WAAS Technical Report
William J. Hughes Technical Center
Pomona, New Jersey
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**DR #135**
FAA Technical Center
Observations of
GPS Increased L1 C/A
Power Tests

Observations based on
data from
25JAN – 12FEB2017
Background

• On January 25, 2017 the US Air Force began a test that increased the power for the GPS L1 C/A signal for the 19 newest GPS satellites (Block IIRM & IIF)
• Data from WAAS reference station (WRS) receivers are used to determine power levels
• Data from WAAS user broadcast is used to determine anomalous WAAS behavior
WAAS SQM

- The WAAS Signal Quality Monitor (SQM) ensures the signal quality for every GPS and GEO measurement is of sufficient quality for use
  - The algorithm prescreens, normalizes and smooth's this measurement data and then linearly combines the 9 correlator inputs from each channel of a receiver to form up to a total of 5 detection metrics
    - Only four detection metrics are used in the current SQM implementation
- These valid measurements are used to ensure the WAAS transmitted User Differential Range Error (UDRE) value for a particular satellite can be supported
- A satellite will be set to “Do Not Use” by WAAS if the SQM detects a deformation in the GPS signal
- The FAA Technical Center developed a tool to monitor SQM
  - The tool is based on the operational WAAS SQM Algorithm Description Document (ADD)
Data in this Presentation

• January 28 WAAS Signal Quality Monitor (SQM) trip for PRN 27
• WAAS broadcast UDRE Spikes seen for several GPS satellites
• GPS IIR-M Satellites C/No levels
• GBAS Observations
  – GBAS slides are courtesy of Shelly Beauchamp (FAA)
WAAS SQM Event – January 28, 2017

• WAAS impact of increased power testing of GPS was observed on January 28, 2017
  – GPS week 1933, day 6
• SQM trip at 00:16:09 GMT on WAAS operational system for PRN 27 (SVN 66)
  – FAA Technical Center SQM tool tripped at 00:16:08 GMT
• SQM trip cleared on the operational WAAS at 02:04:26
  – FAA Technical Center SQM tool trip cleared at 02:04:20
• Shifts in code, carrier, C/No, and correlator measurements were observed. All WREs maintained tracking of PRN-27
• CONUS and Alaska WAAS coverage were not affected by this event; however, Canada coverage observed a slight reduction
Location of PRN 27 on January 28, 2017

Location of PRN 27 at the time of the start of the SQM Monitor Trip 00:16:09 UTC

Location of PRN 27 at the time of the end of the SQM Monitor Trip 02:04:26 UTC
Observations from PRN-27 at the Time of the SQM Trip

- Slight decreases in C/No
- Shift in code and carrier measurements
- Shift in correlator measurements, detection metrics
- All WREs maintained tracking of PRN-27
- Slight reduction in Canada coverage
- See plots on next few pages
SQM Monitor – Raw Data

The 114 WAAS receivers provide raw correlator accumulation counts for 9 spacing's between -0.1 and +0.1 chip of the peak.

Metrics are created by algebraically combining the prompt normalized values using weights derived offline by Stanford University.

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<th>Offset bytes</th>
<th>Spacing</th>
<th>I or Q</th>
<th>AKA</th>
<th>Label</th>
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<td>A</td>
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<td>E</td>
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<td>+0.102300</td>
<td>I</td>
<td>Late - Full (0.1 chip)</td>
<td>I</td>
</tr>
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</table>
More on the SQM Algorithm

• The metrics are combined across receivers after a inter-receiver (calibration) bias is removed per receiver
  – The inter-receiver bias was computed continuously in real time

• The detection metrics are also corrected for a "Type bias"
  – PRN code dependent biases
  – Three types: Normal, Skinny, and Fat

• The final detection metrics are then tested against a threshold that is a function of: (1) off line a priori values, (2) the estimated monitor noise, and (3) the UDRE value that needs to be protected
  – If the monitor trips: WAAS sets the PRN to "Do Not Use" status
  – If WAAS doesn't have sufficient visibility: the UDRE is increased
PRN-27 DM4 PRN Bias

Normal day: 1/25/2017 (Week 1933 day 2)
Trip day: 1/28/2017 (week 1933 day 6)

Red—PRN Bias (Detection Metric 4 normalized across satellites)
Blue—Trip threshold

January 25, 2017

January 28, 2017
PRN-27 DM4 Trip Status
Normal day: 1/25/2017 (Week 1933 day 2)
Trip day: 1/28/2017 (week 1933 day 6)

Red—Trip ratio (PRN Bias/Threshold); Ratio > 1 indicates trip state
Blue—Trip status (1=trip, 0=no trip)
PRN-27 Number of Valid Receivers

Normal day: 1/25/2017 (Week 1933 day 2)
Trip day: 1/28/2017 (week 1933 day 6)

Plot of the number of valid (as determined by SQM algorithm) receivers. The drops were due to measurements failing the 10-second prescreening check.

January 25, 2017

January 28, 2017
PRN-27 DM4 UDREi

Normal day: 1/25/2017 (Week 1933 day 2)
Trip day: 1/28/2017 (week 1933 day 6)

- UDREi for PRN 27 was elevated to 15 (Do Not Use) in trip state
Sharp increase in DM4 occurred when PRN 27 tripped. The decrease in DM4 occurred when the trip went away.
New York WAAS WRS Receivers
SQM Detection Metrics 4

Sharp increase in DM4 occurred when PRN 27 tripped. The decrease in DM4 occurred when the trip went away.
L1 C/No at Boston WAAS WRS-A from January 23 – 28, 2017

Change in C/No for PRN 27 in Red on trip day, January 28, 2017
L1 C/No at New York WAAS WRS-A from January 23 – 28, 2017

Change in C/No for PRN 27 in Red on trip day, January 28, 2017

Red=Code-Carrier
Green=100 second Smooth Code-Carrier
Blue= CNMP Smooth Code-Carrier

Time Of Week

[Graph showing the data with red, green, and blue lines representing the different categories.]

Red=Code-Carrier
Green=100 second Smooth Code-Carrier
Blue= CNMP Smooth Code-Carrier
Boston WAAS WRS-A  L1 Code minus Carrier on Normal Day – January 26, 2017
Boston WAAS WRS-A  L1 Code minus Carrier on Trip Day – January 28, 2017

Red=Code-Carrier
Green=100 sec Smooth Code-Carrier
Blue= CNMP Smooth Code-Carrier
Boston WAAS WRS-A L1 and L2 Carrier Divergence for PRN 27 – January 28, 2017

Red = L1 – L2 Carrier Difference
Green = L1 Carrier Error
Blue = L2 Carrier Error
Boston WAAS WRS-A L1 and L2 Carrier Convergence for PRN 27 – January 28, 2017

Red = L1 – L2 Carrier Difference
Green = L1 Carrier Error
Blue = L2 Carrier Error

PRN 27 Normalized L1 Minus L2 Carrier observations from Boston WRS 1/28/17 Week 1933 Day 6
Normal Day (1/24/2017) Canada Coverage

Week 1933 Day 2
Canada
Area Covered vs Time

Percent of Area Covered

GMT Time

LP
LPV
LPV200
Trip Day (1/28/2017) Canada Coverage

Week 1933 Day 6
Canada
Area Covered vs Time

Time of PRN 27 SQM trip

Percent of Area Covered

GMT Time
Additional SQM Observations

• The following slides show additional abnormal SQM observations that have occurred
• SQM impact seen on PRNs 1, 8, 24, and 26
• Data on following slides is from January 29 to February 4, 2017
• Occurrences repeat daily for the four satellites
• Observations presented are based on results from the Tech Center SQM tool
  – Tech Center SQM Monitor is a stand-alone SQM monitor prototype
  – The UDREi computed by the operational WAAS SQM Monitor is only one factor that goes into the computation of the broadcast UDREi
Events for PRNs 1, 8, 24, and 26

• PRN 1 – January 29, 2017
  – At 03:39 UTC, UDRE remained at 1.75 meters (UDREi = 3)
  – At 15:52 UTC, UDRE jumped from 1.75 to 3 meters (UDREi 3 to 5)

• PRN 8 – February 2, 2017
  – At 01:50 UTC, UDREi remained at 1.75 meters (UDREi = 3)
  – At 14:57 UTC, UDREi jumped from 1.75 to 5.25 meters (UDREi 3 to 8)

• PRN 24 – January 29, 2017
  – 04:30 UTC, UDREi jumped from 1.75 to 3.75 meters (UDREi 3 to 6)
  – 15:25 UTC, UDREi jumped from 1.75 to 3 meters (UDREi 3 to 5)

• PRN 26 – February 1, 2017
  – 11:02 UTC, UDREi jumped from 1.75 to 3 meters (UDREi 3 to 5)
  – 21:54 UTC, UDREi jumped from 1.75 to 4.5 meters (UDREi 3 to 7)
Plots on the following slides

• Plot 1 (top left):
  – Blue=Trip threshold increased at the time of the event
  – Red=DM final may show slight increases

• Plot 2 (top right):
  – Blue=Trip status showing no trips occurred
  – Red=Trip ratio (DM final/threshold) showing slight changes

• Plot 3 (bottom left):
  – Number of valid receivers dropped at the time of the event
  – Measurements failed the screening checks

• Plot 4 (bottom right):
  – UDREi computed by the SQM Monitor
  – Note that the UDRE jumps in these examples are abnormal behavior for WAAS
GPS Satellite UDRE Spikes

- Several GPS satellites have had the WAAS UDRE spike when the satellite transitioned from higher power to lower power or from lower power to higher power.
- The reason for the UDRE spike appears to be data editing within the WAAS SQM function.
- Example: The UDRE spike on PRN 24 early in the day (GMT) has caused a loss of LPV-200 service in northern Alaska for a very short time (less than 1 minute).
- The next few slides show the power levels of PRN 24 at the Kotzebue and Cold Bay WAAS reference stations, the location of PRN 24 during the UDRE spike, VPL at Barrow, and the UDREi plot for PRN 24.
PRN 24 power levels at Cold Bay

L1 power decrease at 4:11 GMT
PRN 24 power levels at Kotzebue

L1 power decrease at 4:11 GMT
Location of PRN 24 on Feb 2

Location of PRN 24 at approximately 4:11 GMT
Barrow Performance on January 24 and February 2, 2017

1/24/2017 – The VPL at Barrow gets close to the LPV200 threshold of 35 meters but does not exceed that value. The number of satellites used in the position solution is 11, including PRN 24.

2/2/2017 – Barrow VPL spikes to 41.36 meters when PRN 24 the power is decreased and PRN 24 is no longer used in the position solution at 4:11 GMT because the UDREi increased to 12 (50 meters). At this time the number of satellites used in the position solution goes from 11 to 10. When PRN 24 is added again to the solution the VPL reduces to 33.92 meters.
PRN 24 UDREi Plot

UDRE spike occurs at 4:11 GMT
PRN 25 UDRE Increase

- On February 18 there was a short loss of WAAS service in Western CONUS
  - PRN 25 had 2 UDRE jumps to 50 meters (UDREi = 12) at ~5:42 GMT when the satellite was east of Japan and at ~6:16 GMT when the satellite was east of Russia
  - The spike at 5:42 caused the WAAS service outage
  - The service outage lasted for less than one minute
  - The spike in the PRN 25 UDRE coincided with the power of this satellite increasing

- The following slides show information regarding this outage
WAAS Service Outage in CONUS – February 18, 2017

The top plot on the left shows that the VPL on February 18, 2017 went above 35 meters, the threshold for LPV200 operations to be available. The bottom left plot shows typical performance, in this case on February 17, 2017. The cause of the increased VPL on February 18 was due to the UDRE of PRN 25 being set to 50 meters. When the UDRE is 50 meters or higher, that satellite cannot be used in the LPV solution.
GPS IIF Satellites with multiple jumps in UDRE

- The number of days with bumps in UDRE per GPS IIF satellite vary
  - All bumps occur at same time as an L1 power level change

- Between January 25 and February 26 (33 days) the number of days with jumps for each IIF in UDRE are:

<table>
<thead>
<tr>
<th>PRN</th>
<th>Days</th>
</tr>
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<td>32</td>
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PRN 25 L1 C/No as seen from WAAS Oakland reference station on Feb 17 (green) vs Feb 18 (red)

L1 C/No increases at 5:42 GMT
Increased L1 Power on GPS IIRM Satellites

• On February 7, 2017 NANUs were issued for maintenance on all GPS IIR-M satellites
  – NANUs were issued less than 48 hours in advance, which violates the current standard

• After the maintenance the L1 C/No as measured by the WAAS G3 receivers slightly increased and the L2 signal slightly decreased

• The following slides show the L1 and L2 C/No from the Kansas City for IIR-M satellites
Kansas City PRN 5 L2 C/No
Kansas City PRN 12 L2 C/No
Kansas City PRN 15 L1 C/No
Kansas City PRN 15 L2 C/No
Kansas City PRN 29 L1 C/No
Kansas City PRN 29 L2 C/No
Kansas City PRN 31 L1 C/No

Kansas City - A PRN 31

[Graph with data points and legend]

LISNR February 12th  
LISNR January 31st  
LISNR January 24th
Kansas City PRN 31 L2 C/No
GBAS Sites & Use

- Honeywell SLS-4000 approved for CAT-I use in CONUS
  - Operational public sites at Newark Liberty Int’l Airport (EWR), George Bush Intercontinental Airport (IAH)
    - Daily use by United Airlines (B737, 787), Delta Airlines (B737, A321), British Airways (B787), Lufthansa (B747-8), Emirates (A380), Cathay Pacific (B747-8), CargoLux (B747-8)
  - Operational private sites owned by Boeing at Grant County Airport (MWH) in Moses Lake, WA & Charleston Int’l Airport (CHS)
    - Used routinely by Boeing in aircraft acceptance testing

- Honeywell SLS-4000 also operational at several non-U.S. airports
  - Frankfurt, Sydney, Malaga, Melbourne, etc.
Nominal GBAS Performance at EWR (1/27/2017)

* VPL < 10m at RWY DH required for GLS (CAT-I) service
GBAS Performance at EWR after PRN 27 SDM Trip (1/28/2017)

- Exclusion of PRN 27 by SDM results in a 27 minute outage
- Predicted Service Outages posted via NOTAM as required:
Notes:

- **SDM event on PRN 27 was severe enough to trigger a ‘hard exclusion’**
  - PRN 27 will remain out of use by SLS-4000s until maintenance personnel manually re-include the SV
  - Service outage still occurring at EWR, Honeywell now scheduling a tech to re-include SV since threat or re-exclusion seems to have diminished

- **Impact of PRN 27 exclusion was exacerbated by exclusion of PRNs 11 & 23**
  - Current sited systems exclude these SVs on SDM
  - Updates to SDM monitor for ‘Block 2’ Honeywell GBAS system should allow their use in the future
    - Block 2 planned for install by EWR, IAH & MWH early to mid-2017

- **PRN 27 hard-excluded by SDM at all CONUS SLS-4000 sites**
  - Only the EWR SLS-4000 experienced service outages as a result

- **CAT-III prototype site at WJHTC (ACY) tripped on multiple SVs during testing (PRN 27, 18, 21, 24)**
  - Uncertain if CAT-III service would be lost during testing due to multiple exclusions
  - CAT-III SDM may be more sensitive to changes in power level
  - Final CAT-III SW development on hold at this time
Conclusion

• The FAA Tech Center, as part of daily GPS and WAAS performance monitoring, observed several events linked to the increased power test on GPS L1.

• The GBAS Team at the Tech Center have also noticed issues since the increased power test began.

• Some events occurred once (i.e. SQM trip on PRN 27) and others continue daily.

• This presentation showed several examples of unexpected GPS and WAAS performance that has occurred since the test began.

• Any additional observations will be reported.