Purpose

• Characterize scintillation observed in WAAS from solar cycle 24

• Characterize frequency of occurrence and system performance

• Investigate geographic spatial extent of scintillation events in Auroral region
Waas Reference Station Data Processing

• Purpose of processing was to associate loss of L1 or L2 signal tracking or cycle slip detections to scintillation
  • Needed to identify and remove similar effects such as RF interference, satellite glitches, multipath, station obstructions, comm. outages...etc.
  • From a “WAAS” point of view, having a cycle slip is very similar to losing a signal, because our CNMP (noise sigma) curve is reset to the maximum value

• Processing utilized individual station data (AGC, ranging data), comparisons across threads, and comparisons across entire network

• Output of processing was L1 and L2 outages (seconds of lost tracking) for one station/satellite pair, as well as dual frequency cycle slip related outages (details in the paper)
Equatorial vs. Auroral Behavior

- Directional dependence (Azimuth / Elevation)
- Boundary regions with respect to mid-latitude
- Time series over entire 4.0 year data set

**NOTE:** “Equatorial” in this sense means furthest south, to the point that a station can sample the equatorial anomaly. There are no WAAS stations actually in the equatorial region.
Behavior tied to magnetic latitude, not geographic latitude, which is to be expected.

Cutoff values look like about 26° and 63° for the two regions.

Three primary contributors in Equatorial region.

Four primary contributors in Auroral region.
Several periods of time where all activity drops to almost nothing.
Black line is 28 day average daily cycle slips

Cycle Slip Activity never drops completely to zero
Mean Daily Cycle Slips for Auroral NorthWest Region

Black line is 28 day average daily cycle slips

Green line is detrended Ap data

Cycle Slip Activity aligned with ionospheric trends
Regional Analysis

• Spatial and temporal analysis conducted to assess size and frequency of events

• Analysis of instantaneous events does not show significant correlation, as many events are close in time, but do not happen at exact same epoch

• Windowing of cycle slip indications from particular geographic regions conducted to assess correlation and geographic extent of scintillation events

• Two pieces of analysis were conducted with the windowed data
  • Correlated Satellite Outages
  • Geographic Spatial Extent
Maximum number of stations affected is 6

Maximum number of satellites affected is 10
Satellites Impacted

• Statistics generated for entire data set by applying ten minute windowing
  • Required at least two stations were lost for this analysis

• Three levels of satellite impacts considered
  • At least one satellite affected
  • At least three satellites affected
  • At least six satellites affected

• Total number of days in entire data set for each level is computed and histogrammed
  • Data is further broken down by number of stations affected for day
  • Time series over whole 4.0 year data set shown on next slide
One satellite impacted for ~34% of the days (as well as two stations)

Six satellites impacted for ~20% of the days
Much fewer days for the Auroral NE region, but the behavior is the same.
Mexican region showed very different behavior. The region never has six satellites impacted over the entire 4 years of data.

Mexican region has the same number of stations as the Auroral Northwest region.
Conclusions for Correlated SVs

• Scintillation in Auroral Regions impacts multiple satellites at multiple stations almost simultaneously
  • Impact to one satellite virtually implies impact to three
  • Impact to one satellite creates ~50% chance of impacting six satellites
  • Auroral Northwest region appears to have a much higher rate of scintillation than the Auroral Northeast

• Mexican region satellite loss histogram shows much different behavior
  • Impact to one satellite does not imply impacting three satellites
Spatial Extent Analysis

• Spatial extent of scintillation in Auroral region implied by cycle slip indications on multiple satellites/stations at nearly the same time
  • Convex hull algorithm / triangulation algorithm creates an estimate of the area of the event

• Short study on different time windows conducted and showed 10 minutes was sufficient to capture majority of events
  • Using data that was instantaneous did not yield significant sizes of scintillation events

• Example for July 15th, 2012 shown in subsequent slides
• Geographic Area Computation
• For some period of time, compute the Ionospheric Pierce Points (IPPs) at 350 km. above the surface of the earth
• Select the IPPs which form the convex hull (CH) of the set
• Compute the median latitude and longitude of the CH
• Project the points to the surface of the earth in ECEF
• Compute the areas of the (three dimensional) triangles and sum
Time window lags by a particular amount of time, and the maximum area for the particular date is computed and plotted.

Twice the area of Alaska

Area of Alaska
Conclusions

- Multiple satellites impacted across multiple stations nearly simultaneously across Auroral Regions
  - Detection of one satellite having cycle slip indications virtually guarantees multiple satellites will be impacted
- Auroral Northwest appears to be most active scintillation region for the WAAS service volume
- Geographic extent of scintillation events in Auroral Northwest region can be very large, exceeding the area of the state of Alaska on several occasions
- Other studies have shown that WAAS is robust, and WAAS coverage is only affected by scintillation in a minor way
  - Results are potentially helpful for future WAAS processing improvements
Appendix

• Data processing
Paper Outline

• DATA SET
• WAAS REFERENCE STATION DATA PROCESSING
• EQUATORIAL VS AURORAL BEHAVIOR
• SCINTILLATION CORRELATED WITH SPACE WEATHER
• SATELLITE OUTAGE STATISTICS (BY REGION)
• GEOGRAPHIC SPATIAL EXTENT ANALYSIS
Geographic Regions

<table>
<thead>
<tr>
<th>Auroral NW</th>
<th>Auroral NE</th>
<th>Mexico</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrow</td>
<td>Iqaluit</td>
<td>Tapachula</td>
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<tr>
<td>Kotzebue</td>
<td>Goose Bay</td>
<td>San Juan</td>
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<td>Fairbanks</td>
<td>Gander</td>
<td>Merida</td>
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<td>San Jose Cabo</td>
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<tr>
<td>Juneau</td>
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<td>Miami</td>
</tr>
</tbody>
</table>

Next three slides show the affect of a ten minute windowing algorithm for the Auroral Northwest, July 15th, 2012
Culling

• Care taken to remove incidents which are most likely not scintillation.
  • RFI events are flagged using processing of receiver L1 and L2 AGC gain
  • Periods of time where more than four stations are not tracking a single satellite are assumed to be a satellite issue
  • Azimuth / Elevation “windows” for particular stations which show repeatable patterns are assumed to be from line of site blockage
Processing Overview

• Processing performed on WAAS measurement data to associate missing measurements with loss of tracking from scintillation activity
  • Processing differentiates scintillation from RFI, network disruptions, satellite maintenance...etc..

• Results contain epoch, PRN, Azimuth, Elevation for each station and frequency number, sorted by week
  • Currently using A thread only (other two redundant threads at each station not processed)
  • Output contains instances of lost tracking not attributed to other sources
  • Mask angle used in processing is 20 degrees (lost tracking below this elevation not considered)
  • Additional culling utilized to remove events that clearly are not scintillation

• Data set spans a little more than two years, starting on January 2\textsuperscript{nd} 2011 and continuing to present day (August 24\textsuperscript{th}, 2013)
  • Currently 138 weeks (~2.6 years)
FORT.10.L1 Daily Events for week 1647 (Y Max = 10, No culling)

Day 6

Day 5

Day 4

Day 3

Day 2

Day 1

Day 0

STN Events
PRN Events

Hours into the Day
Az/El Time Plot for ZFW, FORT.10.L2 Culling by Time: N stations >= 4
Az/El Time Plot for ZFW, FORT.10.L2 Culling by Az/El
File: fort.11.L2.culling none data counts (with RFI in red)