

Modeling and Measuring Variability in 3-D Acoustic Normal Mode Propagation in Shallow Water near Ocean Fronts using Fixed and Moving Sources and Receivers

James H. Miller and Gopu R. Potty
University of Rhode Island
Department of Ocean Engineering
Narragansett, RI 02881
phone (401) 874-6540 fax (401) 874-6837 email miller@uri.edu

Award Number: N000140410147

LONG-TERM GOALS

The long term goals of our research are to:

1. Understand and model the 3-D propagation effects in shallow water and thereby explain some of the variations in acoustic field produced by the presence of shelf-break fronts and internal waves.
2. Apply our long range tomography inversion technique different locations and using different sources and improve the mode arrival estimation to improve it.
3. Explore the possibility of using underwater gliders as acoustic receive platforms and develop processing techniques for data collected using them.
4. Revisit an earlier study to look into sea surface wave effects on modal travel times.

OBJECTIVES

- ◆ Using the data from the J-15 – tow experiment, collected during the SW-06 experiment, we are exploring any evidence of 3-dimensional propagation effects due to frontal/ internal wave reflections.
- ◆ Using the data from Combustive Sound Sources (CSS) deployed by ARL-Texas we are doing inversions for sediment parameters.
- ◆ We are exploring the possibility of using gliders as acoustic recording platforms for shallow water applications. The noise characteristics of glider is being evaluated in collaboration with Rutgers University.
- ◆ The effects of the two tropical storms which passed through the SW-06 experimental area on the acoustic travel times is being investigated.

APPROACH

The PIs (James Miller and Gopu Potty) took part in the SW-06 on the R/V Knorr and participated in the CSS deployments and conducted a J-15 source tow experiment investigating the 3-D acoustic effects. The CSS data, collected on the WHOI HLA/VLA, will be used to perform inversions for

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 30 SEP 2007	2. REPORT TYPE Annual	3. DATES COVERED 00-00-2007 to 00-00-2007			
4. TITLE AND SUBTITLE Modeling And Measuring Variability In 3-D Acoustic Normal Mode Propagation In Shallow Water Near Ocean Fronts Using Fixed And Moving Sources And Receivers		5a. CONTRACT NUMBER			
		5b. GRANT NUMBER			
		5c. PROGRAM ELEMENT NUMBER			
6. AUTHOR(S)		5d. PROJECT NUMBER			
		5e. TASK NUMBER			
		5f. WORK UNIT NUMBER			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Rhode Island, Department of Ocean Engineering, Narragansett, RI, 02881		8. PERFORMING ORGANIZATION REPORT NUMBER			
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)			
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)			
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES code 1 only					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	Same as Report (SAR)	9	

sediment properties. Three students (Kristy Moore – R/V Endeavor, George Dossot and Steven Crocker – R/V Sharp) also participated in the experiments. Kristy Moore helped with the Scanfish and collected oceanographic data which helped to locate the position of the shelf break front on the day of the J-15 tow. WHOI provided the data from the Shark- VLA collected during the two storms (Ernesto and Floyd) which was used to study the effect of these storms on acoustic travel times.

WORK COMPLETED

The data from SW-06 is being analyzed and preliminary results have already been presented at ASA meetings. Two graduate students have completed their Masters at URI based on these studies. One of them, Gregor Langer, focused on the surface wave effects on modal arrivals, while the other, Kristy Moore, investigated the 3-D propagation effects and glider noise. We are currently preparing manuscripts for the proposed JASA special issue based on these results. The results of the preliminary analysis are summarized in the next Section.

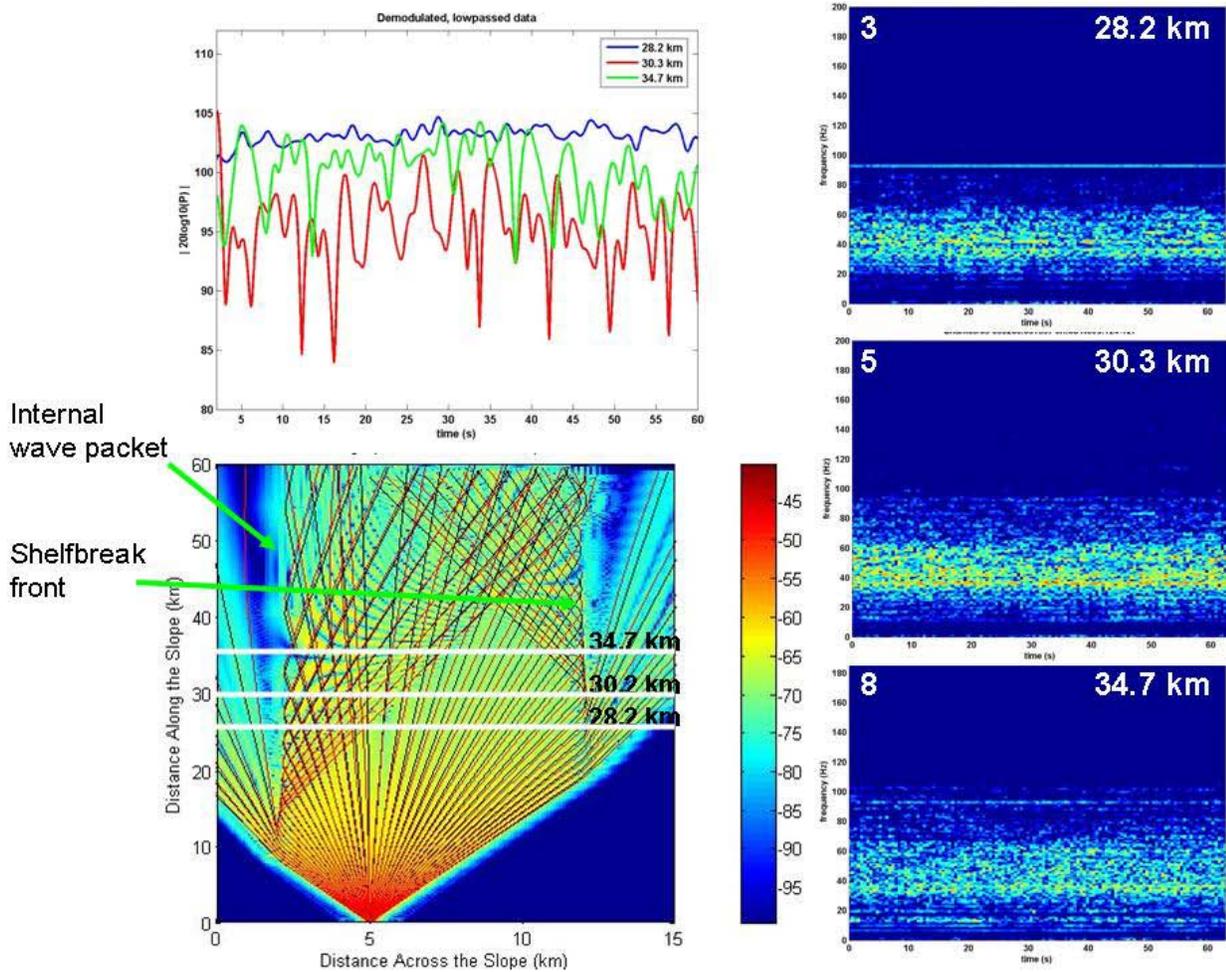


Figure 1. Comparison of acoustic sound levels at distances 28.2, 30.3 and 34.7 km from source to receiver. The three plots on the right show the spectrograms at these ranges. The sound pressure level plot has been demodulated and low-pass filtered in relation to the 93 Hz source signal. Notice the 93 Hz band present in the spectrogram at 28.2 km, which disappears at 30.3 km and reappears at 34.7 km. The top panel on the left show the acoustic signal at 93 Hz at these three ranges showing fluctuations of the order of 5 to 6 dB. Bottom panel on the left shows 3D KRAKEN results of acoustic modal rays reflecting of a shelf break front and non-linear internal wave packet. The source is at (5km, 0)

RESULTS

1. 3_D propagation modeling and analysis:

The object of this study is to verify the potential for horizontal Lloyd's mirror effect¹ at the New Jersey shelf break using modeling and determine if the effect is observable using data collected during the SW-06 experiment. Shelf-break front can totally internally reflect sound incident upon them at low grazing angles. The direct and reflected modal rays can constructively interfere which has the potential to increase the intensity level by 6 dB. There is also the potential for greater reductions in transmission loss due to the presence of an internal wave packet that traveled to the west of the shelf break front and

the J15 source. The modeling will be completed with the KRAKEN normal mode mode using the environmental parameters of the New Jersey shelf. Signals were recorded on the WHOI-VLA/HLA from a ship-towed J15 source, using a simple CW tone at 93 Hz and a source depth of approximately 50 meters. The J-15 was towed for a distance of 60 km parallel to the shelf break front, which was located at the 110 m isobath that day, based on scanfish measurements. Figure 1 shows some preliminary results showing the fluctuations in received acoustic levels of the order of 5 to 6 dB. Modeling also predicts possibility for fluctuations of these magnitudes.

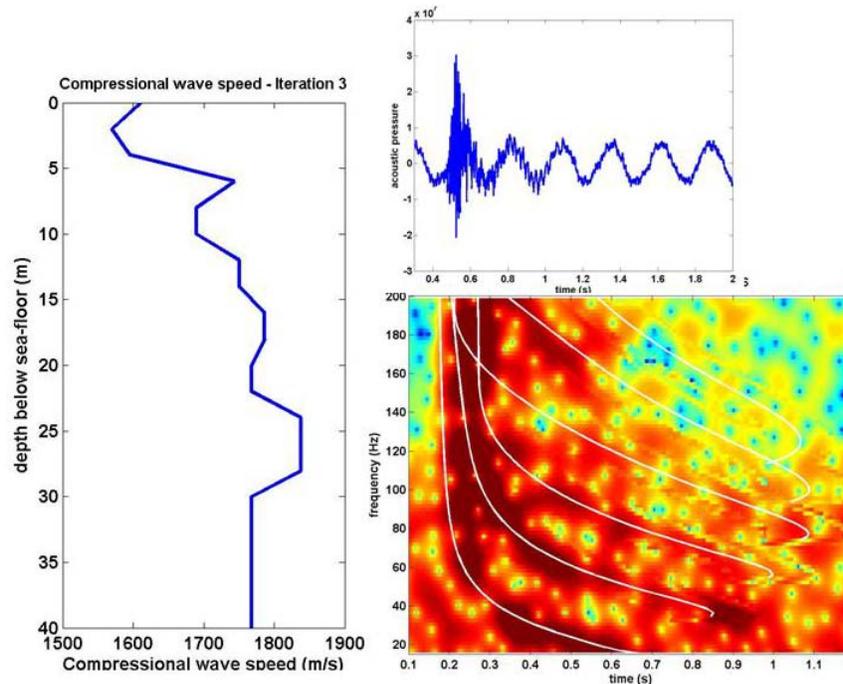


Figure 2. Sediment inversion using Combustive Sound Source (CSS). The estimated compressional wave profile is shown on the left along with acoustic signal from CSS (top panel on the right) and the dispersion based short-time Fourier transform (bottom panel on the right). The continuous lines on the time-frequency diagram are the modal arrival times calculated for the estimated compressional wave speed.

2. Geoacoustic inversions

Geoacoustic inversions are also being carried out using data from Combustive Sound Sources (CSS). These sources were deployed by ARL- UT from R/V Knorr and acoustic data received at the WHOI-VLA is used for inversions. The inversions were carried out using our modal dispersion based long range sediment tomography technique².

A new time-frequency analysis technique – dispersion based short-time Fourier transform³- was applied to the CSS data to calculate the individual modal arrival times as a function of frequency. These form the data for the inversion technique. Figure 2 shows the CSS data, the modal arrivals and the compressional wave speeds calculated using the modal arrivals. Preston Wilson (ARL-UT), James Lynch and Arthur Newhall (WHOI) were collaborators in this study.

3. Glider noise studies and synthetic aperture beamforming for a glider

The intent of this study is to examine whether the underwater gliders are adequate platforms for acoustic remote sensing. During the SW-06 experiment, one of the many gliders deployed by the Rutgers University carried an acoustic recording device (bio-acoustic probe) for many kilometers. Even though the amount of useful data collected during that mission was very short (less than an hour), the mission proved the capability of underwater gliders to tow hydrophones for long distances. We also conducted another study, in collaboration with Rutgers, to understand the noise characteristics of the glider.

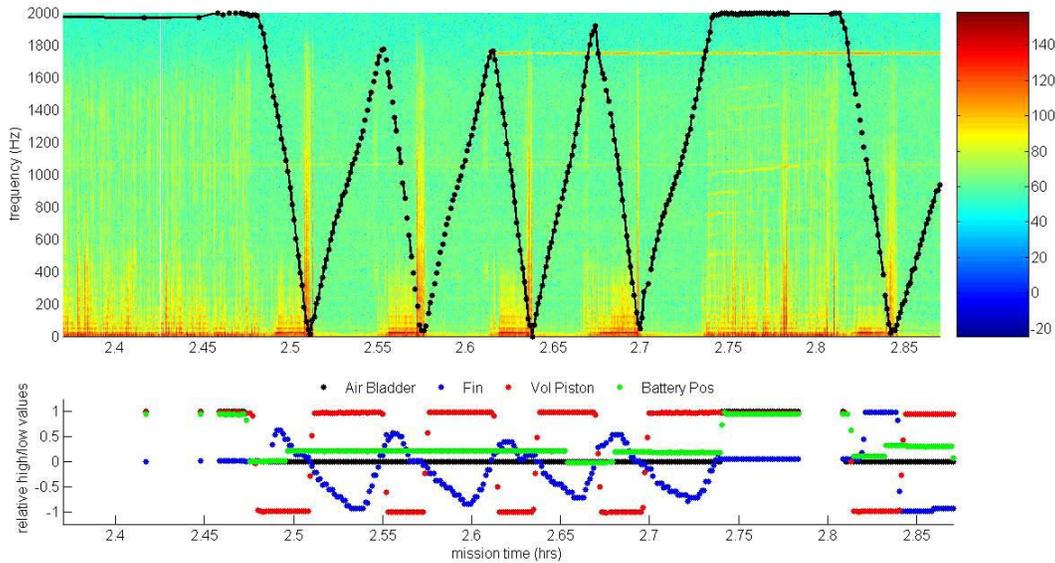


Figure 3. Spectrogram taken from bio-acoustic probe recording during the April 27, 2007 glider deployment compared with the glider's path and internal potential noise sources.

As part of this study acoustic data from the glider-towed receiver was analyzed and compared in time to engineering data from the Slocum glider. Significant noise sources from glider were identified in the acoustic recordings. The increases in noise level by the glider occur at predictable times, leading one to conclude that the glider has potential as a stable and robust acoustic recording platform. Figure 3 shows 45 minutes of acoustic data collected during the noise study along with potential noise sources. Out of the possible noise sources (air bladder, fin steering, battery movement and volume piston), it appears that the volume piston is the likeliest source of noise during dives of the glider. During the underwater dives, the descending dives have a fair amount of noise but the ascending portions are relatively quiet.

4. Sea surface wave effects on modal travel times

During the SW-06 experiment two tropical storms (Ernesto and Florence) passed by the experimental area in September, 2006 which provided high seas. We studied the wandering and spreading of the acoustic normal modes before, during, and after the passage of these tropical storms. The theoretical framework for this study was based on previous work by Miller⁴. Using the data from the 224 Hz and

400 Hz tomography sources received at the WHOI VLA/HLA we calculated the spectra of the travel time variations. Figure 4 shows the travel time spectra indicating a peak around 03:50 UTC time which corresponds to the time when the wind direction was approximately perpendicular to the acoustic path on September 3, 2006.

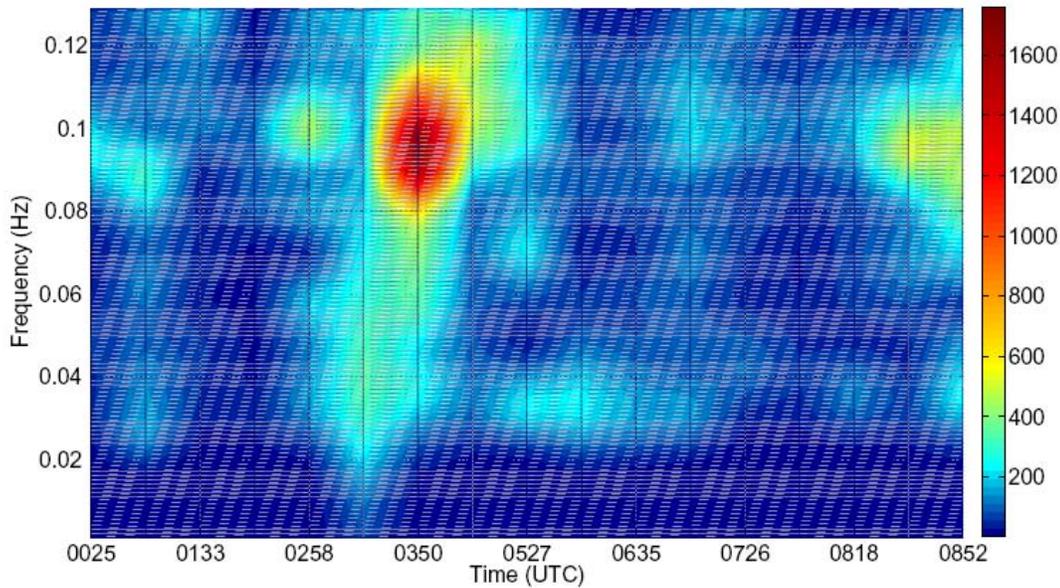


Figure 4. Acoustic travel time spectra before, during and after the passage of tropical storm Ernesto. The peak at 3:50 UTC correspond to a wind direction approximately perpendicular to the acoustic path.

IMPACT/APPLICATIONS

The inversion scheme using explosive sources is suitable for rapid estimation of acoustic properties of sediments in shallow water. This method is cost effective as a single sonobuoy and air-deployed explosives can provide the data. Using multiple sources and receivers sediment properties would allow an area to be mapped. 3-D propagation effects are important to naval applications as it can cause fluctuation in the acoustic field of the order of 5 to 10 dB. Gliders offer stable and low-noise autonomous platforms for acoustic measurements. Synthetic aperture using a glider towed acoustic array is an attractive option for naval applications.

TRANSITIONS

The sediment parameters obtained by this inversion will compliment the forward modeling efforts. The sediment tomography technique is suitable for forward force deployment when rapid assessment of environmental characteristics is necessary. In addition to naval air ASW applications using sonobuoys and SUS charges, this technique would be compatible with Navy special operations involving autonomous vehicles.

REFERENCES

1. J. F. Lynch, J. A. Colosi, G. G. Gawarkiewicz, T. F. Duda, A. D. Pierce, M. Badiey, B. G. Katsnelson, J. H. Miller, W. Siegmann, C-S Chiu, and A. Newhall, "Consideration of Fine-Scale Coastal Oceanography and 3-D Acoustics Effects for the ESME Sound Exposure Model," *IEEE J. of Oceanic Eng.*, 31(1), (2006).
2. Potty, G., Miller, J.H., Lynch, J.F., and Smith, K.B. (2000). "Tomographic mapping of sediments in shallow water," *J. Acoust. Soc. Am.*, 108(3), 973-986.
3. Jin-Chul Hong, Kyung Ho Sun, and Yoon Young Kim, "Dispersion-based short-time Fourier transform applied to dispersive wave analysis," *J. Acoust. Soc. Am.* **117** (5), May 2005
4. James H. Miller, James F. Lynch, and C-S Chiu, "Estimation of sea surface spectra using acoustic tomography," *J. Acoust. Soc. Am.* 86(1), (1989).

REFEREED PUBLICATIONS

1. Potty, G and Miller, J. H., "Dispersion of broadband acoustic normal modes in the context of long range sediment tomography," in *Acoustic Inversion Methods and Experiments for assessment of Shallow Water Environment*, Chapman, Caiti, Hermand. eds., Springer, 57-72, (2006).
2. Knobles D. P., Yudichak, T. W., Koch R. A., Cable P. G., Miller J. H., Potty, G. R., "Inferences on seabed acoustics in the East China Sea from distributed acoustic measurements," *IEEE J. Oceanic Eng.*, 31(1), 129-144, 2006.
3. Zoi- Heleni Michalopoulou, Miller, J. H., and Potty, G. R., "Matched field inversion in the East China Sea with Tabu search," *OCEANS -2006*, 1-4, (2006).
4. Rajan, Potty, Miller, Lynch, Becker and Frisk, "Modal inverse techniques for inferring geoacoustic properties in shallow water," in *Geoacoustic inversion in Underwater Acoustics*, Alex Tolstoy ed., Research Signpost, (submitted in 2007).
5. G. Langer, *Phase and travel time variations of acoustic normal modes in shallow water*, Masters Thesis, University of Rhode Island, (2007).
6. K. A. Moore, *Evaluation of an autonomous underwater vehicle for acoustic surveys, Investigation of 3-D propagation effects at the New Jersey shelf break front and acoustic backscatter in controlled water wave fields*, Masters Thesis, University of Rhode Island, (2007).

OTHER PUBLICATIONS

1. Gopu Potty, James H. Miller, Ying-Tsong Lin and James F. Lynch, "Efficient use of a priori data in sediment inversions through the use of null space," *J. Acoust. Soc. Am.* **120**, 3355 (2006).
2. Kristy A. Moore, James H. Miller, Gopu R. Potty, Georges A. Dossot, Scott M. Glenn, and James F. Lynch, "Measurements of 3-D propagation effects at a shelfbreak front," *J. Acoust. Soc. Am.* **120**, 3222 (2006).
3. Steven E. Crocker, James H. Miller, Gopu R. Potty, Georges A. Dossot, and James F. Lynch, "Propagation of impulsive broadband signals in a coastal ocean setting during the 1996 Shelfbreak Primer experiment," *J. Acoust. Soc. Am.* **120**, 3221 (2006).

4. Steven E. Crocker, James H. Miller, Gopu R. Potty, and James F. Lynch, "Nonlinear optimization for beamforming a geometrically deficient vertical line array: Application to sediment tomography," J. Acoust. Soc. Am. **120**, 3063 (2006).
5. J. L. Miksis-Olds and J. H. Miller, "Transmission loss in manatee habitats," J. Acoust. Soc. Am. **120**, 2320 (2006).
6. Georges A. Dossot, James H. Miller, Gopu R. Potty, Kristy A. Moore, Jason D. Holmes, James F. Lynch, "Acoustic measurements in shallow water using an ocean glider," J. Acoust. Soc. Am., **121**(5), Pt.2, p3108, (2007).
7. Gopu R. Potty, James H. Miller, Colin Lazauski, Preston Wilson, James F. Lynch, and Arthur Newhall, "Geoacoustic inversion using combusive sound source signals," J. Acoust. Soc. Am., **121**(5), Pt.2, p3055, (2007).
8. Kristy A. Moore, James H. Miller, Gopu R. Potty, James Lynch and Arthur Newhall, "Investigation of 3D propagation effects at the New Jersey shelf break front," J. Acoust. Soc. Am., **121**(5), Pt.2, p3126, (2007).
9. Gregor Langer, James H. Miller, Gopu R. Potty, James F. Lynch, "Observation of phase and travel time variations of normal modes during tropical storms Ernesto and Florence," J. Acoust. Soc. Am., **121**(5), Pt.2, p3054, (2007).
10. Ivan Zorych, Zoi-Heleni Michalopoulou, James H. Miller, and Gopu R. Potty, "Particle filtering for dispersion curve estimation from spectrograms of acoustic signals," J. Acoust. Soc. Am., **121**(5), Pt.2, p3171, (2007). (invited).
11. J. H. Miller and J. F. Lynch, "The effect of a rough sea surface on acoustic normal modes," J. Acoust. Soc. Am. **121**, 3039 (2007) (invited)
12. J. L. Miksis-Olds, P. L. Donaghay, J. H. Miller, P. L. Tyack, and J. A. Nystuen, "Noise level correlates with manatee use of foraging habitats," J. Acoust. Soc. Am. **121**, 3011 (2007).
13. Herman Medwin, colleagues, and James H. Miller, Reviewer, *Sounds in the Sea: From Ocean Acoustics to Acoustical Oceanography*, J. Acoust. Soc. Am. **121**, 1265 (2007).
14. P. H. Dahl, J. H. Miller, D. H. Cato, and R. Andrew, "Underwater ambient noise," *Acoustics Today*, Vol. 3(1), (2007).
15. James D. Nickila, Kevin B. Smith and Gopu R. Potty, "Environmental Influences on the Frequency Dependence of Effective Bottom Attenuation," ICTCA'07, Crete, Greece, (2007)
16. I. Zorych, Z.E. Michalopoulou, J.H. Miller, G.R. Potty, "Particle and PHD filters for dispersion curve estimation in underwater acoustics," ICTCA'07, Crete, Greece, (2007)
17. J. H. Miller, J. A. Nystuen, and D. L. Bradley, "Ocean Noise Budgets," Presented at the international conference on The Effect of Noise on Aquatic Life, Nyborg, Denmark, (2007).
18. S. K. Tremblay, T. S. Anderson, E. C. Pettit, P. M. Scheifele, J. H. Miller, and G. R. Potty, "Ocean Acoustic Effects of Explosions on Land: Evaluation of Cook Inlet Beluga Whale Habitability," Acoust. Soc. Am. Meeting, New Orleans, 2007 (to be presented)
19. G. Dossot, J. H. Miller, G. R. Potty, E. Sullivan, J. D. Holms, J. F. Lynch and S. Glenn, "An investigation of the capabilities of a short hydrophone array towed by an ocean glider," Acoust. Soc. Am. Meeting, New Orleans, 2007 (to be presented)
20. G. R. Potty and J. H. Miller, "Inversion of compressional wave attenuation of shallow ocean sediments and their frequency dependence," SYMPOL-07, Cochin University of Science and Technology, December, 2007 (to be presented)
21. S. D. Rajan, J. H. Miller and G. R. Potty, "Range dependent inversions using multiple broadband sources at the East China Sea", SYMPOL-07, Cochin University of Science and Technology, December, 2007 (to be presented)

HONORS/ AWARDS/ PRIZES

James Miller was elected as Chair of the Acoustical Oceanography Technical Committee of the Acoustical Society of America

George Dossot won the Best Student Paper Award for the paper presented at the Salt Lake City, ASA Meeting. The paper was titled “Acoustic measurements in shallow water using an ocean glider.”