



WOODS HOLE OCEANOGRAPHIC INSTITUTION

Applied Ocean Physics and Engineering Department

November 9, 2017

Dr. Robert Headrick
Office of Naval Research, Code 322
One Liberty Center
875 N. Randolph Street
Arlington, VA 22203-1995

Dear Dr. Headrick:

Enclosed is the Final Report for ONR Grant No. N00014-14-1-0040/N00014-16-1-2361 entitled "Shallow Water Acoustic Studies," Principal Investigator, Dr. James F. Lynch

Sincerely,

A handwritten signature in dark ink, which appears to read "Gretchen McManamin", is written over the typed name.

Gretchen McManamin
Administrative Associate I

Enclosure

cc: ✓ Defense Technical Information Center
Naval Research Laboratory
Grant and Contract Services (WHOI)
AOPE Department Office (WHOI)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this 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 this 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 Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 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 any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 11/19/2017		2. REPORT TYPE FINAL		3. DATES COVERED (From - To) 01/01/2014 - 12/31/2016	
4. TITLE AND SUBTITLE Shallow Water Acoustics Studies				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER N00014-14-1-0040/N00014-16-1-2361	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Dr. James F. Lynch				5d. PROJECT NUMBER 130040SP	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Applied Ocean Physics and Engineering Department Woods Hole Oceanographic Institution 98 Water Street Woods Hole, MA 02543-1053				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Dr. Robert Headrick Office of Naval Research Code 322 875 North Randolph Street Arlington, VA 22203-1995				10. SPONSOR/MONITOR'S ACRONYM(S) ONR	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT See Attached					
15. SUBJECT TERMS Acoustics, acoustic propagation, internal waves, Mid-Atlantic Bight					
16. SECURITY CLASSIFICATION OF: Unclassified			17. LIMITATION OF ABSTRACT Unlimited	18. NUMBER OF PAGES 3	19a. NAME OF RESPONSIBLE PERSON James Lynch
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			19b. TELEPHONE NUMBER (include area code) (508) 289-2230

Distribution Statement A: Distribution approved for public release; distribution unlimited

Shallow Water Acoustics Studies – Final Technical Report

James F. Lynch

MS #12, Woods Hole Oceanographic Institution, Woods Hole, MA 02543

Phone: (508)289-2230 Fax: (508) 457-2194 e-mail: jlynch@whoi.edu

Grant Number: N00014-14-1-0040/N00014-16-1-2361

<http://acoustics.whoi.edu/sw06/>

LONG TERM GOALS

The long term goals of our shallow water acoustics work were to: 1) understand the nature of low frequency (10-1500 Hz) acoustic propagation, scattering and noise in shallow water when strong oceanic variability is present in the form of fronts, eddies, boundary layers, and internal waves (using the SW06 and QPE data, primarily) and 2) initiate planning a 2016 bottom acoustics experiment in the Mid-Atlantic Bight and a 2017 field experiment to look at the complicated boundary between deep and shallow water, i.e. the slope/canyon region.

OBJECTIVES

Our primary objectives in the last year were to: 1) finish manuscripts on the QPE shallow water acoustics/Uncertainty work, and publish them in IEEE JOE, 2) begin 2016 (bottom acoustics) and 2017 (Arctic slope and canyon) experimental planning, both on an individual basis, and in conjunction with the whole ocean acoustics community, 3) continue work on modeling scattering by coastal internal waves and other features and 4) look at climate change effects in shallow water.

APPROACH

We devoted a fair effort this year towards finishing the manuscripts on the fall 2009 QPE Uncertainty experiment northeast of Taiwan. We had two manuscripts published by IEEE JOE (one on canyons and one on the Dyer/Abbot PPD).

The work on internal wave scattering of sound continues, and we have looked at mode coupling, ducting by curved waves, and high frequency energy fluctuations,

among other topics. A *J. Atmos. And Oceanic Tech.* paper was published on this work, and another JASA paper is in advanced preparation.

Planning for the next two shallow water experiments was also part of our effort, though at a more modest level due to the delays in the experiments.

Work on climate change effects upon shallow water acoustics was initiated, and is being pursued in 2017, with Lynch as an Emeritus Scientist.

WORK COMPLETED/ACCOMPLISHMENTS

As seen in the References, we had five peer reviewed papers published due to work in the last two years, with other papers on shallow water acoustics being in preparation by Lynch (working in Emeritus Scientist status) and colleagues.

RESULTS

One of our more interesting results was actually on the fluctuation statistics of coastal nonlinear internal waves, derived using the SW06 data. These statistics, which were previously poorly defined, are direct inputs to acoustic scattering models.

IMPACT/APPLICATIONS

The impact of our experiment should be: 1) an increased understanding of the propagation of sound through complicated coastal oceanography, 2) an eventual capability to model these effects for use in sonar performance prediction applications, and 3) showing that the PPD formalism for detection could be a useful extension of the usual sonar equation ROC curves.

TRANSITIONS

One eventual transition of our analyses will be in “the error bars” one needs to place upon ocean acoustic field and system performance predictions. Another transition is the use of our SW06 internal wave data to verify a large “coastal oceanography plus internal wave” model developed under the IODA (Integrated Ocean Dynamics and Acoustics) MURI, which might eventually be used as a Navy standard model that works at all ocean scales down to the internal waves and finescale

References (2015- 2017)

- [1] C. Emerson, J.F. Lynch, P. Abbot, Y.-T. Lin, T.F. Duda, G.G. Gawarkiewicz and C.-F. Chen, "Acoustic Propagation Uncertainty and Probabilistic Prediction of Sonar System Performance in the Southern East China Sea Continental Shelf and Shelfbreak Environments," *IEEE J. Ocean. Eng.*, v.40, pp.1003-1017 (2015).
- [2] Y.-T. Lin, T.F. Duda, C. Emerson, G.G. Gawarkiewicz, A.E. Newhall, B. Calder, J.F. Lynch, P. Abbot, Y.-J. Yang and S. Jan, "Experimental and numerical studies of sound propagation over a submarine canyon northeast of Taiwan," *IEEE J. Ocean. Eng.* Vol. 40, no. 1, pp. 237-249 (2015).
- [3] J.F. Lynch and A.E. Newhall, "Shallow water acoustics", book chapter in "Practical Underwater Acoustics," L. Bjorno, T. Neighbors, and D. Bradley Eds. Elsevier, pp. 403-468. (2017)
- [4] M. Badiey, L.Wan, and J.F. Lynch, "Statistics of nonlinear internal waves during the shallow water 2006 experiment." *J. Atmos. And Oceanic Tech.* <http://dx.doi.org/10.1175/JTECH-D-15-0221.1> (2016.)
- [5] V. A. Grigor'ev, B. G. Katsnel'son, and J. F. Lynch. "Bottom attenuation estimation using sound intensity fluctuations due to mode coupling by nonlinear internal waves in shallow water," *The Journal of the Acoustical Society of America*, Vol.140, No.5. (2016).

[title] Shallow Water Acoustics Studies
[awardNumber1] N00014-14-1-0040/N00014-16-1-2361
[awardNumber2]
[awardNumberMore]
[keyWords] QPE experiment, slopes and canyons, internal waves
[specialCat]
[pi1] James Lynch
[pi2]
[pi3]
[pi4]
[pi5]
[piMore]
[totalUndergradStudents]
[totalUndergradWomenStudents]
[totalUndergradMinorityStudents]
[totalGradStudents]
[totalGradWomenStudents]
[totalGradMinorityStudents]
[totalPostDocs]
[totalWomenPostDocs]
[totalMinorityPostDocs]
[bestAccomplishment] Measured statistics of coastal nonlinear internal waves
[comments]