Progress Towards a ULF Common Mode Signal Estimator with a network of sensors in California

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Talk Outline

- Acknowledgements
- Problem Statement
- Experiment Design
- Experiment Results
- Summary & Future

Acknowledgements

With thanks:

Many people have contributed to this study:

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"Much of what will be shown today has been published before, but here it is deployed as an operational system"

A **HARD** Problem

Problem Statement:

- Build a network of ULF sensors in California to establish if **repeatability** of Loma Prieta signal exists.

Problem Aspects:

-**Daily/Seasonal/Storm variations** of ULF signal are large and complex.

-**Cultural Noise** comes in many flavors, very often strong **impulses**.

-Large **earthquakes**, are **sparse** and **widely distributed** geographically.

-**Huge amounts of data** require parallel processing to attain expedient results.

-**Instrument quality** extremely difficult to test.

Why "Common Mode?"

Typical Goal:

- To remove as much of the Common Mode as possible to reveal "weaker" signals.

Dangerous Hidden Assumption:

- That an earthquake-related electromagnetic signal is either seismo-genic or localized.

Assumption Needs Verification!

- ERGO: Design of experiment is very important

Experiment Design

Investigation Plan:

"Empirical Experiment"

Today
Future

- Per-Coil: RMS and Impulse Occurrence.

- Per-Site: Azimuth and Polarization Ratio.

- Network: Coherence, ISTF, & Cross-phase

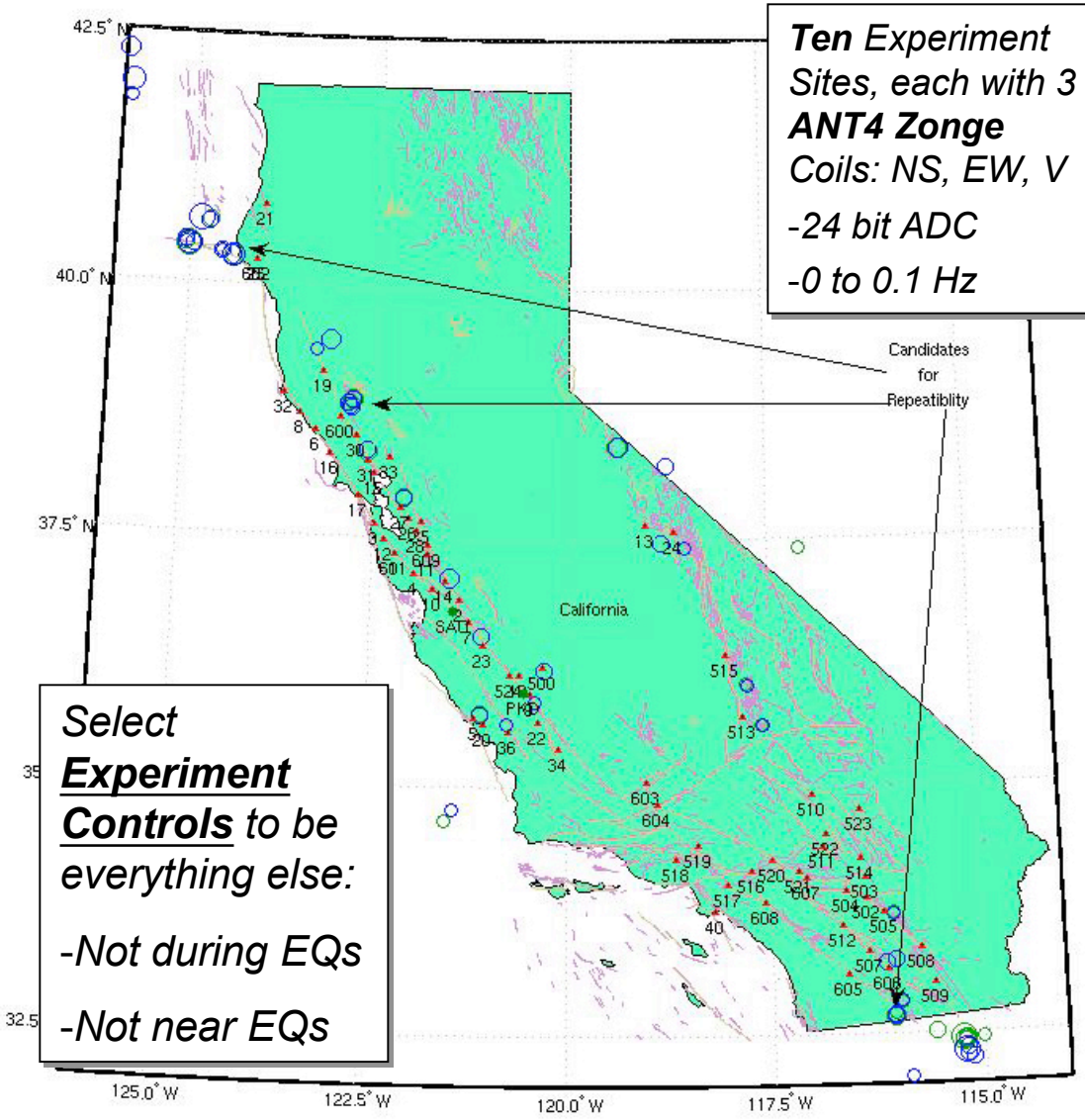
Coherence Buster Suspects:

"Work in Progtess"

- Time of Day Variance
- Solar Storm
- Pc1-4, Pi's, FLHR
- Cultural Noise
- B.A.R.T.
- *Earthquakes?*

Experiment Design

2006/02/20 – 2007/05/30, mag > 4.0



***Ten** Experiment Sites, each with 3 **ANT4 Zonge** Coils: NS, EW, V*

-24 bit ADC

-0 to 0.1 Hz

*Select **Experiment Controls** to be everything else:*

-Not during EQs

-Not near EQs

Select nine-day (9) blocks of data:

7 before earthquake

+

Day of earthquake

+

Day after quake

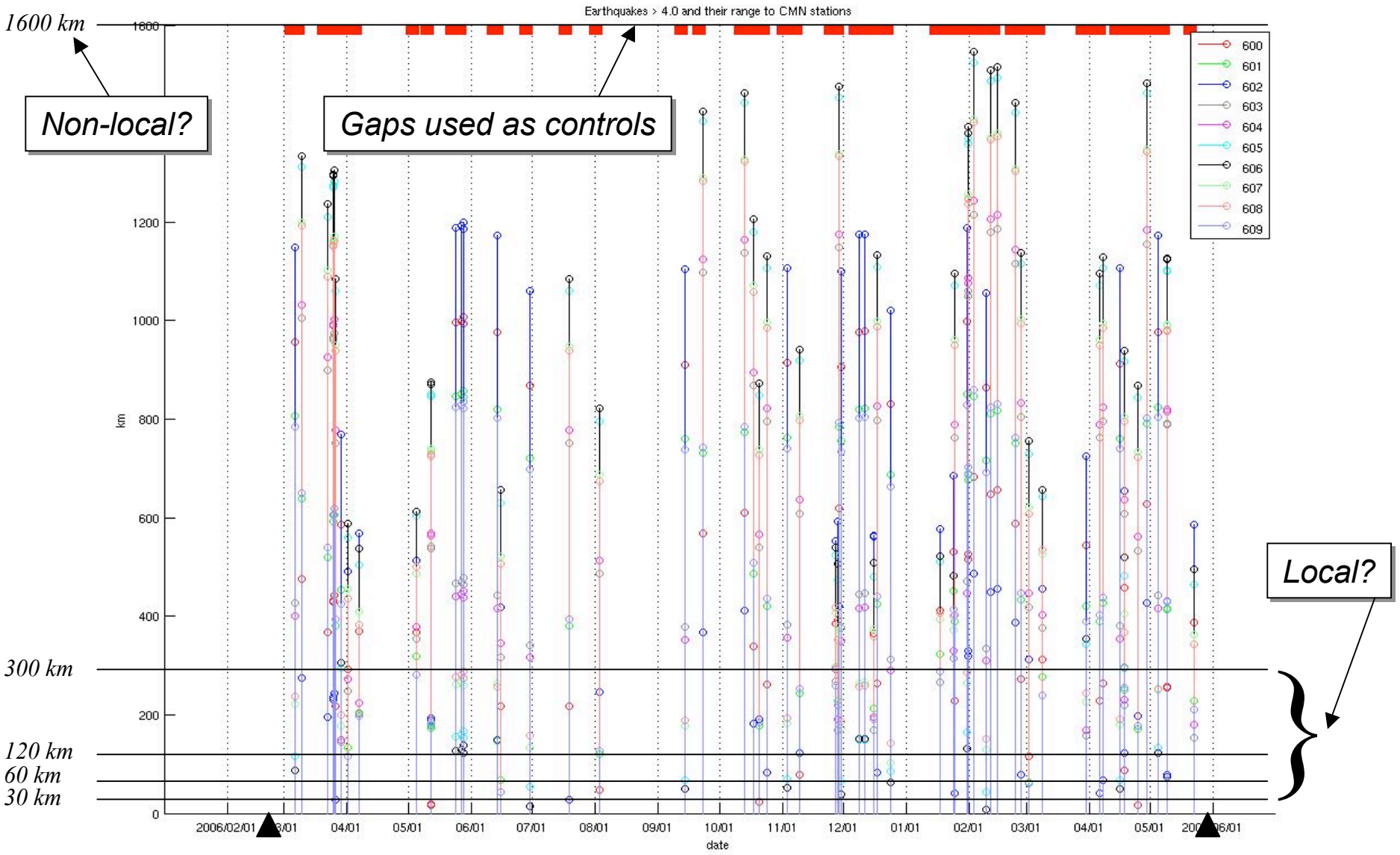
= _____.

Nine day blocks

1600 x 1600 km region

"Not much seismic action in California lately" - **anon**.

Experiment Results



Experiment Results

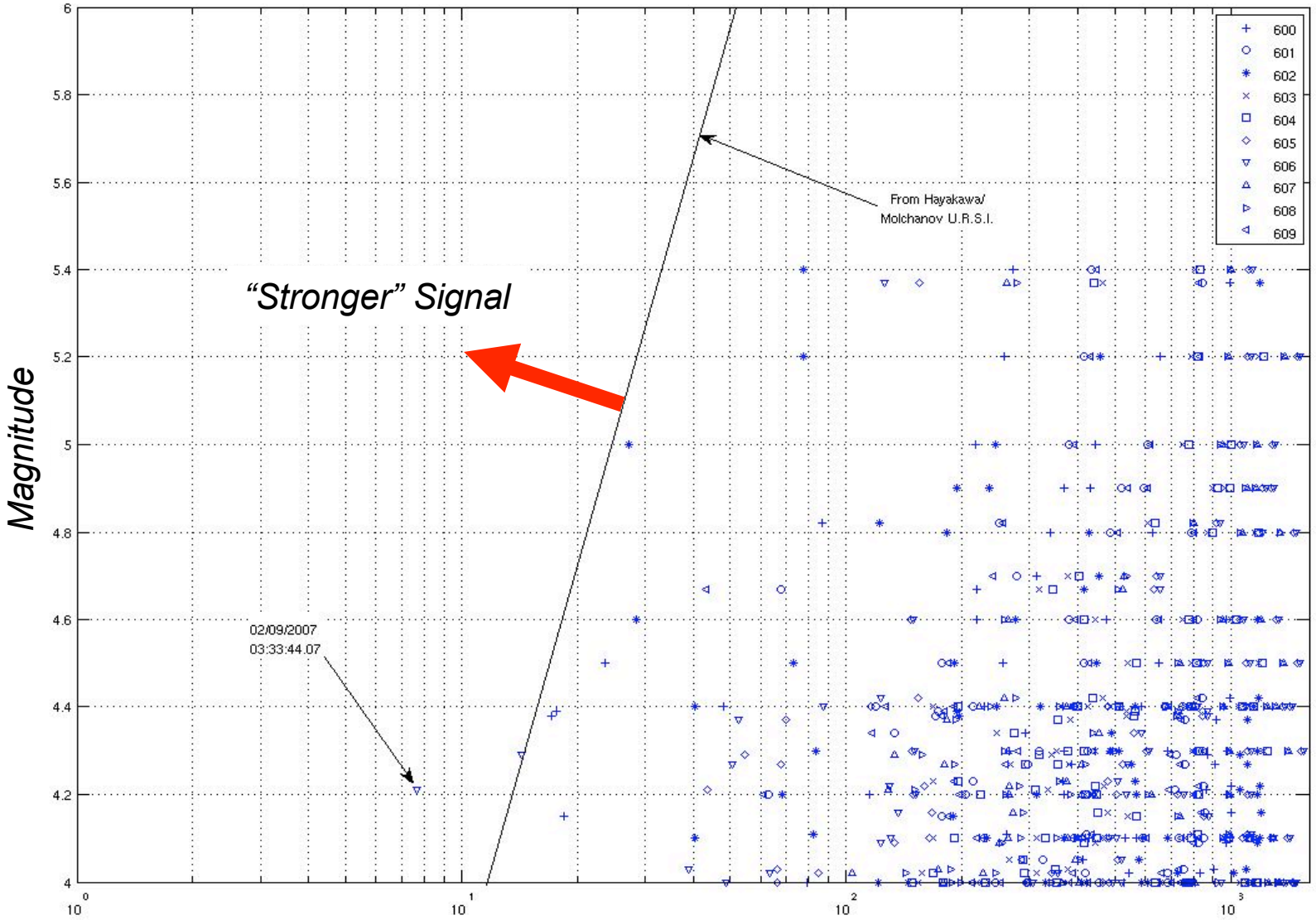
Experiment Variables

Minimum Magnitude:
1-5.4 Chose >4.0, 66 found (NEIC/NCEDC merge)
Earthquake Ranges:
30, 60, 120, 300, 1600(all)
Experiment Length:
7 pre + 1 EQ day + 1 post

	1600 km	*60 km*
Experiments	**70**	**16**
Controls	**220**	**642**

Experiment Results

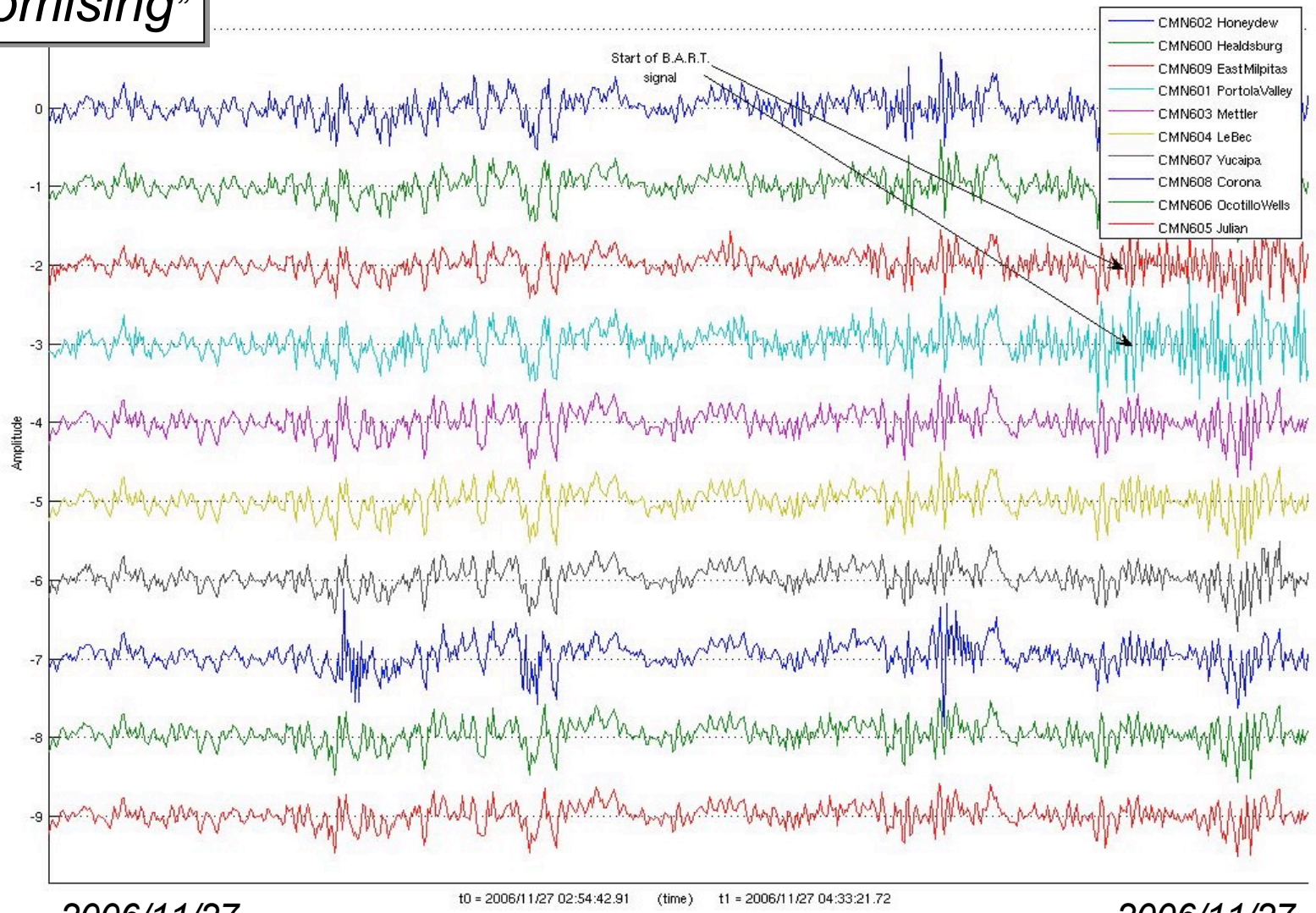
All earthquakes > 4.0, 2006/02/20 – 2007/05/30



Decimated Waveforms

"Promising"

Decimated to have ~0.1 Hz Sample Rate



Uncompensated Volts

North

South

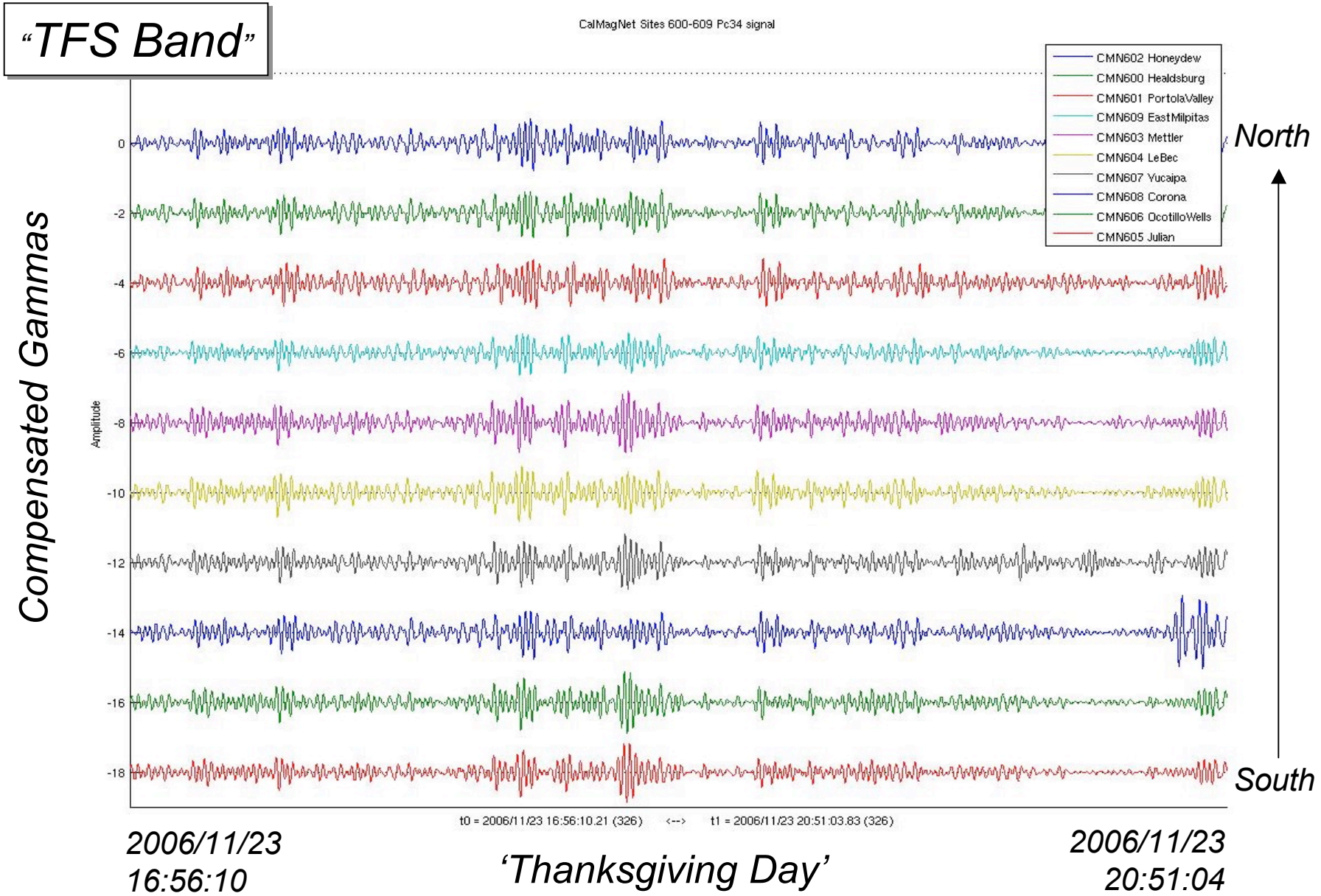
2006/11/27 02:54:43

'Wee hours of the morning"

2006/11/27 04:33:22

Band-pass Waves 0.005-0.02 Hz

"TFS Band"



Compensated Gammas

North

South

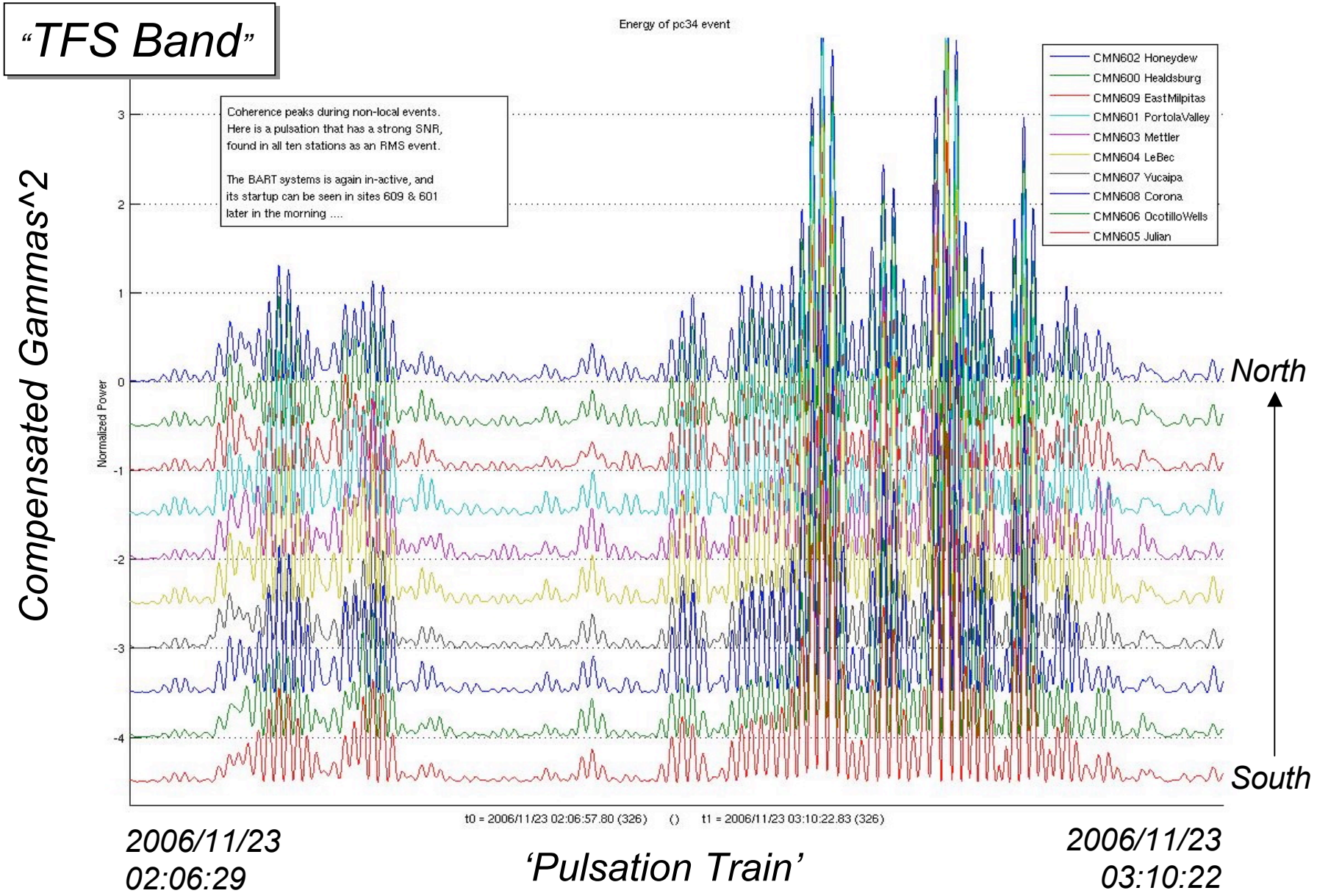
2006/11/23 16:56:10

'Thanksgiving Day'

2006/11/23 20:51:04

Band-pass Energy 0.005-0.02 Hz

"TFS Band"



Compensated Gammas^2

North

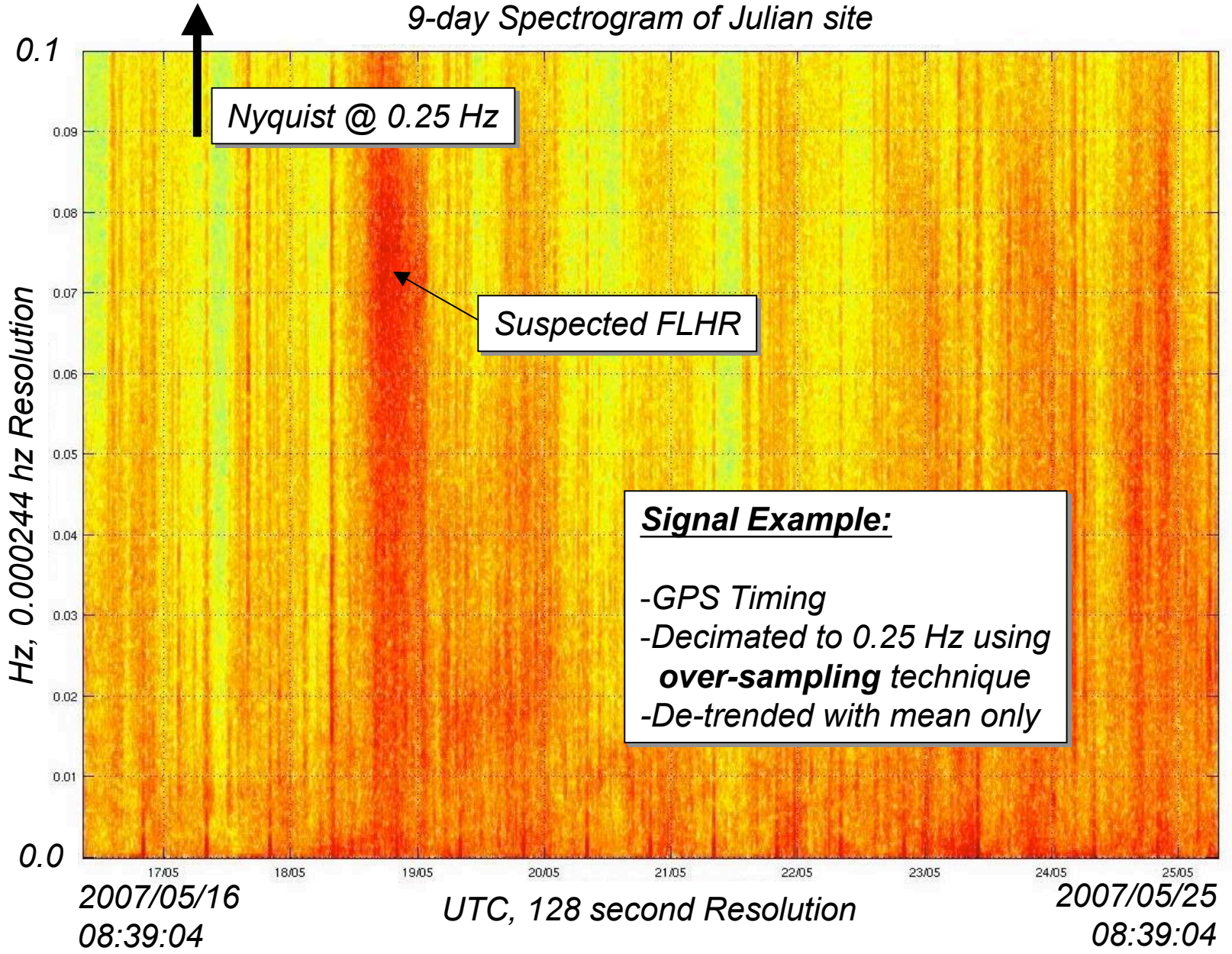
South

2006/11/23 02:06:29

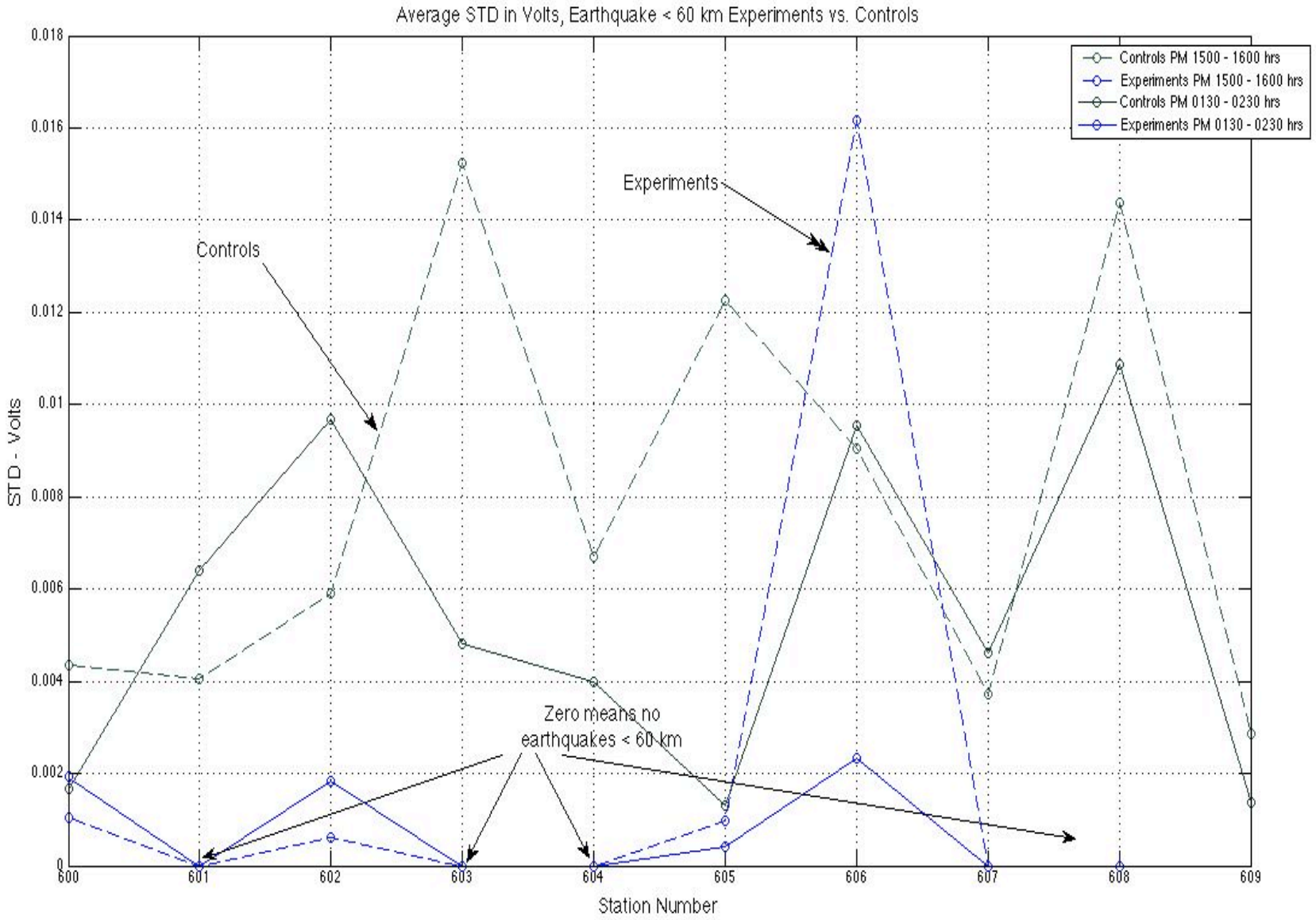
'Pulsation Train'

2006/11/23 03:10:22

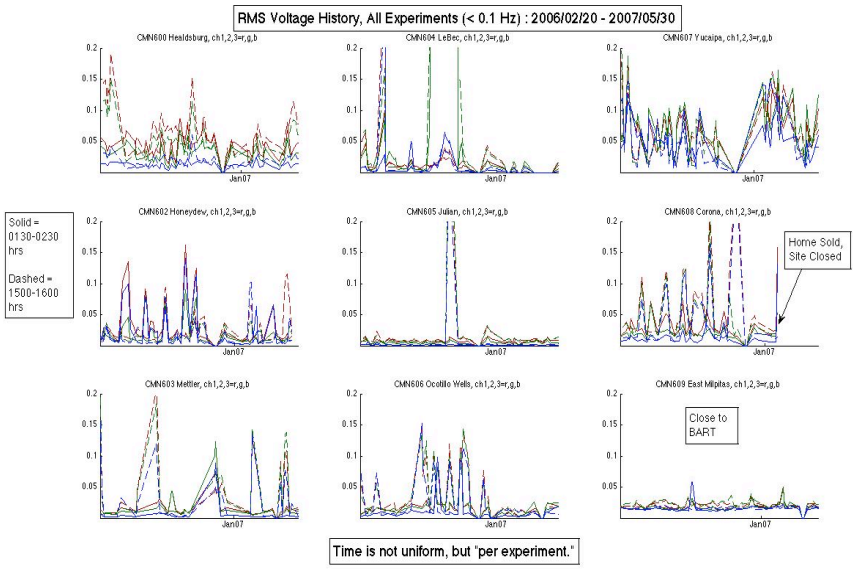
Typical 9-day Signal

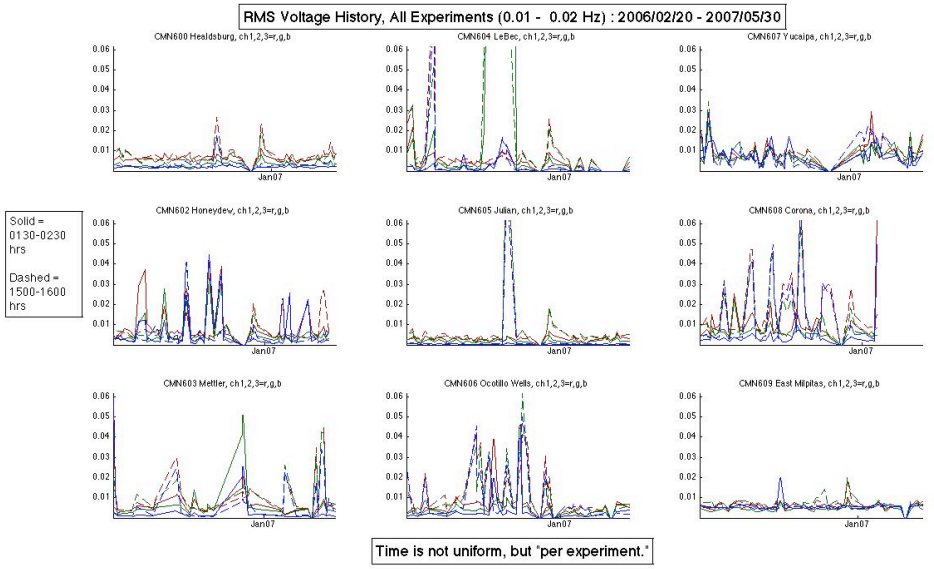


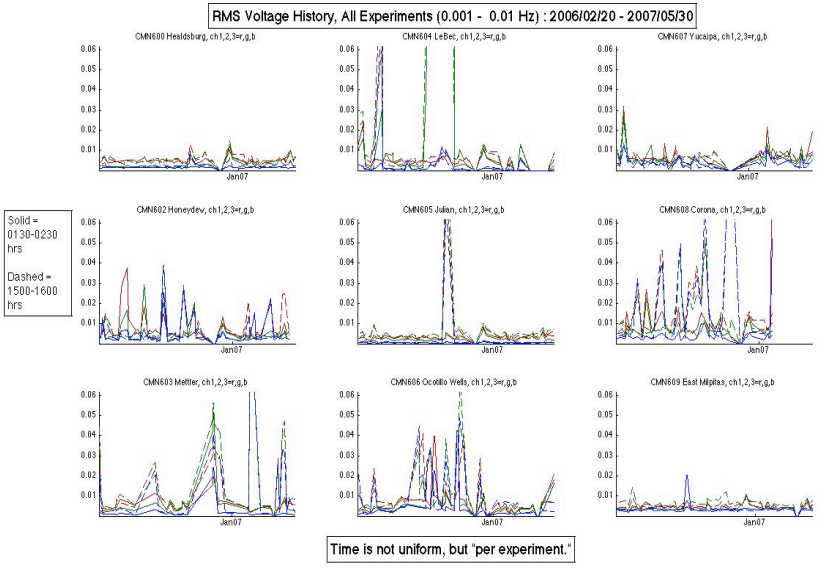
Standard Deviation Results



Standard Deviation Results







All Experiments and Controls plotted on time axis. PM - dashed

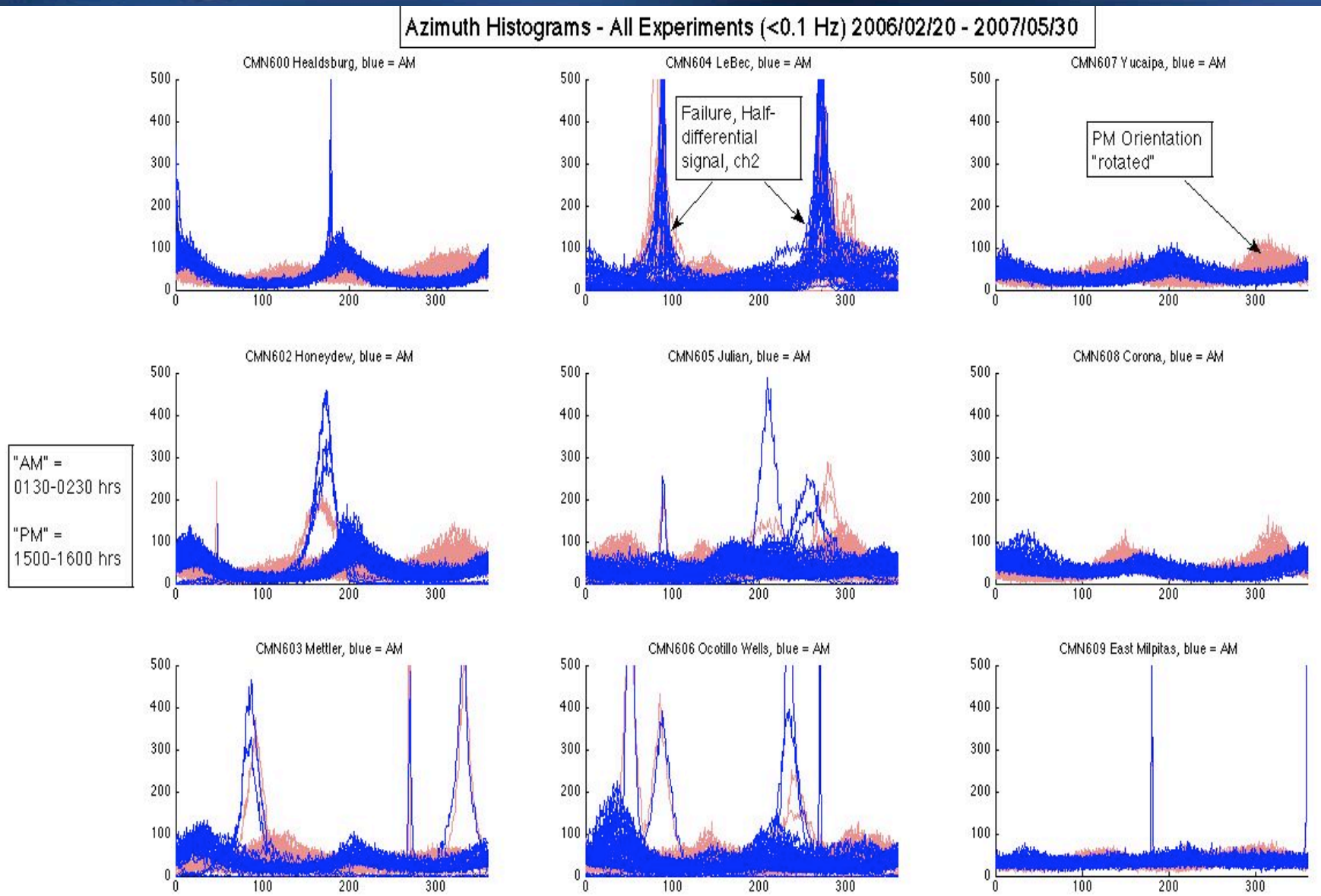
Observations:

-Local noise is more periodic than thought

-Largest Solar Storm Dec,2006 <20x

-BART effect disappears at lower F

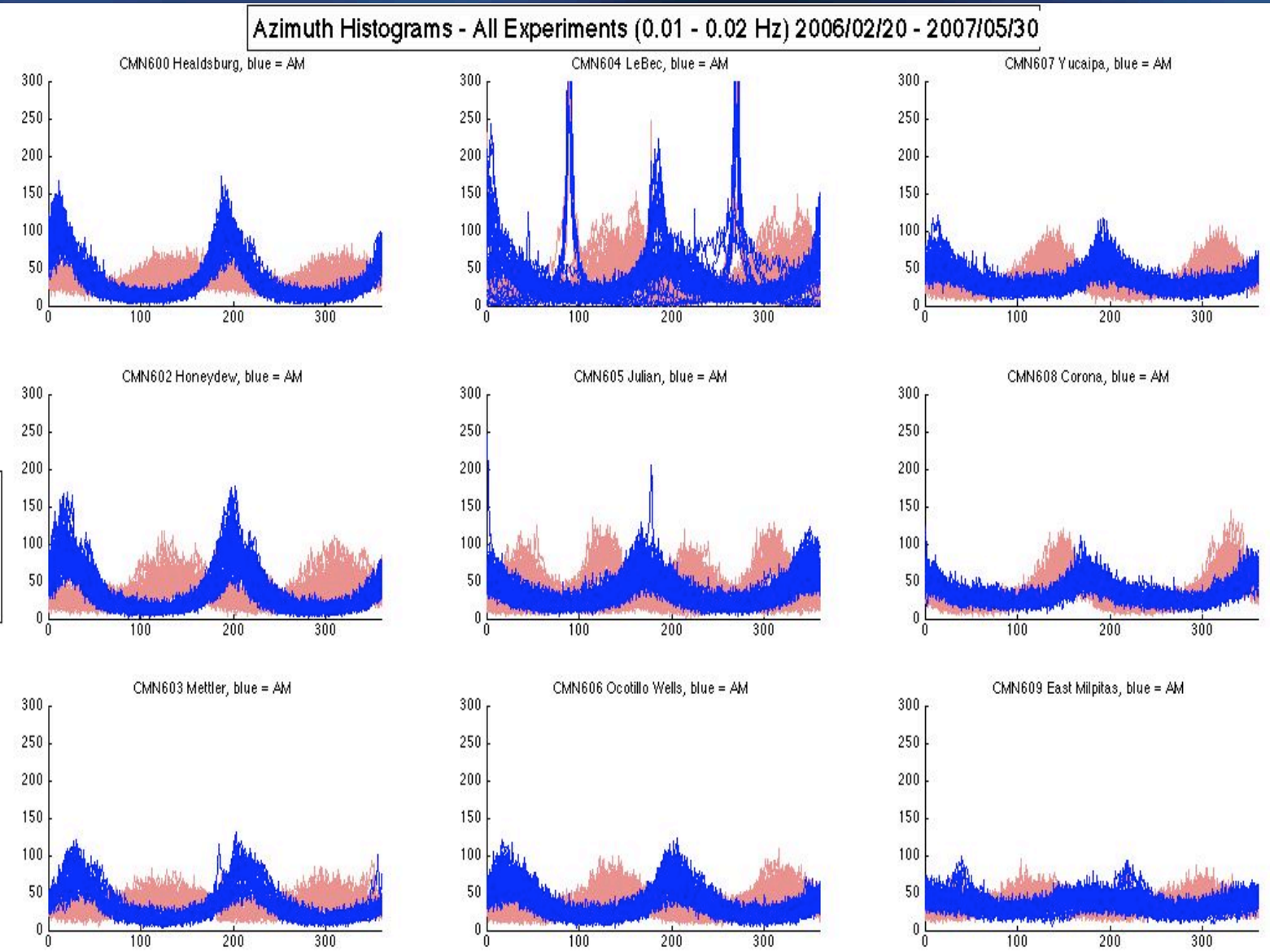
"Azimuth" Results



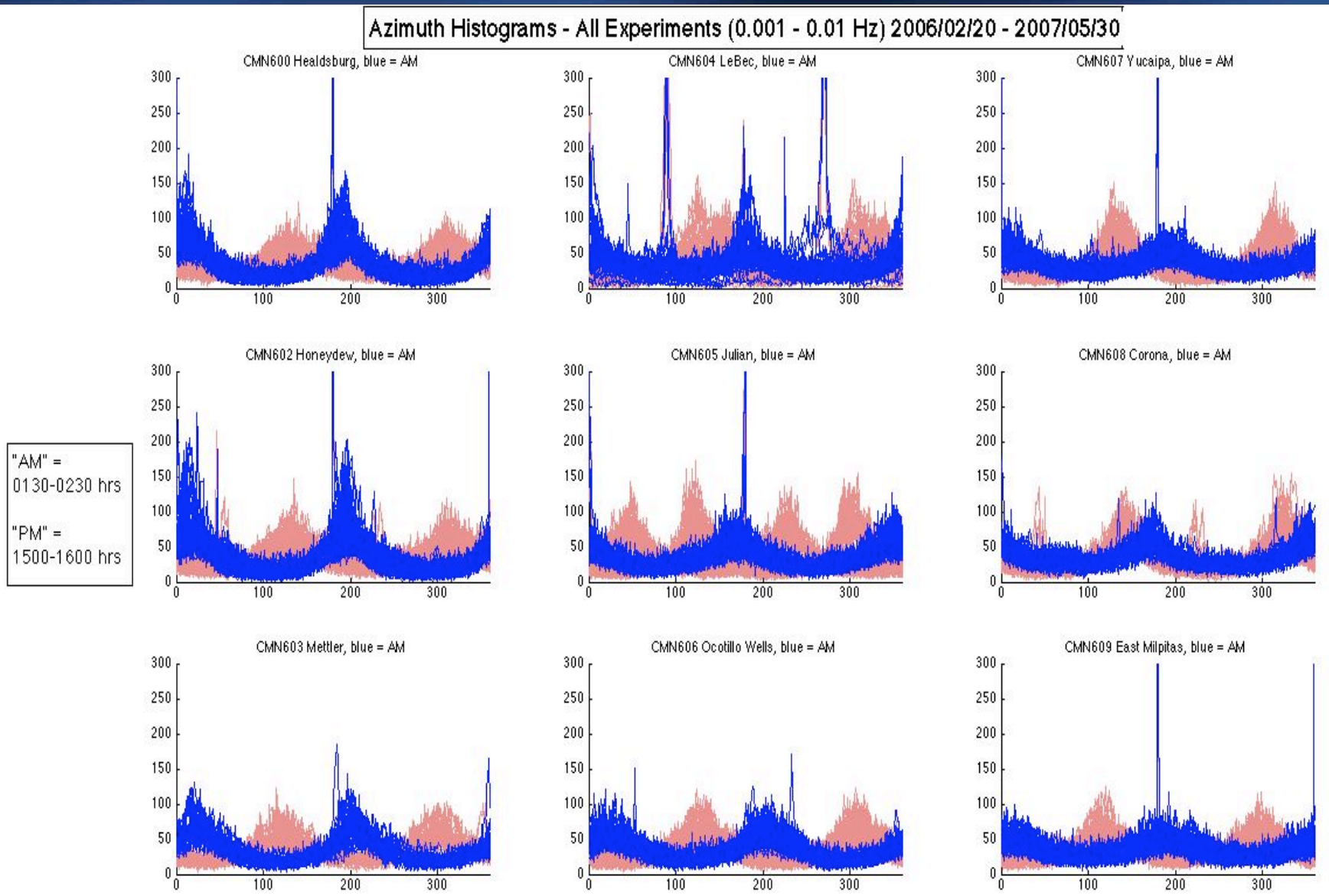
Simple atan2(NS, EW)

"Rotation" from Geographic West

"Azimuth" Results

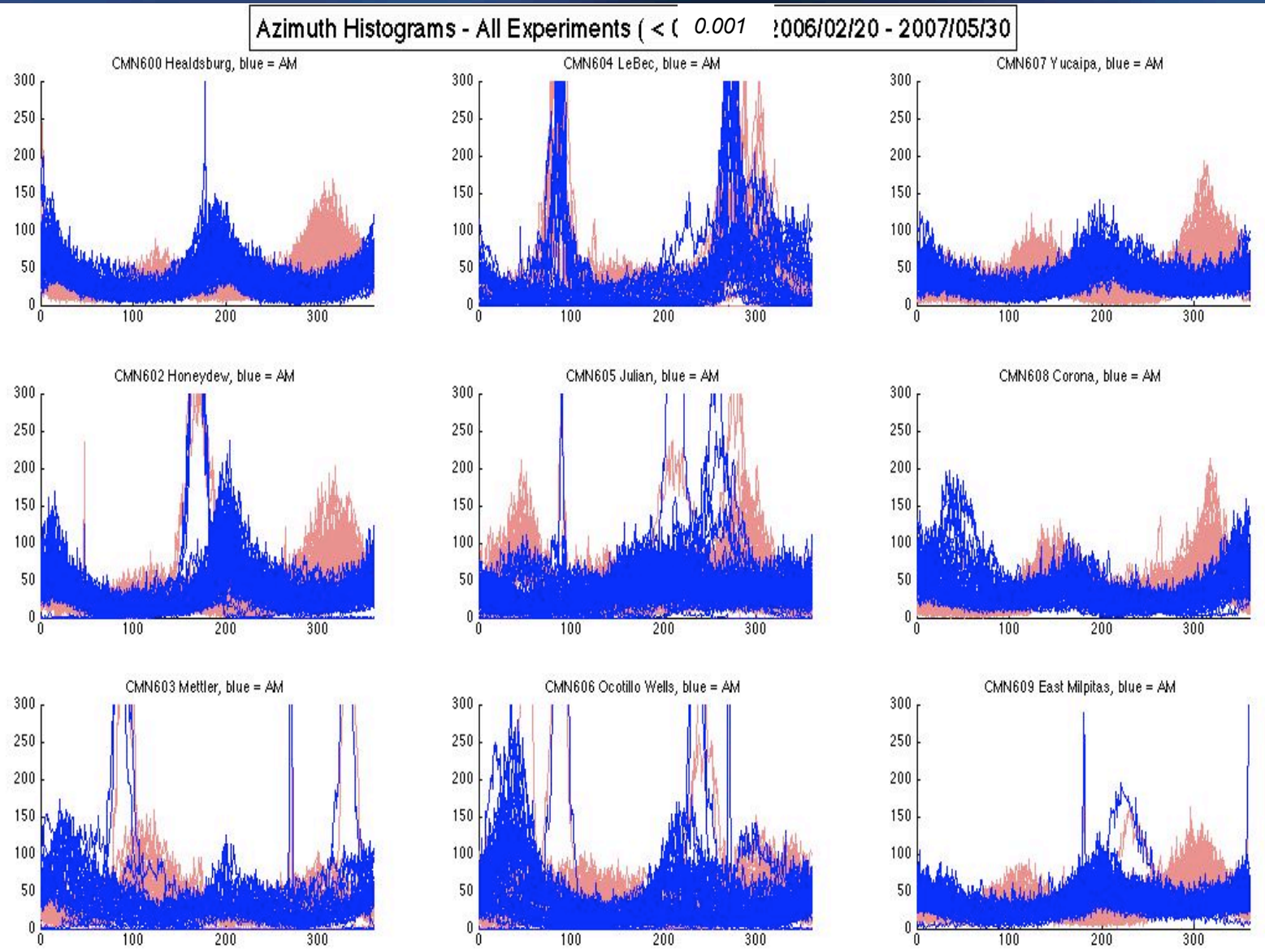


"Azimuth" Results



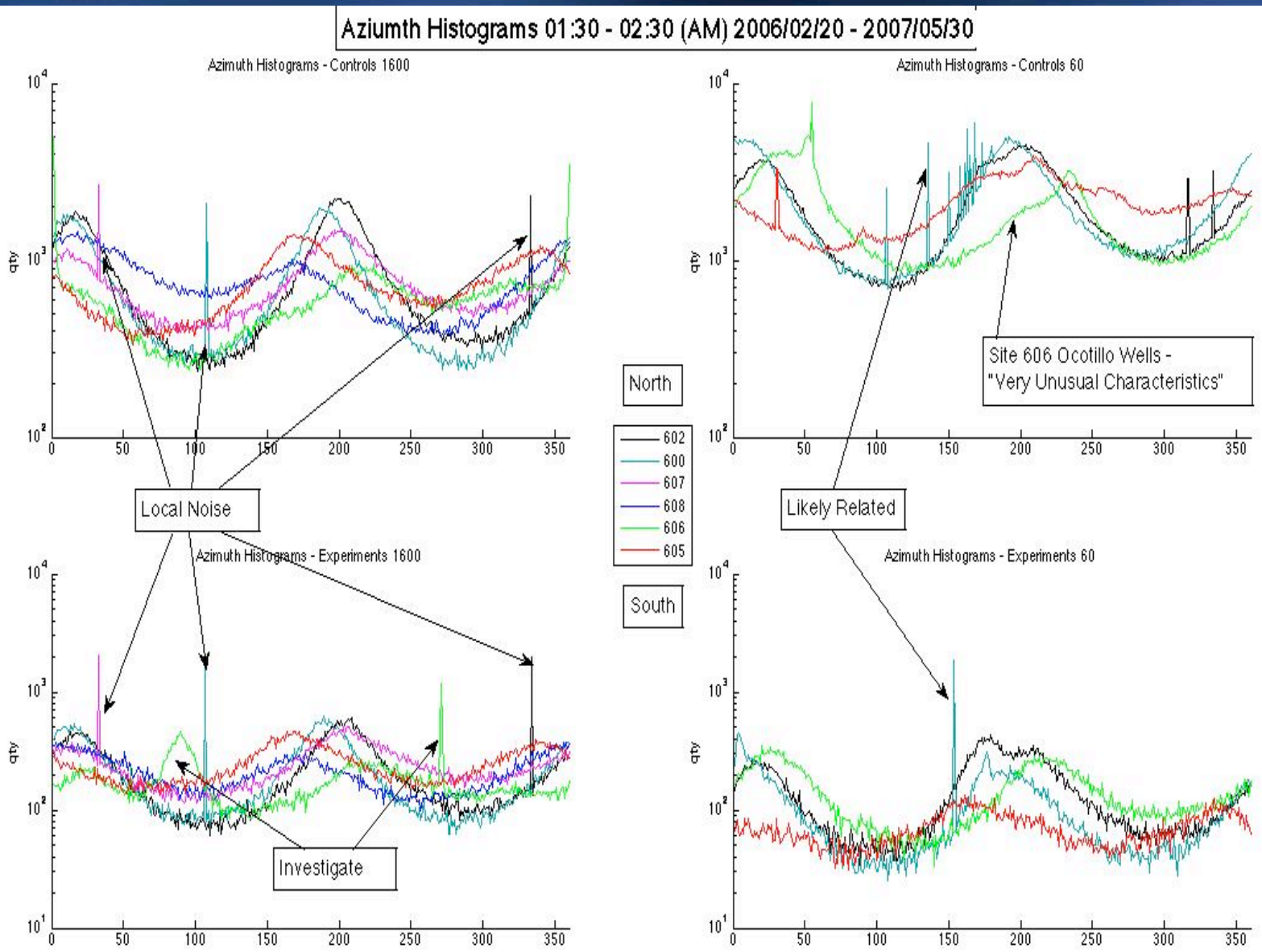
"Rotation" from Geographic West

"Azimuth" Results



"Rotation" from Geographic West

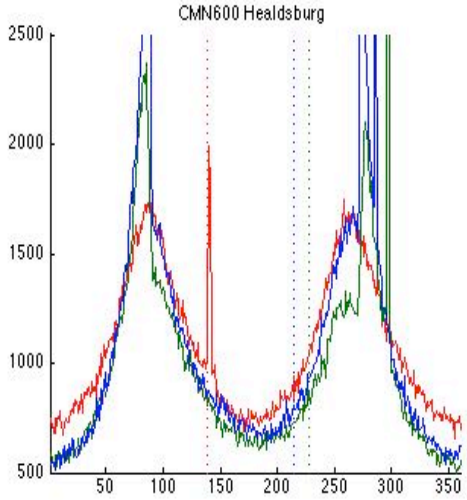
"Azimuth" Results

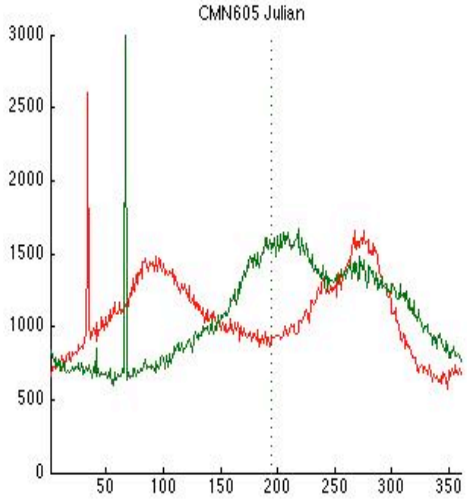


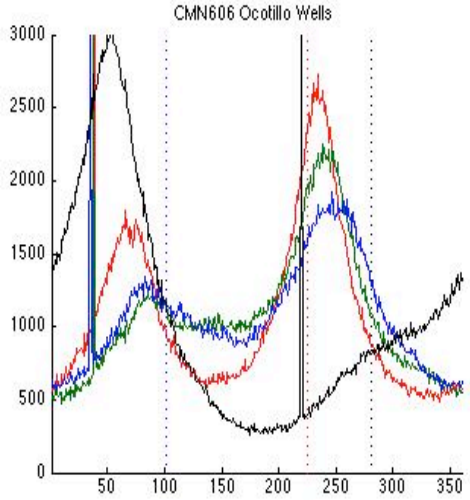
"Rotation" from Geographic West

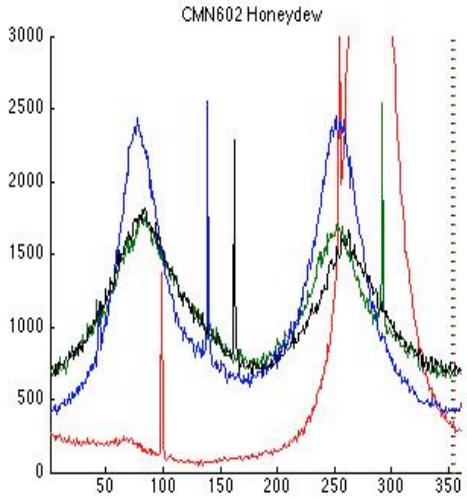
"Azimuth" Results

Azimuth Disturbance Histograms (< 0.1Hz), All Earthquakes < 60 km, 2006/02/20 - 2007/05/30



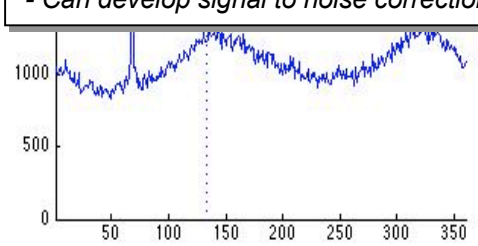






Azimuth Histograms for each 9-day earthquake block are separately colored to match each vertical earthquake line of direction

Some vertical lines are overlapped and hard to distinguish



Azimuth Results:

- Daytime sees consistent shift of peak

- Some stations show four lobe daytime

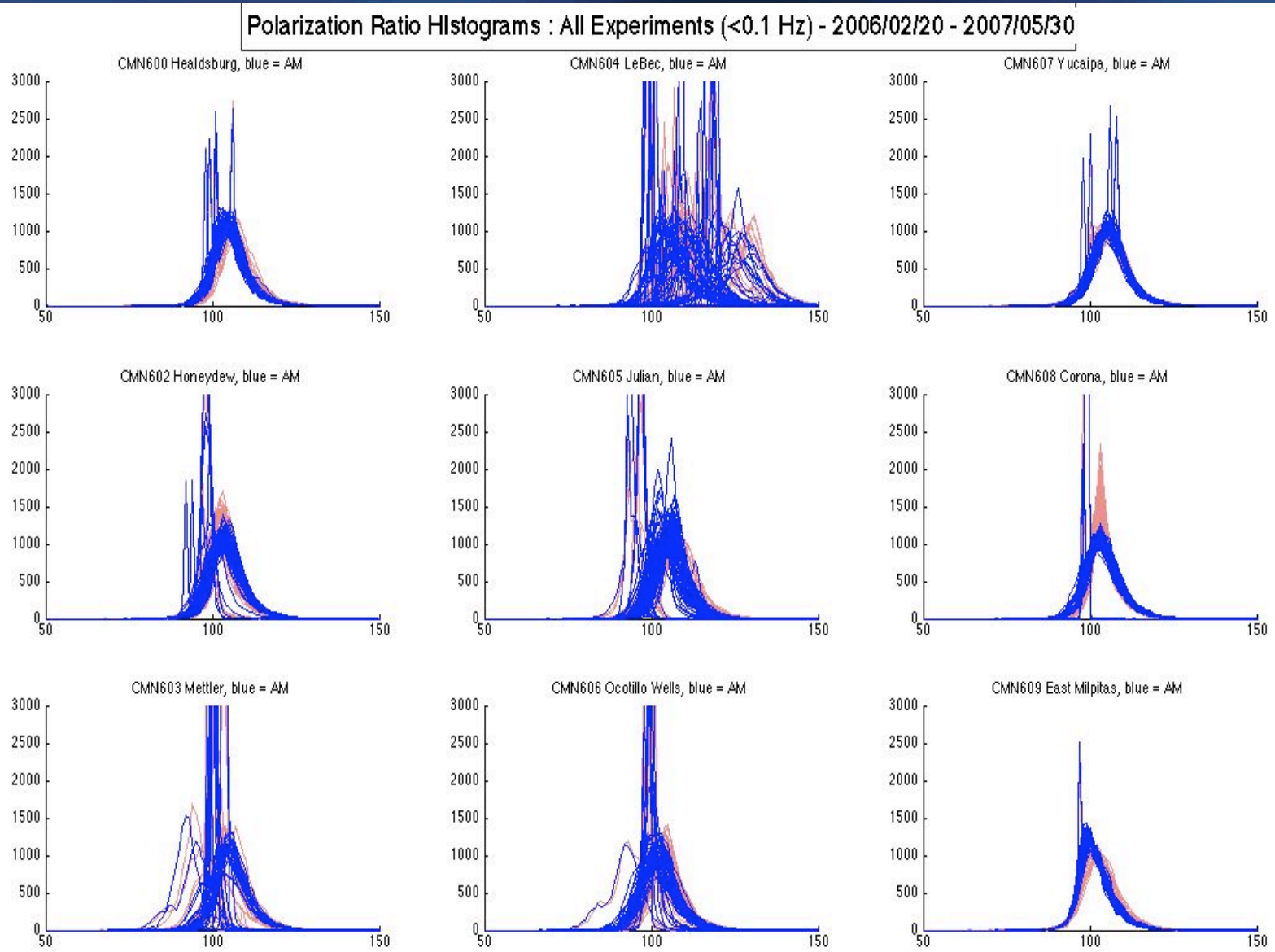
- Signal is better behaved in 0.0-0.02 Hz band

- Cultural Noise tends to flatten result

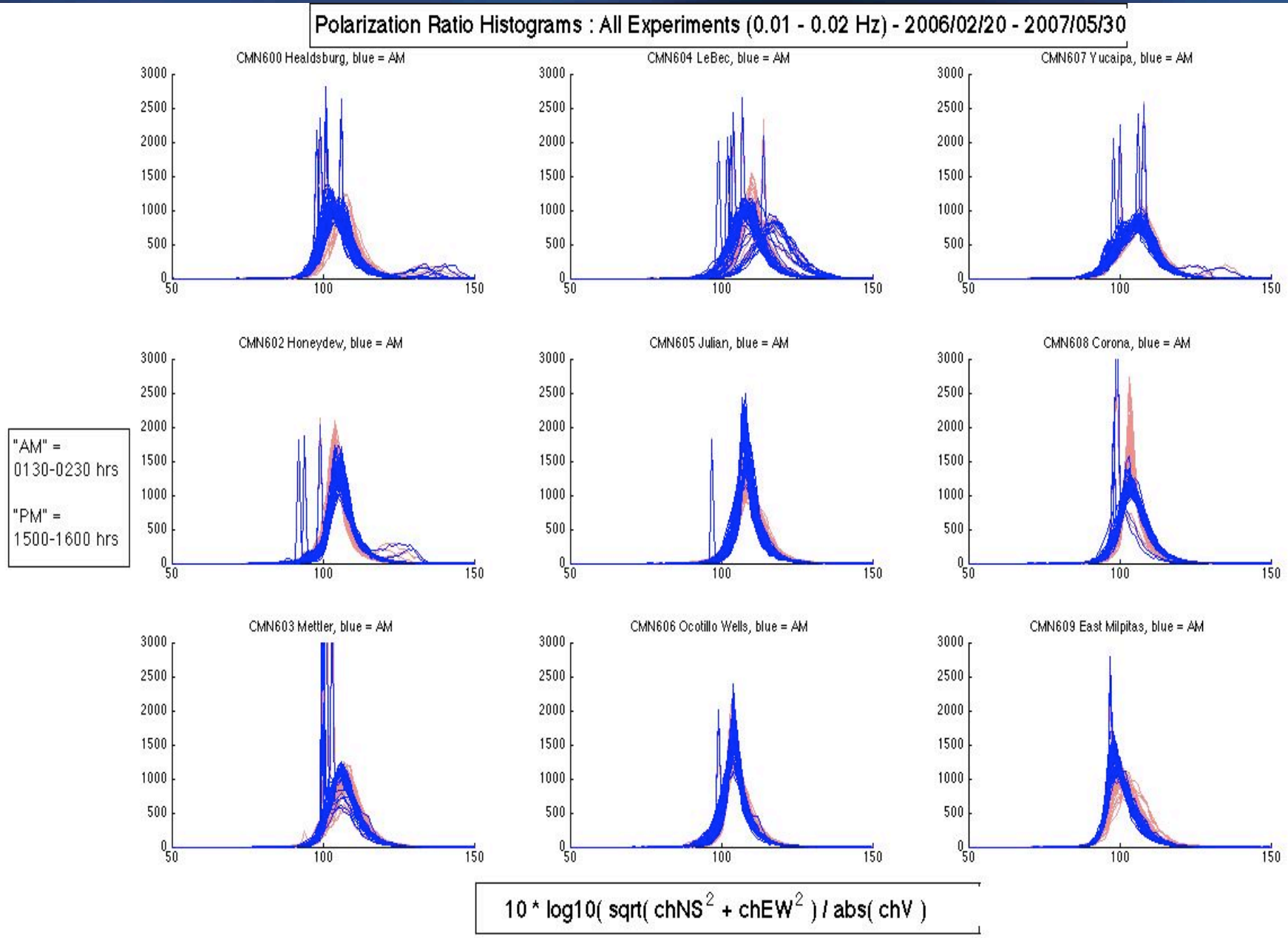
- Can develop signal to noise correction

"Rotation" from Geographic West

QUAKEFINDER "Polarization Ratio" Results



QUAKEFINDER "Polarization Ratio" Results



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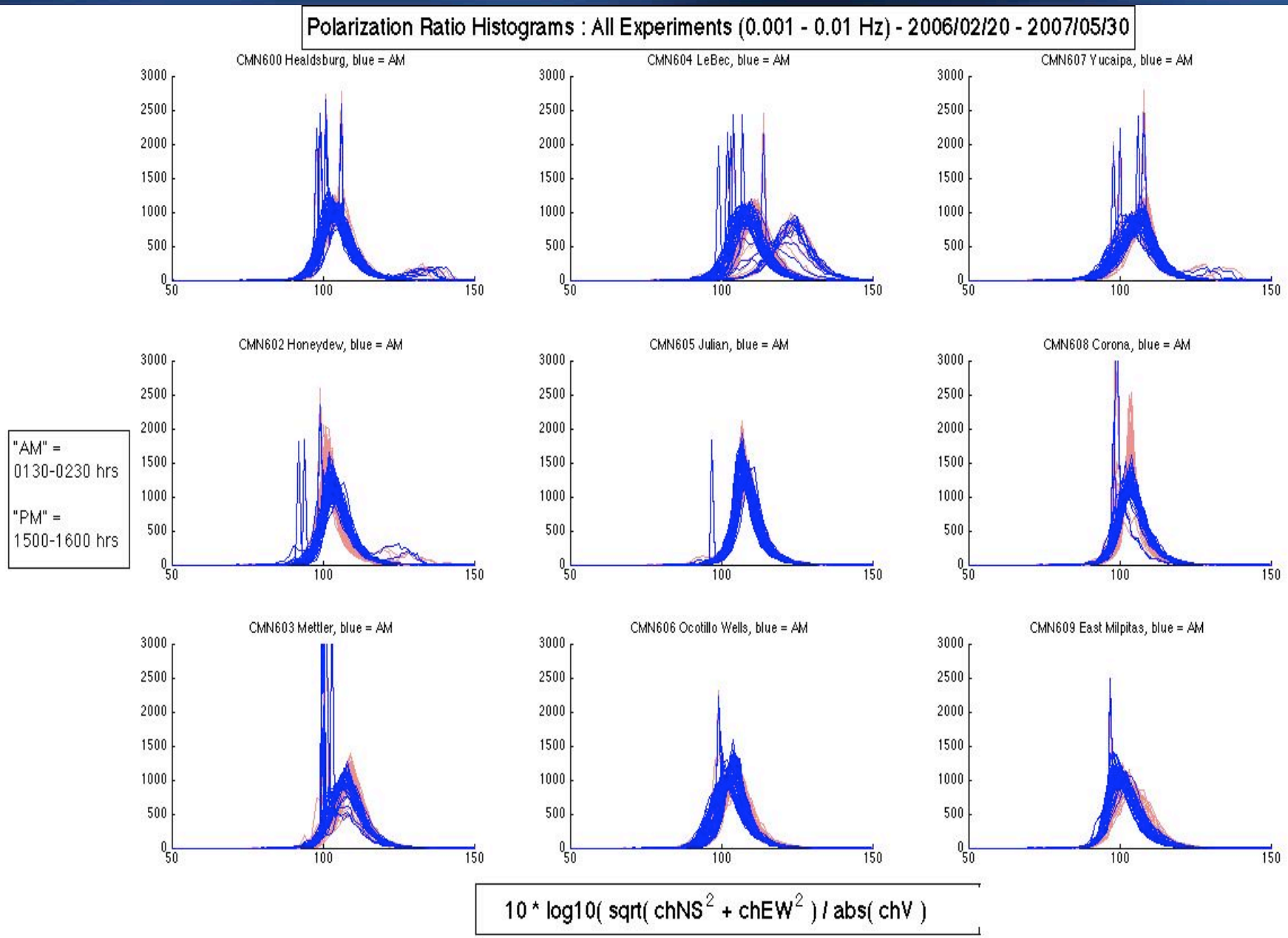
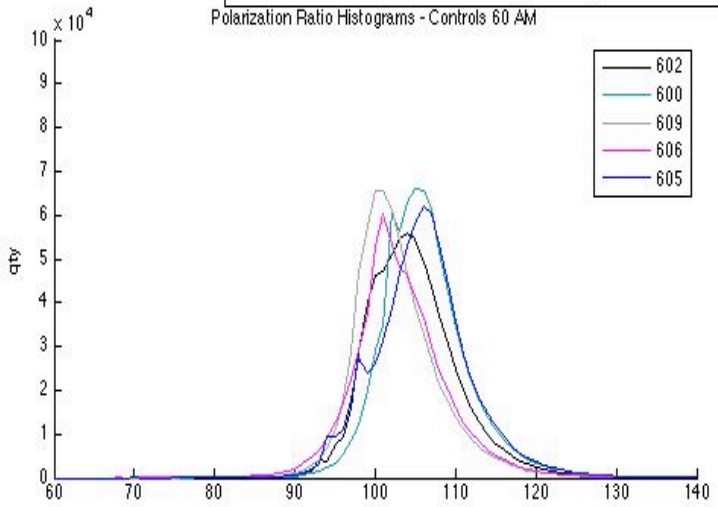
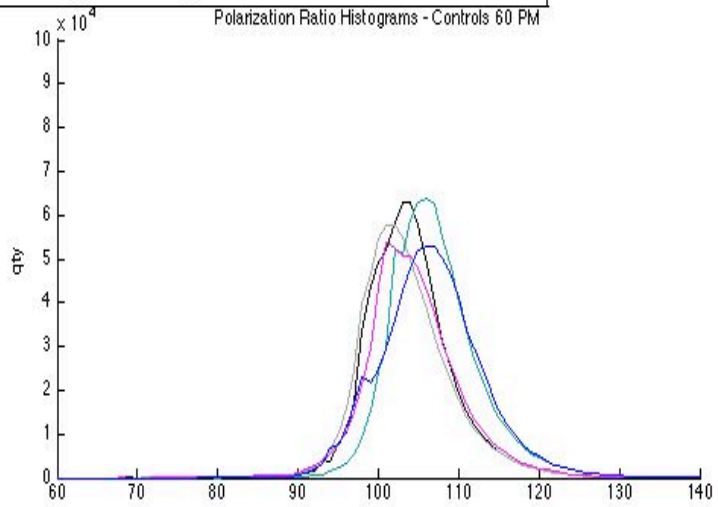


QUAKEFINDER "Polarization Ratio" Results

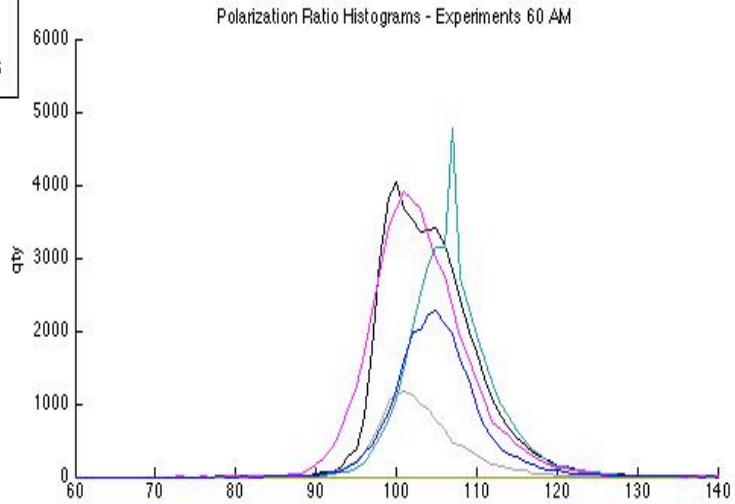
Polarization Ratio Histograms, All Earthquakes < 60 Km (< 0.1 Hz) 2006/02/20 - 2007/05/30

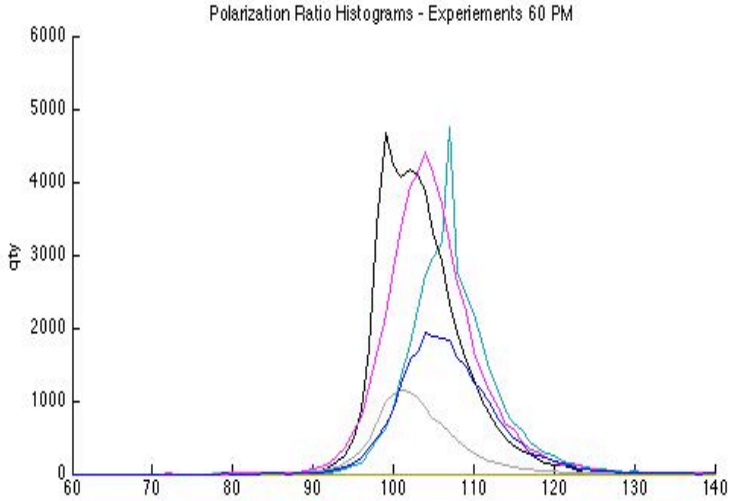




"AM" =
0130-0230 hrs

"PM" =
1500-1600 hrs

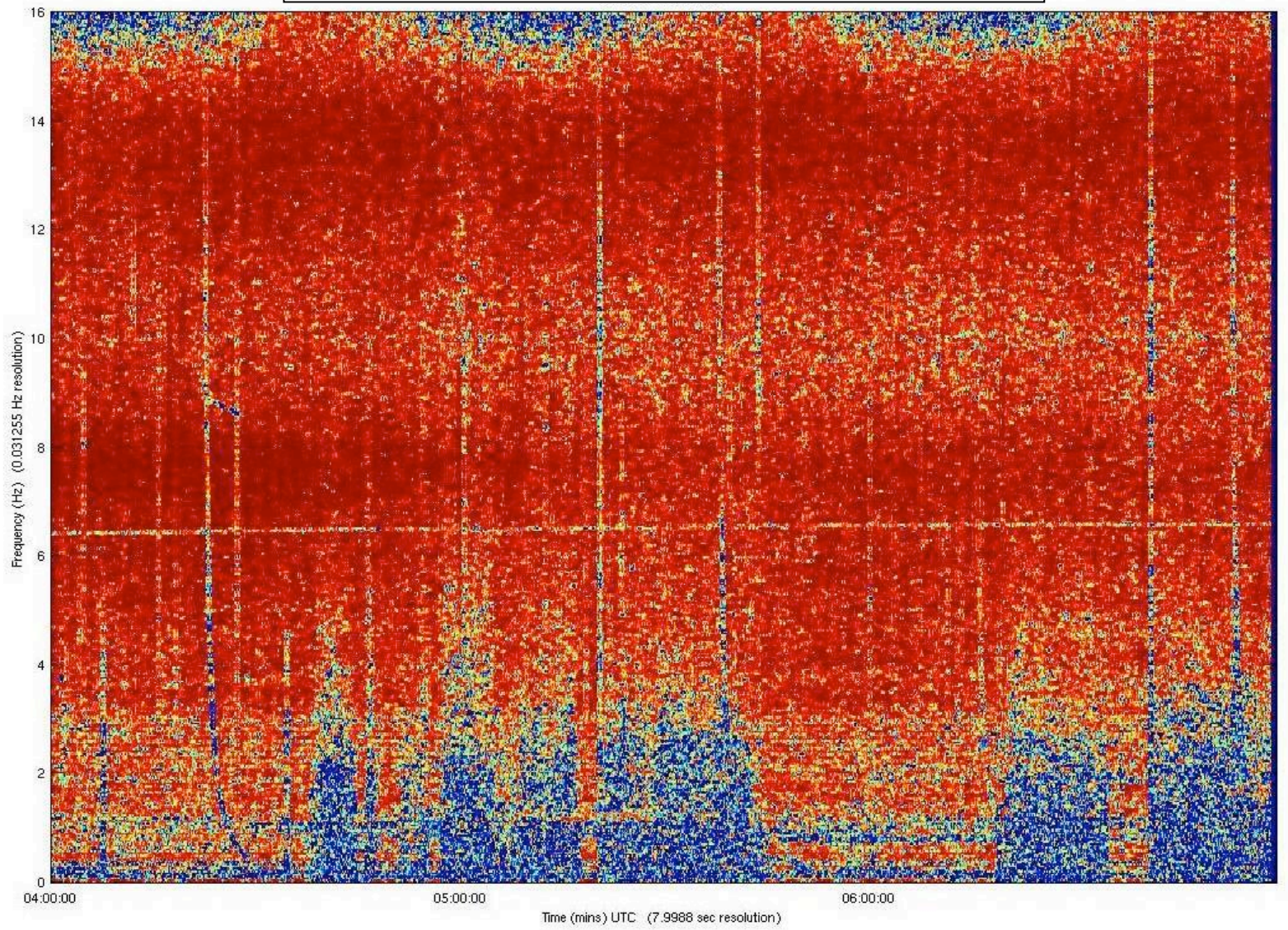




$10 * \log10(\sqrt{chNS^2 + chEW^2}) / abs(chV)$

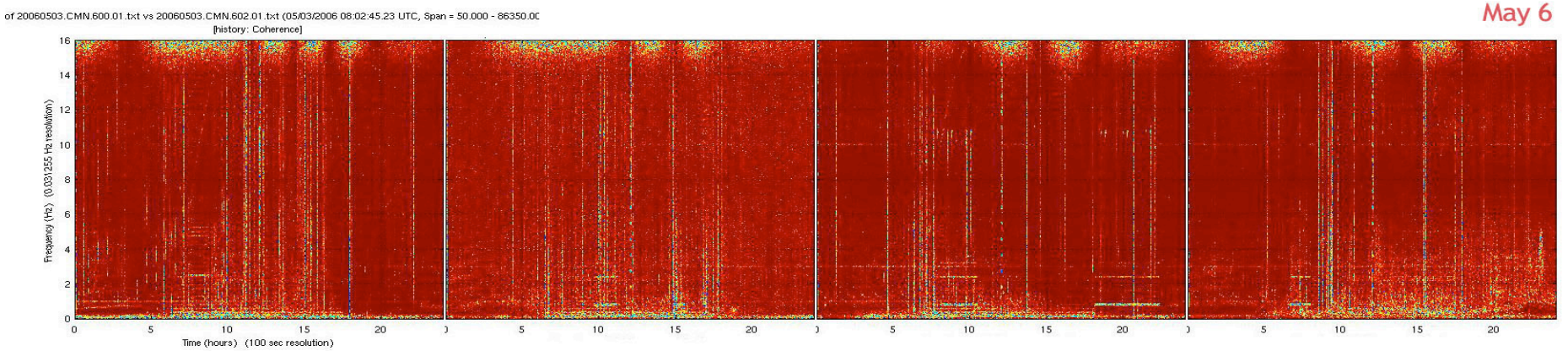
Coherence Exceptions - Dispersion

NorCal to SoCal Coherence, October 10, 2006

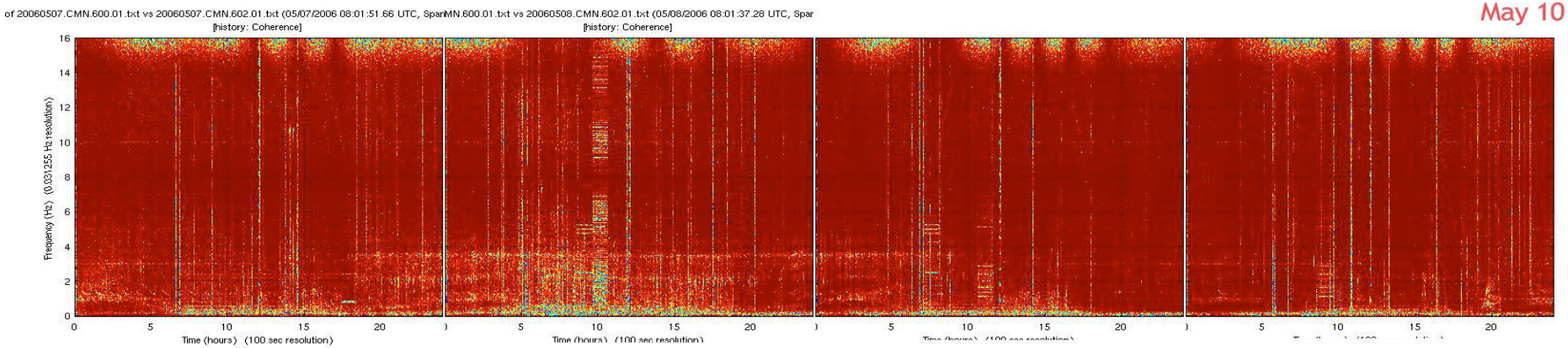


Coherence – 12 day Full Passband

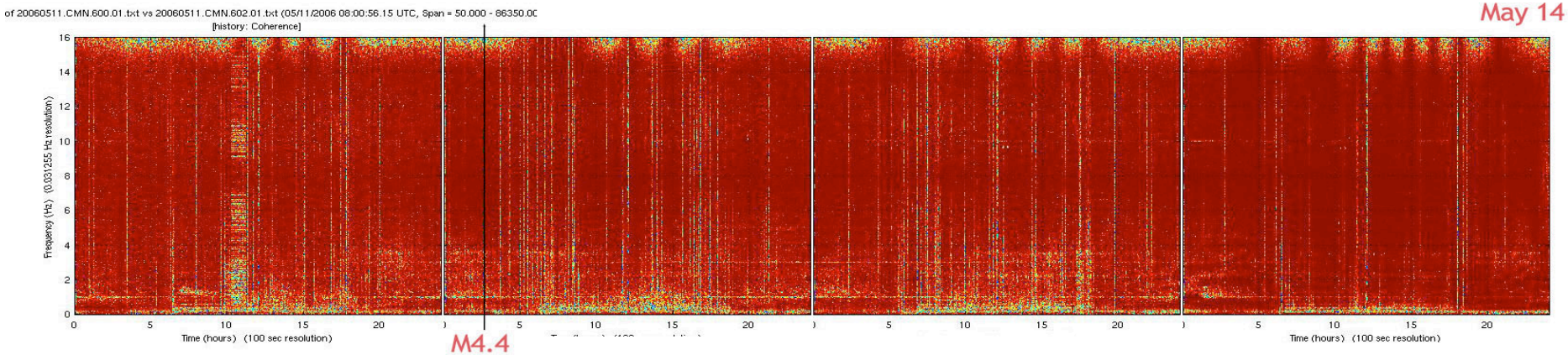
May 6



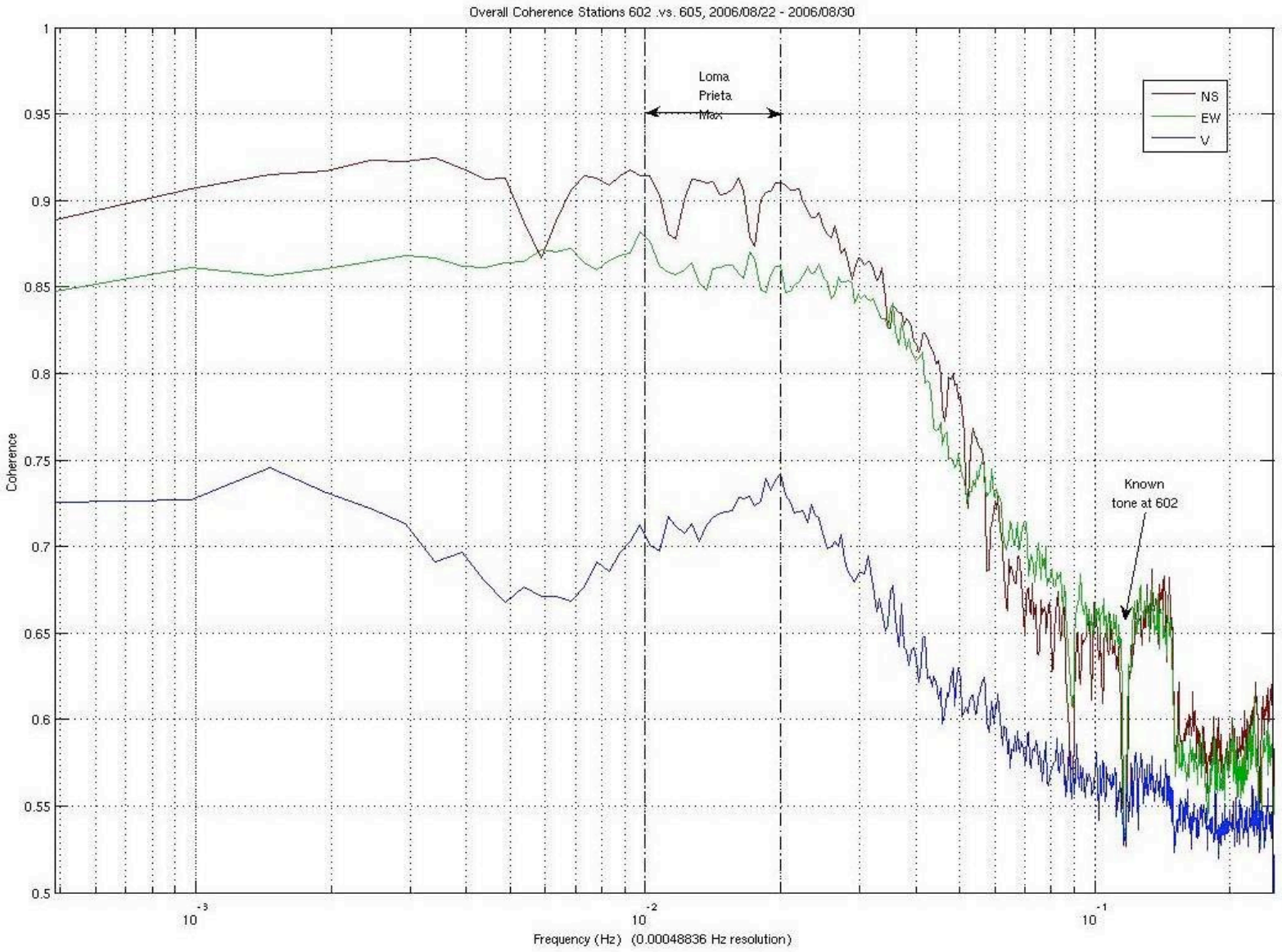
May 10



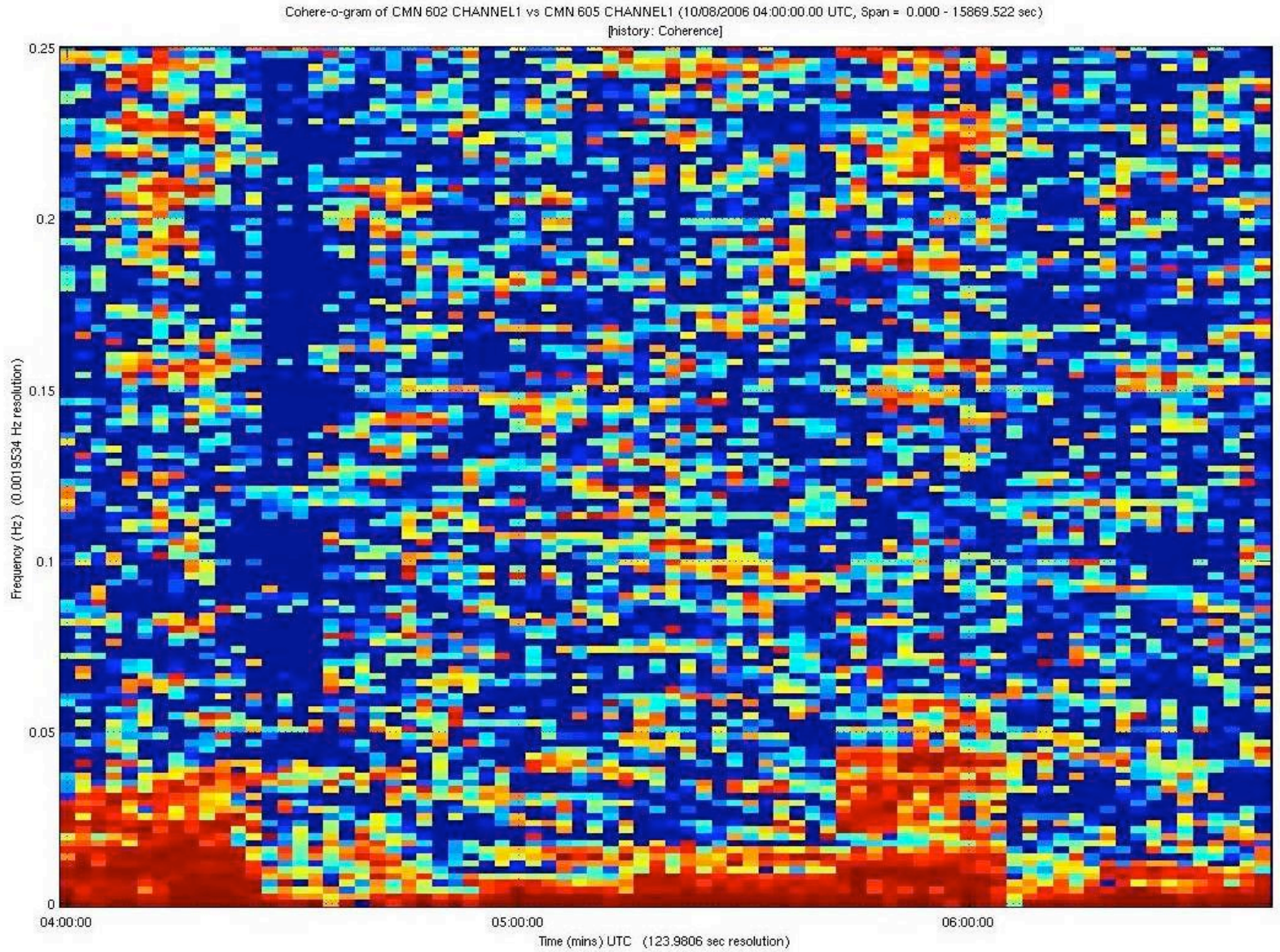
May 14



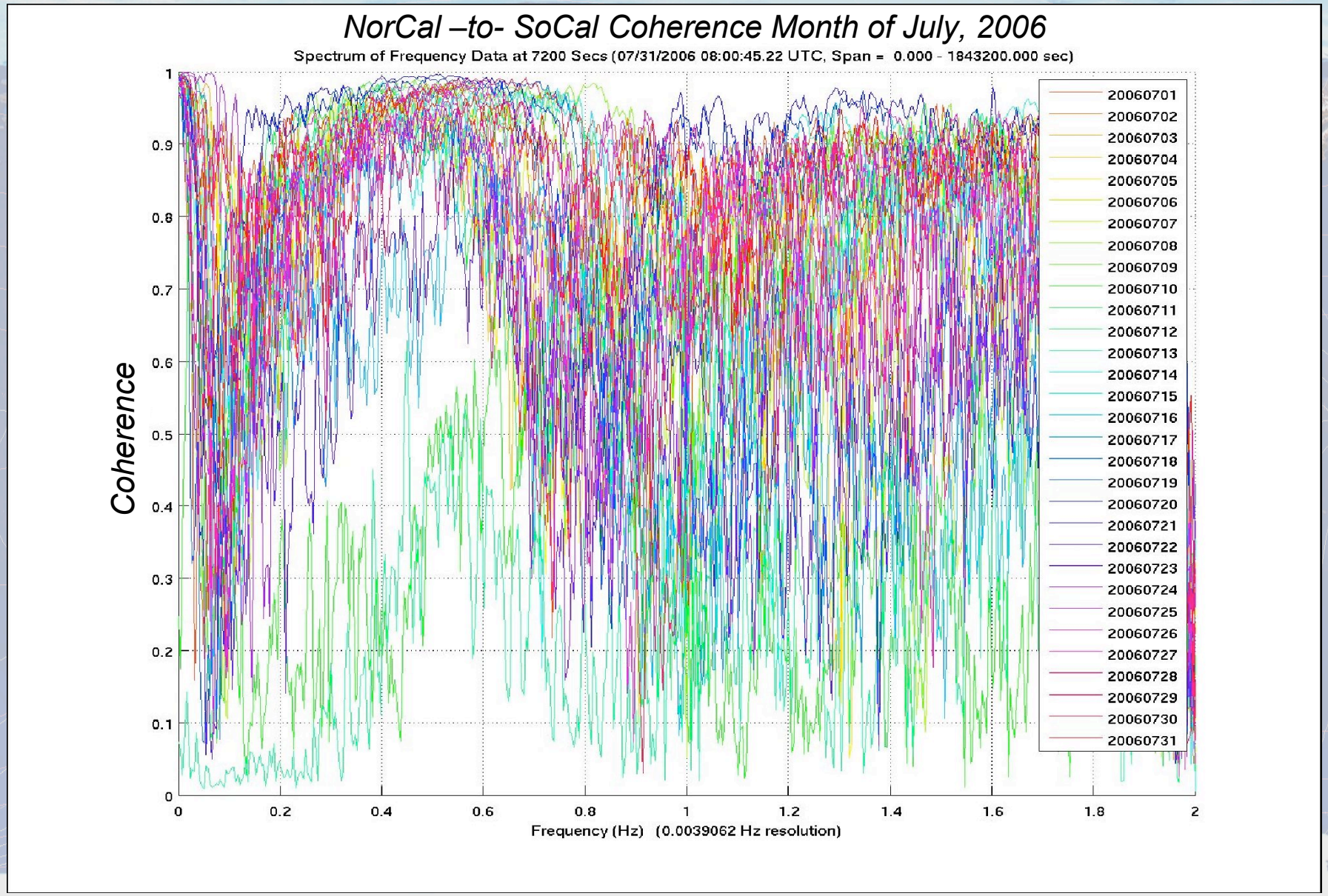
Coherence Result



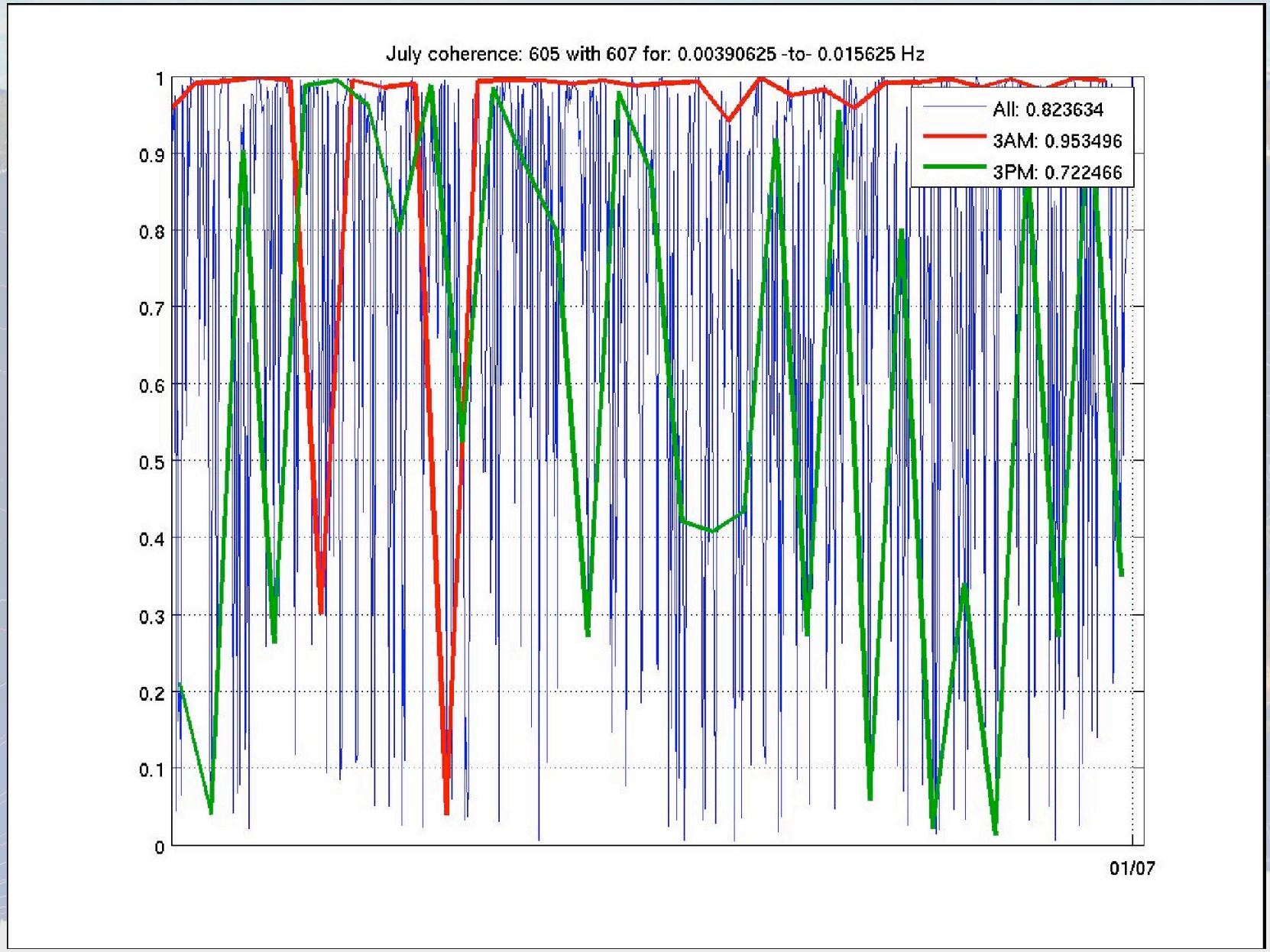
Coherence Exceptions - Dispersion



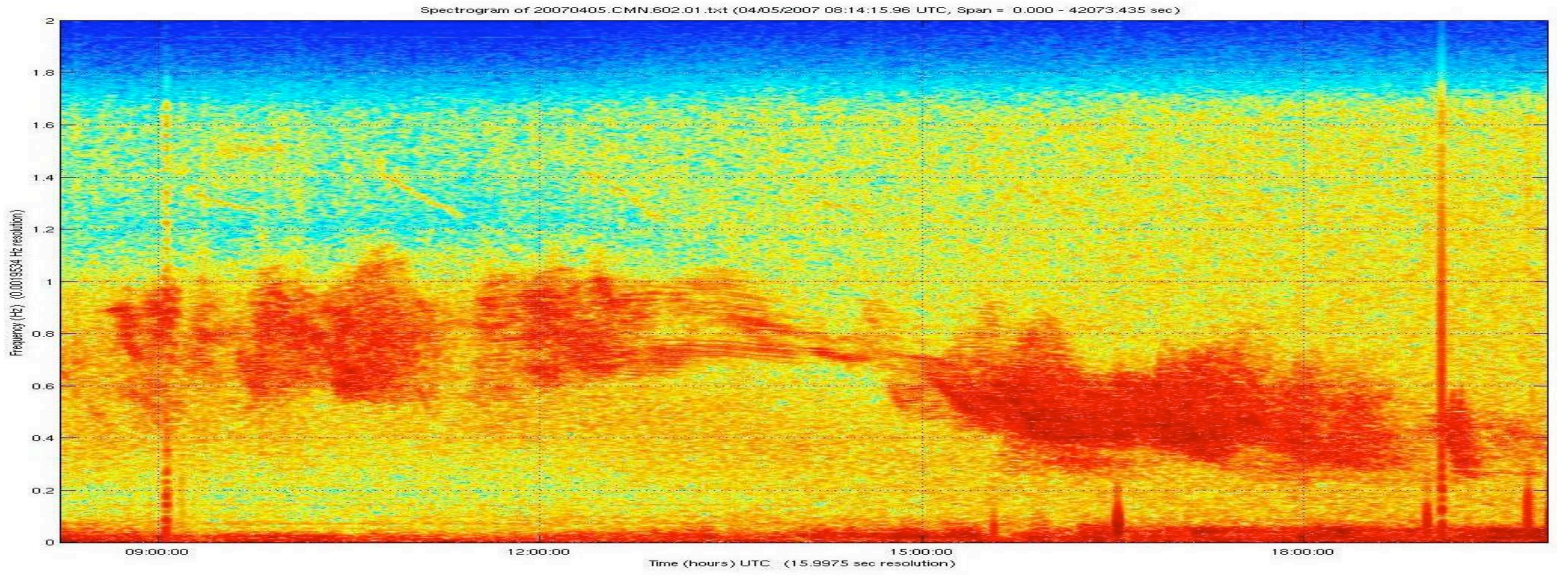
Coherence Monthly

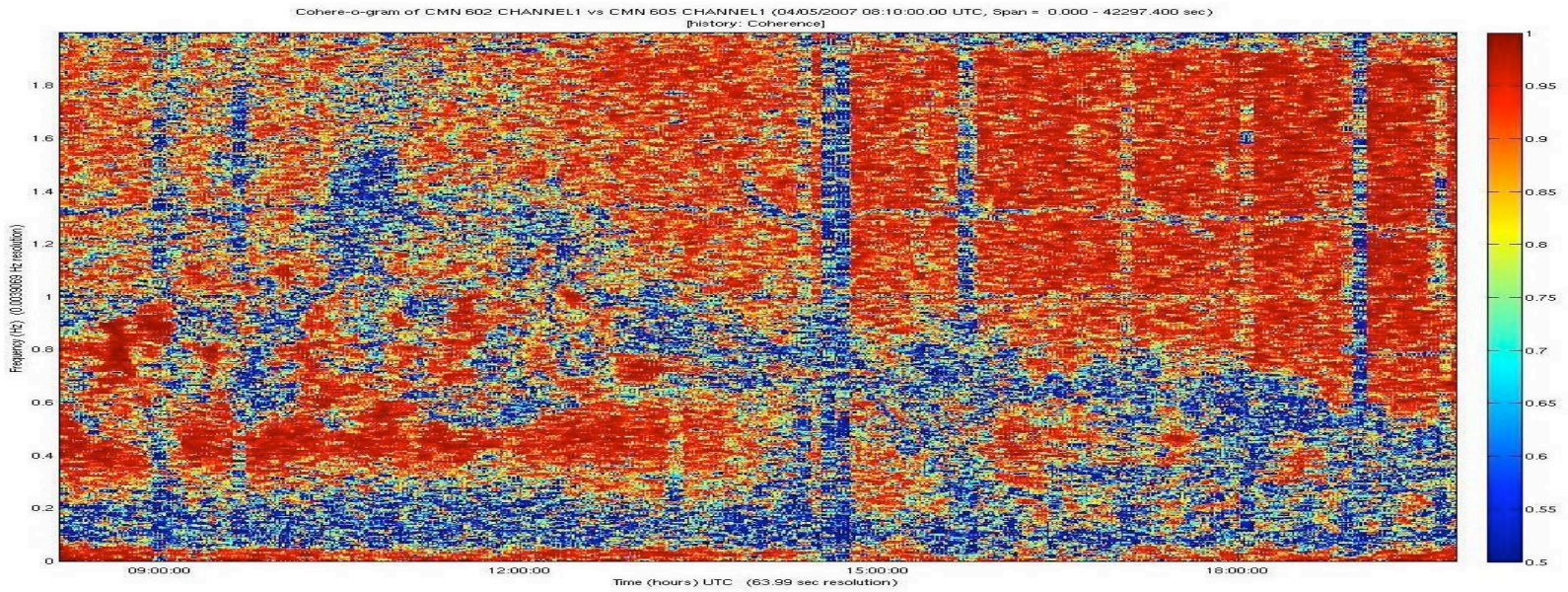


Bulk Coherence - Urban Sensor

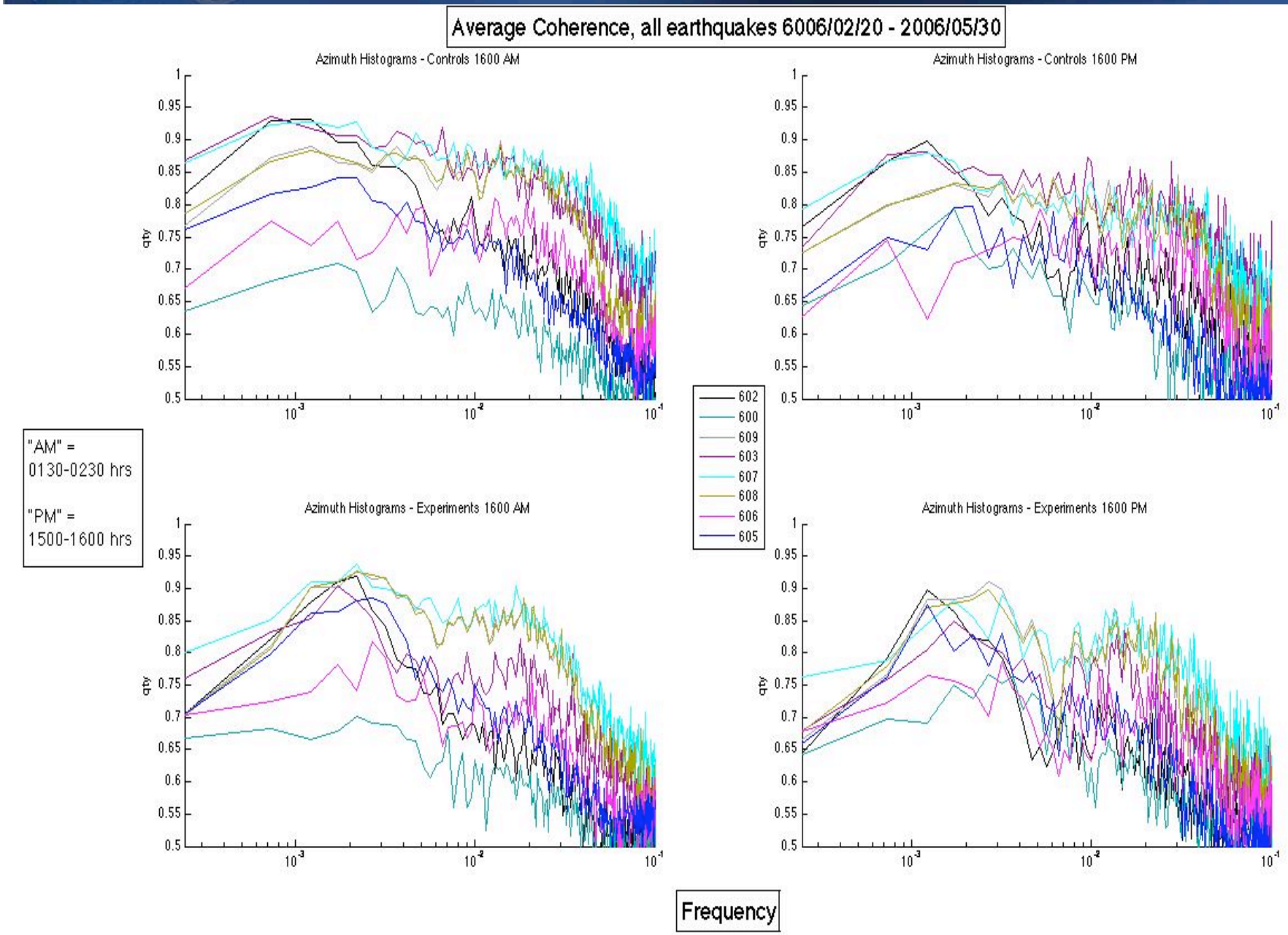


Coherence Exceptions of Pc1





Coherence Controls vs. Experiment



Future

Future:

-Five more stations to be deployed
evaluate additional sensor possibilities
- location (Sensitive Spot?) (On Fault?)
- Orient to strike?

-Complete Event detection tool in Data Center

-Permutations of Experiment Set:
- 3-5 days before? (Liu)
- Large area signal? (Korepanov/Pulinets)
- Strike Skew "Bx" stability? (Dumitri)
- Improved Directionality Model

-Begin de-trending with common mode

QUAKEFINDER

THANK YOU!!