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Intensity measurements and fluctuations of acoustic transmissions from the R/V Sharp during SW06

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157th Acoustical Society of America meeting
Portland, Oregon, May 2009

THINK BIG WE DO℠

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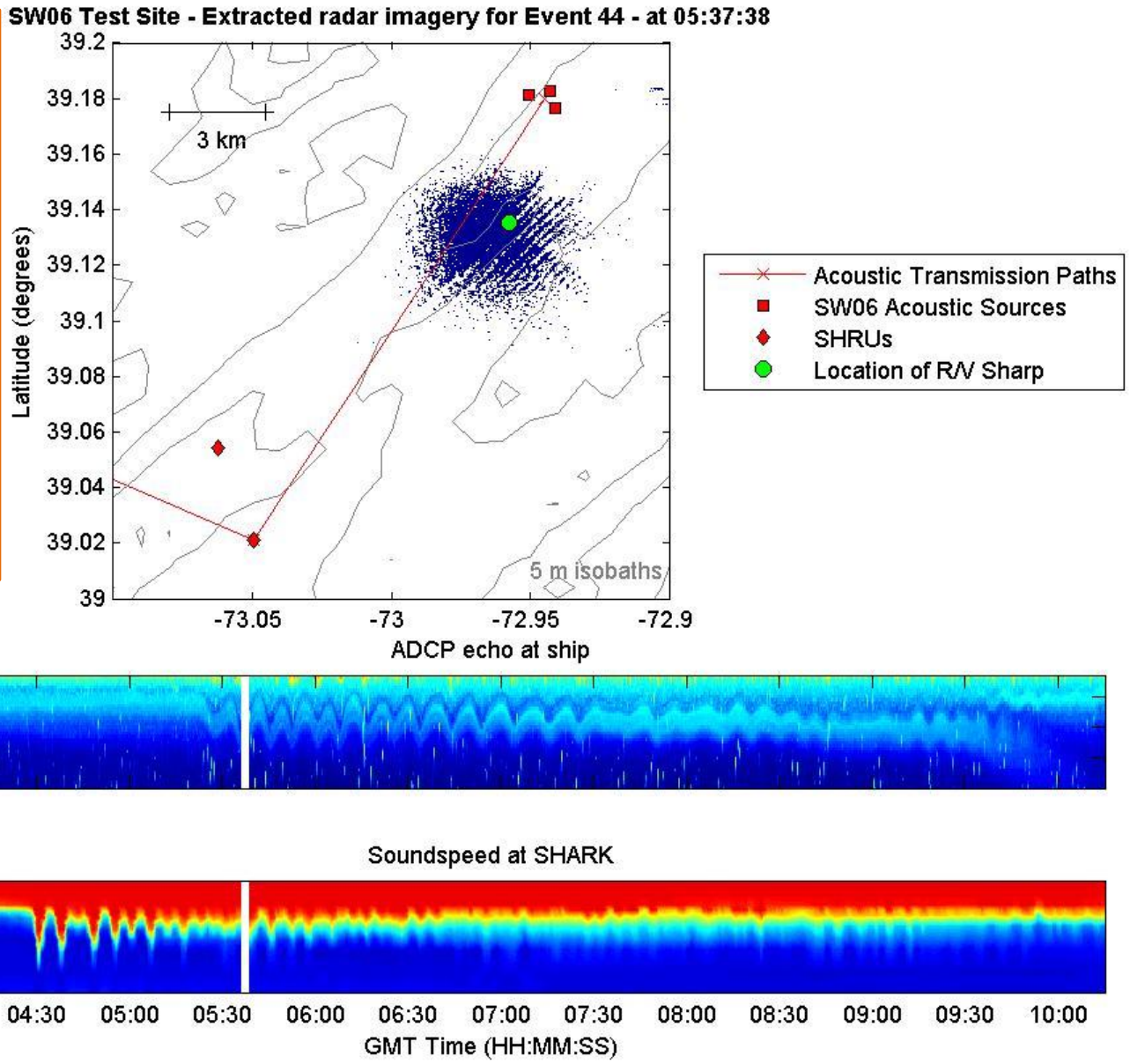
SW06 & R/V Sharp Event 44

R/V Sharp & SW06:

- 180 hours of acoustic transmissions
- 50+ internal wave events witnessed

Event 44:

- Radar data determines the orientation of the wave front
- R/V Sharp ADCP shows internal wave structure
- SHARK soundspeed shows internal wave front arrives at SHARK array one hour prior to location of R/V Sharp



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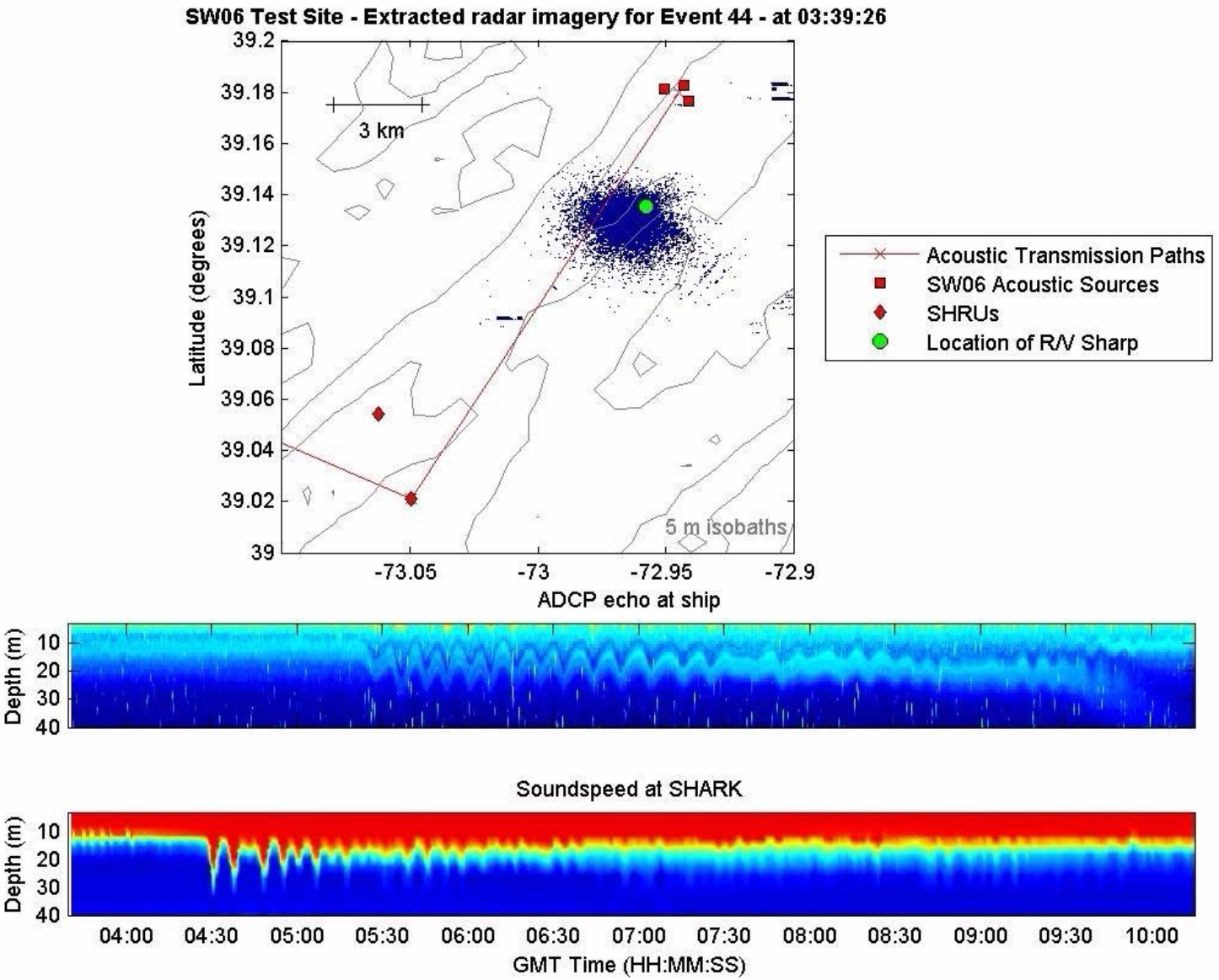
SW06 & R/V Sharp Event 44



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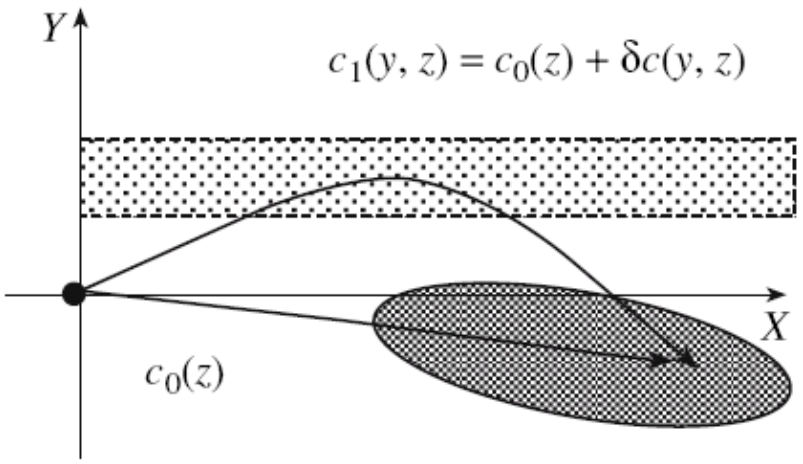
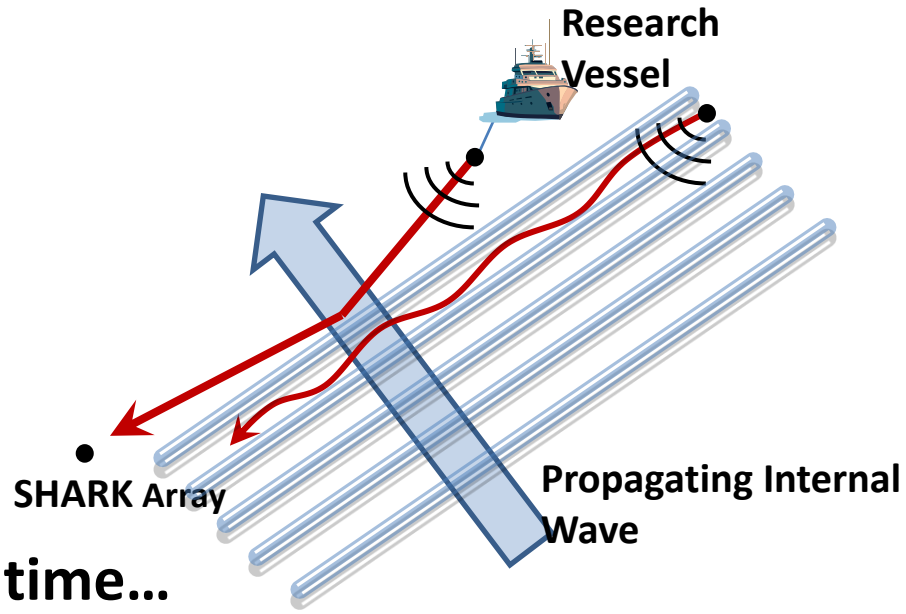
Objectives





Examine intensity fluctuations over time…

→ **before, during, and after Event 44**

Examine intensity fluctuations over space…

→ **depth and modal dependence**

Statistically characterize intensity fluctuations…

$$I(z \| N), k, t, f)$$

$$(z = Depth, \text{ or } N = Mode\,Number)$$

$$k = Chirp\,arrival number \;\; t = Time \;\; f = Frequency$$

B. G. Katsnel'son, J. Lynch, A. V. Tshoidze, "Space-Frequency Distribution of Sound Field Intensity in the Vicinity of the Temperature Front in Shallow Water," Acoustical Physics **53**(5), 611-617 (2007)

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Intensity Measurements

Integrated Energy: $I_{z\tau}(k) = \int dz \int d\tau I(t, z, k)$

Temporally Integrated Energy: $I_{\tau}(t, k) = \int d\tau I(t, z, k)$

Point Observations of Broadband Intensity: $I_{\tau}(t, z, k)$

Observations of Point Scintillations: $SI = \frac{\langle I^2 \rangle}{\langle I \rangle^2} - 1$

Point Observations of Peak Intensity: $I_P(t, k) = \max_{\tau}[(t, z, k)$

Observations of Modal Amplitudes: $I(N, k, f)$

A. Fredericks, J. A. Colosi, J. Lynch, C. Chiu, and P. Abbot, “Analysis of multipath scintillation from long range acoustic transmissions on the New England continental slope and shelf,” J. Acoust. Soc. Am. **117**, 1038–1057 (2005)

Duda, T.F., Lynch, J.F., Newhall, A.E., Lixin Wu, Ching-Sang Chiu, “Fluctuation of 400-Hz sound intensity in the 2001 ASIAEX South China Sea experiment,” Oceanic Engineering, IEEE Journal of, **29**(4), 1264 – 1279 (2004)

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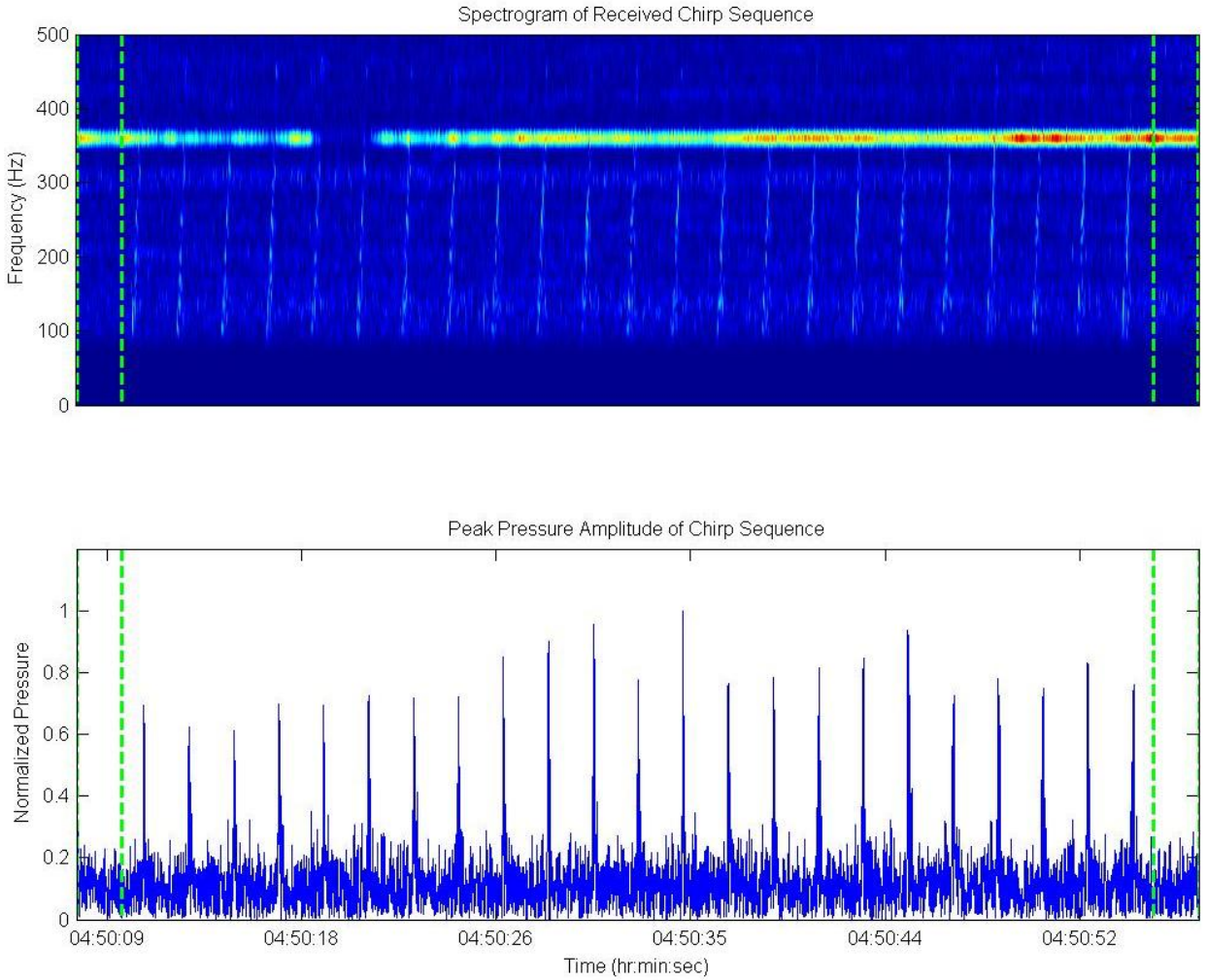
R/V Sharp Transmission Signals

Chirp arrivals are used for intensity calculations



N ~ 1500 chirps over 12 hours

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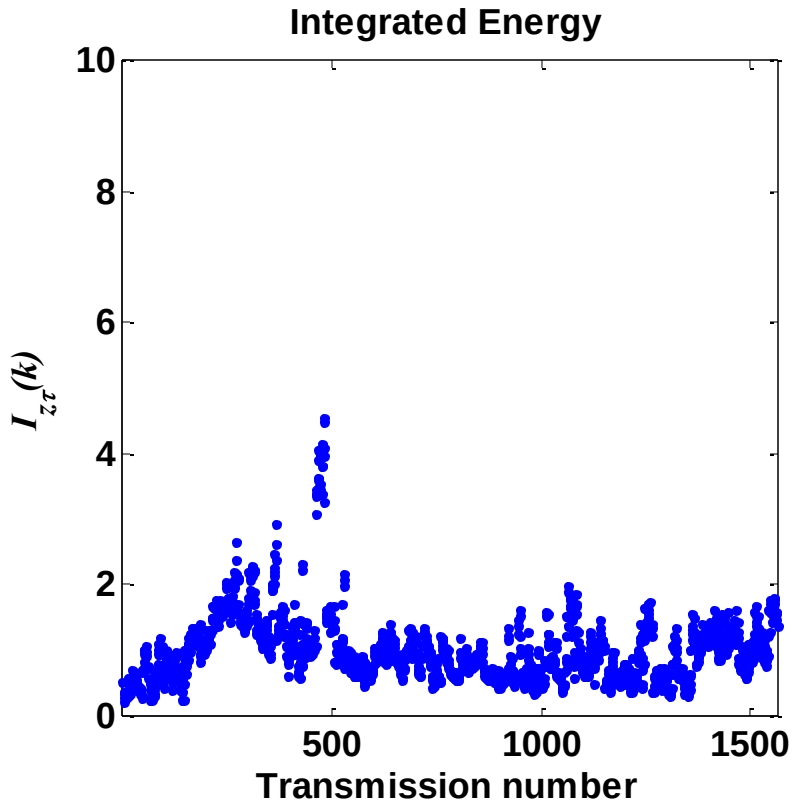
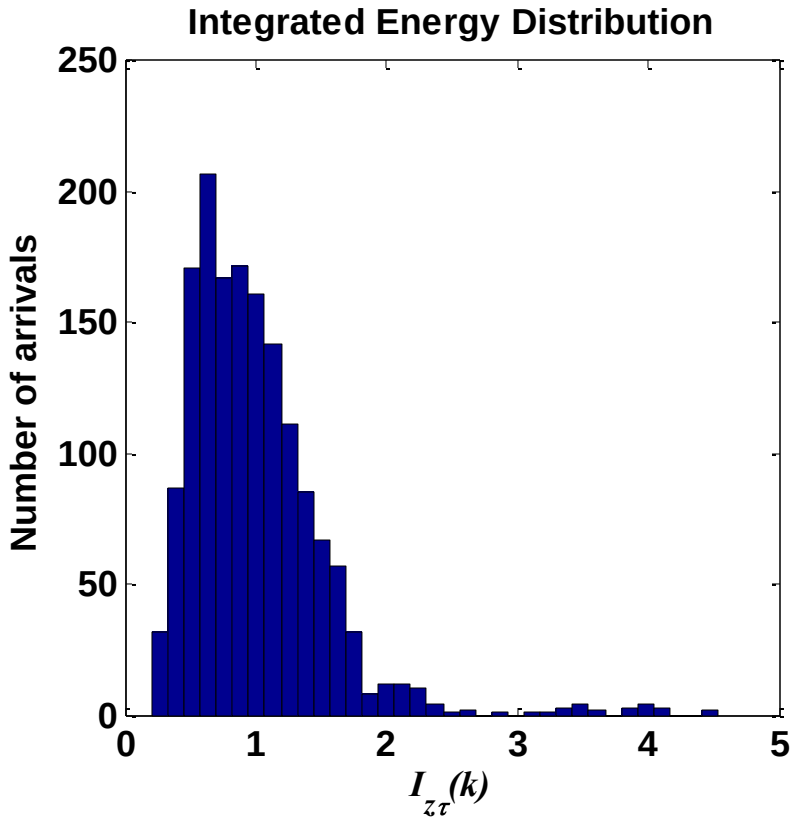
Integrated Energy





$$I_{z\tau}(k) = \int dz \int d\tau I(\tau, z, k)$$

- Total acoustic energy detected at the array, as a function of transmission number
- Intensity integrated over depth and arrival time
  - Depth is integrated over entire array
  - Time integral done over τ, the energetic region of the signal

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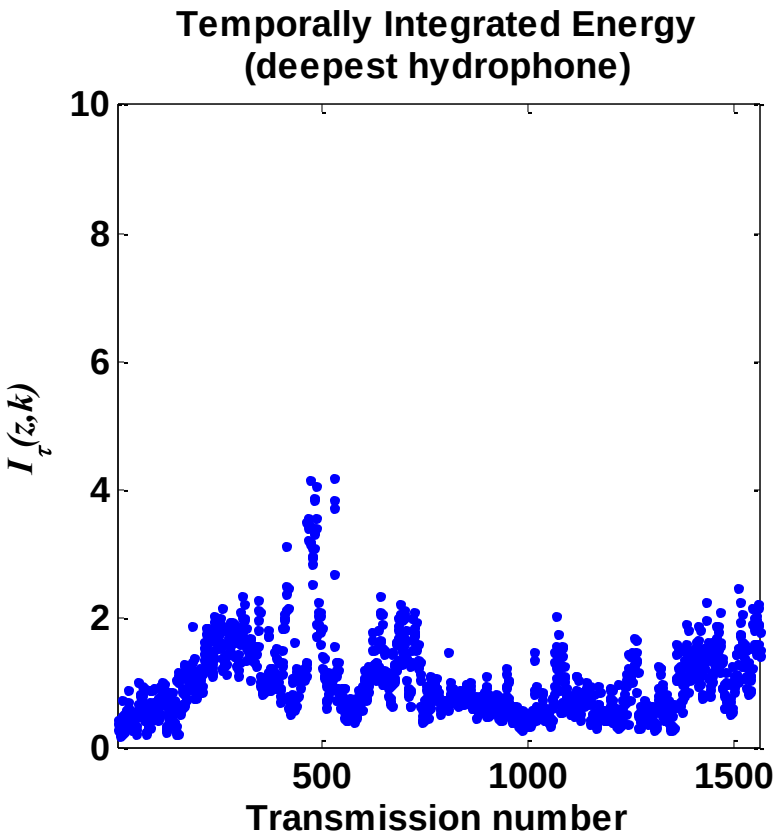
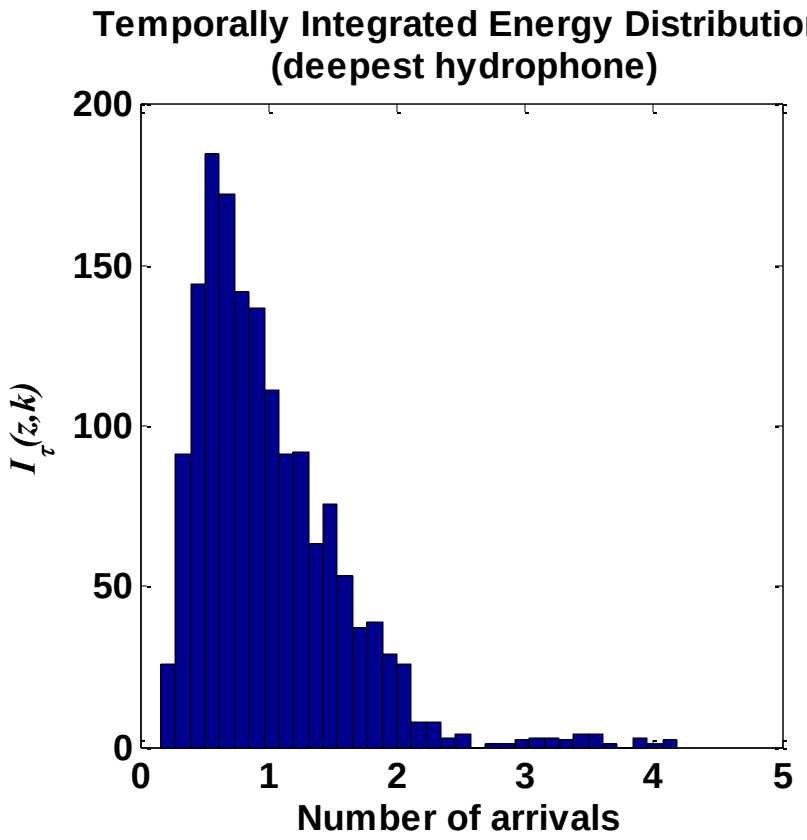
Temporally Integrated Energy





$$I_\tau(k) = \int d\tau I(z,k)$$

- Time integral done over τ, the energetic region of the signal
- "Energy Detector" mode of a sonar system
- Shows depth dependence not seen in Integrated Energy, $I_{z\tau}(k)$
  - Energy redistribution due to mode coupling
  - Energy redistribution due to ray scattering

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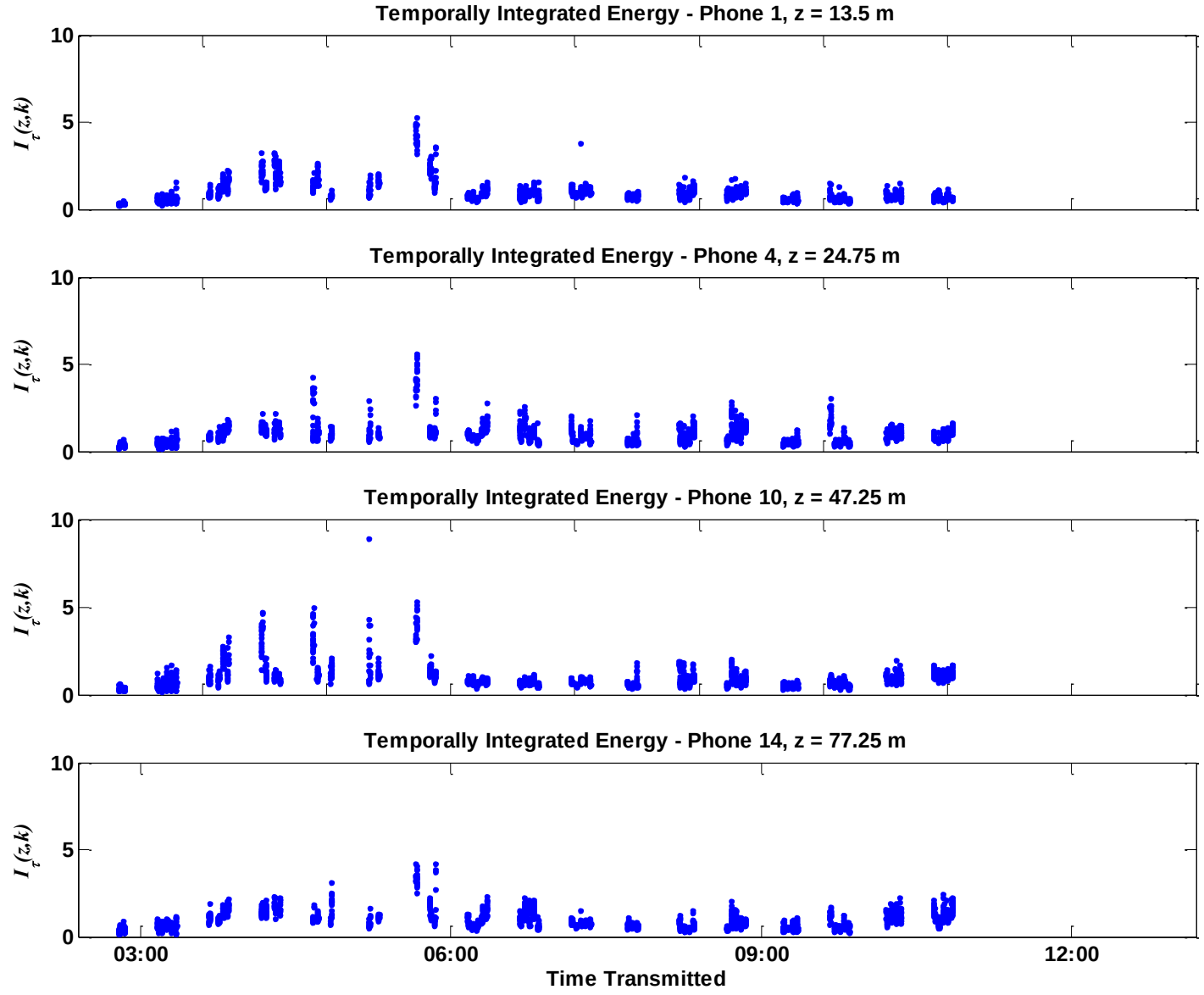
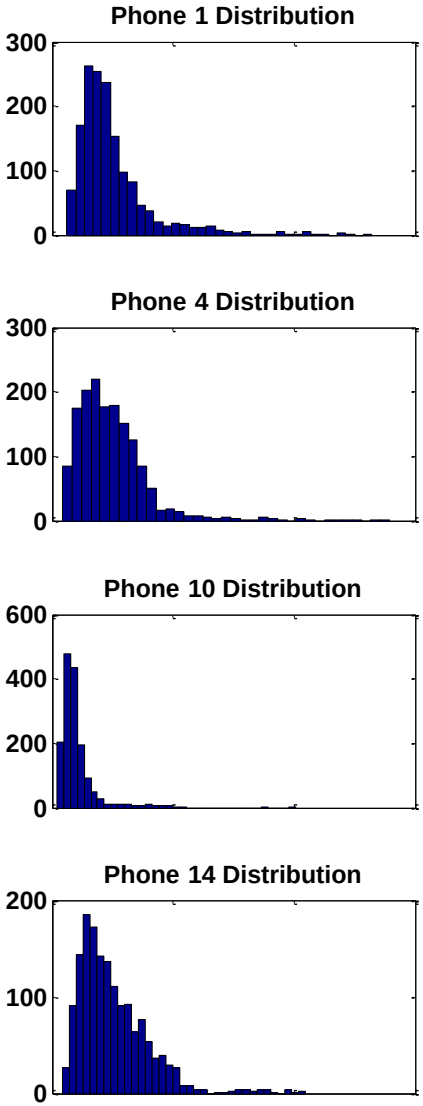
Temporally Integrated Energy





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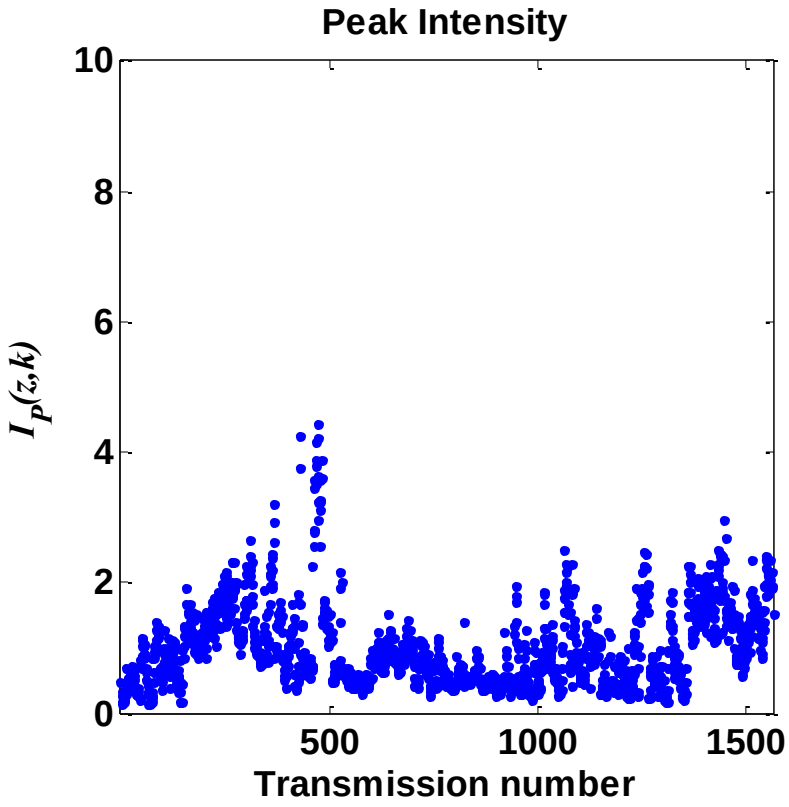
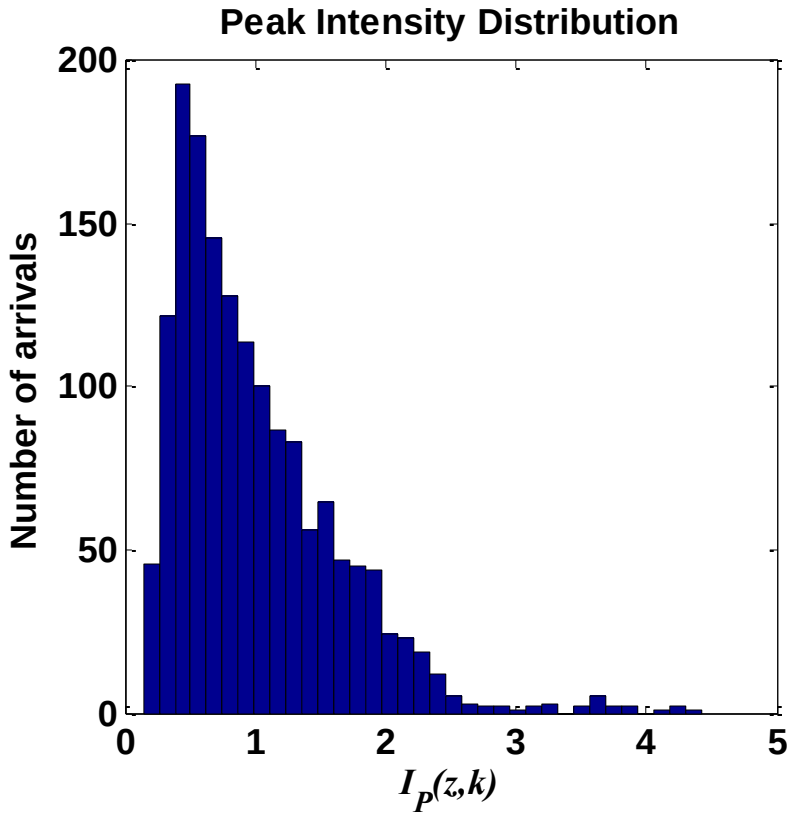
Peak Intensity





$$I_P(\xi,k) = \max_\tau \left[(\xi,z,k) \right]$$

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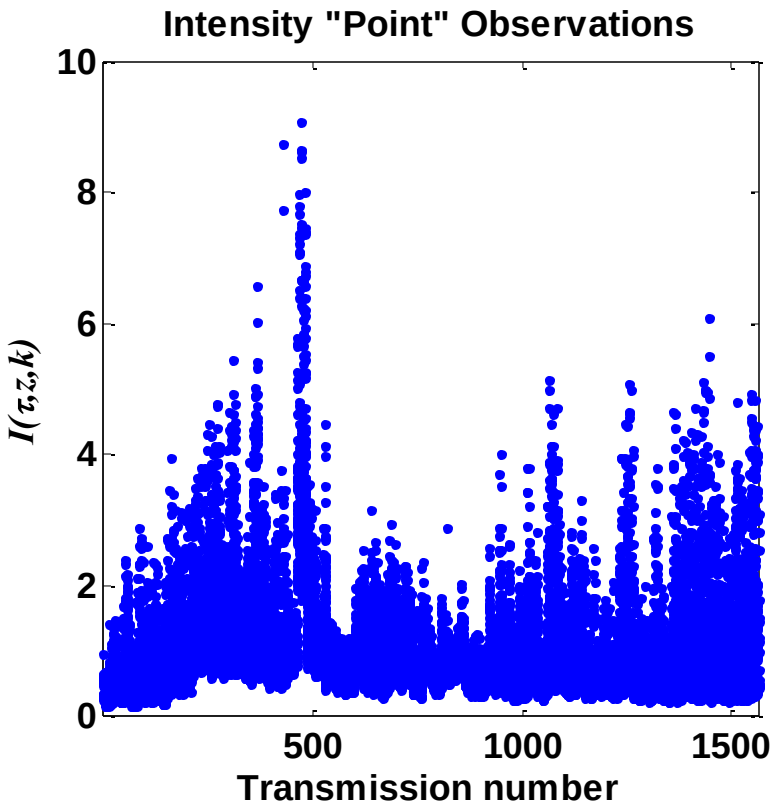
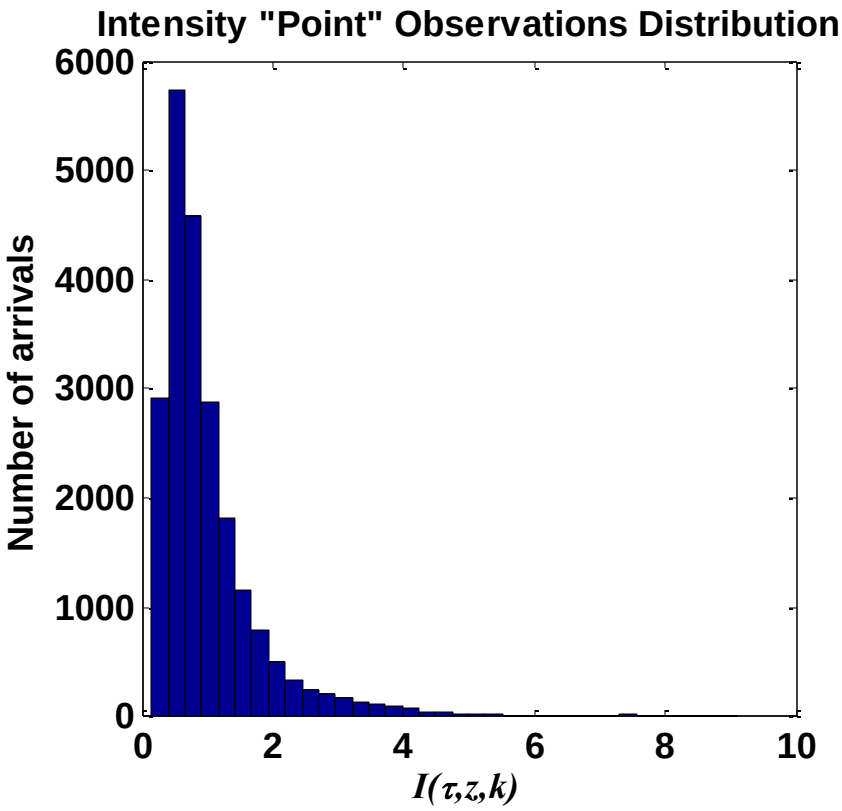
"Point" Observations





$$I_\tau(\epsilon, z, k)$$

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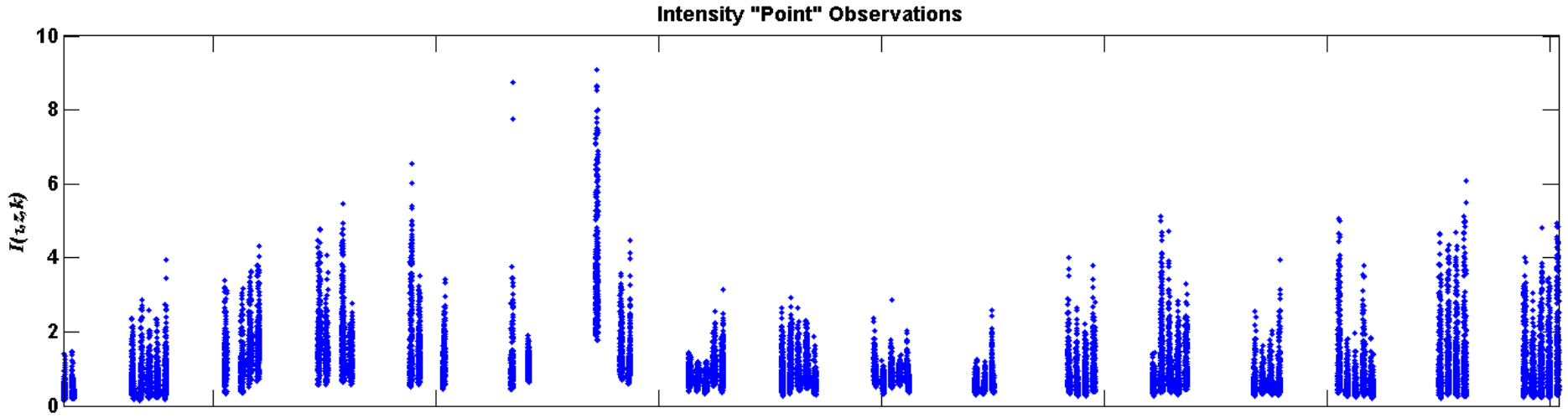
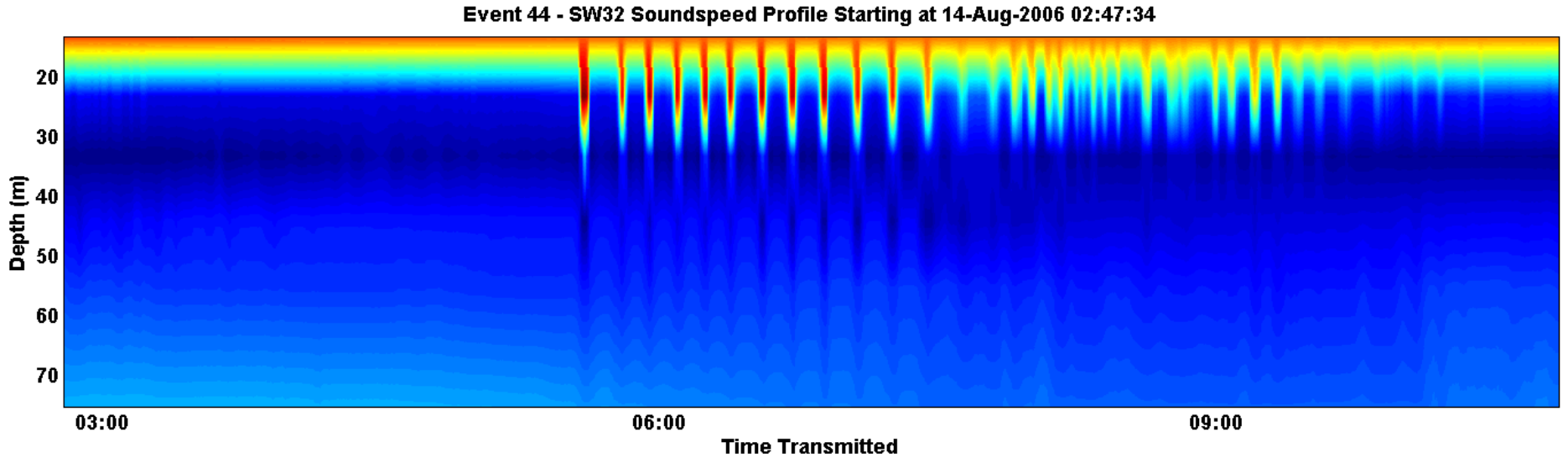
"Point" Observations





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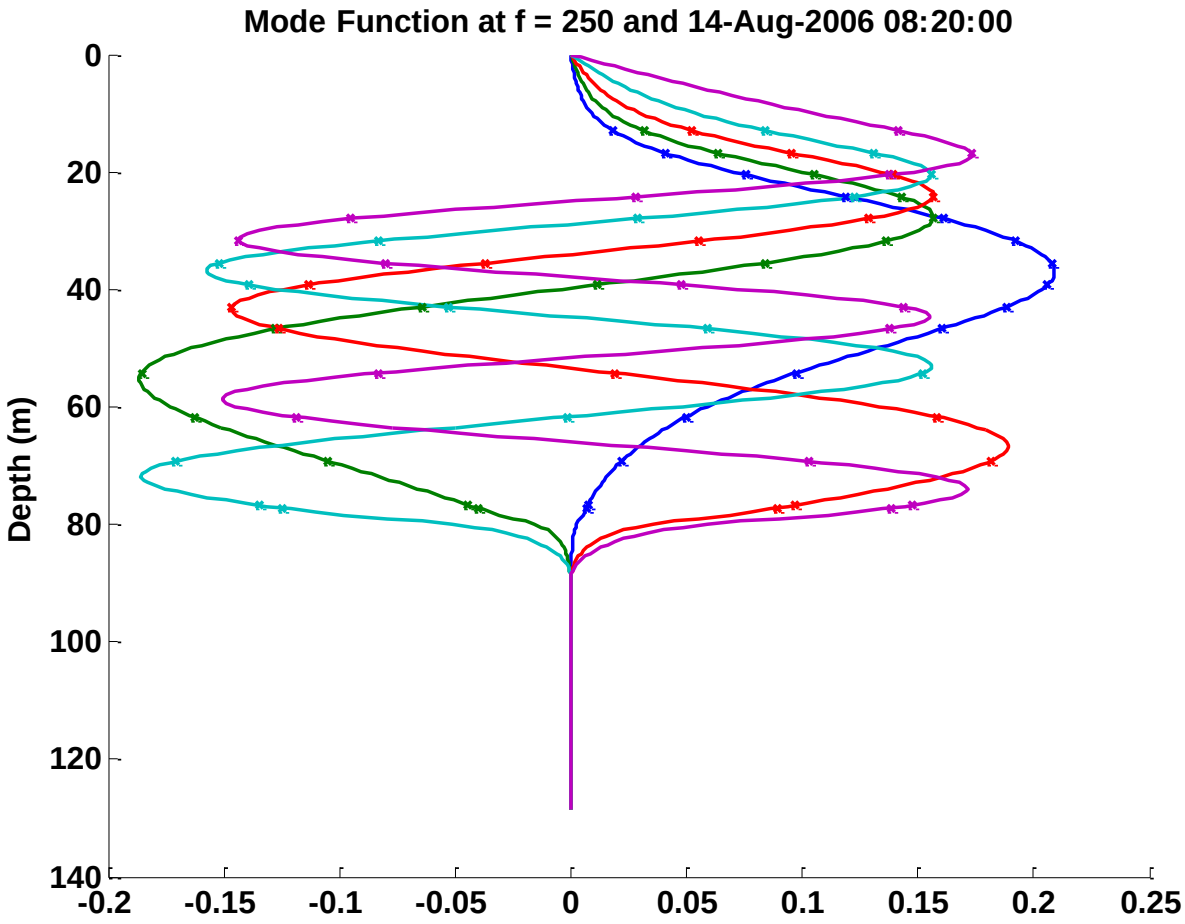
Modal fluctuations



Are there areas of enhancement due to horizontal refraction?

- **Modal dependence**
- **Frequency dependence**

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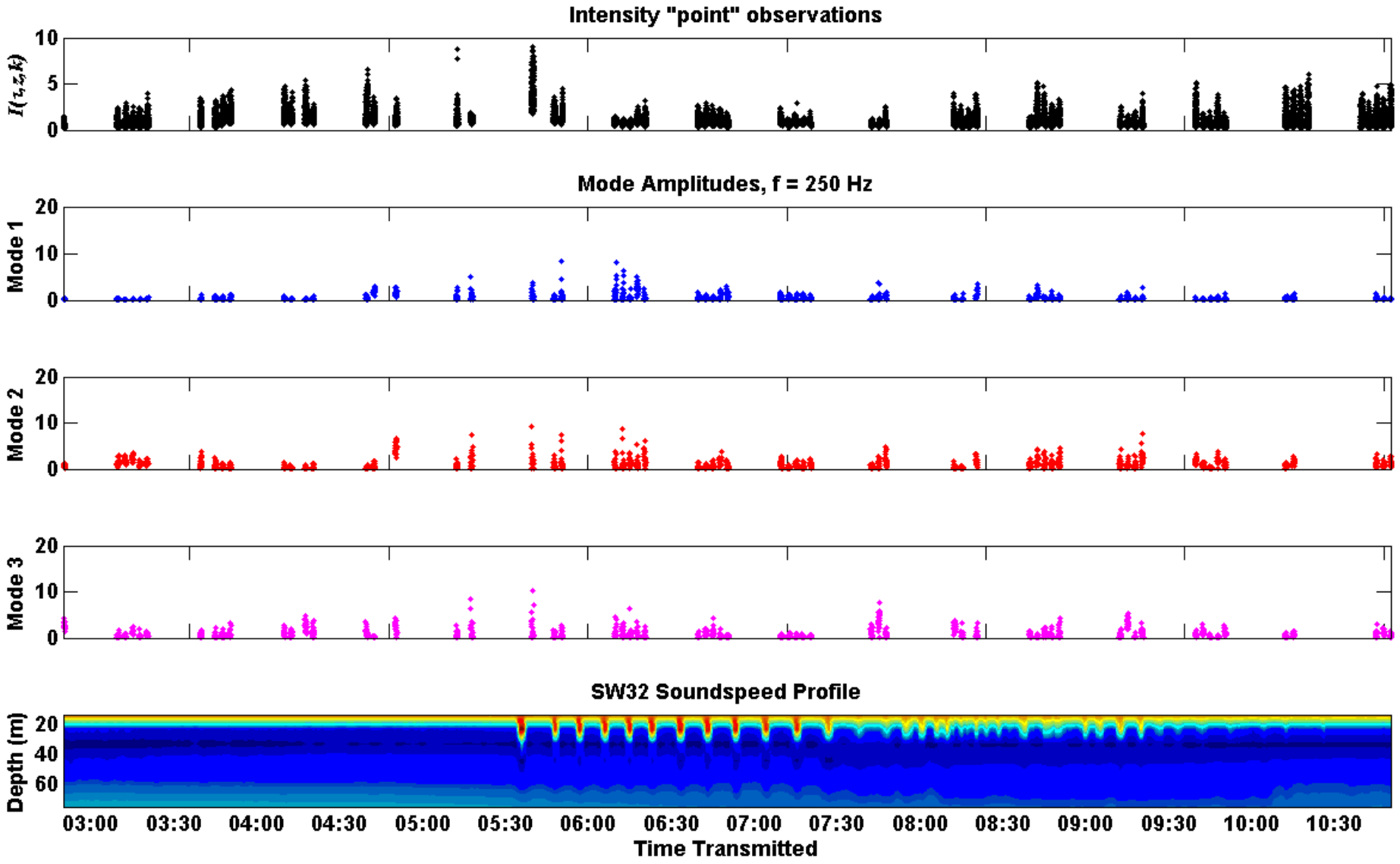
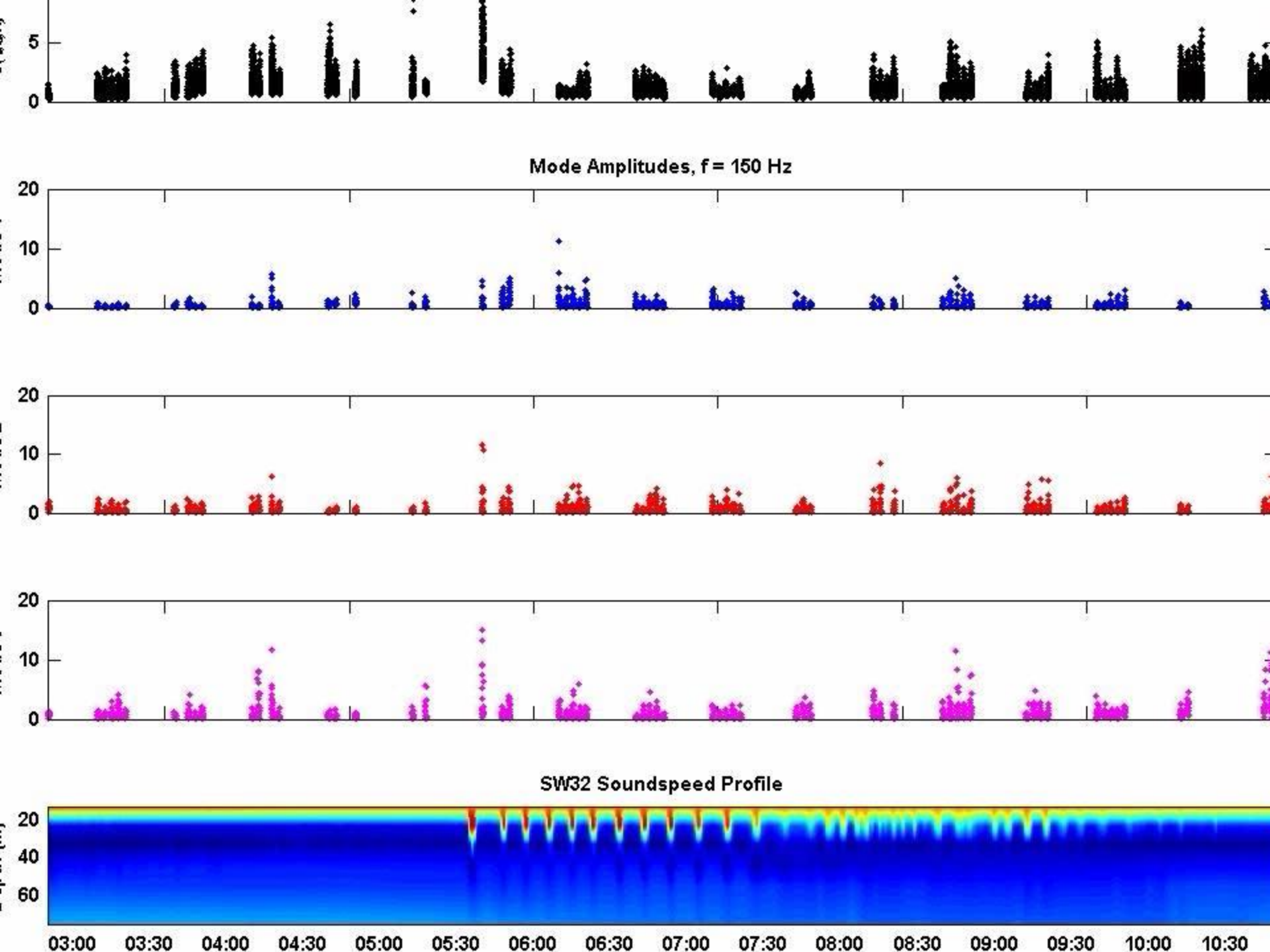
Modal fluctuations




0
5
Mode Amplitudes, f = 150 Hz
20
10
0
20
10
0
20
10
0
SW32 Soundspeed Profile
20
40
60
03:00
03:30
04:00
04:30
05:00
05:30
06:00
06:30
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10:30

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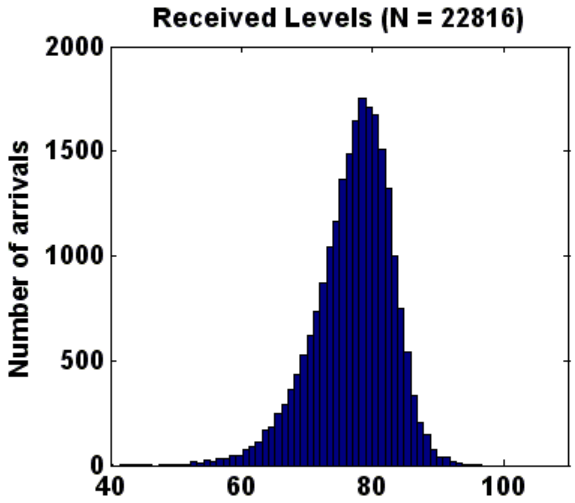
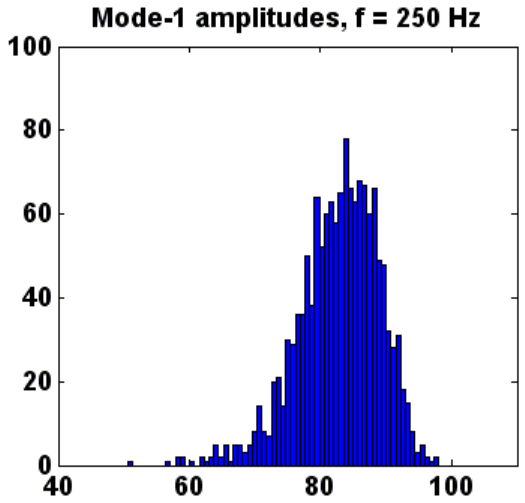
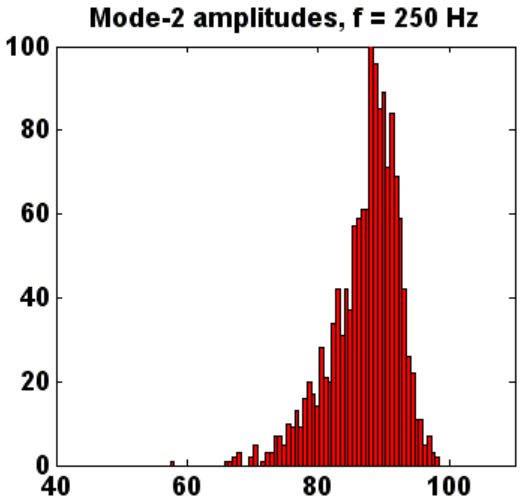
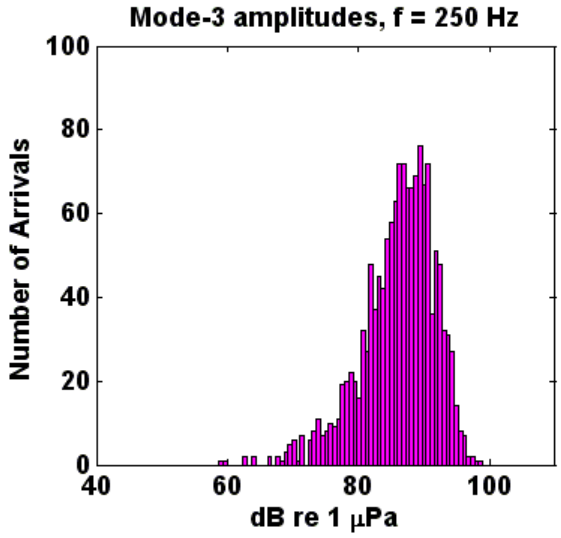
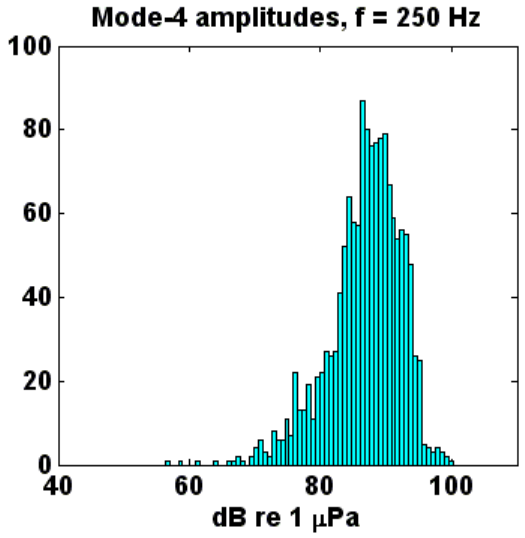
Modal fluctuations

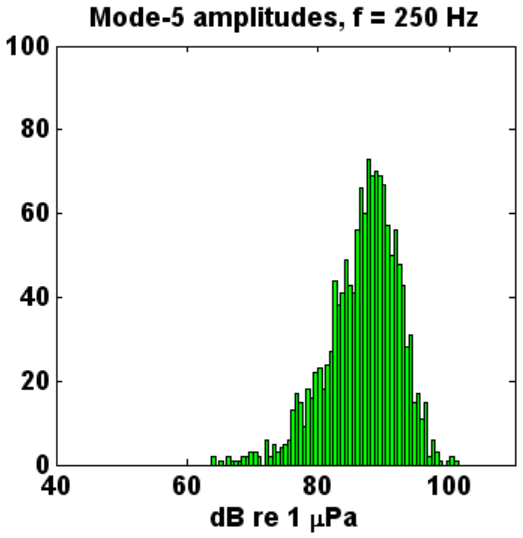












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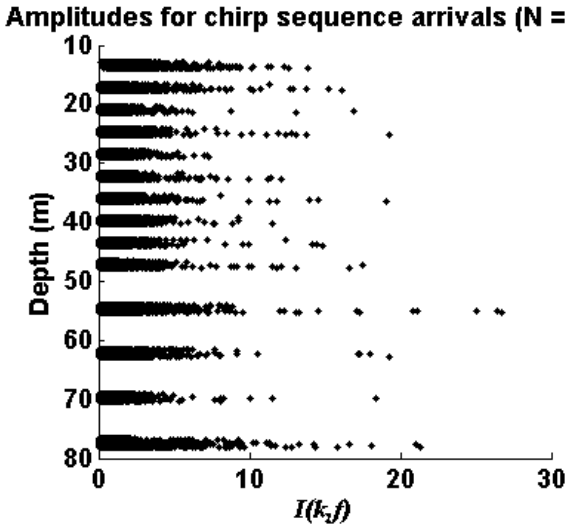
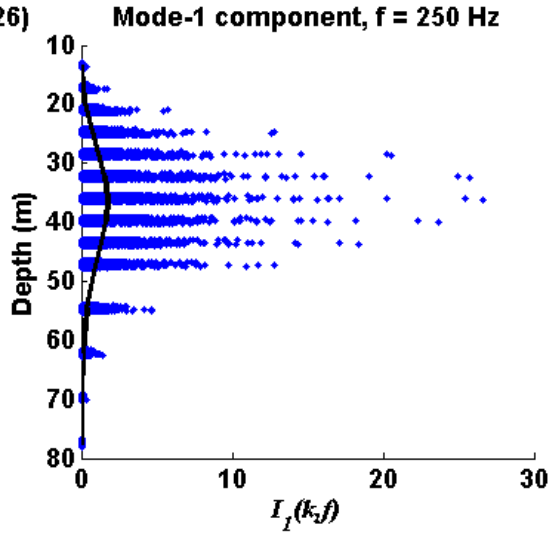
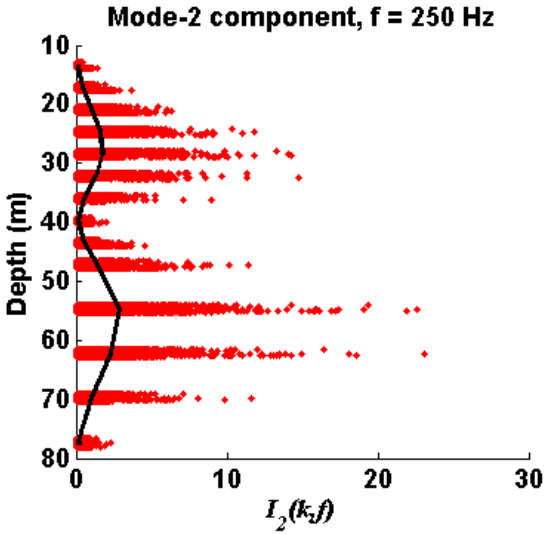
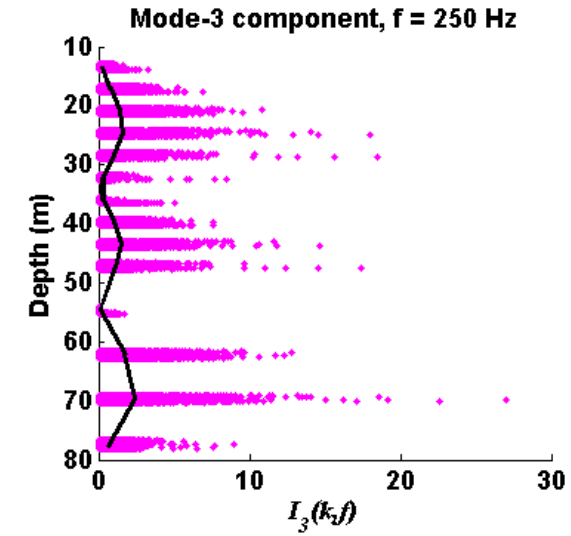
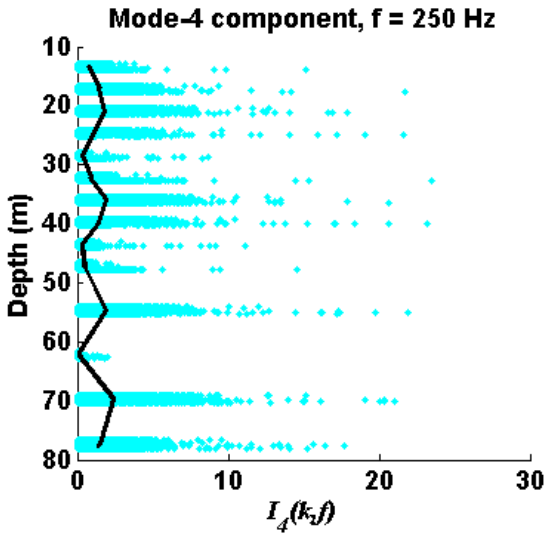
Modal fluctuations

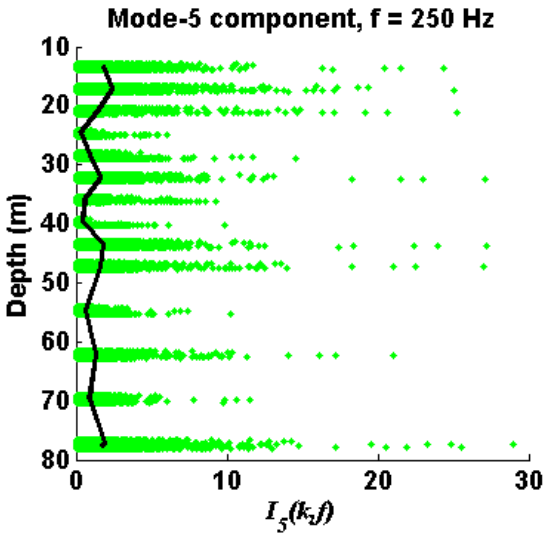












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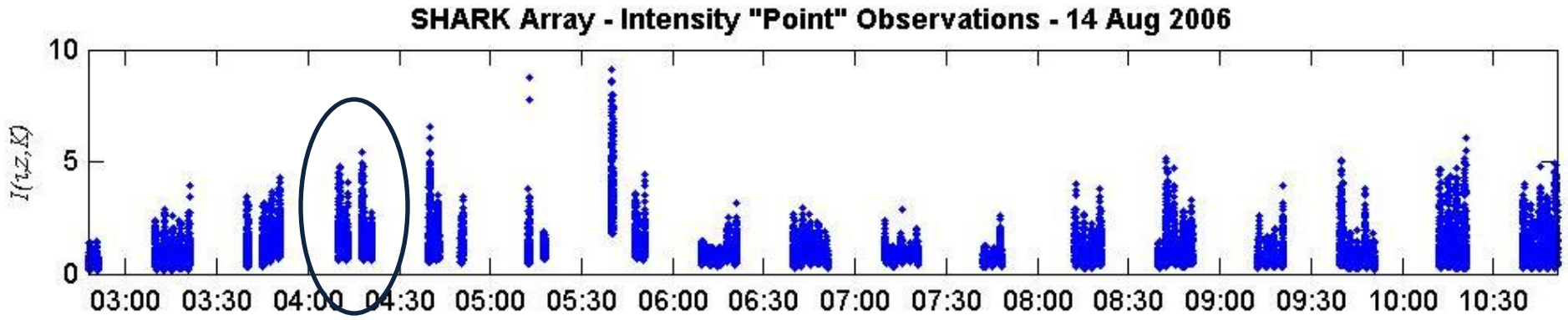
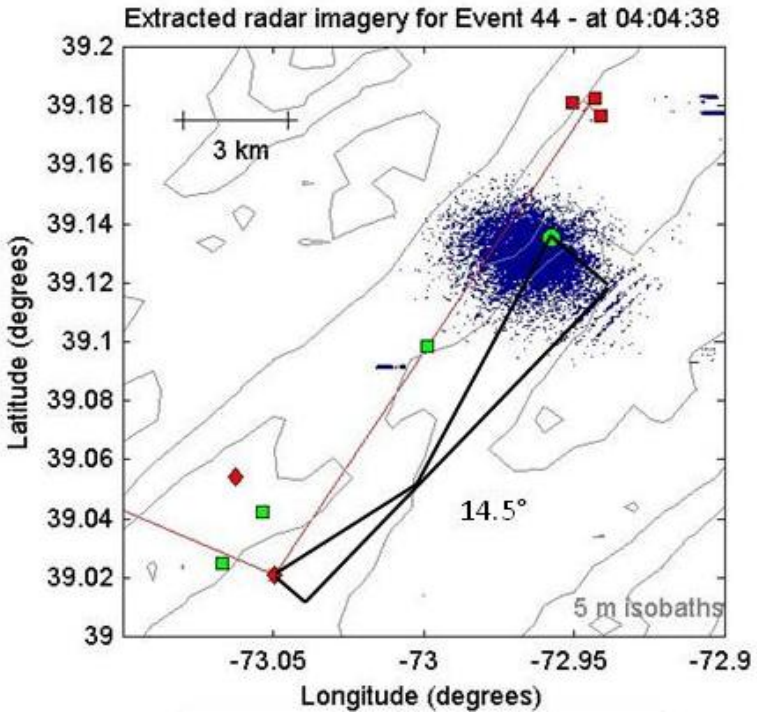
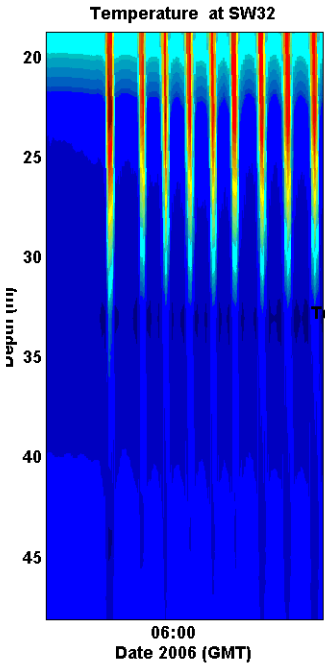
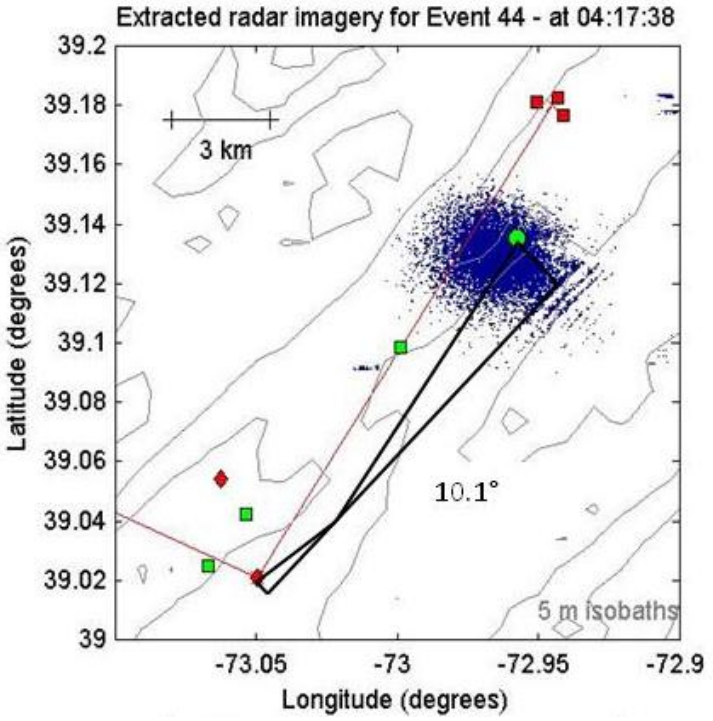
Refraction?

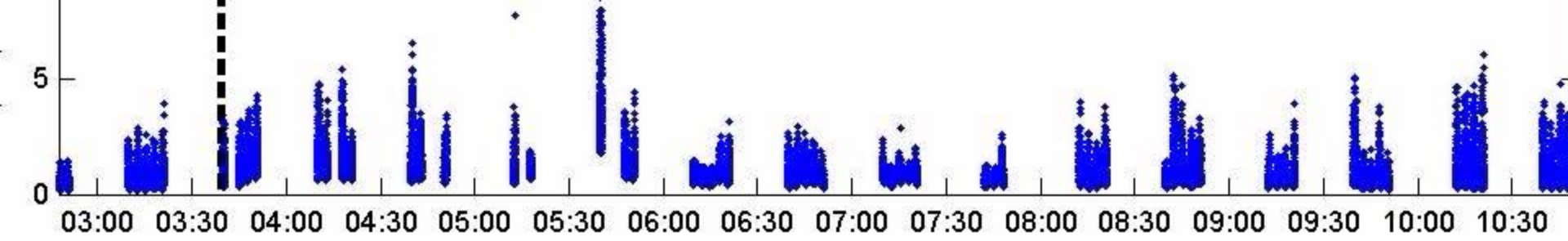








$$\theta_c \approx 13°$$


5
0
03:00
03:30
04:00
04:30
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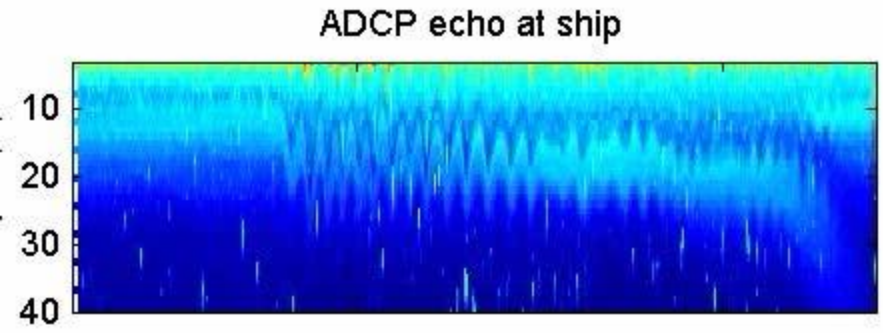
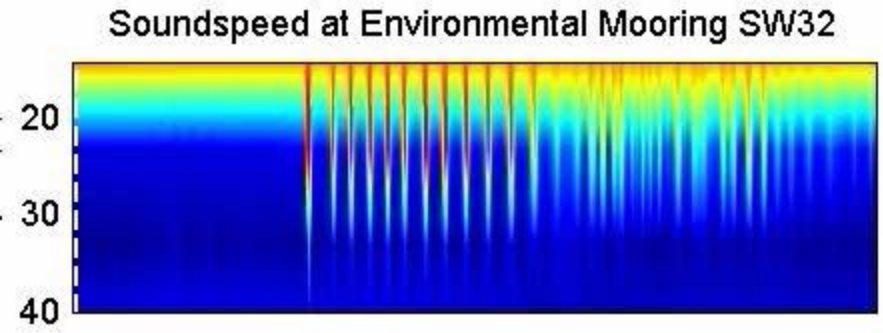
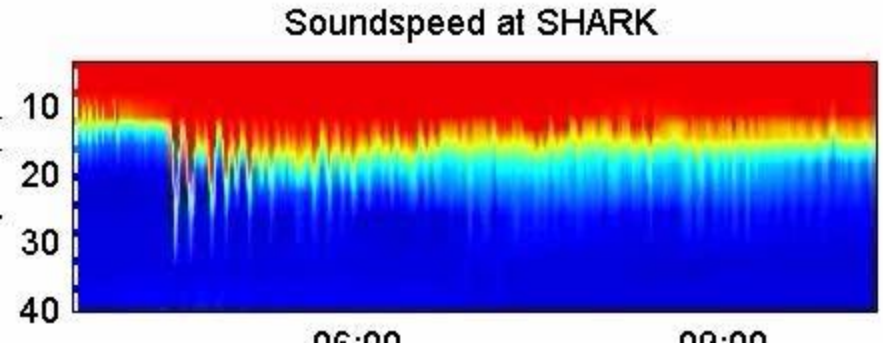
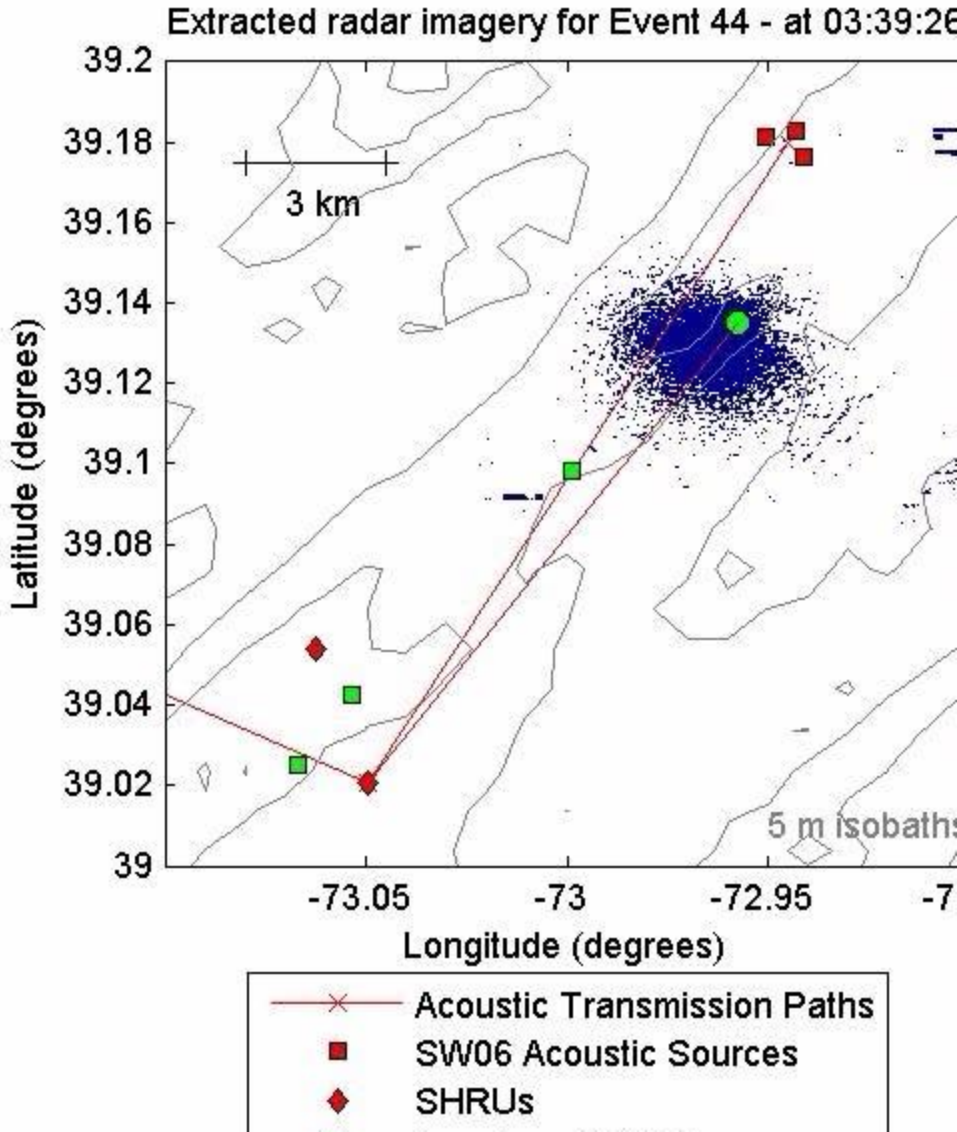
10:00
10:30


ADCP echo at ship
10
20
30
40


Soundspeed at Environmental Mooring SW32
20
30
40


Soundspeed at SHARK
10
20
30
40


Extracted radar imagery for Event 44 - at 03:39:26
39.2
39.18
39.16
39.14
39.12
39.1
39.08
39.06
39.04
39.02
39
Latitude (degrees)
3 km
5 m isobaths
-73.05
-73
-72.95
Longitude (degrees)
Acoustic Transmission Paths
SW06 Acoustic Sources
SHRUs

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Conclusions & Future Work

It appears that there is intensification of the R/V Sharp's transmissions before and during Event 44

To Do:

- **Continue to characterize the intensity fluctuations**
  - Mathematically characterize distributions with PDFs
- **Better understand these fluctuations through modeling**
  - Try to adequately model the internal wave using ADCP, environmental moorings, and radar imagery
  - 3D PE modeling

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Thank you

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

UNIVERSITY OF DELAWARE

DEPARTMENT OF THE NAVY
USN
ONR
Science & Technology

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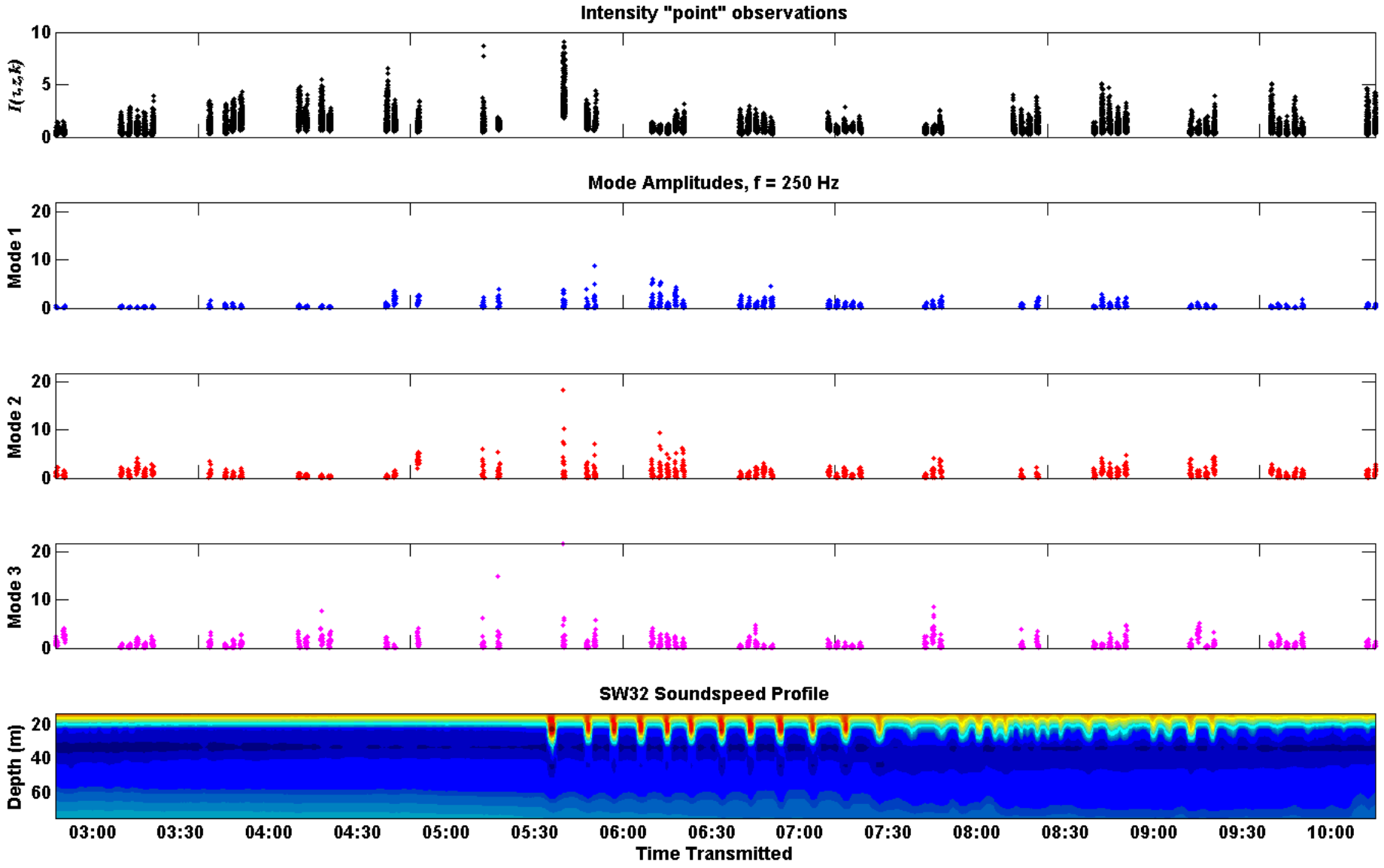
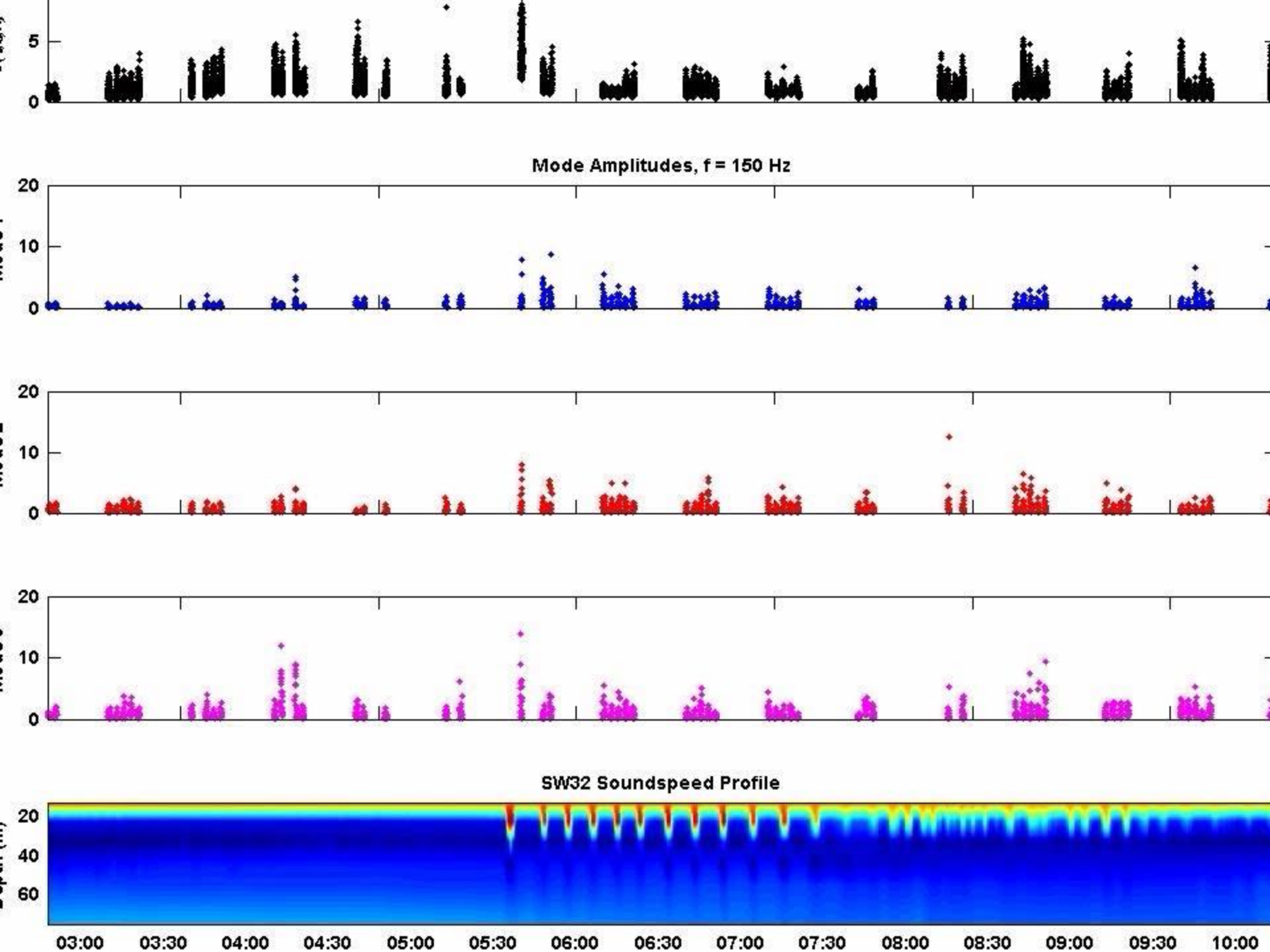
Modal fluctuations




Mode Amplitudes, f = 150 Hz
SW32 Soundspeed Profile
0
5
20
10
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20
10
0
20
10
0
20
40
60
03:00
03:30
04:00
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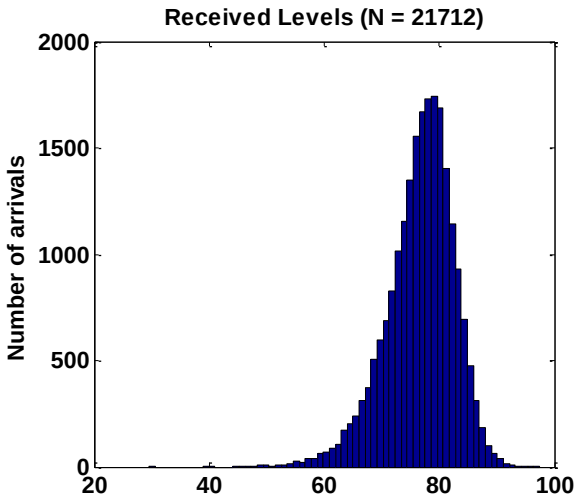
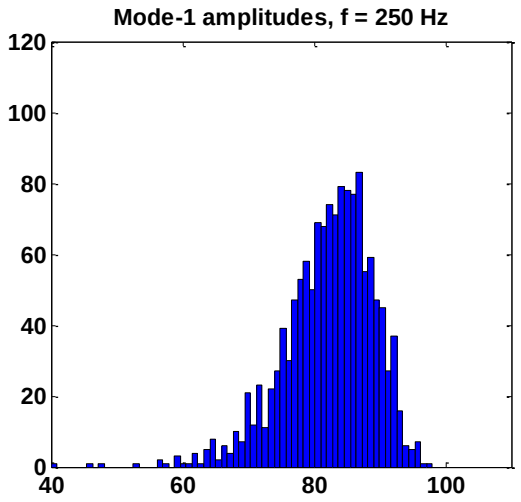
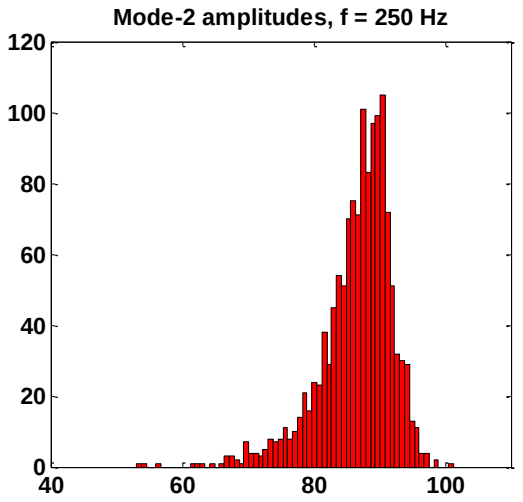
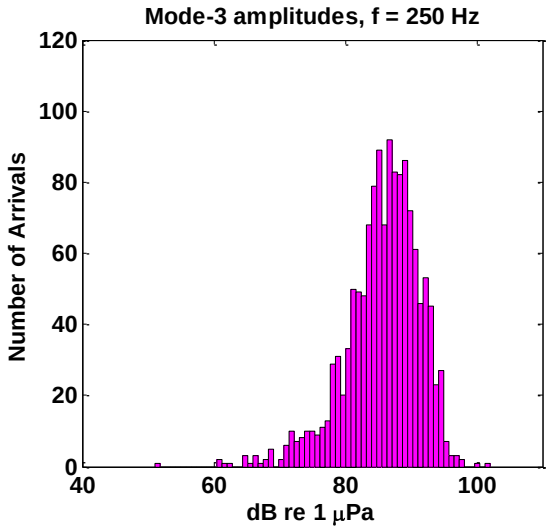
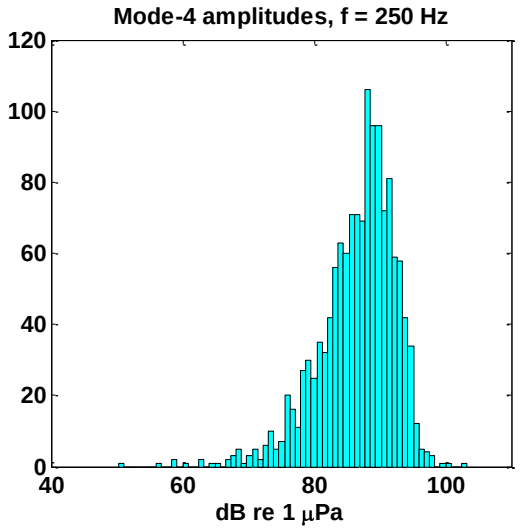
Modal fluctuations

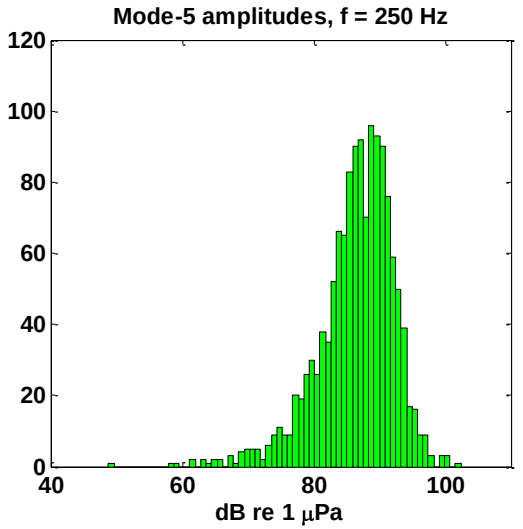


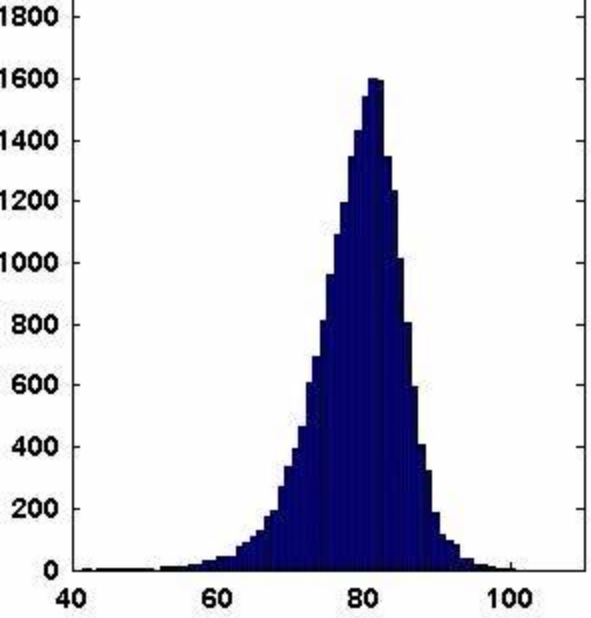


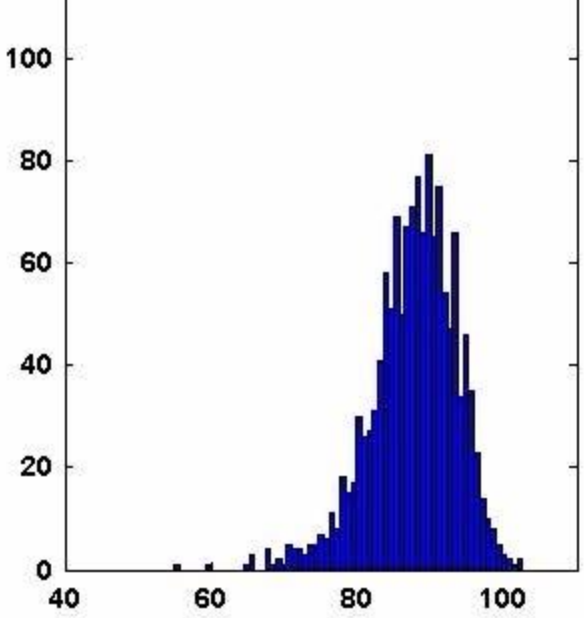


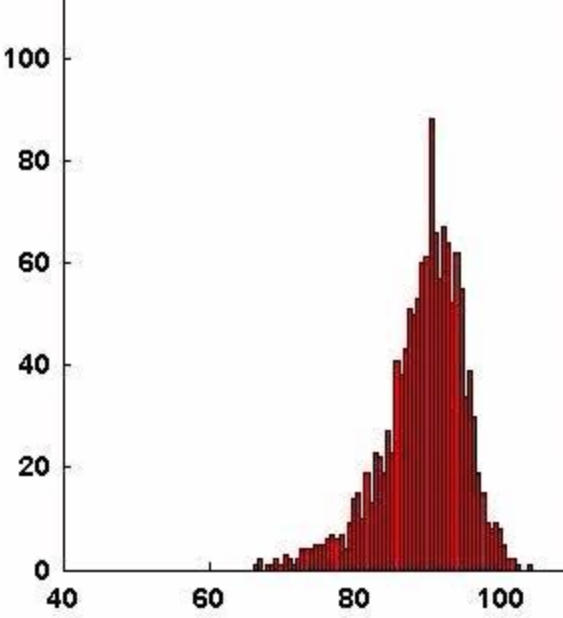


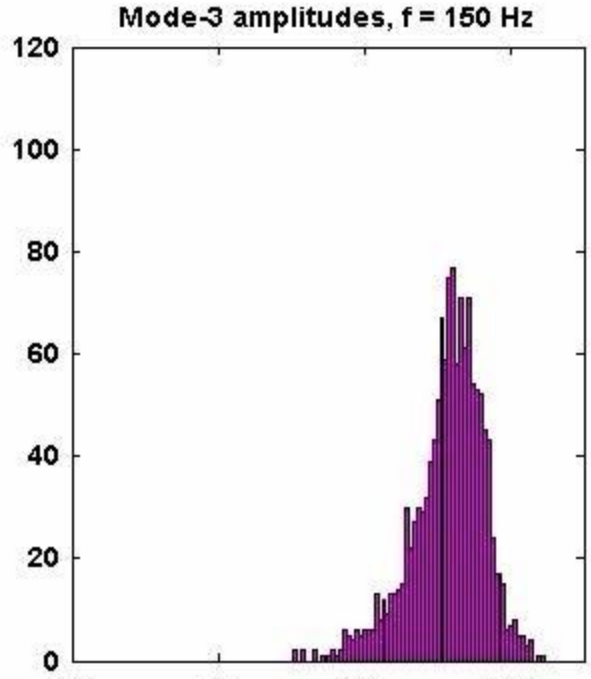


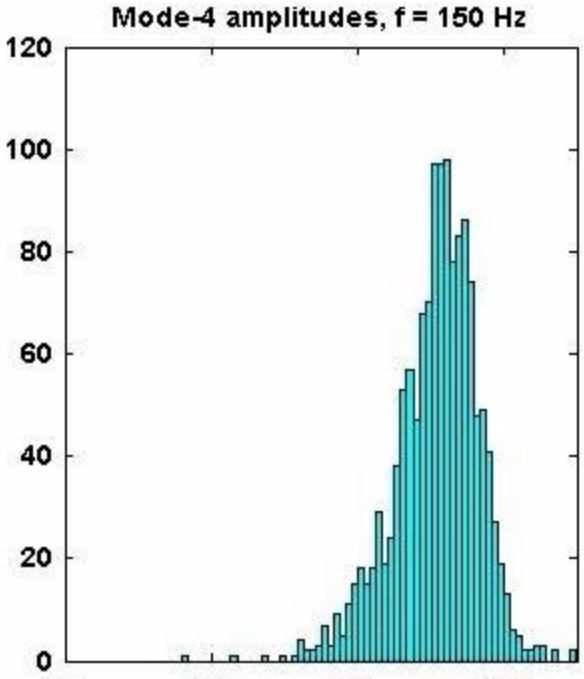


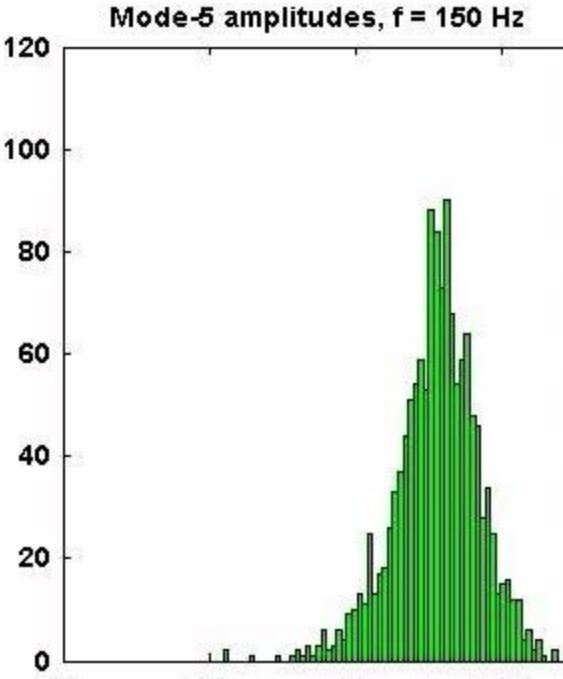

1800
1600
1400
1200
1000
800
600
400
200
0
40
60
80
100


100
80
60
40
20
0
40
60
80
100


100
80
60
40
20
0
40
60
80
100


Mode-3 amplitudes, f = 150 Hz
120
100
80
60
40
20
0


Mode-4 amplitudes, f = 150 Hz
120
100
80
60
40
20
0


Mode-5 amplitudes, f = 150 Hz
120
100
80
60
40
20
0

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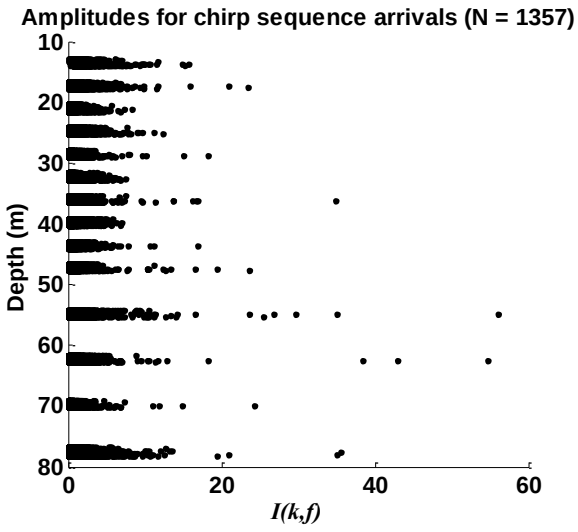
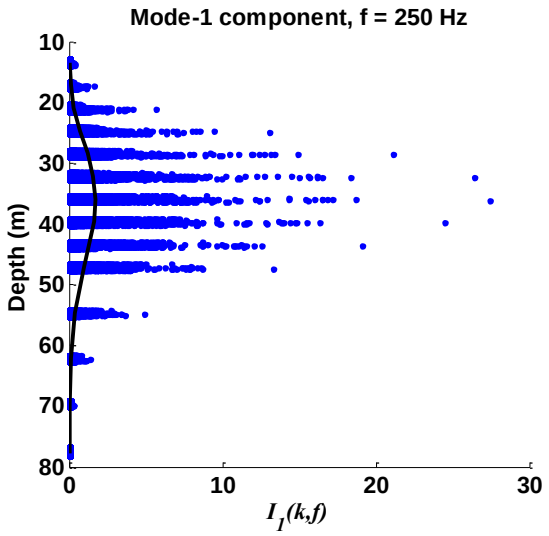
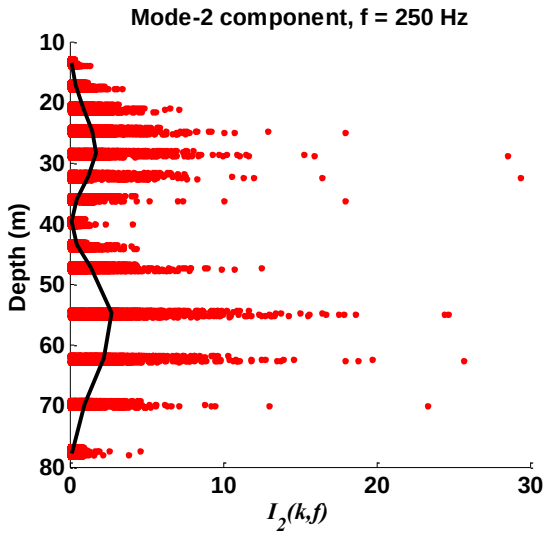
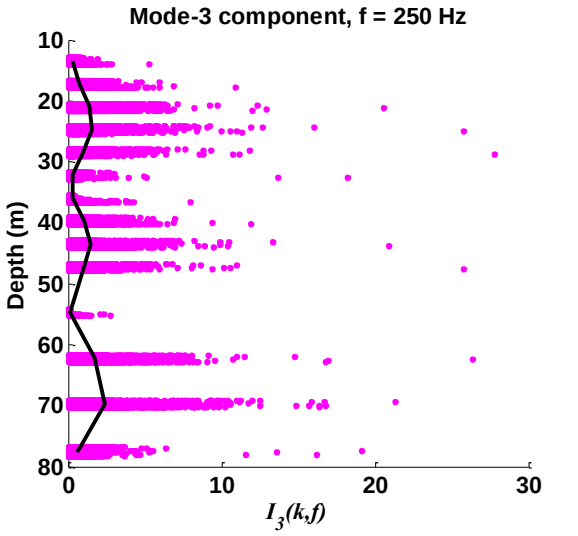
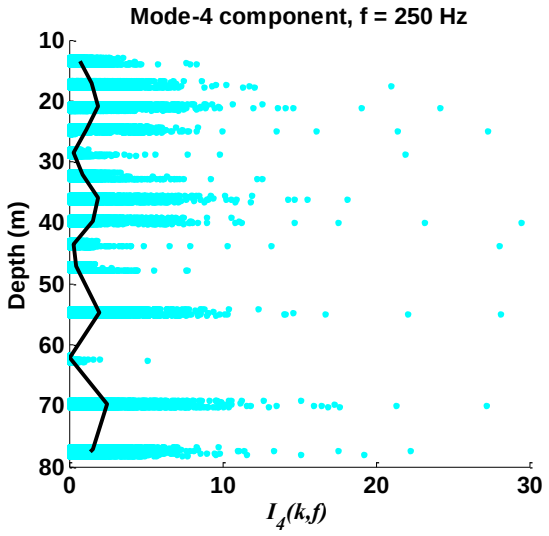
Modal fluctuations

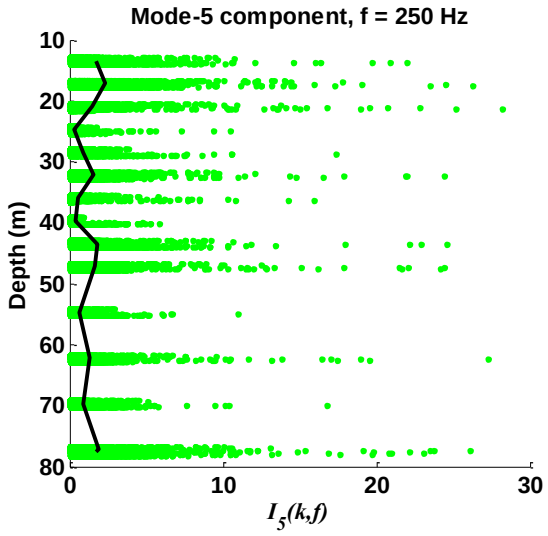


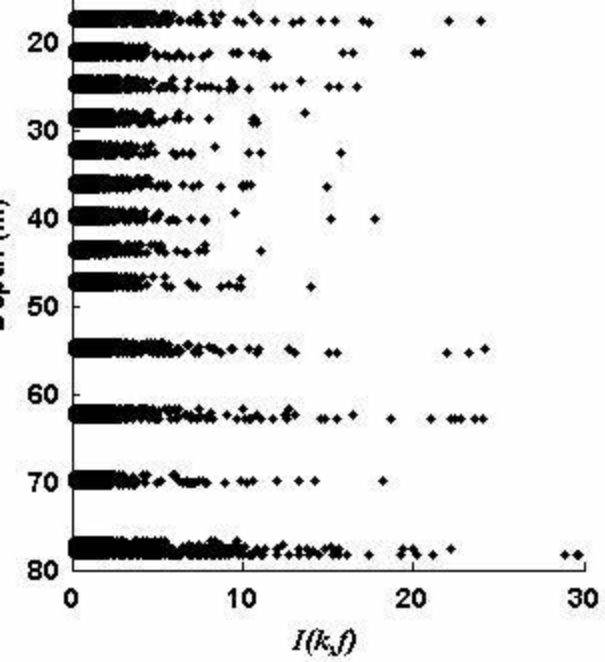


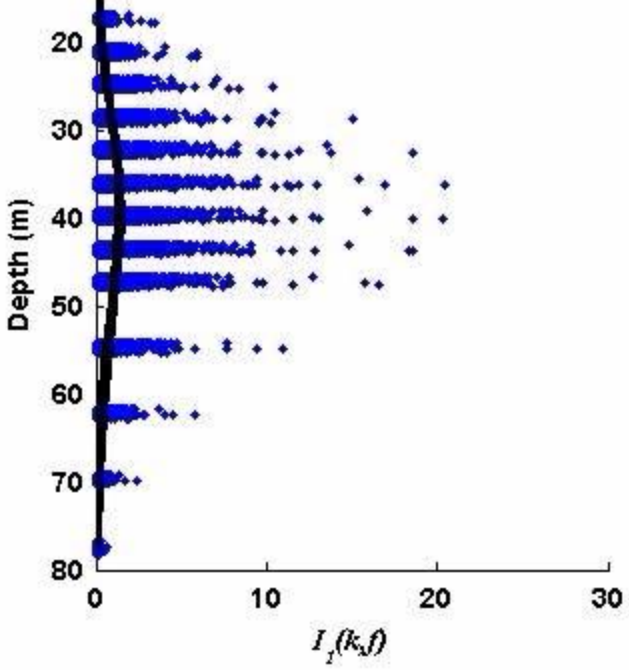


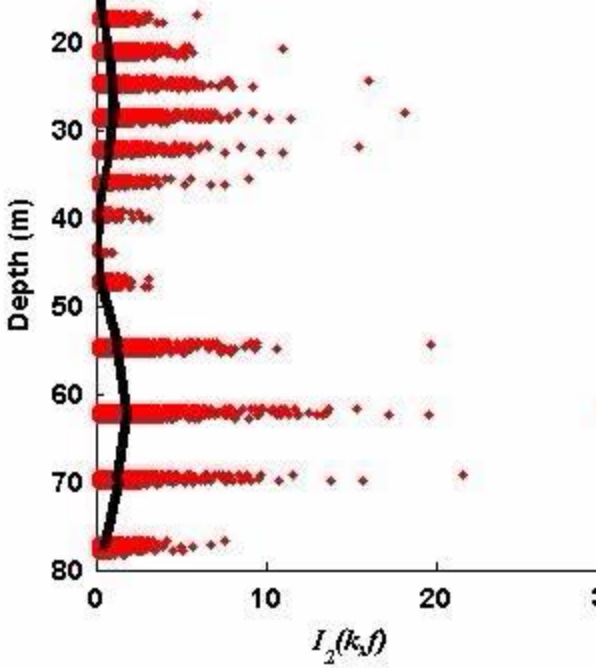


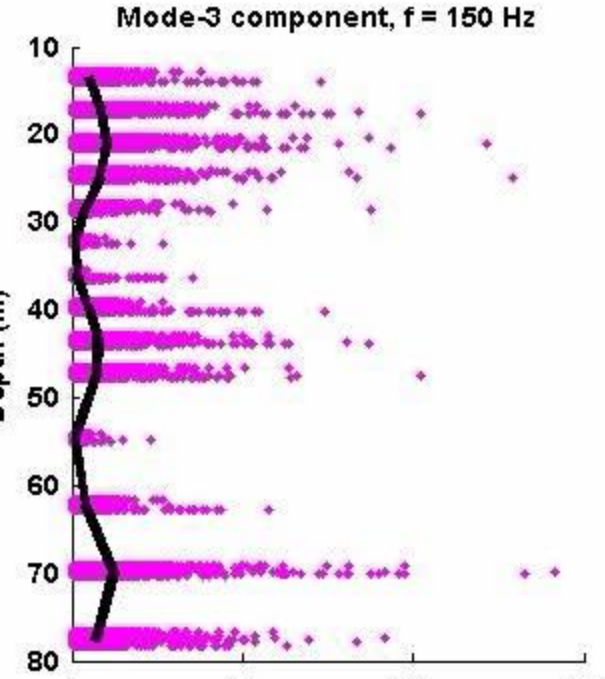


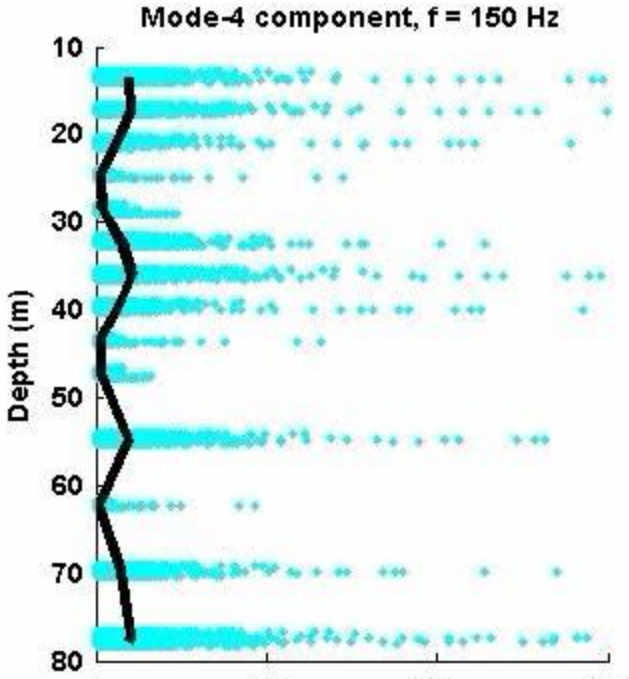


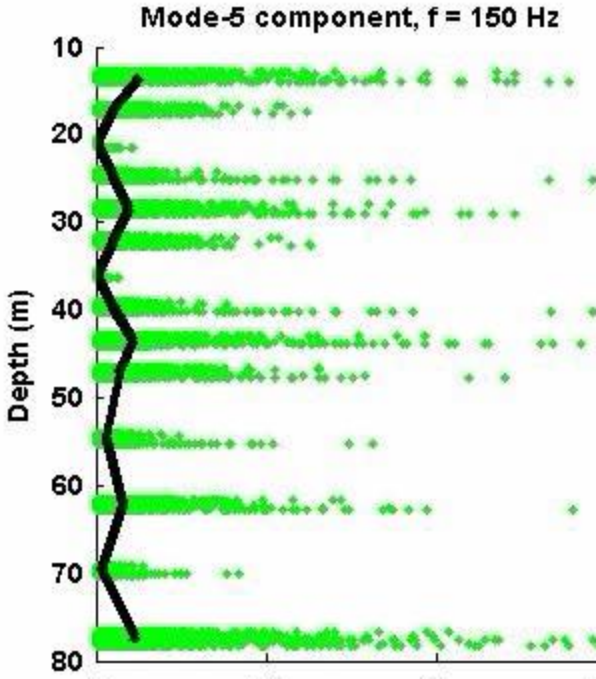

Depth (m)
10
20
30
40
50
60
70
80
0
10
20
30
I(k,f)

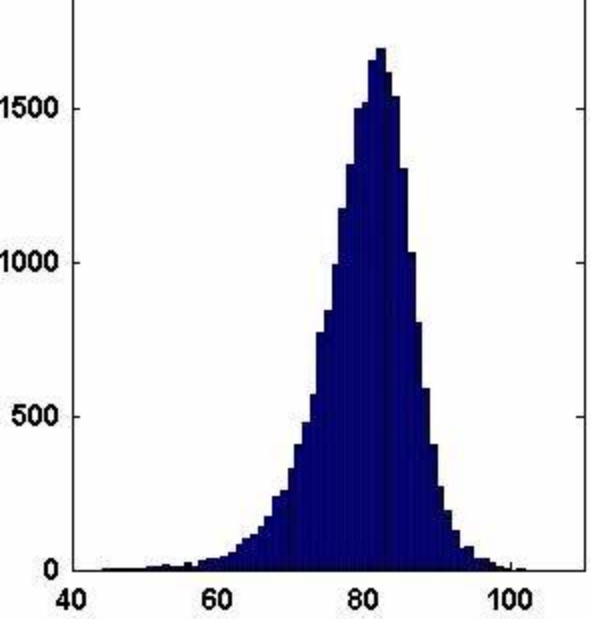

Depth (m)
10
20
30
40
50
60
70
80
0
10
20
30
I1(k,f)

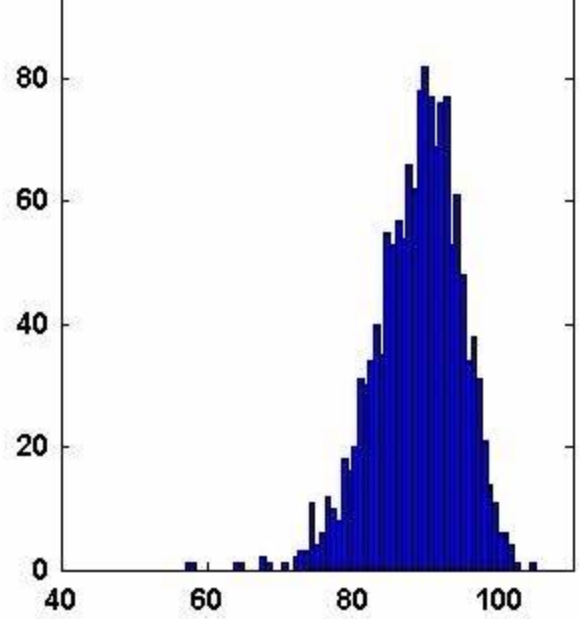

Depth (m)
10
20
30
40
50
60
70
80
0
10
20
I2(k,f)

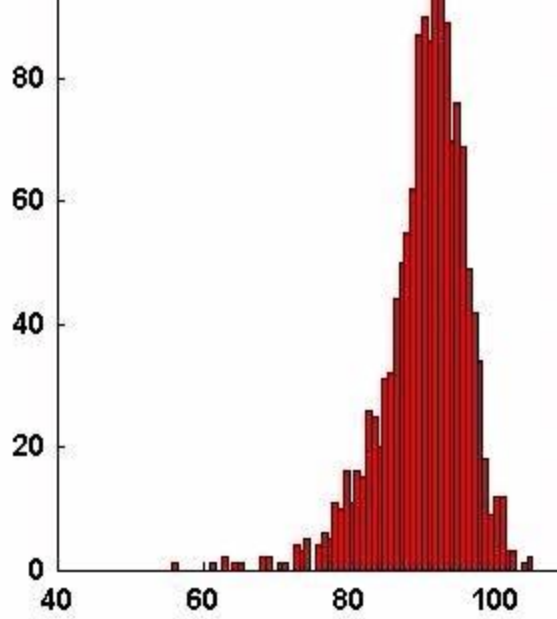

Mode-3 component, f = 150 Hz
Depth (m)
10
20
30
40
50
60
70
80


Mode-4 component, f = 150 Hz
Depth (m)
10
20
30
40
50
60
70
80

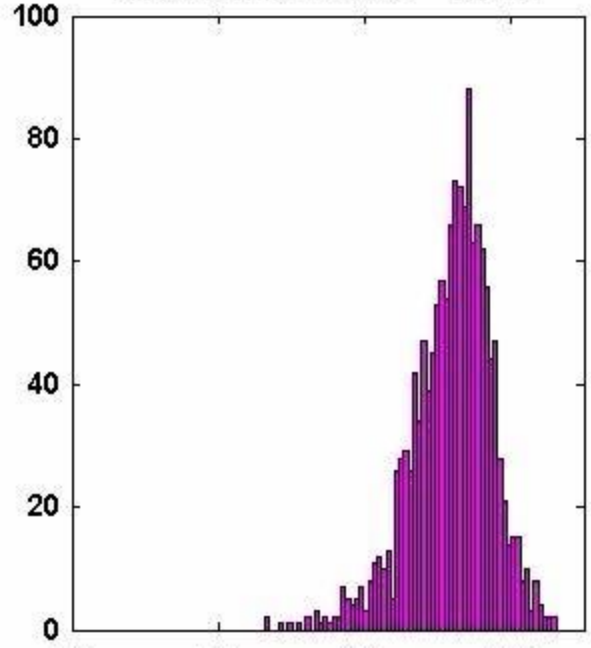

Mode-5 component, f = 150 Hz
Depth (m)
10
20
30
40
50
60
70
80



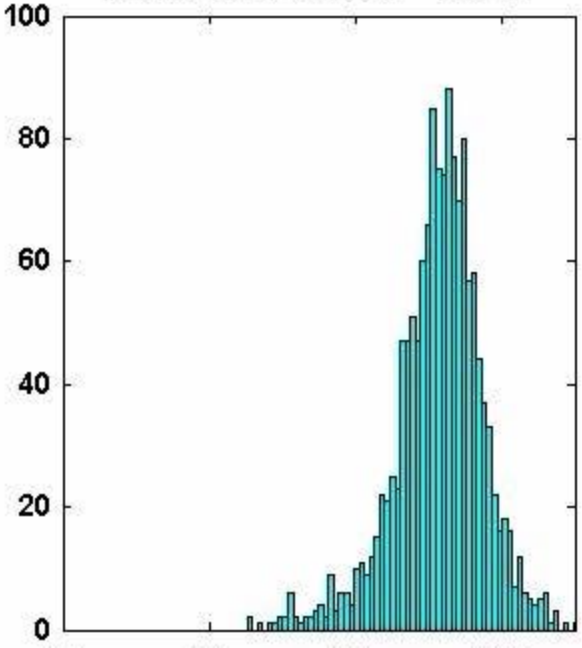




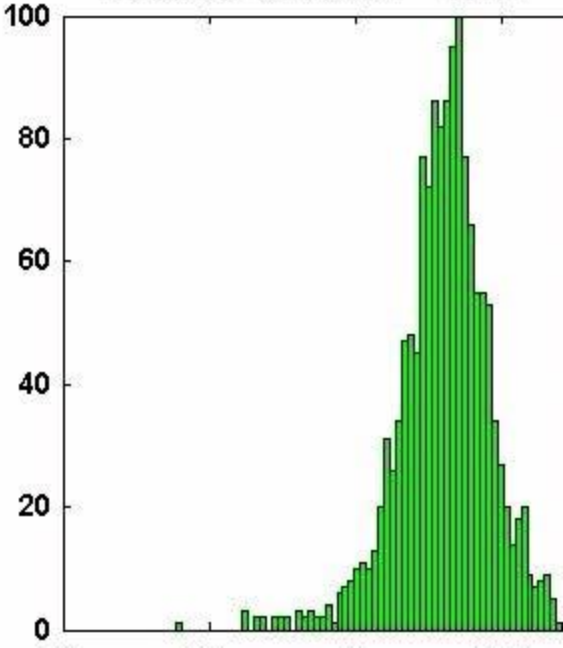
Mode-3 amplitudes, f = 150 Hz

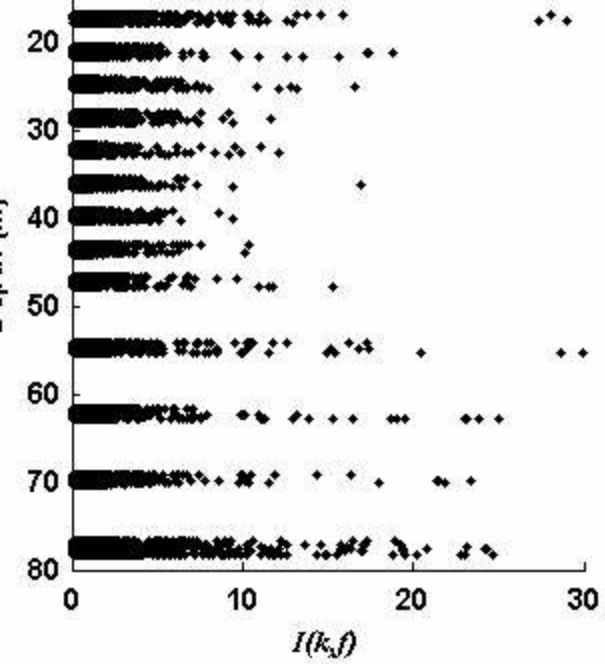


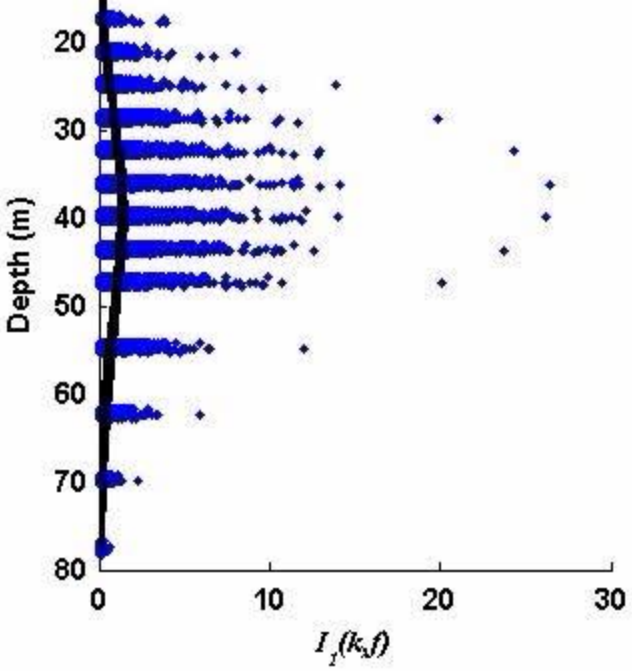
Mode-4 amplitudes, f = 150 Hz

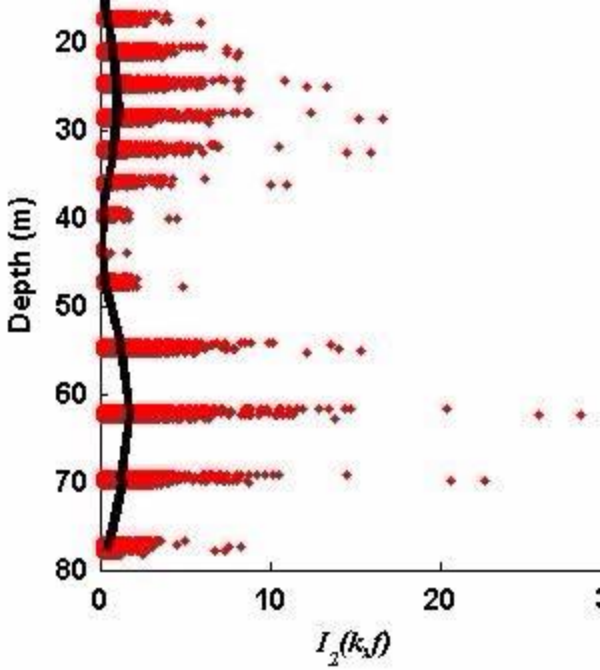


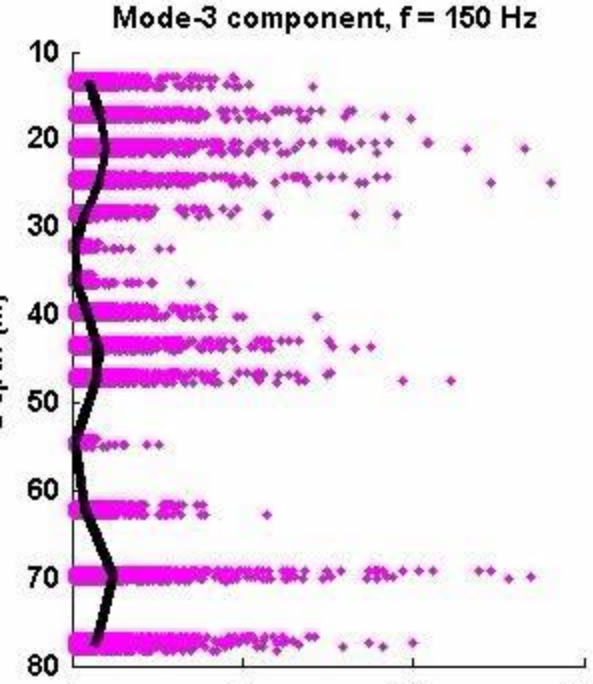
Mode-5 amplitudes, f = 150 Hz

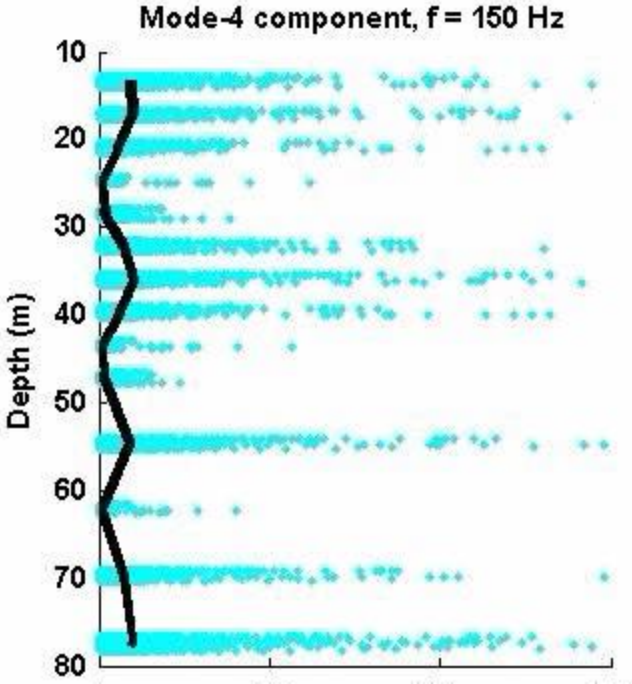


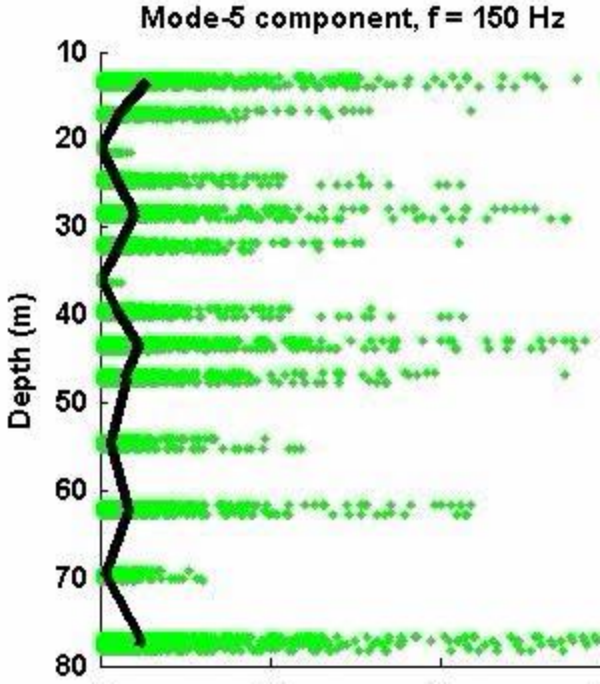

20
30
40
50
60
70
80
0
10
20
30
$I(k,f)$


Depth (m)
20
30
40
50
60
70
80
0
10
20
30
$I_1(k,f)$


Depth (m)
20
30
40
50
60
70
80
0
10
20
$I_2(k,f)$


Mode-3 component, f = 150 Hz
10
20
30
40
50
60
70
80


Mode-4 component, f = 150 Hz
Depth (m)
10
20
30
40
50
60
70
80


Mode-5 component, f = 150 Hz
Depth (m)
10
20
30
40
50
60
70
80