Numerical Modeling of Acoustic Propagation
In a Variable Shallow Water Waveguide

Daniel Rouseff
Applied Physics Laboratory
College of Ocean and Fishery Sciences
University of Washington
1013 NE 40th St., Seattle, WA 98105
phone: (206) 685-3078, fax: (206) 543-6785, email: rouseff@apl.washington.edu

LONG-TERM GOALS

The long-term scientific goal is to better characterize the effects of shallow water variability on acoustic propagation at moderate frequencies. In the current reporting period, we emphasized studying the effects of environmental variability on the "waveguide invariant" discussed in Brekhovskikh and Lysanov [1991].

OBJECTIVES

Brekhovskikh and Lysanov showed how contour plots of acoustic intensity, mapped in range and frequency, would exhibit striations. They defined a parameter "beta" as a simple function of range, frequency and the slope of the striations, and claimed that this parameter was an invariant. They cautioned, however, that this simple formulation was valid only for certain groups of modes. For more complicated environments, Chuprov [1982] suggested using spectral analysis to quantify beta.

In the present funding cycle, the first objective was to develop an image processing algorithm based on spectral analysis that could be used to study the waveguide invariant. The second objective was to quantify the effects of environmental variability on the output of this processing algorithm. Particular emphasis was placed on the effects of time-varying shallow water internal waves. Both random background internal waves and more deterministic, event-like solitary waves were considered.

APPROACH

An image processing method was developed that treats the waveguide invariant as a distribution. Effectively, the "beta content" of the observed acoustic intensity is calculated. This converts two-dimensional range-frequency images of acoustic intensity into line plots of image energy versus beta. The mathematical details are in Rouseff [2001a].

A wide-angle parabolic equation routine was modified to generate images of acoustic intensity plotted versus range and frequency. This was used as input to the image processing algorithm and the beta content calculated. The ocean environment was allowed to change consistent with internal wave activity. The beta content was tracked as the internal wave field evolved.

Report Documentation Page		

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Numerical Modeling of Acoustic Propagation In a Variable Shallow Water Waveguide	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) **Applied Physics Laboratory,University of Washington,College of Ocean and Fishery Sciences,,1013 NE 40th St.,,Seattle,,WA, 98105**	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

14. ABSTRACT
The long-term scientific goal is to better characterize the effects of shallow water variability on acoustic propagation at moderate frequencies. In the current reporting period, we emphasized studying the effects of environmental variability on the ???waveguide invariant??? discussed in Brekhovskikh and Lysanov [1991].

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)**	**5**	

WORK COMPLETED

In the present funding cycle, the internal wave models were improved. A realistic representation for discrete internal wave packets ("solibores"), based on recent field observations [Williams et al. 2001], was included in the calculations. Together with previous calculations for background internal waves, the results were documented in an invited conference presentation [Rouseff 2001a] and a journal paper [Rouseff 2001b].

For the special case of a range-independent environment, we derived an expression for the waveguide invariant distribution in terms of the acoustic modes. This permits efficient parameter studies. Quantities such as source and/or receiver depth or bottom loss can be varied with negligible computational cost. The results have been documented in a book chapter [Rouseff and Spindel, 2002].

RESULTS

For the sample calculations presented in this section, the environment is range-independent. The water depth is 70 m and the bottom is typical of sand. The source depth is 50 m and the range is 10 km. The bandwith is 20 Hz and centered about 410 Hz. Two basic sound speed profiles are considered: an isovelocity (Pekeris) scenario and a profile typical of summertime [Williams et al. 2001]. For further details, see Rouseff and Spindel.

Figures 1 and 2 show the waveguide invariant distribution as calculated using the image processing algorithm. Specifically, the effect of changing the receiver depth is examined. Figure 1 is for the Pekeris waveguide. The level of the maximum varies some with depth, but the location remains at $\beta = 1$, the canonical value for shallow water. A richer structure is observed for the summer profile in Figure 2. The shape of the distribution and the location of the maximum both vary with receiver depth. At 10 m, the receiver is above the thermocline. The measurement is dominated by high order, surface interacting modes and the result is similar to what is observed with the Pekeris waveguide. For a deep receiver, the low order modes become more important. These modes do not interact with the surface and the beta distribution spreads.
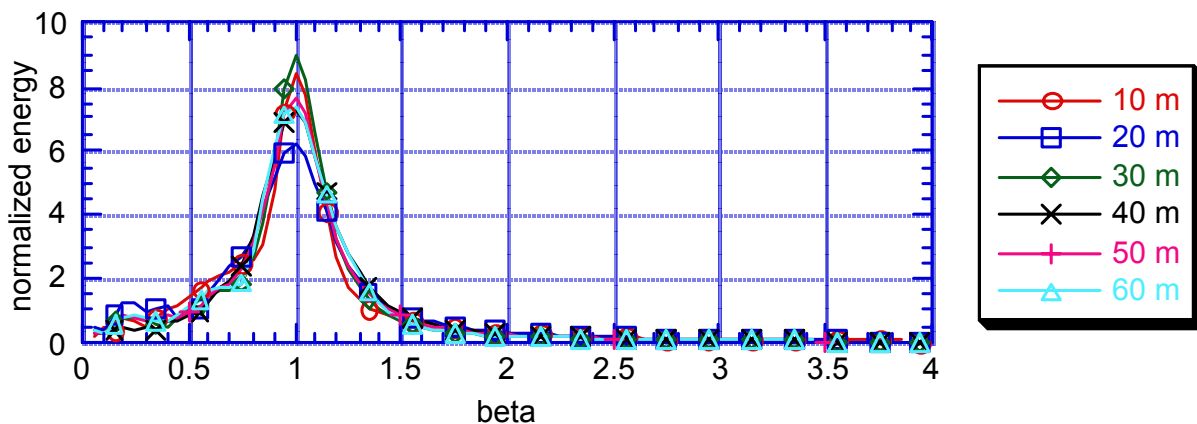
Figure 1. Effect of varying receiver depth on the beta content of range-frequency images of intensity. Pekeris waveguide. Source located at depth 50 m.
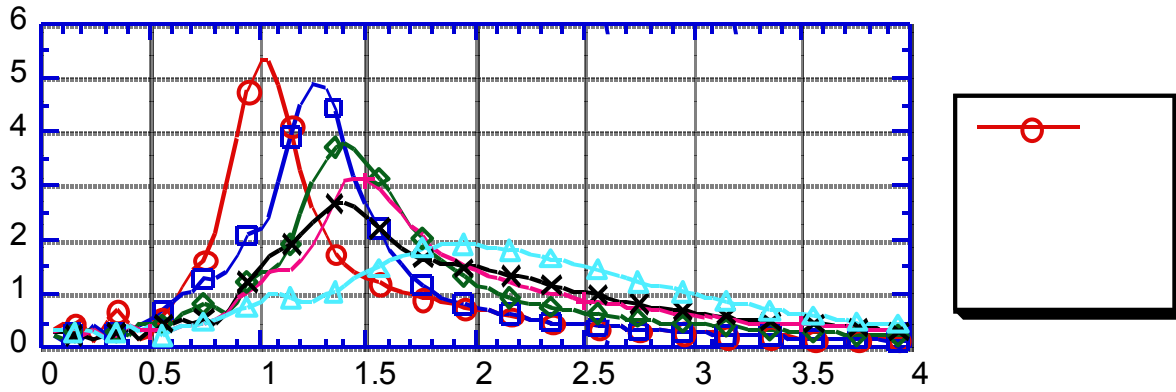
Figure 2. Effect of varying receiver depth on the beta content of range-frequency images of intensity. Waveguide with sound speed profile. Source located at depth 50 m. The distribution shape and the location of maximum change with receiver depth.
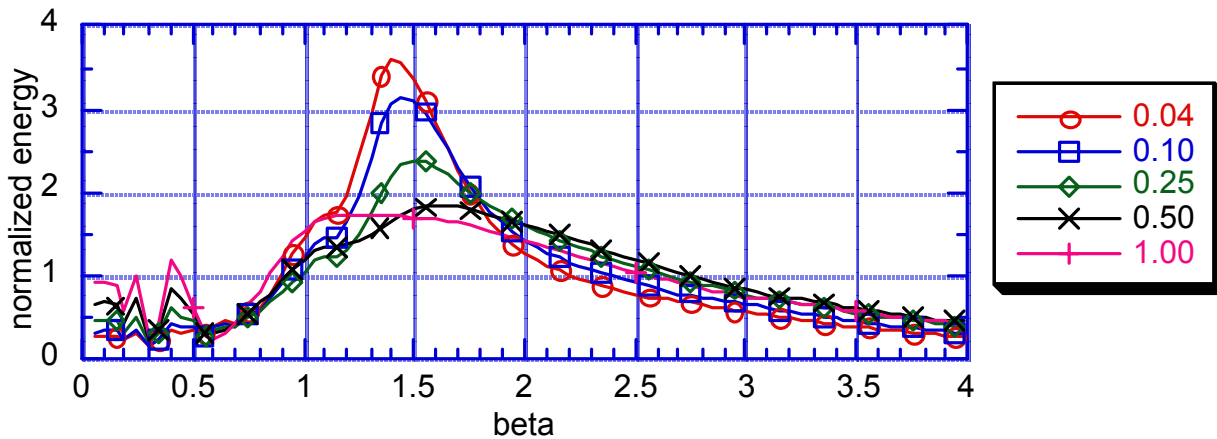
Figure 3. Effect of varying bottom attenuation (dB/λ) on the beta content of range-frequency images of intensity. Waveguide with sound speed profile. Source and receiver both located below thermocline at depth 50 m. Increasing the bottom loss flattens the distribution.

Figure 3 shows the effects of bottom attenuation. The lowest attenuation, 0.04 dB/λ, is consistent with observation made during the SWARM 95 experiment. As the attenuation is increased, the distribution becomes progressively more diffuse. The peak—if a distinct peak remains at all—also starts to shift to higher values of beta. Both effects can be explained by mode stripping. The higher order modes interact more with the bottom and so are more strongly attenuated. As they are stripped away, the detailed structure in intensity is lost, reducing the high wavenumbers and so flattening the peak.

IMPACT/APPLICATIONS

The concept of a waveguide invariant has enormous appeal. When valid, it says that the interference structure of the acoustic field can be largely characterized by a single scalar parameter. This parameter accounts for the dispersion properties of what could be a very complicated propagation environment. Beta constitutes a robust observable; while the details of the intensity striation pattern may change in time, a waveguide invariant should remain constant. The waveguide invariant has been proposed as a method for environmental characterization [Dozier, Wilson and Fabre; presented to EAST Peer Review, 2000].

TRANSITIONS

Our goal is to test the processing algorithm on field data and compare results to predictions. To date, we have acquired one data set and are in discussions to acquire more.

RELATED PROJECTS

Related ONR-sponsored investigations of the waveguide invariant are presented in the book edited by Kuperman and D'Spain [2002].

REFERENCES

L. M. Brekhovskikh and Y. P. Lysanov, *Fundamentals of Ocean Acoustics,* 2nd ed. (Springer-Verlag, New York, 1991), pp. 140-145.

S. D. Chuprov, "Interference structure of a sound field in a layered ocean," in *Ocean Acoustics. Current State*, edited by L. M. Brekhovskikh and I. B. Andreevoi (Nauka, Moscow, 1982), pp. 71-91.

L. B. Dozier, J. H. Wilson and J. Fabre, "Solving the inverse beta problem (IBP) using surface ships of opportunity." Presented to EAST Peer Review, Austin, TX (2000).

W. A. Kuperman and G. L. D'Spain, editors, *Ocean Acoustic Interference Phenomena and Signal Processing,* (AIP Press, New York, 2002).

K. L. Williams, F. S. Henyey, D. Rouseff, S. A. Reynolds and T. E. Ewart, "Internal wave effects on high frequency acoustic propagation to horizontal arrays: Experiment and implications to imaging," *IEEE J. Oceanic Eng*. **26**, 102-112 (2000).

PUBLICATIONS

D. Rouseff, "Quantifying the effect of shallow water internal waves on the waveguide invariant," (invited), *Proc. 17th International Congress on Acoustics,* (2001a).

D. Rouseff, "Effect of shallow water internal waves on ocean acoustic striation patterns," accepted to appear in *Waves in Random Media* **11**, (2001b).

D. Rouseff and R. C. Spindel, "Modeling the waveguide invariant as a distribution," to appear in *Ocean Acoustic Interference Phenomena and Signal Processing,* edited by W. A. Kuperman and G. L. D'Spain, (AIP Press, New York, 2002).