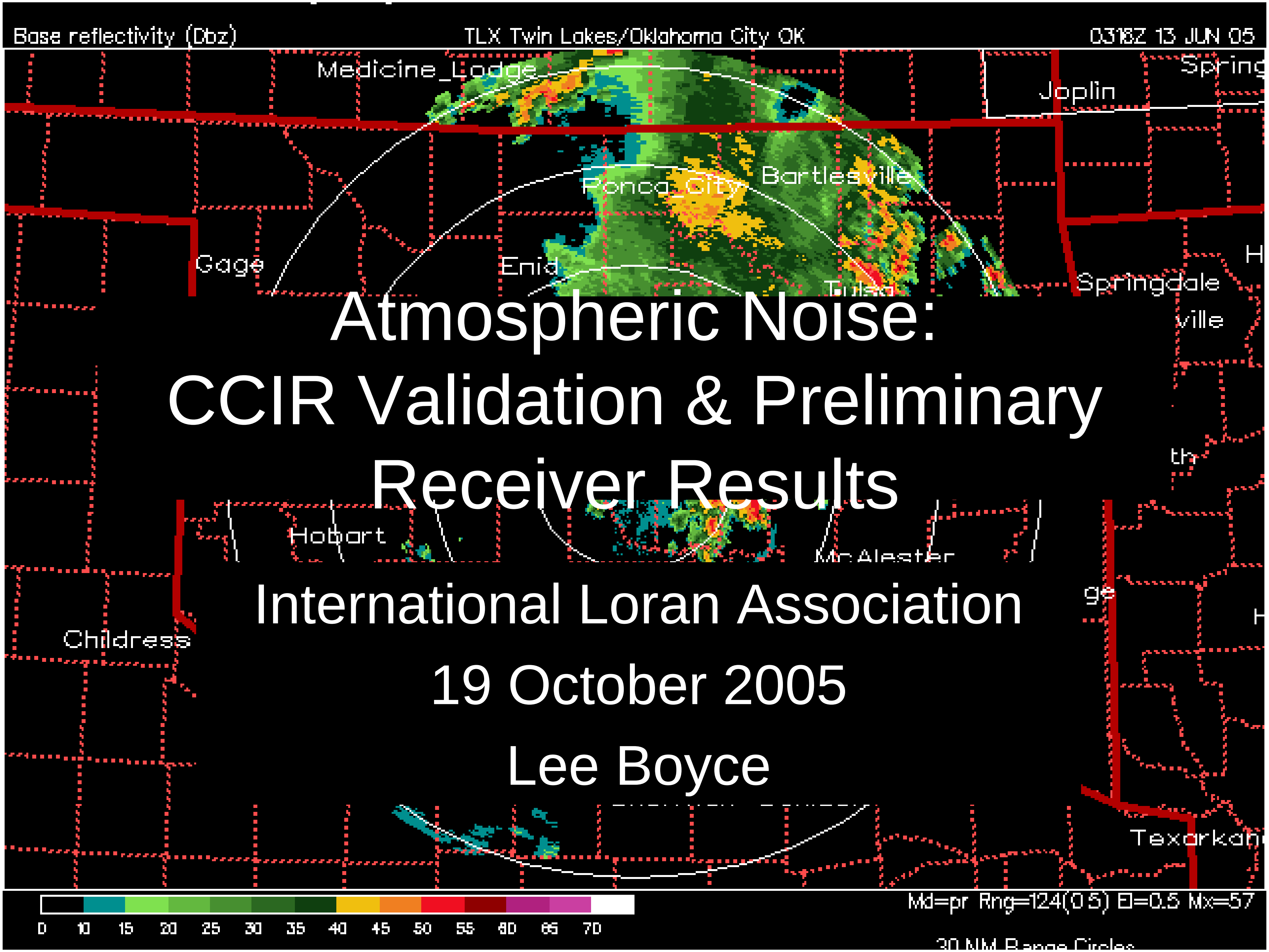


Atmospheric Noise: CCIR Validation & Preliminary Receiver Results

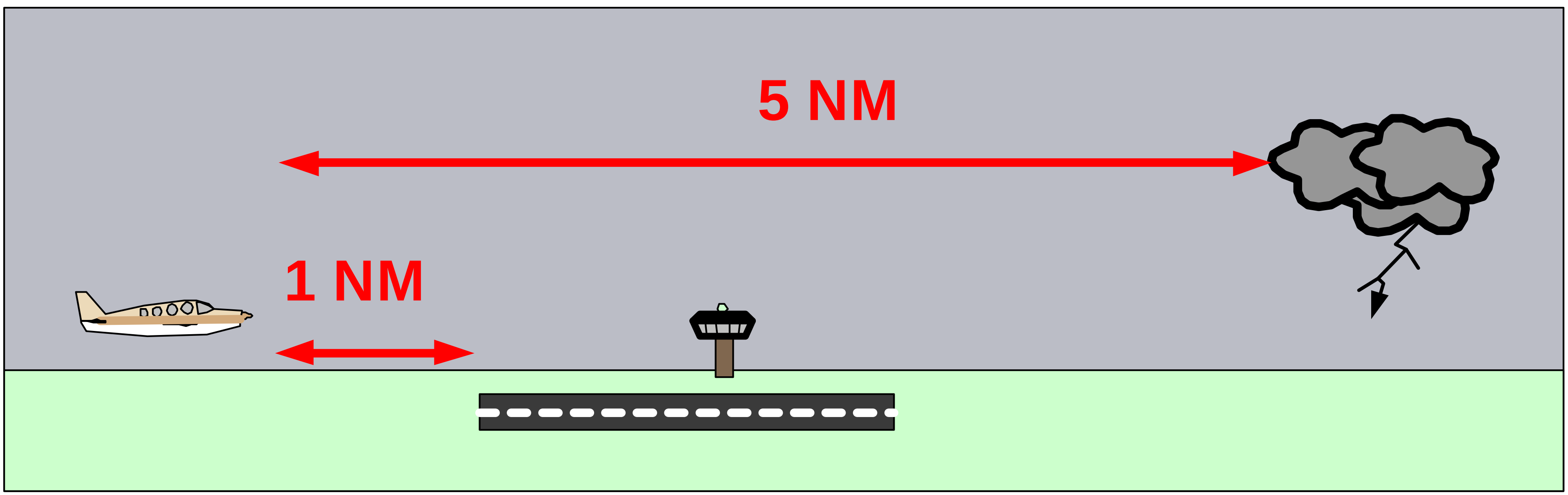
International Loran Association

19 October 2005

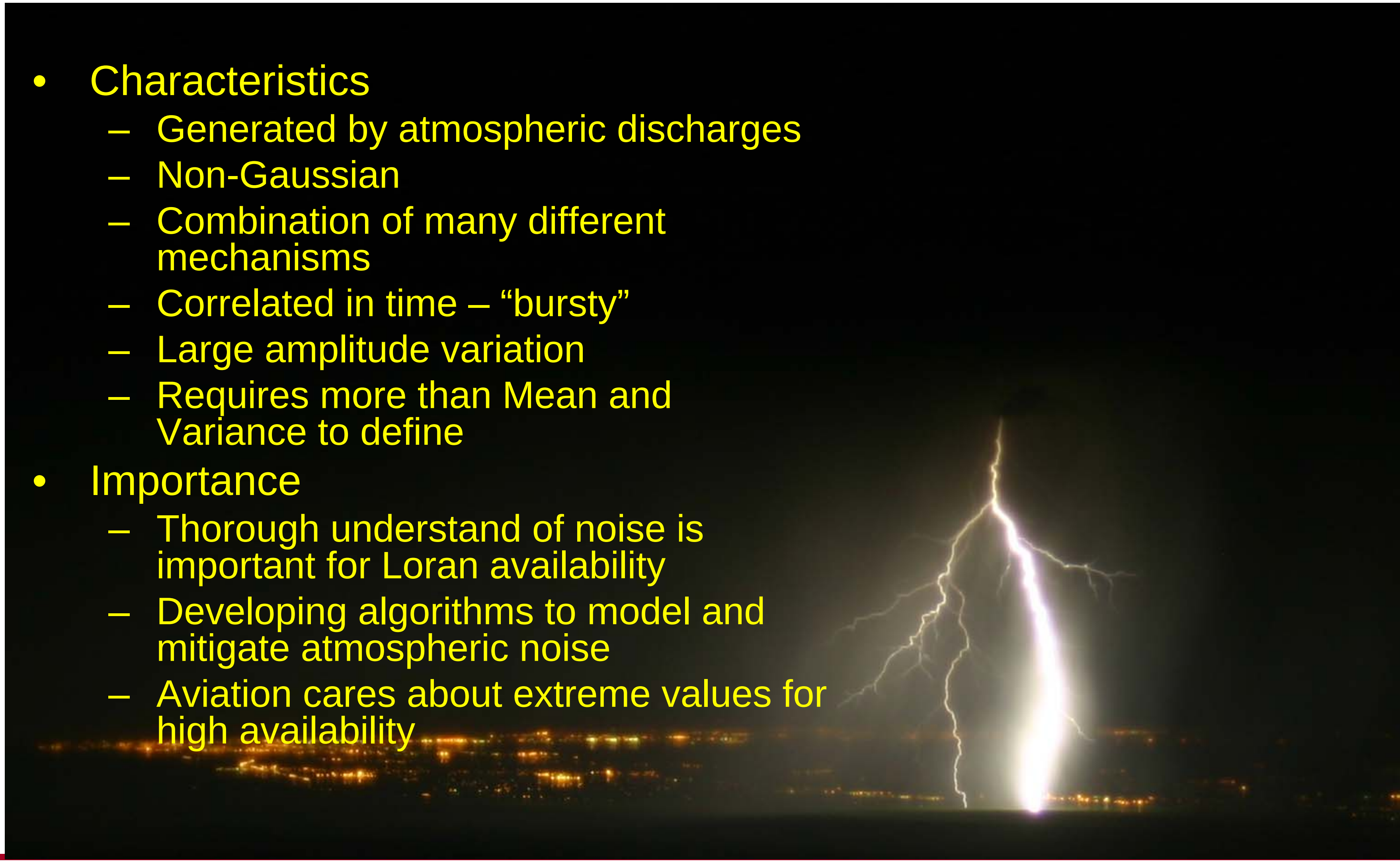
Lee Boyce

Objective – Protect the pilot

- Explore noise mitigation and signal processing techniques that will lead to a Loran receiver design that meets FAA availability requirements.
- Signal Availability ~ SNR



Atmospheric Noise

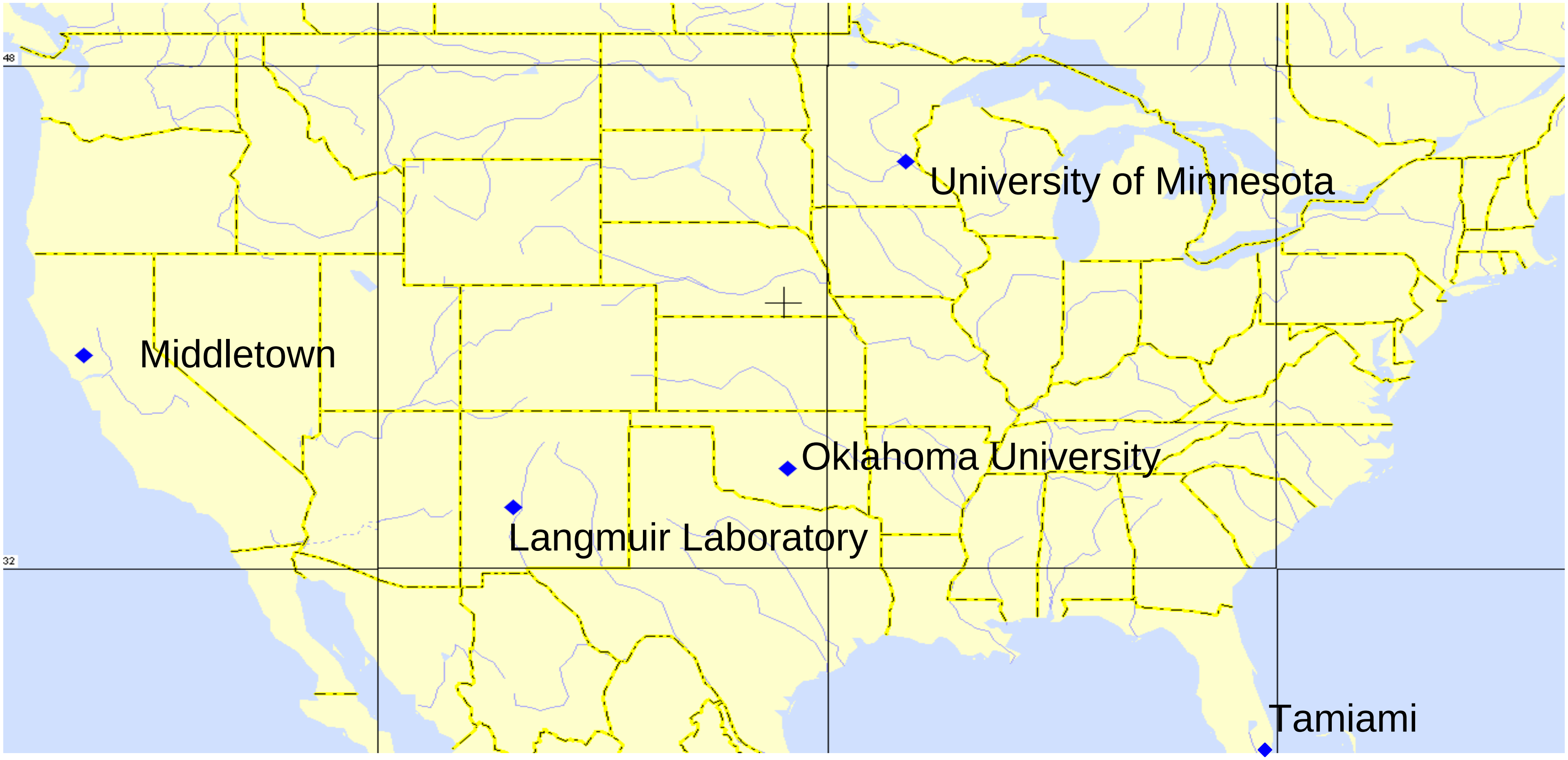


- Characteristics
  - Generated by atmospheric discharges
  - Non-Gaussian
  - Combination of many different mechanisms
  - Correlated in time – “bursty”
  - Large amplitude variation
  - Requires more than Mean and Variance to define
- Importance
  - Thorough understand of noise is important for Loran availability
  - Developing algorithms to model and mitigate atmospheric noise
  - Aviation cares about extreme values for high availability

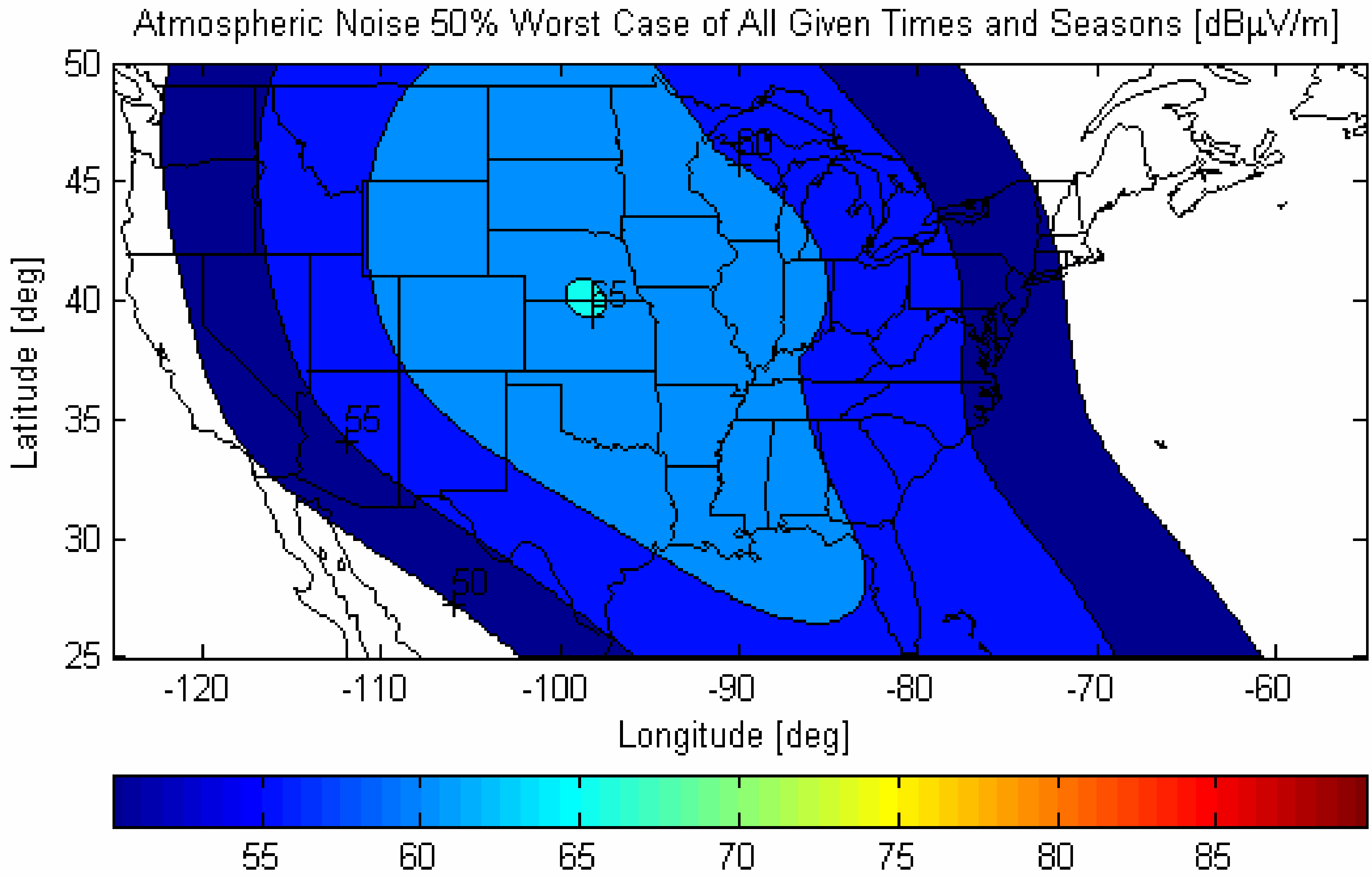
Goals of Testing Program

- Validate CCIR
  - Use more modern techniques
  - Observe local thunderstorms
  - Both wide and narrow bandwidths
    - 35kHz & 200Hz
  - Compare average noise values and “instantaneous” measurements
- Develop a refined noise model
  - Include correlation

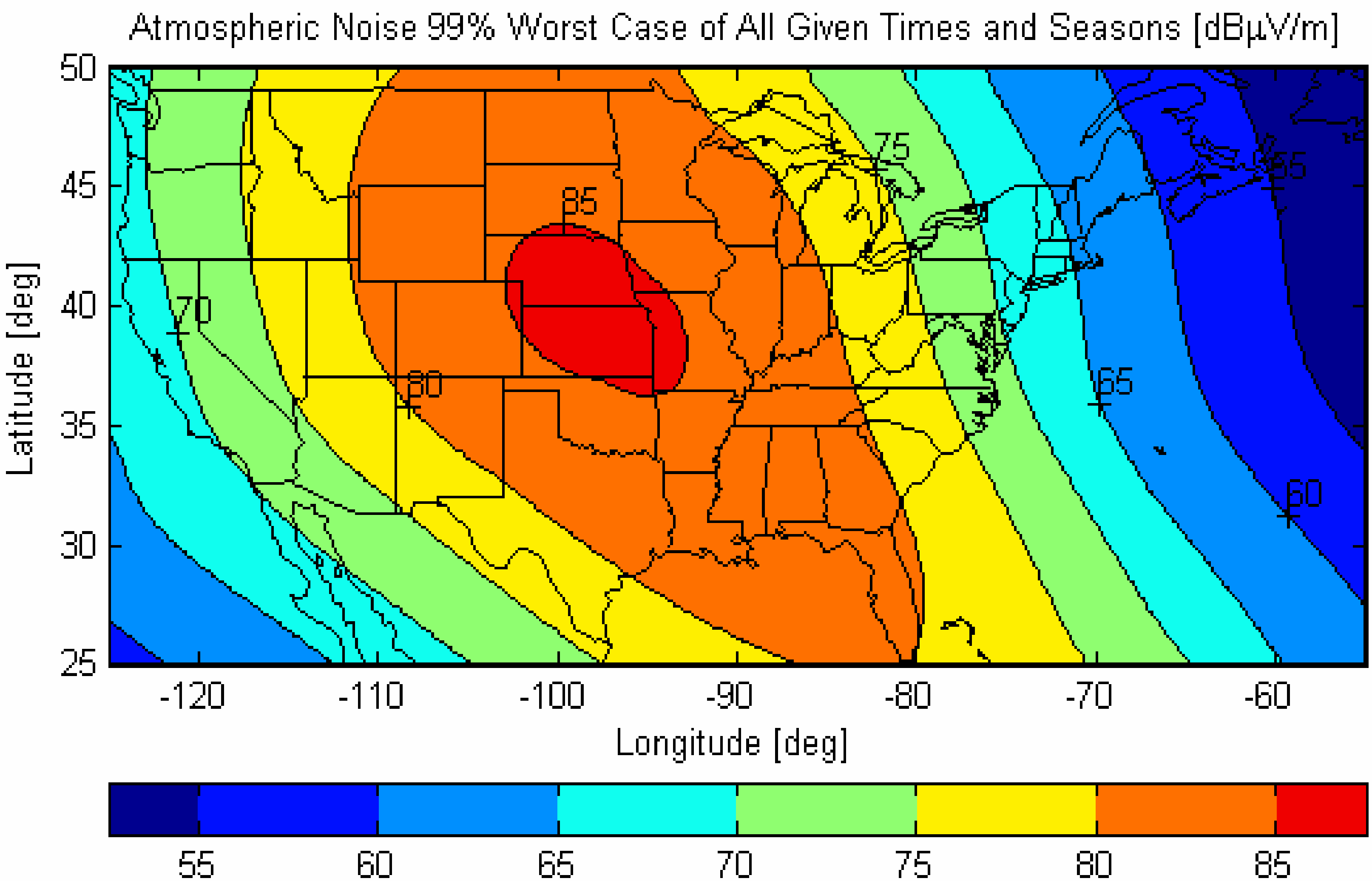
Test Locations



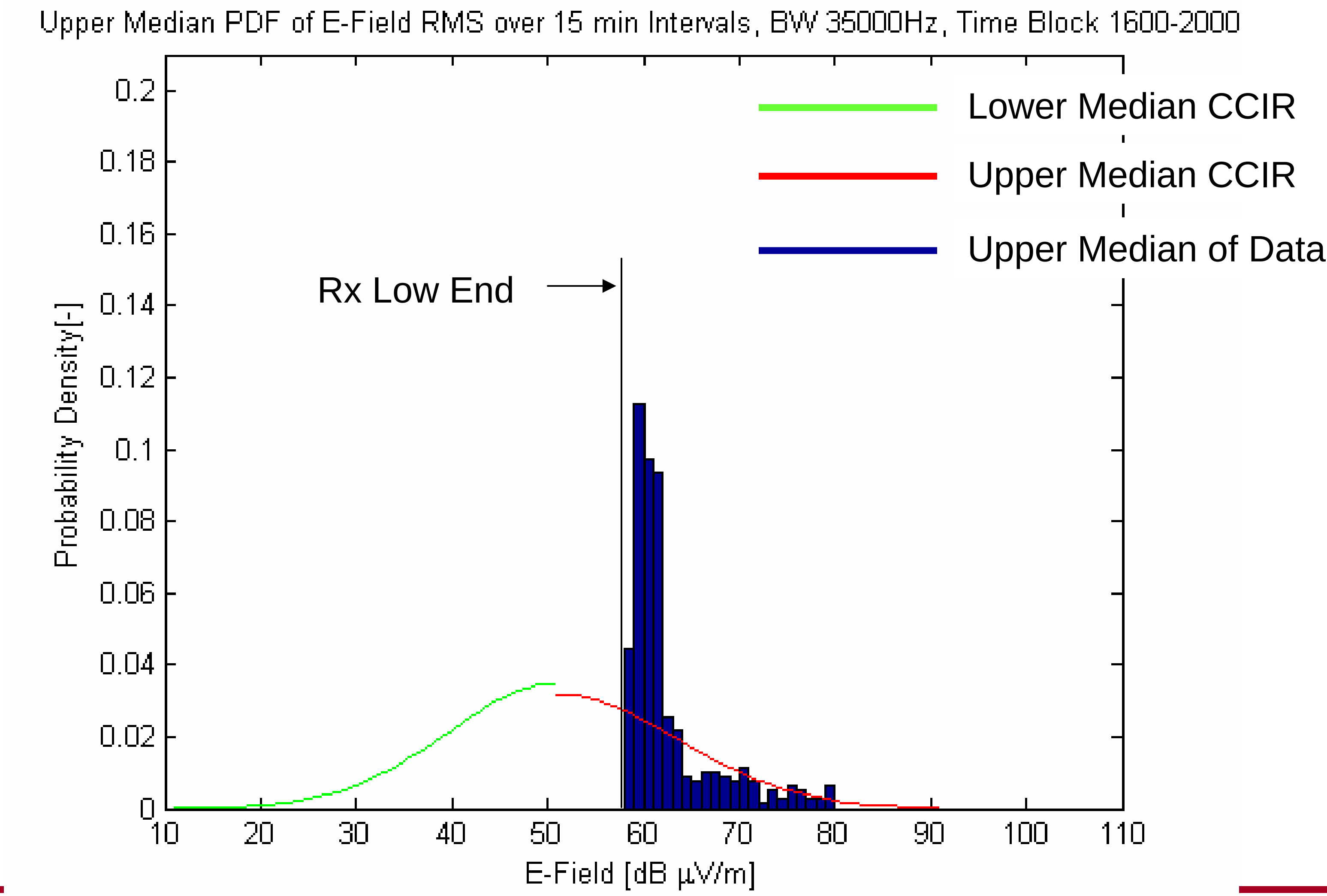
CCIR Validation



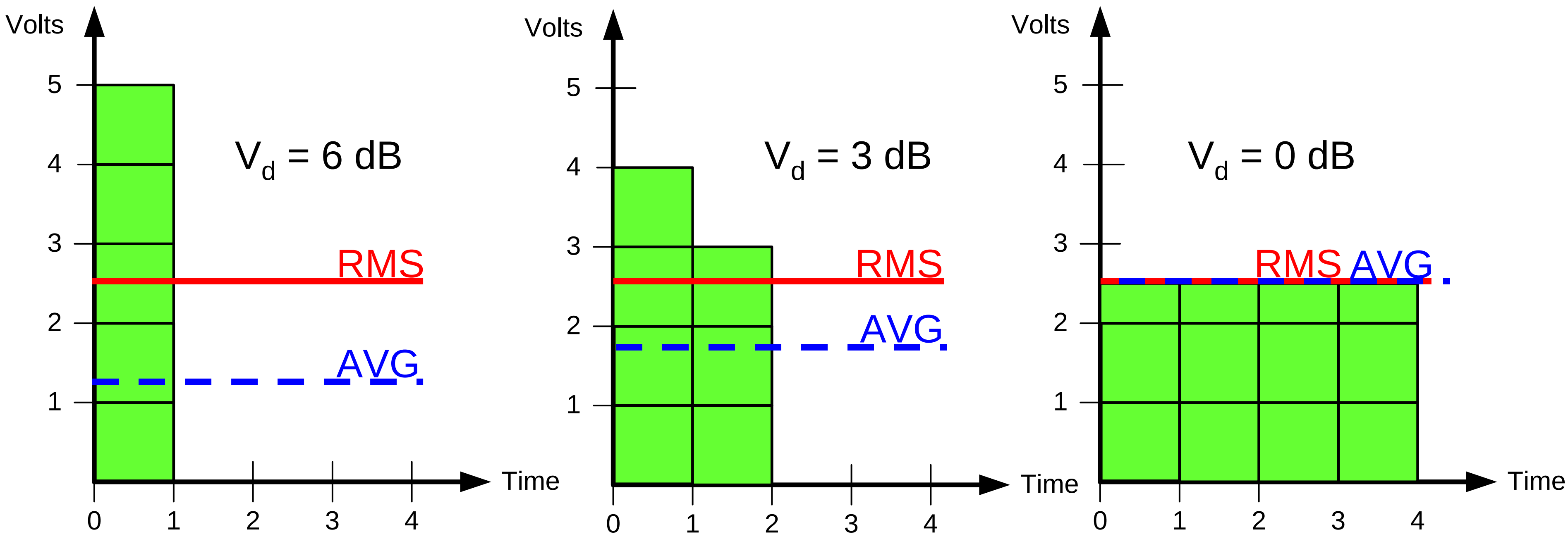
Atmospheric Noise 50% Worst Case of All Given Times and Seasons [dBµV/m]
50
45
40
35
30
25
Latitude [deg]
-120
-110
-100
-90
-80
-70
-60
Longitude [deg]
60
65
55
50
55
60
65
70
75
80
85


Atmospheric Noise 99% Worst Case of All Given Times and Seasons [dBμV/m]
Latitude [deg]
Longitude [deg]
50
45
40
35
30
25
-120
-110
-100
-90
-80
-70
-60
85
80
75
70
65
60
55
55
60
65
70
75
80
85

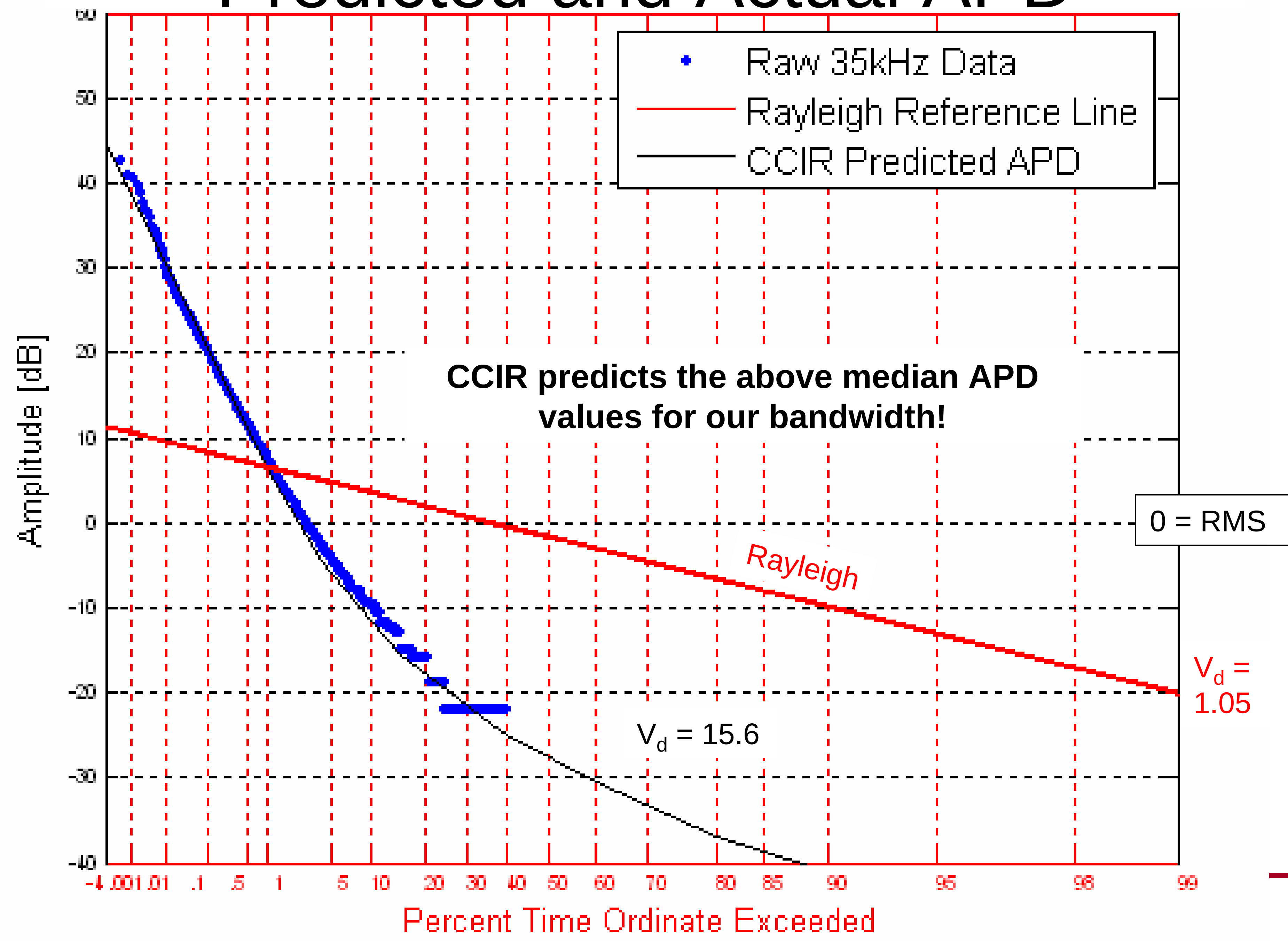
Comparison to CCIR
Distribution of RMS E-field Envelope



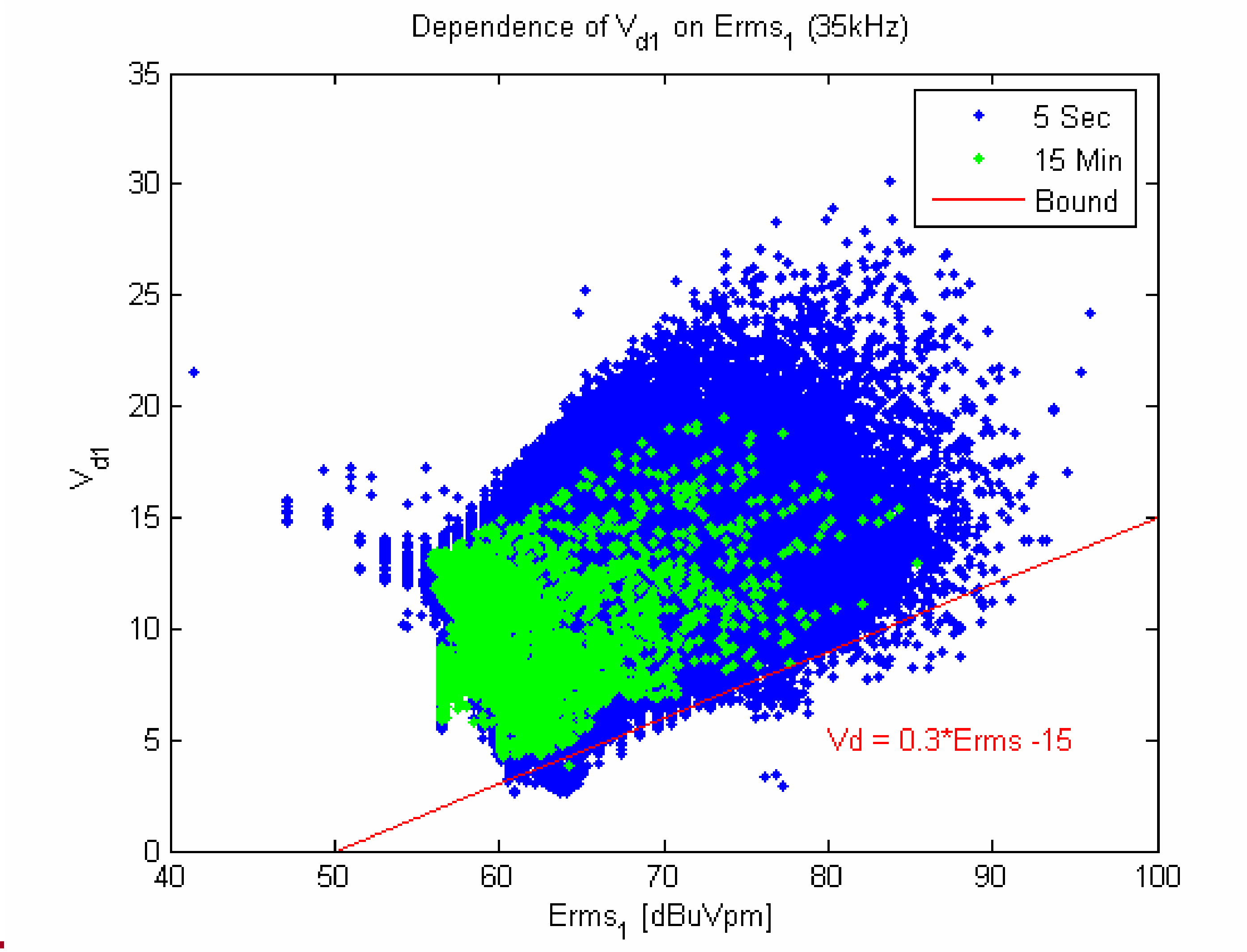
What do these three waveforms have in common over the interval [0,4]?



Predicted and Actual APD

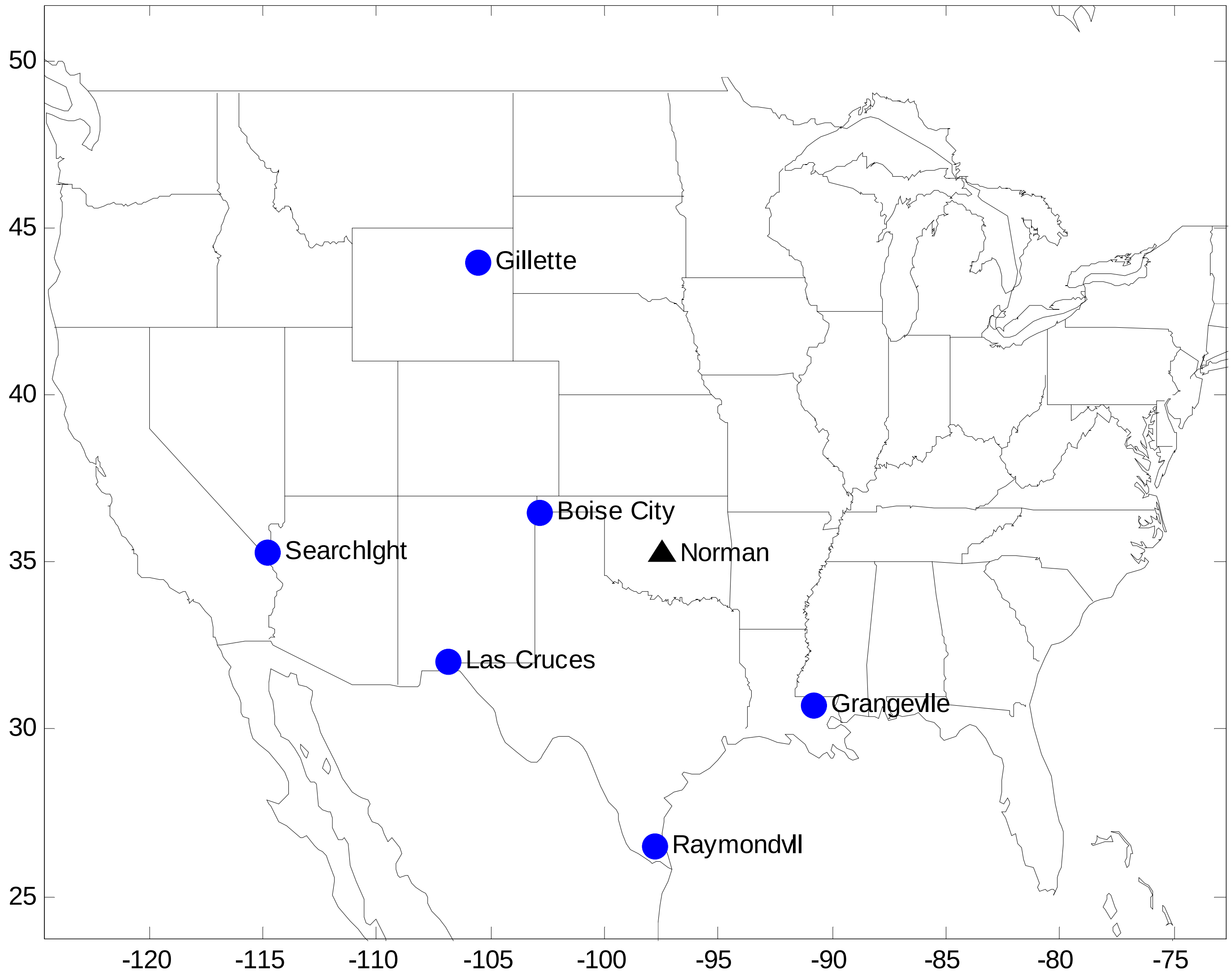


Dependency of V_d on E_{rms}



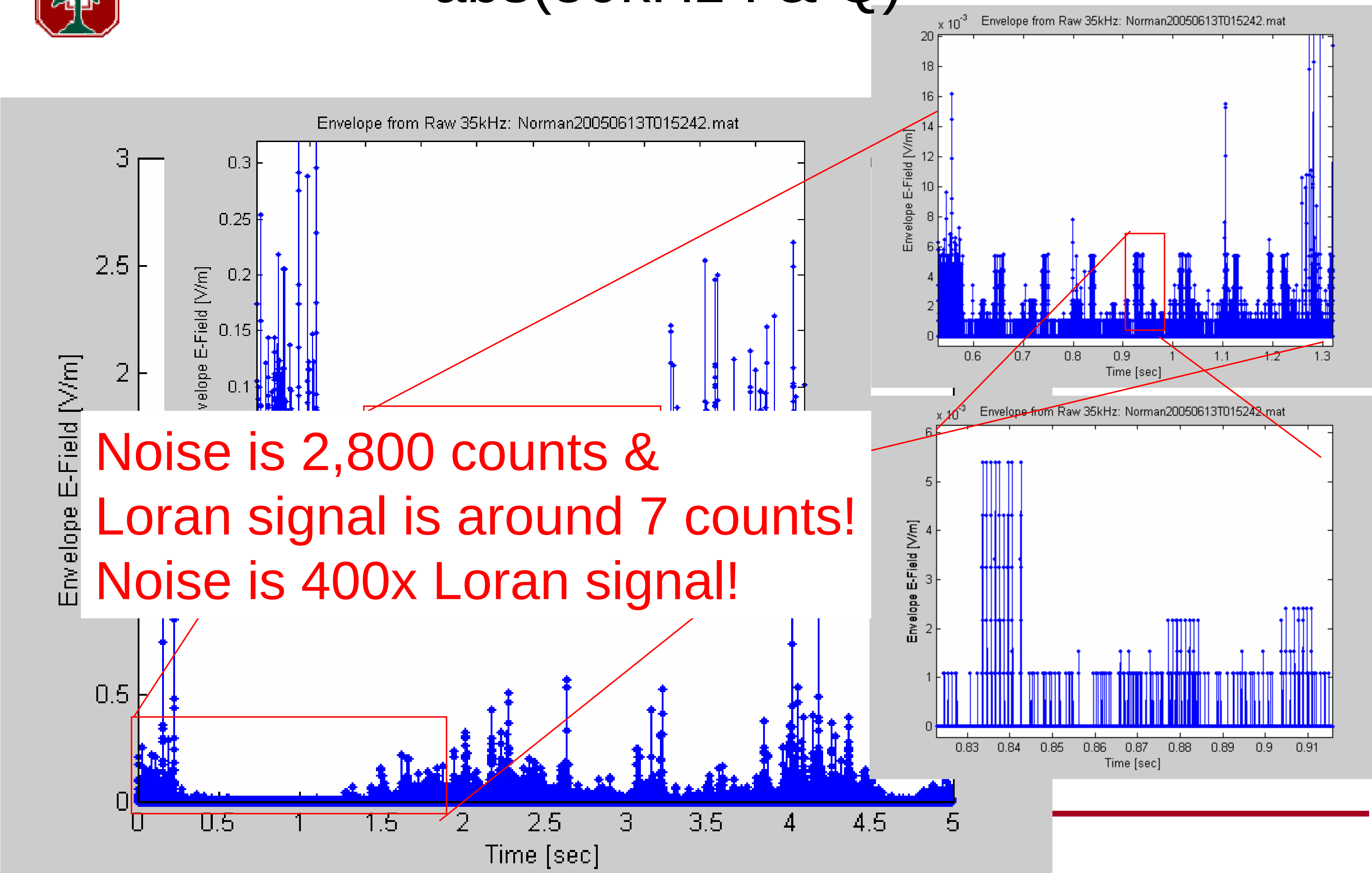
Processing Effects

Geography

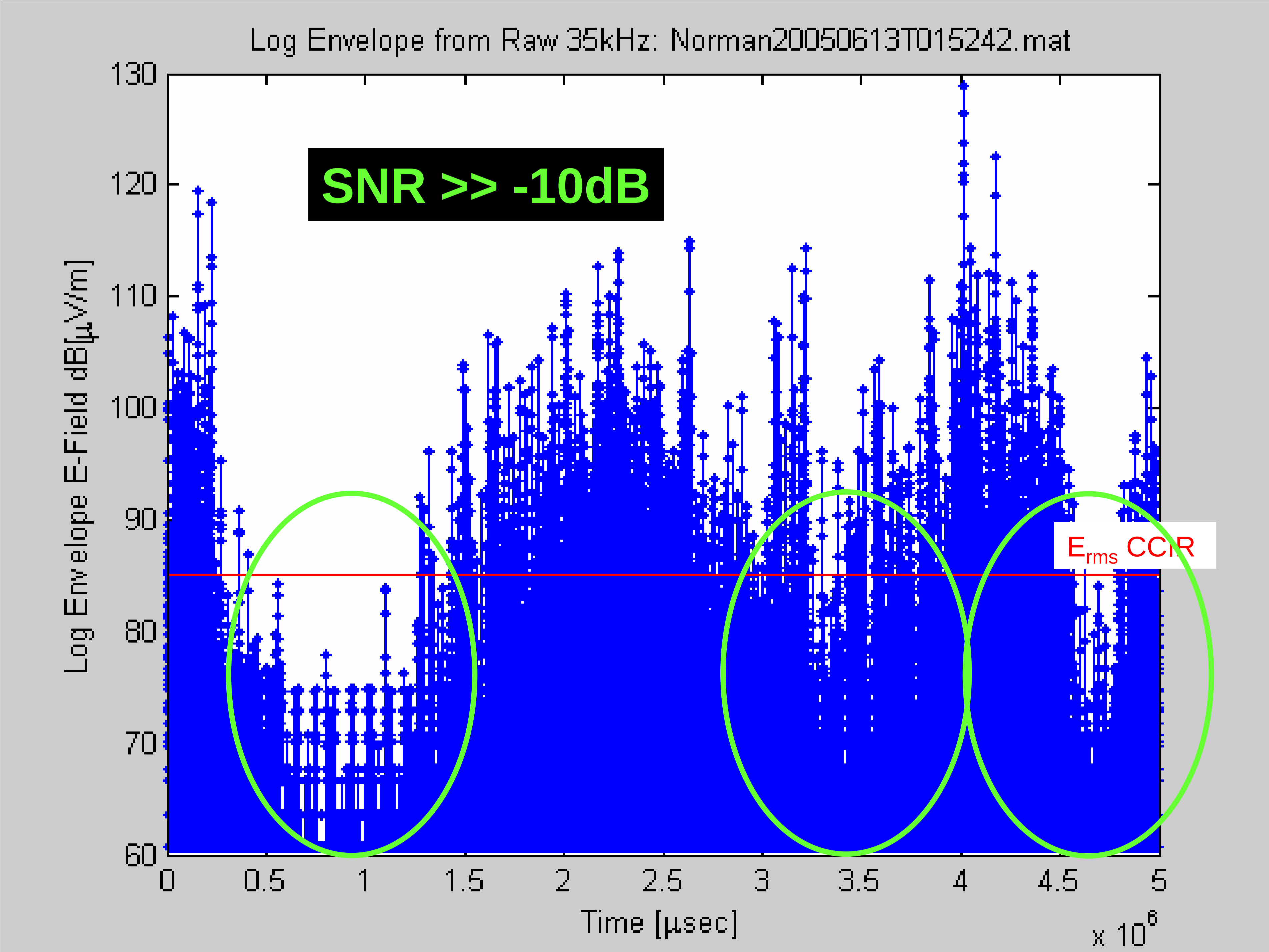


50
45
40
35
30
25
-120
-115
-110
-105
-100
-95
-90
-85
-80
-75
Gillette
Boise City
Searchlght
Norman
Las Cruces
Grangevlle
Raymondvll

5 Seconds of Loran abs(50kHz I & Q)



Noise is 2,800 counts &
Loran signal is around 7 counts!
Noise is 400x Loran signal!

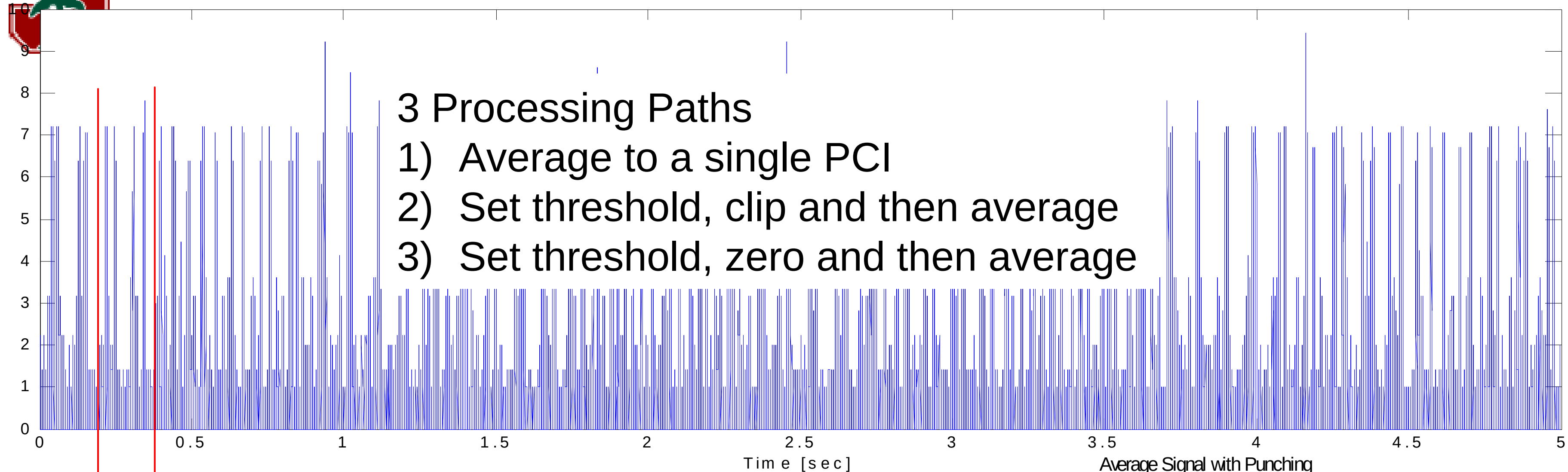

Log Envelope from Raw 35kHz: Norman20050613T015242.mat
SNR >> -10dB
Erms CCIR
Log Envelope E-Field dB[µV/m]
Time [µsec]
x 10^6
130
120
110
100
90
80
70
60
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Processing

- Data Set
  - South Central US Loran Chain – GRI 9610
    - Boise City, OK; Gillette, WY; Searchlight, NV; Las Cruces, NM; Raymondville, TX; Grangeville, LA
  - 5 seconds of 50kHz I & Q from Norman, OK
  - Using an acquisition algorithm
- Straight Averaging
  - Divide roughly 5 seconds into 26 PCI windows
  - Sum windows and divide by 26
  - Dynamic range much larger than a true receiver
- Clipping/Limiting
  - Set a threshold at 10 counts
  - Limit signals to a maximum value of 10
  - Sum windows and divide by 26
- Punching
  - Set a threshold at 10 counts
  - Any data point above 10, zero out and flag as to reduce the divisor <= 26

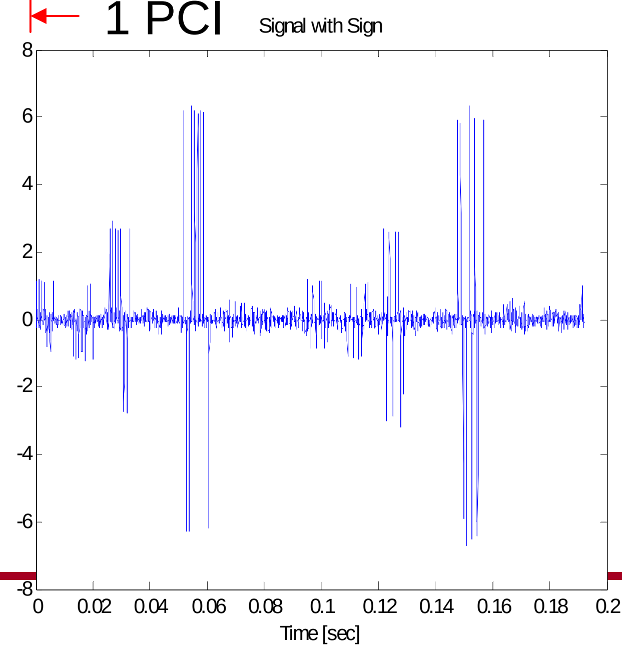
Averaging Algorithm

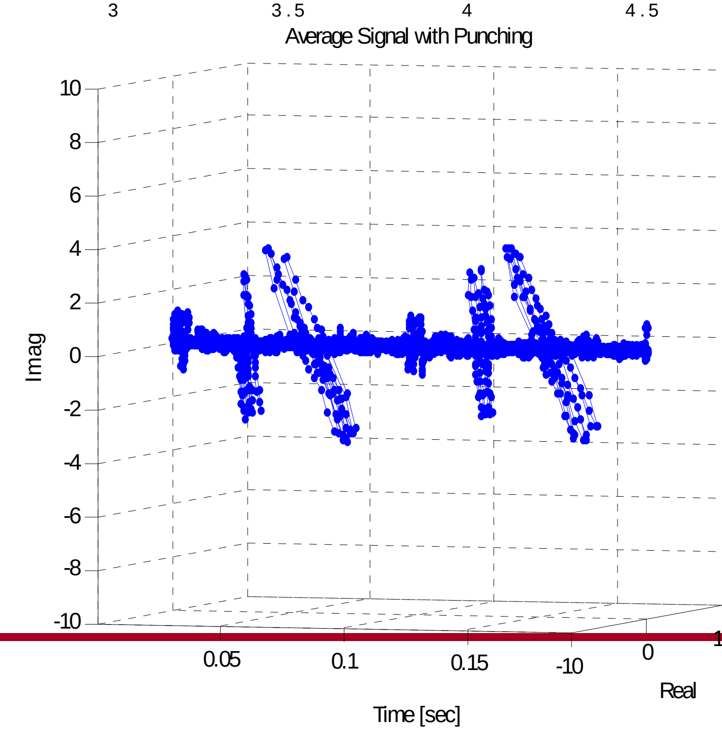
5 sec ~ 26 PCI



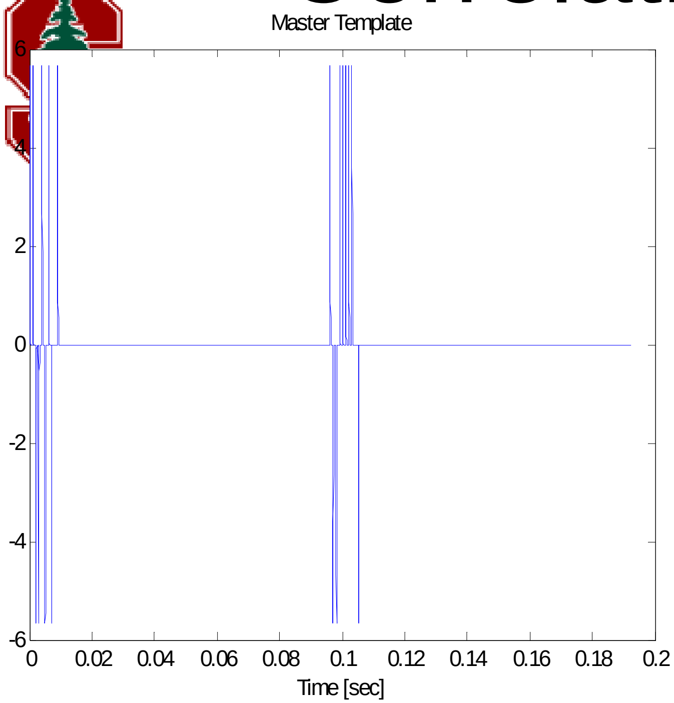
3 Processing Paths
1) Average to a single PCI
2) Set threshold, clip and then average
3) Set threshold, zero and then average

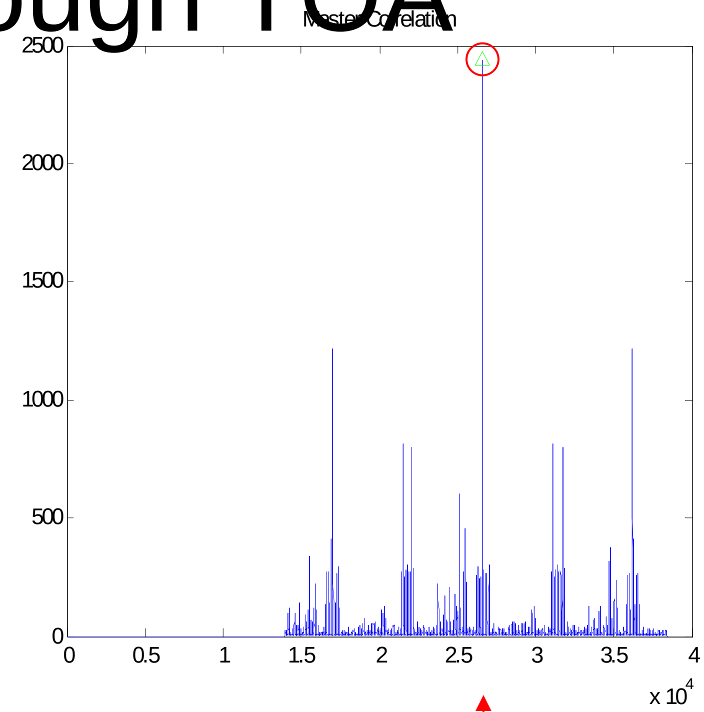
1 PCI



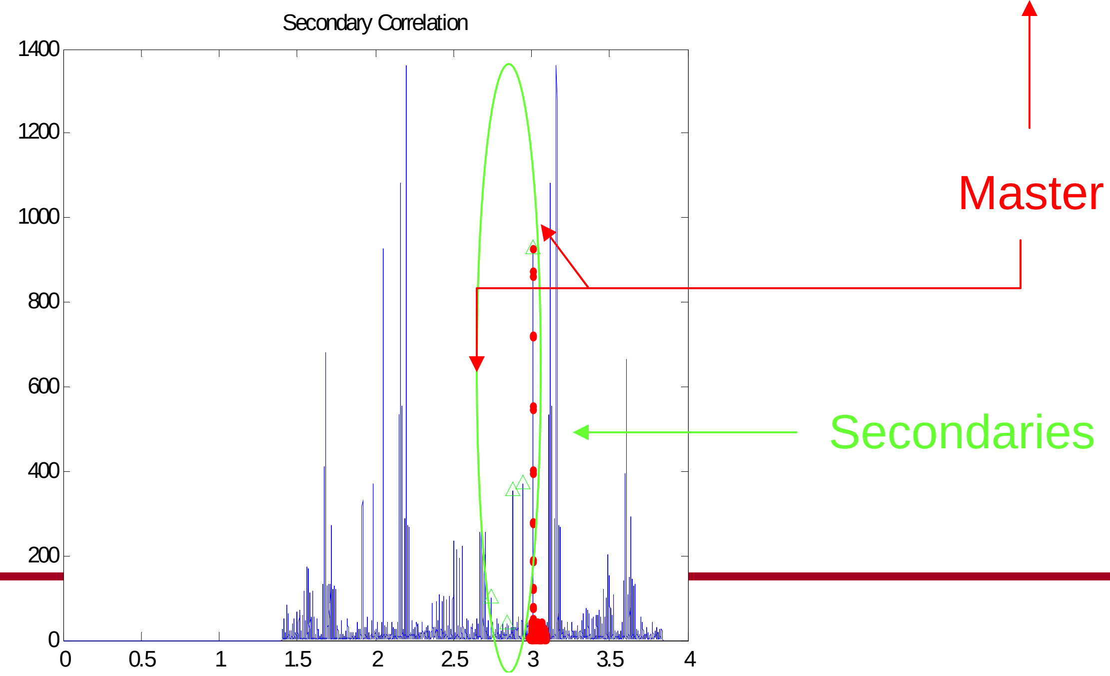


Correlation for Rough TOA

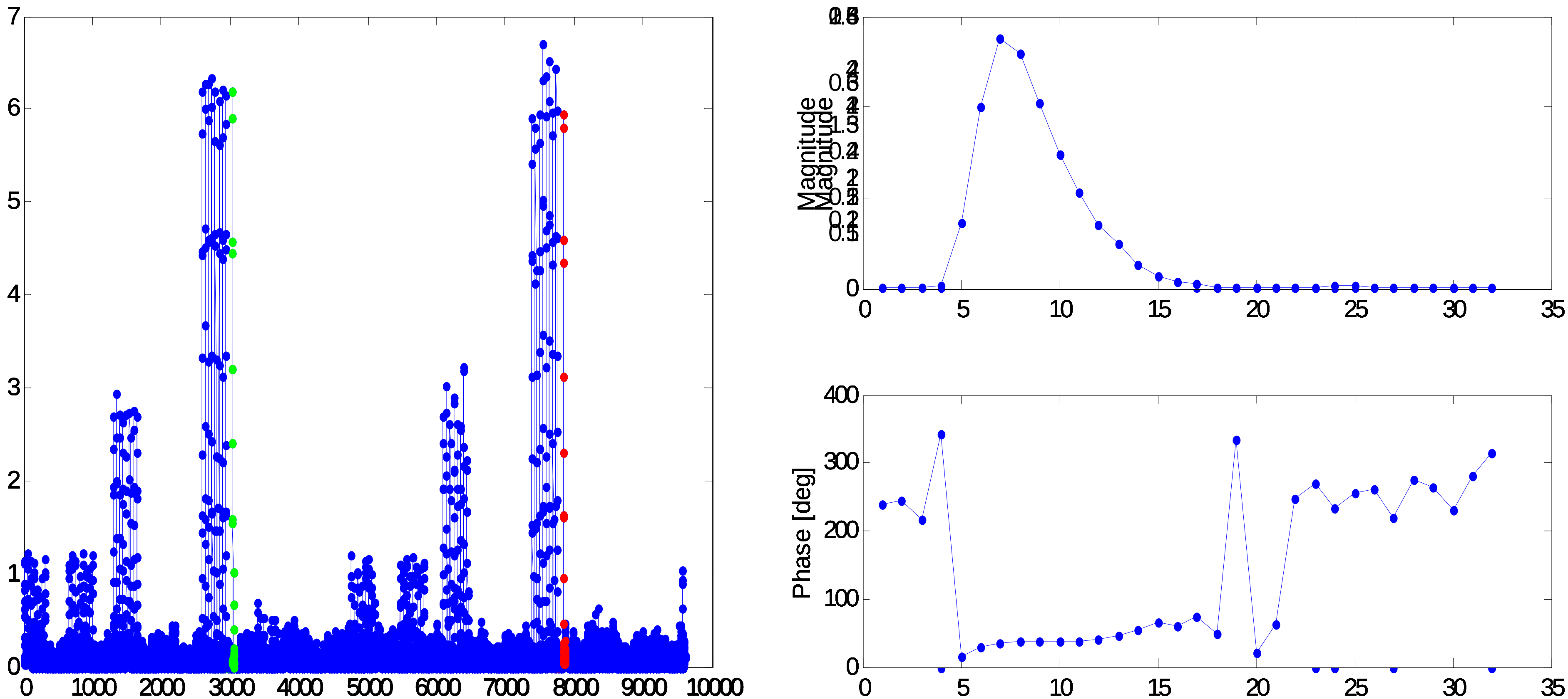




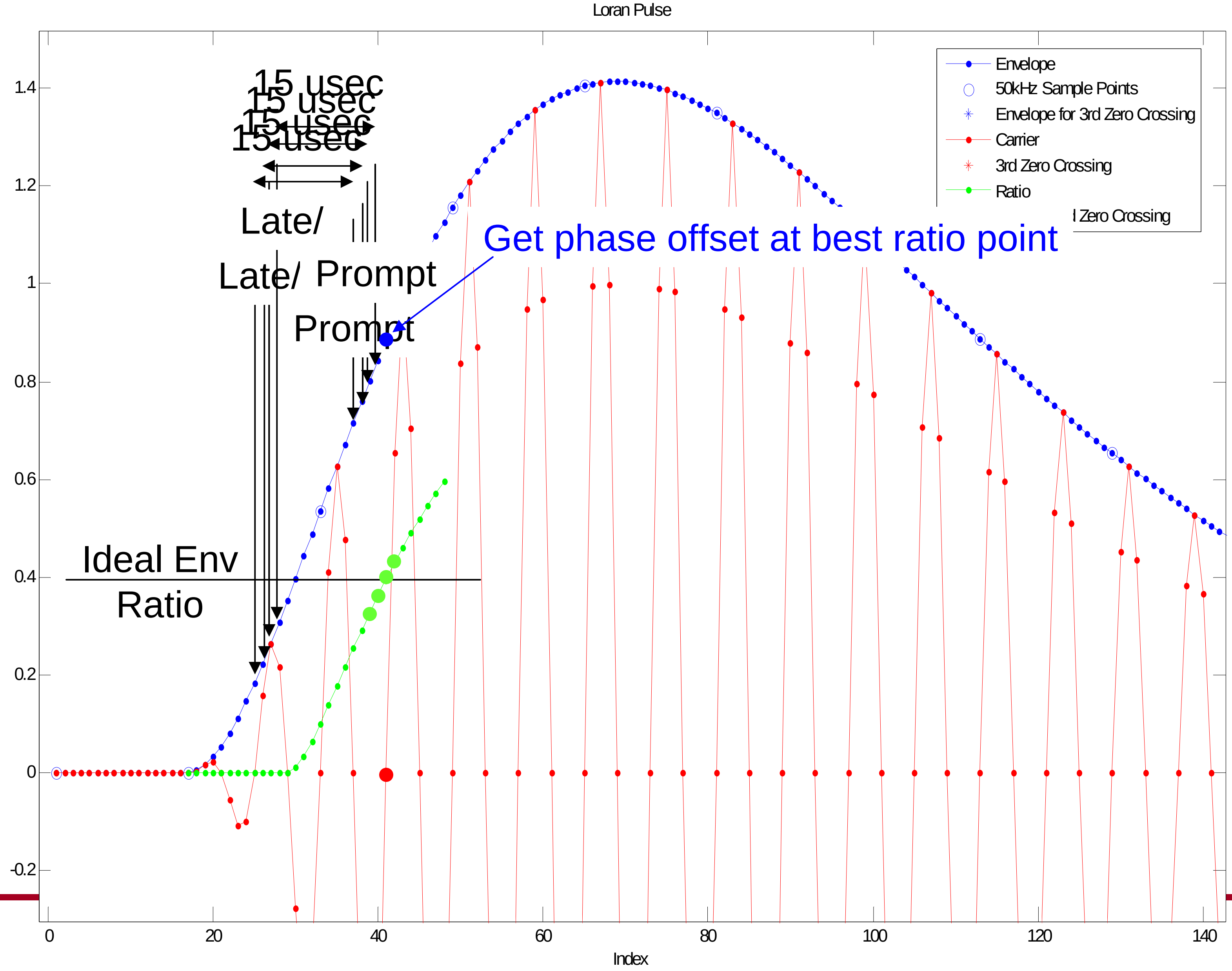
- Averaged data vector was doubled to prodcue an equivalent to circular correlation.



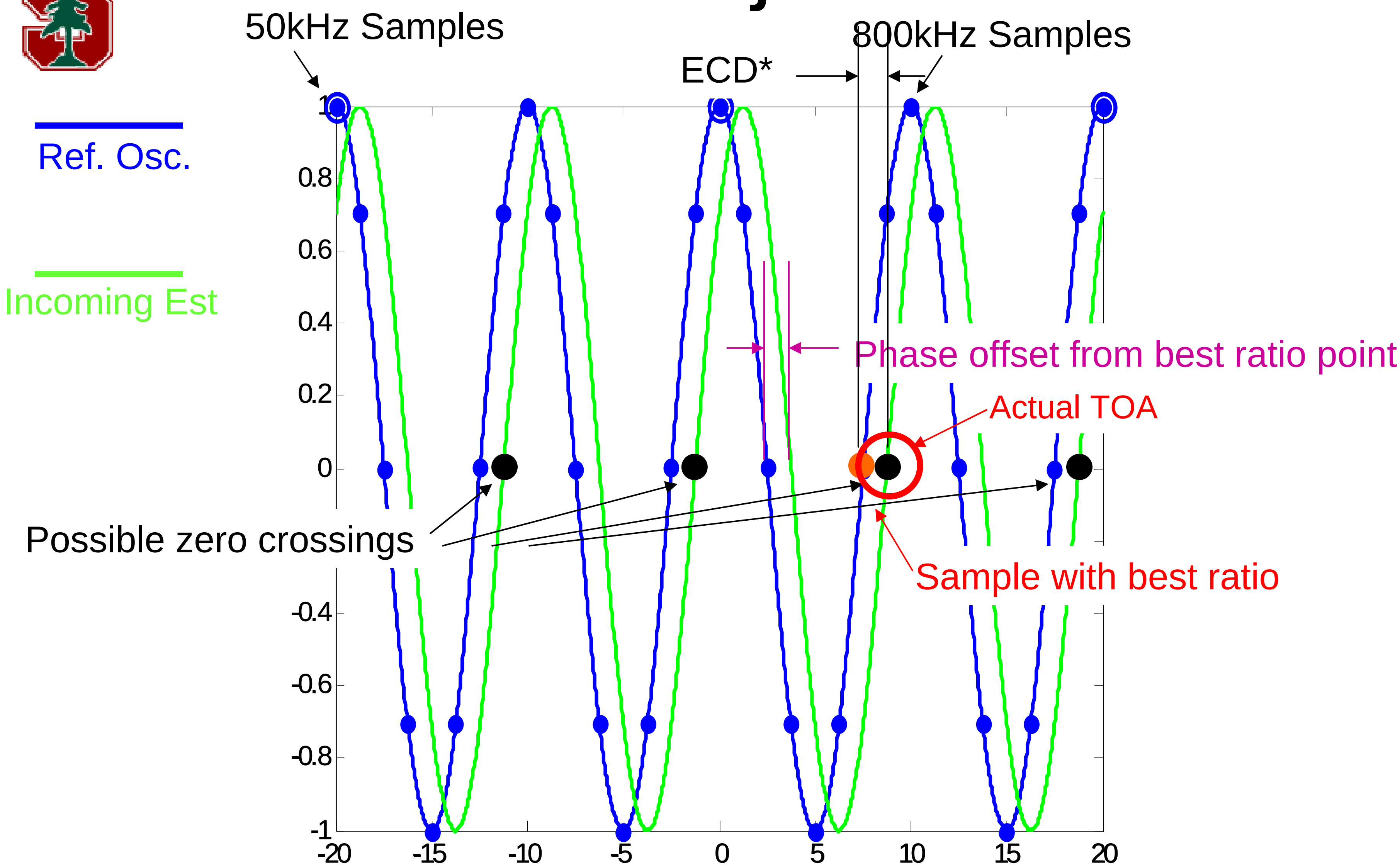
Average Pulses



Ratio Test (No ECD)



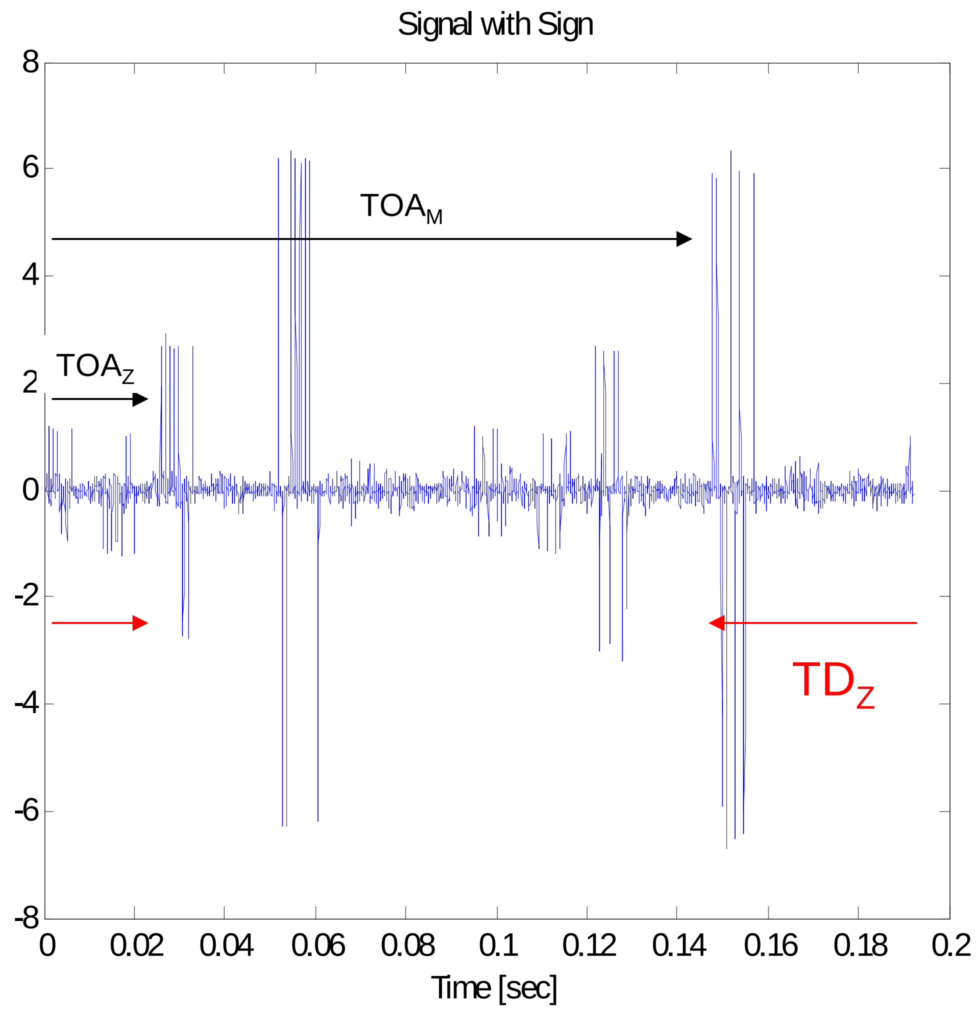
Phase Adjustment



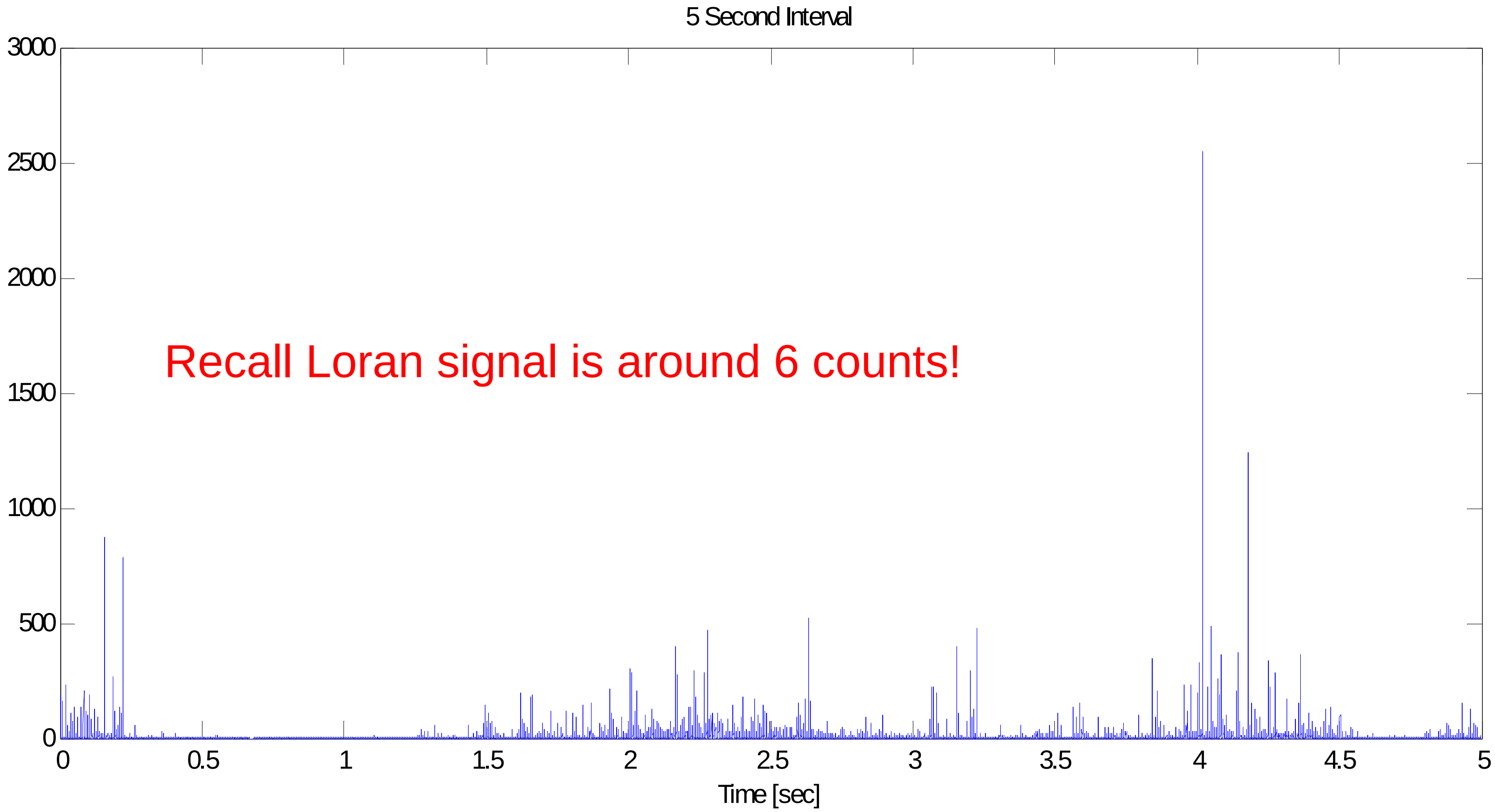
*Deviation from estimated ECD

TOAs

- Get TOAs
- Get TD
- Compare to simulated or nominal value

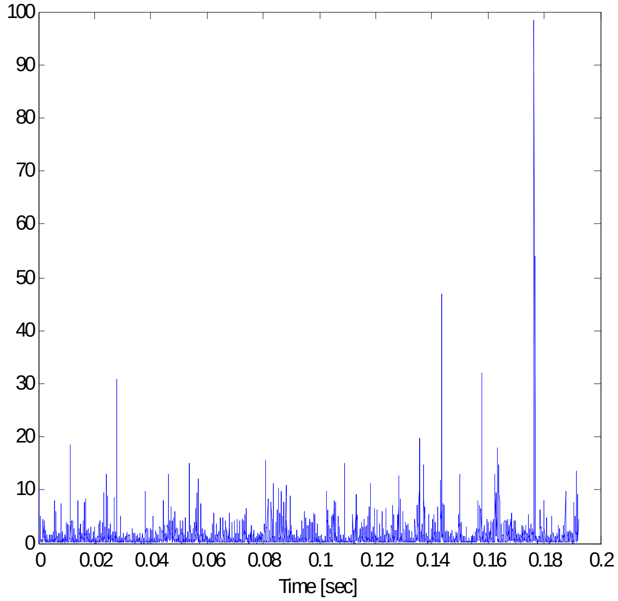


Noisy Data (13 June 2005 01:52:42 UTC)

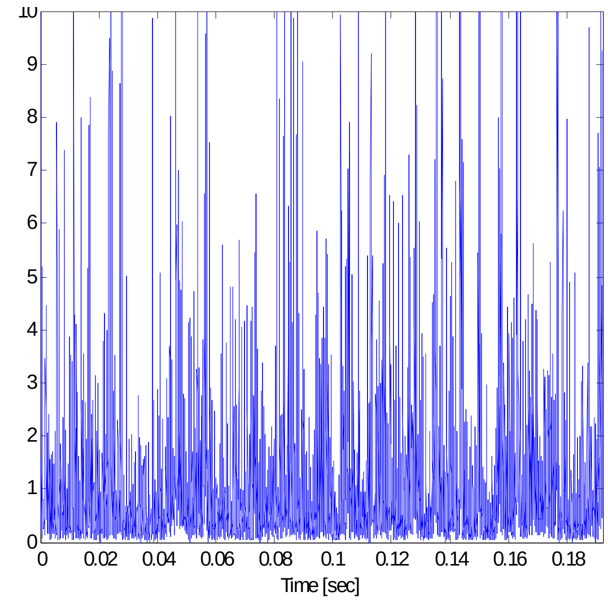


Averaging

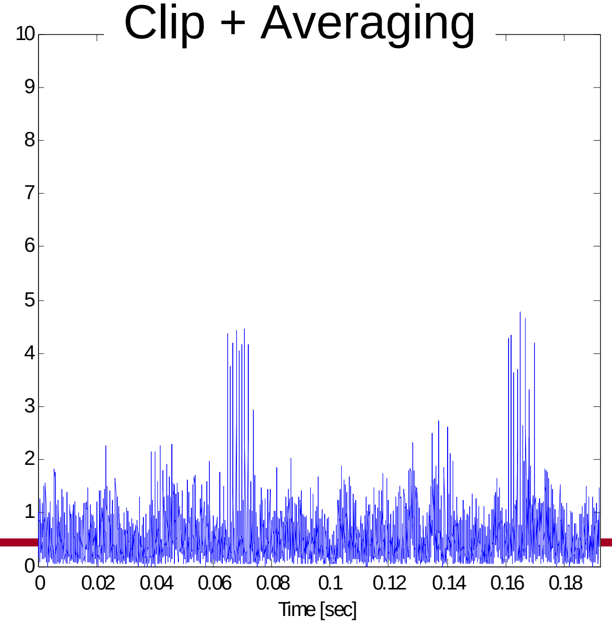
Straight Averaging



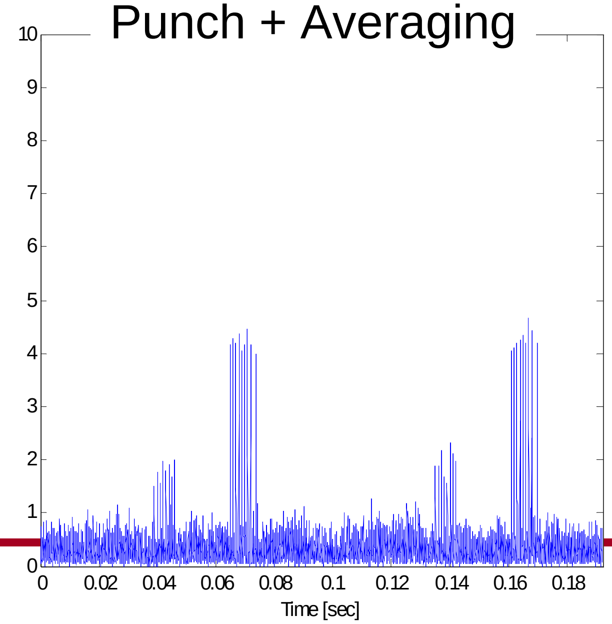
Straight Averaging (Close-Up)



Clip + Averaging

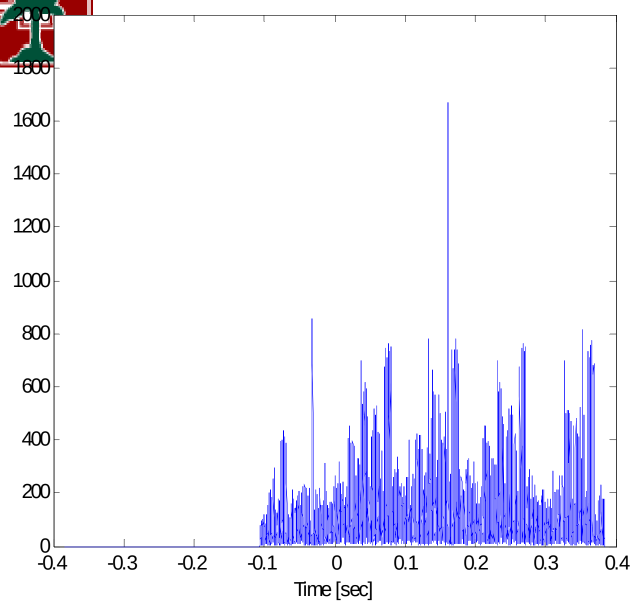


Punch + Averaging

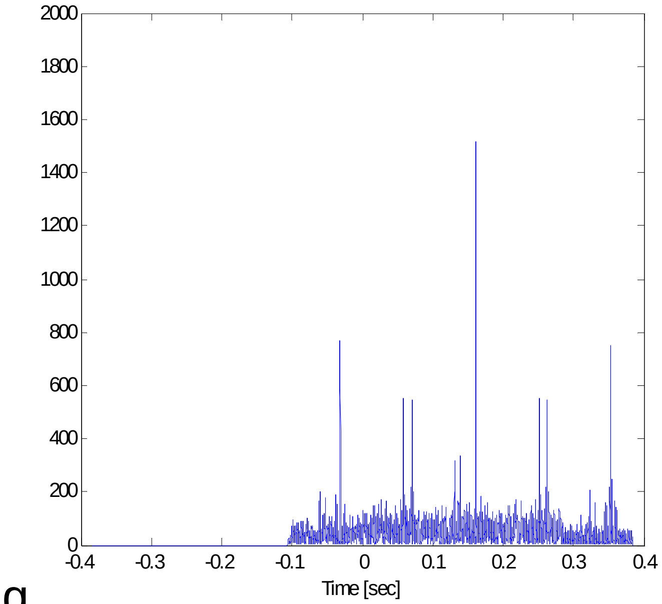


Master Correlation

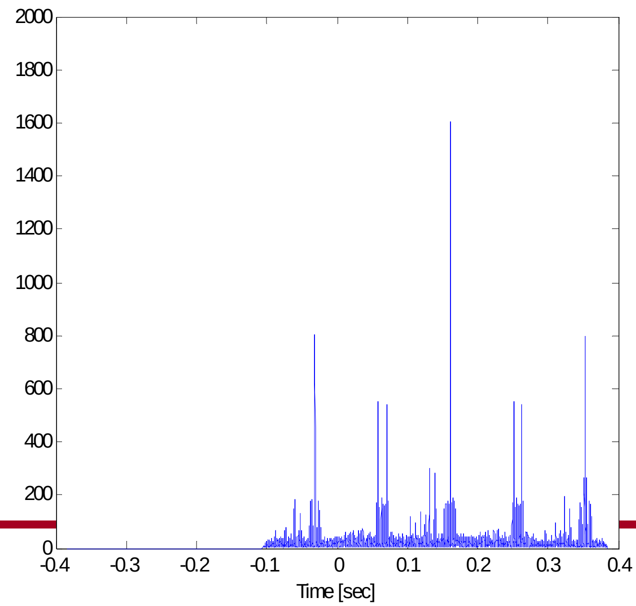
Straight Averaging



Clip + Averaging



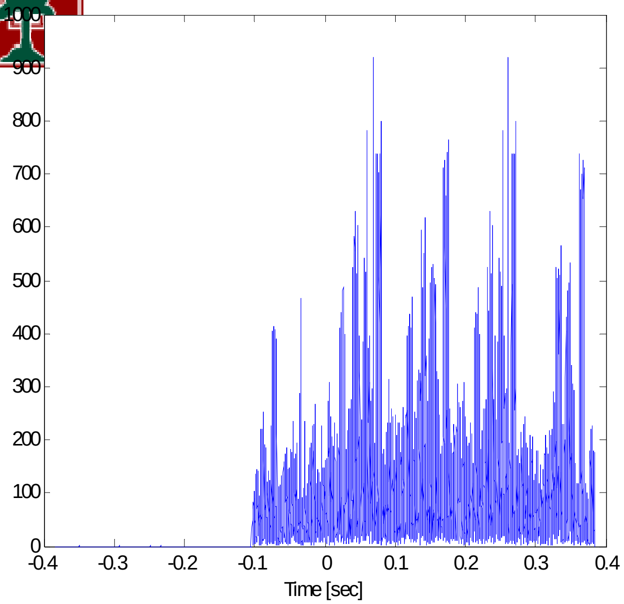
Punch + Averaging



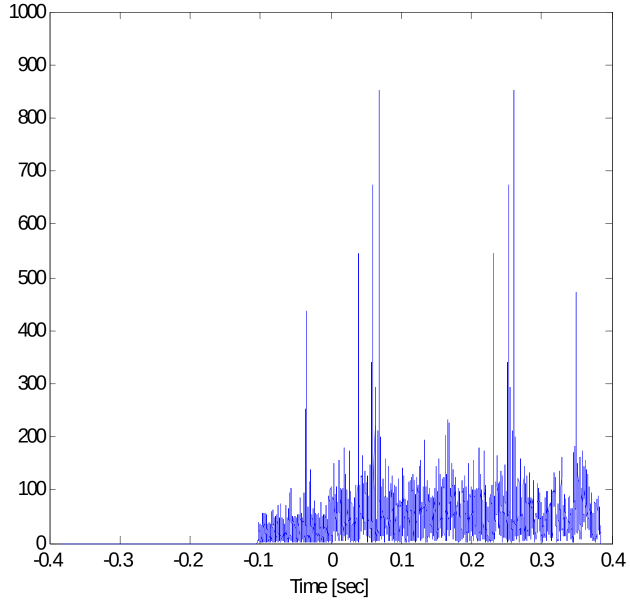
- Correlation works well when the noise power is constant. Here the noise spikes will give a large correlation value and will replicate the template.

Secondary Correlation

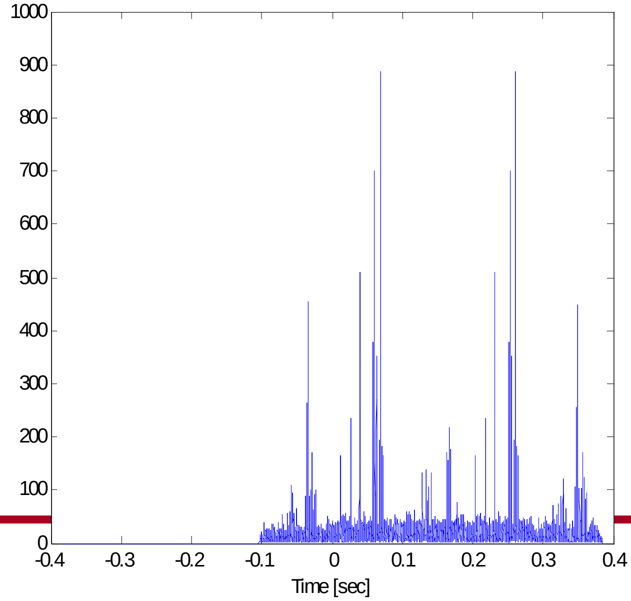
Straight Averaging



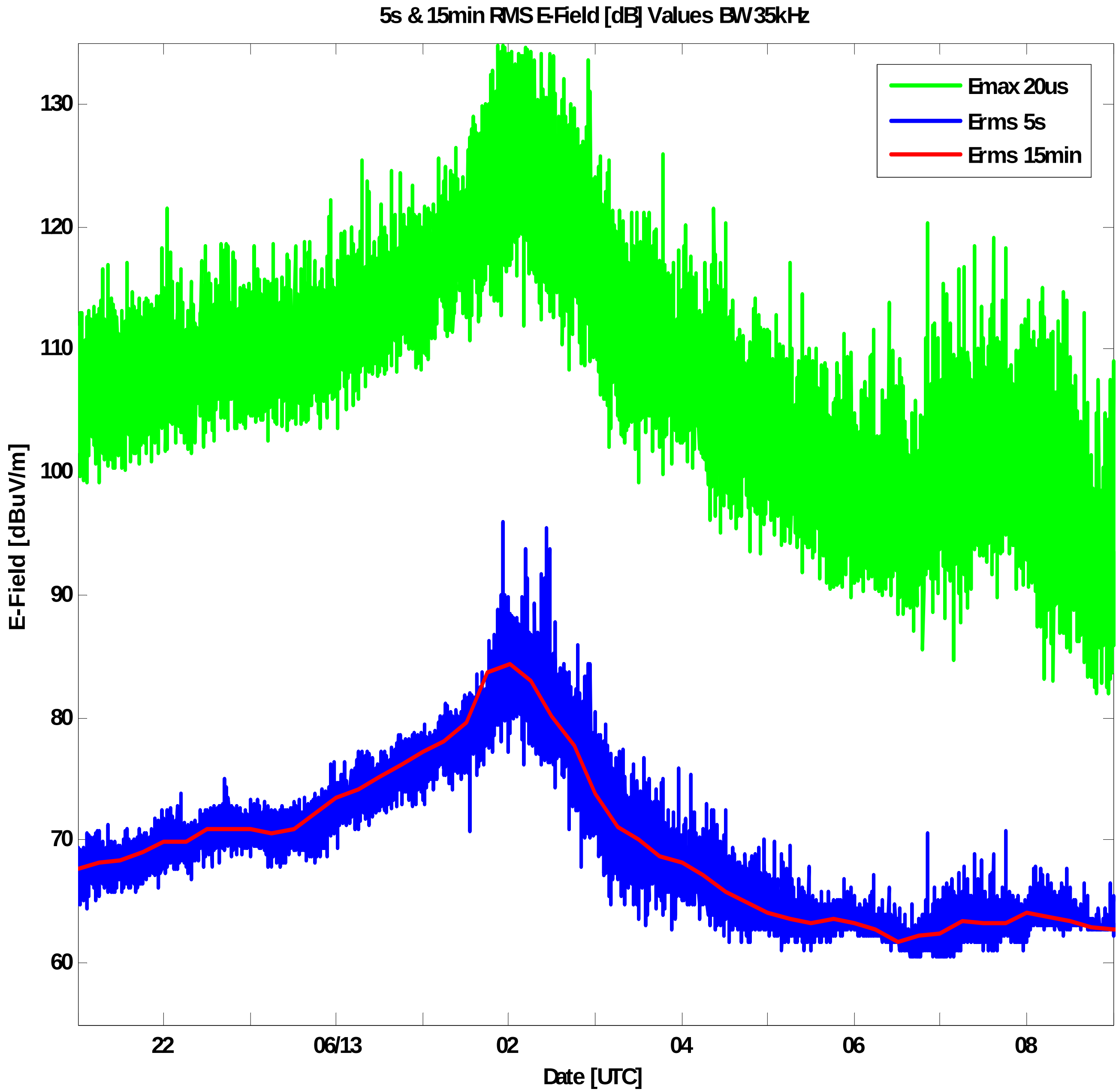
Clip + Averaging



Punch + Averaging

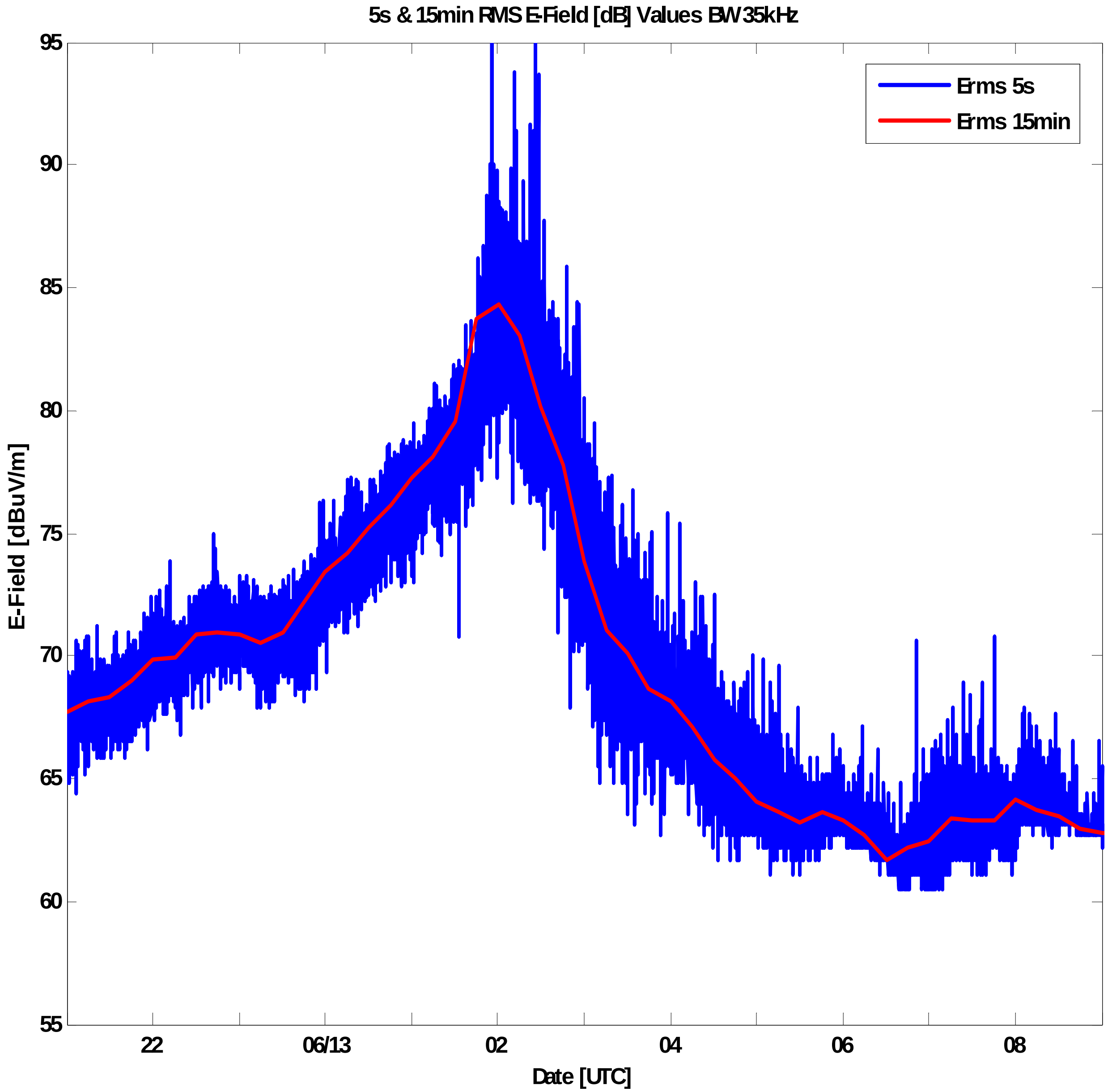


Voltage

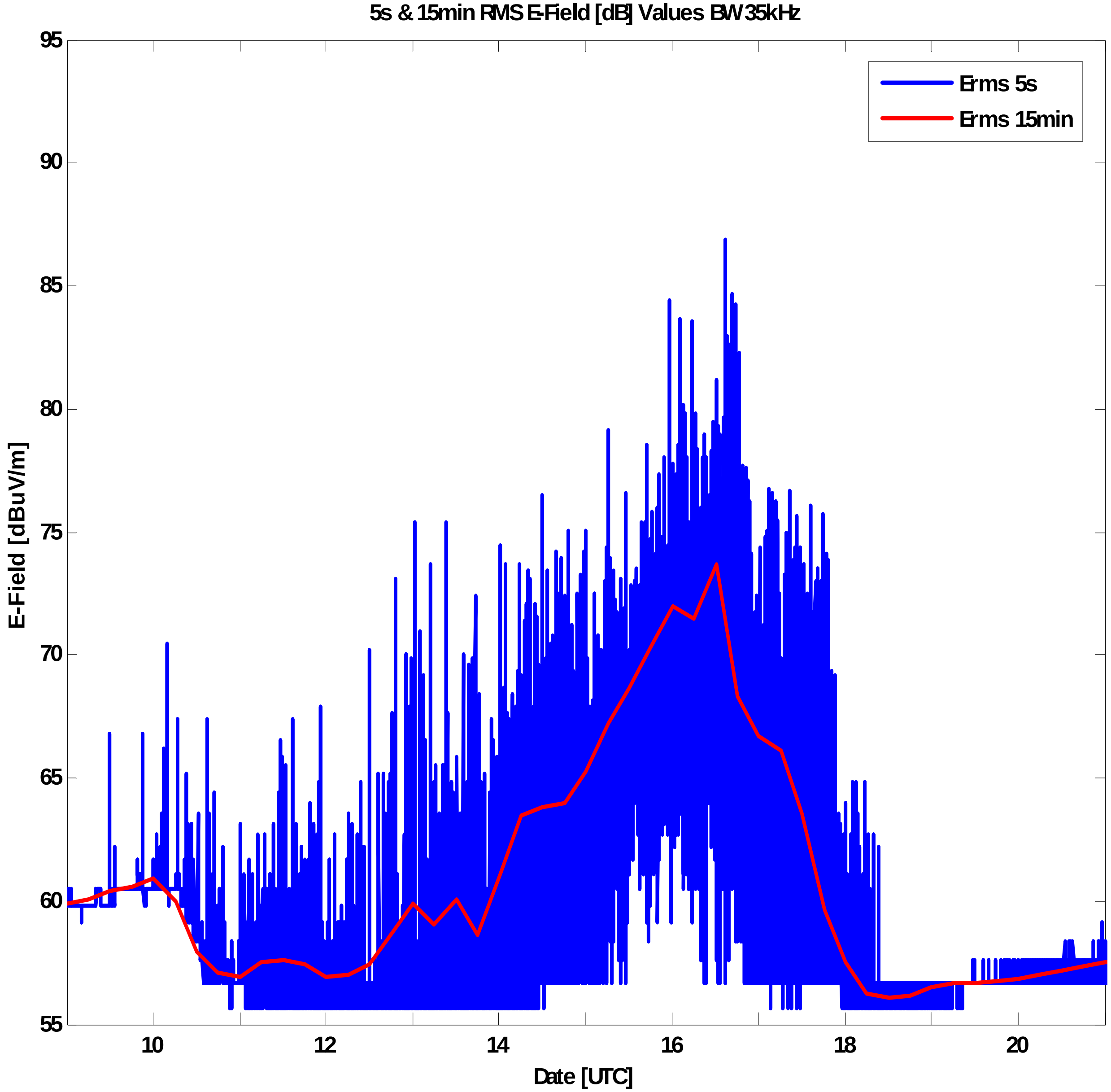


5s & 15min RMS E-Field [dB] Values BW 35kHz
Emax 20us
Erms 5s
Erms 15min
E-Field [dBuV/m]
130
120
110
100
90
80
70
60
22
06/13
02
04
06
08
Date [UTC]

Norman, OK - 13 June 2005



Norman, OK - 15 June 2005

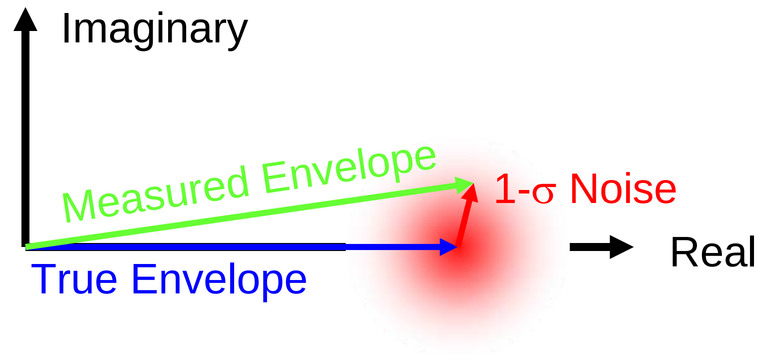


Analysis Parameters

- Simulated Loran signals
  - Quantization noise on actual signals caused more cycle slips than noise
  - Simulated signals similar to those measured in Norman, OK
  - Added Gaussian noise
- SNR – Defined as 20log10(SSP)
  - SSP – 25 usec point on envelope
- Tracking 30 usec point
  - Use phase at 30 usec to get TOA + mod(10us)
  - Use ratio at 15us/30us to determine which cycle
  - Cycle slip when wrong TOA is chosen

P[Cycle Slip] Gaussian Noise

- Given two ideal envelope values, add Gaussian noise inversely proportional to SNR



- Take ratio of two envelope values, 15 usec apart (e.g. 15 usec / 30 usec)

$$Ratio_{30usec} = \frac{\text{Meas. Envelope 15usec}}{\text{Meas. Envelope 30usec}}$$

- Compare to ratio of the envelope that is shifted by +/- 5 usec

$$Ratio_{25usec} < Ratio_{30usec} < Ratio_{35usec}$$

- Cycle slip if my ratio falls outside of range

Estimated Probability of Cycle Slip

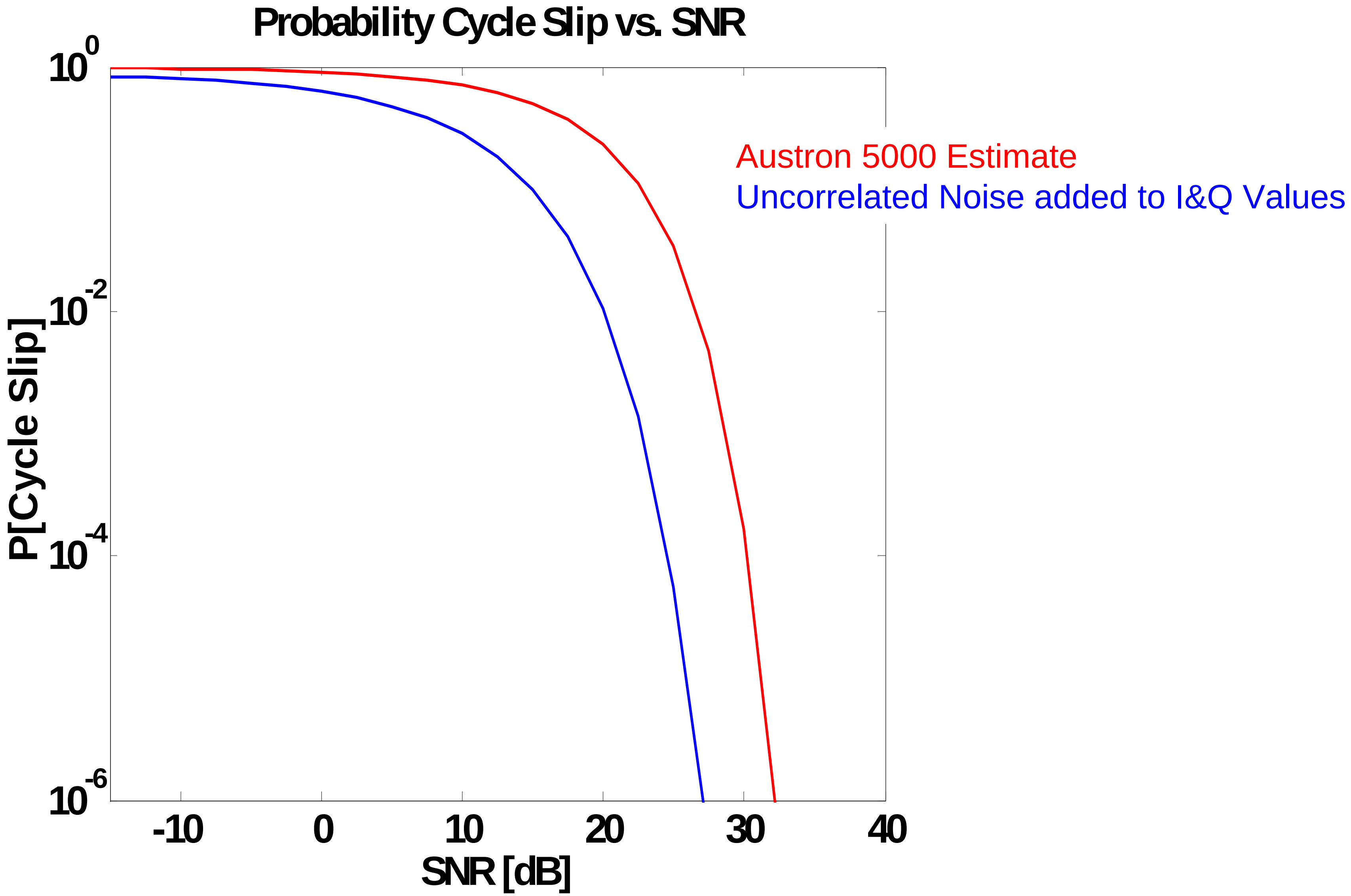
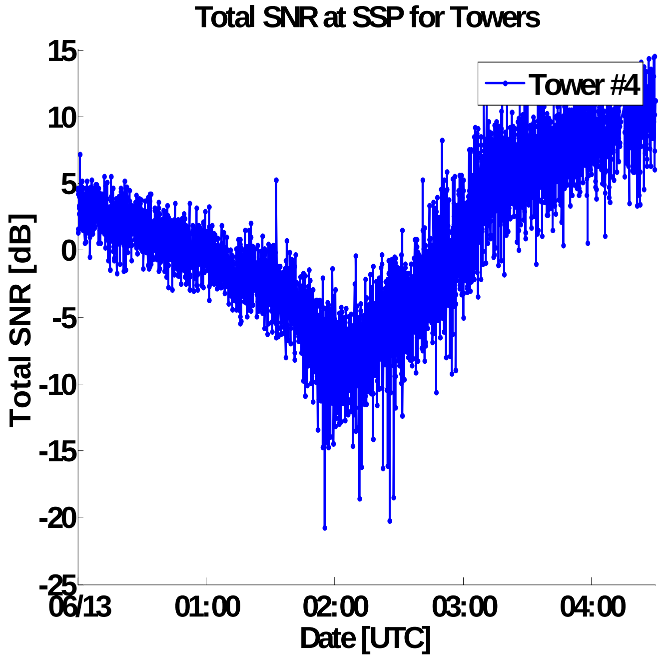
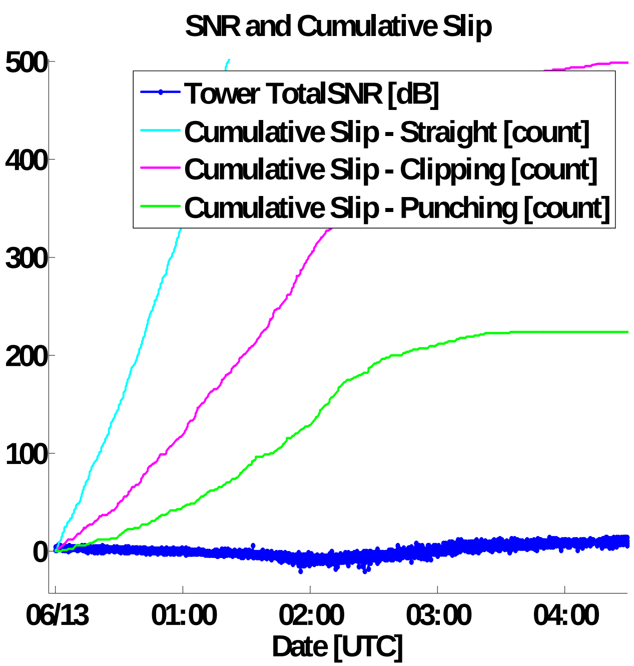
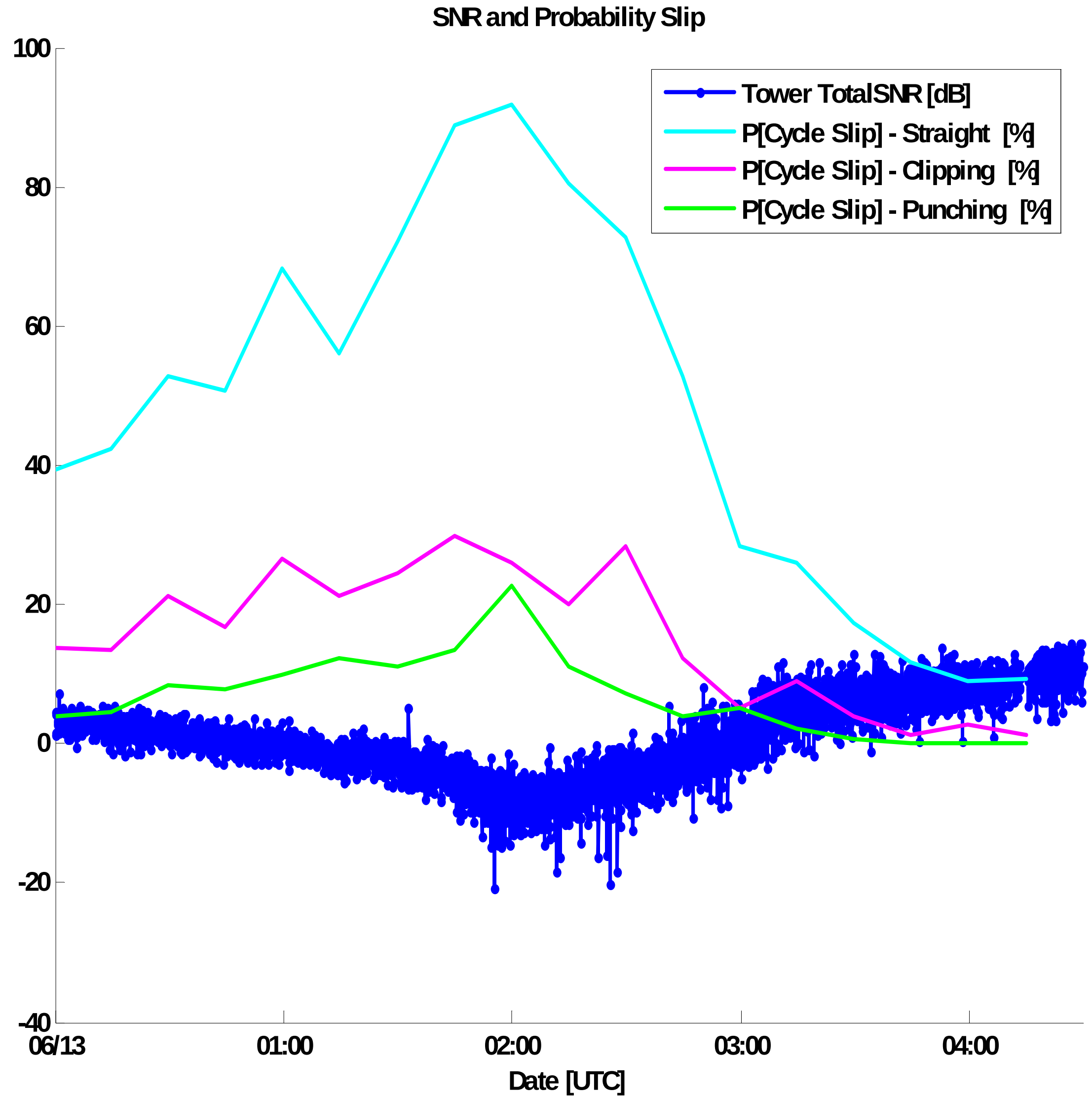


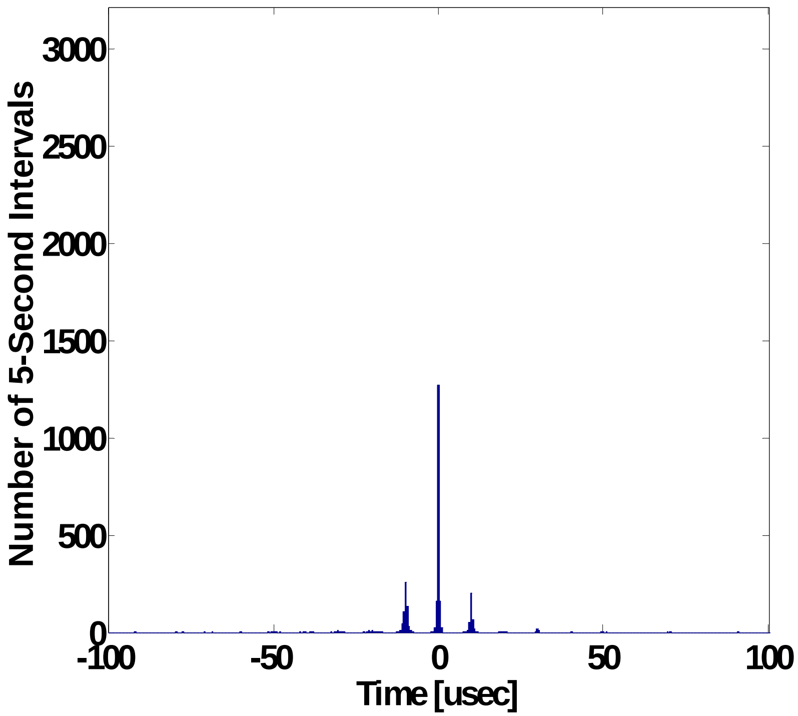
Table of P[Cycle Slip]

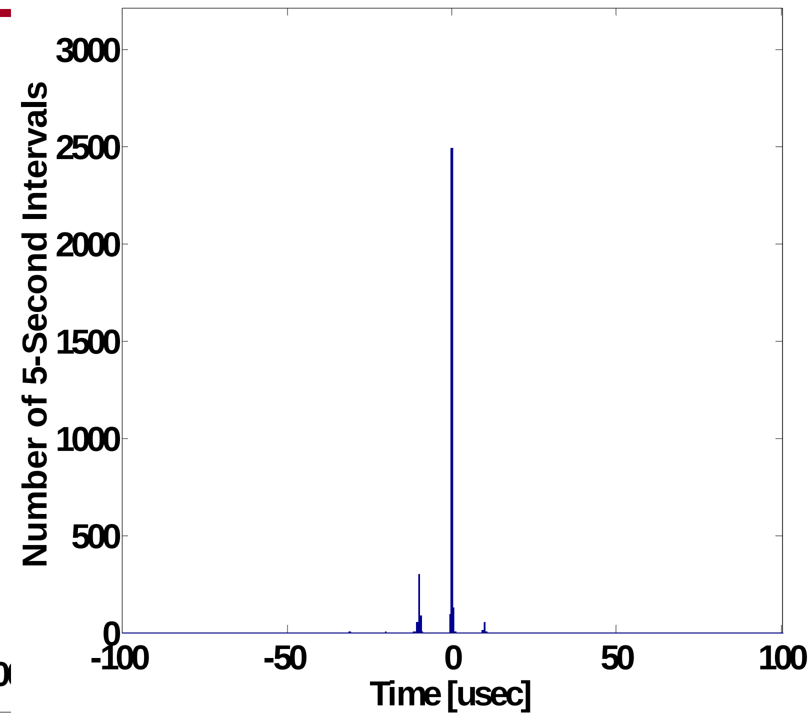
SNR	P[Cycle Slip]
-5	74%
0	63%
5	48%
10	28%
15	10%
20	1.1%
25	0.006%

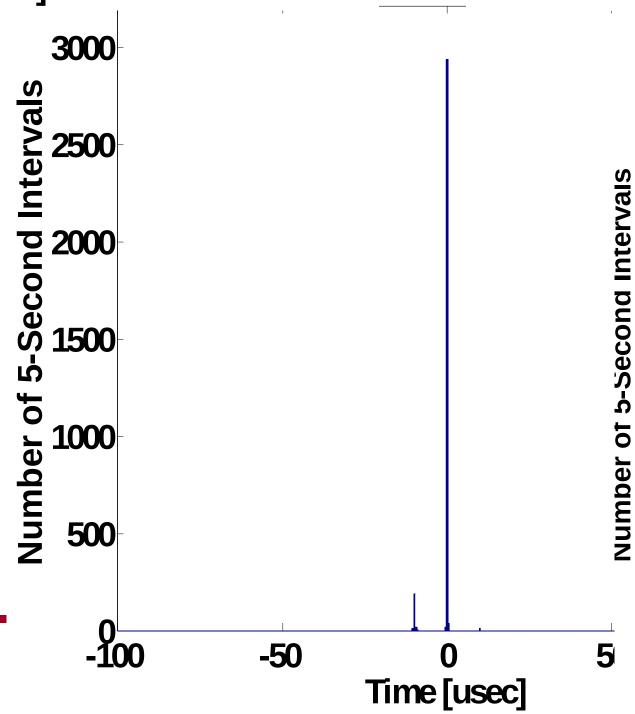

Total SNR at SSP for Towers
Tower #4
Total SNR [dB]
15
10
5
0
-5
-10
-15
-20
-25
06/13
01:00
02:00
03:00
04:00
Date [UTC]

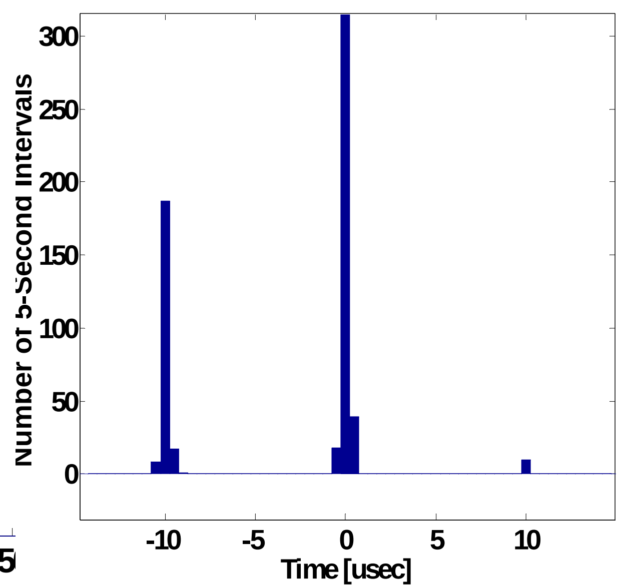

SNR and Cumulative Slip
Tower TotalSNR [dB]
Cumulative Slip - Straight [count]
Cumulative Slip - Clipping [count]
Cumulative Slip - Punching [count]
500
400
300
200
100
0
06/13
01:00
02:00
03:00
04:00
Date [UTC]


SNR and Probability Slip
Tower TotalSNR [dB]
P[Cycle Slip] - Straight [%]
P[Cycle Slip] - Clipping [%]
P[Cycle Slip] - Punching [%]
100
80
60
40
20
0
-20
-40
06/13
01:00
02:00
03:00
04:00
Date [UTC]

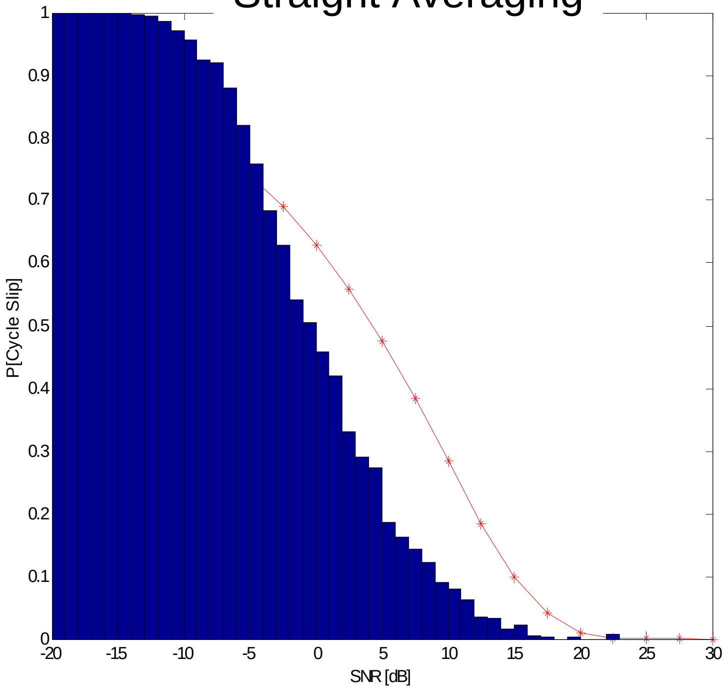

Number of 5-Second Intervals
0
500
1000
1500
2000
2500
3000
-100
-50
0
50
100
Time [usec]


Number of 5-Second Intervals
0
500
1000
1500
2000
2500
3000
-100
-50
0
50
100
Time [usec]

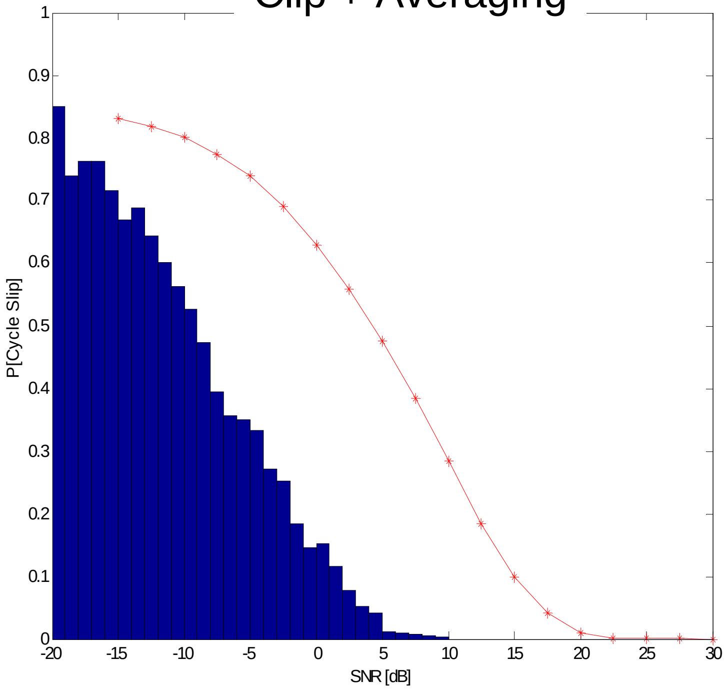

Number of 5-Second Intervals
0
500
1000
1500
2000
2500
3000
-100
-50
0
Time [usec]


0
50
100
150
200
250
300
-10
-5
0
5
10
Time [usec]

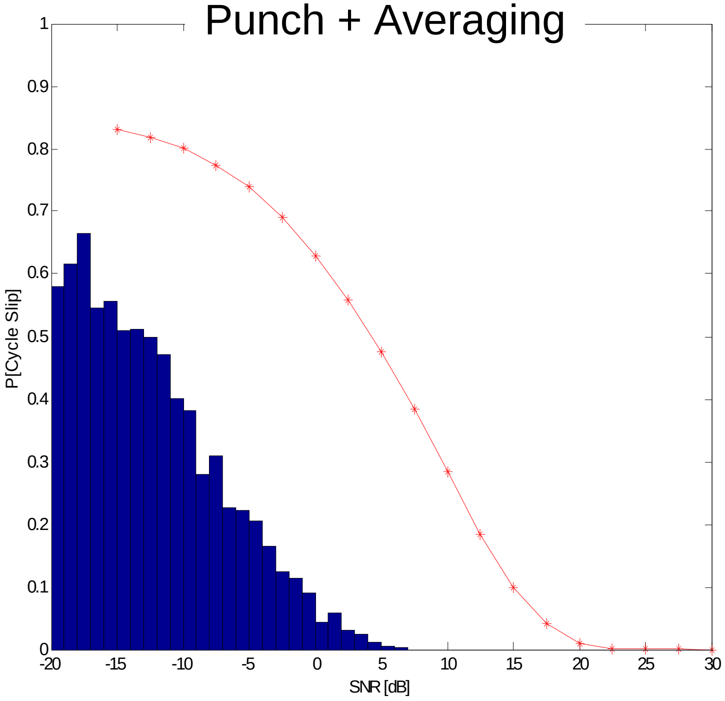
Straight Averaging



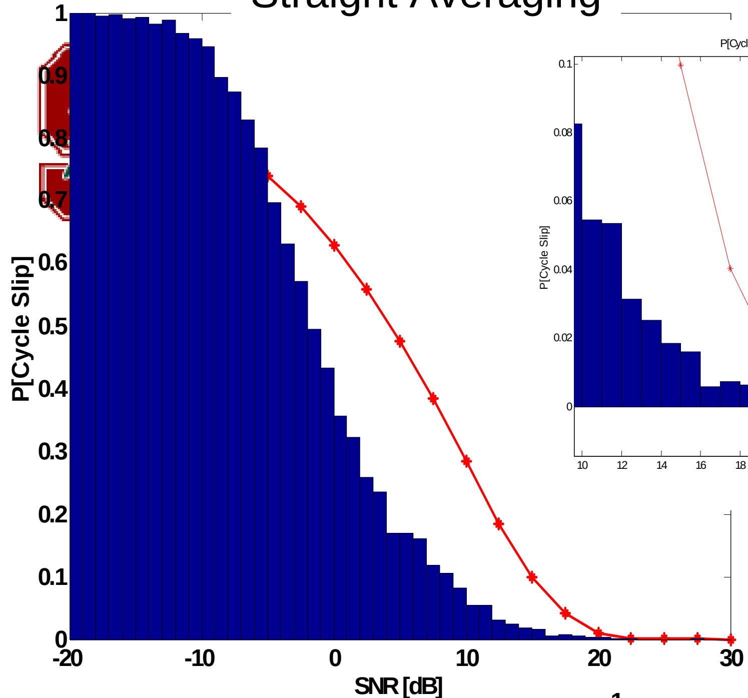
Clip + Averaging



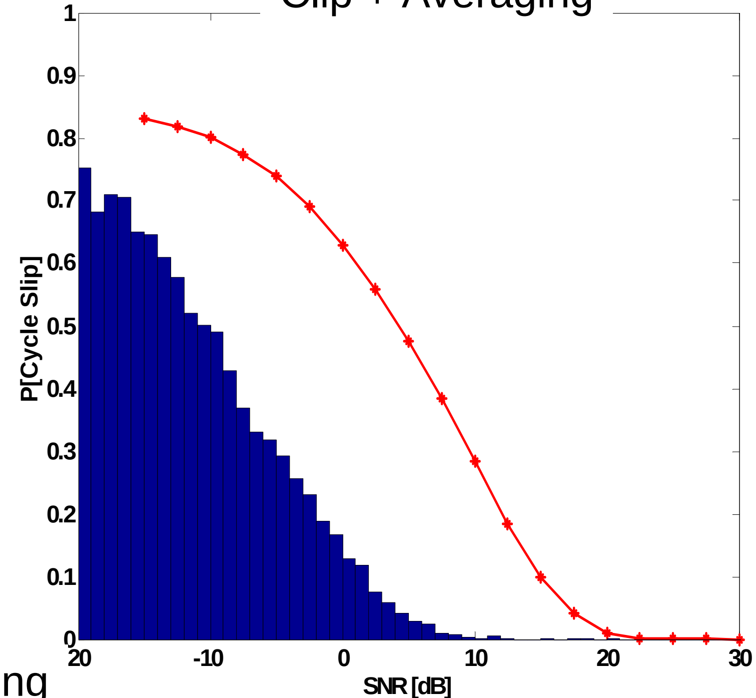
Punch + Averaging



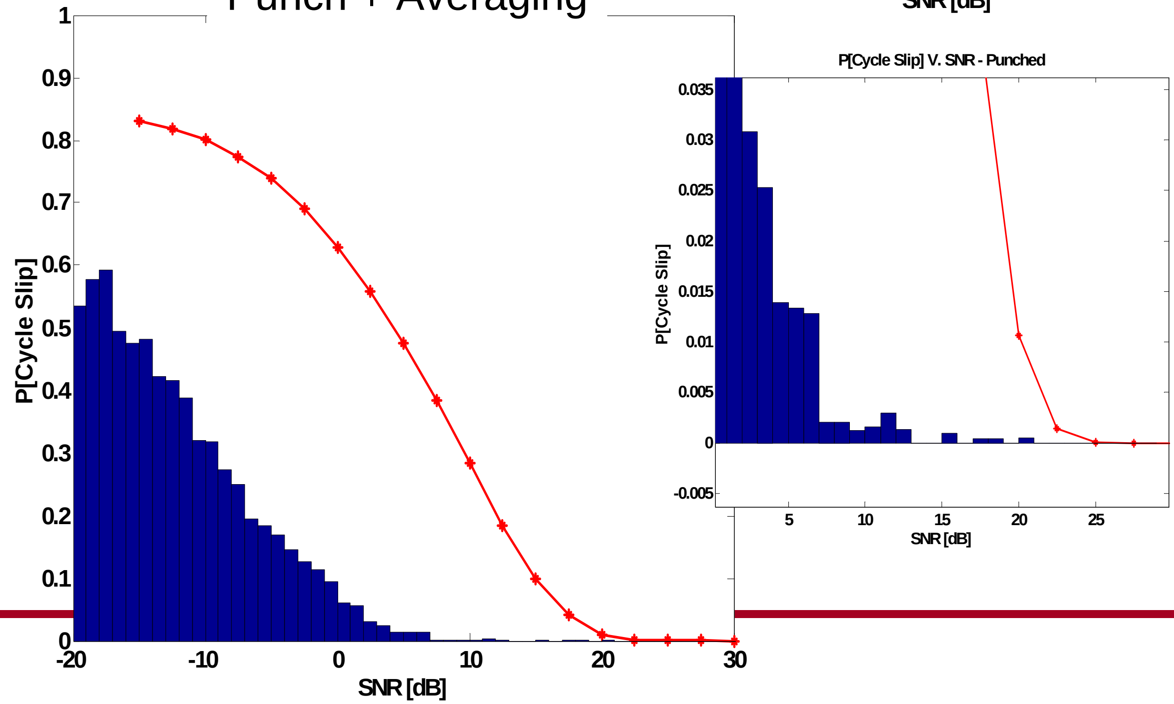
Straight Averaging



Clip + Averaging



Punch + Averaging



Conclusions

- Data compares well with CCIR
  - E_{rms} is averaged over 15 minutes
  - V_d gives distribution of data on the short term
- Processing credit
  - Results using real data are close to initial estimates
  - Details of the credit are still being investigated
    - Improvement to availability
    - Improvement to integrity

Receiver Challenge

- Data will be made available on the FAA website
- Run receiver designs against this data set of noise (50kHz I & Q).
- Design issues
  - Use of RAIM
  - Use of INS
  - Effects of corona
  - Evil waveforms
  - Correlator spacing
  - Etc…

Thanks!

- Mitch Narins – FAA, Loran Program Office
- Dr. Ben Peterson – Peterson Integrated Geopositioning
- Dr. William Beasley – University of Oklahoma
- Dr. William Winn – Langmuir Lab/New Mexico Institute of Mining and Technology
- Dr. Demoz Gebre-Egziabher University of Minnesota
- Dr. Uman Inan – Stanford University
- Vaisala & Unidata – National Lightning Detection Network Data
- Plymouth State – NEXRAD data

Disclaimer

-Note- The views expressed herein are those of the authors and are not to be construed as official or reflecting the views of the U.S. Coast Guard, the U. S. Federal Aviation Administration, or the U.S. Department of Transportation or the U.S. Department of Homeland Security.

Backup Slides

Evil Waveform