Intensity fluctuations during Event 50 RV Sharp Source & Shark VLA Receiver

Badiey, Katsnelson, Lynch

Acoustical Society of America Meeting

Miami, Fl.

November 10, 2008

Acknowledgements

we are thankful to:

- Many colleagues who have made it possible, both before, during, and after the experimental program
- Crew of RV Sharp, RV Oceanus, and their personnel
- ONR for making it all possible and for their long term commitment

Long-Term Goals

Obtain quantitative understanding of the physics governing the broadband frequency (50 Hz to 500 Hz) acoustic signal propagation, reflection, refraction, and scattering in shallow water and coastal regions in the presence of temporal and spatial ocean variability.

Background

- SWARM Experiment
- Theoretical development
- ASIAEX Studies
- SW06 Experiment
  - Event 50 (Source 1)
  - Event 50 (Source 2)
- Summary

Background

- Oceanographic observations of shallow water internal waves [Zhou et al. (1991), Rubenstein et al. (1991), Rubenstein (1999)].
- SWARM95 observation of acoustic effects [Badiey et al. (2002)].
- Theoretical explanation and hypothesis [Katsnelson et al. JASA 117(2), 2005 and JASA 122(2), 2007].

Experiment	Waveguide	Internal solitons	Signal	Results
Zhou *et al*. (1991). JASA 90(4), 2042-2054	Yellow sea L= 28 km; D=40 m	Hypothesized **$\alpha > 45^o$**	Broadband 100-1000 Hz	Freq. fluct. > 20 dB ***Resonant mode Coupling***
Rubenstein & Brill, Ocean Variability and Acoust., 215-228 (1991).	Washington coast L=18.5km; D=150m	N~10 cph Ampl ~ 10 m **$\alpha \sim 10\text{-}15^o$**	Narrowband f = 400 Hz	Temp. intens. fluct. ~ 3 dB ***Adiabatic fluctuations***
Rubenstein, D. (1999) IEEE J. Oceanic Eng. 24(3), 346-357.	Gulf of Mexico L= 30km; D=185m	N ~ 15–20 cph Ampl ~ 10 m **$\alpha \sim 30^o$**	Narrowband f = 240 Hz	Temp. intens. fluct. ~ 2 dB ***Mode coupling***
Badiey, Lynch, *et al.* (2002). IEEE J. Oc.Eng., v.27, N1, 117-129.	New Jersey shelf L=15 km; D=70 m	N ~ 10-15 cph Ampl ~ 12 m **$\alpha \sim 5^o$**	Broadband 30-160 Hz and LFM 50-250 Hz	Space-time int. fluct.~ 6-7dB ***3D effects (horizontal refraction)***
Badiey, Lynch, *et al.* (2002). IEEE J. Oc.Eng., v.27, N1, 117-129.	New Jersey shelf L=19 km; D=70-100m	N ~ 10-15 cph Ampl ~ 12 m **$\alpha \sim 35\text{-}40^o$**	Broadband 30-160 Hz and LFM 50-250 Hz	Space-time int. fluct.~2-3 dB ***Mode coupling***
Badiey, Katsnelson, Lynch, *et al.* JASA 2005 - 117(2), 613-625. 2007 - 122(2), 747-760.	New Jersey shelf L=15 km; D=70 m	N ~ 10-15 cph Ampl ~ 12 m **$\alpha \sim 5^o$**	Broadband 30-160 Hz	Space-time int. fluct.~ 6-7dB ***3D effects*** ***Frequency dependence***

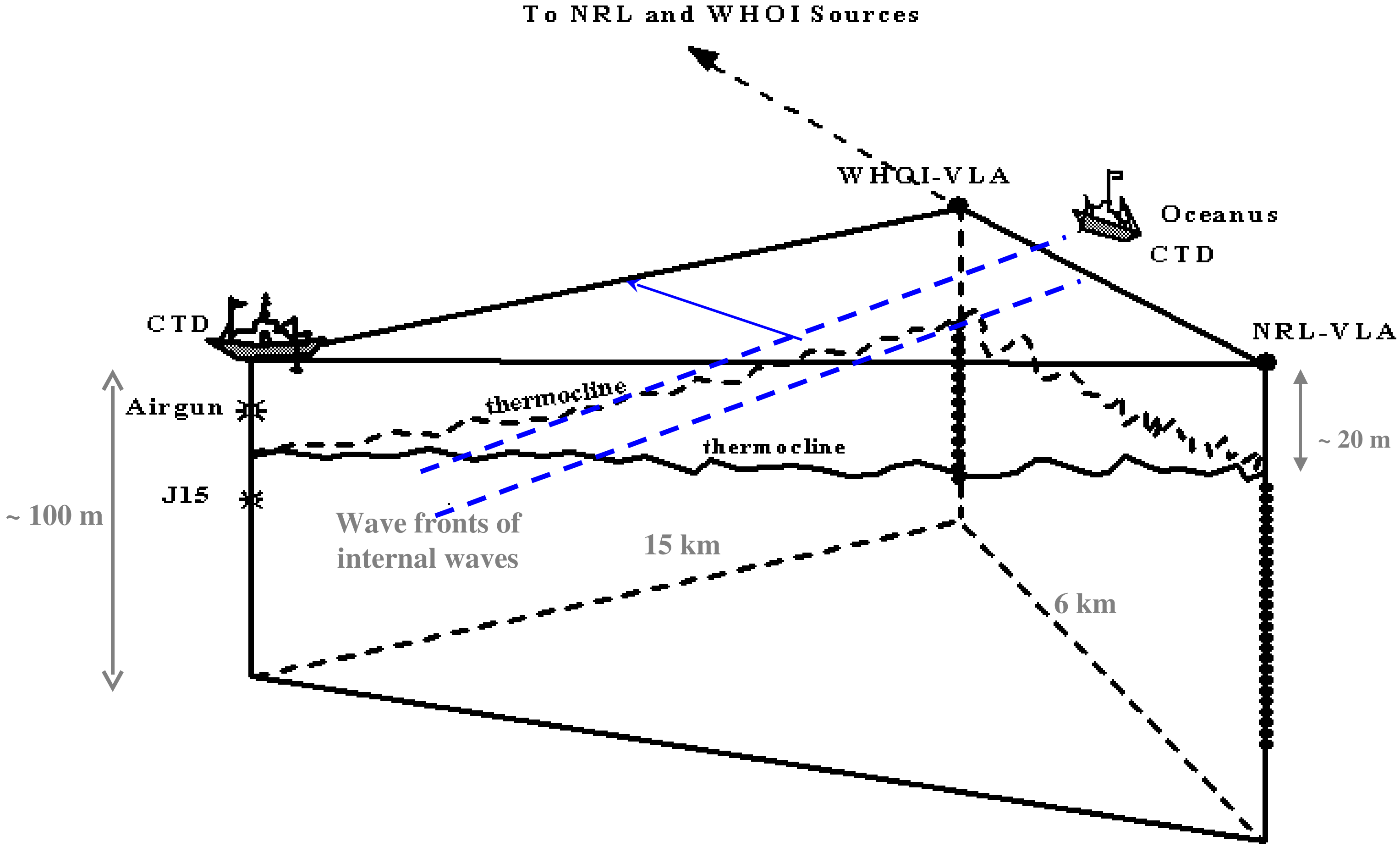
SW06 Experiment

- Multi-disciplinary, multi-institutional, multi-national efforts
- New Jersey continental shelf where SWARM95 was conducted
- Mid-July to mid-September 2006
- 62 acoustics and oceanographic moorings deployed in ‘T’ geometry (along- and across-shelf paths)
- 5 main research vessels: R/V Knorr, R/V Oceanus, R/V Endeavor, R/V Sharp,

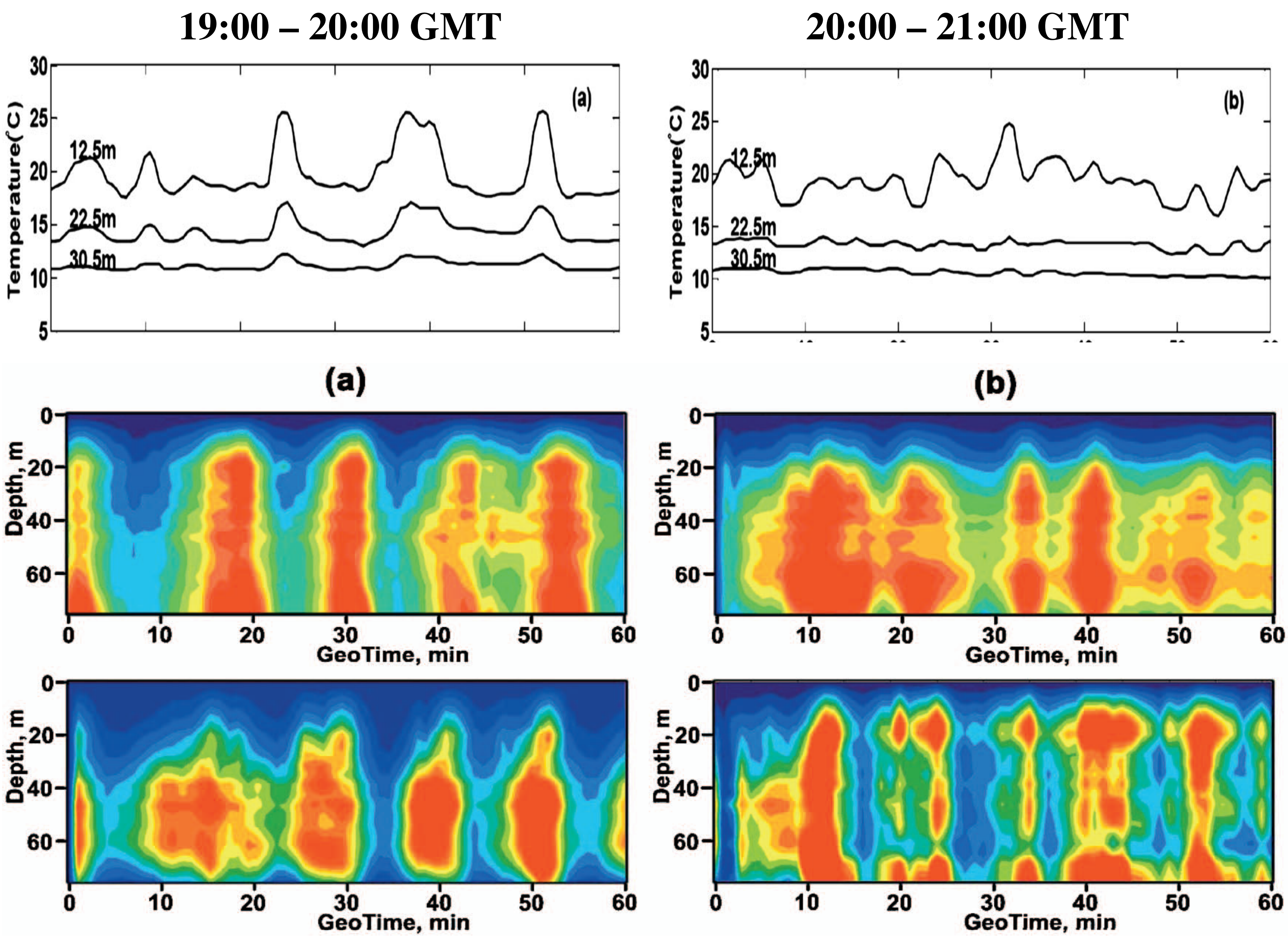
SW06 Experiment

- Objectives
  - Investigate 3D effects of internal wave (IW) on the broadband acoustic propagation:
    - Azimuthal dependency of the field due to IW propagation.
    - Study different regimes of propagation: adiabatic, horizontal refraction, mode coupling, and the transitions between them.
  - Investigate effects of environment on the underwater acoustic communication.

SWARM-95 Experiment



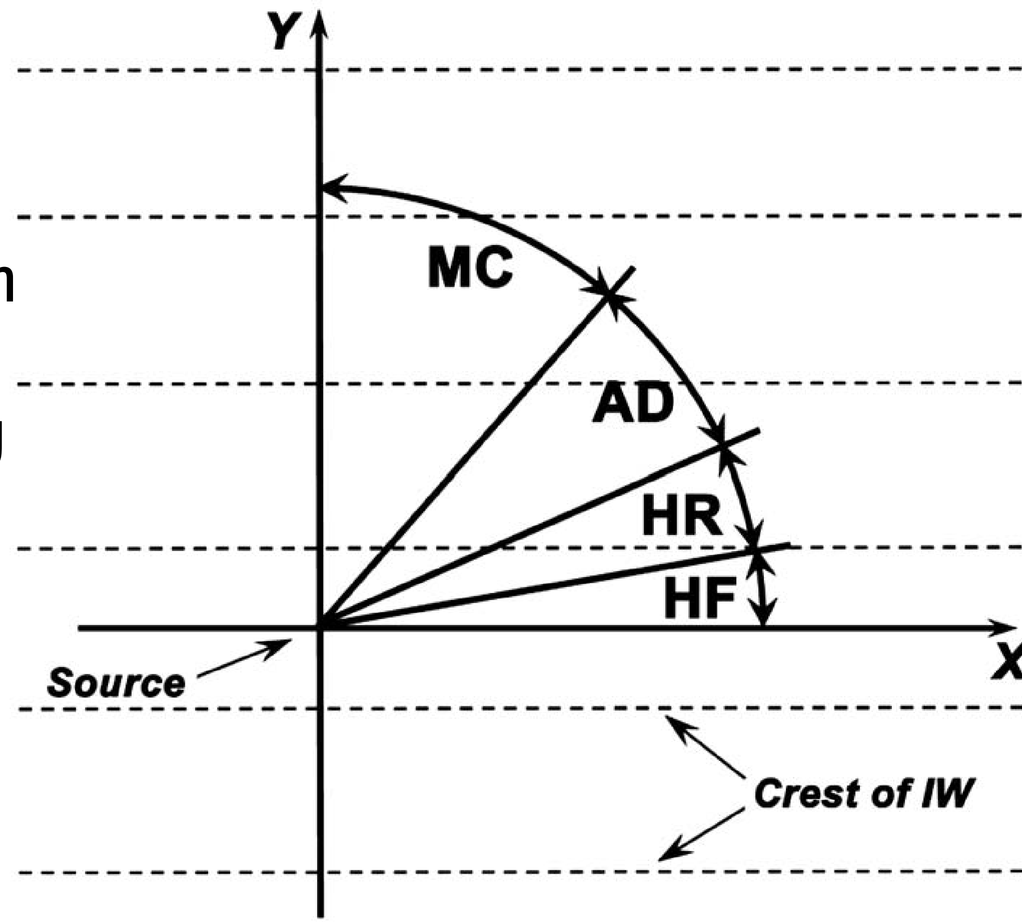
August 4, 1995

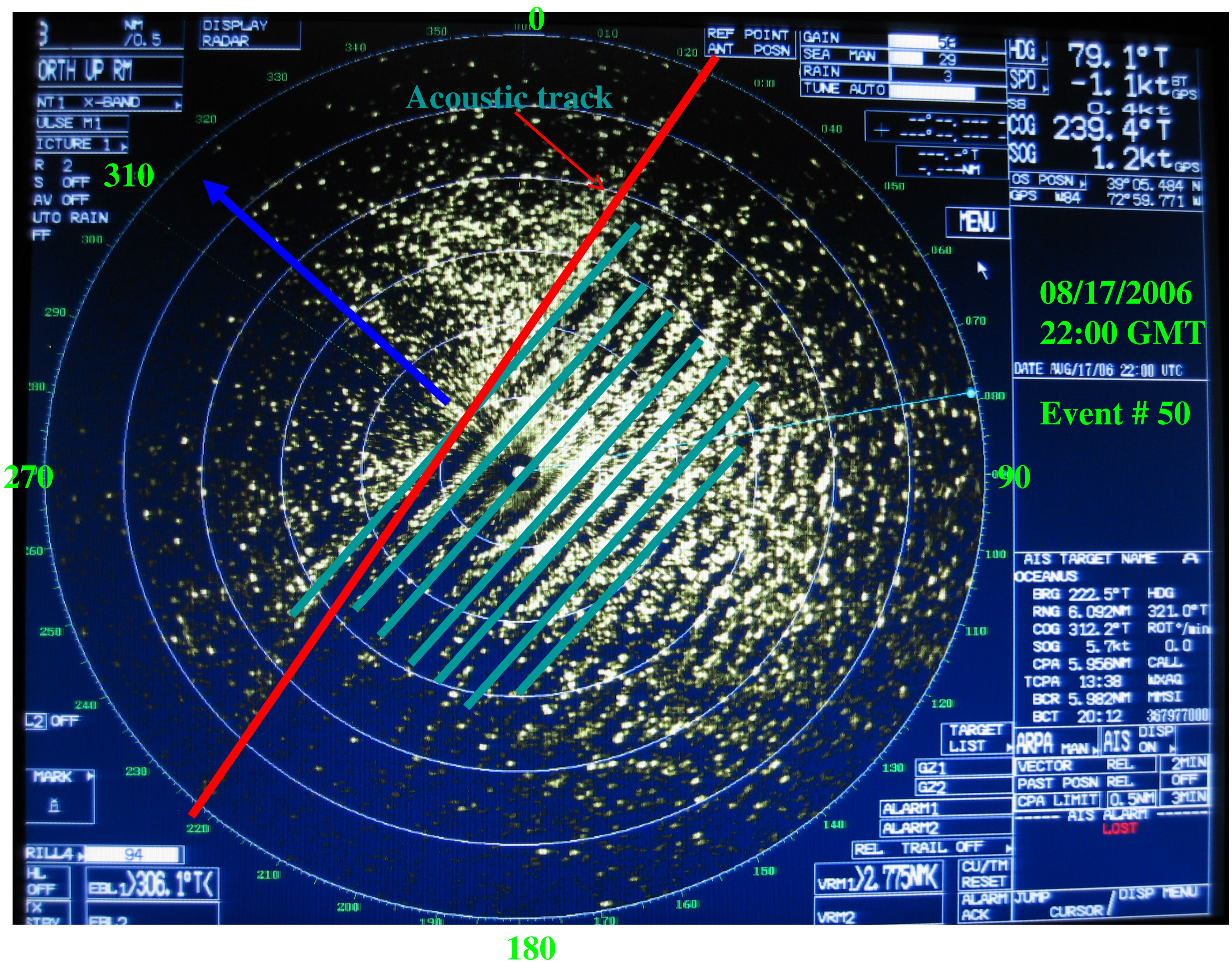


Different mechanisms of acoustic propagation in the presence of internal wave

- MC: mode coupling
- AD: adiabatic
- HR: horizontal refraction
- HF: horizontal refraction and focusing

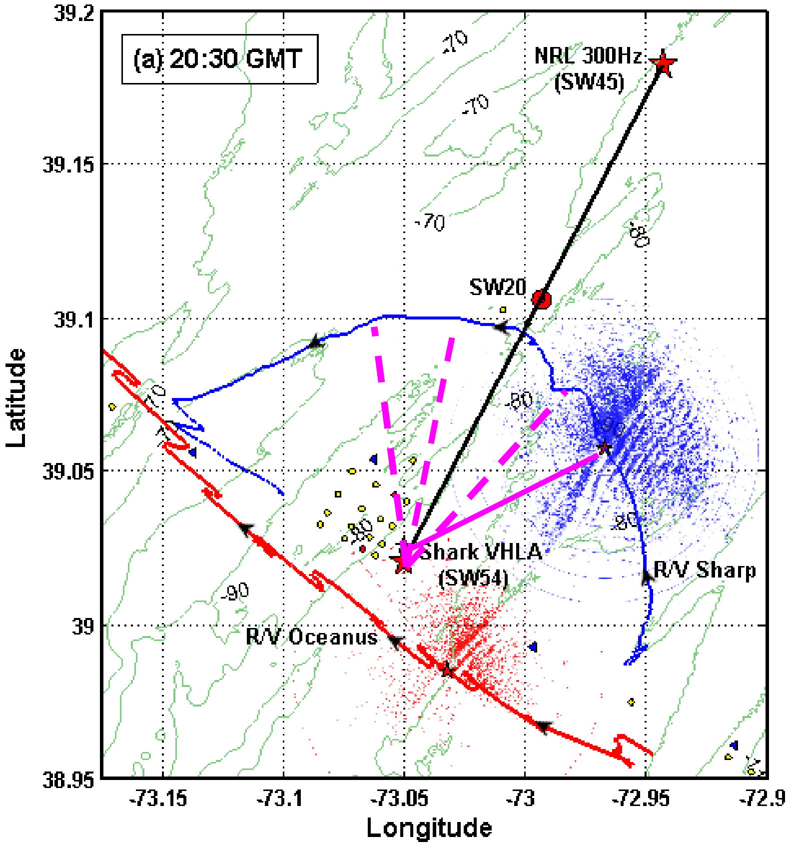
[Katsnelson *et al.* 2007]




0
Acoustic track
310
270
90
180
08/17/2006
22:00 GMT
Event # 50
DISPLAY
RADAR
GAIN
SEA MAN
RAIN
TUNE AUTO
HDG 79.1°T
SPD -1.1kt
COG 239.4°T
SOG 1.2kt
MENU
DATE AUG/17/06 22:00 UTC
AIS TARGET NAME
OCEANUS
BRG 222.5°T
RNG 6.092NM
COG 312.2°T
SOG 5.7kt
CPA 5.956NM
TCPA 13:38
BCR 5.982NM
BCT 20:12
HDG 321.0°T
TARGET LIST
VECTOR REL
PAST POSN REL
CPA LIMIT 0.5NM
ALARM1
ALARM2
REL TRAIL OFF
EBL1 306.1°T
VRM1 2.775NM

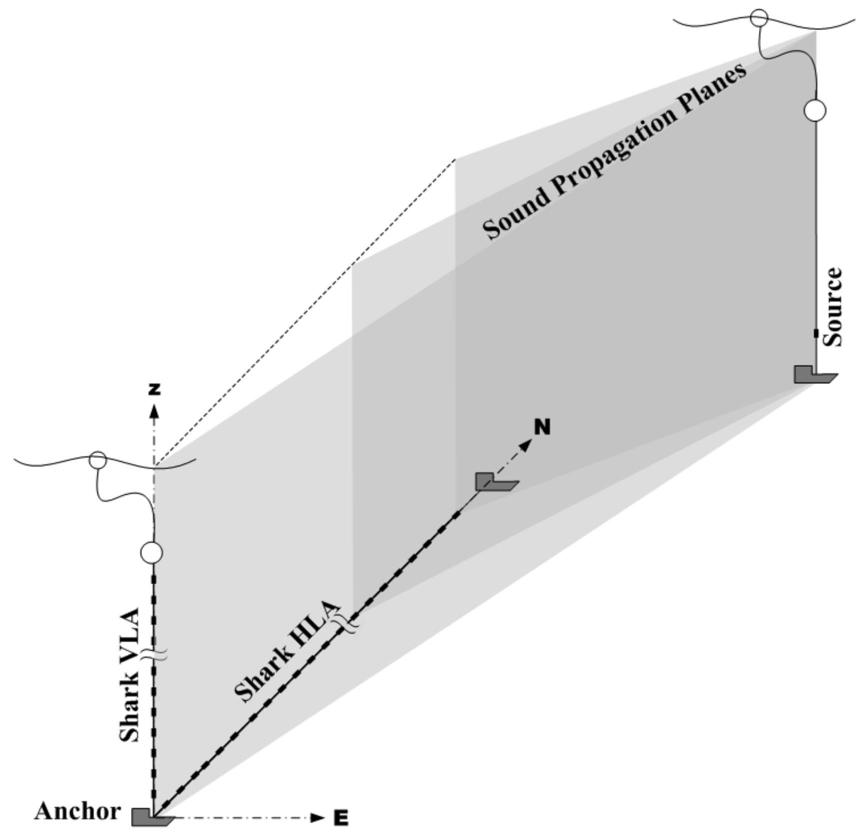
Experimental set up

- Research Vessel:
  - R/V Sharp (blue)
  - R/V Oceanus (red)
- Acoustic source
  - NRL 300Hz
- Acoustic receiver array
  - Shark VHLA
- Temperature sensor array
  - Sw45 (source)
  - Sw20 (mid point)
  - Sw54 (receiver)



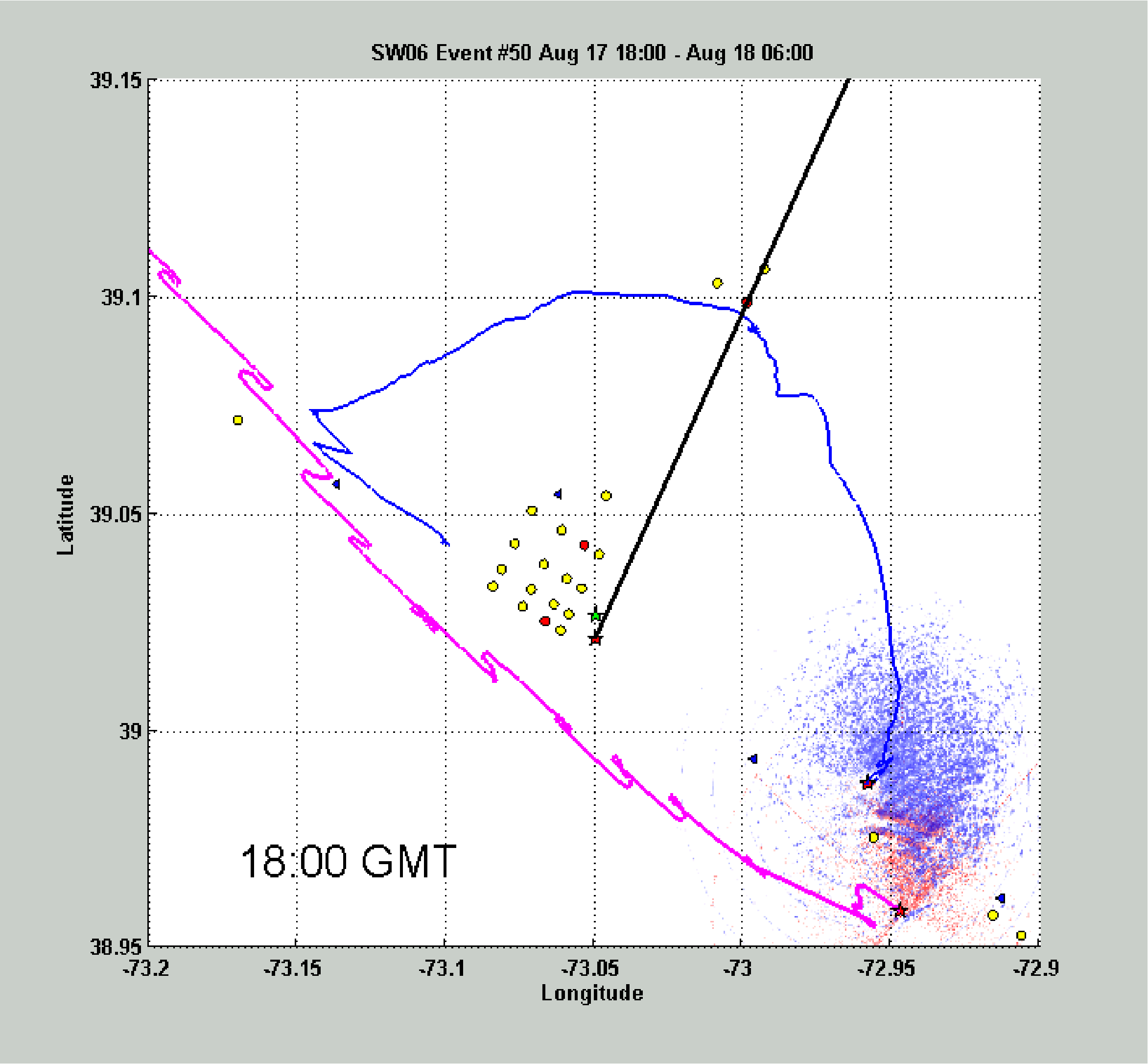
Shark VHLA

- 20.2 km south of the source
- Vertical linear array (VLA)
  16 hydrophones
  3.5 m spacing
  64 m of vertical aperture
- Horizontal linear array (HLA)
  32 hydrophones
  15 m spacing
  478 m of horizontal aperture



Following Rosey

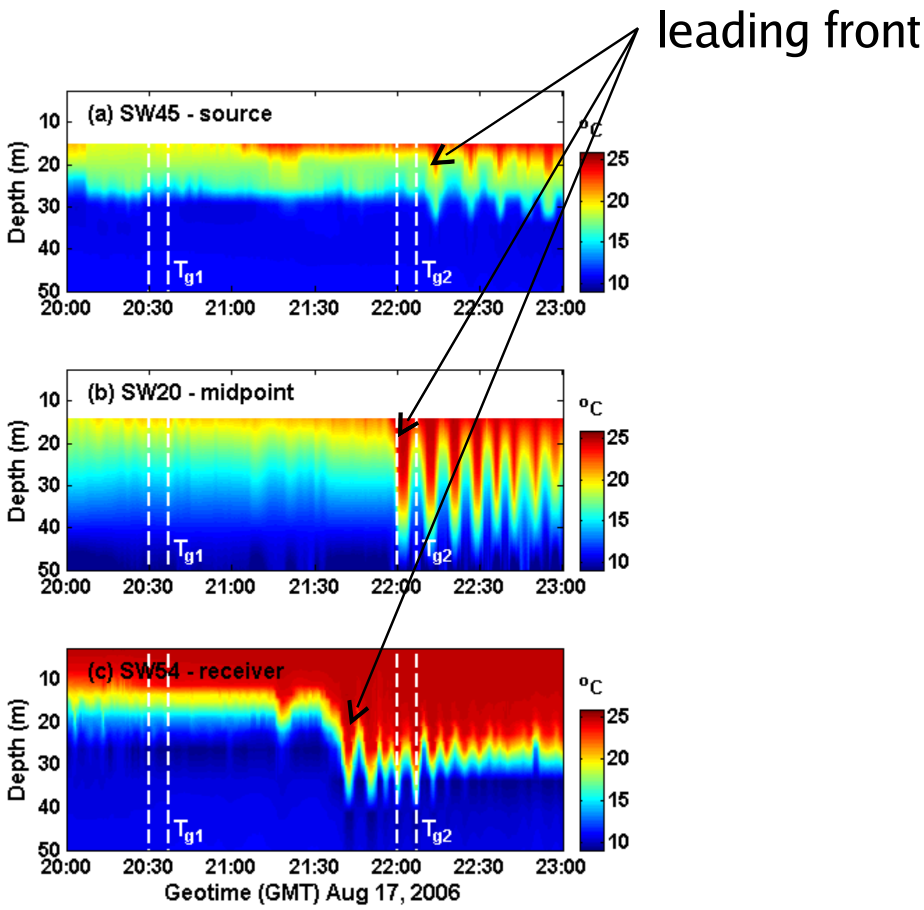
- Start : 18:00GMT, Aug 17
- Arrive at acoustic track: 21:40GMT
- Clear out: 23:00GMT
- End: 6:00GMT, Aug 18



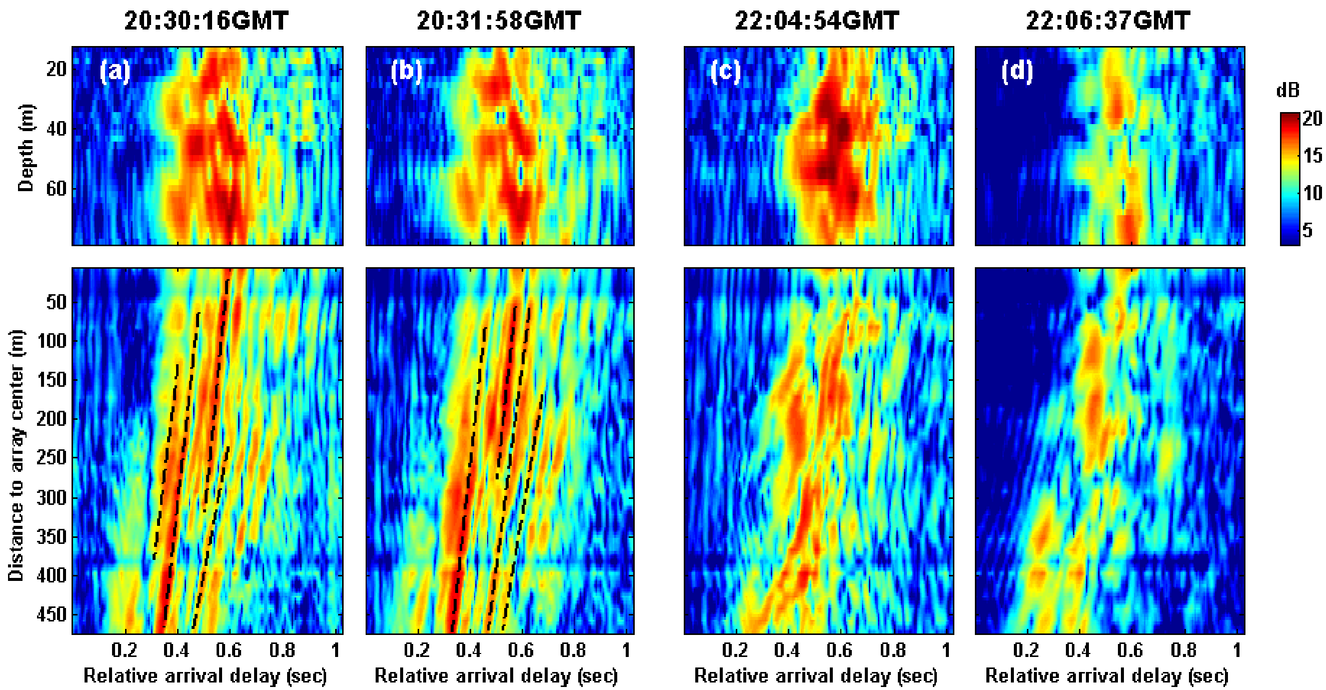
Temperature records

- A sudden increase in the thermocline depth shows the arrival of the ISW at the receiver (21:40), midpoint (22:02) and source (22:15).

- Two acoustic signal transmission windows
  - Tg1 (20:30 to 20:37 GMT) : no ISW
  - Tg2 (22:00 to 22:07 GMT): ISW occupied most of the acoustic track .

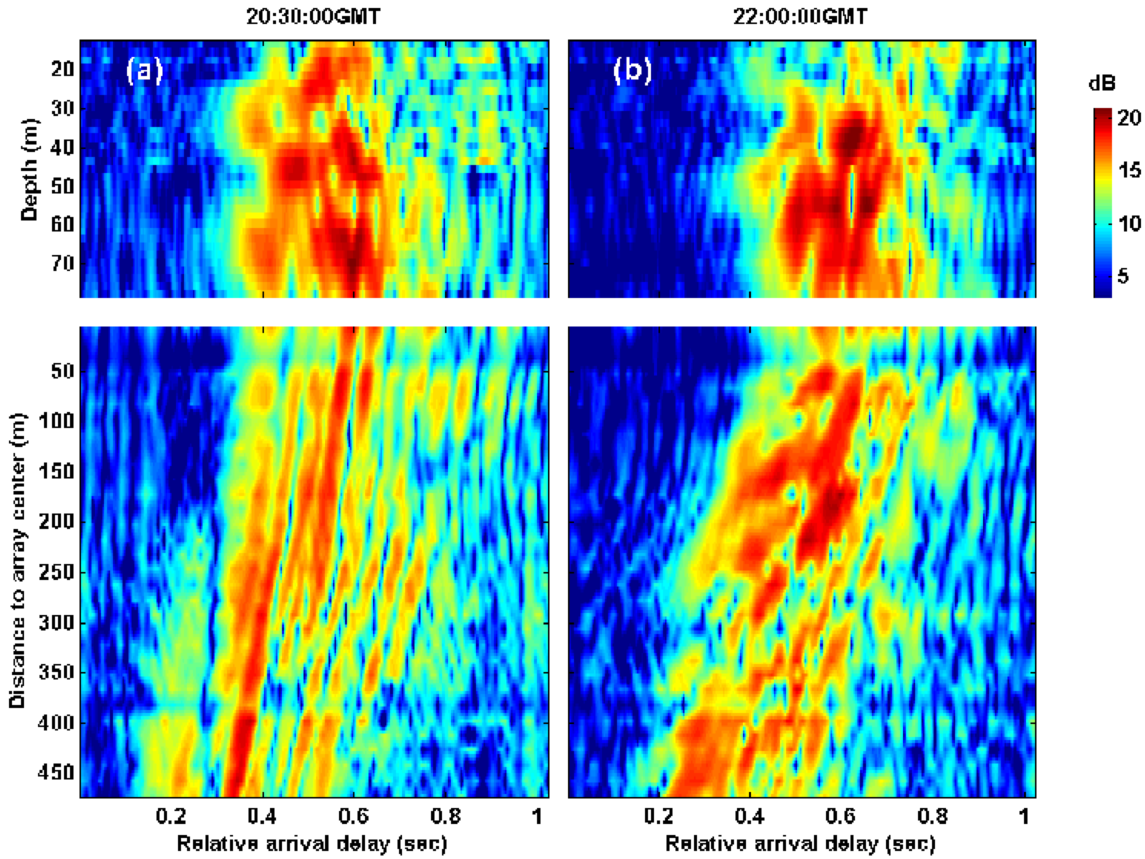


Received signal on the vertical and horizontal array



Tg1 Tg2

Received signal on the vertical and horizontal array



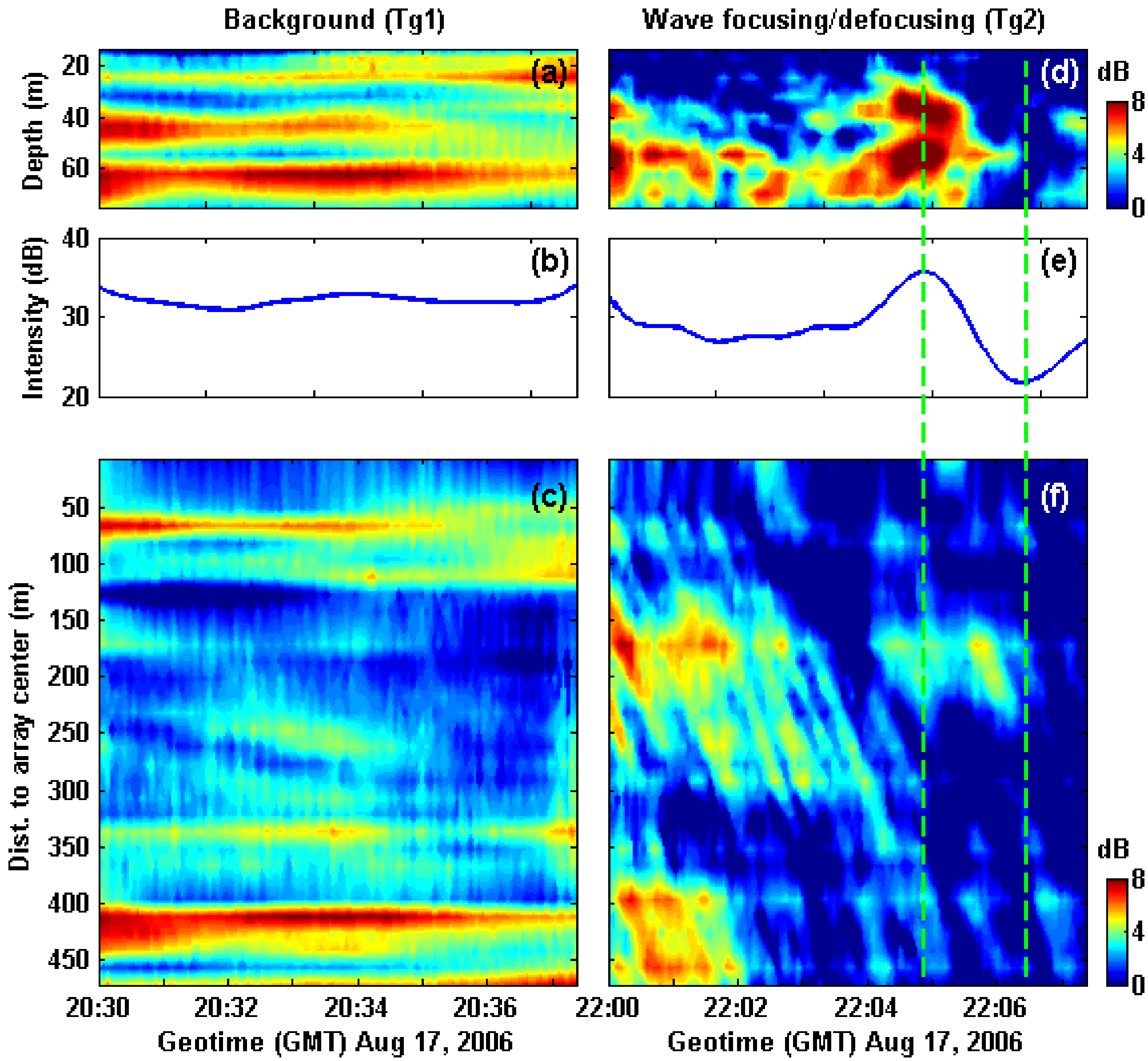
- Total intensity integrated over the depth H :

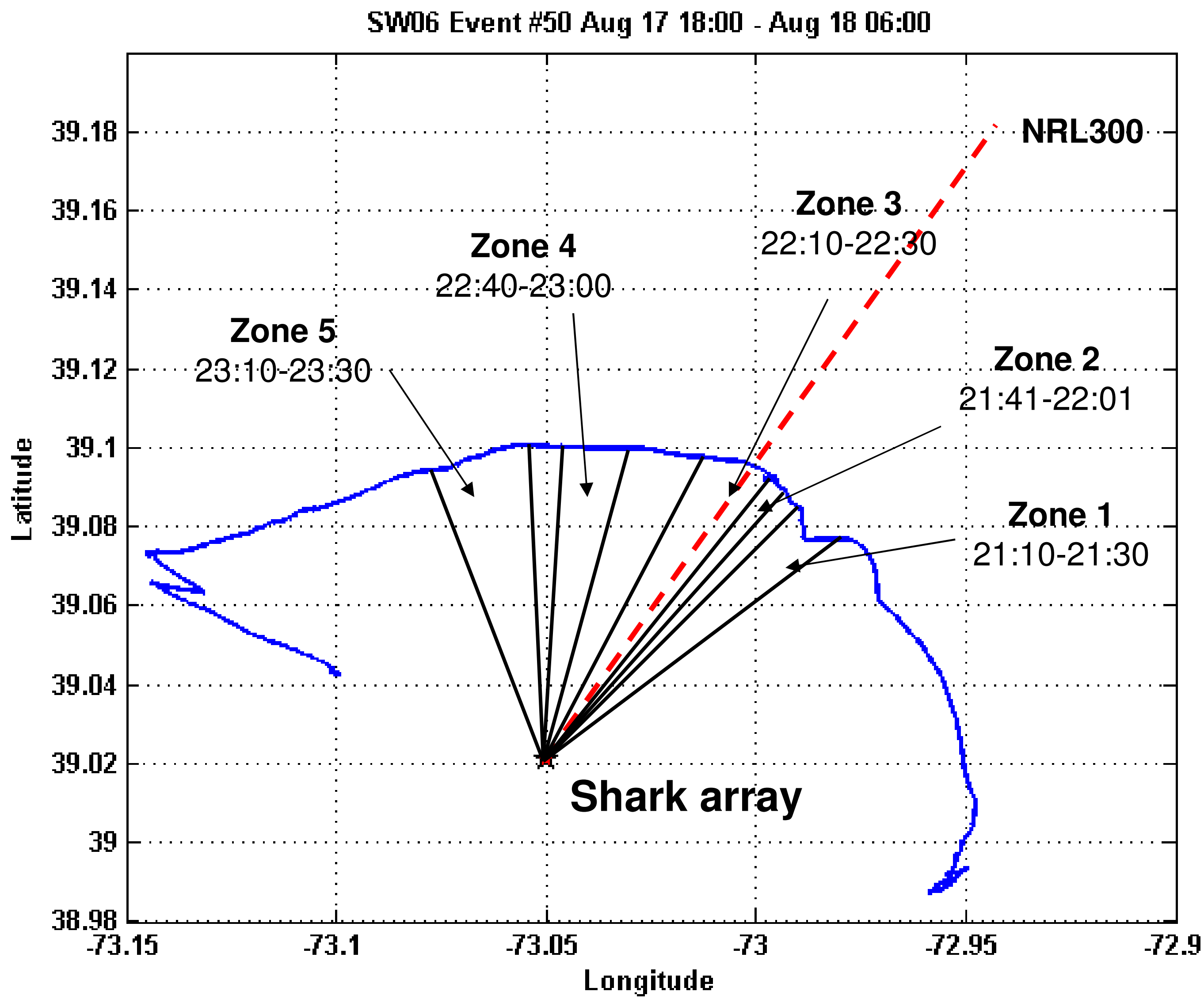
$$I(T) = \int_0^H I(z,T)\,dz$$

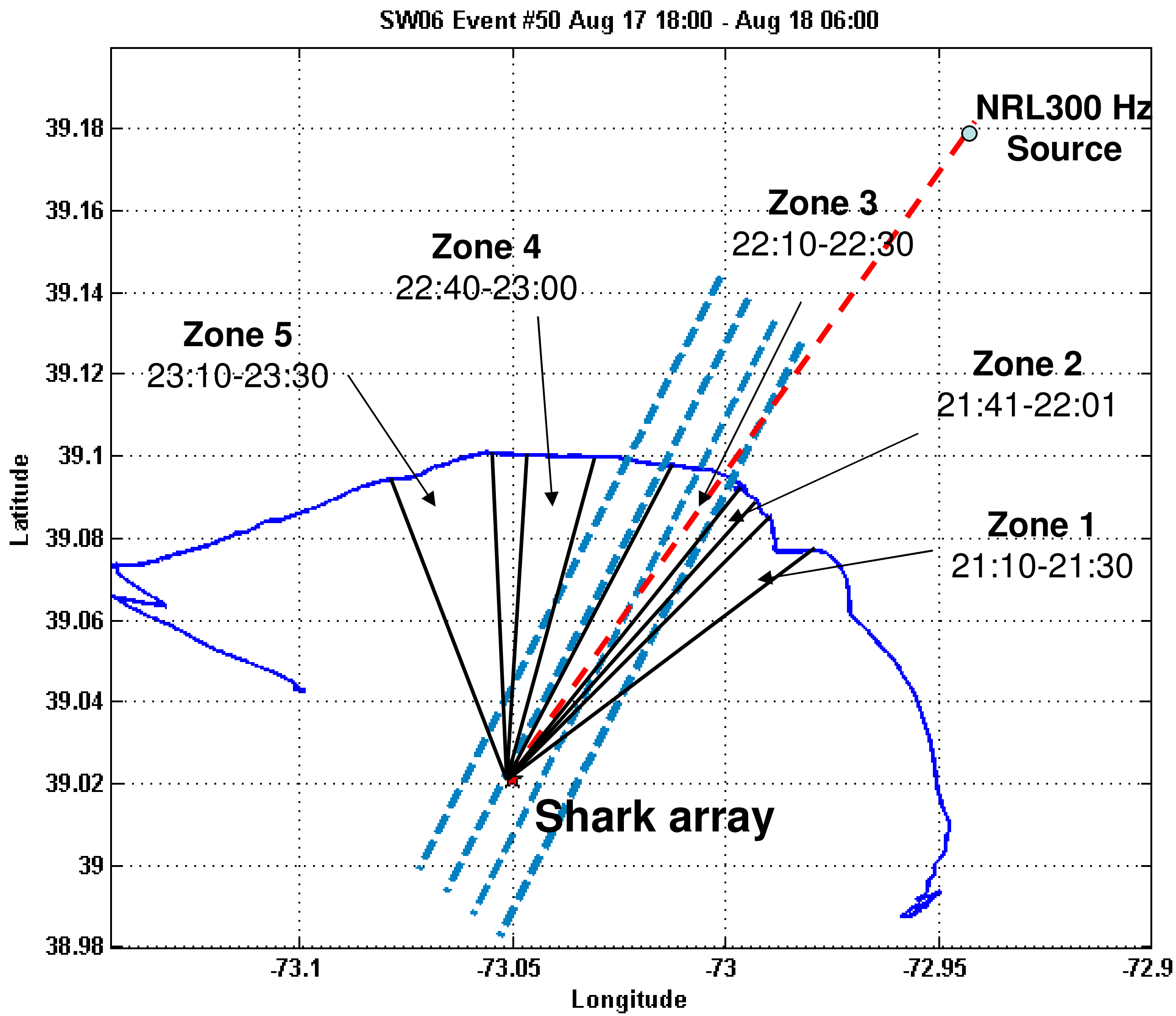
where $I(z,T) = \dfrac{1}{\rho c} \displaystyle\int_{\tau}^{\tau+\Delta\tau} p^2(z,T,t)\,dt$: the intensity of the signal arrivals integrated over the pulse length $\Delta\tau$.

z : depth z, p : acoustic pressure

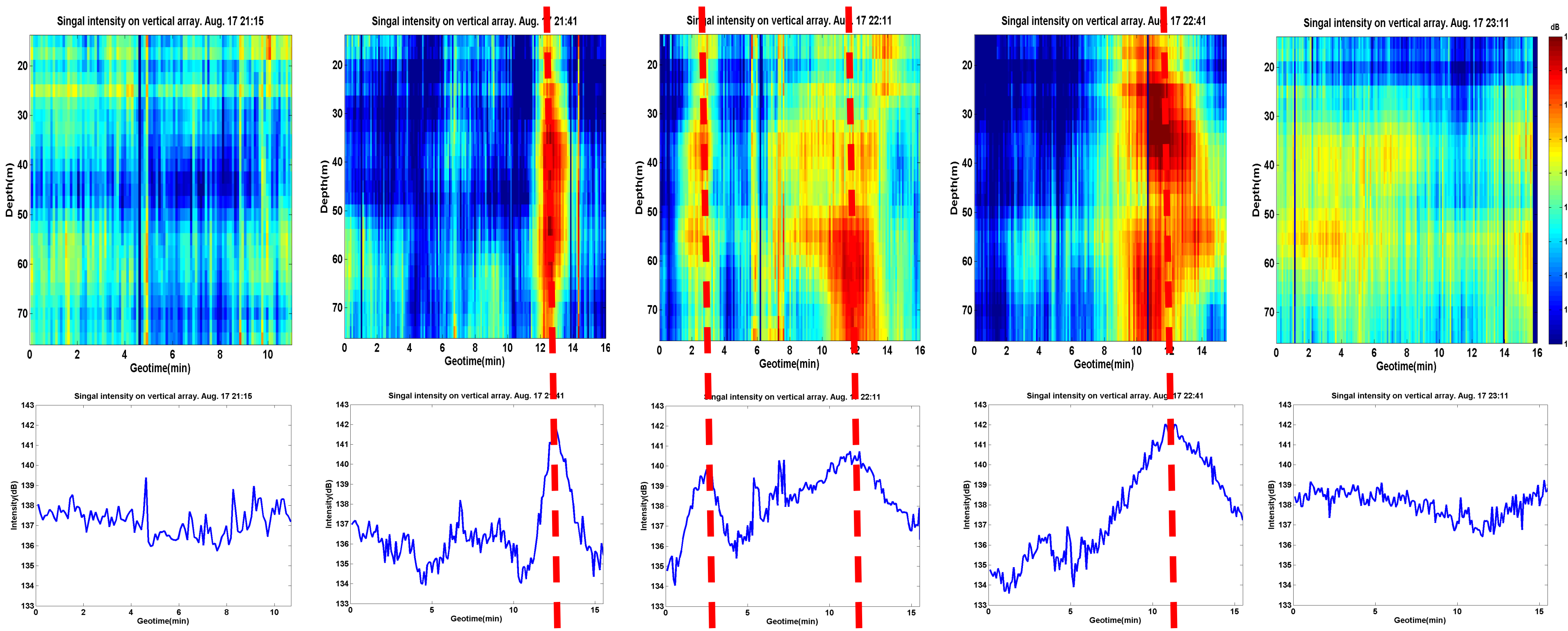
ρ : water density c : sound speed.

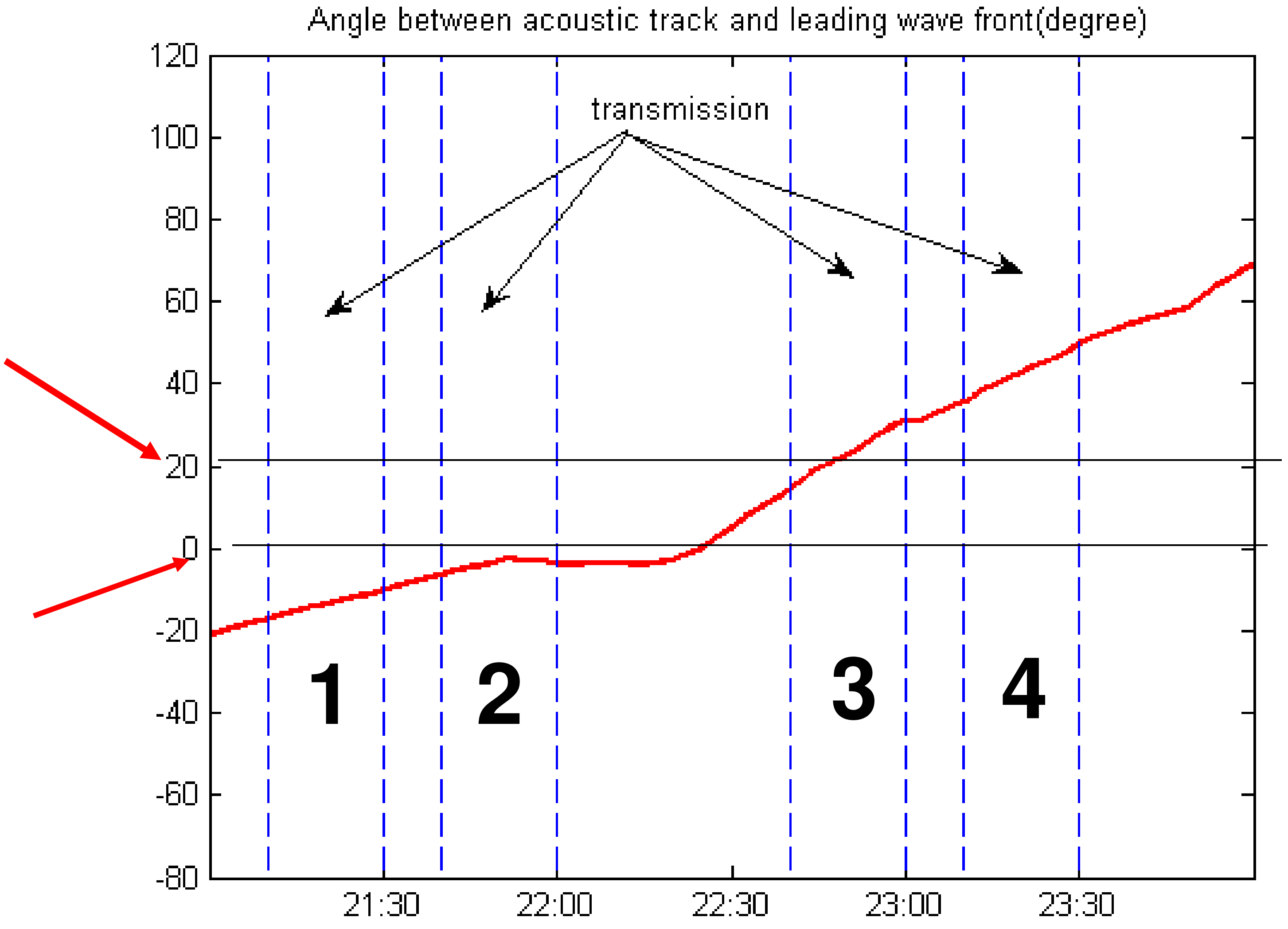

Background (Tg1)
Wave focusing/defocusing (Tg2)
(a)
(b)
(c)
(d)
(e)
(f)
Depth (m)
Intensity (dB)
Dist. to array center (m)
dB
Geotime (GMT) Aug 17, 2006
20:30
20:32
20:34
20:36
22:00
22:02
22:04
22:06


SW06 Event #50 Aug 17 18:00 - Aug 18 06:00
NRL300
Zone 3
22:10-22:30
Zone 4
22:40-23:00
Zone 5
23:10-23:30
Zone 2
21:41-22:01
Zone 1
21:10-21:30
Shark array
Latitude
Longitude
39.18
39.16
39.14
39.12
39.1
39.08
39.06
39.04
39.02
39
38.98
-73.15
-73.1
-73.05
-73
-72.95
-72.9



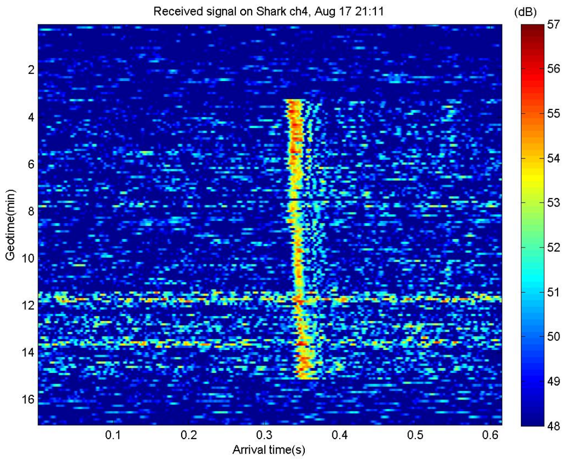
SW06 Event #50 Aug 17 18:00 - Aug 18 06:00
NRL300 Hz Source
Zone 3
22:10-22:30
Zone 4
22:40-23:00
Zone 5
23:10-23:30
Zone 2
21:41-22:01
Zone 1
21:10-21:30
Shark array
39.18
39.16
39.14
39.12
39.1
39.08
39.06
39.04
39.02
39
38.98
-73.1
-73.05
-73
-72.95
-72.9
Latitude
Longitude


Singal intensity on vertical array. Aug. 17 21:15
Singal intensity on vertical array. Aug. 17 21:41
Singal intensity on vertical array. Aug. 17 22:11
Singal intensity on vertical array. Aug. 17 22:41
Singal intensity on vertical array. Aug. 17 23:11
Depth(m)
Geotime(min)
dB
Intensity(dB)

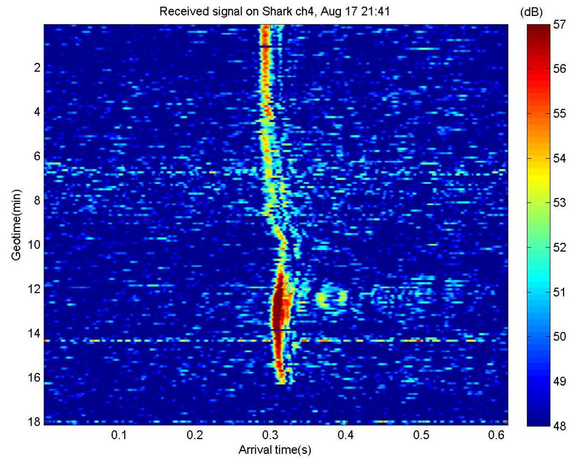


Angle between acoustic track and leading wave front(degree)
transmission
120
100
80
60
40
20
0
-20
-40
-60
-80
21:30
22:00
22:30
23:00
23:30
1
2
3
4

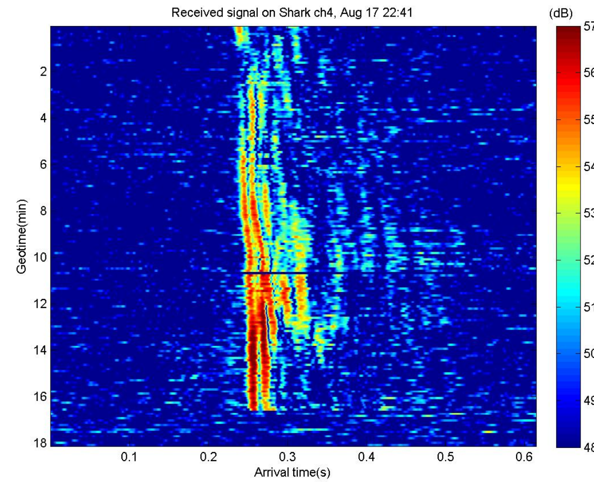
Zone 1



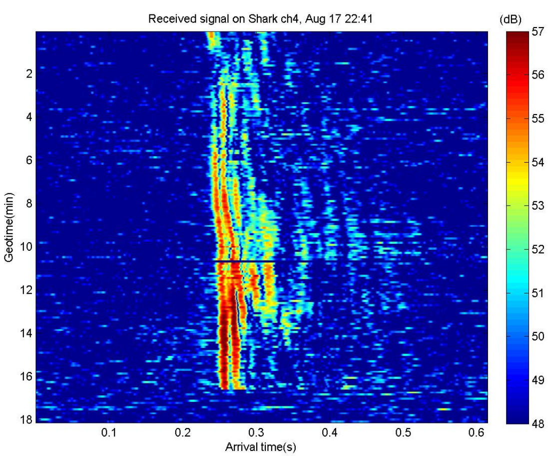
Zone 2



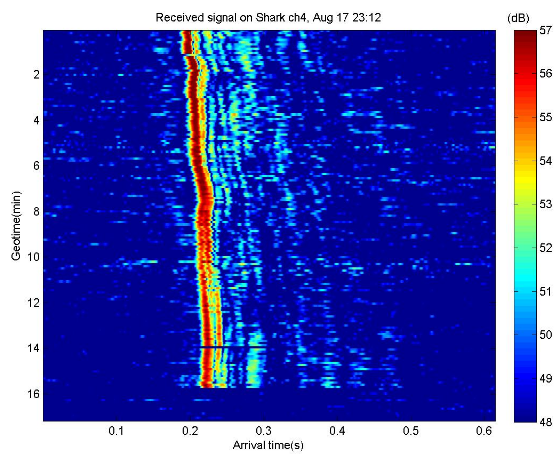
Zone 3



Zone 4



Zone 5



Summary

- High quality acoustic and environmental data were collected during SW06 experiment.
- Acoustic data, observations of radar images and temperature records show that during the passage of an ISW event, horizontal refraction results in significant acoustic intensity variation.
- Observation agrees with the previous theory [Katsnelson, Lynch, Badiey *et al. 2005,* 2007, 2008].
- Future work includes mode and frequency filtering of acoustic data and modeling to establish the transition of acoustic field in the presence of ISW.