Effects of internal waves on acoustic coherent communications during SW06

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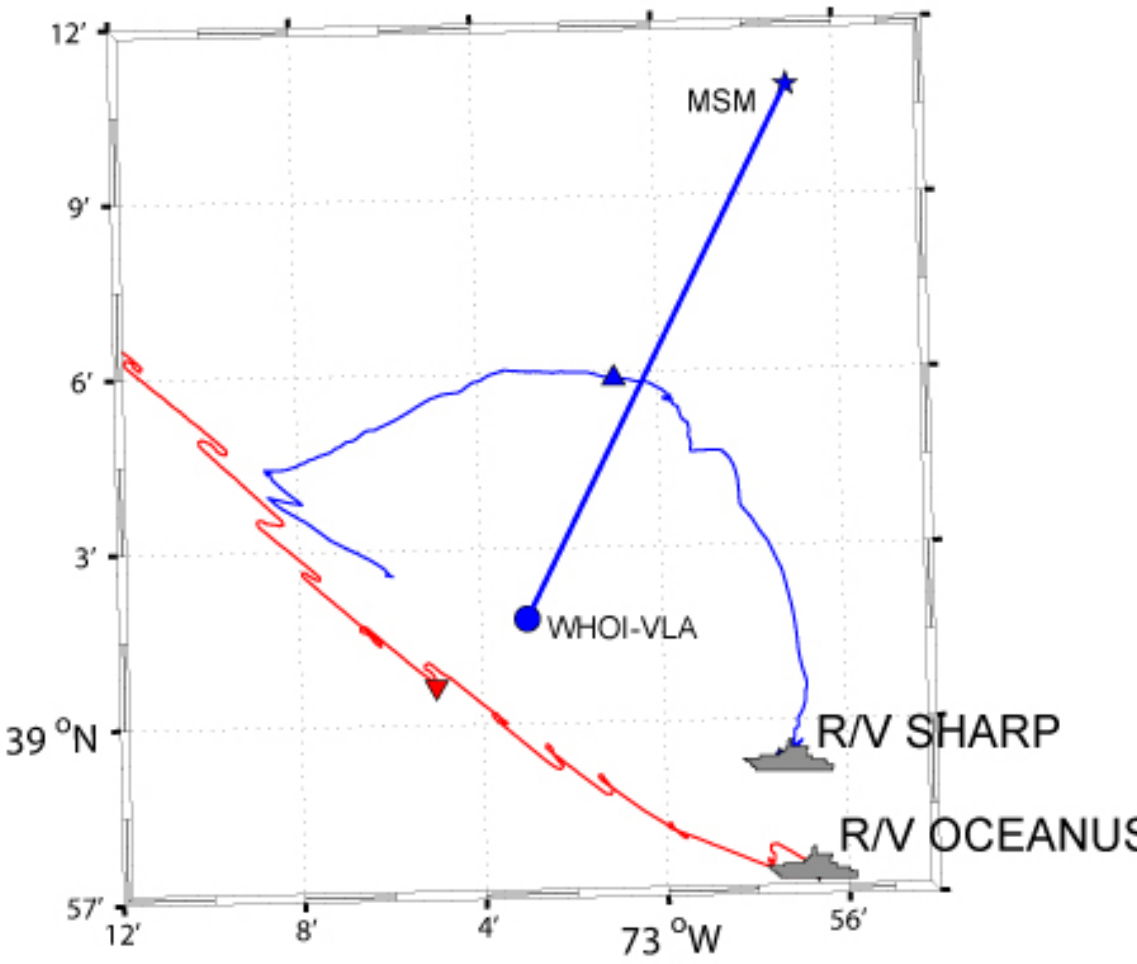
Introduction

- Internal wave effects on acoustic signals (Apel, *et al.*, JOE1997)
  - Intensity fluctuation (Badiey, *et al.*, JASA2005, JASA2007)
  - Temporal coherency variation (Rouseff *et al.*, JASA2002, Yoo, JOE2005)
- Internal wave effects on underwater acoustic communications
  - Expected effects but limited results in the literature
  - Current efforts: 1) concurrent acoustic and environmental measurement; 2) using our time reversal based receiver, 3) the extent of the effects

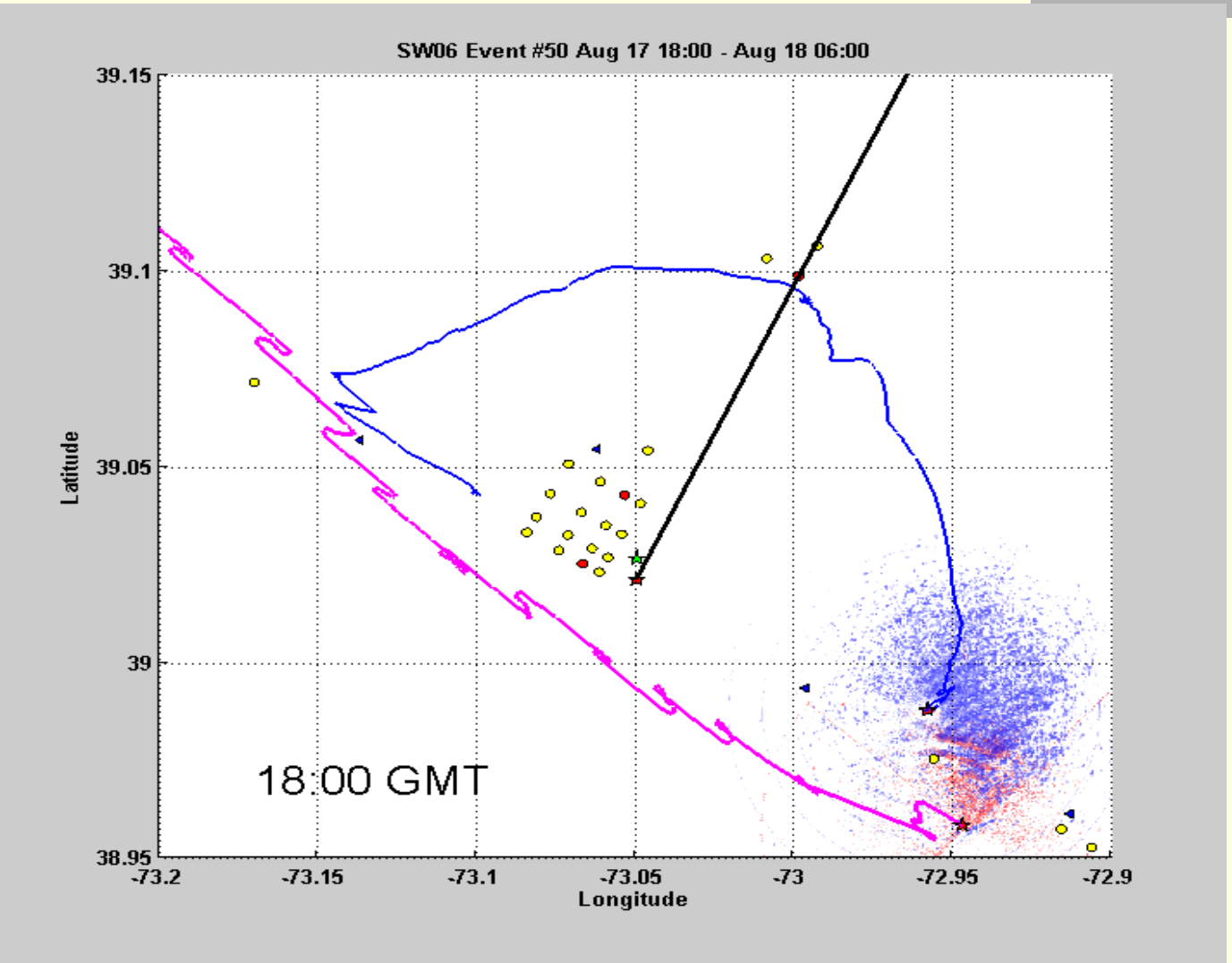
Experimental setting

- Internal wave event # 50: 18:00 (GMT) Aug 17 to 06:00 Aug 18, 2006
- Source: MSM
- Receiver: WHOI-VLA
- Range: about 20 km
- Water depth: about 80 m
- Acoustic signal:

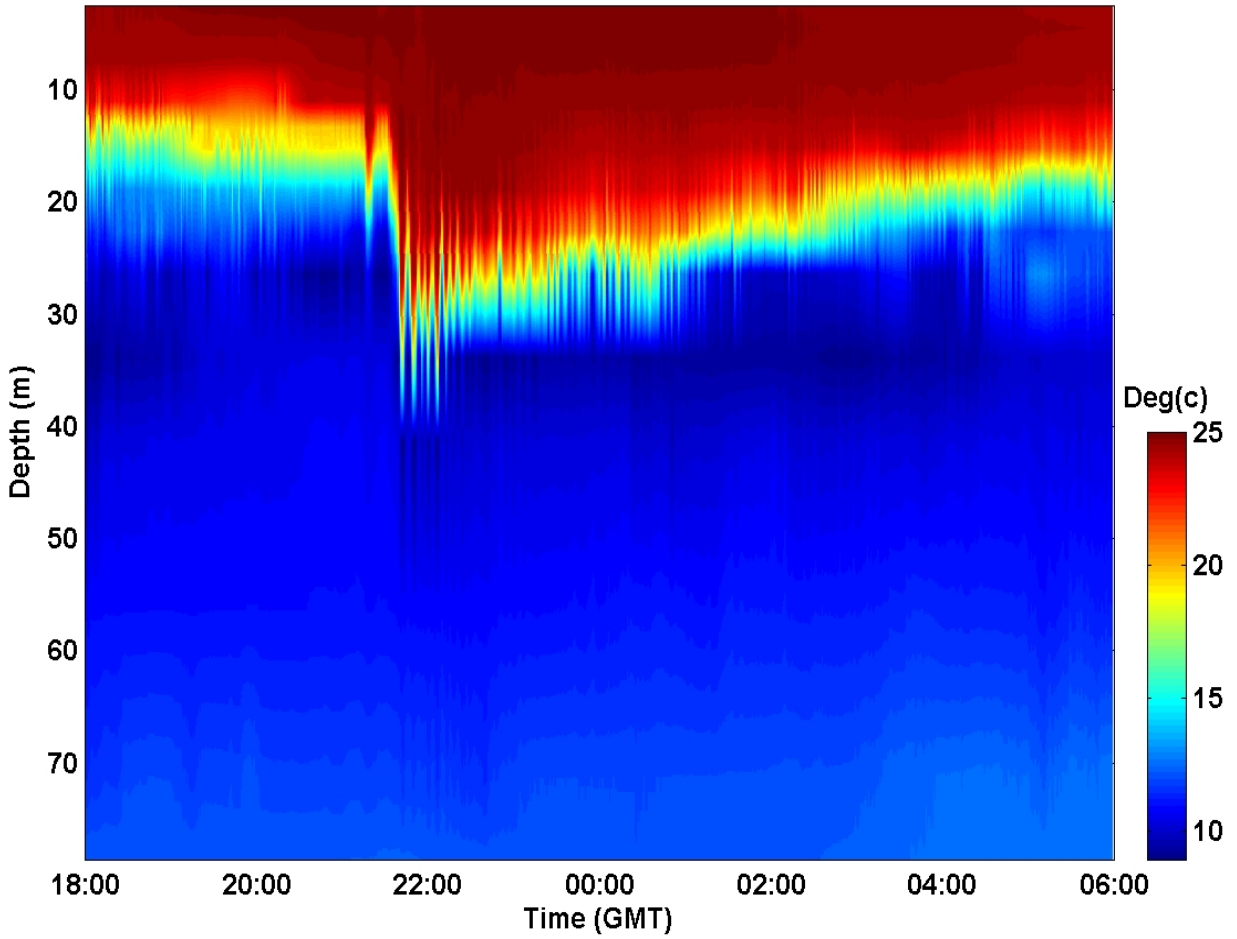
  ~90 s M-sequences (BPSK signals) at carrier frequencies 813 Hz and 1627 Hz
- Source level: 186 dB re 1 micro Pa at 1 m
- Trans. Schedule: Every 30 min



Radar image

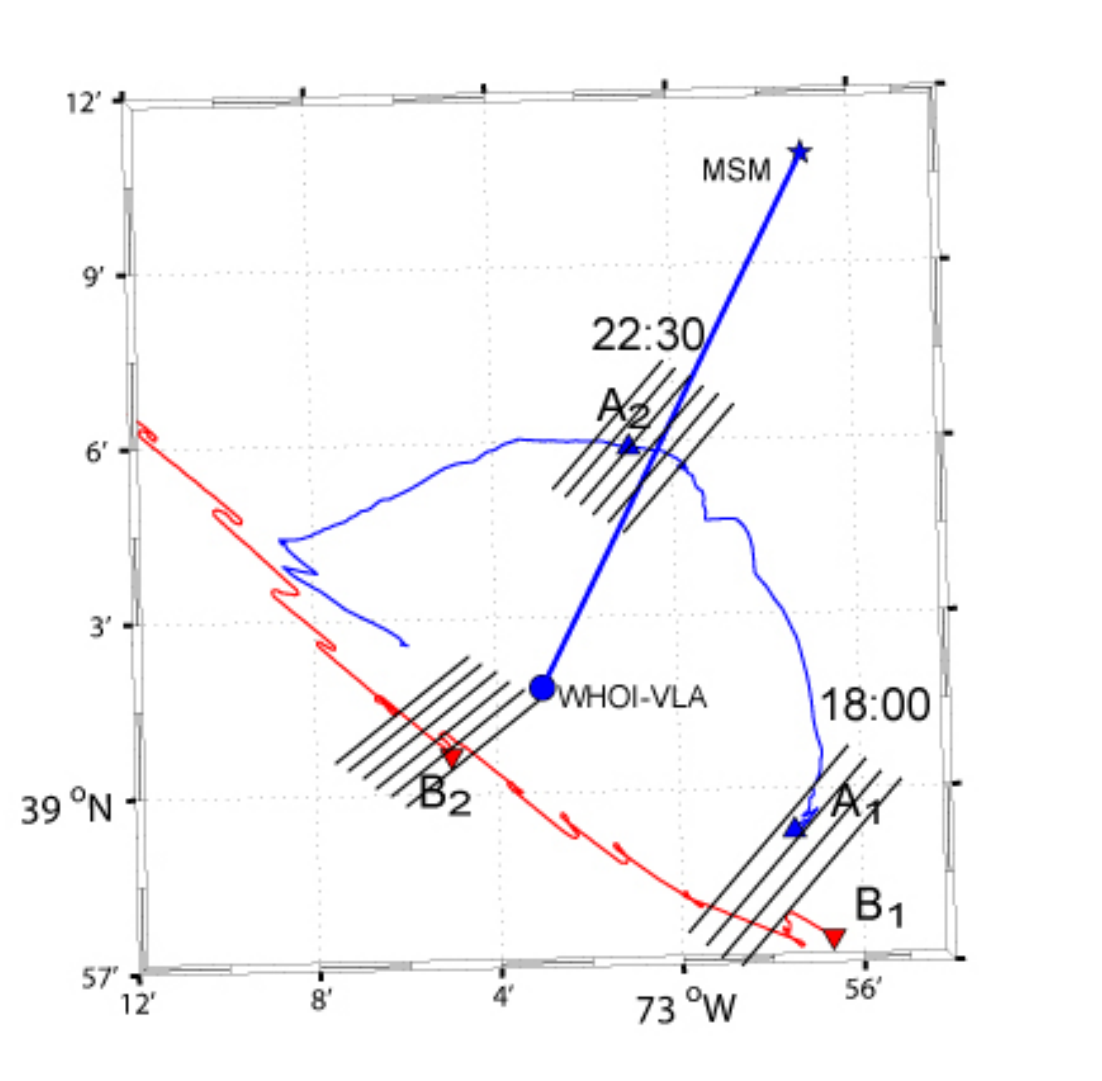

SW06 Event #50 Aug 17 18:00 - Aug 18 06:00
39.15
39.1
39.05
39
38.95
Latitude
-73.2
-73.15
-73.1
-73.05
-73
-72.95
-72.9
Longitude
18:00 GMT

Water temperature profiles



Two environmental conditions

- 18:00: Internal waves had not reached the acoustic track (about 10 km away from the acoustic track)
- 22:30: Internal waves overlap the acoustic track



Receiver structure

- At the source, the transmitted signal in the baseband form is:

$$x(t) = \sum_{n} x(n)\, g(t - nT)$$

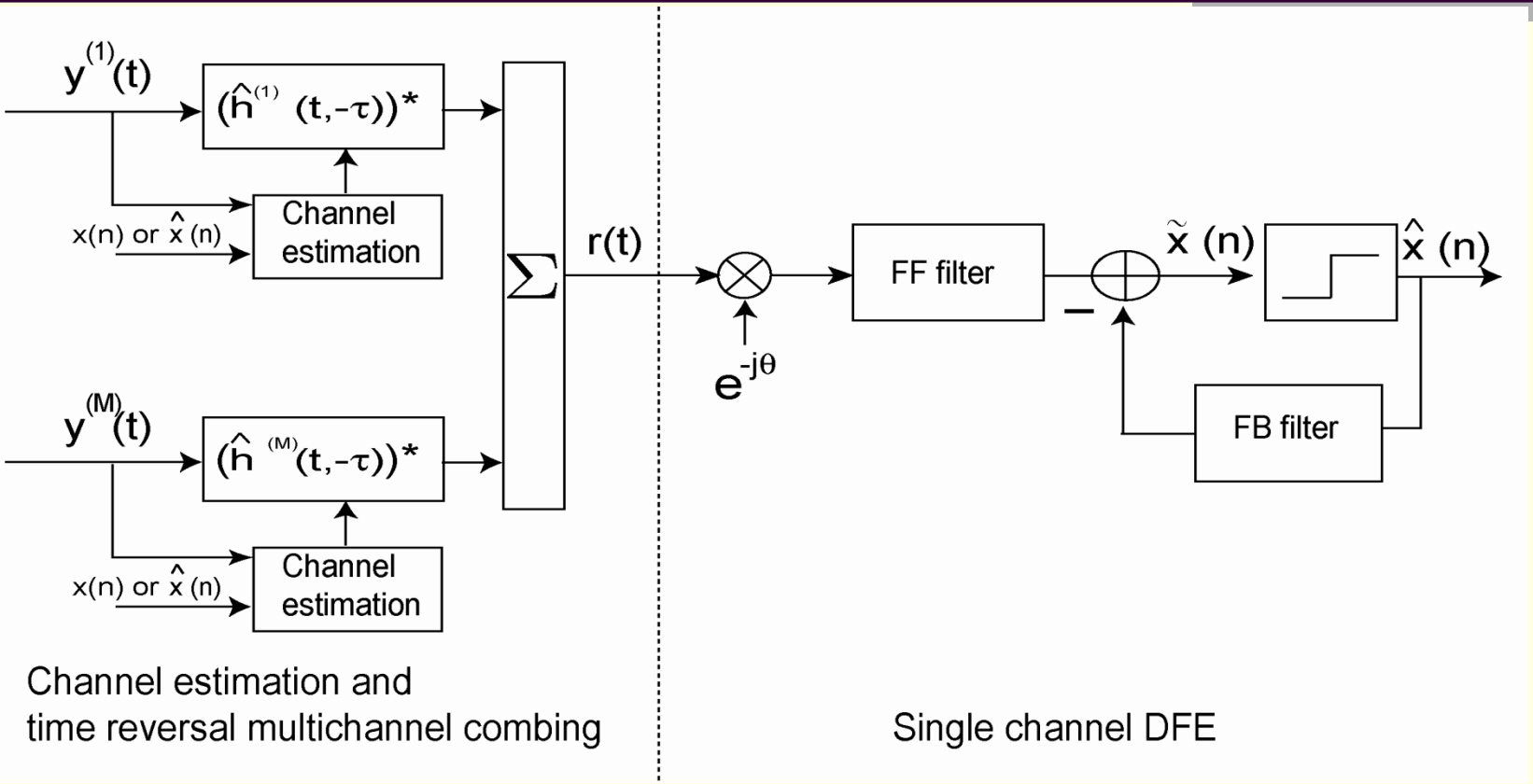
- The channel impulse response (CIR) function: dispersive (multipath), time varying

$$h^{(i)}(t, \tau)$$

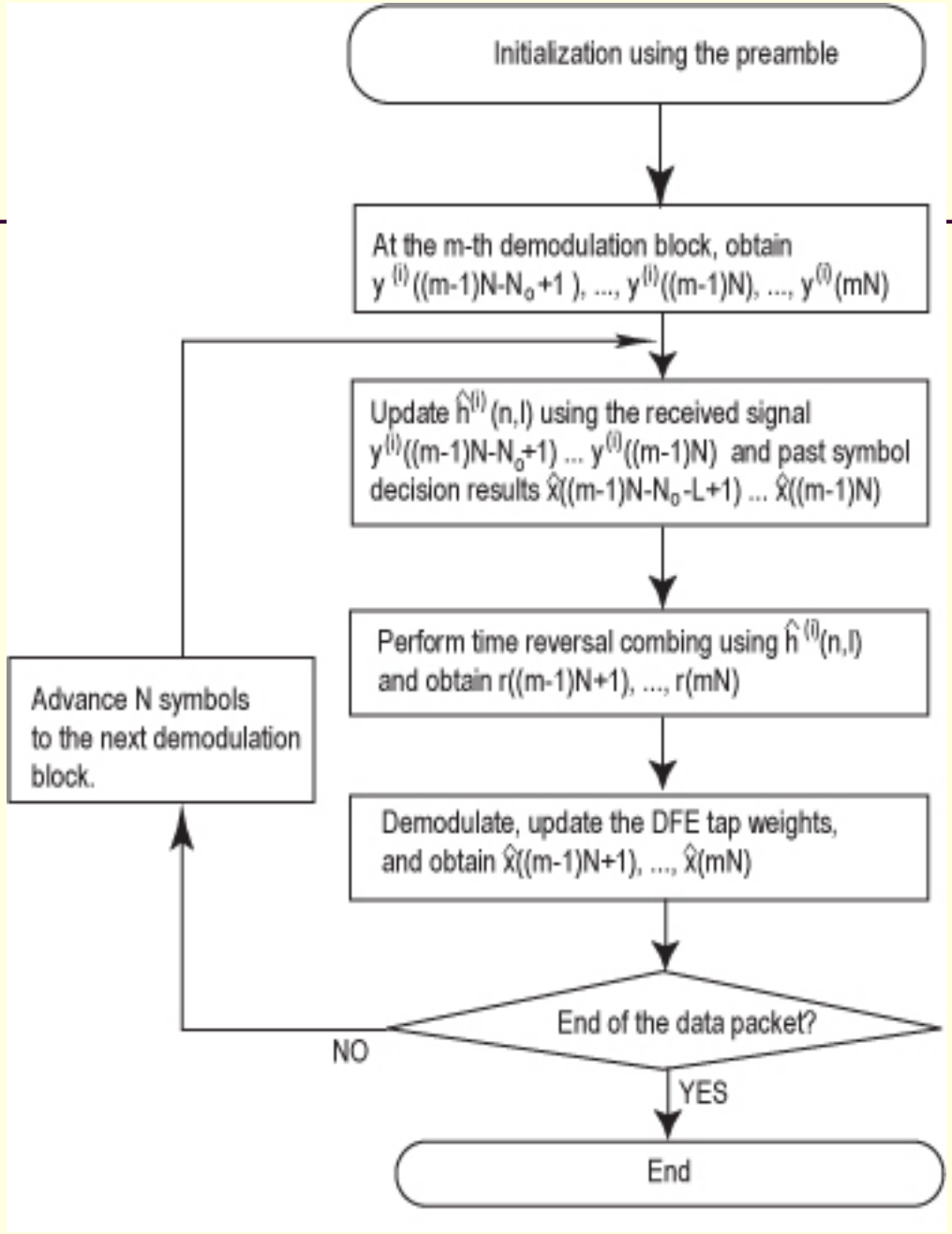
- At the i-th element of the receiver:

$$y^{(i)}(t) = x(t) * h^{(i)}(t, \tau) + v(t)$$

Receiver structure



- Frequent channel estimation
- Soft output signal-to-noise ratio (SNR) of the decision-feedback equalizer (DFE) is the performance metric


Initialization using the preamble
At the m-th demodulation block, obtain
$y^{(i)}((m-1)N-N_o+1), \ldots, y^{(i)}((m-1)N), \ldots, y^{(i)}(mN)$
Update $\hat{h}^{(i)}(n,l)$ using the received signal
$y^{(i)}((m-1)N-N_o+1) \ldots y^{(i)}((m-1)N)$ and past symbol decision results $\hat{x}((m-1)N-N_o-L+1) \ldots \hat{x}((m-1)N)$
Perform time reversal combing using $\hat{h}^{(i)}(n,l)$ and obtain $r((m-1)N+1), \ldots, r(mN)$
Demodulate, update the DFE tap weights, and obtain $\hat{x}((m-1)N+1), \ldots, \hat{x}(mN)$
End of the data packet?
NO
YES
Advance N symbols to the next demodulation block.
End

- Receiver design:
  - Presented in A. Song, M. Badiey, H.-C. Song, W. S. Hodgkiss, M. B. Porter and the KauaiEx group, JASA2008, but without Doppler correction
  - Can achieve robust high data rate communications under dynamic ocean environments
- Comparison with other time reversal/DFE methods (Edelmann, *et al.*, JOE2005, T. C. Yang, JOE2005, H.-C. Song, *et al.*, JASA2006)
  - Frequent channel estimation

Receiver parameters

- Key parameter: channel update internal
- Choose channel update interval:
  - Depending on the fluctuating rate of the channel: Fast fluctuating channels require small channel update interval

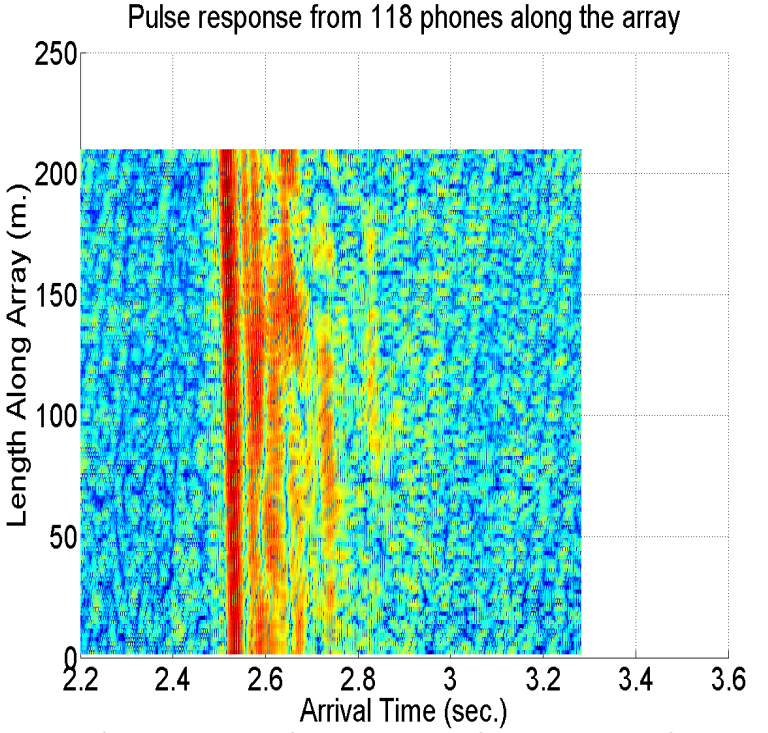
CIR function: 813 Hz

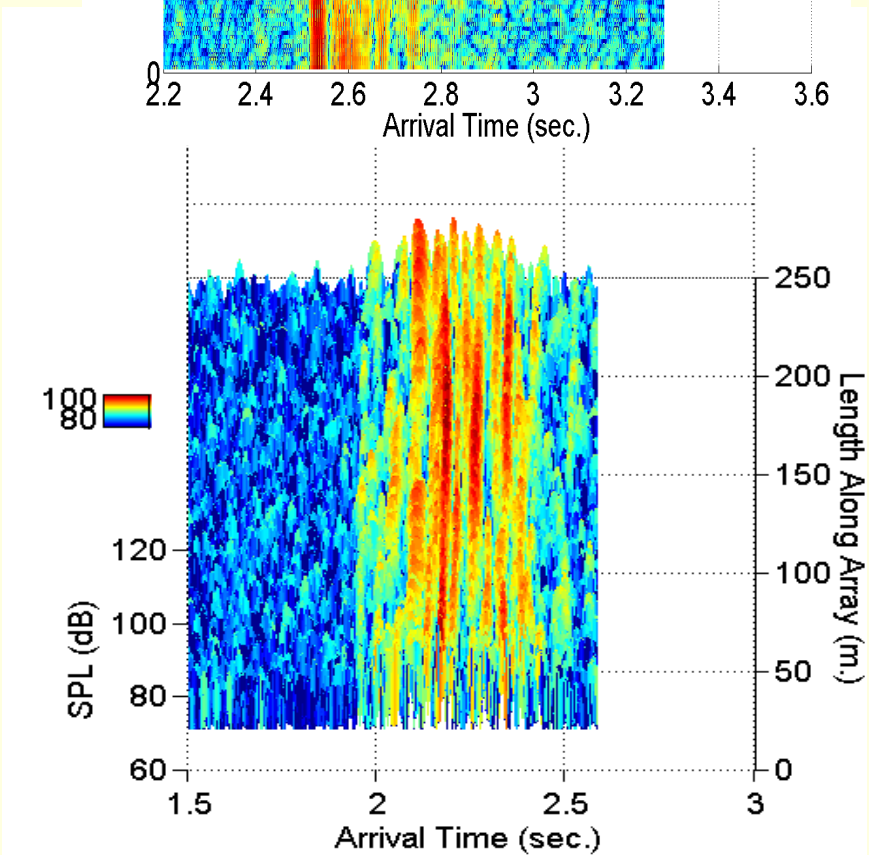
No internal waves(1800)

With internal waves(2230)

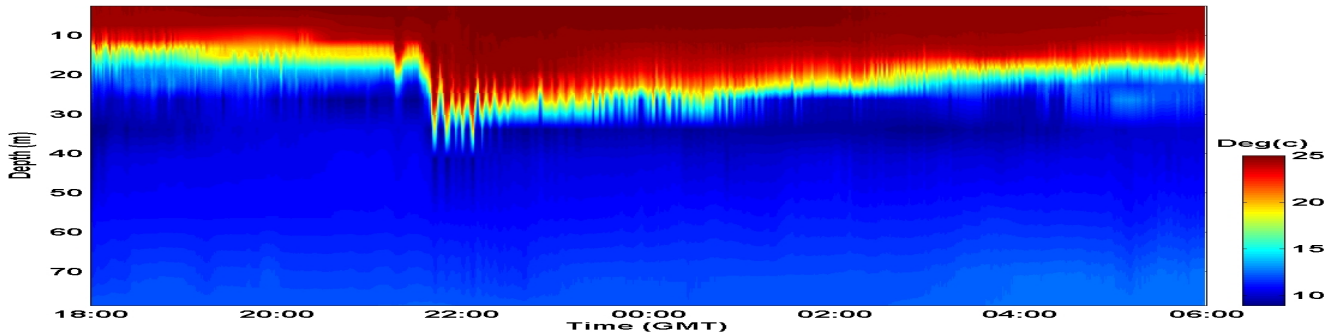
10 km

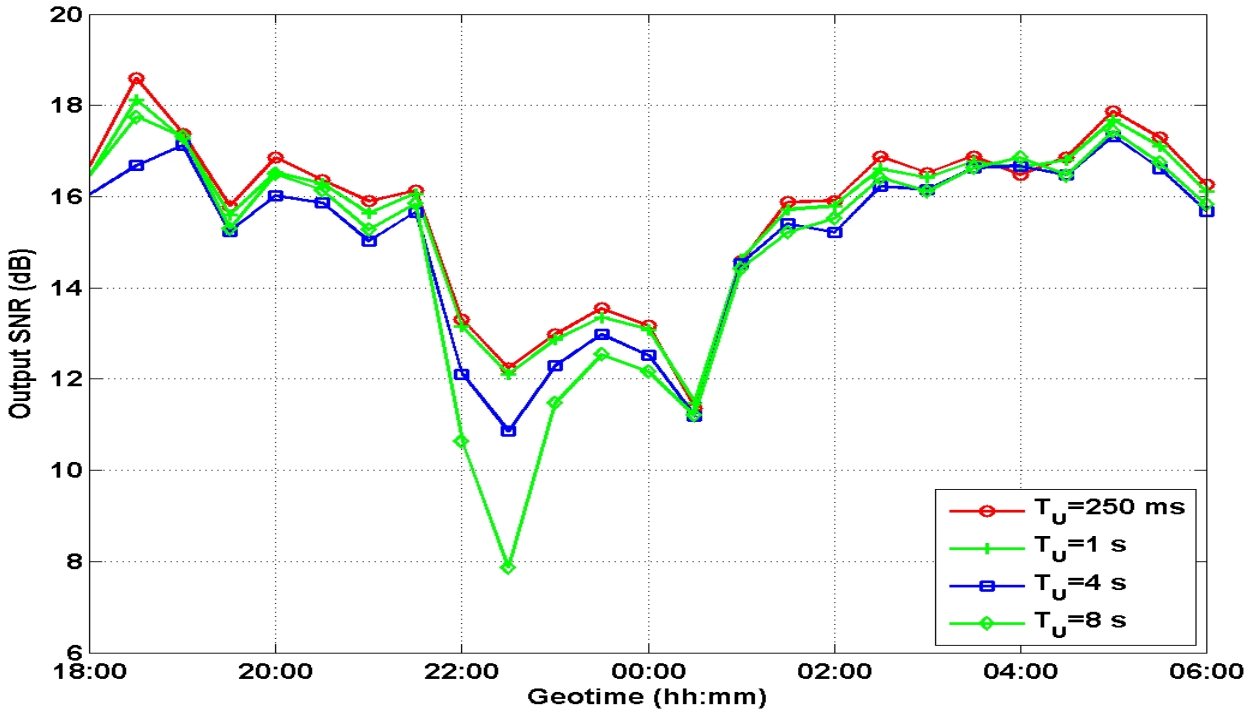
80 km


Pulse response from 118 phones along the array
Length Along Array (m.)
250
200
150
100
50
0
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
Arrival Time (sec.)


100
80
SPL (dB)
120
100
80
60
1.5
2
2.5
3
Arrival Time (sec.)
250
200
150
100
50
0
Length Along Array (m.)

Channel update interval for 813 Hz





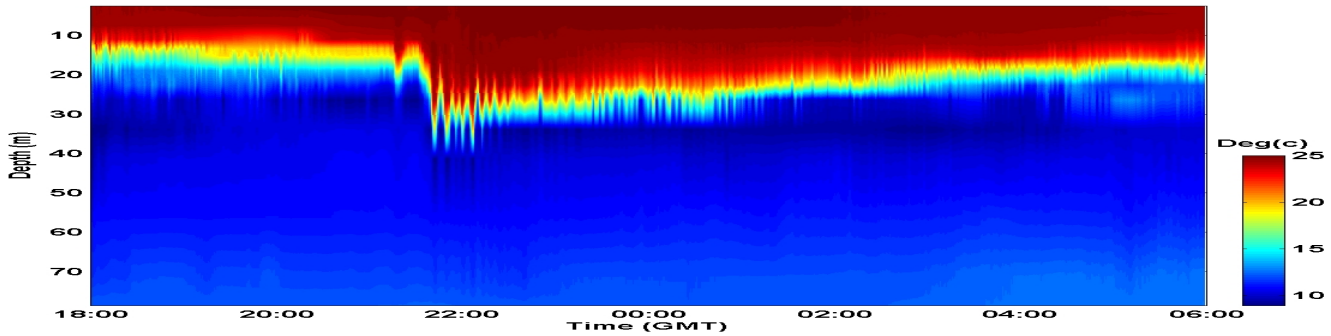
CIR function: 1627 Hz

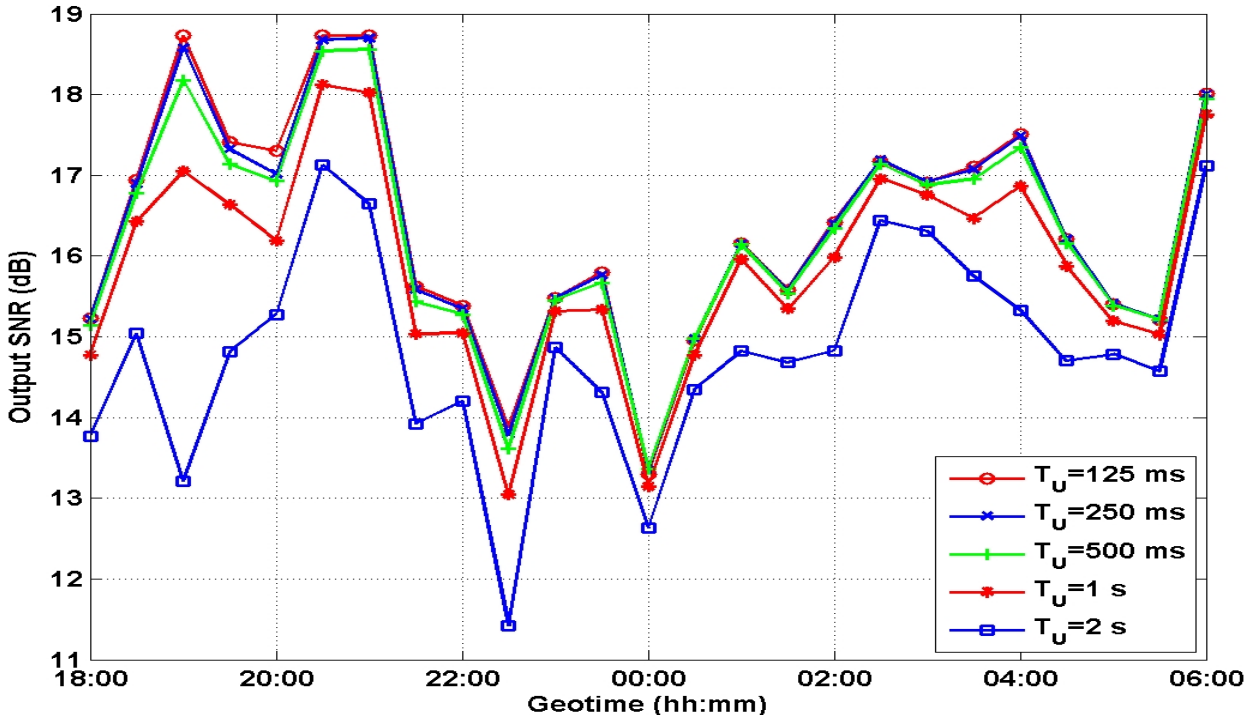
No internal waves(1800)

With internal waves(2230)

cir_1600hz

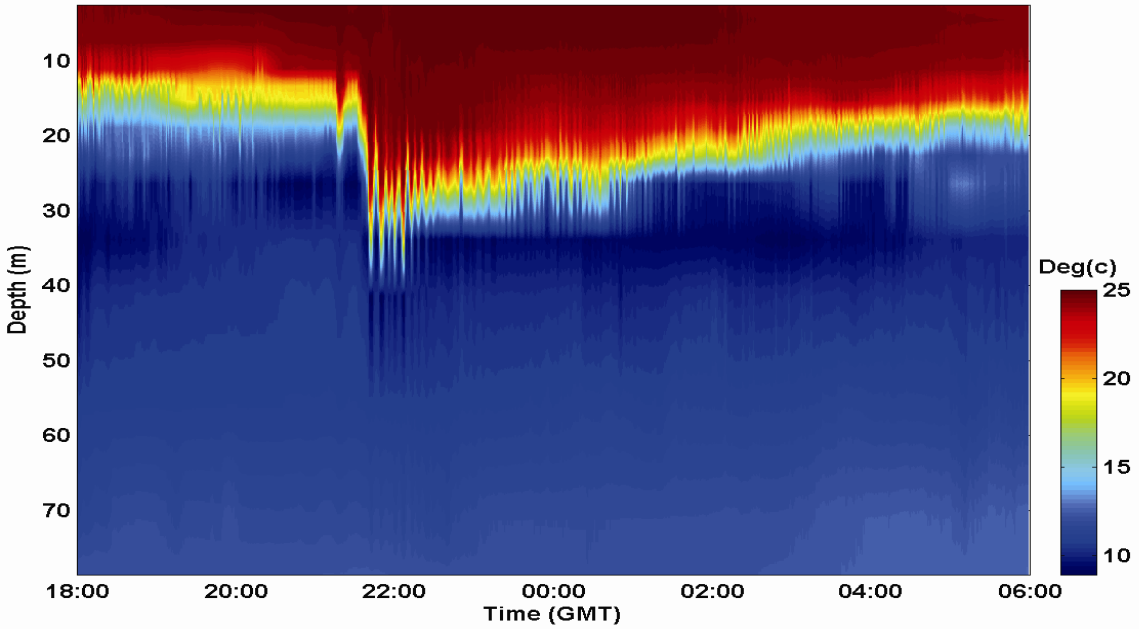
Channel update interval for 1627 Hz



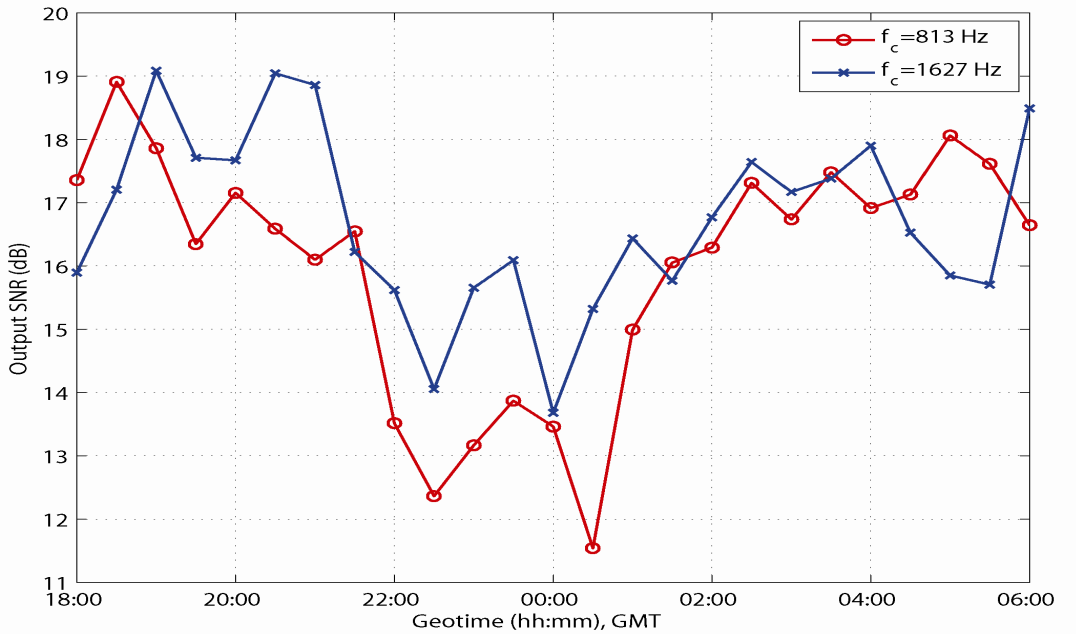


- For 800 Hz carrier frequency:
  - Without internal waves, channel estimation can be performed every 8 s without loss of performance
  - With internal waves, channel estimation needs to be performed every 1 s
- For 1627 Hz carrier frequency
  - Channel estimation needs to be performed every 250 ms regardless the internal wave condition

- Channel update interval: 250 ms
- Frequency dependency



(a) Temperature profiles recorded at the WHOI-VLA



(b) The output SNR of the communications receiver

Summary and future work

- Concurrent acoustic measurements and environmental observations
- Significant internal wave effects on coherent underwater acoustic communications during a 12 h period at 813 Hz and 1627 Hz
- Receiver parameters can be depended on the environment condition and the carrier frequency
- Frequency dependency of the internal wave effects

- Acoustic modeling will be performed to explain the internal wave effects