Using Acoustic Tomography to Monitor Deep Ocean Currents in the Eastern Gulf of Mexico

D. A. Rosenfield,* J. W. Caruthers, and D. A. Nechaev
University of Southern Mississippi
Department of Marine Science
1020 Balch Blvd.
Stennis Space Center, MS 39529 USA

N. A. Sidorovskaia**
University of Louisiana at Lafayette
Department of Physics
210 Broussard Hall
Lafayette, LA 70504 USA

G. E. Ioup and J. W. Ioup
University of New Orleans
Department of Physics
2000 Lakeshore Drive
New Orleans, LA 70148

M. I. Yaremchuk
Naval Research Laboratory
Code 7323, Bldg 1009
Stennis Space Center, MS 39529, USA

* presenting author; ** contact: nsidorovskaia@louisiana.edu

Abstract*- Toward the improved prediction and monitoring of deep-water currents and eddies in the Gulf of Mexico, the Gulf Eddy Monitoring System group (GEMS; researchers from University of Southern Mississippi, University of New Orleans, University of Louisiana at Lafayette, and the Naval Research Laboratory) proposes that a network of acoustic transmitter-receiver pairs be deployed in the northeastern Gulf of Mexico. Acoustic travel times are inverted to recover temperature and velocity between transmitter-receiver pairs. This data can be fed into ocean dynamical models to improve simulation and prediction of the circulation in the deep ocean. While a proven technique, it has only recently been used successfully in deeper waters. The location is ideal for this type of tomographic application for its predictable oceanic parameters and convenient geomorphology. With a sound-channel axis at about 900 m, a lower power output transmission is required, thus providing negligible impact on marine mammals. Because no other technology can be used to monitor for similar events, we are introducing this method to the marine technology community.

I. Introduction

As the potential increases for impact of catastrophic hurricanes on coastal communities surrounding the Gulf of Mexico, the need increases for improved prediction and monitoring of regional weather systems. Currents well below the ocean surface have been observed to flow as fast as 2 m/s (see Fig 1) and have the ability to influence regional weather.

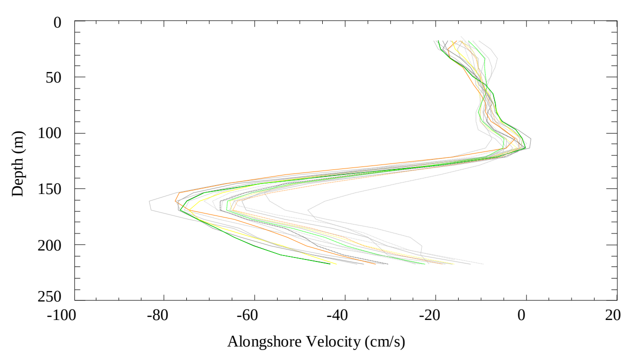

Figure 1. Velocity profiles measured every 10 minutes for 4 hours on Jan 26th, off the coast of Angola; from [1].

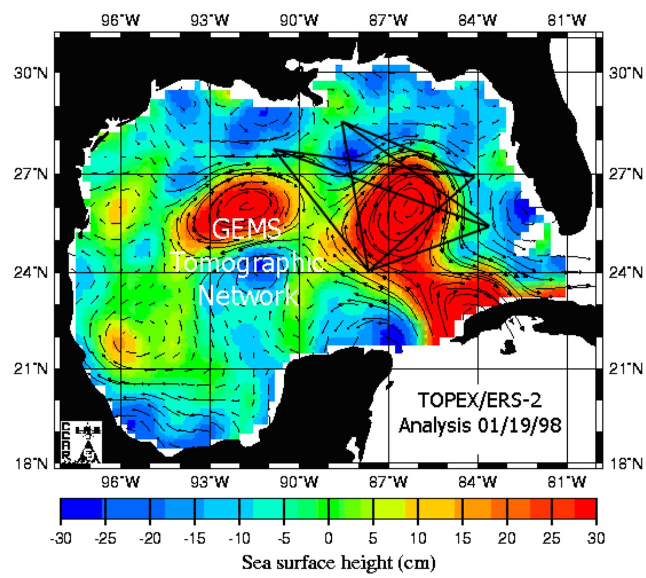

Figure 2. Sea surface height as measured by TOPEX/ERS-2; overlaid by the proposed GEMS Tomographic network of transmitter-receiver pairs (black lines).

The lack of timely and reliable data regarding the location and magnitude of deep-water currents continues to be an issue for the oceanographic community [1]. While there are programs that try to describe and model these currents and eddies, these efforts lack the ability to describe the complete internal 3-D structure. The current state of knowledge on the structure as well as the spatial and temporal variability of these deeper currents is, unfortunately, still in its infancy.

GEMS proposed network

The Gulf Eddy Monitoring System (GEMS) group proposes that a network of acoustic transmitters/receivers be deployed for the continuous monitoring of deep currents and eddies in the northeastern Gulf of Mexico (see Fig. 2) [2]. In such a network, the travel times of acoustic signals propagating in the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 2010	**N/A**	**-**

4. TITLE AND SUBTITLE
Using Acoustic Tomography to Monitor Deep Ocean Currents in the Eastern Gulf of Mexico

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 Southern Mississippi Department of Marine Science 1020 Balch Blvd. Stennis Space Center, MS 39529 USA

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
Distribution authorized to DoD only; (Administrative/Operational Use; Jun 2010). Other requests shall be referred to (Office of Naval Research, 875 N. Randolph St., Arlington, VA 22203-1995.).

13. SUPPLEMENTARY NOTES
See also ADM202806. Proceedings of the Oceans 2009 MTS/IEEE Conference held in Biloxi, Mississippi on 26-29 October 2009. Copyright belongs to the Marine Technology Society., The original document contains color images.

14. ABSTRACT
Toward the improved prediction and monitoring of deep-water currents and eddies in the Gulf of Mexico, the Gulf Eddy Monitoring System group (GEMS; researchers from University of Southern Mississippi, University of New Orleans, University of Louisiana at Lafayette, and the Naval Research Laboratory) proposes that a network of acoustic transmitterreceiver pairs be deployed in the northeastern Gulf of Mexico. Acoustic travel times are inverted to recover temperature and velocity between transmitter-receiver pairs. This data can be fed into ocean dynamical models to improve simulation and prediction of the circulation in the deep ocean. While a proven technique, it has only recently been used successfully in deeper waters. The location is ideal for this type of tomographic application for its predictable oceanic parameters and convenient geomorphology. With a sound-channel axis at about 900 m, a lower power output transmission is required, thus providing negligible impact on marine mammals. Because no other technology can be used to monitor for similar events, we are introducing this method to the marine technology community.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**3**	

depths at select frequencies can be carefully measured and inverted to recover ocean temperature and current velocity between transmitter/receiver pairs. Fig. 3 shows the theoretical paths of sound rays traveling between transmitter-receiver pairs. Note that rays which pass through deeper waters are first to arrive while rays which travel along the sound channel axis arrive last and maintain their intensity. The difference between the predicted and observed eigenray arrival structure conveys information about along-track sound speed. This sound speed can be inverted to calculate the oceanic parameters between the transmitter and receiver.

Deep-water Acoustic Tomography

This technology was first conceived of many years ago [3], but has since only been applied in shallow waters. This proven technology can be used for the continuous remote sensing of the parameters needed to describe the flow the deep ocean [4]. This data can also be fed into ocean dynamical models to improve simulation and prediction of the circulation in the deep ocean [5,6].

Why the Gulf of Mexico?

Aside from it's proximity to the United States (i.e. it's direct impact on local weather systems), the Gulf of Mexico is the ideal location for the type of monitoring network the GEMS group proposes. A contained sea with coastal margins, its deeper waters have a very stable temperature and salinity signature composed of essentially two distinct water types. Eddies composed of Caribbean water pass through Gulf-proper water, while mixing only occurs at transition regions and boundaries (see Fig. 4). Above the sound channel axis, sound speed is a function of water type, and changes proportionately with temperature. Below this axis, no water type effects exist and sound speed is proportional to pressure.

The northeastern Gulf of Mexico has a sound-channel axis (depth of sound-speed minimum: ~900 m), which supports convergence-zone propagation to depths of 1,200 to 3,000 m. This helps concentrate sound signals, requiring a low power output transmission, minimizing marine mammal impact.

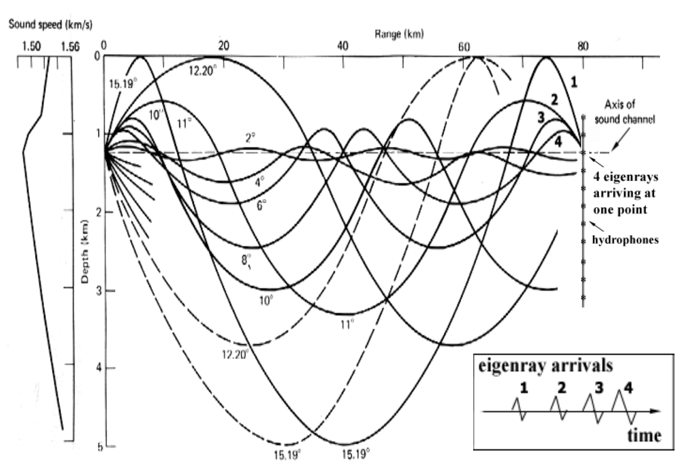

Figure 3. Theoretical paths of acoustic waves (eigenrays) traveling through deeper waters arrive first while rays which travel along the sound channel axis arrive last and maintain intensity. Gulf of Mexico sound speed profile (left).

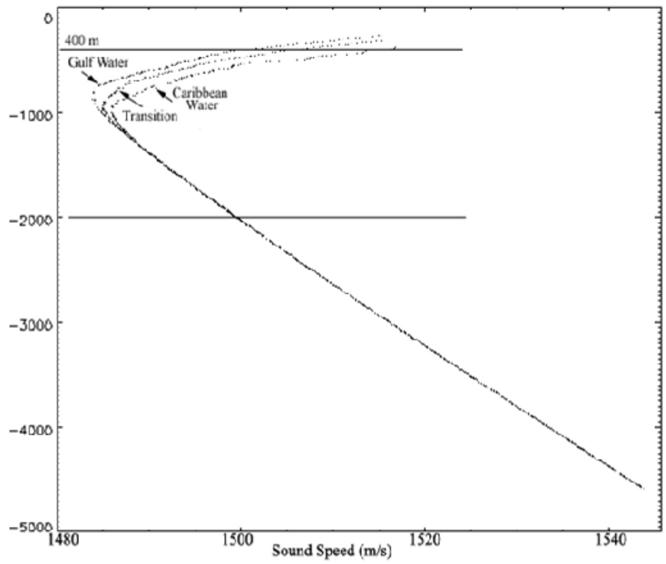

Figure 4. Sound-speed profiles of the three distinct water types found in the northeast Gulf of Mexico. Note the similarity below 1200 m.

Impact on marine mammals

With the understanding that underwater noise can have significant impact on local wildlife, much effort was made to conservatively balance the need for adequate sound transmission while minimizing the impact on marine mammals. The proposed power output level of 190 dB is an accepted standard based on over a decade of work done under the Littoral Acoustic Demonstration Center (LADC). This research was performed in several regions including, but not limited to, the eastern Gulf of Mexico [7,8]. This output level is on the order of the output at which certain mammal species communicate with one another over long distances.

What about other methods?

While other methods are powerful, their inherent drawbacks make them unable to properly monitor the deep Gulf of Mexico currents and eddies. Satellites are often used to monitor large oceanic regions like the Gulf of Mexico, but are unable to sense data from below the ocean surface. Buoys, expendable sensors, and ship surveys provide some information about the flow, conductivity, and temperature beneath the surface but are sparse and sporadic in both space and time.

ACKNOWLEDGMENT

The presenting author thanks Dr. Jerald Caruthers for his knowledge and enthusiasm in the field of acoustic tomography and Dr. Dmitri Nechaev for his patience as my graduate advisor.

REFERENCES

[1] Presentation online by Cortis Cooper of Chevron Energy Technology Co., info.ogp.org.uk/metocean/FloatingSystems/presentations/Cooper.ppt; accessed August, 18th, 2009.

[2] J.W. Caruthers, D.A. Roman, N.A. Sidorovskaia, and S. Vinogradov, An invited session: "Prospects and Techniques for Eddy-Resolving Acoustic Tomography of the Northeastern Gulf of Mexico," Proceedings of the 9th World Conference on Systemics, Cybernetics, and Informatics, July 2005.

[3] W. Munk, P. Worcester, and C. Wunsch, *Ocean Acoustic Tomography*. Cambridge University Press, 1995.

[4] P. Worcester, W. Munk, and R. Spindel, "Acoustic Remote Sensing of Ocean Gyres," Acoustics Today, vol. 1, pp 11-18, October 2005.

[5] S. Vinogradov, J.W. Caruthers, and N.A. Sidorovskaia, "The Use of Tomographic Data in Numeric Simulation of Eddy Propagation into the Northeastern Gulf of Mexico by Assimilations into the Numeric Model," presented at the ASLO/TOS 2004 meeting, Honolulu, HI: February 2004.

[6] M. Yaremchuk, K. Lebedev, and D. Nechaev, "A 4-dimensional inversion of the acoustic tomography, satellite altimetry and in situ data using quasigeostrophic constraints." Inverse Problems in Science and Engineering, vol. 12(4), pp. 409-431, 2004.

[7] J. Newcomb, R. Fisher, R. Field, A. Turgut, G. Ioup, J. Ioup, G. Rayborn, S. Kuczaj, J. Caruthers, R. Goodman and N.A. Sidorovskaia, "Near-bottom hydrophone measurements of ambient noise and sperm whale vocalizations in the northern Gulf of Mexico," presented at the 143rd Meeting of the Acoust. Society Amer., abst. published in J. Acoust. Soc. Am., vol. 111, 2002.

[8] J. Newcomb, R. Fisher, R. Field, G. Ioup, J. Ioup, G. Rayborn, et al., "Using Acoustic Buoys to Assess Ambient Noise and Sperm Whale Vocalizations," Proceedings of MMS-ITM Workshop, January 2003.