# Wide Area Augmentation System Offline Monitoring Quarterly Report

**1 January 2014 - 31 March 2014**

**Prepared for:**

**Federal Aviation Administration**

**Prepared by:**

**Satellite Operations Group AJW-B2**
**and**
**WAAS Engineering Team AJW-14B**

October 9, 2014

## Executive summary

The Wide-Area Augmentation System (WAAS) Engineering Team (AJW-14B) and the Satellite Operations Group (AJW-B2) were tasked with monitoring WAAS to ensure that the integrity requirements were maintained throughout the quarter. This report contains data collected and analyzed between January 1, 2014 and March 31, 2014. These requirements are defined in Section 3.3 of Algorithm Contribution to Hazardous Misleading Information (HMI) (A014-011). Data is collected from the WAAS network and stored at the WAAS Support Facility (WSF) at the Mike Monroney Aeronautical Center (MMAC) in Oklahoma City, OK.

The primary evidence that WAAS meets the top level system integrity requirements relies on a mathematical proof supported by a comprehensive analysis of empirical data. The foundation of the proof is built upon a set of carefully constructed assertions. Some assertions require periodic monitoring to ensure that the physical environment has not changed or degraded in a manner that would invalidate the claim. Certain satellite failure modes which have *a priori* probabilities associated with them must be detected and corrected in a reasonable amount of time to limit the user's exposure to the failure. The following assertions are monitored as called for in the Algorithm Contribution to HMI document:

1. Code-Carrier Coherence (CCC)
2. Code-Noise and Multipath (CNMP)
3. Signal Quality Monitoring (SQM)
4. Satellite Clock Run-off
5. Iono Threats
6. Ephemeris Monitoring

Additional monitoring criteria have been added to the original list. These additional monitoring criteria include

1. Wide-area Reference Station (WRS) Antenna Positions
2. L1L2 Bias Levels
3. Missed WAAS User Messages
4. Monitor Trips
5. CNMP Resets
6. Accuracy
7. Geosynchronous Earth Orbit (GEO) CCC
8. Space Weather

This report will also include major anomalies that occurred during the time period covered in this report. Table 1 is a summary of the criteria that were monitored for this report.

| | |
|---|---|
| **Integrity monitoring** | |
| CCC | 60 trips on ZDC and ZTL, 53 on ZLA |
| CNMP | 9 failing slices under investigation |
| SQM | All metrics below threshold |
| Satellite clock run-off | No run-off events |
| Iono threat model | Days of Interest:<br>2014-02-08<br>2014-02-18<br>2014-02-19<br>2014-02-23<br>2014-02-27<br>2014-02-28<br>2014-03-13<br>2014-03-18 |
| **Availability monitoring** | |
| | SVM currently under development |
| **Continuity monitoring** | |
| System monitoring trips | 12 L1L2 trips on ZDC and ZTL, and 11 on ZLA |
| Missed messages | CRW (PRN-135) - 0<br>CRE (PRN-138) - 29<br>AMR (PRN-133) - 64 |
| **External monitoring** | |
| Antenna positioning | All sites within allowance |
| **Anomaly Investigations** | |
| | Instability on the L1 loopback path at HDH GUS site |

**Table 1:** Monitor summary

# Forward

The scope of this document is limited to analysis performed on data extracted from the WAAS system, or on data that would directly affect the WAAS system. Moreover, the target audience is the Federal Aviation Administration (FAA) WAAS management as well as the engineers that support the WAAS program. This includes (but is not necessarily limited to) federally employed personnel, contractors, sub-contractors, and other FAA WAAS Integrity Performance Panel (WIPP) support members.

The data and information contained in this document is not for general use, as it may contain unexplained anomalies and/or data which may lead to unsupported conclusions. Any dissemination and interpretation of this data should be coordinated with the appropriate management.

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# Chapter 1

# Introduction

## 1.1 The definition of offline monitoring

The goal of Offline Monitoring (OLM) is to track the performance of WAAS, establish baseline performance, and characterize anomalous behavior to determine if further investigation is necessary.

## 1.2 Elements of system monitoring

The monitoring addressed in this document can be categorized into five types, namely Integrity, Availability, Continuity, Accuracy and External Monitoring. Each category represents a class of performance that the system exhibits. The intent of this document is to provide a summary of results for several checks of each of the above types in conjunction with condensed plots that show at-a-glance quarterly performance.

### 1.2.1 Integrity

Integrity monitoring is viewed by many to be the most important type since a breach of this class of performance represents a potentially hazardous situation. Loss of Integrity happens when the user's position is not bounded by the calculated Protection Level and the Protection Level is within the Alert Limit. There are monitors in WAAS which internally ensure that these error bounds represent an overbound of the generated errors. Each monitor has a slightly different method for ensuring integrity, and the individual monitor integrity methodologies are described in their respective monitor subsections.

### 1.2.2 Availability

Availability Monitoring is straightforward, it evaluates the coverage of WAAS over a defined time period. There are specifics to be defined for this type, namely the Alarm Limits (Vertical and Horizontal) as well as the coverage contour.

### 1.2.3 Continuity

Continuity monitoring refers to events which can cause a loss of availability but not a breach of integrity. Typically, this assessment looks at monitor trips, setting satellites unusable, or any issue which would cause a loss of service.

### 1.2.4 Accuracy

Accuracy Monitoring refers to the ability of the WAAS corrections to provide an accurate estimate of the user's position.

### 1.2.5 External monitoring

External monitoring entails events external to the WAAS, including broadcast ephemerides, plate-tectonic movement (antenna positions), space weather, etc., that can result in anomalous WAAS performance.

# Chapter 2

# Tool builds

The following table captures the tool versions used to generate the data in this document.

| **Prototype** | |
|---|---|
| W3SP-0002-NA-WLNAV-01_wfo_r4b | All dates |
| **HMI Tools** | |
| OLM_TOOLS_318j | All dates |
| **Antenna Positions** | |
| PAGE-NT pnt6k | All dates |

**Table 2.1:** Tool builds used for 2014 Q1 data analysis

# Chapter 3

# Integrity

## 3.1 Code-carrier-coherence

### 3.1.1 CCC statistics and monitor trips

During the first quarter of 2014, CCC trips occurred on nine different days. The rows highlighted in gray below represent trips that were weather related.

| Date @ time$_{UTC}$ | PRN | value | threshold | ZLA | ZDC | ZTL | Sel. C&V |
|---|---|---|---|---|---|---|---|
| 2014-01-02 @ 00:35:16 | 133 | 9.7332 | 7.1 | 45 | 45 | 45 | ZTL |
| 2014-01-29 @ 18:37:14 | 138 | 3.0013 | 2.5 | 1 | 2 | 2 | ZDC |
| 2014-02-04 @ 21:14:13 | 133 | 10.5082 | 7.1 | 1 | 2 | 2 | ZTL |
| 2014-02-10 @ 20:35:36 | 138 | 2.5019 | 2.5 | 1 | 1 | 1 | ZDC |
| 2014-02-12 @ 09:43:49 | 138 | 3.0028 | 2.5 | 1 | 2 | 2 | ZDC |
| 2014-02-14 @ 12:58:31 | 138 | 3.0124 | 2.5 | 1 | 2 | 2 | ZDC |
| 2014-02-15 @ 23:00:56 | 138 | 3.0168 | 2.5 | 1 | 2 | 2 | ZDC |
| 2014-02-16 @ 00:11:04 | 138 | 3.0032 | 2.5 | 1 | 2 | 2 | ZDC |
| 2014-03-30 @ 00:35:16 | 138 | 2.5084 | 2.5 | 1 | 2 | 2 | ZDC |

**Table 3.1:** Reported CCC trips

| Statistic | CRW | CRE | AMR | GPS L1$_{agg}$ | GPS L2$_{agg}$ |
|---|---|---|---|---|---|
| mean (m) | 0.01 | 0.03 | -0.11 | -0.01 | -0.01 |
| st dev (m) | 0.46 | 0.50 | 1.09 | 0.14 | 0.14 |
| min (m) | -1.71 | -4.05 | -7.99 | -2.42 | -3.21 |
| max (m) | 2.21 | 5.18 | 7.99 | 2.23 | 2.31 |
| abs max (m) | 2.21 | 5.18 | 7.99 | 2.42 | 3.21 |

**Table 3.2:** CCC metric statistics (unnormalized)

| Statistic | CRW | CRE | AMR | GPS $L1_{agg}$ | GPS $L2_{agg}$ |
|---|---|---|---|---|---|
| mean (m) | 0.00 | 0.01 | -0.01 | -0.01 | -0.01 |
| st dev (m) | 0.18 | 0.20 | 0.12 | 0.05 | 0.05 |
| min (m) | -0.69 | -1.62 | -1.40 | -0.47 | -0.62 |
| max (m) | 0.88 | 2.08 | 1.50 | 0.63 | 0.50 |
| abs max (m) | 0.88 | 2.08 | 1.50 | 0.63 | 0.62 |

**Table 3.3:** CCC continuity statistics (normalized to trip threshold)

| Statistic | CRW | CRE | AMR | GPS $L1_{agg}$ | GPS $L2_{agg}$ |
|---|---|---|---|---|---|
| mean (m) | 0.00 | 0.00 | -0.00 | -0.00 | -0.00 |
| st dev (m) | 0.03 | 0.04 | 0.01 | 0.01 | 0.01 |
| min (m) | -0.13 | -0.31 | -0.12 | -0.19 | -0.21 |
| max (m) | 0.17 | 0.40 | 0.13 | 0.22 | 0.17 |
| abs max (m) | 0.17 | 0.40 | 0.13 | 0.22 | 0.21 |

**Table 3.4:** CCC integrity statistics (normalized to MERR value)

### 3.1.2 Quarterly time-series plot of CCC GEO metric

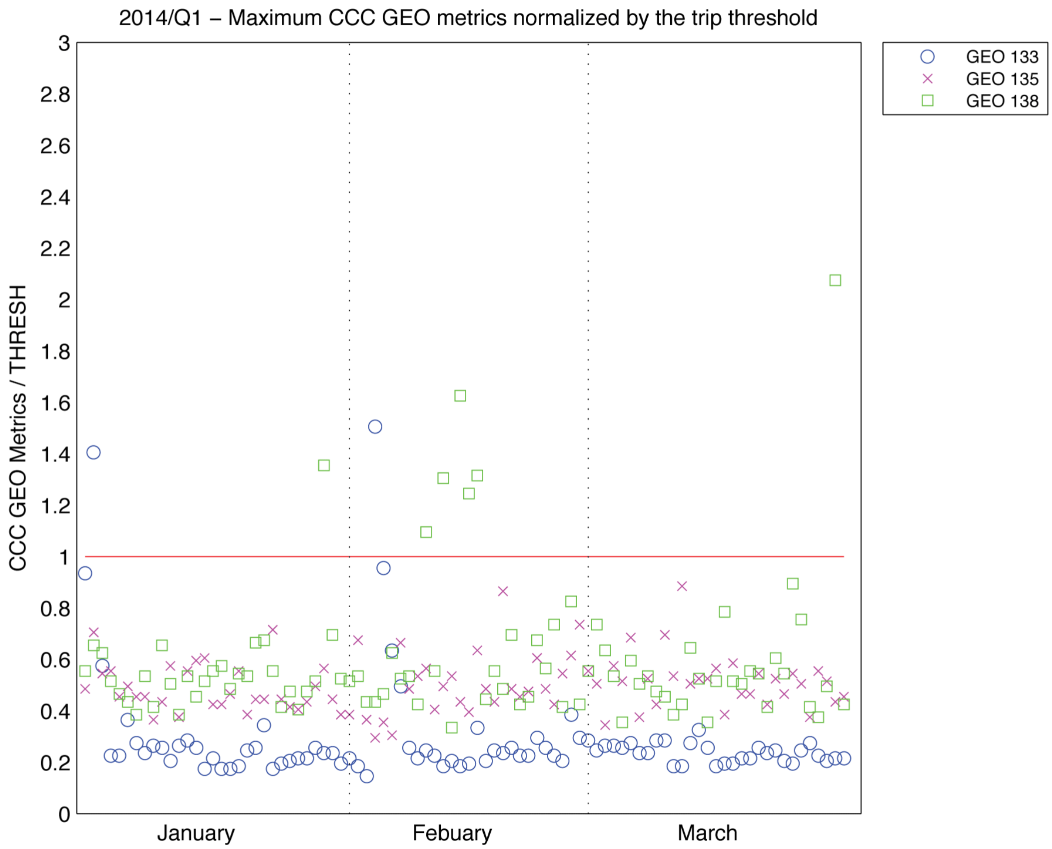


**Figure 3.1:** Time-series graph of max GEO CCC metric normalized to the trip threshold

## 3.2 Code-noise and multipath

Nine failures were found when monitoring the HMI assertion (Appendix C.2) for the first quarter of 2014.

There were no failures for the sigma overbound of the aggregate distribution plots. There were 9 failures for specific slices. Six failures were on Range Domain for the L2 frequency (RDL2). These were for the time track 1, ZSU-C, MMD-C, MMX-B, MMX-C, and PseudoRandom Noise (PRN) 17 slices. These can be seen in figures 3.2 through 3.7. The time track 1 slice also failed for Range Domain for the L1 frequency (RDL1) and delay as seen in Figures 3.8 and 3.9. MMD-C also failed for RDL1 as shown in Figure 3.10. Some of these failures are attributed to bad equipment at MMD-C that has since been replaced. Further investigation of these failures will be presented to close the WIPP action item #0193.

For Figures 3.11, 3.12, and 3.13, CNMP passes if the tails (red and blue lines) do not dip below zero on the vertical axis. If a dip below zero occurs close to zero, that event is not considered a failure. For Figure 3.14, if the values go above the marked threshold of 1, that event is a failure.

High points on Figure 3.14 are being investigated and a full report will close WIPP action item #0193. Figure 3.14 also reveals an uptick in delay, RDL1, RDL2, and Ionospheric Free PseudoRange (IFPR). This has been traced to PRN 31 at ZHU-C. Figure 3.15 and 3.16 show the uptick. The uptick was not visible on other PRN or Wide-area Reference Equipment (WRE) slices. It appears that the multi-path was particularly bad on that track for a period of time which caused the entire daily sigma overbound metric to mirror the increase.

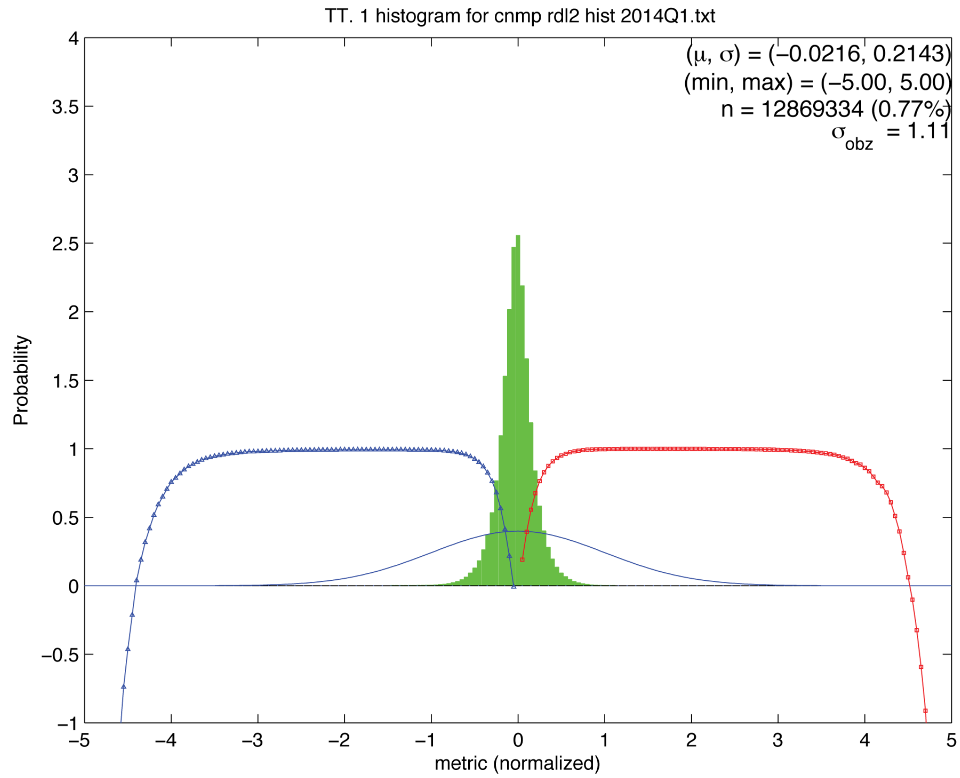


**Figure 3.2:** Failure on RDL2 TT1 slice

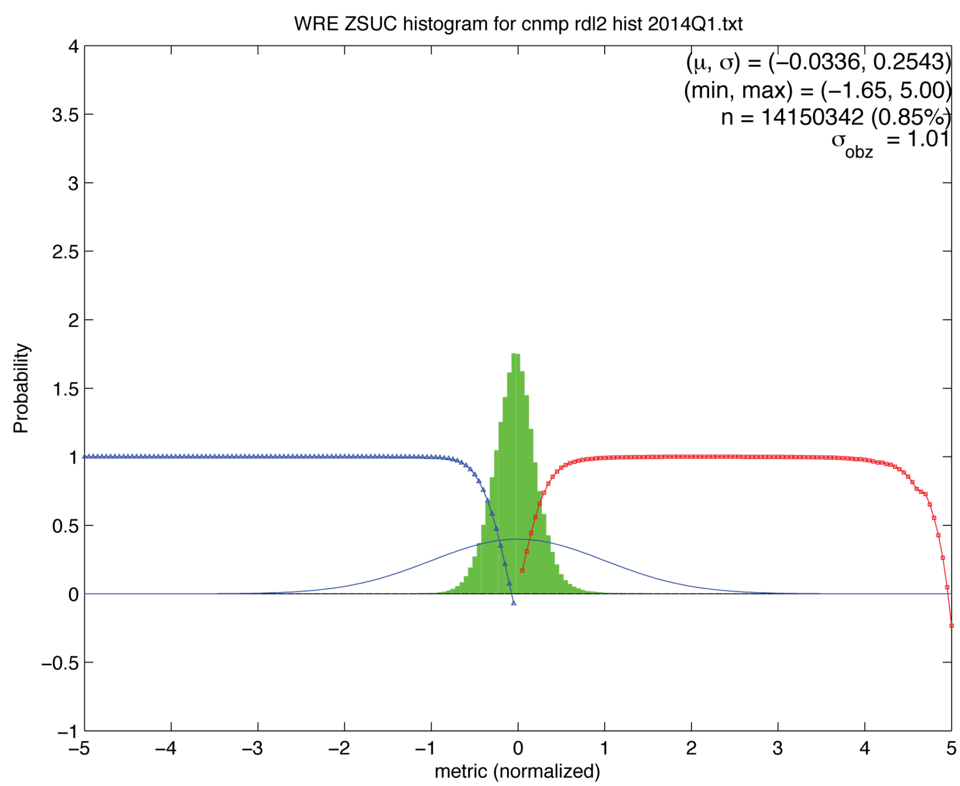


**Figure 3.3:** Failure on RDL2 ZSU-C slice

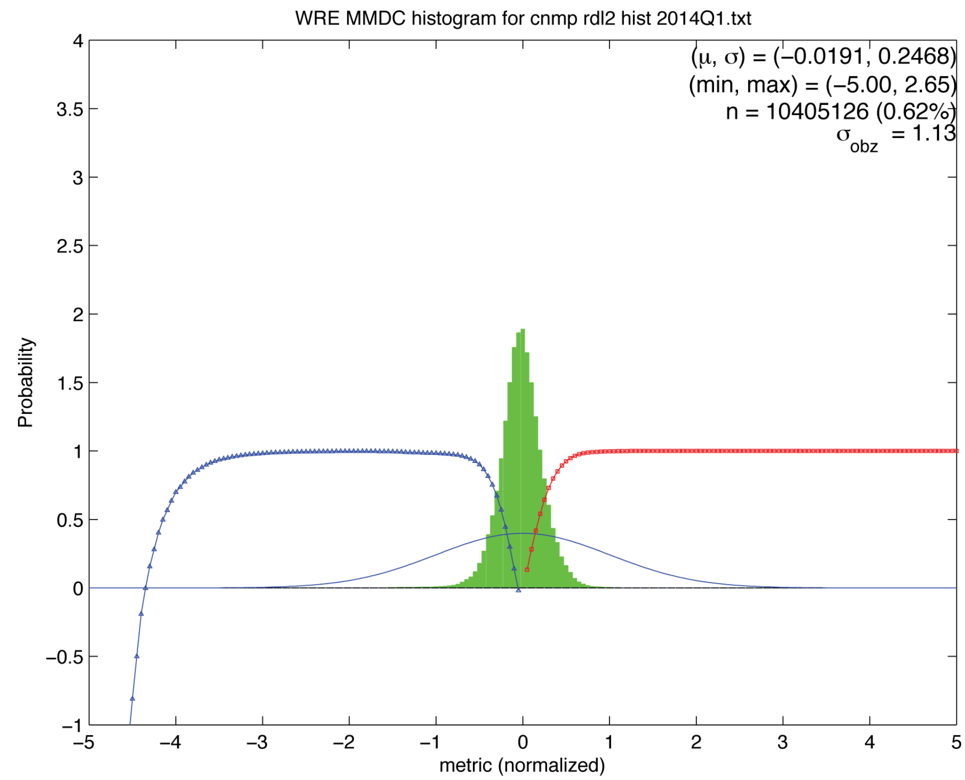


**Figure 3.4:** Failure on RDL2 MMD-C slice

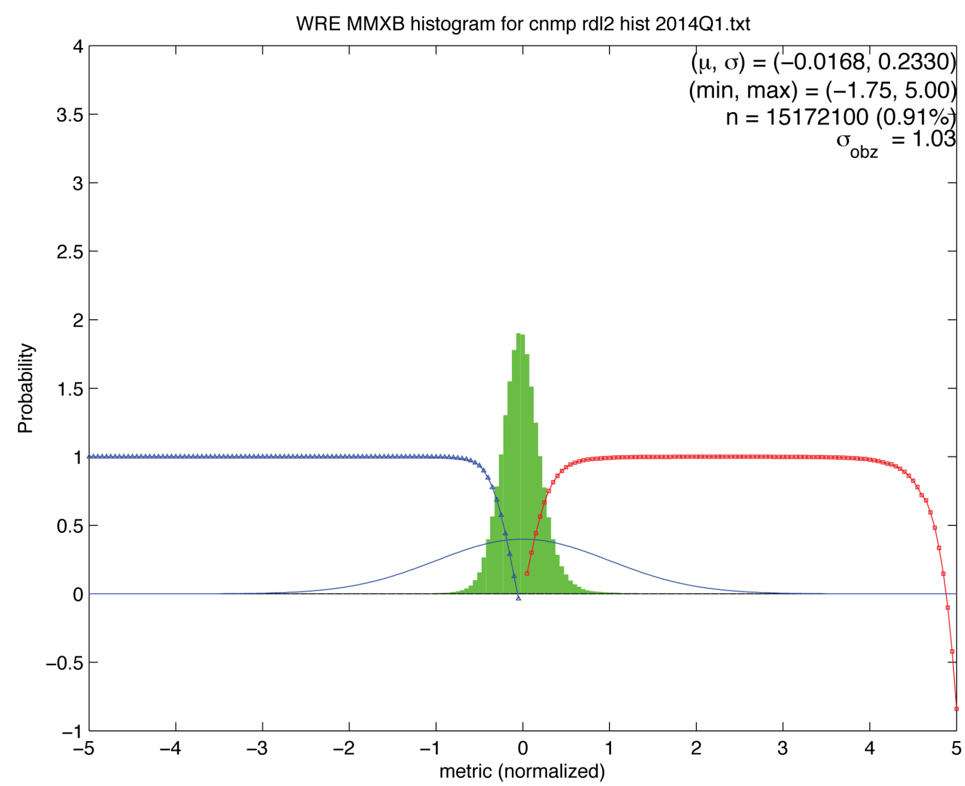


**Figure 3.5:** Failure on RDL2 MMX-B slice

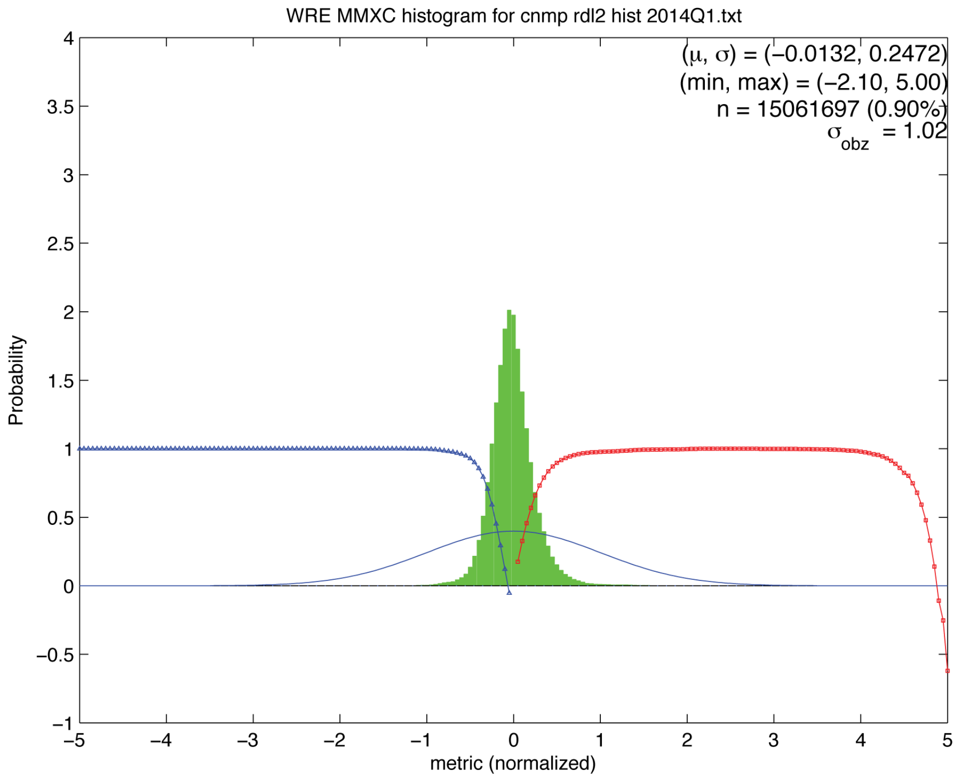


**Figure 3.6:** Failure on RDL2 MMX-C slice

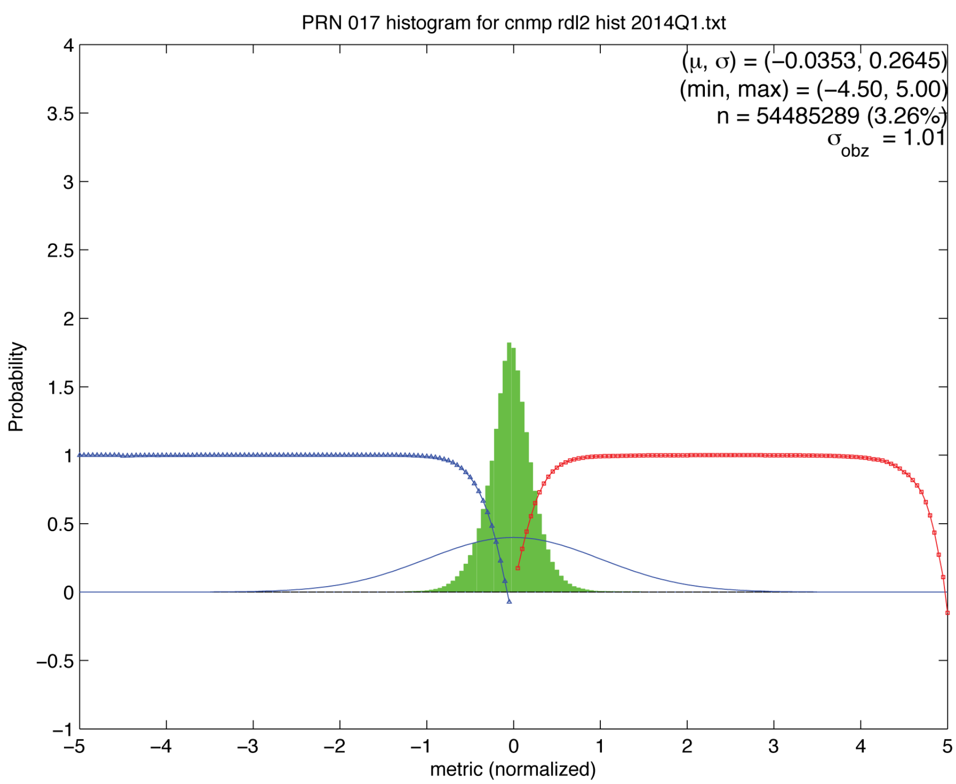


**Figure 3.7:** Failure on RDL2 PRN 17 slice

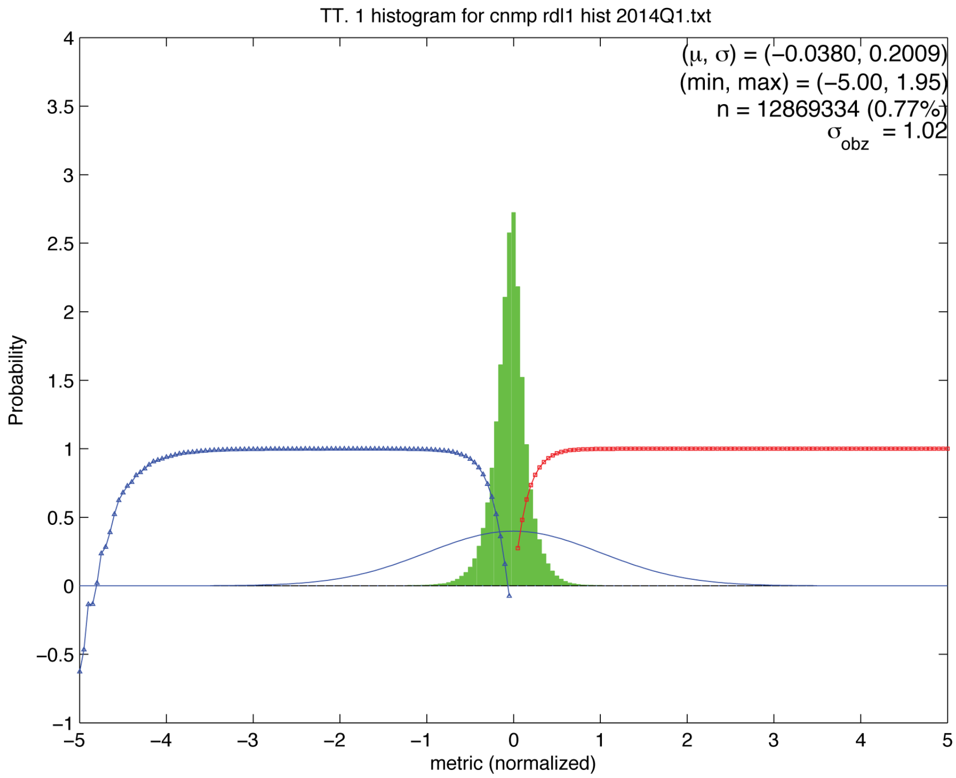


**Figure 3.8:** Failure on RDL1 TT1 slice

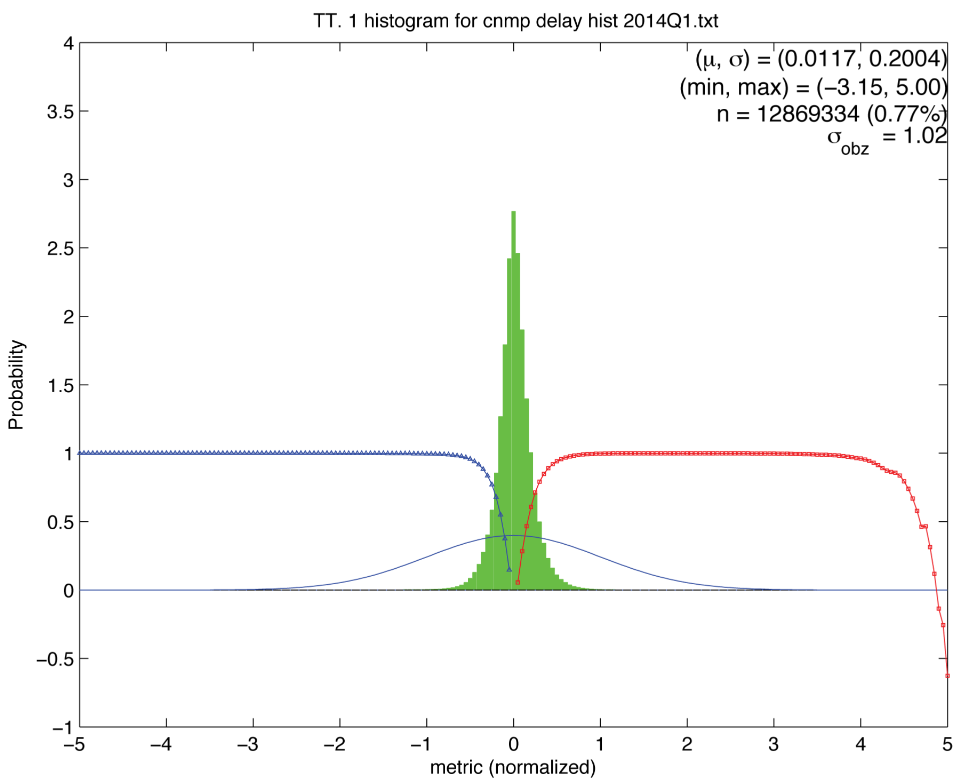


**Figure 3.9:** Failure on Delay TT1 slice

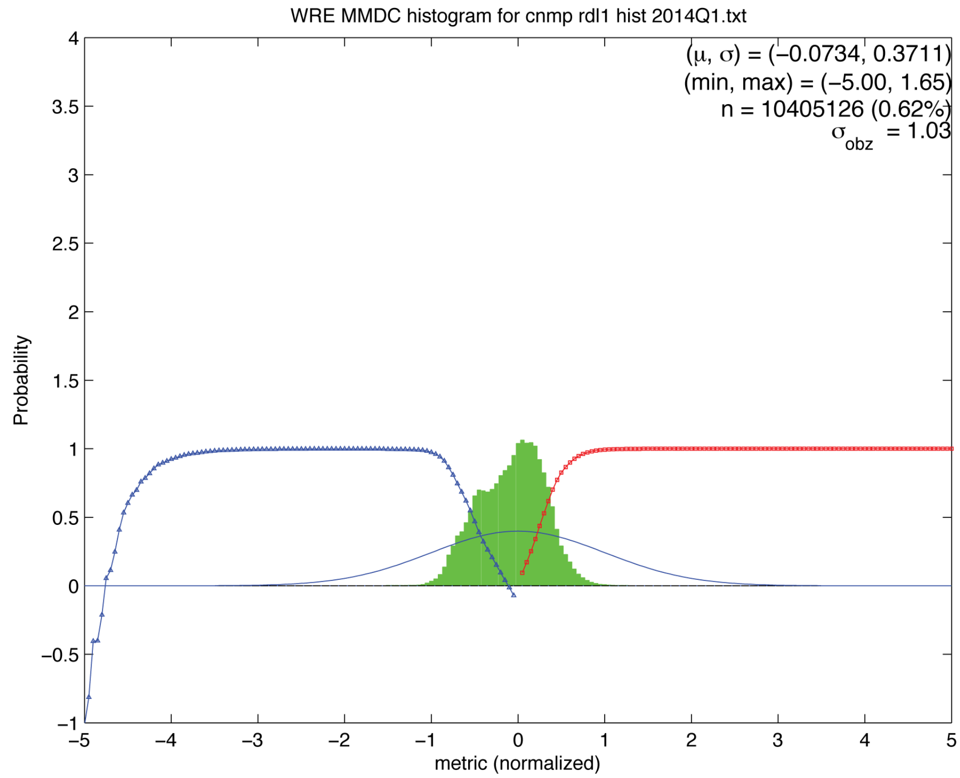


**Figure 3.10:** Failure on RDL1 MMD-C slice

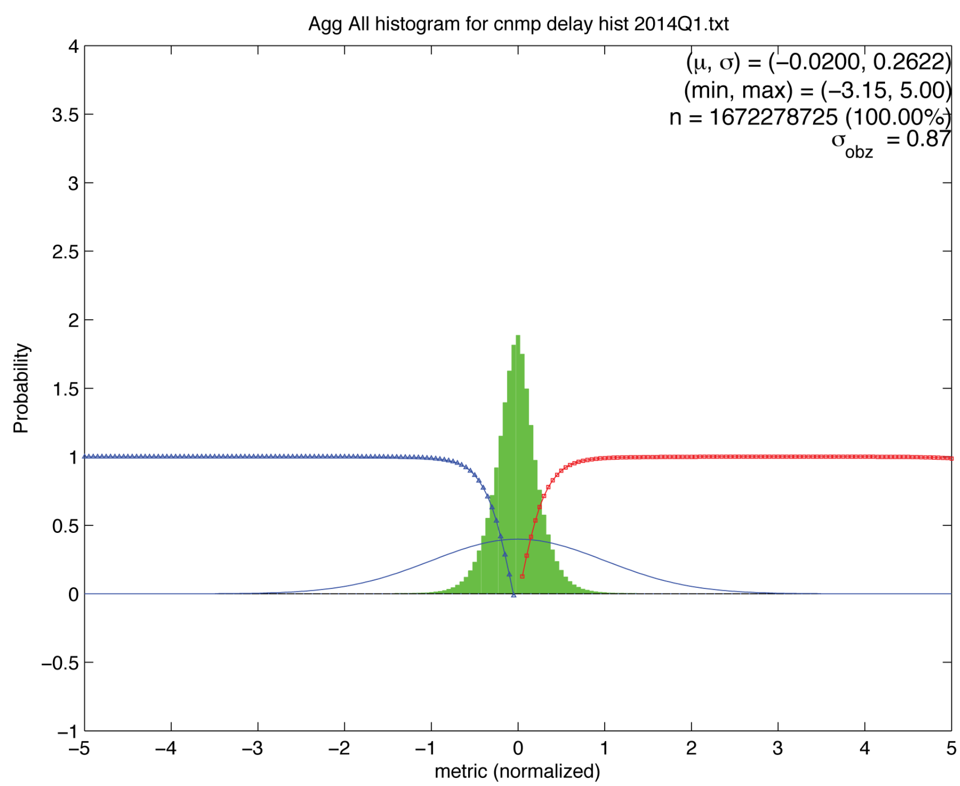


**Figure 3.11:** Aggregate CNMP Delay

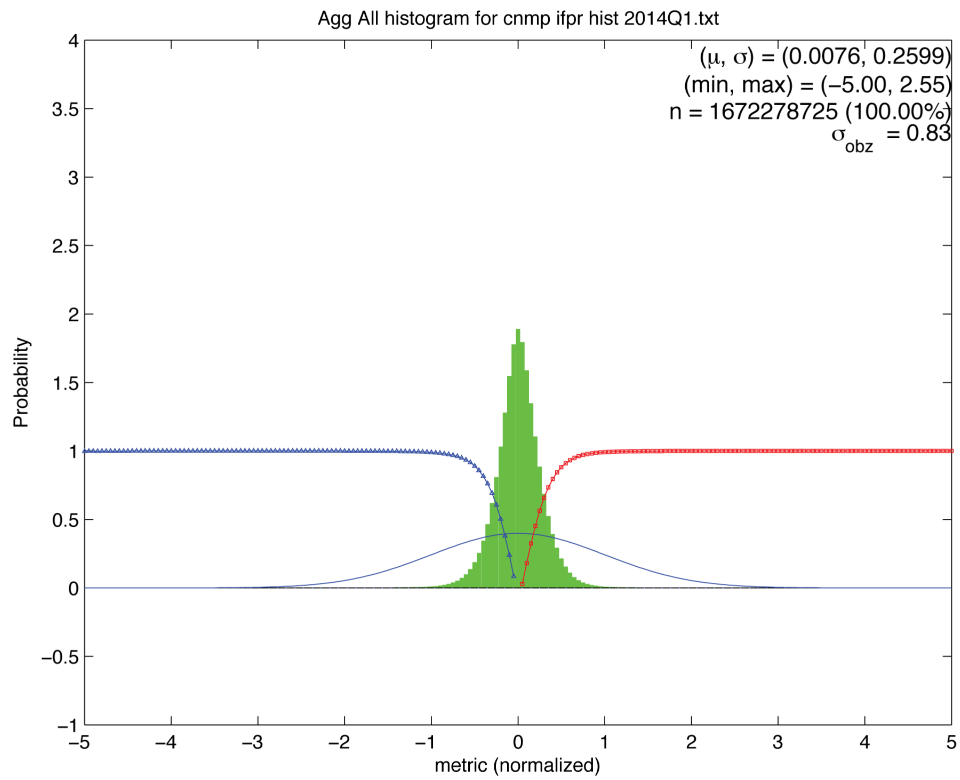


**Figure 3.12:** Aggregate CNMP IFPR

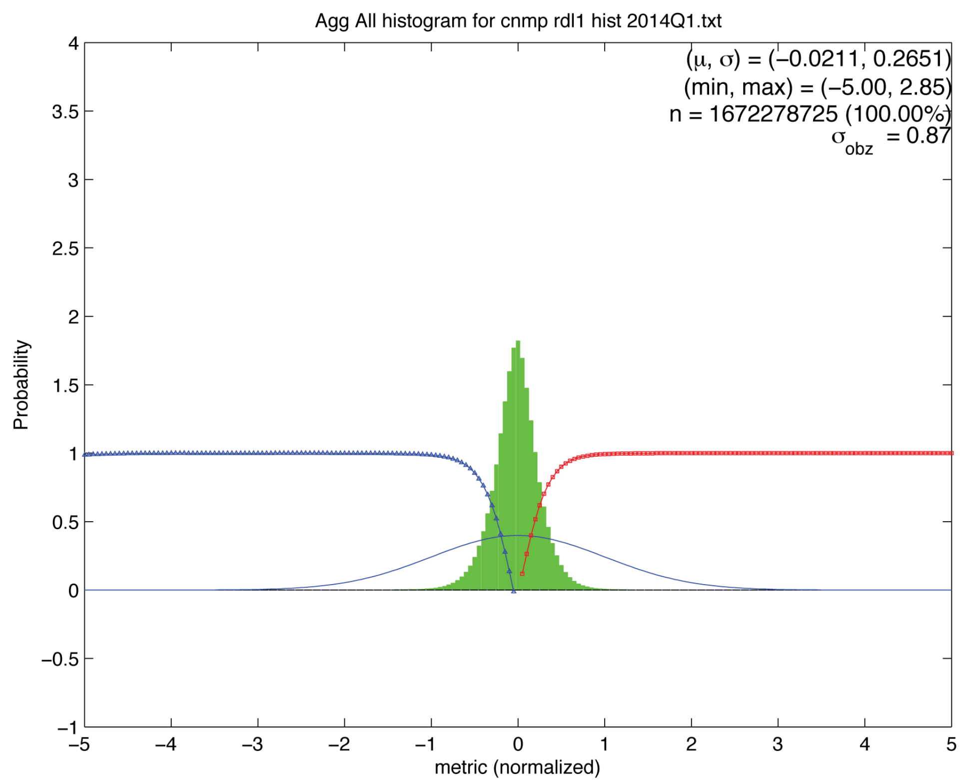


**Figure 3.13:** Aggregate CNMP RDL1

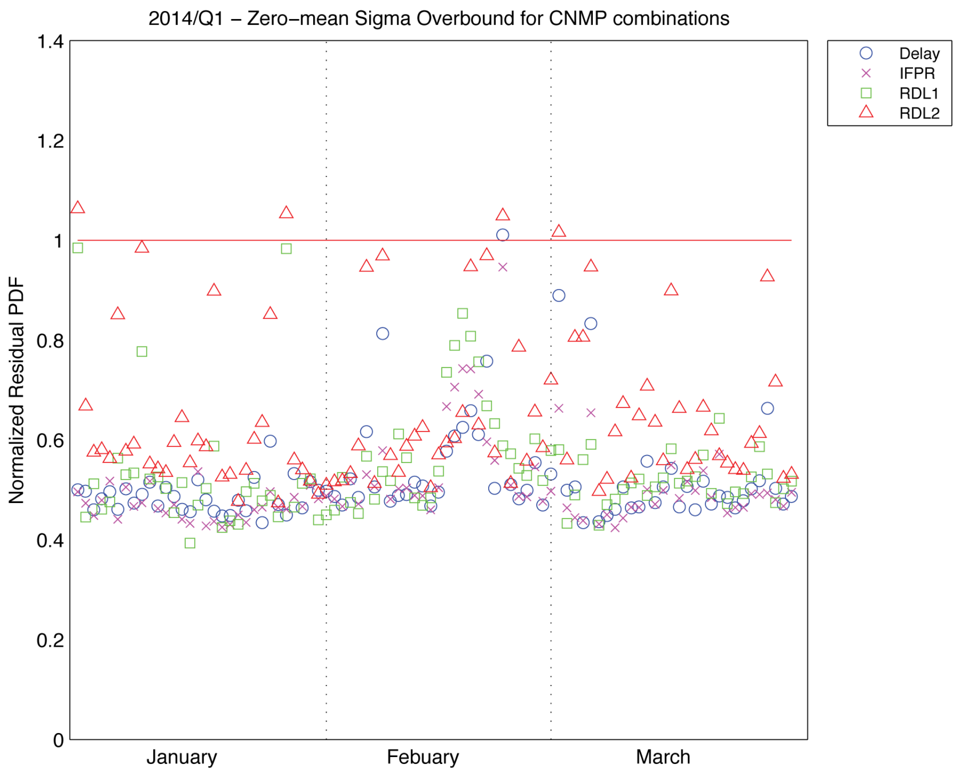


**Figure 3.14:** Daily GPS CNMP Aggregate zero-centered sigma overbound values

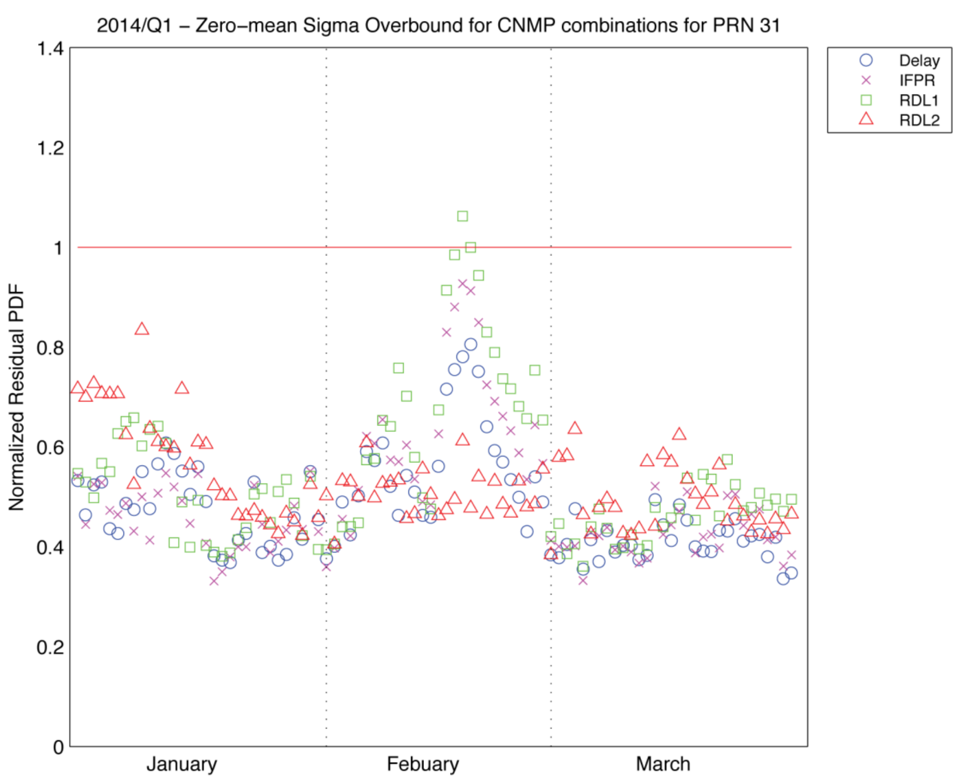


**Figure 3.15:** February uptick seen on PRN 31 slice

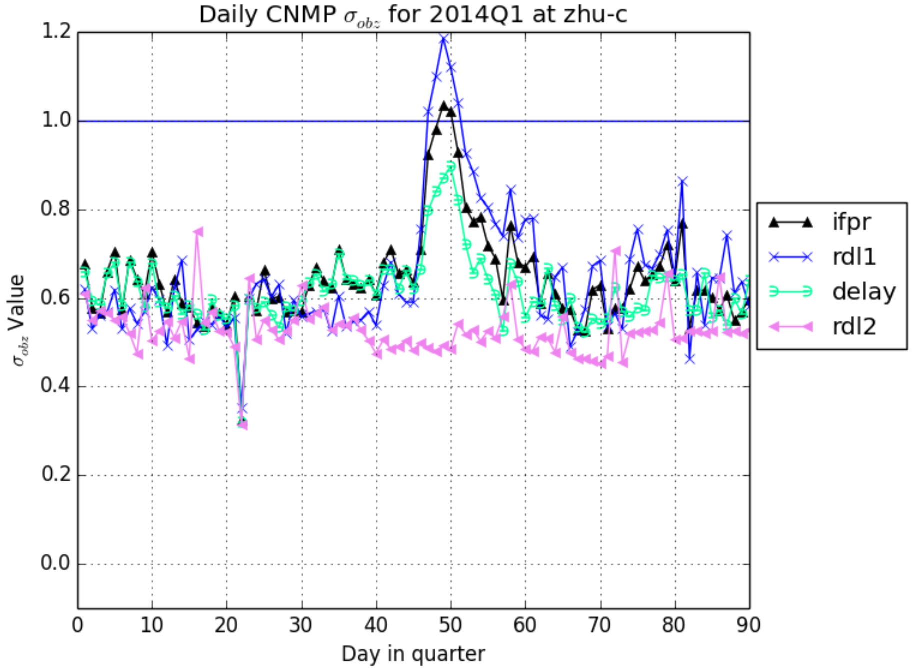


**Figure 3.16:** February uptick seen on ZHU-C slice

### 3.2.1 Analysis of poor performing sites

Table 3.5 contains information on the worst performing sites of the quarter. Table 3.5 is generated by using the method described in Section A.1.5 of the HMI document. Three metrics are considered including the absolute mean, standard deviation and the absolute maximum of the normalized residual distributions sliced by WRE for IFPR CNMP, delay CNMP, RDL1 CNMP and RDL2 CNMP. These twelve metrics are then combined into one ranking metric. Each of the twelve metrics is normalized to a number between 0 - 1 and then those are sorted by WRE and averaged over the twelve metrics. The 10 worst WREs, as determined by the combined metric, are listed in table 3.5.

| Station | | RDL1 | | | | IFPR | | | | Delay | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | Name | $\mu$ | $\sigma$ | $\|max\|$ | sigobz | $\mu$ | $\sigma$ | $\|max\|$ | sigobz | $\mu$ | $\sigma$ | $\|max\|$ | sigobz |
| 30 | ZHU C | 0.07 | 0.436 | 3.80 | 0.872 | 0.11 | 0.428 | 3.35 | 0.784 | -0.11 | 0.419 | 2.95 | 0.678 |
| 29 | ZHU B | -0.04 | 0.438 | 2.55 | 0.585 | 0.03 | 0.472 | 2.40 | 0.576 | -0.06 | 0.479 | 2.50 | 0.609 |
| 23 | ZFW B | -0.05 | 0.321 | 2.15 | 0.483 | 0.06 | 0.334 | 1.85 | 0.449 | -0.10 | 0.347 | 2.00 | 0.466 |
| 38 | ZKC B | -0.02 | 0.327 | 2.15 | 0.501 | 0.05 | 0.341 | 2.20 | 0.519 | -0.08 | 0.351 | 2.35 | 0.539 |
| 108 | MTP C | -0.03 | 0.350 | 2.75 | 0.531 | 0.04 | 0.326 | 2.15 | 0.479 | -0.06 | 0.321 | 2.50 | 0.519 |
| 61 | ZOB A | -0.07 | 0.309 | 2.00 | 0.458 | 0.00 | 0.336 | 2.30 | 0.506 | -0.04 | 0.357 | 2.30 | 0.503 |
| 28 | ZHU A | -0.05 | 0.357 | 1.95 | 0.446 | -0.05 | 0.351 | 2.20 | 0.515 | 0.04 | 0.362 | 2.35 | 0.525 |
| 105 | MSD C | 0.00 | 0.341 | 2.50 | 0.494 | 0.06 | 0.326 | 1.75 | 0.395 | -0.08 | 0.316 | 2.00 | 0.393 |
| 37 | ZKC A | -0.02 | 0.309 | 2.85 | 0.622 | 0.04 | 0.317 | 2.40 | 0.520 | -0.06 | 0.320 | 2.55 | 0.549 |
| 21 | ZDV C | -0.07 | 0.329 | 1.95 | 0.441 | -0.01 | 0.336 | 1.90 | 0.451 | -0.02 | 0.342 | 2.00 | 0.461 |

**Table 3.5:** Poor performing WREs for CNMP

## 3.3 Signal Quality Monitoring

All four metrics for GEO satellites fall below the threshold for 2014 Q1. There were no SQM trips for the quarter.

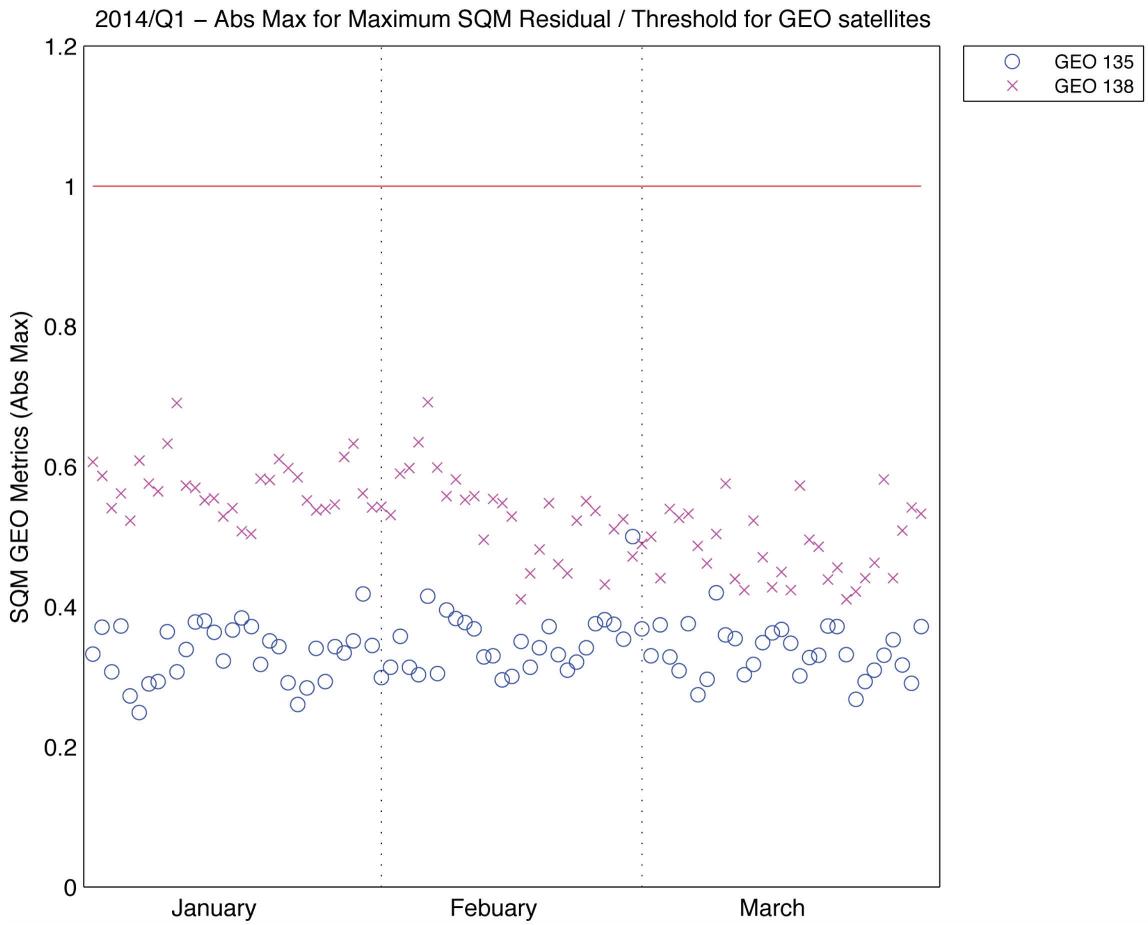


**Figure 3.17:** Time-series graph of GEO SQM max metrics 1-4

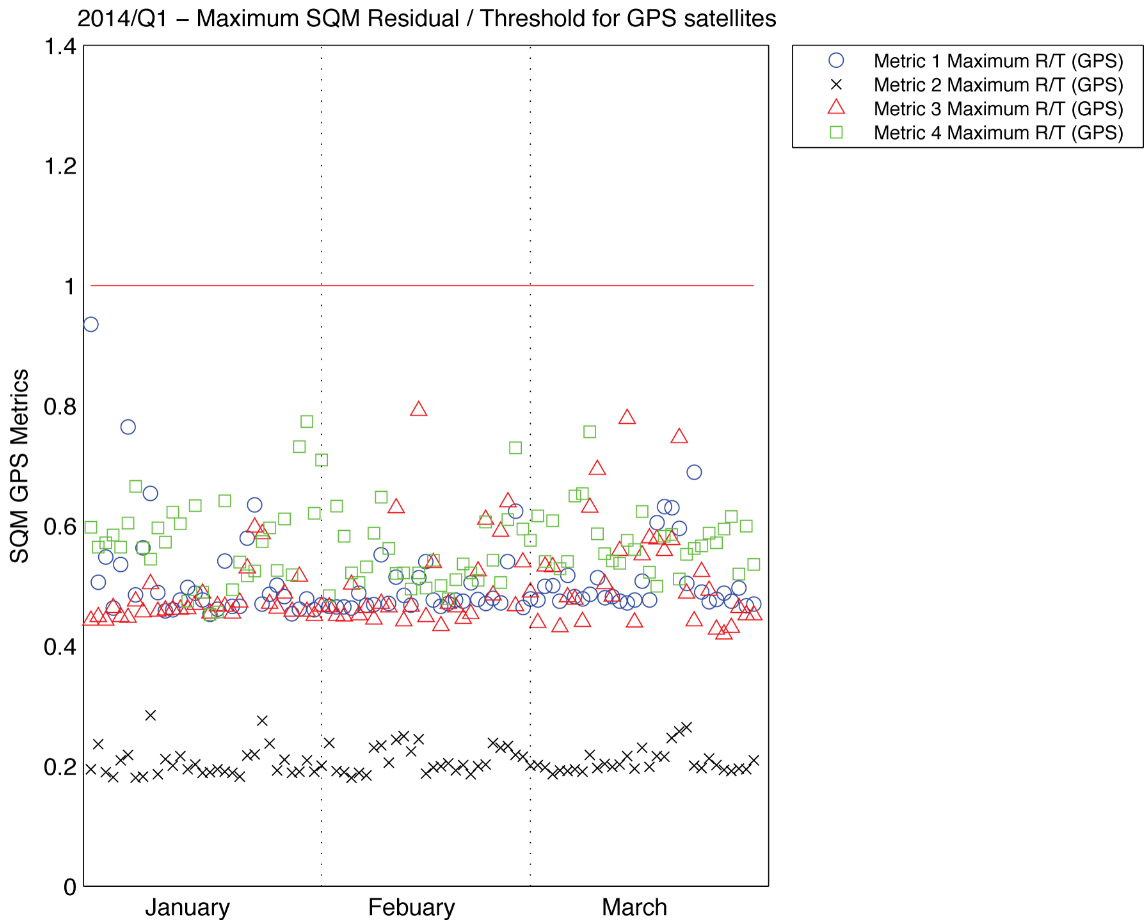


**Figure 3.18:** Time-series graph of GPS SQM max metrics 1-4

## 3.4 Iono threat model

Figure B.1 on page 58 shows a map of the regions used for threat model analysis.

### 3.4.1 Daily percentage of Chi$^2$ values > 1

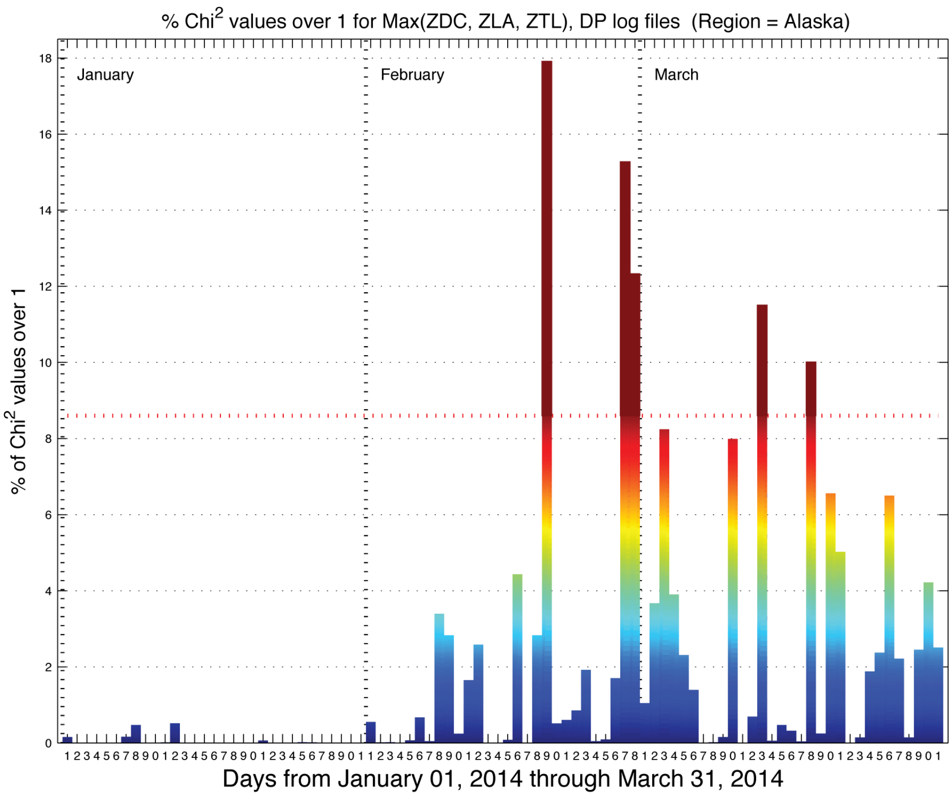


**Figure 3.19:** Alaska region daily % Chi$^2$ values >1 taken from ZDC

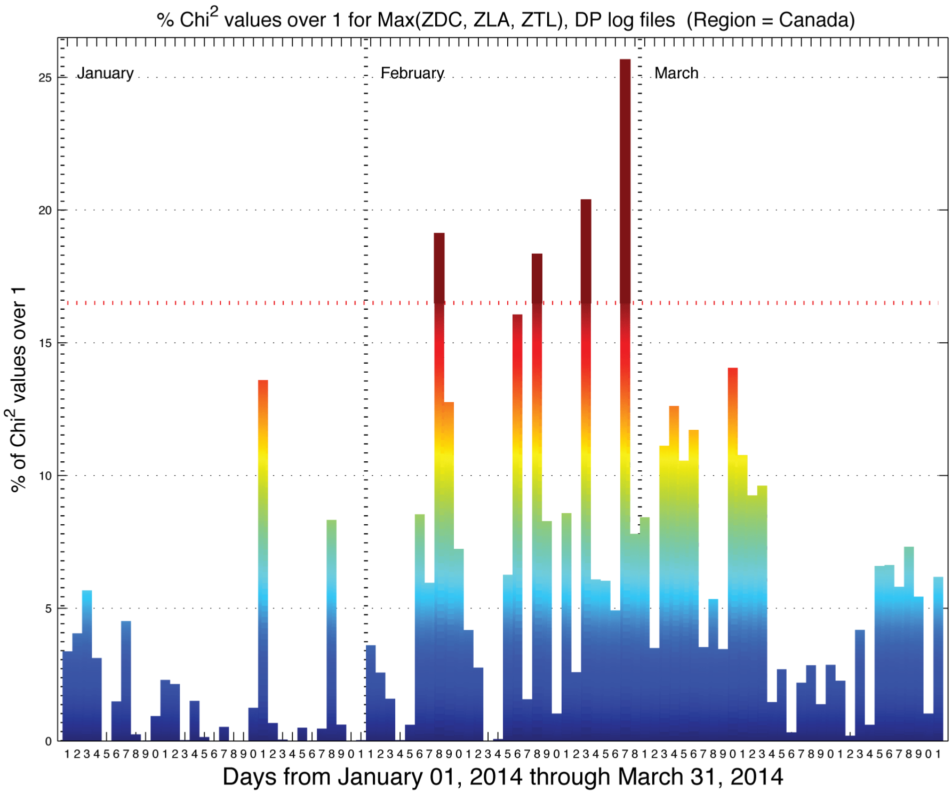


**Figure 3.20:** Canada region daily % Chi$^2$ values > 1 taken from ZDC

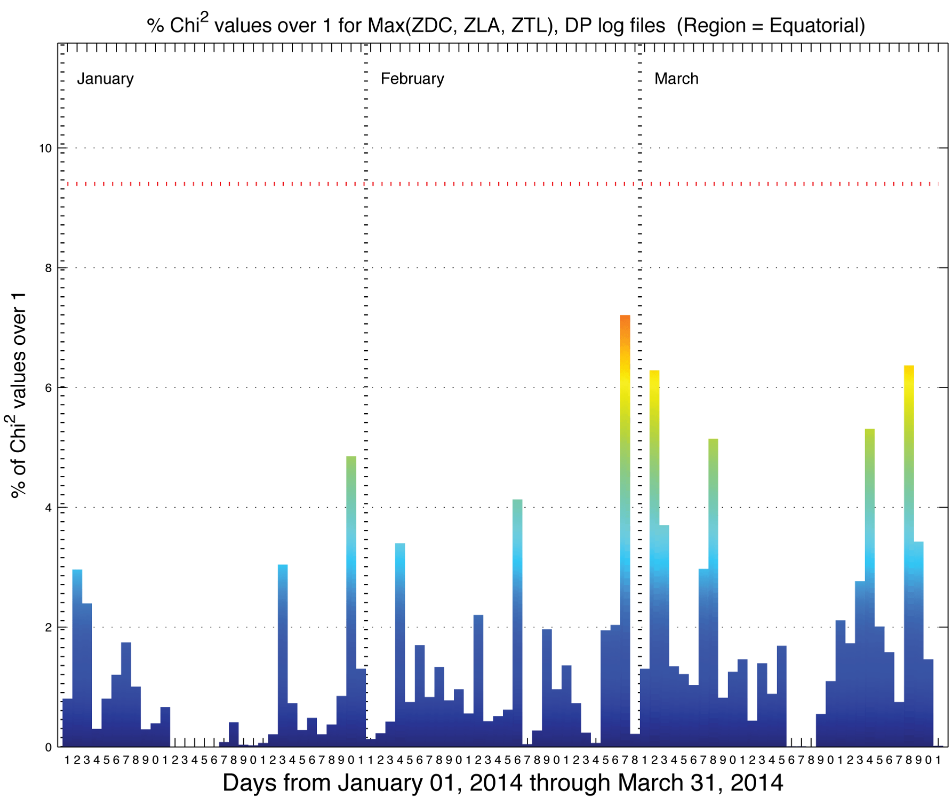


**Figure 3.21:** Equatorial region daily % Chi$^2$ values > 1 taken from ZDC

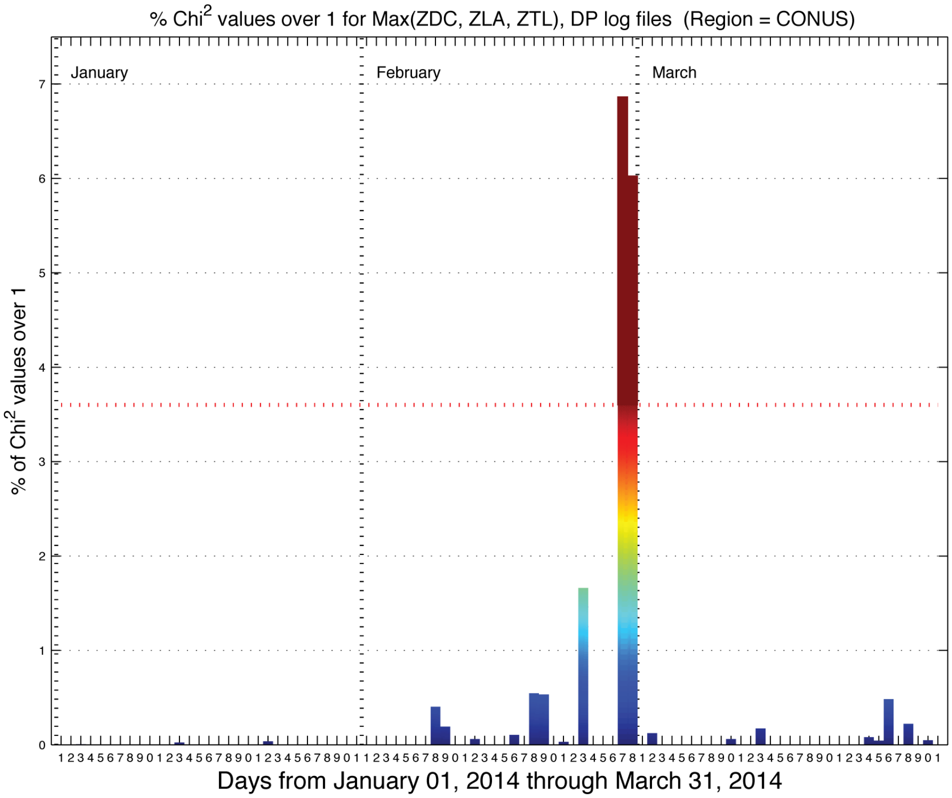


**Figure 3.22:** CONUS region daily % Chi$^2$ values > 1 taken from ZDC

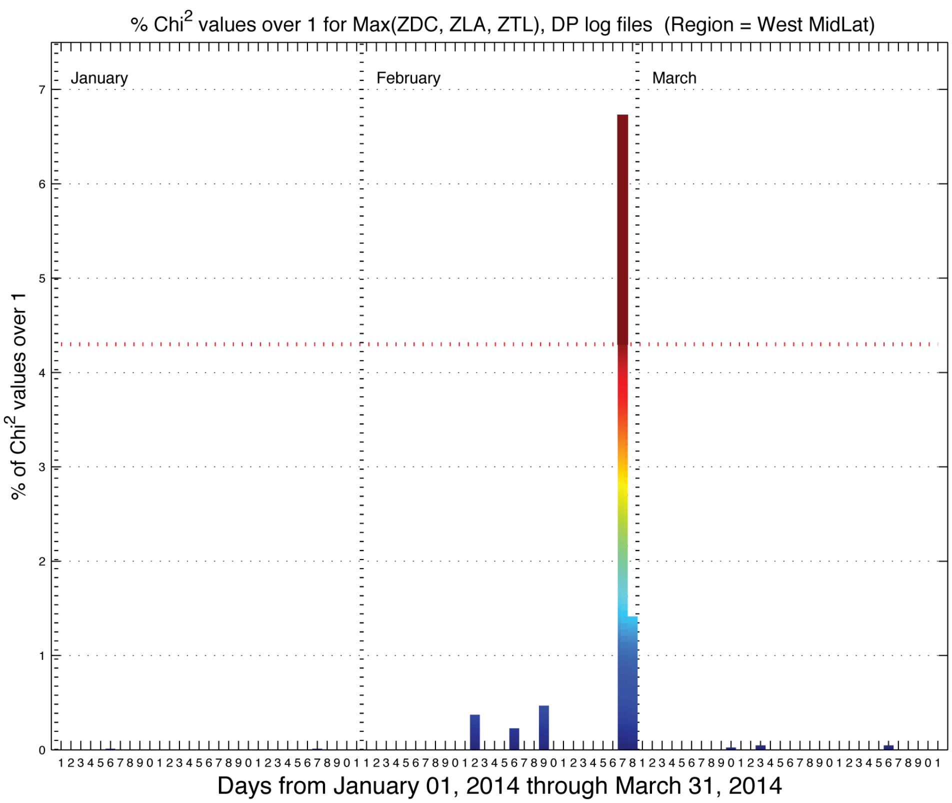


**Figure 3.23:** West mid-latitude region daily % Chi$^2$ values > 1 taken from ZDC

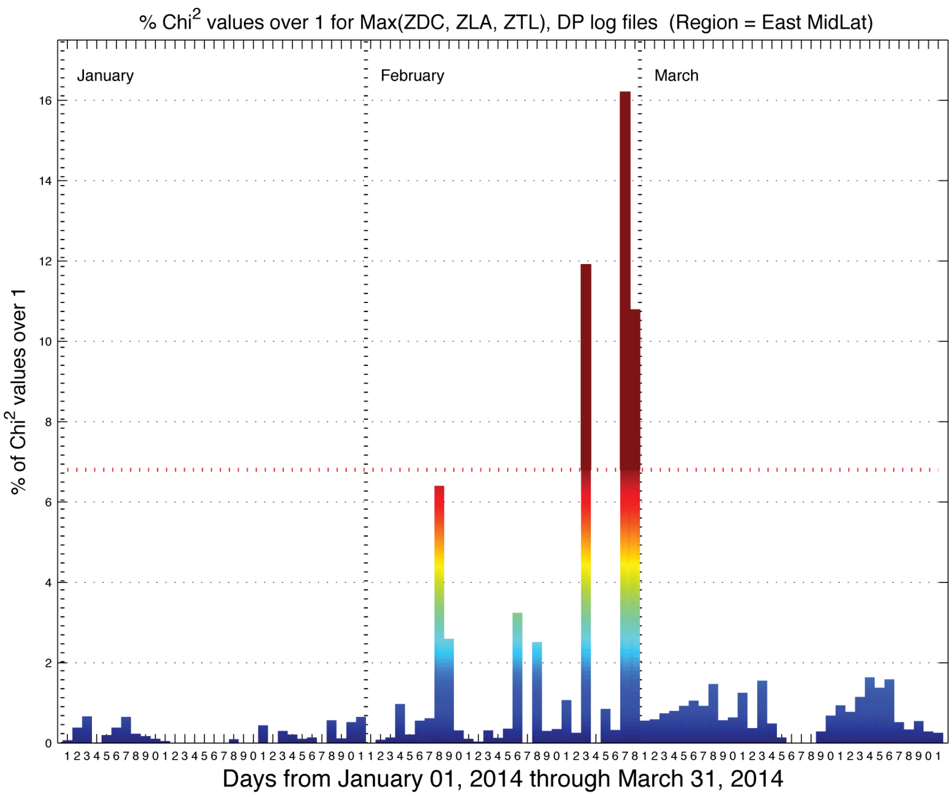


**Figure 3.24:** East mid-latitude region daily % Chi$^2$ values > 1 taken from ZDC

### 3.4.2 Days of interest

The IGP map is now divided into six regions: Alaska, Canada, Equatorial, CONUS, West mid-latitude and East mid-latitude. Figure B.1 on page 58 shows a map of the regions used for threat model analysis.

| **Region** | **CONUS** | **Alaska** | **Equatorial** | **Canada** | **West MidLat** | **East MidLat** |
|---|---|---|---|---|---|---|
| Threshold (%) | 3.6 | 8.6 | 9.4 | 16.5 | 4.3 | 6.8 |
| 2014-02-08 | | | | 19.125 | | |
| 2014-02-18 | | | | 18.347 | | |
| 2014-02-19 | | 17.916 | | | | |
| 2014-02-23 | | | | 20.389 | | 11.91 |
| 2014-02-27 | 6.8638 | 15.278 | | 25.671 | 6.7289 | 16.204 |
| 2014-02-28 | 6.0268 | 12.334 | | | | 10.787 |
| 2014-03-13 | | 11.505 | | | | |
| 2014-03-18 | | 10.012 | | | | |

**Table 3.6:** Days when the % of $Chi^2 > 1$ exceed the threshold value

### 3.4.3 Space weather monitoring

**Planetary A-K indices**

The highest $K_p$ value of 6.3 was measured on February 19th.

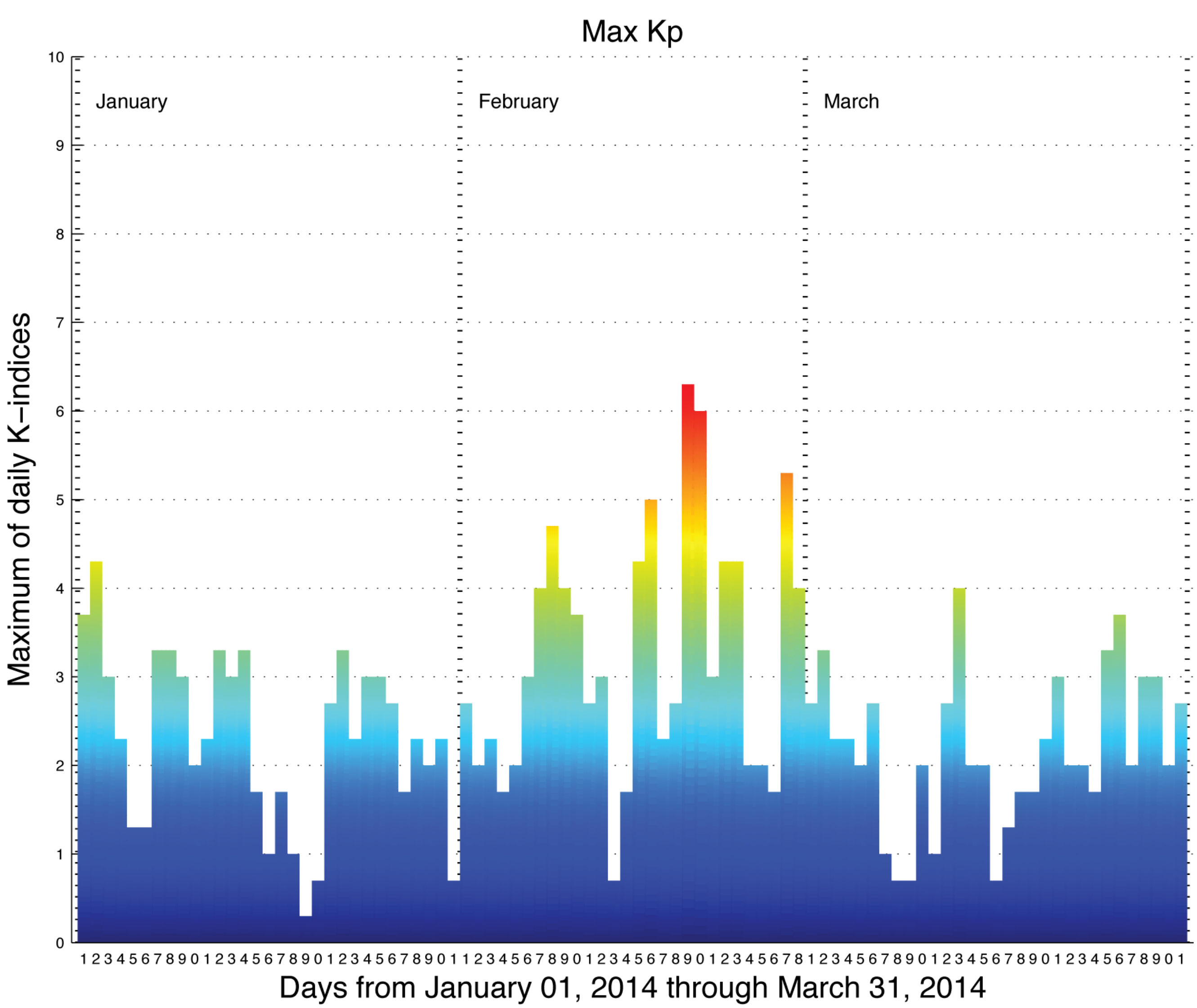


**Figure 3.25:** Planetary $K_p$ values

# Chapter 4

# Continuity monitoring

## 4.1 System monitoring trips

| Component | ZDC | ZLA | ZTL |
|---|---|---|---|
| BMV | 0 | 0 | 0 |
| CCC | 60 | 53 | 60 |
| L1L2 | 12 | 11 | 12 |
| $\text{RDM}_{threshold}$ | 0 | 0 | 0 |
| SQM | 0 | 0 | 0 |
| UPM | 0 | 0 | 0 |
| WNT 133 | 0 | 0 | 0 |
| WNT 135 | 0 | 0 | 0 |
| WNT 138 | 0 | 0 | 0 |
| $\text{WRE}_{bias}$ | 0 | 0 | 0 |

**Table 4.1:** System monitoring trips

## 4.2 WRE thread switches

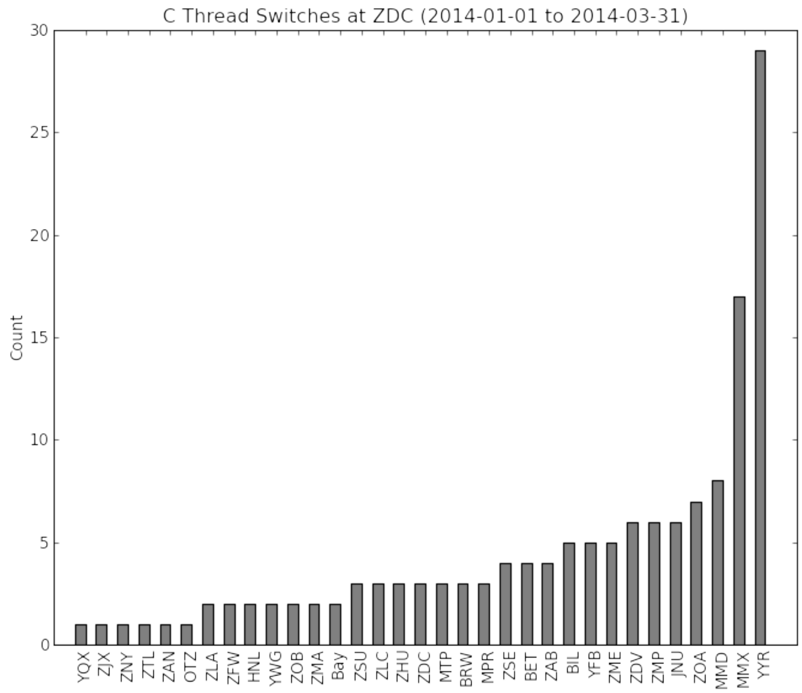


**Figure 4.1:** Count of all days with switches

## 4.3 List of missed messages

The missed messages for the first quarter of 2014 are displayed in the bar chart in this section. Each bar in the chart represents one GEO satellite. Brief explanations for the cause of the missed messages are provided. The totals for missed messages per GEO satellite are as follows:

- CRW (PRN-135) - 0
- CRE (PRN-138) - 29
- AMR (PRN-133) - 64

### 4.3.1 CRW (PRN-135) Events

- No missed messages this quarter.

### 4.3.2 CRE (PRN-138) Events

- 2014-02-12 (16 missed messages) - BRE faulted due to L1 downlink signal degradation due to water intrusion in the L-band feed.
- 2014-02-16 (13 missed messages) - BRE faulted due to L1 loss of lock from weather conditions.

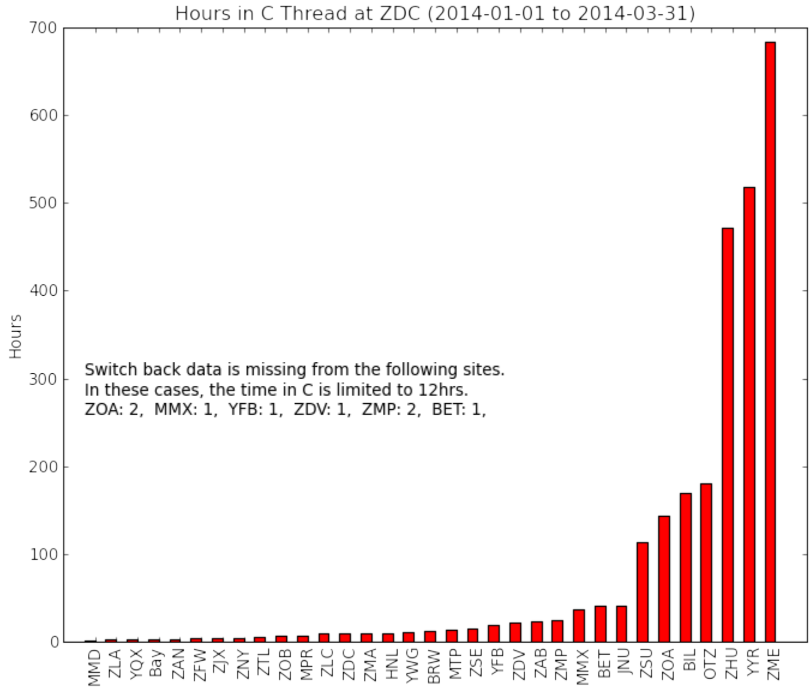


**Figure 4.2:** Time on C thread

### 4.3.3 AMR (PRN-133) Events

- 2014-01-02 (6 missed messages) - GUS switchover due to pseudorange shifts on L5 TLT loopback path at SZP.
- 2014-01-10 (21 missed messages) - HDH experienced unstable C1 uplink; this behavior being the carrier jumps on the L1 TLT path.
- 2014-01-17 (27 missed messages) - HDH experienced unstable C1 uplink; this behavior being the carrier jumps on the L1 TLT path.
- 2014-02-03 (4 missed messages) - GUS switchover, HDH to primary for scheduled maintenance at SZP.
- 2014-02-06 (6 missed messages) - GUS switchover, SZP to primary.

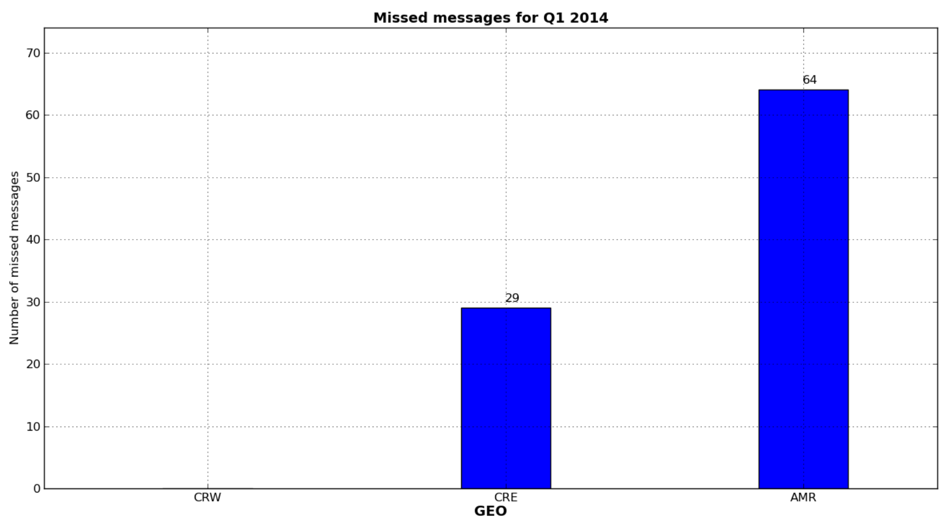


**Figure 4.3:** Missed messages

## 4.4 CNMP resets

This section will be added in a future report.

## 4.5 Satellite clock run-off monitoring

There were no clock run-off events in the first quarter of 2014.

# Chapter 5

# Accuracy monitoring

For additional information on WAAS accuracy, see the WAAS PAN Report for 2014Q1:
`http://www.nstb.tc.faa.gov/REPORTS/waaspan48.pdf`

# Chapter 6

# External monitoring

## 6.1 Antenna phase center positions

Data from 2014-03-17 was used in this survey, and the positions were projected out to 2014-08-01. The results were compared against Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP). In this comparison, Root Mean Square (RMS) ZJX was the only site with position errors greater than three centimeters. The largest error was ZJX-C which is off by 3.5 centimeters in the Y direction.

The survey results were also compared to the coordinates in the currently fielded release 37 software. MSD was off by just over 5 centimeters. HNL and MTP were off by approximately seven centimeters, and MMX was off by approximately 24 centimeters. The rest of the sites were within five centimeters of the fielded coordinates. The differences are all within the allowed 10 cm limit, so no WIPP decision is required.

## 6.2 Ephemerides monitoring

Figures 6.1, 6.2, and 6.3 show the cross-track, in-track, and radial ephemeris deltas between National Geodetic Survey (NGS) precise ephemeris and Continuously Operating Reference Station (CORS) Receiver INdependent EXchange Format (RINEX) ephemeris. Table 6.1 contains the Global Positioning System (GPS) PRN numbers for outliers.

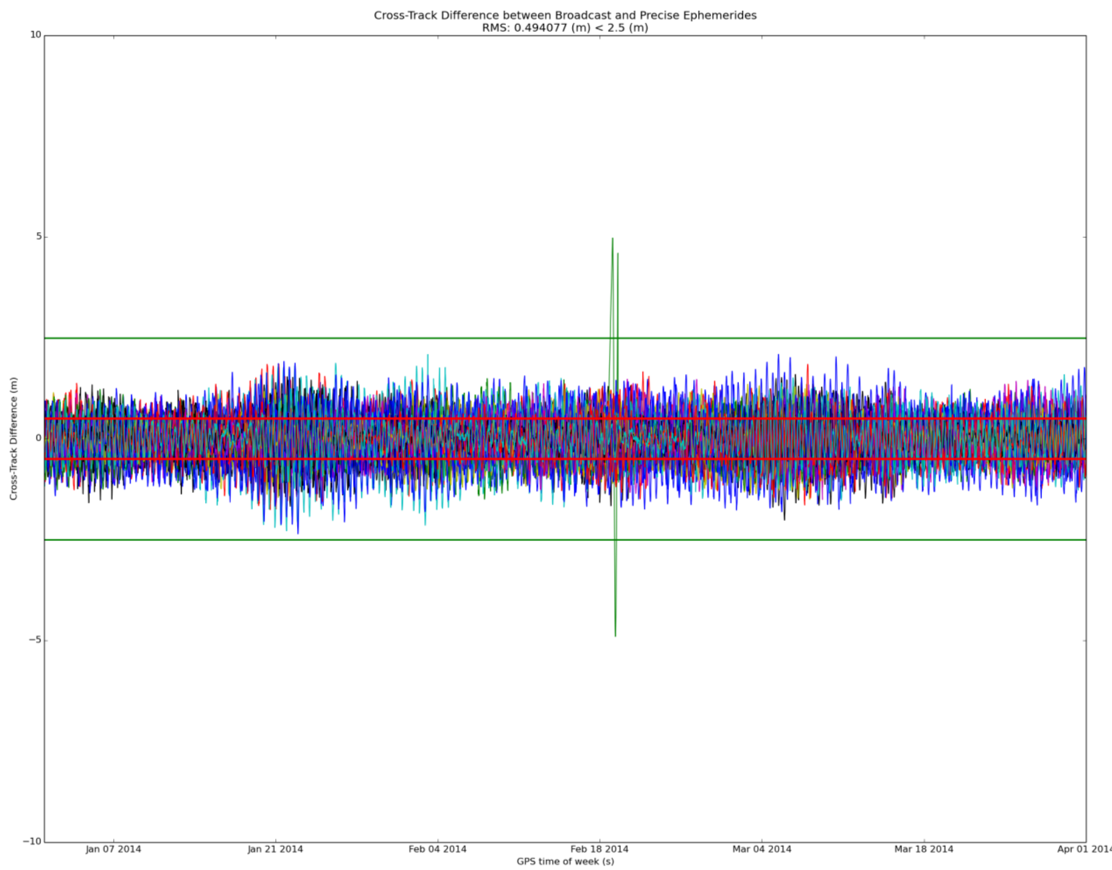


**Figure 6.1:** Q1 2014 Plot of Cross-Track Ephemeris Deltas between NGS and CORS Ephemeris

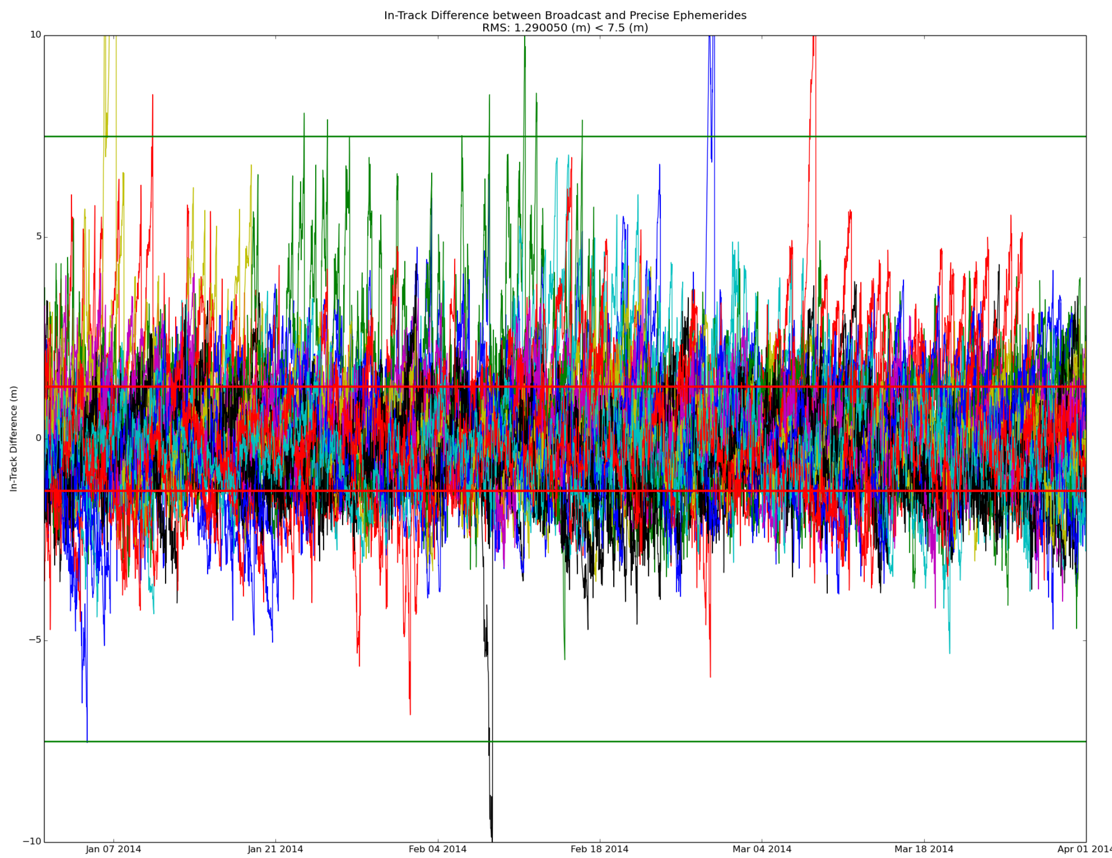


**Figure 6.2:** Q1 2014 Plot of In-Track Ephemeris Deltas between NGS and CORS Ephemeris

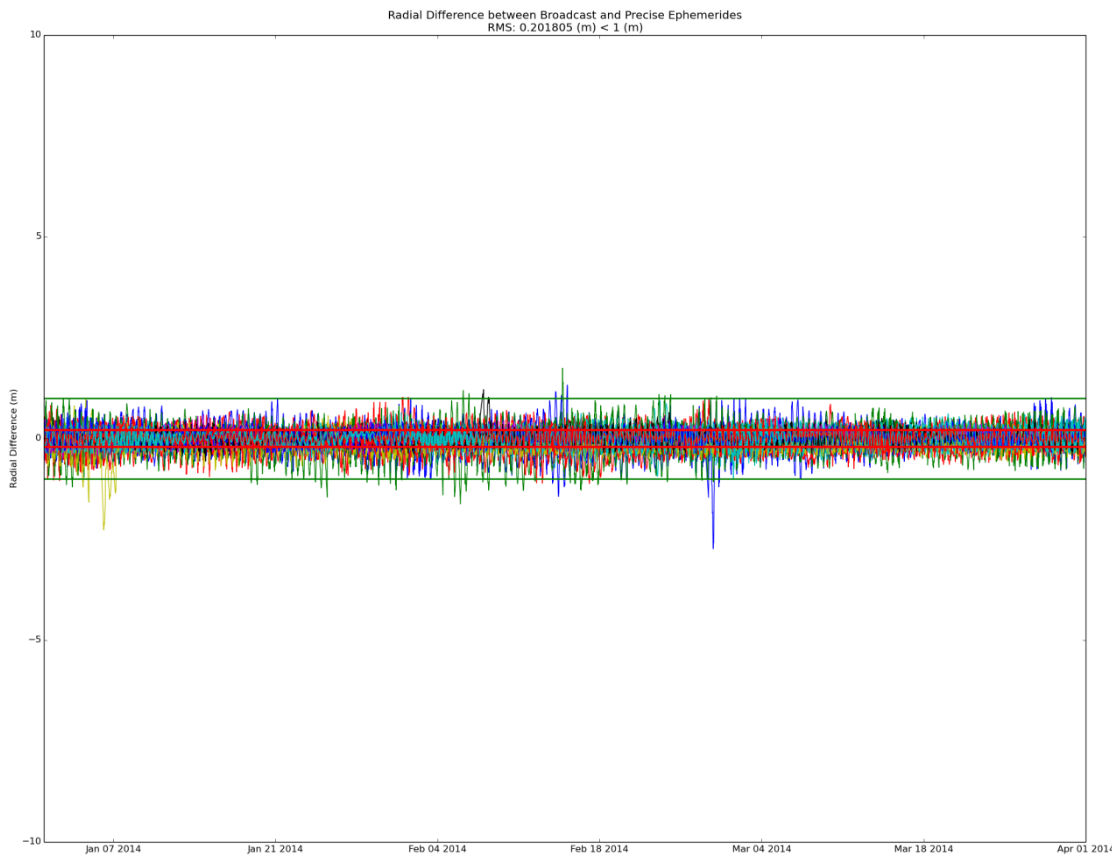


**Figure 6.3:** Q1 2014 Plot of Radial Ephemeris Deltas between NGS and CORS Ephemeris

| GPS PRN | Radial | In-Track | Cross-Track |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 11 | 0 | 0 |
| 3 | 12 | 5 | 0 |
| 4 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 |
| 6 | 19 | 0 | 0 |
| 7 | 0 | 0 | 0 |
| 8 | 79 | 42 | 0 |
| 9 | 238 | 37 | 0 |
| 10 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 |
| 16 | 0 | 0 | 32 |
| 17 | 0 | 51 | 0 |
| 18 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 |
| 21 | 9 | 29 | 0 |
| 22 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 |
| 24 | 11 | 0 | 0 |
| 25 | 0 | 0 | 0 |
| 26 | 0 | 0 | 0 |
| 27 | 70 | 94 | 0 |
| 28 | 0 | 0 | 0 |
| 29 | 0 | 0 | 0 |
| 30 | 0 | 0 | 0 |
| 31 | 0 | 0 | 0 |
| 32 | 0 | 0 | 0 |

**Table 6.1:** Q1 2014 Number of Outliers for each GPS PRN

# Chapter 7

# GEO CCC signal quality analysis (GSQA)

## 7.1 Performance Summary

| | | L1 CCC | | L5 CCC | | CC | |
|---|---|---|---|---|---|---|---|
| | | short-term | long-term | short-term | long-term | short-term | long-term |
| **PRN 135 CRW** | max | OK | OK | OK | OK | OK | OK |
| | mean | OK | OK | OK | OK | OK | OK |
| **PRN 138 CRE** | max | OK | OK | OK | OK | OK | OK |
| | mean | OK | OK | OK | OK | OK | OK |

| **OK** | > **spec** | >> **spec** |
|---|---|---|
| always below spec limit | sometimes above spec limit | normally above spec limit |

**Table 7.1:** GSQA performance summary

## 7.2 Summary

- Data from OKC long-term collect used for analyses
  - Gaps in data appear on switchover / maintenance days
  - No iono ramp correction needed in CCC data
    - Some days had steeper than usual iono ramps but not steep enough to cause metrics to exceed thresholds
    - Correction can be applied because CCC metrics are not meant to include iono effects
- CRE (PRN 138) daily Doppler range large enough this quarter to avoid pseudorange oscillations that would cause long-term CCC threshold to be exceeded

## 7.3 Supporting Figures

Note: missing values indicate days with switchovers or incomplete data

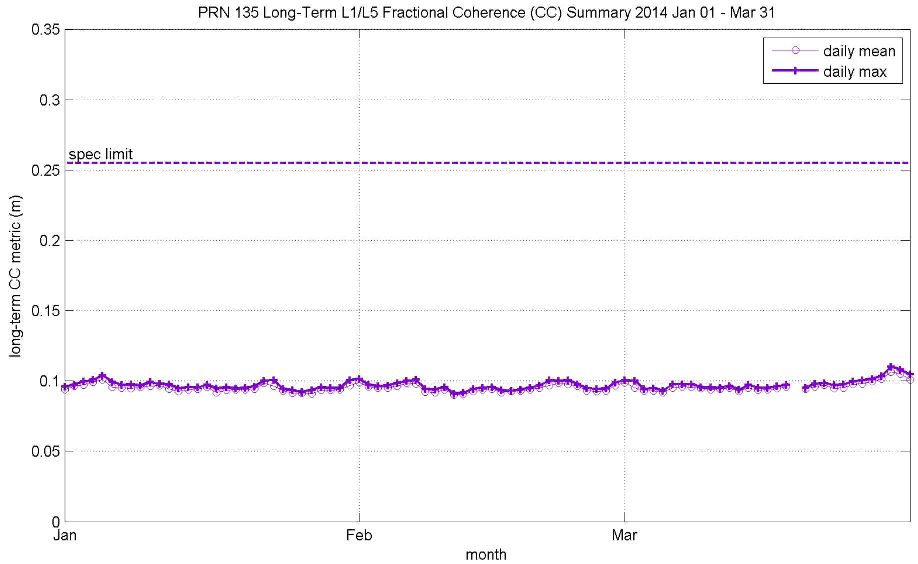


**Figure 7.1:** Long-term fractional coherence (CC) for PRN 135

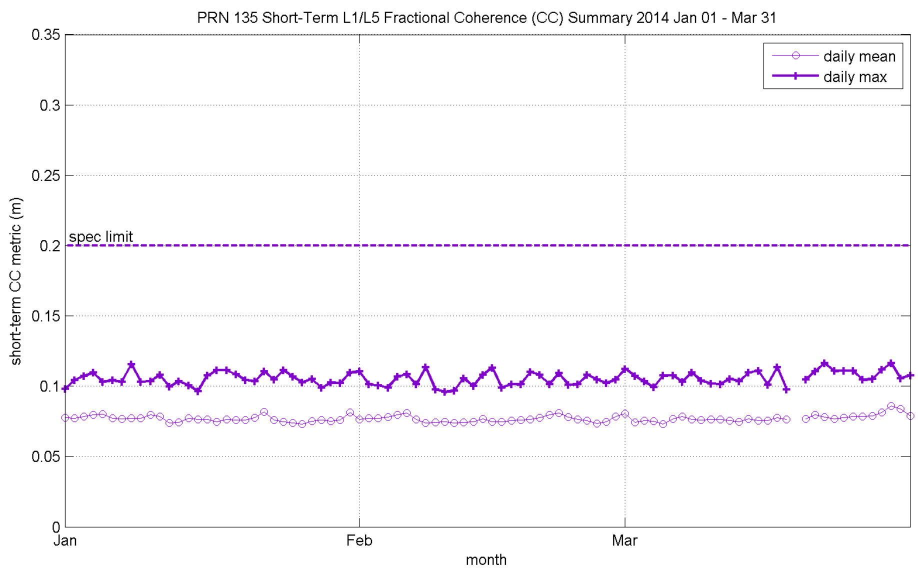


**Figure 7.2:** Short-term fractional coherence (CC) for PRN 135

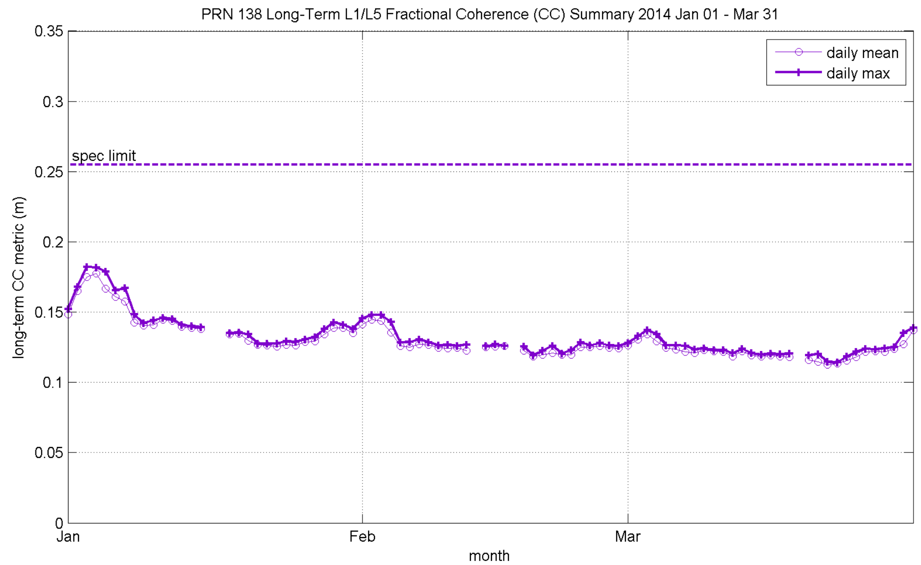


**Figure 7.3:** Long-term fractional coherence (CC) for PRN 138

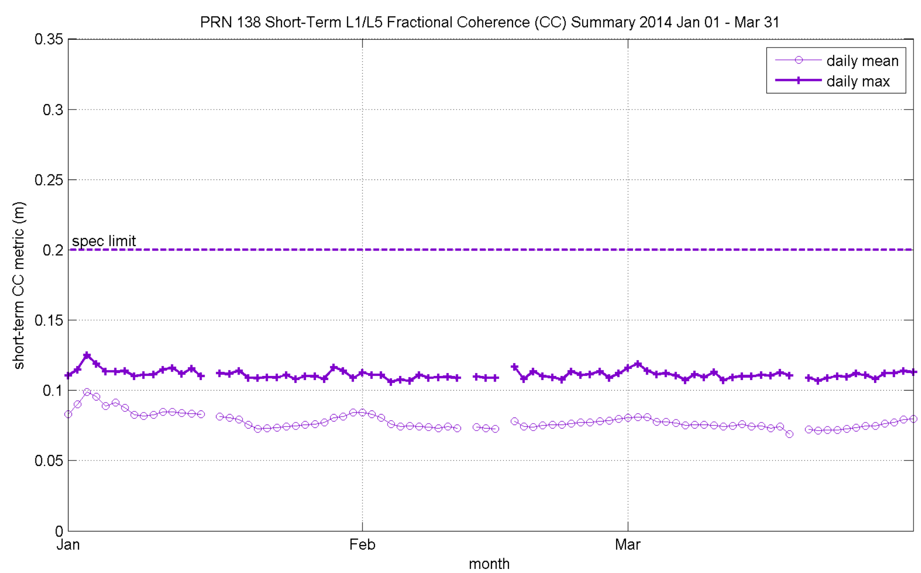


**Figure 7.4:** Short-term fractional coherence (CC) for PRN 138

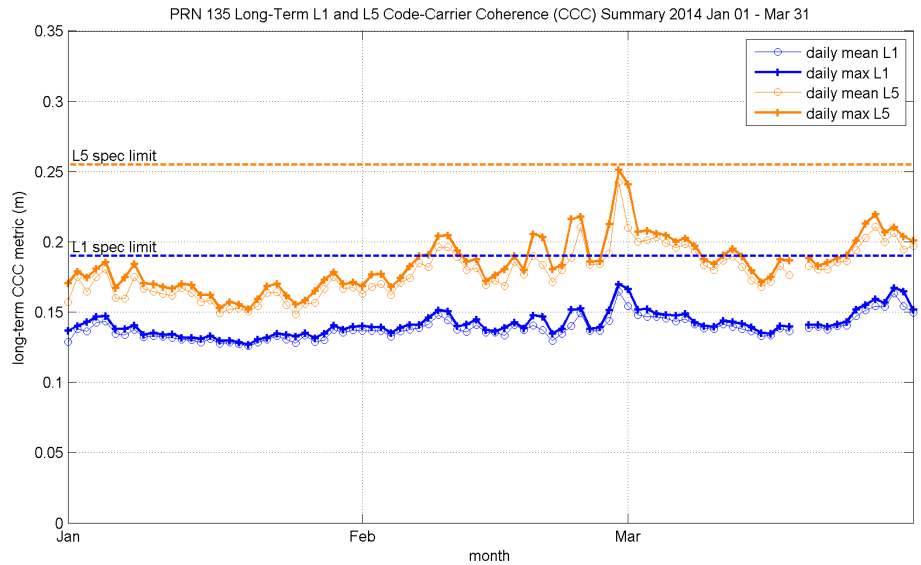


**Figure 7.5:** Long-term code-carrier coherence (CCC) for PRN 135

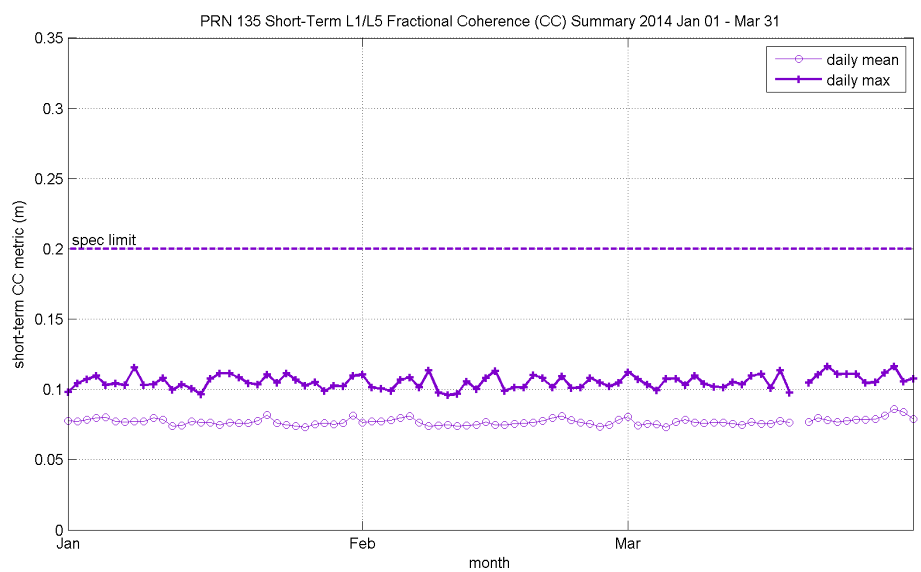


**Figure 7.6:** Short-term fractional coherence (CC) for PRN 135

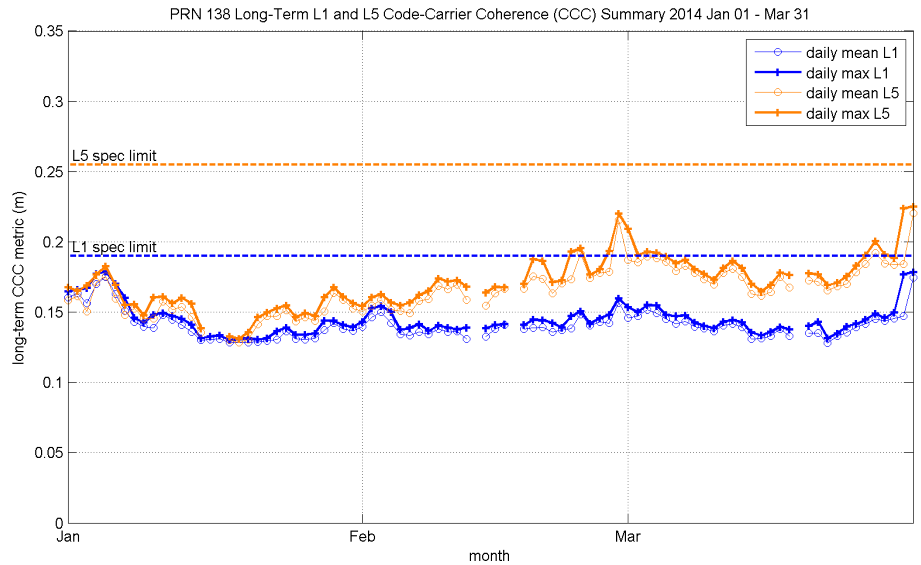


**Figure 7.7:** Long-term code-carrier coherence (CCC) for PRN 138

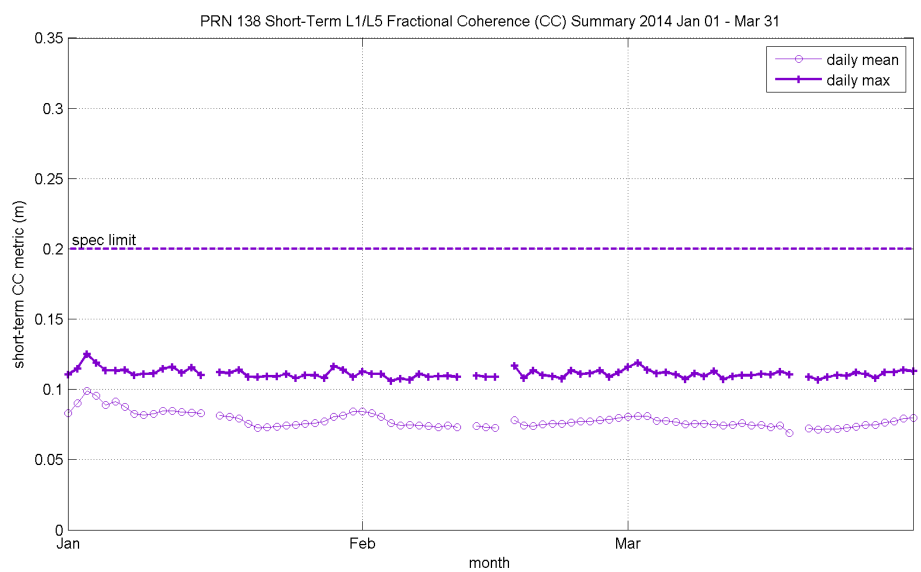


**Figure 7.8:** Short-term fractional coherence (CC) for PRN 138

# Chapter 8

# L1L2 bias levels

## 8.1 Satellites from CP1

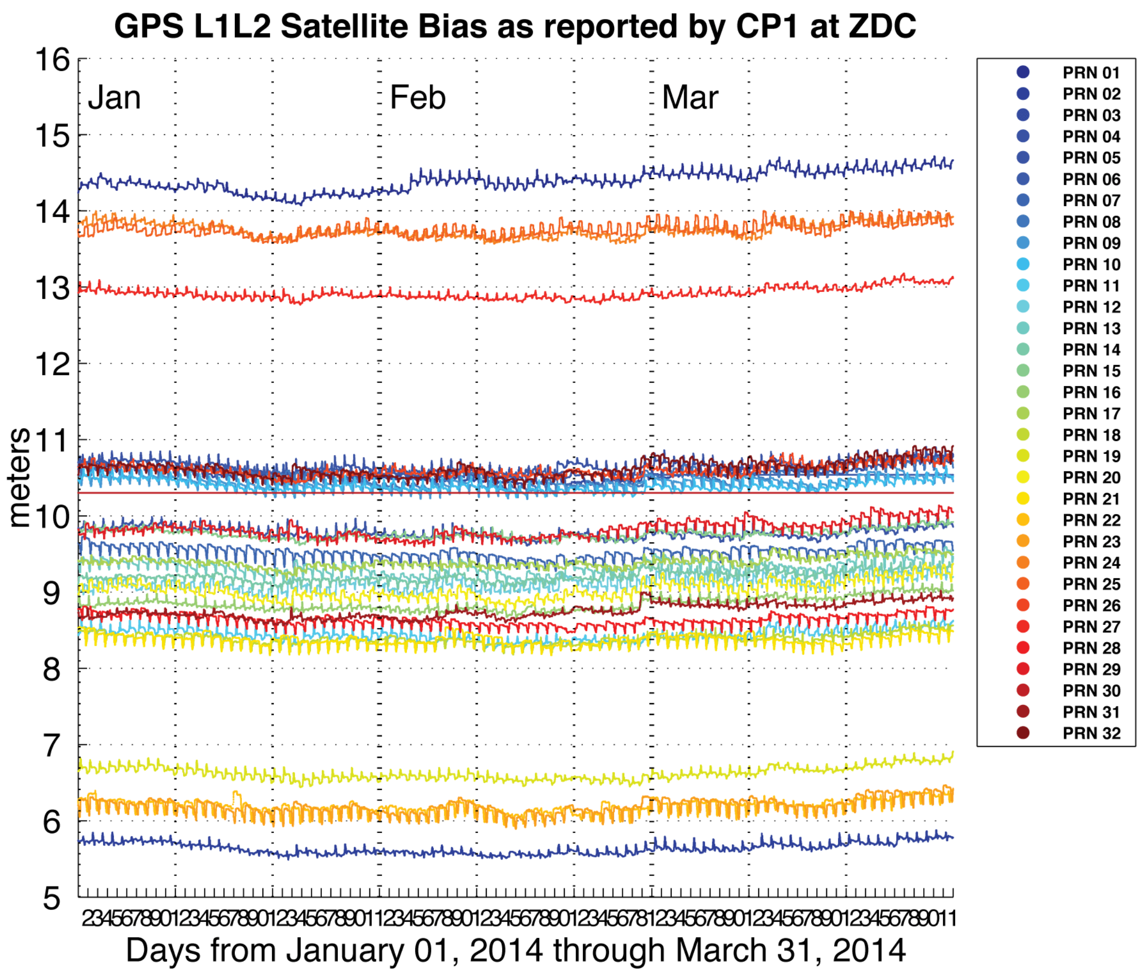


**Figure 8.1:** Q1 2014 L1L2 bias for all PRNs from CP1

## 8.2 Satellites from CP2

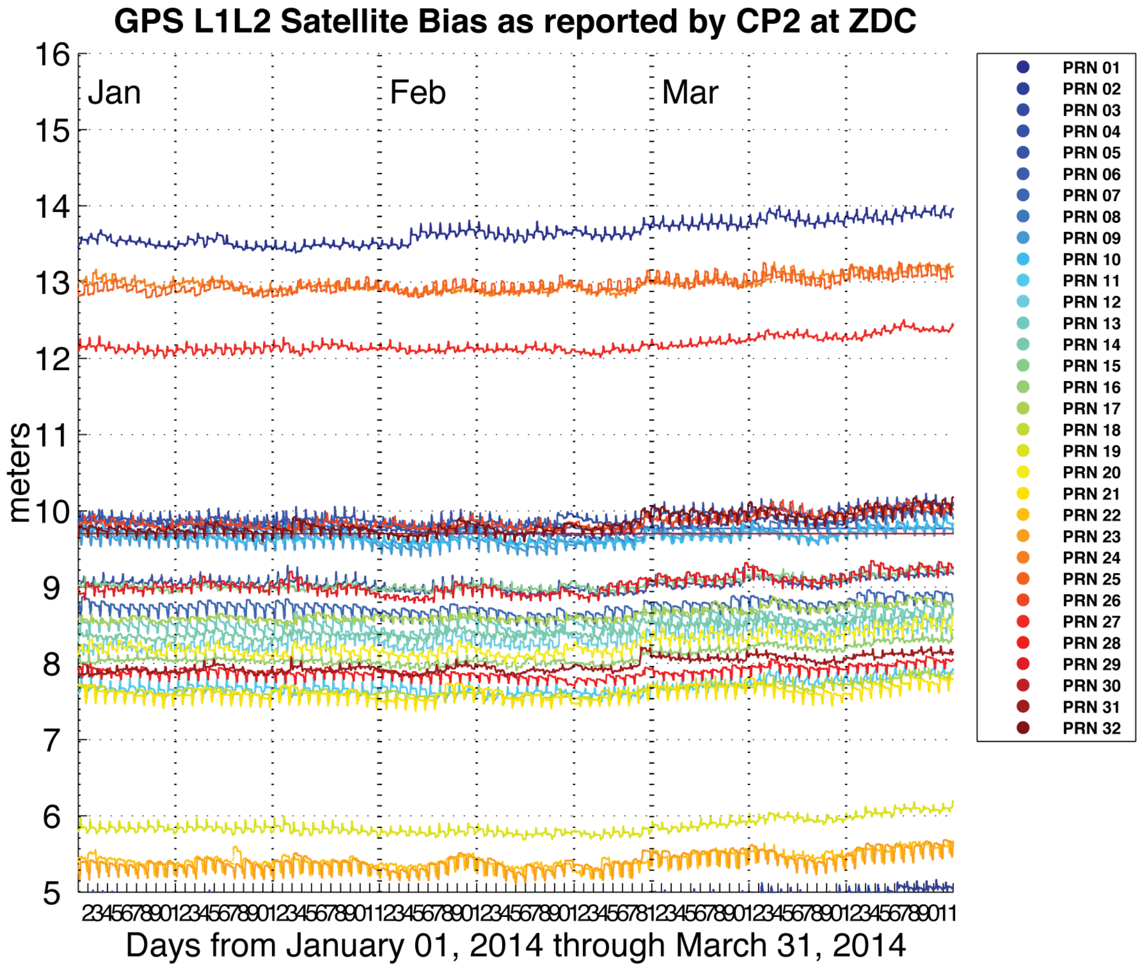


**Figure 8.2:** Q1 2014 L1L2 bias for all PRNs from CP2

## 8.3 WREs from CP1

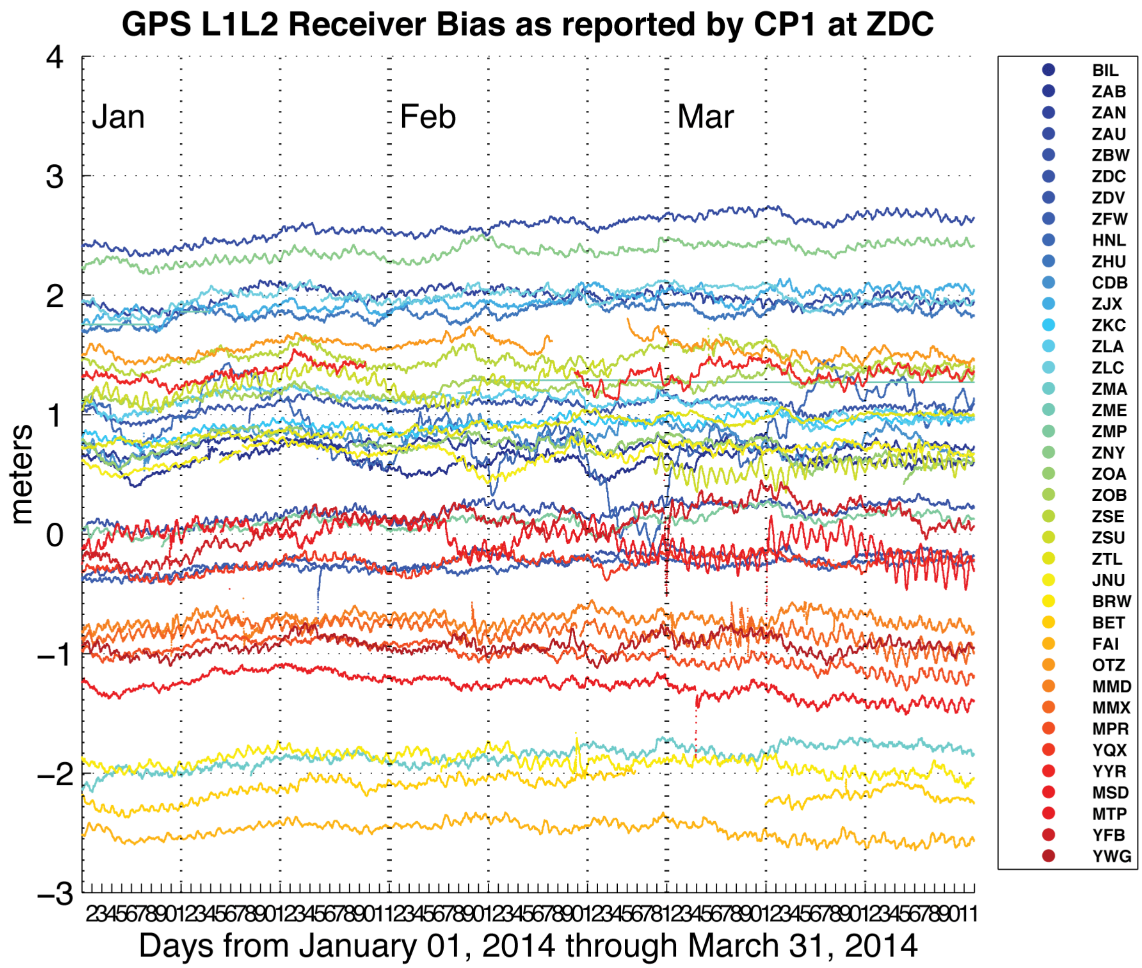


**Figure 8.3:** Q1 2014 L1L2 bias for all WREs from CP1

## 8.4 WREs from CP2

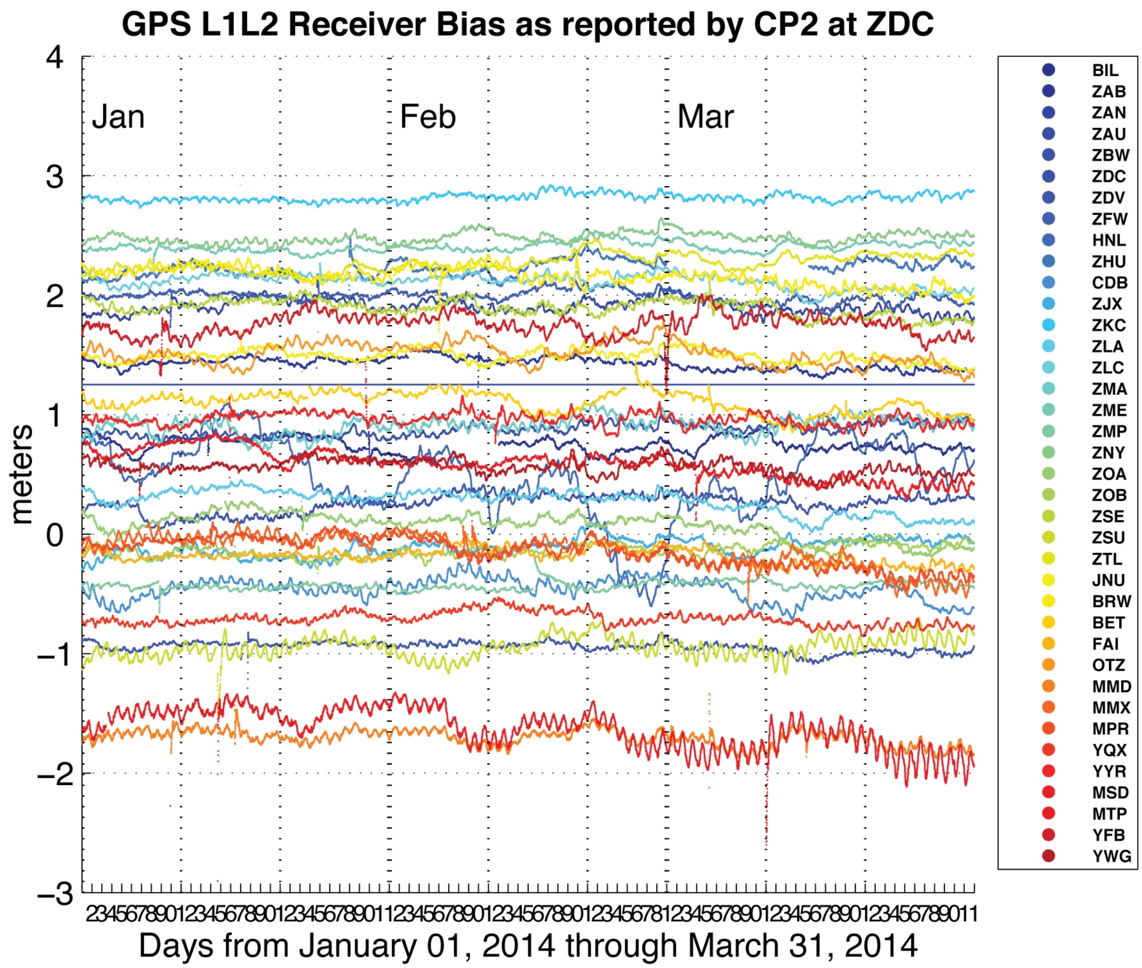


**Figure 8.4:** Q1 2014 L1L2 bias for all WREs from CP2

# Chapter 9

# Anomaly investigation

## 9.1 Major Anomalies

Instability continues on the L1 test loopback path at HDH. On 2013-08-29 Doppler spikes, spikes in carrier phase standard deviation, and drops in carrier to noise were observed on the L1 test section at HDH. This behavior has occurred multiple times on multiple days. No impact to system performance. Stability of the L1 loopback path at HDH has greatly improved since the replacement of the safety computer on 5/22. Below is a chronological list of troubleshooting efforts up to the replacement of the safety computer:

- 2012-05-02 - The standby L1 upconverter was placed online.
- 2012-06-18 - The primary C1 upconverter was replaced with a repaired unit (from a February 2012 local oscillator failure); standby unit still online.
- 2012-07-31 - The replaced, primary C1 upconverter was switched online; L1 Doppler spikes still occurred.
- 2012-08-09 - The standby C1 upconverter was switched back online.
- 2013-05-01 - The primary C1 upconverter was placed back online, Doppler spikes continued on L1 test loopback path.
- 2013-05-17 - Site personnel performed cable and connection testing between the redundancy controller and the primary C1 upconverter.
- 2013-06-05 - Site personnel performed cable and connection testing from the SGS up to the output of the C1 upconverter.
- 2013-08-02 - Site personnel bypass the upconverter redundancy controller.
- 2013-10-09 - Siggen was swapped, Doppler spikes continued 2 days afterward.
- 2013-12-20 - Confirm connectors between the two couplers (after the C1 KPA and after the L1 TLT)
- 2014-01-23 - Swapped the C1 KPA with the standby

- 2014-02-25 - Site visit by SOG contractors and Zeta. An ad hoc repair to the L-band feed was made. Cable connection testing was done along with inspection of the LNA enclosure mounted on the L-band dish. See attached presentation for more details.
- 2014-03-06 - Replace L1 TLT
- 2014-03-06 - Disconnect L1 TLT and SXS IF paths
- 2014-03-12 - Swap 10 MHz reference between L1 and L5 TLT
- 2014-03-14 - Switch from standby KPA back to C1 KPA and reconnect L1 TLT and SXS IF paths
- 2014-03-14 - Disconnect L1 TLT and SXS IF paths
- 2014-05-12 - Safety computer swapped with spare, then swapped back due to being unable to return to backup mode with spare in place
- 2014-05-22 - Safety computer was replaced with new safety computer from the Depot

See anomalies WAAS00008104 and WAAS0007408 for further details.

# Appendix A

# Materials and methods

## A.1 Code-carrier-coherence

Anik, Galaxy 15, AMR and all GPS satellites are monitored for CCC trips. All CCC monitor trips are investigated whenever a trip occurs to determine the cause. Data sources used in correlation and analysis include:

- CCC test statistic
- User Domain Range Error (UDRE) threshold value
- Code Minus Carrier corrected for Iono (CMCI) measurements from WSF Signal Quality Analysis (SQA)
- WAAS Iono calculation
- L1/L5 Iono GEO Uplink Subsystem Type 1 (GUST) calculation
- published planetary $K_2$ and $A_2$ values
- $Chi^2$ values

## A.2 Antenna positioning

Accurate antenna positions are needed for WAAS or any Differential Global Positioning System (DGPS) application. The positions must be updated to correct for time dependent processes like tectonic plate movement and subsidence. They also need to be updated for events which shift the position of the antennas. These might include seismic events or maintenance. Antenna position results from OLM will be used to determine if the WAAS antenna coordinates require an update.

The WIPP reviews antenna position changes based on how much the antenna moves. If the antenna moves more than ten centimeters, the WIPP should review. If an antenna moves more than 25 centimeters, the WIPP must review. Mexico city is a special case due to the rapid subsidence at that site. It is allowed 25 centimeters before review.

The NGS's suite of survey software (PAGE-NT) is used to conduct a survey with WAAS site data from the current quarter. These results are compared against CSRS-PPP using the same input data.

## A.3 Satellite clock Run-off monitoring approach

A GPS clock run-off event is typically correlated with a WAAS fast correction that exceeds 256 meters. When this occurs, the satellite is set to Do Not Use until the correction reaches a reasonable size. A real clock-runoff occurs when these events happen at times that the GPS satellite is in a healthy status, in view of WAAS, and there is no Notice Advisory to NAVigation System with Time And Range (NAVSTAR) Users (NANU) in effect for the specific GPS Space Vehicle (SV).

The approach to monitor for GPS clock run-off events is to collect quarterly data for SV health from CORS RINEX files, NANUs from the US Coast Guard, and Fast Correction and User Domain Range Error Index (UDREI) data from WAAS User Messages (WUMs). Once collected, the data is analyzed for the entire quarter.

## A.4 Ephemerides Monitoring Approach

The difference between the precise GPS orbits provided by the NGS and the ephemeris derived from the CORS RINEX files for all available sites is computed and analyzed. A voting algorithm is employed to select the best set of ephemerides from the CORS data. Outliers are analyzed and tabulated.

## A.5 Iono threat model monitoring approach

Monitor the percentage of $\text{Chi}^2$ values $>$ than 1 each day for the six regions (see 3.4.2) and determine whether the threshold has been reached. The regions and thresholds are:

| Region | Threshold (%) |
|---|---|
| Alaska | 8.6 |
| Canada | 16.5 |
| Equatorial | 9.4 |
| CONUS | 3.6 |
| W Mid-latitude | 4.3 |
| E Mid-latitude | 6.8 |

**Table A.1:** Threat model regions and threshold settings

## A.6 Code-noise and multipath

To monitor the CNMP HMI assertion (appendix C.2), we check the bounding for three statistics, L1, IFPR, and Delay. The equations used to determine a passing or failing grade for the distribution plots are in Appendix B.2.2. The zero-centered sigma overbound plots are considered to be passing if the value is less than one, which is marked in the plots.

## A.7 GEO CCC signal quality analysis (GSQA)

### A.7.1 Data

- Data from OKC long-term collect used for analyses

### A.7.2 Methods

- Graphs of data were generated using MATLAB

# Appendix B

# Supplemental material

## B.1 Iono threat model defined regions

Six regions (Alaska, Canada, CONUS, Equatorial, East mid-latitude and West mid-latitude) define the $Chi^2$ statistical analysis. Those regions are shown in Figure B.1 below.

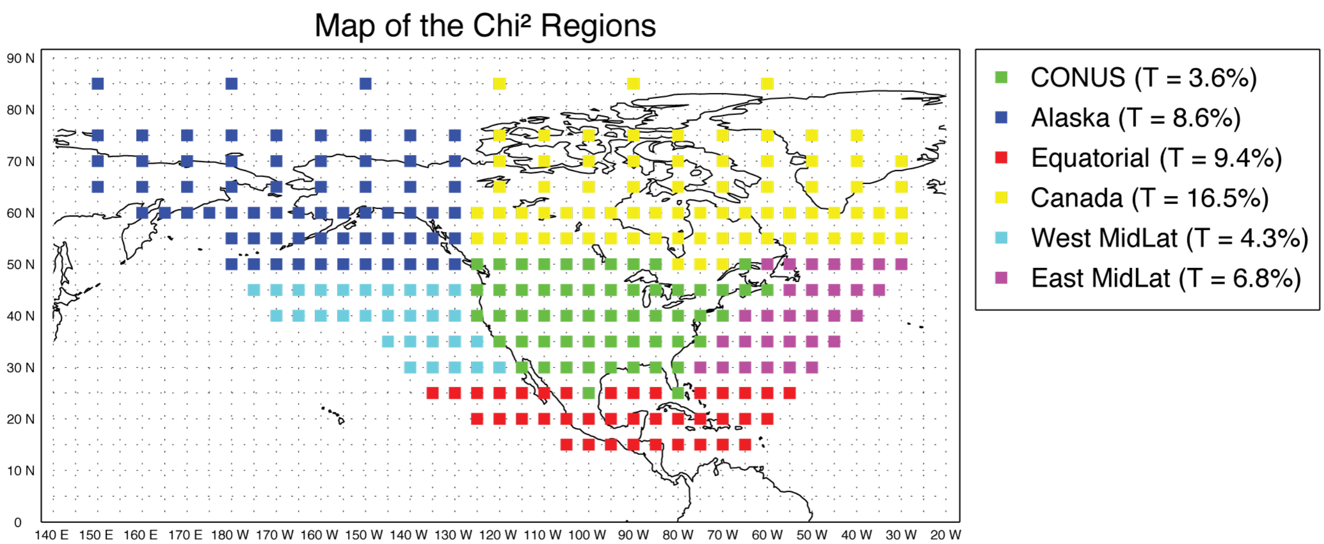


**Figure B.1:** $Chi^2$ region map

## B.2 Equations

### B.2.1 Code-carrier-coherence

$$ccc_y^j = \frac{\sum_i \left[ \frac{\mu^j_{y,cnmp,i}}{(\sigma^j_{y,cnmp,i})^2} \right]}{\sum_i \left[ (\sigma^j_{y,cnmp,i})^{-2} \right]}$$

where:
$\mu^j_{y,cnmp,i}$ is the instantaneous difference of the code measurements vs. the adjusted carrier phase for SV j as measured by WRE i for each $y \in L1, L2$,
$\sigma^j_{y,cnmp,i}$ is the standard deviation of the CNMP measurements for SV j as measured by WRE i for each $y \in L1, L2$,
$|ccc_y^j|$ is the carrier-smoothed, CCC monitor output statistic generated by a first-order smoothing filter with $\tau_c = 25$ seconds.
The probability of the CCC metric exceeding the Maximum Error Range Residual (MERR) is:

$$P_{HMI} = \Phi^R \left( \frac{\text{MERR} - \text{MDE}_{\text{monitor}}}{\sqrt{\sigma^2_{udre,nominal} + F^2_{PP}\sigma^2_{uive,nominal}}} \right)$$

$$\text{MERR} = 5.33\sqrt{\sigma^2_{udre} + (F_{pp}\sigma_{uive})^2}$$

$$\text{MDE} = T_{ccc} + k_{ma}\sigma_{test}$$

$$(\Phi^R)^{-1}(P_{md}) = k_{md}$$

### B.2.2 Code-noise and multipath

The Cumulative Density Function (CDF) is defined as:

$$\Phi^R(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{\frac{-t^2}{2}} dt$$

$$\Delta(x) = \begin{cases} \frac{\Phi^R_{theory}(x) - \Phi^R_{data}(x)}{\Phi^R_{theory}(x)} & \text{if } x \geq 0 \\ \frac{[1-\Phi^R_{theory}(x)] - [1-\Phi^R_{data}(x)]}{1-\Phi^R_{theory}(x)} & \text{if } x < 0 \end{cases}$$

CNMP passes when the following condition is met:

$$\Delta(x) > 0 \text{ for all } |x| > 0.25$$

## B.3 Tables

### B.3.1 Code-carrier-coherence

| UDREI | $\tau_{ccc,gps}$ | $\tau_{ccc,geo}$ |
|---|---|---|
| 5 | 1.94 | 0 |
| 6 | 1.99 | 0 |
| 7 | 3.00 | 0 |
| 8 | 3.88 | 0 |
| 9 | 4.00 | 0 |
| 10 | 6.00 | 2.5 |
| 11 | 12.0 | 3.0 |
| 12 | 40.0 | 7.1 |
| 13 | 100 | 20 |

**Table B.1:** CCC trip thresholds per UDRE index

### B.3.2 WRE listing

| WRS Index | Location | Symbol |
|---|---|---|
| 0 | Billings, Montana | BIL |
| 1 | Albuquerque, New Mexico | ZAB |
| 2 | Anchorage, Alaska | ZAN |
| 3 | Chicago, Illinois | ZAU |
| 4 | Boston, Massachusetts | ZBW |
| 5 | Washington, DC | ZDC |
| 6 | Denver, Colorado | ZDV |
| 7 | Fort Worth, Texas | ZFW |
| 8 | Honolulu, Hawaii | HNL |
| 9 | Houston, Texas | ZHU |
| 10 | Cold Bay, Alaska | CDB |
| 11 | Jacksonville, Florida | ZJX |
| 12 | Kansas City, Kansas | ZKC |
| 13 | Los Angeles, California | ZLA |
| 14 | Salt Lake City, Utah | ZLC |
| 15 | Miami, Florida | ZMA |
| 16 | Memphis, Tennessee | ZME |
| 17 | Minneapolis, Minnesota | ZMP |
| 18 | New York, New York | ZNY |
| 19 | Oakland, California | ZOA |
| 20 | Cleveland, Ohio | ZOB |
| 21 | Seattle, Washington | ZSE |
| 22 | San Juan, Puerto Rico | ZSU |
| 23 | Atlanta, Georgia | ZTL |
| 24 | Juneau, Alaska | JNU |
| 25 | Barrow, Alaska | BRW |
| 26 | Bethel, Alaska | BET |
| 27 | Fairbanks, Alaska | FAI |
| 28 | Kotzebue, Alaska | OTZ |
| 29 | Mérida, Yucatán | MMD/Q9C |
| 30 | Mexico City | MMX/Q9A |
| 31 | Puerto Vallarta, Jalisco | MPR/Q9B |
| 32 | Gander, Newfoundland and Labrador | YQX |
| 33 | Goose Bay, Newfoundland and Labrador | YYR |
| 34 | San José del Cabo, Baja California Sur | MSD/Q9E |
| 35 | Tapachula, Chiapas | MTP/Q9D |
| 36 | Iqaluit, Nunavut | YFB |
| 37 | Winnipeg, Manitoba | YWG |

**Table B.2:** WRE listing

### B.3.3 Space vehicle designators

| SV | Common name | Int. designator | Owner | Launch date |
|---|---|---|---|---|
| CRE | Anik F1-R | 2005-036A | Telesat | 2005-09-08 |
| CRW | Galaxy 15 or PanAm | 2005-041A | Intelsat | 2005-10-13 |
| AMR | Inmarsat 4-F3 or AMR | 2008-039A | Inmarsat | 2008-08-18 |

**Table B.3:** GEO satellite information I

| SV | PRN | GUST sites | Position | Period | Apogee | Perigee | RCS |
|---|---|---|---|---|---|---|---|
| CRE | PRN 138 | WBN BRE | 107.3±0.01°W | 1436.09min | 35796m | 35777m | 5.0139$m^2$ |
| CRW | PRN 135 | LTN APC | 133.0±0.01°W | 1436.08min | 35798m | 35974m | 3.9811$m^2$ |
| AMR | PRN 133 | SZP HDH | 98.0±3.01°W | 1436.11min | 35776m | 35776m | 2.1948$m^2$ |

**Table B.4:** GEO satellite information II

## B.4 References

WAAS CDRL A014-011 *Algorithm Contribution to HMI for WAAS*

# Appendix C

# Assertions

## C.1 Code-carrier-coherence

The *a priori* probability of a CCC failure is less than $1e^{-4}$ per set of satellites in view per hour for GPS satellites and $1.14e^{-4}$ for GEO satellites.

## C.2 Code-noise and multipath

The HMI document for CNMP states:

> The Code Noise and Multipath (CNMP) error bound is sufficiently conservative such that the error in linear combinations of L1 and L2 measurements is overbounded by a Gaussian distribution with a sigma described by the Root Sum Square (RSS) of L1 and L2 CNMP error bounds except for biases, which are handled separately.

## C.3 Antenna positioning

The RSS position error for each WAAS reference station antenna is 10 centimeters or less when measured relative to the International Terrestrial Reference Frame (ITRF) datum for any given epoch (Mexico City is allowed 25 centimeters). The ITRF datum version (realization) is the one consistent with the World Geodetic System's latest reference coordinate system (WGS-84) and also used for positions of the GPS Operational Control Segment monitoring stations.

## C.4 Iono threat model

The values of $\sigma_{\mathrm{decorr\_undersampeled}}$ and $\epsilon_{\mathrm{iono}}$ adequately protect against worst case undersampled ionosphere over the life of any ionospheric correction message, when the storm detectors have not tripped.

## C.5 Satellite Clock Runoff

The *a priori* probability of a GPS satellite failure resulting in a rapid change in the GPS clock correction is less than $1.0\text{x}10^{-4}$ per satellite.

# Appendix D

# Coding standards and guidelines

## D.1 Introduction

The standards and guidelines for the Offline Monitoring effort are recorded here. "Standards" represent a "rule" that is assumed to be "enforceable", that is, it has been agreed to by the stakeholders and recorded as official. Program Change Requests (PCRs) can (but not necessarily will) be blocked due to lack of upholding a standard. Furthermore, standards can certainly have exceptions, but these are dealt with on a case-by-case basis and recorded as such. "Guidelines", on the other-hand, are not enforceable. Guidelines represent good ideas and common engineering practices across the group. PCRs cannot be blocked as a result of not following a guideline.

Transitioning from a guideline to a standard is a done on a case-by-case basis. While there is no hard and fast rule for how this is done, the steps for this usually contain an initial agreement by the stakeholders (which included management and engineers) that a standard ought to be adopted, a resource (with associated level of effort) assigned, and an initial assessment as to how much work is involved (estimated end date, etc). The process of transitioning from a guideline to a standard is known as refactoring, and the practice is encouraged as long as stakeholder buy-in is considered at each step.

The standards and guidelines are differentiated by the words "shall" and "should".

## D.2 Integrity standards for MATLAB

The integrity standards for MatLab were developed during the WAAS FLP Release 6/7 time frame. These standards represent rules that, if broken, could lead to incorrect or erroneous results (not necessarily a tool crash but actual incorrect output). These are documented in the WAAS HMI document (in section 4.3.3 of that document) and are repeated here in their condensed form. More detail can be found in the WAAS HMI document. Note that these standards are enforced by use of the CD_STD_CHK tool which parses the files/scripts line by line checking for breaches.

- MATLAB Calling Ambiguity:
  - Ensure that no MATLAB keywords are used as function names.
  - Use functions, not scripts.
  - Function name and filename being the same is required.
  - One function per file required.
  - Functions should not be influenced by anything other than inputs:

- No **global** variables.
- No **persistent** variables.

- MATLAB Functionality Ambiguity:
  - The **squeeze** function shall not be used.
- Windows Ambiguity:
  - The **exist** function shall not be used.
- Coding Clarity:
  - The **eval** command shall not be used.
- Consistency Check:
  - OSP consistency must be addressed.
  - Critical parameters need to not be hardcoded in the tools
- Repeatability:
  - The actual scripts that were used to generate the data, tables and plots need to be captured along with the outputs, as well as a mapping to the actual data set used.

## D.3 HMI/OLM coding standards

Along with the Integrity standards described in section 9.4.1, there exist several "Offline Monitoring" coding standards. These are coding standards which are attached to the running of the Offline Monitoring code and which have been identified as required for the processing of the offline monitoring data. Currently, there are five standards:

- All open files shall be closed
  - This requirement should be applied over all tools for all Offline Monitoring scripts. This requirement is simple, as it just requires that any file which is opened be appropriately closed in the same script that opens it.
- In MatLab, the **figure** command needs to always have a file ID associated with the open figure
  - The MatLab coding language allows the user to create figures without assigning a file id variable. Closing the specific figure is then impossible in general, and the figure must be closed either by keeping track of the current figure ID, or by applying the **close all** command. Neither of these is desired, and as such, each figure must have a unique file ID in memory.
- In MatLab, the close all command shall not be used.
  - The **close all** command is issued to close all figures with or without a file ID. As standards are in place to assign a file ID for all figures, this line of code is unnecessary and should not be used.

- All open figures should have the option to be closed
  - The MatLab tools should not leave open figures after the analysis is run (by default). For particular tools, it may be desirable to keep the plots up on the screen, but the option to close them should be implemented
- Use **cs_saveplot** for saving plots in MatLab
  - The **cs_saveplot** function is a common script which saves figures to results directories. There are several options when saving a plot, and using this function allows one place to modify the saving requirements.

## D.4 File naming conventions

While no complete convention exists, there are standard "pieces" which shall be enforced for the OLM effort. These refer to the labels inside the actual name of the tool which refer to information in the data file. The requirements are listed below:

- Filenames shall be named using a prefix, followed by an "_", then the ISO8601 date in the form of YYYY-MM-DD, followed by a "." and the extension.
- Filenames shall use lowercase letters, integers, underscores and dashes.
- There shall be no more than one "." in a file name
- Text files shall end with the suffix ".txt"
- Binary files shall end with the suffix ".bin"
- Files which contain data for a particular PRN shall have a six-character label of the form "prnDDD" where DDD are the three digits referring to the PRN number. PRNs less than 100 shall have a leading zero, and PRNs less than 10 shall have two leading zeros.
- Files which contain data for a particular WRE shall have a six-character label of the form "wreDDD" where DDD are the three digits referring to the WRE number. WREs less than 100 shall have a leading zero, and WREs less than 10 shall have two leading zeros. Also note that WREs start counting at 0, so for a 38-station system, the WRE number range from 0 to 113.
- Files which contain data for a particular UDREI shall have a seven-character label of the form "udreiDD" where DD are the two digits referring to the UDREI. UDREIs less than 10 shall have a leading zero. Also note that UDREIs start counting at 0, so UDREIs range from 0 to 15.
- Files which contain data for a particular Grid Ionospheric Vertical Error Index (GIVEI) shall have a seven-character label of the form "giveiDD" where DD are the two digits referring to the Grid Ionospheric Vertical Error (GIVE) index. GIVEIs less than 10 shall have a leading zero. Also note that GIVEIs start counting at 0, so GIVEIs range from 0 to 15.

## D.5 OLM file formats

Standard file formats have been defined for five types of files, listed below. These represent standards, and are enforceable requirements.

### D.5.1 Histogram files

The number of columns in a histogram file shall be one more than the sum of the number of slices. For example, if a histogram file contained an aggregate histogram, slices by UDREI and slices by PRN (both GEO and GPS), there would be 1+1+16+44 = 62 columns. The first column is the bins, the second column is the aggregate, columns 3 through 18 are the 16 UDRE slices (with columns 17 and 18 being NM and DU), columns 19 through 50 are the 32 GPS PRNs, columns 51 through 60 are the GEO PRNs (which the last five being held in reserve), column 61 is the aggregate GPS histogram and column 62 is the aggregate GEO histogram.

- Histogram files are stored as raw counts, not probabilities and the bins are recorded as bin centers.
- Histogram files can be daily or compiled into a report.
- The histogram file shall have a header which has column headings lined up with the columns of the data.

### D.5.2 Statistics files

Each statistic in the statistics file shall be defined to be able to be computed using bins (either centers or edges) and the raw counts, and each column in the histogram file shall have all statistics computed for it. Thus, the dimensions of a statistics file shall be as such.

- The number of rows is the same as the number of statistics
- The number of columns shall be the same as the number of slices

In order to account for the column of bins, a statistic index is placed there, so that each column in a histogram file corresponds to the same column in the statistic file. There are currently 21 descriptive statistics computed for each histogram file:

1. Counts
2. Mean
3. Abs(Mean)
4. Standard Deviation
5. Minimum
6. Maximum
7. Absolute Maximum
8. Sigma Over-bound (Zero-centered)
9. Sigma Over-bound (Mean-centered)
10. 1st Quartile
11. Median (2nd Quartile)

12. 3rd Quartile
13. Mean of Absolute Value
14. Standard Deviation of Absolute Value
15. RMS
16. Variance
17. Level 3 Outliers (outside of mean $\pm$ 3.29$\sigma$, P = $10^{-3}$, relative to the aggregate mean and sigma)
18. Level 4 Outliers (outside of mean $\pm$ 3.89$\sigma$, P = $10^{-4}$, relative to the aggregate mean and sigma)
19. Level 5 Outliers (outside of mean $\pm$ 4.42$\sigma$, P = $10^{-5}$, relative to the aggregate mean and sigma)
20. Level 6 Outliers (outside of mean $\pm$ 4.89$\sigma$, P = $10^{-6}$, relative to the aggregate mean and sigma)
21. Level 7 Outliers (outside of mean $\pm$ 5.33$\sigma$, P = $10^{-7}$, relative to the aggregate mean and sigma)

The statistics file shall have a header which has column headings lined up with the columns of the data, as well as the list of statistics represented in the file. Statistics files can be daily or compiled into a report.

### D.5.3 Time-series files

Time series files represent a quantity which evolves over time. These can be any quantity, but currently only satellite quantities are created. Thus, the file naming convention for PRN (described in 4.4.2) are utilized.

The time series files have as the first three columns three different representation of time. The first is WAAS time, the second is Universal Time, Coordinated (UTC) in ISO-8601 format (HHMMSS) and the third is seconds in the day. After the first three columns, more columns can be added. The intent of the time series file is to have all of the data which a plot would require in the subsequent columns. Time series files are only attached to daily quantities, but several time series files could be concatenated together to create a multi-day file (and plot).

### D.5.4 Quantity files

Quantity files contain two dimensional slices of a particular quantity. For example, creating a UDREI/GPS PRN slice for the absolute maximum of the CCC metric would allow a user to see which satellites have issues at which UDREIs. As both dimensions are used, only one statistic per file can be represented. Quantity files are currently only daily files, but they could be created for a compiled data for some statistics.

### D.5.5 Quarterly files

Quarterly files are the files which are plotted over the period of the quarter. Thus, the first column is the number of the day in the quarter and the second (and subsequent) columns are data to be plotted. The data set can be customized for the particular plot.

## D.6 Histogram slicing and bin requirements

For many of the analyses, histograms are used to show compliance to particular requirements. As there is inherent averaging in creating an aggregate histogram, the concept of slicing was introduced early in the WAAS analysis process. This requires that data from (potentially) different error sources are not averaged into a single histogram, but are examined separately. In order to compile results across multiple days (and data sets), both the bin centers and the number of columns for each type of slice needs to be fixed. Modifying these requirements at a later date would make long term trending difficult, if not impossible.

The table below shows the bin requirements for the data files. Histograms will be created from these files by one or more of the Offline Monitoring analyses. Note that the minimum and maximum data cutoffs are defined to be the bin EDGES, not the bin centers. Thus, the bin centers are in between the defined edges.

| **Data description** | **Filename** | **Data min** | **Bin width** | **Data max** | **Units** |
|---|---|---|---|---|---|
| Raw CCC metric (L1 and L2) | `qstats*` | -8.0 | 0.01 | 8.0 | meters |
| CCC metrics / trip threshold | `qstats*` | -3.0 | 0.01 | 3.0 | none |
| CCC metrics / MERR value | `qstats*` | -2.0 | 0.001 | 2 | none |
| Max SQM metric | `sqm_reduced*` | 0 | 0.001 | 2.0 | none |

**Table D.1:** Data histogram bin requirements

The table below shows the slicing requirements. These include the number of columns and designations for each type of slice.

| **Slice description** | **# of columns** | **Column description** |
|---|---|---|
| Aggregate | 1 | This is the histogram of the entire metric. There is always one column, no more. |
| UDRE index | 16 | Columns 1-14 represent the data associated with a UDREI of one less than the column, i.e., UDREIs of 0-13. The last two columns represent satellites which are NM (not monitored) and DU (don't use) respectively. |
| PRN | 44 | The PRN slices come in a few sets. The first set is the first 32 PRNs. The second set is 10 columns devoted to past, current and future GEOs. The first five GEO columns are the GEO PRNs of 122, 133, 134, 135, and 138. The next five columns are reserved for future GEO PRNS. Finally, the last two columns are the aggregate of the GPS and GEO data respectively. |

**Table D.2:** Data slicing requirements

# D.7 OLM process and procedures

## D.7.1 Schedule and meetings

The OLM group will meet approximately twice a quarter. One set of meetings is to be set for the first week of the new quarter to go over plans for that quarter. The second set of meetings is to be set for shortly before the WIPP. For both meetings, the general purpose is to plan for the next WIPP or the next OLM report, as the case may be. At the meetings, task lists with priorities and resources are created, to be reviewed at the next set of meetings. The OLM document is released once a quarter. The analyses should be running during the quarter, and should be being reviewed on a periodic basis. Once the quarter ends, three dates are pertinent.

- Two weeks after the quarter ends - All analyses complete
- Four weeks after the quarter ends - Draft document released
- Six weeks after the quarter ends - Final document completed

## D.7.2 Data processing

The data processing strategy for the OLM document is to currently run the safety processor prototype on blocks of snoop files, approximately one week long. Along with the snoop files, information from the Field SP logs is used in conjunction with the `FUNCTION_CNMP_SEED` flag in the prototype to seed the prototype with CNMP monitor levels. The blocks are then run in succession to create a "quarter's" worth of data, which spans the three months of the quarter in question. The blocks of data are usually a week long, but due to data issues, as well as week versus month cutoff issues, the lengths of the individual blocks may vary.

Standard processing is applied across the analyses for the individual days. This includes the creation of histogram files, histogram statistics files, time series files, and two dimensional quantity files. There are associated plots as well for each of the above mentioned plots. In addition to the standard processing, analyses specific to the tool are also run for each day. In this way, analysis-specific data reduction and results are generated on a daily basis.

Once the daily analyses have been run, the results are compiled into a "report" directory. This includes the accumulation of histogram data, and the plotting of statistics across the quarter.

## D.7.3 Tool strategy

Tool builds created at both National Airway Systems (NAS) Engineering (NASE) and Sequoia Research Corporation (SRC) are valid, and need to have proper versioning attached to them. All of the results from a single quarter should come from one version of a tool, and this version should be recorded in the OLM document.

Both regression testing and coding standards checking are as automated as possible, and both have tools associated with them. For the regression testing, the "reg" MatLab tool has been created. This tool is stored in the OLM repository, and runs the regression tests for the MatLab tools in an automated way (from `reg_go.m`). The coding standards are checked via the CODE_STD_CHK tool. There is one standard which checks that all of the scripts are in the top-level directory, followed by the ten integrity standards, followed again by the five OLM coding standards.

As is often the case, tools (old and new) do not comply with the coding standard at the outset. As such, a “refactoring” approach is adopted. By “refactoring”, it is meant that some way to assess the level of non-compliance is required (either by manual review or via automation) before work commences on fixing the issue across the tool set. Once this is assessed, the work commences as is best seen fit by the group, and the standard is enforced for future tools.

The SQM tool is the only tool which does not have all of its scripts in the top level folder. Thus, it is not possible to assess any other issues until that first issue has been worked. For the other tools, the ten integrity standards are all met.

# Appendix E

# Acronyms and abbreviations

**CCC** Code-Carrier Coherence . . . . . 1

**CDF** Cumulative Density Function . . . . . 59

**CMCI** Code Minus Carrier corrected for Iono . . . . . 55

**CNMP** Code-Noise and Multipath . . . . . 1

**CORS** Continuously Operating Reference Station . . . . . 39

**CSRS-PPP** Canadian Spatial Reference System Precise Point Positioning . . . . . 39

**DGPS** Differential Global Positioning System . . . . . 55

**FAA** Federal Aviation Administration . . . . . 2

**GEO** Geosynchronous Earth Orbit . . . . . 1

**GIVEI** Grid Ionospheric Vertical Error Index . . . . . 67

**GIVE** Grid Ionospheric Vertical Error . . . . . 67

**GPS** Global Positioning System . . . . . 39

**GUST** GEO Uplink Subsystem Type 1 . . . . . 55

**HMI** Hazardous Misleading Information . . . . . 1

**IFPR** Ionospheric Free PseudoRange . . . . . 15

**ITRF** International Terrestrial Reference Frame . . . . . 64

**MERR** Maximum Error Range Residual . . . . . 59

**MMAC** Mike Monroney Aeronautical Center . . . . . 1

**NANU** Notice Advisory to NAVSTAR Users . . . . . 56

**NAS** National Airway Systems . . . . . 71

**NASE** NAS Engineering . . . . . 71

**NAVSTAR** NAVigation System with Time And Range . . . . . 56

**NGS** National Geodetic Survey . . . . . 39

**OLM** Offline Monitoring . . . . . 9

**PAGE-NT** The NGS's suite of survey software . . . . . 55

**PCR** Program Change Request . . . . . 65