Marine Physical Laboratory

Geo-acoustic Stratification Deep in the Sea Bed from Ambient Noise in Shallow Water

M. Buckingham and G. Deane

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Abstract

The long-term objective is to develop a reliable ambient-noise inversion technique for obtaining the geo-acoustic parameters, including the stratification, of the sea bed from measurements of the broadband vertical coherence of the noise in shallow water. The method would be implemented in a free-floating instrument, self navigated with GPS, and consisting of a pair of vertically aligned hydrophones, to provide a cost-effective sensor system for collecting the required noise data over extensive areas of shallow water. The resultant bottom information would provide essential input to navy propagation loss models.

Scientific Objectives

The following scientific objectives are addressed: 1) most important, development of a new theory of fluid-sediment acoustics, which is consistent with all the available data on sediment acoustic and mechanical properties; 2) embed the new theory in the noise inversions for fluid-like sediments; 3) integrate a shipping noise model into the noise inversions; 4) develop a noise inversion for a shear-supporting bottom; 5) collect broad band noise coherence data from areas with well known bottom properties, including examples of fluid and elastic basements.

Background

The vertical structure of ambient noise in shallow water is largely controlled by the bottom reflectivity, which in turn is governed by the compressional parameters in the case of a fluid-like sediment and shear parameters in an elastic bottom. By measuring the vertical directionality (narrow band) or vertical coherence (broad band), the noise can be inverted to obtain the compressional and shear parameters of the bottom. Under ONR 6.1 support, this technique has been successfully developed to yield the compressional speed and the shear speed of an elastic basement, and the compressional speed and attenuation of a fluid-like sediment. A number of unique, very good quality noise-coherence data sets, extending from 50 Hz to 20 kHz, have been collected off the coasts of southern California (elastic bottom), northern California (fluid-sediment, wind-driven noise), and New Zealand (fluid sediment, wind noise plus ship noise), with very low self-noise hydrophone arrays that were designed and built at SIO. New noise inversion algorithms have been developed, which, when applied to the data, provide accurate estimates of the bottom parameters and, in particular, show significant differences between fluid and elastic basements. Supporting these algorithms is a new theory of sediment acoustics.

Approach

The research program has a strong theoretical component, which has lead to the development of a radically new treatment of the acoustic properties of fluid sediments. There is also a substantial experimental element, based on at-sea measurements of noise coherence using several different hydrophone arrays designed and built intramurally. The broadband data collected using these arrays are processed using dedicated noise inversion algorithms, which are based on the idea of matched-field processing but adapted to the ambient noise problem. Wind-driven noise and shipping noise are included in the algorithms.

Accomplishments and Results

1. Theory of sediment acoustics

To support the noise-inversion program, a new theory of the acoustics of unconsolidated marine sediments has been developed. The approach is unrelated to any previous theories, and links the acoustic properties (compressional wave speed and attenuation) to the mechanical properties (grain size, density and porosity) of the sediment. In a very natural way, t also accounts for the very significant anomalies observed in the reflection coefficient of saturated sediments.

2. Noise measurements, fluid sediment, Eureka, northern California

Working with Michael Richardson and the STRATAFORM research program in June 1996, superb quality, broad band (100 Hz to 20 kHz) noise coherence data were collected over a very well characterized, fluid-like bottom. The theory of shallow-water noise coherence that has also been developed, which incorporates the new sediment theory, shows an excellent fit to the data over the whole 20 kHz band. The complete package has provided a great deal of information on bottom properties and also, at the higher frequencies, about surface wave-breaking processes.

3. Noise measurements, fluid sediment, Hauraki Gulf, New Zealand

During December 1995 and January 1996, broad band ambient noise coherence measurements were performed in shallow water close to Hauraki Gulf, about 64 km north of Auckland. The bottom properties at the site are well known from previous surveys. At this location, individual ships tend to contribute to the noise field much of the time. A shipping plus wind noise model of the noise coherence has been developed which fits the data very well. The model has now been incorporated into our ambient noise inversion algorithms.

4. Noise measurements, elastic bottom, Cortes Bank, southern California

In March 1995 a set of wind-noise coherence measurements, from 100 Hz to 3 kHz, was taken in shallow water over exposed bedrock. The data have been inverted to obtain the compressional and shear speeds of the bottom, which is the first time that shear information has been obtained from ambient noise data.

Impact on Science and Technology

The noise inversion technique has a unique capability for providing bottom parameters for navy ocean-acoustic propagation models. The new theory of sediment acoustics is fundamentally important, since it ties together all the acoustic aspects of unconsolidated marine sediments, and resolves many outstanding issues, for instance the linear dependence of attenuation upon frequency, that are treated unsatisfactorily by existing theories of porous media.

Relationship to Other Projects

Our collaborative program with the Defence Science and Technology Organisation, Sydney, is continuing, with experiments planned for Spencer Gulf, Australia. Also, a MAST proposal has been submitted to the European Union, involving major laboratories in the UK, France, Greece, Italy and Denmark. The Italian partner is SACLANTCEN, the NATO laboratory in La Spezia.

Publications

1. M.J. Buckingham, "Ocean-acoustic propagation in an Arctic profile," in Computational Acoustics: Scattering, Supercomputing and Propagation (Elsevier Science Publishers B. V. (North Holland), Amsterdam, 1993), pp. 93-104.

2. M.J. Buckingham, "Spatial structure of ambient noise in shallow water," J. Acoust. Soc. Am. 94, 1825 (1993).

3. M.J. Buckingham, "Oceanographic inferences from ambient noise in the marginal ice zone," J. Acoust. Soc. Am. 94, 1760 (1993).

4. M.J. Buckingham and G.B. Deane, "Ambient noise oceanography: A new remote sensing technique for shallow water," J. Acoust. Soc. Am. 93, 2267 (1993).

5. M.J. Buckingham, "On surface-generated ambient noise in an upward refracting ocean," Phil. Trans. Roy. Soc. Lond. A 346, 321-352 (1994).

6. M.J. Buckingham, G.B. Deane, and N.M. Carbone, "Determination of elastic sea floor parameters from shallow-water ambient noise," (INVITED) in 2nd European Conference on Underwater Acoustics (European Commission, Lyngby, Denmark, 1994), pp. 19-25.

7. M.J. Buckingham, G.B. Deane, and N.M. Carbone, "Inverting ambient noise in shallow water for the bottom geo-acoustic parameters," (INVITED) in Full Field Inversion Methods in Ocean and Seismo-Acoustics (Kluwer, Lerici, Italy, 1994), pp. 347-352.

8. M.J. Buckingham, G.B. Deane, and N.M. Carbone, "Geo-acoustic surveying of the sea bed using ambient noise in the water column," (INVITED)in Computational Acoustics and its Environmental Applications Computational Mechanics Publications, Southampton, England, (1995), pp. 91-97.

9. M.J. Buckingham, G.B. Deane, and N.M. Carbone, "Estimating the geo-acoustic parameters of the seabed from ambient noise in the water column," in Second International Conference on Theoretical and Computational Acoustics (Honolulu, Hawaii, 1995),

10. M.J. Buckingham, "On causality and acoustic propagation in a viscous fluid," in Second International Conference on Theoretical and Computational Acoustics (Honolulu, Hawaii, 1995),

11. M.J. Buckingham, "Acoustic pulse propagation in dispersive media," (INVITED chapter)in New Perspectives on Problems in Classical and Quantum Physics (Gordon and Breach, 1995),

12. M.J. Buckingham and J.R. Potter (Eds.), "Sea Surface Sound '94 Proceedings of the III International Meeting on Natural Physical Processes Related to Sea Surface Sound," in World Scientific, Singapore, 1995), pp. 494.

13. M.J. Buckingham, "The acoustics of ocean waves," (INVITED) in IUTAM 19th International Congress of Theoretical and Applied Mechanics (Kyoto, Japan, 1996),

14. M.J. Buckingham and N.M. Carbone, "Source depth and the spatial coherence of ambient noise in the ocean," J. Acoust. Soc. Am. in press, (1997).

15. M.J. Buckingham, "Theory of acoustic attenuation, dispersion and pulse propagation in granular materials including marine sediments" J. Acoust. Soc. Am. in press, (1997).

16. M.J. Buckingham, "Acoustic reflection from a seawater-sediment interface," J. Acoust. Soc. Am. In review, (1997).

17. M.J. Buckingham, "The acoustics of ocean waves," International Journal of Acoustics and Vibration in press, (1997).

18. M.J. Buckingham, "Acoustics of granular materials including marine sediments," in Shallow Water Acoustics (INVITED) Beijing, (1997),

19. M.J. Buckingham, "Theory of compressional and shear waves in unconsolidated marine sediments," J. Acoust. Soc. Am. in preparation, (1997).

20. M.J. Buckingham, "Acoustics of marine sediments," in Proceedings of the Third International Conference on Theoretical and Computational Acoustics (INVITED), Newark, (1997),

21. N.M. Carbone, G.B. Deane, and M.J. Buckingham, "The compressional and shear wave speeds of a seabed in shallow water determined from ambient noise measurements," in Sea Surface Sound '94 (World Scientific, Lake Arrowhead, California, 1994), pp. 32-44.

22. N.M. Carbone, G.B. Deane, and M.J. Buckingham, "The continuous spectrum and ambient noise inversions in shallow water," in 128th Meeting of the Acoustical Society of America (Acoustical Society of America, Austin, Texas, 1994),

23. L.A. Crum and M.J. Buckingham, "Hot topics in acoustical oceanography," in 128th Meeting of the Acoustical Society of America (Austin, Texas, 1994),

24. G.B. Deane and M.J. Buckingham, "An analysis of the three-dimensional sound field in a penetrable wedge with a stratified fluid or elastic basement," J. Acoust. Soc. Am. 93, 1319-1328 (1993).

25. G.B. Deane, N.M. Carbone, and M.J. Buckingham, "Determining elastic seafloor parameters in shallow water using ambient noise," J. Acoust. Soc. Am. 94, 1802 (1993).

26. G.B. Deane, "Internal friction and boundary conditions in lossy fluid sea beds" J. Acoust. Soc. Am. 101, 233-240 (1997).

27. G.B. Deane, N.M. Carbone, and M.J. Buckingham, "Determination of the geo-acoustic parameters of an elastic seabed from the ambient noise field in the water column," J. Acoust. Soc. Am. in preparation, (1997).

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