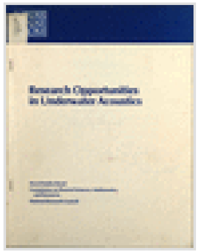

Research Opportunities in Underwater Acoustics (1986)

Pages
22

Size
8.5 x 10

ISBN
0309311535

Panel on Research Opportunities in Underwater Acoustics; Naval Studies Board; Commission on Physical Sciences, Mathematics, and Resources; National Research Council

NRC:NSB:021

RESEARCH OPPORTUNITIES IN UNDERWATER ACOUSTICS

Panel on Research Opportunities
in Underwater Acoustics
Naval Studies Board
Commission on Physical Sciences,
Mathematics, and Resources
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. June 1986

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

This work related to Department of Navy Contract N00014-85-G-0130 issued by the Office of Naval Research under contract authority NR 201-124. However, the content does not necessarily reflect the position or the policy of the Department of the Navy or the government, and no official endorsement should be inferred.

Copies available from:

Naval Studies Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

PANEL ON RESEARCH OPPORTUNITIES IN UNDERWATER ACOUSTICS

Robert C. Spindel, Chairman
Woods Hole Oceanographic Institution

Aubrey L. Anderson
Texas A&M University

Victor C. Anderson
Scripps Institution of Oceanography

David W. Hyde
Science Applications International Corporation

John J. McCoy
Catholic University of America

Chester M. McKinney, Jr.
Applied Research Laboratories

Peter N. Mikhalevsky
Science Applications International Corporation

Walter H. Munk
Scripps Institution of Oceanography

Navy Liaison

Craig E. Dorman
Office of the Chief of Naval Operations

Ronald N. Kostoff
Office of Naval Research

Edward Y. Harper
Office of the Chief of Naval Operations (Submarine Warfare)

Staff

Lee M. Hunt
Naval Studies Board

Naval Studies Board

Commission on Physical Sciences, Mathematics, and Resources

Herbert Friedman, Chairman
National Research Council

Clarence R. Allen
California Institute of Technology

Thomas D. Barrow
Standard Oil Company, Ohio

Elkan R. Blout
Harvard Medical School

Bernard F. Burke
Massachusetts Institute of Technology

George F. Carrier
Harvard University

Charles L. Drake
Dartmouth College

Mildred S. Dresselhaus
Massachusetts Institute of Technology

Joseph L. Fisher
George Mason University

William A. Fowler
California Institute of Technology

Gerhart Friedlander
Brookhaven National Laboratory

Edward D. Goldberg
Scripps Institution of Oceanography

Mary L. Good
Allied Signal Corporation

J. Ross Macdonald
University of North Carolina, Chapel Hill

Thomas F. Malone
Saint Joseph College

Charles J. Mankin
Oklahoma Geological Survey

Perry L. McCarty
Stanford University

William D. Phillips
Mallinckrodt, Inc.

Robert E. Sievers
University of Colorado

John D. Spengler
Harvard School of Public Health

George W. Wetherill
Carnegie Institution of Washington

Irving Wladawsky-Berger
IBM Corporation

Staff

Raphael G. Kasper, Executive Director
Lawrence E. McCray, Associate Executive Director

PREFACE

The Naval Studies Board of the National Research Council was asked by the Office of Naval Research (ONR) to establish and oversee a panel to advise on research opportunities with high potential for advancing the science and technology of underwater acoustics as it relates to the Navy mission. It was anticipated that the panel would provide an important source of input from the scientific and naval communities as ONR formulates long-range plans for underwater acoustics in its core programs and in advanced research initiatives. It was also anticipated that the panel would assist ONR in identifying and documenting promising research opportunities.

The panel is expected to meet on a three year cycle to provide periodic input and timely advice. At its initial meeting on May 4-6, 1986, the panel was briefed by ONR, the Naval Research Laboratory (NRL), and the Naval Oceanographic Research and Development Activity (NORDA) regarding acoustics projects and initiatives in the present Navy 6.1, 6.2, and 6.3A programs. The panel also met in executive session to consider these programs with respect to forefront initiatives, the advance of science and the Navy's interests, and to identify specific areas for promising research. This report presents the consensus of the panel's views concerning major research opportunities in underwater acoustics where significant scientific and technological advances in areas relevant to the Navy's mission can be achieved. The panel's interim findings were made available to ONR shortly after the May 1986 meeting so that they could be incorporated into the planning process. We hope this report will be a useful adjunct to ONR's continuing support of research in this important area.

Robert C. Spindel, Chairman
Panel on Research Opportunities
in Underwater Acoustics

INTRODUCTION

The Panel on Research Opportunities for Underwater Acoustics of the Naval Studies Board was asked to identify and recommend to the Office of Naval Research (ONR) significant and promising areas for underwater acoustics research. The panel met on May 4-6, 1986, to briefly review current initiatives in the Navy's 6.1, 6.2, and 6.3A programs and to evaluate these and other research choices with respect to scientific merit and relevance to national defense and the Navy's mission.

In making recommendations the panel is aware that ONR is the primary source of support for research in underwater acoustics. The Division of Ocean Sciences of the National Science Foundation does not have a program in underwater acoustics, although it has provided support for some recent acoustic tomography research because it has accepted tomography as a potential measurement tool for the ocean scientist. However, ONR maintains the only real commitment to ocean acoustics, and therefore is almost single-handedly responsible for the health, strength, and growth of this important discipline. Considering the nature of the threat, the urgent need for rapid and significant advances in fleet operations and tactics that account for ocean variability, and the need for fleet quieting and improved systems for detection, classification, and localization, the responsibility is great. It must be handled with imagination, a commitment to excellent programs and scientists, and an adequate and continuing financial base. While some of these issues are not the immediate purview of this panel, it will be impossible for ONR to capitalize on research opportunities unless these items are given priority. Of particular concern is the level of commitment; it may be insufficient to maintain a viable research effort within the academic scientific community. Experiment and validation are still fundamental parts of good science, and hence good underwater acoustics, yet ONR supports few academic laboratories capable of mounting effective acoustics field programs. We sense that academic ocean acoustics is beginning to lose the benefits of a young, vigorous research constituency, and we discern a lack of enthusiasm for choosing this career path. These are serious problems that must be addressed if ONR is to take pride in the further development of an underwater acoustics research community whose past contributions have been so important to the Navy and the nation, and whose future contributions are so vitally needed.

The panel is convinced that underwater acoustics plays a major and vital role in naval warfare and the security of the nation. It is central to submarine surveillance and operations; to detection, classification, identification, and localization of submerged and surface targets; to mine fusing and mine countermeasures; to torpedo measures and countermeasures; to navigation, map-matching, beacons, transponders, and ocean charting and geodesy; to underwater communications; to passive, active, and imaging sonars; and to spoofing and jamming devices. Each of these applications requires a solid, and often unique, base of scientific knowledge. The relevant parameters such as frequencies, time constants, propagation modes, controlling environmental factors, and signal processing algorithms can vary so widely between such diverse applications as passive submarine detection and active minehunting sonar, for example, that a research base adequate to the former may not be at all applicable to the latter. Thus, the Navy needs to examine each application in order to identify areas of basic research that will result in meaningful scientific and technological advances.

The primary role of 6.1 research according to panel consensus is to provide a scientific basis to assist the Navy in achieving its defense objectives. ONR's research programs should be in areas of long-term interest to the Navy, and they should be motivated primarily by scientific opportunities and the potential for obtaining new knowledge, rather than by immediate application. They should focus on understanding, measuring, and modeling fundamental physical processes; on inventing new devices and measurement methods; and on assessing the relevance of new science and technology to the Navy mission. Furthermore, the approach must be interdisciplinary, drawing upon the knowledge and work of research in, for example, oceanography, geology, geophysics, seismology, and signal processing. With these fundamental principles in mind, the panel believes further that although there is the potential for conflict between focusing 6.1 research on issues that are perceived to have either immediate or longer-term payoff with respect to the Navy's mission, and the important issues associated with the benefits of pursuing unfettered basic research, the broad scope of problems in underwater acoustics allows simultaneously for good science and responsiveness to Navy needs.

The panel has identified a number of areas that merit ONR support because they present opportunities for excellent underwater acoustics research, for innovative science, and for the improvement of the Navy's current systems, definition of future systems, and operational and tactical effectiveness. Underwater acoustics is vitally important to the security of the nation, and acoustics related to ASW (anti-submarine warfare) is of particular and crucial importance. Certainly a paramount issue is the Soviet submarine threat, which, for a variety of reasons, has become increasingly difficult to counter. Acoustic detection capability for the United States has decreased at an alarming rate, and a decade or more of substantial research and development in nonacoustic methods has not resulted in technologies that offset this decline. The United States still relies on acoustics, and for the foreseeable future will continue to do so. Fortunately, even though acoustic methods are less effective than before, and improvements are more difficult to achieve, there are still many promising opportunities for significant gains.

It is often stated that 6.1 research is an investment in the long-term future, a decade or more from laboratory to fleet. Certainly this is true in many cases, but it must not be forgotten that there are many instances where basic research has had immediate utility. Our rapidly evolving understanding of ocean dynamics and the effects of ocean variability on acoustic propagation are already altering fleet tactics and allowing better use of assets. Non-linear acoustics research gave rapid rise to parametric sonars. Fiber optic sensors and transmission lines are important elements in planned acoustic systems. Basic research is a resource for the present as well as the future.

SUMMARY OF RECOMMENDATIONS

The panel has identified a number of research areas that merit ONR support because they offer substantial potential for high scientific payoff as well as relevance to the Navy's mission. Almost without exception, parts of these recommendations can be found in the current 6.1, 6.2, and 6.3A programs. However, despite the fact that many projects bear similar or identical names, the panel emphasizes that it perceives that ONR is not addressing adequately the following issues, which are therefore all strong candidates for research initiatives.

- *Decoherence and probabilistic acoustics*--in which the stochastic part of the acoustic field that limits the ultimate performance of acoustic systems, especially at low frequencies and with respect to large arrays of two and three dimensions, is quantified.
- *Four-dimensional acoustic modeling*--in which sound propagation codes are coupled with ocean dynamical models to obtain a prediction capability of the acoustic environment extrapolated forward in time.
- *Sea floor acoustics research*--especially at very low frequencies (less than about 20 Hz) where the sub-bottom acoustic wave guide is coupled to the water column wave guide, and at frequencies up to several hundred hertz where the spatial variability of the internal geologic structure of the seafloor has a major effect on the acoustic field, and can cause temporal decoherence when sources or receivers are in motion. This study includes both shallow and deep waters and emphasizes the connection to geologic and seismic research.
- *Rough boundary scattering models*--included as a separate topic for emphasis, but in reality a subset of probabilistic acoustics.

The following sections present a more detailed description of these areas, their scientific basis, and their relevance to the Navy.

It should be noted that a number of excellent programs that warrant continued, generous, core support were brought to the panel's attention. An emerging program in structural acoustics and a more mature program in physical acoustics are examples. Geographical areas of acoustic research remain important because of unique characteristics; the Arctic is an example. Similarly, generic research areas must continue in the core program. In this context, the panel shares the concern expressed in the January 6, 1986, report of its predecessor panel--Committee on ONR Chemical Science Research Planning--"...that the growing role of research initiatives as a source of funds could lead to an emphasis on fashionable research areas to the detriment of stable support for areas of long-term importance to the Navy."

1. DECOHERENCE AND PROBABILISTIC ACOUSTICS

The panel is agreed that a recognition of the intrinsic variability of the ocean environment is essential to the development of realistic, useful, ocean acoustic prediction models, and to the development of efficient and effective naval systems. Further, a proper description of this variability must, on some level, be stochastic. Our current incomplete understanding of acoustic propagation and environmental effects limits deterministic predictions to systems of limited spatial extent using data processing algorithms involving short time averaging. The fundamental limits of passive detection and state estimation of acoustic signals propagated in the ocean are still largely unknown. Matched field processing, wherein the acoustic system takes optimal advantage of *a priori* knowledge of the propagating acoustic field, and the background noise field, will only yield significant gains if the probabilistic character of these fields is incorporated.

Estimates of coherence loss and measures of signal fluctuations that are a consequence of a variable ocean environment are necessary components of acoustic prediction models intended for discussing the performance of ASW and other acoustic systems. Historically, the required statistical estimates were introduced in an *ad hoc* fashion, and no attempt was made to relate these estimates to the environmental fluctuations that ultimately determine them. Recognition that mathematical models could be developed to relate the statistics of the acoustic signal to appropriate measures of the environment was achieved only in the last one to two decades. During the last ten years much has been achieved in relating some lower order statistical measures to fluctuations caused by a few ocean dynamic processes, principally internal waves. This success demonstrates that the goal of developing prediction models, based on measured environmental data and modeled oceanic processes, for estimating the statistics of fluctuating acoustic signals, is achievable.

The task is hardly complete. The research effort to develop a complete theory of probabilistic acoustics is in its infancy and will provide many challenges and opportunities in coming years. It is evident that progress in this area is essential to the Navy to assess technical, economic, and strategic trade-offs, and to implement effective systems, operational guidelines, and tactics in the future.

Initial research should focus on illuminating the fundamental physical limits of coherent array processing for detection and estimation of signal parameters at primarily low (<100 Hz) frequencies with large arrays of two-and three-dimensional topologies and on providing estimates of the expected strength and characteric lengths and times of target strength fluctuations at high frequencies (>10,000 Hz). Increased understanding of the low frequency research issues will impact on the design of future long-range passive systems. Increased understanding of the high frequency issues will impact on the design of short-range active systems. Unacceptable levels of target strength fluctuations have also been shown to contaminate target signature data obtained in sea trials. Broadband and narrow-band signals should be considered, and while low and high frequency domains are of primary interest, spatial and temporal coherence measures and probability density functions for acoustic signals in the intermediate band of frequencies are also important. Previous research has been focused on the intermediate band of frequencies, for which internal waves have been shown to be the dominant cause of the acoustic fluctuations. At both lower and higher frequencies, even the dominant fluctuation mechanisms are unknown.

Maximum performance will require adaptive signal processing techniques, which can include, in an optimal sense, all *a priori* knowledge of the propagating acoustic signal field and the structure of the competing noise field. This research is necessarily interdisciplinary, requiring strong coupling between ocean acoustics, physical oceanography, adaptive signal processing, and geology and geophysics (bottom interactions).

Maximum signal processing gains will only be achieved with detailed knowledge of the propagating acoustic field. Ocean acoustic tomography is making significant progress in quantifying the ocean mesoscale. Such knowledge can be used to develop and can be used in the four-dimensional acoustic codes discussed elsewhere in this report, which will predict the signal replica fields required for maximum likelihood or other adaptive methods. Fundamental research in the area of low frequency interaction with ocean internal waves is needed to assess the effect of these stochastic, unresolvable ocean dynamics on signal processing performance. The three-dimensional wave-number structure of low frequency ocean noise is also needed for inclusion in signal processing algorithms. Scattering and propagation within the bottom, which is discussed elsewhere in this report, particularly at low frequencies, must be understood and included in models. The effects of moving geometries, as they impact Doppler compensation and signal modulation from spatial anisotropy, both in the water column and the bottom, is another area of required research.

2. FOUR-DIMENSIONAL ACOUSTIC MODELS

The development of increasingly accurate and complex models for propagating the deterministic acoustic fields continues to receive a fair amount of research support. Justification for this effort is provided by the intrinsic mathematical interest of some of the newer methods and on the availability of increasingly more powerful computational capabilities. We suggest, however, that a more compelling justification may be in the possibility of their coupling with ocean dynamical models that can provide short-time forecasting of the sound speed field, required as inputs to the acoustical models. A coupled ocean dynamic and acoustic propagation model, possibly used in both a direct and inverse mode, would provide a predictive capability for extrapolating the acoustical environment forward in time which would amount to a step function increase in the performance of both.

The various sound propagation codes rely on some form of sound speed field interpolation, either two- or three-dimensional, depending on the sophistication of the model, to obtain a continuous sound speed field $c(x,y)$ or $c(x,y,z)$. An important point to make here is that the choice of field interpolation may be as crucial, or even more crucial, to the final result as the choice of propagation code. Codes that rely on various quadratic or cubic spline interpolations may be mathematically attractive, but they are not taking advantage of what has been learned about ocean perturbations.

An optimal procedure might be to fit the discrete data with empirical orthogonal functions that properly allow for the known horizontal covariance structure of the ocean and the relative prominence of the lowest ocean dynamic modes. One advantage of this type of fitting is the possibility of extrapolating into the future (in addition to interpolating the present). It is known that the significant ocean fluctuations occur within a week, making it better to predict the sound speed field using linear geostrophic dynamics to produce $c(x,y,z,t)$ rather than to use the propagation code for $c(x,y,z,o)$. If new $c(z)$ profiles are taken, they can be assimilated to produce an improved $c(x,y,z,t)$. The possibility of employing time- varying sound speed fields, based on knowledge of the physics of the ocean, accounts for the four-dimensional nomenclature.

The point can be made that there are interesting possibilities for real-time sound speed field updates. For example, in fleet operations there may be opportunities for acoustic transmissions from ship to ship whose relative positions are known with great precision. Any discrepancy between measured and predicted acoustic propagation carries useful information. This is the essence of ocean acoustic tomography, where the acoustic transmissions themselves are used to measure (or update) the sound speed field. Procedures for implementing such an interactive mode need to be explored.

In many instances one must rely on climatological sound speed, corrected possibly for seasonal variations. Under such circumstances the use of computationally intensive two- or three-dimensional codes may not be justified because generally the mesoscale perturbations are more intense than seasonal variations, and the range dependence associated with the mesoscale dwarfs the climatological range dependence.

In essence, the acoustic community must pay attention to the oceanographic community, and *vice versa*, in order to achieve efficient, accurate, reliable propagation models and codes.

3. SEAFLOOR ACOUSTICS RESEARCH

The seafloor is of major significance for many naval systems and operations. Sonar signals and ambient noise energy interact with the ocean bottom in a variety of still poorly understood ways. In the high frequency range of torpedo, minehunting, and echo-sounding sonars, bottom interactions are dominated by reflection and scattering from an abrupt interface or by reflections from layers or scattering from inhomogeneities within the first few meters below the seafloor. At the lower frequencies associated with geophysical exploration, some ASW sonars, long-range active and passive surveillance, and other Navy systems, a significant amount of acoustic energy propagates in part through the seafloor for at least a portion of its source-to-receiver path. For certain frequencies and operating geometries, the largest fraction of received energy arrives by way of sub-bottom propagation paths. In general, as frequency decreases, water depth decreases, and proximity of the system to the ocean bottom increases, the acoustical significance of the seafloor increases. The implications for the Navy are grave, and currently contribute to poor modeling, unexpectedly poor performance of existing systems, and an inability to fully evaluate future system performance.

To understand sound propagation in the ocean, especially at low and very low (<20 Hz) frequencies, it is necessary to have a thorough understanding of the seafloor as an acoustic wave guide, and of the coupling between the water column and sub-bottom wave guides. Considerable progress in developing such an understanding has been made in recent years, but additional research is required. The rate of progress will be directly related to the degree of interaction among several research communities: ocean acoustics, geophysics, geology, and seismology. Although there have been instances of cooperative efforts, the benefits of a large-scale, sustained effort have not been realized. It is in the Navy's best interest to promote such collaborative research aimed at answering such pertinent questions as the following: where does the energy travel, what wave types carry the energy, how does energy couple among wave types, how does energy couple into and out of the wave guide, what sensors and sensor locations are best for detecting signals and rejecting noise, what parameter descriptions are necessary for numerical simulations, what measurement techniques are available, what geological models best describe the environment and allow extrapolation of results? The answers to some of these questions have been sought by various elements of diverse research communities. Some may be at least partially known. But major questions are still outstanding, and their resolution is essential for optimum performance of the Navy's acoustic systems.

Even at higher frequencies, up to several hundred hertz, the internal geology of the seafloor can be a dominant factor in the spatial and temporal coherence of underwater sound fields over the continental shelves and slopes, sea mounts and ridges. These are typically highly complex environments with a great deal of spatial variability of seafloor geology. The geology itself does not, of course, vary over the time scales of interest in underwater acoustics, but the spatial variability of the seafloor and sub-bottom environment contributes to significant temporal variability of the acoustic field when sources or receivers are moving.

Progress can be made in several important areas. The capabilities of new measurement tools and techniques, combined with inverse theory, should be thoroughly examined with regard to their capacity to provide high resolution of the internal geology of the upper few hundred meters of the seafloor. Results should be combined with limited sampling by coring and drilling and should be incorporated in geologic, acoustic, and geoacoustic models. The ability of geologic models to provide geoacoustic seafloor descriptions should be tested. Geologic models are potentially powerful tools for geoacoustic modeling.

Finally, improved models are required to deal with scattering at very high frequencies or at interfaces with large discontinuities in acoustic impedance. Here, penetration of the acoustic field into the bottom is negligible. Examples include forward and backward scattering from the rough seafloor, scattering of energy within the seafloor from the rough basalt basement, and scattering from the seafloor for active, bistatic geometries. The subject of scattering is covered under the heading of *Decoherence and Probabilistic Acoustics* in another part of this report.

4. ROUGH BOUNDARY SCATTER MODELS

The development of rough surface scatter models is properly a part of a complete theory of probabilistic acoustics, but we consider it separately because it is common to do so, and because we wish to draw several distinctions between boundary and volume scatter applications. In general, our theoretical understanding of rough boundary scatter lags that of scattering by volume processes. Our understanding of scattering at the ocean surface is probably the most advanced, but even here it is limited to the lowest order statistical estimates such as scattering strength. Estimating the loss of coherence across horizontal arrays positioned broadside to an incoming signal is beyond the scope of current theory. Our ability to model the statistics of signals scattered from the seafloor or the under-ice canopy is even more limited. There are many opportunities here for innovative, exciting, and relevant research.

The success of any program in this regard that does not have a strong component aimed at obtaining a reasonably complete description of the morphology and properties of the boundary of interest, whether seafloor or ice, has little chance of being practically useful. Also, there appear to be few new ideas for the practical extension of the simplest of boundary scatter models to account for experimental observations. Thus, the articulation of a research issue in this context is not sufficient justification for support without establishing a reasonable measure of confidence in its possible success.