Livingston Seismic Environment

Mark Coles
LLO

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Main Topics

- Environmental characterization of seismic channel properties
- Multi element array measurements of the seismic environment

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Geophysical measurements along the X arm

- Measure the propagation velocities of the of the shear and compressional wave signals
- Measure velocity dispersion
- Measure the attenuation dependence on distance and frequency
- Use these measurements as guidance in determining possible sources of seismic noise, and for estimating gravity gradient

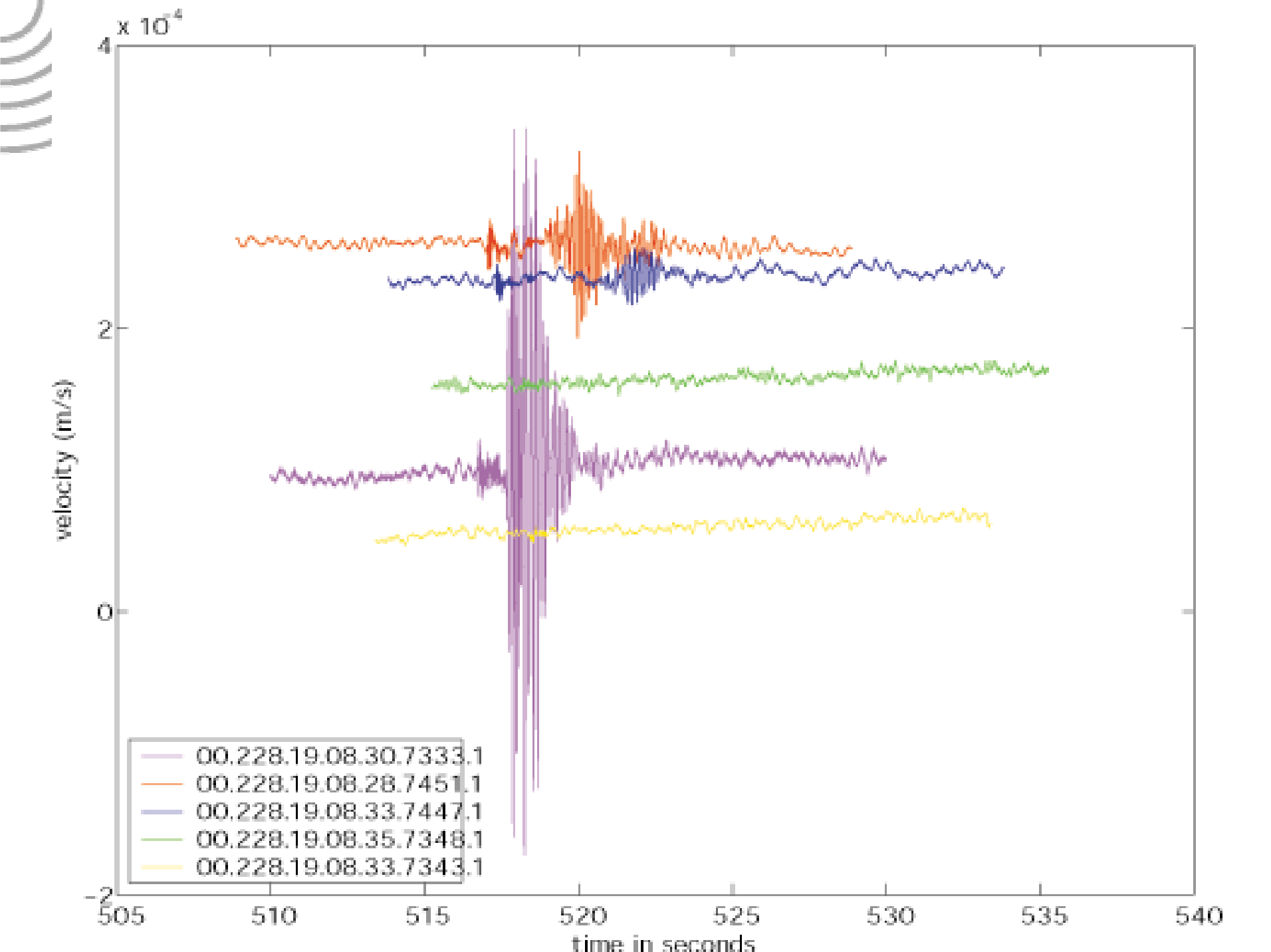
Measurements made with the assistance of Kevin Tubbs – SURF student from Southern University

Measurement Technique

- 5 Guralp CG40T seismometers and Reftek data loggers borrowed from:

  IRIS PASSCAL Instrument Center
  New Mexico Tech
  Socorro, New Mexico

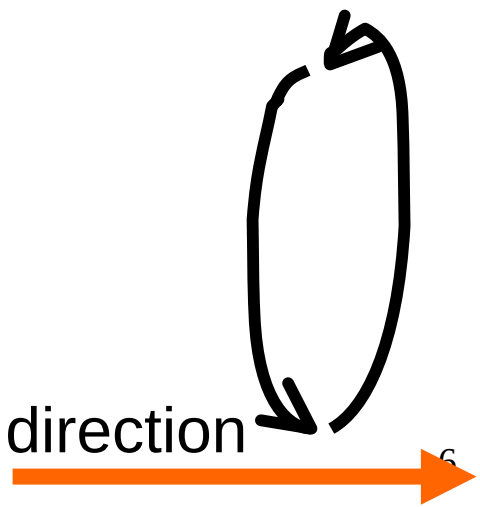
  http://www.passcal.nmt.edu/passcal.shtml
- Placed in linear array along X-arm at 500 meter intervals
- Impulsive source made from soda containers partially filled with liquid nitrogen submerged in erosion control pond. 8 foot depth provides reaction mass to couple sound wave into soil

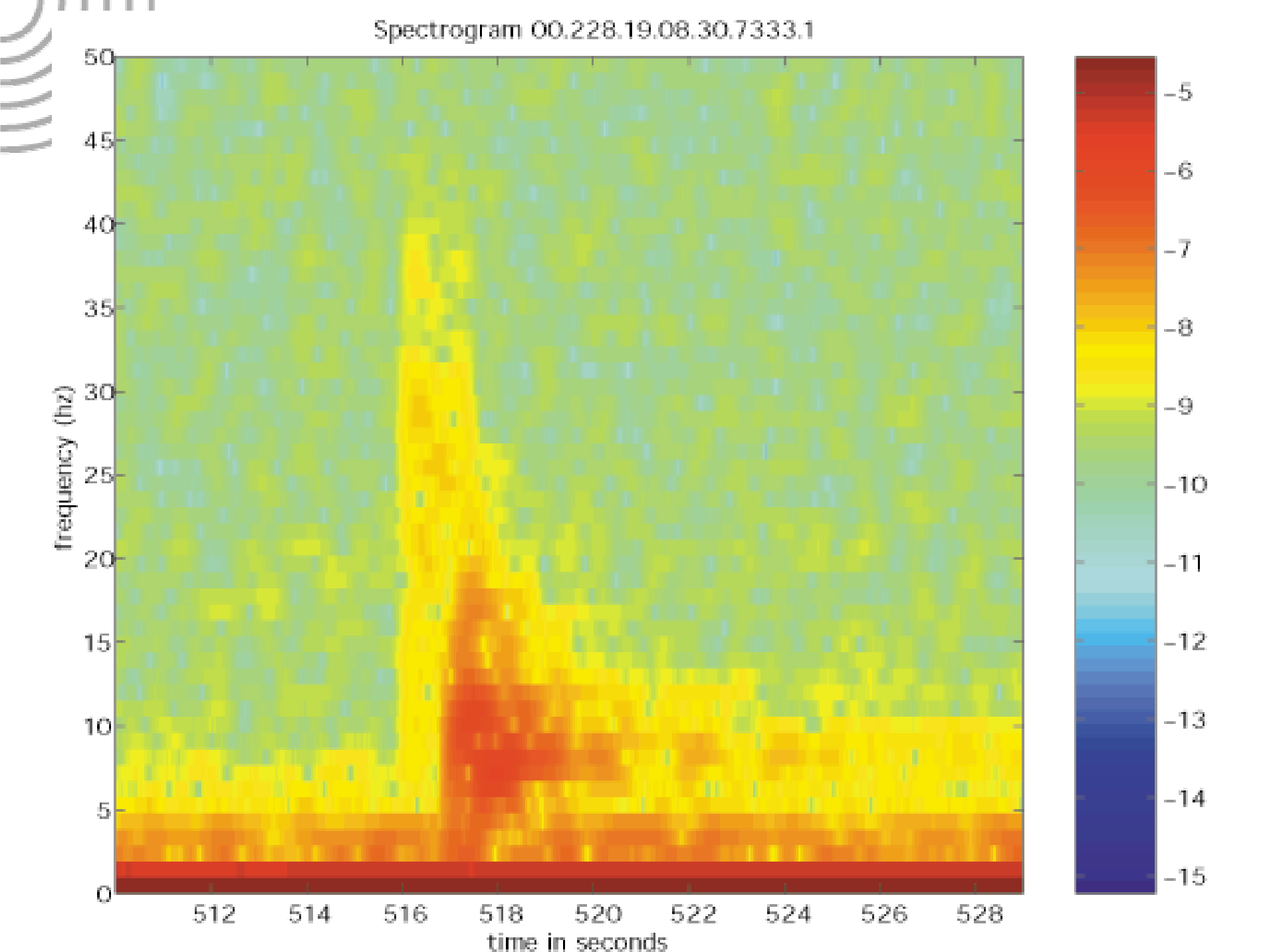

x 10^-4
4
2
0
-2
velocity (m/s)
505
510
515
520
525
530
535
540
time in seconds
00.228.19.08.30.7333.1
00.228.19.08.28.7451.1
00.228.19.08.33.7447.1
00.228.19.08.35.7348.1
00.228.19.08.33.7343.1

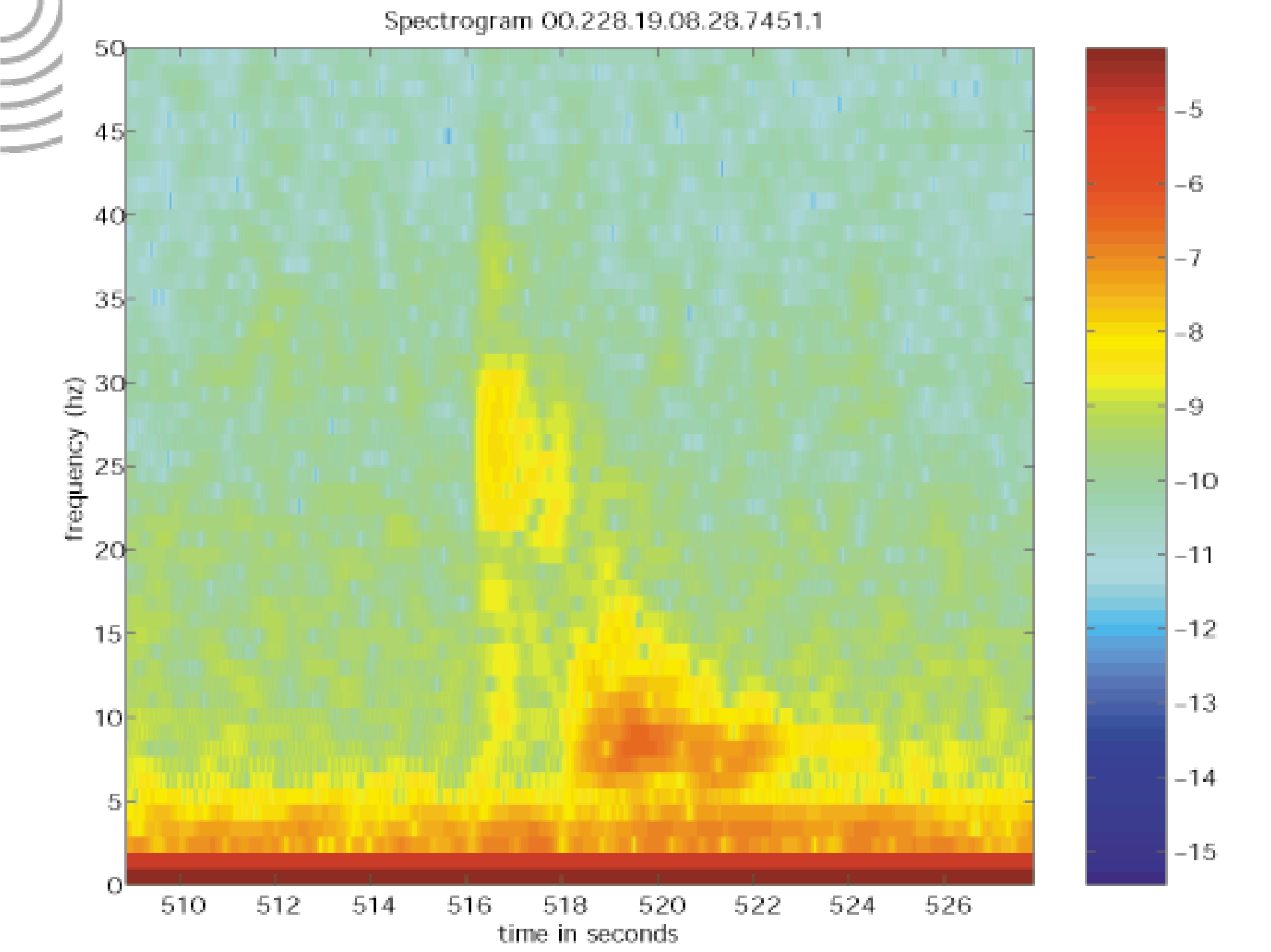
Rayleigh and Compressional Wave Propagation Modes Visible

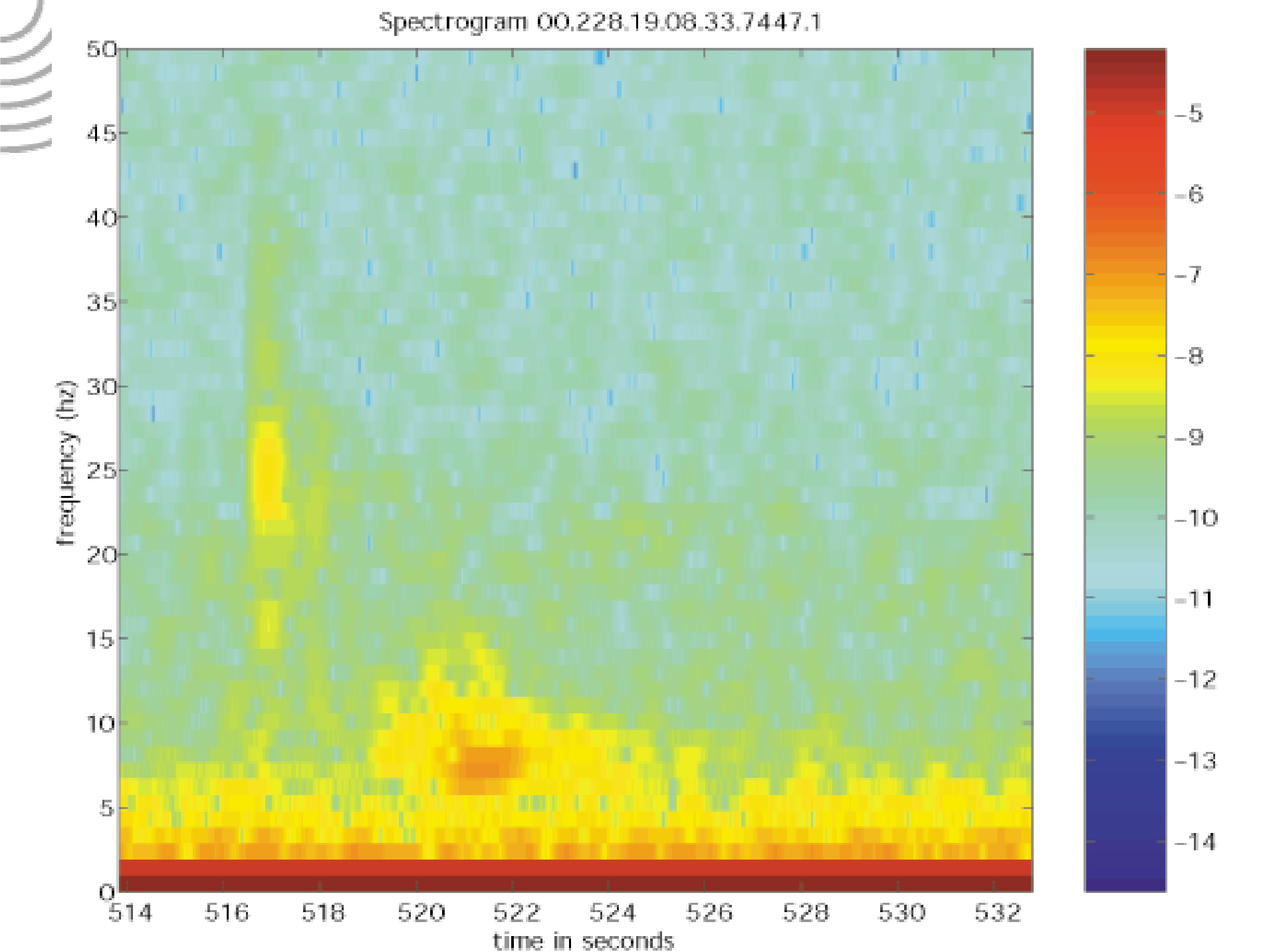
- Differing propagation velocities due to different shear and Young's modulus
- Rayleigh waves:
  - Propagate along surface
  - Combination of vertical shear wave and compressional wave that satisfies boundary condition that vertical stress vanishes at surface.
  - Amplitude is ellipsoidal and retrograde
  - Vertical/horizontal amplitude ratio:

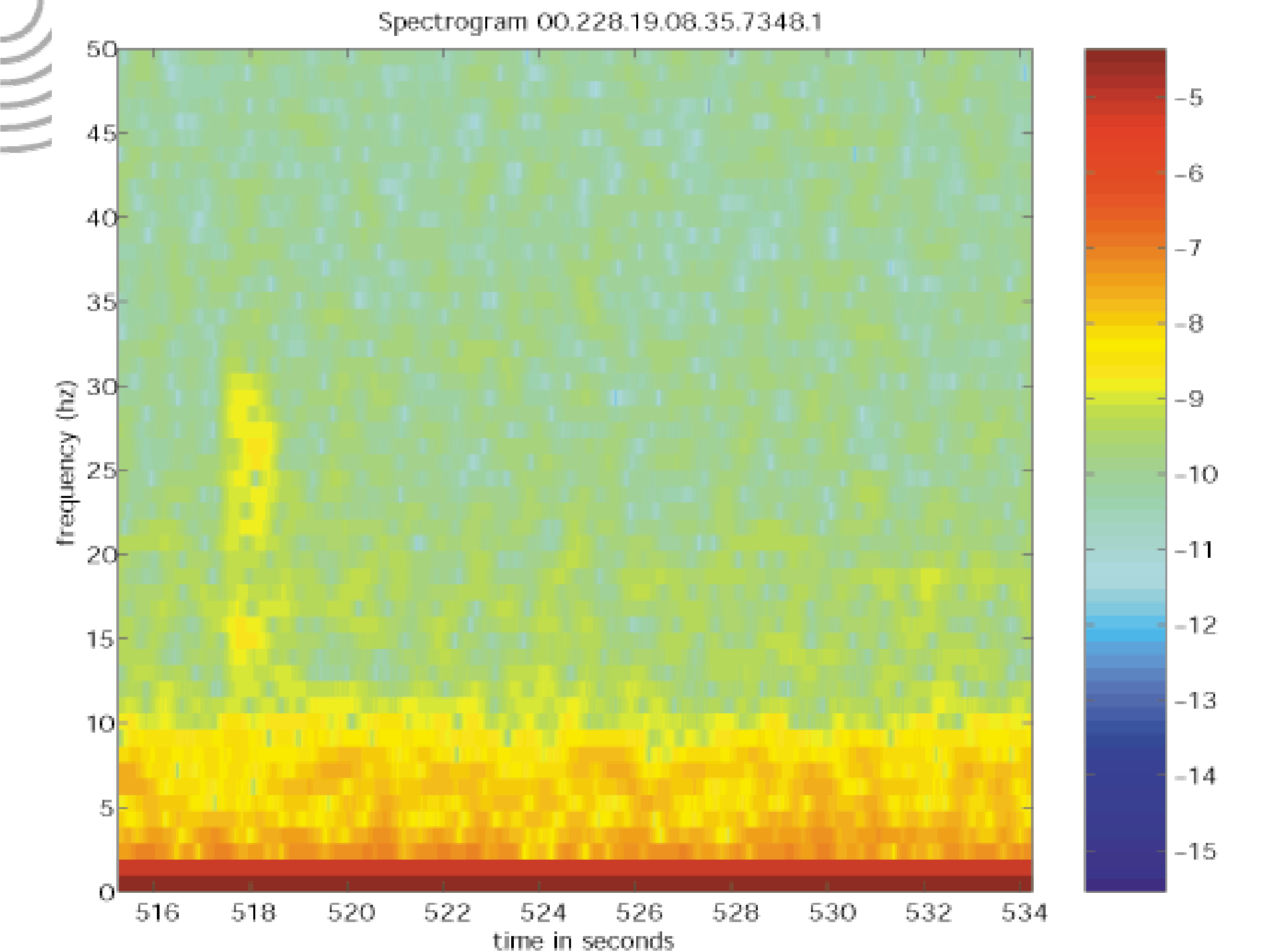
    1.3 -> 1.8 depending on Poisson's ratio

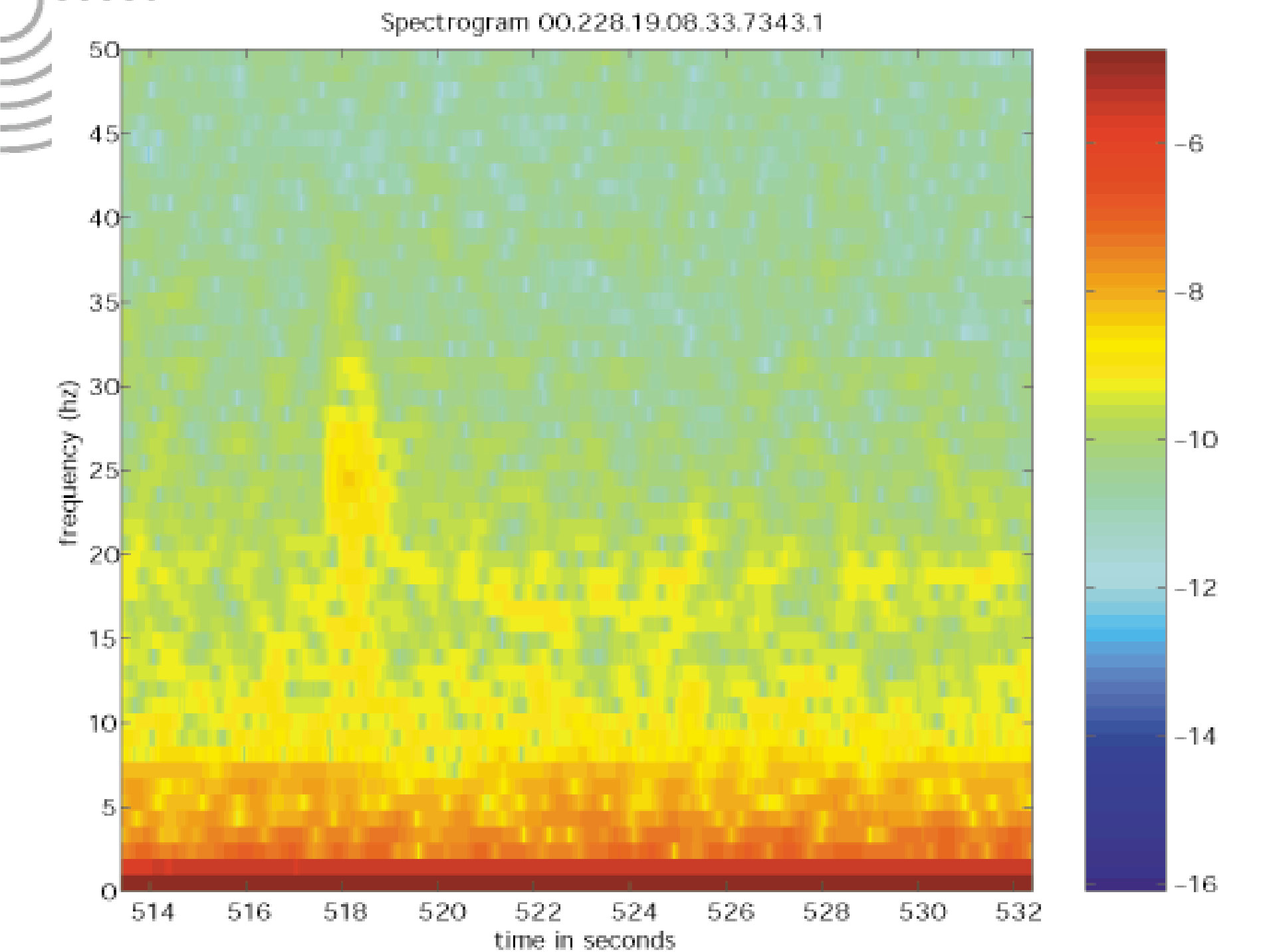


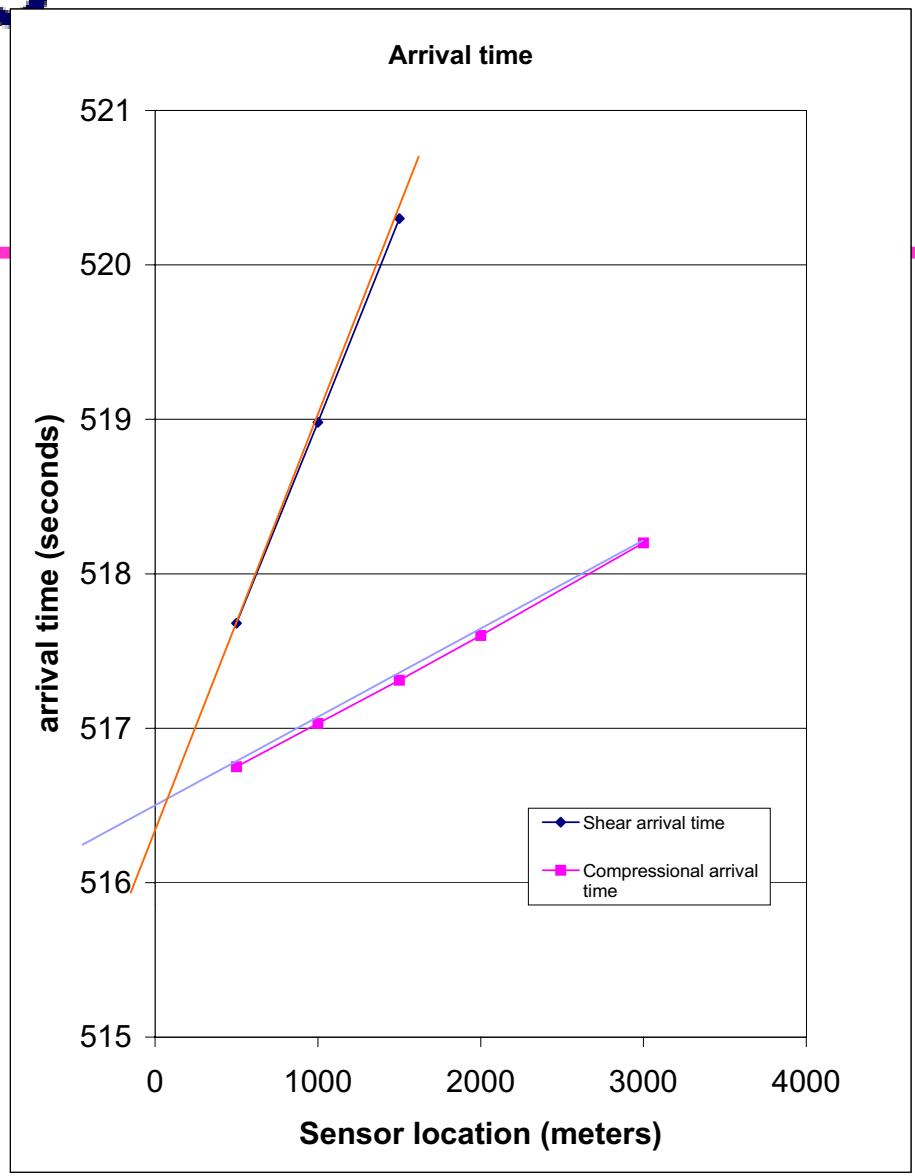

Spectrogram 00.228.19.08.30.7333.1
frequency (hz)
50
45
40
35
30
25
20
15
10
5
0
512
514
516
518
520
522
524
526
528
time in seconds
−5
−6
−7
−8
−9
−10
−11
−12
−13
−14
−15


Spectrogram 00.228.19.08.28.7451.1
frequency (hz)
time in seconds
0
5
10
15
20
25
30
35
40
45
50
510
512
514
516
518
520
522
524
526
−5
−6
−7
−8
−9
−10
−11
−12
−13
−14
−15


Spectrogram 00.228.19.08.33.7447.1
frequency (hz)
0
5
10
15
20
25
30
35
40
45
50
514
516
518
520
522
524
526
528
530
532
time in seconds
−5
−6
−7
−8
−9
−10
−11
−12
−13
−14


Spectrogram 00.228.19.08.35.7348.1
frequency (hz)
0
5
10
15
20
25
30
35
40
45
50
516
518
520
522
524
526
528
530
532
534
time in seconds
−5
−6
−7
−8
−9
−10
−11
−12
−13
−14
−15


Spectrogram 00.228.19.08.33.7343.1
frequency (hz)
0
5
10
15
20
25
30
35
40
45
50
514
516
518
520
522
524
526
528
530
532
time in seconds
-6
-8
-10
-12
-14
-16

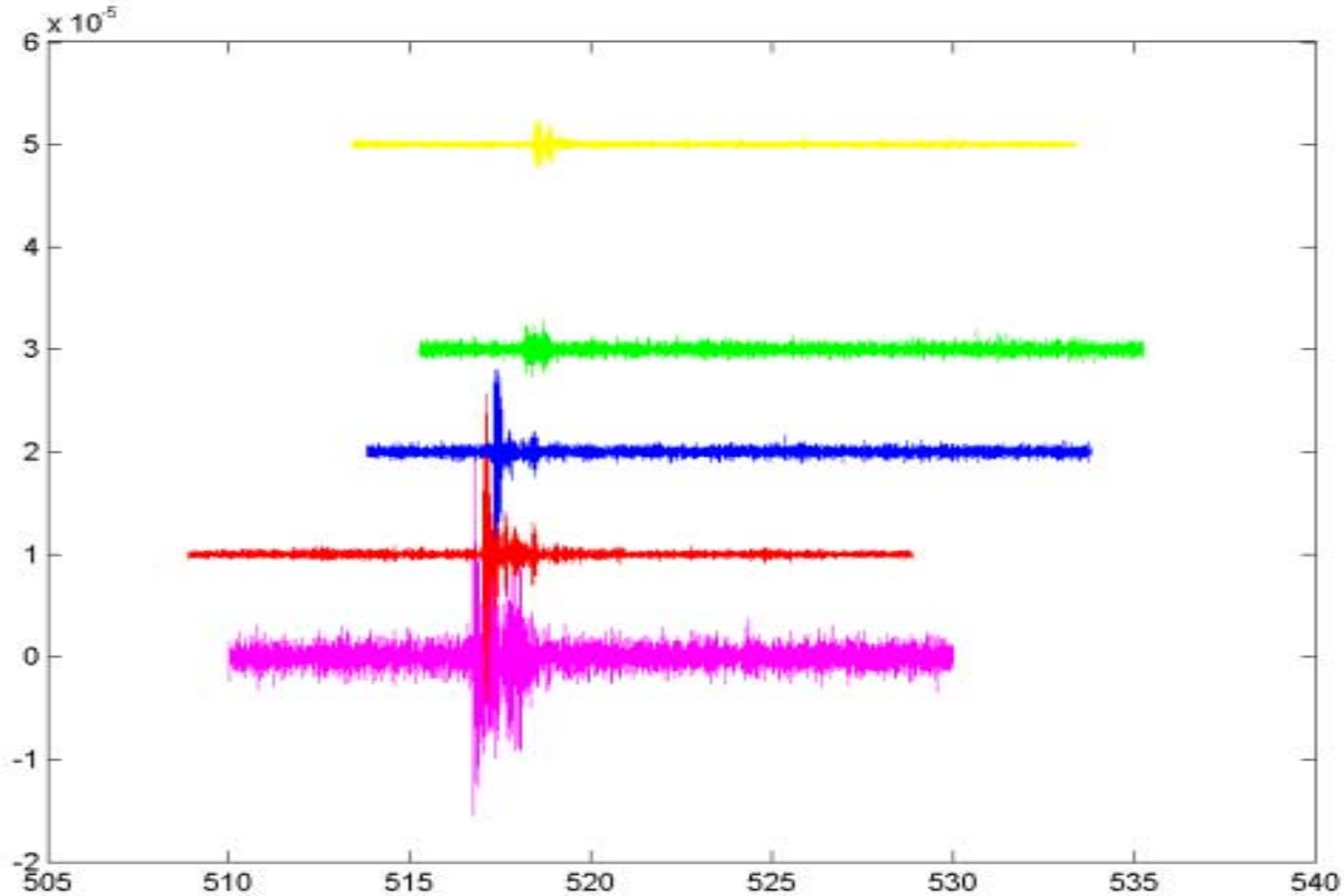


Intersection of arrival times points at pond boundary

Slope is velocity of wave packet:

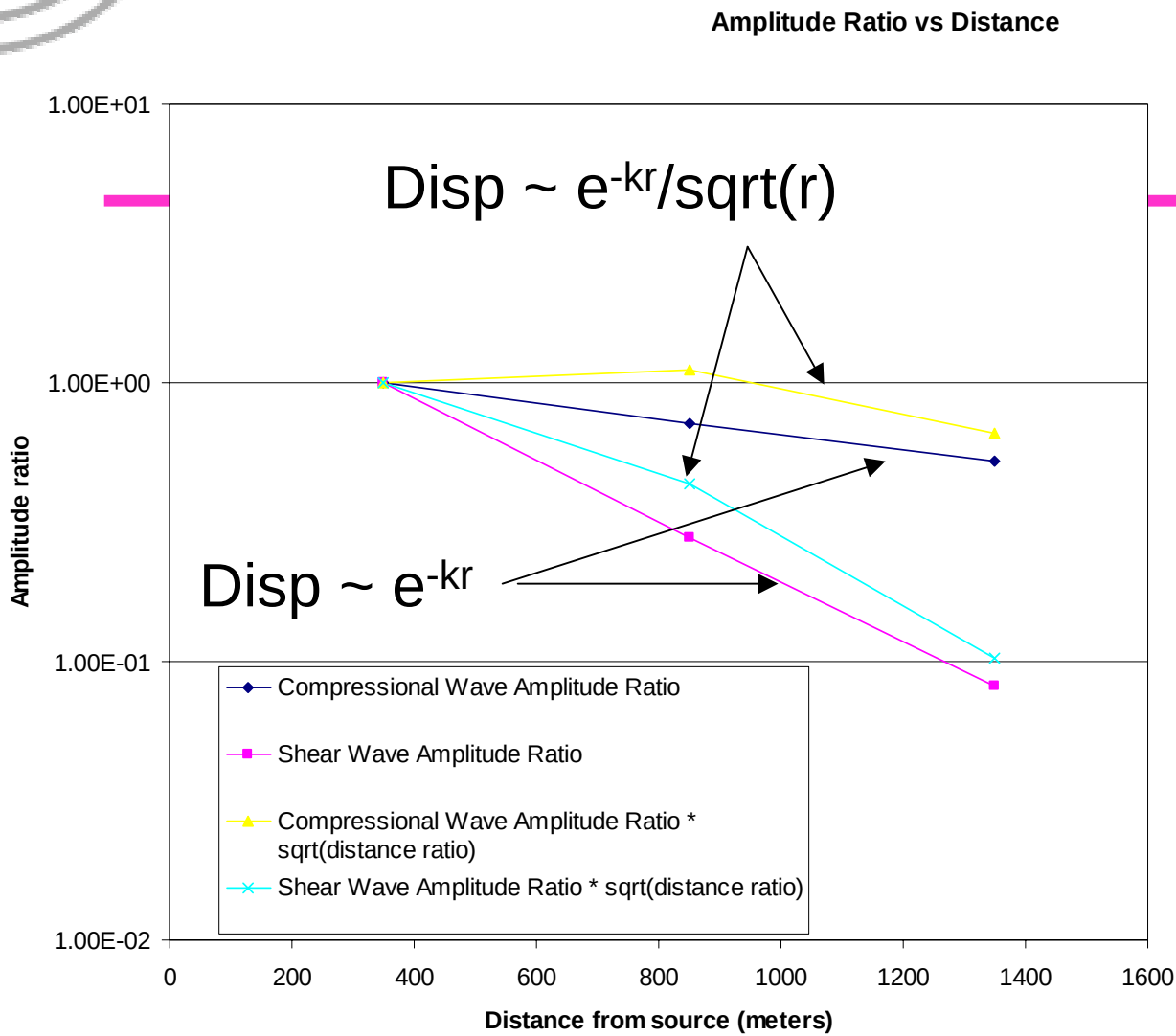
c_R = 368+/- 11 m/sec

c_C = 1780+/- 80



Time domain 4 pole High-pass Butterworth IIR filter

Fc=20 Hz, Fs = 250 Hz



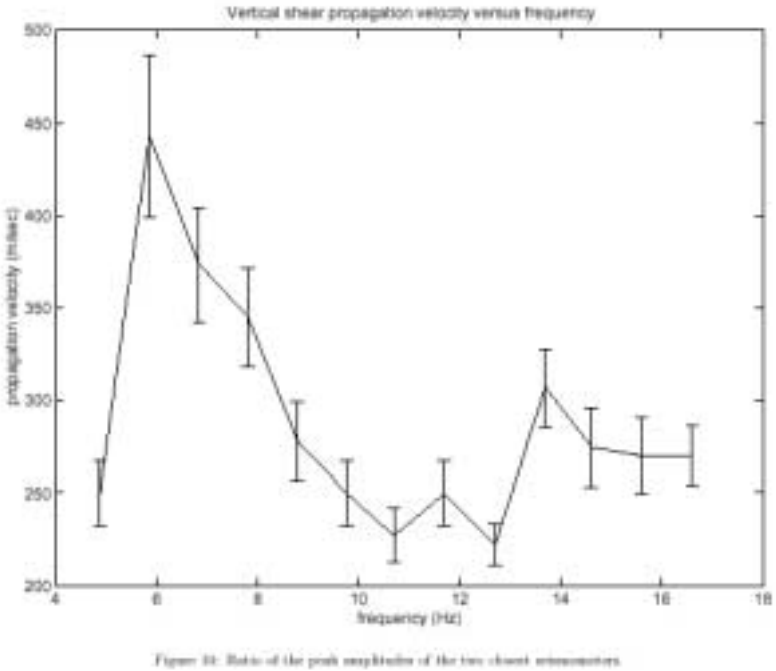
1/e lengths:

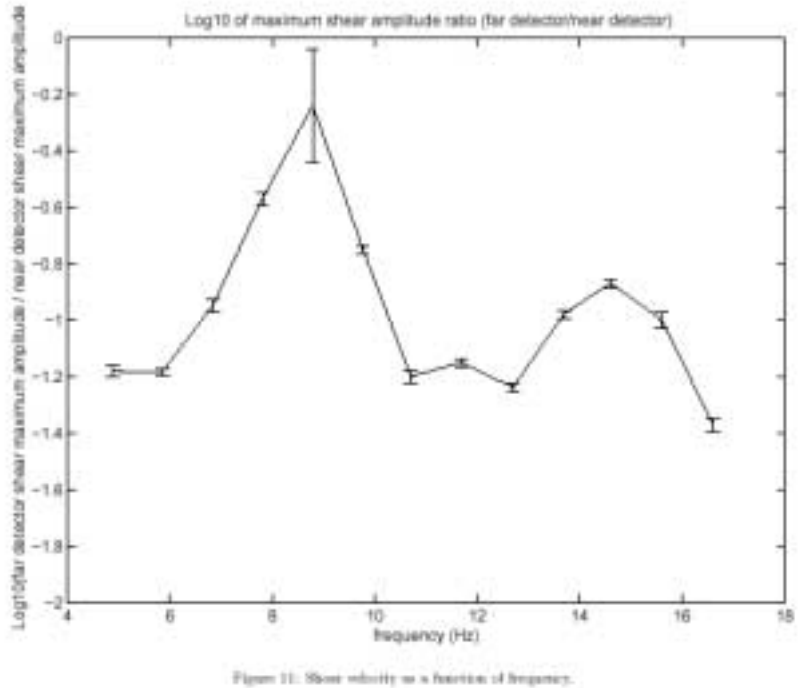
Compressional = 1540+/- 50 meters

Rayleigh = 300+/- 6 meters

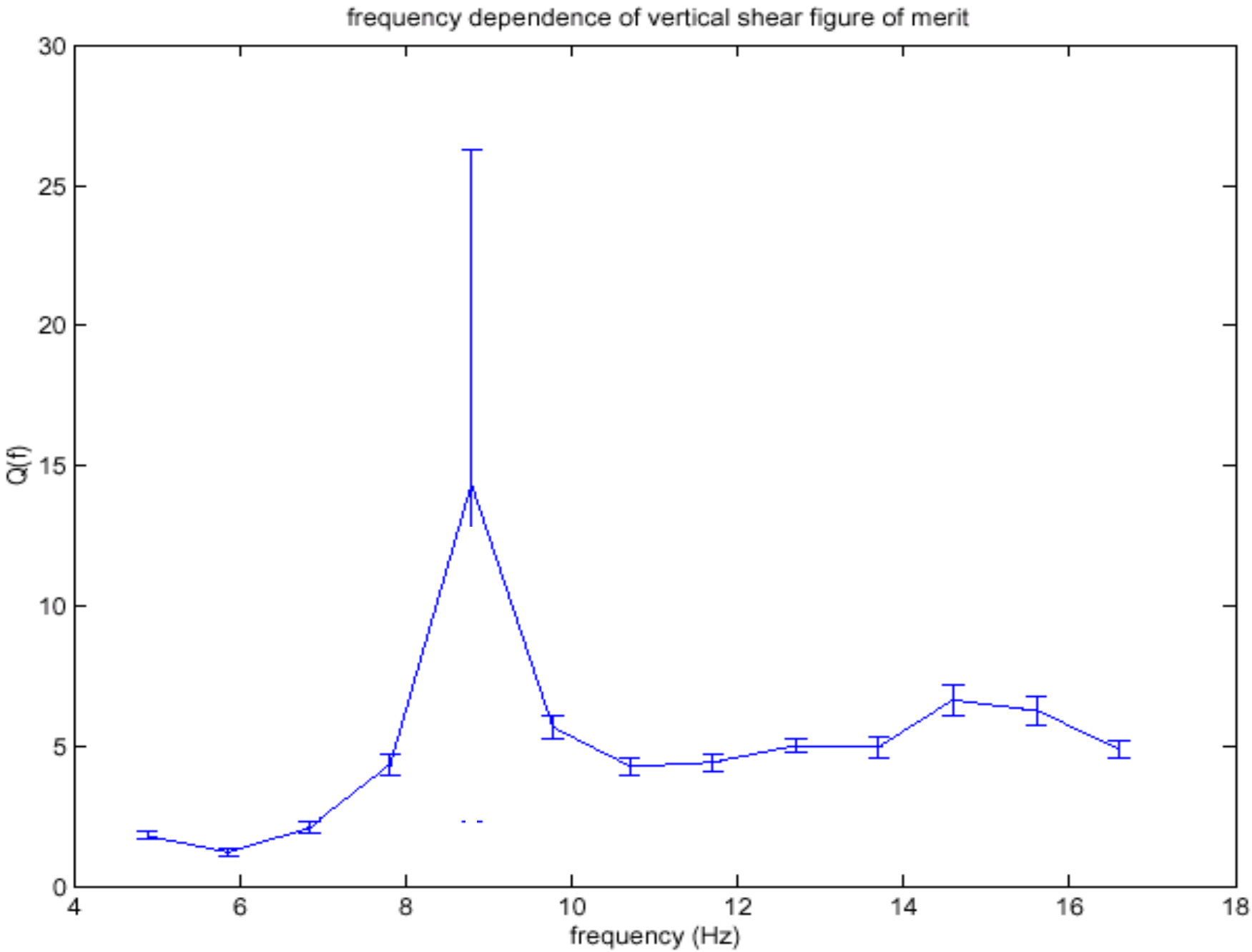
We can couple to seismic sources that are kilometers away.

Some evidence that berm structure or underlying formation guides waves.





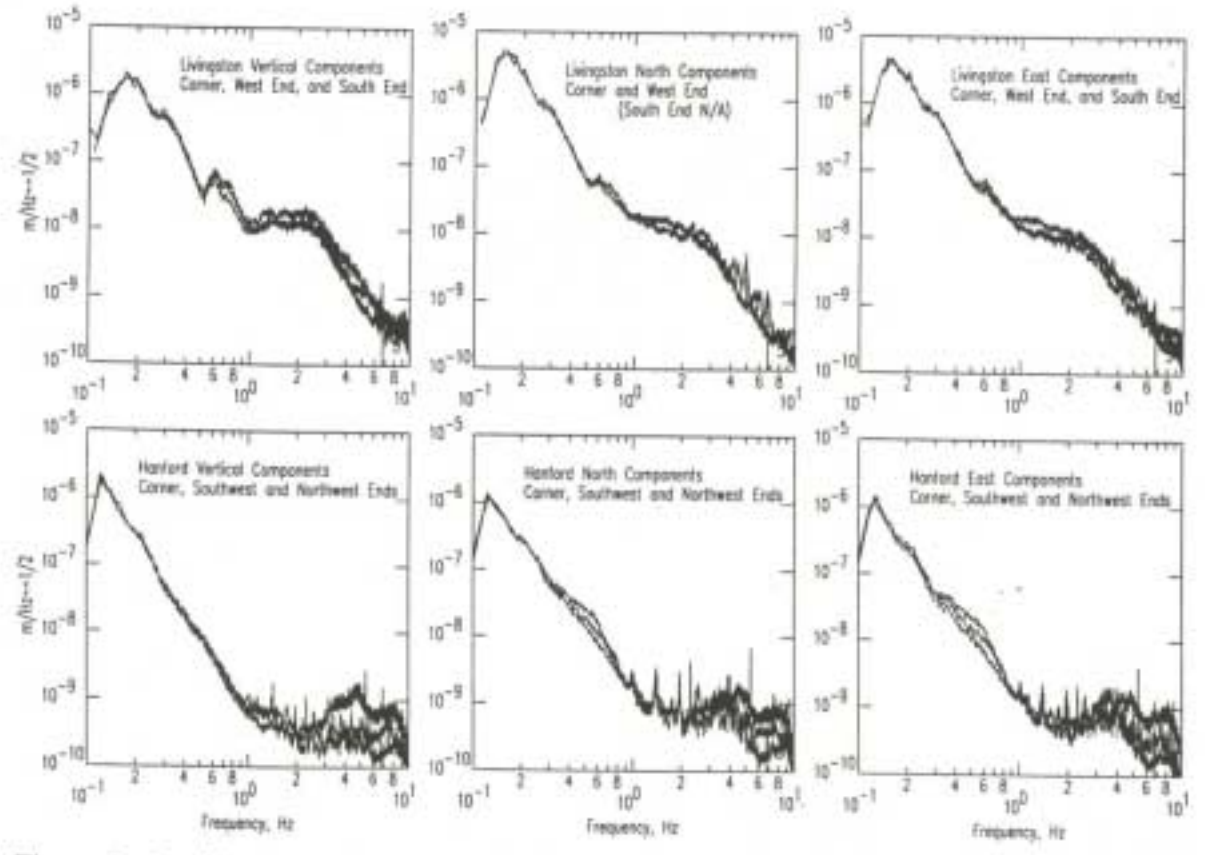
Evidence of berm construction or geological substructure?


frequency dependence of vertical shear figure of merit
Q(f)
frequency (Hz)
0
5
10
15
20
25
30
4
6
8
10
12
14
16
18

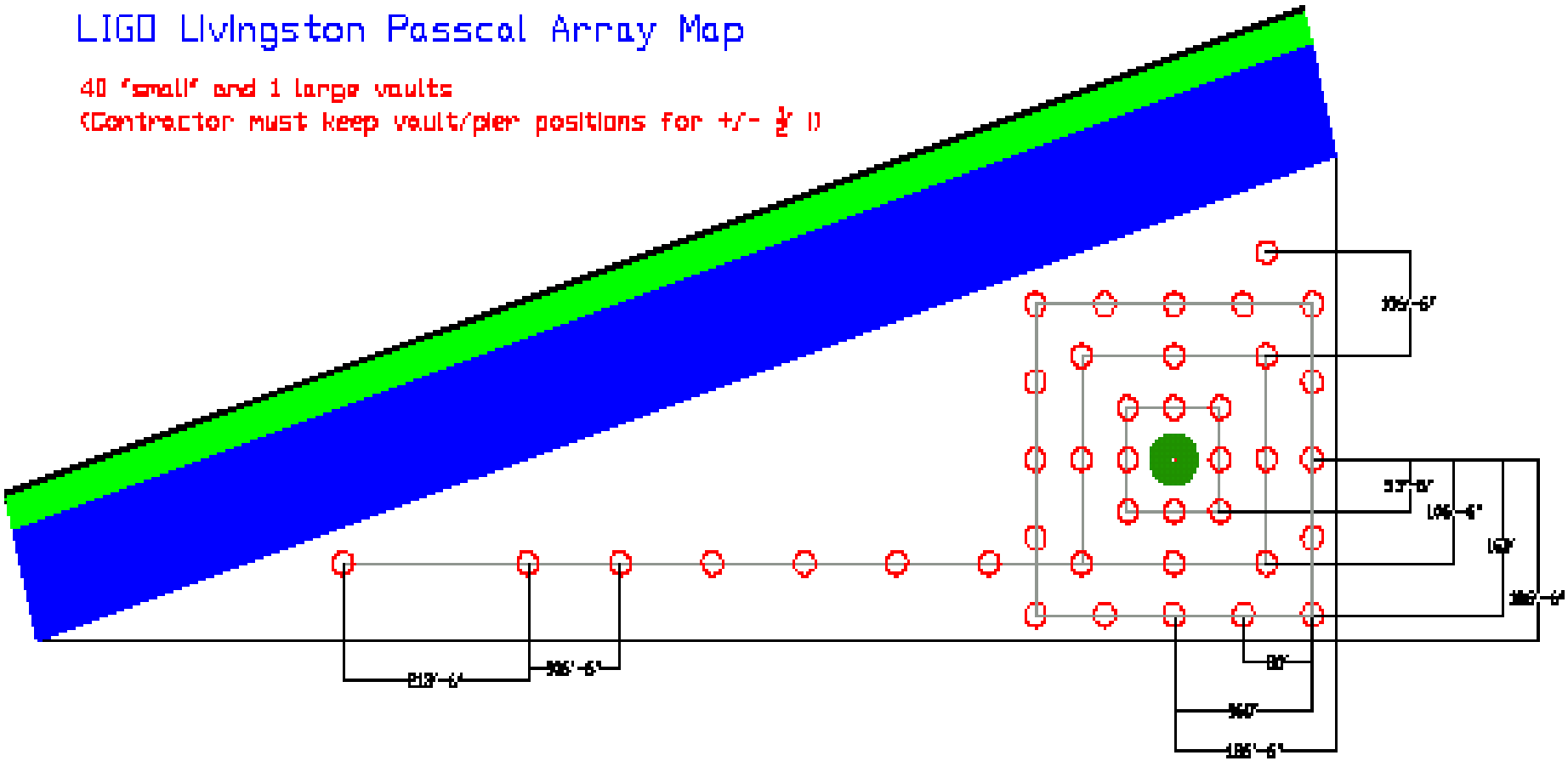
More details of X arm channel characterization at

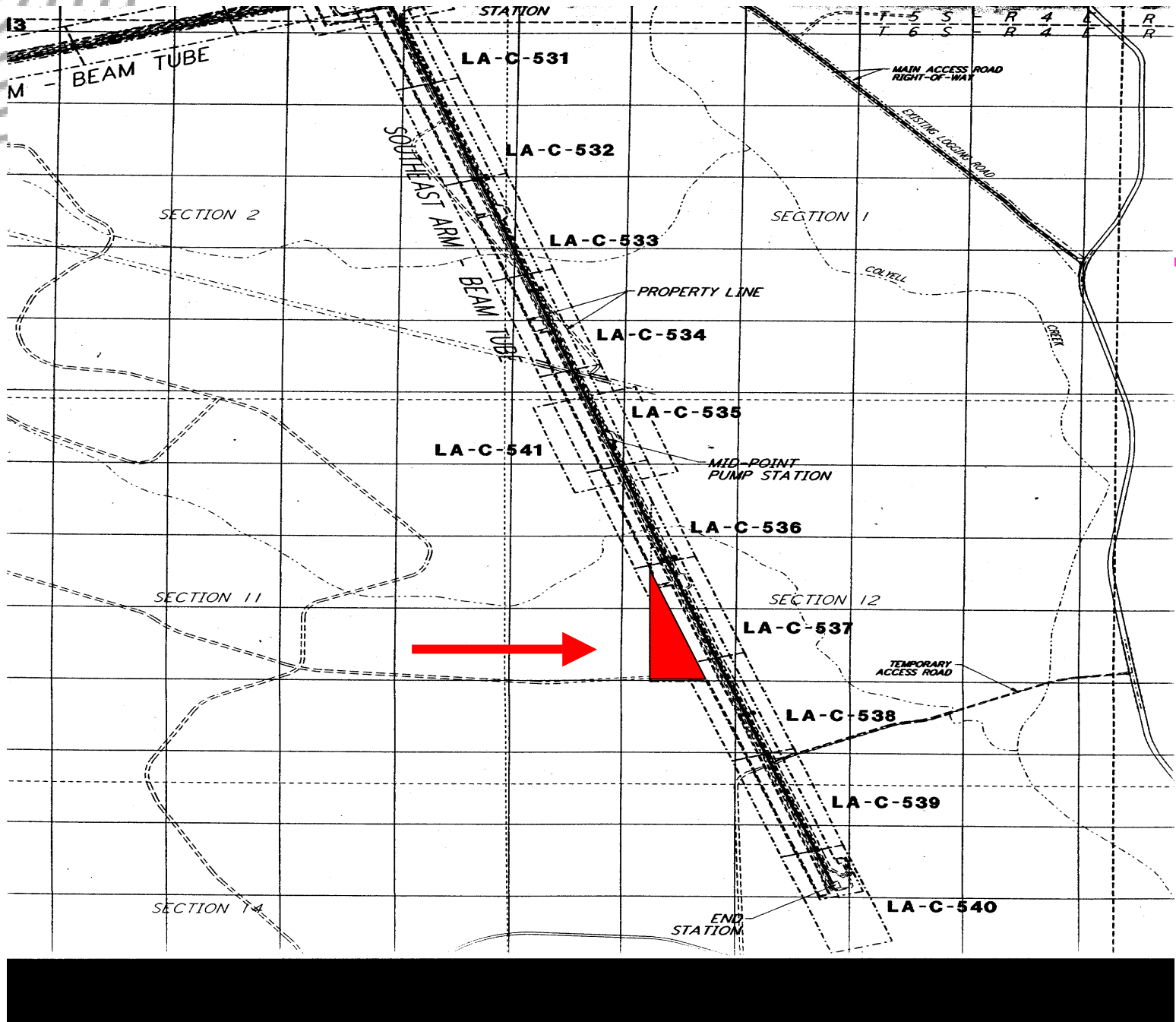
T010073-01-L

Measured Microseismic Motion at Livingston and Hanford



From Alan Rohay 7/9


LIGO Livingston Passcal Array Map
40 'small' and 1 large vaults
(Contractor must keep vault/pier positions for +/- ½' !)


STATION
BEAM TUBE
LA-C-531
LA-C-532
LA-C-533
LA-C-534
LA-C-535
LA-C-541
LA-C-536
LA-C-537
LA-C-538
LA-C-539
LA-C-540
SOUTHEAST ARM - BEAM TUBE
MAIN ACCESS ROAD RIGHT-OF-WAY
EXISTING LOGGING ROAD
PROPERTY LINE
COLVELL CREEK
MID-POINT PUMP STATION
TEMPORARY ACCESS ROAD
END STATION
SECTION 1
SECTION 2
SECTION 11
SECTION 12
SECTION 14

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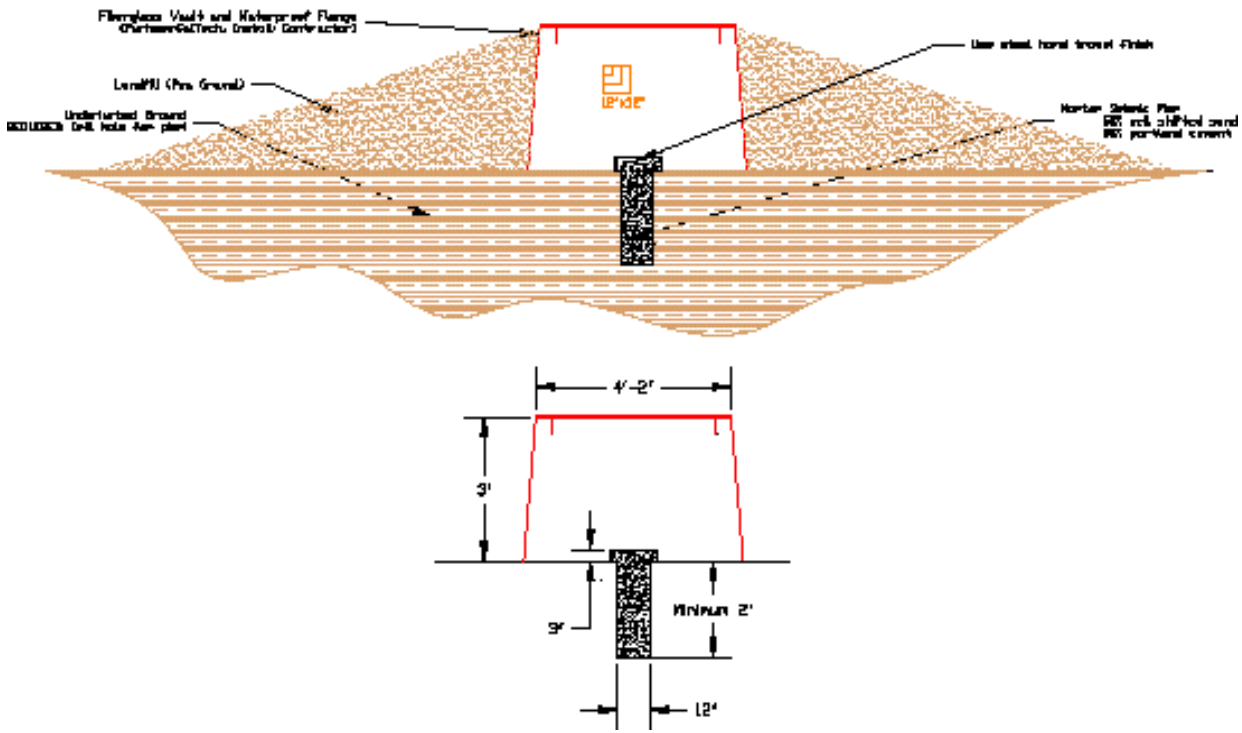
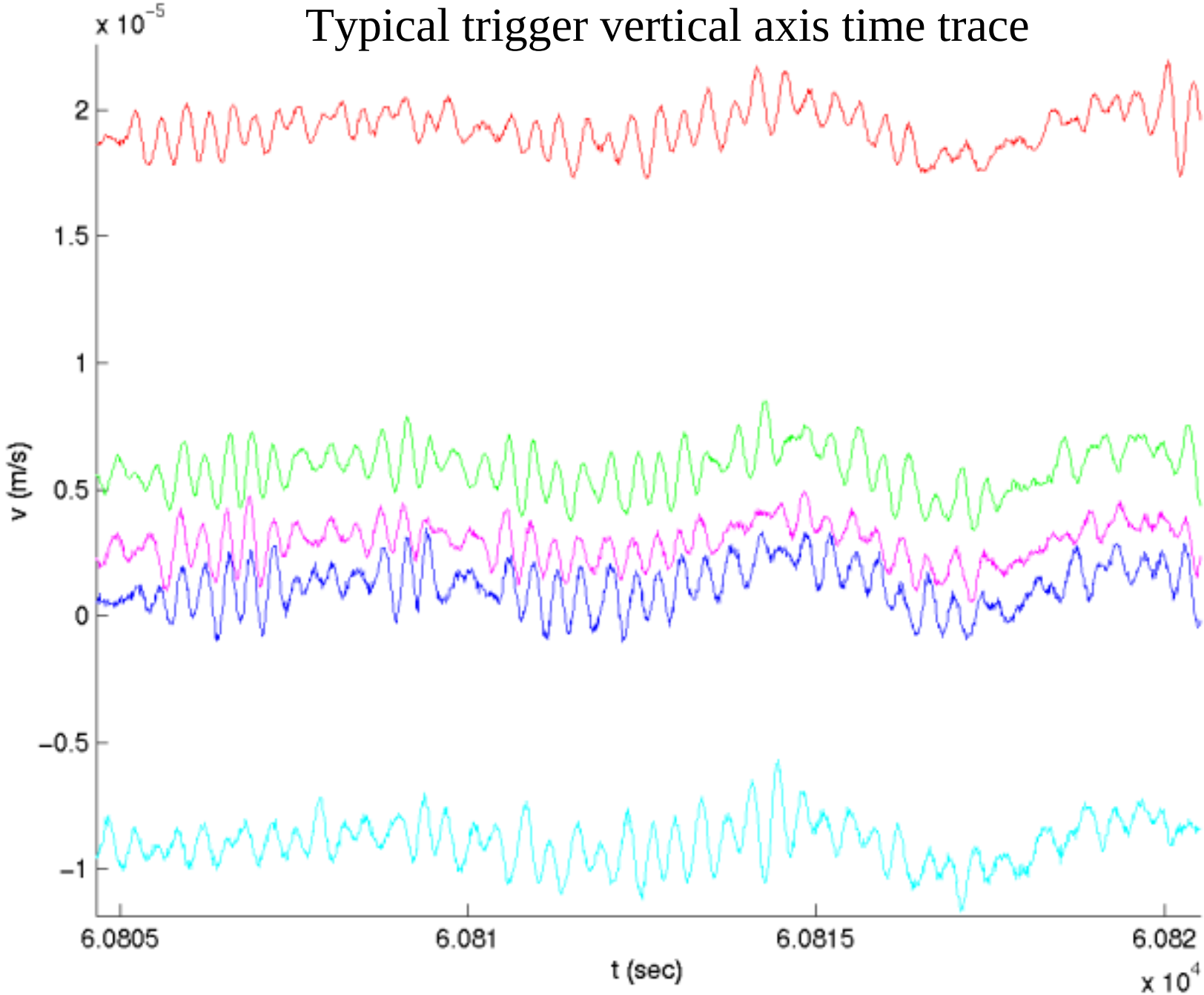
LIGO Livingston Passcal Array Vault



Typical trigger vertical axis time trace



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What level of ground velocity causes lock problems?

OSEM force/amp total 4 OSEMS F/I = 0.08 nt/amp

I_{max} = 90 mA

Assume stack and pendulum add x5 to ground motion over 0-20 Hz interval

Mass = 10 Kg

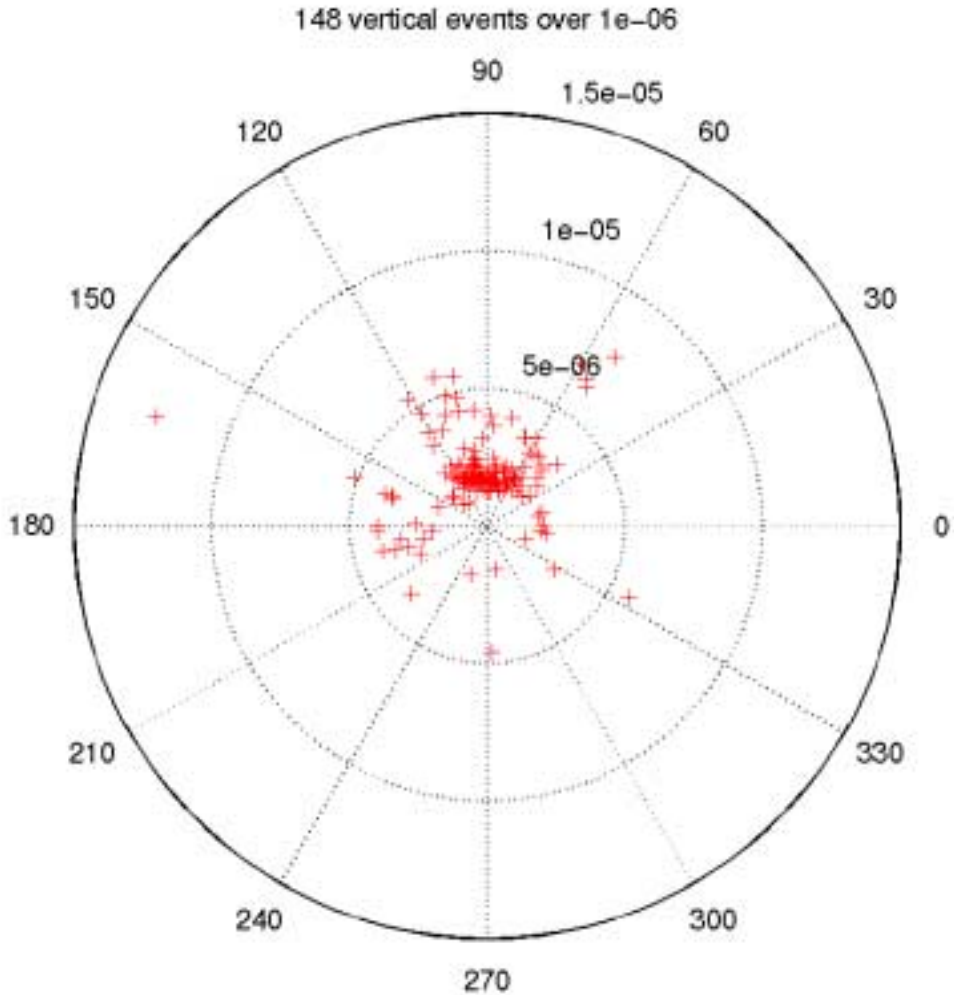
➔Max velocity to hold lock is around 2 microns/sec

➔Look at events that are bigger than this to see what we can learn about them.

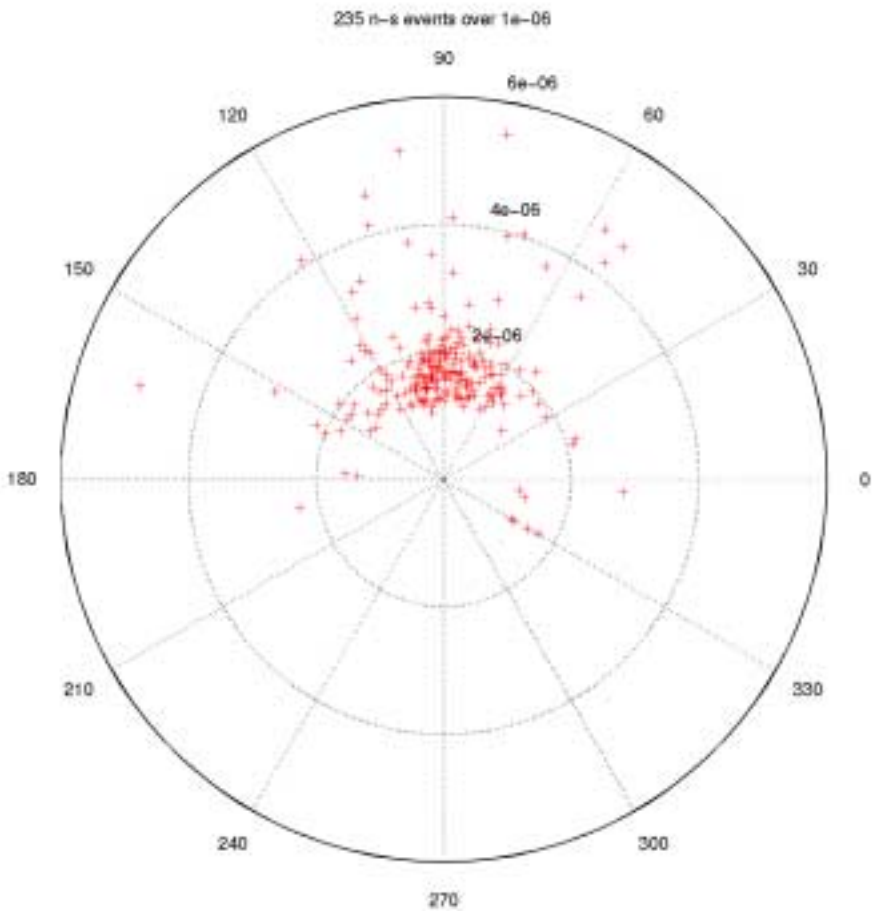
Analysis method

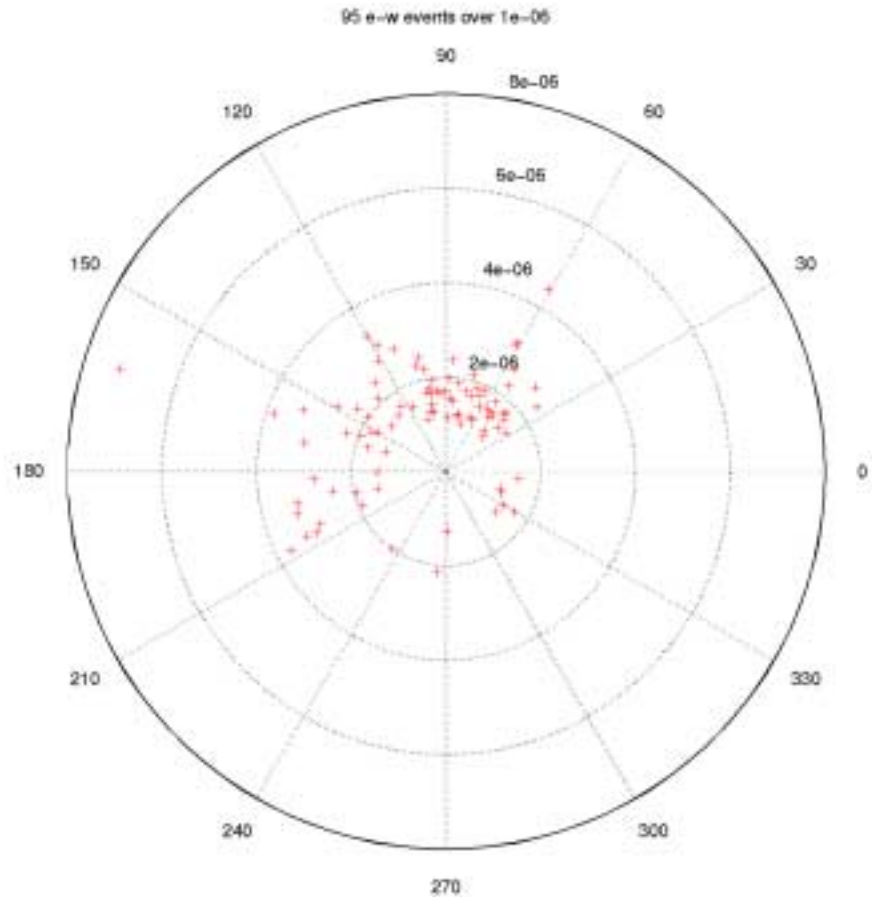
- Time domain filter data using 4 pole Butterworth high pass filter (fc=1 Hz) IIR filter. Look for impulses where velocity > $v_{threshold}$
- Compute cross correlation function between elements of array using 2 second window.
  - 2 seconds is a typical autocorrelation time
- Least squares fit using both horizontal axes of all seismometers in array to determine propagation velocity and direction
- Compare horizontal and vertical amplitudes

Analysis done with Sean Hardesty, Caltech SURF student at LLO

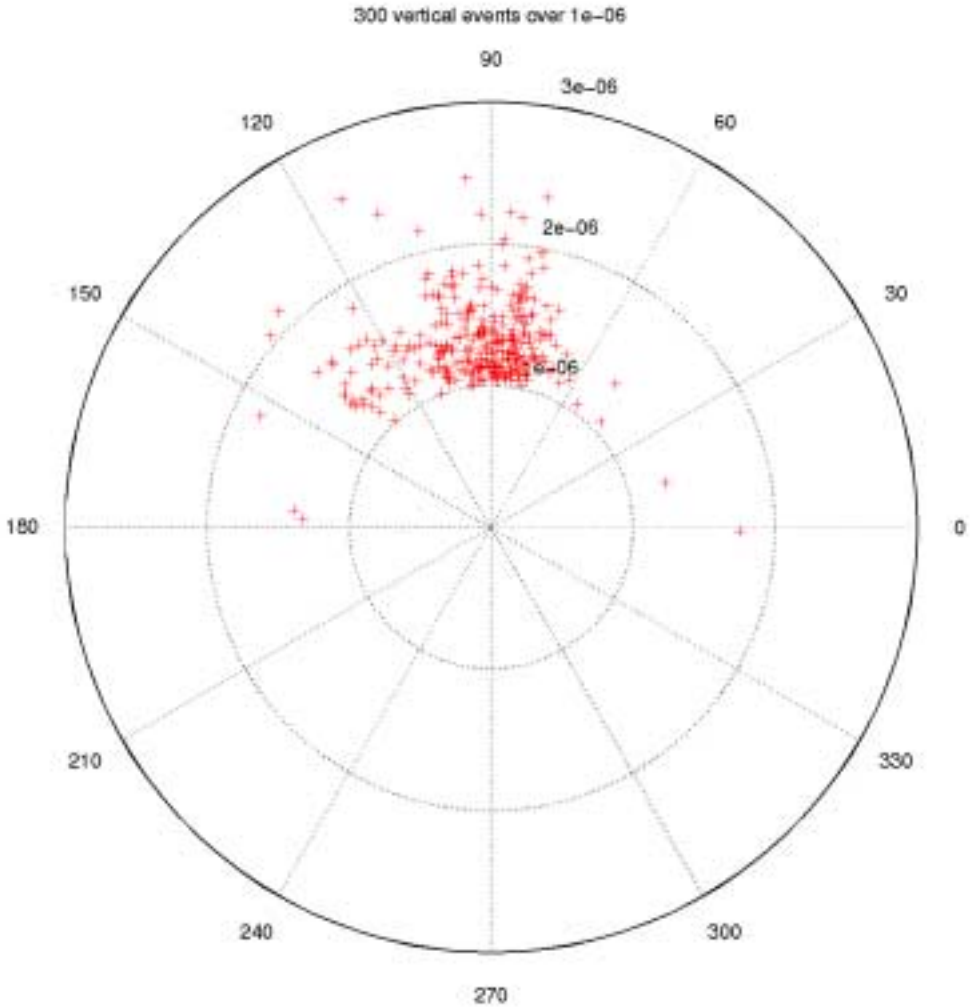


Angular distribution of impulsive events with ground velocity > 1u/sec 9am – 3 pm,

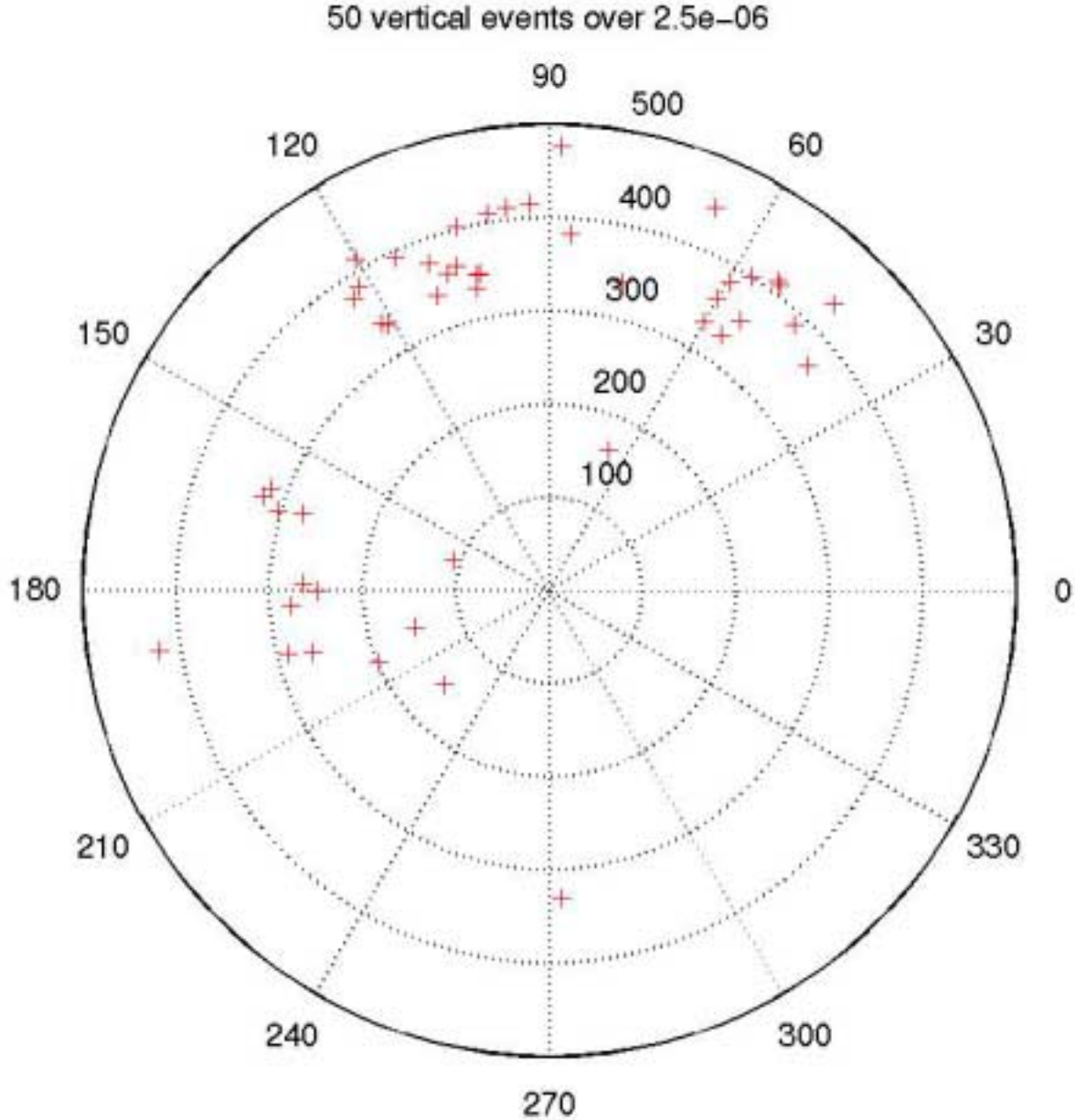

235 n–s events over 1e–06
90
6e–06
120
60
4e–06
150
30
2e–06
180
0
210
330
240
300
270


95 e–w events over 1e–06
90
6e–06
120
60
5e–06
4e–06
150
30
2e–06
180
0
210
330
240
300
270

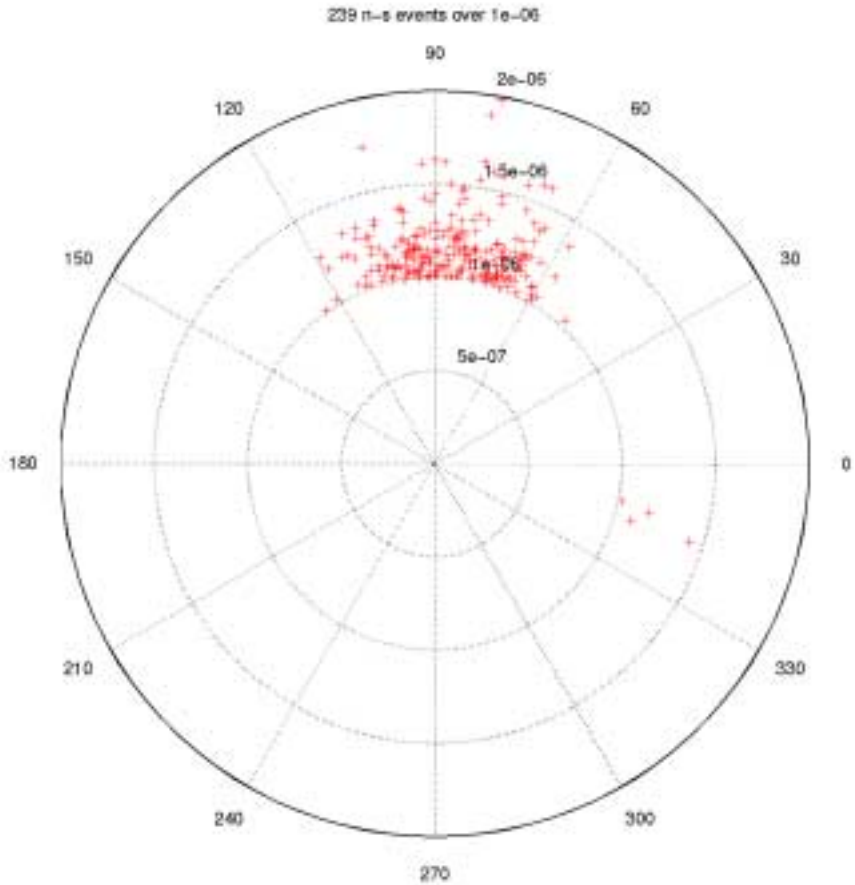
daytime

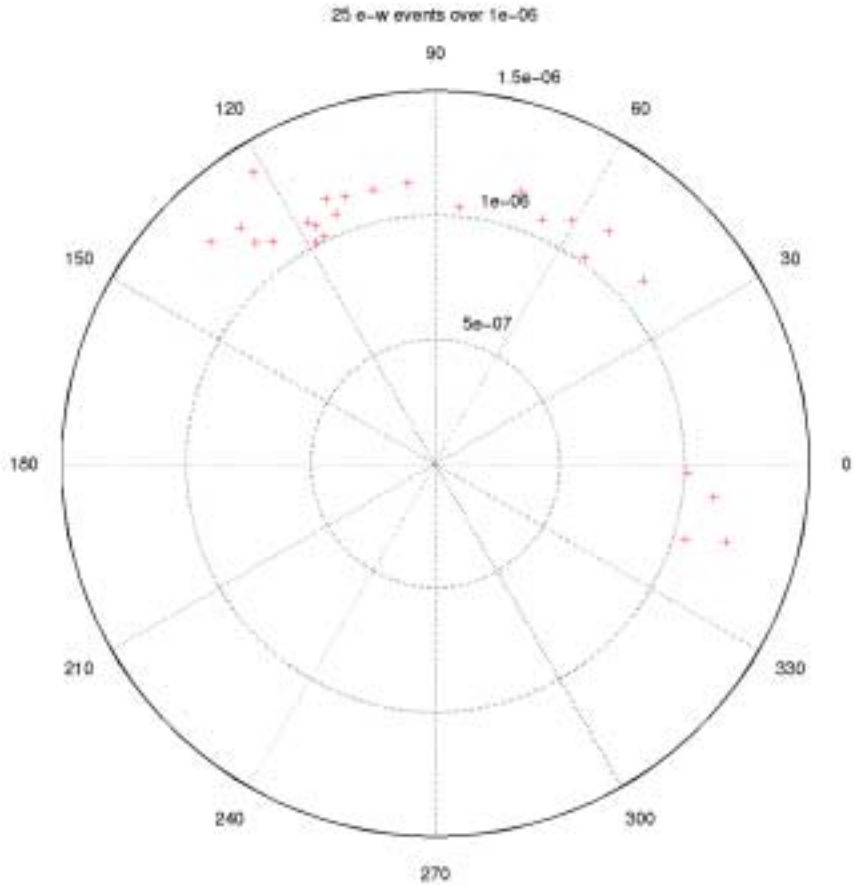


Night time vertical impulses

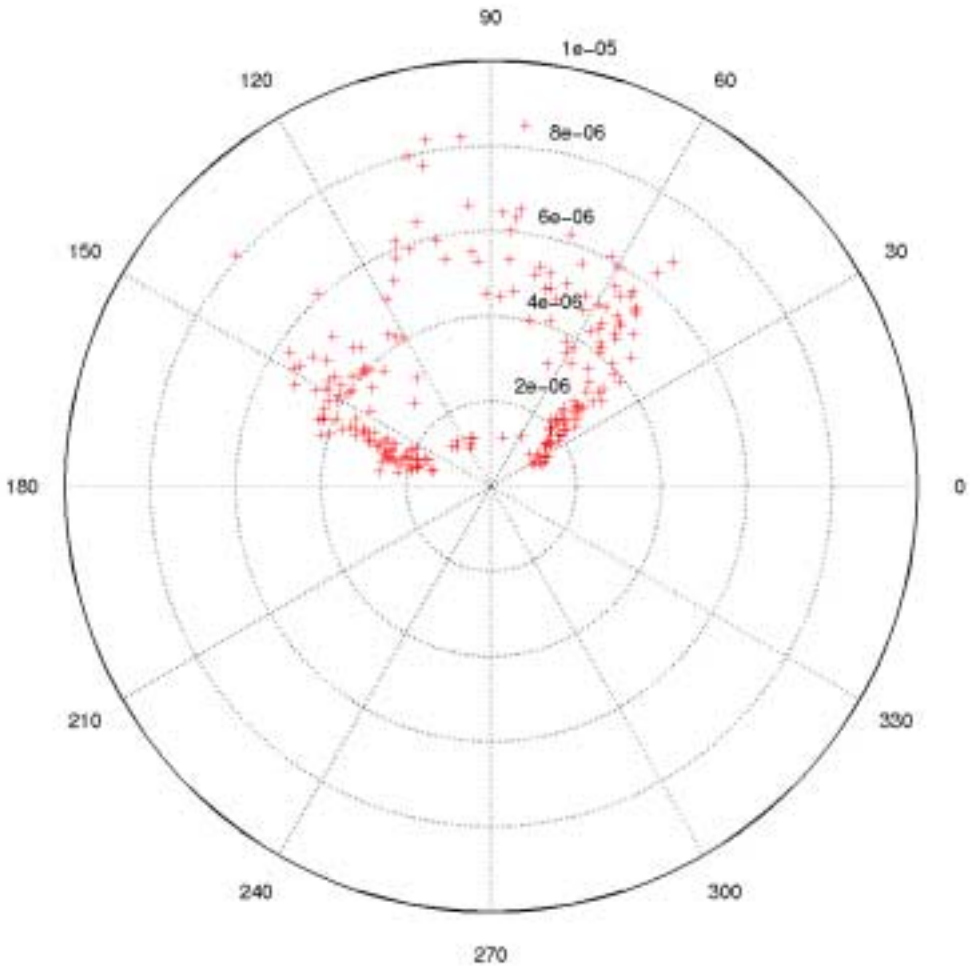


Velocity distribution for vertical triggers


239 n–s events over 1e–06
90
120
60
150
30
180
0
210
330
240
300
270
2e–06
1.5e–06
1e–06
5e–07


25 e–w events over 1e–06
90
120
60
150
30
180
0
210
330
240
300
270
1.5e–06
1e–06
5e–07

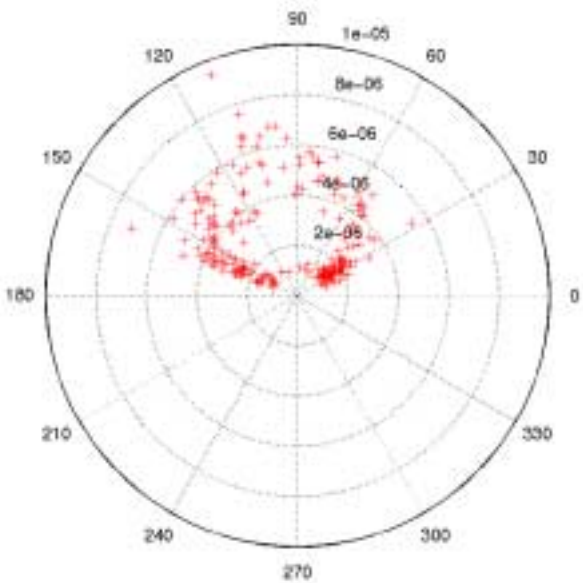
nightime

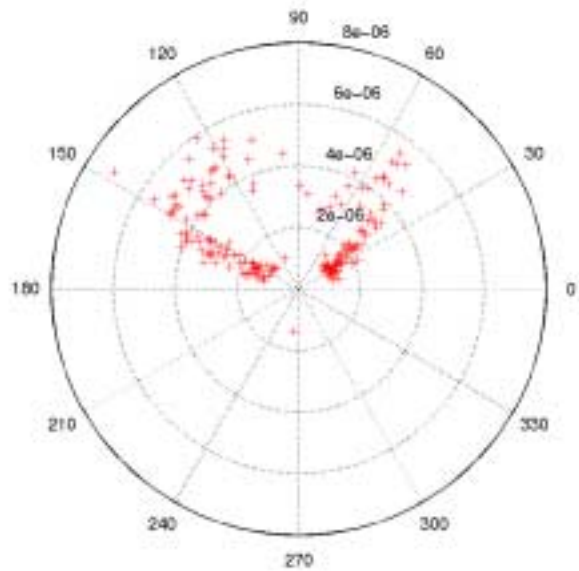


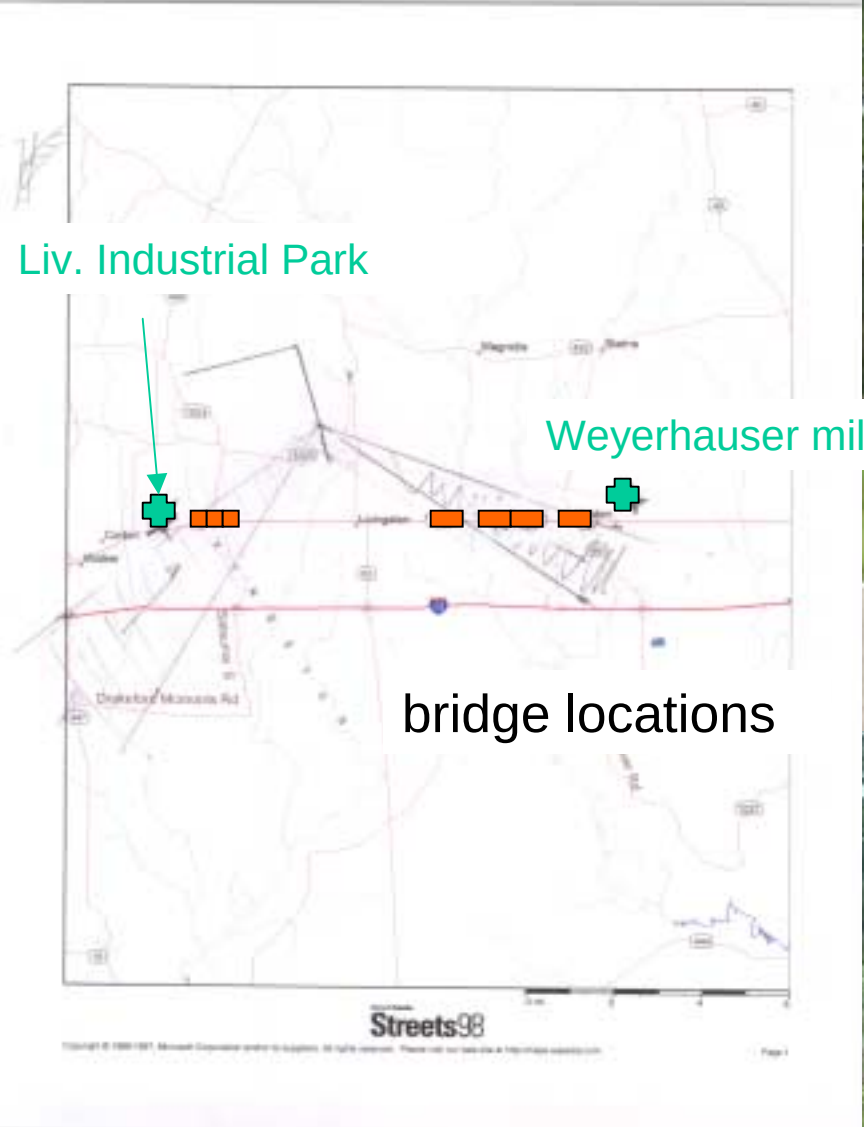
Vertical triggers during train

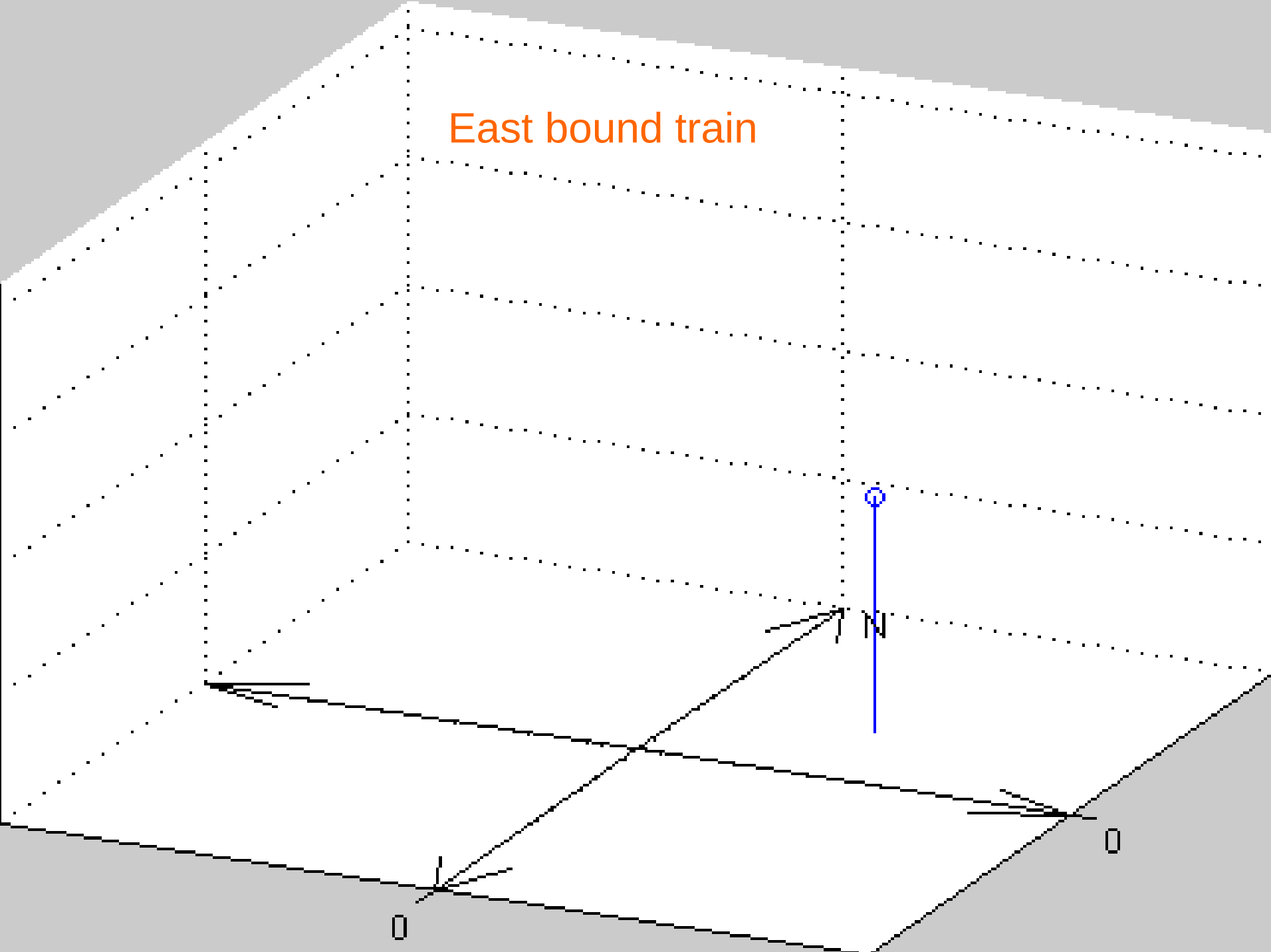
Note angular clustering

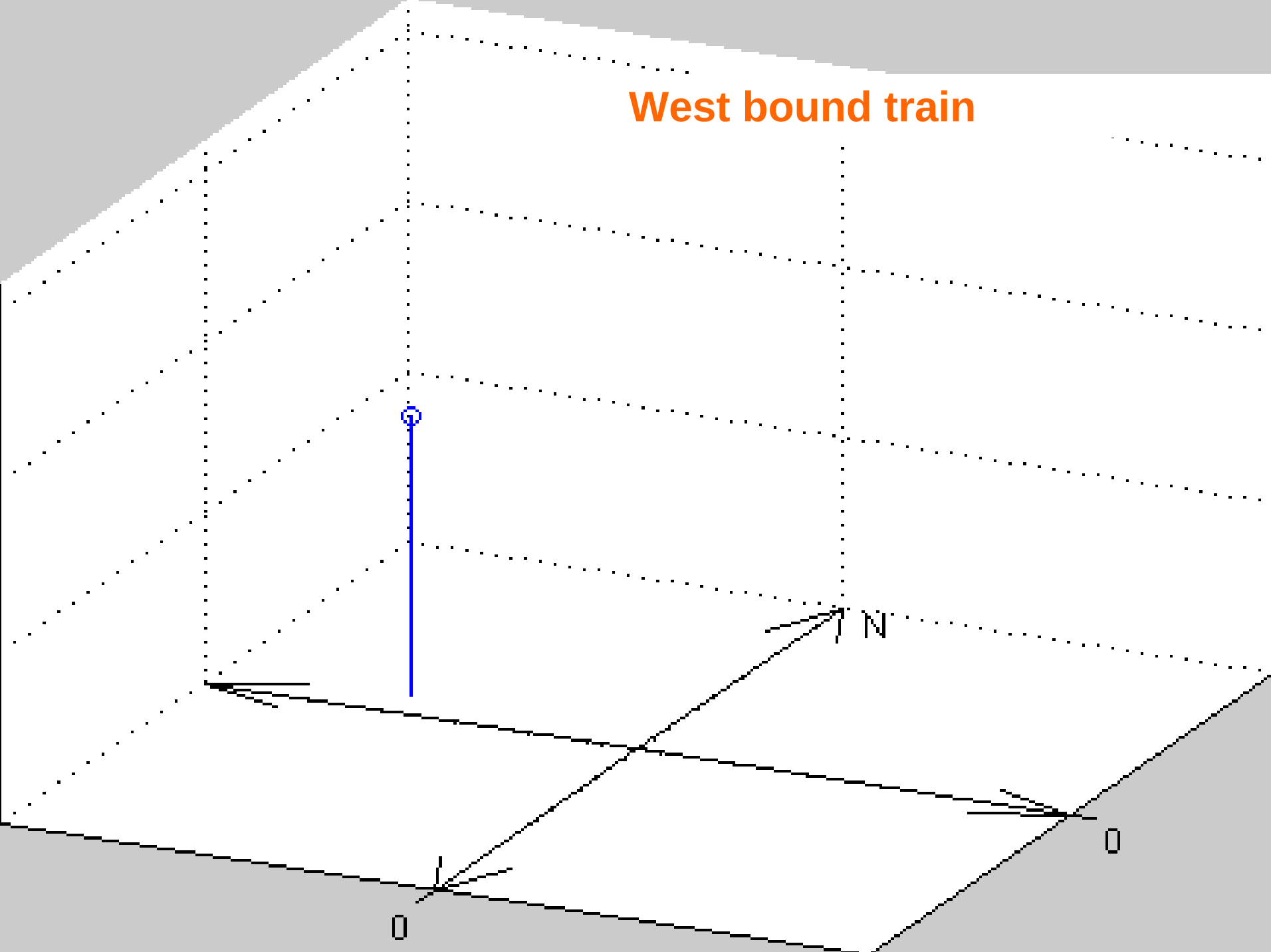
Horizontal train signal



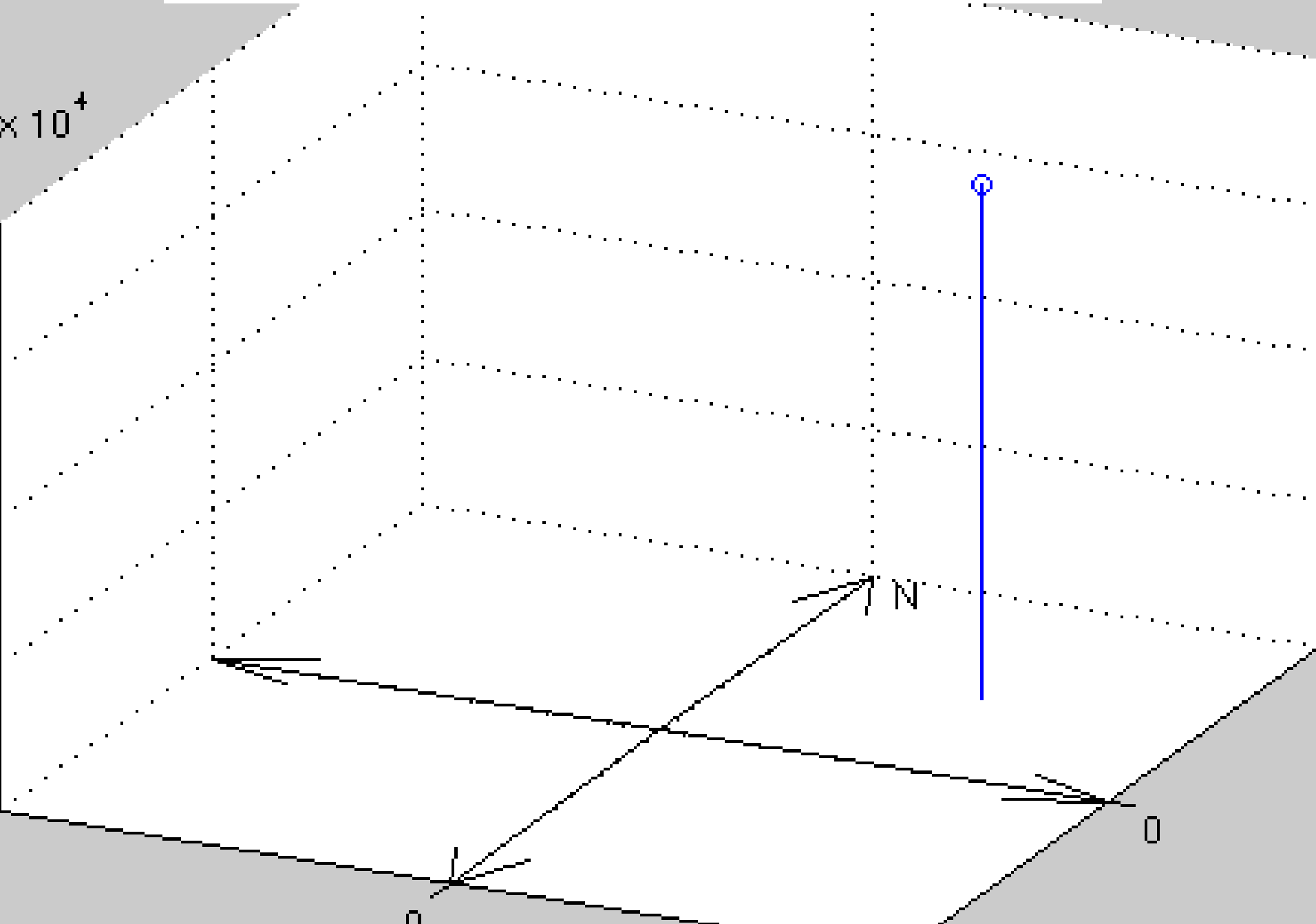



Liv. Industrial Park
Weyerhauser mill
bridge locations
Streets98


East bound train
N
0
0

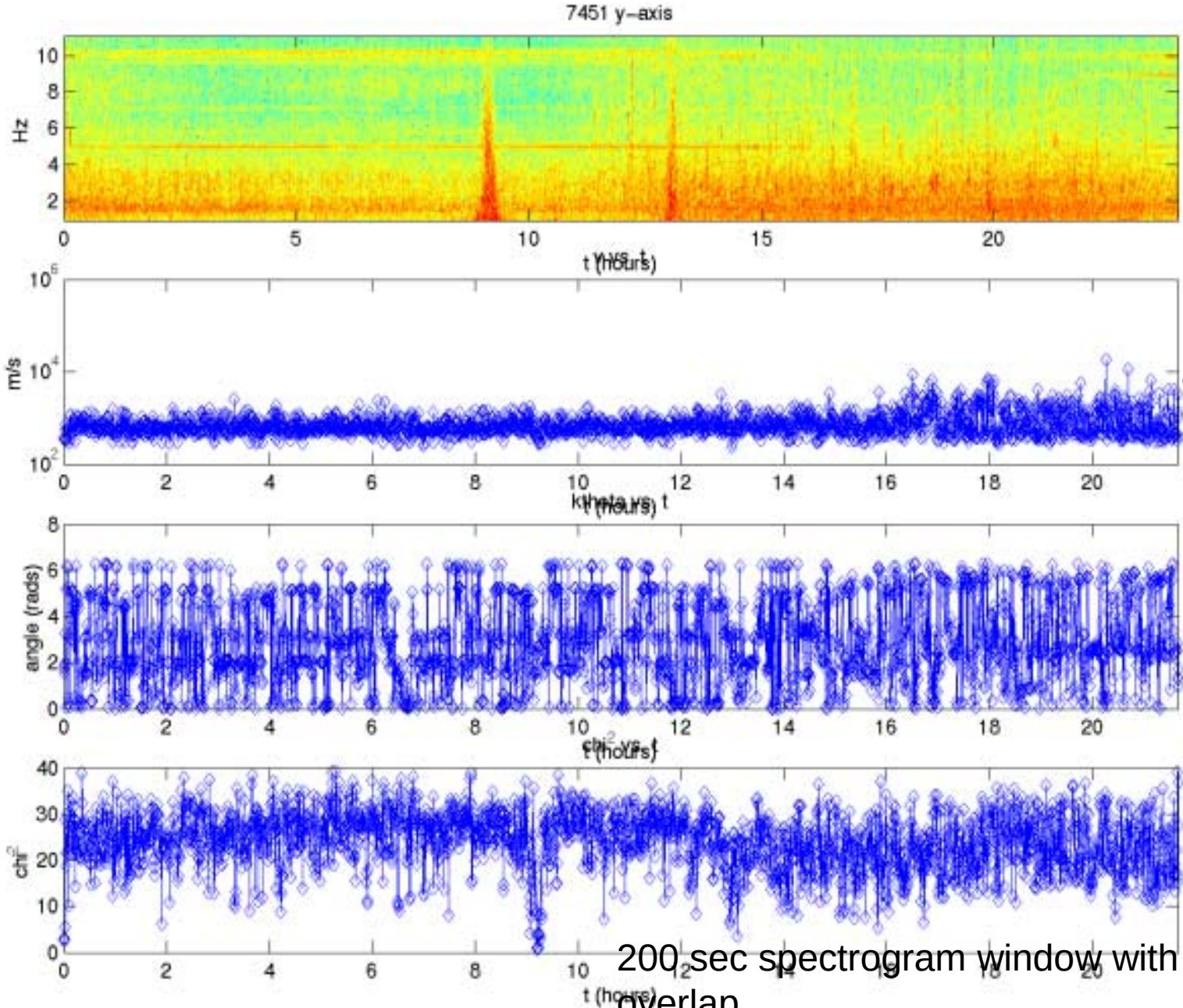

West bound train
N
0
0

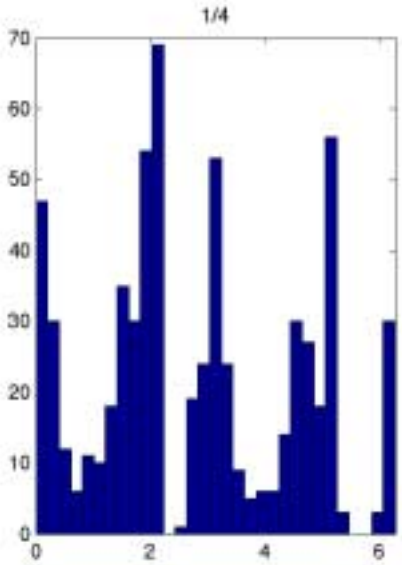
There are some trajectories at other times also

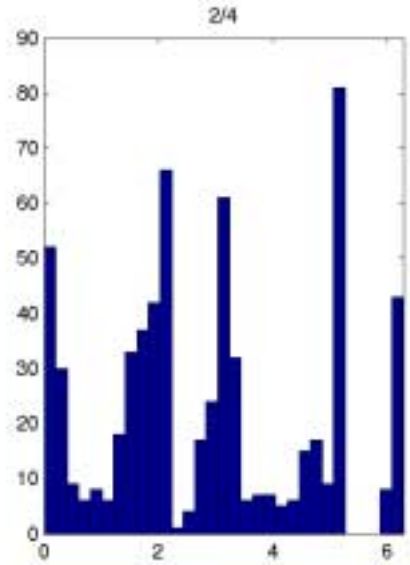


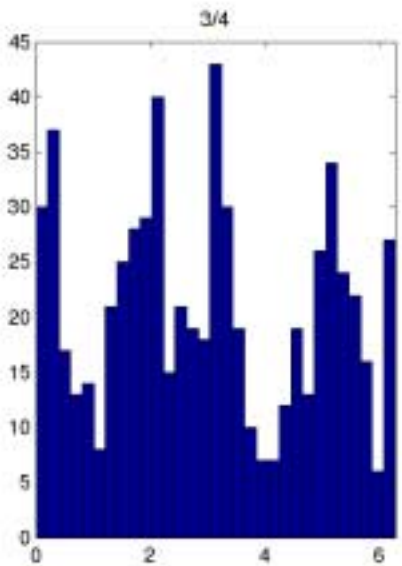
RMS ground vibration

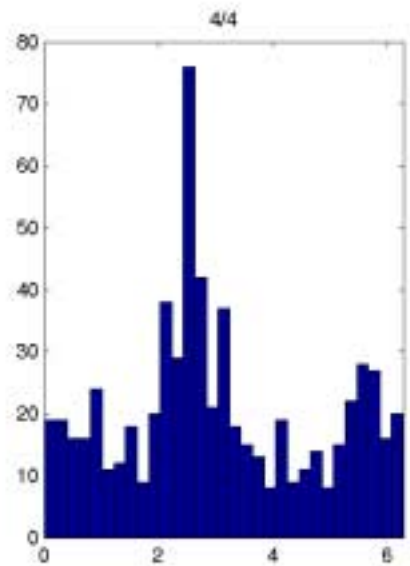
- Analysis technique
- Make spectrograms of 200 sec data with Hanning window, 85% overlap
- Least squares fit of horizontal displacements to both horizontal axes of the array elements
- Fit vertical displacement, ratio of vertical/horizontal amplitudes around 1.6, velocity is around 600 m/sec
- => Rayleigh waves


7451 y−axis
Hz
t (hours)
m/s
angle (rads)
chi2
t (hours)
t (hours)
1.6 Hz
600 m/s
200 sec spectrogram window with 85% overlap









50 mHz band at 1.6 Hz

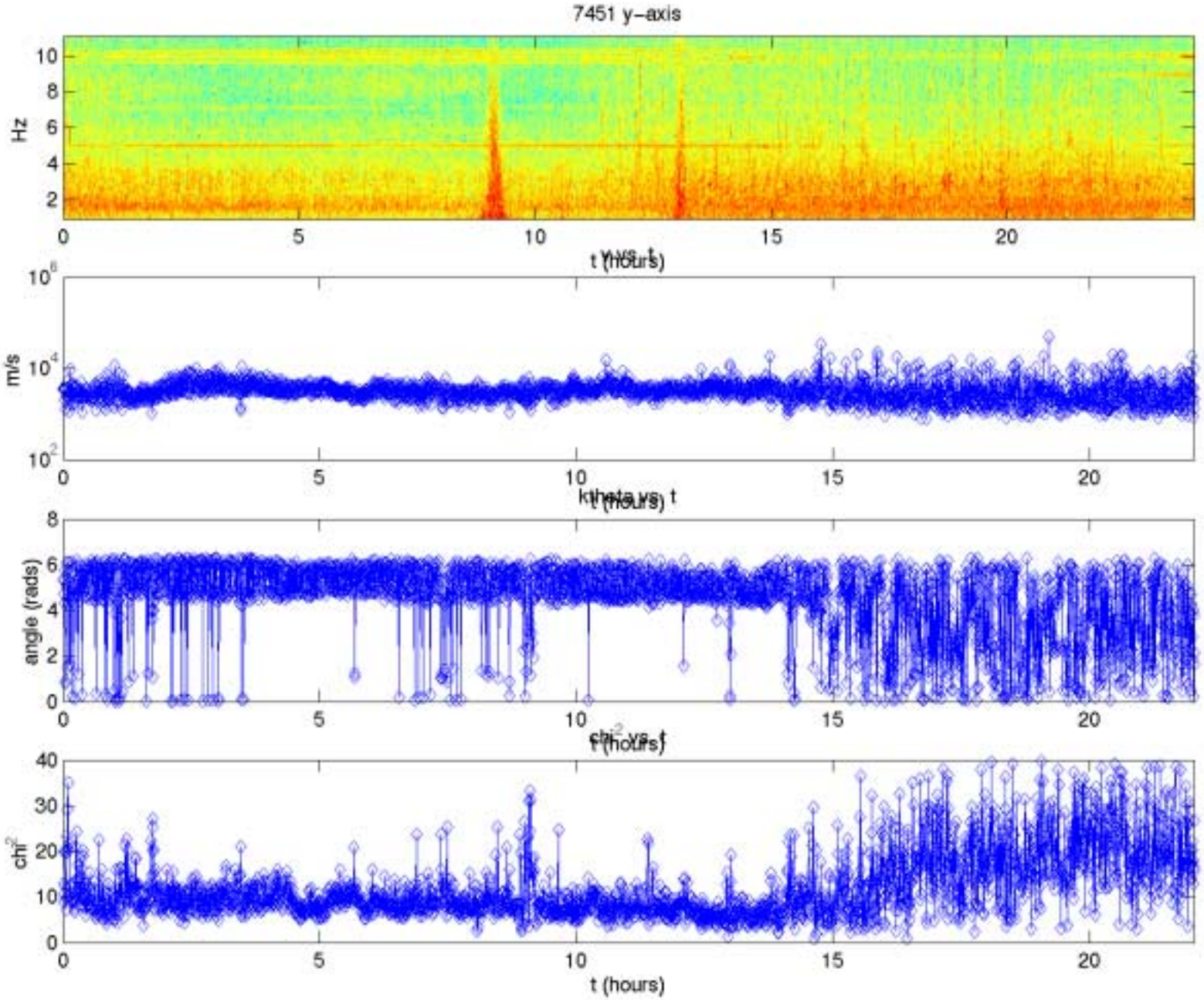
Samples at 6 hour intervals beginning at 6pm on Wednesday

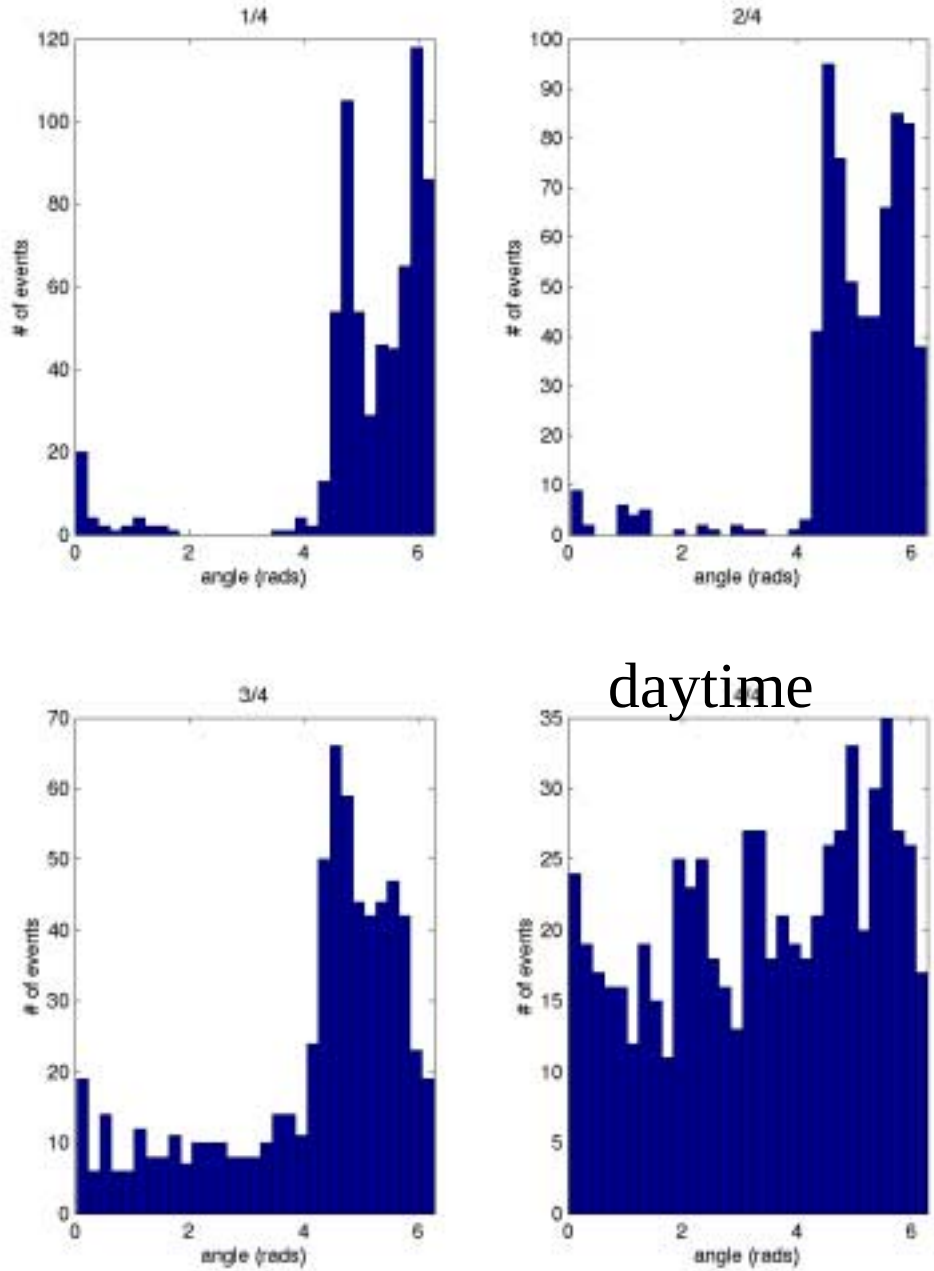
Select data with mean square error<40

Daytime rms noise from south east

Pipeline

- A useful calibration point at 5 Hz and 10 Hz
- Very monochromatic, few mHz, for long periods
- V = 2 km/sec, compressional wave
- Two distinct directions:
- From the west, as expected, since pipeline runs NS
- From the north. Pumping station?


7451 y−axis
Hz
t (hours)
m/s
angle (rads)
chi2
t (hours)



daytime

Data with chisq<40/8df

Pipeline signal comes from the west (0=wave headed east)

2 km/sec => compressional wave

Additional signal from the north (pumping station?)

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Conclusions

- Daytime noise at 2 Hz comes from the south, at 5 Hz from all over. Impulse noise comes broadly from the south, no single source.
- The angular distributions of the seismic disturbance due to the train appear to be coming from the trestle locations
- Local site construction noise was not identified in the array data
- Surface waves are consistent with Rayleigh waves
- Seismic waves waves can travel a long way (multi km) and still be of concern.