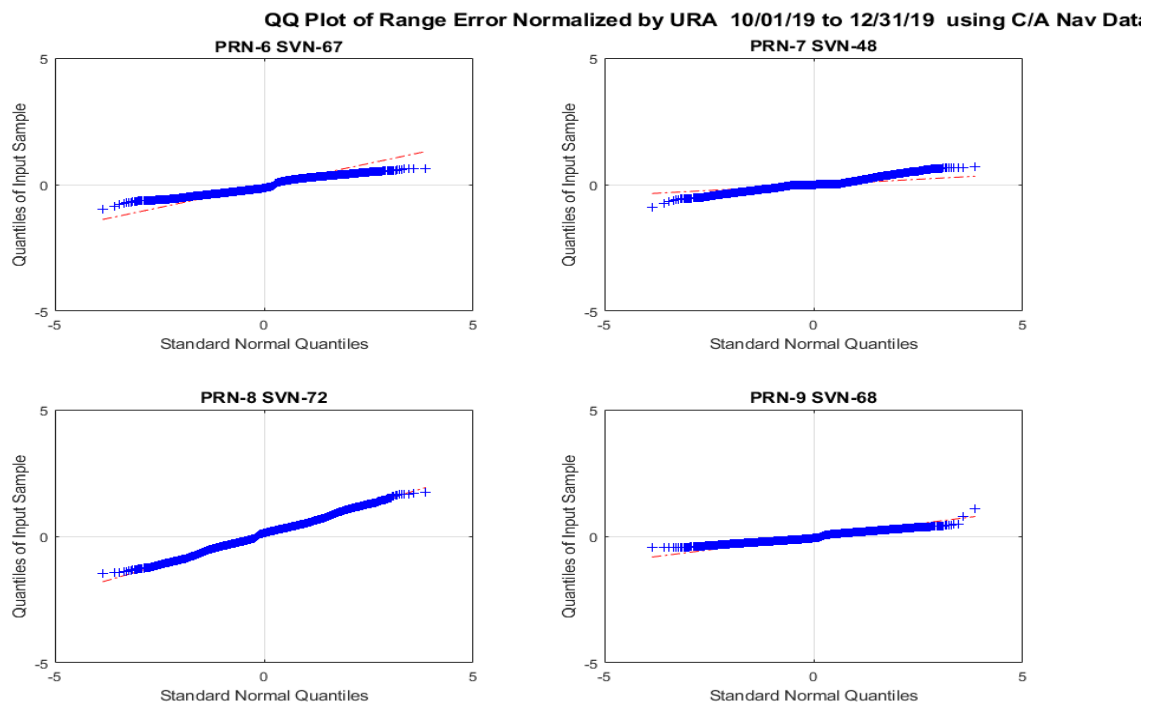
**Figure 10-55. Orbit Error PRN32 (SVN-70) Using C/A Nav Data****Figure 10-56. Orbit Error PRN32 (SVN-70) Using L2C CNAV Data**

## 10.6 QQ Plots of URA Normalized Error for All Satellites

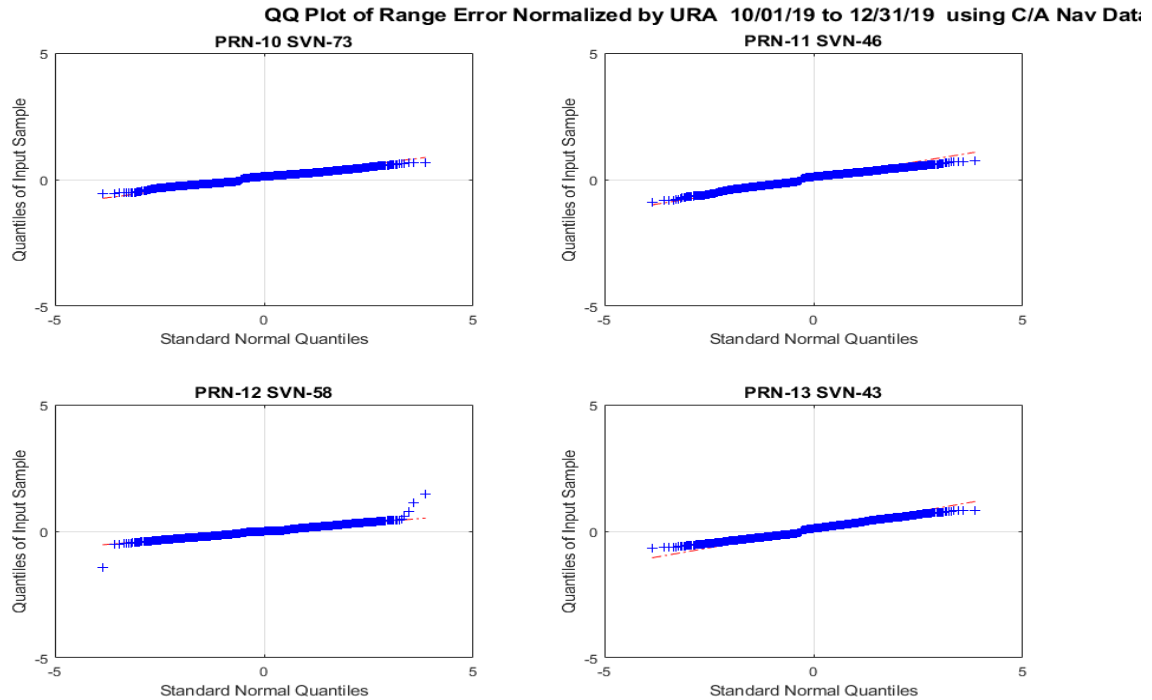
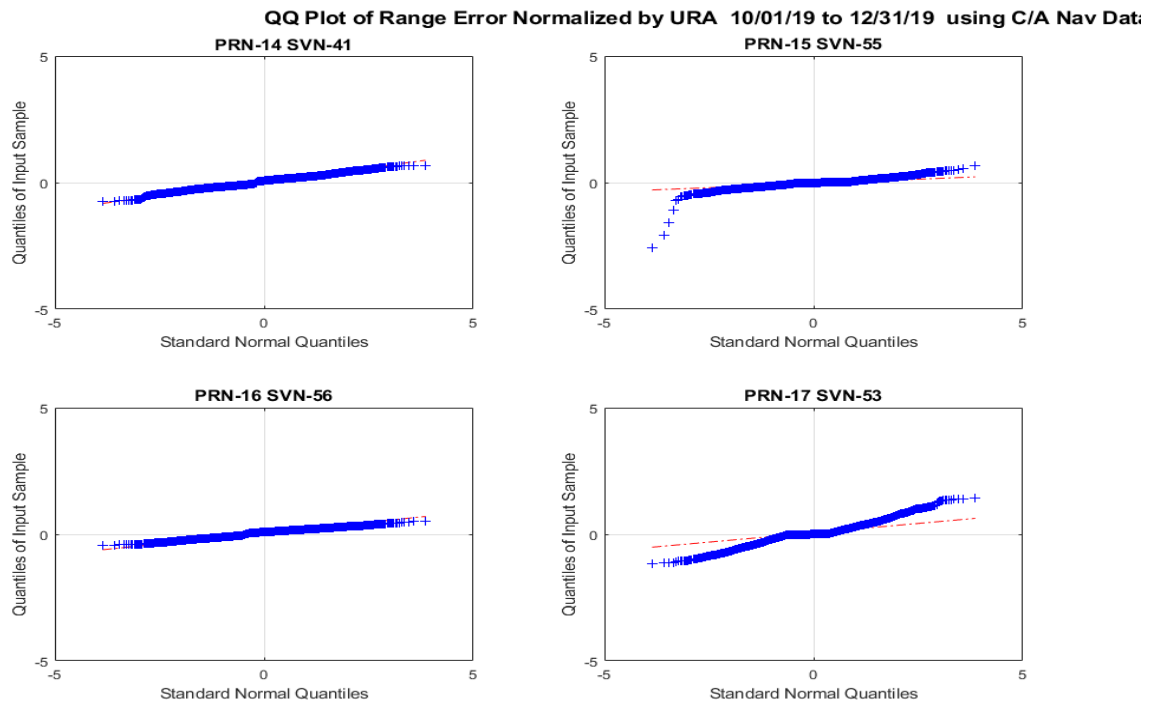
**Figure 10-57. QQ Plots of Range Error PRNs 1 to 5 Using C/A Nav Data**

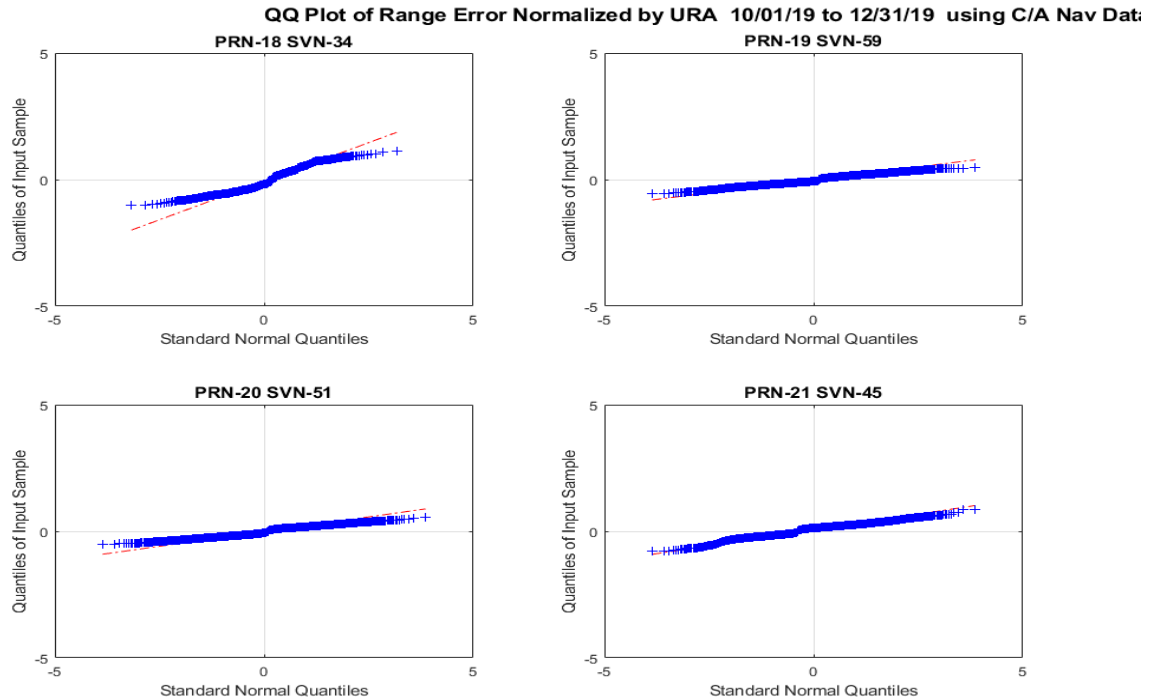
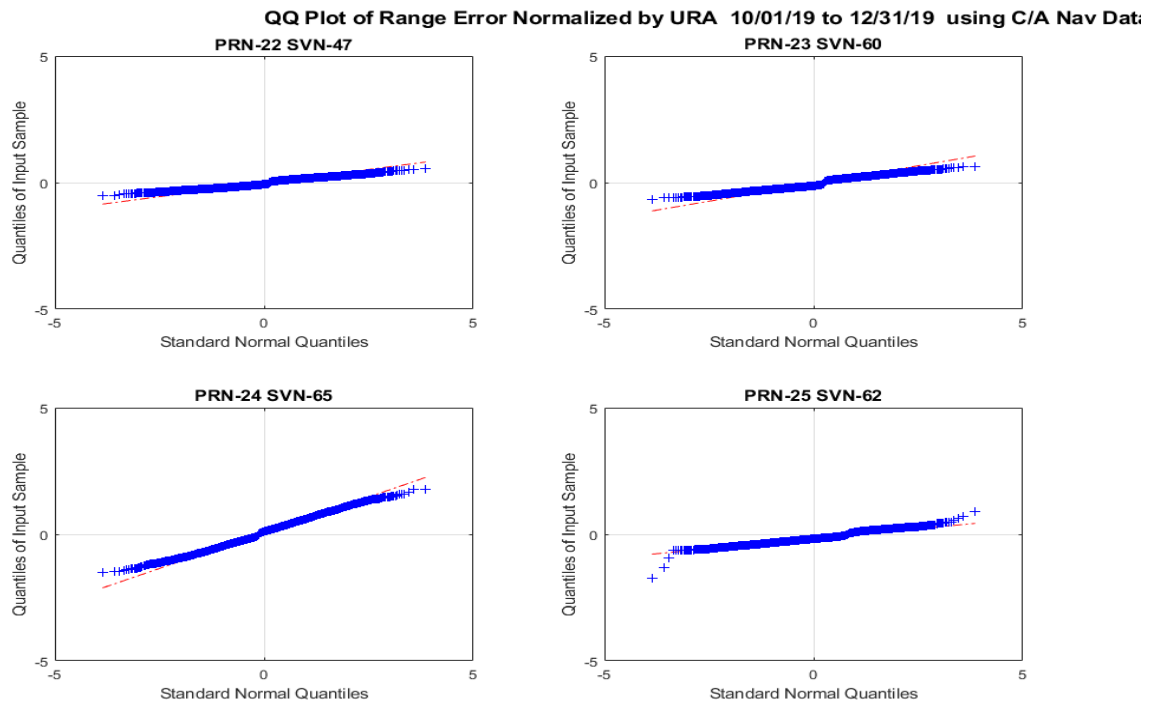


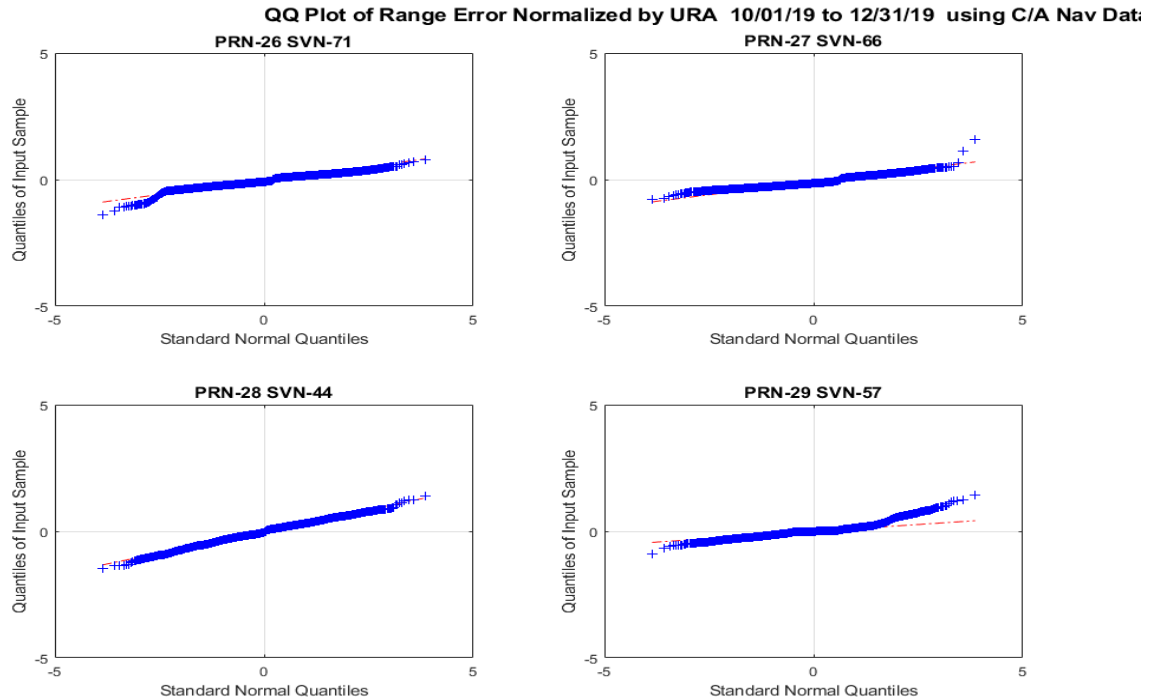
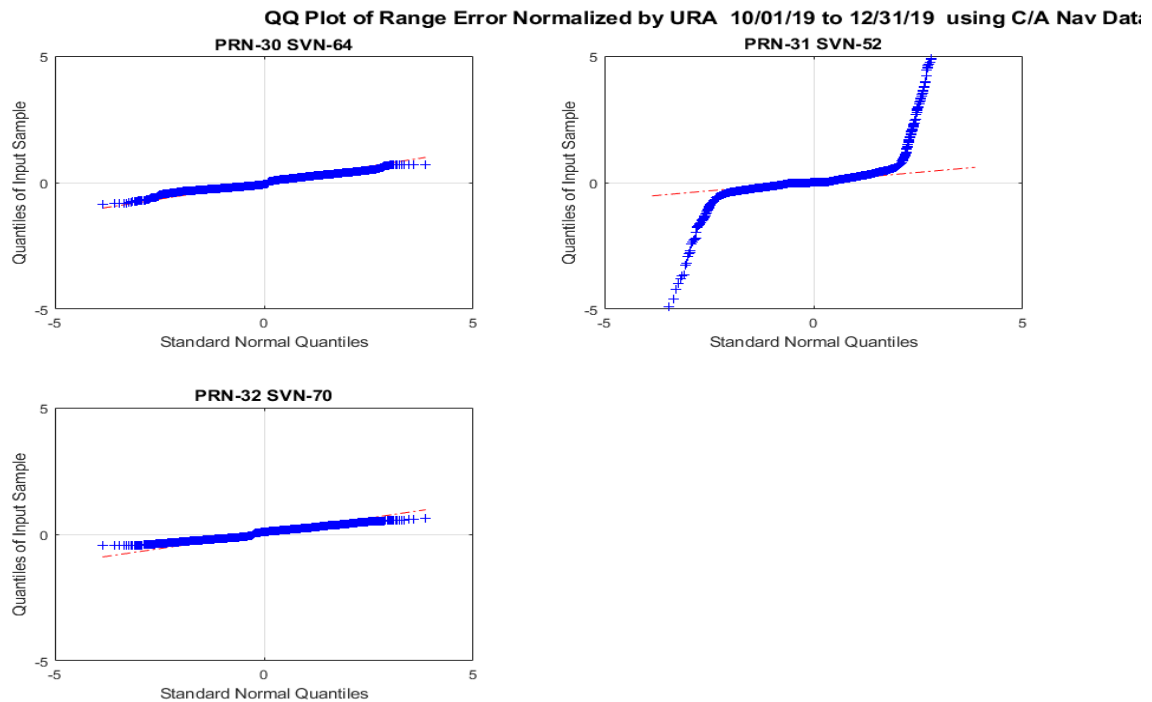
**Figure 10-58. QQ Plots of Range Error PRNs 6 to 9 Using C/A Nav Data**

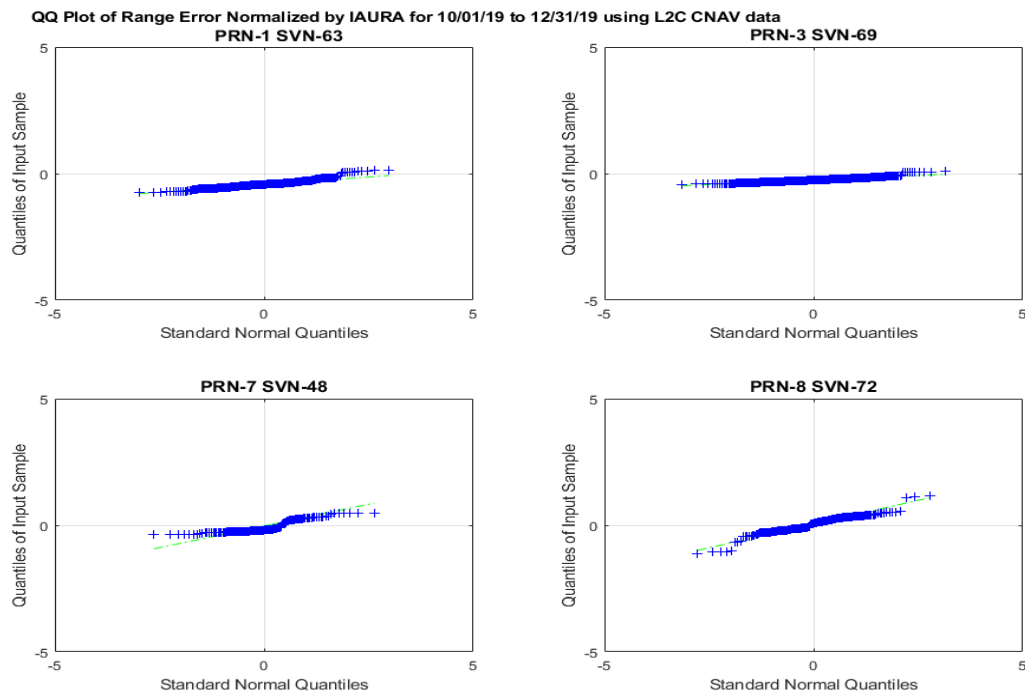
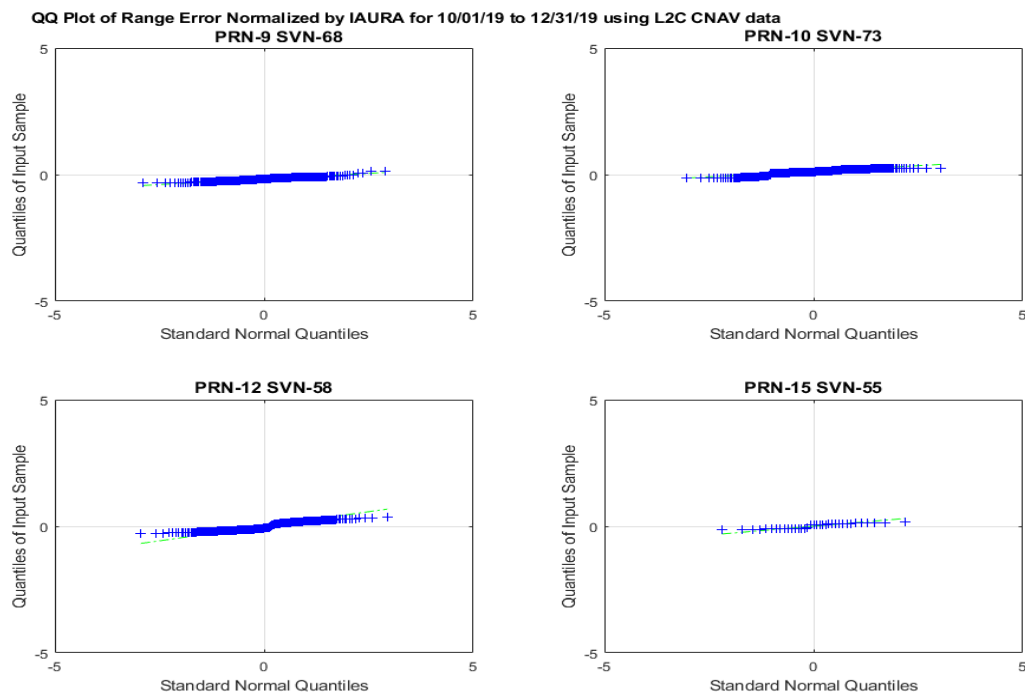


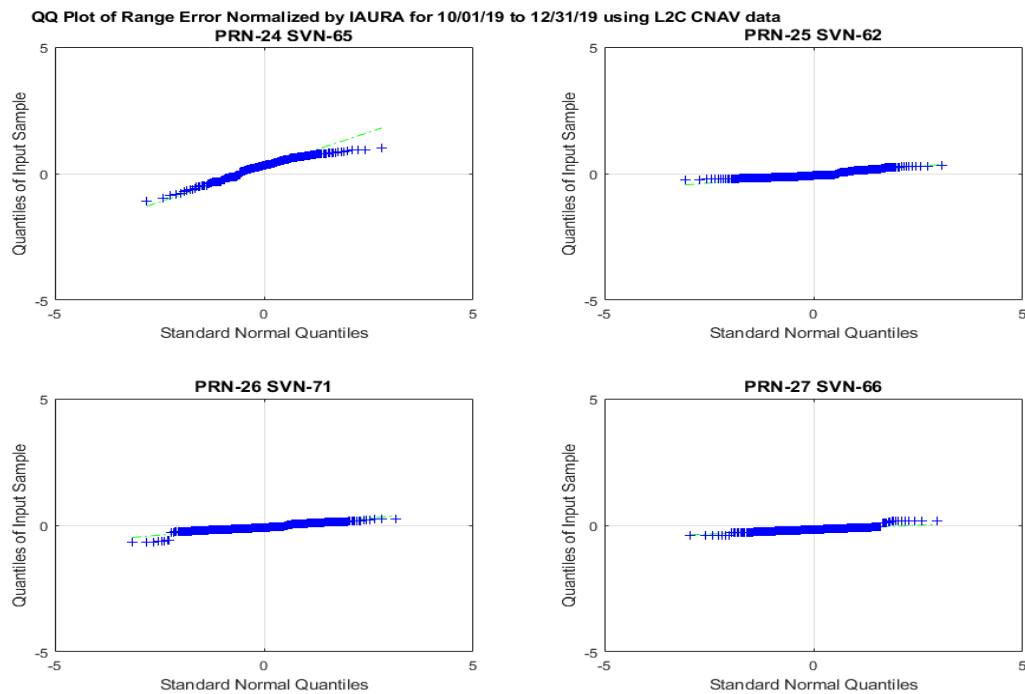
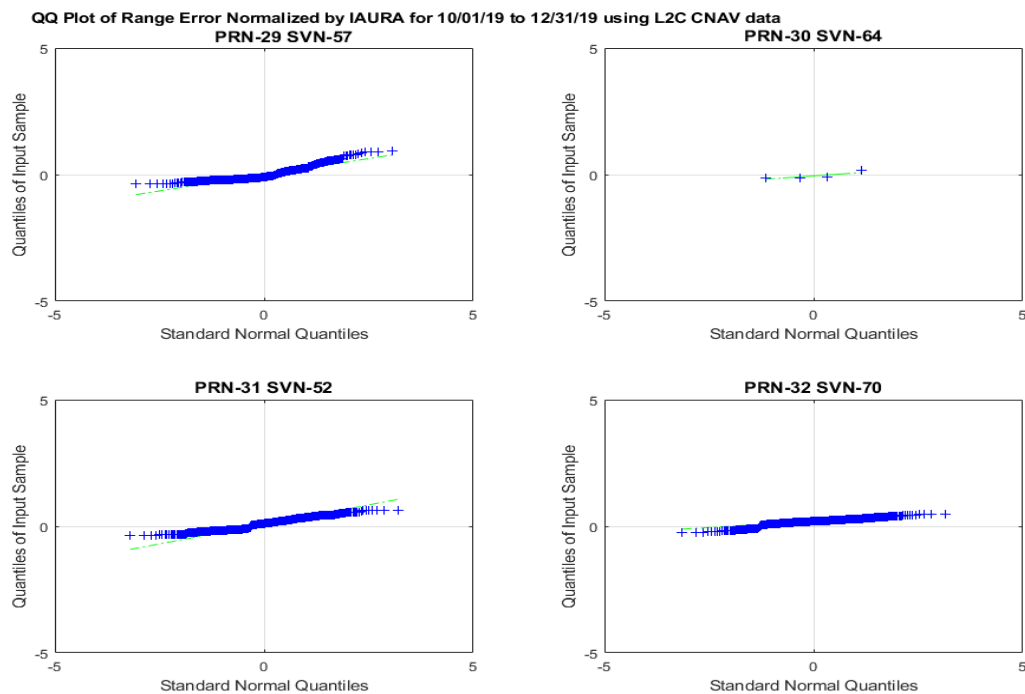


**Figure 10-59. QQ Plots of Range Error PRNs 10 to 13 Using C/A Nav Data****Figure 10-60. QQ Plots of Range Error PRNs 14 to 17 Using C/A Nav Data**

**Figure 10-61. QQ Plots of Range Error PRNs 18 to 21 Using C/A Nav Data****Figure 10-62. QQ Plots of Range Error PRNs 22 to 25 Using C/A Nav Data**

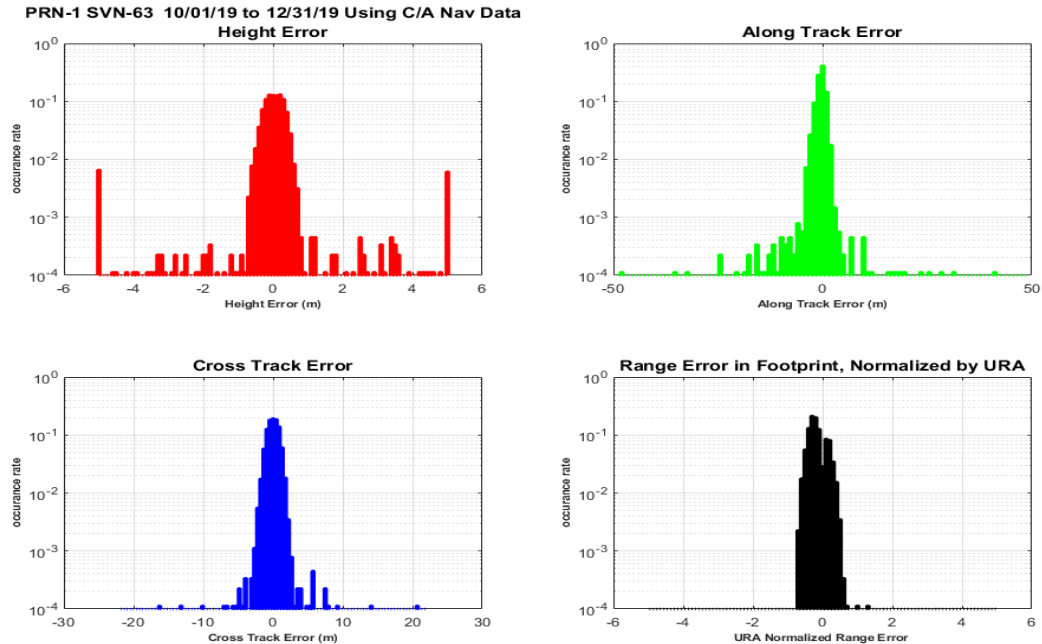
**Figure 10-63. QQ Plots of Range Error PRNs 26 to 29 Using C/A Nav Data****Figure 10-64. QQ Plots of Range Error PRNs 30 to 32 Using C/A Nav Data**

**Figure 10-65. QQ Plots of Range Error PRNs 1, 3, 7, and 8 Using L2C CNAV Data****Figure 10-66. QQ Plots of Range Error PRNs 9, 10, 12, and 15 Using L2C CNAV Data**

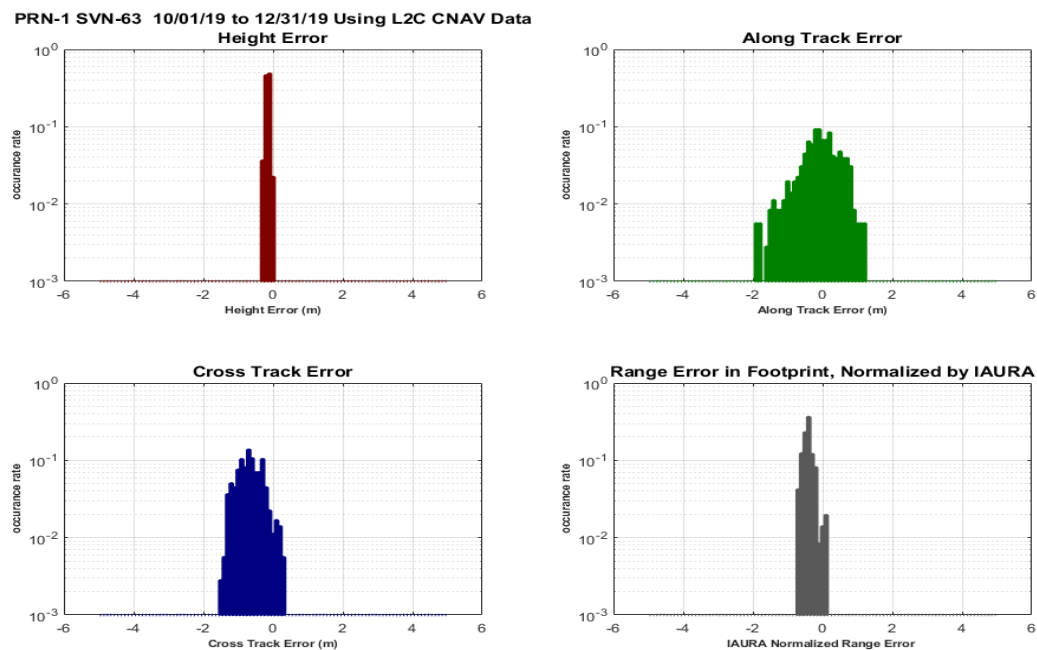
**Figure 10-67. QQ Plots of Range Error PRNs 24, 25, 26 and 27 Using L2C CNAV Data****Figure 10-68. QQ Plots of Range Error PRNs 29, 30, 31, and 32 Using L2C CNAV Data**

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

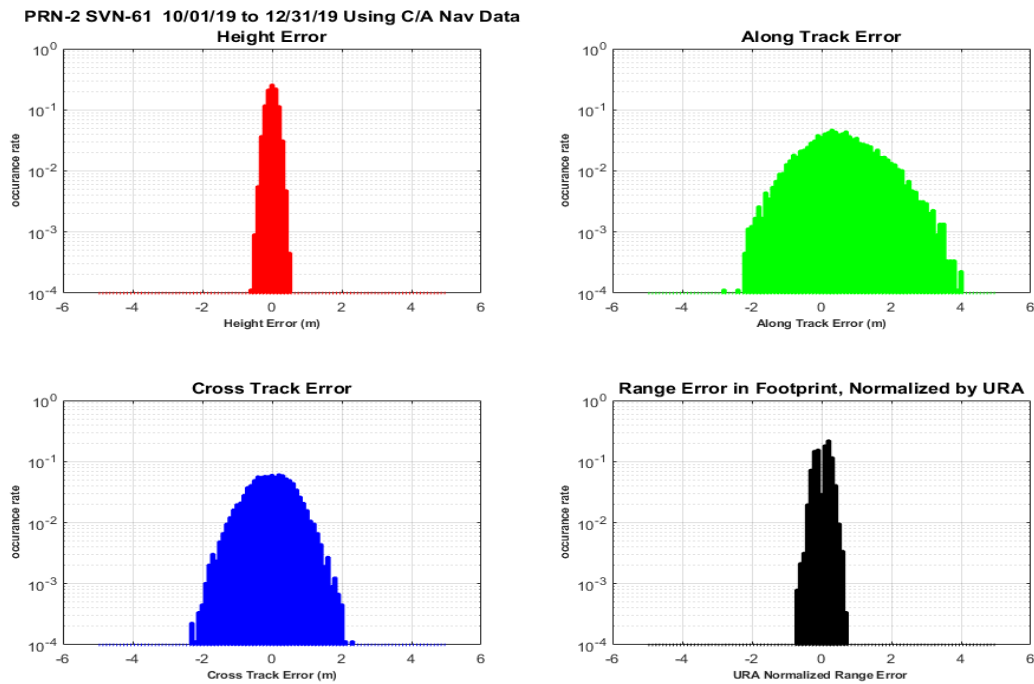
**Figure 10-69. Histograms of H, A, C, and Range Error PRN1 (SVN-63) Using C/A Nav Data**



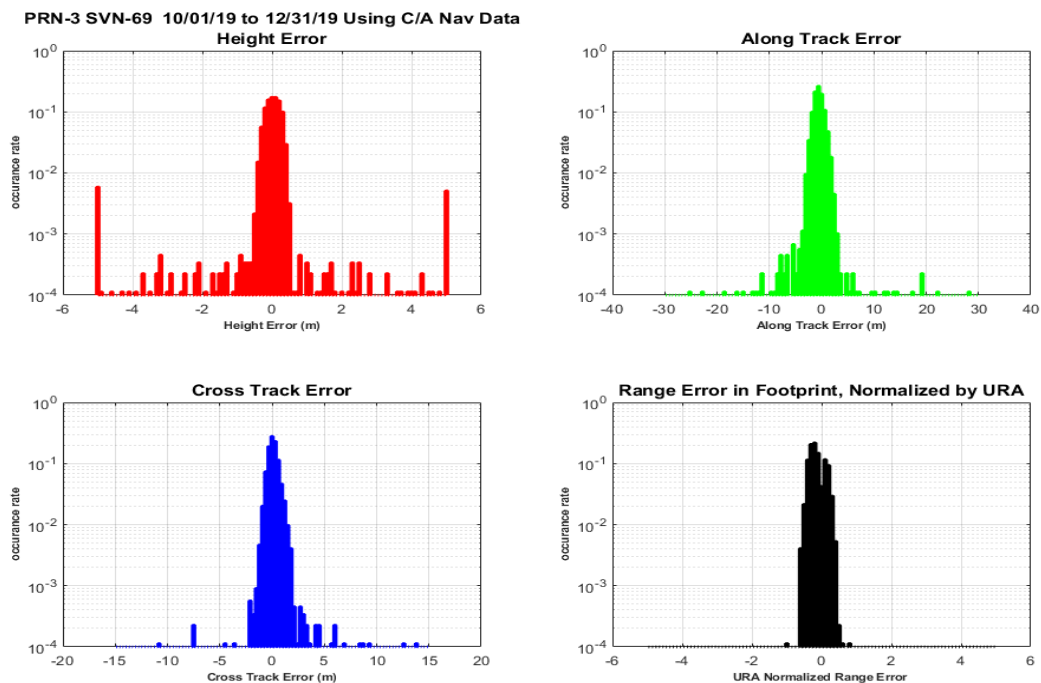
**Figure 10-70. Histograms of H, A, C, and Range Error PRN1 (SVN-63) Using L2C CNAV Data**



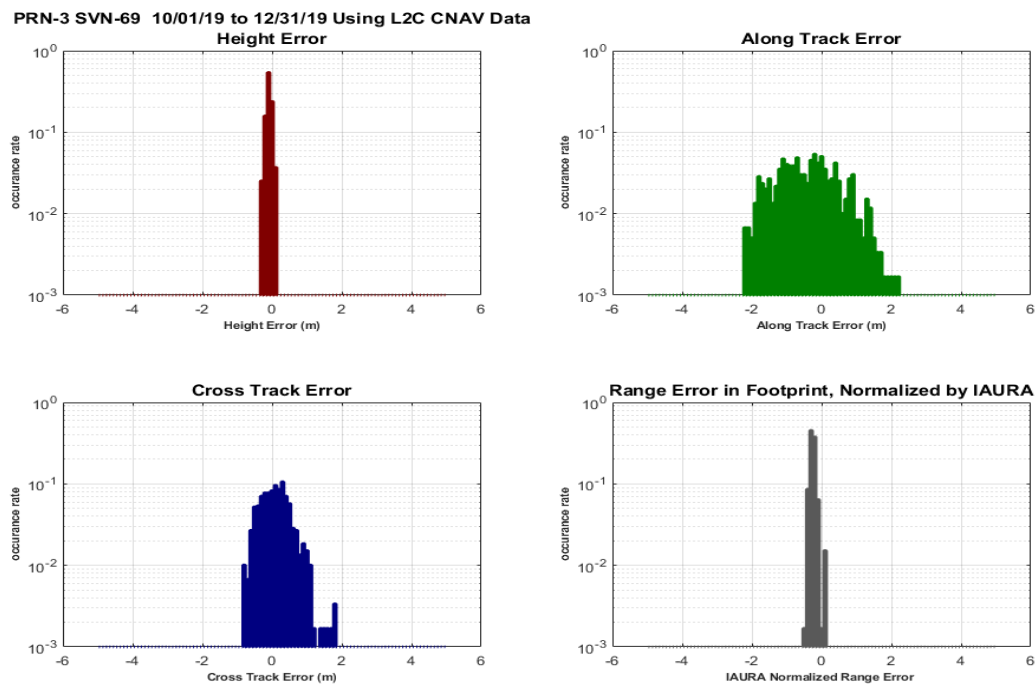
**Figure 10-71. Histograms of H, A, C, and Range Error PRN2 (SVN-61) Using C/A Nav Data**



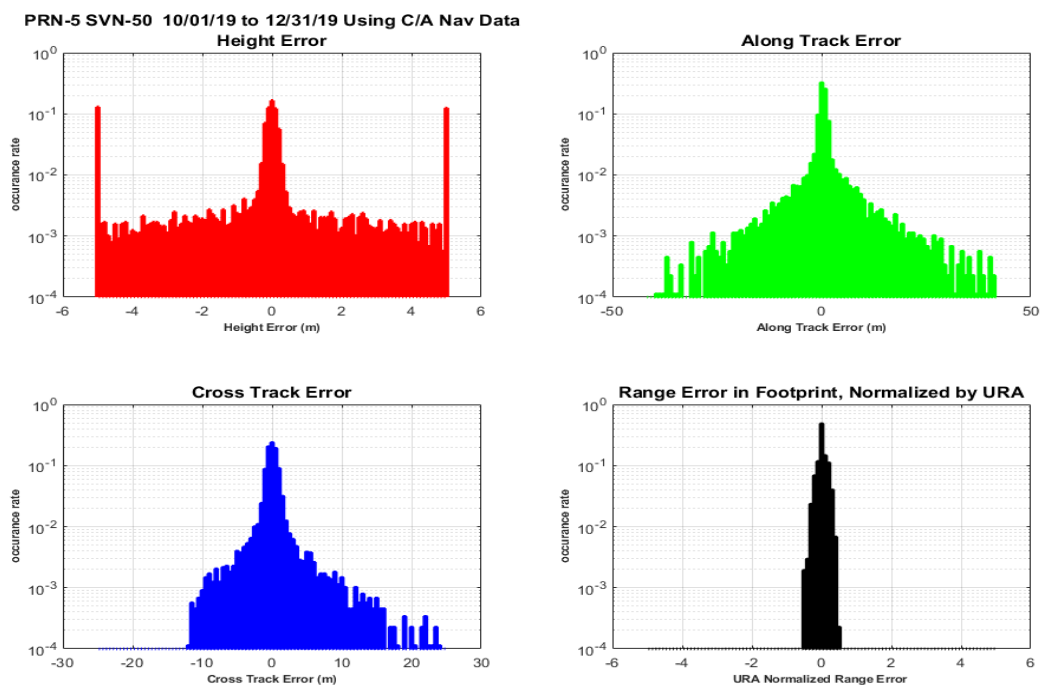
**Figure 10-72. Histograms of H, A, C, and Range Error PRN3 (SVN-69) Using C/A Nav Data**



**Figure 10-73. Histograms of H, A, C, and Range Error PRN3 (SVN-69) Using L2C CNAV Data**

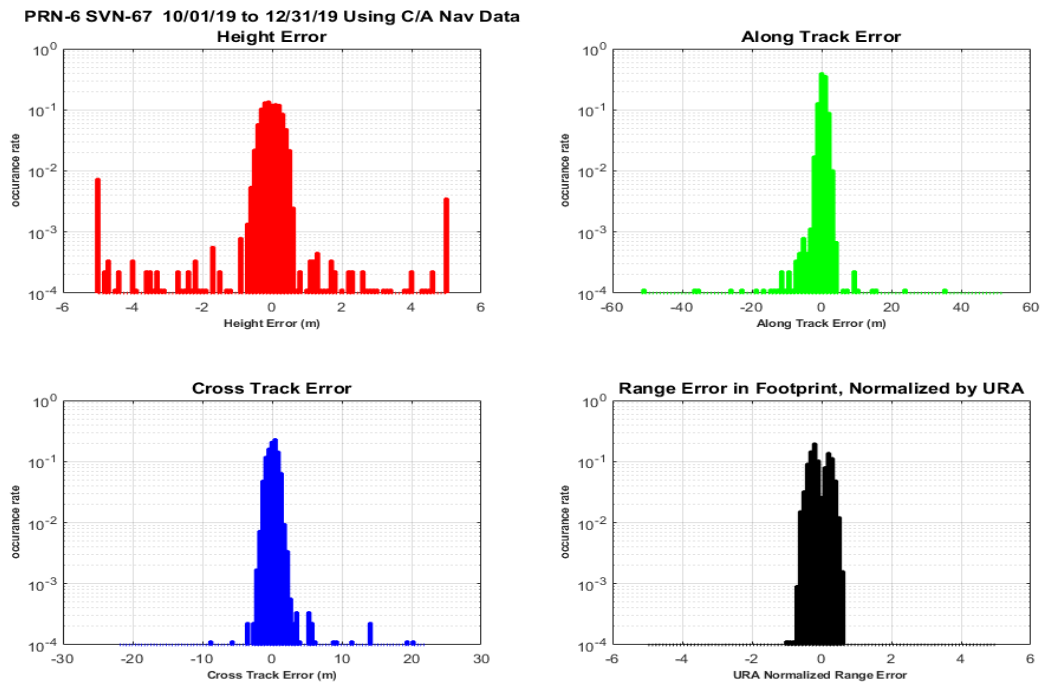


**Figure 10-74. Histograms of H, A, C, and Range Error PRN5 (SVN-50) Using C/A Nav Data**

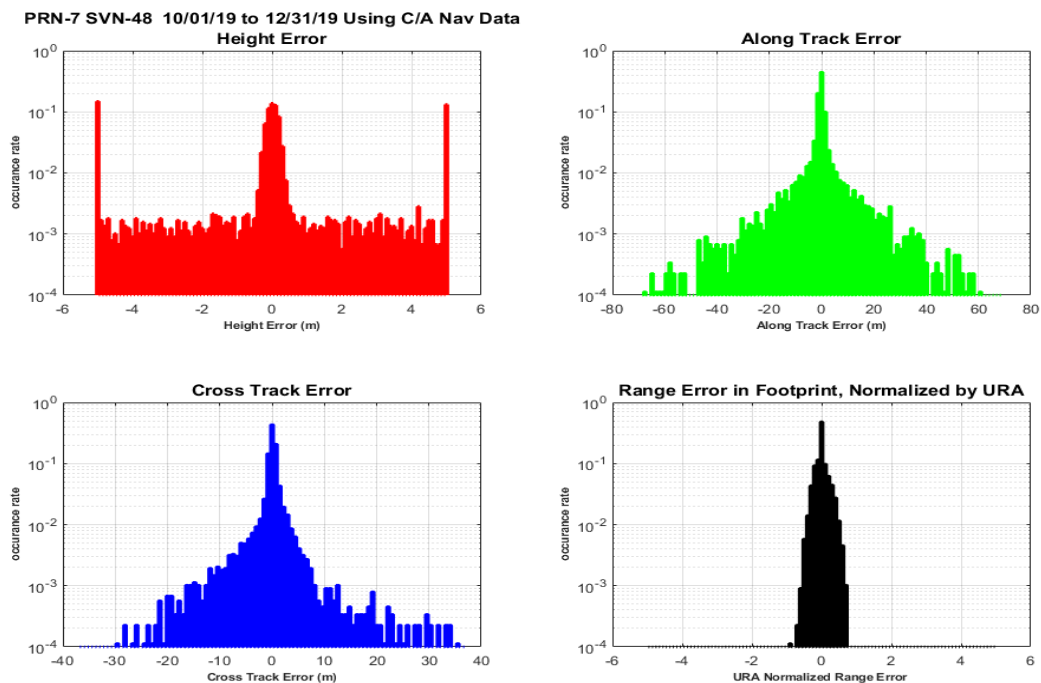




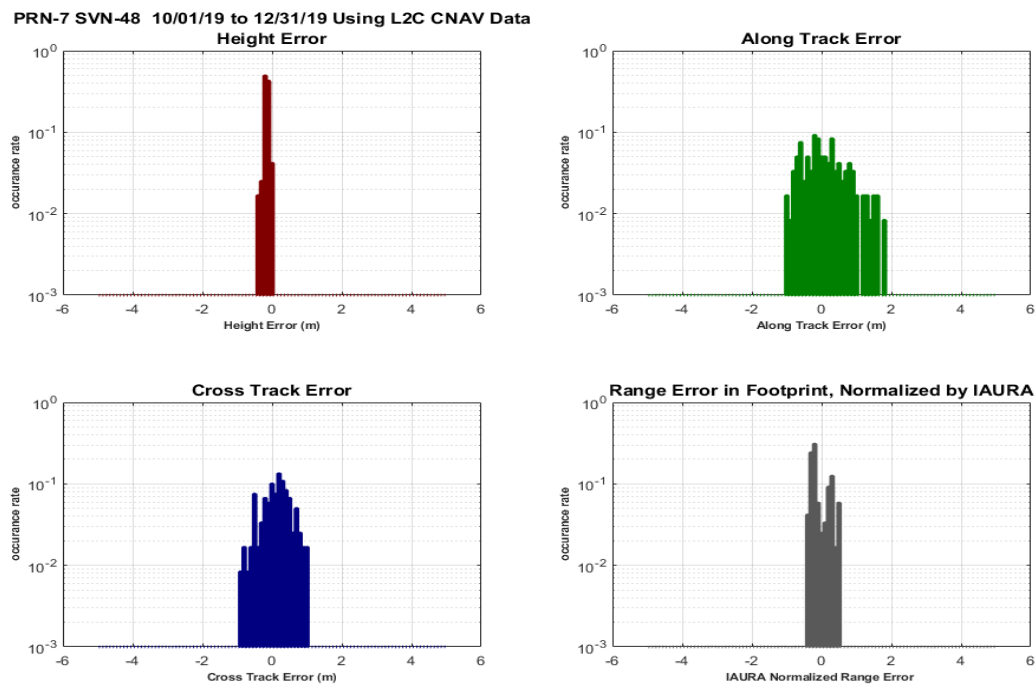
**Figure 10-75. Histograms of H, A, C, and Range Error PRN6 (SVN-67) Using C/A Nav Data**



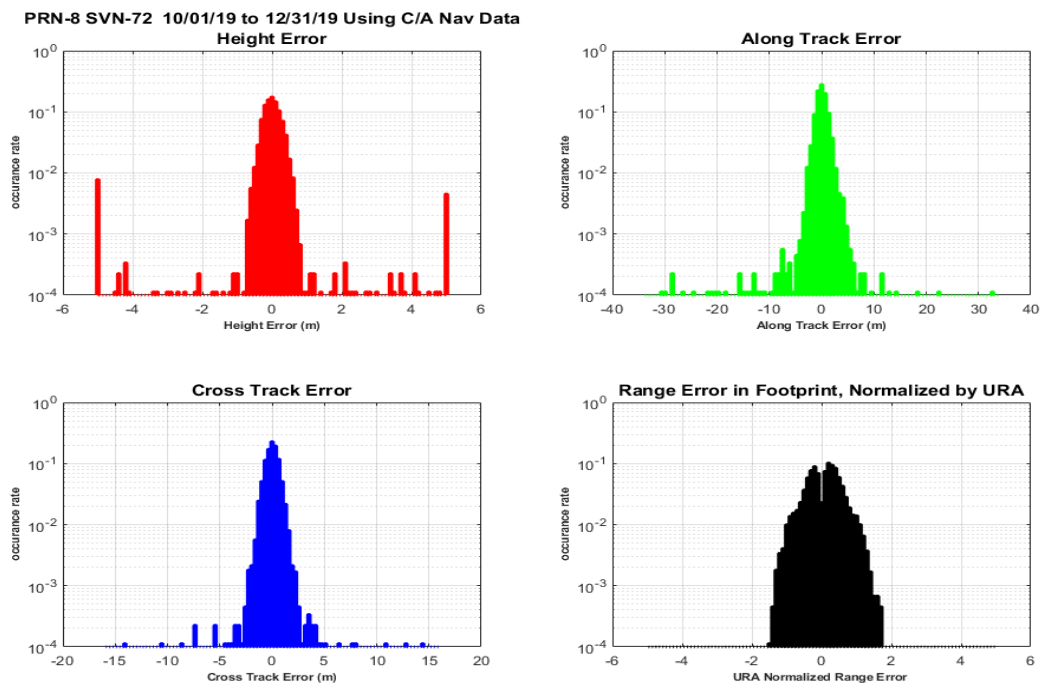
**Figure 10-76. Histograms of H, A, C, and Range Error PRN7 (SVN-48) Using C/A Nav Data**



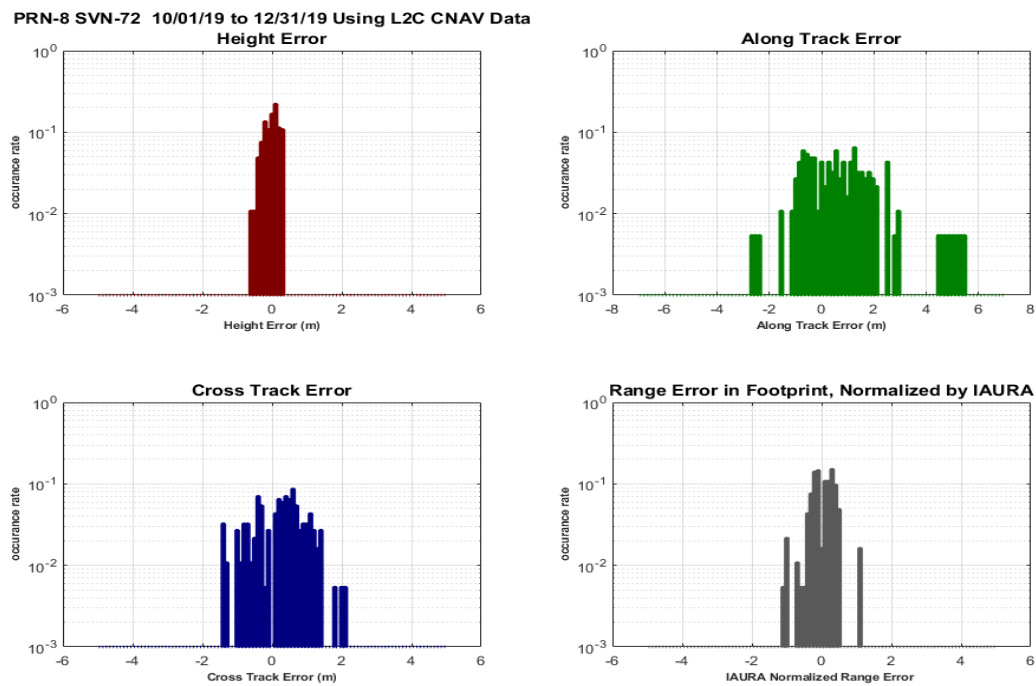
**Figure 10-77. Histograms of H, A, C, and Range Error PRN7 (SVN-48) Using L2C CNAV Data**



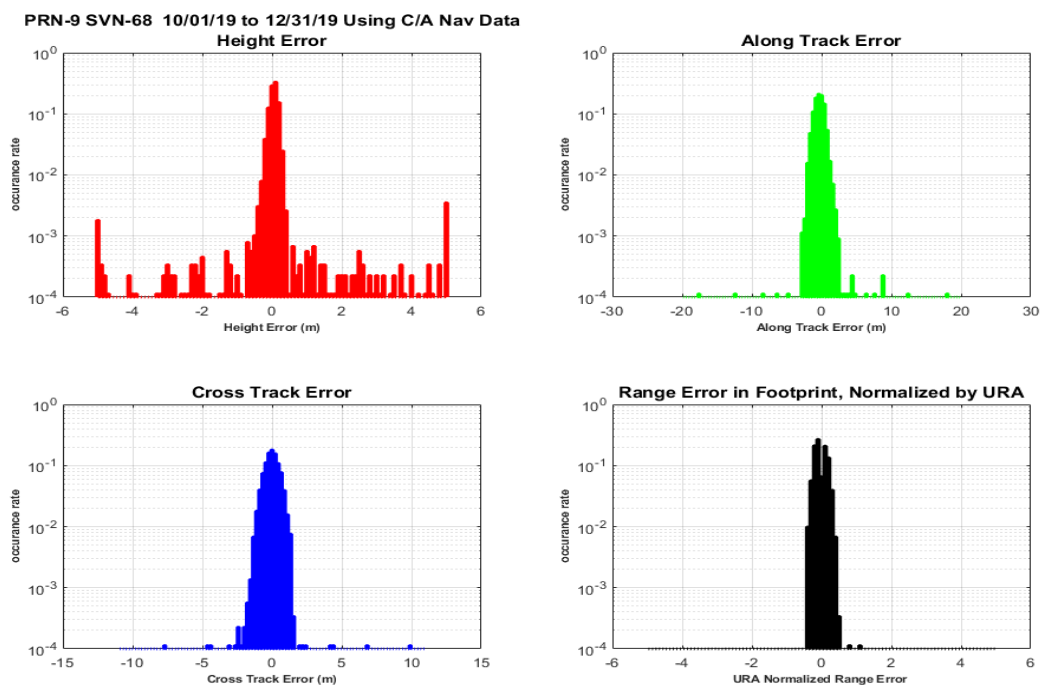
**Figure 10-78. Histograms of H, A, C, and Range Error PRN8 (SVN-72) Using C/A Nav Data**



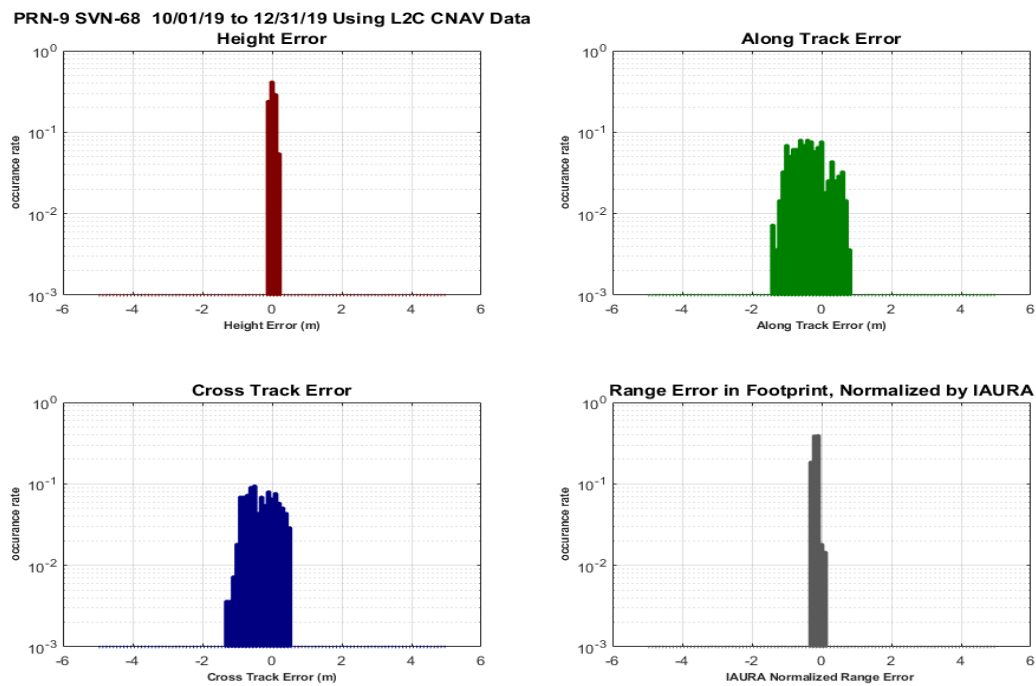
**Figure 10-79. Histograms of H, A, C, and Range Error PRN8 (SVN-72) Using L2C CNAV Data**



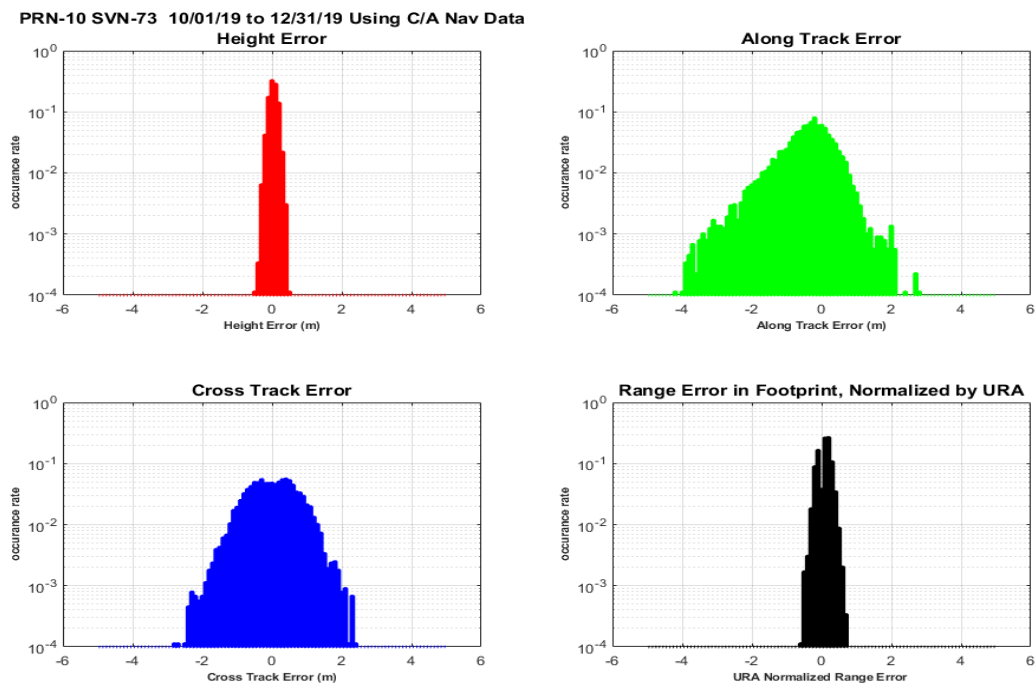
**Figure 10-80. Histograms of H, A, C, and Range Error PRN9 (SVN-68) Using C/A Nav Data**



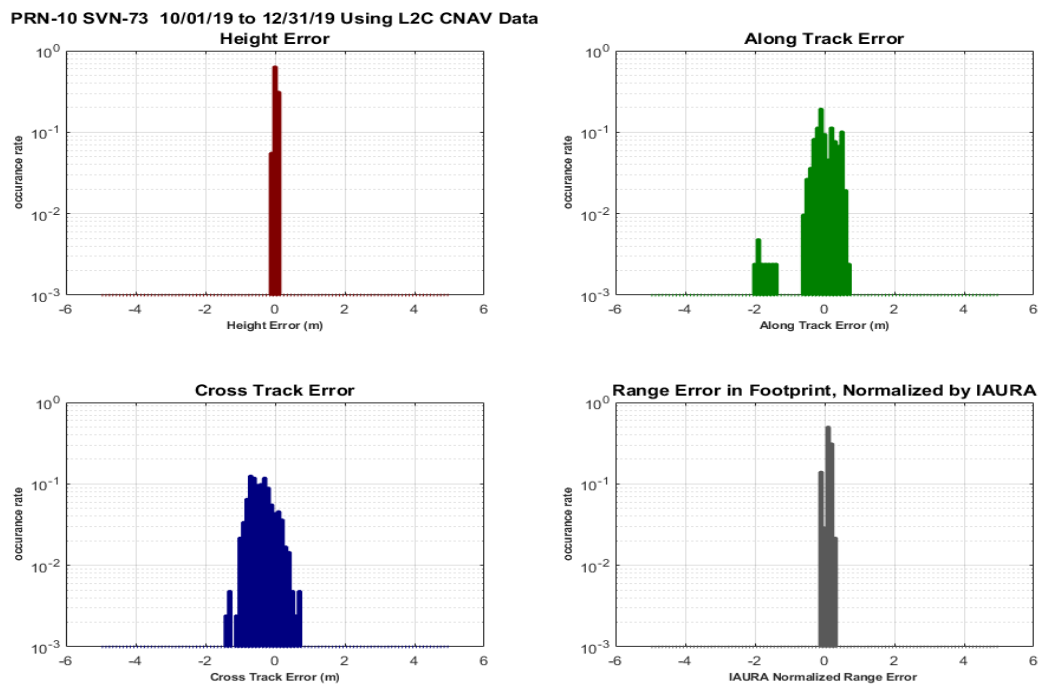
**Figure 10-81. Histograms of H, A, C, and Range Error PRN9 (SVN-68) Using L2C CNAV Data**



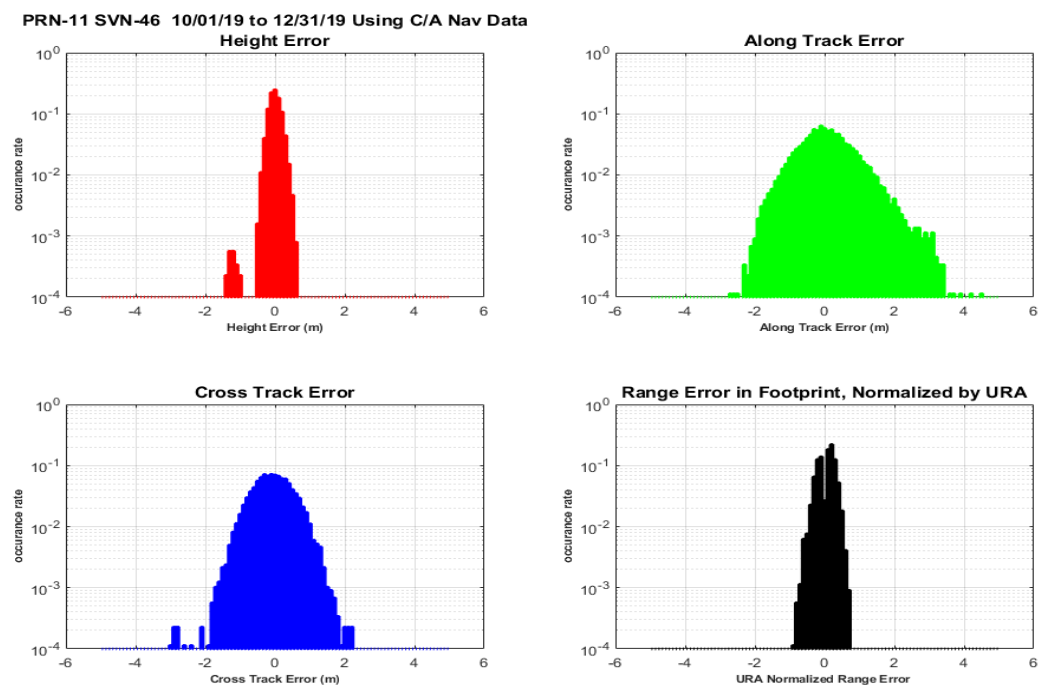
**Figure 10-82. Histograms of H, A, C, and Range Error PRN10 (SVN-73) Using C/A Nav Data**



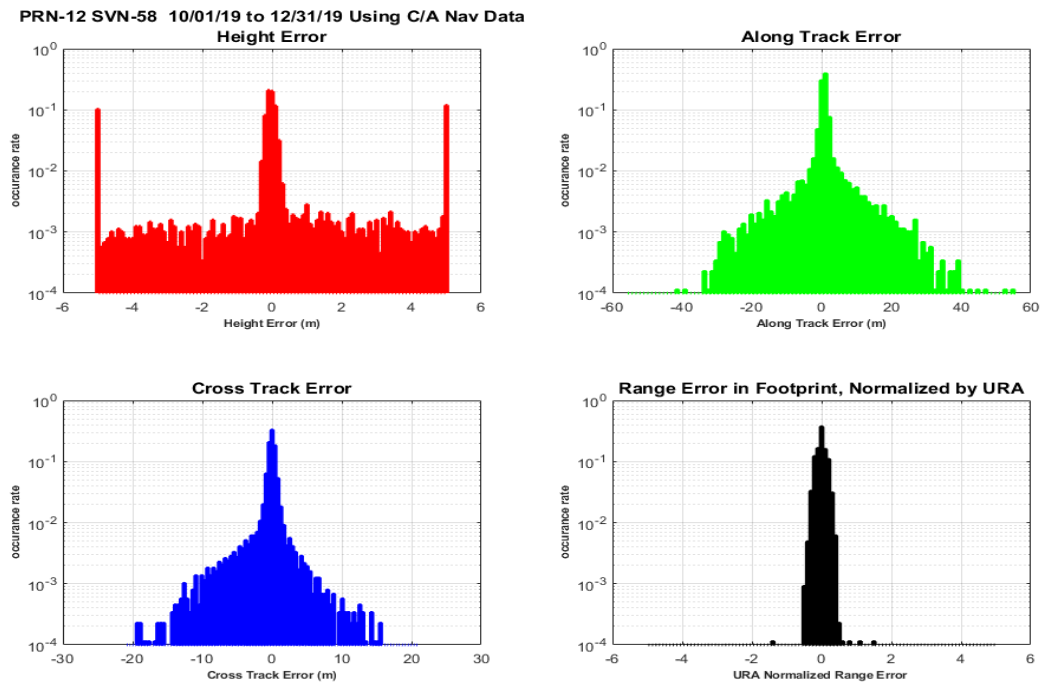
**Figure 10-83. Histograms of H, A, C, and Range Error PRN10 (SVN-73) Using L2C CNAV Data**



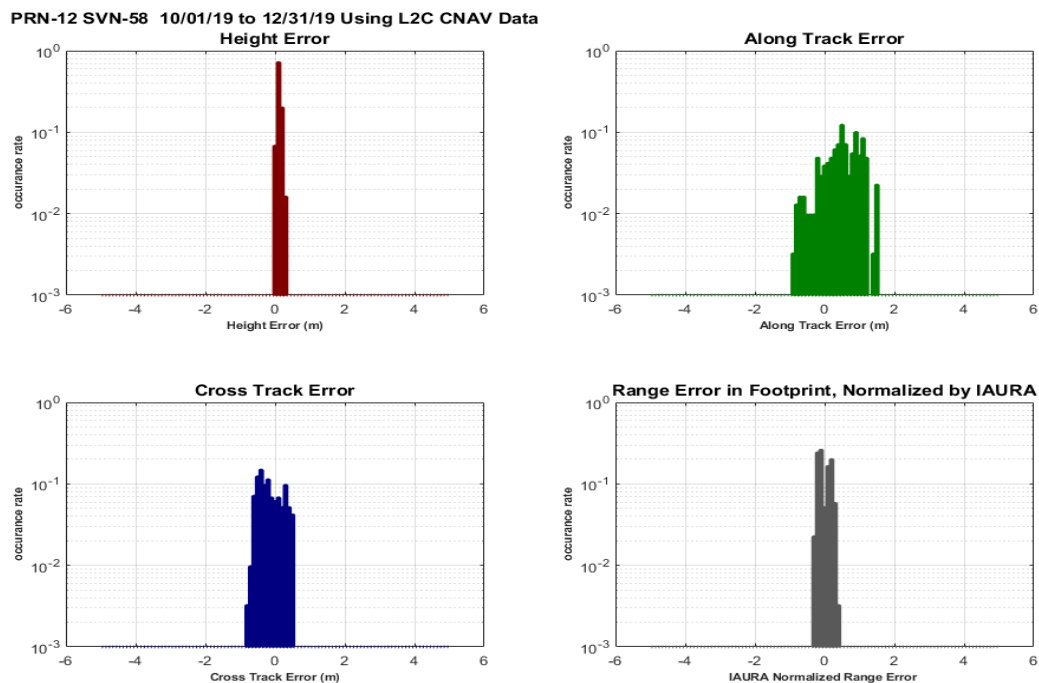
**Figure 10-84. Histograms of H, A, C, and Range Error PRN11 (SVN-46) Using C/A Nav Data**



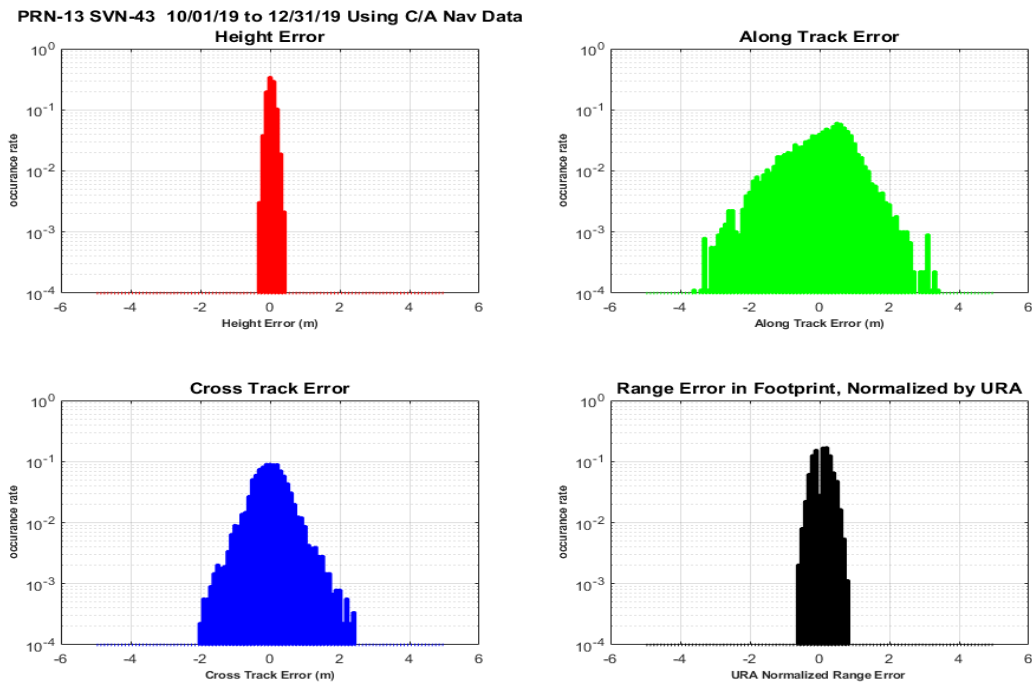
**Figure 10-85. Histograms of H, A, C, and Range Error PRN12 (SVN-58) Using C/A Nav Data**



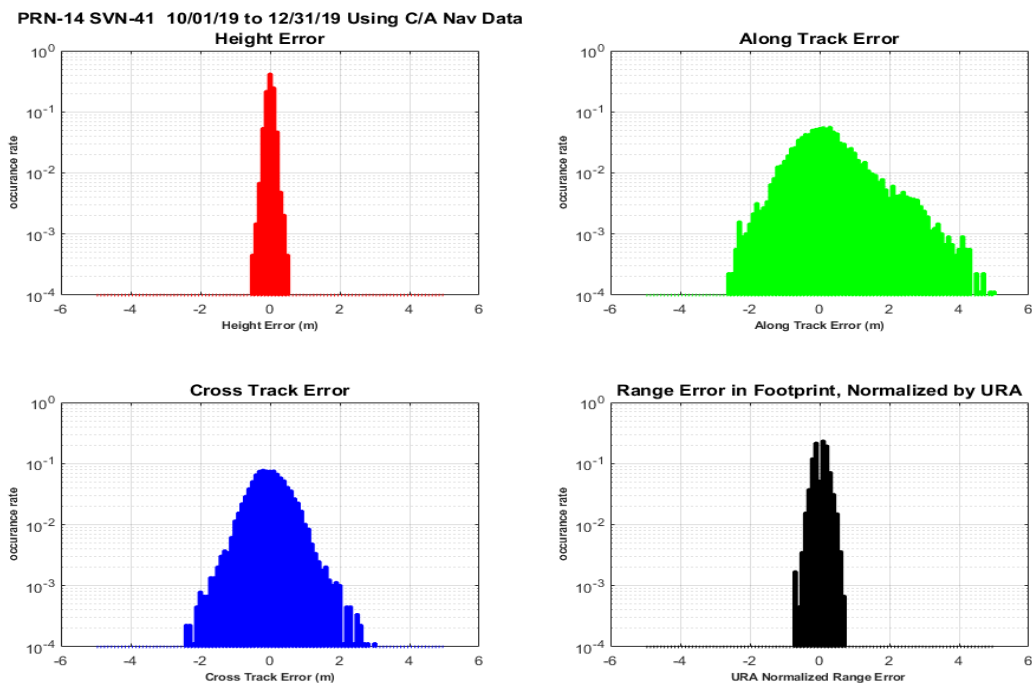
**Figure 10-86. Histograms of H, A, C, and Range Error PRN12 (SVN-58) Using L2C CNAV Data**



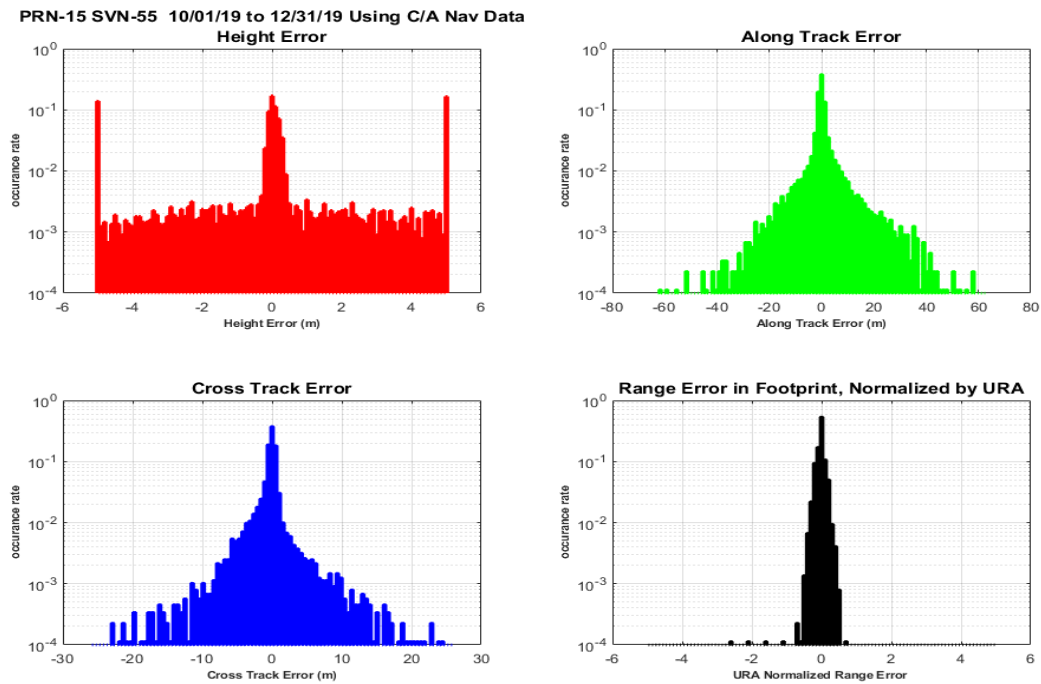
**Figure 10-87. Histograms of H, A, C, and Range Error PRN13 (SVN-43) Using C/A Nav Data**



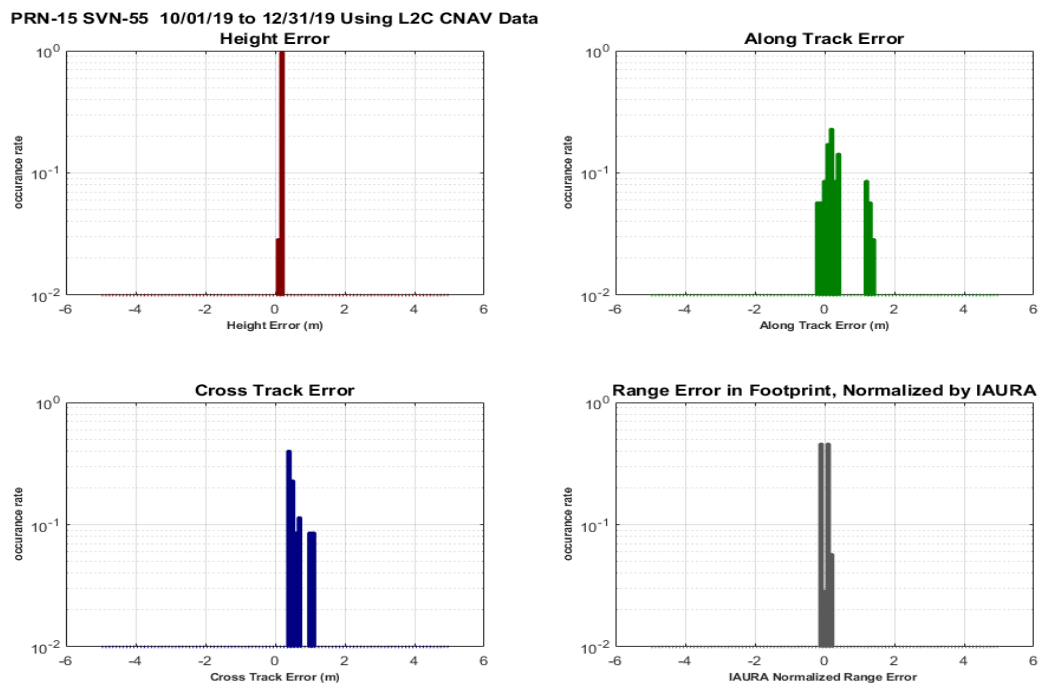
**Figure 10-88. Histograms of H, A, C, and Range Error PRN14 (SVN-41) Using C/A Nav Data**



**Figure 10-89. Histograms of H, A, C, and Range Error PRN15 (SVN-55) Using C/A Nav Data**

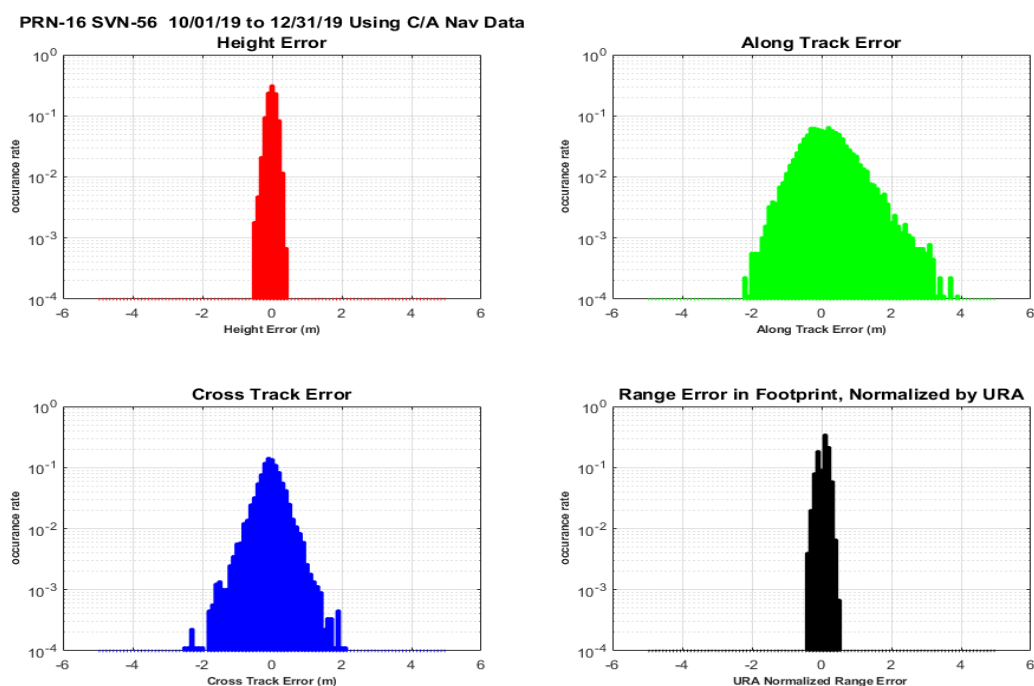


**Figure 10-90. Histograms of H, A, C, and Range Error PRN15 (SVN-55) Using L2C CNAV Data**

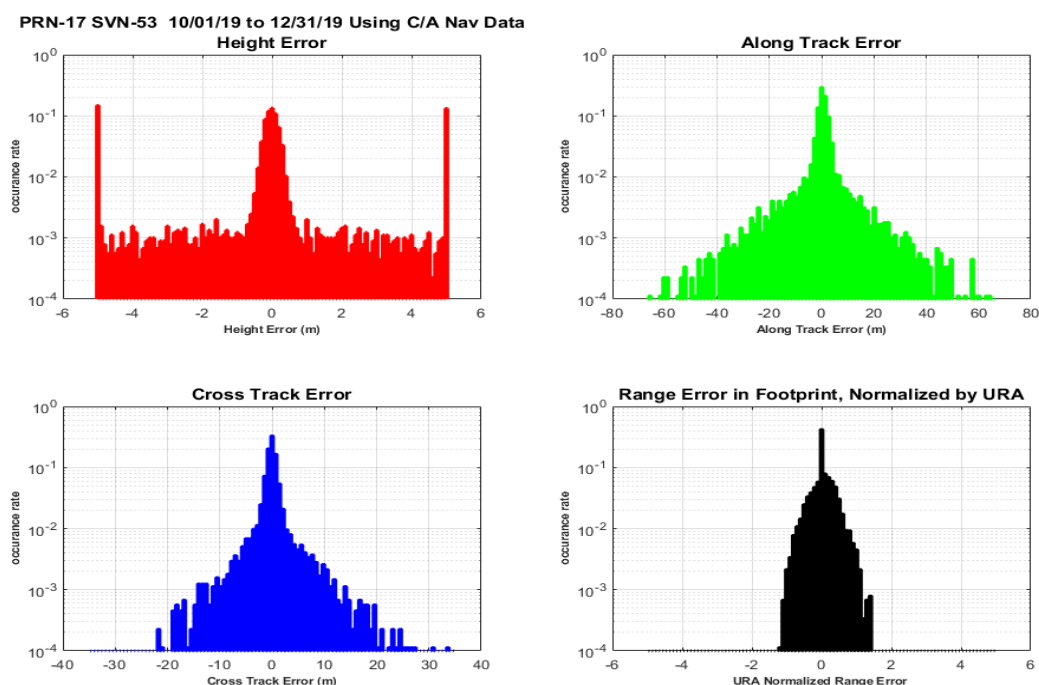




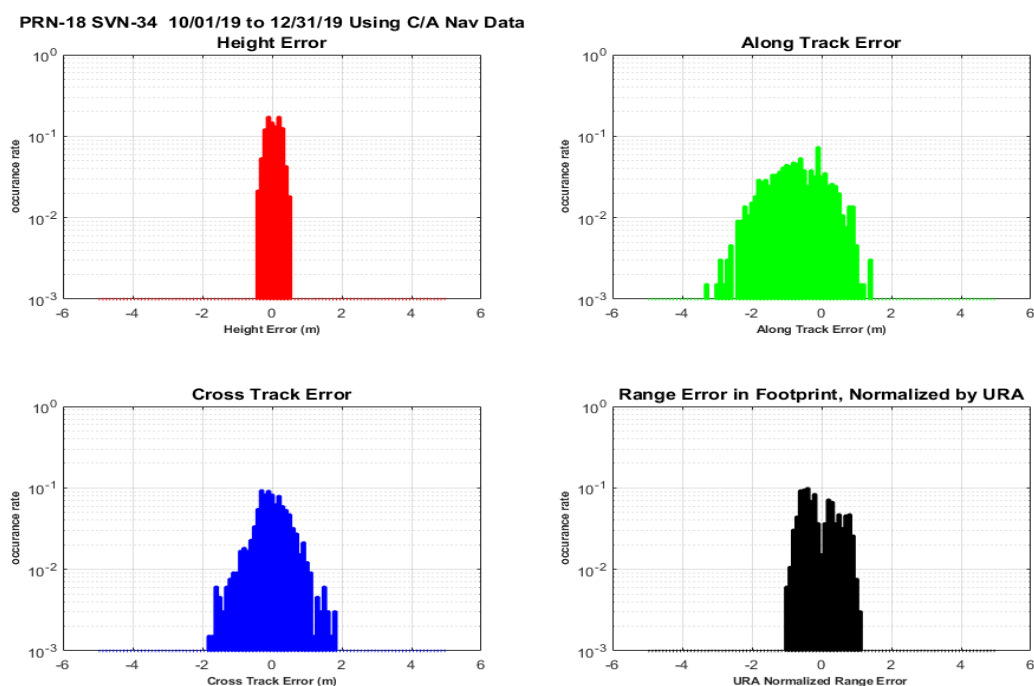
**Figure 10-91. Histograms of H, A, C, and Range Error PRN16 (SVN-56) Using C/A Nav Data**



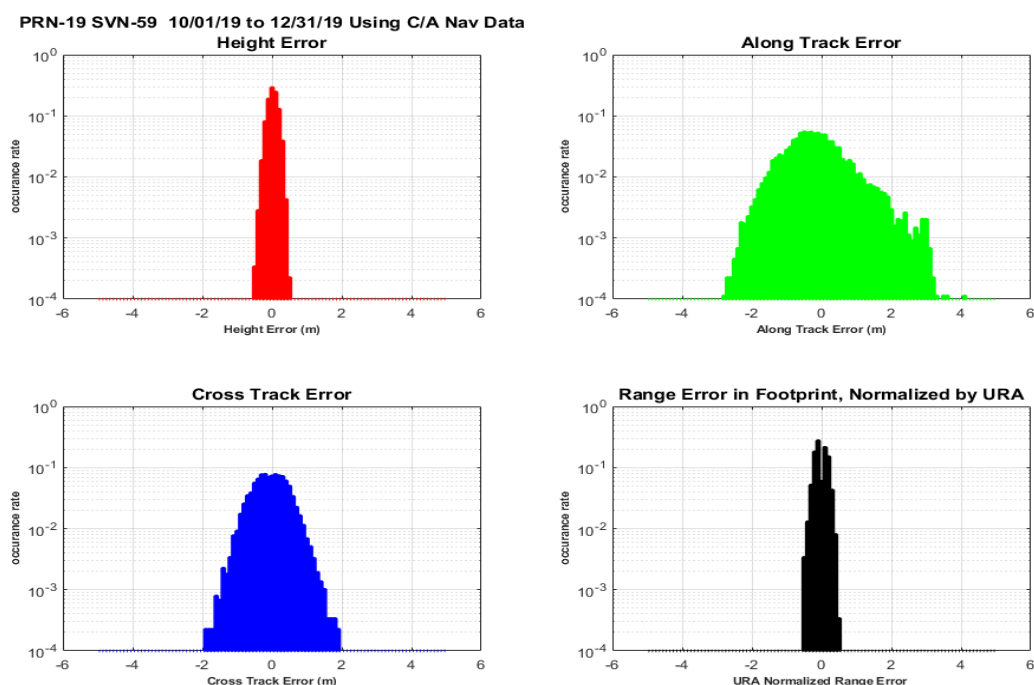
**Figure 10-92. Histograms of H, A, C, and Range Error PRN17 (SVN-53) Using C/A Nav Data**



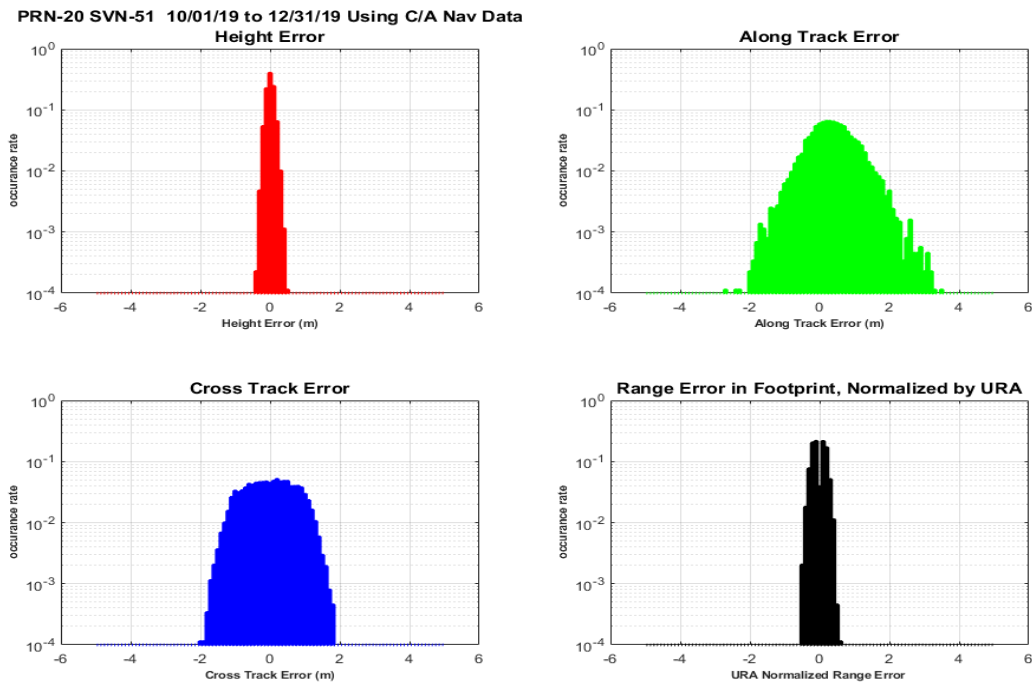
**Figure 10-93. Histograms of H, A, C, and Range Error PRN18 (SVN-34) Using C/A Nav Data**



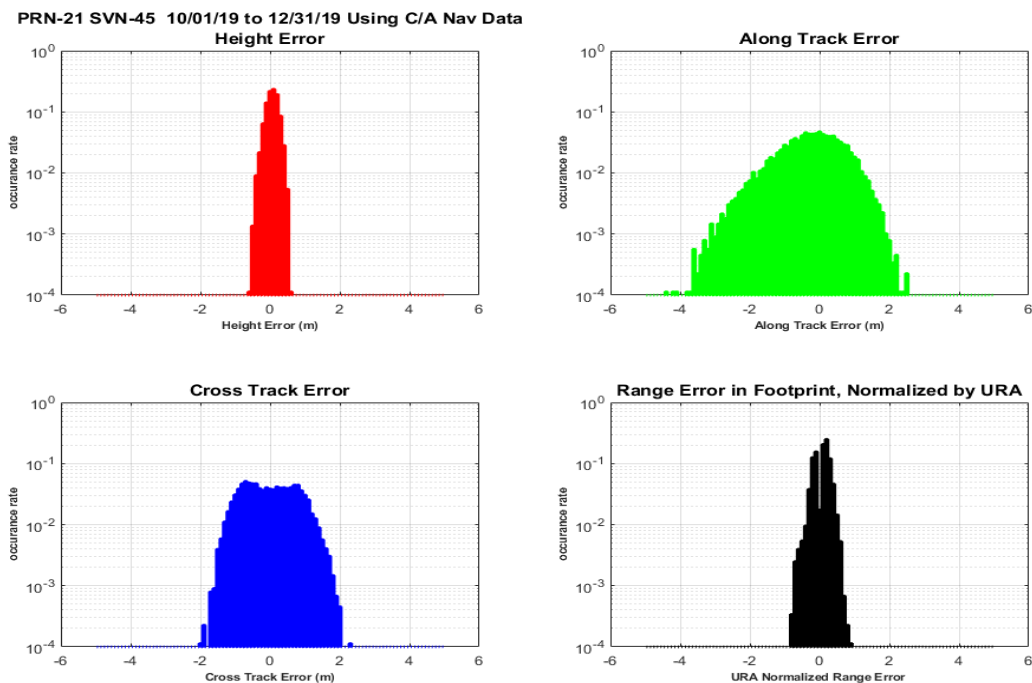
**Figure 10-94. Histograms of H, A, C, and Range Error PRN19 (SVN-59) Using C/A Nav Data**



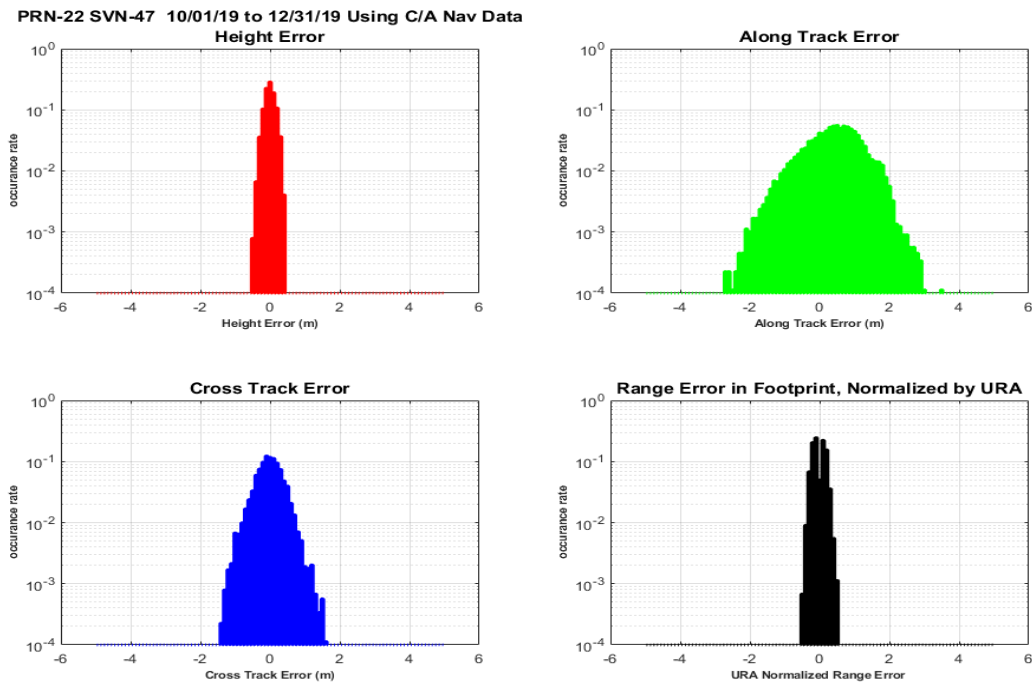
**Figure 10-95. Histograms of H, A, C, and Range Error PRN20 (SVN-51) Using C/A Nav Data**



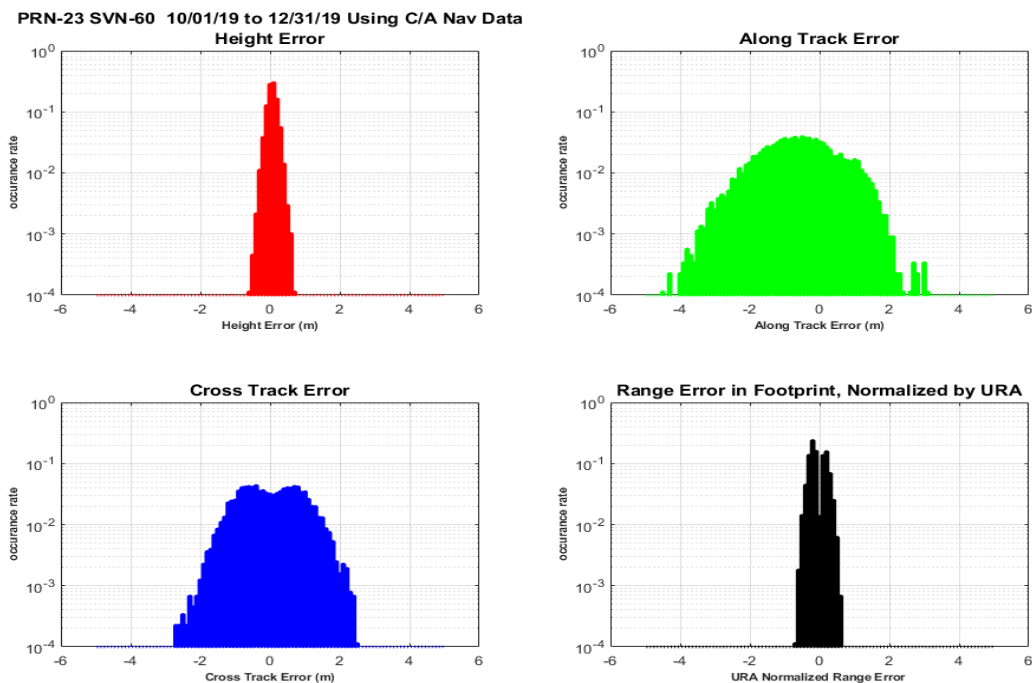
**Figure 10-96. Histograms of H, A, C, and Range Error PRN21 (SVN-45) Using C/A Nav Data**



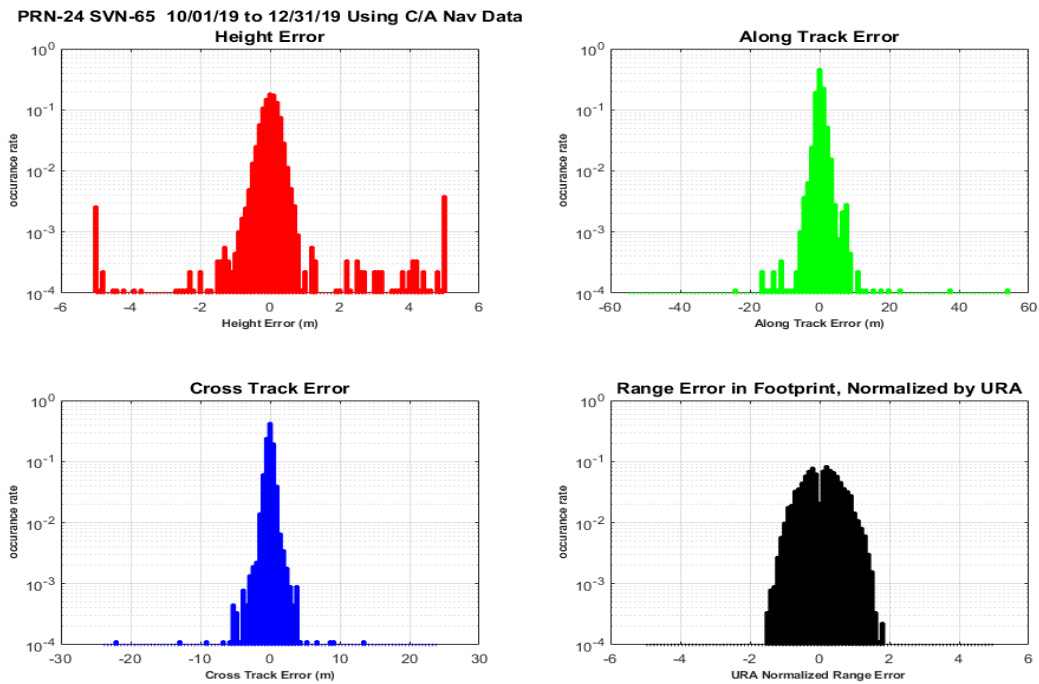
**Figure 10-97. Histograms of H, A, C, and Range Error PRN22 (SVN-47) Using C/A Nav Data**



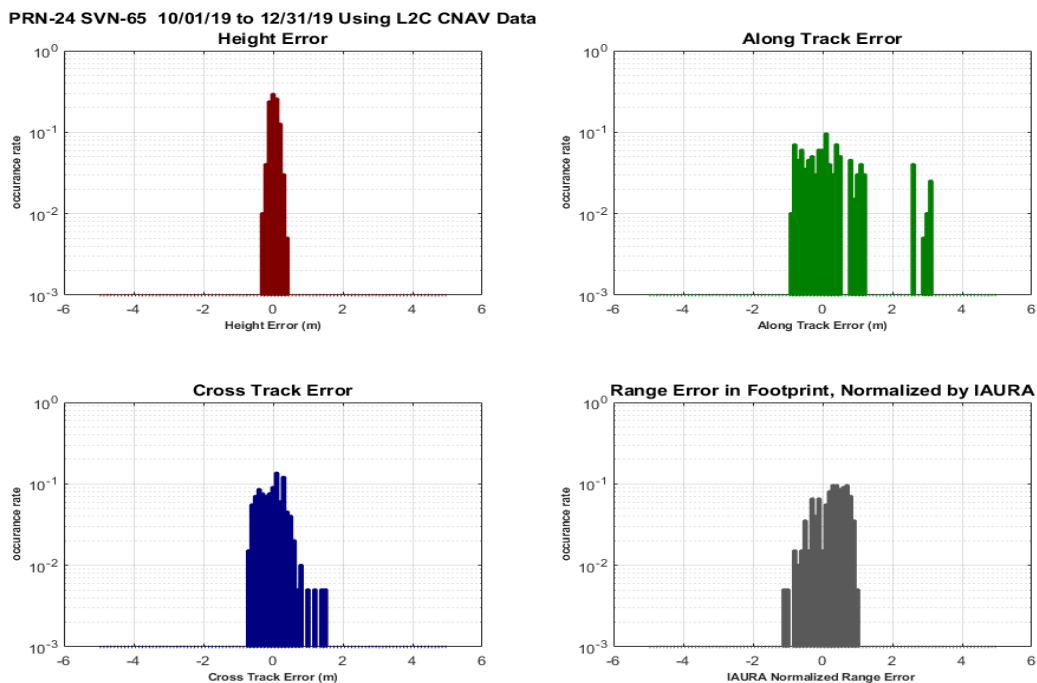
**Figure 10-98. Histograms of H, A, C, and Range Error PRN23 (SVN-60) Using C/A Nav Data**



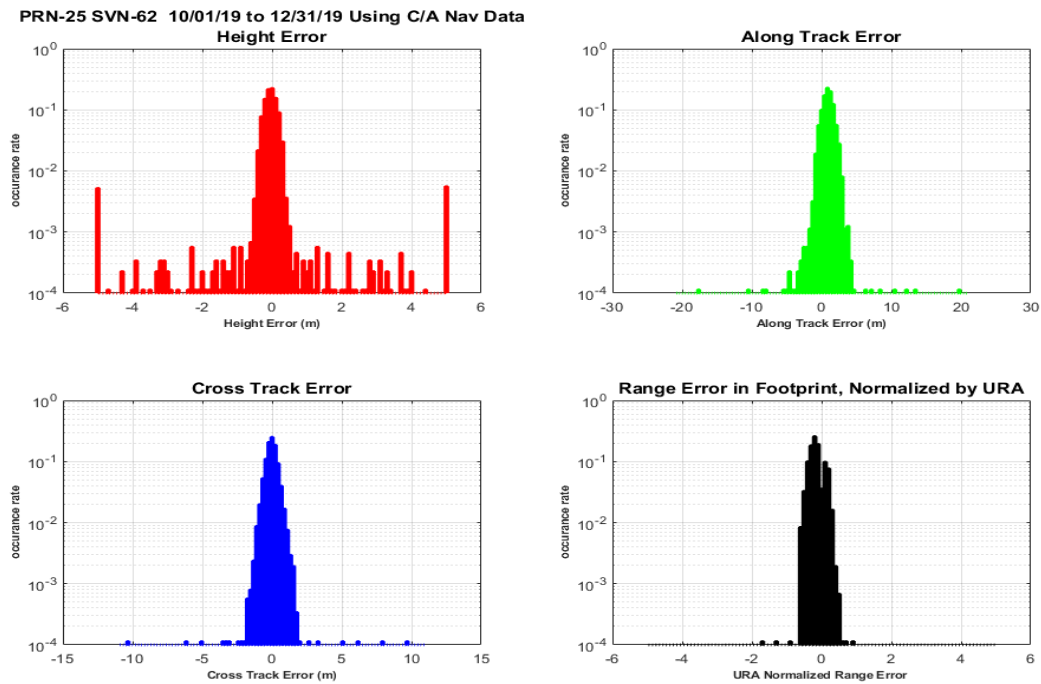
**Figure 10-99. Histograms of H, A, C, and Range Error PRN24 (SVN-65) Using C/A Nav Data**



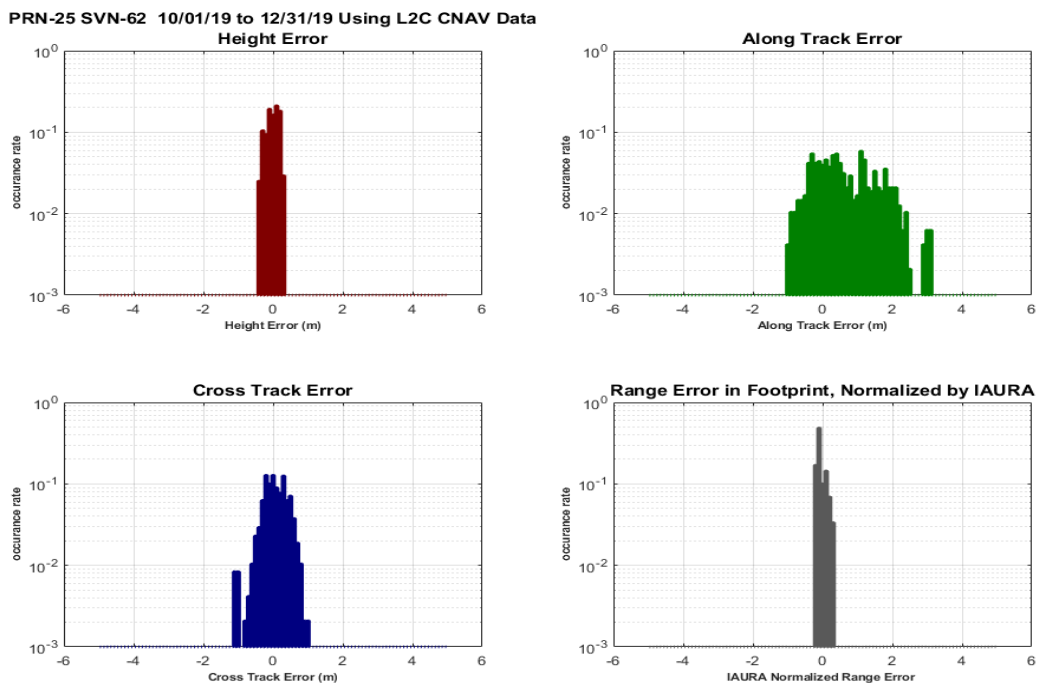
**Figure 10-100. Histograms of H, A, C, and Range Error PRN24 (SVN-65) Using L2C CNAV Data**



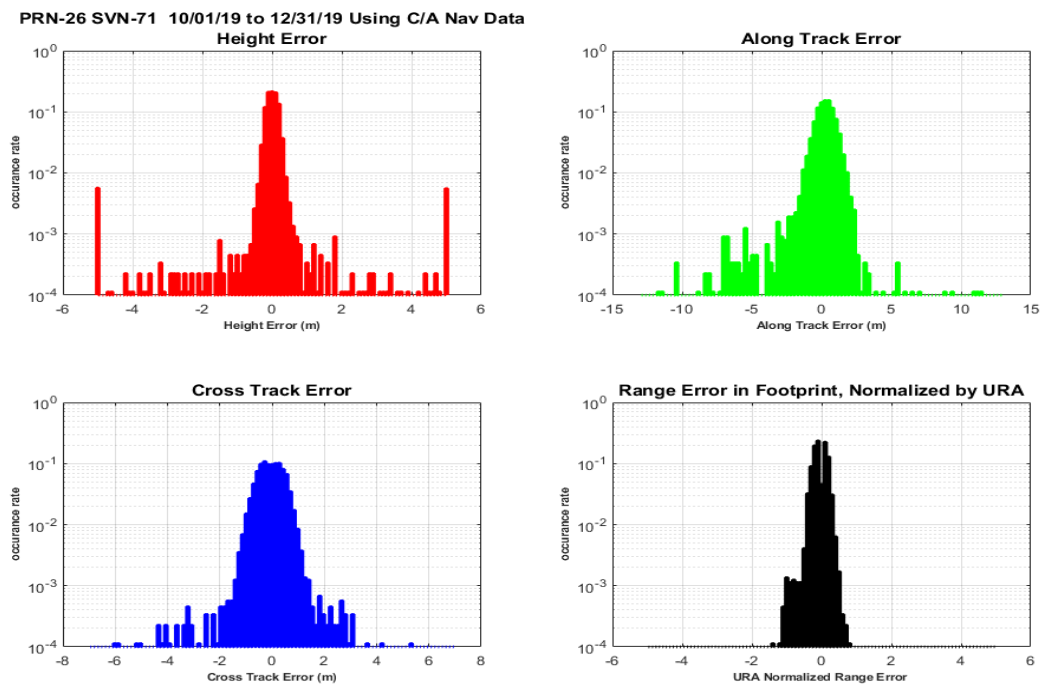
**Figure 10-101. Histograms of H, A, C, and Range Error PRN25 (SVN-62) Using C/A Nav Data**



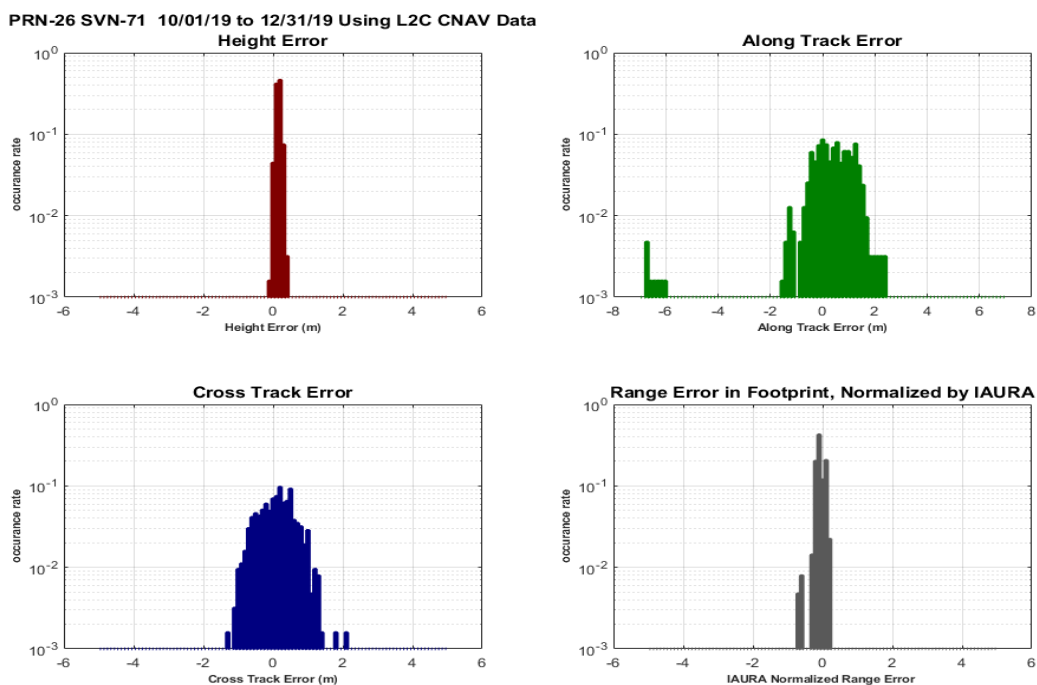
**Figure 10-102. Histograms of H, A, C, and Range Error PRN25 (SVN-62) Using L2C CNAV Data**



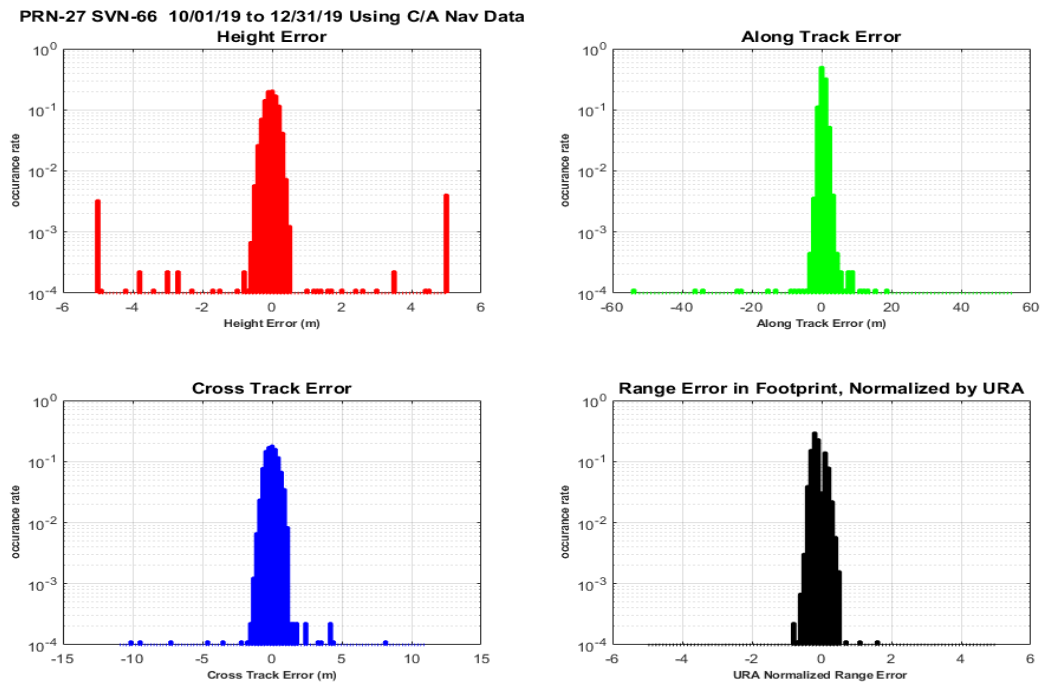
**Figure 10-103. Histograms of H, A, C, and Range Error PRN26 (SVN-71) Using C/A Nav Data**



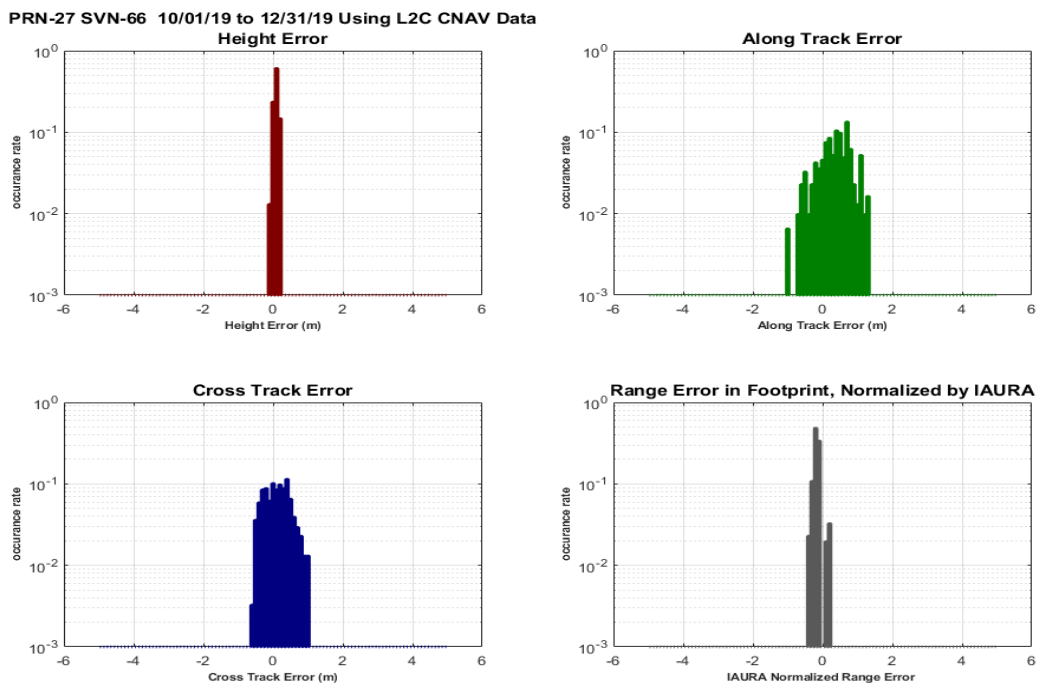
**Figure 10-104. Histograms of H, A, C, and Range Error PRN26 (SVN-71) Using L2C CNAV Data**



**Figure 10-105. Histograms of H, A, C, and Range Error PRN27 (SVN-66) Using C/A Nav Data**

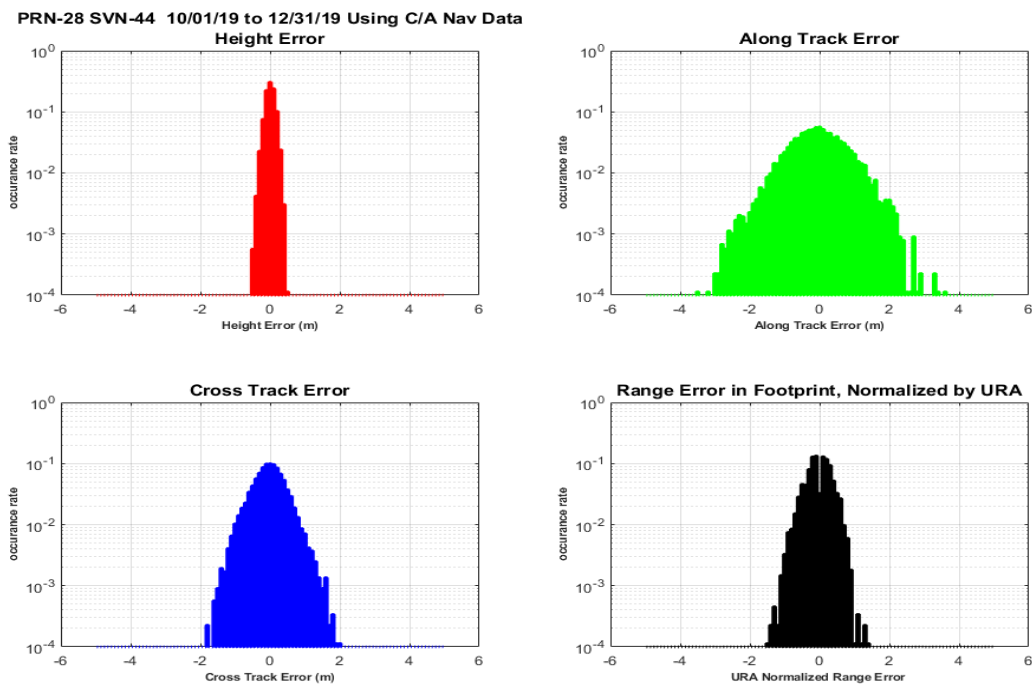


**Figure 10-106. Histograms of H, A, C, and Range Error PRN27 (SVN-66) Using L2C CNAV Data**

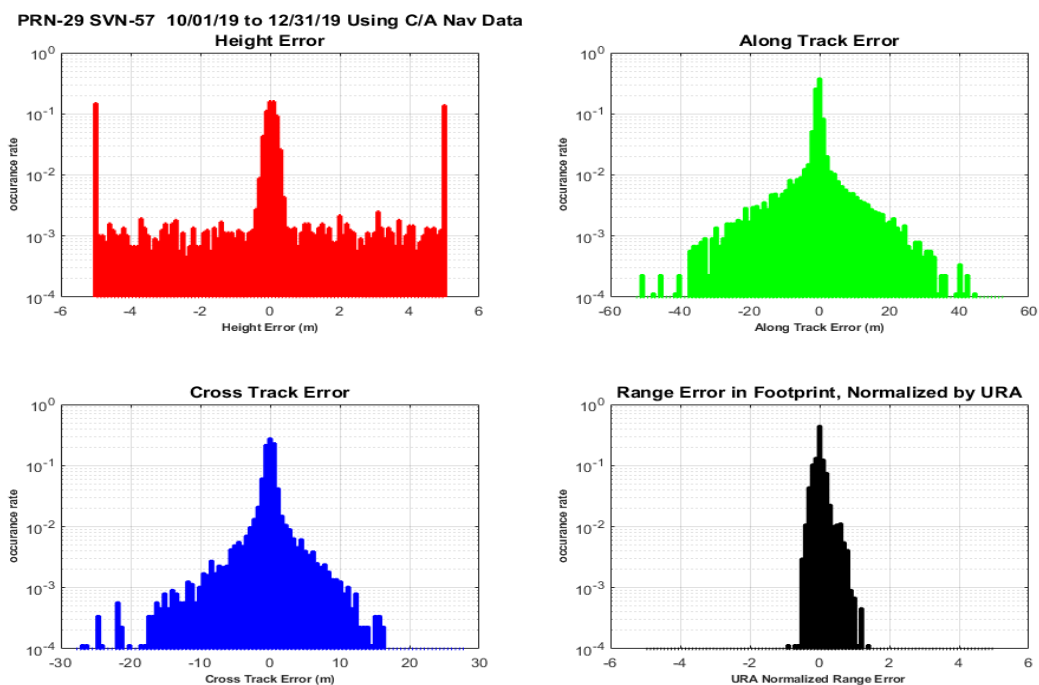




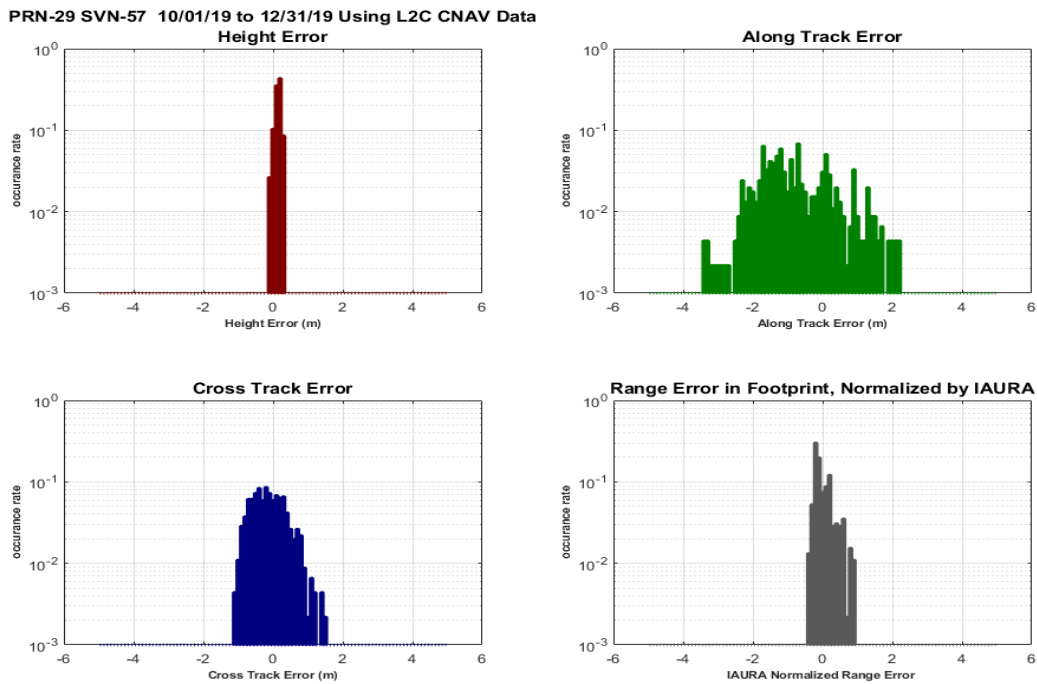
**Figure 10-107. Histograms of H, A, C, and Range Error PRN28 (SVN-44) Using C/A Nav Data**



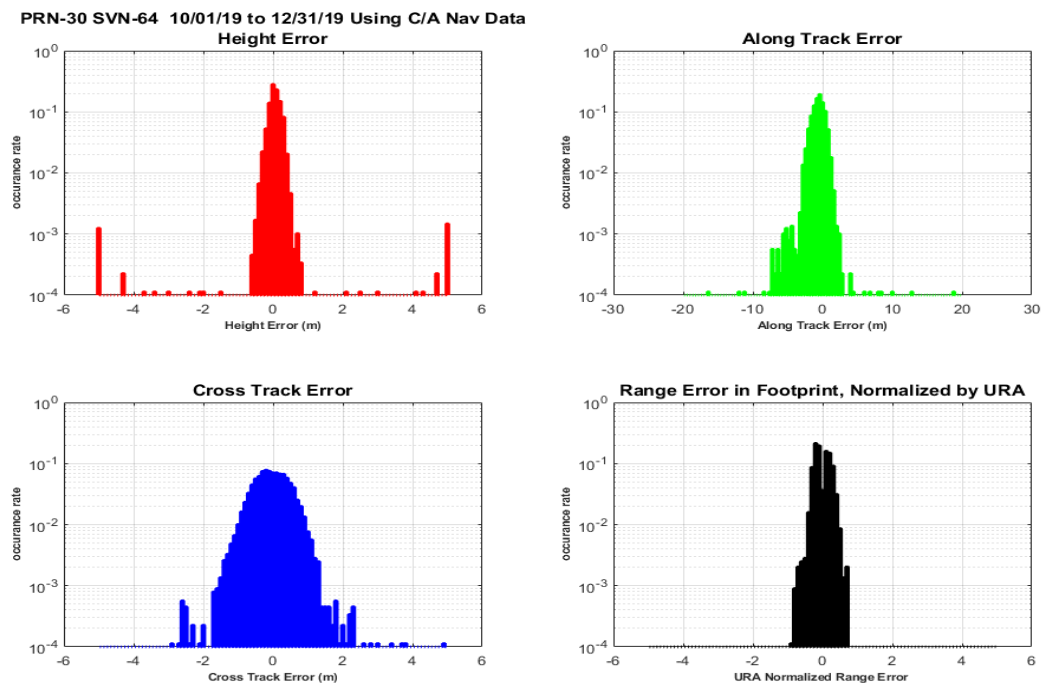
**Figure 10-108. Histograms of H, A, C, and Range Error PRN29 (SVN-57) Using C/A Nav Data**



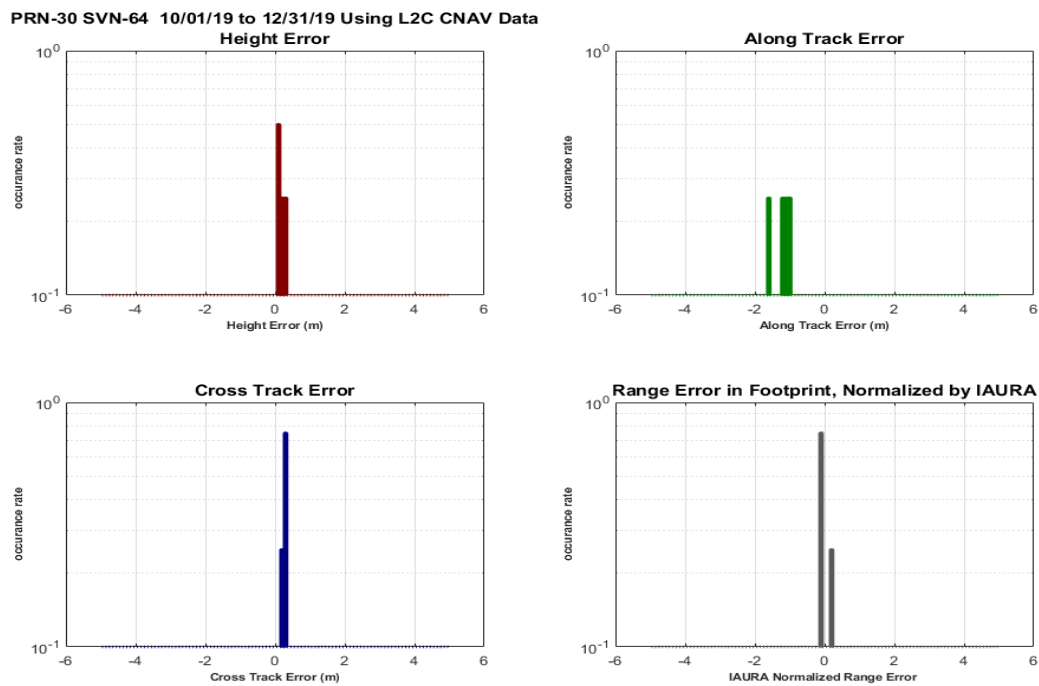
**Figure 10-109. Histograms of H, A, C, and Range Error PRN29 (SVN-57) Using L2C CNAV Data**



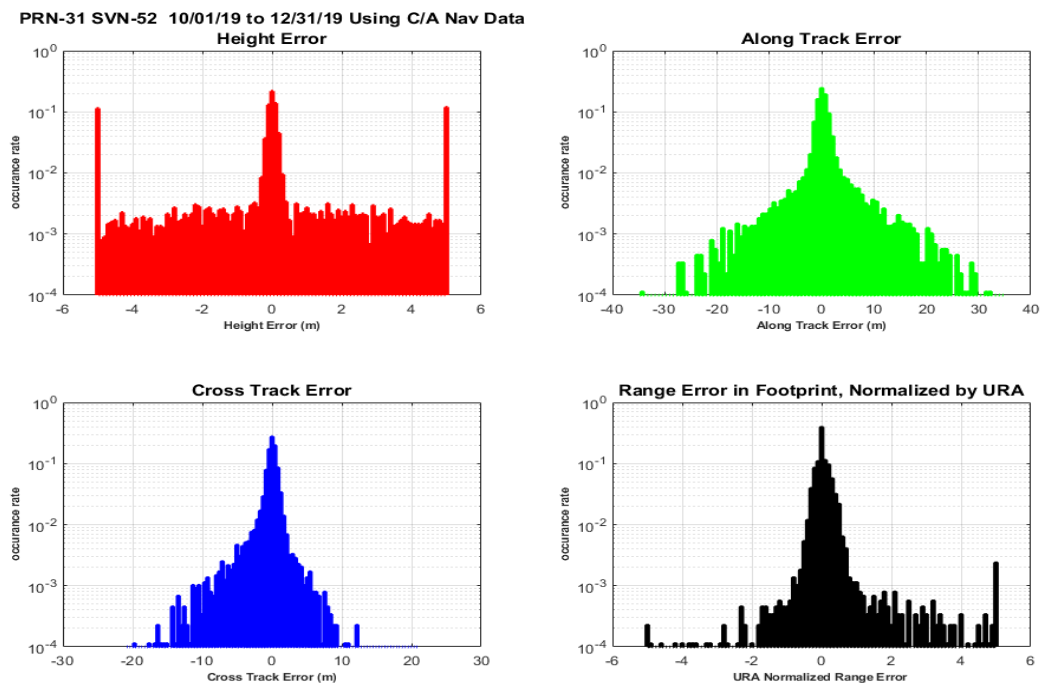
**Figure 10-110. Histograms of H, A, C, and Range Error PRN30 (SVN-64) Using C/A Nav Data**



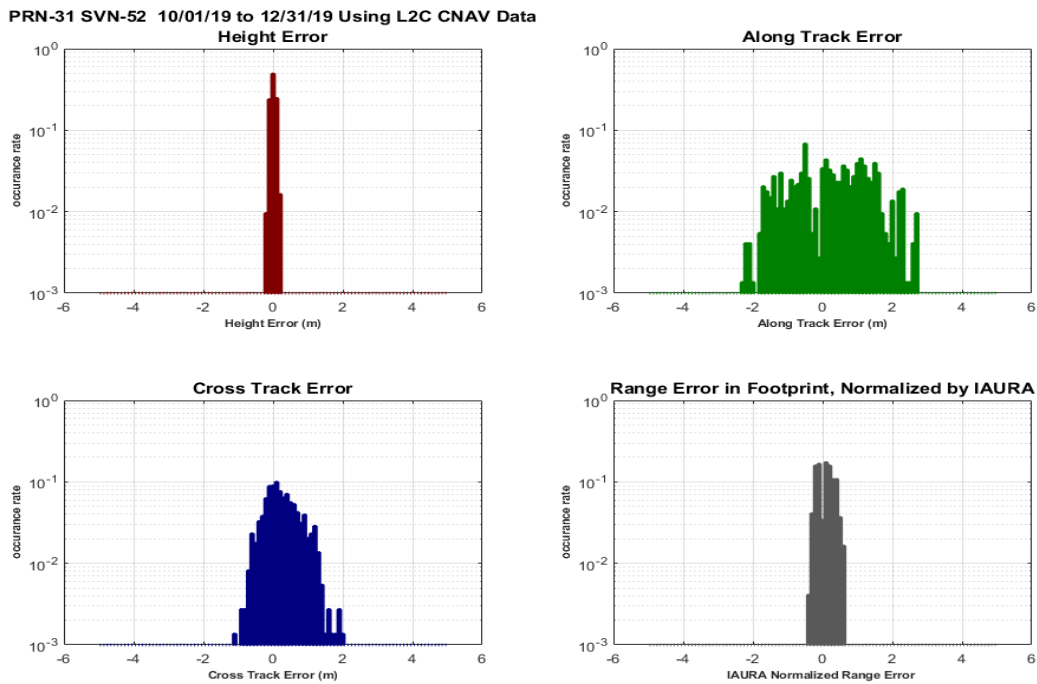
**Figure 10-111. Histograms of H, A, C, and Range Error PRN30 (SVN-64) Using L2C CNAV Data**



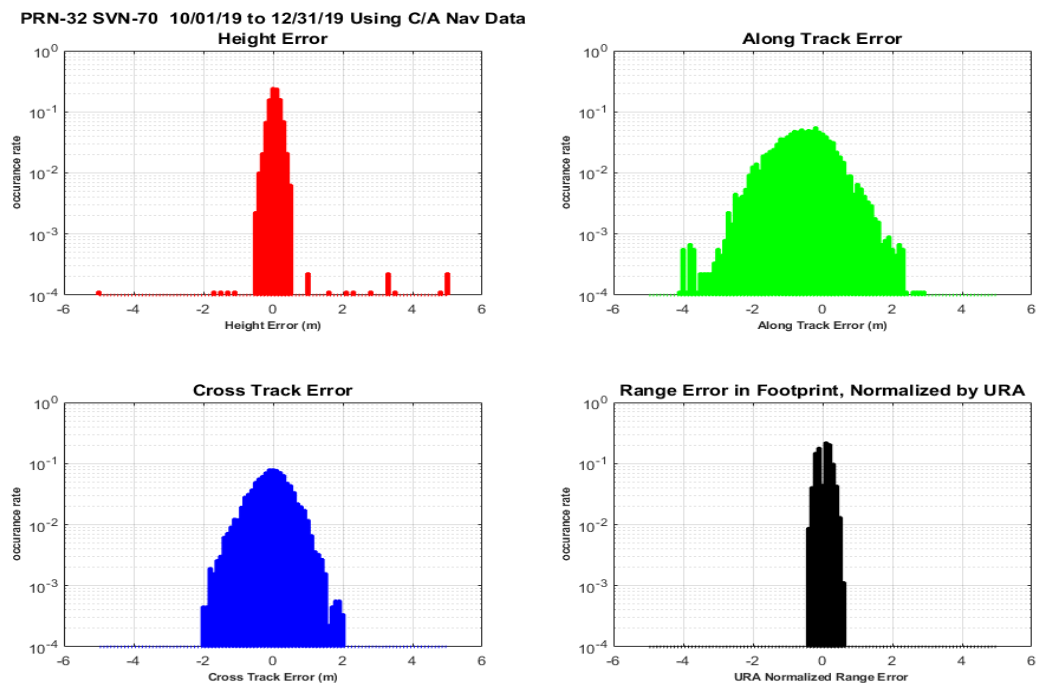
**Figure 10-112. Histograms of H, A, C, and Range Error PRN31 (SVN-52) Using C/A Nav Data**



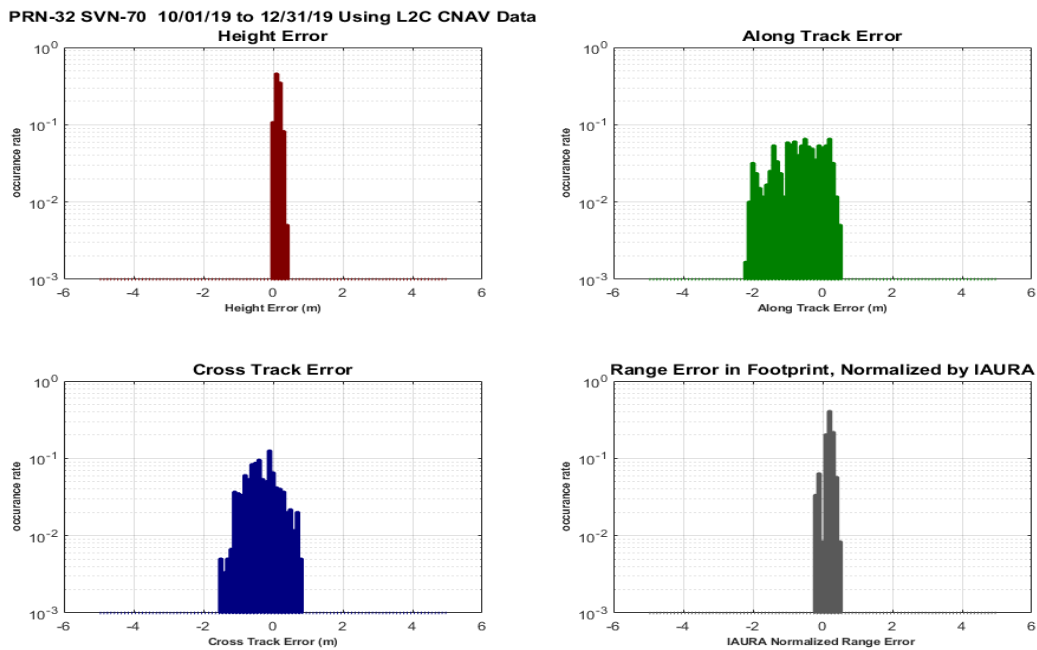
**Figure 10-113. Histograms of H, A, C, and Range Error PRN31 (SVN-52) Using L2C CNAV Data**



**Figure 10-114. Histograms of H, A, C, and Range Error PRN32 (SVN-70) Using C/A Nav Data**

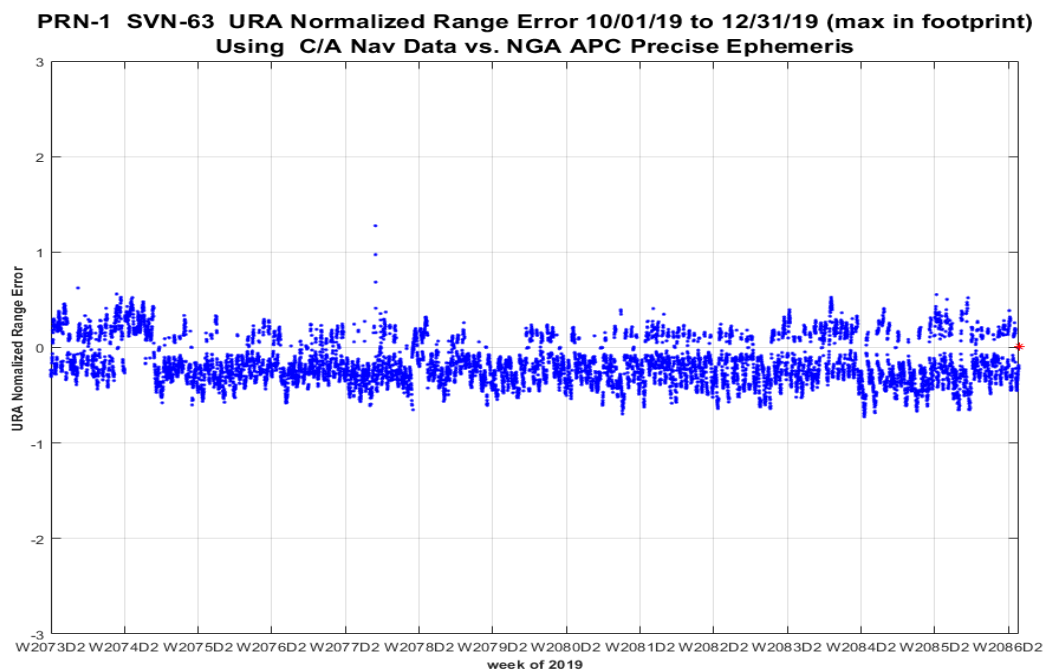


**Figure 10-115. Histograms of H, A, C, and Range Error PRN32 (SVN-70) Using L2C CNAV Data**

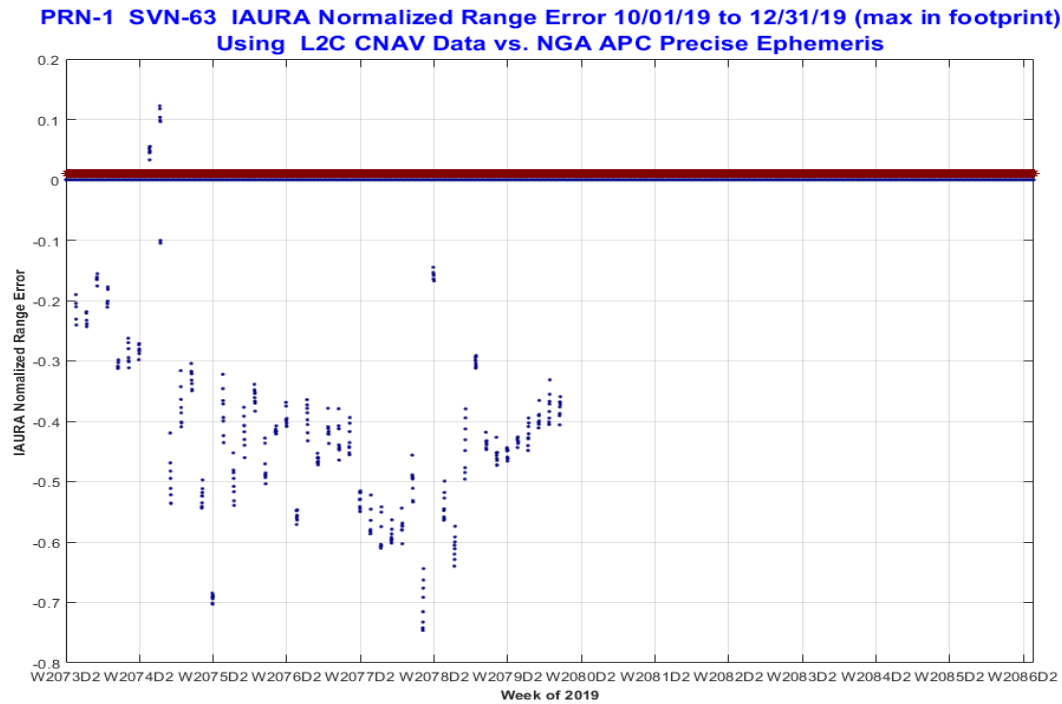


## 10.8 Timeline of URA Normalized Range Error for All Satellites

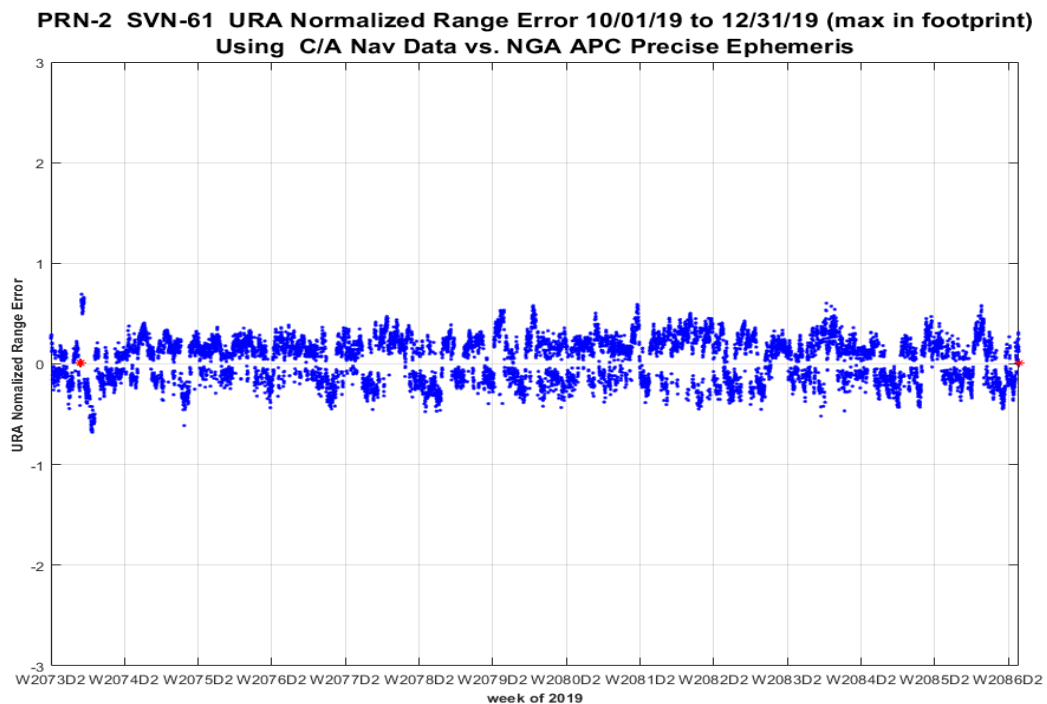
**Figure 10-116. Timeline of URA Normalized Range Error PRN1 (SVN-63) Using C/A Nav Data**



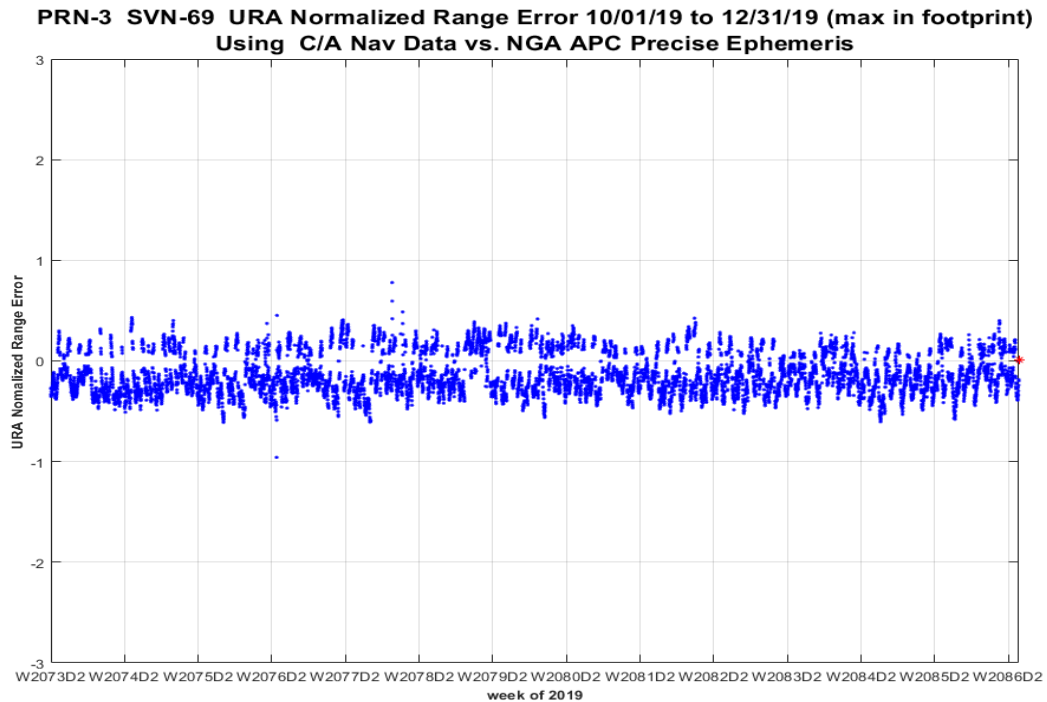
**Figure 10-117. Timeline of IAURA Normalized Range Error PRN1 (SVN-63) Using L2C CNAV Data**



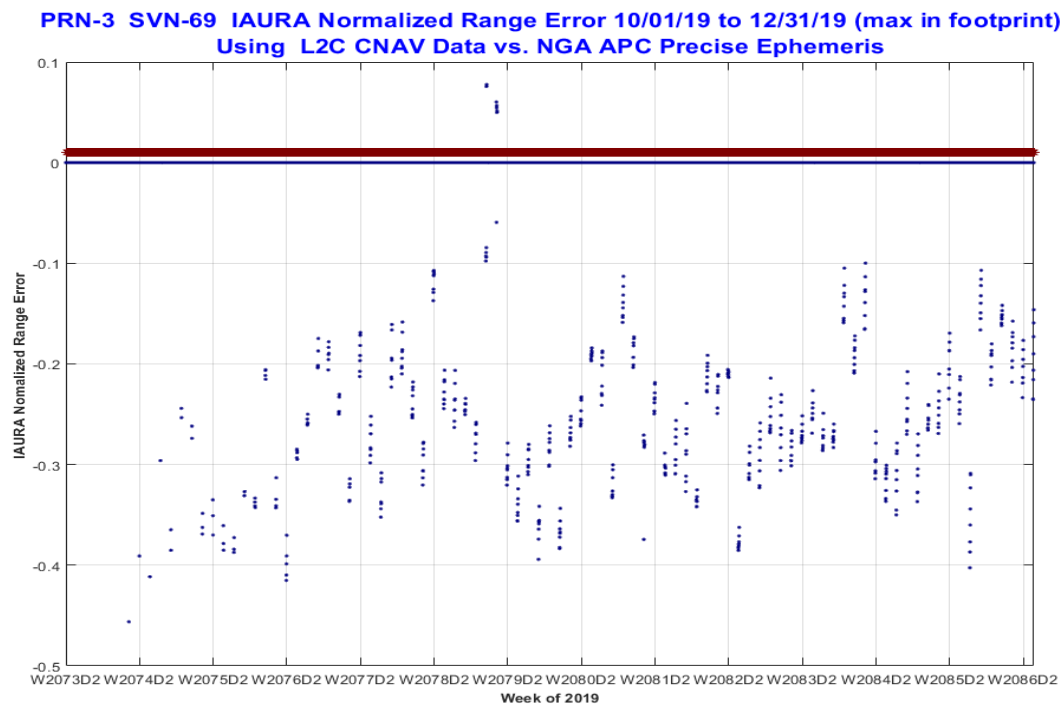
**Figure 10-118. Timeline of URA Normalized Range Error PRN2 (SVN-61) Using C/A Nav Data**



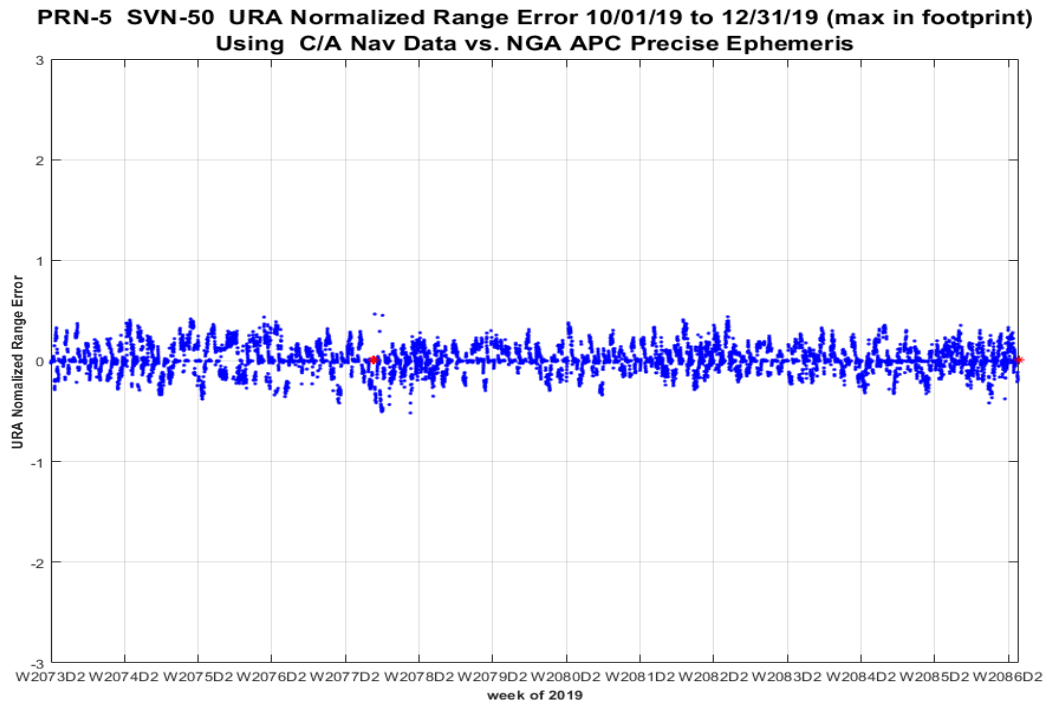
**Figure 10-119. Timeline of URA Normalized Range Error PRN3 (SVN-69) Using C/A Nav Data**



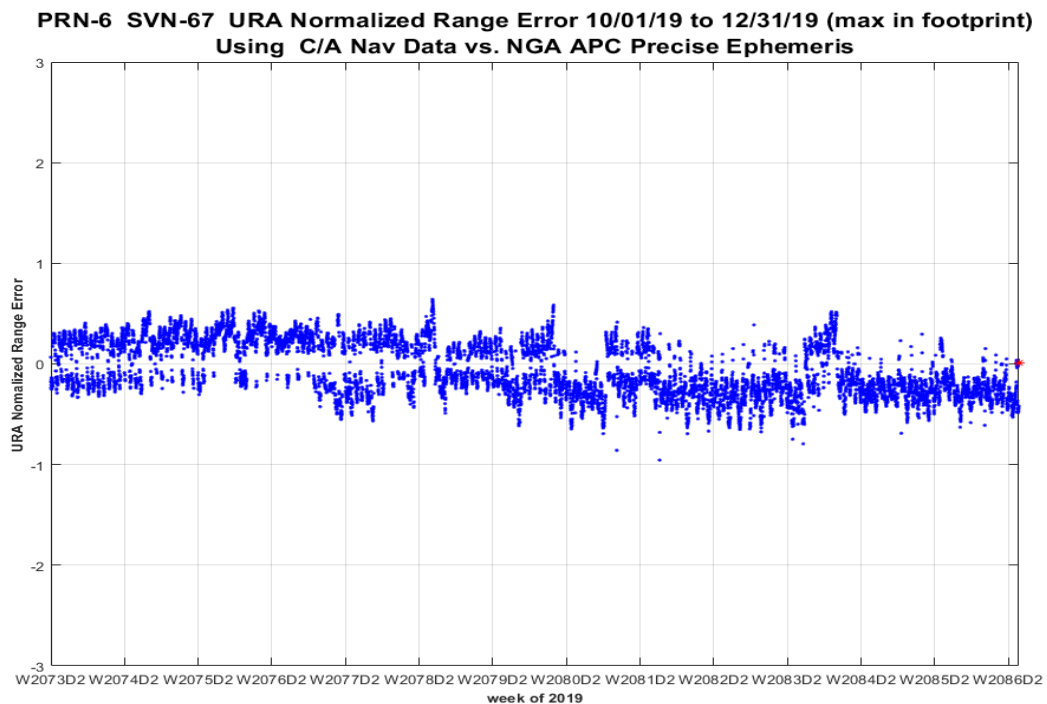
**Figure 10-120. Timeline of IAURA Normalized Range Error PRN3 (SVN-69) Using L2C CNAV Data**



**Figure 10-121. Timeline of URA Normalized Range Error PRN5 (SVN-50) Using C/A Nav Data**

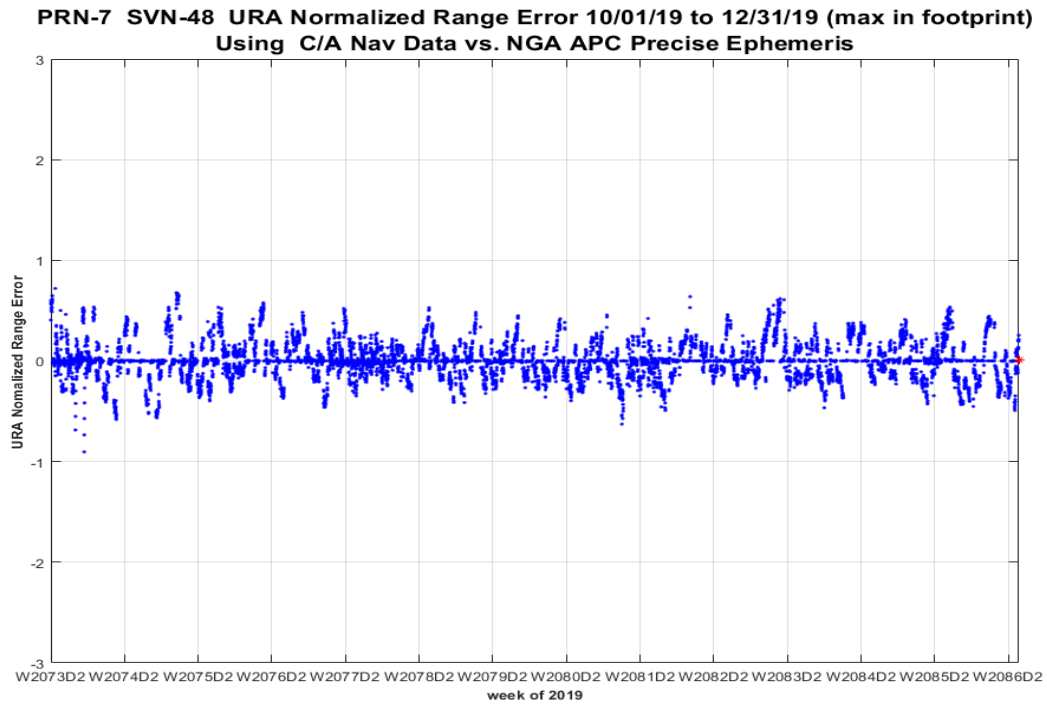


**Figure 10-122. Timeline of URA Normalized Range Error PRN6 (SVN-67) Using C/A Nav Data**

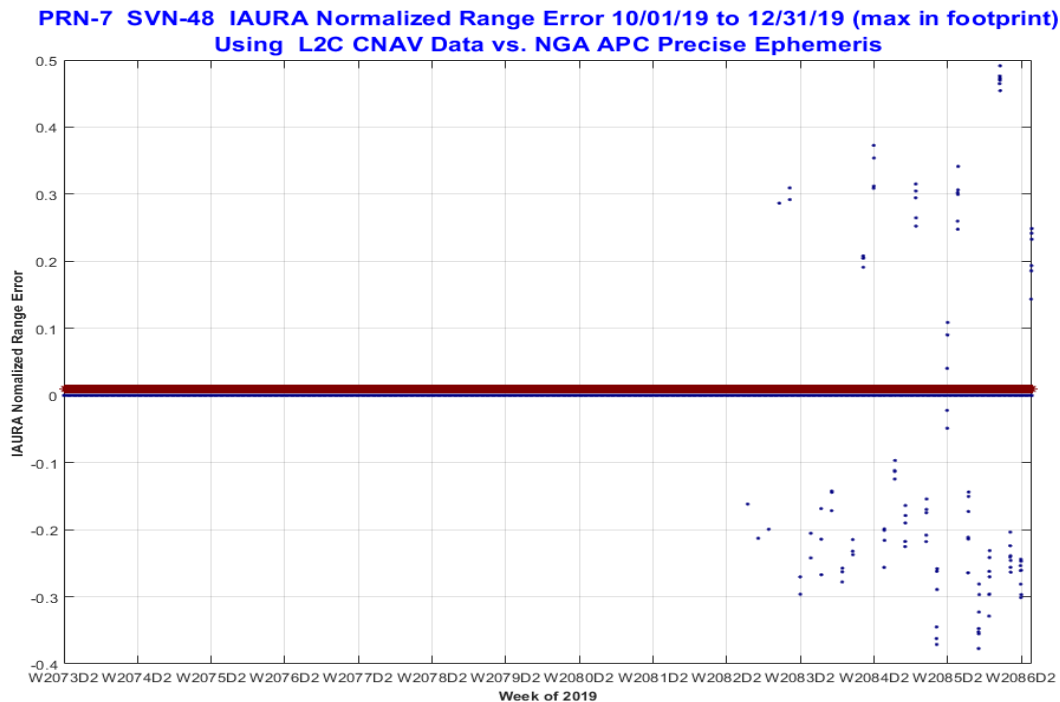




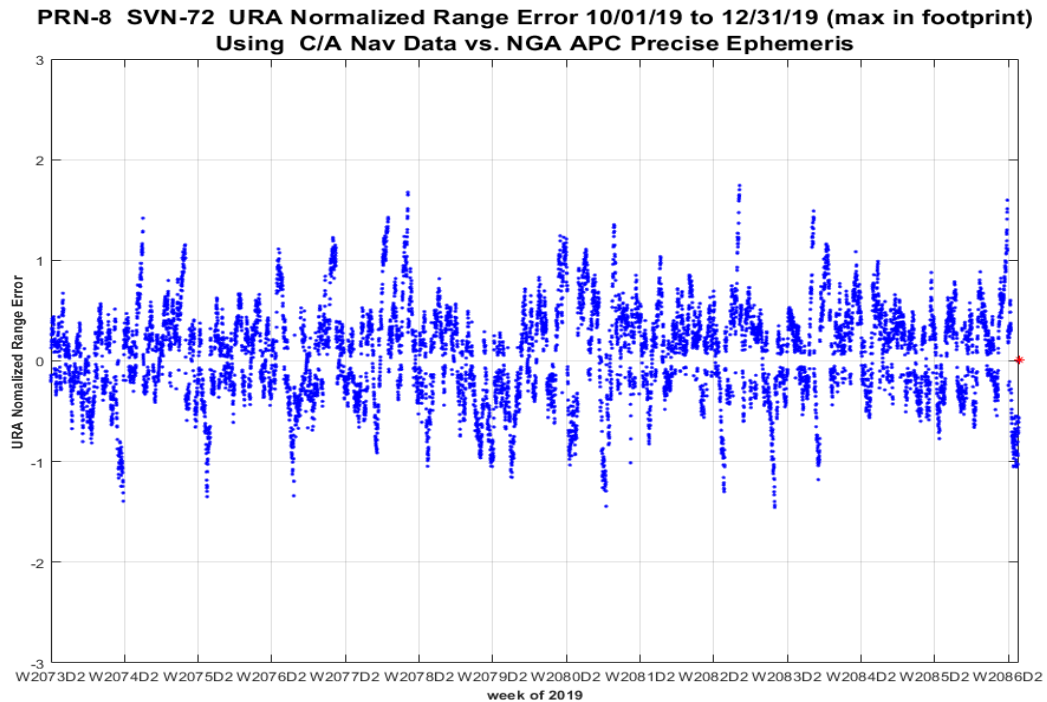
**Figure 10-123. Timeline of URA Normalized Range Error PRN7 (SVN-48) Using C/A Nav Data**



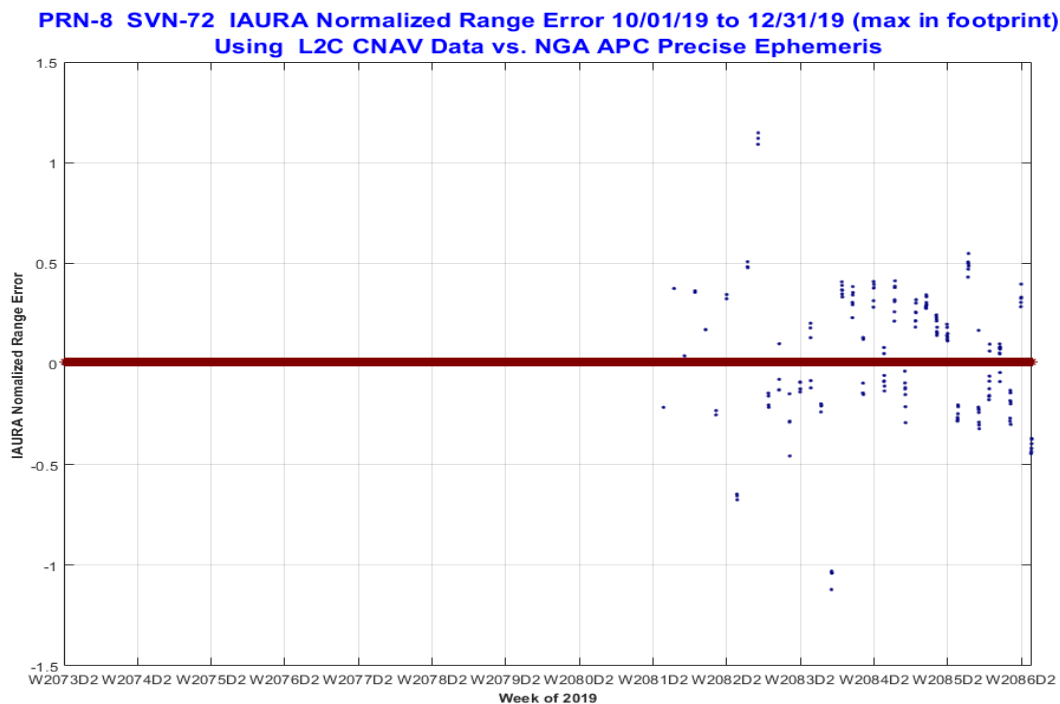
**Figure 10-124. Timeline of IAURA Normalized Range Error PRN7 (SVN-48) Using L2C CNAV Data**



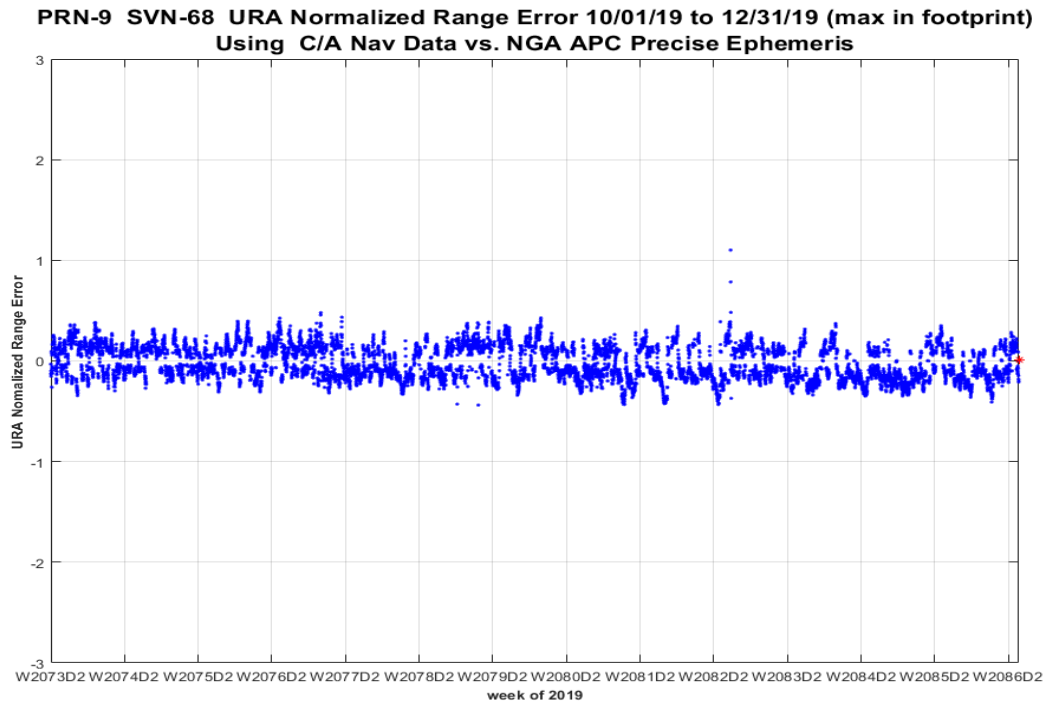
**Figure 10-125. Timeline of URA Normalized Range Error PRN8 (SVN-72) Using C/A Nav Data**



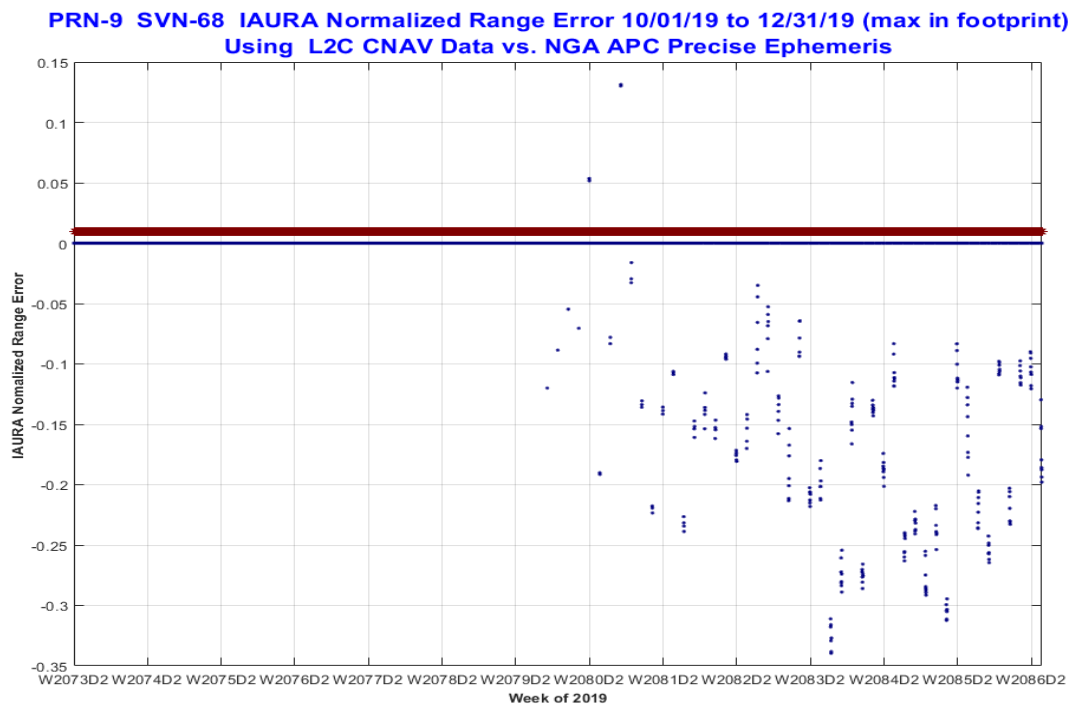
**Figure 10-126. Timeline of IAURA Normalized Range Error PRN8 (SVN-72) Using L2C CNAV Data**



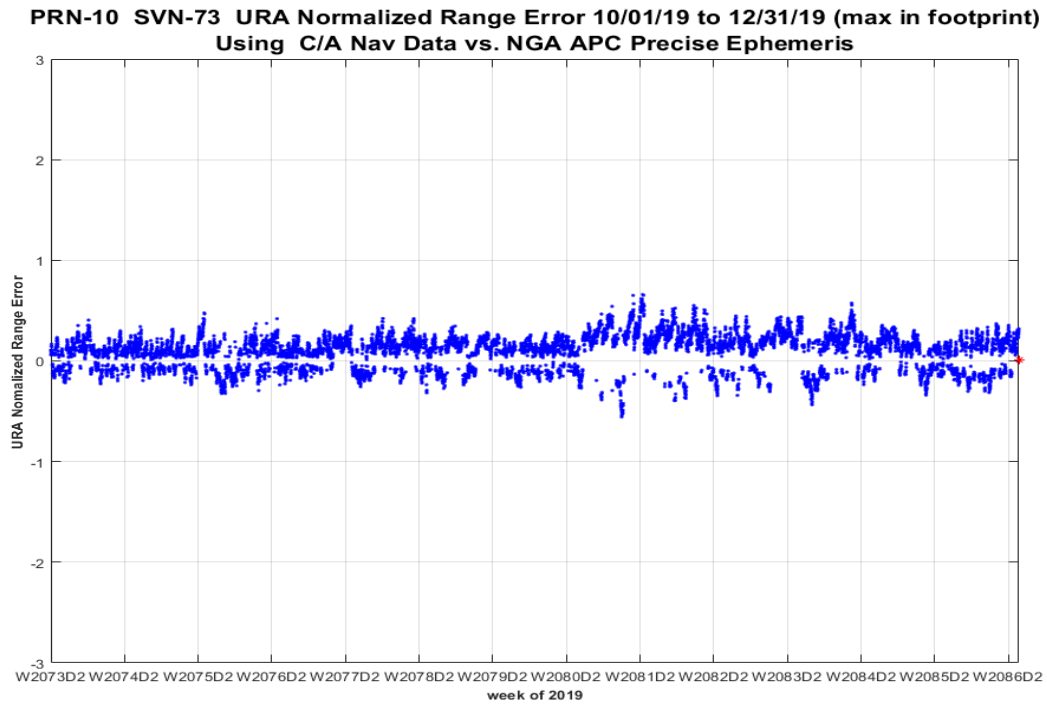
**Figure 10-127. Timeline of URA Normalized Range Error PRN9 (SVN-68) Using C/A Nav Data**



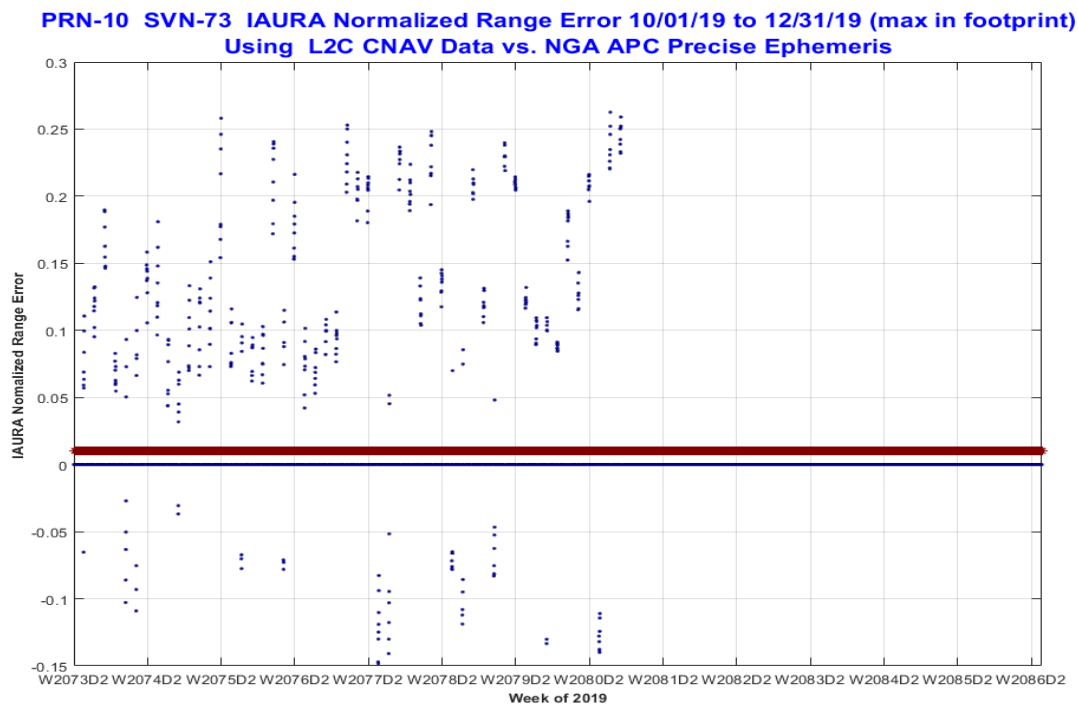
**Figure 10-128. Timeline of IAURA Normalized Range Error PRN9 (SVN-68) Using L2C CNAV Data**



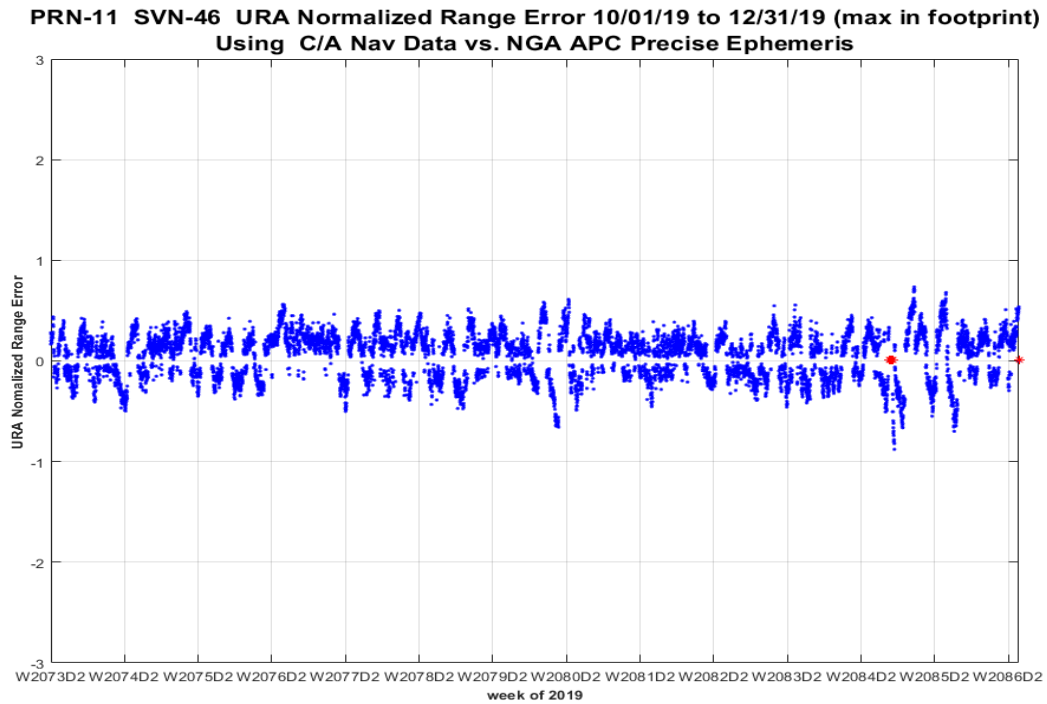
**Figure 10-129. Timeline of URA Normalized Range Error PRN10 (SVN-73) Using C/A Nav Data**



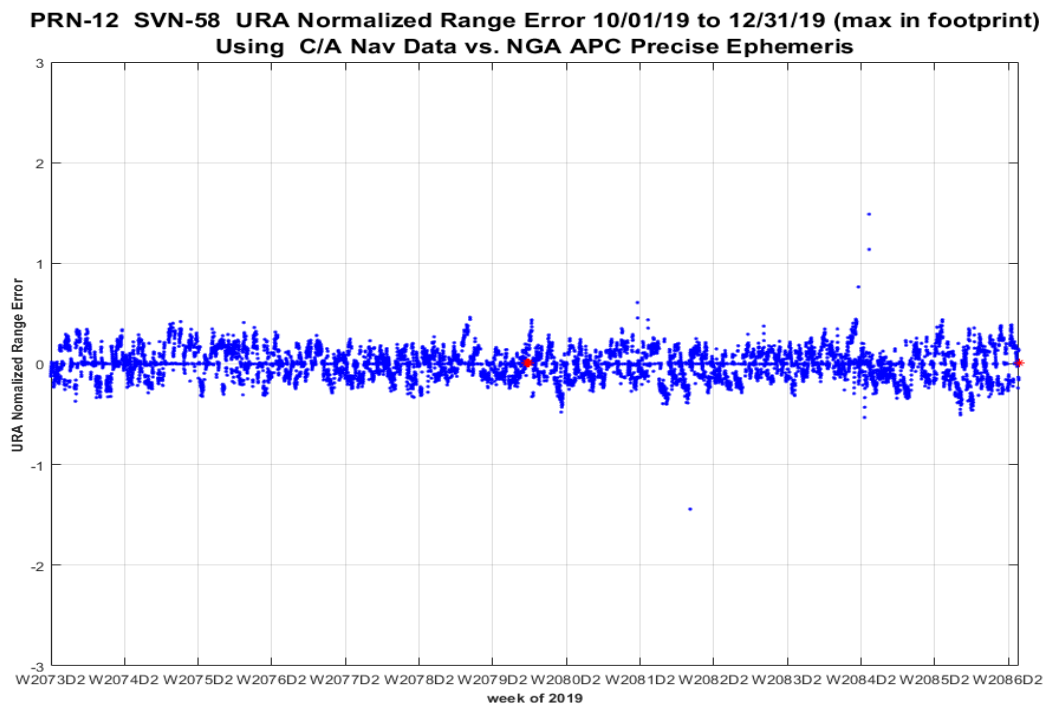
**Figure 10-130. Timeline of IAURA Normalized Range Error PRN10 (SVN-73) Using L2C CNAV Data**



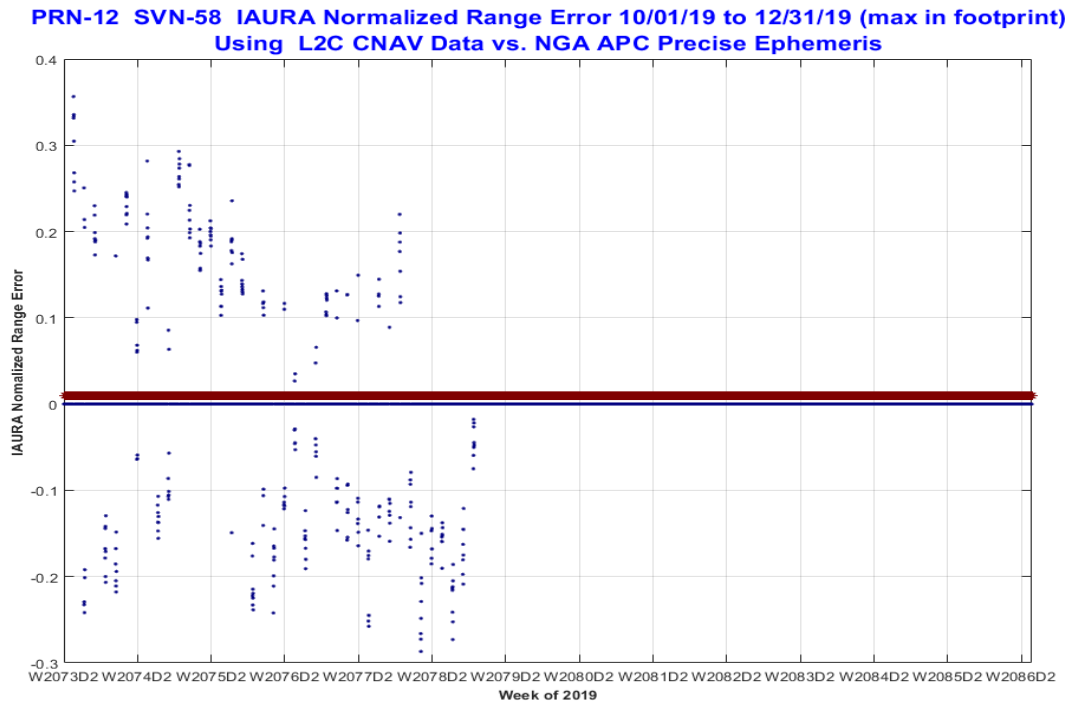
**Figure 10-131. Timeline of URA Normalized Range Error PRN11 (SVN-46) Using C/A Nav Data**



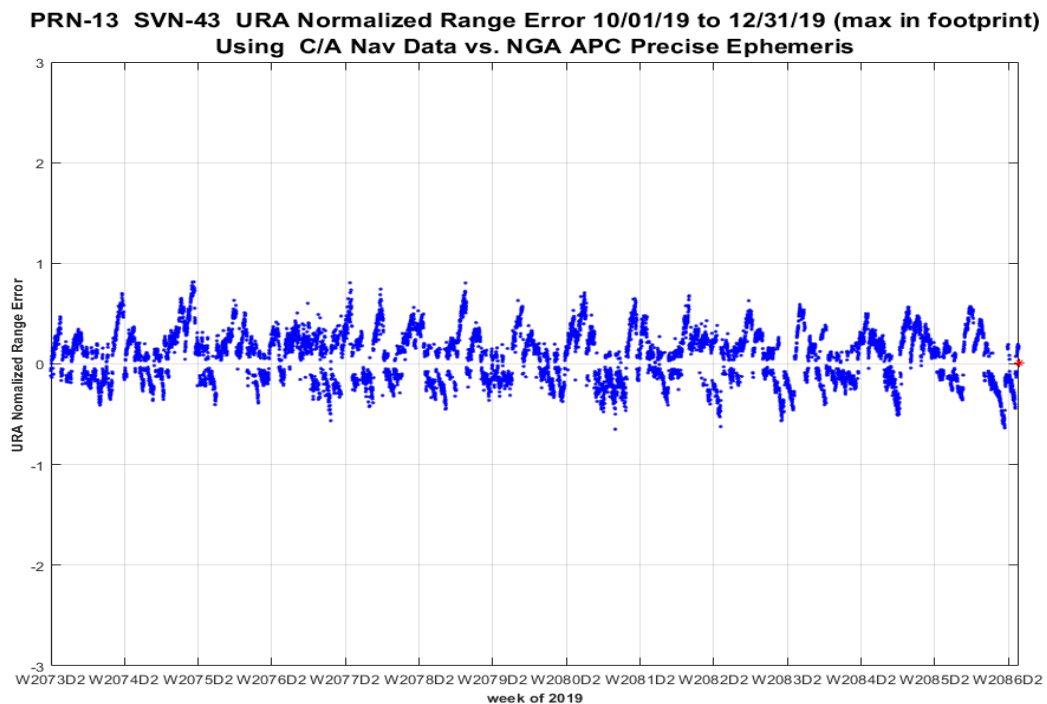
**Figure 10-132. Timeline of URA Normalized Range Error PRN12 (SVN-58) Using C/A Nav Data**



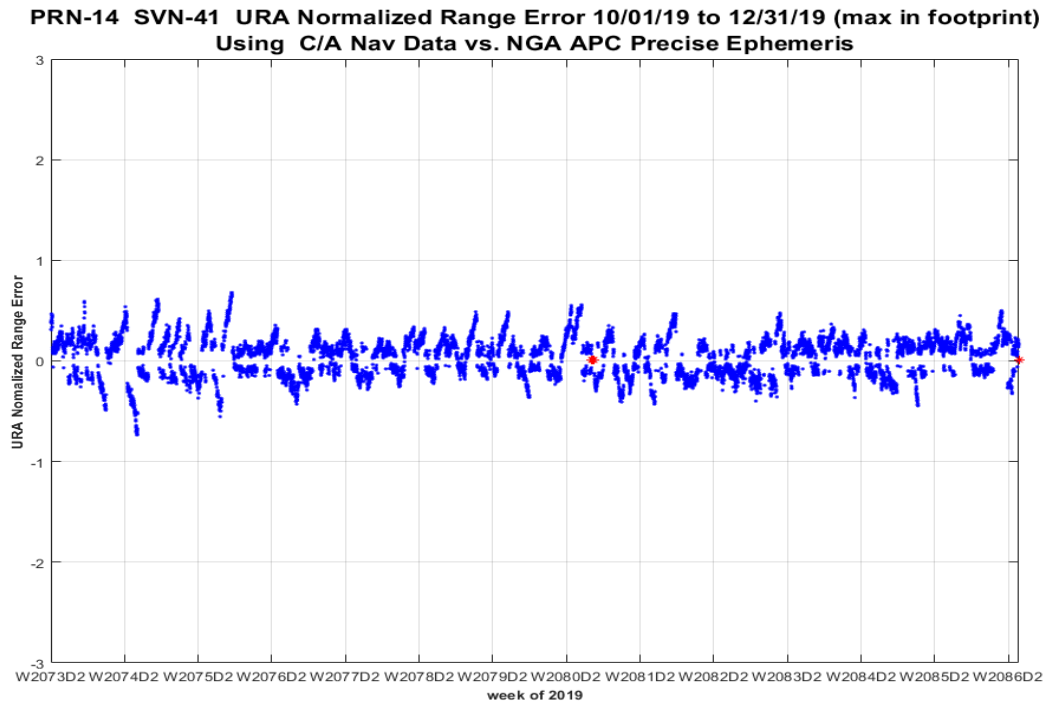
**Figure 10-133. Timeline of IAURA Normalized Range Error PRN12 (SVN-58) Using L2C CNAV Data**



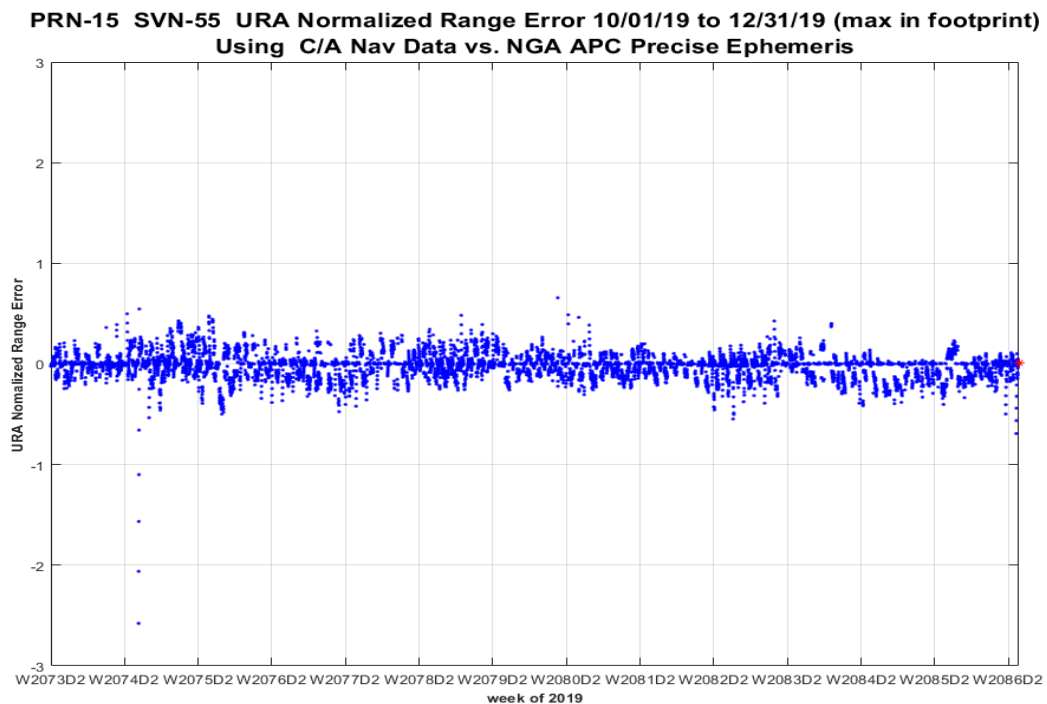
**Figure 10-134. Timeline of URA Normalized Range Error PRN13 (SVN-43) Using C/A Nav Data**



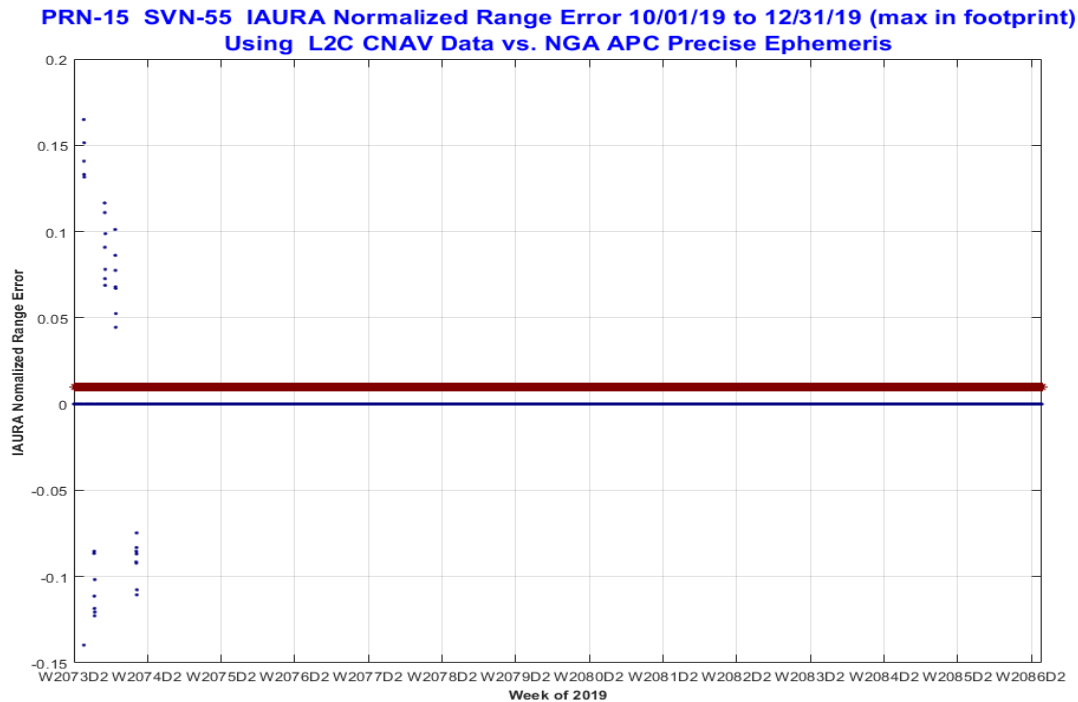
**Figure 10-135. Timeline of URA Normalized Range Error PRN14 (SVN-41) Using C/A Nav Data**



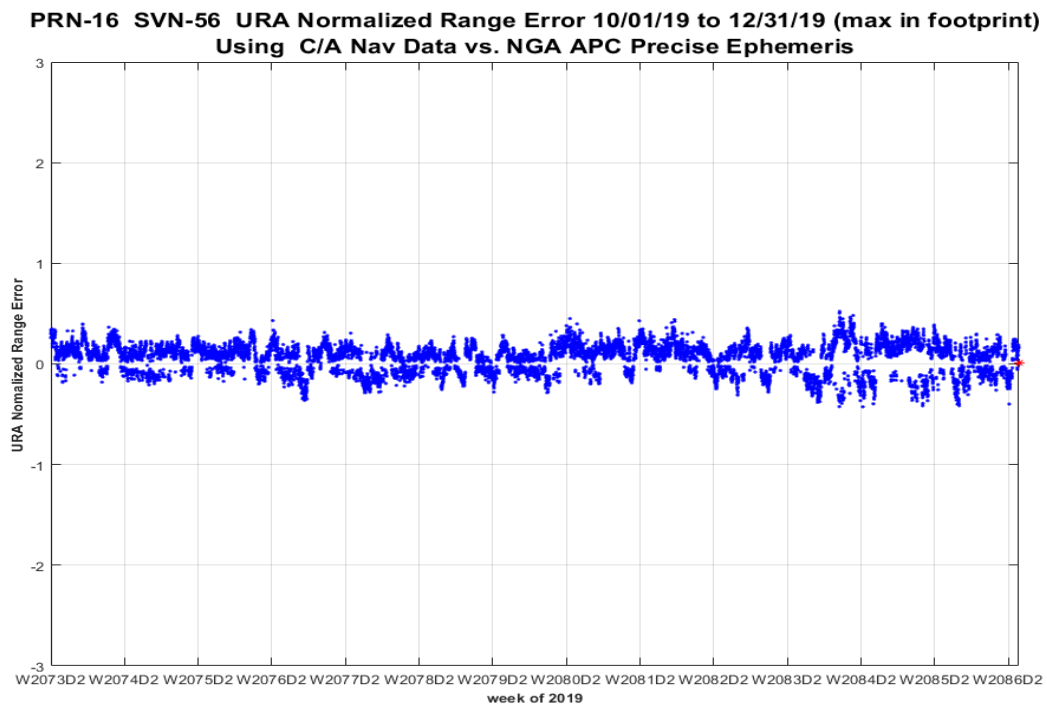
**Figure 10-136. Timeline of URA Normalized Range Error PRN15 (SVN-55) Using C/A Nav Data**



**Figure 10-137. Timeline of IAURA Normalized Range Error PRN15 (SVN-55) Using L2C CNAV Data**

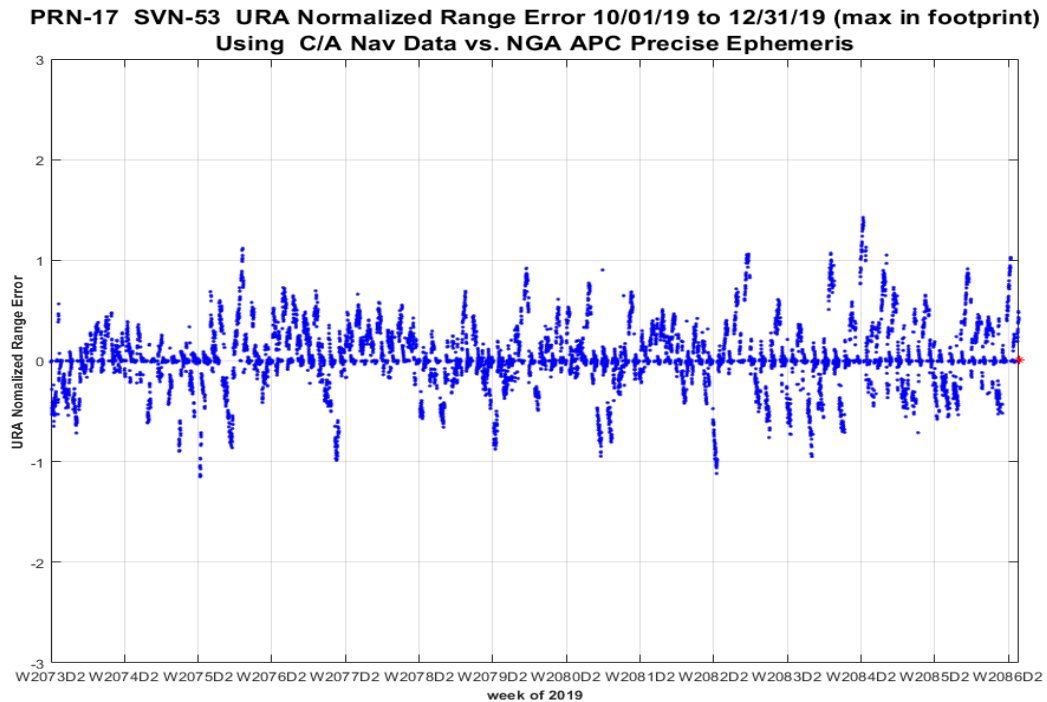


**Figure 10-138. Timeline of URA Normalized Range Error PRN16 (SVN-56) Using C/A Nav Data**

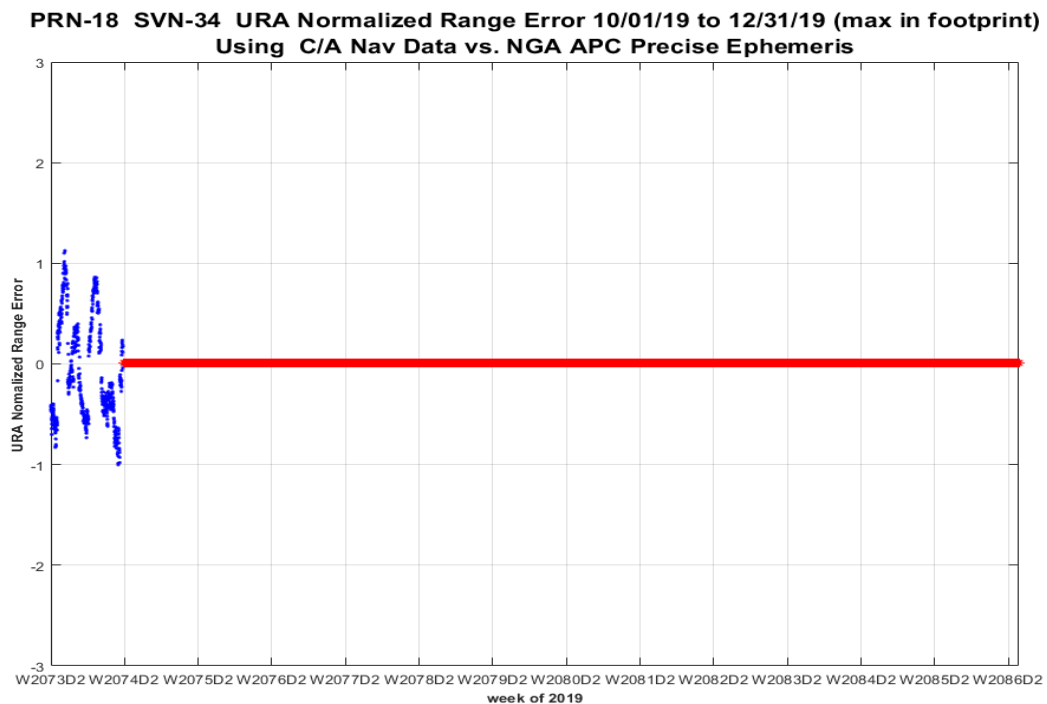




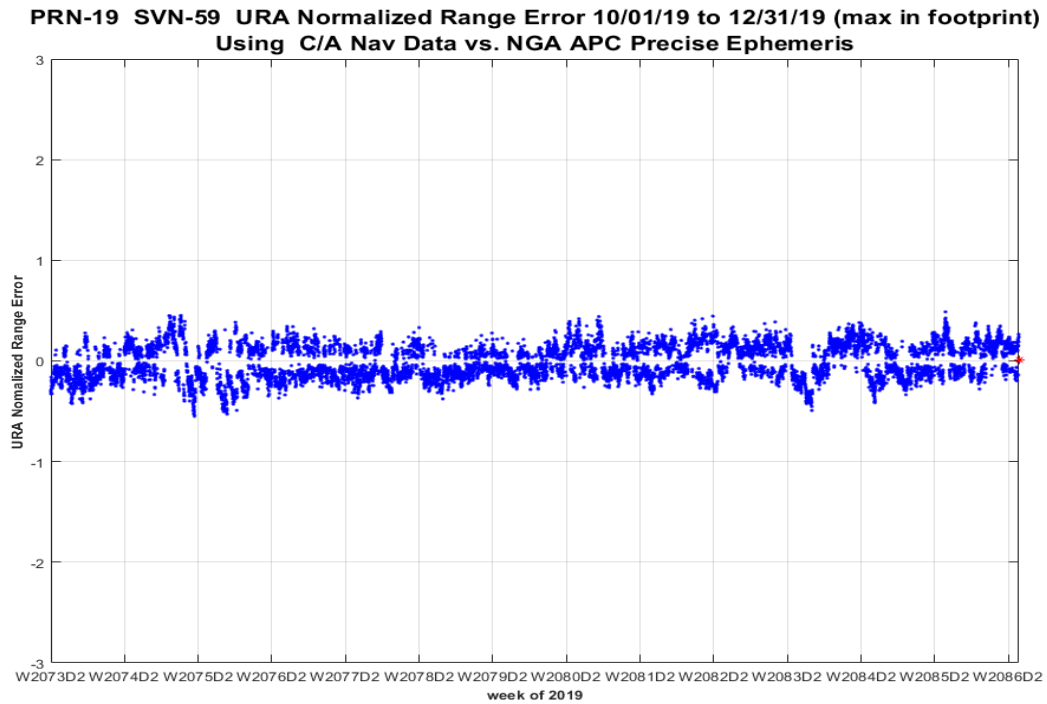
**Figure 10-139. Timeline of URA Normalized Range Error PRN17 (SVN-53) Using C/A Nav Data**



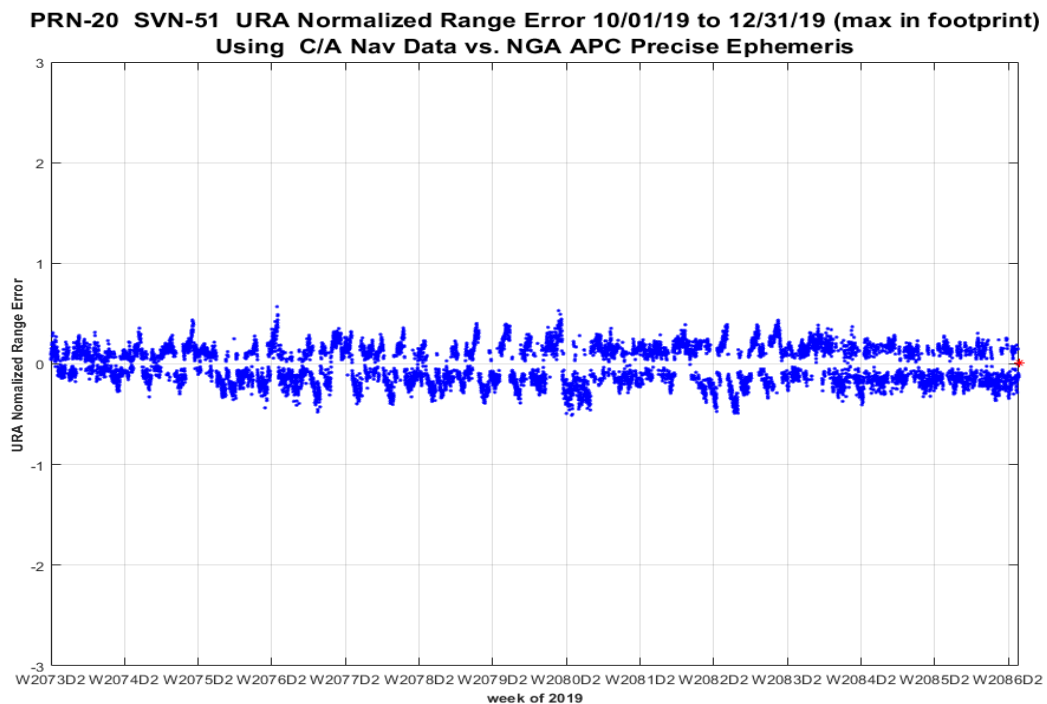
**Figure 10-140. Timeline of URA Normalized Range Error PRN18 (SVN-34) Using C/A Nav Data**



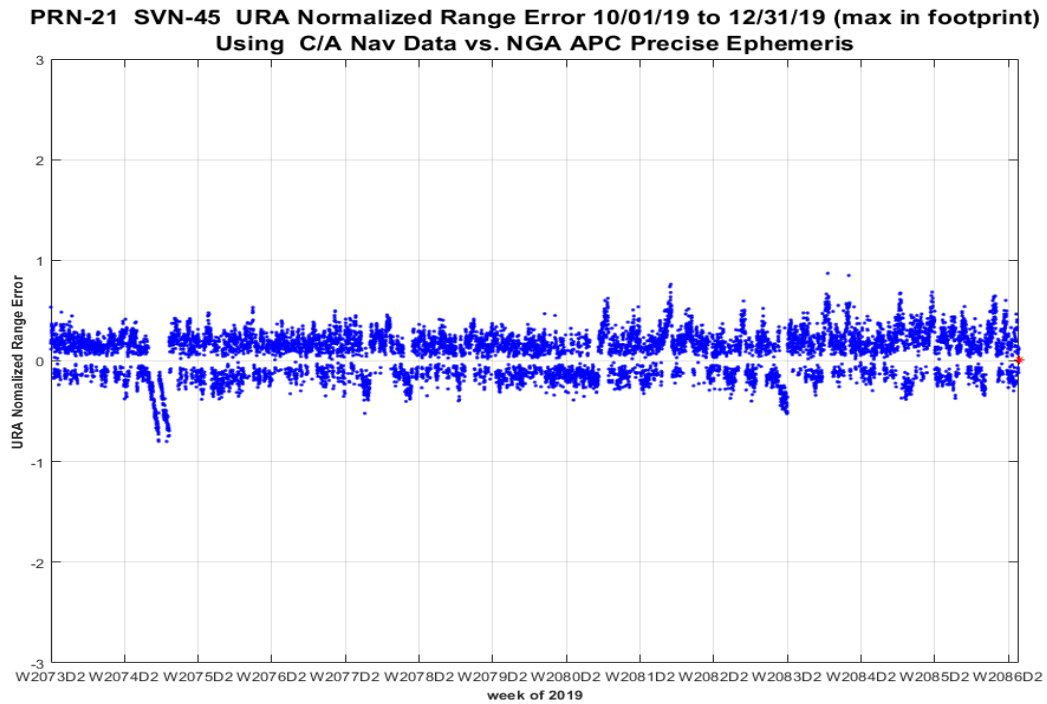
**Figure 10-141. Timeline of URA Normalized Range Error PRN19 (SVN-59) Using C/A Nav Data**



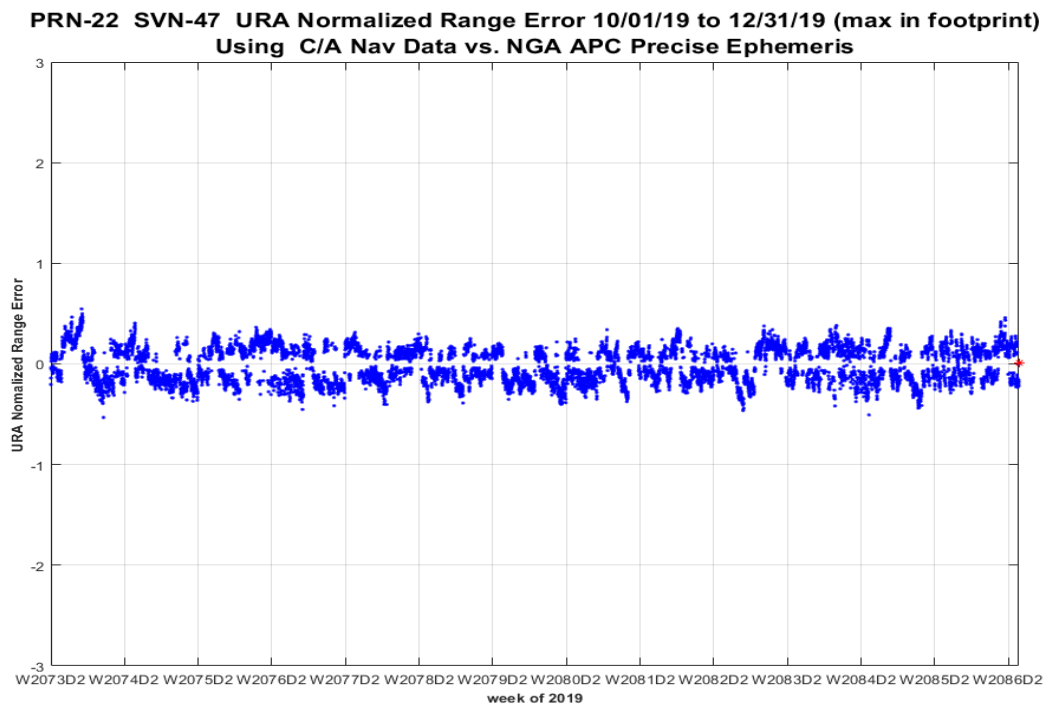
**Figure 10-142. Timeline of URA Normalized Range Error PRN20 (SVN-51) Using C/A Nav Data**



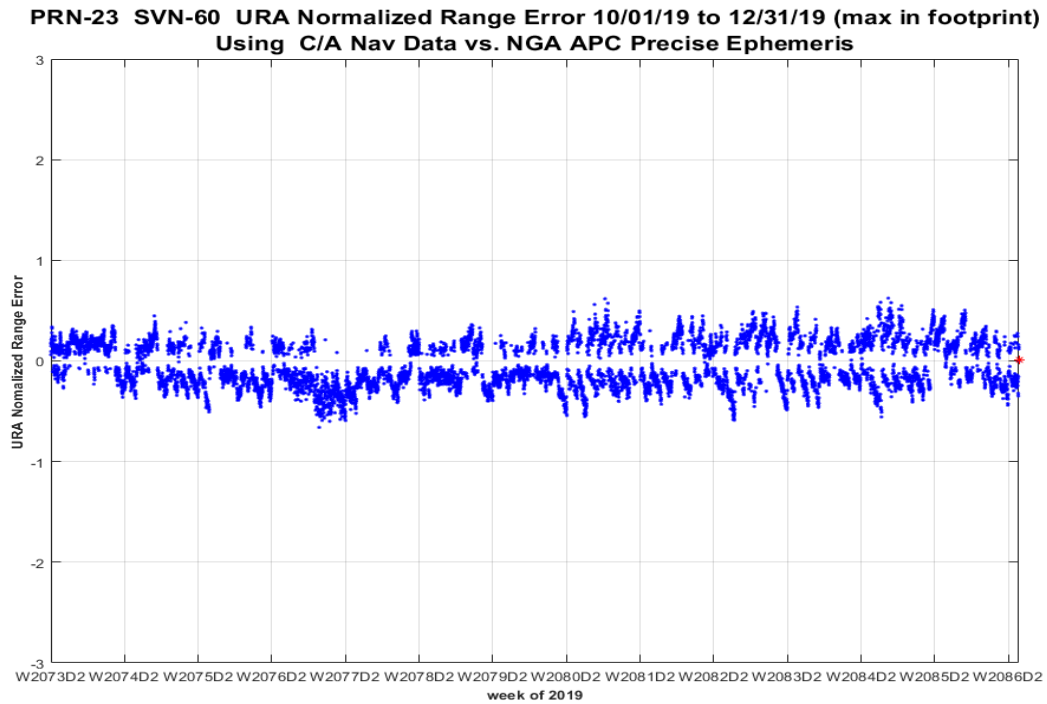
**Figure 10-143. Timeline of URA Normalized Range Error PRN21 (SVN-45) Using C/A Nav Data**



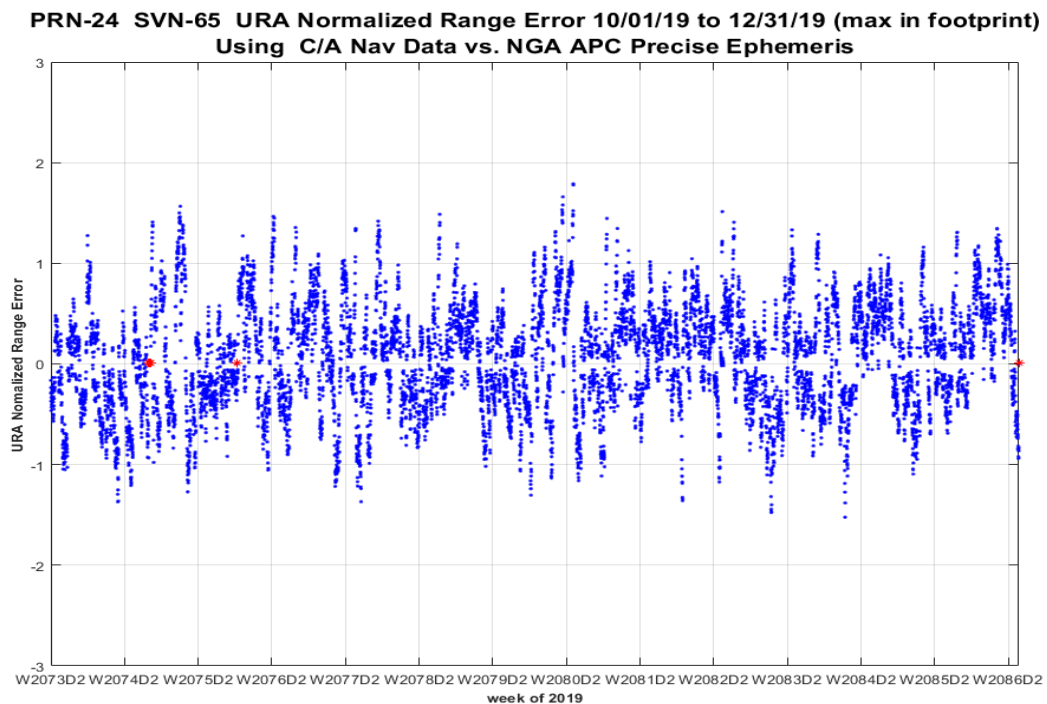
**Figure 10-144. Timeline of URA Normalized Range Error PRN22 (SVN-47) Using C/A Nav Data**



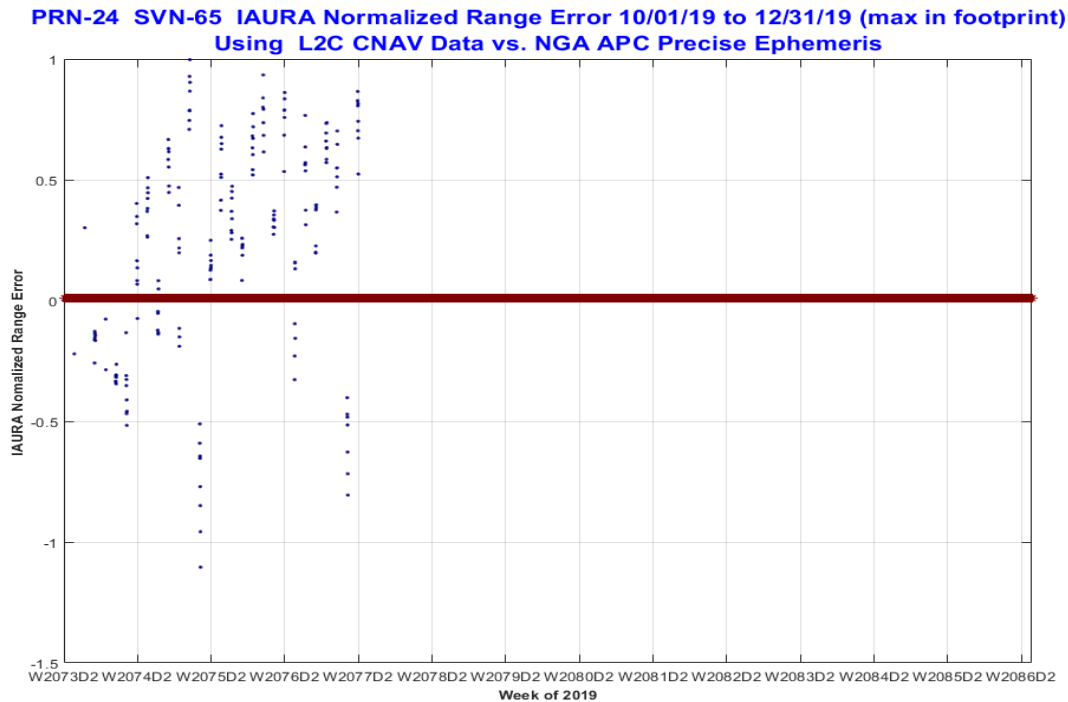
**Figure 10-145. Timeline of URA Normalized Range Error PRN23 (SVN-60) Using C/A Nav Data**



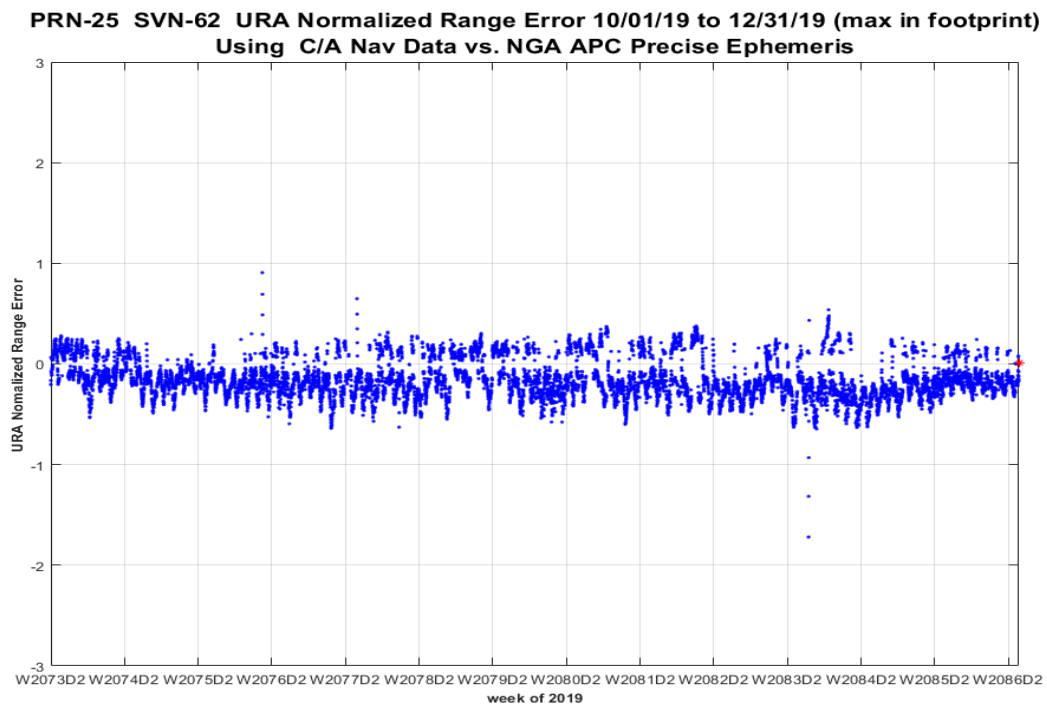
**Figure 10-146. Timeline of URA Normalized Range Error PRN24 (SVN-65) Using C/A Nav Data**



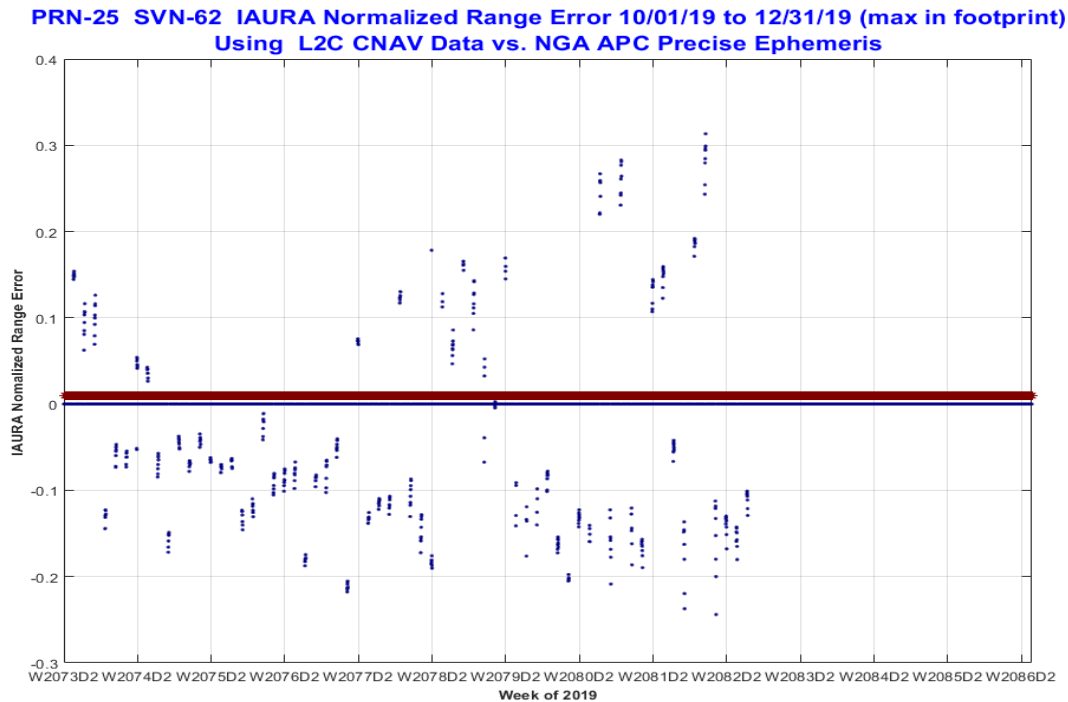
**Figure 10-147. Timeline of IAURA Normalized Range Error PRN24 (SVN-65) Using L2C CNAV Data**



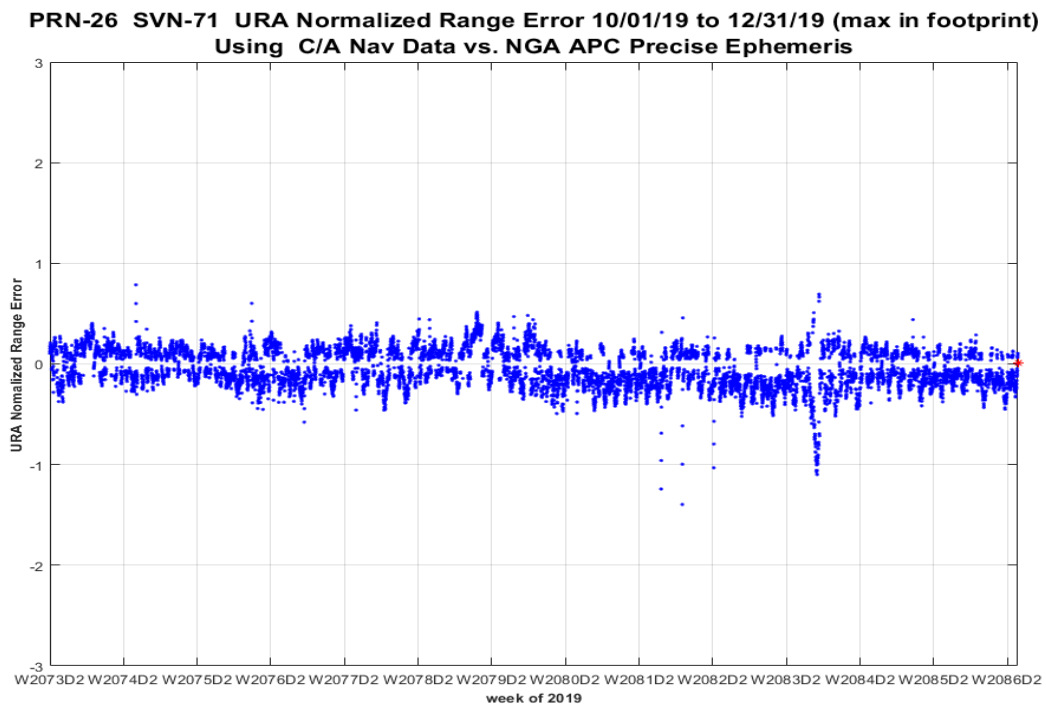
**Figure 10-148. Timeline of URA Normalized Range Error PRN25 (SVN-62) Using C/A Nav Data**



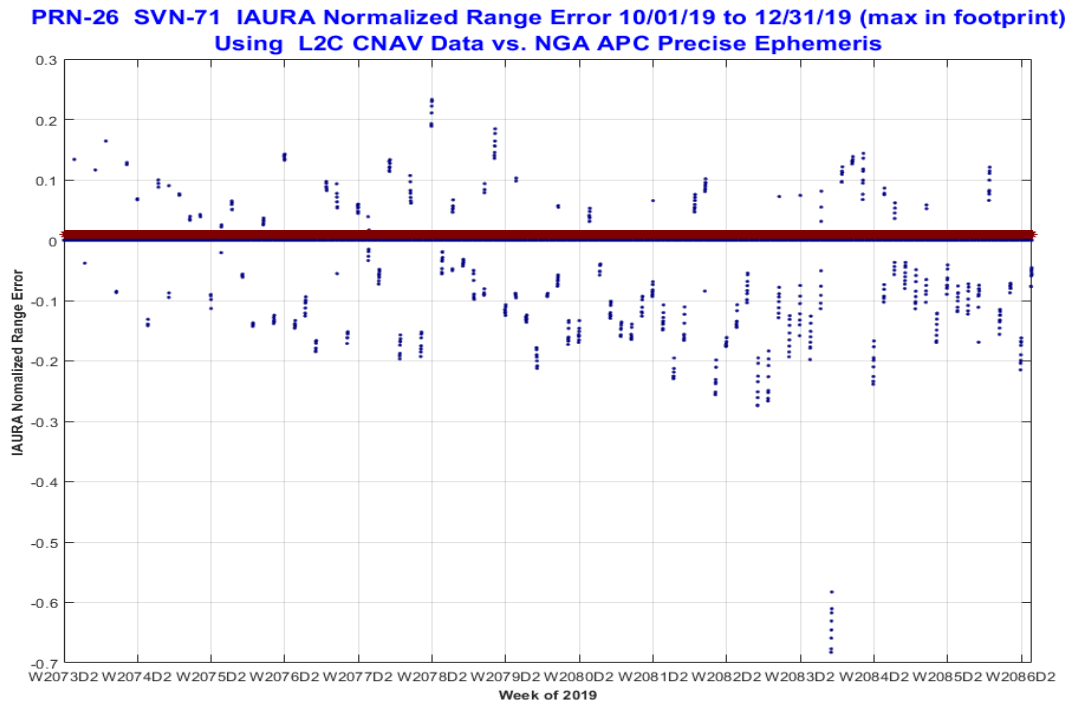
**Figure 10-149. Timeline of IAURA Normalized Range Error PRN25 (SVN-62) Using L2C CNAV Data**



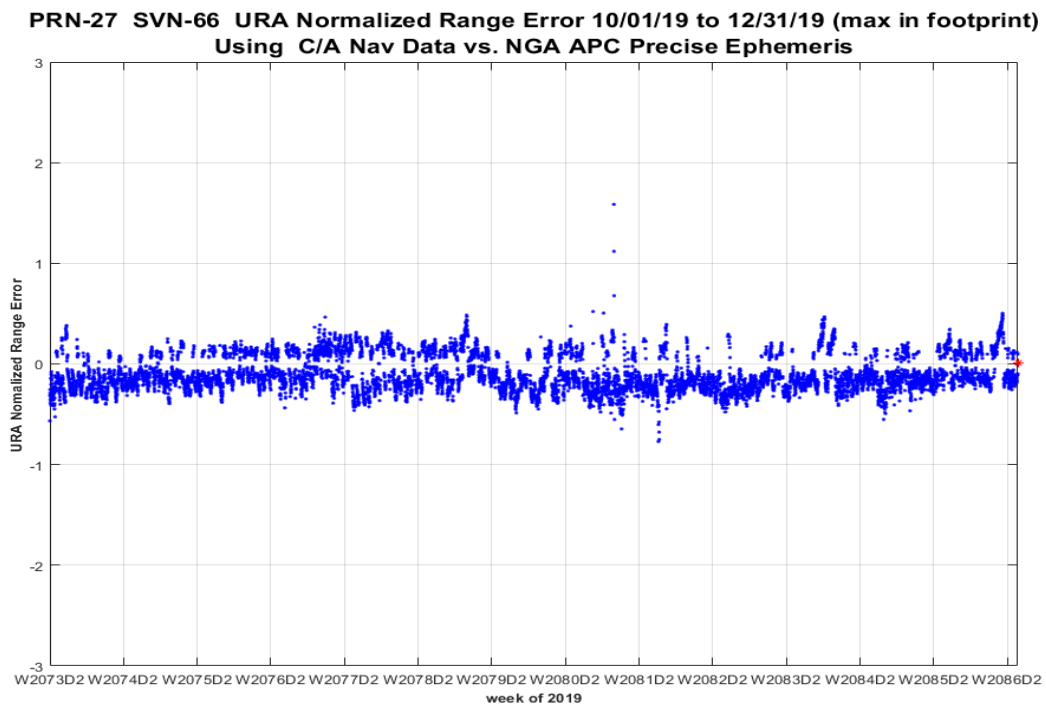
**Figure 10-150. Timeline of URA Normalized Range Error PRN26 (SVN-71) Using C/A Nav Data**



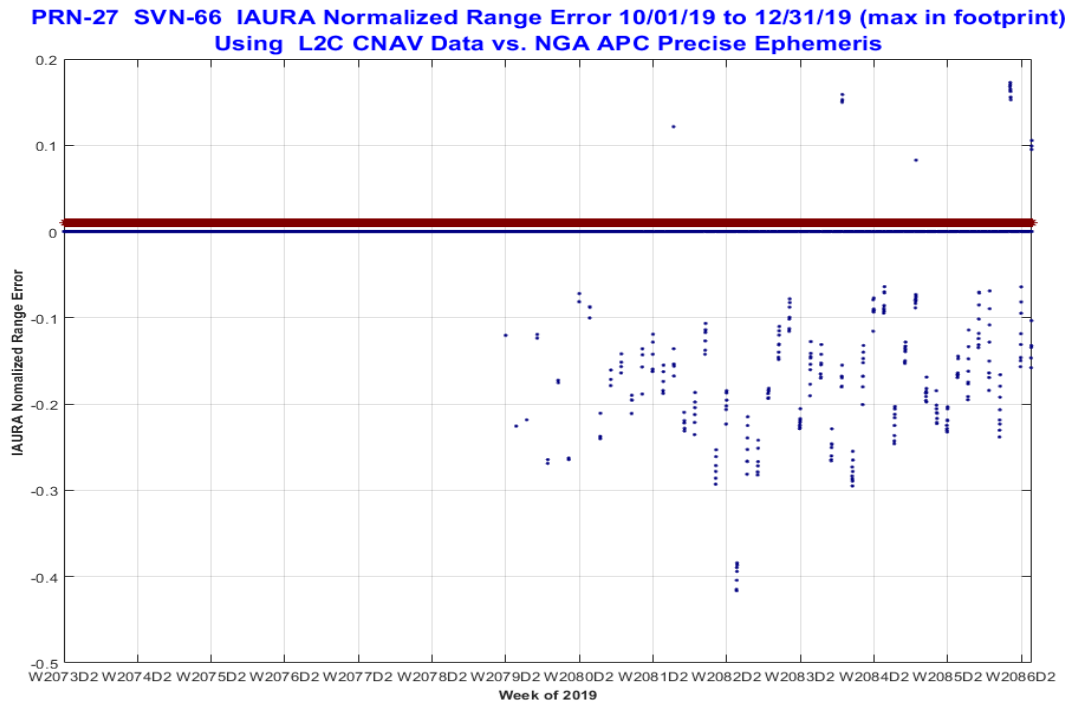
**Figure 10-151. Timeline of IAURA Normalized Range Error PRN26 (SVN-71) Using L2C CNAV Data**



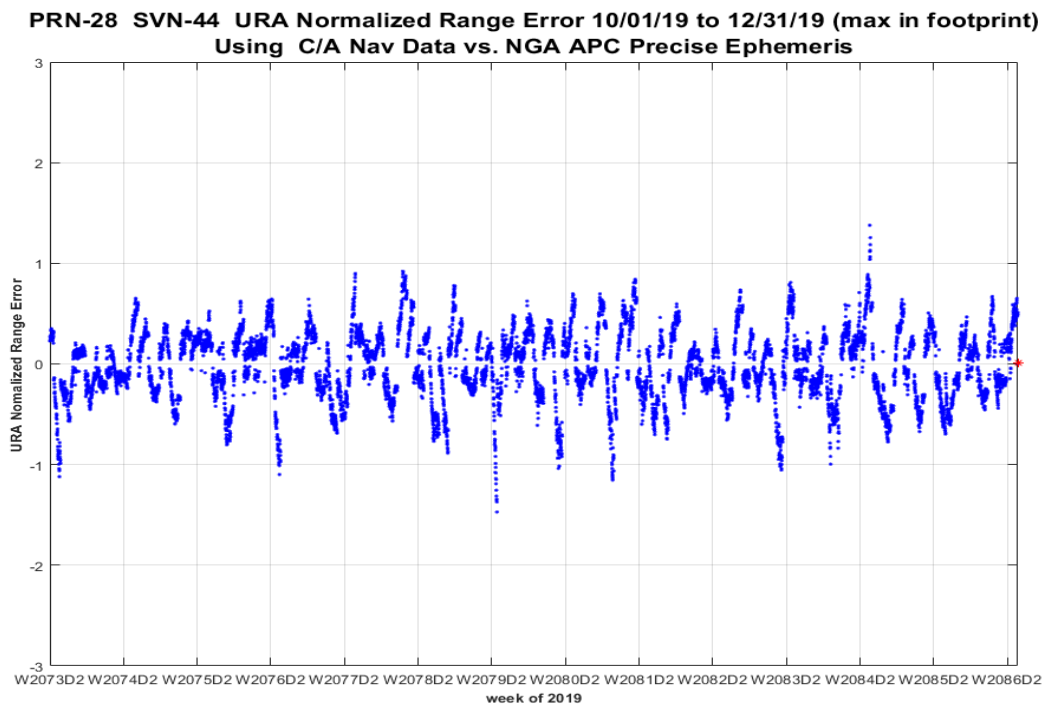
**Figure 10-152. Timeline of URA Normalized Range Error PRN27 (SVN-66) Using C/A Nav Data**



**Figure 10-153. Timeline of IAURA Normalized Range Error PRN27 (SVN-66) Using L2C CNAV Data**

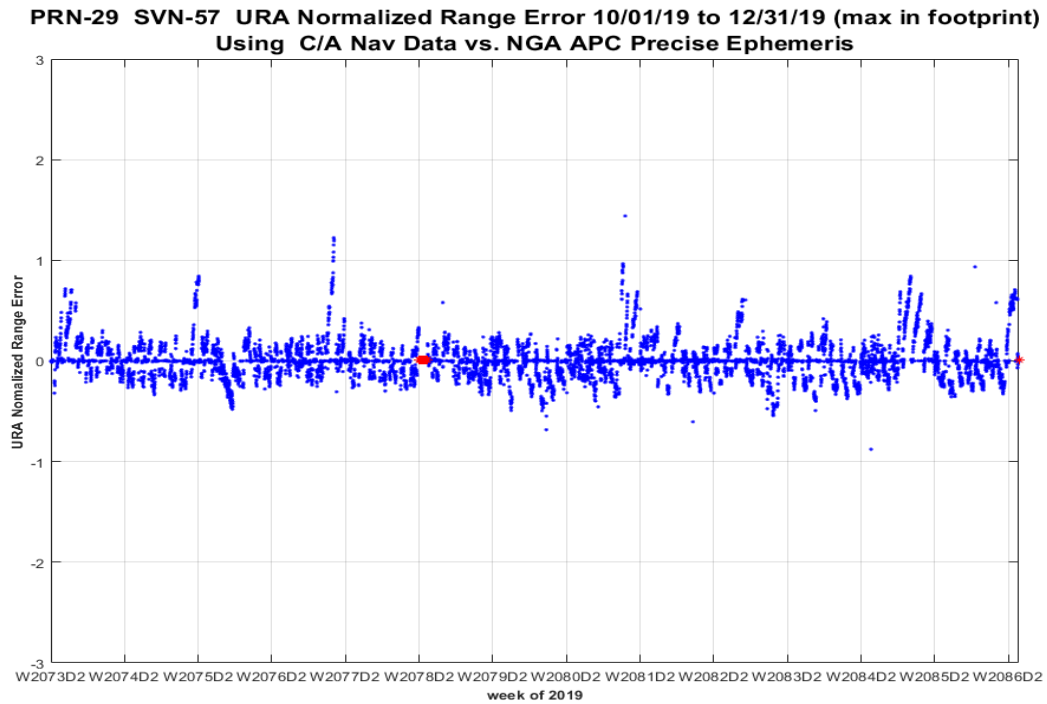


**Figure 10-154. Timeline of URA Normalized Range Error PRN28 (SVN-44) Using C/A Nav Data**

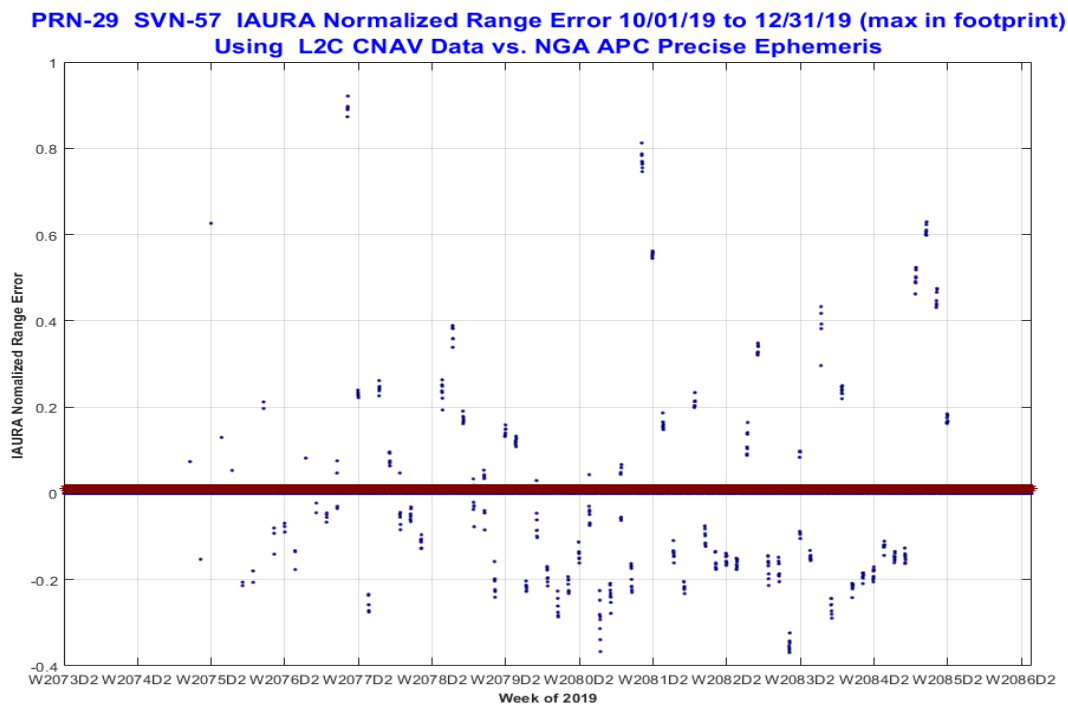




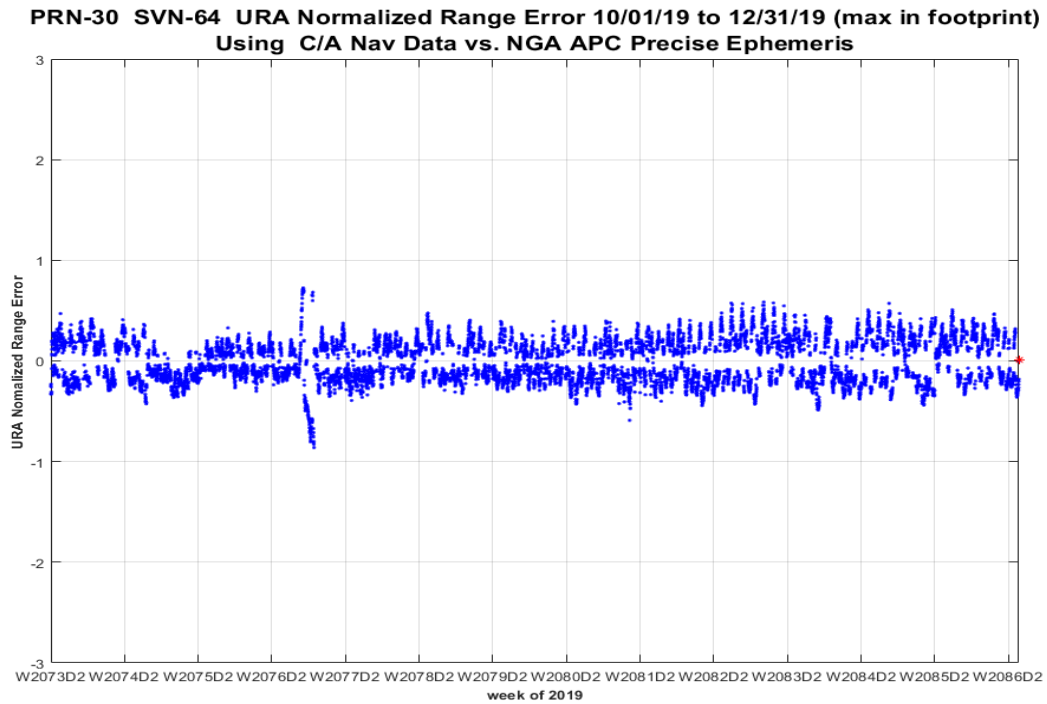
**Figure 10-155. Timeline of URA Normalized Range Error PRN29 (SVN-57) Using C/A Nav Data**



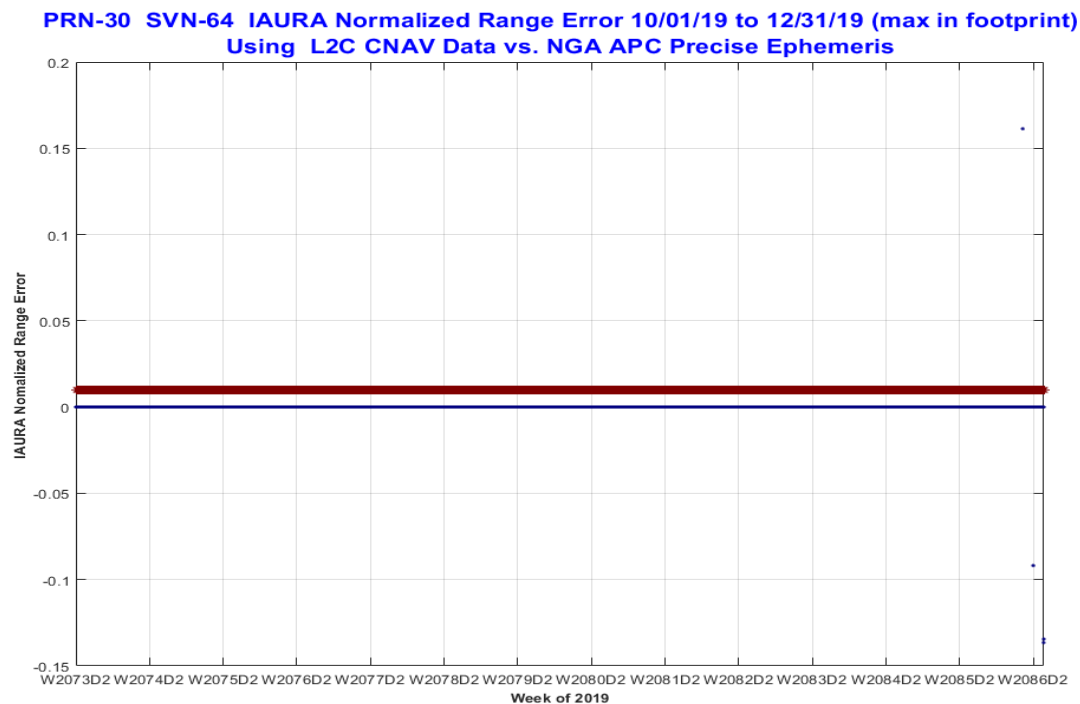
**Figure 10-156. Timeline of IAURA Normalized Range Error PRN29 (SVN-57) Using L2C CNAV Data**



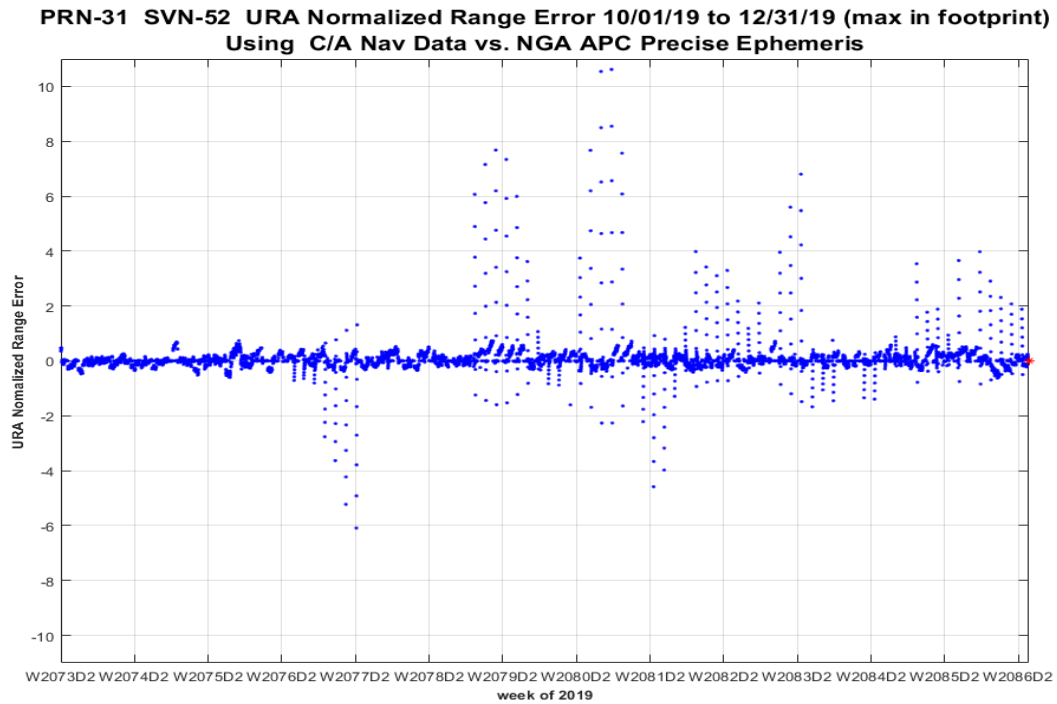
**Figure 10-157. Timeline of URA Normalized Range Error PRN30 (SVN-64) Using C/A Nav Data**



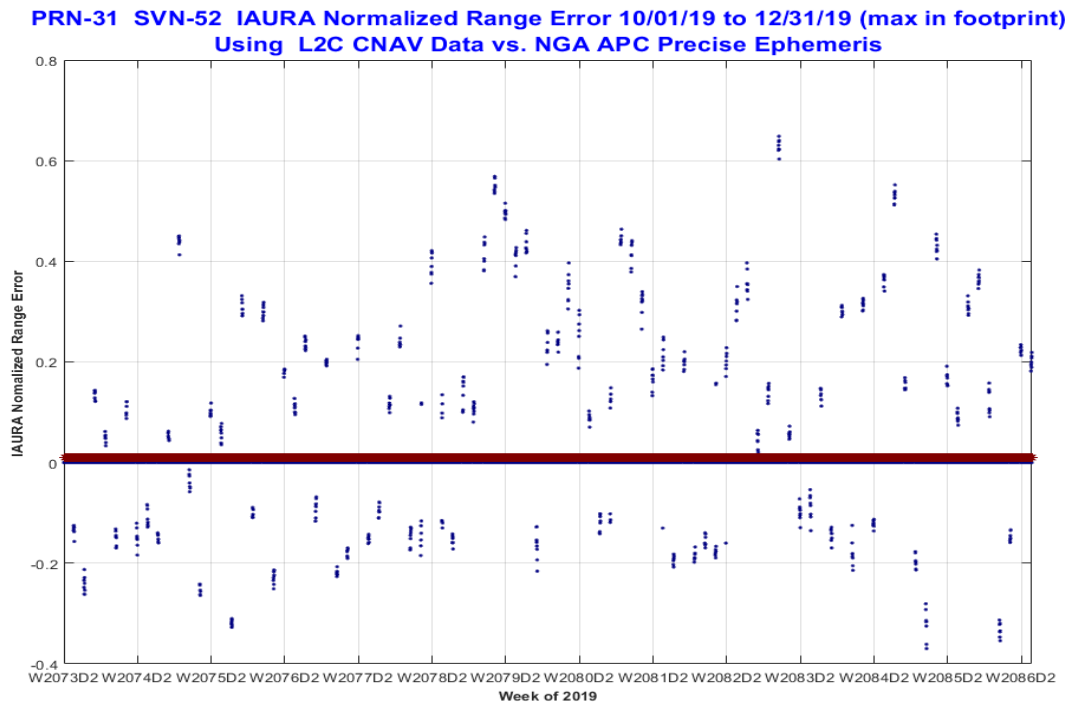
**Figure 10-158. Timeline of IAURA Normalized Range Error PRN30 (SVN-64) Using L2C CNAV Data**



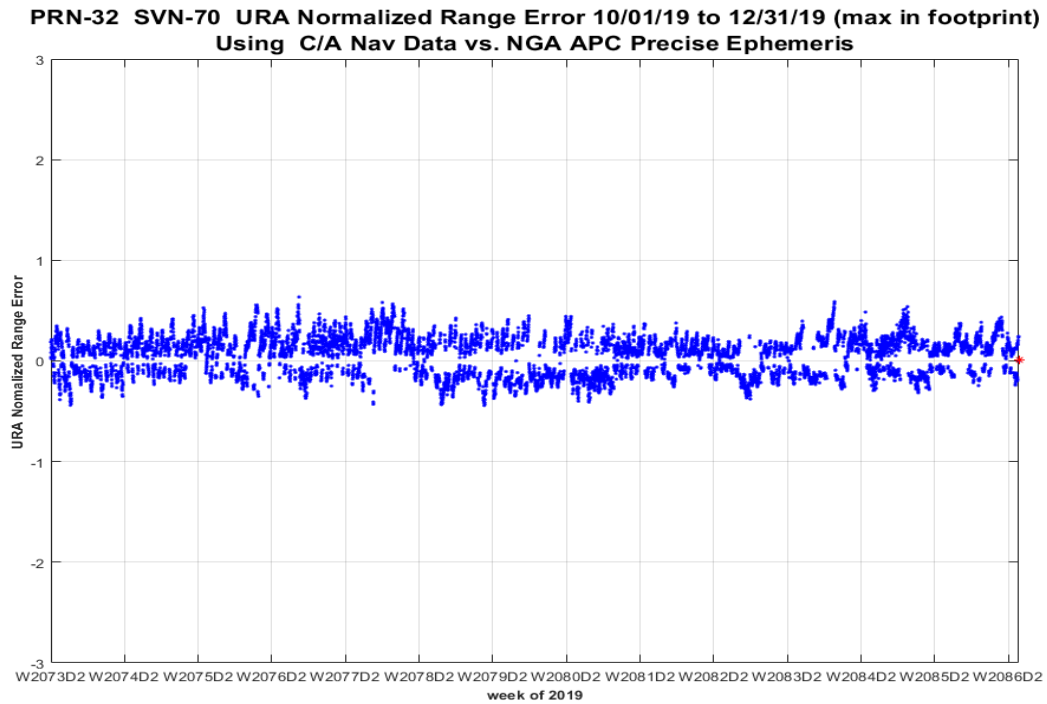
**Figure 10-159. Timeline of URA Normalized Range Error PRN31 (SVN-52) Using C/A Nav Data**



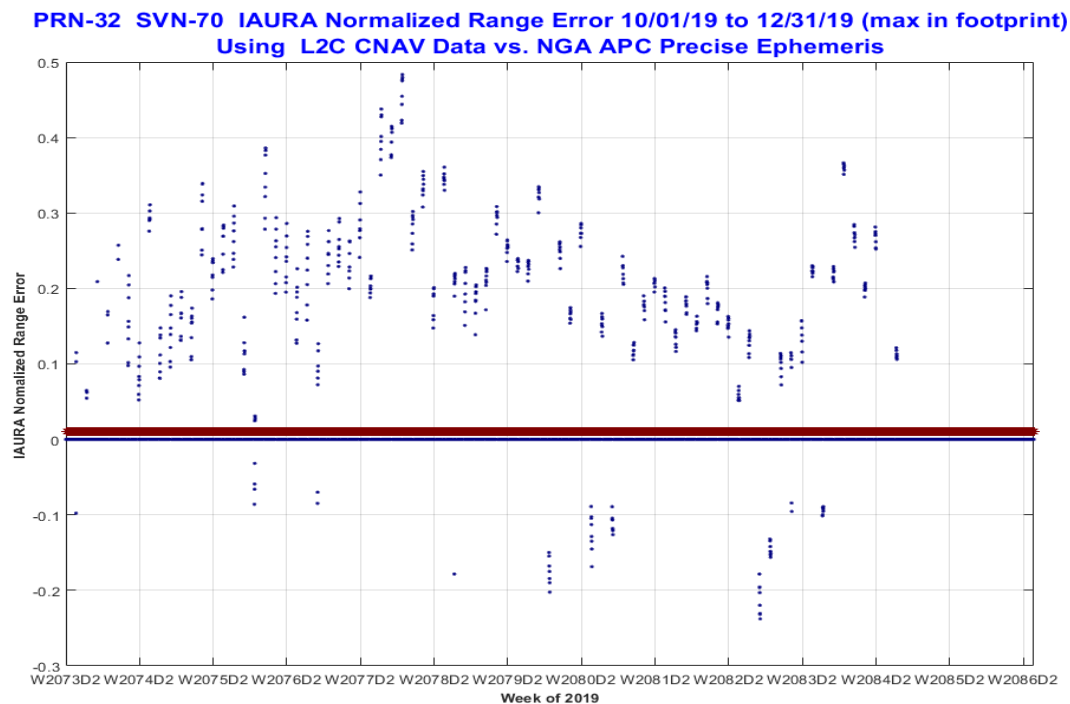
**Figure 10-160. Timeline of IAURA Normalized Range Error PRN31 (SVN-52) Using L2C CNAV Data**



**Figure 10-161. Timeline of URA Normalized Range Error PRN32 (SVN-70) Using C/A Nav Data**



**Figure 10-162. Timeline of IAURA Normalized Range Error PRN32 (SVN-70) Using L2C CNAV Data**



**APPENDIX A: PERFORMANCE SUMMARY****Table A-1. Performance Summary**

| <b>Parameter</b>  | <b>Measured Performance</b>   | <b>Conditions and Constraints</b>  |
|---|---|--|
| <b>User Range Error Accuracy</b><br>Single-Frequency C/A-Code <ol style="list-style-type: none"> <li>1. <math>\leq 7.8\text{m}</math> 95% Global Average URE during normal operations over All AODs</li> <li>2. <math>\leq 6.0\text{m}</math> 95% Global Average URE during operations at Zero AOD</li> <li>3. <math>\leq 12.8\text{m}</math> 95% Global Average URE during normal operations at Any AOD</li> </ol> | <ol style="list-style-type: none"> <li>1. <math>\leq 2.935\text{ m}</math></li> <li>2. N/A</li> <li>3. N/A</li> </ol> | For any healthy SPS SIS.<br><br>Neglecting single-frequency ionospheric delay model errors.<br><br>Including group delay time correction ( $T_{GD}$ ) errors at L1.<br><br>Including inter-signal bias (P(Y)-code to C/A-code) errors at L1.   |
| <b>User Range Error Accuracy</b><br>Single-Frequency C/A-Code <ol style="list-style-type: none"> <li>1. <math>\leq 30\text{m}</math> 99.94% Global Average URE during normal operations</li> <li>2. <math>\leq 30\text{m}</math> 99.79% Worst Case single point average during normal operations</li> </ol>   | <ol style="list-style-type: none"> <li>1. 100% Global</li> <li>2. 100% WCP</li> </ol>                                 | For any healthy SPS SIS.<br><br>Neglecting single-frequency ionospheric delay model errors.<br><br>Including group delay time correction ( $T_{GD}$ ) errors at L1.<br><br>Standard based on measurement interval of one year; average of daily values within service volume<br><br>Standard based on 3 service failures per year, lasting no more than 6 hours each |

| Parameter   | Measured Performance         | Conditions and Constraints  |
|---|------------------------------|---|
| <b>User Range Rate Error Accuracy</b><br>Single-Frequency C/A Code:<br><br>$\leq 6 \text{ mm/sec}$ 95% Global Average URRE over any 3-second interval during normal operations at Any AOD           | $\leq 2.627 \text{ mm/sec}$  | For any healthy SPS SIS.<br><br>Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers.<br><br>Neglecting single-frequency ionospheric delay model errors. |
| <b>User Range Acceleration Error Accuracy</b><br>Single-Frequency C/A Code:<br><br>$\leq 2 \text{ mm/sec}^2$ 95% Global Average URAE over any 3-second interval during normal operations at Any AOD | $\leq 21.567 \text{ mm/s}^2$ | For any healthy SPS SIS.<br><br>Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers.<br><br>Neglecting single-frequency ionospheric delay model errors. |
| <b>Per-Satellite Coverage</b><br>Terrestrial Service Volume:<br>100% Coverage   | 100%                         | For any healthy or marginal SPS SIS.  |
| <b>Constellation Coverage</b><br>Terrestrial Service Volume:<br>100% Coverage   | 100%                         | For any healthy or marginal SPS SIS.  |

| Parameter  | Measured Performance                     | Conditions and Constraints   |
|--|--|--|
| <b>Status and Problem Reporting</b><br>Scheduled event affecting service<br>Appropriate NANU issued to the Coast Guard and the FAA at least 48 hours prior to the event  | $\geq 136.0$ hours<br><br>Prior to event | For any SPS SIS.   |
| <b>Status and Problem Reporting</b><br>Unscheduled outage or problem affecting service<br>Appropriate NANU issued to the Coast Guard and the FAA as soon as possible after the event                                   | $\leq 0.750$ hours                       | For any SPS SIS.   |
| <b>Status and Problem Reporting</b><br>Unscheduled Failure Interruption Continuity:<br><br>$\geq 0.9998$ 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.<br><br>Given that the SPS SIS is available from the slot at the start of the hour.  |
| <b>Operational Satellite Count</b><br>$\geq 0.95$ 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  |
|--|--|---|
| <b>PDOP Availability</b> <ol style="list-style-type: none"> <li>1. <math>\geq 98\%</math> global PDOP of 6 or less</li> <li>2. <math>\geq 88\%</math> worst site PDOP of 6 or less</li> </ol>  | <ol style="list-style-type: none"> <li>1. 100%</li> <li>2. 100%</li> </ol>   | <p>Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.</p>   |
| <b>Service Availability</b> <ol style="list-style-type: none"> <li>1. <math>\geq 99\%</math> Horizontal Service Availability, average location</li> <li>2. <math>\geq 99\%</math> Vertical Service Availability, average location</li> </ol>       | <ol style="list-style-type: none"> <li>1. 100% Horizontal</li> <li>2. 100% Vertical</li> </ol>   | <p>17m Horizontal (SIS only) 95% threshold.</p> <p>37m Vertical (SIS only) 95% threshold.</p> <p>Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.</p> |
| <b>Service Availability</b> <ol style="list-style-type: none"> <li>1. <math>\geq 90\%</math> Horizontal Service Availability, worst-case location</li> <li>2. <math>\geq 90\%</math> Vertical Service Availability, worst-case location</li> </ol> | <ol style="list-style-type: none"> <li>1. 100% Horizontal</li> <li>2. 100% Vertical</li> </ol>   | <p>17m Horizontal (SIS only) 95% threshold.</p> <p>37m Vertical (SIS only) 95% threshold.</p> <p>Defined for a position/time solution meeting the representative user conditions and operating within the service volume over any 24-hour interval.</p> |
| <b>Position/Time Accuracy</b><br>Global Average Position Domain Accuracy: <ol style="list-style-type: none"> <li>1. <math>\leq 9\text{m}</math> 95% Horizontal Error</li> <li>2. <math>\leq 15\text{m}</math> 95 % Vertical Error</li> </ol>       | <ol style="list-style-type: none"> <li>1. <math>\leq 1.800\text{ m}</math> Horizontal</li> <li>2. <math>\leq 4.269\text{ m}</math> Vertical</li> </ol> | <p>Defined for a position/time solution meeting the representative user conditions.</p> <p>Standard based on a measurement interval of 24 hours averaged over all points in the service volume.</p>   |



| Parameter   | Measured Performance   | Conditions and Constraints   |
|---|--|--|
| <b>Position/Time Accuracy</b><br>Worst Site Position Domain Accuracy:<br>1. $\leq 17\text{m}$ 95% Horizontal Error<br>2. $\leq 37\text{m}$ 95% Vertical Error | 1. $\leq 2.910\text{ m}$ Horizontal<br>2. $\leq 5.120\text{ m}$ Vertical | Defined for a position/time solution meeting the representative user conditions.<br><br>Standard based on a measurement interval of 24 hours averaged over all points in the service volume. |
| <b>Position/Time Accuracy</b><br>Time Transfer Domain Accuracy:<br><br>$\leq 40$ nanoseconds time transfer error 95% of time<br><br>(SIS only)                | $\leq 12$ nanoseconds  | Defined for a time transfer solution meeting the representative user conditions.<br><br>Standard based on a measurement interval of 24 hours averaged over all points in the service volume. |
| <b>Position/Time Accuracy</b><br>Instantaneous UTCOE Integrity:<br><br>NTE $\pm 120$ nanoseconds 99.999% of time without a timely alert.<br><br>(SIS only)    | $\leq 19.2$ nanoseconds  | For any healthy SPS SIS.<br><br>Worst case for delayed alert is 6 hours.   |

| Parameter  | Measured Performance   | Conditions and Constraints   |
|--|--|--|
| <p><b>Per-Slot Availability</b></p> <ol style="list-style-type: none"> <li>1. <math>\geq 0.957</math> Probability that a slot in the baseline 24-slot configuration will be occupied by a satellite broadcasting a healthy SPS SIS</li> <li>2. <math>\geq 0.957</math> Probability that a slot in the expanded configuration will be occupied by a pair of satellites each broadcasting a healthy SPS SIS</li> </ol>   | <ol style="list-style-type: none"> <li>1. 100%</li> <li>2. 100%</li> </ol> | <p>Calculated as an average over all slots in the 24-slot constellation, normalized annually</p> <p>Applies to satellites broadcasting a healthy SPS SIS that also satisfy the other performance standards in the SPS performance standard.</p>    |
| <p><b>Constellation Availability</b></p> <ol style="list-style-type: none"> <li>1. <math>\geq 0.98</math> 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.</li> <li>2. <math>\geq 0.99999</math> 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.</li> </ol> | <ol style="list-style-type: none"> <li>1. 100%</li> <li>2. 100%</li> </ol> | <p>Calculated as an average over all slots in the 24-slot constellation, normalized annually.</p> <p>Applied to satellites broadcasting a healthy SPS SIS that also satisfies the other performance standards in the SPS performance standard.</p> |

**APPENDIX B: GEOMAGNETIC DATA**

```
# Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
# Please send comment and suggestions to SWPC.Webmaster@noaa.gov
#
# Current Quarter Daily Geomagnetic Data
#
#
# Middle Latitude High Latitude Estimated
# - Fredericksburg - ---- College ---- --- Planetary ---
# Date A K-indices A K-indices A K-indices
2019 10 01 11 4 3 3 3 2 1 1 1 18 3 3 5 5 3 1 0 1 13 4 4 3 3 1 0 1 1
2019 10 02 7 3 0 0 2 3 2 1 2 15 2 1 0 5 5 1 1 2 8 3 0 0 2 3 1 1 2
2019 10 03 5 2 1 1 1 2 1 2 1 3 1 1 2 2 0 1 1 0 5 2 1 2 1 1 1 2 1
2019 10 04 6 1 2 2 2 2 1 2 1 6 1 1 3 1 1 3 1 0 7 2 2 3 2 2 2 2 1
2019 10 05 6 1 1 1 1 2 2 2 3 10 1 1 3 4 3 2 1 1 7 1 2 2 2 2 2 3
2019 10 06 5 2 2 2 2 1 1 1 0 7 1 2 2 4 2 1 0 0 5 2 2 2 2 1 1 0 0
2019 10 07 4 0 1 1 1 2 2 1 2 7 0 0 0 3 4 2 1 1 6 1 1 1 1 2 2 2 2
2019 10 08 4 1 1 2 1 1 1 1 1 6 1 0 3 3 2 1 0 1 5 2 2 2 1 1 1 2 1
2019 10 09 7 1 2 2 3 1 1 2 2 17 0 2 3 6 4 1 1 1 9 2 3 2 4 2 1 1 2
2019 10 10 10 1 4 3 2 2 2 1 2 17 1 3 5 4 2 4 2 1 13 2 4 4 2 2 3 2 2
2019 10 11 6 0 1 3 2 2 2 2 1 15 0 0 3 5 4 4 1 0 8 1 1 2 2 2 3 2 2
2019 10 12 4 2 2 1 2 1 1 1 0 6 1 1 2 3 3 1 1 0 5 2 2 1 2 2 0 1 1
2019 10 13 1 1 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 2 1 0 0 0 0 0 1 0
2019 10 14 5 1 2 1 1 2 2 1 1 3 0 0 0 1 2 2 1 0 6 1 2 1 1 1 2 2 1
2019 10 15 5 3 1 0 1 1 1 2 2 1 2 0 0 0 0 0 1 0 5 3 1 1 1 0 1 2 2
2019 10 16 5 2 2 2 1 1 1 2 1 3 0 0 2 2 0 0 1 1 6 2 2 3 2 1 1 2 2
2019 10 17 4 2 1 1 1 1 1 1 1 6 1 0 3 3 3 1 0 0 6 2 2 2 2 1 1 1 1
2019 10 18 4 1 2 1 1 2 1 1 1 5 0 1 3 3 2 1 0 0 6 1 2 2 2 2 1 1 2
2019 10 19 3 1 0 1 1 2 1 1 0 8 0 0 2 4 3 2 1 2 5 1 1 1 2 2 2 2 1
2019 10 20 4 1 2 1 1 1 1 1 2 8 1 0 3 3 3 1 1 2 6 2 2 2 1 1 1 1 3
2019 10 21 4 2 1 1 1 2 0 1 1 3 2 0 0 3 1 0 0 0 5 3 1 1 2 1 0 1 1
2019 10 22 2 0 0 1 0 1 1 2 0 0 0 0 1 0 0 0 0 0 3 0 0 1 0 1 1 1 0
2019 10 23 1 0 0 0 0 1 1 1 0 1 0 0 0 0 1 0 0 0 2 1 0 0 0 0 1 1 0
2019 10 24 12 0 1 2 3 3 3 3 4 25 0 0 0 5 6 5 3 2 18 0 2 1 4 3 4 4 4
2019 10 25 29 4 4 5 6 3 3 2 3 62 5 5 7 7 5 5 3 2 29 5 4 6 5 3 3 3 3
2019 10 26 17 3 2 3 4 4 3 3 3 59 2 3 6 7 7 5 3 4 25 3 3 4 5 4 4 4 4
2019 10 27 11 4 3 3 1 2 2 2 2 25 3 3 6 4 3 3 4 2 15 4 3 3 2 2 3 3 3
2019 10 28 8 2 2 3 2 2 2 2 2 21 2 3 4 5 5 3 2 1 11 3 3 3 2 2 2 3 2
2019 10 29 8 3 3 1 1 2 2 2 1 -1 2 -1 -1 -1 0 -1 -1 -1 8 3 3 1 1 1 2 2 1
2019 10 30 6 1 2 1 1 2 2 2 2 -1 -1 -1 -1 -1 0 2 0 9 1 2 2 2 3 3 3 2
2019 10 31 5 3 1 0 1 2 1 2 1 -1 -1 0 -1 2 0 1 1 -1 7 4 1 0 1 1 1 3 1
2019 11 01 2 1 2 0 0 1 1 1 0 -1 0 1 0 0 0 -1 -1 -1 4 2 2 1 1 1 0 0 0
2019 11 02 1 0 0 0 0 1 0 0 1 -1 -1 -1 -1 -1 -1 -1 2 0 0 0 0 0 0 0 1
2019 11 03 1 1 1 0 0 1 0 0 0 -1 -1 -1 -1 -1 -1 -1 2 2 1 0 0 0 0 0 0
2019 11 04 4 1 1 2 1 2 1 1 0 -1 -1 -1 -1 -1 -1 -1 4 1 1 2 1 1 1 1 1
2019 11 05 2 1 0 0 1 1 1 1 1 2 0 0 0 0 2 2 1 0 5 2 1 1 1 1 2 2 2
2019 11 06 4 1 1 0 0 2 1 1 3 -1 0 0 -1 -1 -1 -1 -1 5 2 1 0 1 2 1 1 3
2019 11 07 3 2 1 1 1 1 1 1 0 -1 -1 -1 -1 -1 -1 -1 5 2 2 1 1 0 1 1 1
2019 11 08 2 0 1 0 1 1 1 1 0 -1 -1 -1 -1 0 0 0 -1 -1 3 1 0 0 1 1 1 1 1
2019 11 09 3 2 1 0 0 1 1 1 1 1 0 0 0 1 1 0 0 0 4 2 2 0 0 1 1 1 2
2019 11 10 2 0 0 2 1 0 1 1 0 -1 0 0 2 1 1 0 0 -1 3 1 1 2 1 1 0 0 0
2019 11 11 7 0 2 2 3 2 1 2 2 -1 -1 -1 -1 -1 3 -1 -1 7 0 1 2 3 2 2 2 2
2019 11 12 3 2 0 0 0 2 1 1 0 -1 0 -1 -1 0 0 1 0 -1 4 2 1 1 1 1 1 1 0
2019 11 13 1 0 0 0 0 1 0 1 1 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 1 1
```

2019 11 14 3 2 1 1 1 1 1 1 0 1 1 0 0 0 1 0 0 0 4 2 1 1 1 1 0 1 0  
2019 11 15 2 0 1 0 1 0 1 1 1 0 0 0 0 0 0 0 1 0 4 0 1 0 1 0 1 2 1  
2019 11 16 5 2 1 0 1 2 2 2 2 3 0 0 1 2 1 1 2 0 6 2 2 1 1 1 2 2 2  
2019 11 17 3 1 1 0 0 1 1 1 2 2 1 1 2 0 0 0 0 1 5 2 1 1 0 0 1 1 3  
2019 11 18 1 0 0 0 0 1 1 1 0 0 0 0 0 1 0 0 0 0 2 0 0 0 0 0 0 1 0  
2019 11 19 1 0 1 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 2 0 1 0 0 0 1 1 0  
2019 11 20 1 0 1 0 0 0 1 0 1 0 0 0 0 0 0 0 0 1 2 0 1 0 0 0 0 0 1  
2019 11 21 7 2 2 1 1 2 2 2 3 9 0 0 1 3 3 3 2 3 12 2 2 2 2 2 3 3 4  
2019 11 22 8 3 1 2 2 2 2 2 2 19 4 1 2 5 4 3 3 2 13 4 2 2 2 3 3 3 2  
2019 11 23 7 2 1 2 3 2 1 2 2 15 1 1 3 -1 5 -1 -1 2 10 3 2 2 3 3 2 3 2  
2019 11 24 8 3 2 3 2 1 2 1 2 15 2 2 3 4 5 2 1 1 11 3 3 3 2 2 3 1 3  
2019 11 25 5 2 1 2 2 1 1 1 1 5 0 0 3 3 1 1 0 0 5 2 1 2 2 1 1 1 2  
2019 11 26 3 1 2 0 0 1 2 0 0 0 0 0 0 0 0 0 1 0 3 2 2 0 0 0 1 1 1  
2019 11 27 2 0 1 0 1 1 2 1 0 2 0 0 1 1 1 1 0 0 4 1 1 1 1 1 2 2 1  
2019 11 28 2 1 0 0 0 1 1 2 0 1 0 0 0 0 1 0 1 0 4 2 0 1 0 1 1 2 1  
2019 11 29 3 1 1 0 1 1 0 1 2 1 0 0 0 1 0 0 1 1 5 1 1 0 1 1 1 2 3  
2019 11 30 2 1 1 1 0 1 0 1 1 4 1 0 0 0 1 2 3 1 4 2 1 1 0 1 1 2 2  
2019 12 01 2 1 0 1 0 1 1 1 1 2 1 1 0 0 1 0 1 0 4 1 1 0 0 1 1 2 2  
2019 12 02 2 0 1 2 0 0 1 0 0 0 0 0 0 0 0 0 0 0 2 0 1 1 0 0 0 0 0  
2019 12 03 1 0 0 0 0 0 1 0 1 0 0 0 0 1 0 0 0 0 2 0 0 0 0 0 0 0 1  
2019 12 04 2 1 2 1 0 1 0 0 0 1 0 0 0 2 1 0 0 0 3 1 2 1 1 1 0 1 0  
2019 12 05 1 0 0 0 1 1 1 0 0 2 0 0 0 2 2 0 0 0 3 0 0 0 1 1 1 1 0  
2019 12 06 2 0 1 1 1 1 1 0 0 1 0 0 0 1 1 0 0 0 4 0 2 1 1 1 1 1 1  
2019 12 07 1 0 0 0 0 0 1 1 0 0 0 0 0 1 0 0 0 0 2 1 0 0 1 0 0 1 1  
2019 12 08 2 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 3 0 0 0 0 1 1 1 1  
2019 12 09 2 2 1 0 0 0 1 0 1 1 1 0 0 0 0 1 0 0 4 3 1 0 0 0 1 0 2  
2019 12 10 2 0 2 1 0 0 0 1 1 1 0 0 1 2 0 0 0 0 4 1 2 1 1 0 0 1 1  
2019 12 11 3 3 1 0 0 1 1 0 1 2 1 1 0 0 1 2 1 0 6 3 2 0 1 1 2 1 2  
2019 12 12 3 0 0 2 1 1 1 1 2 1 1 0 2 0 0 0 0 0 4 1 1 2 1 0 0 1 2  
2019 12 13 3 1 2 1 1 1 1 0 0 1 1 0 1 1 0 0 0 0 4 1 2 1 1 0 0 1 0  
2019 12 14 2 0 0 0 0 1 1 0 2 0 0 0 0 0 0 0 0 3 1 0 1 0 0 0 0 2  
2019 12 15 5 2 2 1 0 1 2 1 2 2 1 0 1 0 0 0 1 1 5 2 2 1 1 0 1 1 2  
2019 12 16 1 0 0 0 1 1 1 0 0 2 1 0 0 0 2 1 0 0 1 0 0 0 0 1 1 0 0  
2019 12 17 2 1 1 1 0 1 1 1 0 1 0 0 1 1 0 0 0 0 2 0 0 1 1 0 0 0 0  
2019 12 18 12 1 1 1 3 4 4 3 1 34 0 0 1 7 6 4 3 1 13 1 2 1 3 4 4 3 2  
2019 12 19 12 3 3 4 3 2 2 2 1 21 1 3 4 6 4 2 2 0 13 3 4 4 3 2 2 2 1  
2019 12 20 4 2 1 1 0 1 2 1 1 4 0 1 1 2 3 2 0 0 5 2 1 1 0 2 2 1 2  
2019 12 21 4 2 0 2 2 1 1 1 1 8 0 0 3 3 4 0 0 1 5 2 0 2 1 1 0 1 1  
2019 12 22 2 1 0 2 0 1 1 0 1 2 1 0 2 1 1 0 0 0 4 1 0 2 0 0 0 1 1  
2019 12 23 2 0 1 0 1 1 1 0 0 4 0 0 0 3 3 0 0 0 4 0 2 0 2 1 1 0 0  
2019 12 24 2 1 0 0 1 1 1 0 0 0 0 0 0 1 0 0 0 0 3 2 0 1 1 0 0 0 0  
2019 12 25 3 0 0 0 0 1 1 2 2 1 0 0 0 0 0 1 1 1 4 0 0 0 1 0 1 2 2  
2019 12 26 3 2 1 1 1 0 1 1 0 2 1 0 2 2 0 0 0 0 5 3 1 1 1 0 1 1 1  
2019 12 27 2 1 0 2 0 0 1 1 0 1 0 0 2 0 0 0 0 0 3 1 1 1 1 0 0 1 0  
2019 12 28 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 2 1 0 0 0 0 0 0 1  
2019 12 29 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 2 0 0 0 0 0 0 0 1  
2019 12 30 2 0 1 1 0 0 2 1 1 0 0 0 0 1 0 0 0 0 3 1 1 0 1 0 1 1 1  
2019 12 31 4 1 2 1 0 1 2 1 1 1 0 0 0 1 1 0 1 0 5 1 2 1 1 1 1 1 1

**APPENDIX C: PERFORMANCE ANALYSIS (PAN) PROBLEM REPORT**

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

**Problem Description:**

There were no problems this quarter.

## APPENDIX D: GLOSSARY

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

### General Terms and Definitions

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

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

**Corrected Longitude of Ascending Node ( $\Omega_k$ ) 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,  $\lambda$ , 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  $\Omega_k$  when the argument of latitude ( $\Phi$ ) 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,  $\lambda$ , 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  $\Omega_k$  when the argument of latitude ( $\Phi$ ) 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 ( $1\sigma$ ) 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.