Wide Area Augmentation System Offline Monitoring Quarterly Report

1 April 2014 - 30 June 2014

Prepared for:

Federal Aviation Administration

Prepared by:

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and
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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 April 1, 2014 and June 30, 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	1 CCC trip
CNMP	No failures after accounting for PRN 10 issue
SQM	All metrics below threshold
Satellite clock run-off	No run-off events
Iono threat model	Days of Interest: 2014-04-11 2014-04-12 2014-05-04 2014-05-08 2014-05-23 2014-06-08
Availability monitoring	
	SVM currently under development
Continuity monitoring	
System monitoring trips	20 L1L2 trips on ZDC and 19 on ZLA and ZTL
Missed messages	CRW (PRN-135) - 5074 CRE (PRN-138) - 23 AMR (PRN-133) - 248
External monitoring	
Antenna positioning	All sites within allowance
Anomaly Investigations	
	CRW SIS outage on 2014-06-03 EIRP faults at HDH and SZP

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-0003-NA-WLNAV-01_wfo_r4b	All dates
HMI Tools	
OLM_TOOLS_330a	All daily data
OLM_TOOLS_331a	All compiled data
Matlab 2010b	All dates
Antenna Positions	
PAGE-NT pnt6k	All dates

Table 2.1: Tool builds used for 2014 Q2 data analysis

Chapter 3

Integrity

3.1 Code-carrier-coherence

3.1.1 CCC statistics and monitor trips

During the second quarter of 2014, one CCC trip occurred. The cause of this trip was bad weather at the Santa Paula GUS site.

Date @ time$_{UTC}$	PRN	value	threshold	ZLA	ZDC	ZTL	Sel. C&V
2014-04-02 @ 05:55:47	133	7.2010	7.1	1	1	1	ZTL

Table 3.1: Reported CCC trips

Statistic	CRW	CRE	AMR	GPS L1$_{agg}$	GPS L2$_{agg}$
mean (m)	0.00	-0.06	0.03	-0.01	-0.01
st dev (m)	0.46	0.41	0.58	0.14	0.14
min (m)	-3.71	-2.38	-7.99	-4.36	-3.15
max (m)	1.71	6.76	3.34	7.99	7.99
abs max (m)	3.71	6.76	7.99	7.99	7.99

Table 3.2: CCC metric statistics (unnormalized)

Statistic	CRW	CRE	AMR	GPS L1$_{agg}$	GPS L2$_{agg}$
mean (m)	0.00	-0.02	0.01	-0.01	-0.01
st dev (m)	0.18	0.16	0.08	0.05	0.05
min (m)	-0.88	-0.95	-1.62	-0.49	-0.52
max (m)	0.69	0.95	0.47	0.54	0.54
abs max (m)	0.88	0.95	1.62	0.54	0.54

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	0.03	0.01	0.01	0.01
min (m)	-0.17	-0.18	-0.14	-0.18	-0.18
max (m)	0.13	0.11	0.04	0.16	0.18
abs max (m)	0.17	0.18	0.14	0.18	0.18

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

3.1.2 Quarterly time-series plot of CCC GEO metric

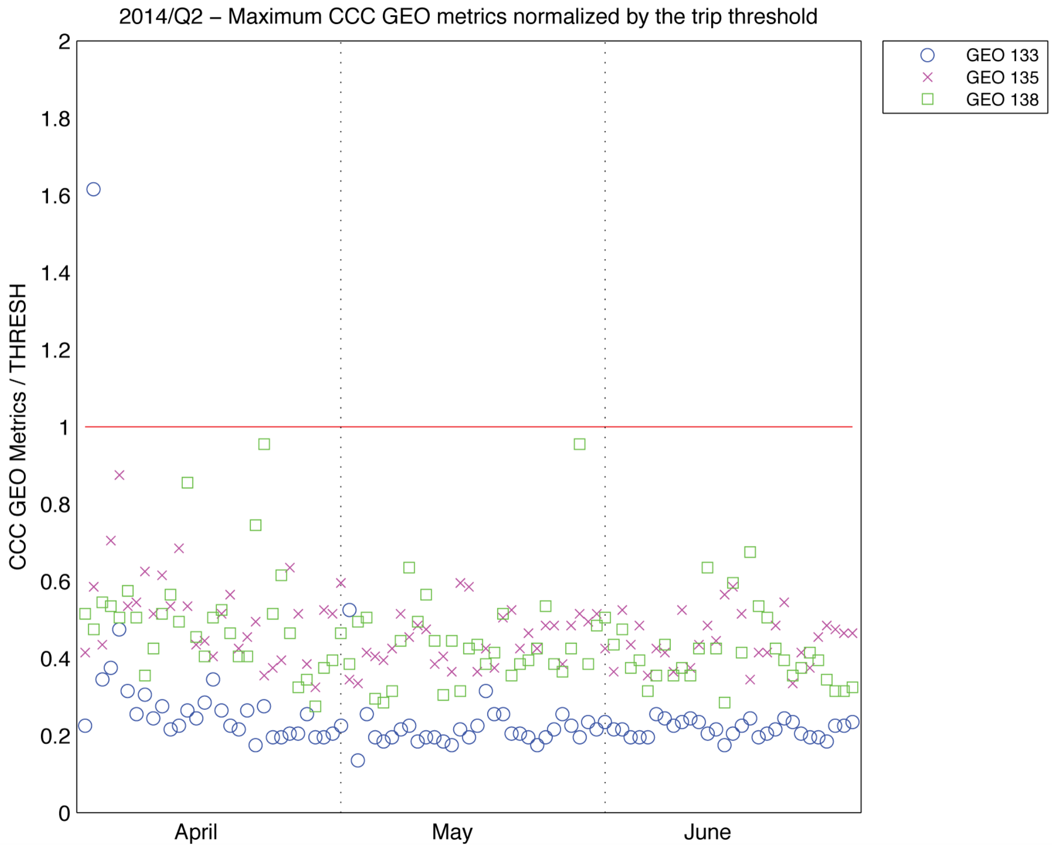

Figure 3.1: Time-series graph of max GEO CCC metric normalized to the trip threshold

3.2 Code-noise and multipath

No failures were found when monitoring the HMI assertion (Appendix C.2) for the second quarter of 2014, after accounting for a glitch on PRN 10. There were 19 slices that failed before removing the bad track. The failure occurred at ZOA-B for PRN 10 at 2014-04-24 22:25:04 GPS time. The pseudorange on PRN-10 jumped around 8 meters on L1 and L2. The details on the PRN glitch are covered in a note by B. J. Potter, Karl Shallberg, and Swen Ericson dated 2014-11-05.

There were 19 failures before removing the PRN 10 glitch. These can be reviewed in Table 3.5. All 19 failures passed when the bad PRN 10 glitch was removed.

Num	**Type**	**Slice**	**Value**
01	IFPR	El 1	1.0644
02	IFPR	El 2	1.0306
03	IFPR	TT4	1.0245
04	IFPR	ZOA B	1.2244
05	IFPR	PRN10	1.1415
06	RDL1	Agg	1.0142
07	RDL1	El 1	1.0644
08	RDL1	El 2	1.0596
09	RDL1	El 3	1.0617
10	RDL1	TT4	1.0548
11	RDL1	ZOA B	1.2762
12	RDL1	PRN10	1.1835
13	RDL2	Agg	1.0148
14	RDL2	El 1	1.0644
15	RDL2	El 2	1.0596
16	RDL2	El 3	1.0617
17	RDL2	TT4	1.0555
18	RDL2	ZOA B	1.2774
19	RDL2	PRN10	1.1844

Table 3.5: Failures caused by PRN-10 glitch

Aggregate plots with the glitch included are shown here. For Figures 3.2, 3.3, and 3.4, 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 3.5, if the values go above the marked threshold of 1, that event is a failure. Figures 3.6 and 3.7 are with the PRN 10 glitch removed. They show drastic improvement and no failures.

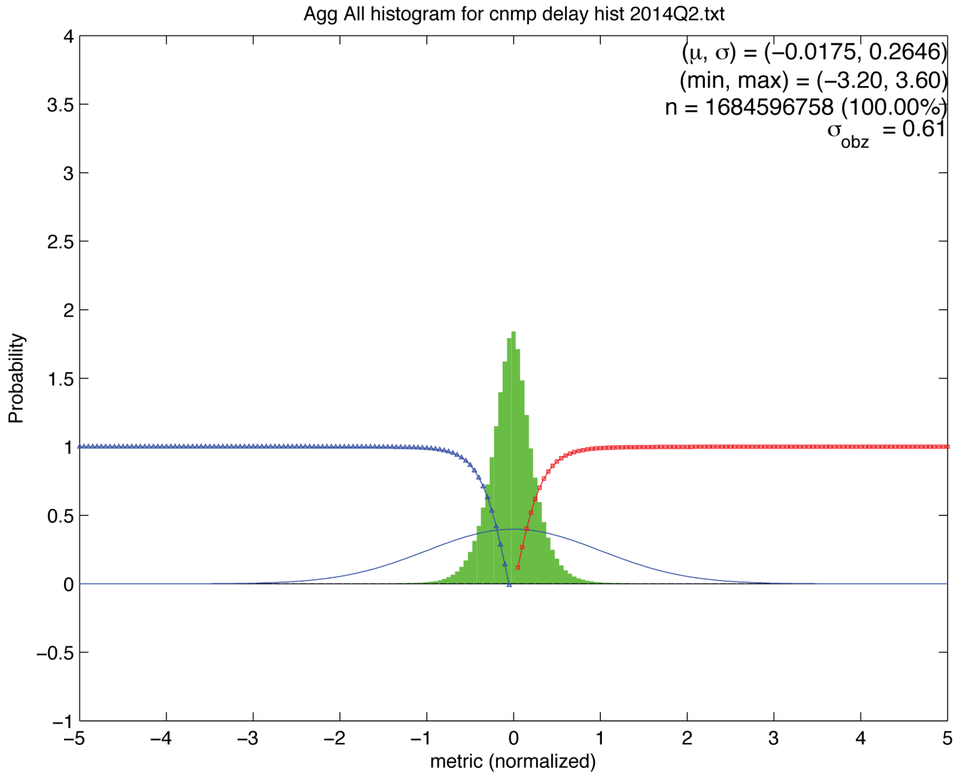

Figure 3.2: Aggregate CNMP delay with glitch

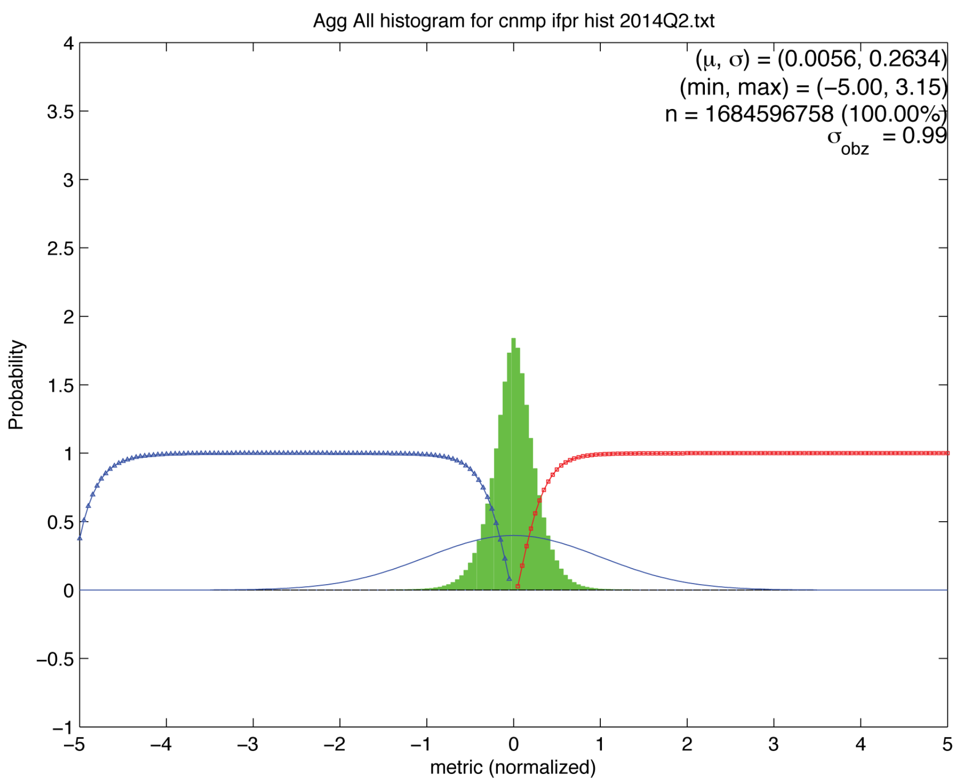

Figure 3.3: Aggregate CNMP IFPR with glitch

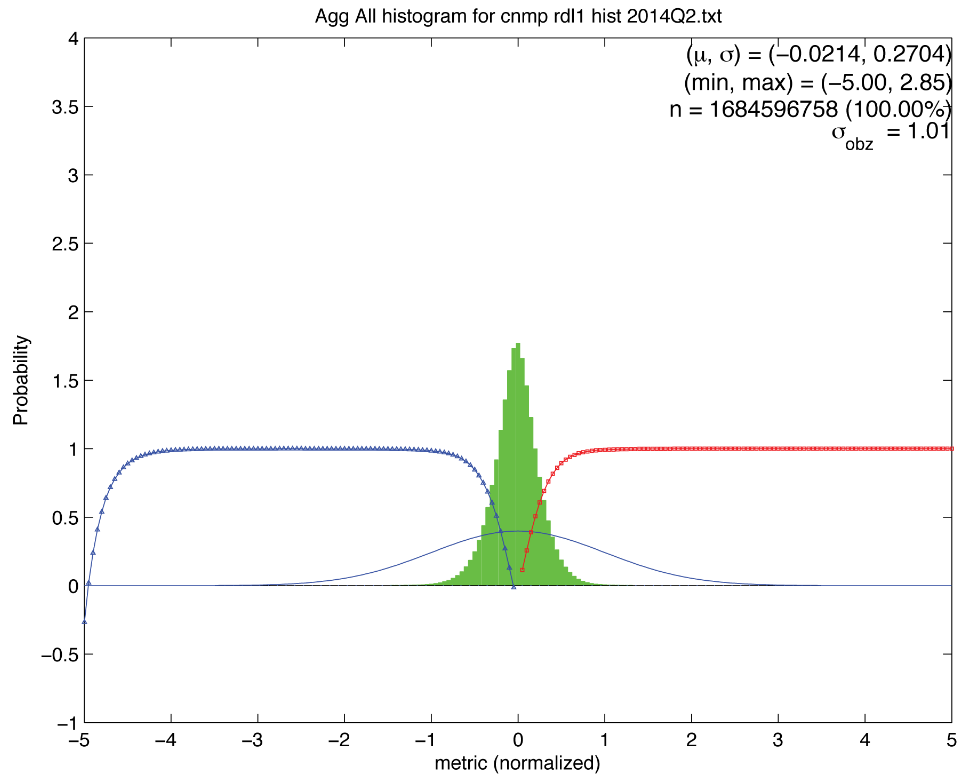

Figure 3.4: Aggregate CNMP RDL1 with glitch

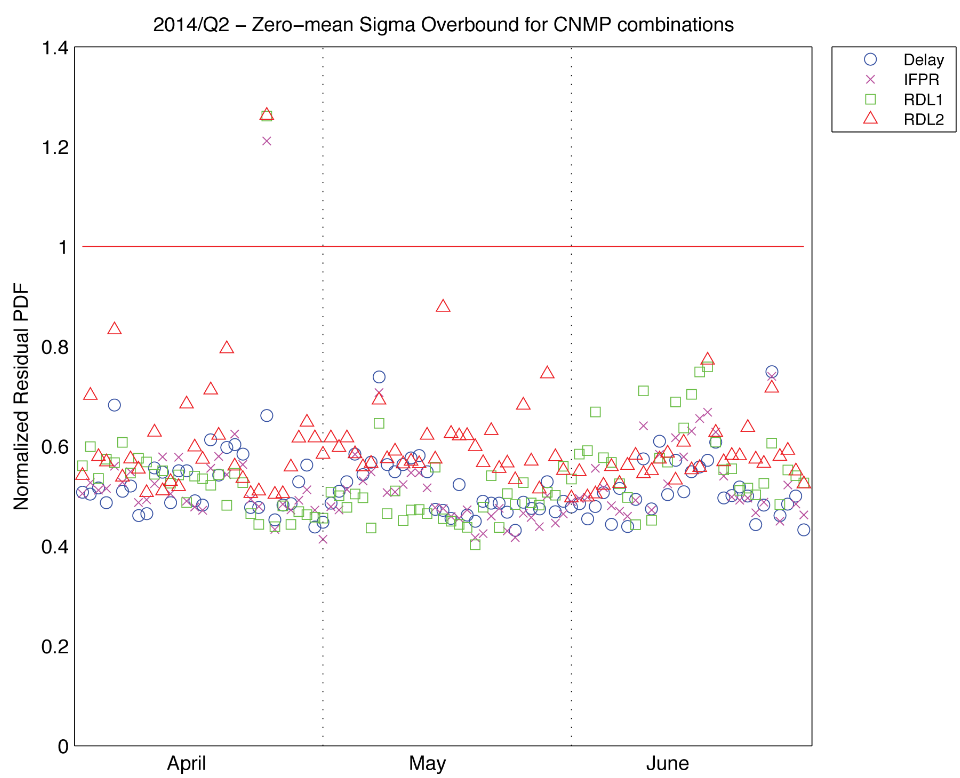

Figure 3.5: Daily GPS CNMP aggregate zero-centered sigma overbound values with glitch

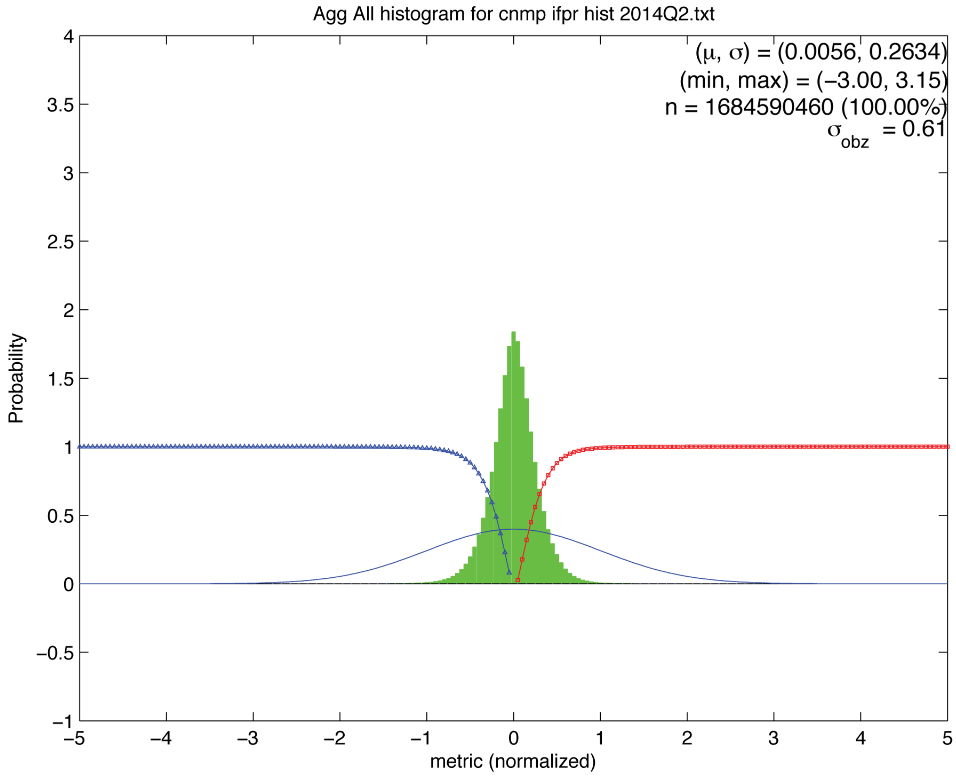

Figure 3.6: Aggregate CNMP IFPR glitch removed

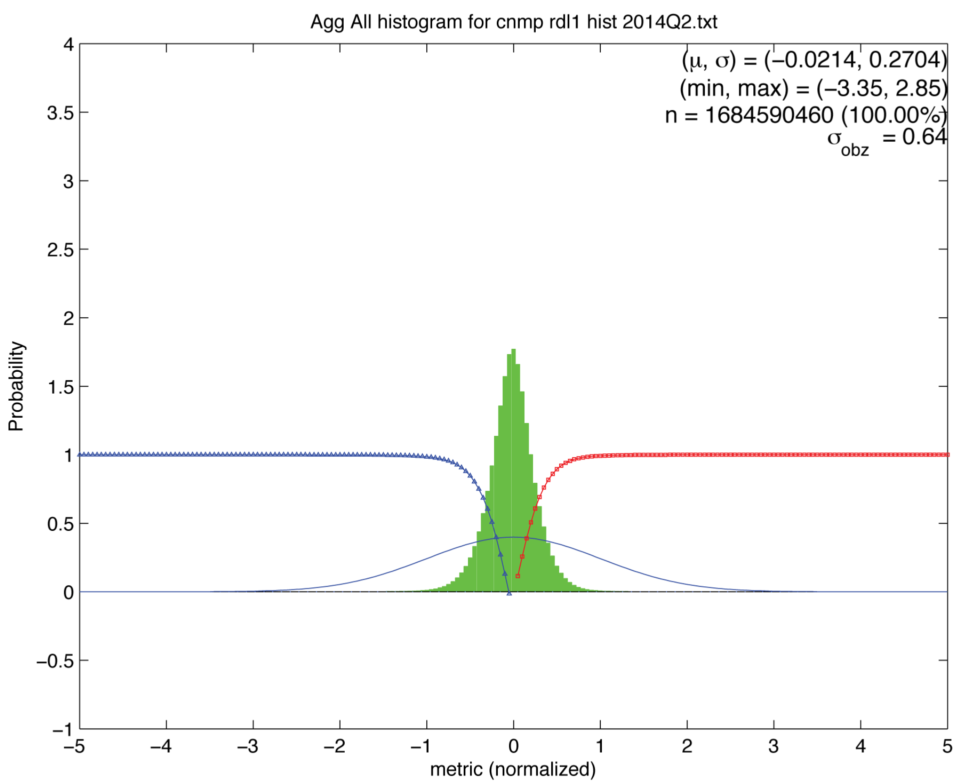

Figure 3.7: Aggregate CNMP RDL1 glitch removed

3.2.1 Analysis of poor performing sites

Table 3.6 contains information on the worst performing sites of the quarter. Table 3.6 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 Wide-area Reference Equipment (WRE) for Ionospheric Free Pseudo-Range (IFPR) CNMP, delay CNMP, Range Domain for the L1 frequency (RDL1) CNMP and Range Domain for the L2 frequency (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 3.6.

Station		**RDL1**				**IFPR**				**Delay**			
#	Name	μ	σ	$\lvert max\rvert$	sigobz	μ	σ	$\lvert max\rvert$	sigobz	μ	σ	$\lvert max\rvert$	sigobz
30	ZHU C	0.05	0.441	3.35	0.794	0.08	0.421	3.15	0.751	-0.09	0.410	3.20	0.761
29	ZHU B	-0.04	0.427	2.90	0.660	0.03	0.448	2.85	0.694	-0.06	0.455	2.95	0.727
108	MTP C	0.00	0.346	2.60	0.574	0.06	0.313	2.10	0.492	-0.09	0.307	2.45	0.554
38	ZKC B	-0.03	0.367	2.50	0.574	0.04	0.351	2.95	0.632	-0.06	0.345	2.85	0.610
28	ZHU A	-0.06	0.370	2.40	0.568	-0.05	0.369	3.05	0.705	0.04	0.378	3.05	0.701
63	ZOB C	-0.03	0.287	1.80	0.435	0.06	0.294	1.80	0.421	-0.09	0.313	1.90	0.434
23	ZFW B	-0.04	0.339	2.05	0.486	0.04	0.341	2.10	0.520	-0.07	0.345	2.05	0.505
61	ZOB A	-0.09	0.323	2.30	0.486	-0.04	0.331	2.15	0.479	0.01	0.351	2.20	0.508
21	ZDV C	-0.06	0.343	2.10	0.520	-0.01	0.333	1.95	0.430	-0.01	0.340	1.85	0.484
105	MSD C	0.01	0.334	1.85	0.413	0.06	0.318	1.95	0.390	-0.08	0.307	2.45	0.469

Table 3.6: Poor performing WREs for CNMP

3.3 Signal quality monitoring

All four metrics for GEO satellites fall below the threshold for 2014 Q2. There were no SQM trips for the quarter.

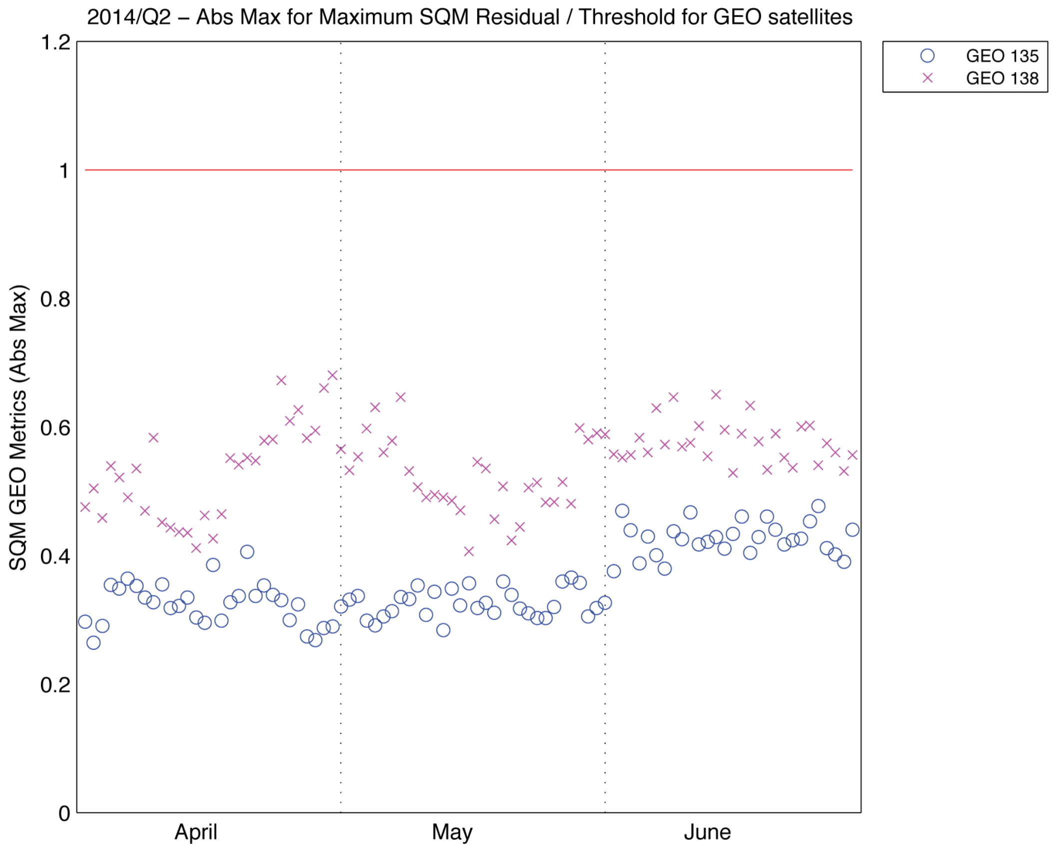

Figure 3.8: Time-series graph of GEO SQM max metrics 1-4

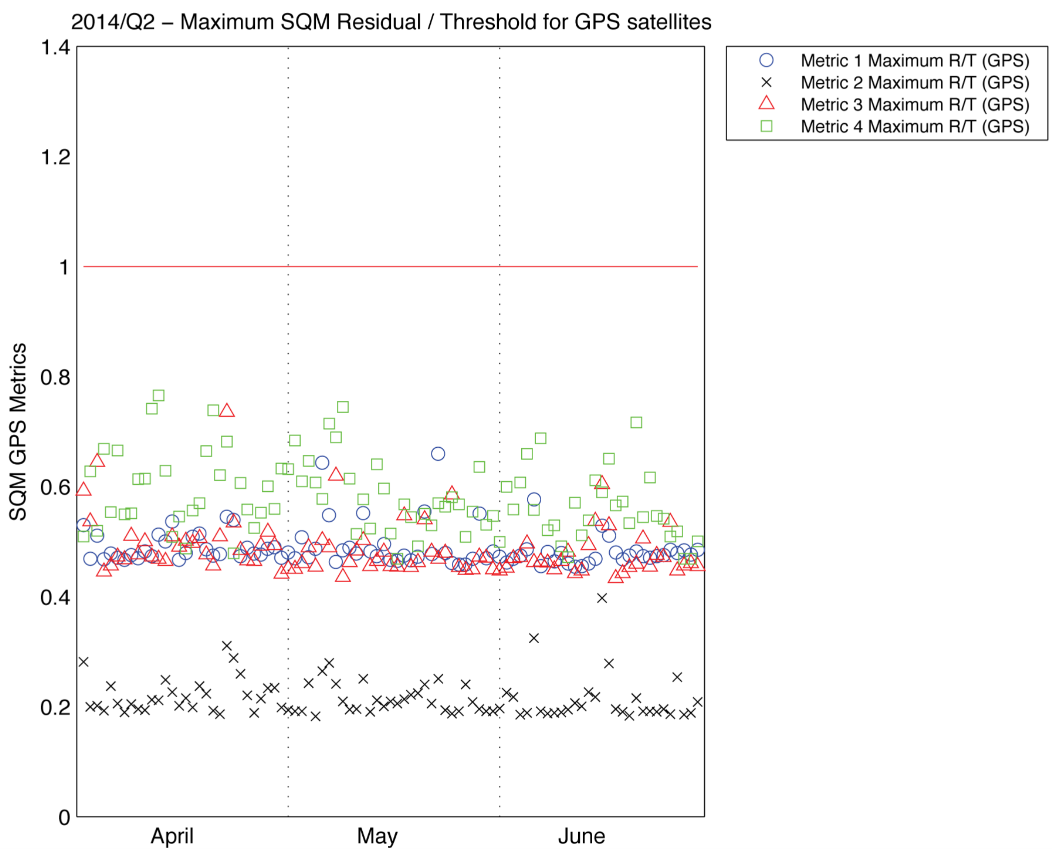

Figure 3.9: Time-series graph of GPS SQM max metrics 1-4

3.4 Iono threat model

There are three criteria that allow a particular day to be identified as an iono day of interest. If any of these criteria are met, the day is considered an iono day of interest:

1. **Any day where the Chi^2 "percentage statistic" is over the threshold for a region.** The "percentage statistic" is the percentage of the day that the normalized chi^2 statistic at IGPs within a given region exceed a threshold of 1.0 (not the system threshold of 2.5 or 3.0). The thresholds for use in determining days of interest from a particular region were computed based on a 1% level in the CDF of the data distributions, i.e., the thresholds were set so that only 1% of the days (again, for each region) had percentages over the threshold.

2. **Any day where there is a significant coverage drop for the Alaska or CONUS regions in combination with a Max K_p value of ≥ 4**

3. **Any day that has a Max K_p value of ≥ 7**

Figure 3.10 shows the iono days of interest for each criteria for Q2 2014.

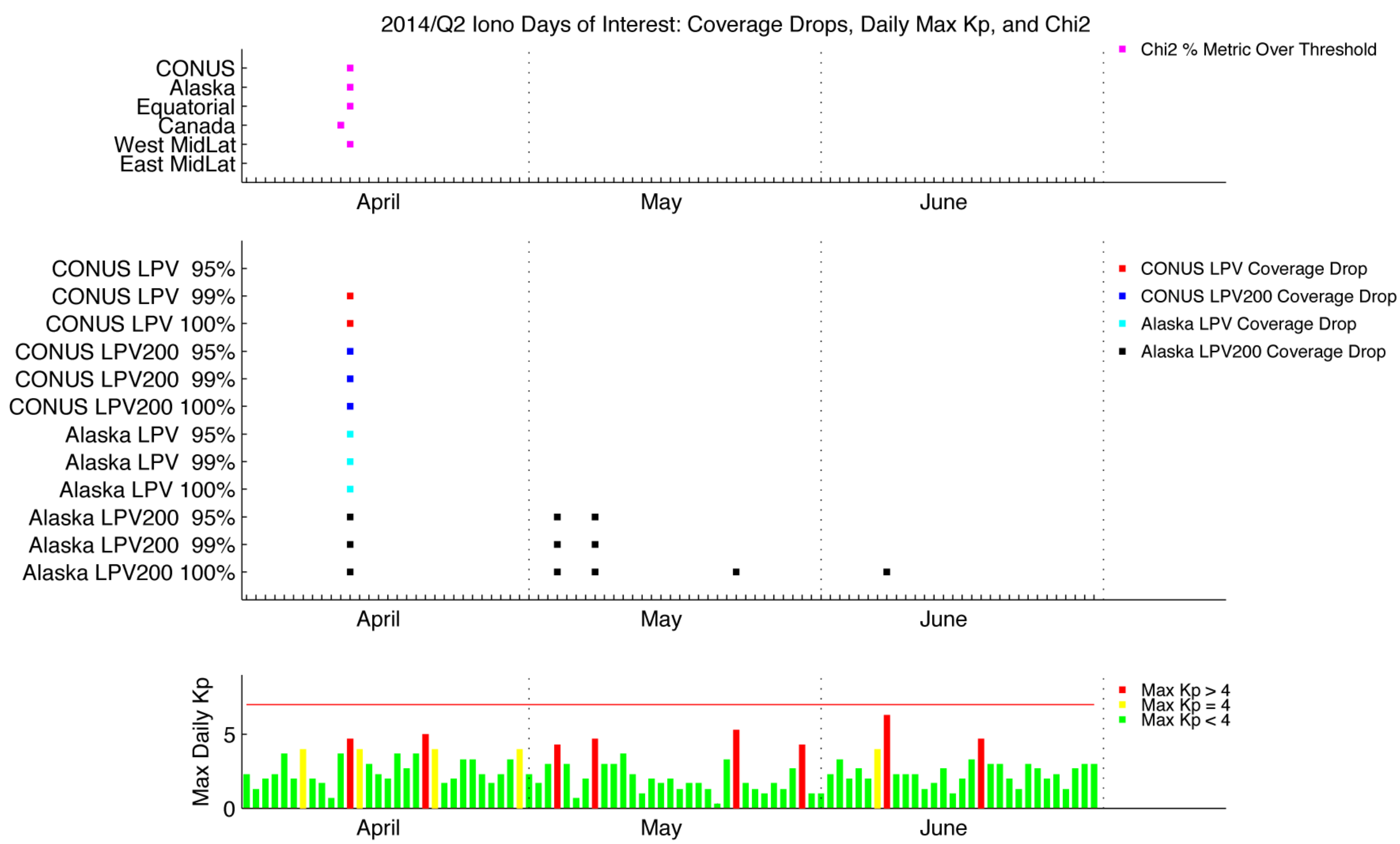

Figure 3.10: Iono days of interest

3.4.1 Chi^2

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 49 shows a map of the regions used for threat model analysis.

3.4.1.1 Daily percentage of Chi^2 values > 1

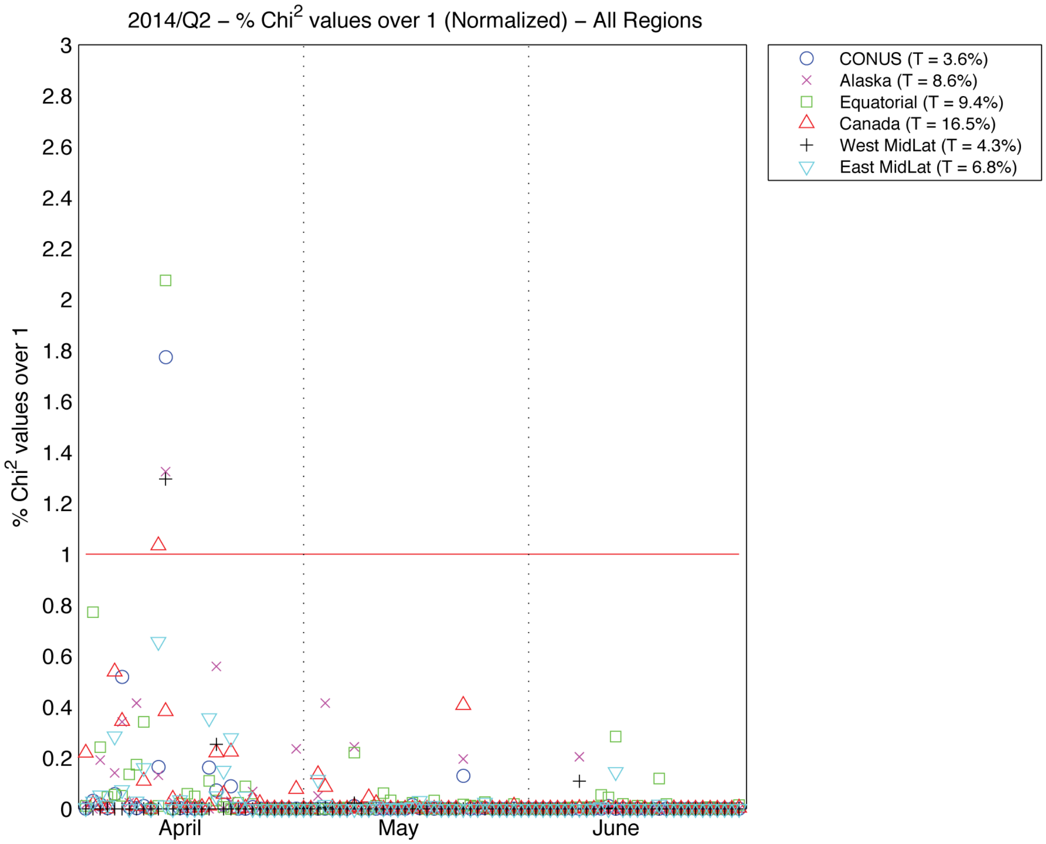

Figure 3.11: All regions daily % Chi^2 values >1 taken from ZDC

3.4.1.2 Chi^2 days of interest

Table 3.7 lists the days of interest from chi^2.

Region	**CONUS**	**Alaska**	**Equatorial**	**Canada**	**West MidLat**	**East MidLat**
Threshold (%)	3.6	8.6	9.4	16.5	4.3	6.8
2014-04-11				17.06		
2014-04-12	6.3802	11.381	19.499		5.5675	

Table 3.7: Days when the % of Chi^2 > 1 exceed the threshold value

3.4.1.3 Coverage drop days of interest

Table 3.8 on page 24 lists the days of interest from coverage drops.

3.4.2 Space weather monitoring

3.4.2.1 Planetary A-K indices

The highest K_p value of 6.3 was measured on June 8^{th}.

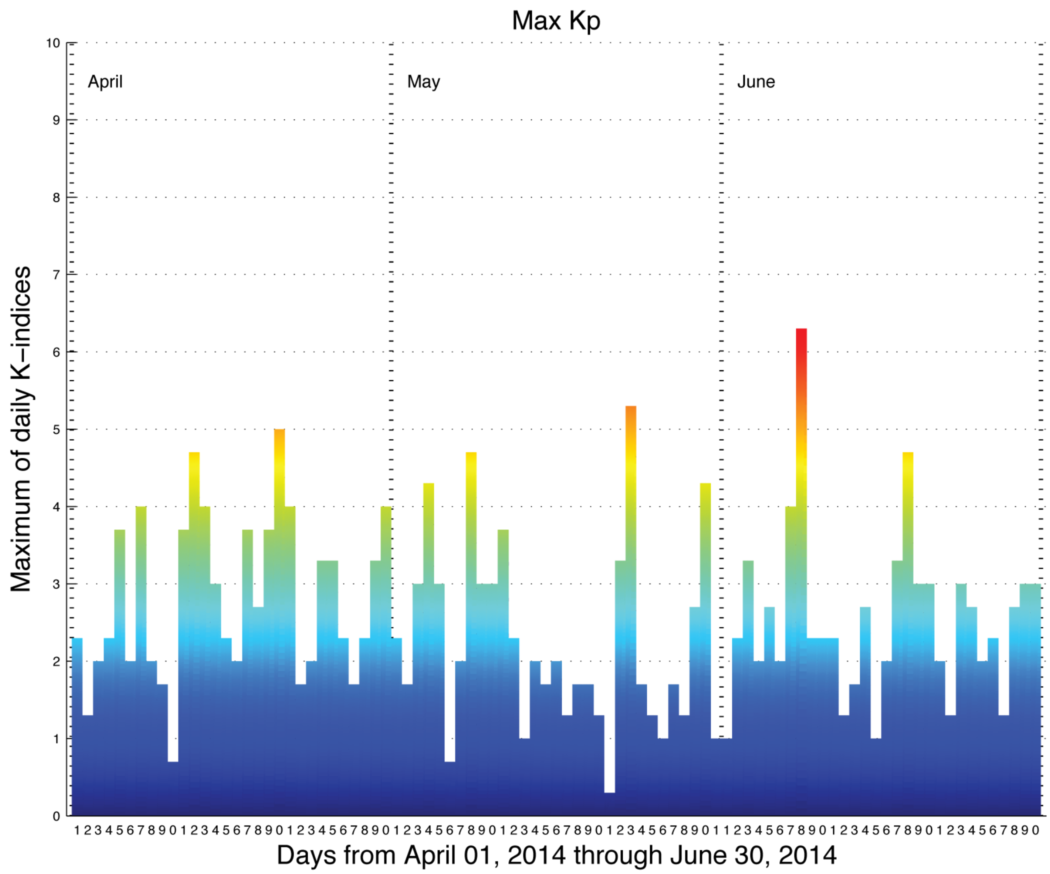

Figure 3.12: Planetary K_p values

	CONUS						Alaska						
	LPV			LPV200			LPV			LPV200			Max K_p
Threshold	**95%**	**99%**	**100%**	**95%**	**99%**	**100%**	**95%**	**99%**	**100%**	**95%**	**99%**	**100%**	
	6.0877	6.9762	7.6964	6.519	8.1276	10.351	7.5799	13.4297	15.8086	9.0748	18.1353	20.3815	
2014-04-12		20.3271	23.1308	11.4486	30.1402	38.5514	23.5955	78.0899	94.9438	73.0337	85.9551	70.7865	4.7
2014-05-04										12.3595	28.6517	43.8202	4.3
2014-05-08										14.6067	47.191	46.0674	4.7
2014-05-23												24.1573	5.3
2014-06-08												22.4719	6.3

Table 3.8: Days of interest for coverage drop with daily max $K_p \geq 4$

Chapter 4

Continuity monitoring

4.1 System monitoring trips

Component	ZDC	ZLA	ZTL
BMV	0	0	0
CCC	1	1	1
L1L2	20	19	19
$RDM_{threshold}$	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
WRE_{bias}	2	2	2

Table 4.1: System monitoring trips

4.2 WRE thread switches

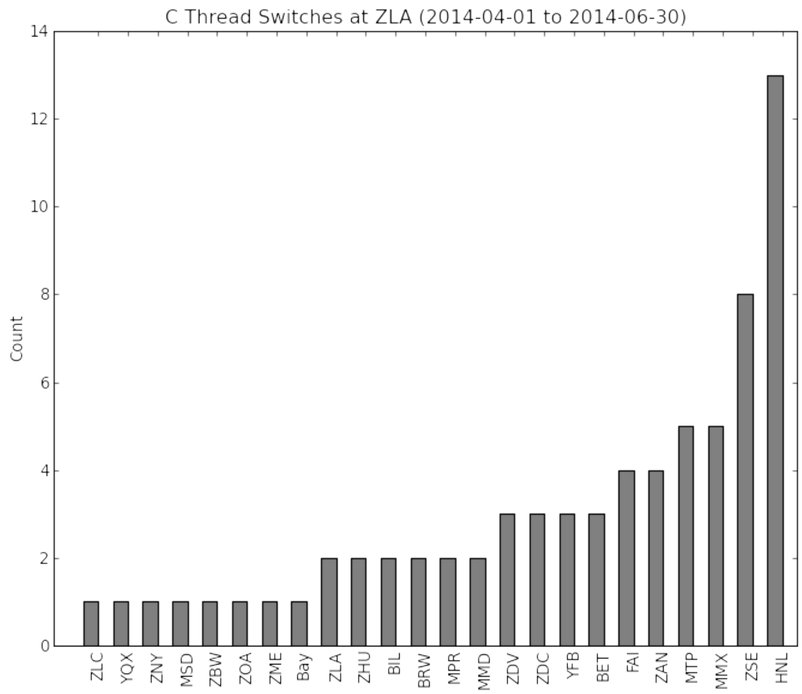

Figure 4.1: Count of all days with switches

4.3 List of missed messages

The missed messages for the second quarter of 2014 are displayed in the histogram 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) - 5074
- CRE (PRN-138) - 23
- AMR (PRN-133) - 248

4.3.1 CRW (PRN-135) Events

- 2014-06-03 (5056 missed messages) - Problems occurred with the LTN GUS antenna/dummy load waveguide switch connections (due to human error during the previous maintenance period at LTN on the 21st of May). APC was in maintenance during this period which prohibited a switchover.
- 2014-06-18 (14 missed messages) - LTN experienced an interruption in power which impacted power to the drives on the antenna. The antenna remained pointed at the satellite during the power hit thereby minimizing signal degradation.
- 2014-06-18 (4 missed messages) - APC faulted due to a receiver SCAF.

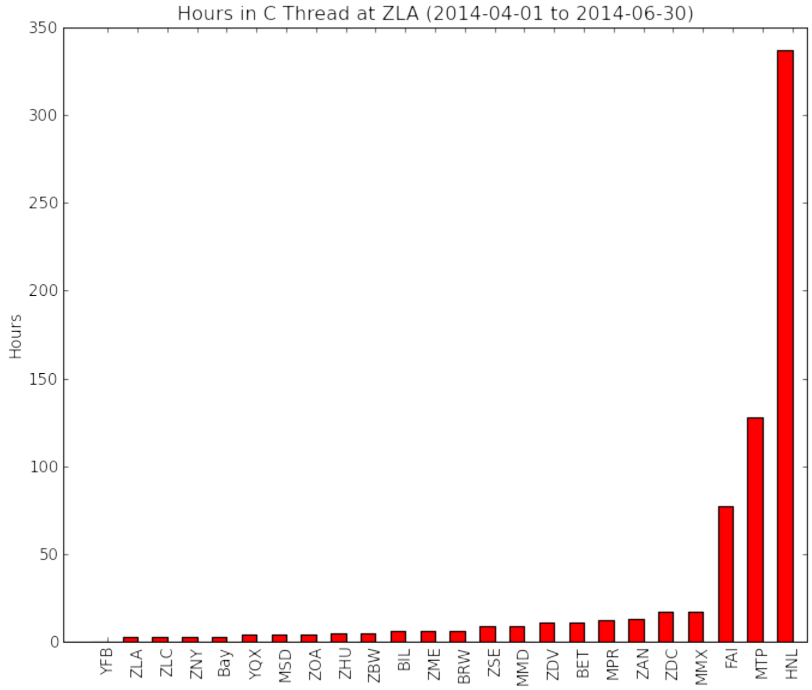

Figure 4.2: Time on C thread

4.3.2 CRE (PRN-138) Events

- 2014-04-17 (14 missed messages) - Switchover, BRE to primary for scheduled maintenance at WBN on 4/21.
- 2014-04-24 (1 missed message) - Missed message caused by C1 KPA at BRE. The missed message coincides with a high voltage arc alarm on the C1 KPA.
- 2014-05-08 (4 missed messages) - GUS switchover, WBN to primary.
- 2014-05-29 (4 missed messages) - GUS switchover, BRE to primary for scheduled maintenance at WBN.

4.3.3 AMR (PRN-133) Events

- 2014-04-02 (14 missed messages) - SZP faulted from primary due to a loss of lock on L1 and L5. Rain at the time of the fault, causing water intrusion in the L-band feed was suspected as the cause of the loss of lock.
- 2014-04-11 (4 missed messages) - Switchover, SZP to primary.
- 2014-05-01 (7 missed messages) - GUS switchover, HDH to primary for KPA replacement at SZP.
- 2014-05-02 (216 missed messages) - Missed messages caused by carrier phase jumps on the C1 transmit path at HDH.

- 2014-05-03 (1 missed message) - Missed message caused by carrier phase jumps on the C1 transmit path at HDH.
- 2014-05-03 (6 missed messages) - Missed messages caused by carrier phase jumps on the C1 transmit path at HDH.

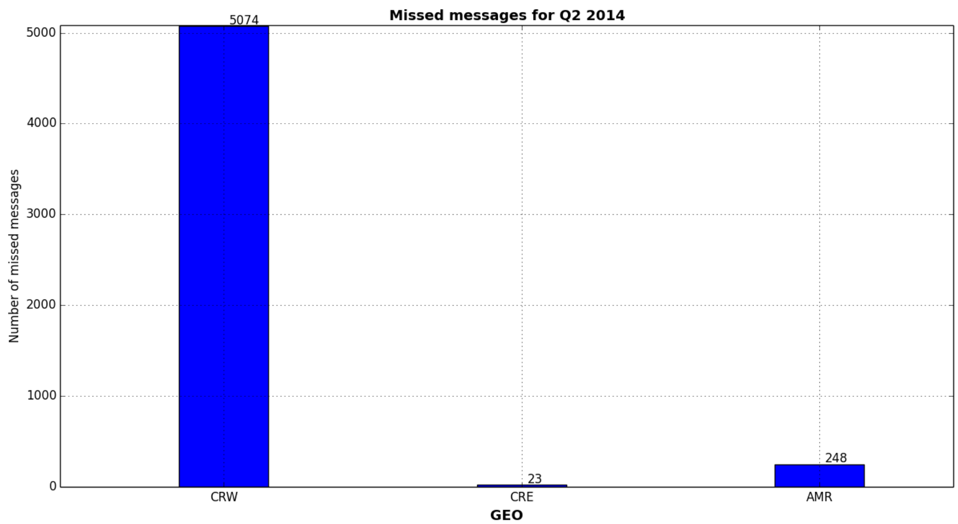

Figure 4.3: Missed messages

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 second quarter of 2014.

Chapter 5

Accuracy monitoring

For additional information on WAAS accuracy, see the WAAS PAN Report for 2014Q2:
`http://www.nstb.tc.faa.gov/REPORTS/waaspan49.pdf`

Chapter 6

External monitoring

6.1 Antenna phase center positions

Data from 2014-06-02 was used in this survey, and the positions were projected out to 2014-09-11. The results were compared against Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) and the following sites were off by more than 3 cm: ZJX2 by 3.66 cm for the Y measurement and ZJX3 by 3.08 cm for the Y measurement. A secondary cross check projected both R40 coordinates and the 2014-06-02 survey results to 2014-09-11 and showed that all sites were off by less than 1 cm. MMX is expected to approach an offset of zero cm upon reaching the R40 projection date of 2015-04-01. Therefore, at the projected date of 2014-09-11, MMX will be off by 14.5 cm. The R40 coordinates were released to the last C&V on 2014-08-04.

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 orbits and broadcast ephemeris. Table 6.1 contains the Global Positioning System (GPS) PseudoRandom Noise (PRN) numbers for outliers.

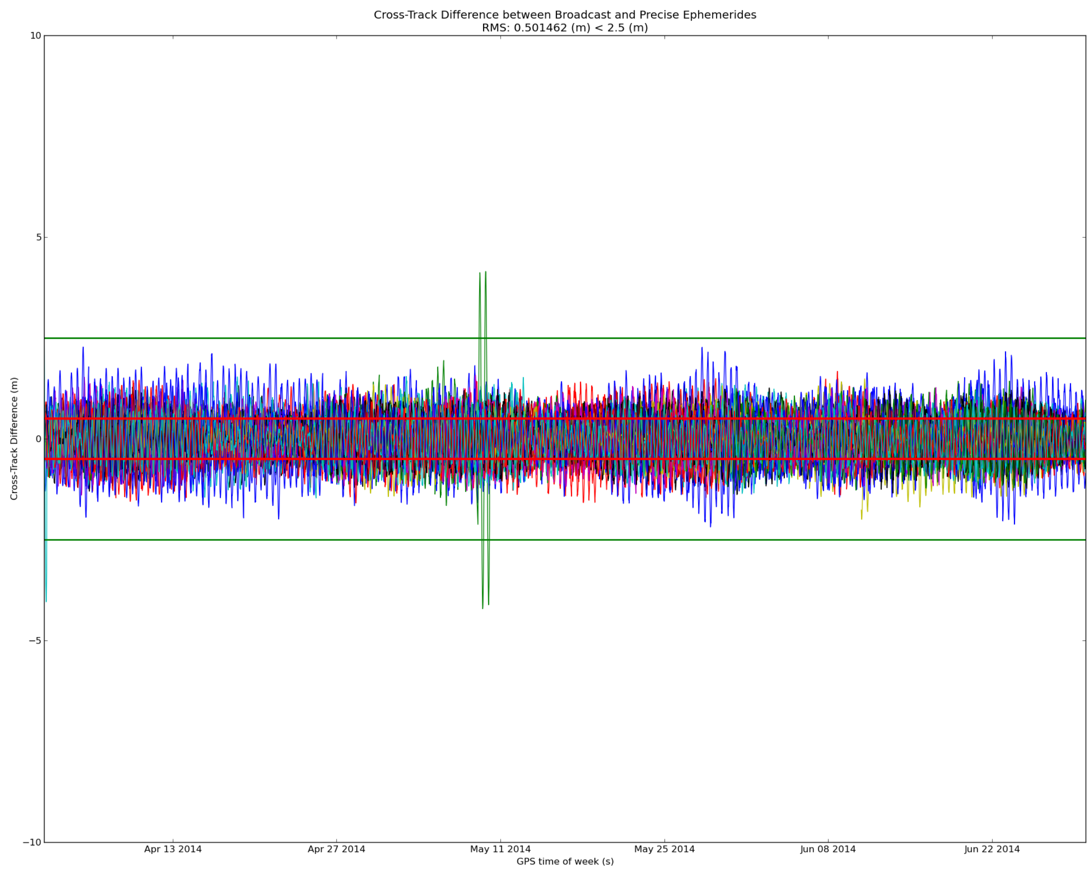

Figure 6.1: Cross-track ephemeris deltas between NGS precise orbits and broadcast ephemeris

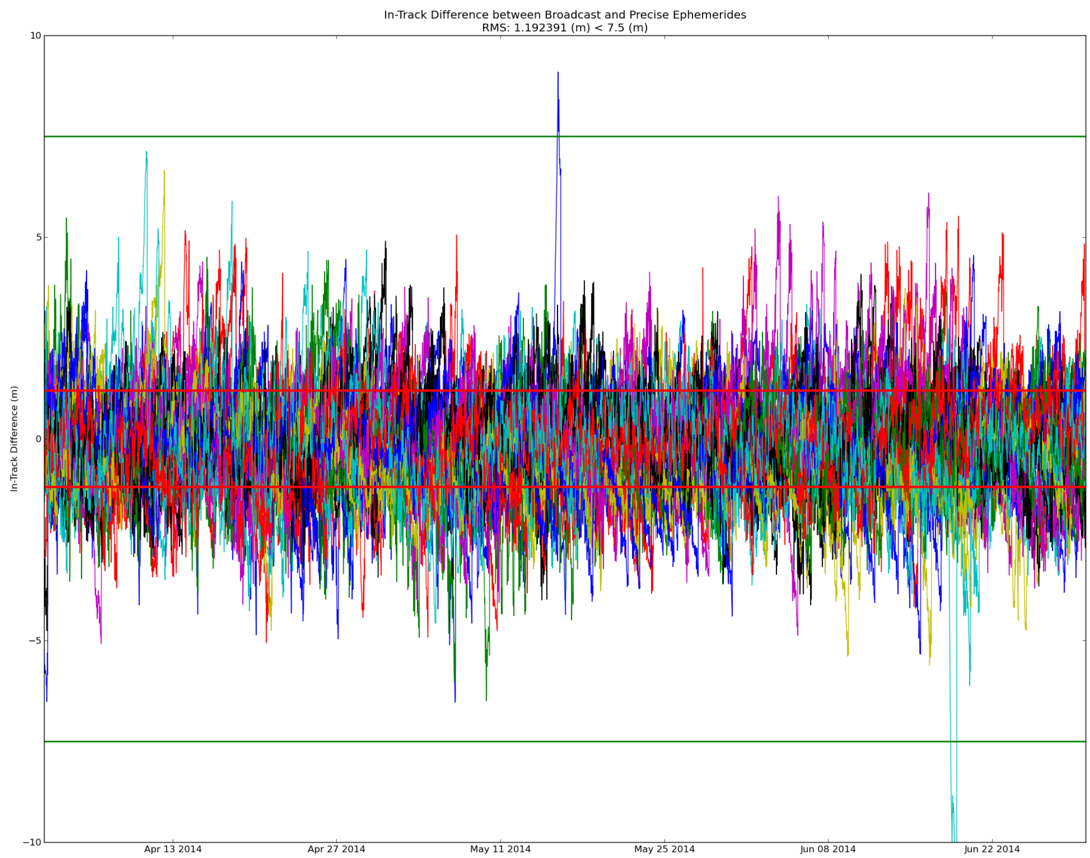

Figure 6.2: In-track ephemeris deltas between NGS precise orbits and broadcast ephemeris

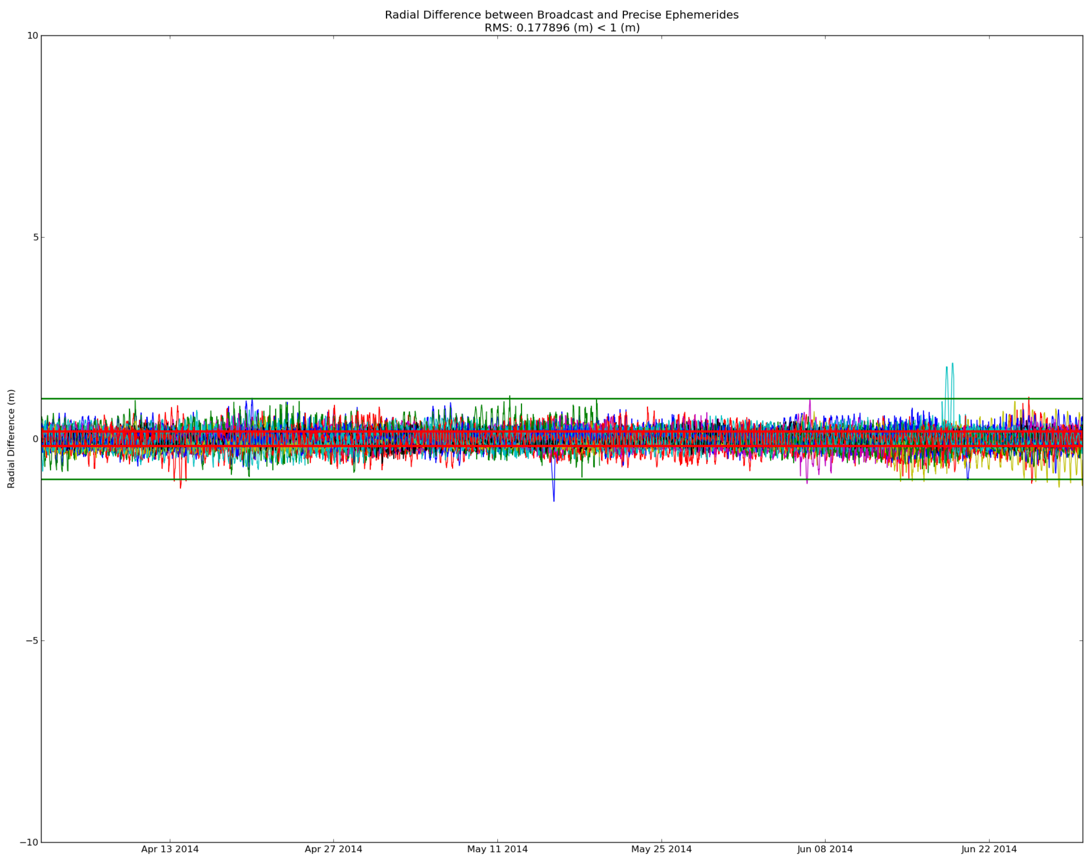

Figure 6.3: Radial ephemeris deltas between NGS precise orbits and broadcast ephemeris

GPS PRN	Radial	In-Track	Cross-Track
1	6	0	0
2	0	0	0
3	9	0	0
4	0	0	0
5	0	0	0
6	33	0	0
7	0	0	0
8	7	15	0
9	2	0	0
10	18	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	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	56
24	0	0	0
25	43	50	0
26	8	0	0
27	0	0	0
28	0	0	0
29	0	0	0
30	0	0	0
31	0	0	0
32	0	0	14

Table 6.1: 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 most of the analysis
  - ~2-week OKC data down time in April covered using backup GUS site data
  - Gaps in data appear on switchover / maintenance days
  - No iono ramp correction needed in CCC data
    - Iono ramps not steep enough to cause long-term CCC metrics to exceed thresholds
    - In cases where iono ramps are too steep, 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

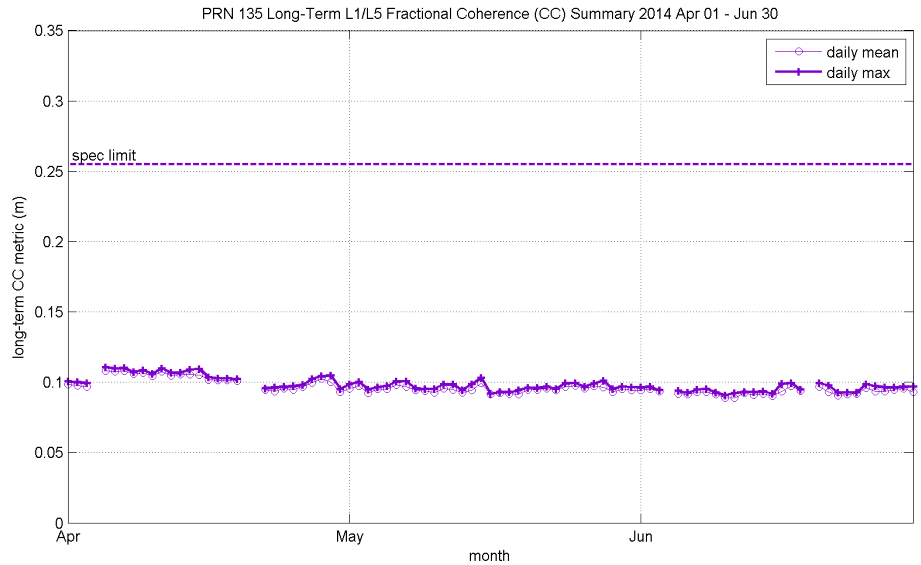

Figure 7.1: Long-term fractional coherence (CC) for PRN 135

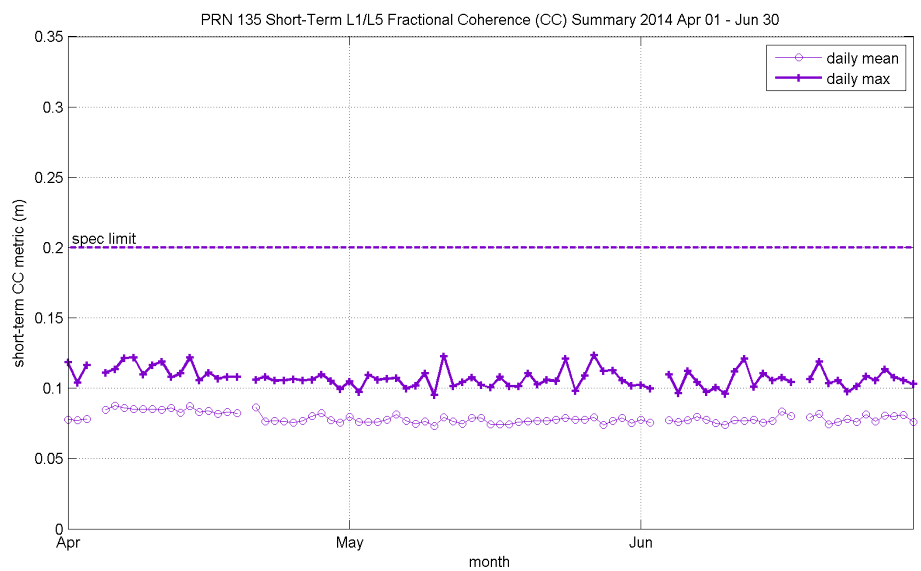

Figure 7.2: Short-term fractional coherence (CC) for PRN 135

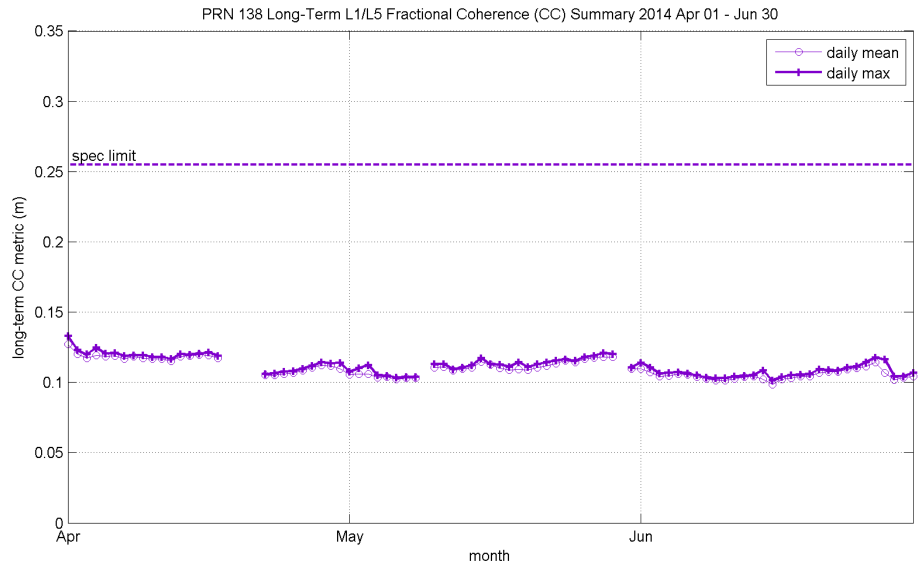

Figure 7.3: Long-term fractional coherence (CC) for PRN 138

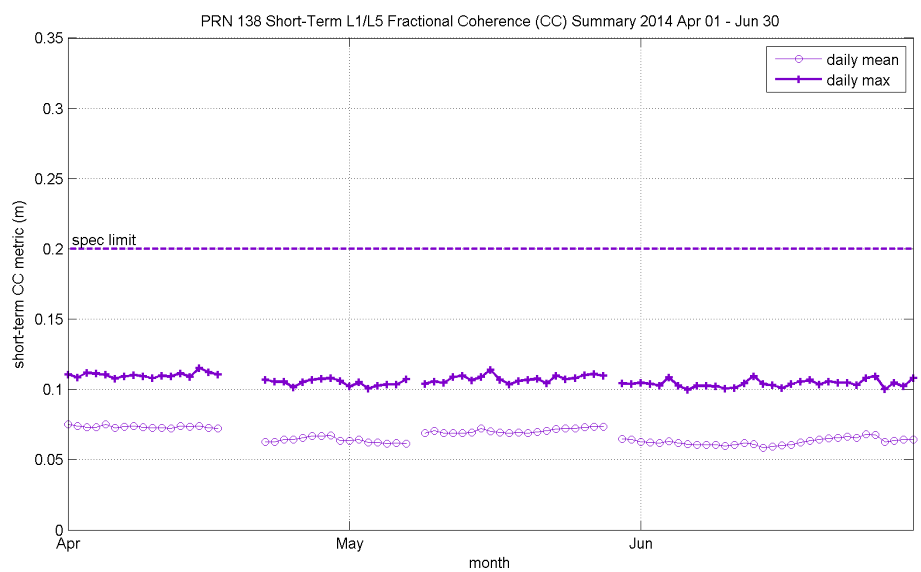

Figure 7.4: Short-term fractional coherence (CC) for PRN 138

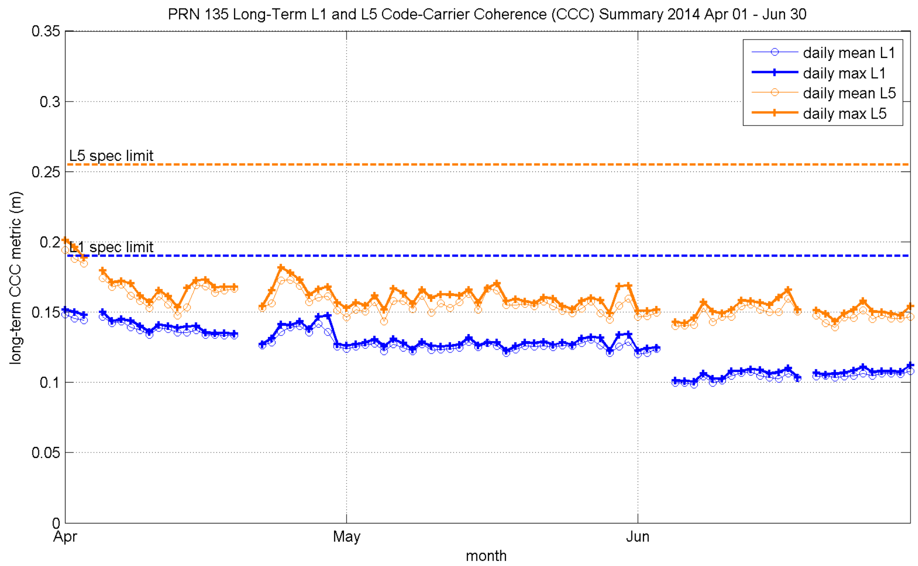

Figure 7.5: Long-term code-carrier coherence (CCC) for PRN 135

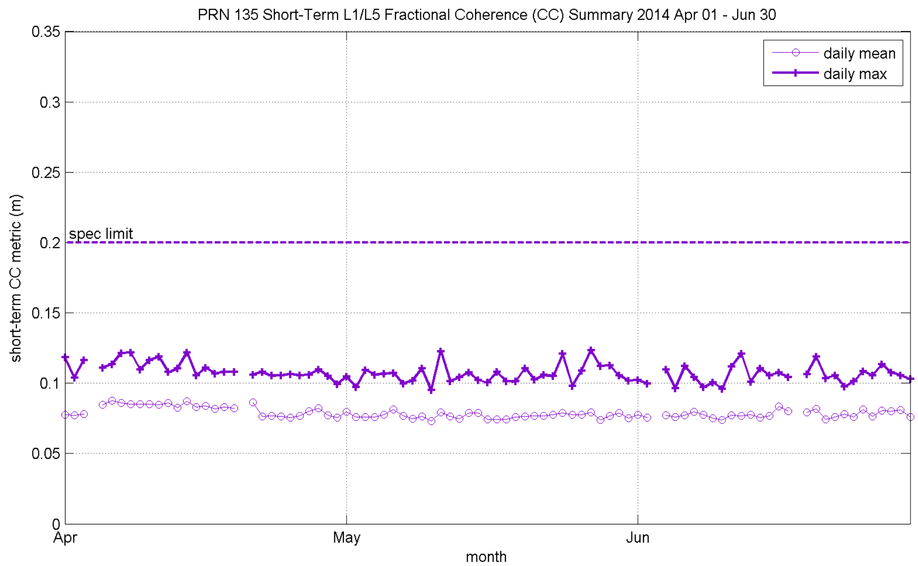

Figure 7.6: Short-term fractional coherence (CC) for PRN 135

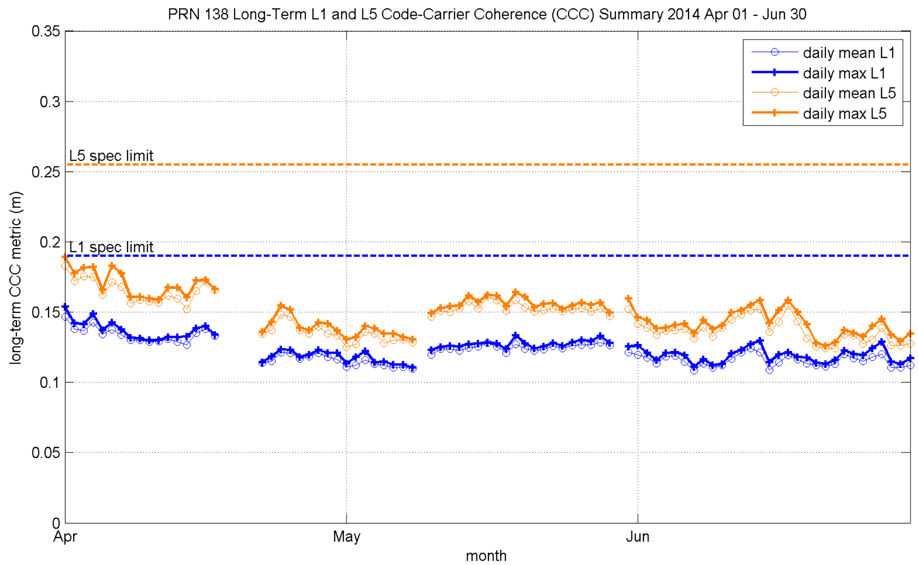

Figure 7.7: Long-term code-carrier coherence (CCC) for PRN 138

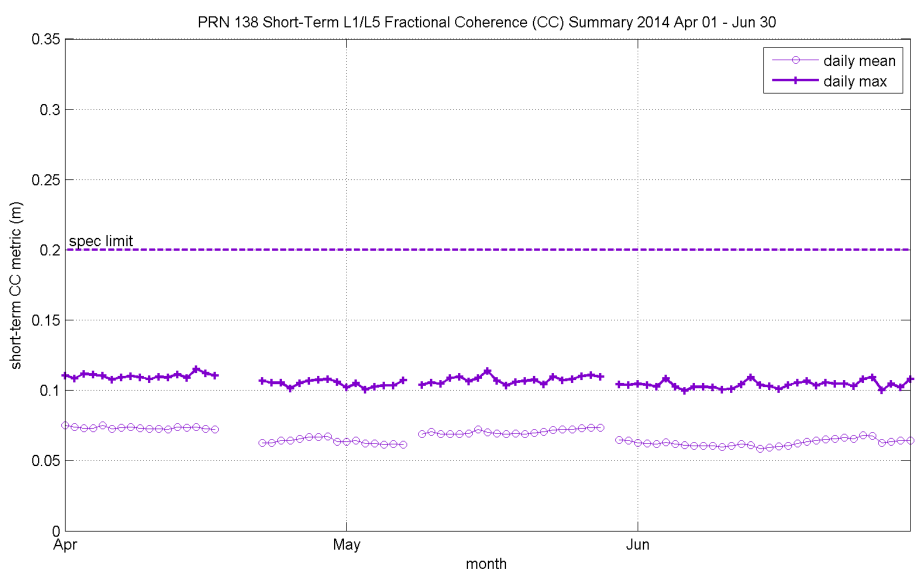

Figure 7.8: Short-term fractional coherence (CC) for PRN 138

Chapter 8

L1L2 bias levels

8.1 Satellites from CP1

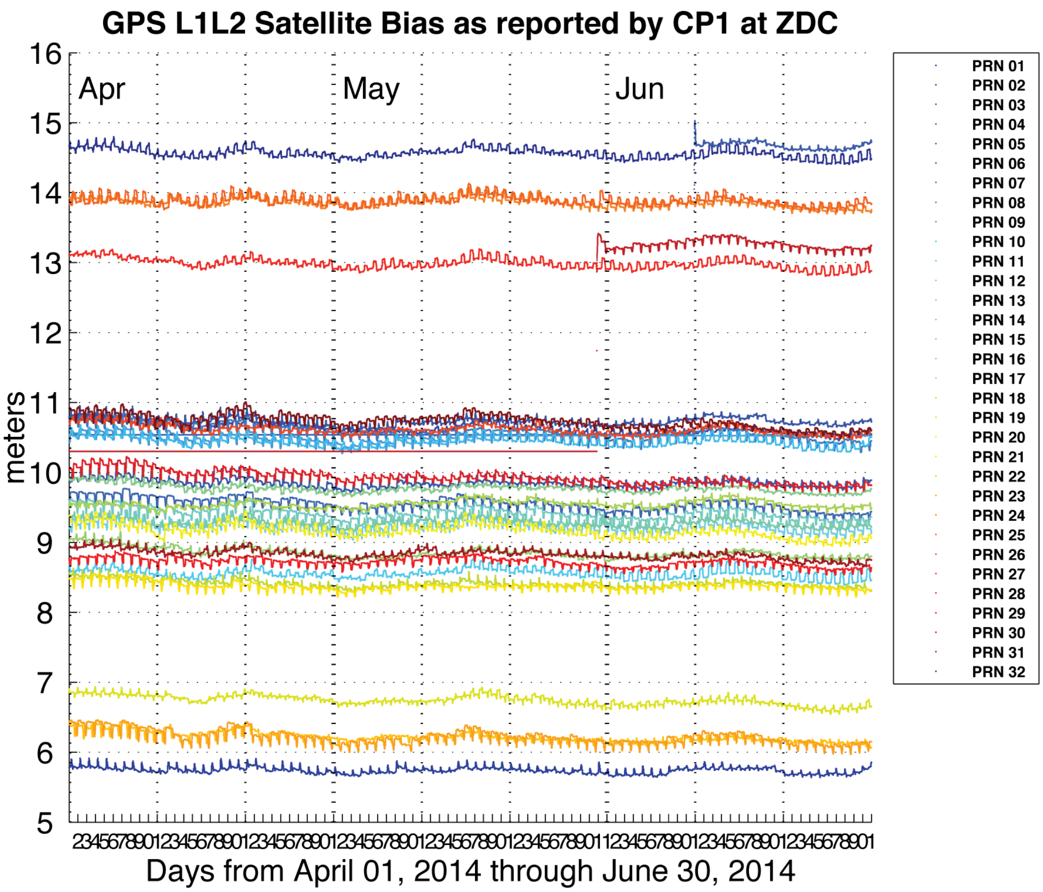

Figure 8.1: L1L2 bias for all PRNs from CP1

8.2 Satellites from CP2

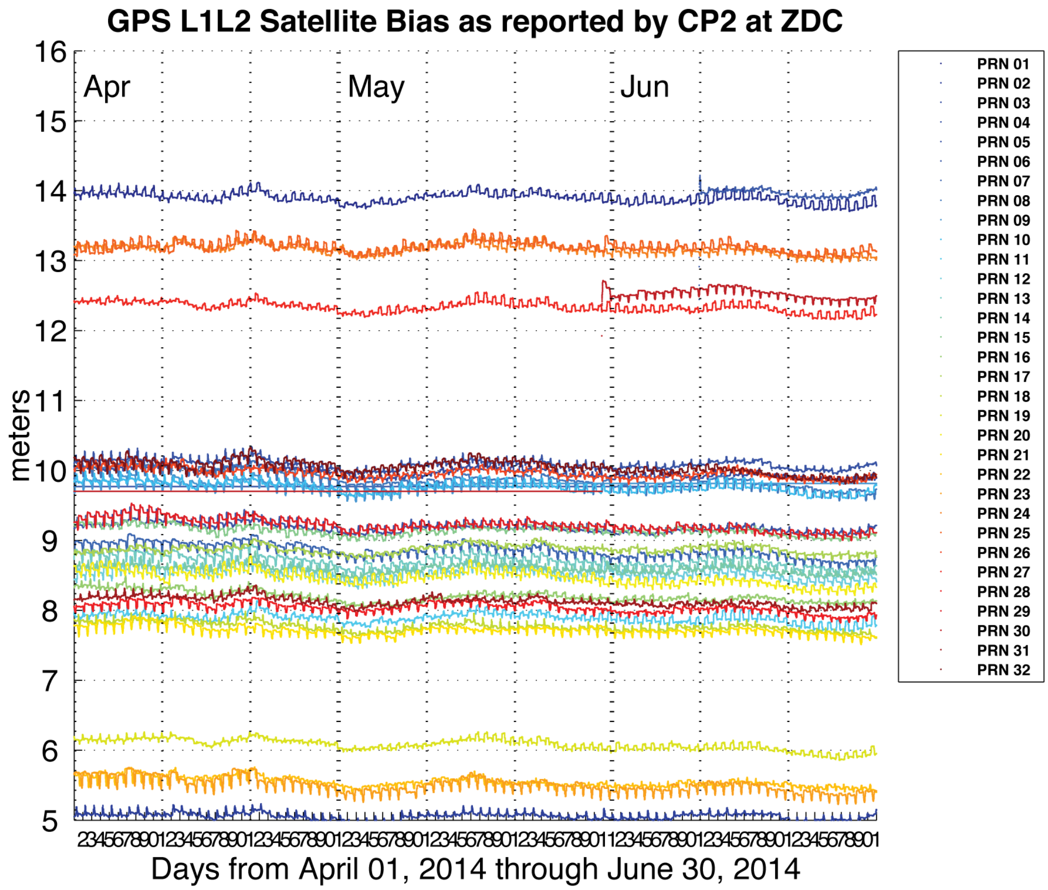

Figure 8.2: L1L2 bias for all PRNs from CP2

8.3 WREs from CP1

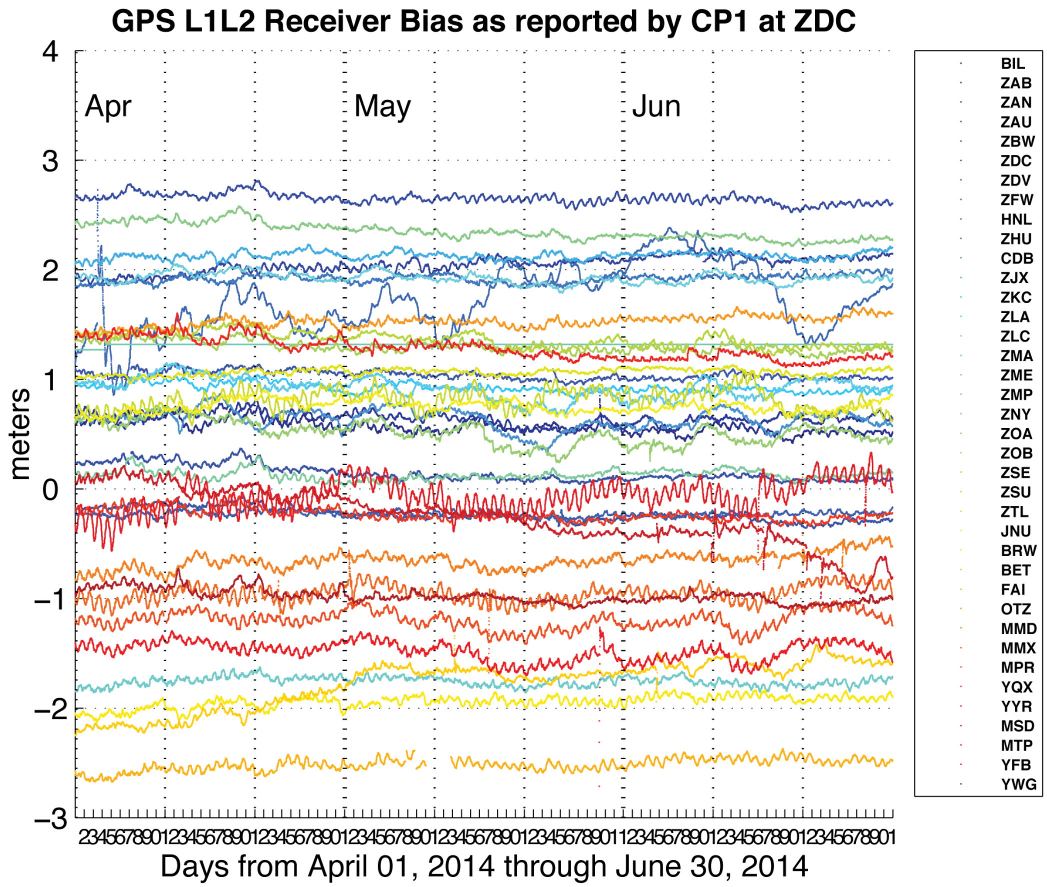

Figure 8.3: L1L2 bias for all WREs from CP1

8.4 WREs from CP2

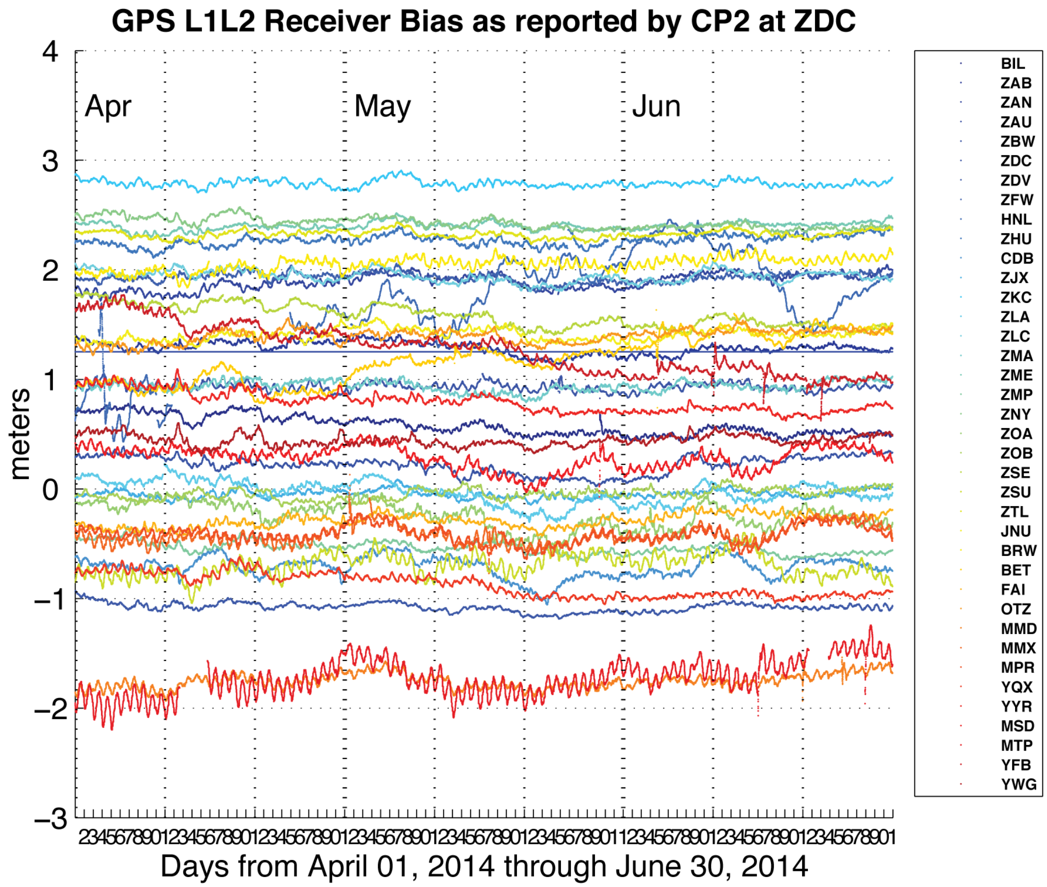

Figure 8.4: L1L2 bias for all WREs from CP2

Chapter 9

Anomaly investigation

9.1 Major Anomalies

CRW SIS outage on 2014-06-03

A brief SIS outage occurred on 2014-06-03 beginning at 08:16 and lasting until 09:36. APC was transitioned to backup mode for scheduled quarterly maintenance. LTN was transitioning to primary mode but was unable to acquire lock causing the LTN site to fault multiple times. APC had been control powered just prior to LTN faulting, thus resulting in a loss of SIS. LTN was unable to acquire lock due to waveguide connection issue in the uplink antenna/dummy load switch. This caused the L1 downlink Doppler frequency search to time out after six tries. A GUS switchover was initiated once APC was able to become primary. The waveguide connection issue was later determined to be due to human error that occurred at the previous LTN RFU maintenance period on 5/21.

See anomaly WAAS00008934 for further details.

EIRP faults at HDH and SZP

Numerous faults have occurred at the Inmarsat sites; HDH and SZP during the second quarter of 2014 (and some prior to this). After investigation into these faults it was determined that the two sites were not operating the KPA's with the ALC (Automatic level control) mode enabled, unlike the four other GUS sites. Upon enabling ALC mode at HDH, EIRP faults ceased to occur at HDH. An attempt to enable ALC at SZP did not result in the stability that occurred at HDH. EIRP faults are still occurring at SZP. Investigation and testing are still ongoing at SZP.

See the following anomalies for further details: WAAS00008250, WAAS00008264, and WAAS00008392

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 Continuously Operating Reference Station (CORS) Receiver INdependent EXchange Format (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 broadcast 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 Chi^2 values > than 1 each day for the six regions (see 3.4.1.2) 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.

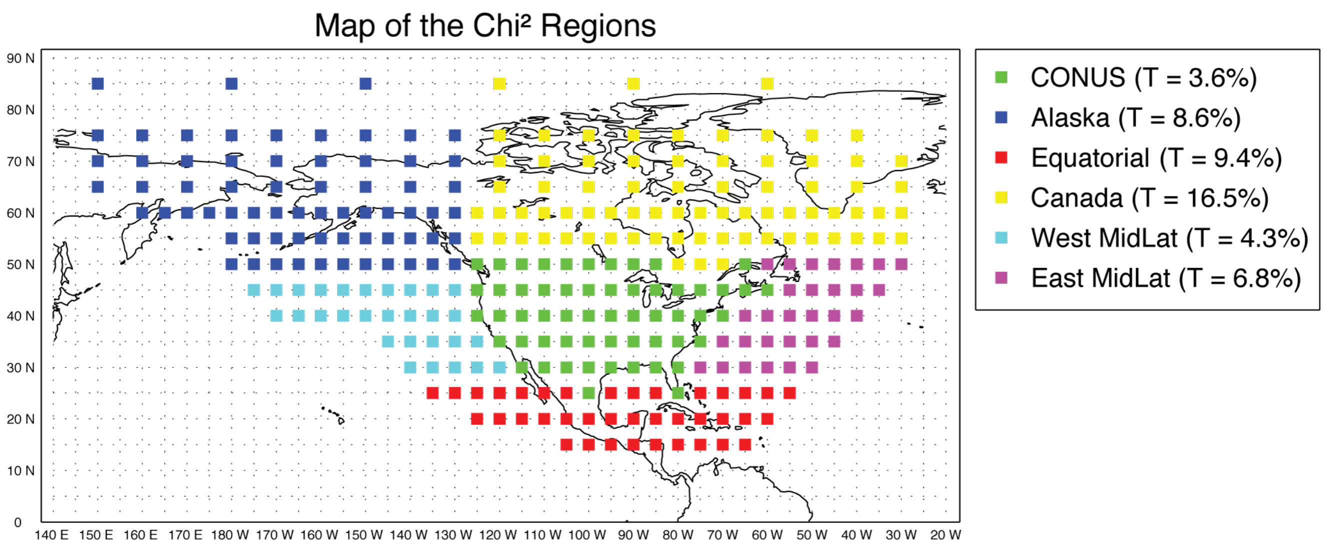

Figure B.1: Chi^2 region map

B.2 Equations

B.2.1 Code-carrier-coherence

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

where:
$\mu_{y,cnmp,i}^j$ is the instantaneous difference of the code measurements vs. the adjusted carrier phase for SV j as measured by WRE i for each $y \in L1, L2$,
$\sigma_{y,cnmp,i}^j$ 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:

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

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

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

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

B.2.2 Code-noise and multipath

The Cumulative Density Function (CDF) is defined as:

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

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

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	5.0139m^2
CRW	PRN 135	LTN APC	133.0±0.01°W	1436.08min	35798m	35974m	3.9811m^2
AMR	PRN 133	SZP HDH	98.0±3.01°W	1436.11min	35776m	35776m	2.1948m^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 $\sigma_{\text{decorr\_undersampled}}$ and ϵ_{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. Root Mean Square (RMS)
16. Variance
17. Level 3 Outliers (outside of mean ± 3.29σ, P = 10^{-3}, relative to the aggregate mean and sigma)
18. Level 4 Outliers (outside of mean ± 3.89σ, P = 10^{-4}, relative to the aggregate mean and sigma)
19. Level 5 Outliers (outside of mean ± 4.42σ, P = 10^{-5}, relative to the aggregate mean and sigma)
20. Level 6 Outliers (outside of mean ± 4.89σ, P = 10^{-6}, relative to the aggregate mean and sigma)
21. Level 7 Outliers (outside of mean ± 5.33σ, 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 Matlab integrity standards are all met.

Appendix E

Acronyms and abbreviations

CCC Code-Carrier Coherence . . . 1

CDF Cumulative Density Function . . . 50

CMCI Code Minus Carrier corrected for Iono . . . 46

CNMP Code-Noise and Multipath . . . 1

CORS Continuously Operating Reference Station . . . 47

CSRS-PPP Canadian Spatial Reference System Precise Point Positioning . . . 31

DGPS Differential Global Positioning System . . . 46

FAA Federal Aviation Administration . . . 2

GEO Geosynchronous Earth Orbit . . . 1

GIVEI Grid Ionospheric Vertical Error Index . . . 58

GIVE Grid Ionospheric Vertical Error . . . 58

GPS Global Positioning System . . . 31

GUST GEO Uplink Subsystem Type 1 . . . 46

HMI Hazardous Misleading Information . . . 1

IFPR Ionospheric Free PseudoRange . . . 18

ITRF International Terrestrial Reference Frame . . . 55

MERR Maximum Error Range Residual . . . 50

MMAC Mike Monroney Aeronautical Center . . . 1

NANU Notice Advisory to NAVSTAR Users . . . 47

NAS National Airway Systems . . . 62

NASE NAS Engineering . . . 62

NAVSTAR NAVigation System with Time And Range . . . 47

NGS National Geodetic Survey . . . 31

OLM Offline Monitoring . . . 8

PAGE-NT The NGS's suite of survey software . . . 46

PCR Program Change Request . . . 56