A normal mode back-propagation approach for broadband sound source localization and the effects of water column variability

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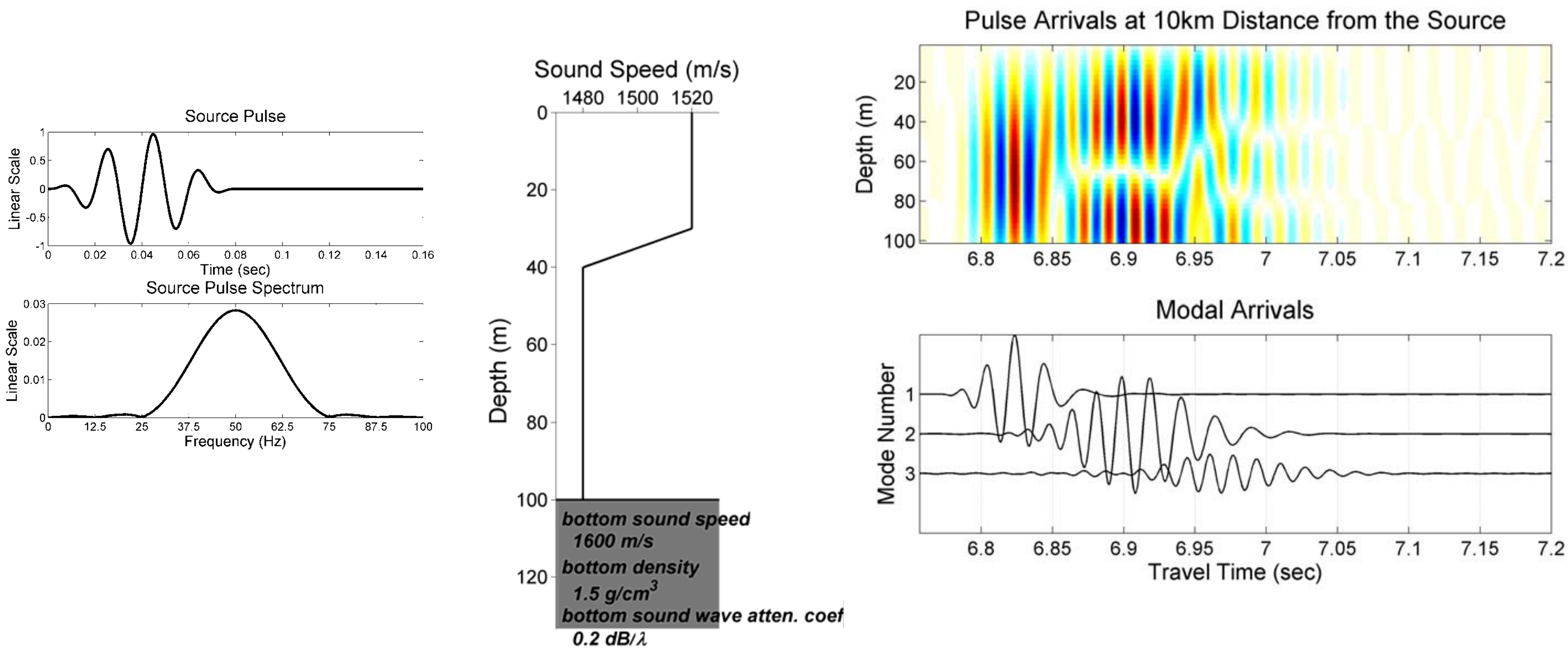
Outline

- An acoustic normal mode back-propagation approach for low-frequency broadband sound source localization in a shallow-water ocean
- Application to the New Jersey Shallow Water 2006 (SW06) experiment data
- Effects of water-column variability on source range estimates

I. Introduction - Acoustic normal mode theory

- Acoustic normal modes are orthogonal bases to decompose a sound pressure field, and can describe the spatial field coherence.

Shallow-water low-frequency broadband sound propagation simulation



Sound pulse propagation in a shallow-water mixed-layer waveguide model
Source at 25m depth (fc = 50Hz, BW = 50Hz)

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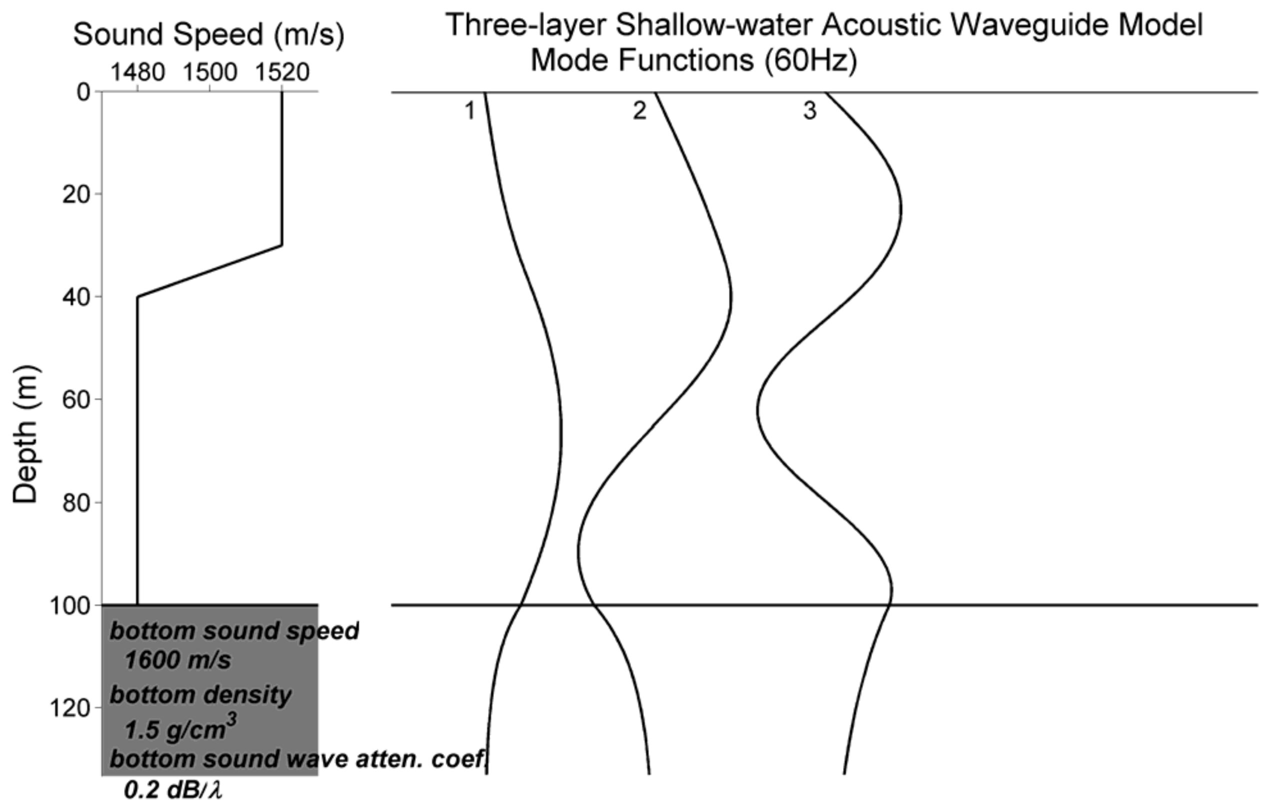
Modes are frequency-dependent!!



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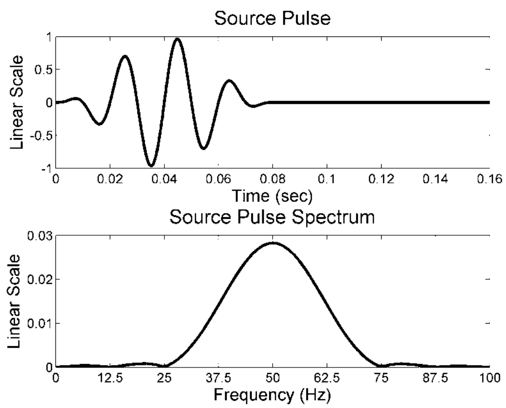

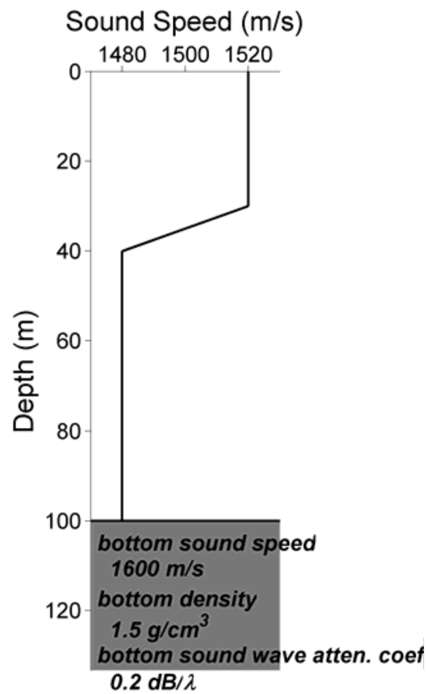

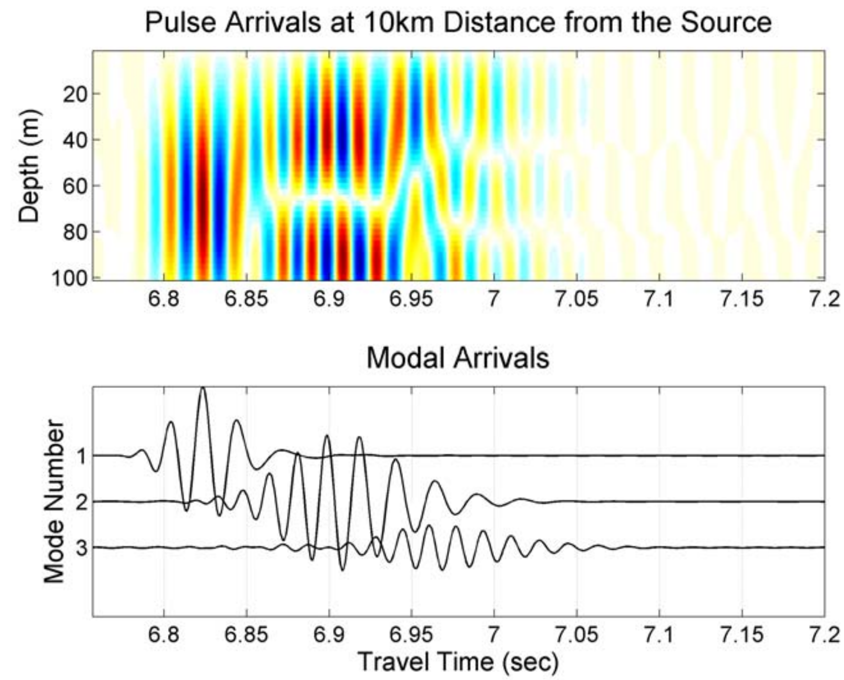

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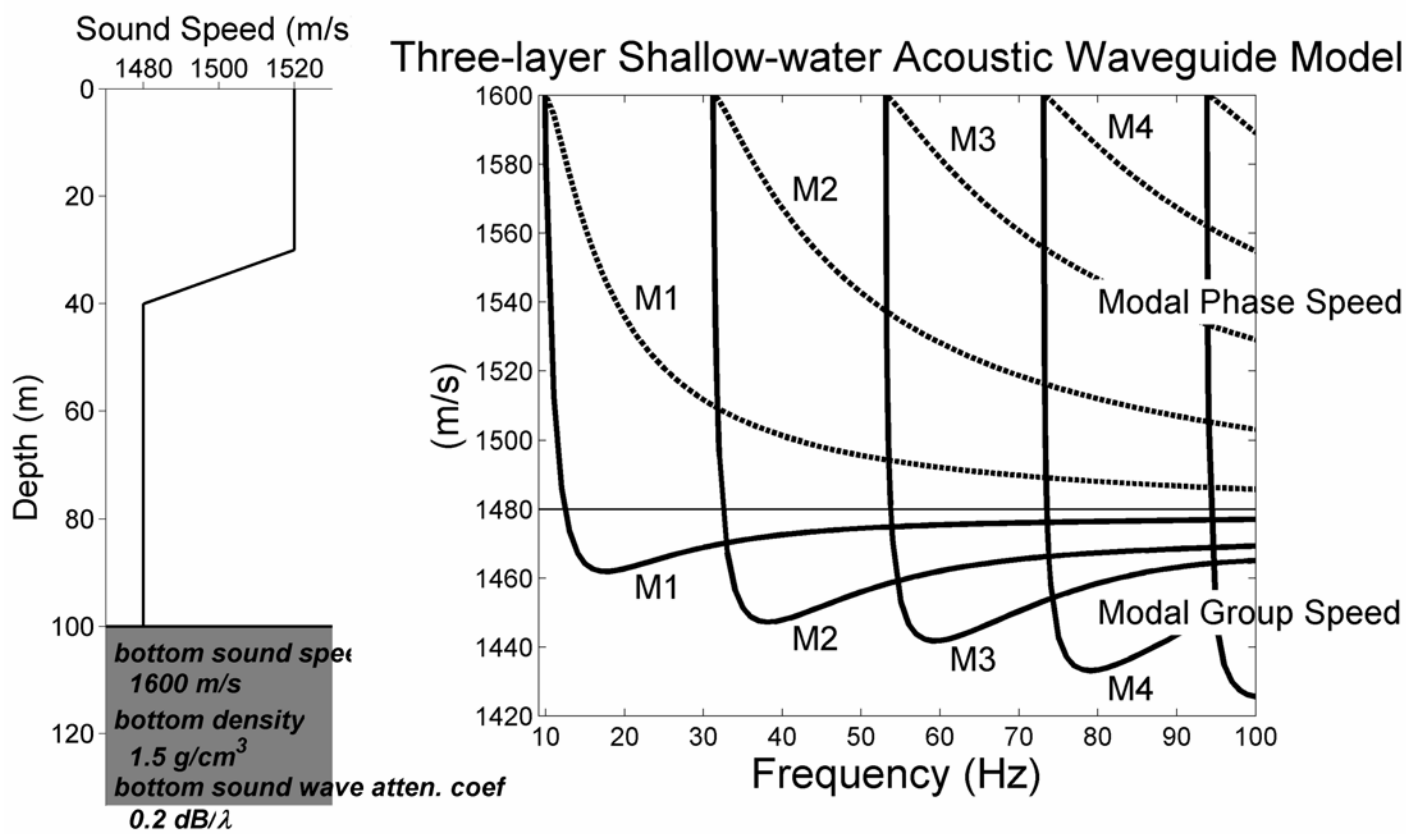
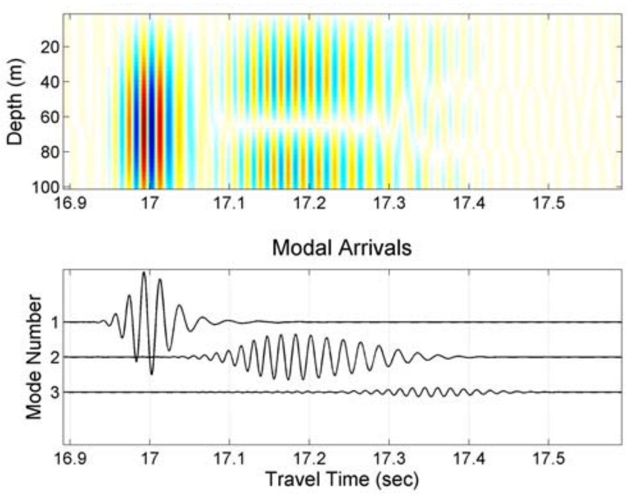


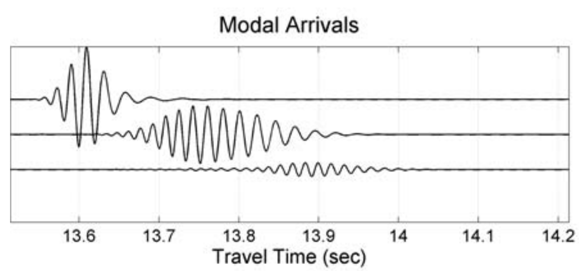
II. Low-frequency broadband source localization by back-propagating acoustic normal modes

- This method is theoretically straight forward — utilizing modal dispersion to localize a sound source.
- The first step is to implement a ***vertical mode filter*** to obtain individual modal arrivals. Then, back propagate the modal arrivals with their own speeds, which are derived from the ***waveguide parameters***. The ***source range estimate*** is where the back-propagated modes line up with each other.

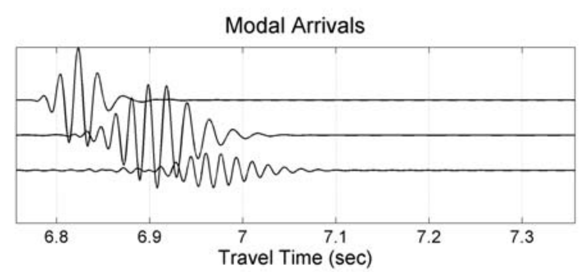
received signal



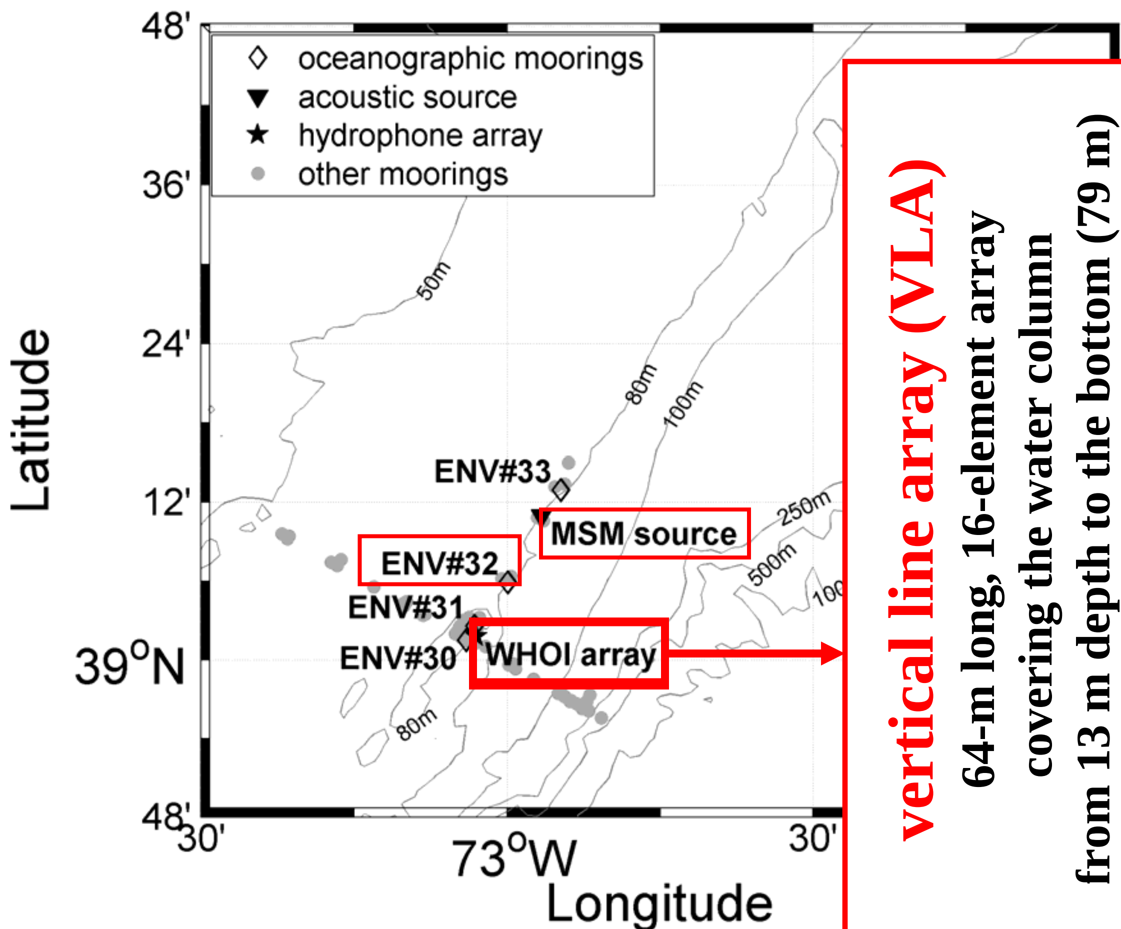
back propagate modes for 5 km



back propagate modes for 15 km

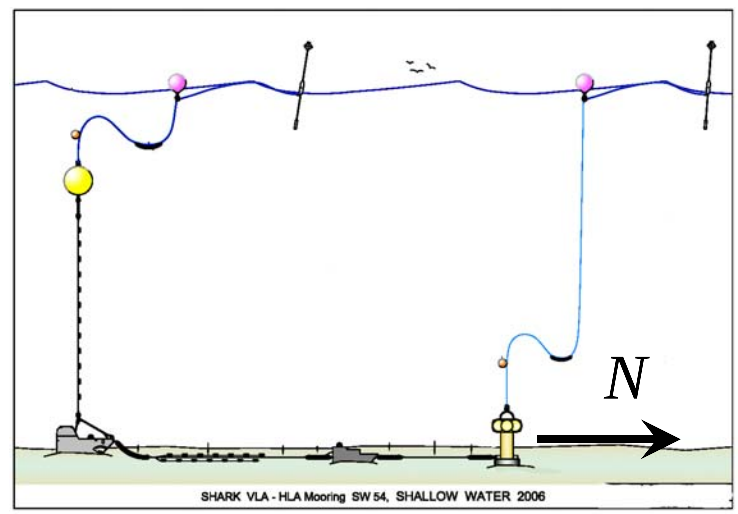


III. Application to the New Jersey Shallow Water 2006 (SW06) experiment data



vertical line array (VLA)

64-m long, 16-element array covering the water column from 13 m depth to the bottom (79 m)



465-m long, 32-element array

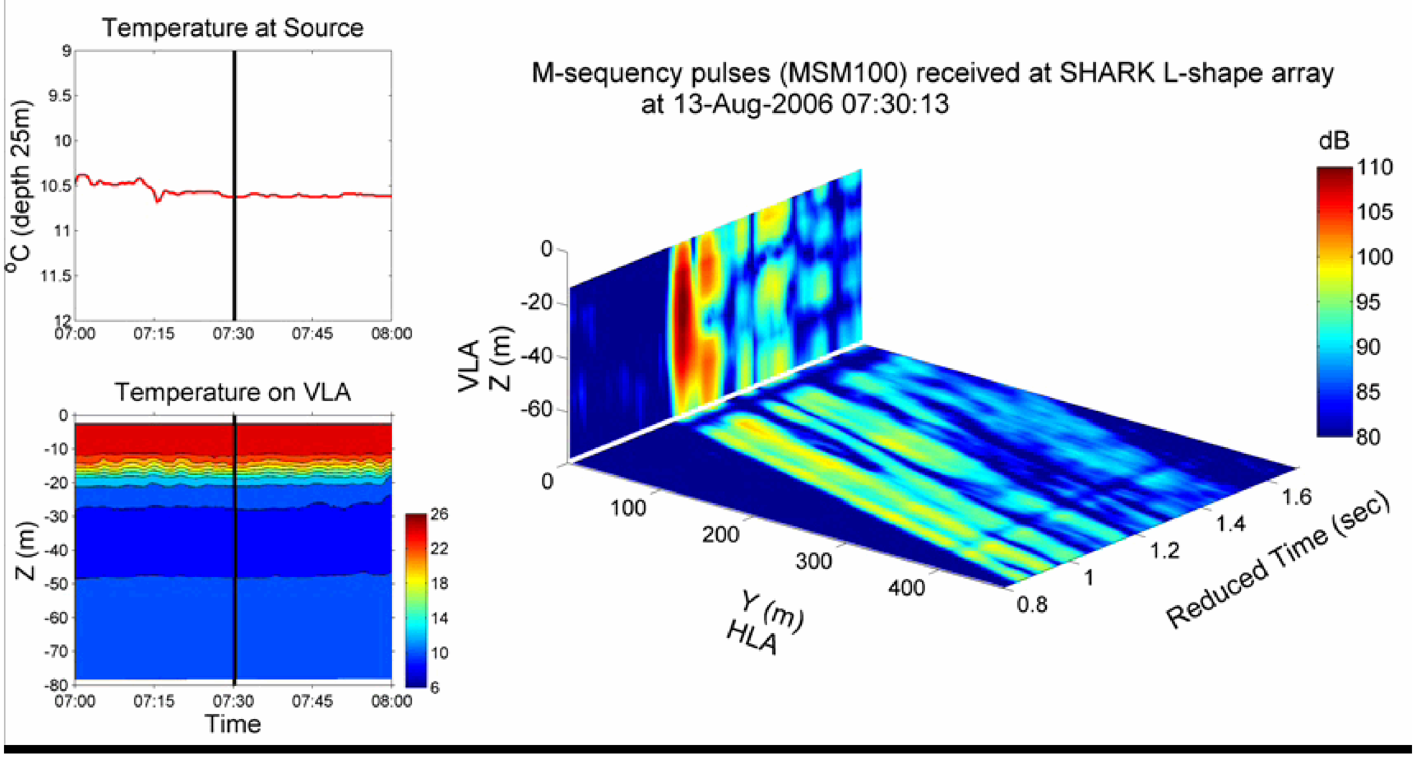
horizontal line array (HLA)

III. Application to the New Jersey Shallow Water 2006 (SW06) experiment data — U. Miami sound source (MSM) localization

• MSM source was ***19.74 km*** northeast (25.73° due north) away from the WHOI VLA.

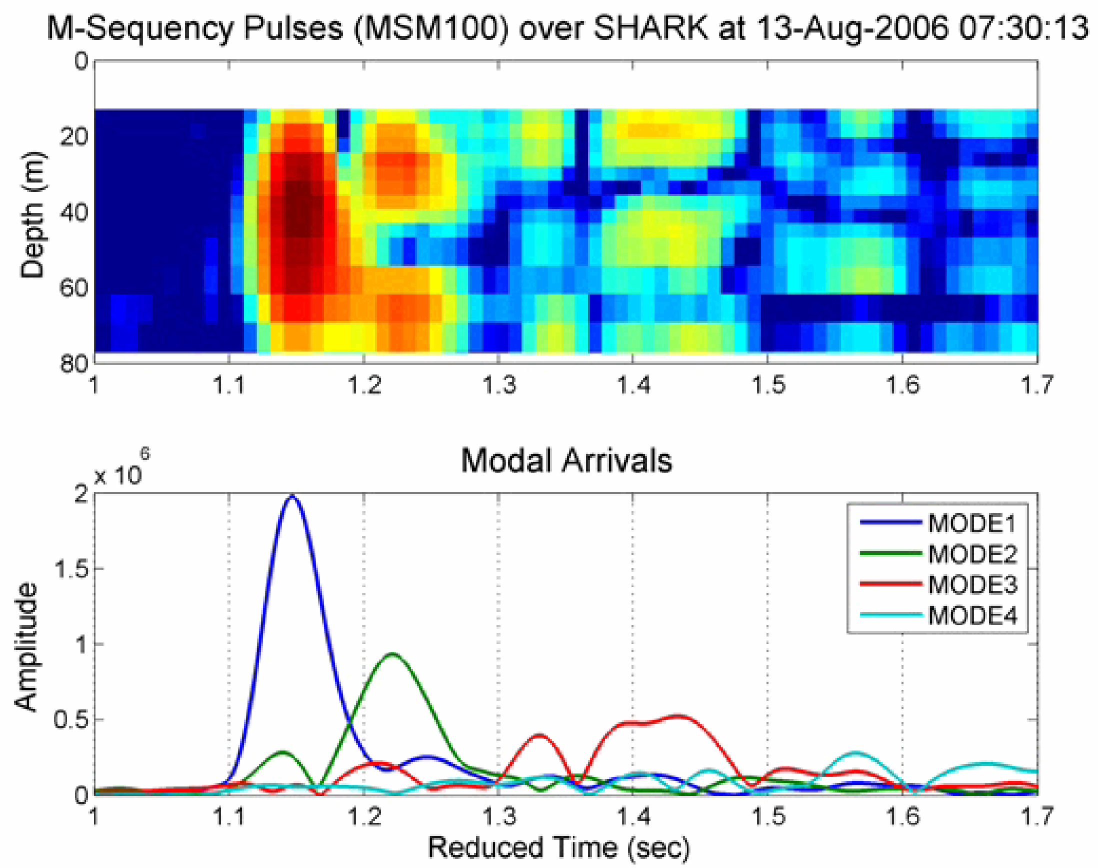
• M-sequence phase encoded source signals. 5 different frequency bands.

• **100 Hz signal (25 Hz bandwidth) is considered here**. Every ½ hour, a 1.5-min long transmission, which contained 36 identical M-sequence phase encoded signals, is emitted. Complex pulses are obtained from matched filter (pulse compression).



III. Application to the New Jersey Shallow Water 2006 (SW06) experiment data — U. Miami sound source (MSM) localization

- ***Least squares mode filtering the VLA data***
- Mode functions are derived ***full water-column sound speed profile*** (SSP) measurements[1] and a bottom geoacoustic model from a previous study[2].



[1] Y.-T. Lin, A.E. Newhall, T.F. Duda, P.F.J. Lermusiaux and P.J. Haley Jr., "Statistical Merging of Data Sources to Estimate Full Water-Column Sound Speed in the New Jersey Shallow Water 2006 Experiment," submitted to IEEE JOE (2009).

[2] Y.-M. Jiang, N. R. Chapman and M. Badiey, "Quantifying the uncertainty of geoacoustic parameter estimates for the New Jersey self by inverting air gun data," J. Acoustic. Soc. Am. **121**, 1879-1894 (2007).

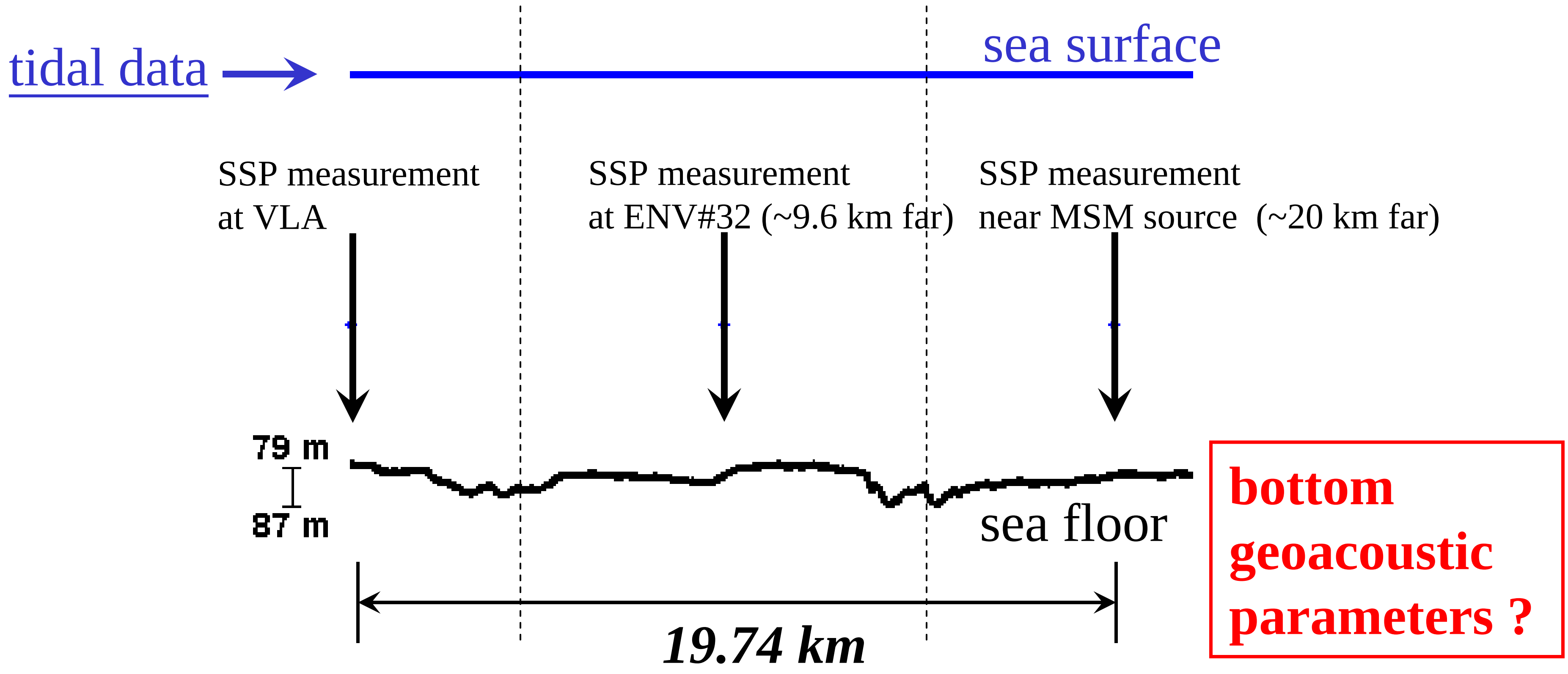
III. Application to the New Jersey Shallow Water 2006 (SW06) experiment data — U. Miami sound source (MSM) localization

- ***Normal mode back-propagation***

— Assumptions: 2-D in-plane propagation and no mode-coupling.

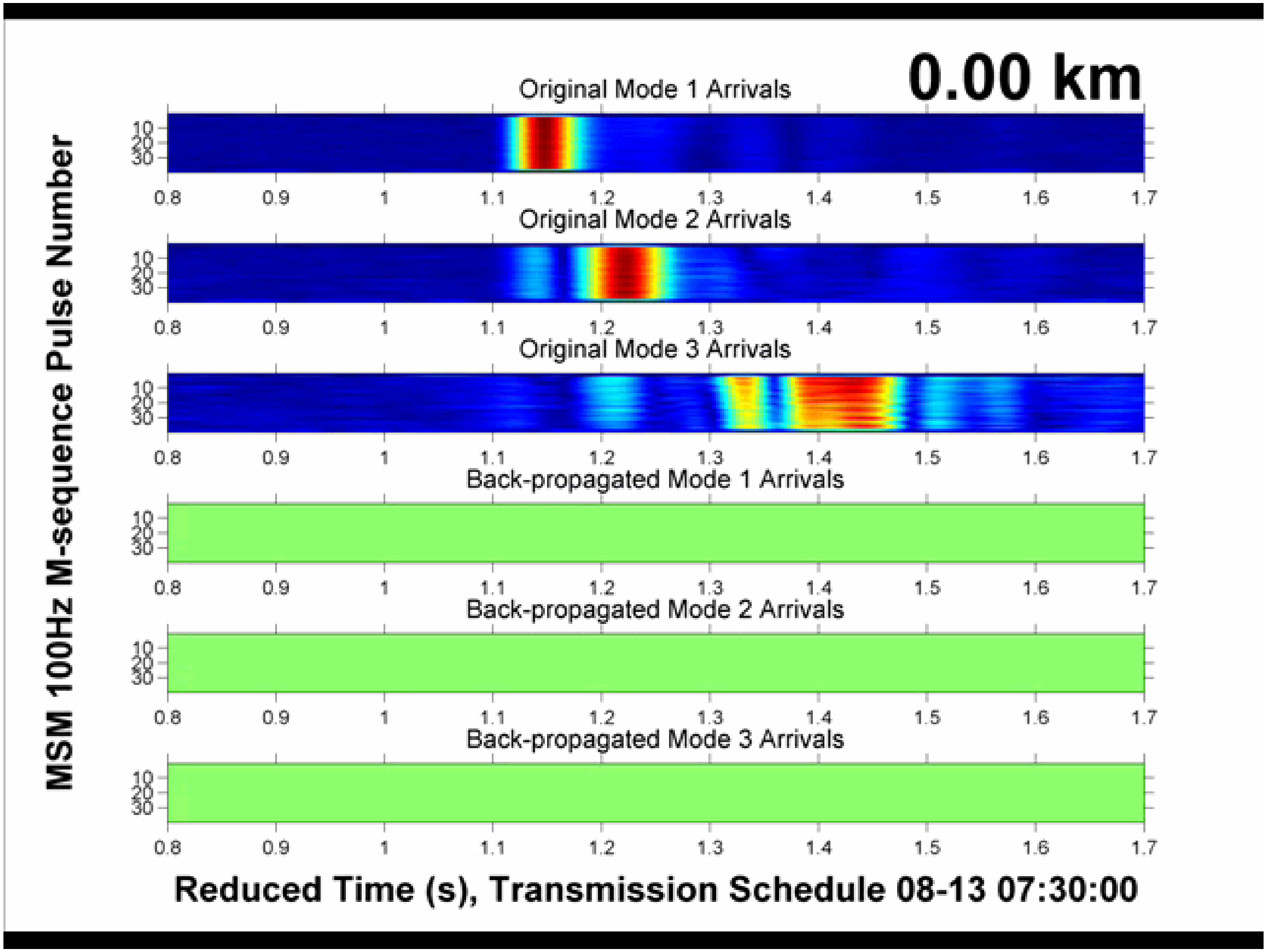
— Environmental reconstruction: 3 range-independent water-column SSP patches, accurate bathymetry and tidal data.

— Normal modes are calculated every 150 m and back-propagated in a 25-m interval.



III. Application to the New Jersey Shallow Water 2006 (SW06) experiment data — U. Miami sound source (MSM) localization

• ***An example of normal mode back-propagation***



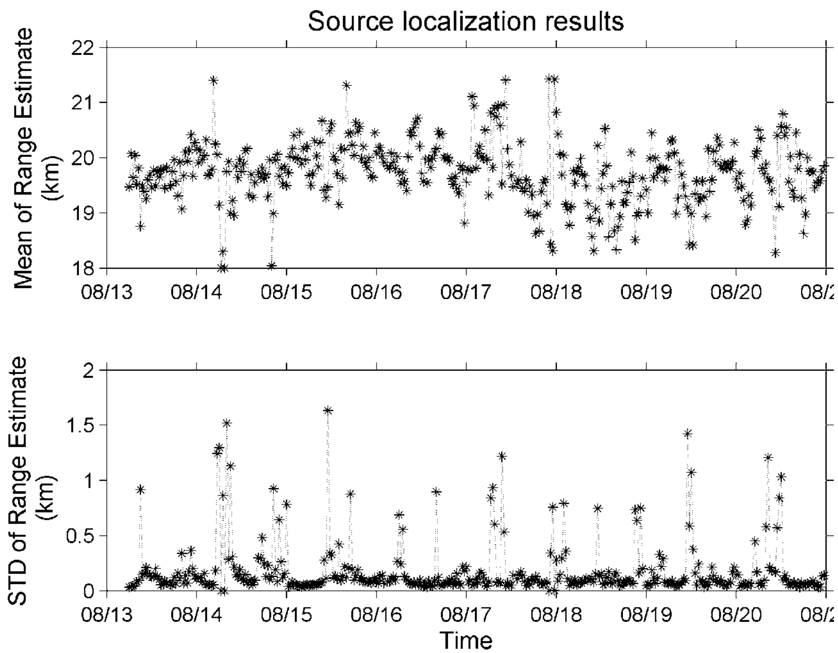
III. Application to the New Jersey Shallow Water 2006 (SW06) experiment data — U. Miami sound source (MSM) localization

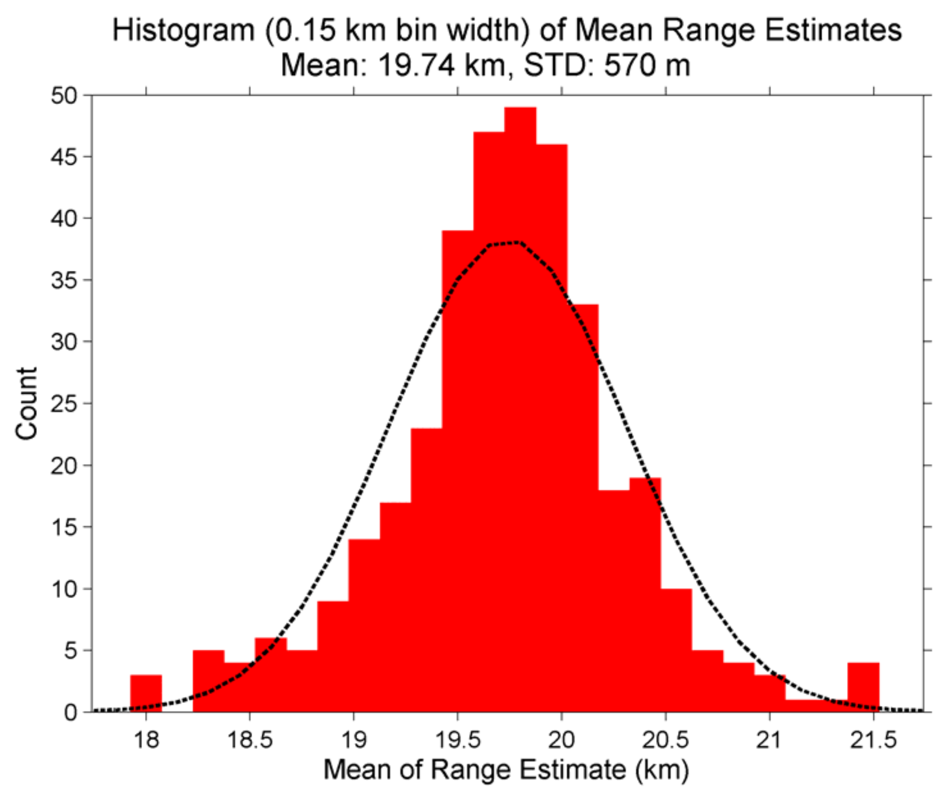
• ***Source localization results***

— 8 days data are processed. Every ½ hour, 35 M-sequence pulses are analyzed and 35 range estimates are obtained. The average value and standard deviation (STD) of these estimates are plotted.

— The total mean range estimate is ***19.74 km***, the same as the true distance, along with STD ***570 m***.

— Bottom geoacoustic model : homogeneous bottom with sound speed ***1,700 m/s*** and density ***1.8 g/cm³***.



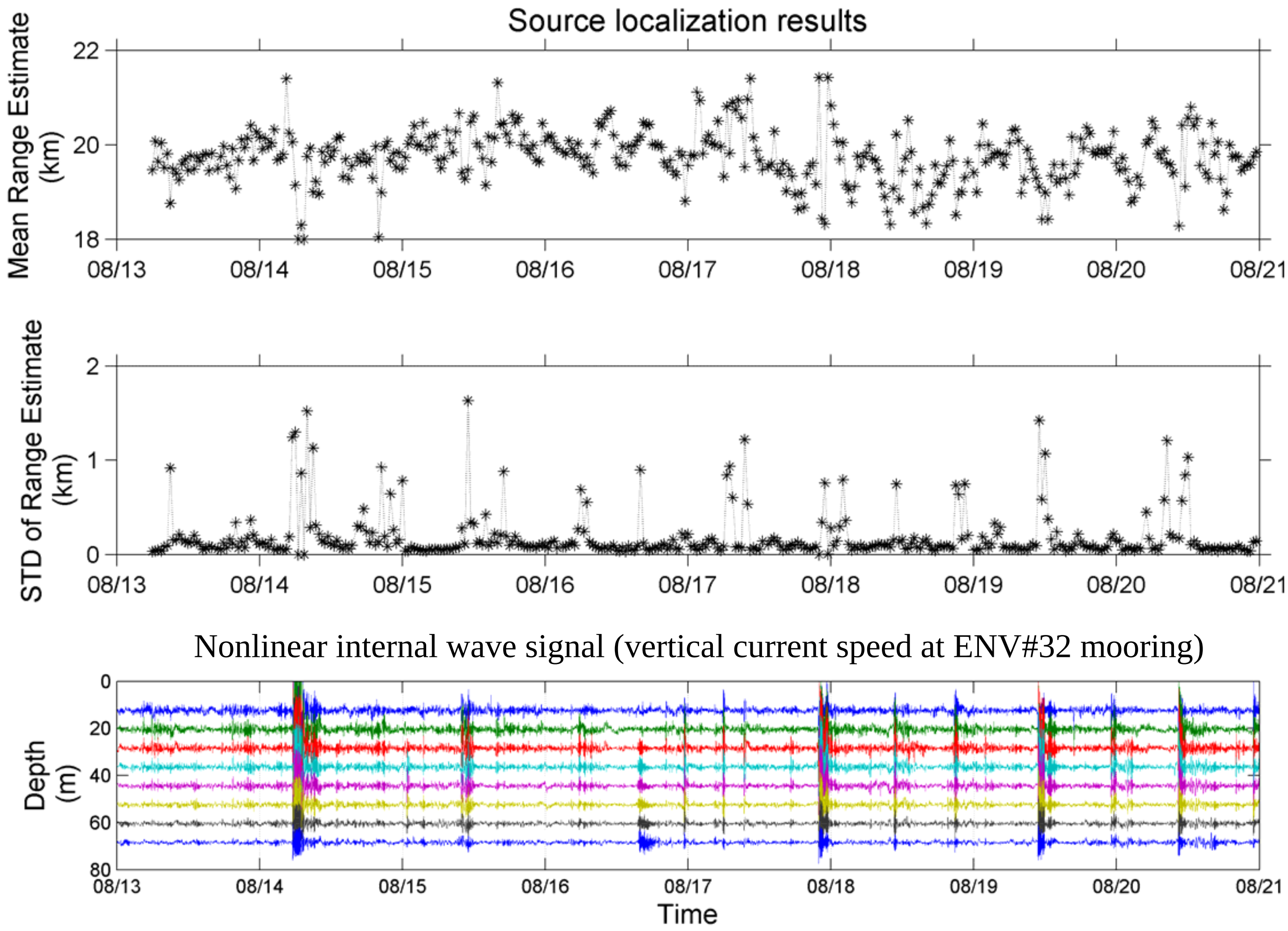


IV. Effects of water-column variability

— U. Miami sound source (MSM) localization

- ***Nonlinear internal waves***

  — The peaks of the standard deviations correlate with nonlinear internal wave events exactly.



IV. Effects of water-column variability

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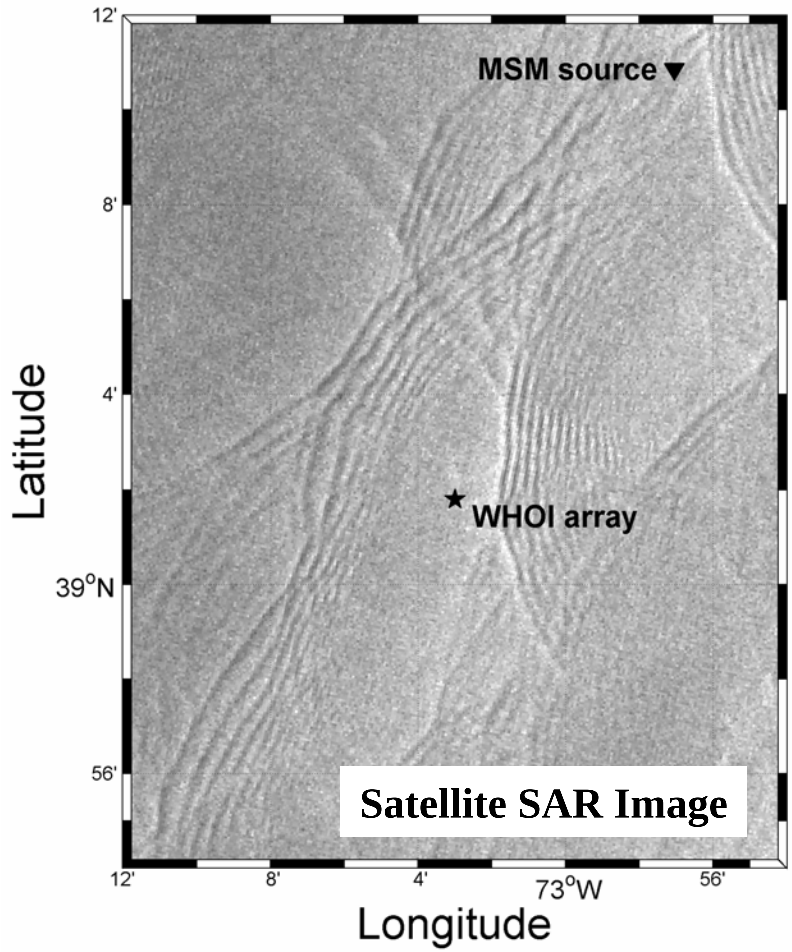
• Nonlinear internal waves distort the coherent structure of the sound field due to ***mode coupling*** and ***3-D sound propagation effects***[1,2] (acoustic ducting, radiation, refraction and shadowing).



2pAO8 (3:05) Acoustic ducting, refracting, and shadowing by curved nonlinear internal waves in shallow water, J.F. Lynch, Y.-T. Lin, T.F. Duda, A.E. Newhall and G. Gawarkiewicz

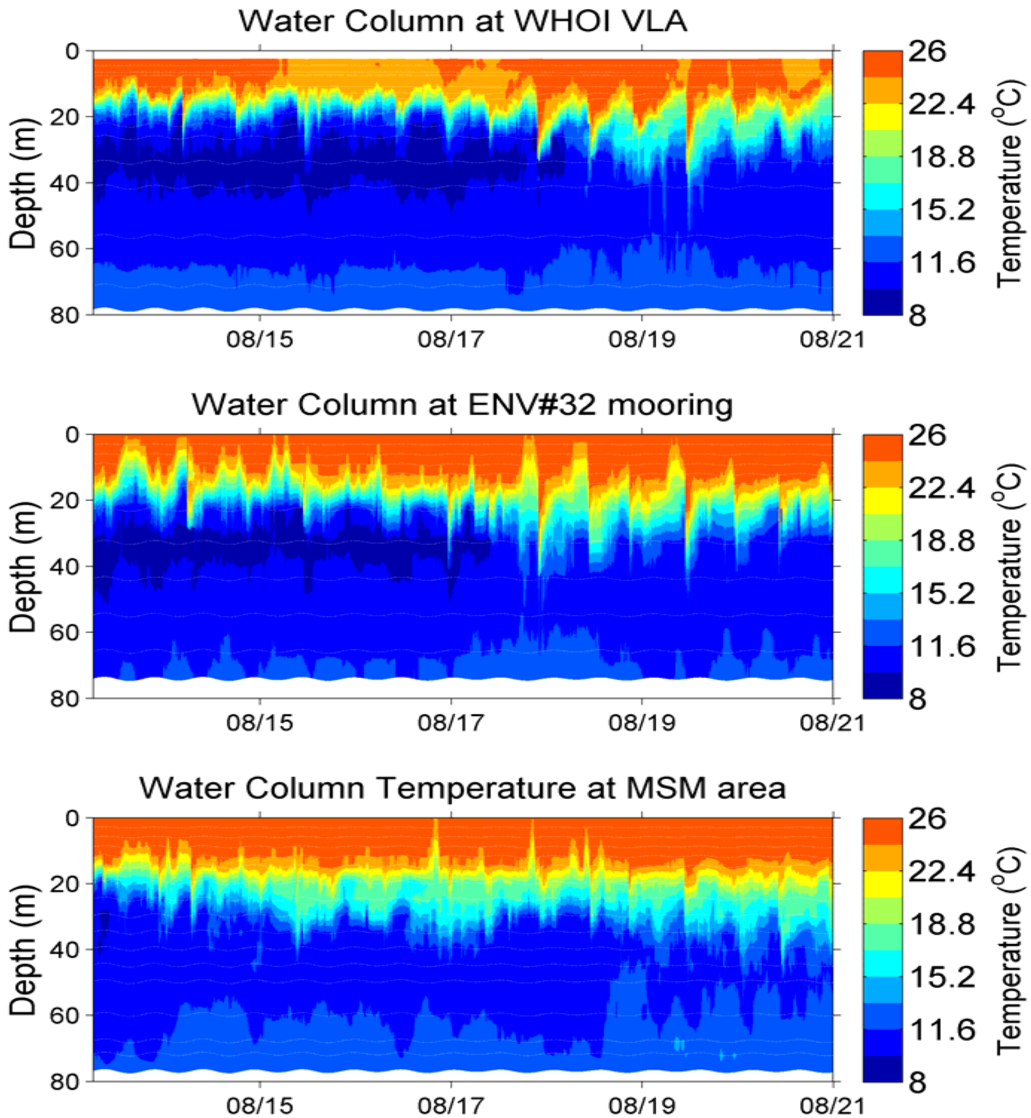
1 J.F. Lynch, Y.-T. Lin, T.F. Duda and A.E. Newhall, "Acoustic Ducting, Shadowing, Refraction and Dispersion by Curved Non-Linear Internal Waves in Shallow Water," submitted to IEEE JOE (2009)

2 Y.-T. Lin, T.F. Duda and J.F. Lynch, "Acoustic mode radiation from the termination of a truncated nonlinear internal gravity wave duct in a shallow ocean area," submitted to JASA (2009)

IV. Effects of water-column variability

— U. Miami sound source (MSM) localization

- Mesoscale variability
  - — SSP measurements separated by ~10 km from each other.
  - — Spatial Nyquist sampling rate of the SSP measurements is 20 km.
  - — The SSP measurements can not resolve water-column variability that has wavelength less than 20 km.

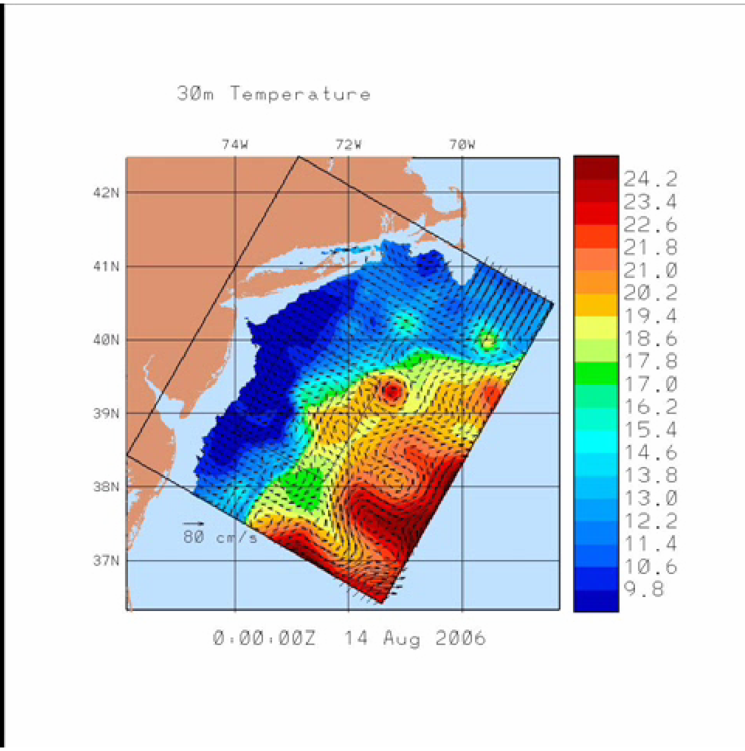


IV. Effects of water-column variability

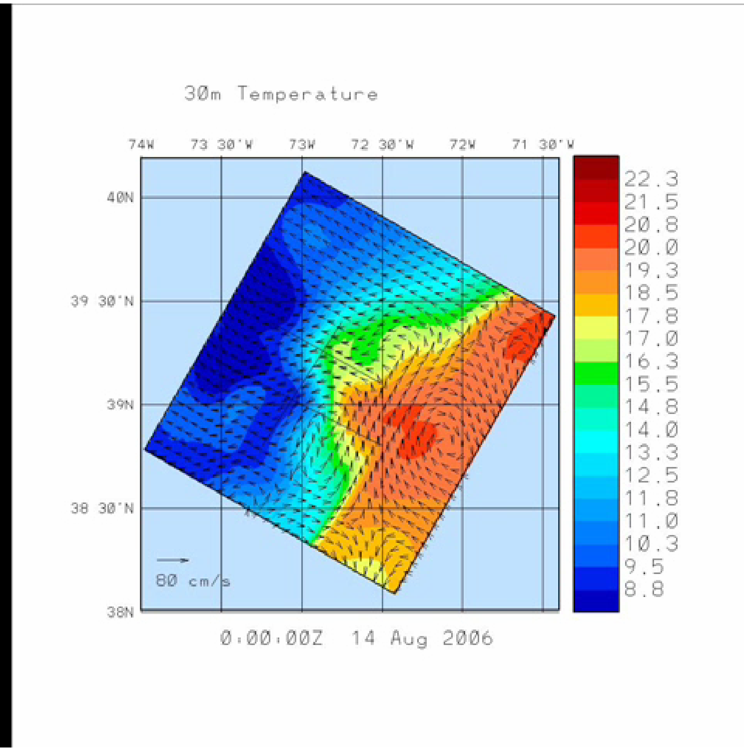
— U. Miami sound source (MSM) localization

- MIT-MSEAS[1] (HOPS) data assimilation ocean model
  (water temperature at 30 m depth)

Large domain simulation



small domain nested simulation



[1] P. F. J. Lermusiaux, P. J. Haley, Jr., W. G. Leslie, O. Logoutov, A. R. Robinson, Real-time forecasts and re-analyses for the Autonomous Wide Aperture Cluster for Surveillance (AWACS-06) exercise in the Middle Atlantic Bight Shelfbreak Front and Hudson Canyon region, http://mseas.mit.edu/archive/AWACS/index_AWACS.html, 2006.

IV. Effects of water-column variability

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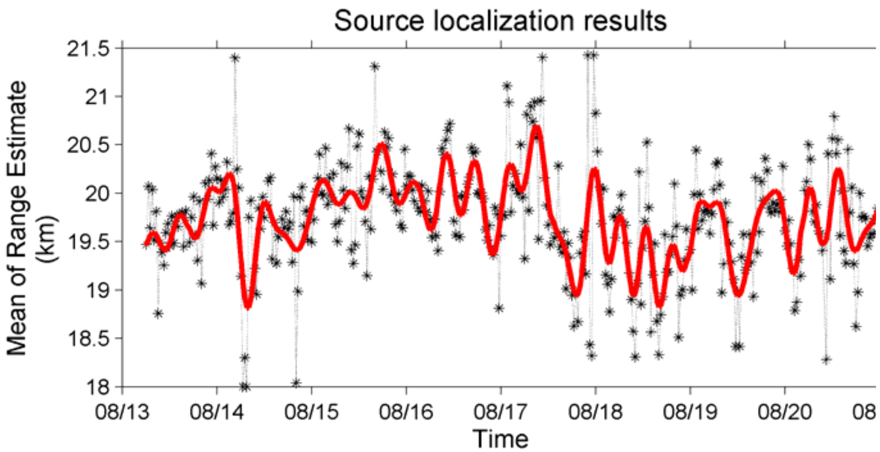
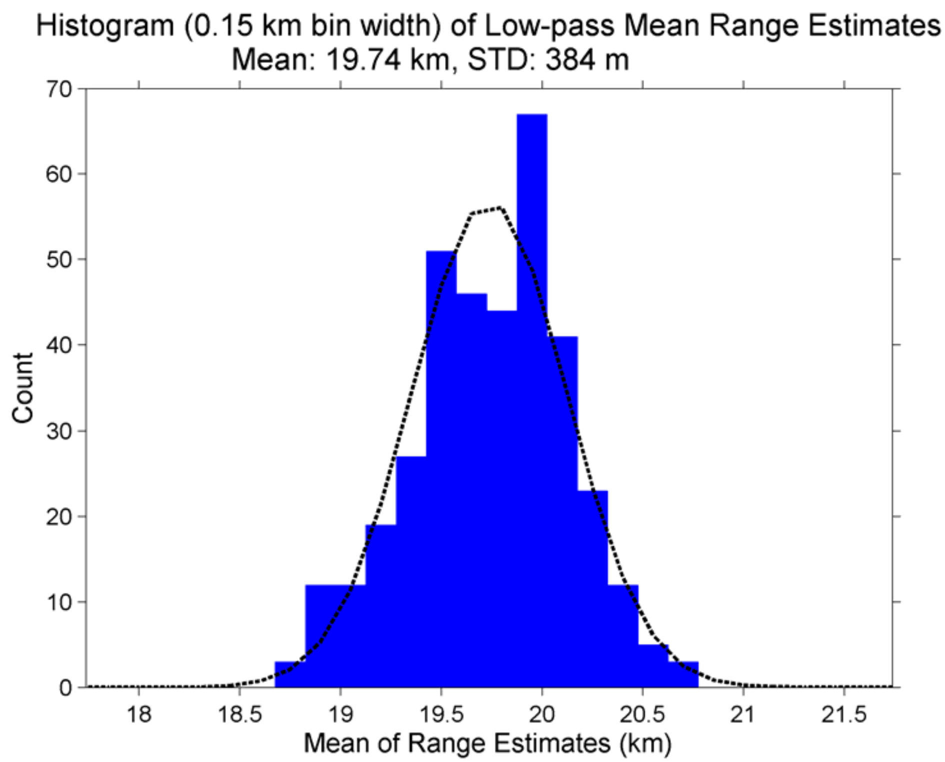
- Low-pass filtering source range estimates (cutoff frequency: 4 cycles per day)

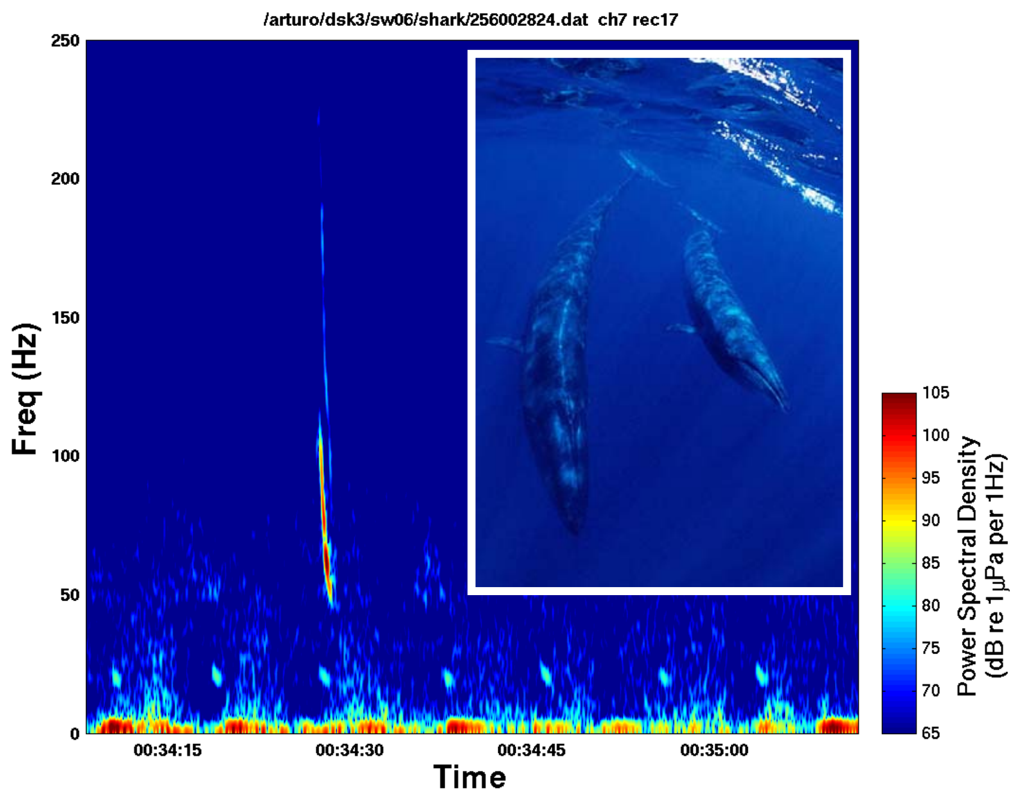
  — A large portion of range estimate deviations contains in the frequency band less than 4 cycle per day.

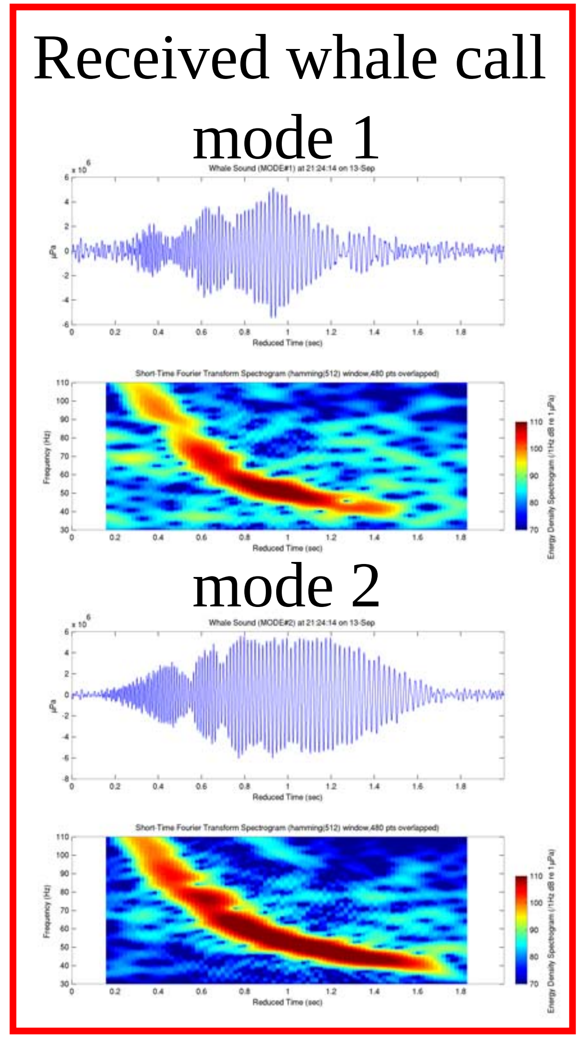




Application to the New Jersey Shallow Water 2006 (SW06) experiment data — Sei whale localization

• Sei whale calls have a frequency bandwidth from 40 to 120 Hz.





5aAB7 (9:30) Sei whale localization and vocalization frequency sweep rate estimation during the New Jersey Shallow Water 2006 experiment, A.E. Newhall, Y.-T. Lin, J.F. Lynch, and M.F. Baumgartner, ASA Portland meeting 2009.

Conclusions and future work

- A normal mode back-propagation approach for low-frequency broadband sound source localization in a shallow-water ocean is applied to the SW06 data.
- Nonlinear internal waves is responsible for the range estimate deviations in small time-scale (< 2 min).
- Insufficient mesoscale structure measurement (in terms of sound speeds) also cause range estimate deviation in a larger time-scale (hours).
- The normal mode back-propagation approach has been applied for localizing Sei whales presented in the SW06 experiment.
- Future work: careful examination of meso-scale oceanographic variability and connection to acoustics. Comparison of different source localization approaches. Reduction of estimation uncertainty.