NOAA Workshop on

OCEAN ACOUSTIC REMOTE SENSING

Seattle, Washington – January 21-24, 1980

Volume II
Presentations and
Working Group Reports

April 1980

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Chairman

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Rockville, Maryland 20852

OCEAN ACOUSTIC REMOTE SENSING WORKSHOP

VOLUME II. PRESENTATIONS
AND WORKING GROUP REPORTS

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FOREWORD

This is Volume II of a two-volume record of the NOAA Workshop on Ocean Acoustic Remote Sensing held in Seattle, Washington, on January 21-24, 1980. Volume I provides a concise summary of the Workshop conclusions and recommendations, as well as summary reports of the discussions of the four Working Groups on Climate and Weather, Fisheries, Ocean Pollution, and Ocean Services. Volume II contains the programmatic and technical presentations made at the Workshop, as well as the complete Working Group reports. These documents were edited only to the extent of eliminating obvious typographical errors. In the interests of expediency, compactness and time-saving, no attempt was made to achieve uniformity of paper structure. Figures were left in the "raw" form since these would take the greatest expenditure of time and money to redraft. Nor have the discussions following the presentations been included. It is felt, however, that the overall product does reflect quite accurately the supporting documentation available to the Working Groups of the Workshop in helping them reach their conclusions and recommendations.

Some caveats are in order here. This volume is considered a NOAA internal report with a limited number of copies. It is not meant to be quoted as a publication. Many of these papers may have been or are to be published elsewhere with copyright protection. Be advised also that the organizational identifiers for some of the NOAA participants have been changed since the dates of the Workshop.

Morris Schulkin
Technical Editor

ACKNOWLEDGMENTS

It is important to acknowledge the indebtedness of the Workshop Steering Committee to the non-NOAA speakers and participants who contributed their expertise freely and enthusiastically. We are also indebted to the NOAA participants who contributed the leadership and dedication in addressing the Workshop tasks. Finally, we acknowledge the sustained effort of the Washington Sea Grant personnel who handled the extraordinary typing and support activities to keep the Workshop operating smoothly and happily. Headed by Sue Latourell, they also devoted many post-Workshop hours to produce and distribute these reports.

Support for this Workshop and publication of this report were provided by Grant No. NA79AA-D-00054 from the National Oceanic and Atmospheric Administration to the Washington Sea Grant Program.

Additional copies of this publication may be obtained from Washington Sea Grant, Division of Marine Resources, University of Washington HG-30, Seattle, WA 98195.

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April, 1980

OARS Paper #1

INTRODUCTION

by
Stanley R. Murphy, Workshop Chairman
Division of Marine Resources
University of Washington

This Workshop began as a result of a recommendation from the Remote Sensing Workshop held in Estes Park in August last year that there be a serious and careful look at the opportunities and potential of acoustic remote sensing techniques for ocean observations as an adjunct to and a supplement to the work that is going on in the electromagnetic area.

A Steering Committee was established--a very fine group--that in turn planned this Workshop. I'd like to mention the names of the Steering Committee because these are people that you can call on for assistance during the course of the next four days: Dr. Gordon Little, Director of the Wave Propagation Laboratory; Dr. John Proni, from the Atlantic Oceanic and Meteorological Laboratory; Dr. Robert Bunney from the Office of Ocean Engineering, on assignment to the Applied Physics Laboratory at the University of Washington; Dr. Andy Kemmerer from the National Fisheries Engineering Laboratory; Dr. Ron New from the National Ocean Survey; Dr. Morris Schulkin, on my left, from the Applied Physics Laboratory, University of Washington, who is the technical Program Chairman of the Workshop. He will be available to Workshop working group chairmen to assist wherever possible for reaching a successful conclusion.

The Workshop is organized in four major program areas: Climate and Weather, Fisheries, Ocean Services, and Ocean Pollution. Dr. Mike Hall from the Office of Ocean Engineering is Chairman of Climate and Weather; the Assistant Chairman is Dr. Don Hansen from AOML. The Fisheries Chairmen are Dr. Paul Smith from the Southwest Fisheries Center, and Andy Kemmerer, who is also on the Steering Committee. Ocean Services has Dr. Stan Alper from the Office of Marine Technology, assisted by Morris Ringenbach, Engineering Development Laboratory. And finally, for Ocean Pollution, Dr. John Proni will chair that working group; the Assistant Chairman is Capt. Lawrence Swanson from the Office of Marine Pollution Assessment (later replaced by Dr. W. Woodward, Office of Ocean Engineering).

Each of you has a list of the participants that have been invited. This list is in two forms. One list is alphabetical; the second form is a list of participants by assignment to working groups. The Steering Committee asks that each of you assigned to a working group work with that group. Each chairman or assistant chairman of a working group will establish the proper and appropriate liaison with the other groups and you may be asked to assist in that liaison function. But we ask that each of you begin your work with the working committee as assigned. There is also a list of working group tasks established by the Steering Committee. Each chairman has been encouraged to establish more specific objectives and tasks for the special groups that they chair. Many of you have been contacted by the chairmen in that function.

We have a little over a day and a half of interesting speakers as input to the Workshop itself. Each speaker has been asked to, if at all possible, provide an extended summary of his remarks and copies of the important illustrations that can be a part of the record of the Workshop. Each speaker has 30 minutes to make his presentation and 15 minutes for discussion and questions. The questions and discussion, of course, are in many ways an extremely important aspect in providing inputs into the working groups themselves. The sessions today and tomorrow will be recorded so we will be able to go back and reproduce particularly the discussions resulting from the presentations.

Speakers were, of course, chosen both from outside NOAA and inside NOAA as representing a cross section of the area or field of acoustic remote sensing from the technological, scientific, requirements, and/or programmatic points of view. We are very fortunate to have as our first speaker Mr. James Walsh, Deputy Administrator of NOAA, who will give us some remarks and comments on NOAA Program Missions and Requirements that relate to the area of Ocean Acoustic Remote Sensing. So it is my pleasure to introduce as our first speaker Mr. James Walsh.

OARS PAPER #2

Remarks of

James P. Walsh
Deputy Administrator
National Oceanic and Atmospheric Administration

Ocean Acoustic Remote Sensing Workshop
January 21, 1980; Seattle, Washington

This is an unusual opportunity for me. Over the next several days, you will be discussing in this workshop a highly technical subject--ocean acoustic remote sensing. Stan Murphy has asked me to provide an overview of the missions of the National Oceanic and Atmospheric Administration as they relate to applications of this sophisticated technology.

My perspective will, of course, be that of a manager, and not of someone with the familiarity of ocean acoustics that most of you possess. But I do welcome the opportunity to study the technology and questions you are addressing this week. I am continually confronted with management and budget decisions which require a working knowledge of a variety of technological systems.

In general, as I understand it, the purpose of this workshop is to review the state of the art in ocean acoustic remote sensing and to identify specific applications to NOAA missions in four areas: (1) climate and weather; (2) fisheries; (3) ocean services; and (4) pollution.

What I would like to do this morning is, first, provide an overview of NOAA missions that might use applications of acoustic remote-sensing and, second, comment generally on the problem of managing programs utilizing evolving technology of this sort.

Most of you work for, or are fairly familiar with NOAA. But I would like to say a few words about the general character of our agency. This year--1980--marks our tenth anniversary, although our origins can be traced back to Thomas Jefferson and 1807. Oceanic and atmospheric science and services on behalf of and for the nation was the overriding mission of the several agencies brought together to create NOAA by Presidential Reorganization Order #4 in 1970.

Since that time, new statutory programs--all in the broad areas of oceans and atmosphere--have been enacted not only expanding NOAA's traditional science and services missions but adding new resource management, regulation and enforcement responsibilities. To this day, the strength of our agency remains our science and services base, which provides the knowledge and expertise to deal with our management missions.

Let me briefly expand on our missions and identify where ocean acoustic remote sensing might serve those missions. I do not intend my remarks to be all-inclusive of such applications, but illustrative of present uses and some opportunities.

Fisheries. Of all of NOAA's agencies, the National Marine Fisheries Service has experienced the greatest change in its fundamental purpose over the last ten years. With passage of the Marine Mammal Protection Act and the Fishery Conservation and Management Act, NMFS took on some extremely difficult management tasks and has had to evolve away from its previous primary role of research and service to the States. As a result, we have become the nation's principal fishery manager, with all the problems that job brings. The needs of management have also placed enormous pressures on our fishery research program, in particular stock assessment. Fishing effort is increasing faster than catch, since U.S. fishermen are still concentrating on the traditional high-value, low volume fisheries. What this all means is that our fishery assessment techniques are put in great strain to be more precise to allow more refined allocations among fishermen and a more defensible overall cap on fishing effort--e.g., optimum yield. Knowing what fish stock size will be next summer still remains educated guesswork. We are not even certain what's in the ocean right now.

With the need to know about fish stocks more critical economically and politically, we might find more efficient and more effective techniques for assessing the abundance, composition, location and condition of fish stocks. The need for information and knowledge extends to those factors in the marine environment that influence fish stocks. Consequently, the regional fisheries centers are continually searching for new methods, new techniques and new theories to do stock assessment. The use of acoustic remote sensing can help. Determining how much is the goal of this conference. To the extent remote sensing can either add to our tools, or improve the tools we now use, we in NOAA must move quickly to use the technology.

There may be other applications in marine mammal assessment, which remains more difficult than fish stock assessment because there is almost no harvest data for marine mammal stocks and their wide range. Perhaps you will also focus on this problem as well.

Climate and Weather. Combining these two mission areas creates a problem. Our mission in weather services is greatly different from our climate role. Our weather services require a major operational, near real time technological system. Our climate responsibilities are basically research-oriented, at least as it may relate to acoustic sensing in the ocean.

Our fundamental role in weather is to provide information, in particular warning of severe weather, to the public in time for them to use it. We are seeking to expand our ocean weather services to include useful forecasts of storm surge, waves, regional coastal winds, ice, and currents in our coastal zone. Our remote sensing work has concentrated on those technologies that use the electromagnetic spectrum, in particular satellites, skywave radar or aircraft sensors. At present user needs place greater demands on surface weather phenomena. And lacking the surface observational system present on land, we are struggling to find ways to obtain surface weather data from remote sensing. Subsurface data is becoming important to us as well, particularly in heavily used and populated coastal areas. But in our basic need in ocean weather services, except perhaps for currents, ocean acoustics may play a smaller role than other remote sensing techniques. You may determine differently after this workshop.

Our role in climate is research and information services. One of our research emphases is sea surface temperature analomies. Acoustic remote sensing may help in understanding this phenomenon.

Ocean Services. I spoke of ocean weather services earlier. By the term ocean services used in this workshop, I assume the prediction of waves, currents, and tides but also mapping and charting of geophysical features on our continental shelf. The National Ocean Survey (NOS) plays a large role in this area, along with the National Weather Service. NOS is another service organization which seeks new ways to improve their tide, current and wave monitoring programs. And NOS is seeking to develop techniques for acoustic sensing of currents.

We are now utilizing swath sonar to add to our efforts to improve bathymetric charts. It promises to simplify and improve greatly our present ship- and labor-intensive method of locating contours on the sea floor. Improved efficiency of a routine service program is the result.

Pollution. As most of you know, NOAA has gained a large role in directing the federal government's marine pollution research and monitoring program. We also have a sizable pollution research program, about $50 million per year. We play this as a result of statutory authorities such as the Fish and Wildlife Coordination and the Ocean Dumping Acts, and simply because our other agencies need expertise, for example the OCSEAP program founded by the Bureau of Land Management.

We are presently utilizing acoustic sensing in our pollution programs. John Proni will speak about his ocean dumping monitoring work. For large-scale pollution events, the application is not too clear, but perhaps in a week it will become clearer.

Other areas of application may exist, for example in fishery enforcement, but these are the principal NOAA mission areas in which acoustic remote sensing is now used or looks promising.

Let me finish with a few general comments on factors I see as being important in your "brain-storming" effort. First, please be mindful of economies. If off-the-shelf technology exists, by all means we should adapt it to our needs and then use it. This includes not only the technology itself but also the support systems that will be needed to apply the technology--data management, communication, etc. These support systems are likely to be different for research and operations.

Secondly, and along the same line, technology transfer between the military and our civilian agencies is a key problem. Stan (Murphy) has charged you with examining this issue. I know these are classification constraints but in some cases this may be a perceived rather than real hindrance. We need to communicate more with the Navy to find out what can be done.

That, I hope is the overview that initiates a good discussion of this subject. We in NOAA recognize the need to embrace new technologies not only to expand our research capabilities but to make our basic service programs more efficient and effective.

Thank you.

OARS Paper #3

HOW TO MONITOR CLIMATE VARIATIONS BY MEASURING THE OCEAN

by

J.O. Fletcher

Environmental Research Laboratories/NOAA

Our purpose here is to consider the prospects and needs for monitoring ocean variability.

One of the reasons for observing ocean variability is to follow the development of climate processes. Unfortunately, we don't know what those processes are. How do we find out?

Every climate plan has a statement that the ocean is the memory and flywheel of the coupled ocean/atmosphere system.

The atmosphere has a very short memory, it responds quickly to a change in thermal forcing, but the ocean has thousands of times the heat capacity, hundreds of times the mass and several times the momentum. Its present state should reflect the forcing by the atmosphere over a considerable time. The two fluids are closely coupled, with each forcing the motion of the other in important ways--so we have good reasons to suspect that the ocean is the memory and the flywheel and that we should monitor its variability to gain insight to the behavior of the coupled system.

So what do we monitor? Do we disperse our efforts over the whole ocean or do we focus on particular areas? Can we identify particular areas which exhibit large climate signals? If so, do we know what they mean? What is the time scale of their variability? Do we need to observe them daily, weekly, monthly or yearly? With what accuracy? On what spacial scales?

To answer these kinds of questions, we must know something about the anatomy of climate variability. Does the coupled system exhibit coherent behavior? Are there characteristic modes of fluctuation which recur again and again? If so, how are they manifested? What are their oceanic signals?

To investigate these questions, we have examined the century-long data base known as the marine deck, extending from 1861 to 1960. The summary tape for this data set contains sea surface temperature (SST), wind direction and speed, air temperature and a few other things, enough to describe the changing patterns of these fields in space and time over the world's oceans.

We ask of this data set, "are there coherent modes of fluctuations which repeat themselves? If so, how many? What behavior do they exhibit in space and time? What is the location and magnitude of their most characteristic signals? What kind of measurement, with what accuracy, over what space and time scales, is needed to monitor their behavior?"

Preliminary analysis indicates that two coherent modes of fluctuation account for most of the observed variability in sea surface temperature and in the atmospheric fields. Both are global in spacial extent; both appear to be basically autofluctuations of the coupled ocean/atmosphere system, influenced to some degree by external forcing not yet identified.

One mode of fluctuation is manifested by individual anomalous years. It recurs on a time scale of 3 to 6 years during some climate epochs (before 1900 and after 1940); less frequently during other climate epochs (1900 to 1940). It is associated with long-recognized climate fluctuations such as the southern oscillation and the "El Nino." The largest SST signals occur in the eastern equatorial Pacific, particularly the latitude zone 0-10^{o}S, although coherent patterns of SST anomaly can be seen over the entire Pacific and Indian Oceans (the Atlantic is not included in the data set used).

Although much additional investigation is needed to understand the ocean's behavior in this mode of fluctuation, preliminary estimates of monitoring requirements suggest that for SST patterns appropriate resolution in time is one month and in space several hundred kilometers.

In relative temperature a resolution of $\pm 1^{o}$C is needed, preferably $\pm 5^{o}$ over the space and time scales indicated. In theory, these requirements can be met by contemporary satellite sensors; in practice, further refinement of techniques for data reduction is required.

The second mode of fluctuation of the coupled ocean/atmosphere system seems to operate on a time scale of about a century. Thus, the evidence that it is a recurring mode does not come from the marine deck but rather from proxy indicators for which there is a long time sequence; for example, discharge of the Nile River (since 622 A.D.) and air temperature in a New Zealand cave derived form isotope analysis (since 1000 A.D.). Such proxy indicators suggest that the "century scale" fluctuation does recur, although its duration and amplitude is variable (50 to 90 years from 600-900 A.D., no occurrence from 900-1200, more than 120 years after 1200 and about 120 years since 1700). The available marine data set allows us to explore the anatomy of the fluctuation since 1861. (In the audio visual presentation at the workshop, coherent changes in atmospheric and SST fields for both the century scale fluctuation and the interannual fluctuation were illustrated.)

The most striking features of the century scale fluctuations are as follows:

THE ATMOSPHERE: The overall vigor of the global atmospheric circulation fluctuates from high (1860-75) to low (1920-40) to high (1965-present). The wind stress on the ocean during a period of high vigor is at least twice, probably three times greater than during the period of low vigor. Although the general global trend is relatively smooth, abrupt changes of large magnitude are reflected in the most energetic features of the atmospheric circulation, especially in the Indian Ocean sector, where about 1875 the trade winds decreased abruptly, and in 1902 the mid-latitude westerlies decreased abruptly (more than halving wind stress on the ocean).

During periods of high circulation vigor the Asian monsoon is extended farther east and the subtropical highs are crowded toward the equator and displaced westward.

THE OCEAN: The ocean surface temperature fields reflect basin-wide coherence, evolving in time over the whole century. The largest signals appear in the latitudes 40-50°S and 35-45°N. The general evolution is most conspicuous in the southern hemisphere circumpolar current and is highlighted by the following sequence. In the 1860's, the Antarctic circumpolar current (ACC, 40-50°S) was warm relative to the century mean. About 1870, it became abruptly colder in the New Zealand sector and in following decades this coldness spread to encompass the entire circumpolar flow, the southeast Pacific and, from 1900 to 1940, the equatorial ocean. In 1917, a warm anomaly appeared in the same region in which the cold anomaly had appeared in 1870. In following decades, it spread and intensified in patterns similar to the spreading and intensifying of the previous cold anomaly, embracing the equatorial latitudes early in the 1940's. The sparse data south of 50°S indicate that these anomalies, which appear first in the Australian/New Zealand sector, develop earlier at higher latitudes and move into the region from high latitudes.

As a first step in gaining more understanding of this observed sequence of events and for designing an ocean climate monitoring system, the following straightforward modeling experiments are needed. To elucidate the striking ocean variability described above, a global ocean circulation model should be forced by the observed surface winds from the data set (mean montly values for each data square since 1861). It is expected that the ocean model behavior will exhibit the sequence of SST anomalies reflected in the data set. If so, then the internal dynamics of the model should reveal the processes by which these anomalies develop; the response to wind forcing, the time lags, and where and how to monitor the most revealing signals. Quite independently, a global atmospheric model can be used to simulate atmospheric behavior during extremely different patterns of SST exhibited by the data set, say the 1920's decade compared to the 1970's decade, in an attempt to simulate the different climatic characteristics of these different epochs. Such an experiment should yield insight to feedback on the atmosphere of changing ocean SST patterns.

Pending these further investigations, we can make some preliminary estimates from the data set of how to monitor climate by observing the ocean. To follow the development of the century scale fluctuations, it appears most feasible to monitor the SST anomalies described above which develop first poleward of 50°S, then in the 40-50°S zone, most strongly in the New Zealand sector of the ACC, later spreading across the S. Pacific. This could be done by a combination of SST maps (derived independently from satellite and ship sources until the two agree) and North-South hydrographic sections south of New Zealand. Wind stress over the southern ocean can be computed form surface weather charts and the gross response of the ocean can be monitored by a few pressure gauges distributed across the circumpolar flow. The time resolution needed for SST is probably not more than a season (3 months) and the space resolution a few hundred kilometers. The accuracy for this space and time scale should be better than $\pm .5^{o}C$, preferably half of that.

In conclusion, I would emphasize that to monitor climate by measuring the ocean we must know what ocean processes we are measuring, and what their relation is to global climate changes. This seems quite feasible to do. The "shotgun" approach, measuring all possible things in all places, is not only unfeasible but unnecessary. Secondly, I would emphasize that the reason we observe the ocean to monitor climate change is that the more ponderous ocean has greater thermal and mechanical inertia and responds more slowly and with greater coherence than the atmosphere. It follows that we do not need great resolution in time or space because averages over a few hundred kilometers and a season are probably good enough. The accuracy needed depends on the particular feature we are monitoring and the size of signal associated with it and is thus not the same for different parts of the ocean.

OARS Paper #4

OCEAN ACOUSTIC TOMOGRAPHY: A METHOD FOR MEASURING LARGE-SCALE VARIABILITY

by Walter H. Munk
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University of California, San Diego

1. We have formed a joint venture to study what we have called "ocean acoustic tomography." Our group consists of Bob Spindel and his associates at WHOI, Carl Wunsch and his associates at MIT, Ted Birdsall and Kurt Metzger at the University of Michigan, and our group at Scripps (Peter Worcester, John Spiesberger, Mike Brown, Bob Knox and Walter Munk). We are working closely with AMOL/NOAA; David Behringer of that laboratory will be participating in a major experiment in spring 1981.

2. The basic idea behind ocean acoustic tomography is to use variable travel times from many acoustic sources to many acoustic receivers as a way of inferring the changes in the interior ocean. The emphasis is on mesoscale processes, with typical scales of 100 km and two months.

3. Figure 1 shows the result of an experiment conducted in October 1978, for a 1000 km transmission path from a moored receiver southwest of Bermuda. We have resolved about 12 multipath arrivals, and these are stable over the two-month period of the experiment. The tides are faintly visible as small wiggles.

But the important things are the slow variations in travel time. Because of some clock problems, the only thing that can be used in Figure 1 are slight variations in the relative travel times, and these can be discerned by glancing from left to right along the figure. But in a subsequent experiment conducted in April 1979 to the northwest of Bermuda a meander of the Gulf Stream came into the path of the transmission and left a very noticeable imprint on the travel time pattern (Figure 2).

4. Figure 3 is a schematic indication of what we are trying to do. The upper path shows the circulation pattern as it would appear from a long-term average of two years or more. The lower cycle shows the situation at any given time. We might consider these two displays as corresponding to climate and weather. One purpose of acoustic tomography is to monitor the ocean with sufficient resolution so as to give the equivalent of weather maps.

5. Once the matrix of travel time perturbations has been observed, we use the formalism of inverse theory to construct the best possible maps of the interior ocean. Here we mean by "best possible" that

particular field which is consistent with the observation and has the minimum wiggliness. For details, I would like to refer you to Munk and Wunsch.*

6. Figure 4 shows a result of inverse theory from a numerical experiment. Figure 5 shows similar considerations in a vertical plane; here the aim is to apportion the distribution in depth of any travel time perturbations. Taken together, one ends up with a three-dimensional chart of sound speed perturbations.

7. We are planning a major experiment in early 1981. This will consist of 4 sources and 5 receivers, plus some transmissions to 4 remote stations. Some of the arrangements are indicated in Figures 6, 7, and 8. David Behringer of NOAA will be making some CTD surveys at the beginning, middle, and end of the experiment. The Navy will also take some AXBT sections.

8. Even if this experiment should prove reasonably successful, there are many problems that need to be looked into before one could even think of an operational system. I will mention a few experimental problems. We would like to develop a broadband source to improve the resolution of multipaths. We are now limited to 50-sec resolution. We would like to study reciprocal propagations and use the difference in travel time as a means of measuring the velocity of flow. We will experiment with stiffer moorings to see whether the present method of position-keeping (which is expensive and a nuisance) could be dropped. We shall also experiment with acoustic communications to get the data ashore in "real time."

9. Along theoretical lines, we are trying to learn how much better we can do to use the entire received signal instead of just the travel times of the resolved arrivals. With regard to inverse theory, we need to learn about the trade-off between better dynamic models and actual hardware for the measurements.

10. In 1983, we are planning to conduct a local experiment using the tomographic tool. This experiment is to be dictated by its oceanographic importance and not by the development of the tool itself. One possibility is to measure the stability of the equatorial undercurrent. Such an experiment would fit into the ongoing plans for equatorial studies in the early 1980s. The details of such an experiment need to be worked out.

11. The ultimate goal is to observe the ocean to mesoscale resolution on the scale of an ocean basin. We are vaguely thinking in terms of conducting an experiment along these lines in 1985. As we now see it, such an experiment would work in close conjunction with a satellite-borne radio altimeter. Satellite altimetry and acoustic tomography complement one another rather nicely; the altimetry ought to give a good first estimate of positions of the larger ocean eddies, and the tomography should give information concerning the continuation of these features into the interior ocean.

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*Munk, W.H. and C. Wunsch (1979) Ocean acoustic tomography: a scheme for large scale monitoring. Deep-Sea Research 26A, 123-161.

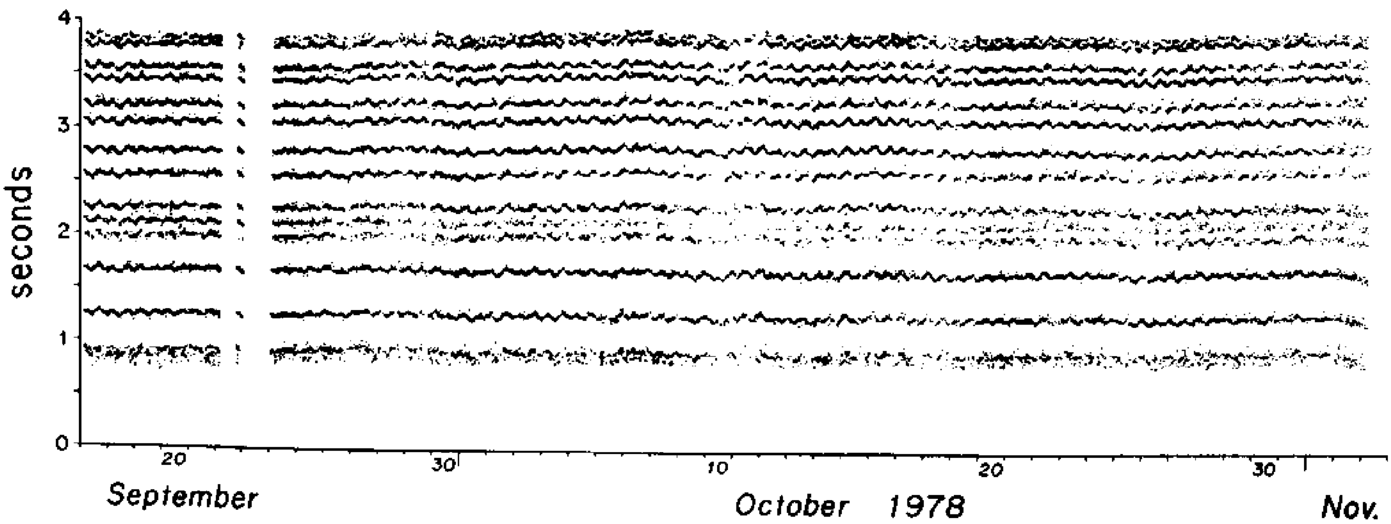


Figure 1. The relative travel time of multipath arrivals at 10-minute intervals over a 48-day period (except for five gaps) for the Fall 1978 experiment. The transmission was over an 850 km range from a moored source southwest of Bermuda. The figure displays 14 selected multipaths for peaks having signal-to-noise ratios larger than 10 dB's, with dot size proportional to this ratio. The two cycle per day oscillation evident on all multipaths is due (apart from mooring motion) to the barotropic tidal current component along the source-receiver line. (From Spiesberger, J.L., R.C. Spindel and K. Metzger (1980) Stability and identification of ocean acoustic multipaths. Submitted to J.A.S.A.)

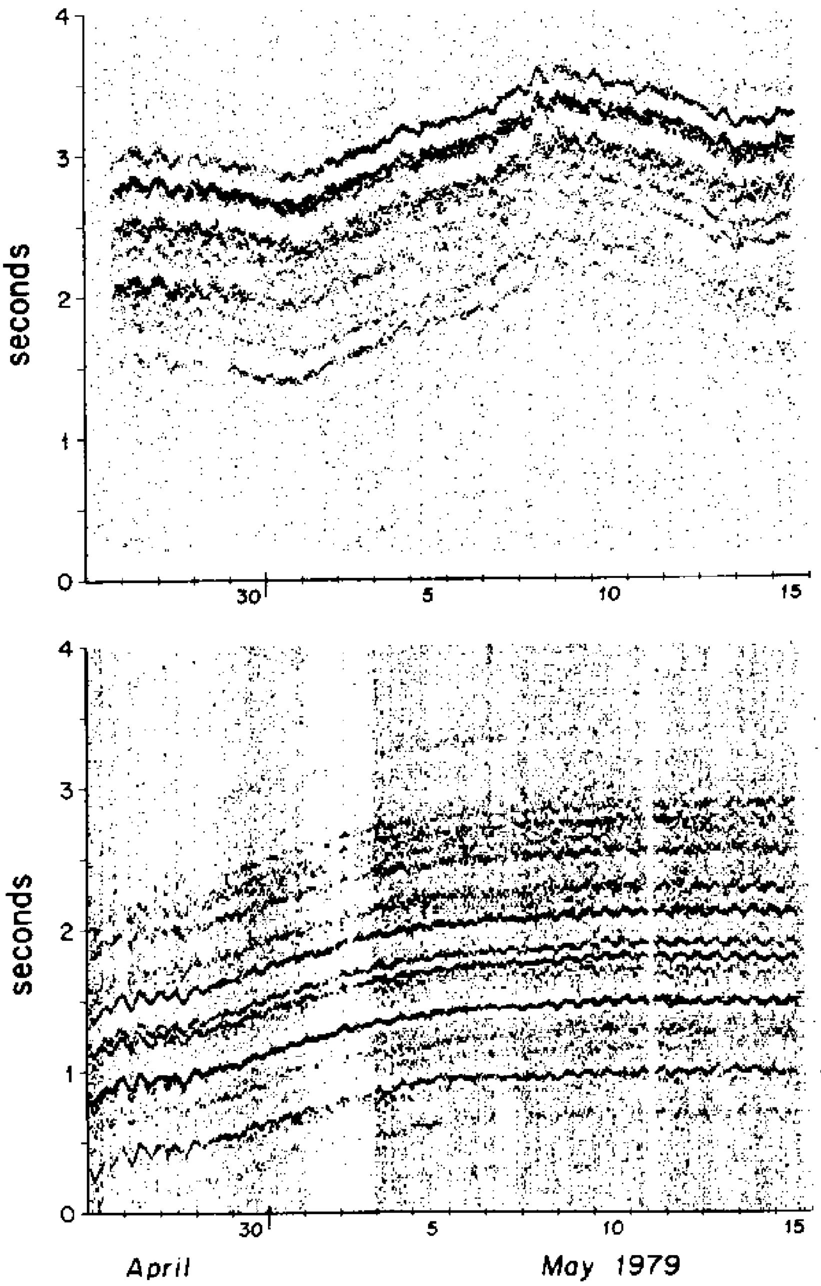
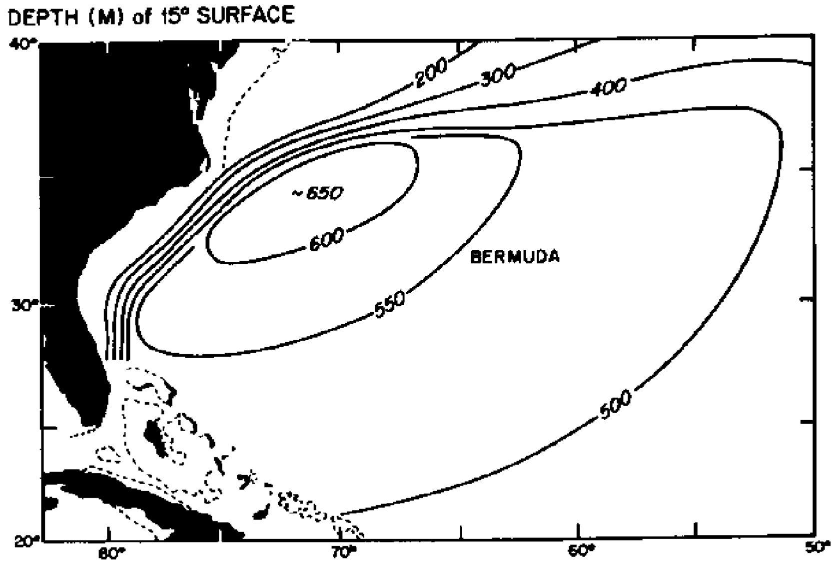


Figure 2. Multipath travel times at 300 km range from mooring to mooring (top) and from mooring to a fixed Bermuda receiver (bottom). The variation in travel time by about 0.7 second is believed to be the result of a southward meander of the Gulf Stream (from Spindel R.C. and J.L. Spiesberger, in preparation).



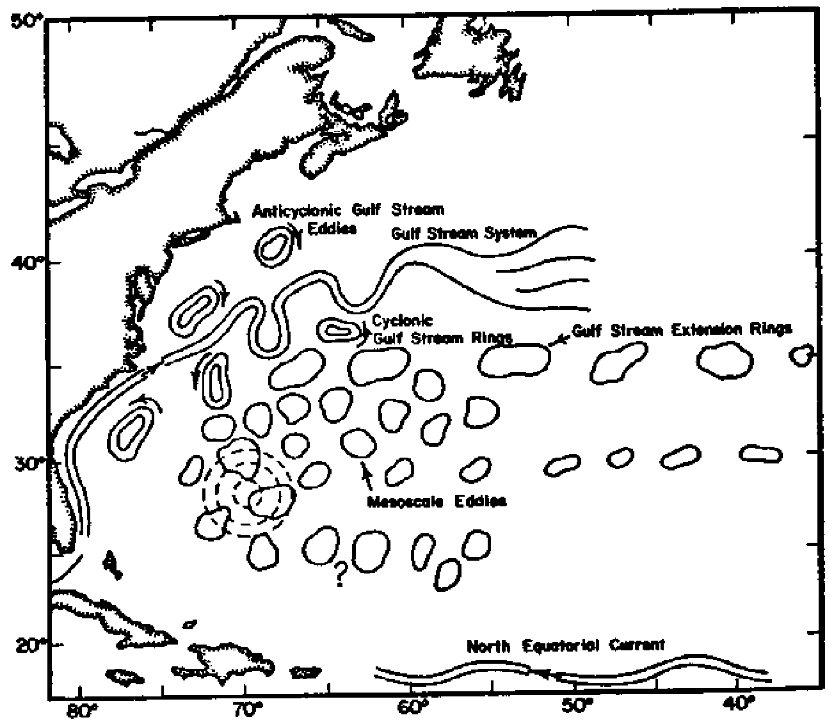
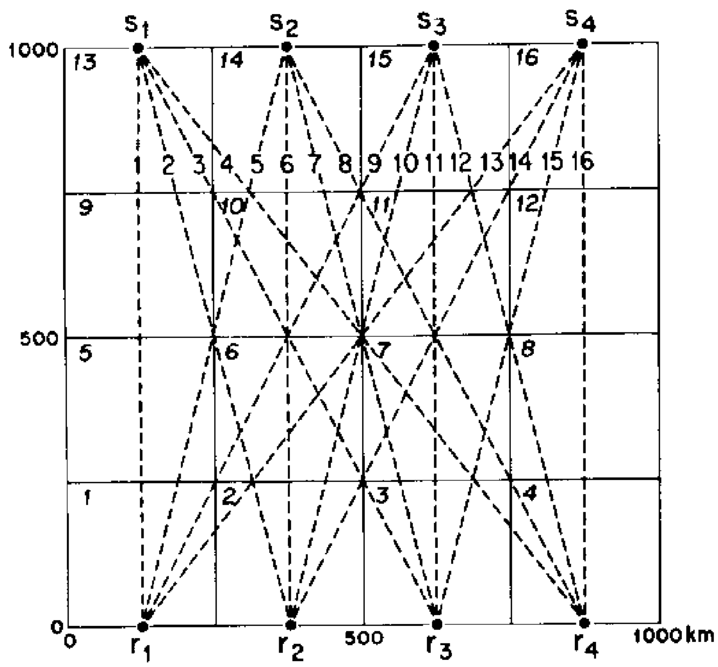


Figure 3. TOP: The long-term average (or climate) of the North Atlantic; BOTTOM: the momentary structure (or weather).



2. / 1.1 / 0.7	-2. / -1.9 / -1.6	2. / 3.0 / 4.2	-4. / -2.0 / -2.5
-1. / 0.3 / 2.0	-1. / -0.7 / -1.1	5. / 4.3 / 3.3	-2. / -3.6 / -3.4
1. / 0.5 / -0.1	2. / 0.5 / 0.4	3. / 0.6 / 0.9	2. / -1.4 / -0.4
4. / 4.1 / 3.8	-4. / -2.9 / -2.3	-4. / -1.9 / -1.5	-2. / 1.0 / 0.7

0 500 1000km

Figure 4. Horizontal slice. An area of 1000 km x 1000 km is divided into 16 grid areas. LEFT: acoustic travel time is measured along the 16 paths between 4 sources and 4 receivers. RIGHT: in each grid area the top number gives the assumed departure in sound speed in ms^{-1}; the two bottom numbers give the values computed from an inversion of the travel time departures, assuming 0 and 0.1 s rms errors in travel time, respectively.

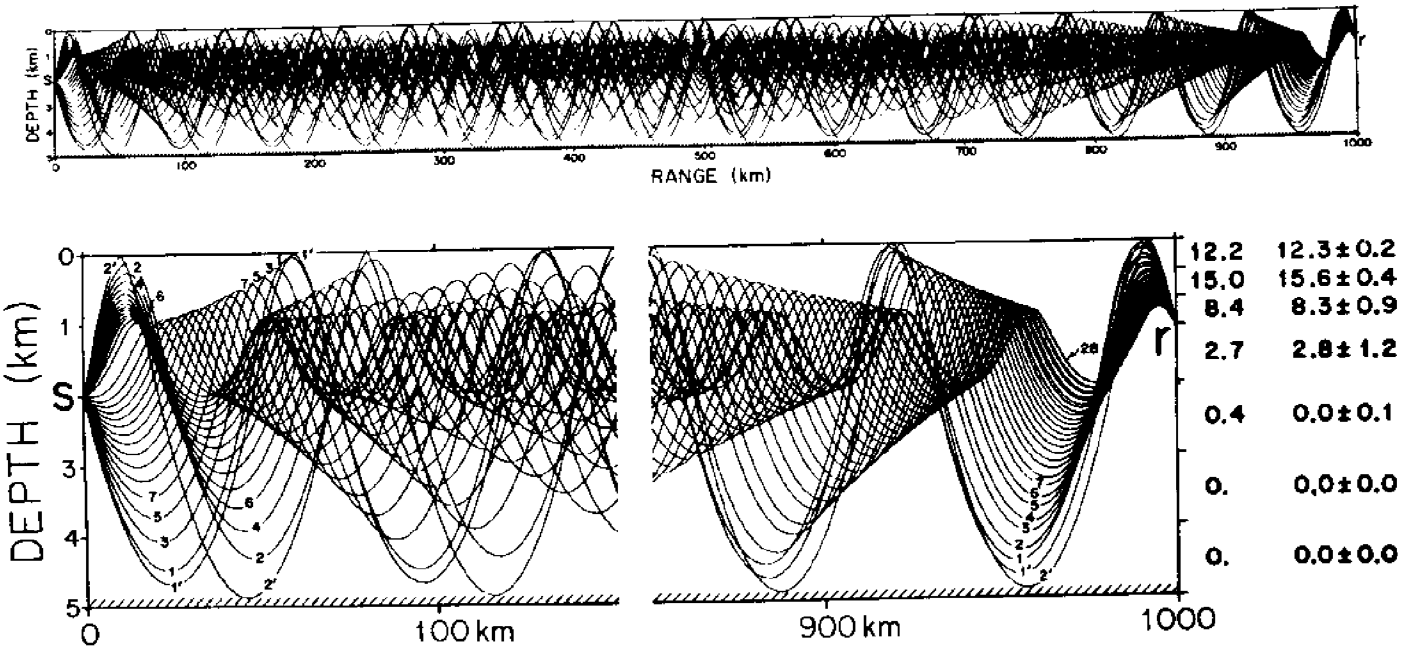


Figure 5. Vertical slice. Ray diagram for a 1000 km range, using the mean sound profile along a path between Eleuthera and Bermuda. The source is at 2000 m depth, the receiver is axial at 1280 m. For simplification only those rays that travel downward towards the receiver are plotted. The first and last 150 km are shown on an enlarged scale, with the earliest 9 rays and the latest (28th) ray labeled in order of their arrival. The first column on the right gives the assumed anomaly in sound speed in ms^{-1} for each of seven layers. The second column gives the sound speed values computed by the inverse technique, given only the perturbations in travel time. A 0.1 s rms error in travel time was assumed.

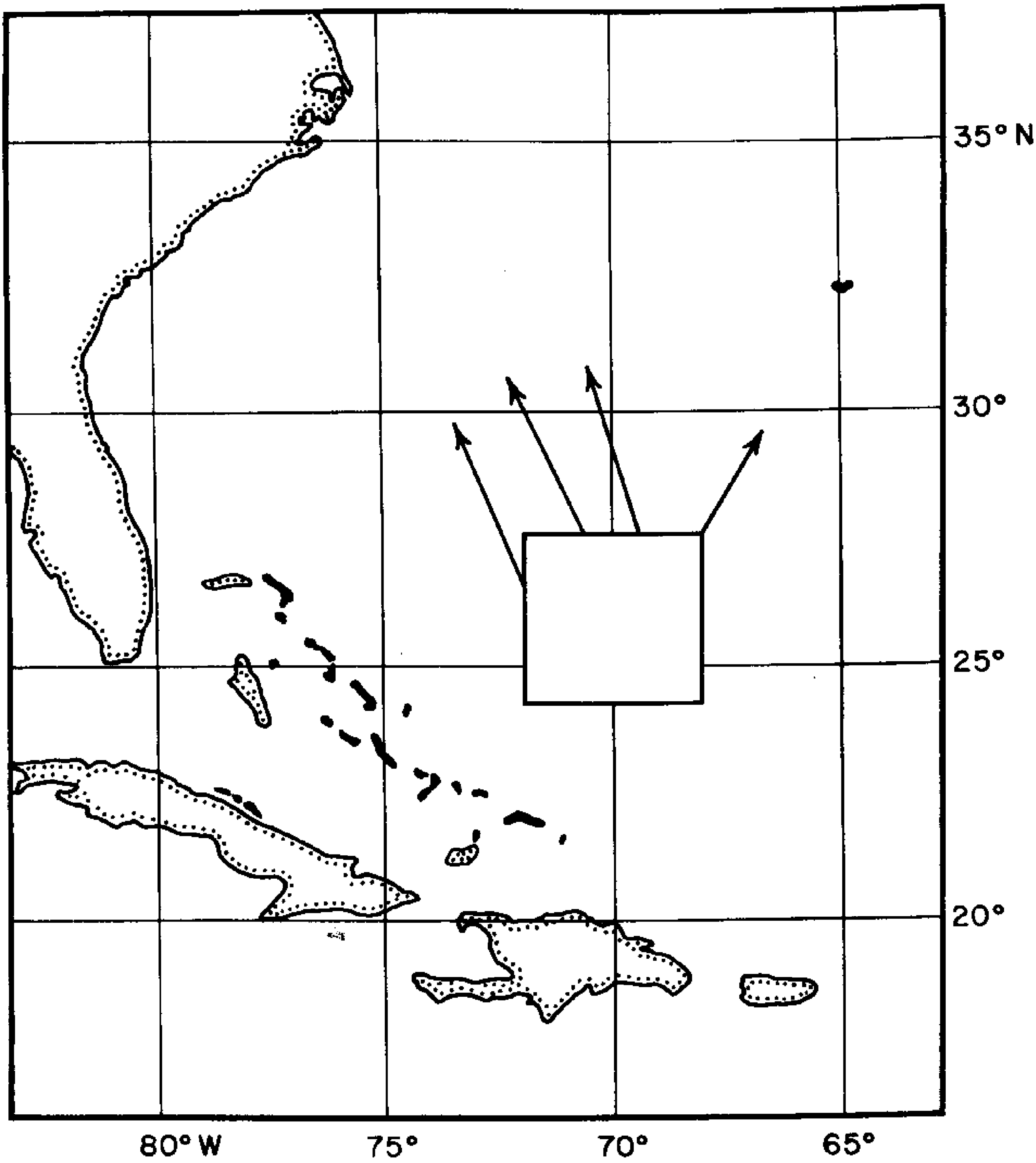


Figure 6. Location of 1981 experiment. Arrows indicate directions to remote receiving sites.

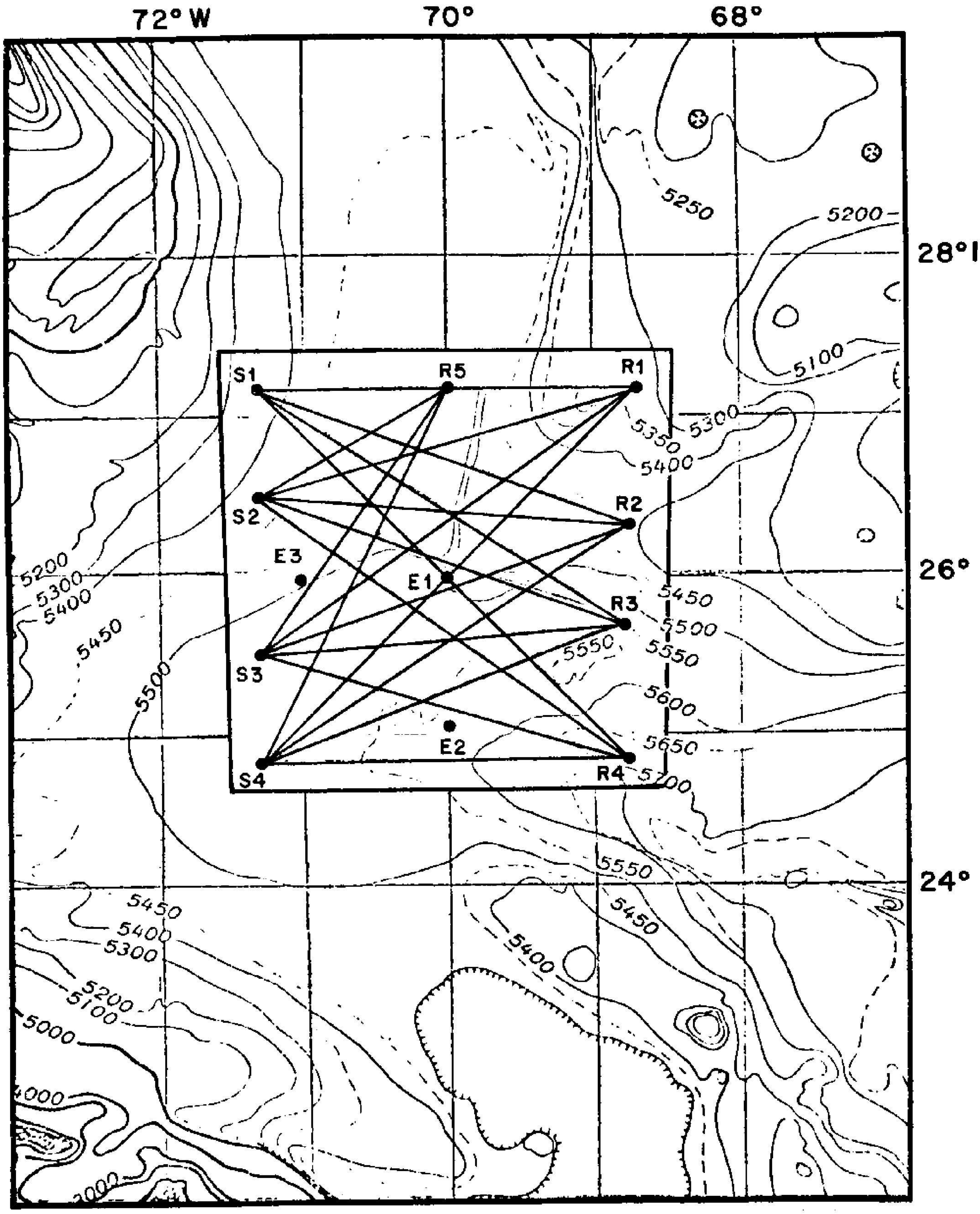


Figure 7. Arrangement of moorings in 1981 experiment, over chart of bottom topography (meters). S, R, E denote source, receiver, environmental moorings (E3 is to be set by University of Miami as part of a separate experiment).

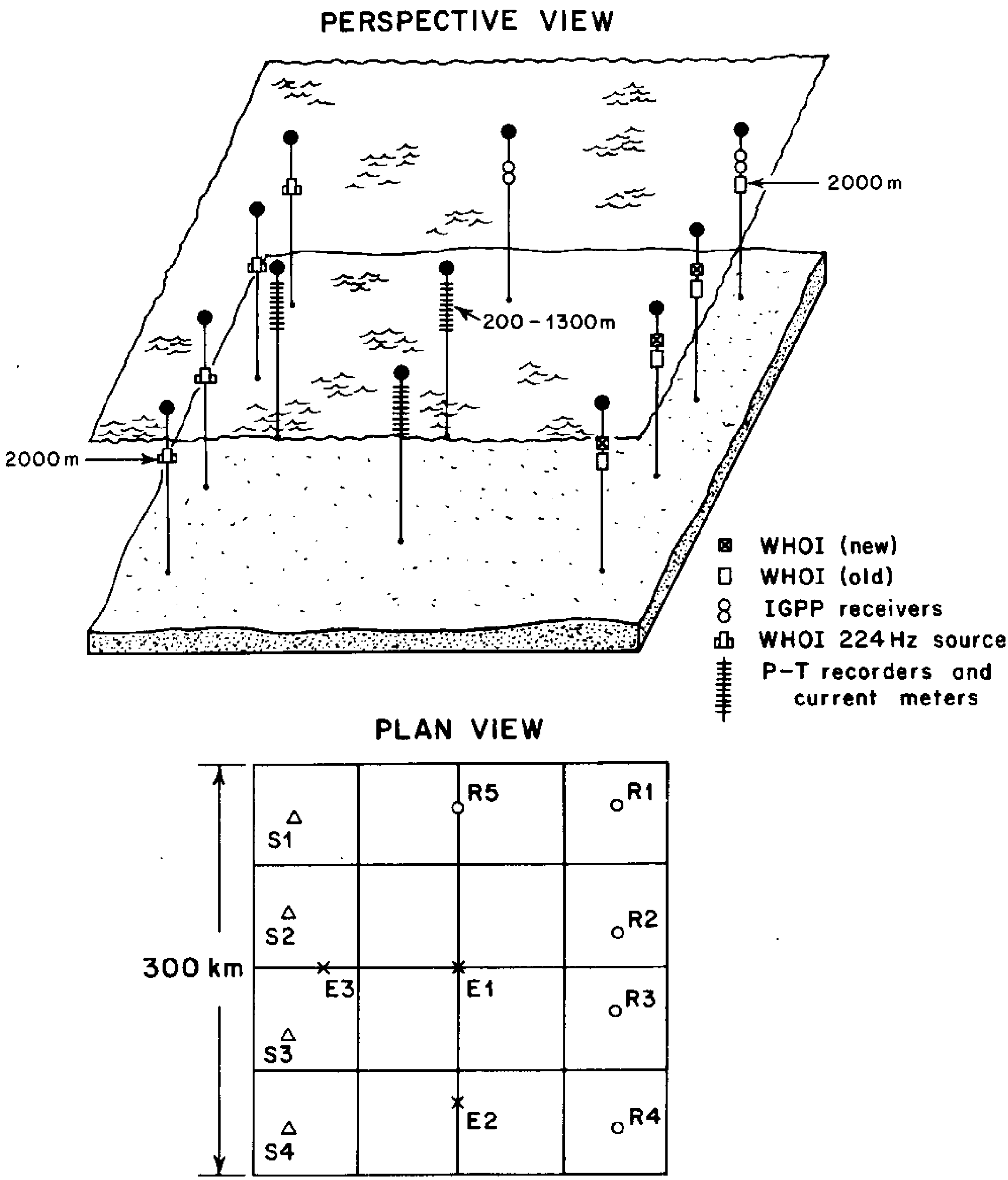


Figure 8. Perspective and plan views of proposed 1981 mooring array.

OARS Paper #5

OCEAN VARIABILITY AS OBSERVED BY LOW FREQUENCY ACOUSTICS

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ABSTRACT

This paper presents experimental data which indicate that acoustical fluctuations in the ocean can be caused by a variety of ocean and atmospheric processes. The data are derived primarily from studies in the Straits of Florida, and between Eleuthera, Bahamas and Bermuda by the Universities of Miami and Michigan in a cooperative research program termed Project MIMI, sponsored by the Office of Naval Research in the period 1962-1975. Limited data by other investigators, and more recent data obtained by the Institute for Acoustical Research - a non-profit corporation formed by the group formerly at the University of Miami - are also included.

OUTLINE

I. INTRODUCTION

In the early 1960's the Universities of Miami and Michigan, under ONR sponsorship, initiated a research program termed PROJECT MIMI, to determine the relationships between ocean and atmospheric and acoustic fluctuations. The Navy interest derived from the need to develop improved concepts for undersea surveillance and communications.

To separate acoustic fluctuatuions associated with source or receiver motion from those caused by fluctuations in the ocean or atmosphere, the MIMI experiments, for the most part, utilized fixed-sources and fixed-receivers. To make possible acoustical measurements at long range with moderately powered transducers, MIMI took advantage of modern signal and receiver design techniques exploiting periodic sequences with high average to peak power ratios, bandwidths and line spacings appropriate for simultaneous measurements of signals and noise, for measurement of medium transfer junctions, or for multipath studies.

The measurements show that acoustic fluctuations can be related to a number of ocean and atmospheric processes having a wide range of space and time scales, as will be discussed in Section VI.

II. OCEAN ENVIRONMENTAL AND ACOUSTIC FLUCTUATIONS

CAUSES:

* Sound speed and current fluctuations;
* Boundary motions;
* Source/Receiver motions; boundary proximity.

ENVIRONMENTAL PROCESSES:

Seasonal changes;	Internal waves:
Current systems, fronts, eddies;	Surface waves;
Gravitational forcing;	Biomass movement.
Atmospheric phenomena;	

III. MEASURABLE ACOUSTIC QUANTITIES

There are a variety of acoustic quantities that can be measured, as indicated in the table below:

1st Order - Range, Frequency Dependent	Signal level, phase, spectrum; Propagation loss; Noise; Array gain; Signal excess;
2nd Order - Range, Frequency, Time, Motion Dependent	Medium transfer function; Spatial coherence - angular spread; Temporal coherence - bandwidth; Frequency coherence - travel time spread; Multipath structure; Single path amplitude, phase; Pulse time-spread and wander.

Which quantity should be measured is dependent on what information is desired. In general, acoustic phase and travel time are the most sensitive indicators of changes in ocean structure, although the changes in propagation loss associated with passage of sound through a feature such as the Gulf Stream are also very significant.

IV. MEASUREMENT TECHNIQUES

A number of new underwater acoustic measurements techniques were developed, principally by Prof. T. G. Birdsall and his associates at the University of Michigan for use in the MIMI program. Most of these have made use of periodic sequences with amplitude or phase modulation to achieve required spectral or temporal resolution characteristics.

PERIODIC SEQUENCE *

Periodic sequence signals - often termed pseudorandom sequence signals - consist of a periodic train of contiguous CW pulses, either the amplitude or phase of which is changed from pulse to pulse. They can have the same spectral character and correlation properties of a periodic pulse, yet the average power of a CW signal. They are useful in sound propagation experiments because much more information can be obtained than with CW signals or explosive shots. The periodic sequence can be designed to have a broad line spectrum centered about the frequency of the sinusoid used in generating it, often termed the carrier frequency, and to have a narrow auto-correlation function. Because of its spectral character, the sequence can be used to distinguish between refractive and multipath fading processes, to measure the bandwidth of fading processes, to obtain data for the comparison of the statistics of single frequency and multifrequency (broadband) amplitude fluctuations, to determine the correlation bandwidth of the propagation channel (the bandwidth over which fluctuations in the complex signal are highly correlated), and to make possible the simultaneous measurement of signal and noise in the same frequency band.

Figures 4, 5, and 6 illustrate characteristics of periodic sequence signals. Figure 7 shows the characteristics of a dual comb filter implemented for simultaneous measurement of CW signal amplitude and phase, of comb signal power, of ambient noise, and forward scattered reverberation. Figure 8 presents a sample of the data obtained. Figure 9 illustrates the use of a periodic sequence for measuring medium-induced pulse time spread.

As a caution, it should be recognized that long time series measurements place severe requirements on system stability. For example, in transmission experiments across the Straits of Florida -- a distance of about 43 nautical miles -- a phase change on the order of 240 phase cycles has been observed to occur in a period of about 1/2 year. If the phase measurement is to be good to 0.1%, the oscillator driving the source must not shift phase by more than 0.240 phase cycles over that period, or by more than about 7×10^{-9} Hertz. It follows that the oscillator required to drive the source must be stable in frequency to about 1 part in 10^{10}. Signal synthesizers, available from a number of commercial sources, when locked to a rubidium standard, meet this requirement.

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* See Figures 4 through 9 and Bibliography pp. 5-8.

V. FIXED vs MOVING SOURCES AND RECEIVERS

Since both changes in ocean structure and changes in acoustic multipath structure associated with source/receiver motion cause acoustic fluctuations, it is necessary for most purposes to study ocean environmentally induced acoustic fluctuations using fixed sources and receivers, although limited information about large ocean features, for example, changes in propagation loss associated with the Gulf Stream, can be obtained using towed sources. Section VI presents data showing environmentally induced acoustic fluctuations using both measurement techniques.

VI. PHENOMENA ASSOCIATED WITH ACOUSTIC FLUCTUATIONS

Acoustic fluctuations can be associated with a number of ocean environmental processes and with source motion.

A. SEASONAL COOLING

Figure 11 presents acoustic phase data obtained at the 43 MI hydrophone indicated in the diagram of the MIMI Straits of Florida environmental acoustic range in Figure 10. The 250-cycle decrease in phase over the period September to January can be attributed primarily to the seasonal cooling that is recorded in the upper part of the water column by the Miami thermistor string. The calculated temperature change from the phase data is of the order of that observed.

B. LARGE SPACE-TIME SCALE OCEAN PROCESSES - FRONTS, CURRENTS, AND EDDIES

Figures 12 thru 24 present data showing fluctuations associated with large space time-scale ocean processes. The 42 and 43 MI data in Fig. 12 show phase fluctuations with a period of a month believed to be associated with the change in lunar declination, on which are superimposed fluctuations with a duration of 4 to 8 days or so which are associated with atmospheric effects. The intermediate hydrophone phase data in Figs. 13, 15, and 16 show large, relatively rapid phase changes over periods of about 1 week to 1 month which may be associated with the passage of large ocean cold eddies through the sound paths, and the associated cooling.

Figure 17 shows the variation of propagation loss observed when a shallow acoustic source is towed into the Gulf Stream; Figure 18 shows the sound speed cross-section along the sound track; Fig. 19, 20, and 21 show how the acoustic multipath structure changes as the source passes from a point somewhat northwest of the Gulf Stream through the North wall into the core; Fig. 22 shows the variation in propagation loss as the projector is towed through a warm eddy; Fig. 23, the sound speed cross-section through the eddy; Figure 24, a picture of the multipath structure as the source is towed through a cold eddy.

C. GRAVITATIONAL EFFECTS

Figures 25 through 36 present data showing gravitational effects. Figs. 25 and 26 show the effect of changes in lunar declination and the tides on acoustic phase. Figure 27 shows variations in acoustic signal amplitude associated with the tides; Figure 28 shows variations in acoustic phase, both experimental and theoretical, associated with a slowly decreasing sound speed and a tidal current; Figures 29 and 30 show variations in acoustic phase which are related to Gulf Stream transport fluctuations at tidal and lower frequencies; Figure 31 presents a comparison of experimental and theoretical phase variations associated with measured transport variation. Figures 32 through 34 show tidal phase fluctuations observed in the deep ocean; Figure 35, a spectrum of the phase variations in Figure 34; Figure 36, a tidal frequency analysis of the data in Figure 34.

D. METEOROLOGICAL EFFECTS

Figures 37 through 41 present data showing meteorological effects. Figure 37 shows changes in propagation loss associated with the wind; Figures 38, 39, and 40 show variations in temperature and acoustic phase which appear to be correlated with the wind. The change in propagation loss between Bermuda No. 1 and Bermuda No. 2 is believed to be associated with the passage of a hurricane through the sound path.

E. INTERNAL WAVES

Because the emphasis in this paper is on the longer, larger space time scale processes important for climate and weather, the subject of internal waves is mentioned only in passing.

The study of acoustic fluctuations associated with internal waves has been intense for the past few years, and a by-no-means-complete bibliography is appended for the interested reader.

F. SURFACE WAVES

Again, because of their time-scale, little will be said about surface waves. They are of interest from the weather forecasting point of view; and, in fact, acoustical techniques could be used for the measurement of wave height, and the directional spatial spectrum of the waves. Figure 42 shows the spectrum of the forward scattered reverberation for a CW signal propagated 7 miles in the Straits of Florida. The sideband structure associated with the surface wave modulation is evident. Figure 43 is a second spectral example; Figure 44 shows an ambiguity function which shows the multipath arrival structure is spread both in time and space.

A bibliography listing papers discussing the interaction of acoustic signals with the sea surface is included.

G. BIOMASS MOTION

Figure 45 presents time-series of acoustic data as a function of range and frequency. The data at 0.431, 0.500, and 0.625 kHz shows amplitude fluctuations associated with the coming of sunrise and sunset. These fluctuations are attributed to the formation of schools of fish as the light intensity increases, and their break-up with the arrival of darkness.

There is a considerable body of information in the use of acoustics for studying biological phenomena, and some of this material will be discussed by the other speakers.

H. SOURCE MOTION

Source motion, as well as changes in environment, causes acoustic fluctuations. In a stable ocean with a sound speed independent of time and position, with a flat motionless surface and a flat bottom, the signal received at a fixed receiver from a moving CW source will vary in time because of range-dependent changes in multipath structure, and because the signals received over the various multipaths will have slightly different frequencies because of differences in source emission angle.

Figures 47-52 show the results of calculations of acoustic fluctuations as a function of range for an ocean with the sound speed profile in Figure 46 for a projector being towed away from a receiver at a speed of 5 kts for a source depth of 150 m and receiver depth of 2500 m for a frequency of 350 Hz for a range increment from 500 to 520 km. Figure 47 shows the change in the set of paths reaching the receiver as a function of range; Figures 48 and 49 show the relative amplitudes of the various arrivals as a function of travel time, angle of emission, angle of reception, Doppler, and total rate of change of phase with time taking account of surface and bottom reflections; Figure 50 shows the variation in signal level for incoherent and coherent summations of the multipath arrivals, as well as the time-series of acoustic phase for the received signal. Figure 51 is identical with Figure 50, except that the time-series of acoustic phase has been modified by subtracting out the mean rate of change of phase with time obtained from the multipath data in Figures 48 and 49. Figure 52 shows that although the rate of change of phase is nearly constant for each arrival over a 22 sec. time interval, the rate of change of phase of the multipath sum varies quite rapidly; Figure 52 presents a time series showing time variation of the channel frequency response caused by multipath interference effects.

VII. CONCLUSION

The purpose of this paper has been to summarize a series of experimental studies carried out in the late 1960's and early 1970's, primarily for the US Office of Naval Research, which were investigating what factors in the ocean and atmosphere cause underwater acoustic fluctuations. The studies showed that many environmental factors do influence sound propagation in the ocean and suggest that acoustic techniques, when combined with accurate physical models, can be used for acoustic remote sensing of ocean processes. In particular, evidence was presented which suggests that acoustic techniques can be applied in the measurement of sound speed and current, their fluctuations, and of surface and biomass motion. Secondary purposes of the paper have been to indicate what acoustic quantities are usually measured, some of the more advanced techniques that have been developed for measuring them,and to make the reader aware of the acoustic fluctuations associated with source motion, which must be accounted for if moving source experiments are to be used for studying spatial or temporal variations in ocean.

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X. ILLUSTRATIONS

ILLUSTRATIONS (cont.):

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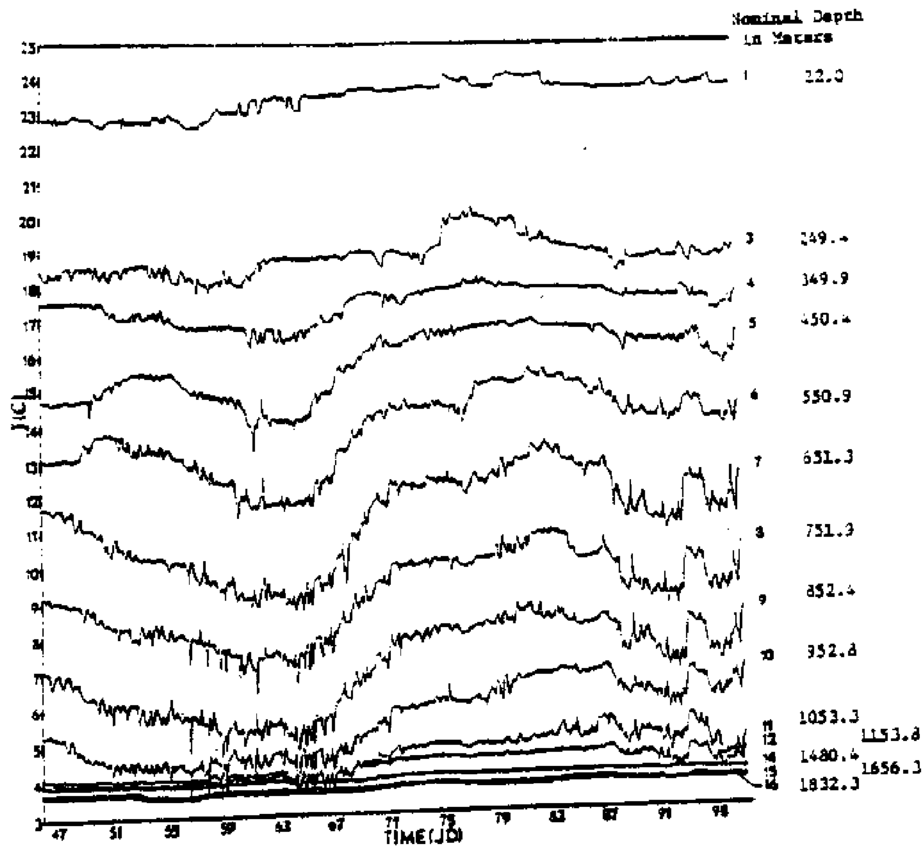


FIG. 1-THE BEAR BUOY 3-HOURLY TEMPERATURE TIME SERIES (ECHTERNACHT, REF. 13)

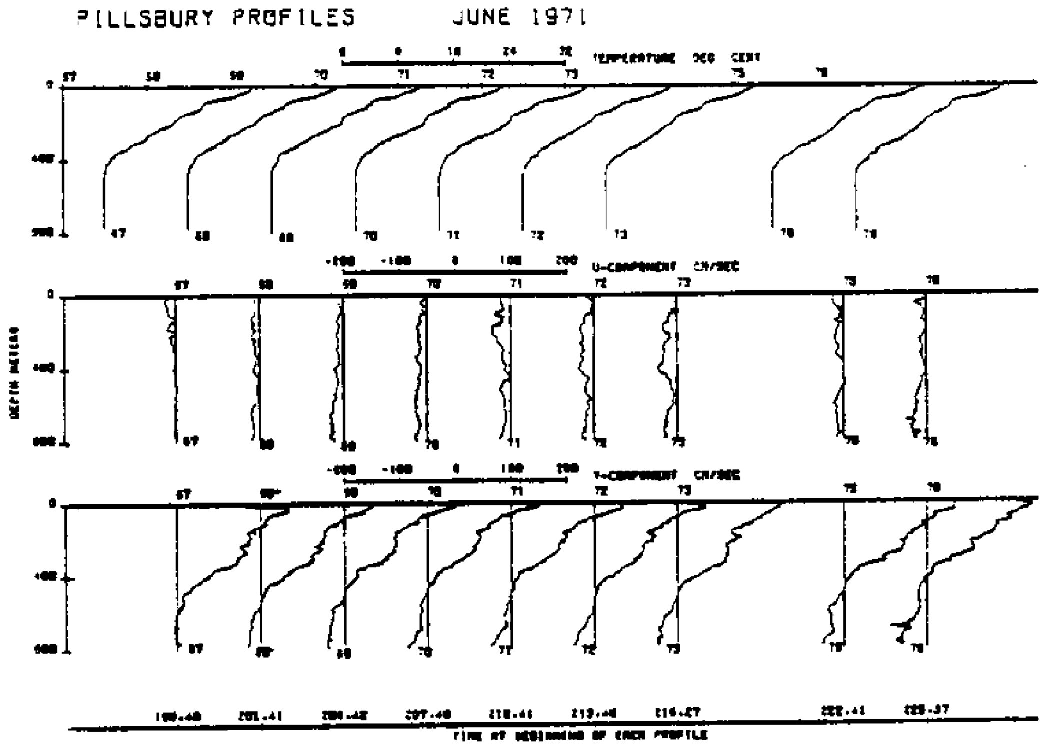


FIG. 2 - TIME-SERIES OF TEMPERATURE AND CURRENT PROFILES (DUING, REF. 14)
U COMPONENT OF THE CURRENT IS TAKEN POSITIVE TOWARD THE EAST;
V COMPONENT OF THE CURRENT IS TAKEN POSITIVE TOWARD THE NORTH.

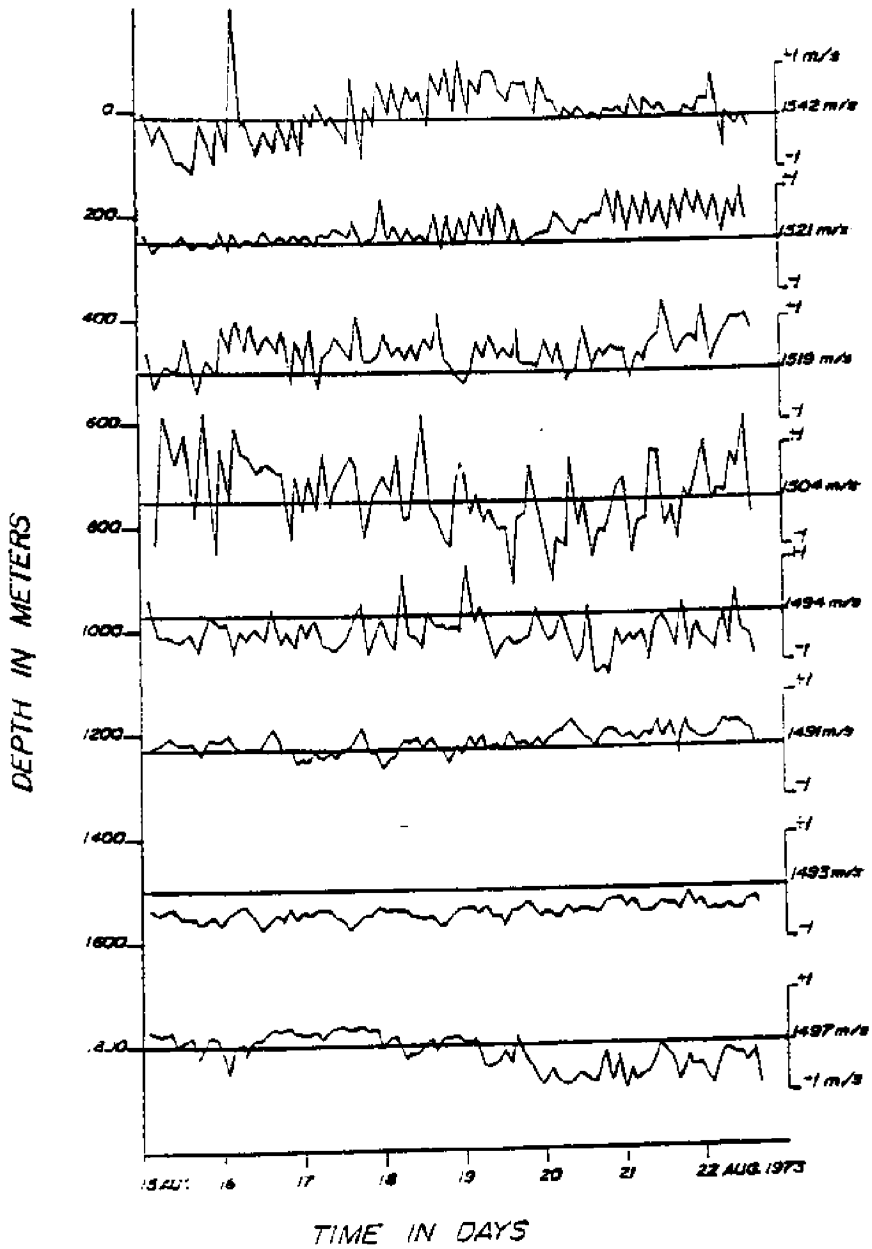


FIG. 3 - TIME SERIES OF SOUND SPEED AS A FUNCTION OF DEPTH (TURNER, REF. 15)

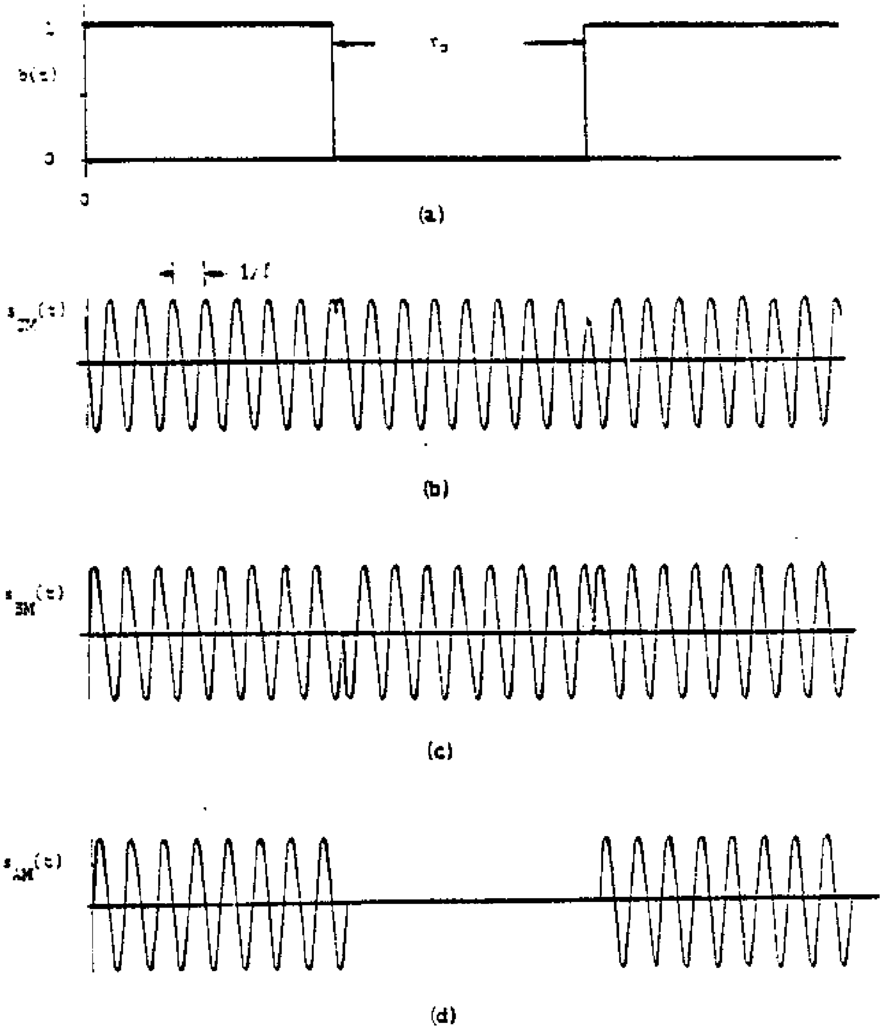


FIG. 4 - THE MODULATED SIGNAL; (A) A PORTION OF B(T), (B) $S_{CM}(T)$, (C) $S_{BM}(T)$, (D) $S_{AM}(T)$

(BIRDSALL ET AL., REF. 12)

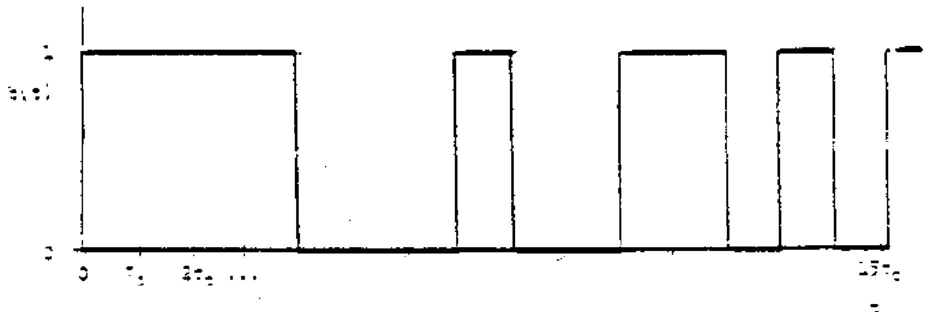


FIG. 5 - ONE PERIOD OF A 15 DIGIT BINARY LM SHIFT REGISTER SEQUENCE (ADAPTED FROM BIRDSALL ET AL , REF 12)

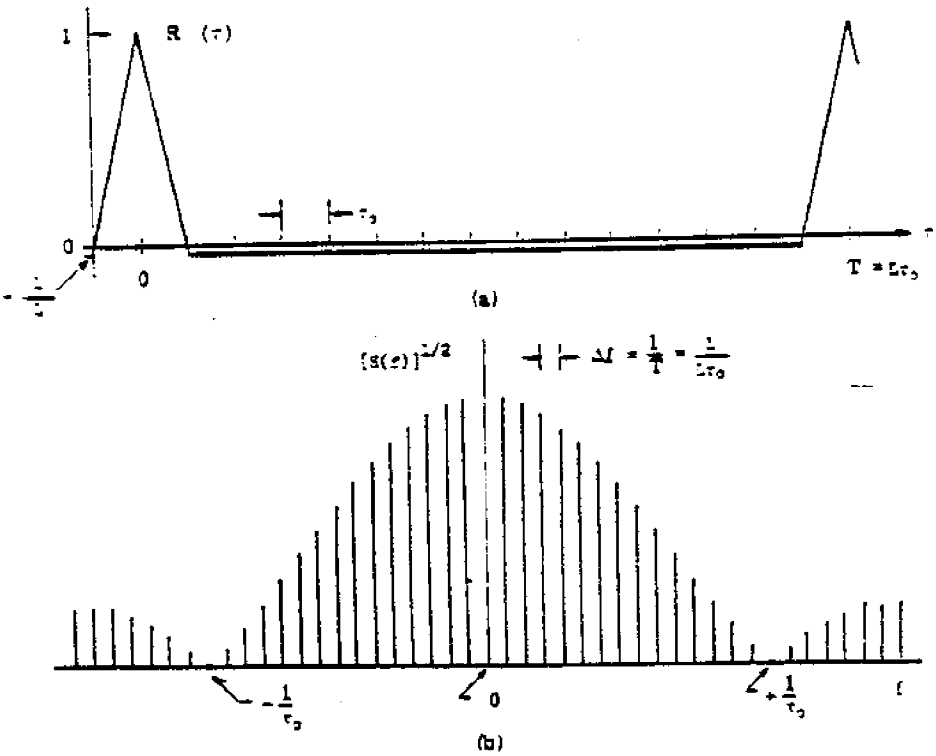


FIG. 6 -(A) AUTOCORRELATION FUNCTION R (T),
(B) RMS POWER SPECTRUM S (F) 1/2
(BIRDSALL, ET AL., REF. 12)

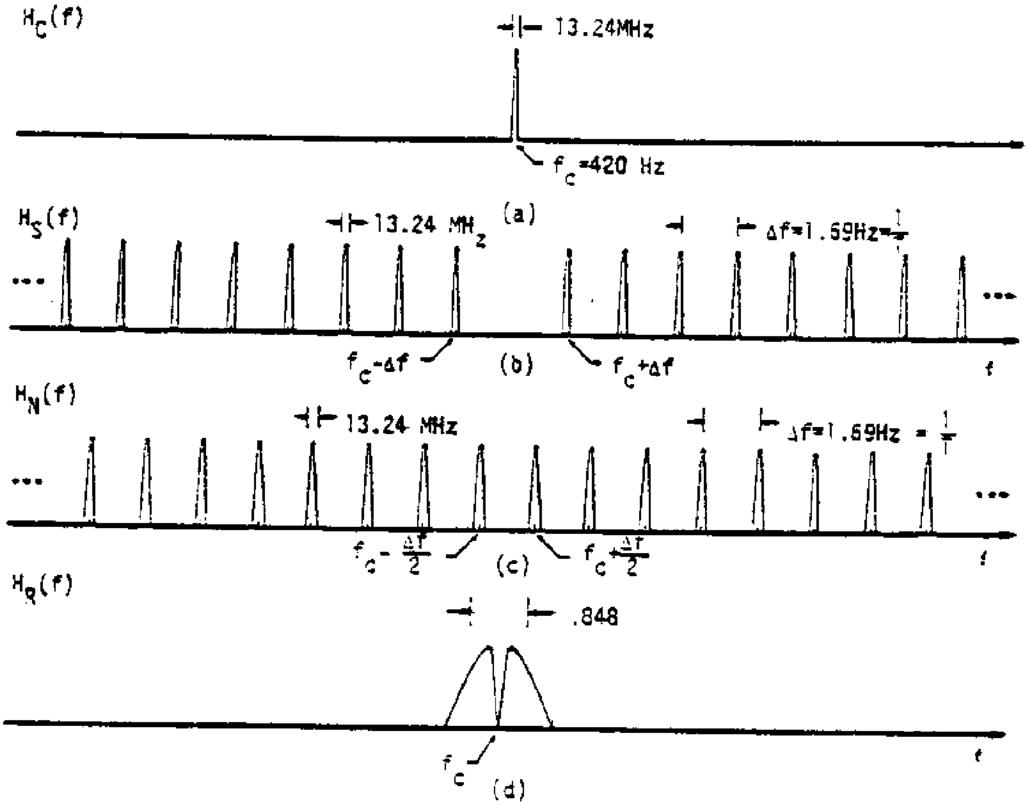


FIG.7 - THE FREQUENCY RESPONSES OF THE DUAL PROCESSING FILTERS (COMMUNICATION FROM T. G. BIRDSALL)

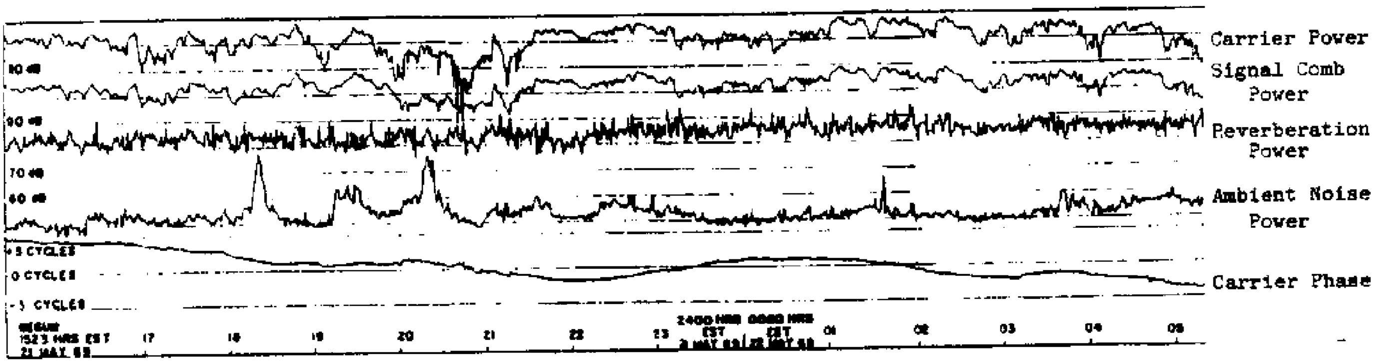


FIG. 3 -DIGITAL ON-LINE DATA PRINT-OUT FROM A DUAL COMB FILTER; CARRIER FREQUENCY - 420Hz.
(COMMUNICATION FROM T.G. BIRDSALL)

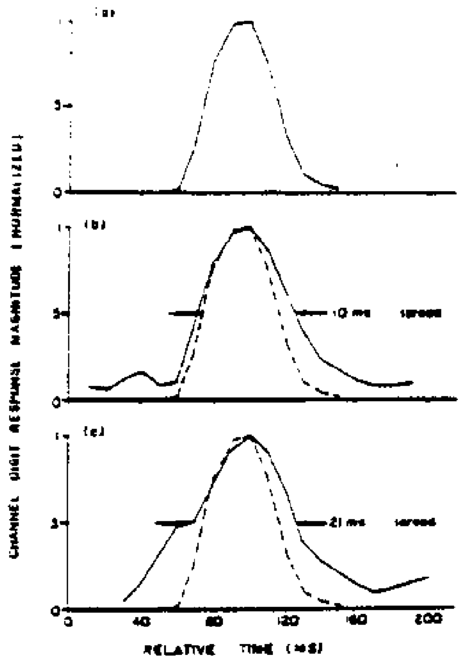


FIG. 9 -CHANNEL DIGIT RESPONSE: (A) TRANSMITTED SIGNAL, (B) TYPICAL RECEIVED REFRACTED ARRIVAL, (C) REFRACTED ARRIVAL WITH LARGE TIME SPREAD. TIME SPREAD IS THE DIFFERENCE BETWEEN TRANSMITTED AND RECEIVED PULSE ENVELOPES MEASURED AT HALF AMPLITUDE POINTS. RANGE - 500 KM; CARRIER FREQUENCY - 200 Hz. (JOBST AND DOMINIJANNI, REF. 16).

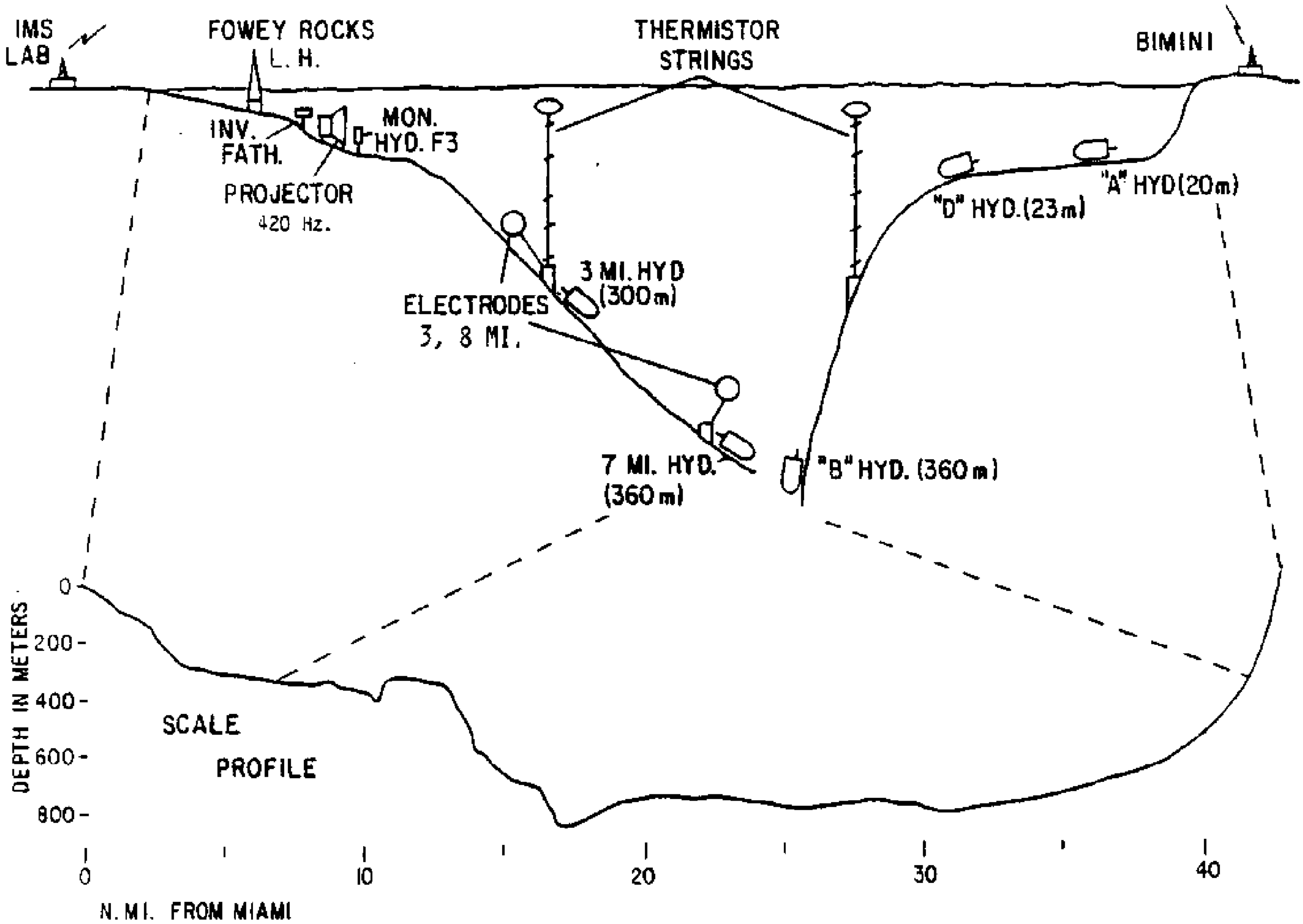


FIG. 10 - ELEMENTS OF ACOUSTIC-ENVIRONMENTAL SYSTEM. (STEINBERG, ET AL., REF. 1)

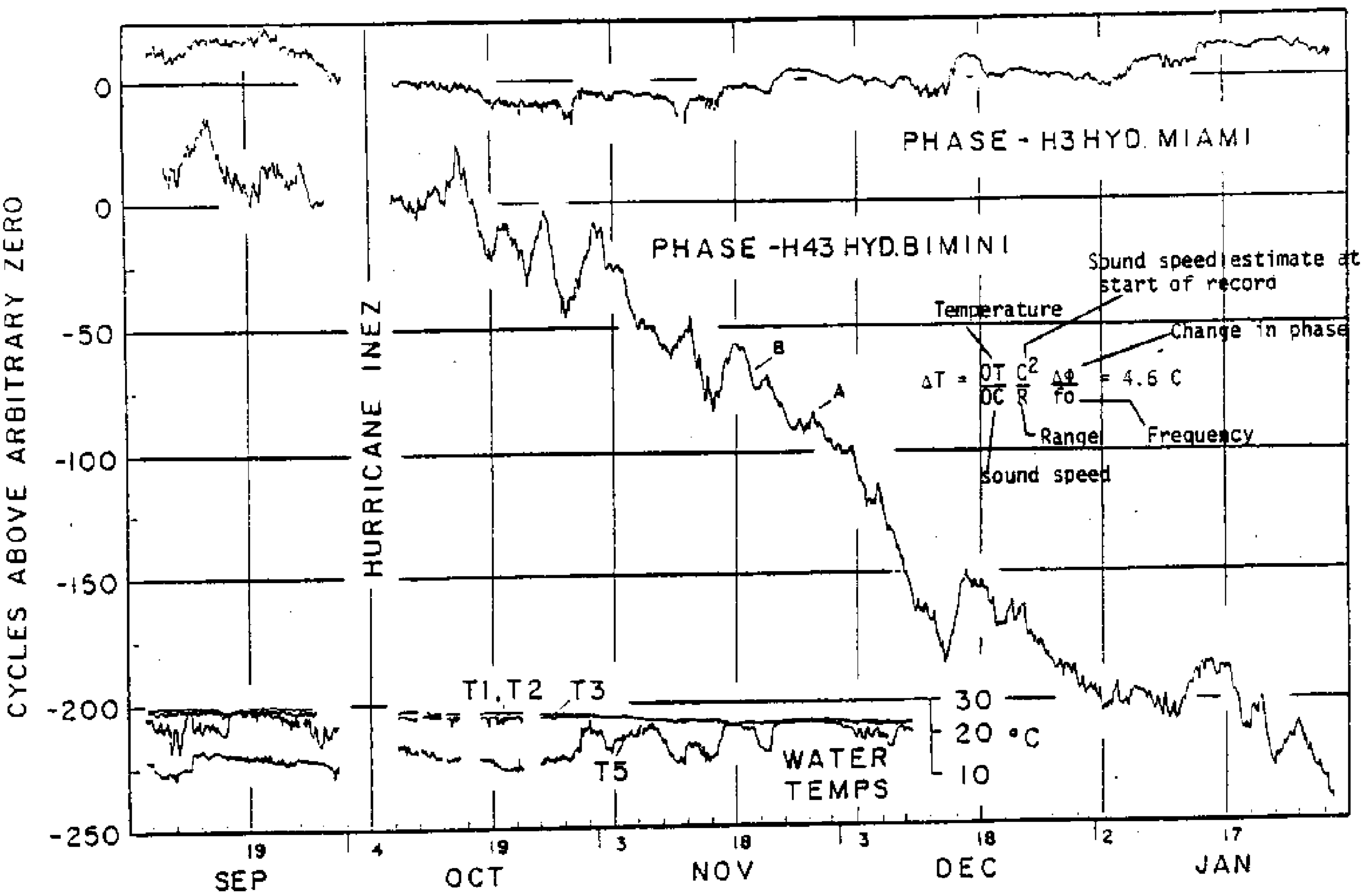


FIG. 11 - PHASE AND TEMPERATURE PATTERNS, SEP 1966 - JAN 1967
CARRIER FREQUENCY - 420 Hz. (CLARK AND YARNALL, REF. 2.)

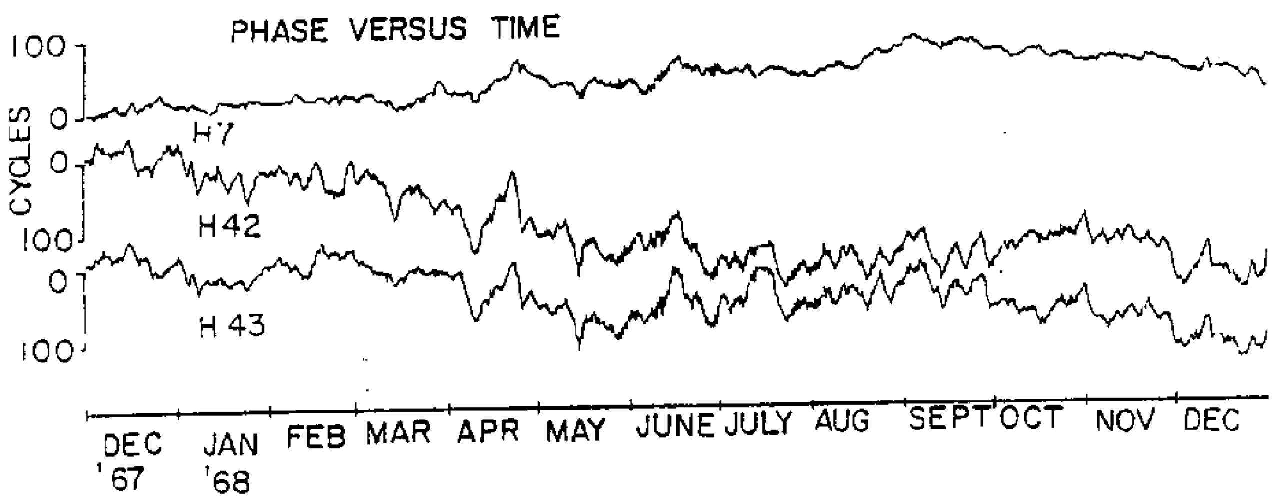


FIG. 12 - VARIATIONS OF ACOUSTIC PHASE WITH TIME AT THE 7, 42, AND 43-MILE HYDROPHONES DURING A 13-MONTH INTERVAL. CARRIER FREQUENCY - 420 Hz. (STEINBERG, ET AL., REF. 1.)

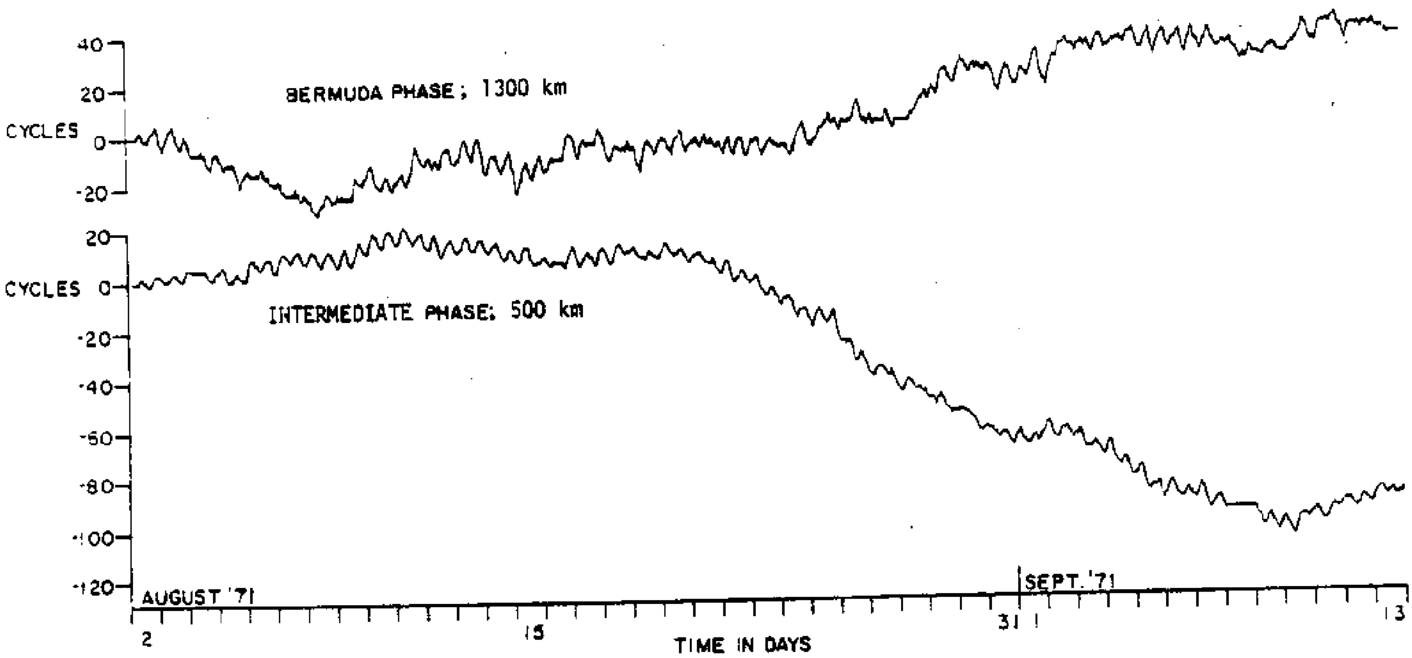


FIG. 13 - LONG TIME SERIES OF BERMUDA AND INTERMEDIATE-HYDROPHONE PHASE DATA. THESE DATA ARE UNFILTERED. TWO REGIMES OF FLUCTUATION ARE APPARENT: TIDAL VARIATIONS SUPERIMPOSED ON LARGE VARIATIONS OF EXTRATIDAL TIME SCALE. FREQUENCY - 406 HZ. (CLARK AND KRONENGOLD, REF. 3.)

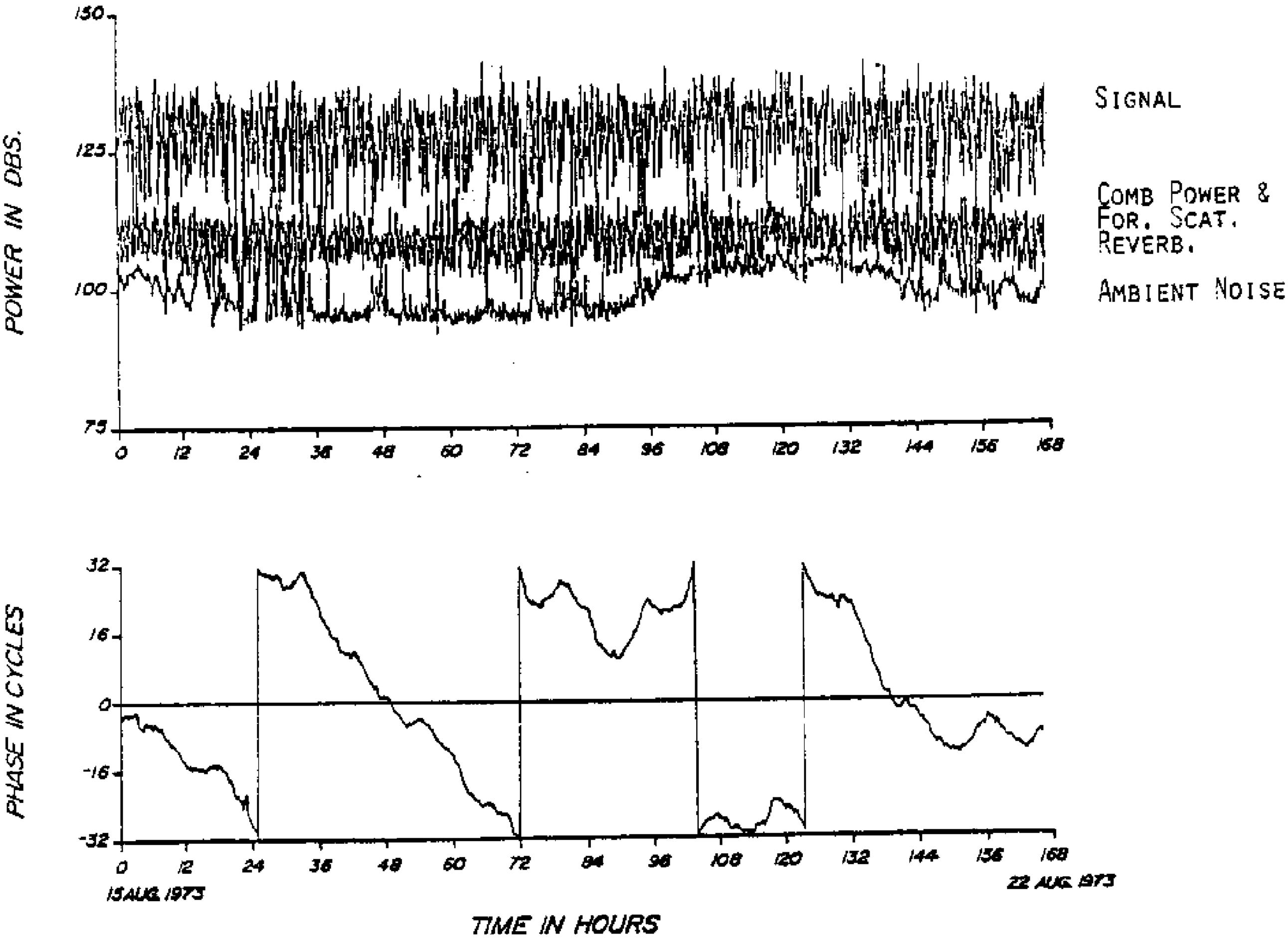


FIG. 14 - DUAL COMB TIME SERIES; 406HZ; 500KM. (COMMUNICATION FROM DR. JOHN CLARK.)

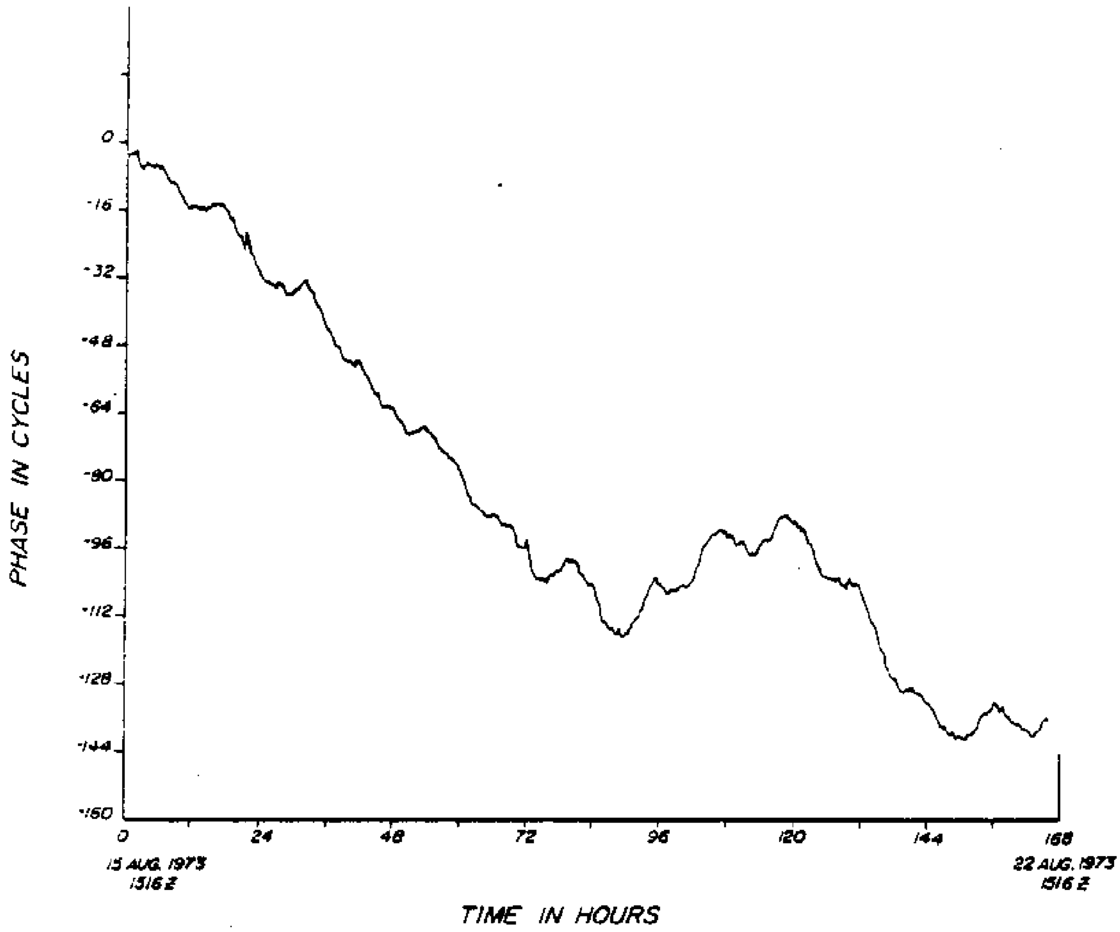


FIG. 15 - PHASE TIME SERIES; 406HZ; 500KM. (COMMUNICATION FROM DR. JOHN CLARK.)

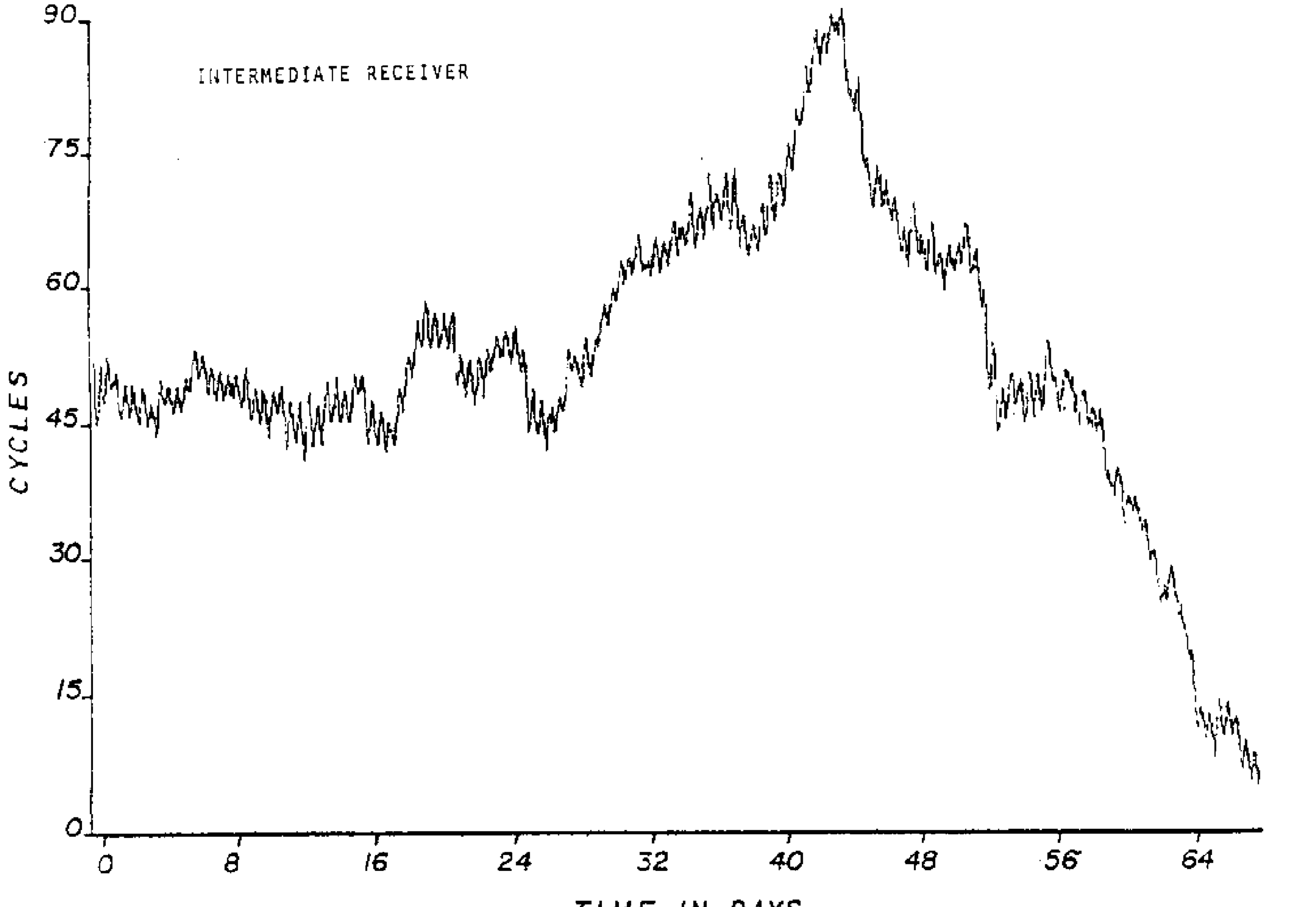
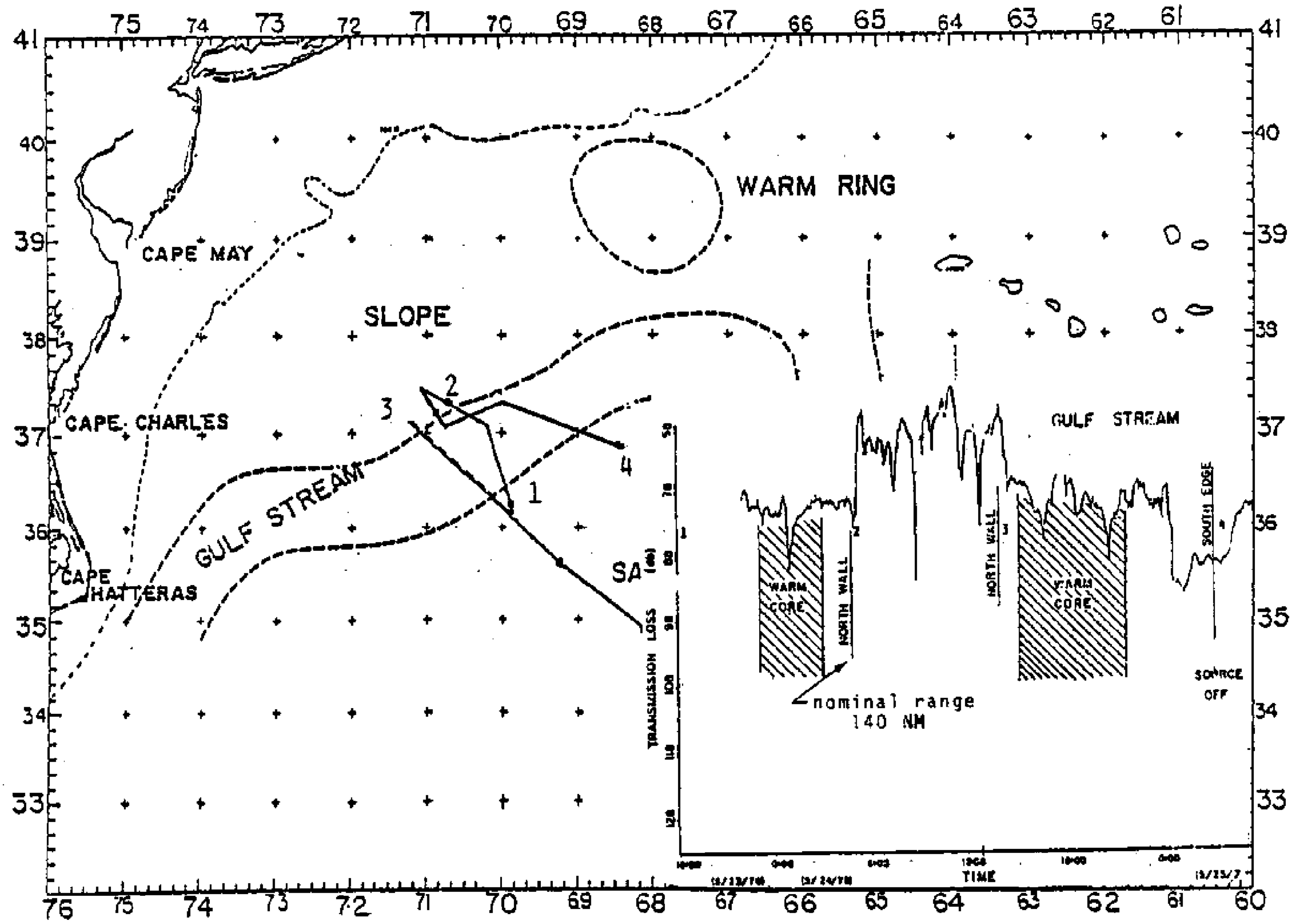


FIG. 16
12/9/75 PHASE TIME SERIES; 206Hz; 500KM. (COMMUNICATION FROM DR. JOHN CLARK.) 2/15/76



IG. 17-PROJECTOR TRACK AND TRANSMISSION LOSS. (CHENEY, REF. 4; COMMUNICATION FROM DR. JOHN CLARK.)

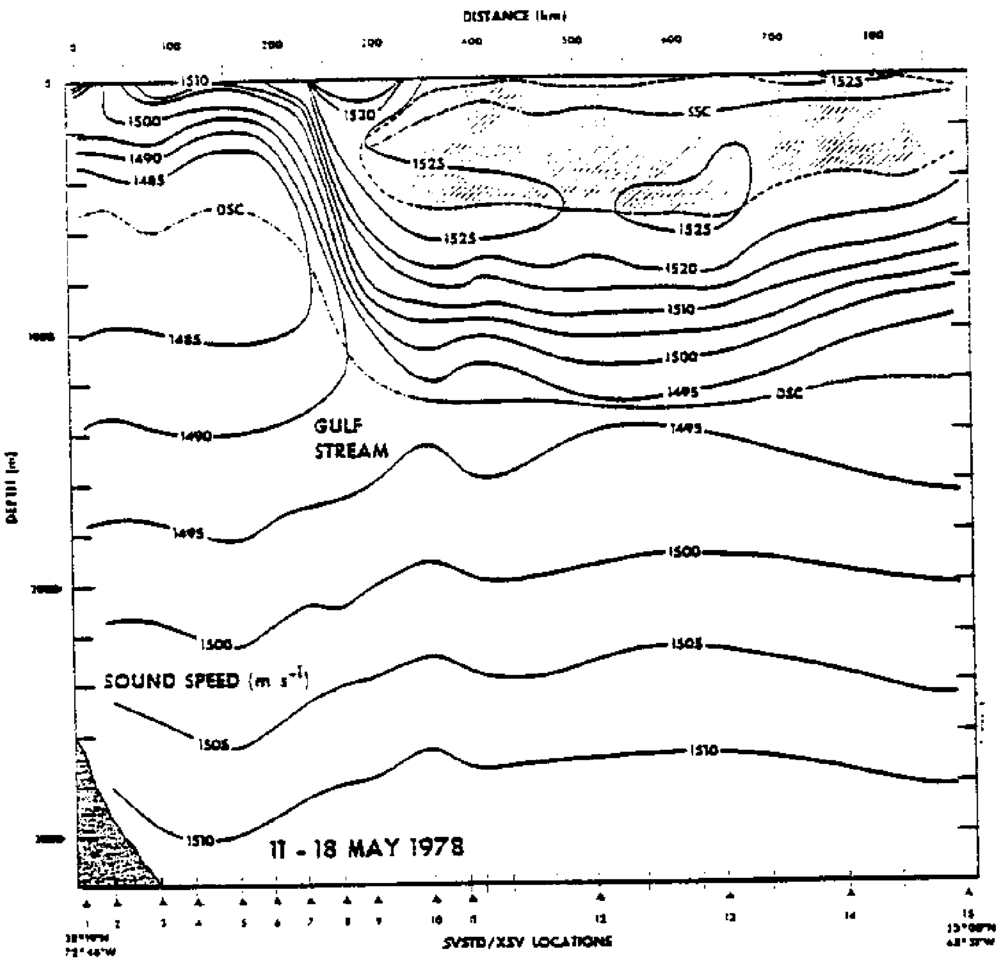


FIG. 18 –SOUND SPEED SECTION ALONG CENTRAL TRACK IN FIGURE 6. DEPTH OF MINIMUM SOUND SPEED IS INDICATED BY THE DEEP SOUND CHANNEL (DSC) AXIS. A SECONDARY MINIMUM FORMS A SHALLOW SOUND CHANNEL (SSC) IN THE UPPER 600 M. (CHENEY, REF. 4.)

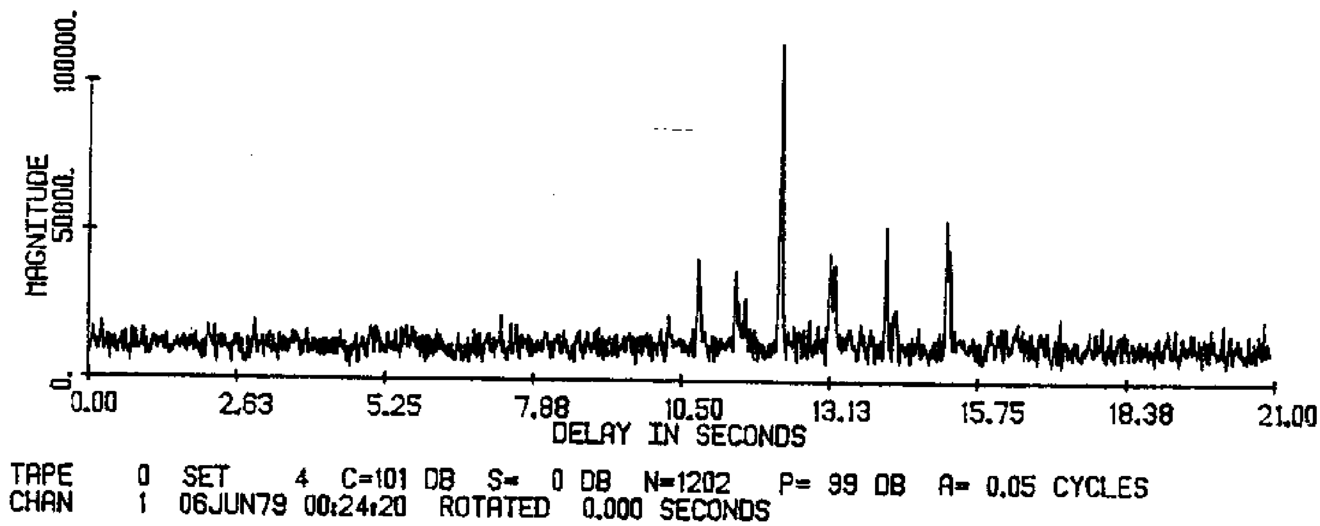


FIG. 19 -MOVING SOURCE MULTIPATH MEASUREMENT; PROJECTOR AT NORTH WALL 98.27Hz; 3dB BANDWIDTH 20.83Hz; LINE SPACING 0.041Hz; SEQUENCE LENGTH 24.576 SEC; DIGIT LENGTH 0.048 SEC; NOMINAL RANGE 250KM. (COMMUNICATION FROM PROF. T. G. BIRDSALL.)

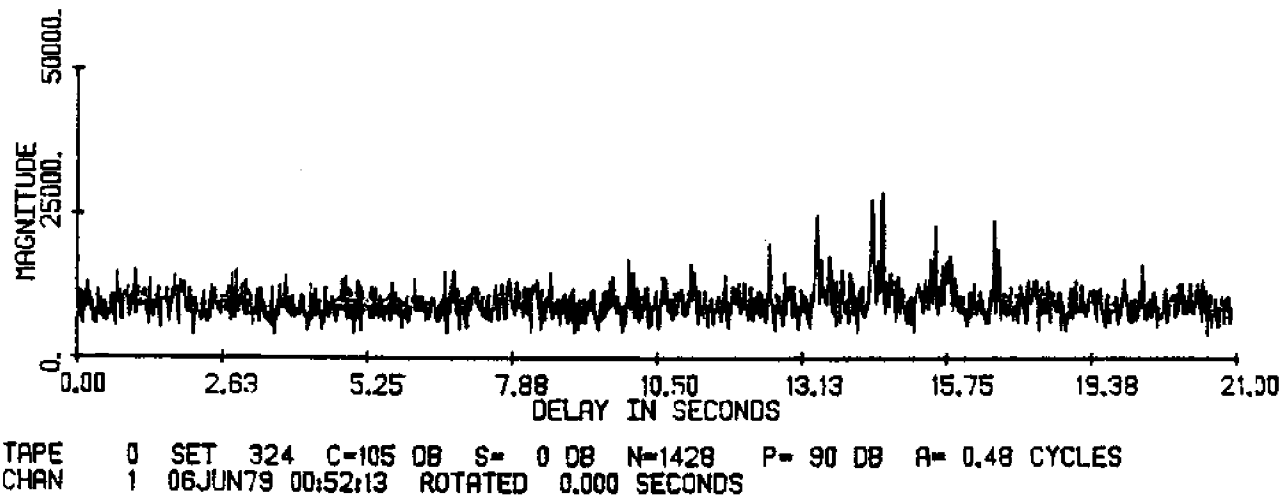


FIG. 20 - MOVING SOURCE MULTIPATH MEASUREMENT; PROJECTOR IN NORTH WALL; 98.27HZ; 3DB BANDWIDTH 20.83HZ; LINE SPACING 0.041HZ; SEQUENCE LENGTH 24.576 SEC; DIGIT LENGTH 0.048 SEC; NOMINAL RANGE 250KM. (COMMUNICATION FROM PROF. T. G. BIRDSALL.)

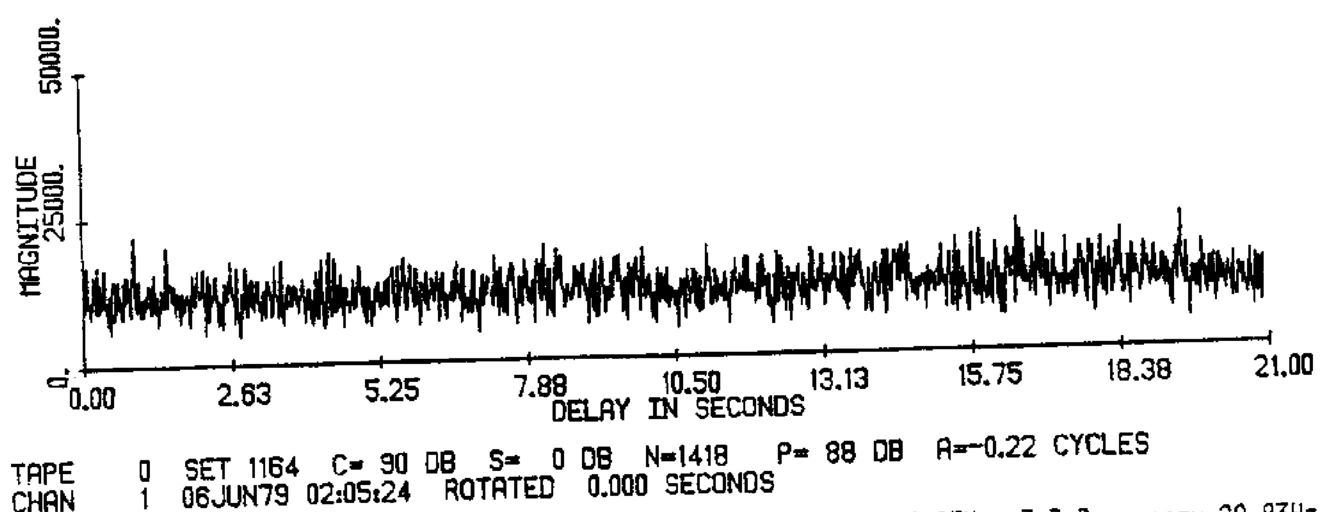


FIG. 21 -MOVING SOURCE MULTIPATH MEASUREMENT; PROJECTOR IN WARM CORE; 98.27Hz; 3dB BANDWIDTH 20.83Hz; LINE SPACING 0.041Hz; SEQUENCE LENGTH 24.576 SEC; DIGIT LENGTH 0.048 SEC; NOMINAL RANGE 250 KM. (COMMUNICATION FROM PROF. T. G. BIRDSALL.)

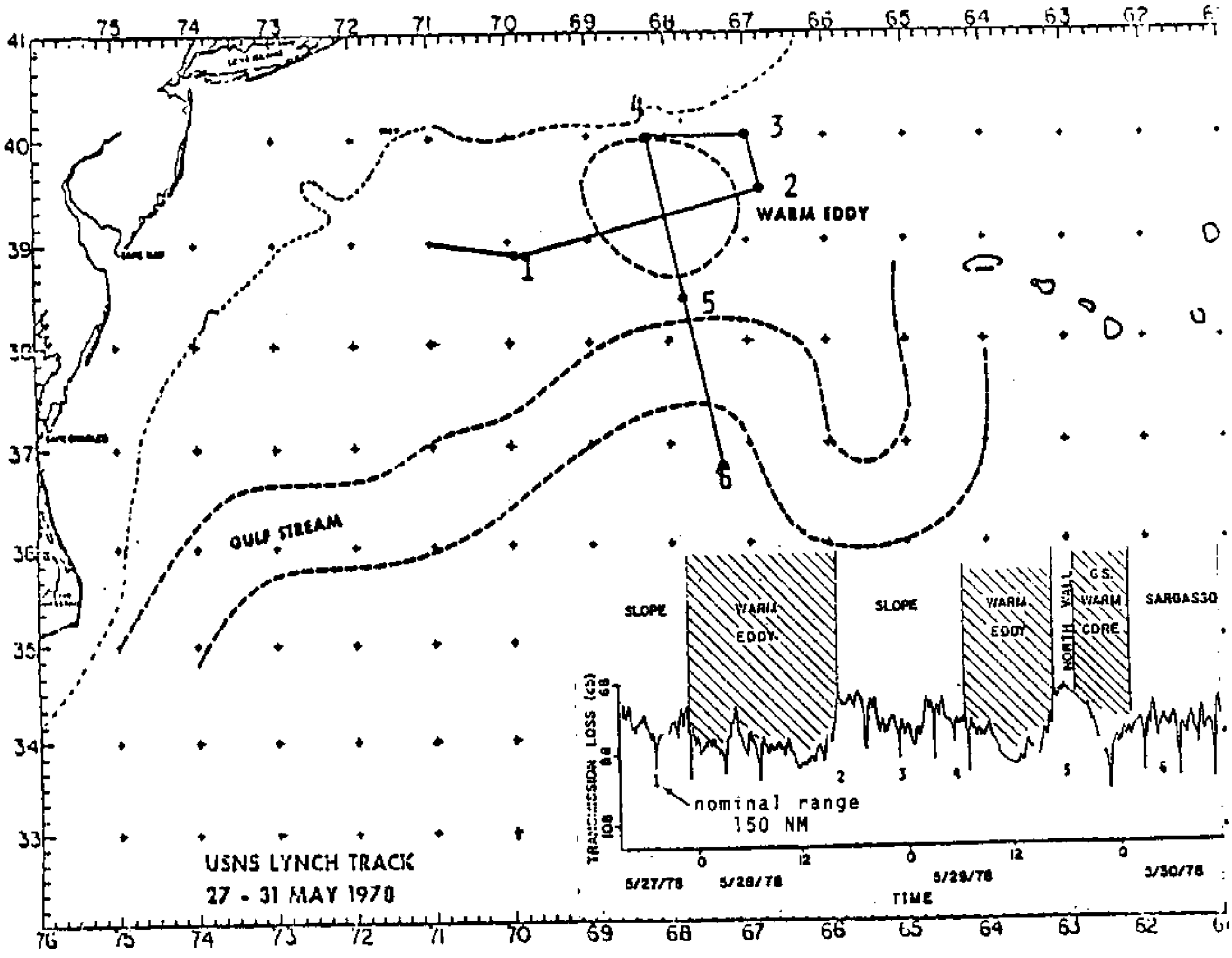


FIG.22- PROJECTOR TRACK AND TRANSMISSION LOSS. (CHENEY, REF. 4; COMMUNICATION FROM DR. JOHN CLARK.)

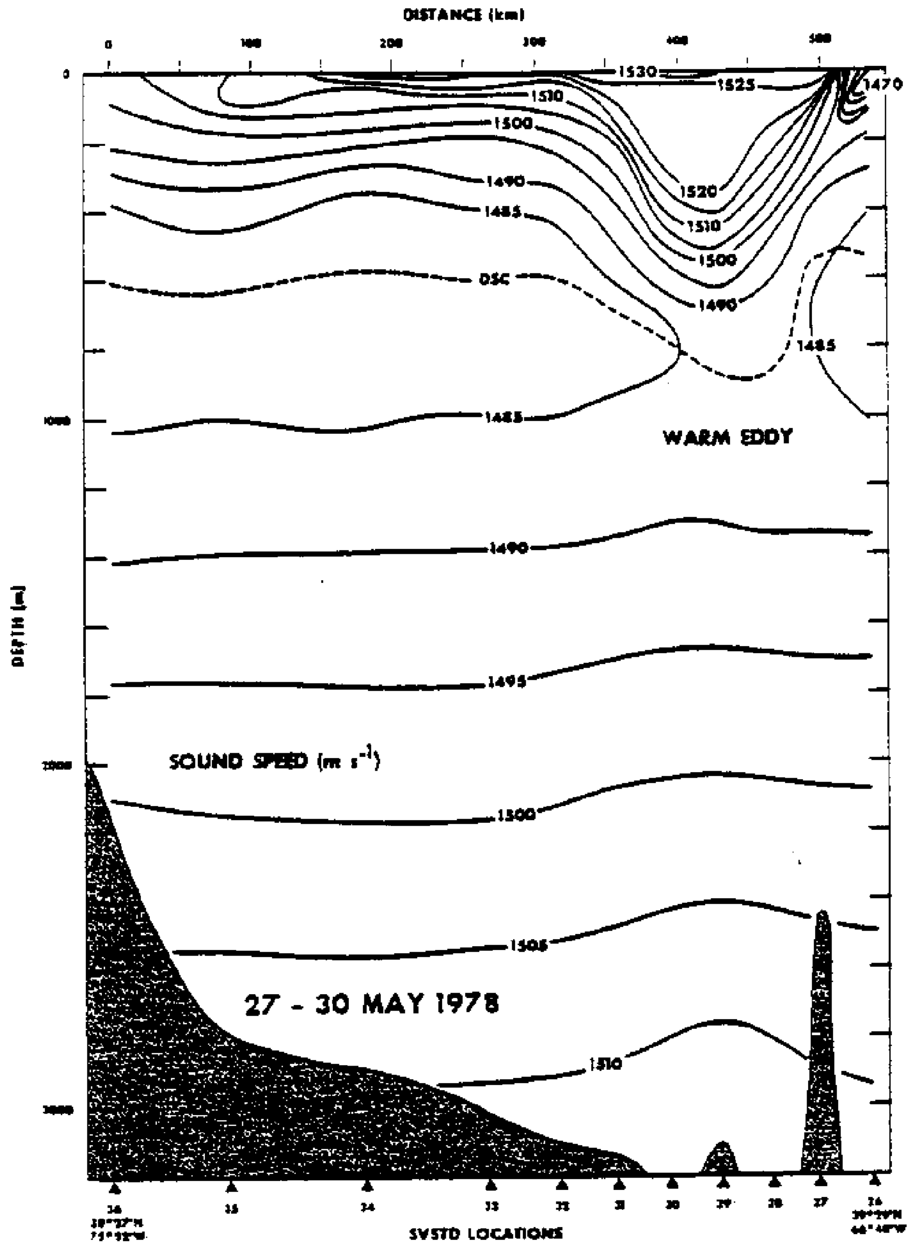


FIG. 23-TEMPERATURE SECTION THROUGH SLOPE WATER AND THE WARM EDDY. ISOTHERMS THROUGHOUT THE WATER COLUMN ARE 400 M DEEPER IN THE EDDY THAN IN THE SURROUNDING WATER. AT A DEPTH OF 350 M THE EDDY REPRESENTS A 9°C ANOMALY. (CHENEY, REF. 4.)

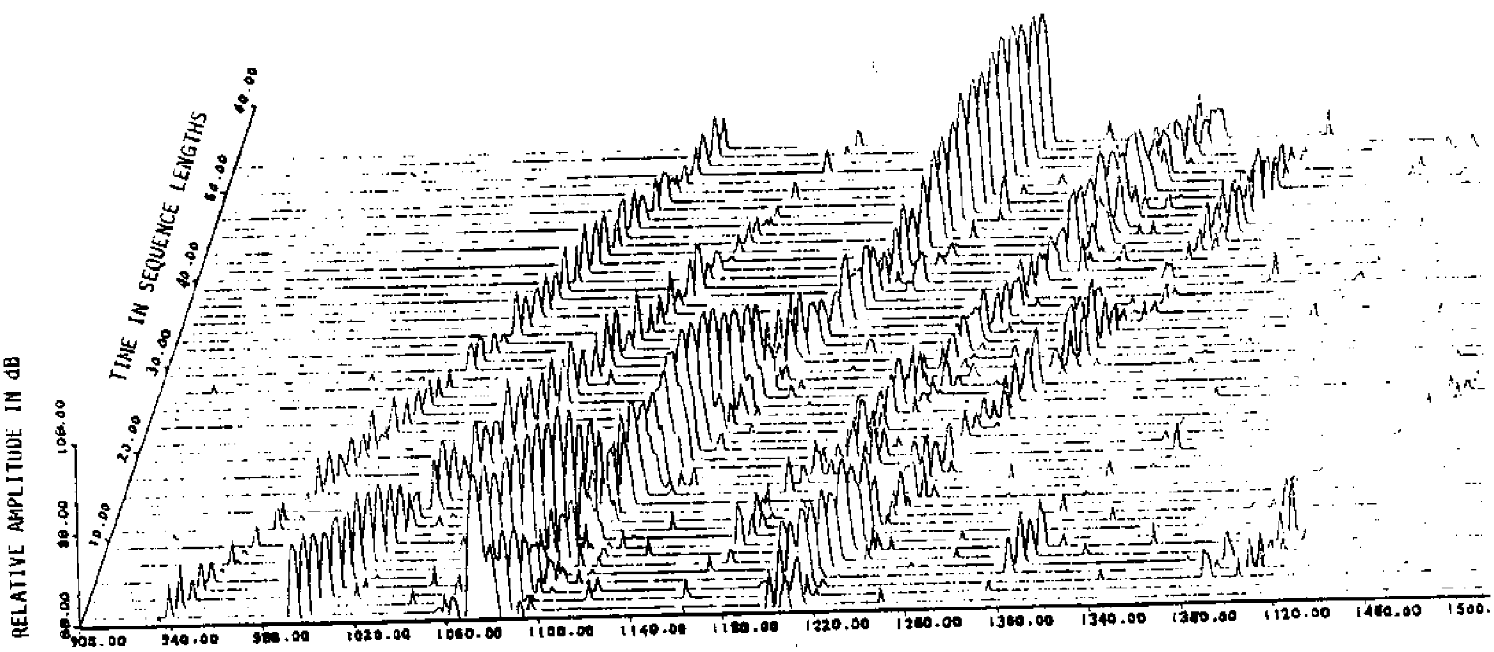


Fig. 24: ARRIVAL TIME IN CARRIER PERIODS (FIXED TIME REFERENCE)

Moving Source Multipath Measurement; 98.27 Hz; 3dB Bandwidth 20.83 Hz; Line Spacing 0.041 Hz; Sequence Length 24.576 sec; Digit Length 0.048 sec; Nominal Range 300 km. (Communication from Dr. John Clark.)

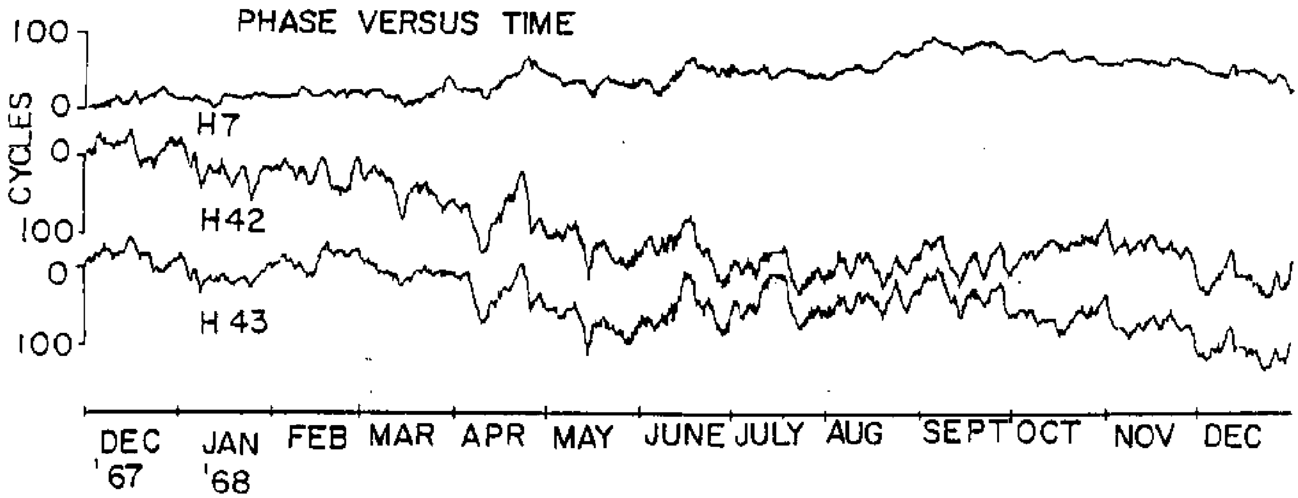


FIG. 25-VARIATIONS OF ACOUSTIC PHASE WITH TIME AT THE 7, 42, AND 43-MILE HYDROPHONES DURING A 13-MONTH INTERVAL. FREQUENCY - 420 HZ (STEINBERG, ET AL., REF. 1.)

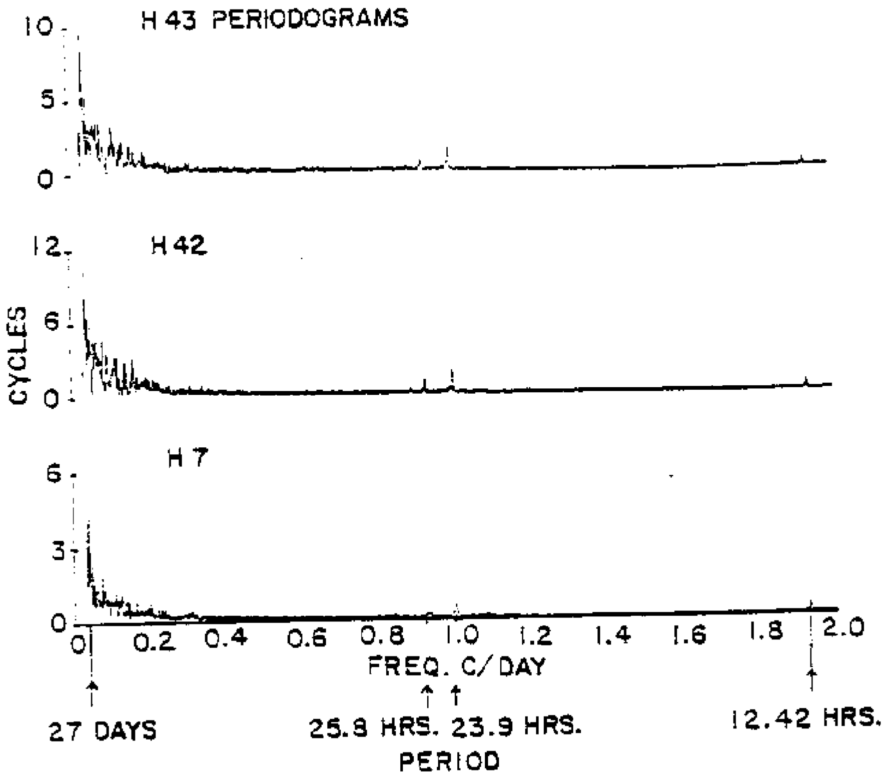


FIG. 26- PERIODOGRAMS OF THE PHASE VARIATIONS AT THE 7, 42, AND 43-MILE HYDROPHONES IN THE 13-MONTH TIME SERIES. FREQUENCY - 420 Hz. (STEINBERG, ET AL., REF. 1.)

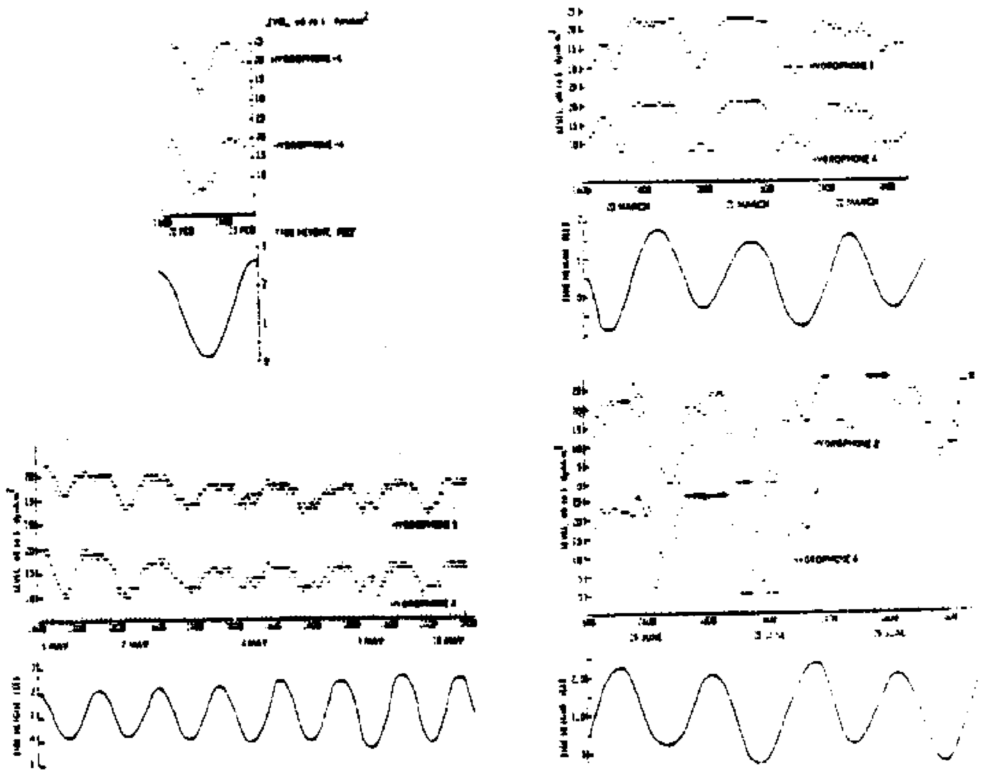


FIG. 27- AMPLITUDE FLUCTUATIONS ON SEVERAL DAYS AND THE HEIGHT OF THE TIDE. FREQUENCY - 1120 Hz. (URICK, REF. 5.)

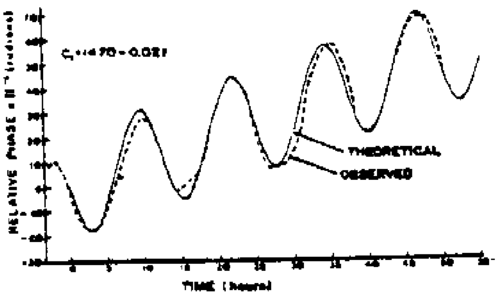


FIG. 28-THEORETICAL RELATIVE PHASE OF THE TOTAL FIELD FOR A TIDAL CURRENT AND A SLOWLY DECREASING MEAN SOUND SPEED AND OBSERVED RELATIVE PHASE. FREQUENCY - 1700 Hz. (STALLWORTH & JACOBSON, REF. 6.)

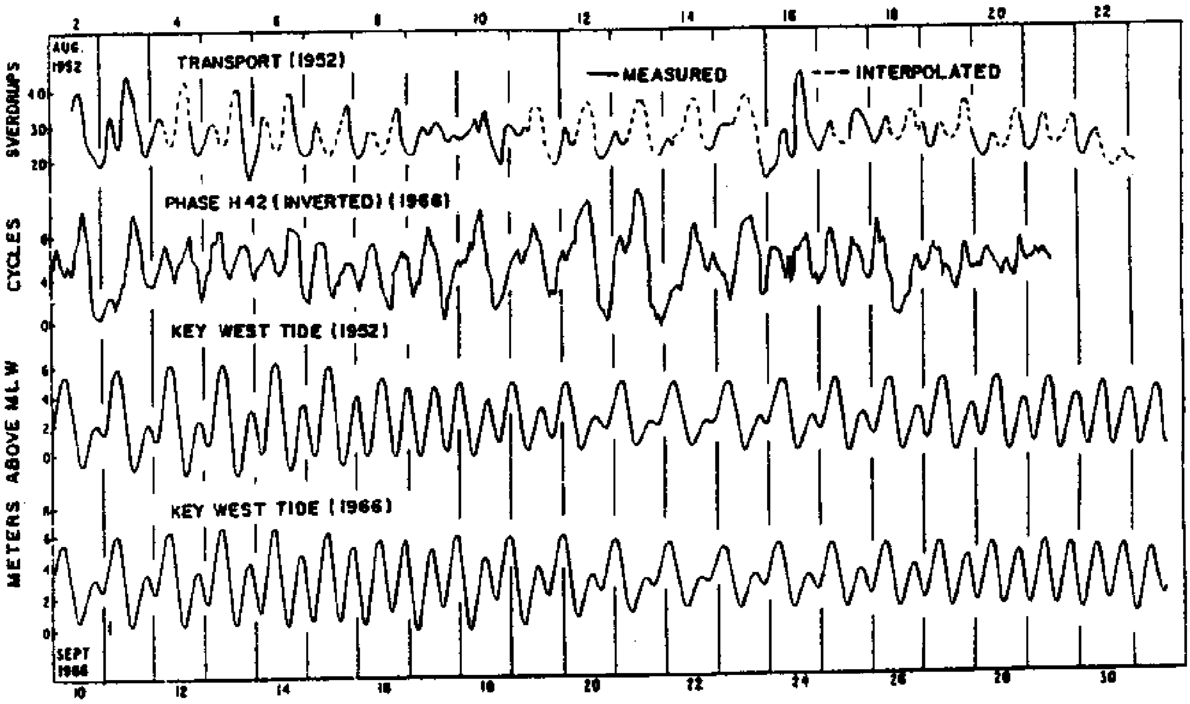


FIG. 29- KEY WEST TRANSPORT, BIMINI PHASE, AND KEY WEST TIDE FLUCTUATIONS. FREQUENCY - 420 HZ. (STEINBERG, ET AL., REF. 1.)

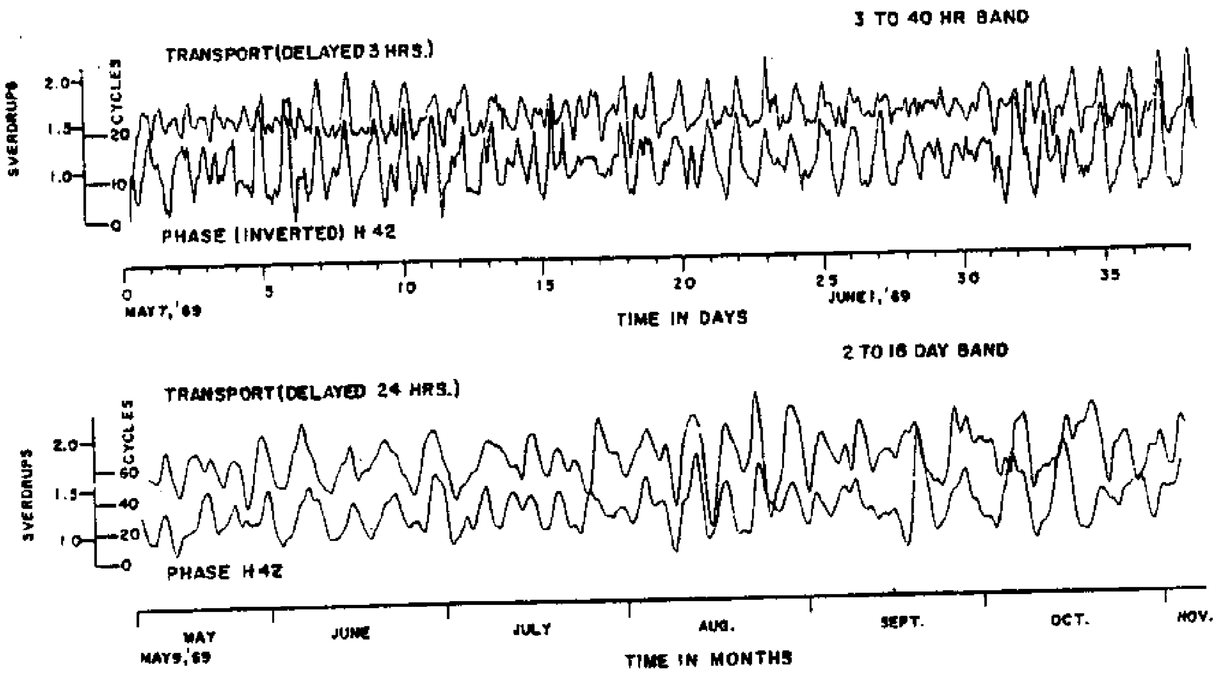


FIG. 30- MIAMI SHELF TRANSPORT AND BIMINI PHASE. FREQUENCY 420 HZ. (STEINBERG, ET A., REF. 1.)

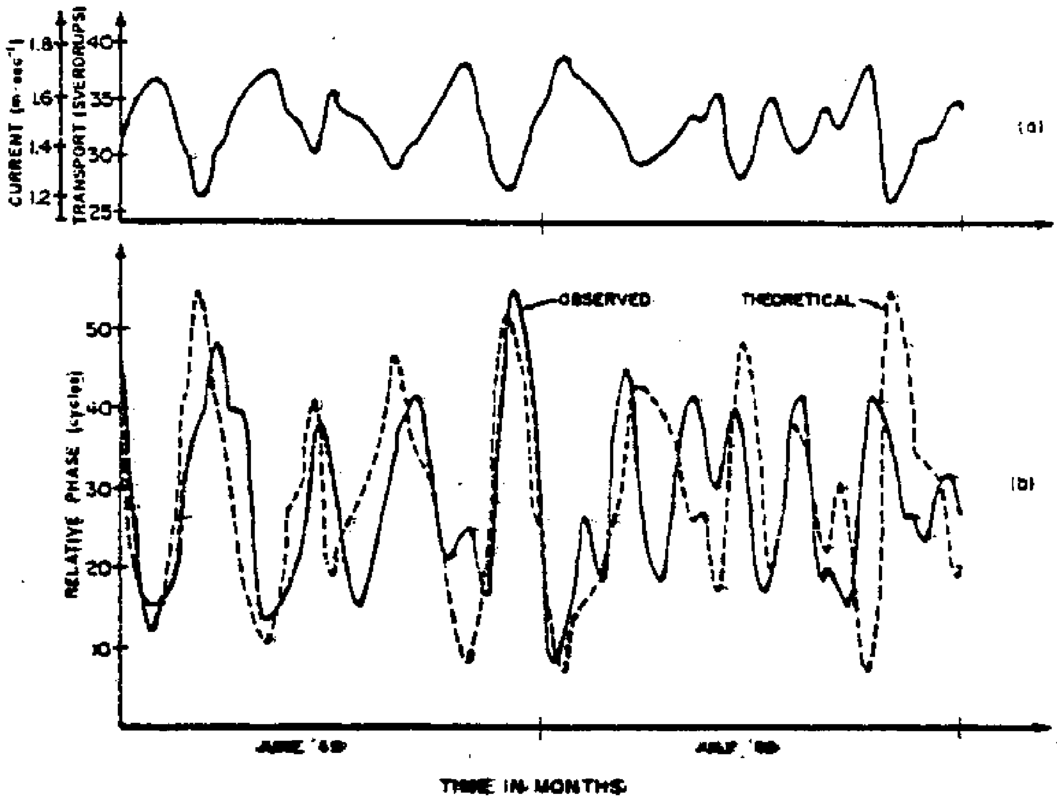


FIG. 31 (A) TRANSPORT VARIATIONS IN THE FLORIDA STRAITS.
(B) OBSERVED (SOLID CURVE) AND THEORETICAL (BROKEN CURVE) PHASE VARIATIONS AT 420 Hz. (FRANCHI AND JACOBSON, REF. 17).

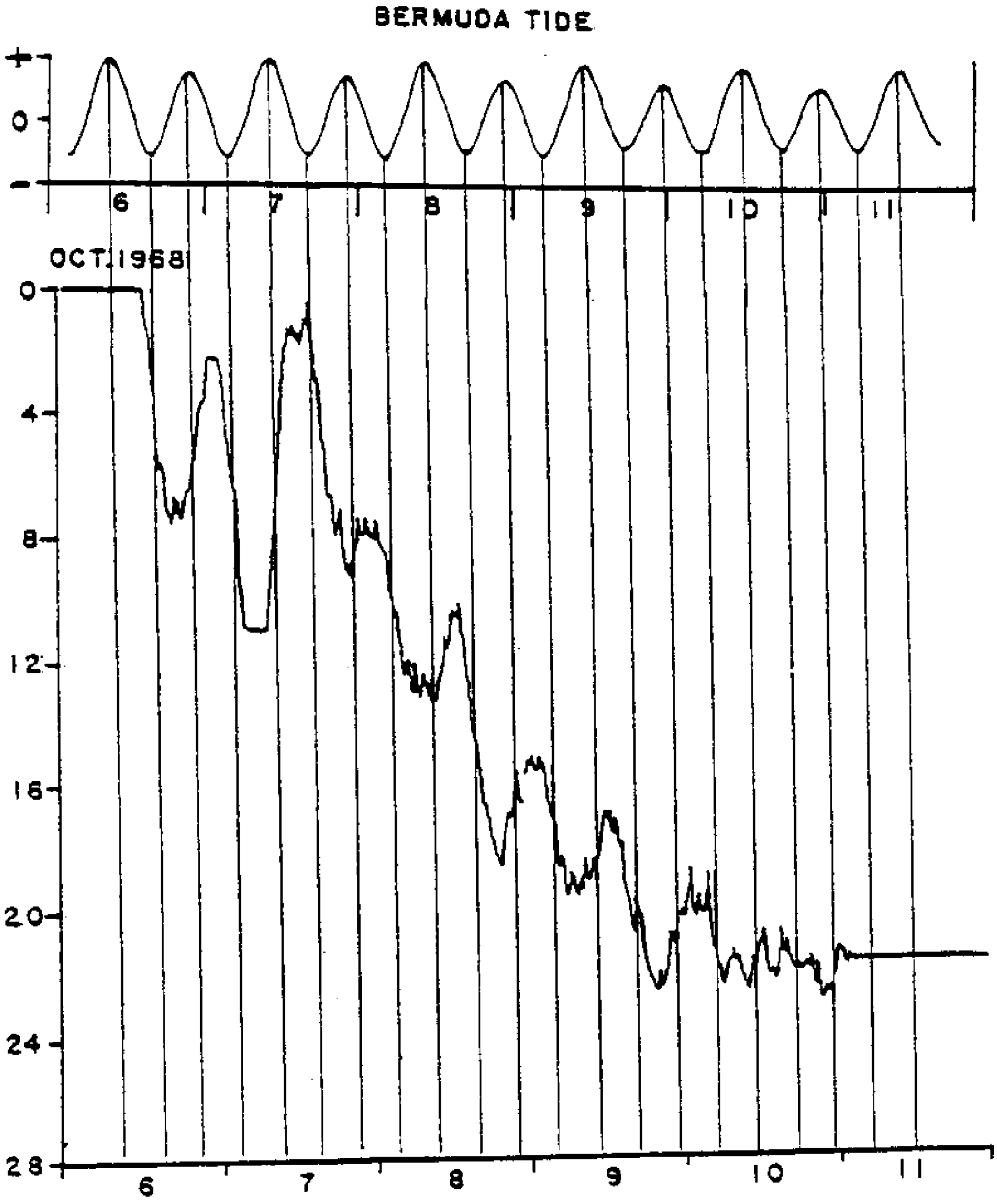


FIG. 32- PHASE DATA FROM A SHORT-RANGE FIXED-SYSTEM EXPERIMENT NEAR BERMUDA. FREQUENCY - 750 HZ.; RANGE - 80 KM. (CLARK AND KRONENGOLD, REF. 3.)

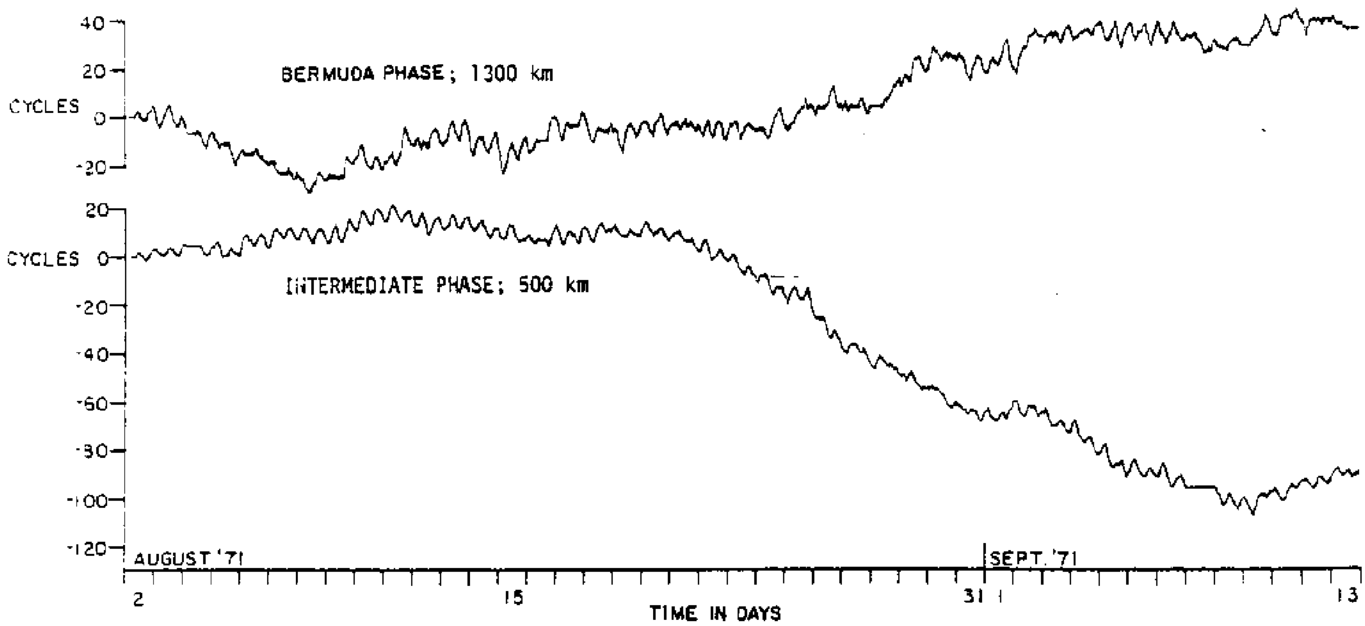


FIG. 33- LONG TIME SERIES OF BERMUDA AND INTERMEDIATE-HYDROPHONE PHASE DATA. THESE DATA ARE UNFILTERED. TWO REGIMES OF FLUCTUATION ARE APPARENT IN THESE DATA: TIDAL VARIATIONS SUPERIMPOSED ON LARGE VARIATIONS OF EXTRATIDAL TIME SCALE. FREQUENCY 406 HZ. (CLARK AND KRONENGOLD, REF. 3.)

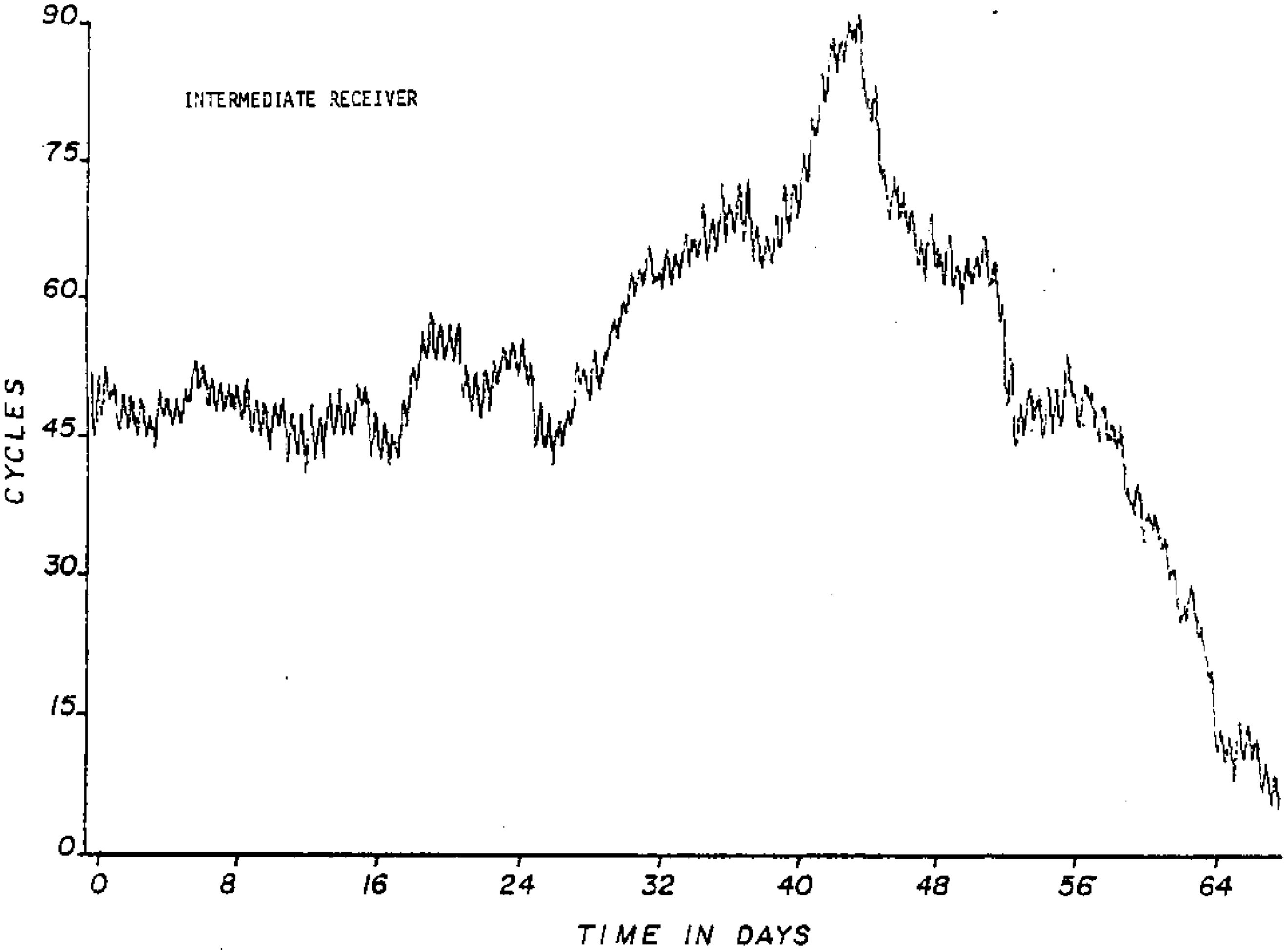


FIG.34- 12/9/75 PHASE TIME SERIES; 206Hz; 500KM. (COMMUNICATION FROM DR. JOHN CLARK.) 2/15/76

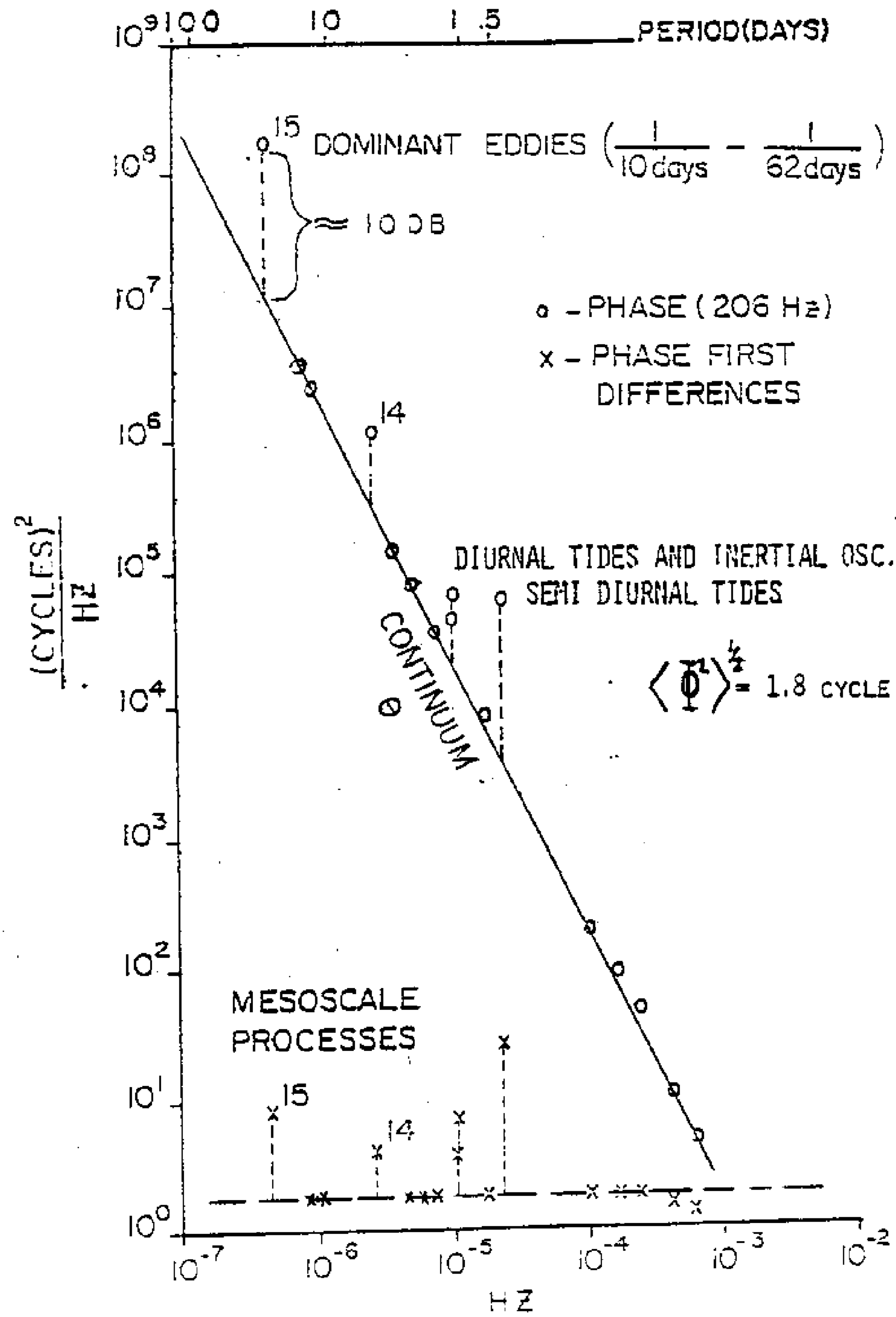


FIG. 35- 206 Hz PHASE SPECTRUM. (COMMUNICATION FROM DR. JOHN CLARK)

CONSTITUENT		PERIOD IN SOLAR HOURS	°G	AMPL. (CYCLES)	COEFFICIENT RATIO (DEFANT)
LARGER LUNAR ELLIPTIC	Q_1	26.87	20.5	0.07	0.079
PRINCIPAL LUNAR DIURNAL	O_1	25.82	14.3	0.20	0.415
PRINCIPAL SOLAR DIURNAL	P_1	24.07	218.9	0.08	0.194
LUNI-SOLAR DIURNAL	K_1	23.93	217.0	0.29	0.239
LARGER LUNAR ELLIPTIC	N_2	12.66	27.7	0.21	0.192
PRINCIPAL LUNAR	M_2	12.42	38.7	1.00	1.000
PRINCIPAL SOLAR	S_2	12.00	36.0	0.24	0.466
LUNI-SOLAR SEMIDIURNAL	K_2	11.97	32.4	0.06	0.127

(°G and AMPL.: Communication from Dr. B. Zetler)

FIG. 36

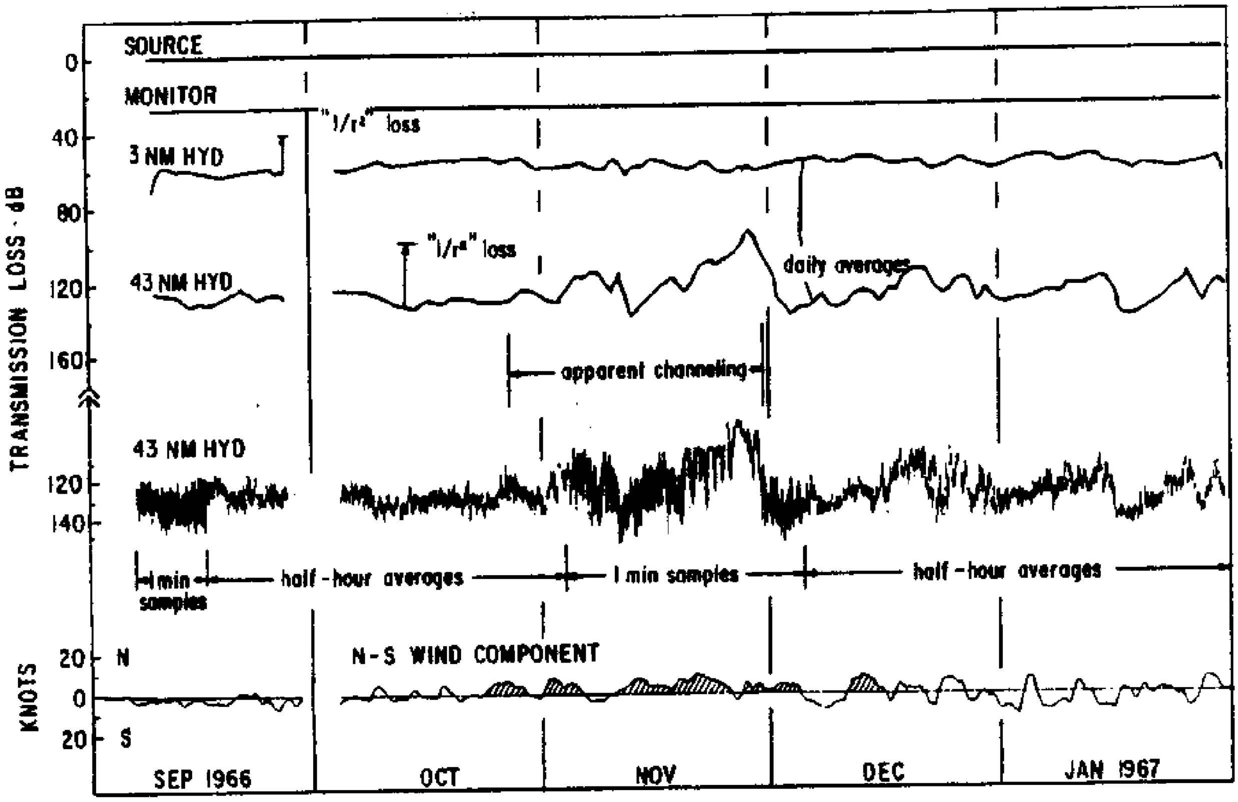


FIG. 37-TRANSMISSION LOSS AS A FUNCTION OF TIME. FREQUENCY - 420 HZ. (CLARK AND YARNALL, REF. 7.)

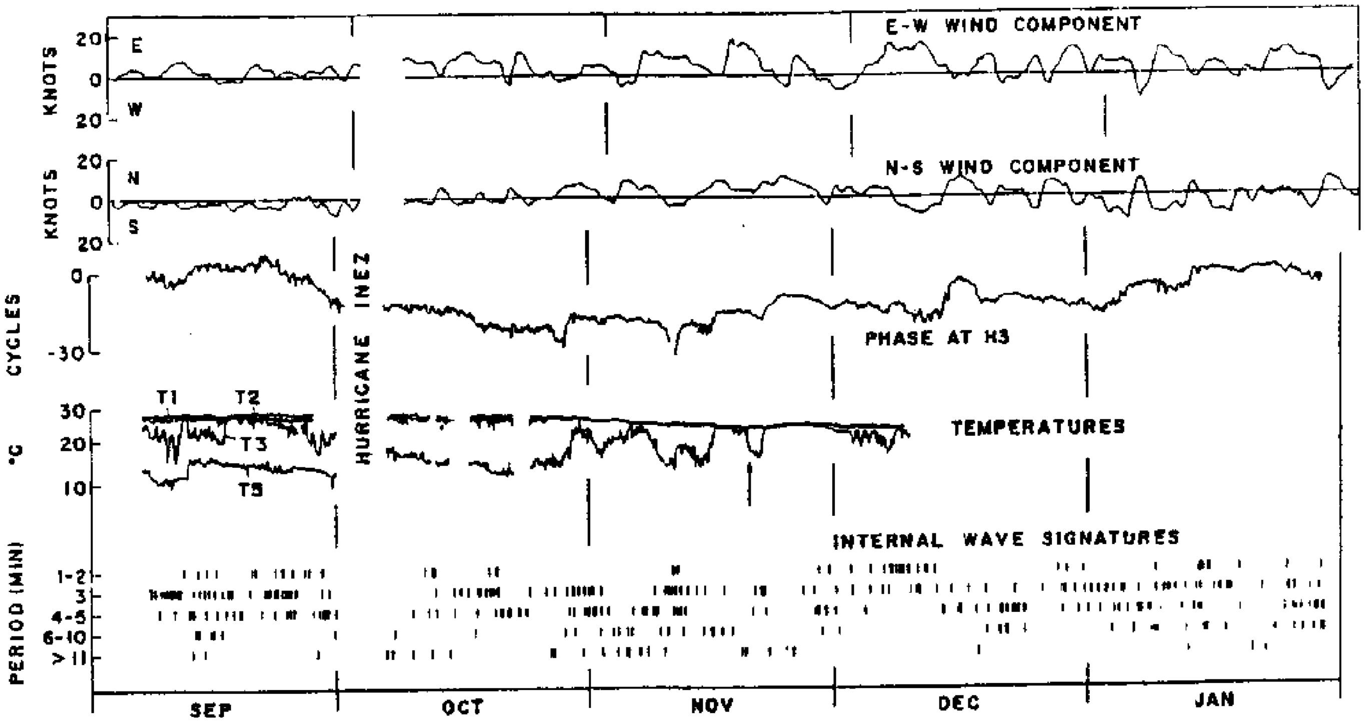


FIG. 38-HYDROPHONE H3 PHASE-ENVIRONMENTAL RELATIONSHIPS; FREQUENCY - 420 HZ. (CLARK AND YARNALL, REF. 2.)

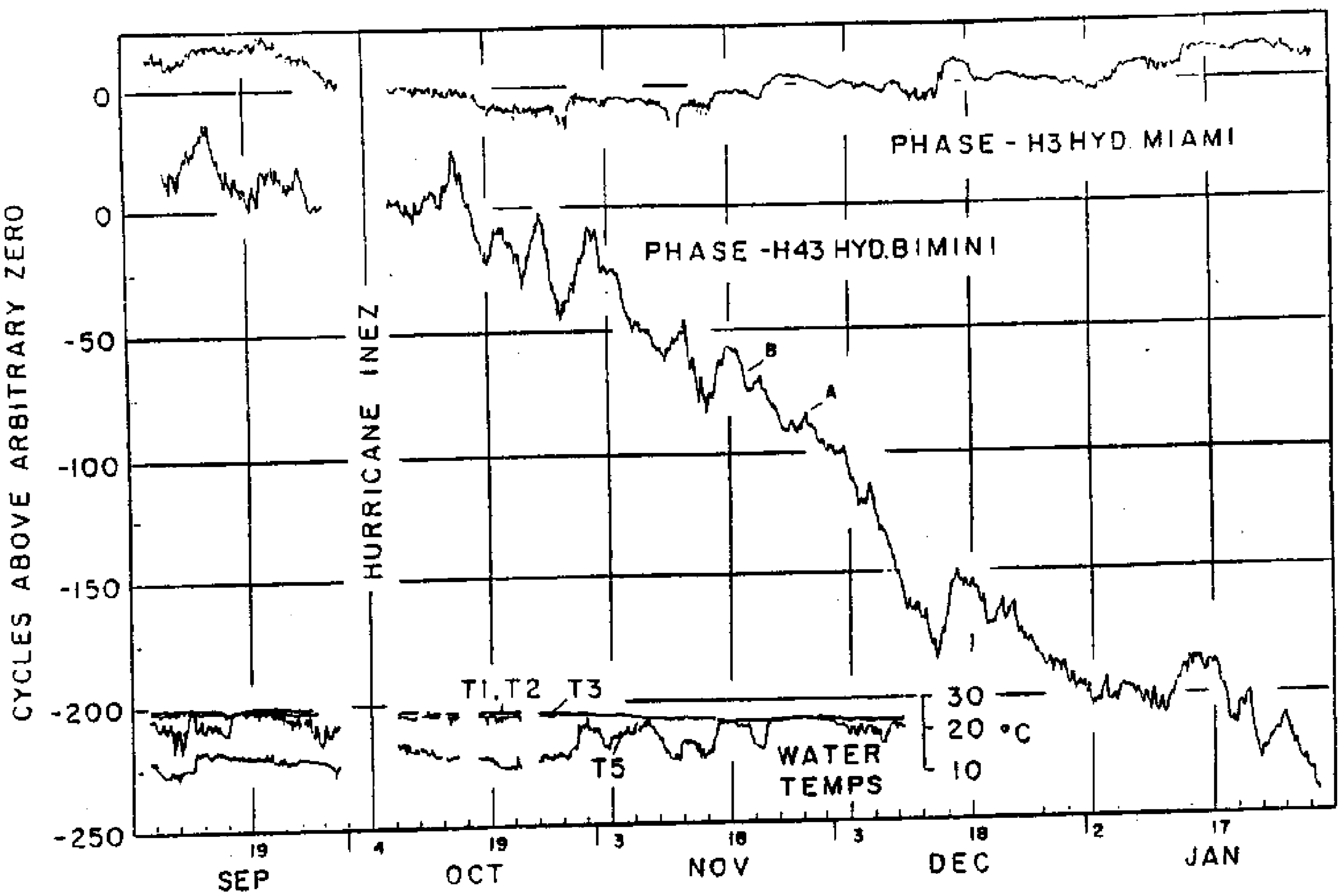


FIG. 39- PHASE AND TEMPERATURE PATTERNS. FREQUENCY - 420 Hz. SEP 1966-JAN 1967. (CLARK AND YARNALL, REF. 2.)

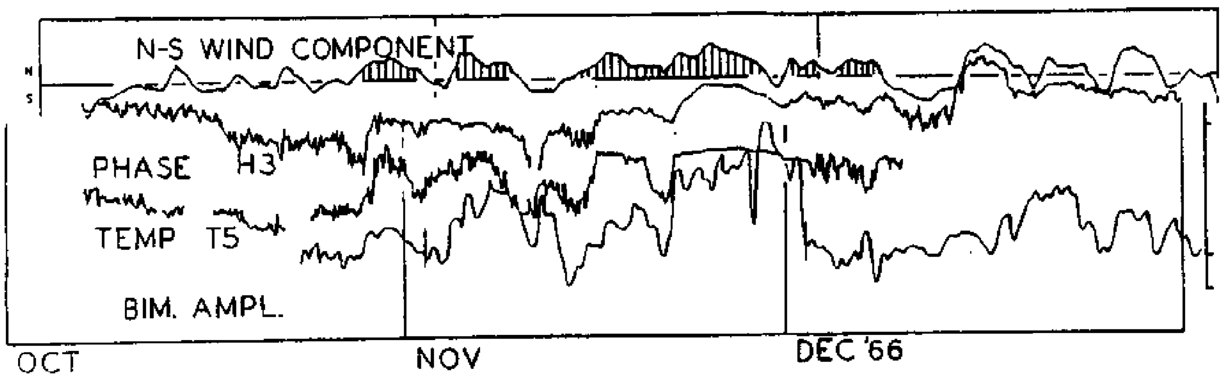


FIG. 40- TIME-SERIES OF NORTH-SOUTH COMPONENT OF THE WIND, TEMPERATURE, ACOUSTIC AMPLITUDE AND PHASE. FREQUENCY - 420 HZ. (CLARK AND YARNALL, REF. 2.)

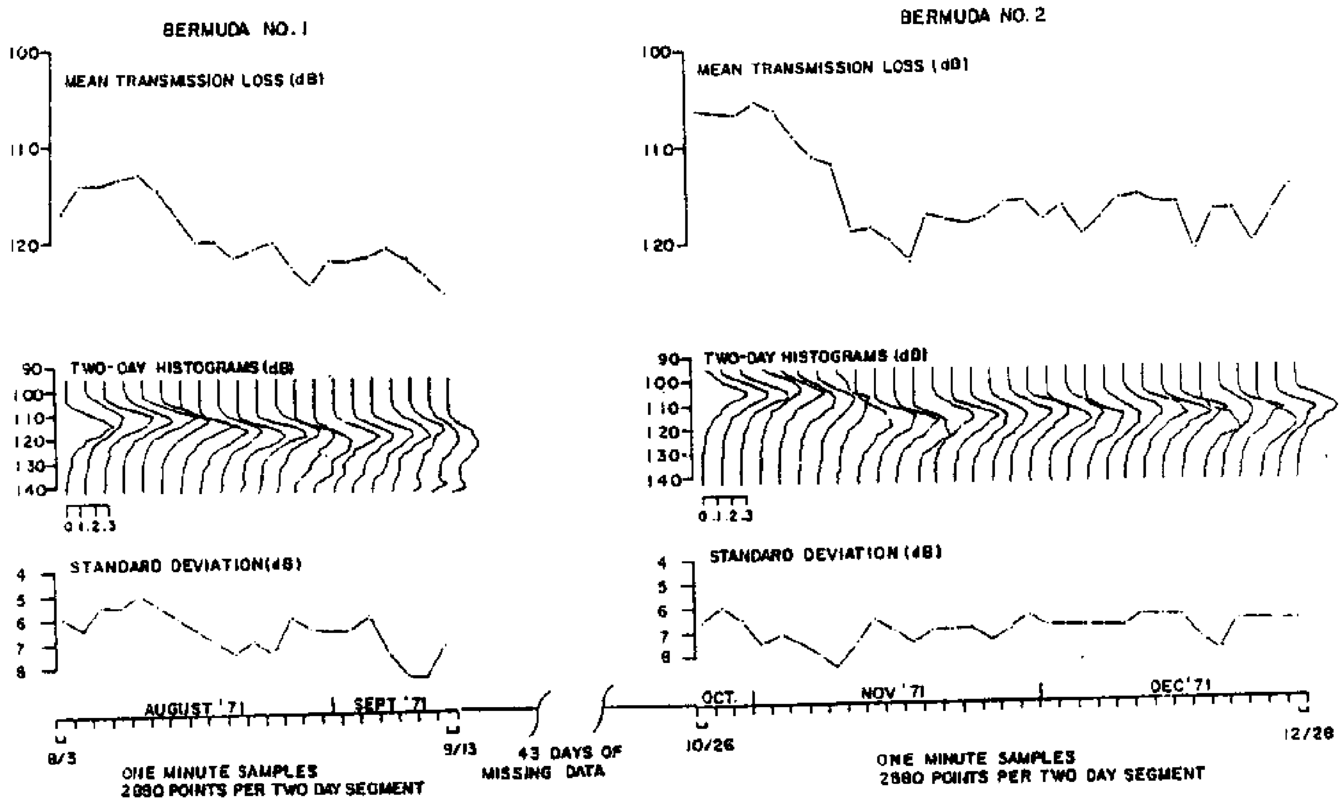
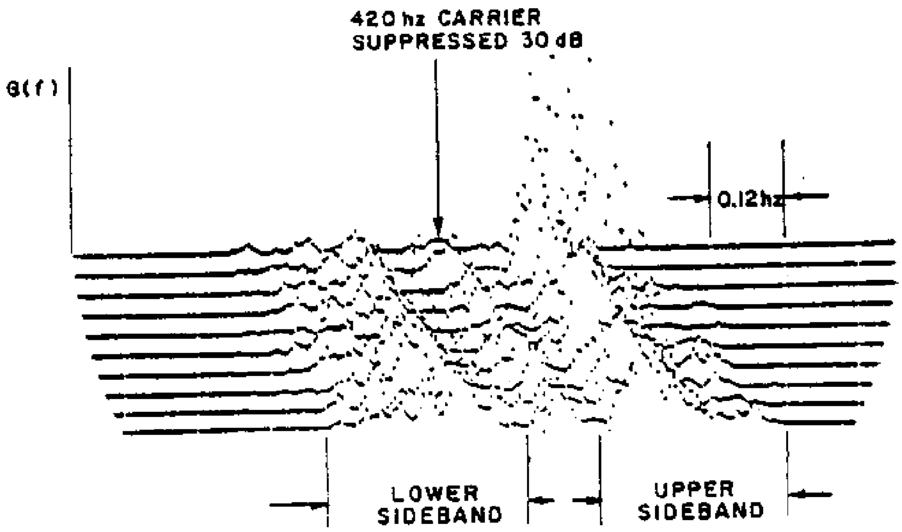


FIG. 41- TWO DAY MEAN AND VARIANCE OF THE TRANSMISSION LOSS FOR THE TIME-SERIES OF FIGURE 4.7; FREQUENCY - 406 HZ. (CLARK AND KRONENGOLD, REF. 3.)



$$\lim_{T \to \infty} \frac{1}{T} \int_0^T \left[p(t) \right]^2 dt = \int_0^\infty G(f)\, df$$

FIG. 42 -SPECTRUM OF FORWARD-SCATTERED REVERBERATION; FREQUENCY - 420 Hz. (COMMUNICATION FROM DR. HARRY DEFERRARI.)

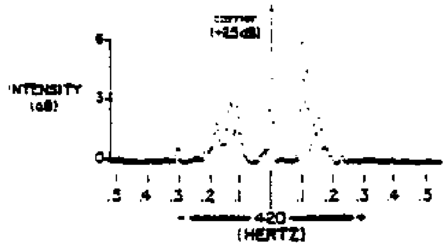


FIG. 43 - SPECTRUM OF THE SIGNAL RECEPTION FOR A CW TRANSMISSION. (DEFERRARI AND NGHIEM-PHU, REF. 8.)
SOURCE-RECEIVER DISTANCE – 7 NM
FREQUENCY - 420 Hz
SOURCE DEPTH - 30 M
RECEIVER DEPTH - 350 M

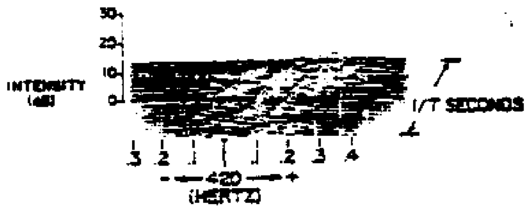


FIG. 44 - SCATTERING FUNCTION, SEAS 6-8 FT. DURING PASSAGE OF A COLD FRONT. (DEFERRARI AND NGHIEM-PHU, REF. 8.)

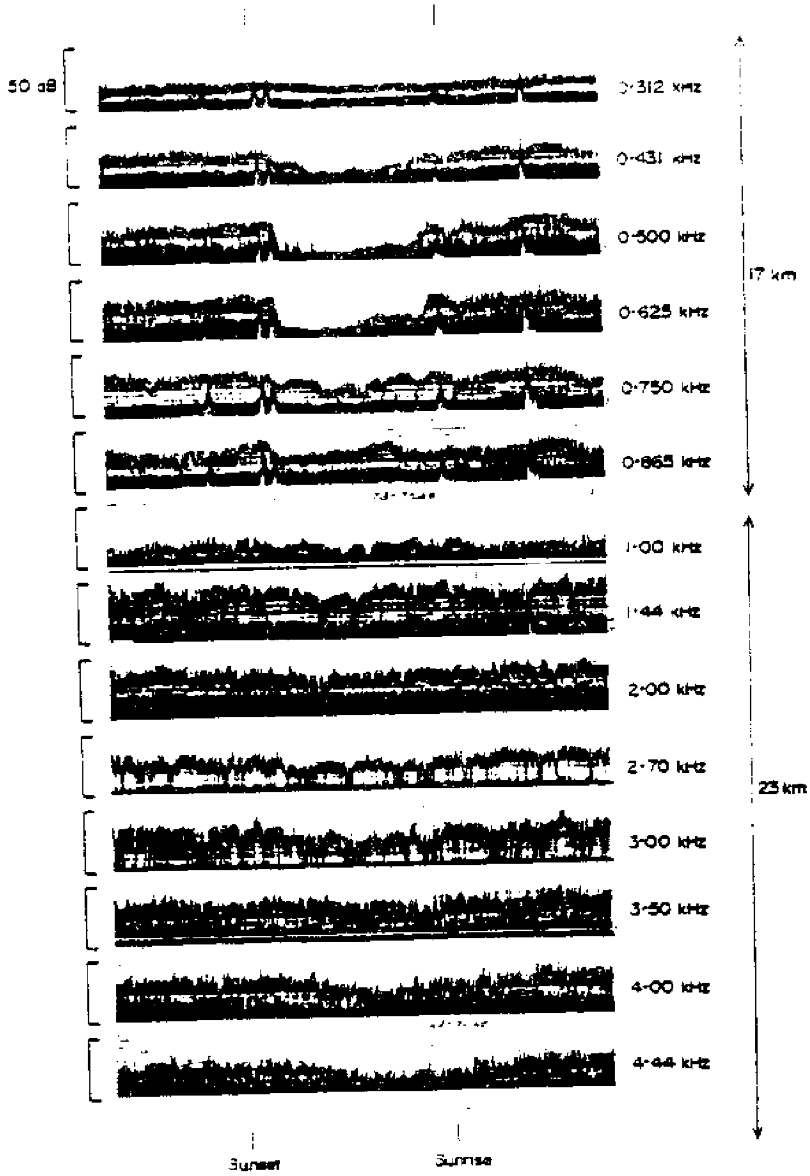


FIG. 45 - SAMPLE DISPLAY SHOWING FREQUENCY DEPENDENCE OF ATTENUATION PATTERNS OVER SHORT-RANGE PATH. 22ND-23RD JULY 1969 (WESTON, ET AL., REF. 9.)

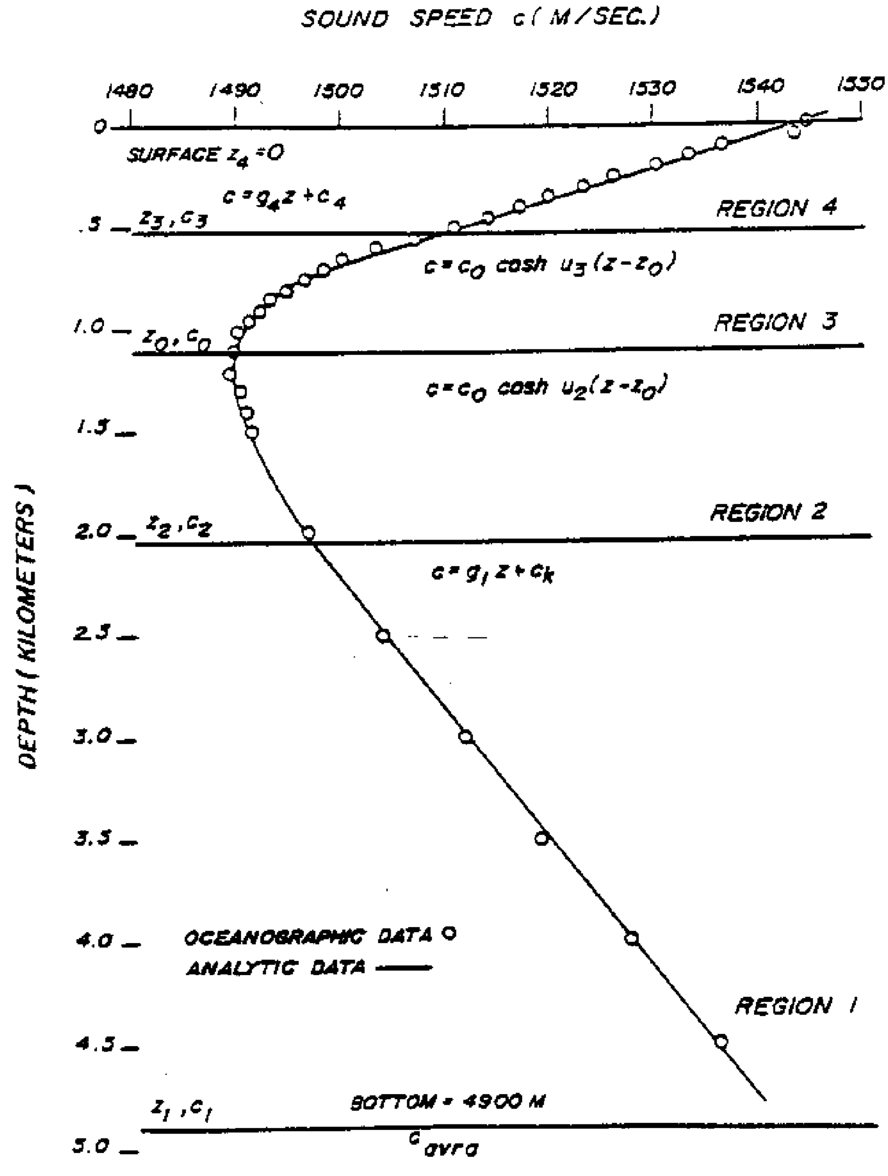


FIG.46- GEOMETRY FOR ACOUSTIC MODEL WITH DATA AND MATHEMATICAL REPRESENTATION OF AVERAGE PROFILE. (FLANAGAN, WEINBERG, AND CLARK, REF. 10.)

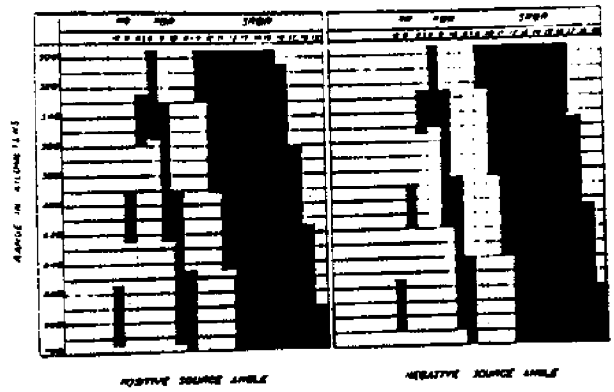


FIG. 47 - ALLOWED RAYS VERSUS RANGE FROM SOURCE TO RECEIVER FOR A SOURCE DEPTH OF 150 M AND A RECEIVER DEPTH OF 2500 M. FREQUENCY - 350 HZ. (SHADING INDICATES INTERACTION OF RAY WITH RECEIVER.) (FLANAGAN, WEINBERG, AND CLARK, REF. 10.)

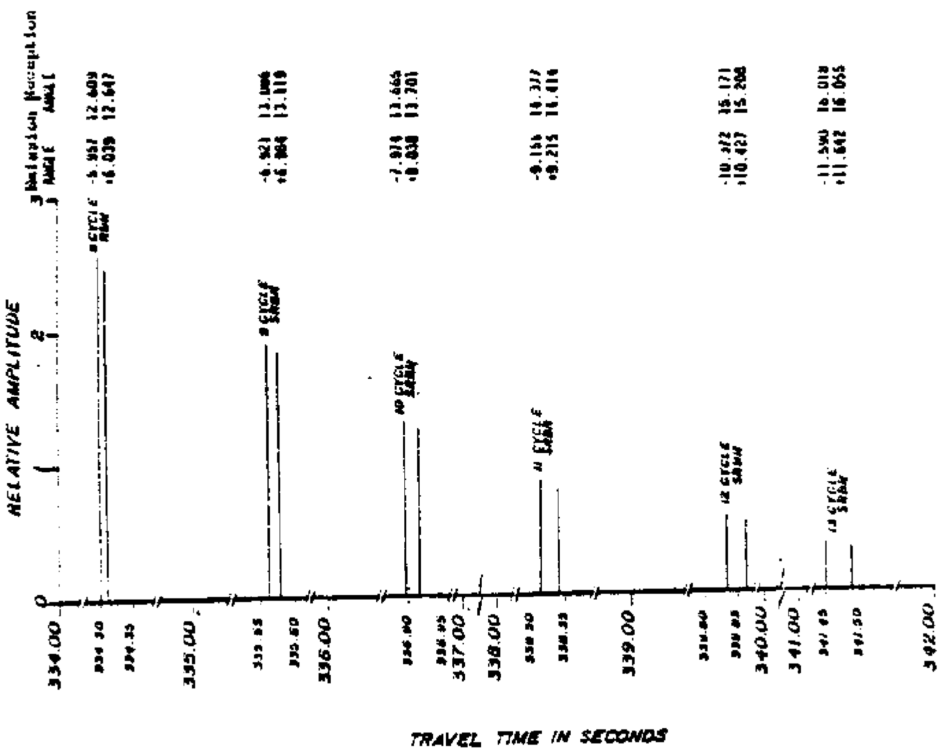


FIG. 48- TRAVEL TIMES, ANGLES OF EMISSION, AND ANGLES OF RECEPTION. SOURCE AND RECEIVER FIXED AT A RANGE OF 500 KM. FREQUENCY - 350 Hz. (FLANAGAN, WEINBERG, AND CLARK, REF. 10.)

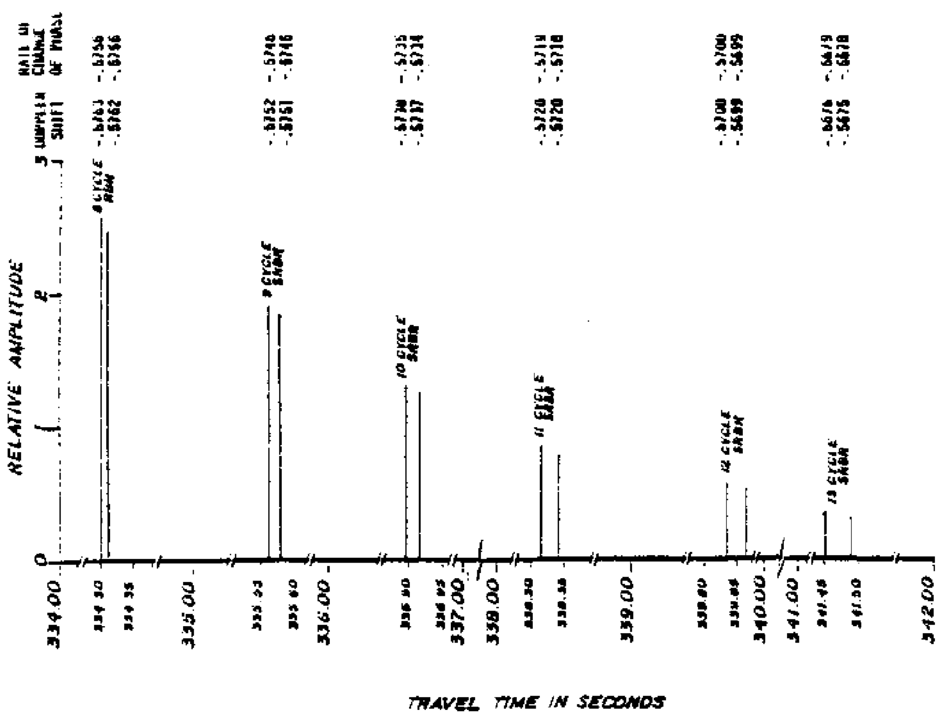


FIG. 49 - TRAVEL TIMES FOR FIXED SOURCE AND RECEIVER AT A RANGE OF 500 KM. MOVING SOURCE AT A RANGE OF 500 KM. FREQUENCY - 350 HZ. (UNPUBLISHED COMMUNICATION FROM R. P. FLANAGAN.)

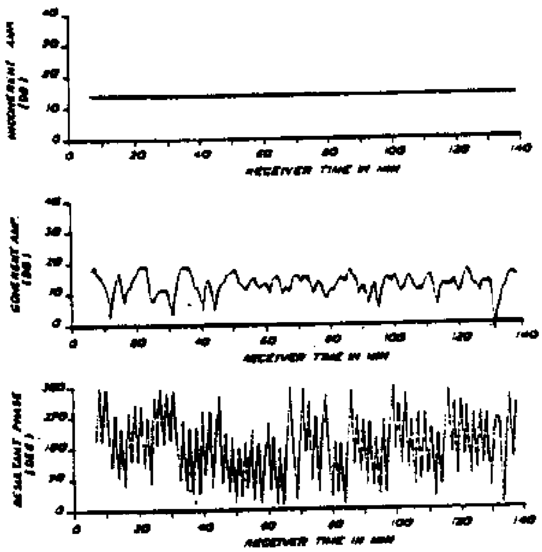


FIG. 50 - TIME SERIES FOR PROPAGATION FROM A SOURCE MOVING AWAY FROM A FIXED RECEIVER. RANGE AT TIME ZERO, 500 KM; SHIP SPEED, 5 KNOTS; RANGE AT TIME 140 MIN. 520 KM. FREQUENCY - 350. (FLANAGAN, WEINBERG, AND CLARK, REF. 10.)

350 Hz.

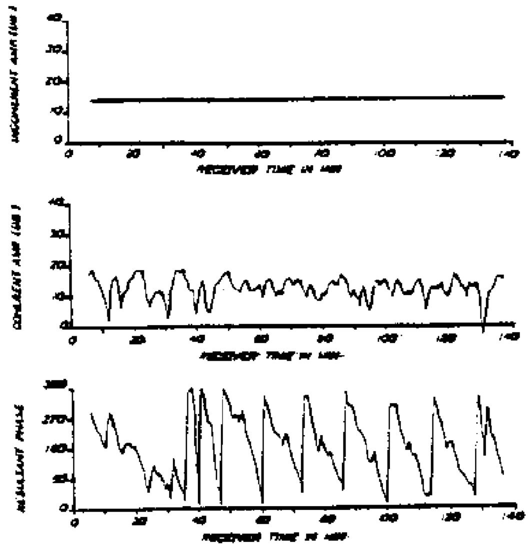


FIG. 51 - TIME SERIES FOR PROPAGATION FROM A SOURCE MOVING AWAY FROM A FIXED RECEIVER. RANGE AT TIME ZERO, 500 KM; RANGE AT TIME 140 MIN, 520 KM; RATE OF CHANGE OF PHASE "CORRECTED" FOR SHIP MOTION. (FLANAGAN, WEINBERG, AND CLARK, REF. 10.)

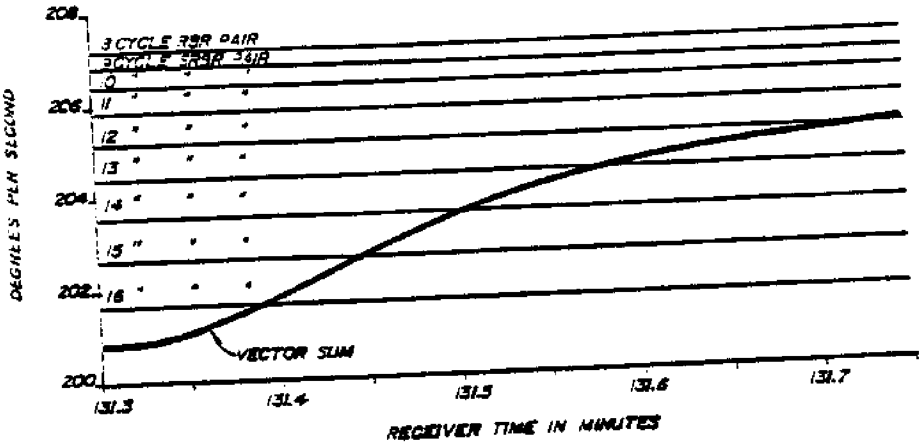


FIG. 52 - RATE OF PHASE CHANGE TIME SERIES FOR EACH RAY AND THE RESULTANT FOR A MOVING SOURCE. RECEIVER TIME INTERVAL IS APPROXIMATELY FROM 131 MIN 18 SEC TO 131 MIN 45 SEC IN FIGURE 50; FREQUENCY - 350 Hz. (FLANAGAN, WEINBERG, AND CLARK, REF. 10.)

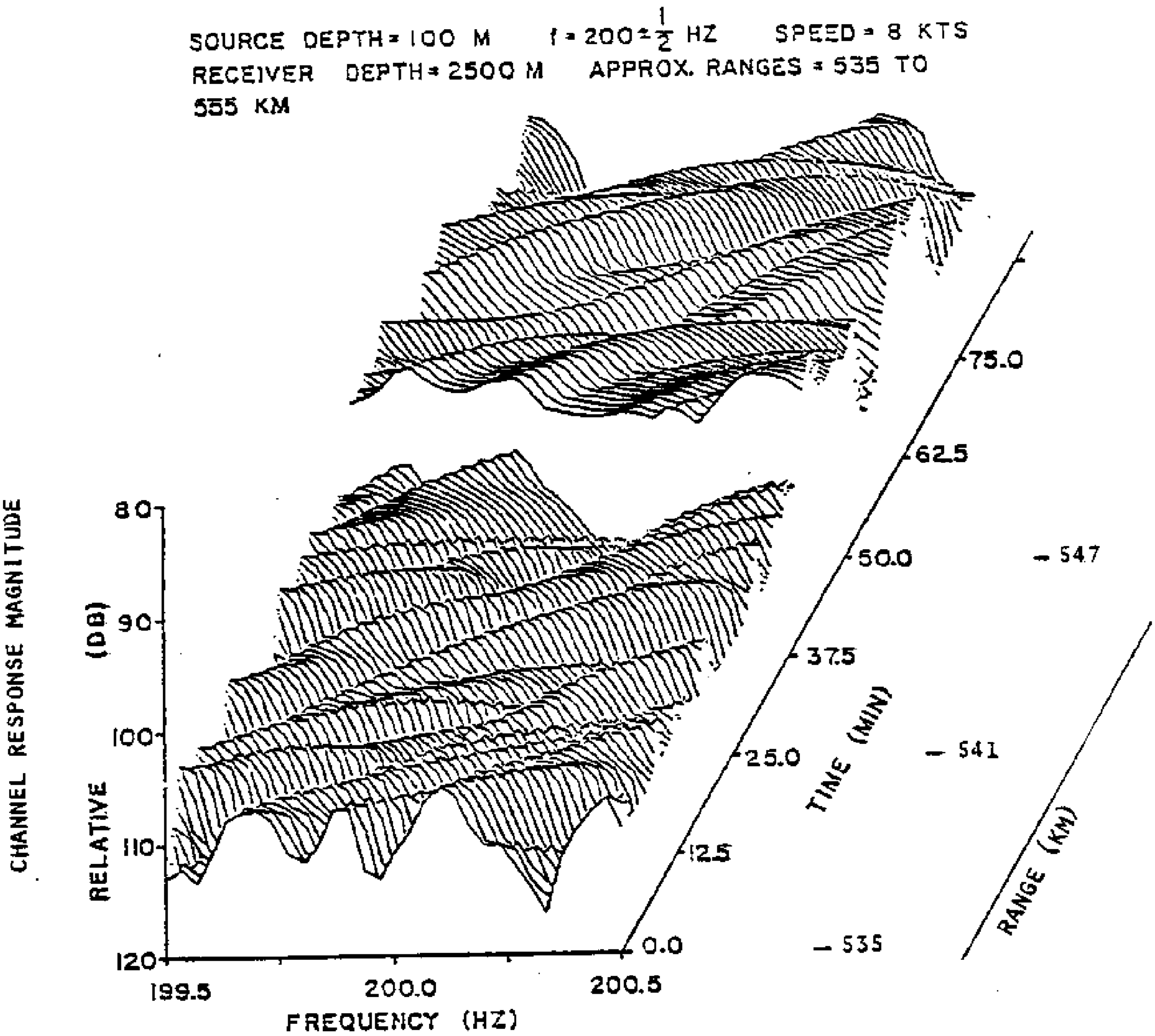


FIG. 53- CHANNEL FREQUENCY RESPONSE MAGNITUDE AS A FUNCTION OF RANGE. (FLANAGAN, REF. 11.)

OARS Paper #6

FISHERIES PROGRAM REQUIREMENTS

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UNAVAILABLE AT TIME OF

PUBLICATION

OARS Paper #7

ACOUSTICAL TECHNIQUES IN FISHERIES RESOURCE MANAGEMENT

by Paul H. Moose
Naval Postgraduate School

One might characterize the task of determining the location and size of the world fisheries as a problem of measuring all or part of the following quantities: (A) Abundance density ρ, (B) The mass density M, and (C) The composition vector $\vec{\theta}$ (i.e., size, species and age) as a function of space and time.

Slide #1: Formal Definition of Problem

One important question for us to consider is, "To what extent does and/or can acoustical equipment and processing techniques help estimate some or all of these population parameters?" This is a purely technical question.

Slide #2: Some Important Characteristics of the Problem

--Another question is, "Which of these parameters, and what resolution (S-T) and accuracy is (A) needed or (B) useful in the management of this dynamic ecosystem?" This is a broader question, one partly technical, but with major management and policy components as well. Some important characteristics of the problem, seen from this broader view, are listed in Slide #2. --What I would like to do today is to briefly overview the acoustical methods that have been brought to fruition in the last ten years, and point out some of the work that still needs to be done to improve the estimates even more.

--Secondly, I would like to throw out some new ideas aimed at provoking a bolder, more ambitious view for the role of acoustical remote sensing in the coming decade.

--Finally, I would like to suggest that some cooperative effort among biologists, managers and technologists in tackling the second question may lead to some useful new direction for acoustics in particular and for effective utilization of remote sensing capabilities in general.

Slide #3: Acoustic Methods

Let's turn our attention first to a brief survey of the acoustical methods that have already demonstrated a practical utility (list).

Slide #4: Sonar Mapping of Fish Schools

Sonar mapping is a technique that is used to identify the general shape and location of schools or shoals of fish. It is very much analogous to radar weather mapping of rain clouds and squalls. Radar weather mapping is typically done around major airports, and frequently shown to us on the evening news.

Both the breadth and height resolution of the sonar mapping technique, obviously degrade with increasing range, they also depend directly on the beam width of the sonar transducer. Lower frequencies are needed for long range transmission, but beam widths tend to broaden at low frequencies. The range or thickness resolution, depends on system bandwidth which also tends to degrade with lower frequency. The result is that a design tradeoff must be made between range, and hence volume coverage, and volume resolution. Most practical systems for shipboard use are found in the 3 to 30 kHz band, and may operate successfully to ranges as great as 3 km or more, or to as little as 700 m or even less, depending on the frequency, the acoustical scattering strength of the school and the background noise. Also, severe thermal gradients in the water column can refract the sound energy to the extent that certain regions may lie in an "acoustic shadow" and hence be inaccesible to the sonar mapper altogether. Variable depth towed systems, such as illustrated in the drawing, are less susceptible to severe shadowing problems than hull mounted systems.

In spite of these limitations, sonar mappers are useful tools to estimate the number and approximate volume of fish schools in a given region. Also, from the strength of the echo returned from a school taken in combination with other available knowledge of density, one can make estimates of the total school mass.

Slide #5: Acoustic Fish Counter

At one far end of the spectrum of spatial distributions are those in which the fish are spread out great distances from one another, fish that are not "schooled" in any real sense at all.

For such species, fish counters are more useful than sonar mappers. The acoustic fish counter simply counts the number of echos returned from any given depth Z. The system volume resolution must be great enough in relation to the true density $\rho(\bar{X})$ that the only probable counts are zero or one. If this in fact is true, and the ship moves about taking many soundings in independent volumes of water of a horizontally homogeneous field, then the sample mean of $\hat{\rho}(Z)$ will converge to the true mean.

Slide #6: Variance in Counting Low Density Populations

The normalized variance depends on the ratio of probability of zero counts to one count, a number much greater than one so there is to be expected considerable intrinsic scatter in fish counter estimates of abundance, even for a fairly large number of samples in the survey. Even more serious errors occur if the density increases and multiple fish are insonified at one time. This biases the estimate downward.

Of course, if one can count every single fish unambiguously in a water volume, or the flux of fish through a constricted passage or channel, the question of statistical parameters is moot; the total number of fish is, after all, a definite quantity, not a random variable. Statistical characteristics are of importance only when statistical inference is involved, as in sampling surveys.

It is clear that the counting method is quite inappropriate for tightly schooled or shoaled fish "clouds" of the type one tries to map out with sonar. However these are numerous species whose concentrations fall above the 10^{-6} to 10^{-8} fish/m^3 where counters do work (to 100-200 m depth) and below the 1 to 10 fish/m^3 found in dense fish "clouds." Many concentrations of fish in this intermediate range, though not "schooled" in the strict sense, do accumulate along different distinct depth strata with horizontal scales of inhomogeneity that are quite large, compared with the vertical. An acoustic technique called "fish echo integration" has evolved that works quite well for these horizontally stratified populations.

Slide #7: Fish Echo Integration

In echo integration, all signals returning from a given depth stratum are normalized for transmission loss, squared and integrated. The ship moves along, collecting a number of samples from the same stratum to produce a sample mean: it should be noted that a number of strata of varying thicknesses can be examined simultaneously. Considering a single stratum for the moment, the expected value of the integrator sample mean is proportional to the total number of fish insonified and the average return from a single fish. Looking at it another way, it is directly proportional to the average scattering/unit volume.

Slide #8: Echo Integrator Statistics

The variance of this estimate can be made arbitrarily small, at least in theory, by looking at a great many fish $\rho V \rightarrow \infty$ with a very high range resolution system, $\Delta r \rightarrow 0$. In practice, the stratum is not infinite in extent and one wants to see its edges. Also, system bandwidth which limits range resolution, is limited to 10% or so of the carrier frequency. Nevertheless, it is quite reasonable to expect standard deviations of 20% or less of the true mean after a few hundred soundings.

The problem with the integrator, of course, has been to convert this relatively well stabilized numerical quantity, the integrator output, into an estimate either of abundance or biomass. One must be able to calibrate his system quite precisely and determine the sample volumes accurately; one must also know the average target strength of the fish in the population. Target strength, that is how much sound a fish reflects, is known to depend on a number of factors including the aspect of insonification, the fish size, structure and gas content, and the sonar frequency used. Over the years, a number of experiments have been undertaken to obtain empirical formulas for fish target strength from laboratory measurements, and more recently several clever methods have been described to measure target strength in situ. Unfortunately, most of these methods require observation of single fish, a condition we have already pointed out to be a difficult one to obtain in situ in the more dense and/or remote aggregations. Considerable research is going and has gone into the target strength problem and one might hope we can reduce our uncertainty in this parameter from say a factor of ten, which may be where we were a decade ago, to a factor of two or so by using a combination of the laboratory knowledge and _in situ_ measurements. This may represent a practical limit and would be comparable to what we might hope for in calibration accuracy and stability of the field instrumentation.

Another possibility is to note that the integrator output is really an estimate of "scattering strength/unit volume." It may be that biomass scattering strength is more simply related to biomass/unit volume, and is relatively independent of individual fish characteristics.

Slide #9: Biomass vs Volume Scattering

However, it seems that the only way to estimate this relationship is inferentially, through comparison with another non-acoustic estimate of biomass. This brings in the set of errors associated with the non-acoustic technique. Whether or not this could improve the overall biomass estimate isn't totally clear, but it seems to warrant more discussion.

There are two potential problems with the integrator theory itself. These are (1) the acoustic shadowing or multiple scattering effect and (2) the possibility that fish aggregate in well ordered structures, that is, not randomly as assumed in the theory. Considering the first issue, we expect that when the density becomes too great, that first order acoustic scattering theory will begin to fail. That is, we cannot treat the acoustic return to be the simple superposition of echoes from the individual fish, each calculated as if the others weren't present. Fish in front begin to reduce the amount of signal that reach fish in back, and partially block the echo return as well. Also, the total signal reaching a fish comes from other fish scattering the pulse from the source as well as directly from the source.

It appears from recent research results that these multiple scattering effects may become important at somewhat lower mass densities than previously believed.

Finding out more about this and determining the best way to incorporate corrective terms for multiple scattering into the integrator equations should be decided on as soon as possible. A re-analysis of past data records may be useful, particularly if any acoustically produced estimates have turned out in retrospect to appear faulty.

With regard to the second issue of regular vice random fish spacings, I am not aware of any evidence that this has been a problem. However, neither am I aware of any experiments specifically designed to look for the potential acoustic effects. What I would expect to see would be an unusually large scatter in the data. It may be useful to estimate higher moments of the integrator output in addition to the mean value, on a continuous basis in order to look for any unexpected statistical behavior. If such evidence is uncovered, then further research would be warranted.

I would now like to briefly outline some of the acoustical techniques for differentiating among fish in an aggregation and for looking at their dynamics.

Slide #10: Composition Determination Methods

From what I can see, all of these techniques have been shown capable of contributing important composition data, but do not yet seem to be in very wide use.

I suppose this stems partly from the rather specialized nature of their application; nevertheless, I was somewhat surprised to see that a relatively small effort is being expended on acoustical identification methods and on how to integrate them into survey equipment on a broad scale.

Slide #11: Some Candidate Systems

I would like for just a moment to propose some other techniques as candidates for investigation in the years ahead. Installing some fixed acoustic sites to get continuous data in critical geographical spots is an obvious candidate. Short range systems have been developed and tested for a habitual route of passage of sockeye salmon south of Adak Island. These systems were quite useful and I'm sure a number of similar routes could be identified around the world where such a continuous capability of monitoring flux would be beneficial to fisheries managers. Long range, low frequency systems operating to 60 km or more, have tracked the movement of fish shoals in the Bristol Channel for years. Further deployment of such systems, which I understand will be discussed at this meeting, could help provide fisheries biologists with a wealth of information about concentrations, behavior, etc., of both pelagic and demersal fisheries.

Let me now discuss, in a little more detail, the possibilities of acoustic imaging, particularly for the horizontally stratified fish distributions.

Slide #12: Technique of Reflection Seismology, Common Depth Point

The problem can be made analogous either to that of synthetic aperture radar or reflection seismology. The best analogy is probably reflection seismology. The basic technique of reflection seismology, CDP for "common depth point," is shown in Slide #12.

The method consists of simultaneously recording the outputs of N equally spaced hydrophone receivers towed in a long line array behind the ship. If the source is pulsed every time the ship has traveled a half hydrophone spacing, then by the time it has traveled half the array length and pulsed N times, N echoes have been obtained, one on each hydrophone, from exactly the same point, say X_1. After properly compensating for different travel times, the N echoes are integrated. The process is equivalent to forming a one-dimensional acoustic image. However, note that this is true for any arbitrary depth, hence every depth can be imaged simultaneously.

Slide #13: Example of a Marine Seismological Section

An example of a marine seismological section obtained in this manner is shown in Slide #13. Although a fair amount of processing is required to obtain these images, this is now routinely done on board seismic ships for many days on end. Again, just as ten years ago, the opportunity to "look into the sea" with acoustics has been greatly expanded by the advent of powerful and affordable modern digital electronics.

Beyond acoustic sections, we might look forward to 3-D images by using techniques analogous to acoustic holography. These slides are photographs of acoustic holographic images mostly obtained at short range and high frequency. Producing such images of fish distributions will require a two-dimensional array of receivers, a technology yet to be developed but one I'm certain we will see in this decade. Perhaps the fisheries community will be the one to pioneer it.

Slide #14: Chlorophyll Distribution (not available)

Finally, let's look at these satellite images recently obtained by Howard Gordon at the Univ. of Miami from the Nimbus-7 Coastal Zone Color Scanner. They are color coded to show chlorophyll distribution and by inference the "standing crop" of phytoplankton. The next slide shows the same variable measured by the R/V Athena II on a transect through the same zone. Quantitative agreement is within a factor of two. I would like to emphasize that anybody with a receiver can read out Nimbus-7 as it passes over your area. There is now a receiver at Scripps for example. What I am trying to suggest is that acoustic surveys should be correlated with other remote sensor data, particularly the satellites which produce synoptic data from large areas. I know the surface properties do not tell the whole story, yet they must be tied in, perhaps through some time delays and other factors. Many powerful techniques are available from estimation theory and stochastic optimal control to determine these relationships and help make much better inferences about total fish biomass, its rate of growth and its geographical distribution.

Thank You

LIST OF SLIDES

FORMAL DEFINITION OF THE PROBLEM

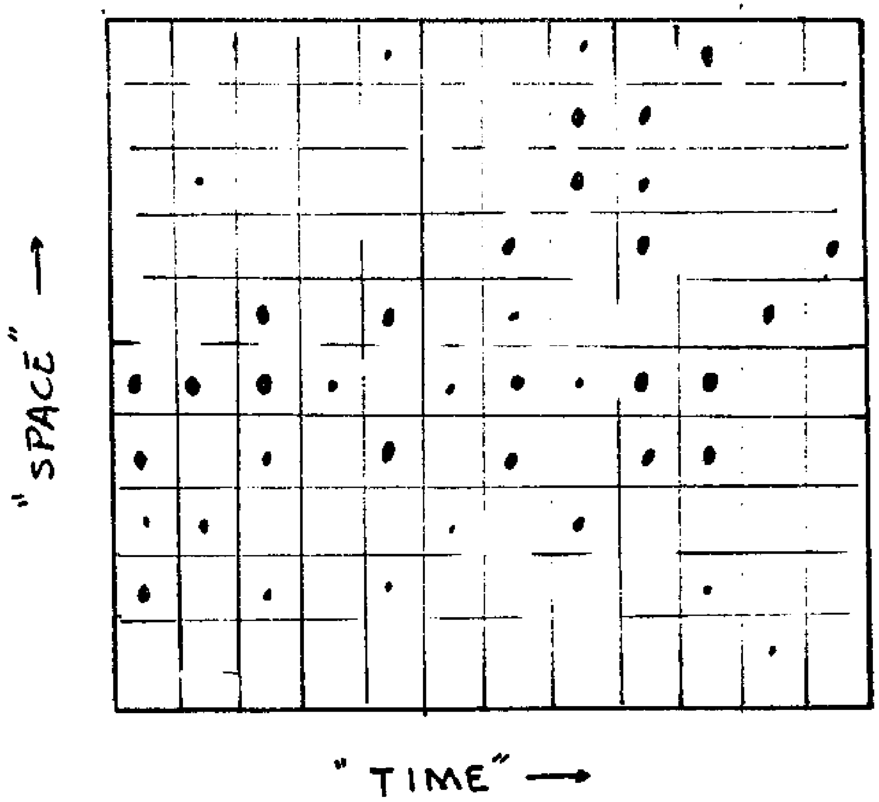
$m(\vec{X})$: mass distribution

$\rho(\vec{X})$: abundance distribution

$\vec{\Theta}(\vec{X})$: composition (species, age, etc)

$\vec{X}$: space-time coordinates $\{x, y, z, t\}$

Slide #1: Formal Definition of Problem



CHARACTERISICS

1. Non-conservative (births/deaths)

2. Non-homogeneous
   Macroscopically (Regional)
   Microscopically (Schooled, Layered)

3. Non-stationary
   Macroscopically (Eco cycles)
   Microscopically (Dynamic)

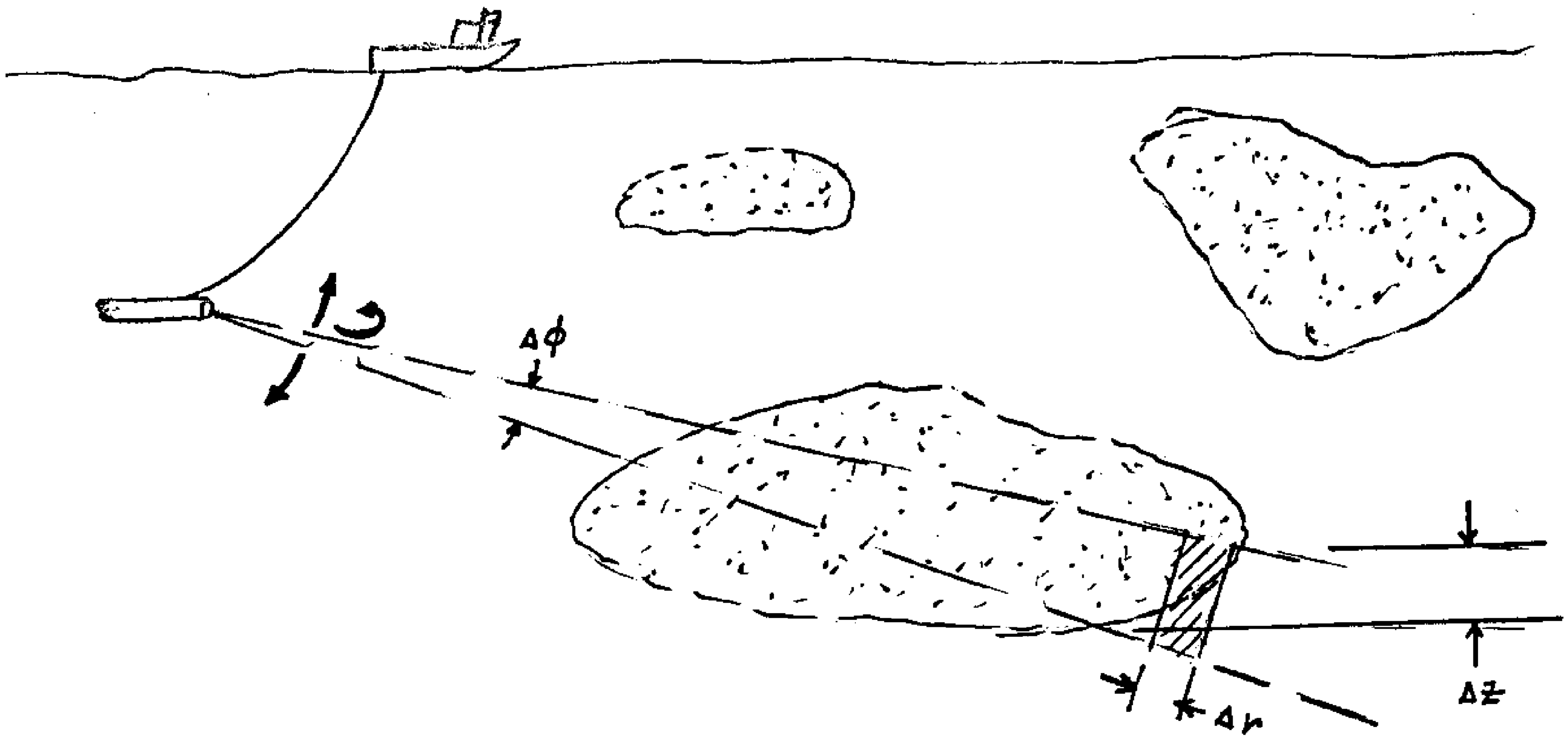
4. Far from equilibrium (Ordered)

Slide #2: Some Important Characteristics of the Problem

ACOUSTIC METHODS

- Sonar Mapping
- Fish Counting
- Echo Integration
- Doppler Signature
- Resonance Technique

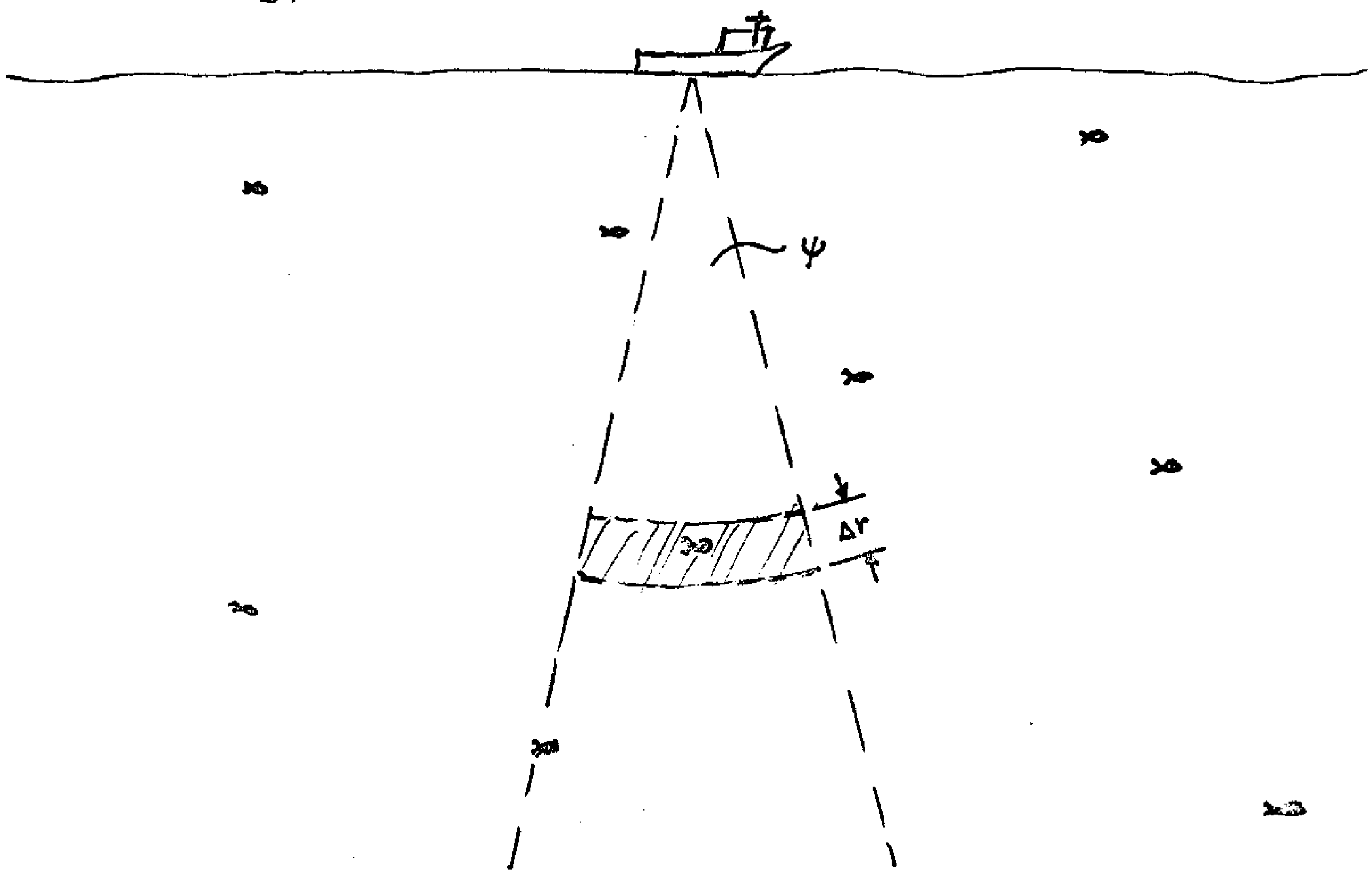
Slide #3: Acoustic Methods



Slide #4: Sonar Mapping of Fish Schools

$$\Delta V = z^2 \Delta r \, \psi \qquad n(z) = \begin{cases} 1 & \text{"Fish"} \\ 0 & \text{"No Fish"} \end{cases}$$

$$\hat{\rho}(z) = \frac{n(z)}{\Delta V}$$



Slide #5: Acoustic Fish Counter

LOW DENSITY POPULATIONS

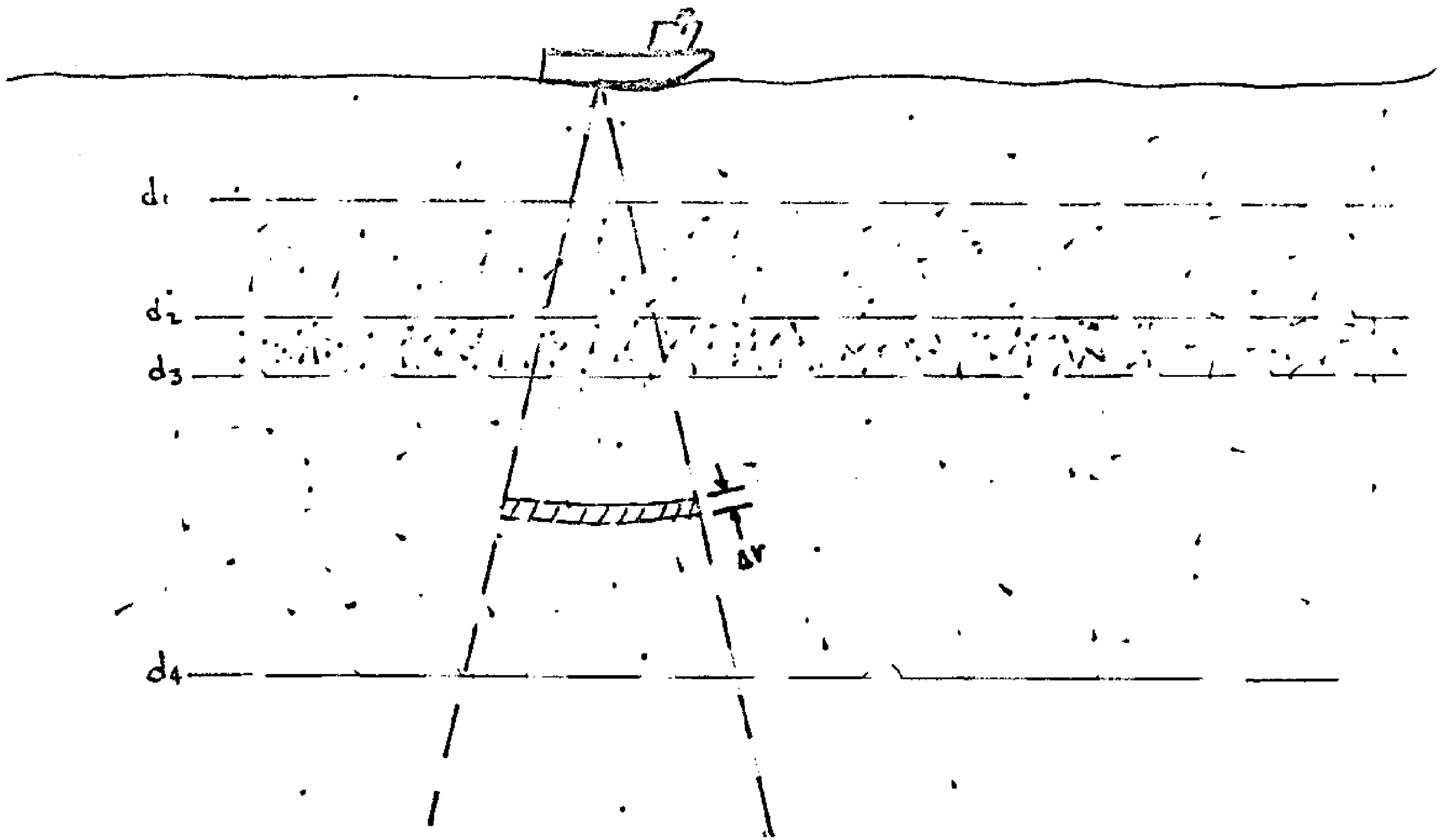
Mean

$$E\left[\hat{\rho}(z)\right] = \rho(z)$$

Normalized Variance

$$\frac{\mathrm{Var}\left[\hat{\rho}(z)\right]}{\rho^2(z)} = \frac{1}{N}\,\frac{\Pr\left[n(z)=0\right]}{\Pr\left[n(z)=1\right]}$$

Slide #6: Variance in Counting Low Density Populations



Slide #7: Fish Echo Integration

Echo Integrator Statistics

Mean

$$E(I_i) = A \, \Delta r \, \bar{t}_s \, \rho_i$$

t_s : single fish target strength $(10^{.1T_s})$

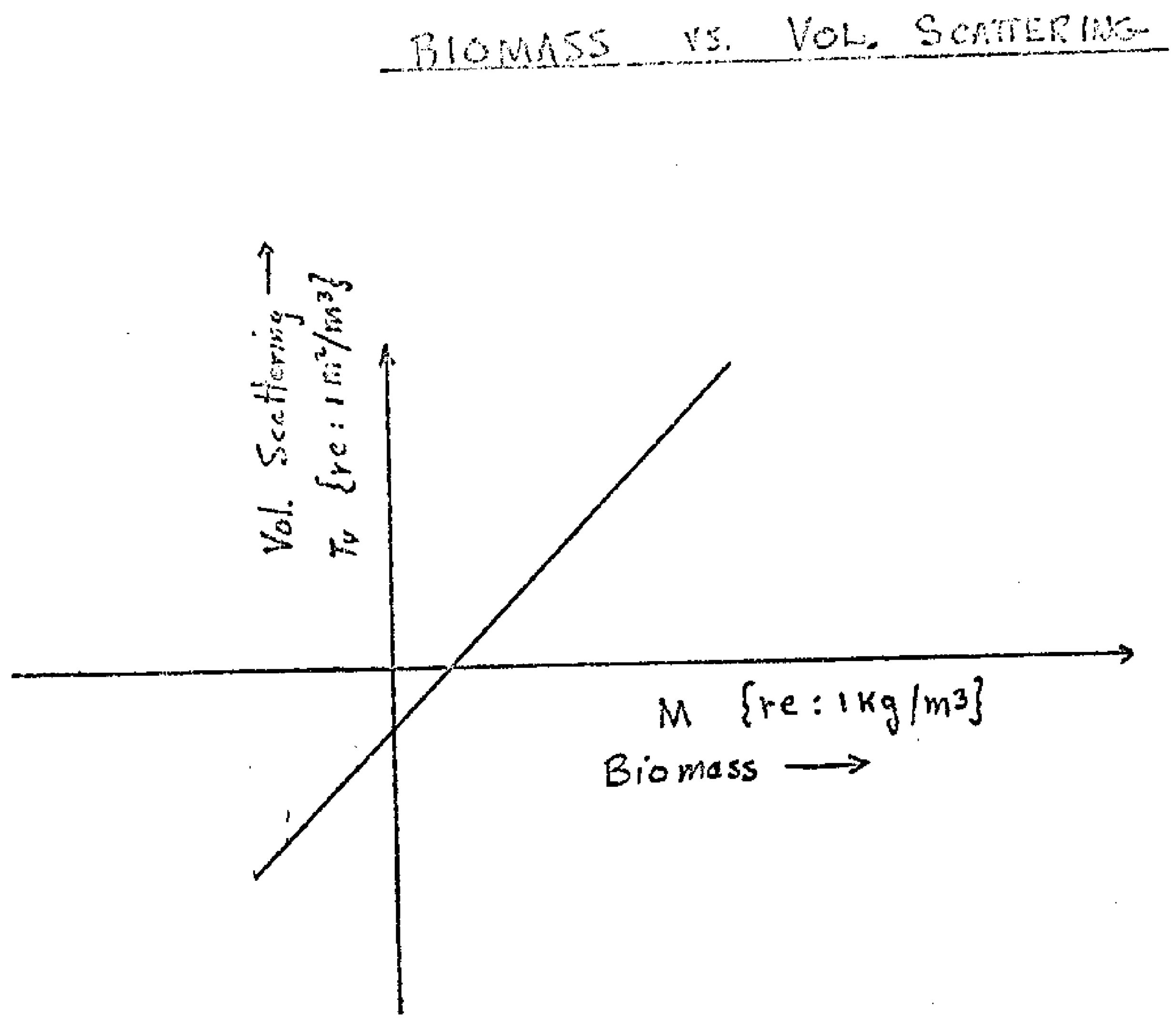
$$E(I_i) = A \, \Delta r \, \bar{t}_v$$

t_v : "biomass" target strength

Normalized Variance

$$\frac{Var[I_i]}{E^2[I_i]} = \frac{B}{\rho V_i} + C \, \Delta r$$

Slide #8: Echo Integrator Statistics



Slide #9: Biomass vs. Volume Scattering

COMPOSITION DETERMINATION METHODS

	Method	Acoustical Characteristics	Inferred Parameters ($\vec{\Theta}$)
1.	Target Strength	High Range Res. (WB) · Angular Depndt · Freq. Depndt	{Length} ⟹ {Age}
2.	Doppler Signature	High Vel. Res. (Long Pulse) · Angular Depndt	{Swim Speed, "Tail" Freq} ⟹ {Length} ⟹ {Age, Target Strength} {Internal Energy (mean velocities)} ⟹ {$\dot{\rho}$, Feeding} ⟹ {ρ, Species}
3.	Resonant Freq.	Low Freq, VWB (.5-3KHz) · Poor Spatial Discrimination · Depth Depndt	{Bladder Size} ⟹ {Length, Age} ⟹ {Target Strength}

Slide #10: Composition Determination Methods

SOME POSSIBLE FUTURE DIRECTIONS

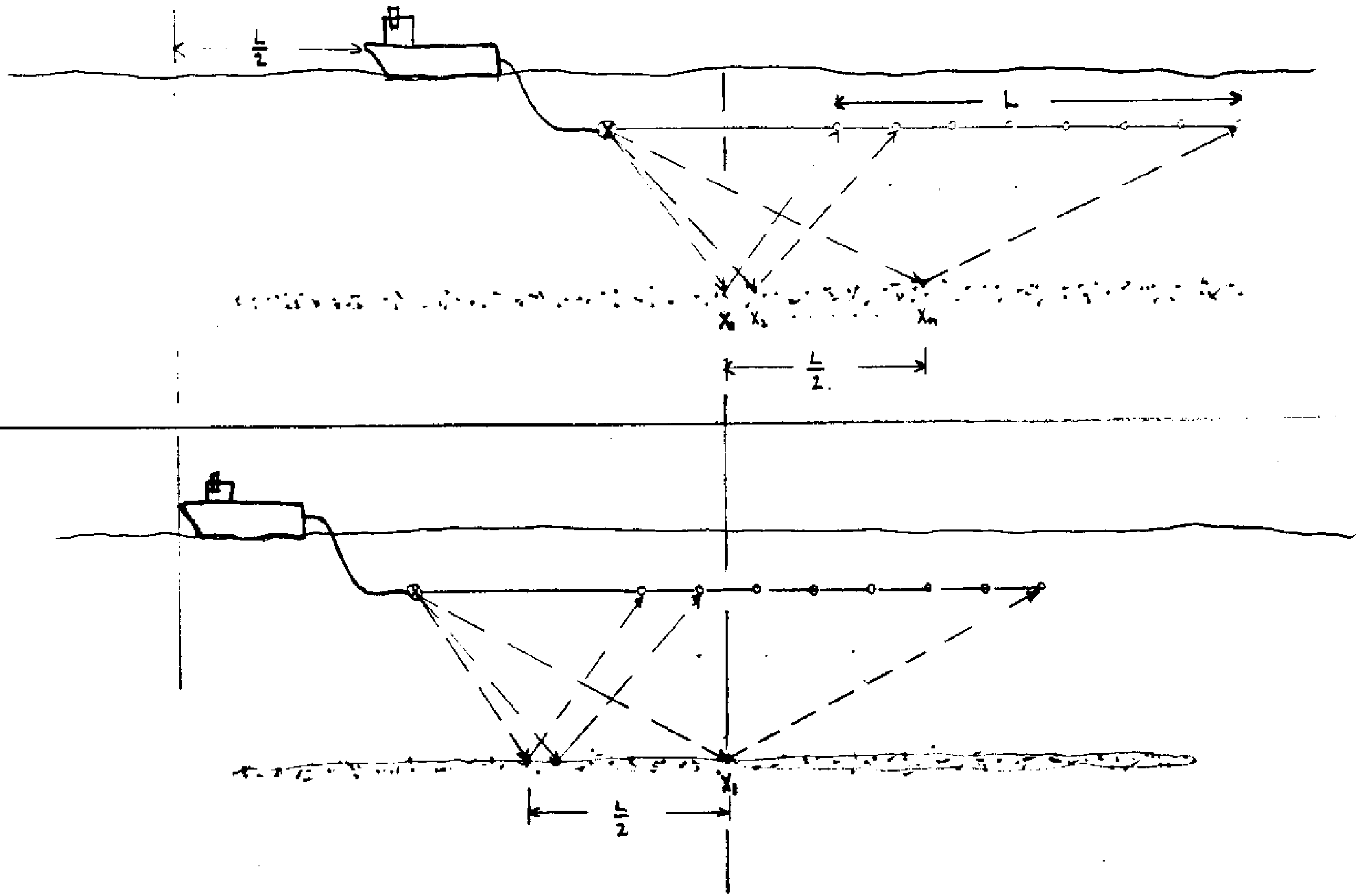
1.) Fixed Sites
- Long Range
- Short Range

2.) Acoustic Imaging
- Synthetic Aperture
- CDP Method
- 3-D Images

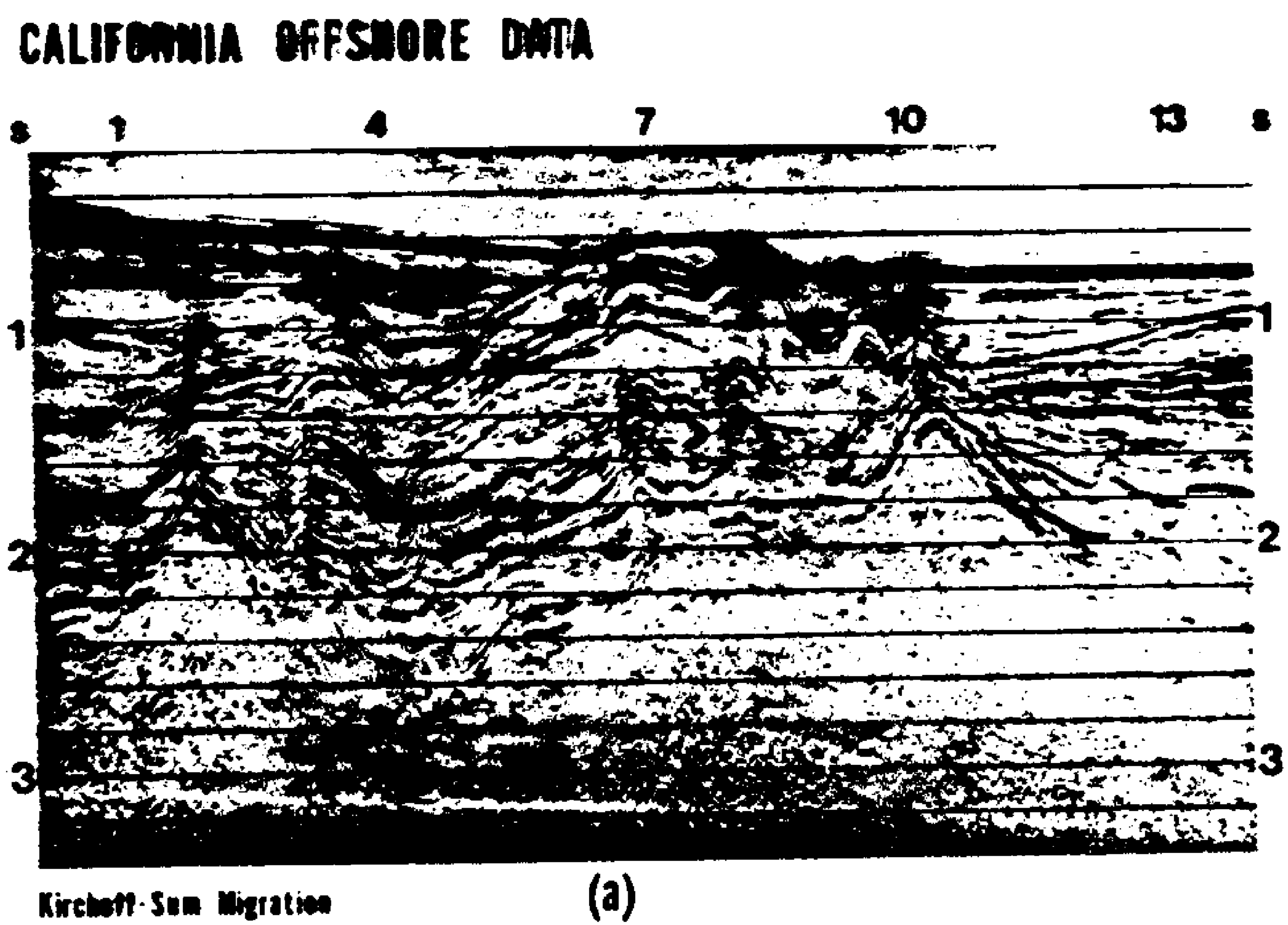
3.) Correlative Techniques
- Satellites
- Oceanography

Slide #11: Some Candidate Systems

CDP METHOD



Slide #12: Technique of Reflection Seismology, Common Depth Point



(a)

Slide #13: Example of a Marine Seismological Section

OARS Paper #8

MARINE POLLUTION AND OCEAN ACOUSTIC REMOTE SENSING: REQUIREMENTS

by C.A. Parker and R.L. Swanson
National Oceanic and Atmospheric Administration

Introduction

During NOAA's first decade marine pollution research, development and monitoring have become major issues and NOAA has been charged with coordinating much of the Federal effort in this regard (Public Law 95-273: The Ocean Pollution Research and Development and Monitoring Planning Act of 1978). An early NOAA effort dealing with marine pollution was the Marine EcoSystems Analysis (MESA) New York Bight Project. This research was motivated primarily by concerns over the deleterious effects of ocean dumping of large volumes of various wastes into the waters of the New York Bight.

Since then, several new programs addressing different problems have been undertaken. These include outer continental shelf development, hazardous material (including oil) spill response, resource mining (both deep ocean and coastal), energy utilization, and waste disposal (municipal and industrial).

The steady growth of marine pollution programs, particularly in coastal waters throughout the Nation, reflects the ever-increasing social awareness of the magnitude, pervasiveness, and gravity of environmental pollution. It is now apparent that land-based waste disposal alternatives are not as attractive as once believed, and the ocean is being reexamined as a major waste receptacle. Thus, there is an urgent need for fresh scientific approaches and new technology dealing with pollution and the marine environment. Ocean acoustic remote sensing (OARS) can help meet this need.

Our first experience with acoustic remote sensing (other than traditional geophysical applications) was associated with an ocean dumping experiment conducted in September 1975 (Proni, et al., 1976). The aim of the experiment known as STAX (for Sludge Tracking Acoustic Experiment), was to demonstrate that sewage sludge dumped in the ocean was acoustically detectable. At the time, we were interested in testing the hypothesis that sewage sludge remained principally in the water column after dumping, particularly at the thermocline. Standard water column sampling had not proven to be effective. If the method were successful, it was then our intent to map the time-space evolution and short-term fate of the dumped sewage sludge and to guide selective chemical sampling of interesting features. The primary objective was met (figure 1) and the resulting ability to "see" sewage sludge in the water column assisted greatly in our understanding of the dispersion processes. The experiment, however, also emphasized a need for much more research in acoustic profiling methods if we were to quantify our data and refine our interpretation.

STAX-I, and similar experiments that followed, pointed to other potential applications of acoustic systems. One example was the observation (in STAX II) of turbulent flow of dumped sewage sludge radiating along the pycnocline surfaces and the concomitant generation of internal wave-like oscillations (Proni, et al., 1977; figures 2 & 3). Knowledge of the characteristic acoustic signature of internal waves has led to general studies of this phenomenom on continental shelves. Specifically, these studies have made it possible to apply acoustic methods to the problem of dispersion of drilling muds in the Flower Garden region of the Gulf of Mexico (Proni, personal communication).

Today NOAA faces a number of challenges in the marine pollution field which, if not met agressively and innovatively, may tax resources at the expense of other important programs, or may go unresolved. Without trying to be exhaustive nor to reflect other concerns within NOAA external to OMPA, we turn our attention to programmatic/observational requirements and opportunities for OARS development or interface (essentially workshop objective 3).

Needs and Applications

Our needs fall into four general categories:

1. reconnaissance
2. mapping
3. directing sampling
4. time series observations

1. Reconnaissance. Occasions occur when there is a need to find and rapidly measure the extent of a pollution field. This frequently happens with hazardous material spill responses, but the need also arises in our research programs. An example of the latter occurred in June 1976 when sport divers off the New Jersey Coast reported pink to brown clouds or flocs of material in the subpycnocline layer; coincident with the floc were dead or lethargic benthic organisms. We had no idea of the extent or cause of the floc. We could not easily disrupt ship schedules and divert a ship for a preliminary survey, and if we had, we could not have optimally directed her course. The episode turned out to be a major ecosystem perturbation and received considerable research attention (Swanson and Sindermann, 1979). The floc was a decaying bloom of *Ceratium tripos*, a dinoflagellate which utilized the available dissolved oxygen in the bottom water layer, thereby causing the death of benthic organisms. An acoustic profiling system mounted in a helicopter could have been a useful reconnaissance and monitoring tool in that instance.

The IXTOC I oil spill in the Gulf of Mexico is another example where improved reconnaissance tools would be beneficial. Based on the estimated flow rate, the quantity of material released at the well was not consistent with the estimates of the volume of oil on the sea surface calculated from field surveys and remote sensing observations. Subsurface transport was suggested but could neither be verified nor quantified. When the RESEARCHER cruise to the well site was designed in August of this past year, our office encouraged the exploration of acoustics as a tool to locate and track any subsurface oil, if present. Initial indications are that the experiment was successful and that it is worth continuing to explore further the use of acoustics in this manner.

At present, we are concerned with questions as to where and how much of the oil remains in the marine environment from the IXTOC I spill. It has been hypothesized that much of the oil has settled to the bottom several kilometers offshore and is perhaps working its way into the sediments. If acoustics can help with this problem, perhaps this workshop can give us some guidance.

2. Mapping. Mapping is a more detailed delineation of concentrations than normally required by reconnaissance. The importance of synopticity should be underscored in this regard. Many marine pollution problems occur in nearshore or estuarine environments at depths less than 30 m, a very dynamic environment. Suspended sediment and chlorophyll observations of the Bight Apex, made from a helicopter equipped with water bottles, can be obtained in a fraction of the time required for comparable ship coverage. This technique has provided excellent ground truth data for remote sensing experiments as well as yielding data of equal, if not superior, quality to that obtained by ships. Perhaps acoustic techniques can be used similarly from airborne platforms to improve mapping and sampling programs.

Concurrent use of a towed acoustic profiling system, appropriately interfaced with chemical sampling systems, would also be beneficial. For example, a profiling system used in conjunction with an undulating chemical sampler would enhance the depth selectivity of sampling.

3. Directing Sampling. A generic problem for marine pollution programs is the need to minimize the number of water samples taken in the field and the number of chemical analyses performed on each sample. Our understanding of the physics of acoustic systems, as applied in STAX, points to applications where there is either sufficient particulate material or density contrast within the water column to present a useful acoustic target.

We will leave to acousticians the precise definition of the critical limits and constraints for application of acoustic methods; however, many polluting activities or sources generate the necessary conditions. Many pollutants exhibit an affinity for particulate matter, while others are partitioned in the dissolved phase and disperse with a fresh water plume. The ability to track the distribution of these conditions, therefore, can frequently provide the means for directing chemical sampling in space and time in a most efficient manner.

Chemical pollutants are often associated with specific size fractions of suspended matter. To the extent that we understand this relation in a given environmental setting, acoustic systems that can discriminate size fractions could help to limit the number of samples taken in the field and the specific analyses required aboard ship or in the laboratory.

4. Time Series. In addition to mapping and reconnaissance tools, single site, vertically-resolved, time-series observations are often required for pollution research and monitoring. Of course towed systems can be utilized in this manner, but they would generally be inefficient. Also such measurements are often required in shipping lanes and/or harsh environments (strong currents, high waves, etc.) making operations hazardous and difficult to accomplish. In such cases unattended, bottom mounted systems would be beneficial.

The determination of fluxes of water and pollutants over various time periods through a given vertical section is a major programmatic need which in general is difficult to achieve with presently available technology. A major example of this is the section separating the New York Bight Apex and the Hudson-Raritan Estuary (figure 4). The estuary is a major source of pollutant loading to the Bight. Cost efficient technologies and operations are not available to obtain the temporal and spatial observations of currents, sea level, and pollutant concentrations required for determining the exchanges between these two environmental regions. Spatial density, marine fouling, corrosion, and damage from ship traffic are major problems to be considered in the design of such instrumentation.

A bottom-mounted, upward-looking, acoustic current meter, coupled with serial measurements of sea level, suspended particulates, salt, temperature and possibly other specific pollutants, would be a major step toward pollutant flux determinations and a contribution to the entire marine pollution research program.

Conclusions

We believe that ocean acoustic remote sensing has a bright future in marine research in general and holds the promise of being an important technological development in NOAA's efforts to meet the Nation's marine pollution challenge. The close association many pollutants form with particulate material, and the speed with which concentration fields can be determined, make acoustic profiling systems valuable reconnaissance tools. These tools should serve to minimize costly chemical sampling.

Used as a mapping tool in conjunction with other sampling, acoustic profiling systems greatly facilitate the determination of dispersion and fate of pollutants from a variety of pollutant sources. Also, as specific management criteria are established for various pollutant sources, it may well provide the means for cost effective compliance monitoring. Our recently established cooperative 301(h) program with EPA is concerned with reviewing requests to waive the upgrading of sewage treatment plants to secondary treatment. We will be assisting EPA in developing compliance guidelines and monitoring procedures. Other monitoring applications should be identified and explored.

The development of bottom-mounted, vertically-profiling, time-series packages, particularly the current meter, is long overdue. Because of the costs and many difficulties in maintaining fixed moorings in the field, the development of this technology could vastly improve our ability to determine pollutant fluxes. Another application for the acoustic current meter is possible within the framework of the newly established Northeast Pollution Monitoring and Research Program along the Atlantic coast. In conjunction with the National Data Buoy Office's environmental data buoys, such current meters could provide the essential, real-time data necessary for diagnostic models of the New York Bight circulation.

The opportunities that we have discussed for ocean acoustics remote sensing applications to marine pollution problems represent only a beginning. We need to get the tools out of the hands of the acousticians and into the hands of marine scientists. Until more operational tools become available, the number of actual application may remain small.

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Proni, J.R., F.C. Newman, R.A. Young, D. Walter, R. Sellers, P. McGillivary, I. Duedall, H.M. Stanford, and C.A. Parker (1977). Observations of the Intrusion into a Stratified Ocean of an Artificial Tracer and the Concomitant Generation of Internal Oscillations. Presented to AGU, May 1977, Washington, D.C.

Swanson, R.L. and C.J. Sindermann. (Editors). (1979; in press). Oxygen Depletion and Associated Benthic Mortalities in New York Bight, 1976. NOAA Professional Paper. 16 Chapters.

Figures

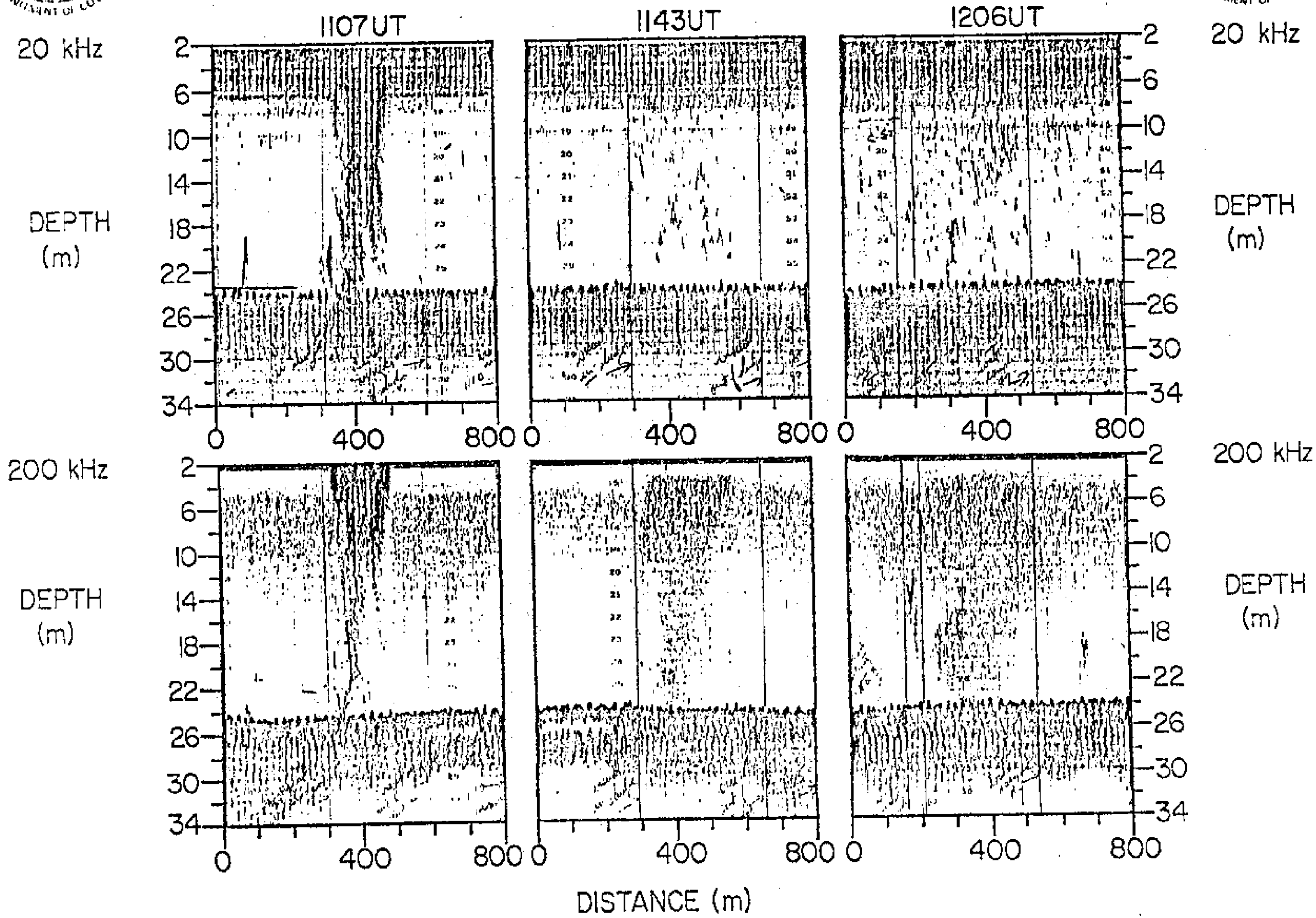
Figure 1: Three lateral sections across a sewage sludge line dump, 22 September 1975, (STAX-I) occurring 9, 45 and 68 minutes (left to right) after beginning dump. Upper panels present acoustic output from 1-KW, 20 kHz, echo sounder; lower panels present acoustic output from 80-KW, 200 kHz echo sounder.

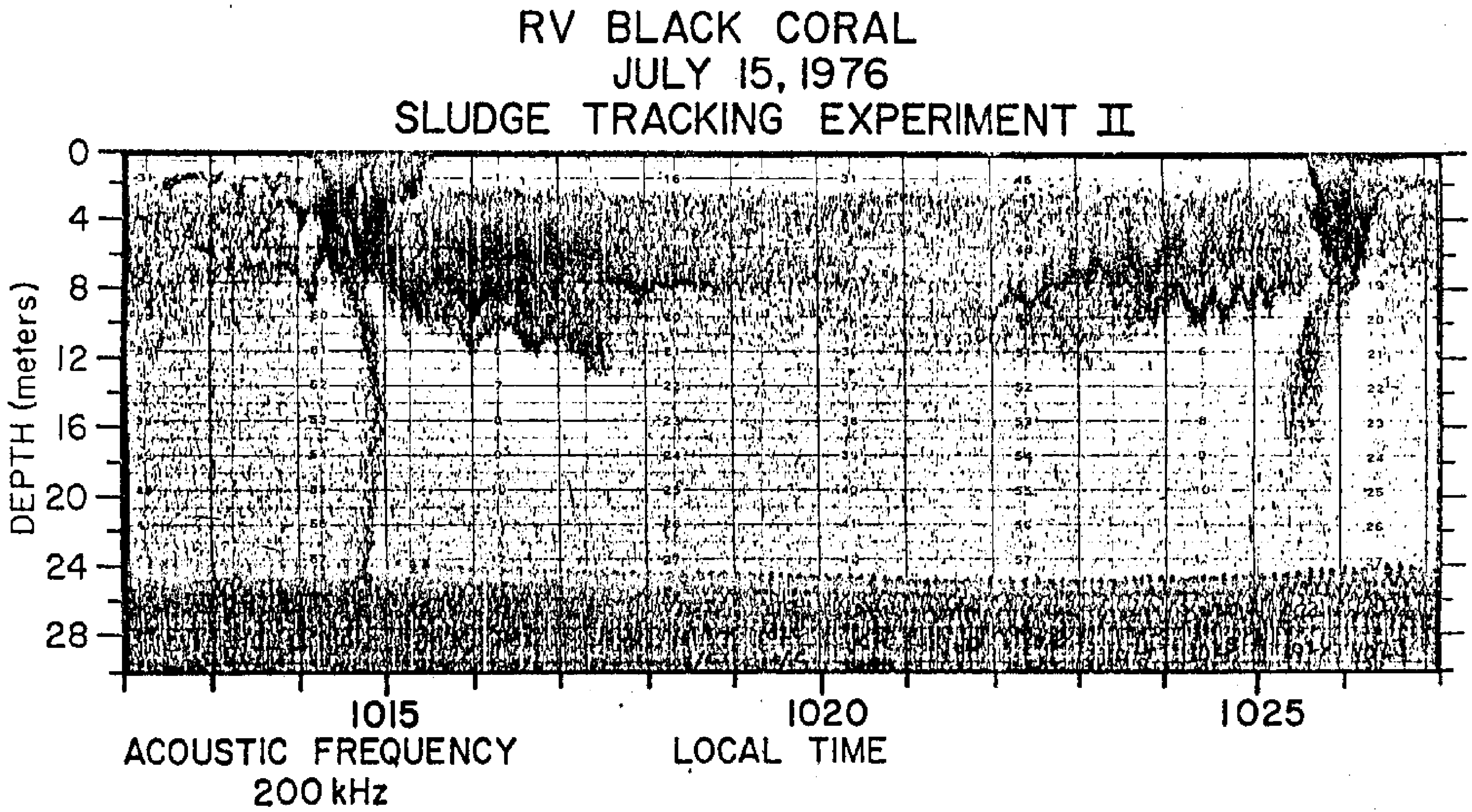
Figure 2: A 200 kHz record traversing a sewage sludge "spot" dump on 15 July 1976 (STAX-II) made between 14 and 29 minutes after dumping. Change in ship's course occurred between 1018 LT and 1022 LT.

Figure 3: Ship track corresponding to Figure 2.

Figure 4: Hudson-Raritan estuary and New York Bight Apex. Section of interest separating these two regions is situated between Sandy Hook, NJ and Rockaway, NY.

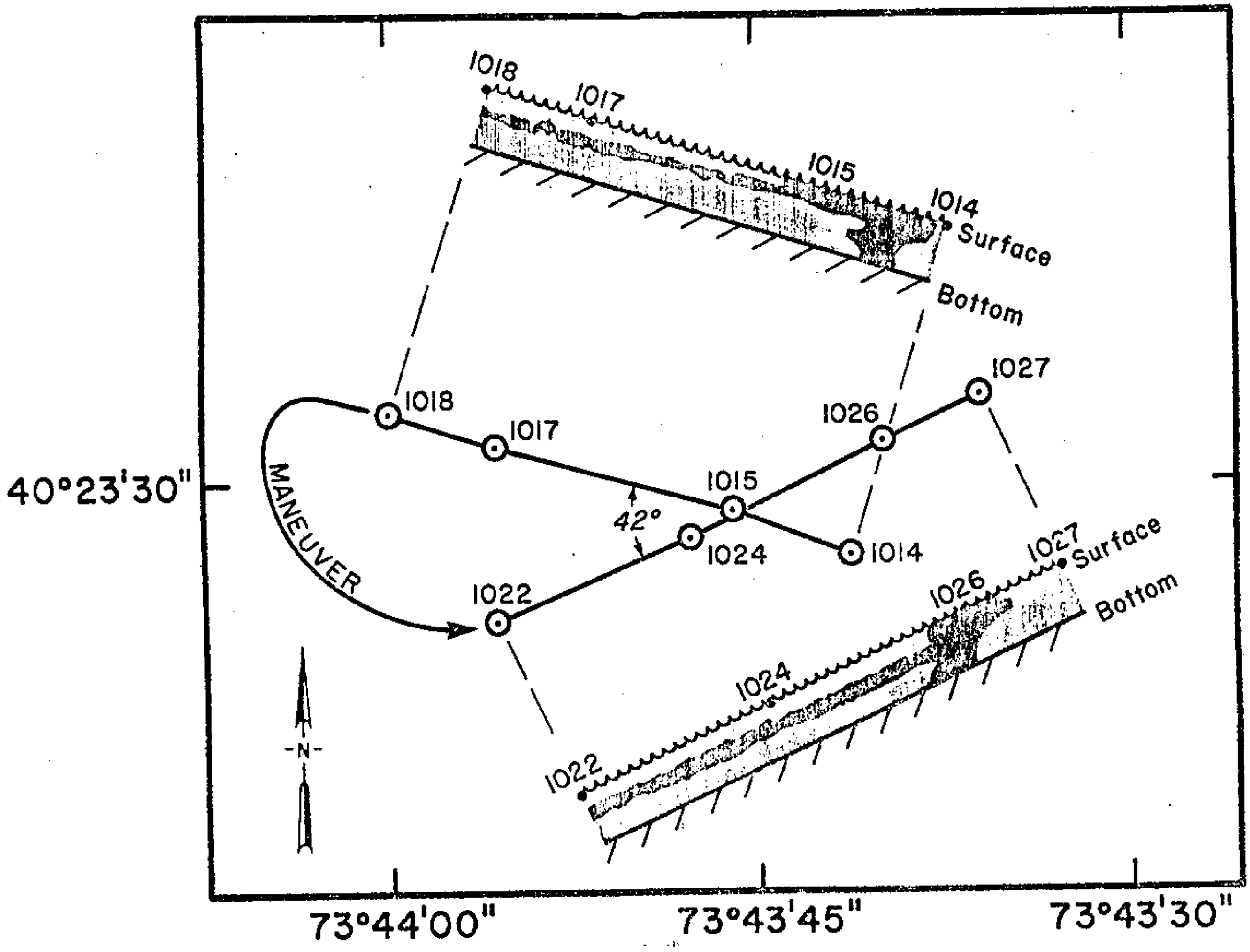
SLUDGE TRACKING EXPERIMENT STAX
SEPTEMBER 22,1975





Acoustic record obtained by the Black Coral during the fourth and fifth passes over the sludge (spot) dump. Note the presence of "thermocline particle surges" and material oscillations.

Fig. 2



R/V BLACK CORAL
15 JULY 1976
SLUDGE TRACKING EXPERIMENT II

Fig. 3

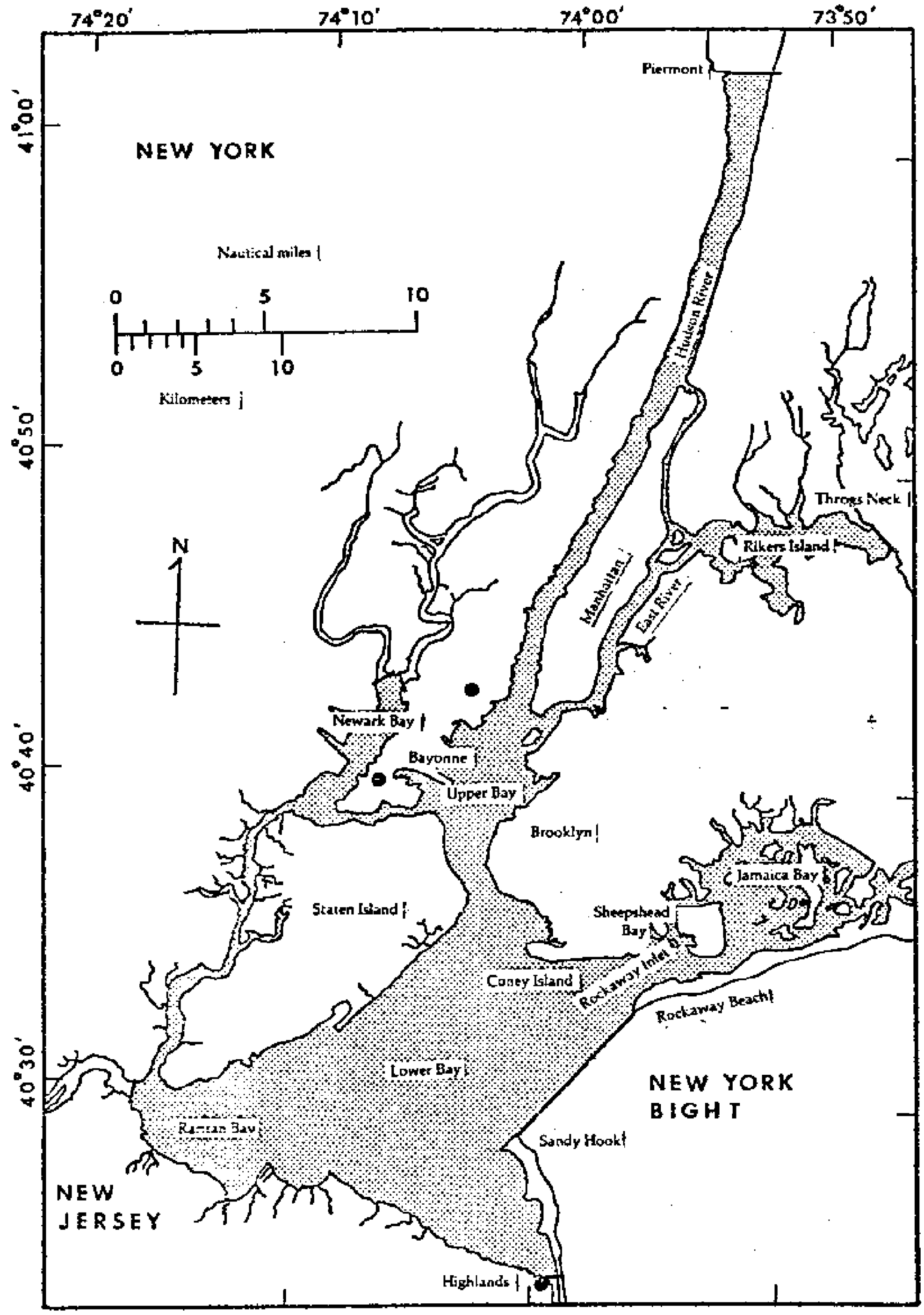

74°20'
74°10'
74°00'
73°50'
41°00'
40°50'
40°40'
40°30'
Piermont
NEW YORK
Nautical miles
0
5
10
0
5
10
Kilometers
N
Hudson River
Throgs Neck
Rikers Island
Manhattan
East River
Newark Bay
Bayonne
Upper Bay
Brooklyn
Jamaica Bay
Staten Island
Sheepshead Bay
Coney Island
Rockaway Inlet
Rockaway Beach
Lower Bay
NEW YORK BIGHT
Raritan Bay
Sandy Hook
NEW JERSEY
Highlands

Fig. 4

OARS Paper #9

ON THE USE OF ACOUSTICS IN OCEANIC POLLUTION PROBLEMS

by John R. Proni
National Oceanic and Atmospheric Administration

The use of acoustics in studying oceanic pollution problems has risen substantially in the last five years. As far as the author knows the first use of acoustics in an oceanic pollution problem occurred in September 1975[1]. In that case 200 kHz and 20 kHz sound signals were used to obtain an estimate of the concentration field, C $(\vec{r},t)$, of ship dumped sewage sludge. Since that time numerous uses of acoustics have been made in studying dumped materials; these materials include sewage sludge, dredge material, petrochemical wastes, industrial wastes[2], pharmaceutical wastes, subsurface oil (from the IXTOC-1 oil spill) and, recently, drilling muds.

Three specific examples using acoustics to map the concentration field, C $(\vec{r},t)$, and to guide chemical sampling will be presented. These examples are (i) the IXTOC-1 oil spill, (ii) pharmaceutical wastes and, (iii) dredge material disposal. The data for these examples were gathered in the same way, namely a research vessel towed two acoustical systems which transmitted sound vertically downward and then recorded the backscattered acoustical signals. The backscattered signal strength is then interpreted as a measure of the concentration of the specific substance under investigation.

Figure 1 shows a real-time data record gathered near the IXTOC-1 oil well spill. Depth is the vertical coordinate and time or distance is the horizontal coordinate; since the research ship towing the acoustic sensors was moving at about 2m/s, total distance shown in the horizontal is about 3.6 km. Note that most of the subsurface oil (the darkened portion of the acoustic record) appears to be contained within the upper 30 m of the water column. The kind of data shown in Figure 1 is useful in determining whether or not a chemical sample should be taken and at what depth it should be taken. The next stage of acoustical data processing may be seen by examining Figures 2 and 3 which present data from example (ii) above--i.e. pharmaceutical wastes.

Figure 2 shows real-time data of two dumps of pharmaceutical wastes--i.e. the darker areas shown at about 1157 universal time. Figure 3 shows these same data but now reconstructed from magnetic tape recordings of the acoustic backscattered signal. The two dumps referred to in Figure 2 are shown between 11:54:30 and 11:57:30 in Figure 3. The dump shown at aboue 12:01:30 took place at least 24 hours prior to the dumps of interest. In Figure 3 contour lines of equal backscattered sound intensity have been drawn; that is a representation of the field I $(\vec{r},t)$ has been made. It is the hope of the writer and other acousticians as well that C $(\vec{r},t)$ may be deduced to some degree from I $(\vec{r},t)$.

One of the most important characteristics of a given volume of oceanic water is the rate at which dilution of a given dump material occurs in that water. There are various factors which influence the dilution rate, these include water column stratification, currents and dispersion (turbulent) characteristics. Accurate dilution rates are extremely difficult to obtain. However, using the acoustic data from example (iii), dredge material dumping in the New York Bight, estimates may be made of horizontal dispersion coefficients, K, which are fundamental in dilution rate predictions.

Figure 4 presents acoustic intensity contours $I(\vec{r},t)$ for dredge material dumped in shallow water (bottom depth 23 m to 24 m) in July 1979. Assuming C is essentially distributed as is I we may observe that, as is shown in Figure 5.

$$C(\vec{r},t) \sim 1130\, e^{-\frac{r^2}{319}}$$

That is $C(\vec{r},t)$ is essentially distributed in a Gaussian curve. Note that $I(\vec{r},t)$ or $C(\vec{r},t)$ is expressed as a function of equivalent radius, r. This term is discussed by Okubo[3] and is defined as the radius of a circle (or sphere) whose area is equal to that area enclosed between any two iso-concentration curves. A dispersion coefficient K of 8.6×10^2 cm^2/s is obtained after a time 9.3×10^2 s has elapsed since dumping. A so-called diffusion speed, P = 0.61 cm/s is deduced, These data are very difficult to obtain through any non-acoustic means.

The basic question regarding acoustics is what precisely is being measured? Does $I(\vec{r},t)$ indeed have a well defined relationship to $C(\vec{r},t)$? The writer considers this as one of the basic research areas for acoustics in pollution. Some things may be stated definitely now by means of a few simple considerations. Now, basically

$$I(\vec{r},t) = C' \int_0^\infty a^n\, N(a,\vec{r},t)\, da$$

where a = a typical dimension of a scattering particle
$N(a,\vec{r},t)$ = the size distribution of particles at $\vec{r},t$
C' = a constant
n = integer denoting nth moment of particle size distribution.

Likewise the total suspended material, TSM, may be written as

$$TSM = D \int_0^\infty a^m\, N(a,\vec{r},t)\, da$$

where D = a constant
m = integer denoting mth moment of particle size distribution.

Thus the relationship between $I(\vec{r},t)$ and $TSM(\vec{r},t)$ depends to a large degree on the particle size distribution.

A deceptively simple appearing relationship may be written between differentials of I and C. If one assumes a simple geometric dependence on particle size for any constituent of interest (e.g. TSM, chemical x, etc.) then

$$dI = \beta\, a^{n-m}\, dc$$

where n is an integer denoting the nth moment of the particle size distribution, m is an integer denoting the mth moment of the particle size distribution and β is a constant in which many perplexing problems are hidden. For I, often n=6 and for TSM, assume m=3. In general one must examine on a case-by-case basis the relationship between I $(\vec{r},t)$ and TSM $(\vec{r},t)$.

In summary, the use of acoustics in pollution research and monitoring has increased from essentially zero prior to 1975 to a standard item in today's NOAA ocean pollution programs. There is a substantial demand for acoustical techniques from outside of NOAA as well; the EPA and the Corps of Engineers both have significant needs in acoustic pollution techniques. The future of acoustics in pollution research and monitoring appears to be very bright, but a substantial amount of research is still needed in interpreting acoustical data.

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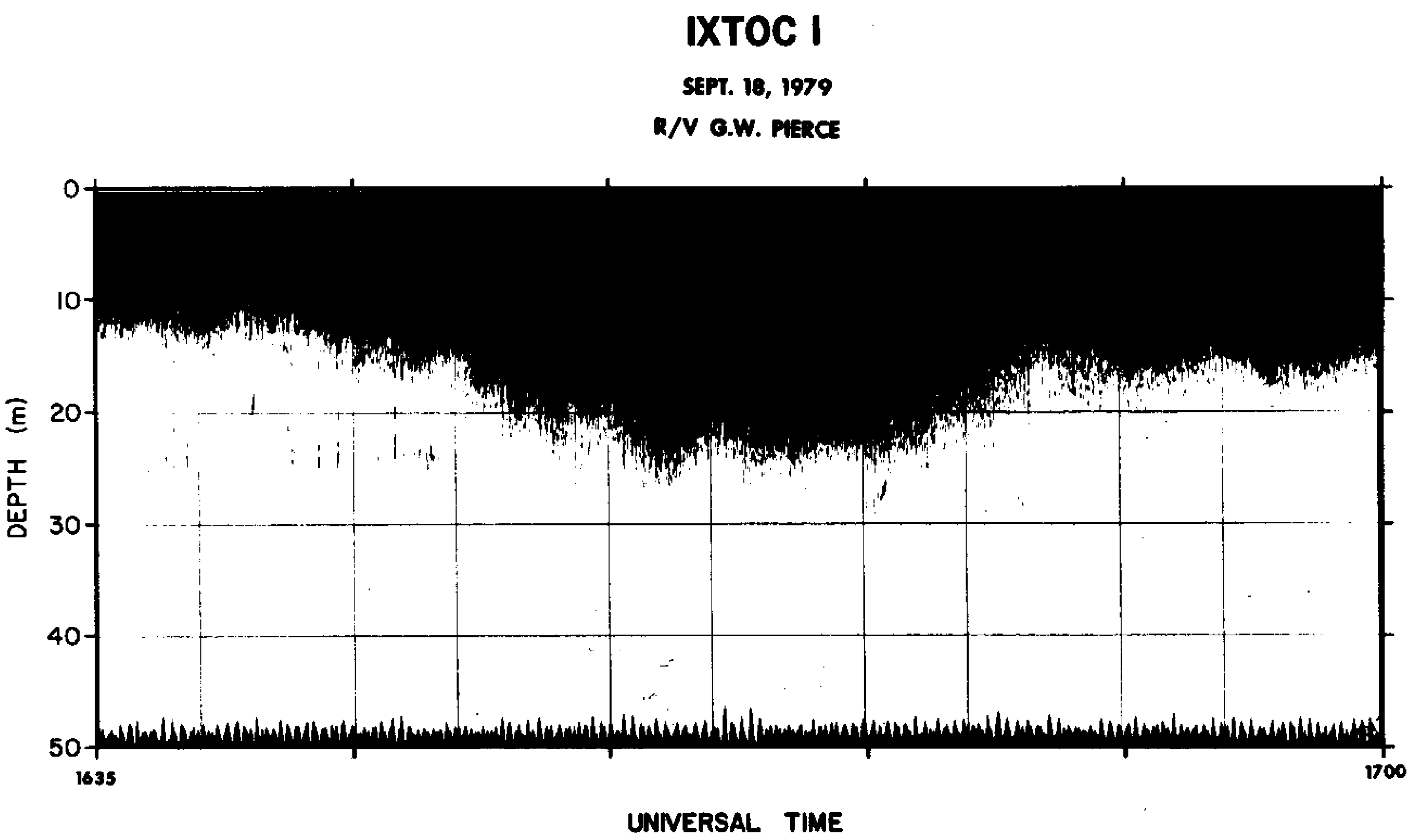

IXTOC I
SEPT. 18, 1979
R/V G.W. PIERCE
DEPTH (m)
0
10
20
30
40
50
1635
1700
UNIVERSAL TIME

Figure 1

PUERTO RICO OCEAN DUMPING EXPERIMENT (PURDEX II)

ARECIBO INDUSTRIAL DUMPSITE

NOAA SHIP MT. MITCHELL

OCT. 29, 1978

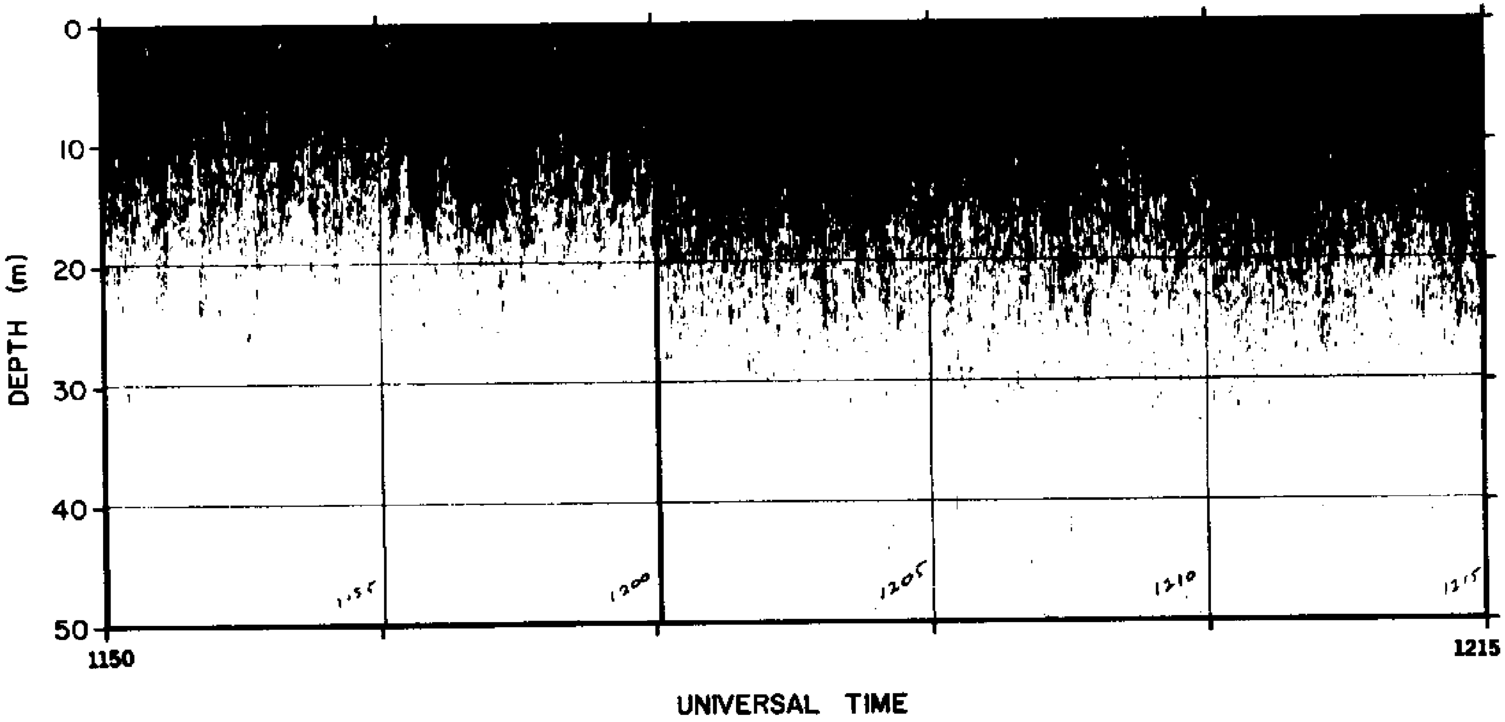
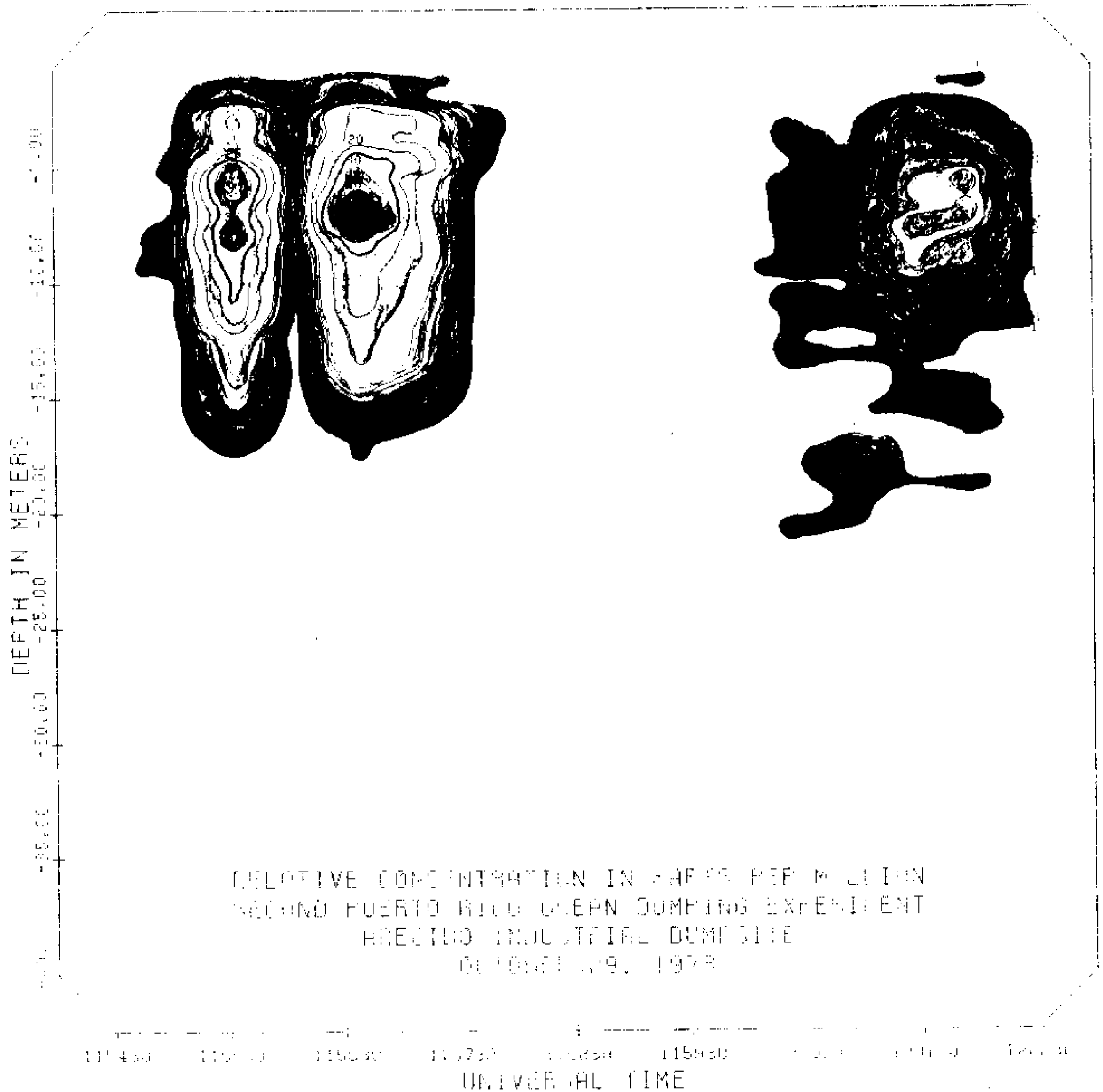


Figure 2



DEPTH IN METERS
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
RELATIVE CONCENTRATION IN PARTS PER MILLION
SECOND PUERTO RICO OCEAN DUMPING EXPERIMENT
ARECIBO INDUSTRIAL DUMPSITE
UNIVERSAL TIME

Figure 3

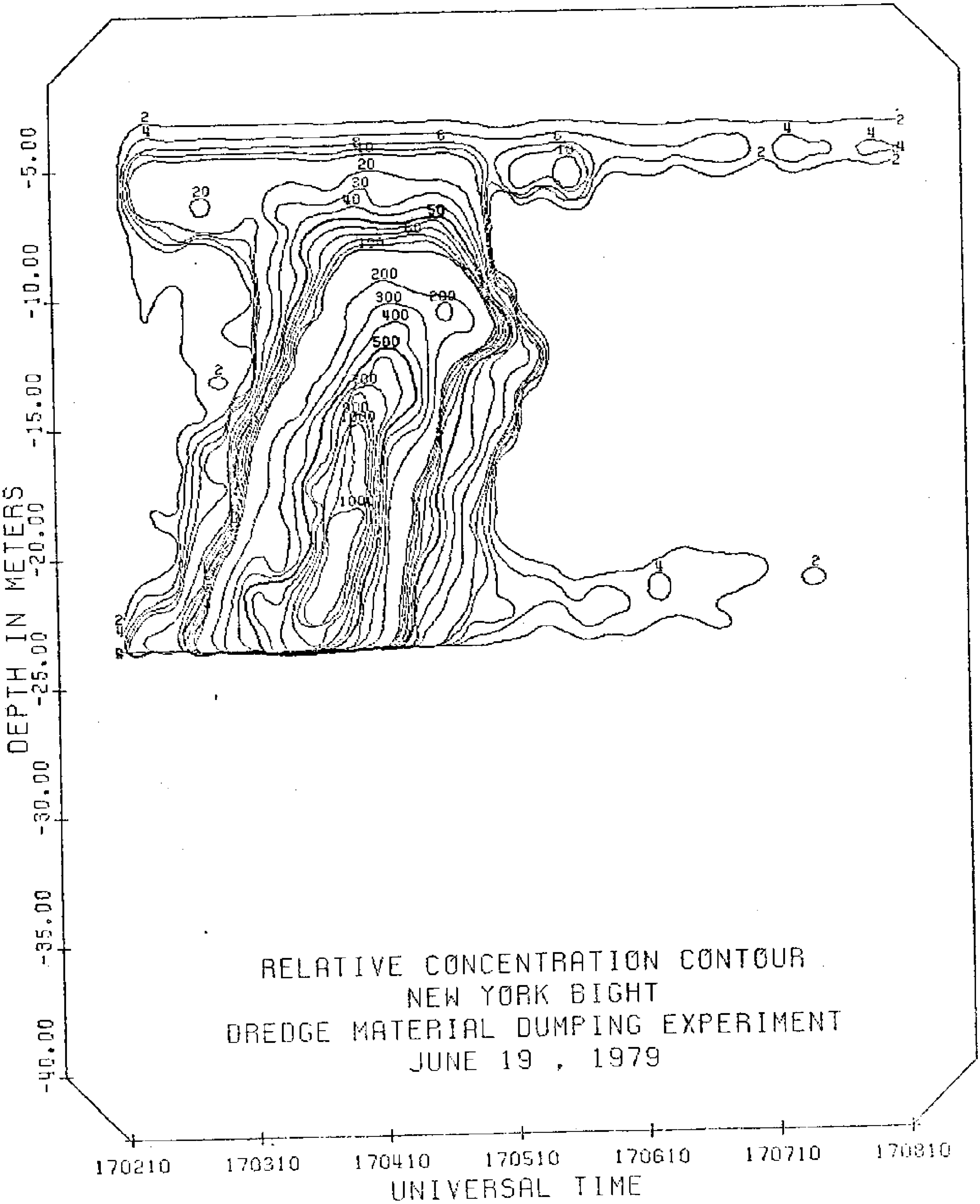
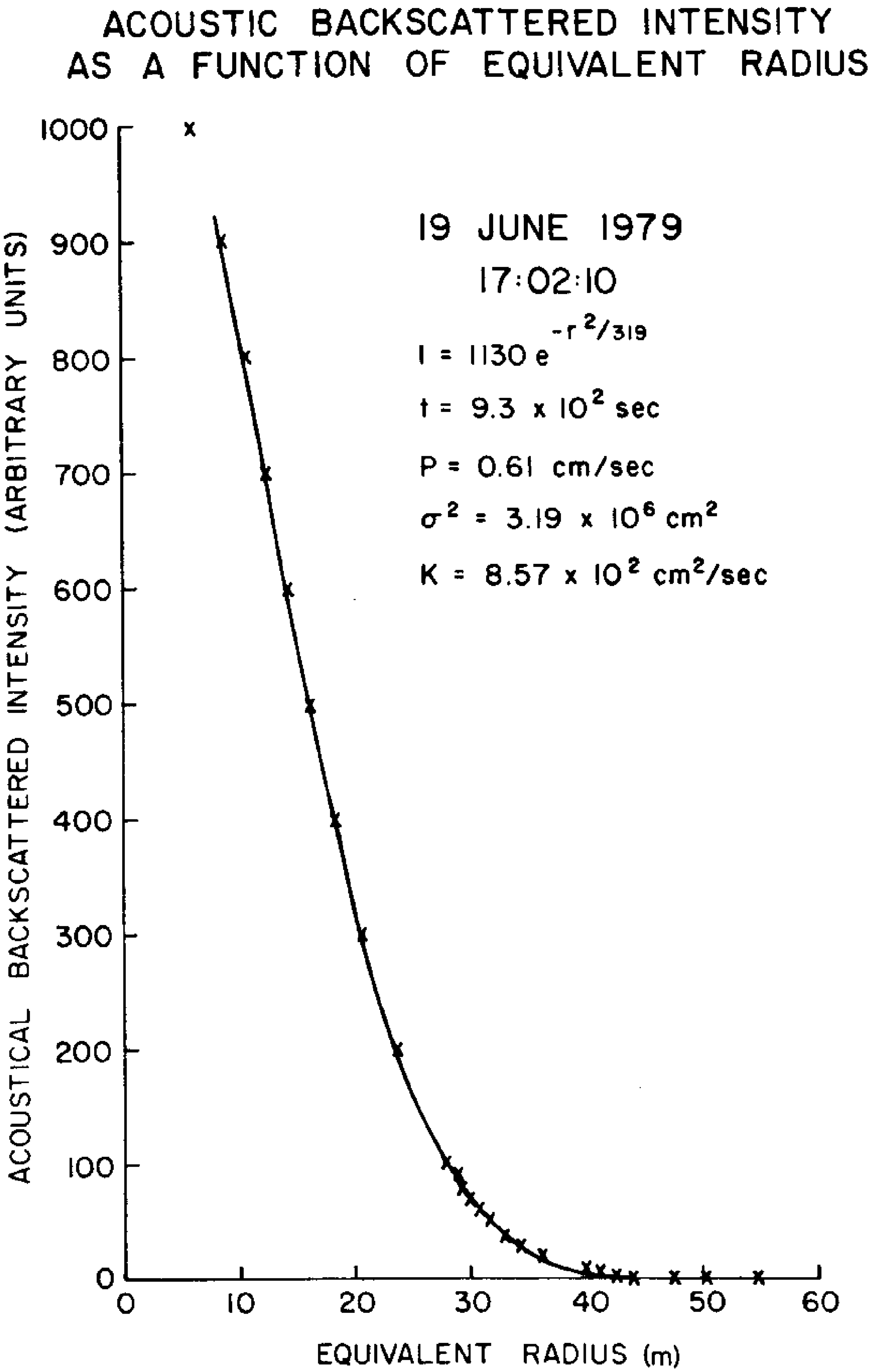

DEPTH IN METERS
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
RELATIVE CONCENTRATION CONTOUR
NEW YORK BIGHT
DREDGE MATERIAL DUMPING EXPERIMENT
JUNE 19 , 1979
170210
170310
170410
170510
170610
170710
170810
UNIVERSAL TIME

Figure 4



ACOUSTIC BACKSCATTERED INTENSITY
AS A FUNCTION OF EQUIVALENT RADIUS
19 JUNE 1979
17:02:10
I = 1130 e^{-r²/319}
t = 9.3 x 10² sec
P = 0.61 cm/sec
σ² = 3.19 x 10⁶ cm²
K = 8.57 x 10² cm²/sec
ACOUSTICAL BACKSCATTERED INTENSITY (ARBITRARY UNITS)
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
EQUIVALENT RADIUS (m)

Figure 5

OARS Paper #10

OCEAN ACOUSTICS AND CHEMISTRY

by

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What has chemistry got to do with ocean acoustics and remote sensing?

First, looking at ocean acoustics, the chemical properties of sea water have a large effect on its sound absorption. Two household chemicals, epsom salts and eyewash, cause nearly all the sound absorption in the ocean below 200 kHz as seen in Figure 1. Near 200 kHz chemical absorption losses can be as high as 60 dB/km, a reduction in sound intensity by a factor of a million for a distance of one kilometer. This is the same as the inverse square or spherical spreading loss for a receiver at a distance of one kilometer from a sound source. At 2 km the spreading loss is 66 dB while the chemical absorption loss at 200 kHz is 120 dB. Therefore, absorption losses can be a major factor in limiting sound propagation.

Below 100 kHz the large increases in absorption in addition to that attributed to water are due to relatively small amounts of magnesium sulfate and boric acid. For example, only four parts per million of boric acid increases absorption by a factor of 300 above that due to water.

The pH of the ocean determines the magnitude of the boric acid contribution to absorption. The coefficient of the boric acid term in absorption equations for sea water appears to be directly proportional to the hydroxyl ion concentration. In Figure 2 we see that the coefficient of the boric acid term for the Atlantic Ocean data summarized by Thorp (1) is a factor of two greater than that for the Pacific Ocean data of Morris (2) and Lovett (3). Refining the work of Mellen and Browning (4), Lovett (5) has just published a worldwide map of the coefficient for the boric acid term in the Thorp equation. His results for the Pacific are shown in Figure 3 and for the Atlantic in Figure 4.

Depending upon range, frequency, temperature, pressure, salinity, and pH, the answer to part of the question is "chemistry has a lot to do with ocean acoustics because of chemical sound absorption." Keep in mind that absorption due to water itself is no longer negligible at higher frequencies; above 300 kHz water becomes the dominant absorber of sound in the ocean.

The next part of the question is "what has chemistry got to do with acoustic remote sensing?" Once chemical absorption can be described quantitatively, then departures from predicted absorptions can be used to remotely sense chemical variations of the ocean or to infer other processes affecting acoustic propagation.

In principle, if sound absorption measurements at several low frequencies and ranges were added to the acoustic tomography technique (6), it would be possible to monitor the pH variability of the region under study.

Absorption data are acquired by measuring transmission loss as a function of range and frequency as illustrated in Figure 5. While chemical absorption can be very large compared to water absorption, it does not mean that the measurements are easy to make either in the ocean or in the laboratory. The laboratory acoustic data, of course, are necessary for a quantitative understanding and analysis of ocean propagation experiments.

At low frequencies the absorption effects are so small compared to spreading losses that measurements need to be made at long ranges in order to detect the absorption. For example, at 100 Hz, chemical absorption at a range of 1,000 km accounts for only a 1 dB loss, compared to a spreading loss of 100 to 110 dB. By normalizing spreading losses in propagation data to a low frequency such as 50 Hz, the absorption effects can be more readily measured as seen in Figure 6 from the work of Morris (2).

Typically explosive shots are used which yield a broad spectrum for multifrequency analysis. Pulsed CW work has been used at low frequencies but is more suitable for work above 1 kHz. The normalization of spreading losses in multifrequency experiments has been used at higher frequencies; the normalization in this case being made to a frequency for which good absorption data exist. The normalization process assumes that spreading losses are the same for all frequencies.

Once chemical absorption can be described quantitatively, the way is also clear for analyzing other attenuation mechanisms such as those due to volume scattering, as well as calculating target strengths of fish or volume scattering strengths.

A superb example of this is shown in Figure 7 where a radical departure from the expected frequency dependence for spreading and absorption losses was observed by Vic Anderson in some recent work at ranges of 90 to 110 km. He attributes the unusually high losses around 2 kHz to scattering by fish larvae and juvenile fish. This discovery is of prime significance to large-scale remote sensing of the ocean biomass.

Attenuation in its own right may be of interest as a synoptic sensor for the particulates entrained in a water mass. Scattering due to particulate matter in a pollution plume would have a large effect on attenuation of horizontal sound propagation. Multifrequency measurements would have to be made in order to distinguish attenuation losses other than those due to absorption.

For the design of remote sensing systems operating at higher frequencies such as echo sounders, side-looking sonars or acoustic imaging systems, absorption losses are the price to be paid for higher resolution. Quantitative data on absorption are necessary in order to make informed trade-offs of the various design criteria. The effect of pressure reduces absorption substantially, an important consideration for systems to operate at great depths. As yet this effect is not well defined, as will be discussed later in this paper.

The question was "what has chemistry got to do with acoustic remote sensing?" It is clear that through chemical sound absorption, chemistry is already important to remote sensing ocean acoustics in the design of high-frequency systems and in the evaluation of ocean biomass. The potential for using attenuation and absorption measurements in other applications seems promising.

At this point I would like to give several examples of how good propagation data and good laboratory work interact to lead to further discoveries. In the history of sound absorption measurements in the ocean this cycle has now been repeated three times. First, the anomalous absorption in the ocean was observed at high frequencies in 1935 by Stephenson (7). It was anomalous in the sense that it was greater than expected for pure water. The cause of the first anomaly was identified as magnesium sulfate by Leonard, Skidmore and Combs (8) using the laboratory acoustic resonator technique.

For the second cycle, as results from measurements in the ocean at lower frequencies became known, Thorp (1) pointed out that the absorption below 1 kHz, as seen in Figure 8, exceeded that predicted by the Schulkin and Marsh (9) equation by a factor of ten. Yeager, et al., (1) used a temperature-jump technique of chemistry to identify boric acid as having a 1 kHz relaxation frequency and Simmons (11) confirmed the acoustic absorption in the laboratory using a 200 liter resonator, as well as the temperature-jump technique. On the basis of Simmons' data, Fisher and Simmons (12) generated a sound absorption equation for a pH = 8 ocean. With this equation the third relaxation in the ocean was discovered.

For the third cycle, in Figure 9 is shown the plot of Pacific Ocean data of Morris (2) and Lovett (3) in a different format; absorption per wavelength versus frequency. The advantage of the $\alpha\lambda$ over the α plot is that the ordinate extends over only one decade instead of three in going from 100 Hz to 10 kHz. Only by including a third unknown relaxation could Lovett's one point at 3 kHz be explained (13). Adding the third relaxation to the boric acid and magnesium sulfate relaxation effects provides good agreement with Thorp's data (1) as seen in Figure 10. Subsequently, the laboratory work of Mellen, Simmons and Browning (14) has identified the magnesium and carbonate ions as being involved in the third relaxation. Urick (15) provides a highly useful treatment of much of the work summarized here.

If you are beginning to get the idea that not everything is known about chemical absorption in the ocean, you are right.

Illustrating why this is so, I would like to show some comparisons of two equations (9, 12) for sound absorption in sea water. In Table 1 comparisons are made between the two equations at two temperatures and pressures. Substantial differences exist and are shown in Figure 11. In Figure 12 the Fisher-Simmons equation is given. Besides the boric acid term, the other differences with the Schulkin and Marsh equation are: a different pressure effect for both water and magnesium sulfate, a lower magnitude and different relaxation frequency for magnesium sulfate. In Table II these two equations are compared against the data of Murphy, Garrison and Potter in Dabob Bay with a salinity of 30 o/oo. The Fisher-Simmons equation provides a better fit in this case. However, for the low temperature Arctic data of Garrison, Early and Wen (17) shown in Table III, the results are mixed. Schulkin and Marsh (18) have a newer paper out which treats the low temperature puzzle.

Remaining work that needs to be done on chemical absorption includes the effect of pressure on magnesium sulfate absorption. Bezdek (19) made high-frequency measurements at sea of the effect of pressure on sound absorption and relaxation frequency. The results are shown in Figure 13 in which we see a decrease in absorption and a shift in relaxation frequency upwards with increasing depth. The only laboratory work on the pressure effect was done many years ago and then only in a 0.5 molar solution of magnesium sulfate, hardly a sea water substitute. Schulkin and Marsh (9) used that work for the pressure term in their 1962 equation as seen in Figure 14. The actual measurements are also shown. Bezdek's results indicated a greater effect of pressure, a linear decrease twice that of the Schulkin and Marsh equation. Actually, his results are in fair agreement with the laboratory data in Figure 14. However, his results to 3,000 m, if extrapolated to greater depths, indicate no magnesium sulfate absorption at 7,000 m. Laboratory measurements of the effect of pressure on sound absorption in sea water are about to commence. A 100 liter titanium ballast tank sphere from the research submarine ALVIN will be used as an acoustic resonator up to a pressure equivalent to a depth of 3,000 meters over a frequency range of 20 to 300 kHz.

The boric acid, magnesium sulfate and the third relaxation contributions to absorption as yet do not explain the propagation data of Skretting and Leroy (20) in the Mediterranean as seen in Figure 15. Other differences between laboratory (12) and field (4) data are summarized in Table IV.

In terms of theoretical understanding of chemical absorption in the sea, the best understood relaxation is that due to magnesium sulfate. Liebermann (21) provided the basic understanding of how pressure-dependent chemical reactions can produce sound absorption. Stuehr and Yeager (22) provide a comprehensive review of chemical sound absorption. Extensive experimental work by Kurtze and Tamm (23) and theoretical work of Eigen and Tamm (24) led to the multistate dissociation model which comes close to explaining both acoustic absorption and ion-pairing of magnesium sulfate in the complex polyelectrolyte medium of sea water.

As yet no quantitative explanations exist for the boric acid and the third acoustic relaxations in the ocean. What makes it difficult is that these reactions couple into other chemical reactions. Normal coordinate mathematical treatments are required. These are not simple even when the reaction schemes are known.

To sum up, absorption does indeed play a major role in ocean acoustics and remote sensing. Major effects are fairly well in hand on an empirical basis, with the exception of the pressure effect. Unexplained anomalies do exist and theoretical understanding is incomplete.

I would like to conclude by pointing out that one of the most exciting new areas in acoustic remote sensing is the work of Dr. Robert Pinkel. He has developed a powerful narrow beam 75 kHz sonar system for measuring ocean currents to a resolution of 1 cm/sec out to ranges of 1.6 km in 20 m range bins. It is mounted on FLIP and transmits horizontally as shown in Figure 16. He also measures the strength of the scattering from zooplankton and other organisms as shown in Figure 17. At the maximum range of 1.6 km, absorption amounts to about a 63 dB loss and spherical spreading amounts to 128 dB. Instead of using only the Doppler shift for current measurements, he is exploiting the amplitude as well. His graduate student, Paul Greenblatt, is currently relating the acoustic data to simultaneous biological sample data and looking at probability density of echo strength in terms of multiple scattering. For quantitative biomass assay, here again chemical absorption becomes vitally important to remote sensing.

Finally, I would like to remind you that all the chemical relaxation absorption processes described in this paper were initially discovered by remote sensors. Now we are ready to do the inverse problem: to use what we already know about these absorption processes to monitor by remote sensing either the chemical absorption processes themselves or other attenuation mechanisms in the ocean.

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LIST OF FIGURES AND TABLES

Fig. 15. Absorption per wavelength vs. frequency for the Mediterranean Ocean: Data of Skretting and Leroy vs. prediction of the Fisher-Simmons equation with and without the third relaxation.

Fig. 16. Schematic diagram of sound transmitted horizontally from a 75 kHz sonar mounted at the bottom of FLIP.

Fig. 17. Time series of backscattered energy losses (compensated for spreading) sonar transmitting horizontally. Depth increases with range due to refraction. Energy decreases with increasing range because of absorption. Note day-night differences due to vertical migration of deep scattering layer (DSL). Lower losses are observed at longer range at night because of strong DSL backscatter.

Table 1. Comparison of Schulkin and Marsh (SM) Equation with Fisher-Simmons (FS) Equation for Sound Absorption in Sea Water as a Function of Frequency, Pressure and Temperature for S = $35^{o}/oo$; pH = 8.0.

Table 2. Comparison of Murphy, Garrison and Potter (MGP) Sound Absorption in Sea Water Data Against Fisher-Simmons (FS) and Schulkin and Marsh (SM) Equations. T = 10^{o}, S = $30^{o}/oo$, P = 1 ATM.

Table 3. Comparison of Garrison, Early and Wen (GEW) Data with Schulkin and Marsh (SM) Equation and Fisher-Simmons (FS) Equation. T = -1.6^{o}, S = $32^{o}/oo$, P = 1 ATM.

Table 4. Comparison of Field and Laboratory Derived Formulas for Absorption in Various Oceans Due to Boric Acid and Magnesium Sulfate for Frequencies Below 10 kHz (f in kHz).

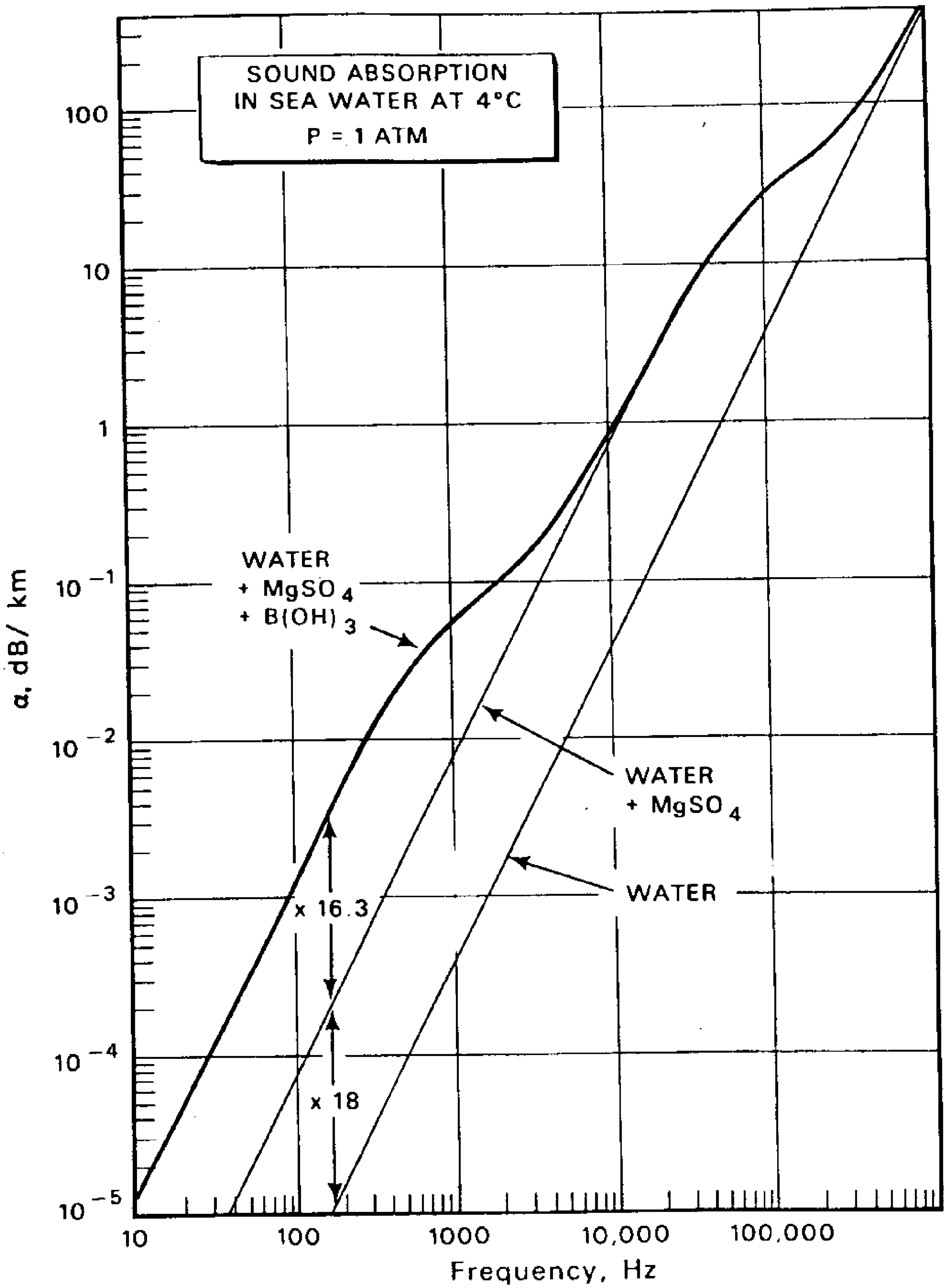


Figure 1. Sound absorption in the ocean as a function of frequency calculated from the Fisher-Simmons equation.

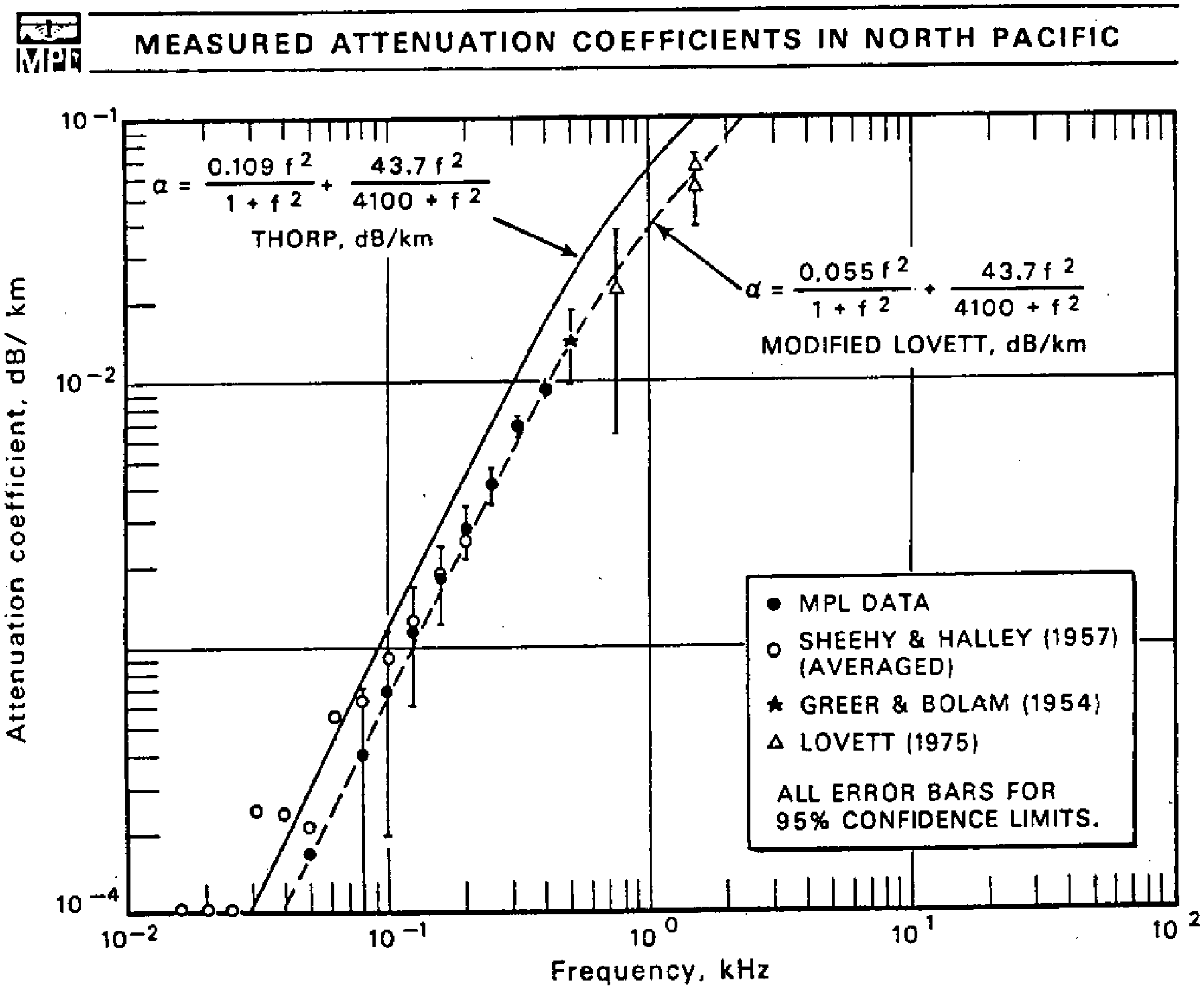


Figure 2. Note that the coefficient in the Thorp equation for the boric acid contribution in the Atlantic is twice that for the Pacific.

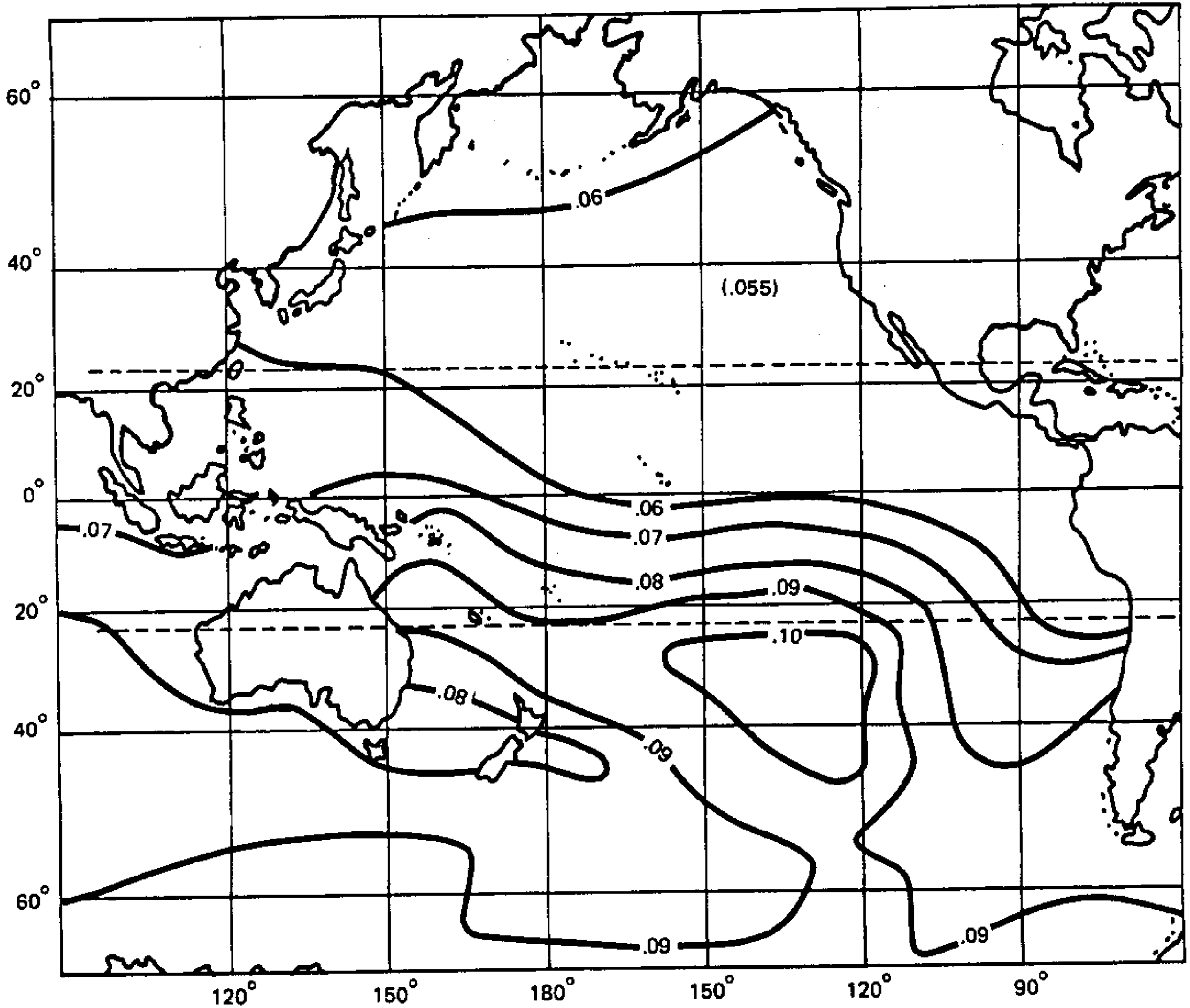


Figure 3. Revised contour plot of the Value A in the Pacific Ocean for use with Thorp sound absorption equation.

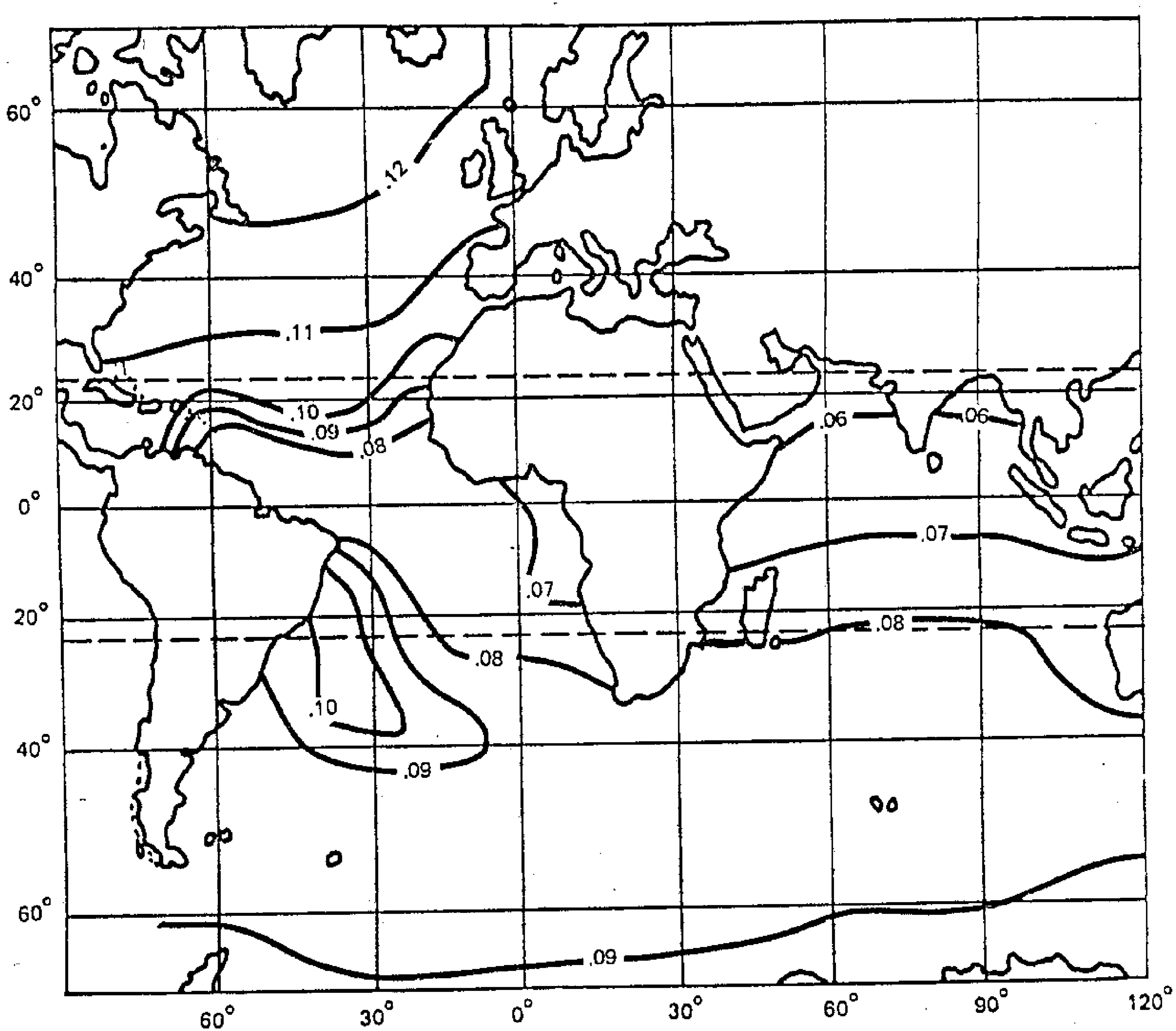


Figure 4. Contour plot of the value A in the Atlantic and Indian Ocean for use with Thorp sound absorption equation. A determined from the pH at the SOFAR axis.

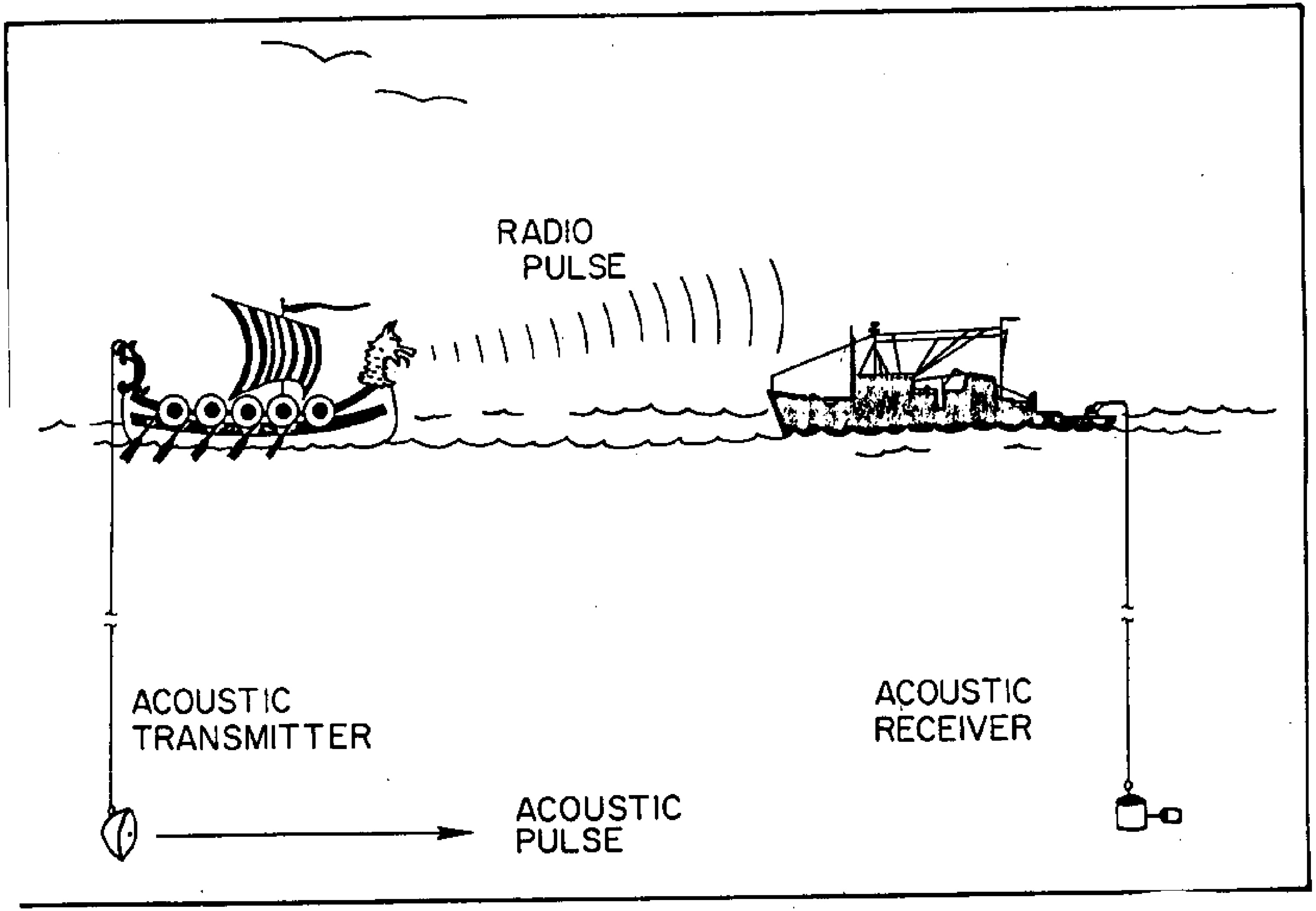


Figure 5. Schematic diagram for making attenuation measurements in the ocean. Range is calculated by the difference in travel-time of the acoustic and radio signals.

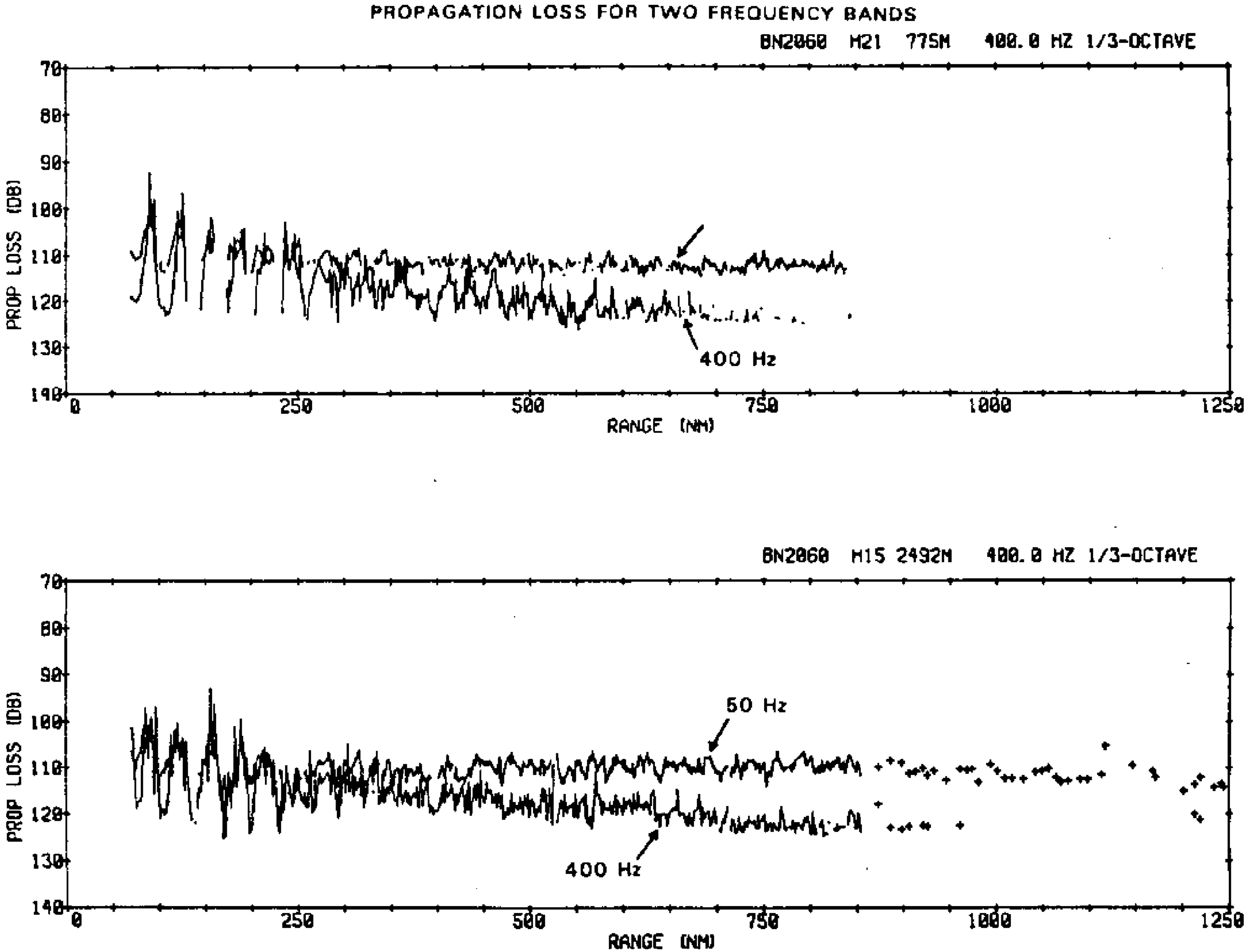
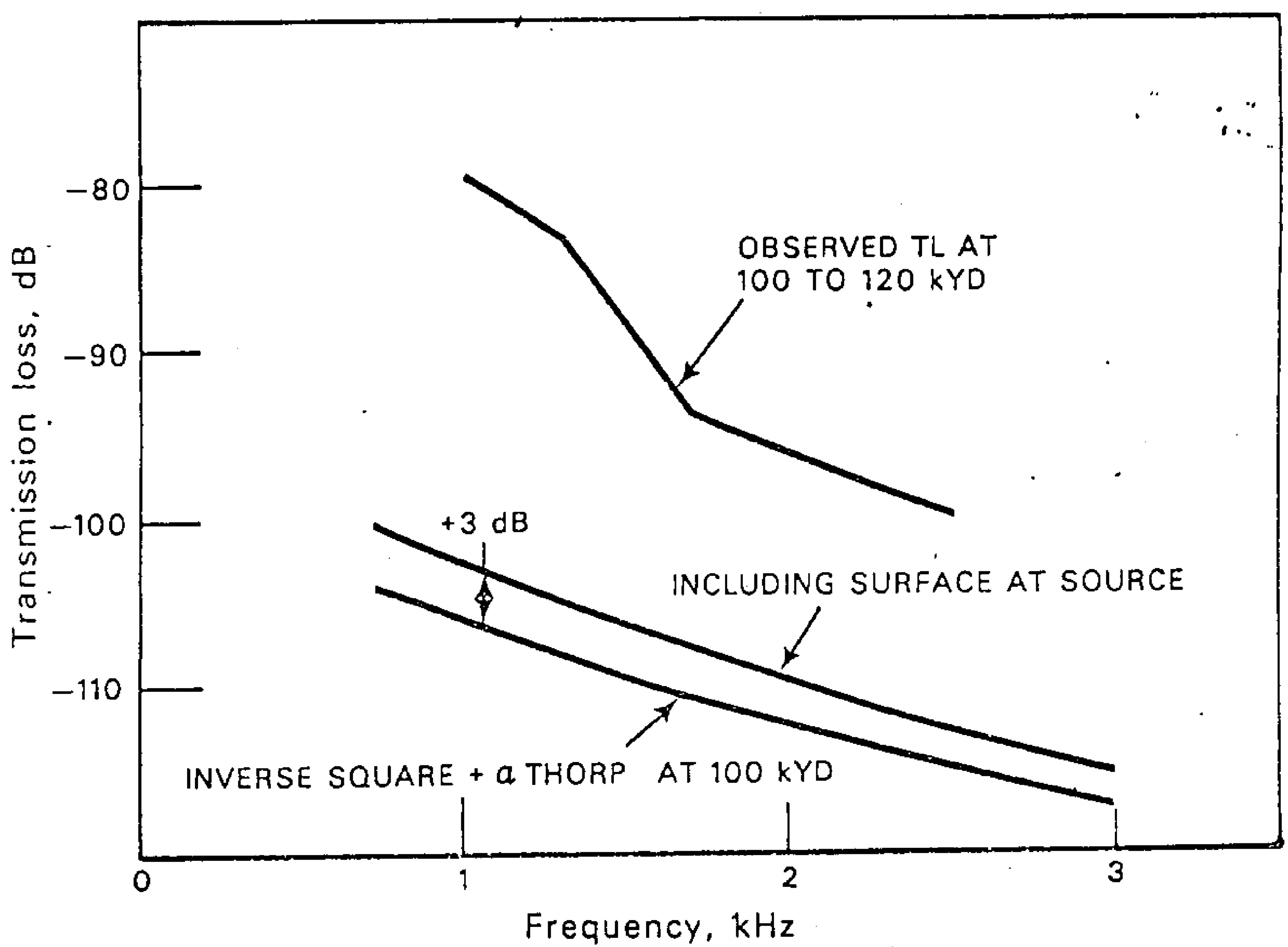


Figure 6. Propagation loss vs. range for explosive shot sources as received by hydrophones at 775 m and 2492 m depths. Note the 10 dB difference at 1000 km (600 nm) range between the 50 Hz and 400 Hz data. Convergence zone focussing effects cause large variability in signal levels. Attenuation is deduced from linear fit at long range normalized to 50 Hz.

Figure 7. Transmission loss vs frequency at 90 to 110 km range. Inverse square compensation is probably 10 dB too much at such a long range. Cylindrical spreading or inverse spreading after 10 Kyd is usually used; that is, 80 dB + 10 log R. The low transmission loss at 1 kHz is due to convergence zone focussing. Scattering is responsible for the added losses at 2 kHz.



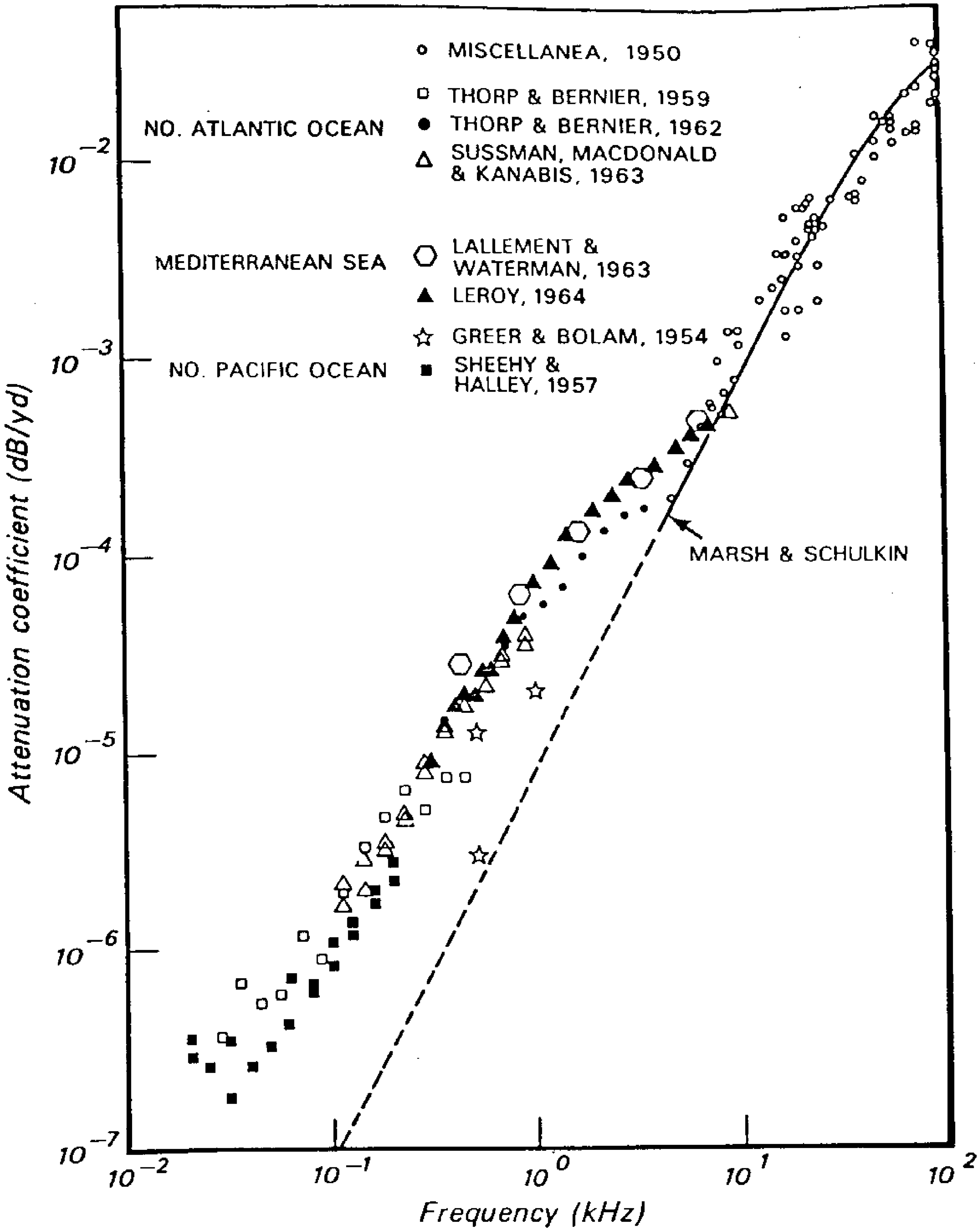


Figure 8. Sound attenuation at low frequency in the ocean after Thorp.

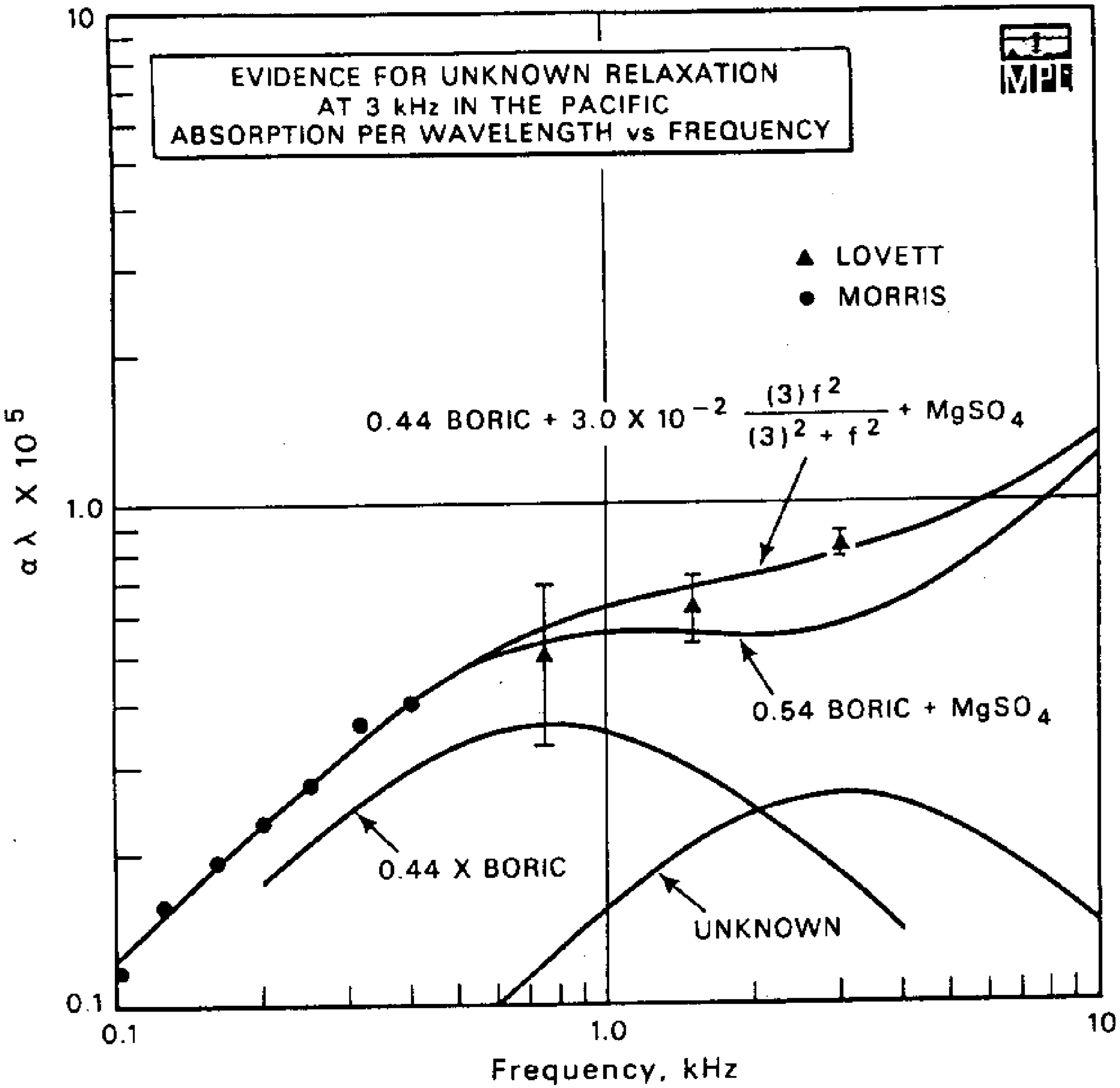

EVIDENCE FOR UNKNOWN RELAXATION
AT 3 kHz IN THE PACIFIC
ABSORPTION PER WAVELENGTH vs FREQUENCY
▲ LOVETT
● MORRIS
$0.44 \text{ BORIC} + 3.0 \times 10^{-2} \frac{(3) f^2}{(3)^2 + f^2} + MgSO_4$
$0.54 \text{ BORIC} + MgSO_4$
0.44 X BORIC
UNKNOWN
$\alpha\lambda \times 10^5$
10
1.0
0.1
0.1
1.0
10
Frequency, kHz

Figure 9.

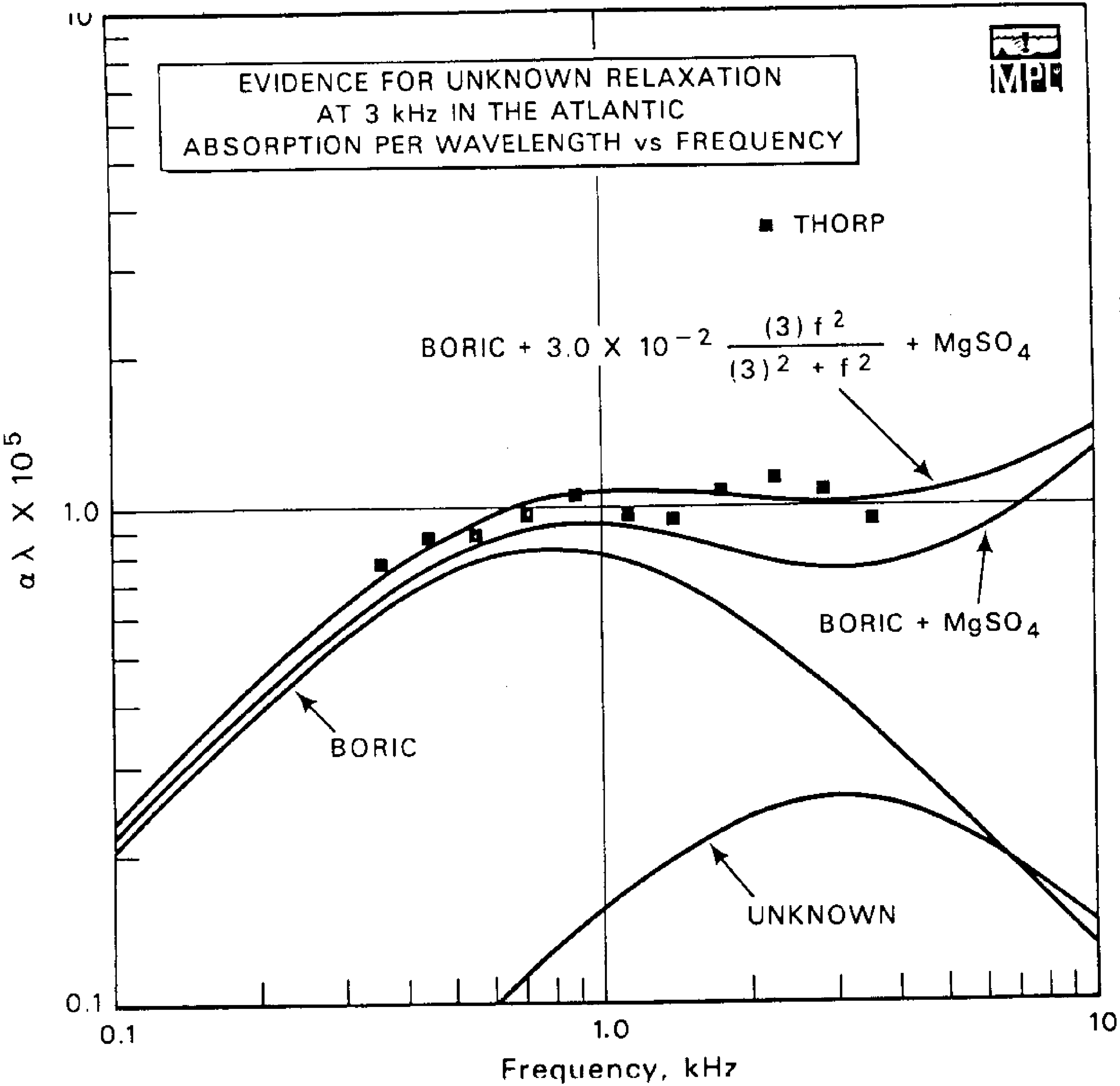

EVIDENCE FOR UNKNOWN RELAXATION
AT 3 kHz IN THE ATLANTIC
ABSORPTION PER WAVELENGTH vs FREQUENCY
MPL
THORP
BORIC + 3.0 X 10^{-2} $\frac{(3) f^2}{(3)^2 + f^2}$ + $MgSO_4$
BORIC + $MgSO_4$
BORIC
UNKNOWN
$\alpha\lambda \times 10^5$
10
1.0
0.1
0.1
1.0
10
Frequency, kHz

Figure 10.

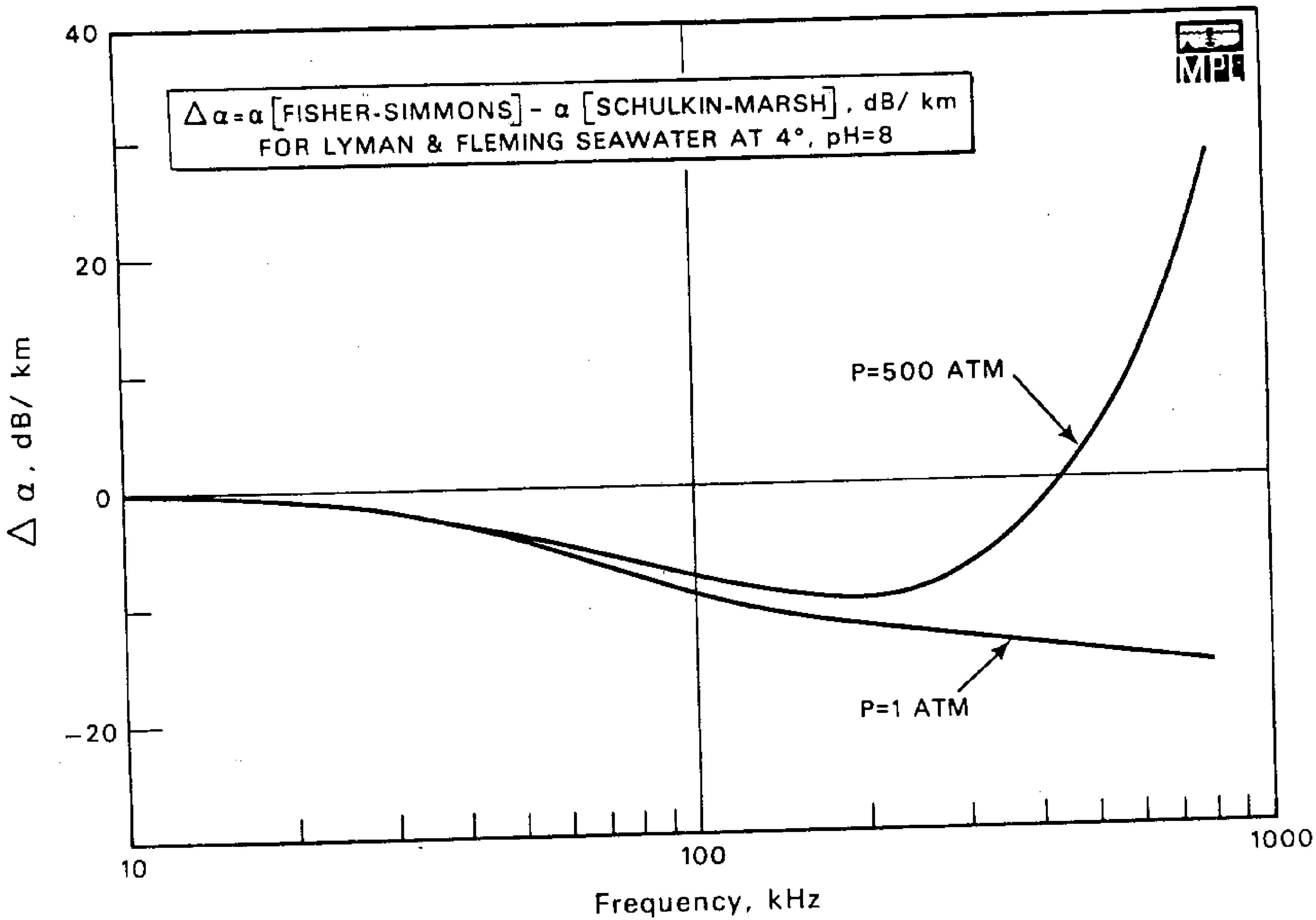


Figure 11. Difference between the Fisher-Simmons (1977) and the Schulkin-Marsh (1963) equations for sound absorption as a function of frequency and pressure.

EQUATION FOR SOUND ABSORPTION IN SEAWATER, S = 35‰, pH = 8

$$\alpha = A_1 P_1 \frac{f_1 f^2}{f_1^2 + f^2} + A_2 P_2 \frac{f_2 f^2}{f_2^2 + f^2} + A_3 P_3 f^2$$

BORIC

$$A_1 = (1.03 \times 10^{8} + 2.36 \times 10^{-10} T - 5.22 \times 10^{-12} T^2) \text{ sec/ m}$$

$$f_1 = 1315 (T + 273.1) e^{-\frac{1700}{T + 273.1}} \text{ Hz}$$

$MgSO_4$

$$A_2 = (5.62 \times 10^{8} + 7.52 \times 10^{-10} T) \text{ sec/ m}$$

$$f_2 = 1.55 \times 10^7 (T + 273.1) e^{-\frac{3052}{T + 273.1}} \text{ Hz}$$

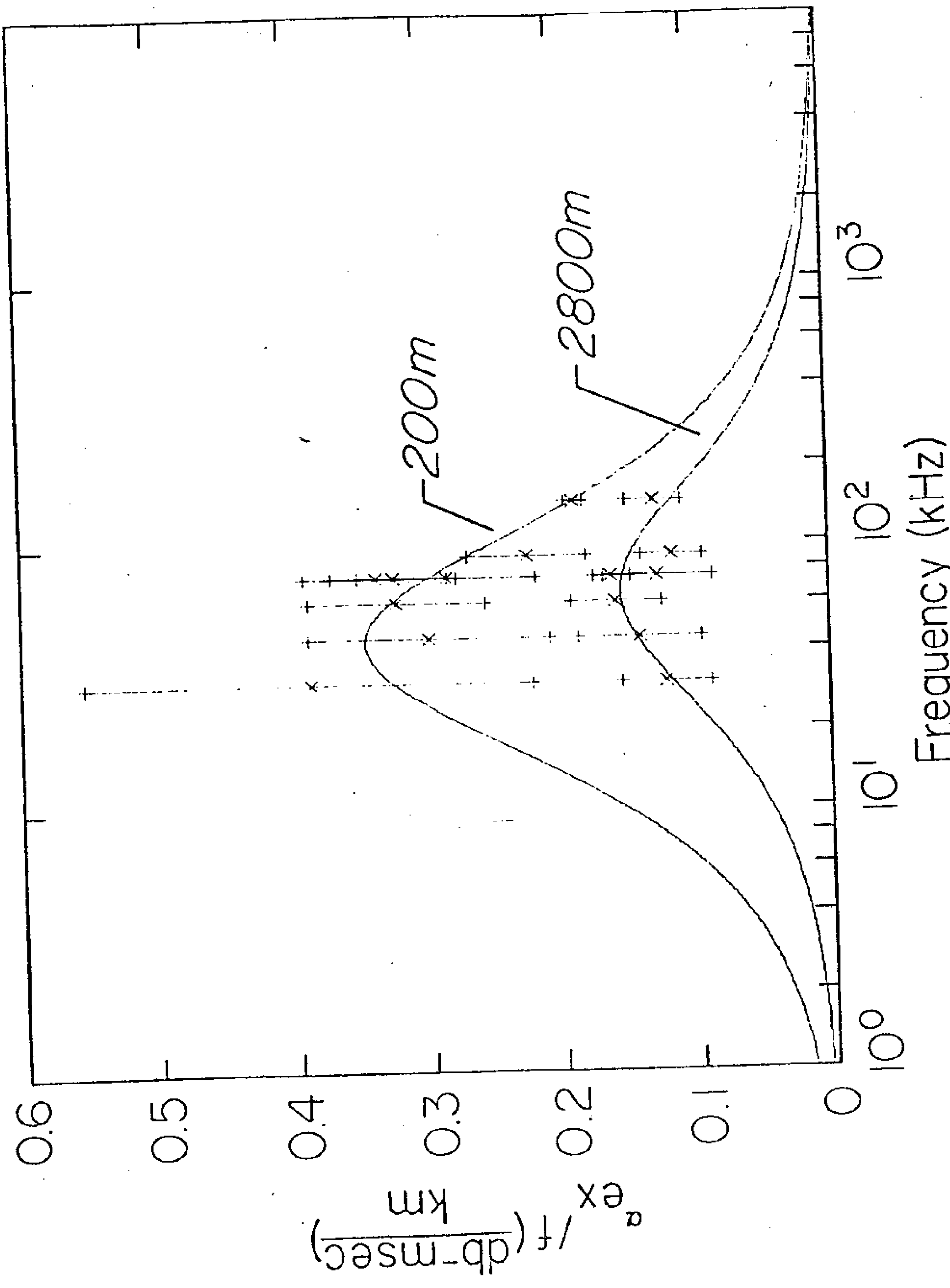
$$P_2 = \alpha_2 (P)/\alpha_2 (1) = 1 - 10.3 \times 10^{-4} P + 3.7 \times 10^{-7} P^2$$

WATER

$$A_3 = \left[55.9 - 2.37 T + 4.77 \times 10^{-2} T^2 - 3.48 \times 10^{-4} T^3\right] \times 10^{-15} \text{ sec}^2 \text{ m}^{-1}$$

$$P_3 = \alpha_3 (P)/\alpha_3 (1) = 1 - 3.84 \times 10^{-4} P + 7.57 \times 10^{-8} P^2$$

Figure 12. Fisher-Simmons sound absorption equation for seawater. The P coefficients are for the pressure effects where p is in atmospheres. The f coefficients are for the relaxation frequency.



... absorption measurements at two depths

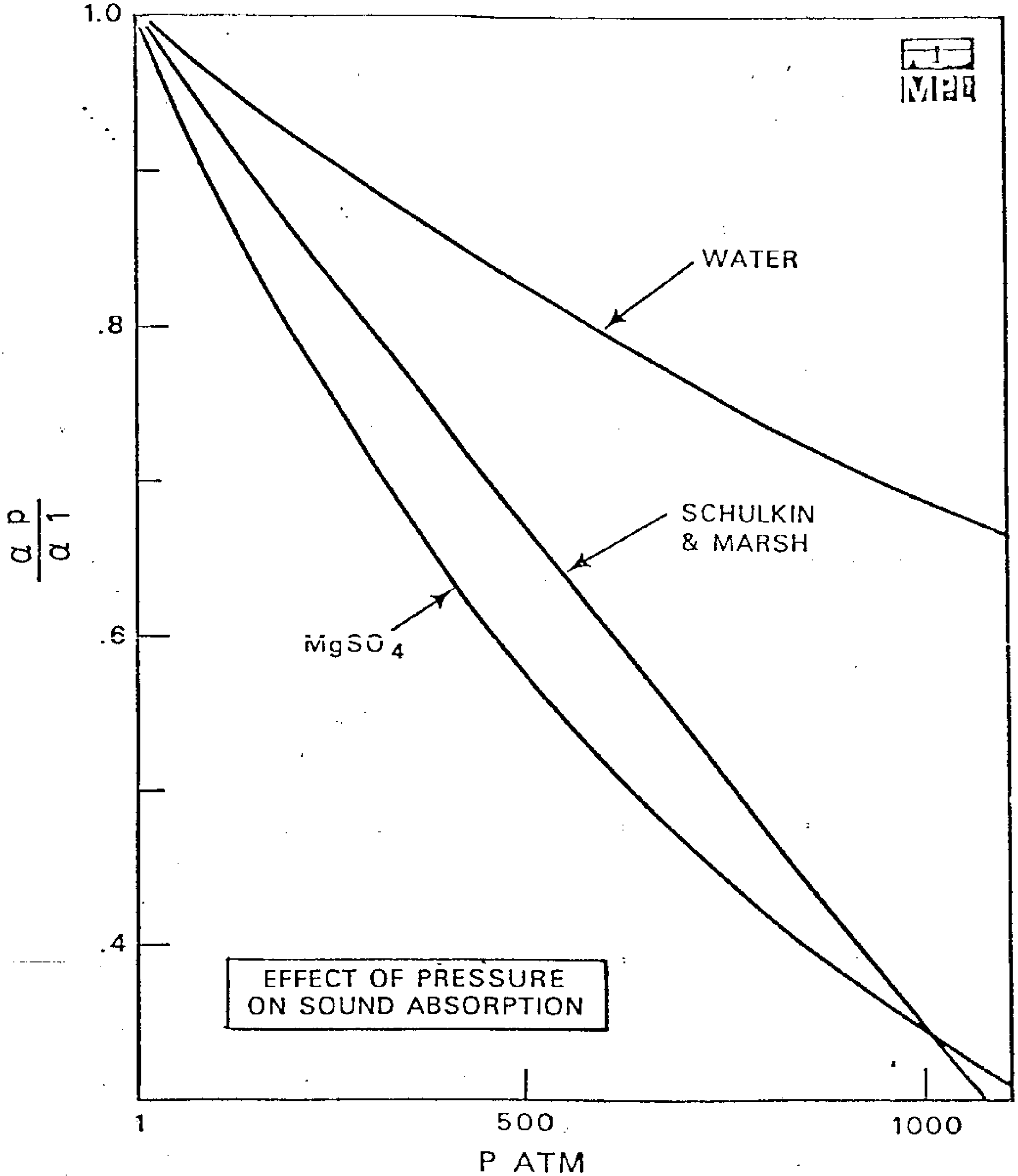


Figure 14. Ratio of absorption at pressure P to that of atmospheric pressure. The $MgSO_4$ data are for 0.5 molar $MgSO_4$ solutions

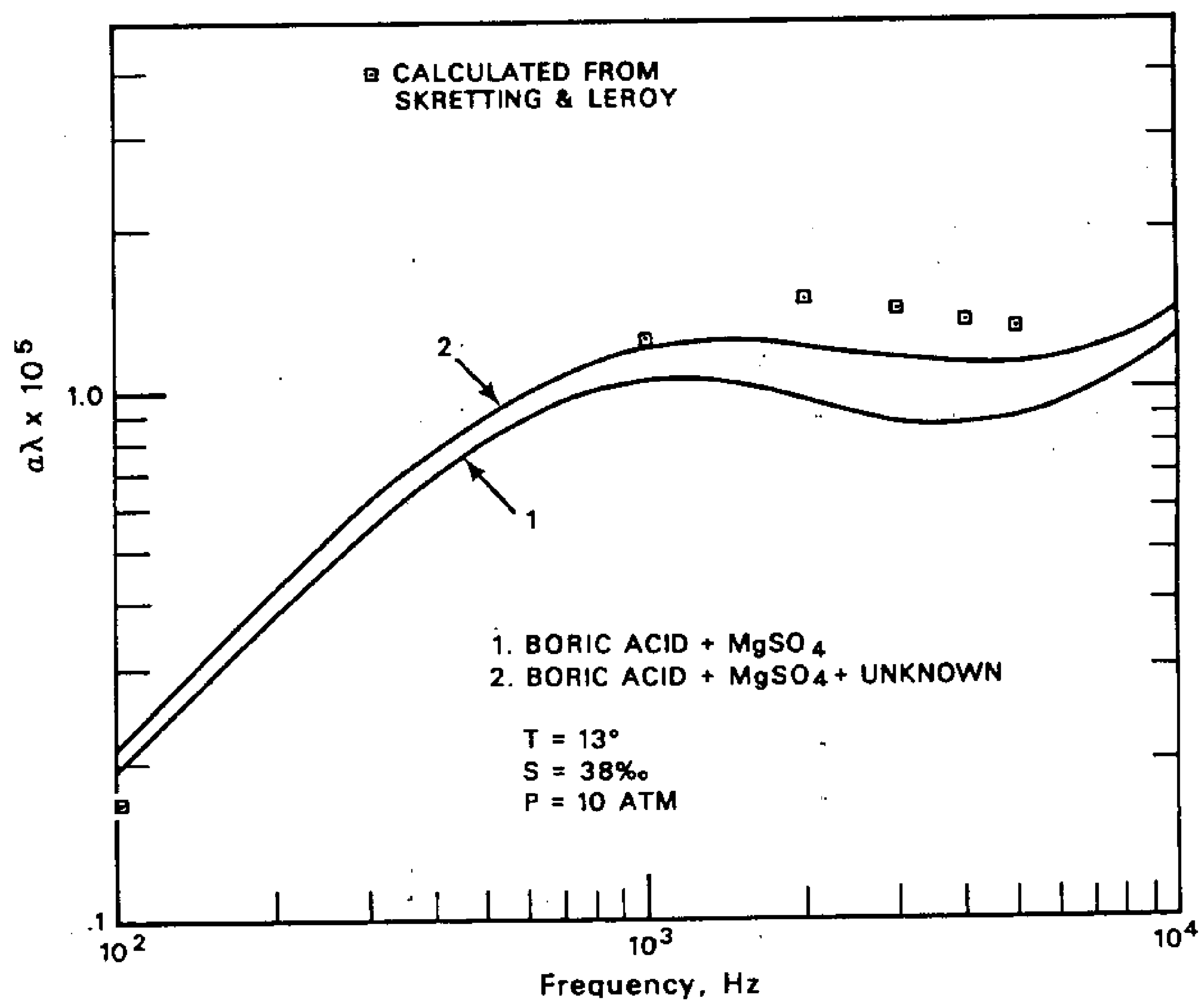


Figure 15. Absorption per wavelength vs. frequency for the Mediterranean Ocean: Data of Skretting and Leroy vs. prediction of the Fisher-Simmons equation with and without the third relaxation.

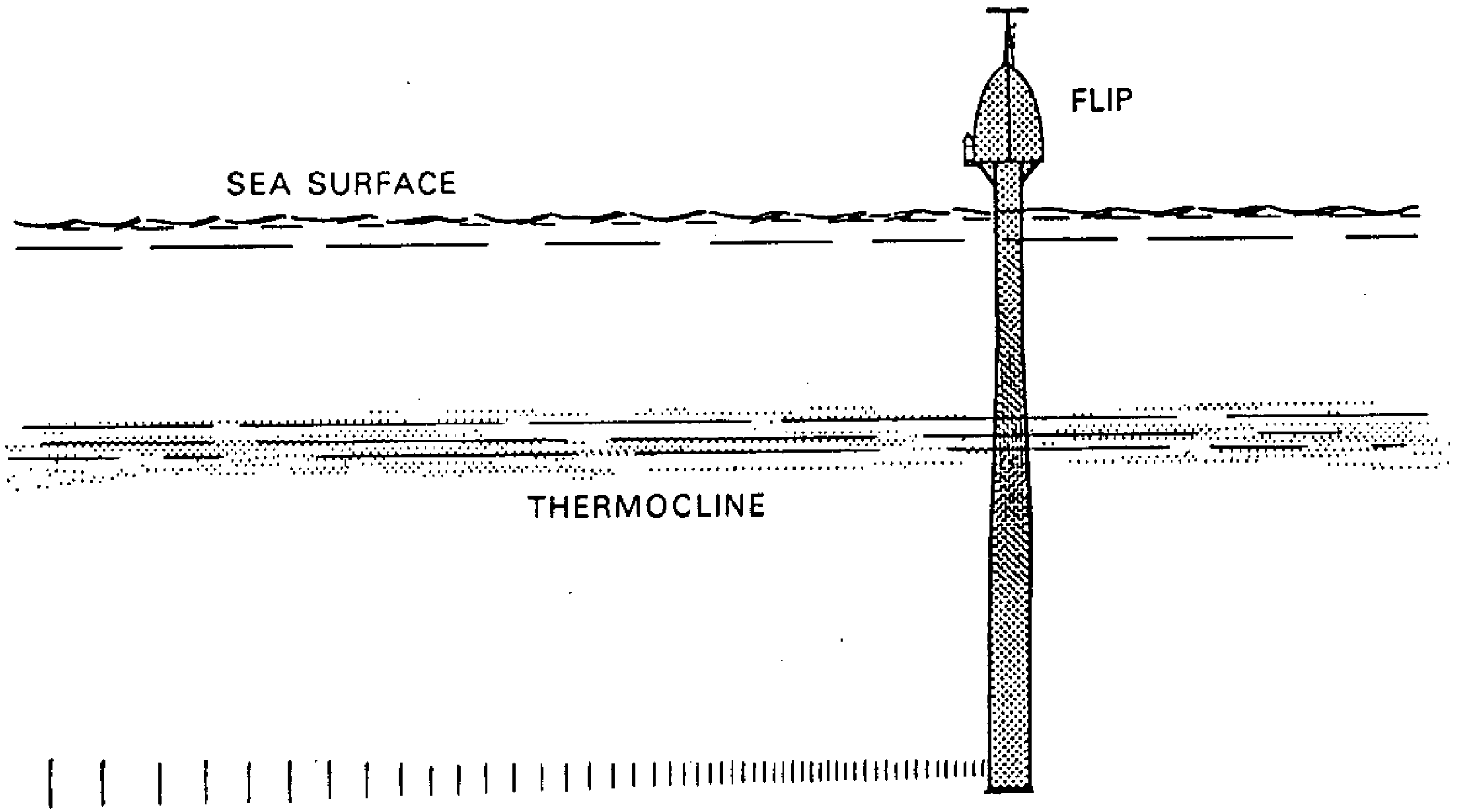


Figure 16. Schematic diagram of sound transmitted horizontally from a 75 kHz sonar mounted at the bottom of FLIP.

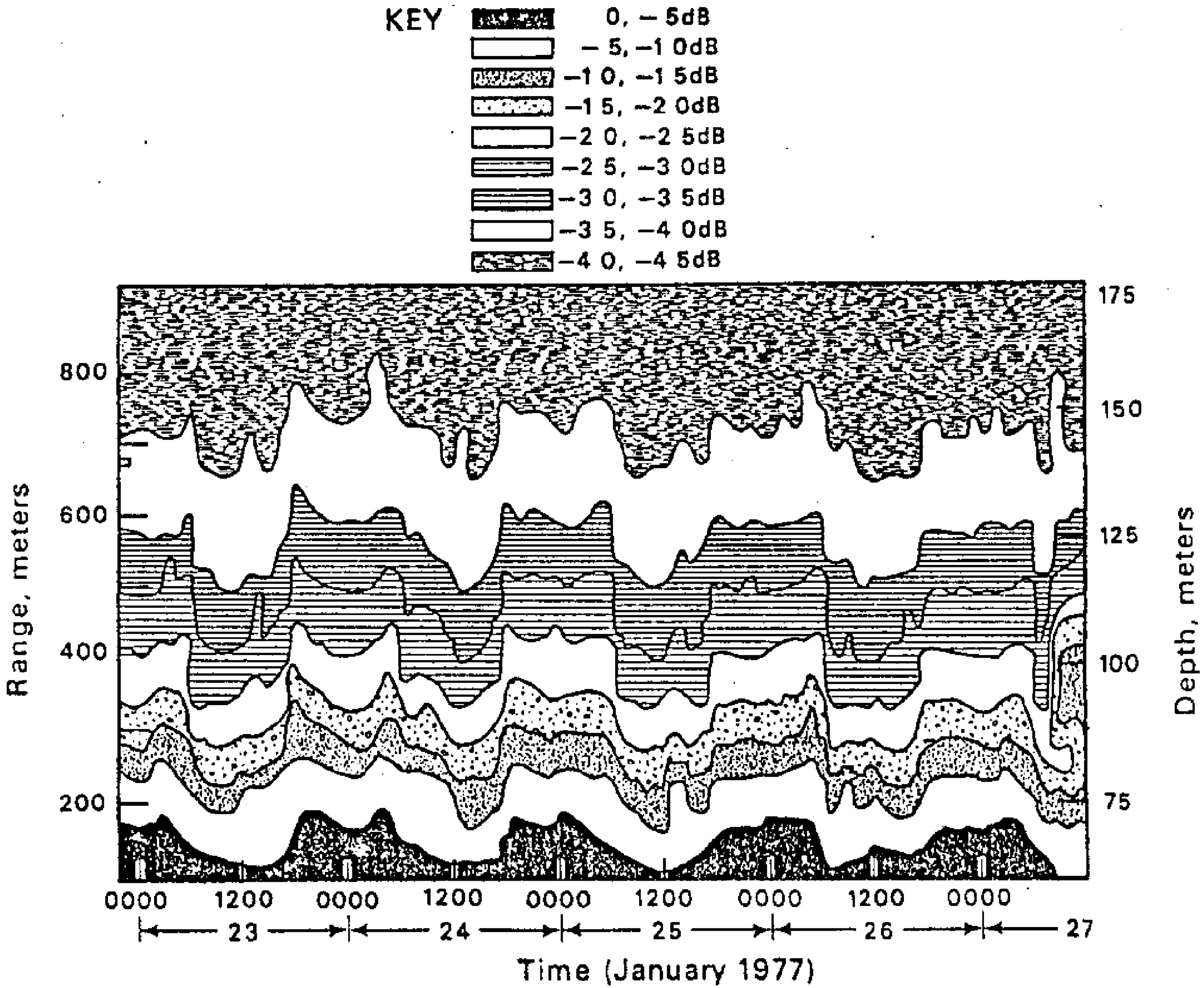


Figure 17. Time series of backscattered energy losses (compensated for spreading) sonar transmitting horizontally. Depth increases with range due to refraction. Energy decreases with increasing range because of absorption. Note day-night differences due to vertical migration of deep scattering layer (DSL). Lower losses are observed at longer range at night because of strong DSL backscatter.

TABLE I

Comparison of Schulkin and Marsh (SM) Equation with Fisher-Simmons (FS) Equation for Sound Absorption in Sea Water as a Function of Frequency, Pressure and Temperature for S = 35 $^{o}/oo$; pH = 8.0.

Frequency (kHz)	Sound Absorption (dB/Km)					
	T = 4°, P = 1 ATM		T = 4°, P = 500 ATM		T = 20°, P = 1 ATM	
	FS	SM	FS	SM	FS	SM
3.5	.17	.13	.13	.09	.18	.064
5.0	.27	.26	.19	.17	.24	.13
7.5	.50	.58	.33	.39	.39	.29
10.0	.83	1.0	.52	.69	.60	.52
25.0	4.4	5.8	2.6	3.9	3.0	3.2
50.0	13.2	17.7	7.9	11.9	10.7	11.6
75.0	21.6	28.9	13.1	19.5	20.9	23.2
100.0	28.4	37.7	17.5	25.4	31.8	35.5
200.0	48.8	61.4	32.3	41.4	66.4	75.4
400.0	101.0	115.0	74.7	77.4	110.0	123.0
800.0	298.0	314.0	238.0	211.0	220.0	230.0

TABLE II

Comparison of Murphy, Garrison and Potter (MGP) Sound Absorption in Sea Water Data Against Fisher-Simmons (FS) and Schulkin and Marsh (SM) Equations*. $T = 10°$, $S = 30$ ‰, $P = 1$ ATM.

Frequency f(kHz)	Sound Absorption (dB/Km)		
	MGP	FS	SM
60	15.8	14.3	17.8
142	39.0	37.2	46.0
272	62.3	62.5	74.1
467	110.5	111.2	123.3

*Note: Relaxation frequency from MGP = 83.5 ± 2 kHz

Relaxation frequency from FS $\cong$ 90 kHz

TABLE III

Comparison of Garrison, Early and Wen (GEW) Data with Schulkin and Marsh (SM) Equation and Fisher-Simmons (FS) Equation. $T = -1.6°$, $S = 32^{o}/oo$, $P = 1$ ATM.

Frequency	Sound Absorption(dB/Km)		
f(kHz)	GEW	SM	FS
7.1	.66	.61	.48
10.0	1.3	1.2	.86
20.0	4.3	4.4	3.1
30.0	7.5	8.7	6.0
40.0	10.5	13.2	9.2
60.0	14.7	21.3	15.0

TABLE IV

Comparison of Field and Laboratory Derived Formulas for Absorption in Various Oceans Due to Boric Acid and Magnesium Sulfate for Frequencies Below 10kHz (f in kHz)

Ocean	T/S	Mellen & Browning, Field α db/km	Fisher & Simmons, Lab α db/km (P = 1 ATM)
Atlantic	4°/35 °/₀₀	$\frac{.11(1)f^2}{1+f^2} + .011f^2$	$\frac{.094(.8)f^2}{(.8)^2+f^2} + .0072f^2$
Pacific	4°/34 °/₀₀	$\frac{.055(1)f^2}{1+f^2} + .011f^2$	$\frac{(.094)(.8)f^2}{(.8)^2+f^2} + .0070f^2$
Mediterranean	13°/38 °/₀₀	$\frac{.15(1.7)f^2}{(1.7)^2+f^2} + .0066f^2$	$\frac{.11(1)f^2}{1+f^2} + .0060f^2$
Red Sea	22°/40 °/₀₀	$\frac{.15(1.5)f^2}{(1.5)^2+f^2} + .0077f^2$	$\frac{.11(1.2)f^2}{(1.2)^2+f^2} + .0049f^2$
Gulf of Aden	15°/36 °/₀₀	$\frac{.078(1.2)f^2}{(1.2)^2+f^2} + .0066f^2$	$\frac{.11(1)f^2}{1+f^2} + .0050f^2$

OARS Paper #11

OCEAN ACOUSTIC REMOTE SENSING OF THE SEA FLOOR

by Fred N. Spiess
Marine Physical Laboratory
Scripps Institution of Oceanography

Introduction

Ocean acoustic remote sensing can be used in a variety of ways to sense the nature of the sea floor and sub-bottom and systems of wide variety have been proposed and developed for this purpose. Given the state of current sonar technology and NOAA's needs, this paper will concentrate on four types of sonars, for a combination of reasons that will be delineated below. The four are:

1. Echo Sounders
2. Side Looking Sonars
3. Shallow-penetration Sub-bottom Profilers
4. Acoustic Transponders

All four relate to missions or tasks that are of importance to NOAA, in fact each has more than one such application which is apparent to me and others will undoubtedly arise in the reader's imagination as well. Echo Sounders provide the primary means for mapping sea floor topography, which in itself is a NOAA responsibility. In addition particular aspects of sea floor morphology are of direct interest in fisheries, ocean dumping and resource assessment. Side Looking Sonars (SLS), providing as they do the ability to portray bottom roughness distributions and small-scale sea floor irregularities (natural or man-made), are of use in locating obstructions, mapping distributions of some resources (manganese nodules, sand, gravel, placers) and evaluating the effects of man's sea floor activities (dumping, mining, trawling, etc.). Shallow penetration sub-bottom penetration systems can provide indications of bottom instabilities--faulting, slumping, gas pockets, etc.--which are of importance in resource utilization and waste disposal, and further system development could provide the capability for mapping buried objects--again in the waste disposal context. Finally, acoustic transponder techniques, particularly those currently under development, can play a major role in geodesy on the sea floor (presuming that NOAA's scope of interest in geodesy can be extended, as one might expect, into the oceanic realm), allowing study of time-dependent effects not only in the near shore environment due to localized events, but in the measurement of relative motions at spreading centers and transform faults in the plate tectonic context.

All four of these sonar types are at a state such that a variety of new options and capabilities are waiting in the wings and can be brought forth in forms which are relevant to NOAA's missions if development programs are properly formulated and supported. Remote sensing of the sea floor using acoustics is a fairly old activity. Simple echo-sounding was postulated as a useful technique in the late 1800's, but it was primarily developed in parallel with submarine detection sonars in the period from about 1915 to 1940. Use of acoustics to study the sub-bottom grew rapidly immediately after World War II, building on techniques developed to use explosive sound sources for propagation studies as part of the newly developing sonar programs of that era. Somewhat later, as an outgrowth of mine-hunting sonar developments, side looking sonar technology began to merge in other contexts. In all of these (and subsequent transponder development in the 60's as well), as they occurred in the United States, the major innovations were carried forward primarily by the academic institutions and Navy laboratories in collaborative programs supported by the Navy with impact on both ocean science and technology.

Although the Navy continues to be an active supporter of developments in these areas, many of NOAA's requirements are such that they should be influencing the course of events. It would seem appropriate for NOAA to follow the Navy pattern and draw on the expertise of the academic community in a similar major way as well as developing in-house strength. The expertise developed under Navy sponsorship is in fact limited only insignificantly by security classification and has substantial existence in the academic community. Recent management statements, and the invitation of several of us from that community to participate here in the formulation of NOAA's future programs in OARS is an encouraging indicator that such will be the case.

The sonar concept approaches in all four of the sonar functional categories are essentially those of active sonar--studying the transmission and reflection of sound produced under the control of the system designer and operator. The passive approach, in which natural (or at least uncontrolled) sound sources are used, has only been exploited in the case of sub-bottom studies, some of which have relied on interpretation of signals generated by earthquakes.

Commonly all of the active systems transmit a signal of restricted duration and then receive (usually, but not always, at a point near the transmitter) and record the resulting energy as a function of time. In the simplest systems one processes to find the time of arrival of a strong replica of the transmitted pulse and works primarily with resulting travel time information. In more advanced cases one may look for the nature of the distortions of pulse shape which have occurred and at the more continuous variations in the levels of received energy as a function of time-after-ping. All advanced systems utilize multiple receivers, combining the outputs to accentuate arrivals from particular directions or locations. Beyond that sea-floor-oriented systems can take advantage of the fact that the material being observed is stationary and thus the outputs from successive transmissions can also be combined to enhance resolution. Different versions of the many resulting combinations of system geometry, signal forms, transmit or receive transducers, and signal processing methods are appropriate to different system requirements, and examples of these will be discussed under each of the major functional categories. The discussion will emphasize new approaches which are emerging or which could be brought into being in the future, rather than producing an extensive treatment of today's capabilities.

It may be useful to contrast the characteristics of ocean acoustic and the more familiar electromagnetic (particularly optical) remote sensing systems as used above water. The principal differences are in propagation speed and attenuation. These enter in combination to lead primarily to differences in system resolution. The essential system element in producing fine resolution in the angular sense is the receiving aperture as measured in wavelengths. The much lower acoustic propagation speed results in correspondingly shorter wavelengths for a given frequency. Sound absorption in water and crustal materials, however, is such that one must work in the megahertz regime or below. Wavelengths thus range from millimeters to centimeters for bottom roughness systems, to decimeters and meters for echo sounders and meters to decameters for subbottom use. The result is that, for a given aperture, the angular resolution is far better for optical or radar systems than for useful sonars. A 15 kHz sonar system, for example, must have an aperture of 6 m. to achieve a one degree beamwidth. The low propagation speed, on the other hand, means that it is easy to obtain good range resolution from travel time measurements in the underwater acoustic regime and considerable reliance is thus placed on this aspect.

One last introductory point: Acoustic remote sensing should never be taken as an isolated, independent approach. Its great strength is in complementing other kinds of remote observations (photography, magnetics, gravity, etc.) and direct sampling or in situ physical or chemical measurements on sea floor materials.

Echo Sounders

Systems to determine sea floor topography must be designed on the basis of some kind of compromise between resolution and area coverage. The conventional, hull mounted single beam echo sounder is not optimized for either of these two aspects. Even with a one degree stabilized beam its footprint would be 50 m. across in 3,000 m. of water, and most systems are thought of as reasonably good if their beam widths are 3 to 6 times as wide. Range resolution is limited by system band width which is typically about one kilohertz. At the same time their area coverage, since they produce data only along a single line, can be thought of as good only in comparison with the use of a one point at a time sounding machine.

Optimization for resolution can best be achieved by operating the transducer close to the sea floor (Fig. 1). The Marine Physical Laboratory has been operating such a deeply towed echo sounder as part of our deep tow geophysical system[1] for many years, indeed it was the first subsystem of that unit to be implemented. By going close to the sea floor one can work at higher frequencies and thus have greater bandwidth (with resulting improved range resolution) while also being able to achieve narrow beams with modest transducer dimensions. Our present system (Fig. 2 - deep tow fish systems) uses a 125 kHz carrier and a 0.1 msec pulse (10 kHz bandwidth) with a 3° beamwidth. This gives a footprint 2 m. across at our typical working elevation of 40 m. off the bottom. Even with this one can find terrain, for example at the crest of the East Pacific Rise, where improved resolution could occasionally be used as one moves across numerous nearly vertical walled scarps and fissures.

The true limitations on this system are not acoustic. With a one cm. wavelength and a pulse about 10 cm. long it is feasible to make determinations of the vehicle's height off the bottom to within about 5 cm. Some reference must be provided, however, as a baseline to which the measurements are referred. In the past the method for doing this has been to echo sound on the sea surface, looking up from the vehicle. In order to achieve adequate returning signal level one must drop down in frequency (we use 23 kHz) with resulting decrease in bandwidth and loss of range resolution. Furthermore, the round trip travel time for the signal in such a system will typically be several seconds, during which the vehicle, coupled to the ship by its long wire, will have moved vertically, in severe seas by as much as five meters. Since the disturbing vertical motions have periods primarily in the 5 to 10 second range these effects can be averaged out over a period of 20 seconds which, at a tow speed of 0.75 m/sec represents a horizontal distance of 15 m.

In order to improve this resolution we are in the process of integrating a quartz crystal pressure gauge into our present system. This produces readings good to 10 cm. depth resolution and 2 m. patch size. Since the latter is comparable to our navigational precision it does not seem useful to pursue further improvement in this regard. The stereo camera system on the vehicle can be used to delineate the forms of feature smaller than this (e.g. erosional furrows).

If one has a vehicle which can sit on the bottom, then it can use a scanning system very close to the sea floor with no transducer motion for which to compensate during a single scan. Such a system[2] was built and operated in conjunction with V.C. Anderson's RUM[3] vehicle (Fig. 3) at MPL in order to profile the depressions made in the sea floor by the tractor's treads. In this case the water close to the track was so murky that stereo photography would have been impractical. Operating one meter off bottom, at a frequency of 3 MHz and a 10 μsec pulse with a 1° beamwidth, this is probably the highest resolution echo sounder system to be used at depths greater than 1,000 m.

Systems such as the ones described above are optimized for resolution. Their area coverage rates are low (although they can be improved--as will be described below). Optimization for area coverage is a different matter. It can be achieved in two ways and both must be used if true optimization is to be claimed. Clearly one must go faster and one must cover a swath rather than a single line. Given the nature of both sonar and ship design, one can make more substantial gains by pushing for a swath than for emphasizing increased speed. Moreover, from the parochial underwater acoustic viewpoint, the achievement of swath width can be had as a sonar system development, independent of what the shipbuilders may do.

The first swath mapping sonars[4] were built under U.S. Navy sponsorship and are essentially multiple beam systems. One commercial model[5] for deep sea use is currently in production utilizing essentially the same design approach. Both systems use separate hull mounted transmitting and receiving elements. The sending transducer is a fore-and-aft linear unit which thus transmits a fan shaped beam--narrow fore-and-aft and broad athwartships. The receiving elements, each wired individually into the ship, are arranged in an athwartships line with their outputs fed to a multiple channel beam-former. (Single channel narrow beam sounders of this type have been used for many years on both Navy and NOAA survey ships.) This forms, simultaneously, a set of approximately fan shaped beams (Fig. 4) in the fore-and-aft direction, intersecting the transmitted beam to view the sea floor at a set of patches (Fig. 5). The system then recognizes the time of arrival of the first echo on each beam, computes the horizontal and vertical coordinates of the patch (as represented from the first arrival) and produces a contoured plot (Fig. 6) taking ship speed into account. Since depths are assigned at all relevant points, the contouring becomes a deterministic mathematical problem rather than involving judgment.

The primary attributes of systems of this kind are controlled by the effective beamwidths, number of beams and the pulse repetition interval (which in present systems must be greater than the round trip travel time to the most distant sounding point). Since these systems are new to many people it is essential that one not fall into the trap of equating all types (existing and future) of swath mapping sonars or of ascribing to them some magical resolution capabilities. Fortunately, they behave in a reasonable way, and their gross geometric properties characterize their performance adequately for most purposes.

For the system described in Table I the patch size is about 5% of the water depth. Referring to the bottom profile of Figure 1 this would mean picking the first arrival in each 140 m. step--certainly a great improvement over the trace from a conventional research ship echo sounder, but still clearly of less resolution than for the near bottom system. Given the need for some redundancy or continuity to distinguish true readings from bursts of noise, it appears that this system should be able to recognize isolated hummocks if they are greater than about 300 m. across in this water depth.

Given the proportionality of both patch size and round trip travel time to water depth, the constraint of only one pulse in the water at a time is not onerous. Ship speed, S, should be such that the advance per ping interval, T, is less than the patch size, P. T is related to the speed of sound (1500 m/sec) thus

$$S \leq \frac{CP}{3D} \text{ but } P = .05\ D, \text{ thus}$$

$$S \leq \frac{.05 \times 1500}{3} = 25 \text{ m/sec (50 knots)}$$

In any sounding operation, ship navigation is important; however additional aspects emerge in this context, particularly the need to know ship's heading as well as track orientation. If the ship yaws, or makes appreciable leeway, the positions of the outer beam points will not be properly placed unless these effects are accurately measured. While they have greater influence by about a factor of 4 for the Navy system (swath about twice as wide and patch about half), they are still a matter for concern for the Seabeam units as well. A heading error of of B^o will produce an error in location of the outer beam point of about $E = .4D\ B/(60)$, or in 5,000 m. of water and 3^o, E = 100 m. E equals the footprint size for $B = 7\frac{1}{2}^o$.

In the gross sense, much of the navigation can be bootstrapped by running swaths at right angles, since the athwartship dimensions of sea floor features are depicted in a manner independent of ship speed.

Resolution of steep features by the Navy system has been directly compared with deep tow profiles in the FAMOUS area[6] on the mid Atlantic Ridge. In the region of overlap the deep tow observations showed a number of vertical steps (85^o or steeper) where elevation changes were up to 50 m. and one slope of 75^o persisting laterally for 100 m. (about 400 m. change of elevation). The steepest slope shown by the multibeam system was just over 60^o.

An alternative to the multibeam style swath mapping system is the interferometer style devised by Anderson[7] in the context of a forward looking obstacle avoidance system for small submersibles and currently being implemented with ONR sponsorship as an adjunct to the deep tow system.

The system uses the side looking sonar transmitting unit and receives the returning reverberation backscattered from the sea floor at two rather than the usual single receiver. In its simplest form the two transducers' signals are added together and, if the spacing between them is several wavelengths (Fig. 7) a set of nulls will exist at elevation angles which are fixed by transducer geometry and acoustic wavelength. In the more sophisticated unit under construction the electrical phase difference between the signals arriving at the two receivers is continuously measured and this can then be converted into a measure of the vertical angle from which the energy is coming at a given time-after-ping (or range). As a result a depth profile athwartships to the vehicle is produced. Design goals for the system are a swath 100 m. wide with depth resolution of 1 m. As with the multibeam swath mapping systems this has the advantage of determining the actual shapes of localized sea floor features in a single pass. Its principal advantages relative to the multibeam system are that the transducer arrangement is much simpler (two fore-and-aft line transducers with only one output from each) and the processor is also substantially simpler, being only a single channel. Its disadvantage is that whenever the bottom slope is steep enough or rough enough that facets at appreciably different depression angles occur at the same slant range then the output is indeterminate (depends on the relative intensities of the several reflections). Geometric situations of this type occur less frequently when the grazing angles are small, thus the technique is more adaptable to systems operating in side-looking sonar style. These could very well, however, be long range, near surface operating systems such as Gloria (to be discussed in the next section), remembering that measurement precision is angular, rather than linear.

Near-surface operated systems using this principle may be degraded by the superposition of energy backscattered from the sea surface and arriving from the same range as the sea floor return. Such systems require tailoring of the beam pattern to suppress surface reverberation (as in Gloria, which has only a 10^o vertical beam width). Beyond this, special signal processing techniques to reduce the effect might also be developed.

Side Looking Sonar

In addition to its shape, the sea floor has variable texture and related variations in acoustic scattering properties. These variations can be mapped in a number of ways, but primarily this is done with a variety of versions of side-scan or side-looking sonars.[8] The outputs of such systems are useful not only for displaying textural variability *per se* but for indicating the shapes and orientations of outcrops, scarps and the like and in searching for man-made objects--shipwrecks, debris dumped in the sea--and to delineate the effects of sea floor activities such as trawling, sea floor mining and waste disposal. In connection with a number of recently mandated NOAA responsibilities, this category of sea floor remote sensing systems may be the most important.

To take a specific example, there have been indications that legislation may be enacted which would establish the government's liability in case of loss of fishing gear because of uncharted obstacles on the sea floor. Side-looking sonars not only provide, if properly designed for the task, the best means for mapping the existence of such obstacles, they can also be employed in the verification process to determine whether trawl tracks actually intersect real existing obstacles and thus whether nets were lost through hangup on bottom irregularities or through equipment malfunction.

Most systems in this category are fairly simple dual channel systems using two separate long, thin transducers to project fan beams at right angles to the vehicle track to port and starboard. Time varied gain is used to keep the returns within the dynamic range of the display recorder as the backscattered energy comes in from increasing range after each ping. The most fundamental differences among the various systems in use are in their resolution (beam-width) effective range and operating depth. Most are towed, but a few, for shallow-water use, are hull mounted. The general nature of such systems is shown schematically in Figure 8.

Some examples of the types of sea floor "pictures" that these produce are shown in Figures 9, 10 and 11, all made in the deep ocean with our MPL system, again part of the deep tow instrument complex. The first shows a set of erosional furrows on the outer continental slope off the U.S. east coast.[9] These grooves are a meter or so deep and a couple of meters across, as shown in the accompanying photograph. The second is of a furrowed manganese nodule covered area in the Pacific,[10] showing the patchy nature of the coverage. The third shows sand dunes and streamers on a manganese pavement on the Carnegie Ridge.[11] Fourth (Fig. 12) is an ocean dumping example.[12] This is the debris patch resulting when a Liberty ship loaded with overage explosives was detonated while sinking in a disposal area at 3,000 m. depth on the Nitinat deep sea fan off the Washington coast. We were asked to find and document the sites of 5 such events in a twenty mile area and were successful in this. Our system, which operates to 7,000 m. depth at 125 kHz with a $3/4^{o}$ beamwidth, can detect a 20 m. piece of a ship at half a mile, giving a full nautical mile swath width for such objects and a resulting 1.5 square nautical mile per hour search rate.

At the other extreme in resolution and area coverage is the Gloria system.[13] This is a large side-looking sonar, developed and used by the Institute of Ocean Science in England. There have been several versions built, but all of them have in common the long range (order of 20 km.) and large, near surface towed body (8 m. long and 0.7 m. wide). Gloria is primarily useful in delineating the fabric of sea floor morphology. Figure 13 gives an example[14] of the type of coverage and detail which the system can achieve with its $2\frac{1}{2}^{\circ}$ beamwidth.

Side looking sonars have considerable room for development in two areas: improved coverage (in both area search rate and in resolution) and data processing, but both of these, in spite of substantial available technology, are hampered by lack of fundamental information. We will treat the two improvement areas and then discuss the underlying research requirements.

There is a traditional relationship between search rate and resolution for simple, side-looking systems which asserts $\dot{A} \approx cw$ where $\dot{A}$ is the area coverage rate, c the speed of sound in water and w the width of the system resolution cell. This is based on the fact that for simple systems such as those illustrated above, one must transmit one pulse for each lane equal in width to the resolution cell. If one then picks a maximum range, R, and a vehicle speed, v, the round trip travel time, $T = 2R/C$, must also be the time between transmissions, which in turn must equal the time for the sonar to advance the distance, w, or $T = w/v$. The average coverage is thus $\dot{A} = vR = \frac{wc}{2}$ for each side of the track.

Some years ago, however, it was noted that if the receiving transducer is partitioned into m elements which can be processed individually, it is possible to multiply the area coverage rate by m, giving the SLS equivalent of a multibeam sonar.[15] While this opens up new possibilities (in fact a demonstration version of such a sonar, Fig. 14, was built and operated briefly[16] in 1972), it has not been applied, largely because of other, more practical constraints.

Principal among these are the hydrodynamic restrictions on the speeds of deeply towed vehicles. Improved search rates must thus be achieved by increasing effective system ranges, either so that they will complement the low vehicle speeds or so that the transducer systems can be operated near the sea surface where higher speeds are practical. Longer ranges mean lower frequencies and thus longer wavelengths and resulting larger aperture requirements. For example, if one wants 10 m. resolution--a good number for mapping outcrops or sea floor debris and wrecks, and about the same as the deep tow system at 800 m. range--out to a range of even 2 km then the transducer must be about 200 wavelengths long. At 50 kHz this would require a 6 m long transducer, which would still have to be operated only about 200 m. off bottom. Such a system would be particularly useful in intermediate depth environments where towing speeds of up to 2 m/sec could be achieved, with area coverage of 30 km^2 per hour.

For the same resolution at Gloria ranges, operation, at most, at 10 kHz is required and, for 10 m. at 10 km the aperture would total 1000 wavelengths or 140 m. Since a real aperture of this size implies at least a large ship and investment in transducer hardware it seems logical to look toward implementing a multi-lane hybrid synthetic-real aperture system.[17]

Although there is substantial synthetic aperture radar experience in existence,[18] preliminary studies at Scripps (Cutrona at Vis Lab in collaboration with Lowenstein and Anderson at MPL) show that there would be substantial differences in approach for an underwater acoustic version. The processor can be much simpler, since the frequency range used is much lower than radar and the time available for computation on a real time basis is much larger. Moreover the radar community has not yet absorbed the multi-beam approach. The longer time to traverse the synthetic aperture, however, places more emphasis on the problem of measuring and correcting for the small scale irregularities in platform speed and orientation. It does appear, however, that a long range system capable of 10 m. resolution could be built.

The other area is in data processing to produce consistent, corrected images over large areas. At present a number of units exist which include on-line processing to rectify images by correcting for slant range and including the input of ship speed so that one can scale features directly from the display. Beyond that the next step is processing to correct for survey track curvature (particularly a problem when the vehicle is towed at several thousand meters depth). This is being done now at Marine Physical Laboratory among others.

A more interesting aspect arises out of the ability to digitize and handle the outputs in a quantitative manner. One then opens up the possibility of generating statistical measures of bottom roughness, for example, which, if used in multi-frequency systems might allow one to assess the nature of the sea floor texture and determine such things as variations of manganese nodule sizes and densities of coverage.

Certain basic information on which to design new side looking sonars and to capitalize on quantitative analyses of returns is lacking, however. In both contexts there is a real need to know the back-scattering properties of typical deep sea assemblages. While some have proposed modelling experiments, it seems most logical simply to make direct measurements from a system such as the deep tow, which would include complementary photography and bottom sampling.

A second gap in knowledge, particularly important as one seeks to improve system range, is the lack of good information as to the variation of sound absorption with pressure (depth) in the sea. This has a marked effect on design since usually one is limited by the loss factor rather than spreading loss.

Shallow Penetration Sub-bottom Profilers

Detailed knowledge of the structure of the sea floor to depths of tens of meters is required in a number of applied situations--selection and monitoring of ocean dump sites, particularly when burial is involved; prediction of stability of local geological formations in whose vicinity resource utilization (mining, oil and gas production and distribution) is likely to take place. High resolution systems can aid in delineating the character of faults and slumps as well as locating potential points of disturbance from gas pockets and determining whether obstructions seen on side-looking sonar have associated deeper underlying aspects.

For many purposes existing hull mounted sounders operating in the low kilohertz range, 3.5 kHz primarily, provide adequate coverage. As an aside, the existence of 3.5 kHz as the most common frequency for such systems attests to the Navy's influence since originally the concept was to learn about bottom reflectivity in relation to the first of the high power, low frequency sonars, for which this was the operating frequency. The hull mounted systems suffer, however, from the same difficulty as the echo sounders--typically their footprint is at least 20% of the water depth, which means in deep ocean dumping or manganese nodule mining a patch 1 km across.

Given that the kinds of applications which have been visualized tend to be of a local site survey nature, the use of deeply towed sonars to provide improved lateral resolution when necessary is satisfactory, although a number of improvements and advances can be made beyond today's operating systems.

Some examples of the types of features which one sees with a deeply towed system having lateral resolution of 10 to 50 meters, depending on its mode of operation, are shown in figures 15 through 17. Figure 15 shows a region in which a fairly transparent, featureless sediment blanket overlies a pre-existing structure having greater relief.[10] Indications here are that the present sea floor material has little structural strength and has probably been deposited fairly rapidly. Not infrequently very sharp changes in the nature of the reflectors occur as in Figure 16.[19,20]

Very often if one cores sediments in which the reflectors are spaced fairly well apart, as in Figure 15, one easily observes changes in sediment properties, or major discontinuities such as layers of chert or basement rock. When finer scale layering is encountered, this is not always the case. Figure 17 is taken from Mayer's thesis.[20,21] Here we profiled at 4 kHz and then took two cores, positioned within 5 m. laterally from the deep tow vehicle track at the points shown on the slide. Both were about 10 m. long and thus penetrated the layered structure shown in the expanded display. No obvious discontinuities of sediment properties were observable which could constitute reflectors of this strength. Mayer, however, made, with assistance from Hamilton at Navy Ocean Systems Center, a very detailed analysis of the cores, producing among other things a profile of acoustic impedance variability or effective relectivity for normal incidence sound. He then, by computer, created the convolution of the original pulse form with this reflection profile and achieved remarkable agreement with the in situ acoustic record. This is summarized in Figure 18. Clearly the acoustic output represents an interference effect in which the characteristic wavelength of 4 kHz accentuates the return from small scale variations in sediment properties which that dimension matches to give constructive interference.

We subsequently added to our 4 kHz system an option to switch to 6 kHz. This has not been widely used, but in one instance in a turbidite sediment area near the East Pacific Rise off the Mexican coast we did test it with the dramatic results shown in Figure 19.[22] While the changes of overall intensity relate to system characteristics and differential sound absorption the change of pattern can only be due to the fact that different locales in the graded bedding sequence match the different acoustic wavelengths of the two types of pulses used.

While the fact that interference effects could be important were not surprising, particularly from the somewhat earlier conclusions of Tyce,[19] the fact that they could be related to the detailed nature of the carbonate sediments as well as they were had not been fully foreseen. The implications of this work, then, are two-fold.[21] First, if one is interested in studying deposition and dissolution processes in carbonate sediments, or similar details in other finely layered media, one should be able to devise a multiple frequency subbottom penetration system from which the acoustic reflectivity profile can be reconstructed. In this case there are climatic implications. The acoustic impedance variations were determined to be primarily correlated with changes in saturated bulk density and in turn with percent calcium carbonate. These variations are ultimately caused by climate changes, thus the acoustic signal offers the possibility of obtaining paleo-oceanographic data.

In relation to the applied problems noted above, however, one can distinguish between the existence of a reflector arising from a major discontinuity (e.g., layer of buried manganese nodules) and one arising through interference effects by use of a simple two frequency system such as the 4/6 kHz choice illustrated. The strong discontinuity will be a good reflector in both representations.

In addition to the interference question there is the one of lateral continuity of layering. If the sonar footprint is 10 m. or more across then the presence of a few reflecting points in 100 sq. m. will give rise to an acoustic reflector, which again may not be seen in a core or may not be relevant in a practical problem. For this reason, as well as to be able to define the existence of sediment patches in irregular terrain, where they are easily confused with side-echoes, it is desirable to have narrower beams and higher resolution. This can be approached in three ways. First by going to a narrower 4 kHz beam. An apparently practical means for achieving this within the small dimensions of deeply operating vehicles is to use high transmit levels at relatively high frequencies and rely on the non-linear acoustic effects in the water to produce a narrow 4 kHz beam ("parametric sonar"). The second approach would be to go to a much higher frequency. This would reduce the depth of penetration, since in most sedimentary materials the attenuation per wavelength remains about constant. If the loss of penetration is not a problem (for example, if one's interest is in the first 10 m. rather than 100) then this approach yields the further advantage of better resolution in depth as well.

The ultimate approach to resolution in subbottom imaging could be developed and used in connection with buried objects or particularly interesting localized structures. This would involve essentially a two dimensional synthetic aperture. A sea floor vehicle such as RUM could move a transducer in small increments over a substantial area, transmitting identically reproducible pulses, receiving and recording and constructing what the optically oriented community would call a hologram after the fact to image the volume below.

Acoustic Transponders

Acoustic transponder technology[23,24] has grown to the point at which it plays a major role in most fine scale sea floor research and development activity. Not only are transponders used as the navigation bases for surveys such as those from which the deep tow illustrations in this paper were taken, they also are used in relay mode[25] to locate the sampling devices (corers, heat flow probes, cameras, etc.) and observing vehicles (submersibles) which provide the ground truth essential to the full use of ocean acoustic remote sensing.

The state of the art is such that local positioning to within a few meters can be achieved for near bottom, deep water systems to ranges of 5 to 10 km. from the units in use. This was the case, for example, in the carbonate area survey in which tight correlation between survey track and piston coring was essential and achieved to within about 3 m. Transponder deployment and recovery has also become a fairly straightforward matter and loss rates among careful operators are about 5%.

These capabilities are ripe for expansion in two directions. First is the extension of coverage range per transponder. The logistic requirements for surveys of areas of the order of 10 to 20 km. in extent are not extreme, but if mid-frequency SLS systems are to be used effectively, for example in manganese nodule resource assessment, much larger areas should be sampled and the ability to increase the coverage of individual units should be developed. This is more a matter for system consideration than for individual transponder development. Today's limitations arise because transponders are moored relatively near the sea floor and thus their ranges are limited by topographic blockage, or even over the flat sea floor by shadow zones created by upward refraction of sound in deep water[24] (Fig. 20). Users are unwilling to moor their units a thousand meters or so above the sea floor because of loss of position accuracy. The loss occurs primarily because of the difficulty of holding the transponder in place to within a few meters at such elevations. While more complicated moorings could be devised to do this a preferable method is to let the units wander slowly (usually with tidal periods) and provide them with a capability to interrogate each other under command from the survey vehicle to make direct measurements of the various baselines. Transponders with this capability (essentially relay transponders) have been devised in other contexts and should be developed, along with the necessary computing algorithms for readjusting network coordinates and taking into account the vertical variations of sound speed over the depth regime involved.

A second aspect of range limitation occurs in the operation of vehicles close to the bottom in very rough terrain. Here the use of a relay ten to a hundred meters or so above the vehicle can provide the solution.

The other area for system improvement appears in the geodetic (and related geological) context in which one desires to document gradual changes of sea floor geometry. This could be in coastal or slope areas where large scale creeping slumping may occur and in the vicinity of ocean spreading centers and transorm faults. These can be documented using networks of transponders and appropriate trilateration approaches. Transponder designs have been formulated and bench tested which can control the response delay times to within a microsecond or better if necessary,[26] thus eliminating this problem from contributing to uncertainty. Similarly it seems feasible to build sound velocity meters for use in survey areas to give reliable values of speed of sound to a part in 10^5 (about one cm/sec).[27] With these two capabilities it becomes possible to resolve motions of a few cm. over distances as great as a few km., given careful design of the overall experiment and related computational methods. This would make it feasible to measure spreading rates directly at intermediate and fast spreading centers. In such situations the full rate is from 5 to 20 cm. per year and the region over which this builds up ranges from 2 to 10 km.[28] In this context, then, acoustic transponder techniques can become in themselves acoustic remote sensing instruments, providing measurements of geodynamic effects as they occur at the sea floor.

Conclusions

Ocean Acoustic Remote Sensing of the sea floor is now being done in a variety of ways that are relevant to NOAA missions. Opportunities exist to extend these in ways that are specific to such missions and would clearly improve NOAA's capabilities.

For topographic mapping the present approach of bringing multibeam swath sounders into action is a very good one. The systems now available for purchase, however, represent technology mostly over 10 years old. Substantial improvements could be made in resolution through use of larger arrays and modern signal processing approaches, particularly to provide multiple ping capability for redundancy. Causes of performance degradation due to weather and related ship motion should be investigated. Is the problem primarily due to intensity loss during transmission through bubbles, noise from them or distortion of the returning wave front which would degrade beamforming? If these answers were known, the motion of ships and the sweep-by of bubble clouds could be sensed and pulse timing adjusted to minimize these effects with resulting ability to increase ship operating speeds.

For improving charting obstacles in shallow water (10-200 m), side looking transducers and associated signal processing to reduce the effects of energy backscattered from the sea surface should be developed. Wide swath topographic mapping in shallow water can be achieved by combining such surface reverberation rejection techniques with phase difference measurement to produce bottom profiles over swath angles up to 160^{o}.

For resource assessment and mapping sea floor obstructions consideration should be given to use of longer-range side looking sonars operated both at intermediate frequencies (multiple frequencies for resources--e.g., manganese nodules, sand and gravel) and hundreds of meters off bottom and with less resolution but more rapid area coverage from near surface. Possibility of combining multi-element receiving systems with synthetic aperture techniques should also be investigated at least to the detailed design level. Existing fine-scale capabilities should be used for monitoring effects of resource exploitation.

In the general side looking sonar context there are fundamental ocean properties which must be documented if optimal designs for any new systems for deep water use are to be produced. Sea floor backscattering coefficients as a function of frequency, grazing angle and material should be determined in situ and dependence of sound absorption on pressure as a function of frequency must also be measured.

Sub-bottom information on a fine scale is particularly essential in the context of sea floor waste disposal and resource exploitation. High resolution near bottom systems with narrow beamwidth should be developed as well as means for using sea floor work vehicles to produce detailed 3-D acoustic views of the interior of limited volumes of the sea floor.

Geodesy can be extended into the realm of documenting time-dependent effects in the coastal and continental slope zones as well as at sea floor spreading centers and transform faults through use of new opportunities emerging in precision acoustic transponder development.

Resource assessment and sea floor obstruction mapping could both benefit from the development of transponder systems providing significantly larger area coverage per transponder. Approaches to achieve such advances are understood and could be developed on a reasonable time scale relative to user needs.

Finally, acoustic remote sensing of the sea floor in the ways discussed above and others not treated in this paper will be most fruitful when applied to complement other observational and sampling techniques to achieve the desired particular goal. Acoustic techniques may never be able to provide unique answers about the nature of the ocean bottom, but they offer the most comprehensive means for interpolating between widely scattered ground truth observations and providing a context for other types of remote sensing data.

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TABLE I

Frequency	12 kHz
Pulse width	7 ms
Keying interval:	
Manual	1 to 15 sec (1-sec increments)
Automatic	Controlled by depth tracking of echo processor
Maximum sounding depth	11,000 meters
Bottom width coverage	42-⅔° (80% of vertical depth)
Transmitting array:	
Number of projectors	20
Beam dimensions	54° x 2-⅔°
Receiving array:	
Number of hydrophones	40
Beam dimensions	20° x 2-⅔°
Formed beams:	
Beam dimensions	2-⅔° x 2-⅔°
Beam spacing	2-⅔°

- Real time digital contour plot on 11″ continuous strip chart.
- Crosstrack profile display on CRT for each ping.
- Numeric display of vertical depth beneath the ship for each ping.
- Vertical beam analog output on graphic recorder.
- Digital data outputs: time of day, heading, and up to 16 pairs of (X, Z) sounding coordinates in meters for each ping cycle.

- Nova 800 computer.
- 3 Magnetic tape cassette drives.
- Full floating and fixed point hardware.
- 32K Memory.
- 16 receiving channels with computer calibrated gain.
- On-line automatic fault detection.

Roll	±20°
Pitch	±10°
Speed	15 knots
Sea state	4

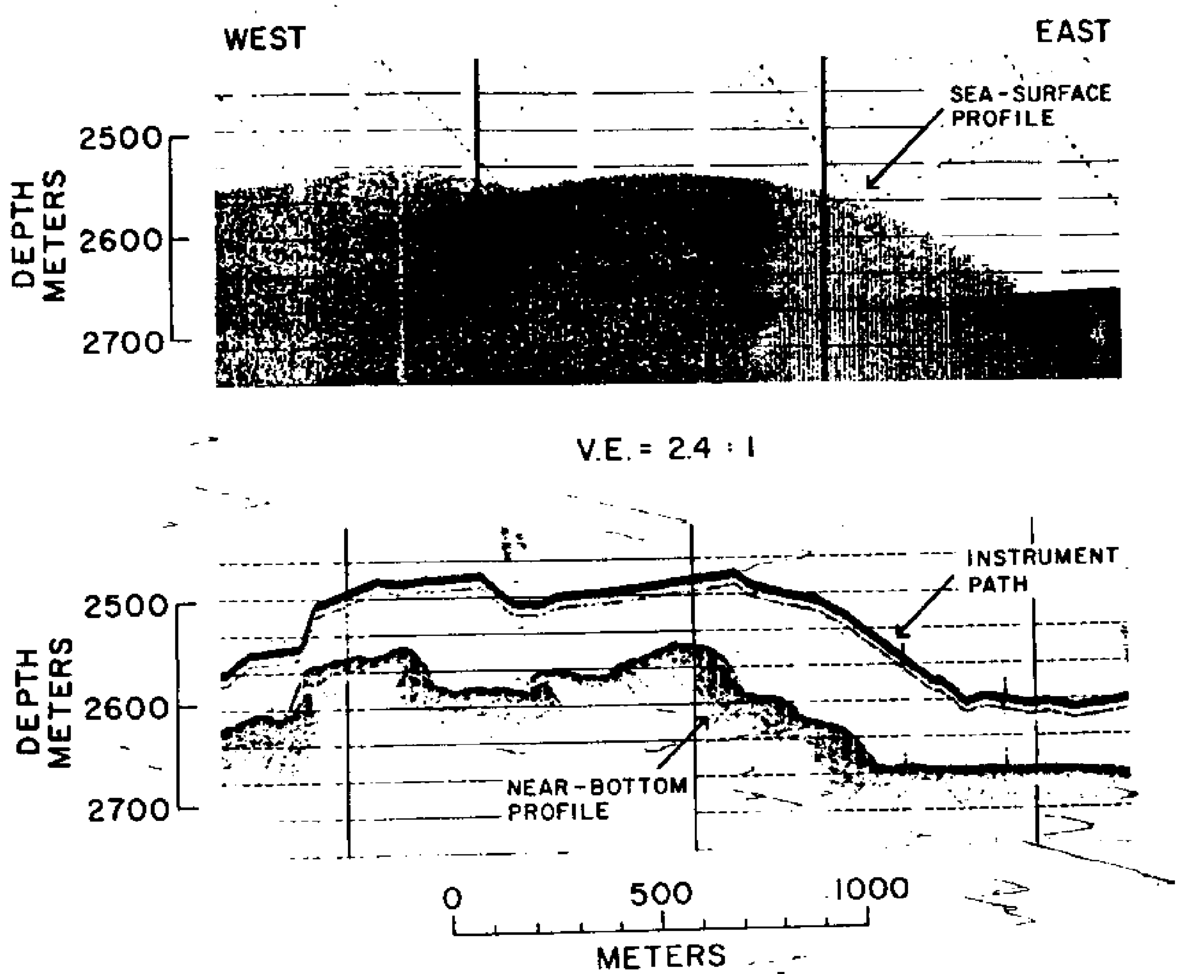

WEST
EAST
SEA-SURFACE PROFILE
DEPTH METERS
2500
2600
2700
V.E. = 2.4 : 1
INSTRUMENT PATH
NEAR-BOTTOM PROFILE
0
500
1000
METERS

Figure 1

DEEP TOW INSTRUMENTATION SYSTEM

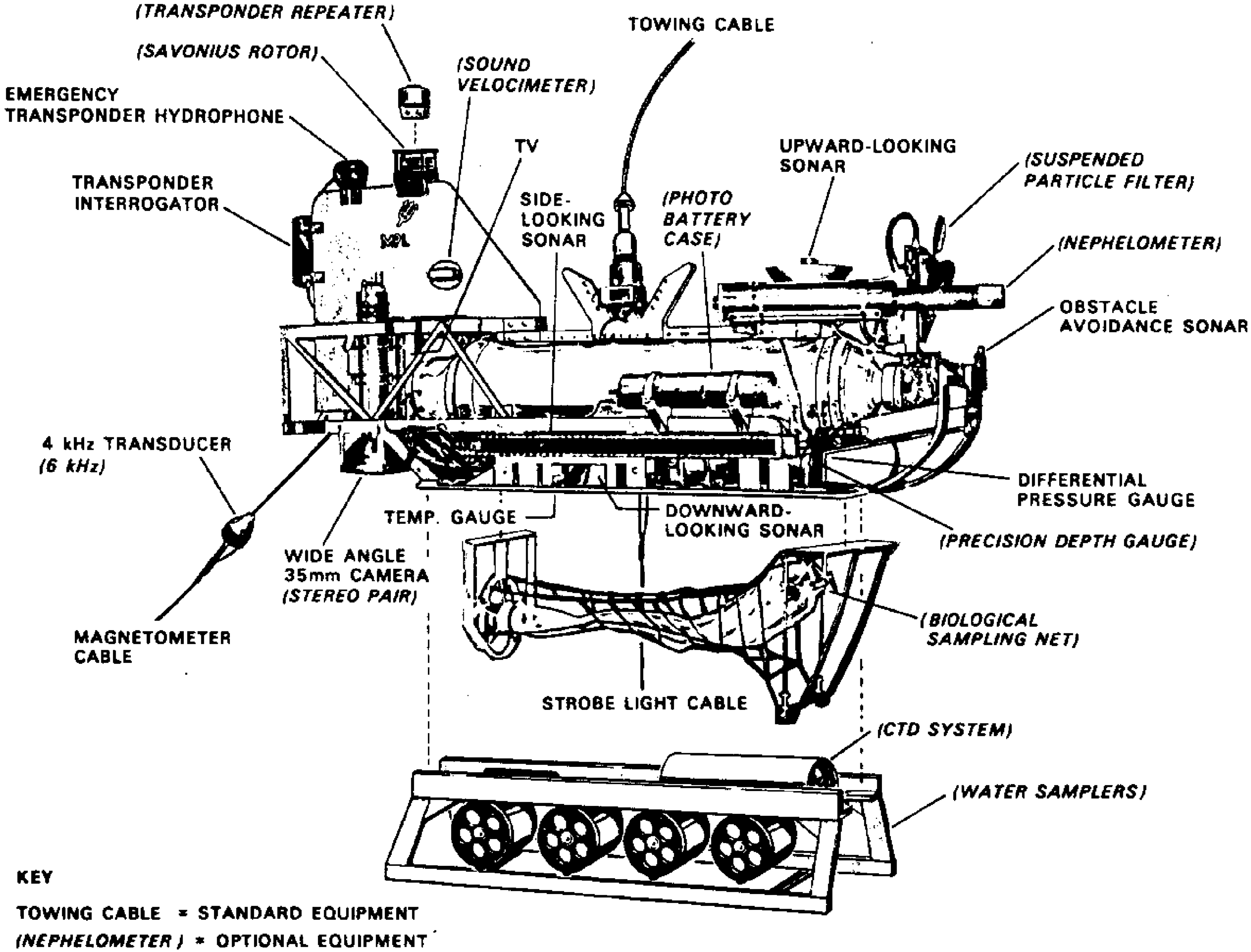


Figure 2

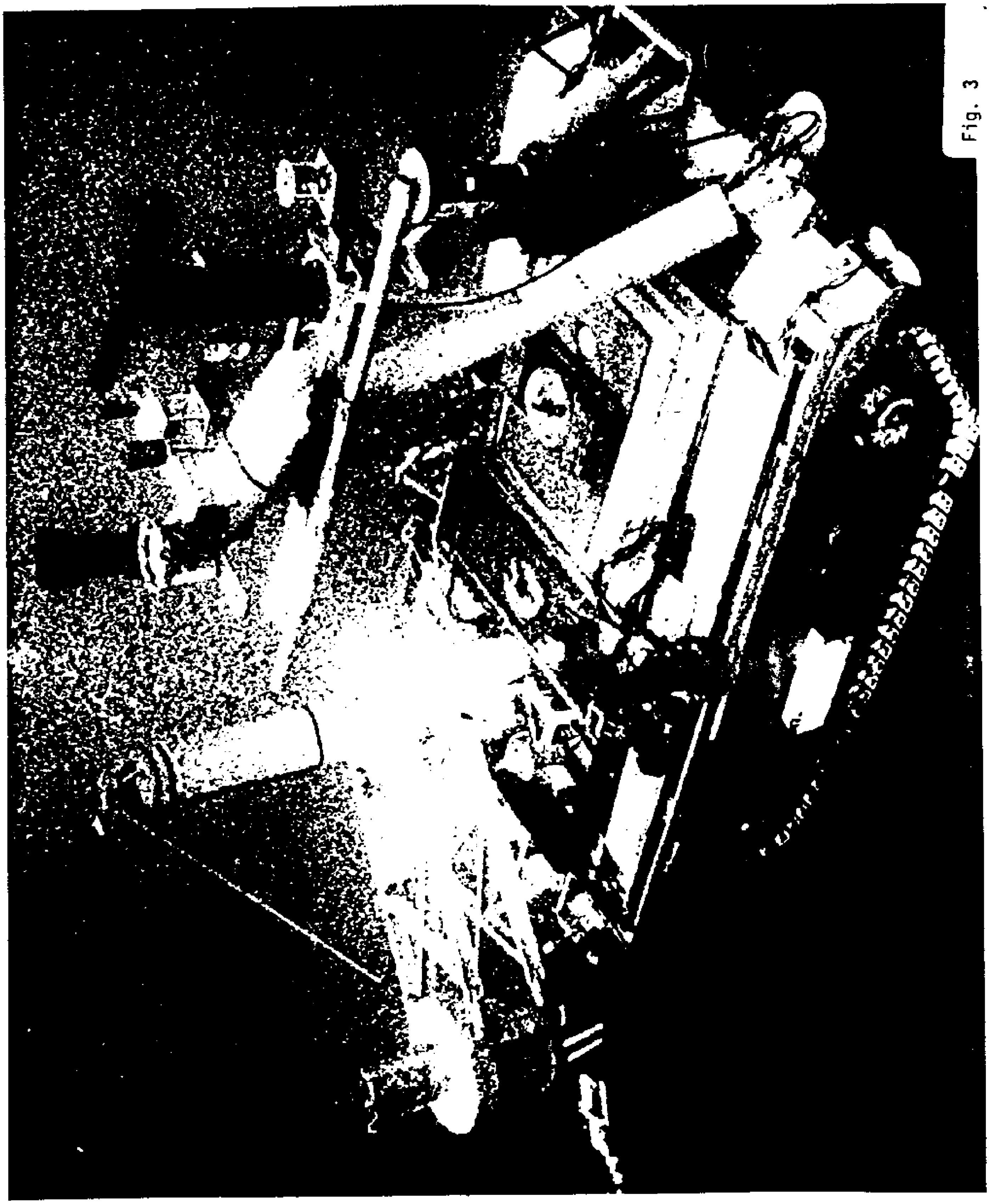
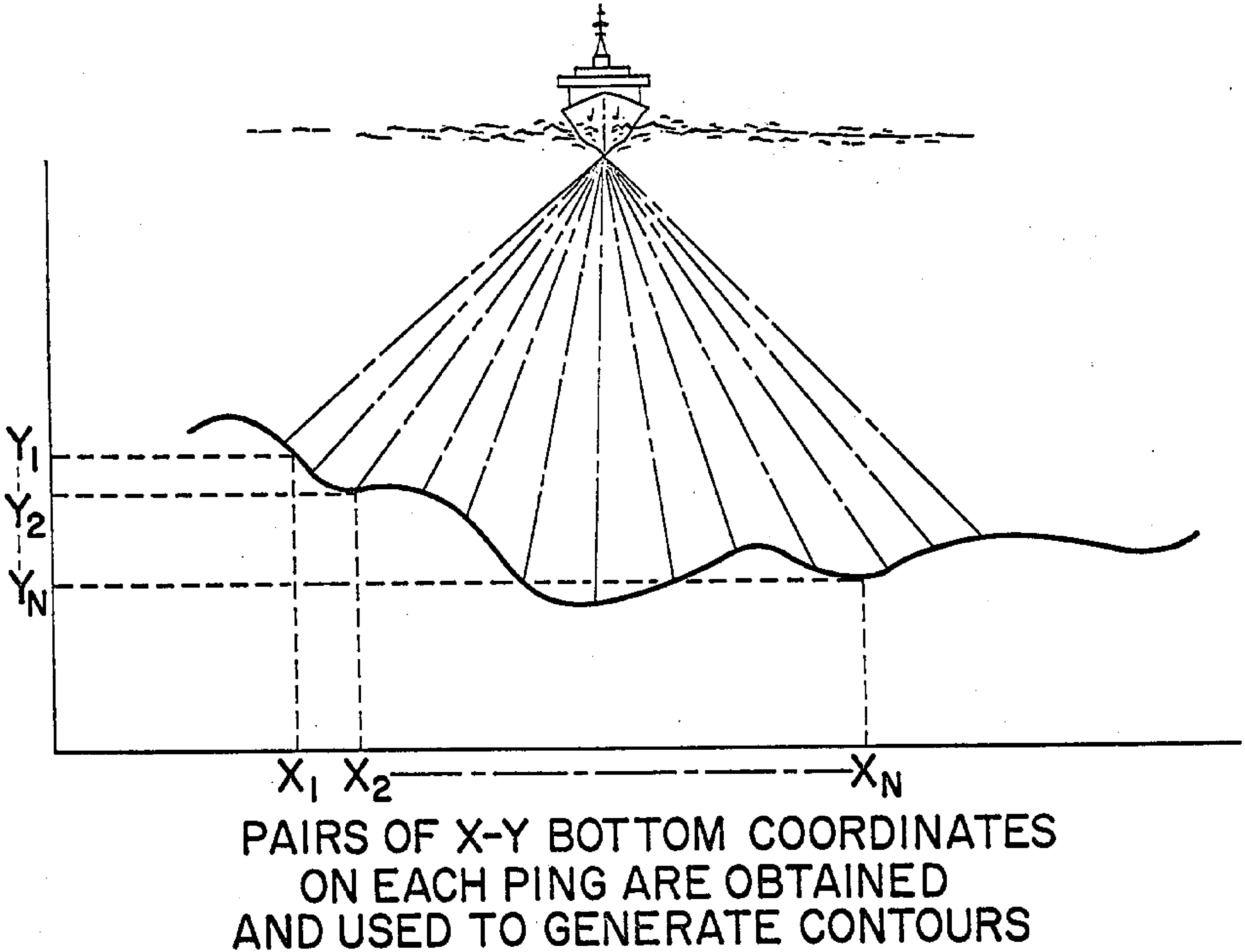


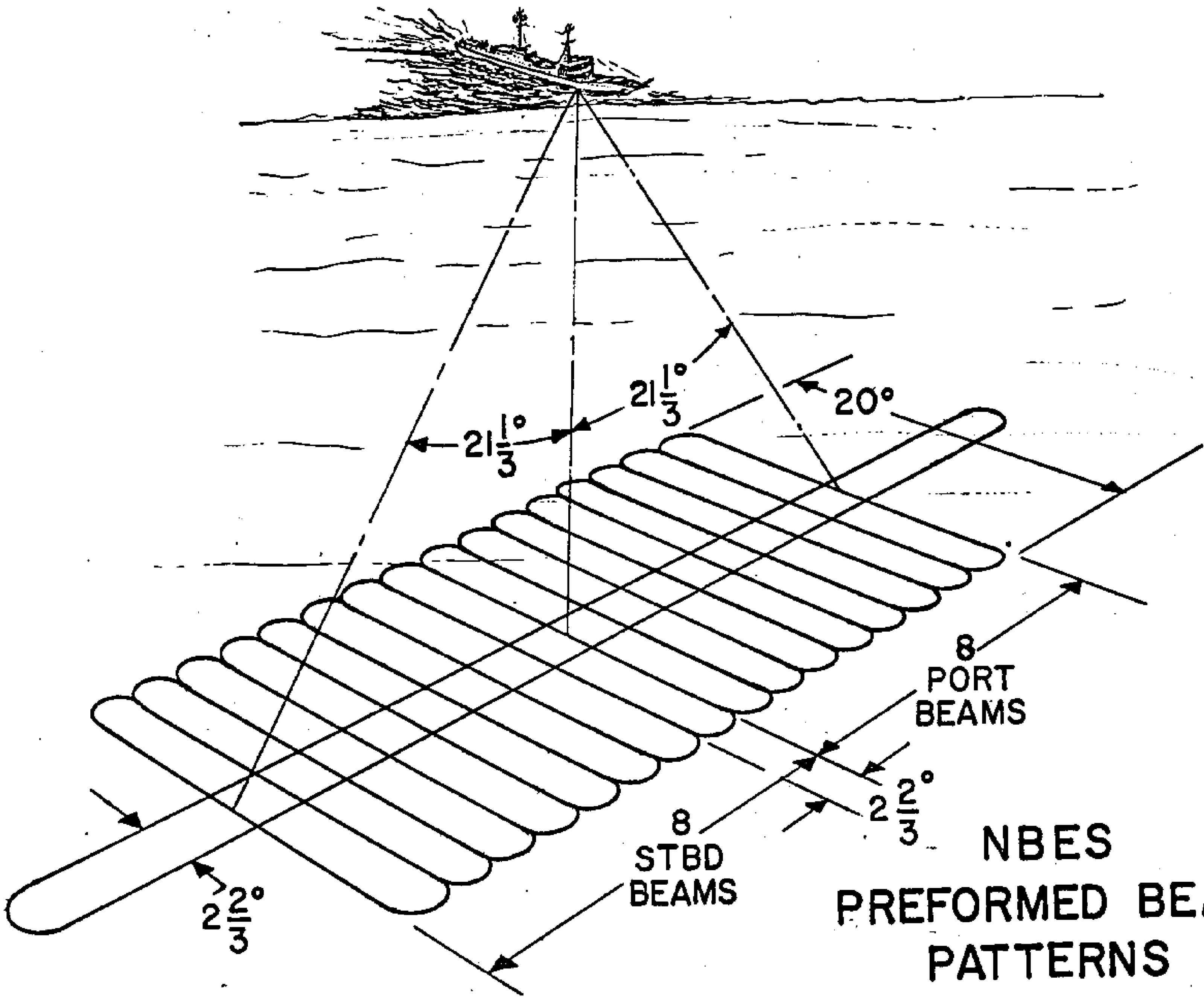
Fig. 3



Y_1
Y_2
Y_N
X_1
X_2
X_N
PAIRS OF X-Y BOTTOM COORDINATES
ON EACH PING ARE OBTAINED
AND USED TO GENERATE CONTOURS

Figure 4

Figure 5



NBES
PREFORMED BEAM
PATTERNS

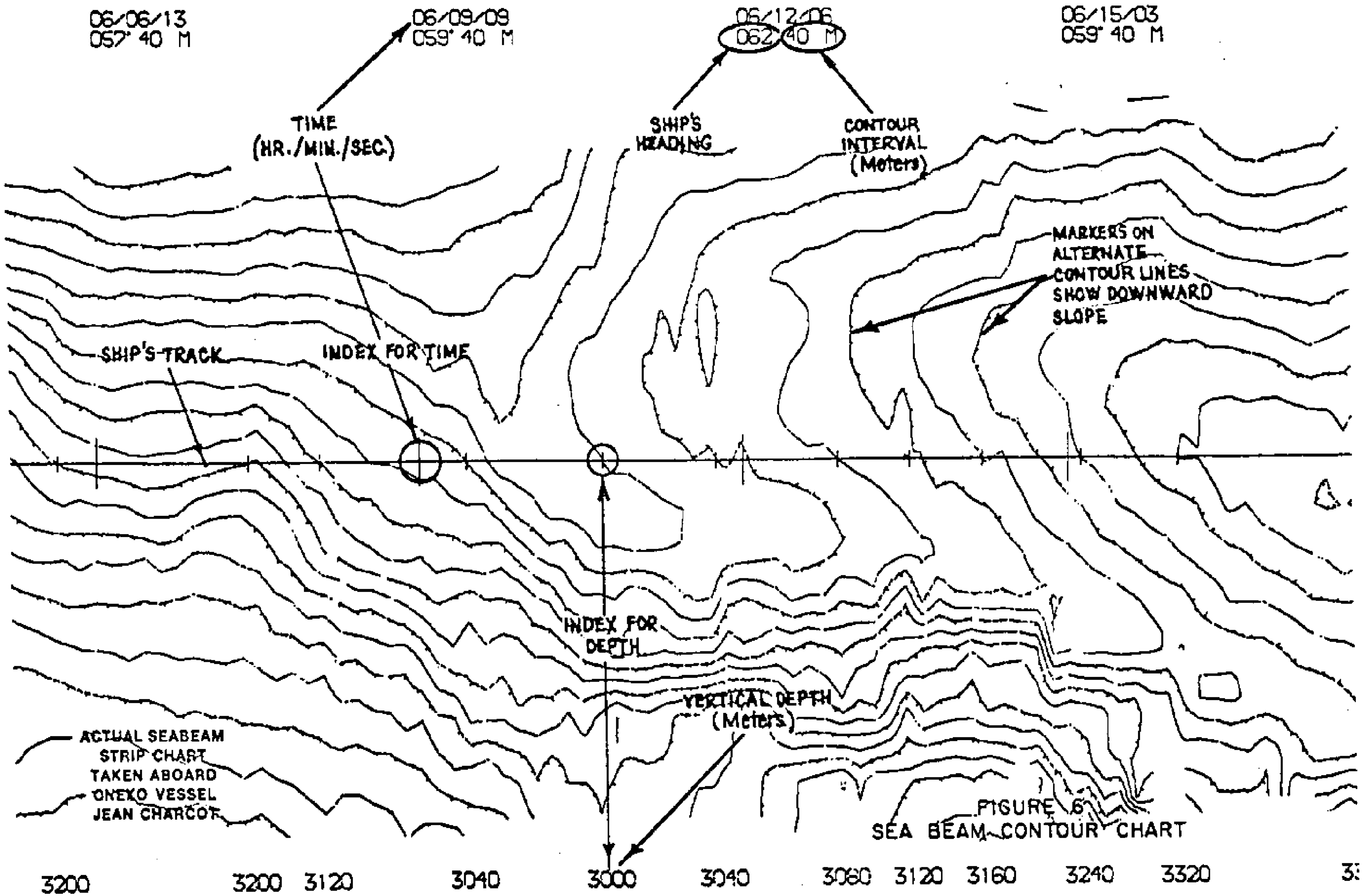
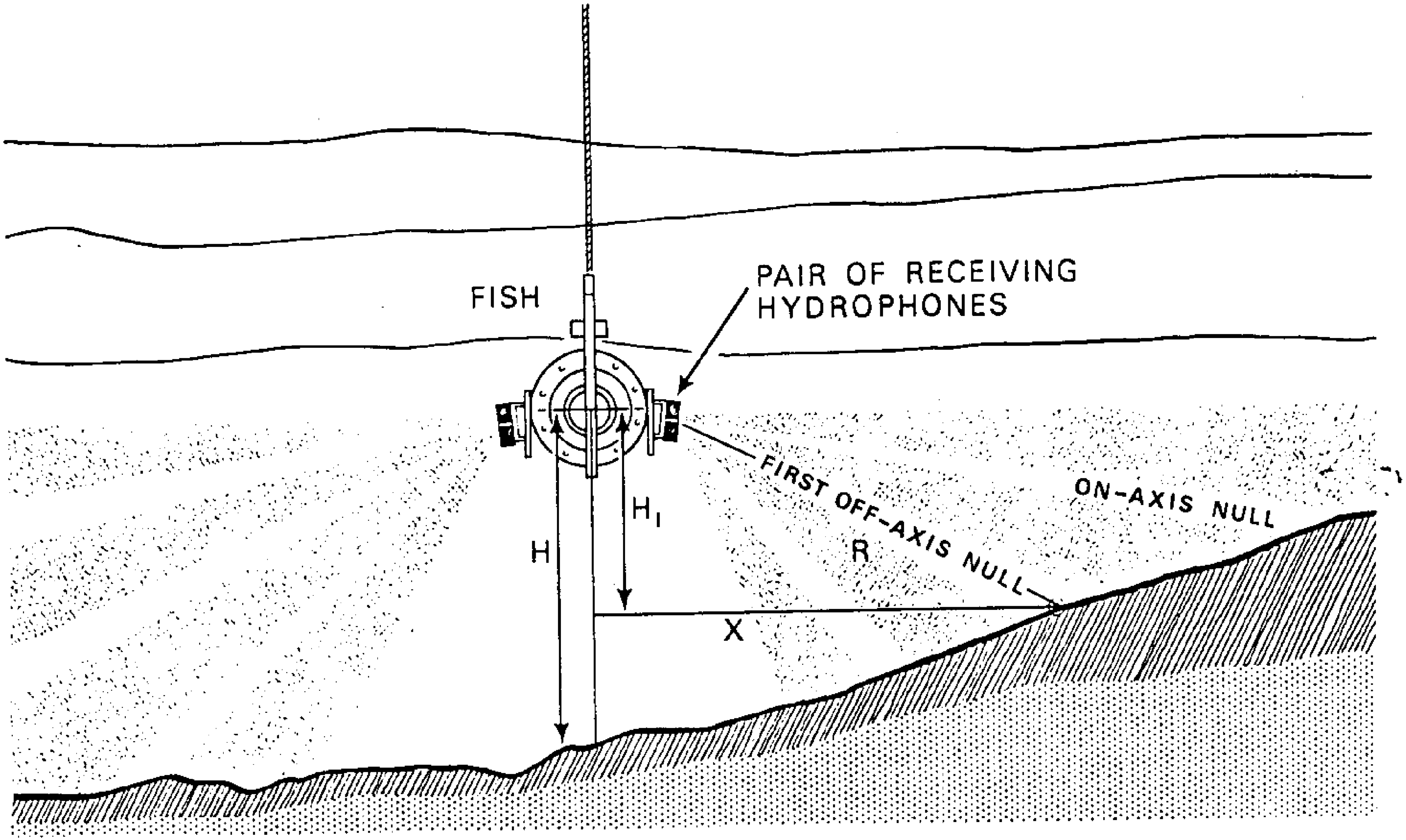

06/06/13
057° 40 M
06/09/08
059° 40 M
06/12/06
062 40 M
06/15/03
059° 40 M
TIME
(HR./MIN./SEC.)
SHIP'S
HEADING
CONTOUR
INTERVAL
(Meters)
MARKERS ON
ALTERNATE
CONTOUR LINES
SHOW DOWNWARD
SLOPE
SHIP'S TRACK
INDEX FOR TIME
INDEX FOR
DEPTH
VERTICAL DEPTH
(Meters)
ACTUAL SEABEAM
STRIP CHART
TAKEN ABOARD
ONEKO VESSEL
JEAN CHARCOT
FIGURE 6
SEA BEAM CONTOUR CHART
3200
3200
3120
3040
3000
3040
3080
3120
3160
3240
3320

Figure 6



INTERFERENCE METHOD FOR
OFF-TRACK DEPTH DETERMINATION

Figure 7

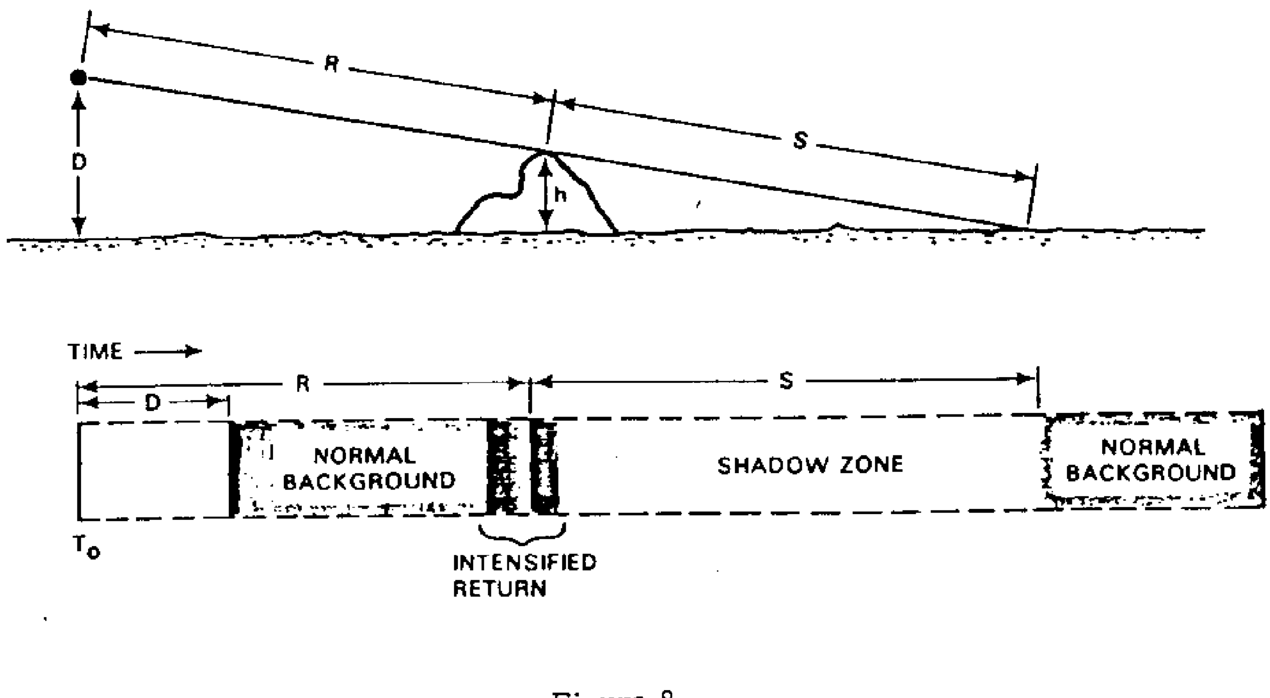

R
S
D
h
TIME
R
S
D
NORMAL BACKGROUND
SHADOW ZONE
NORMAL BACKGROUND
T_o
INTENSIFIED RETURN

Figure 8

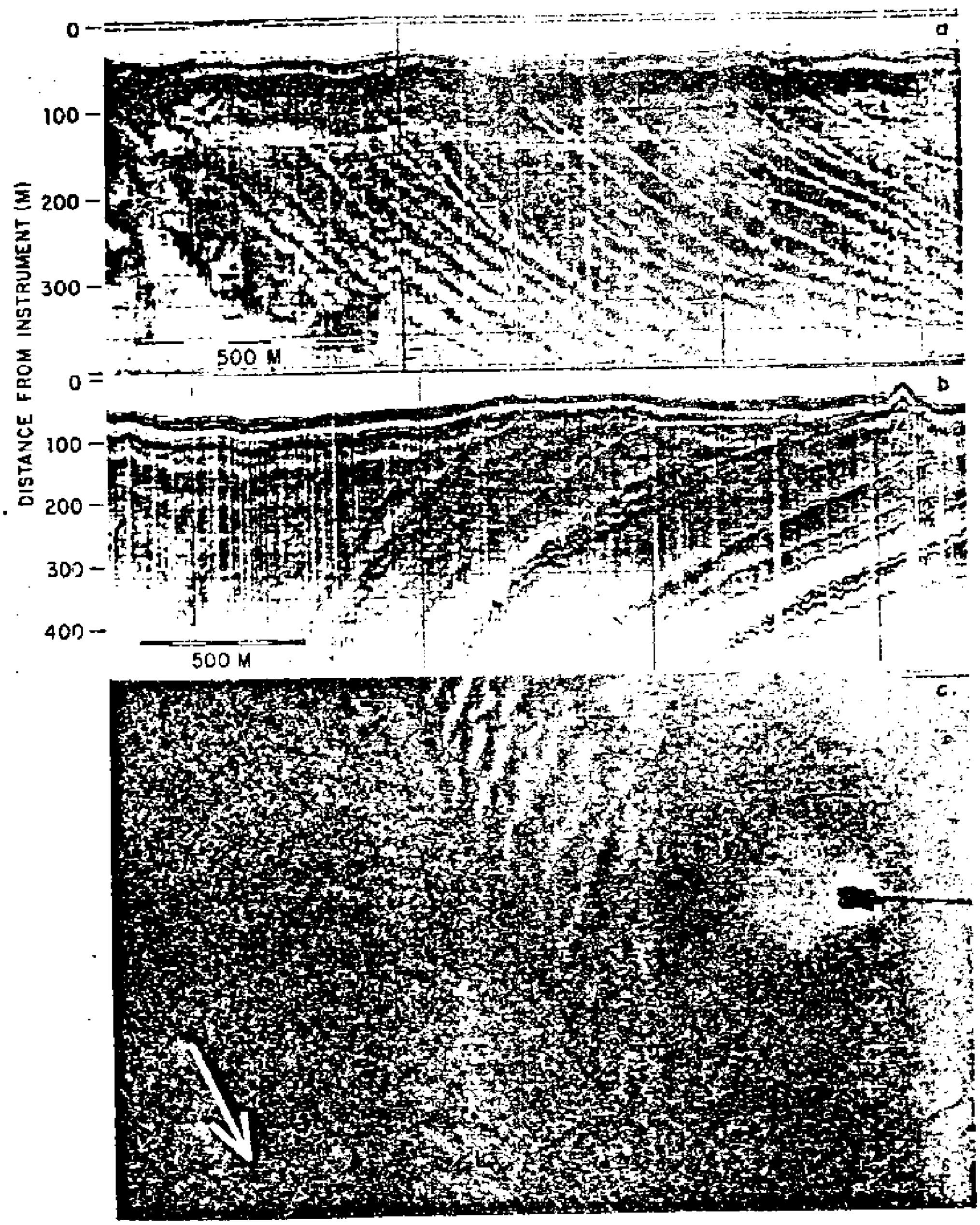


Figure [illegible]

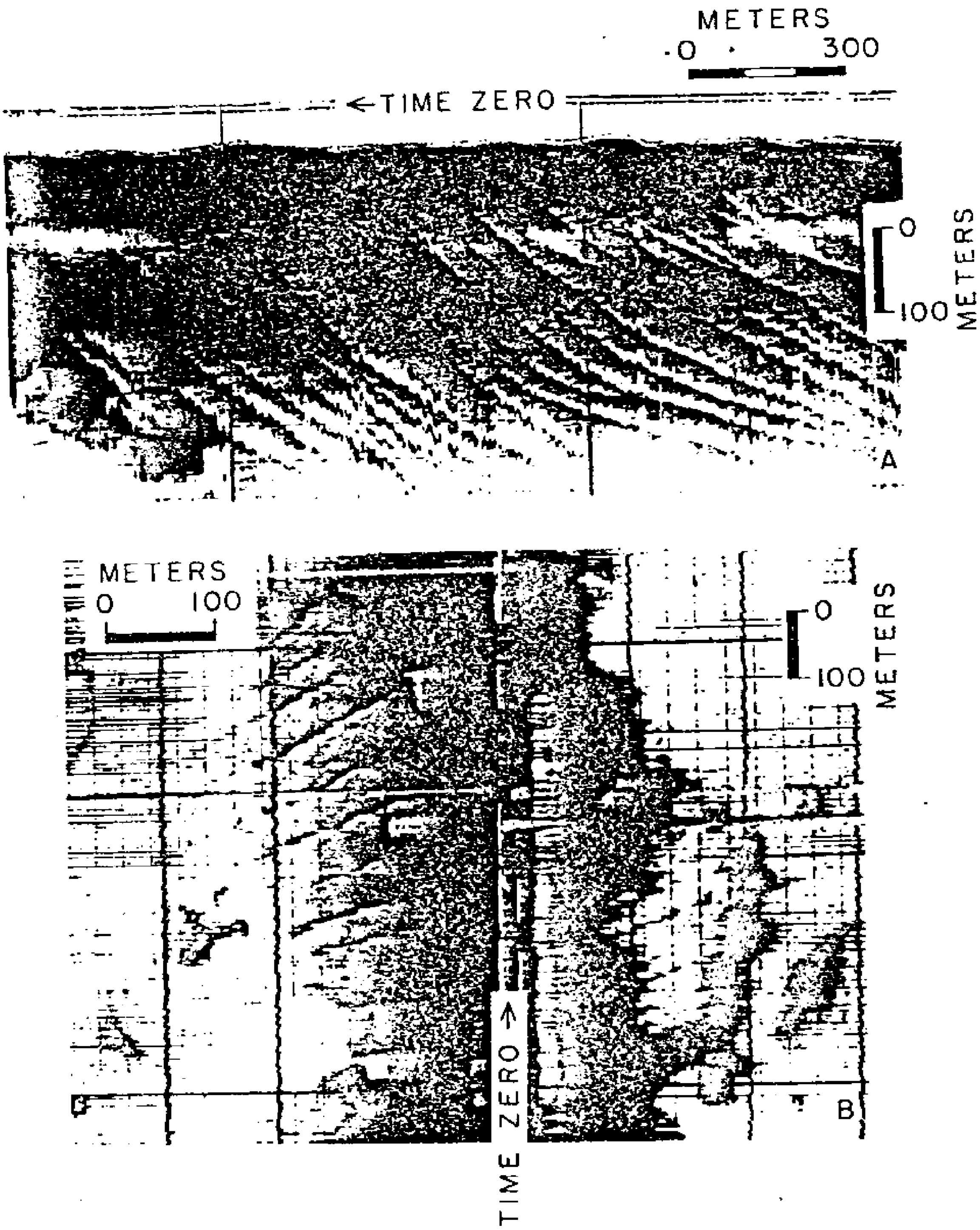
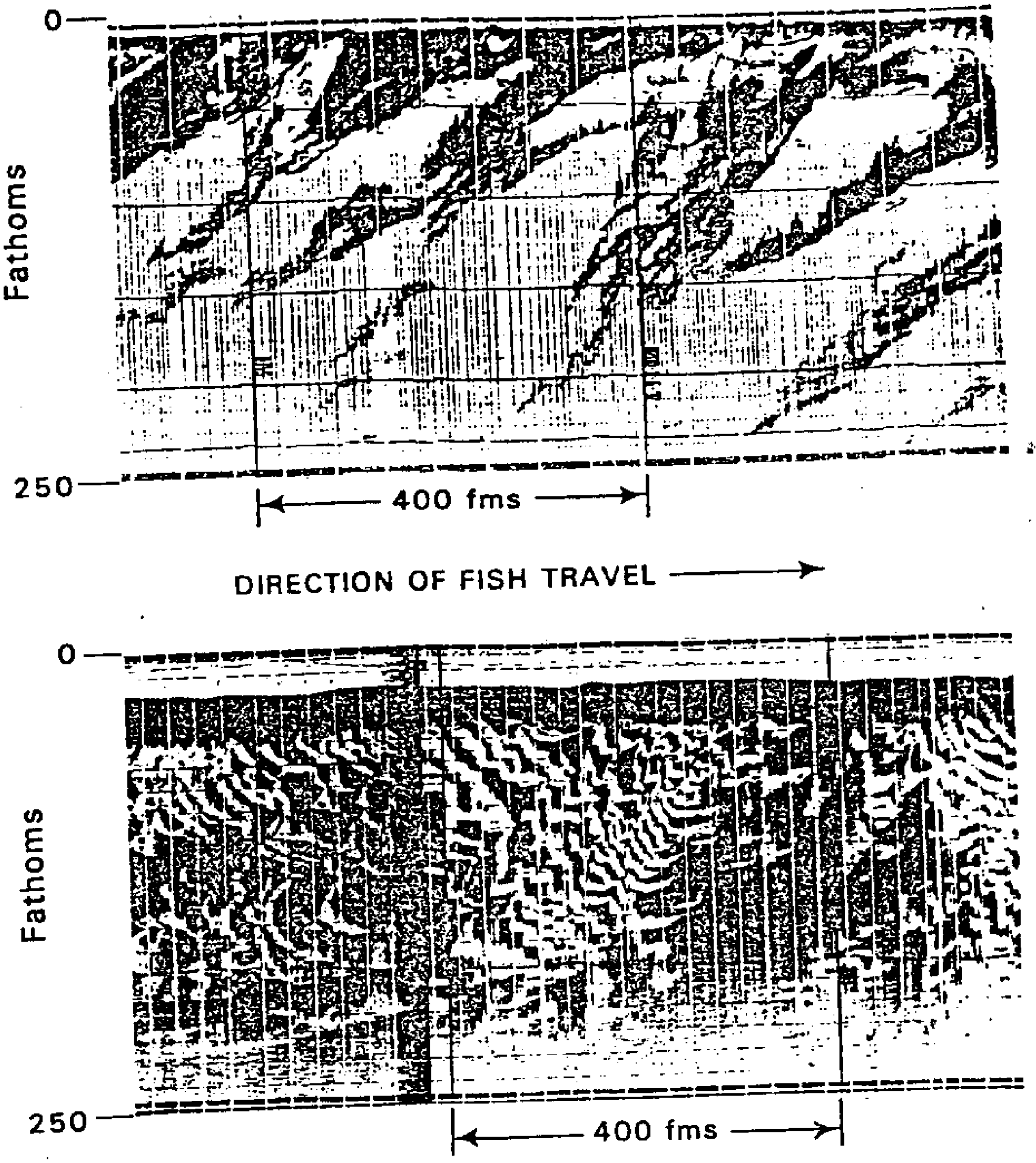

METERS
0
300
← TIME ZERO
0
100
METERS
A
METERS
0
100
0
100
METERS
TIME ZERO →
B

Figure 10



0
Fathoms
250
400 fms
DIRECTION OF FISH TRAVEL
0
Fathoms
250
400 fms

Figure 11

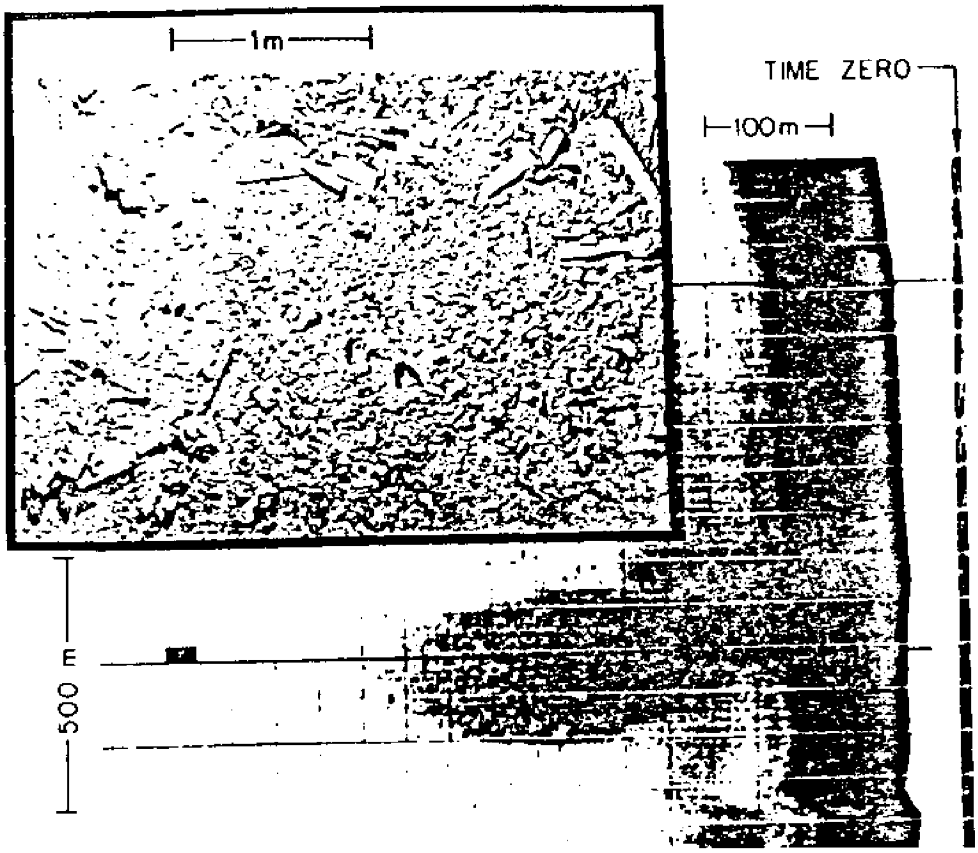


Figure 12

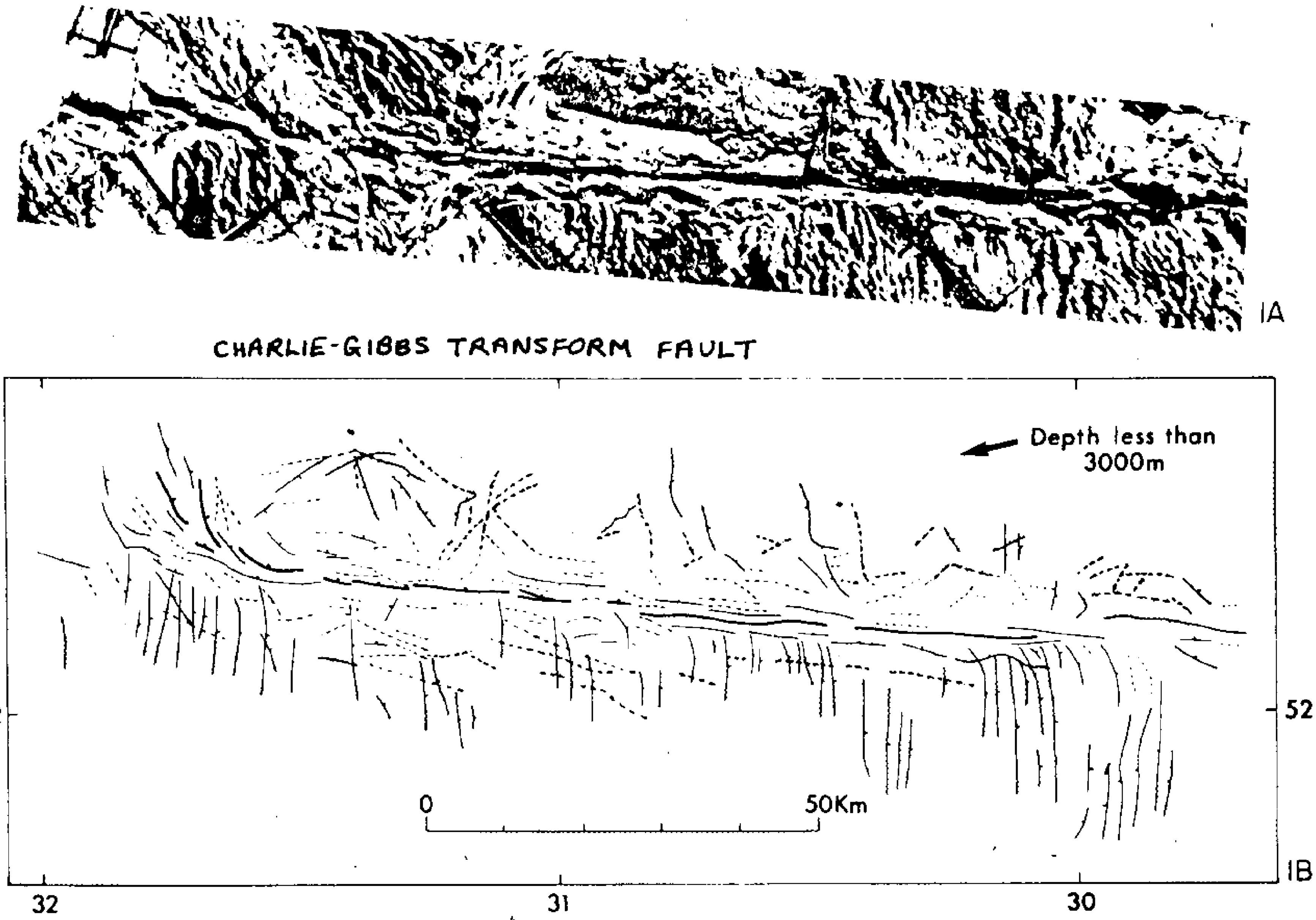

IA
CHARLIE-GIBBS TRANSFORM FAULT
Depth less than 3000m
0
50Km
52
52
IB
32
31
30

Figure 13

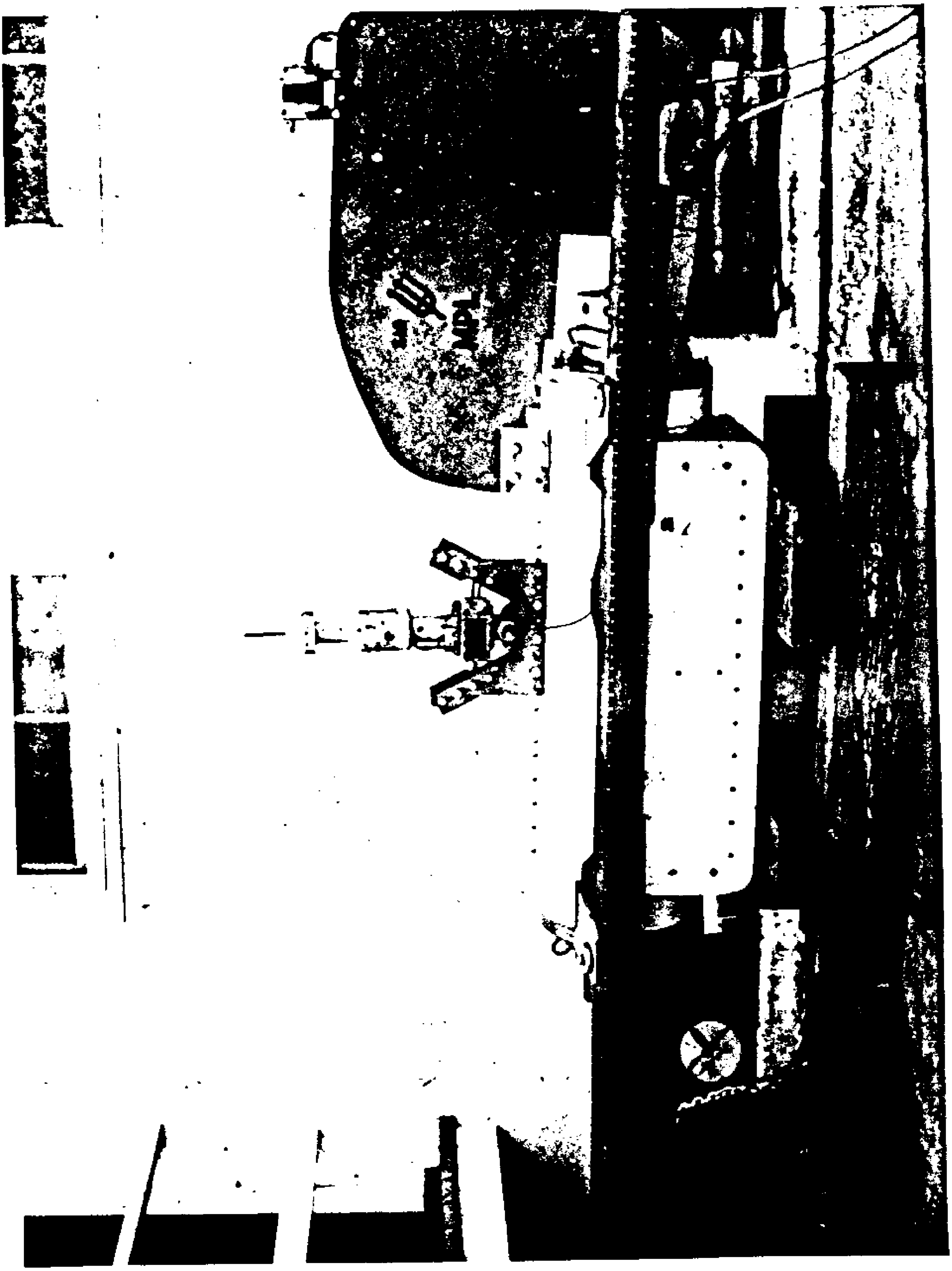


Figure 14

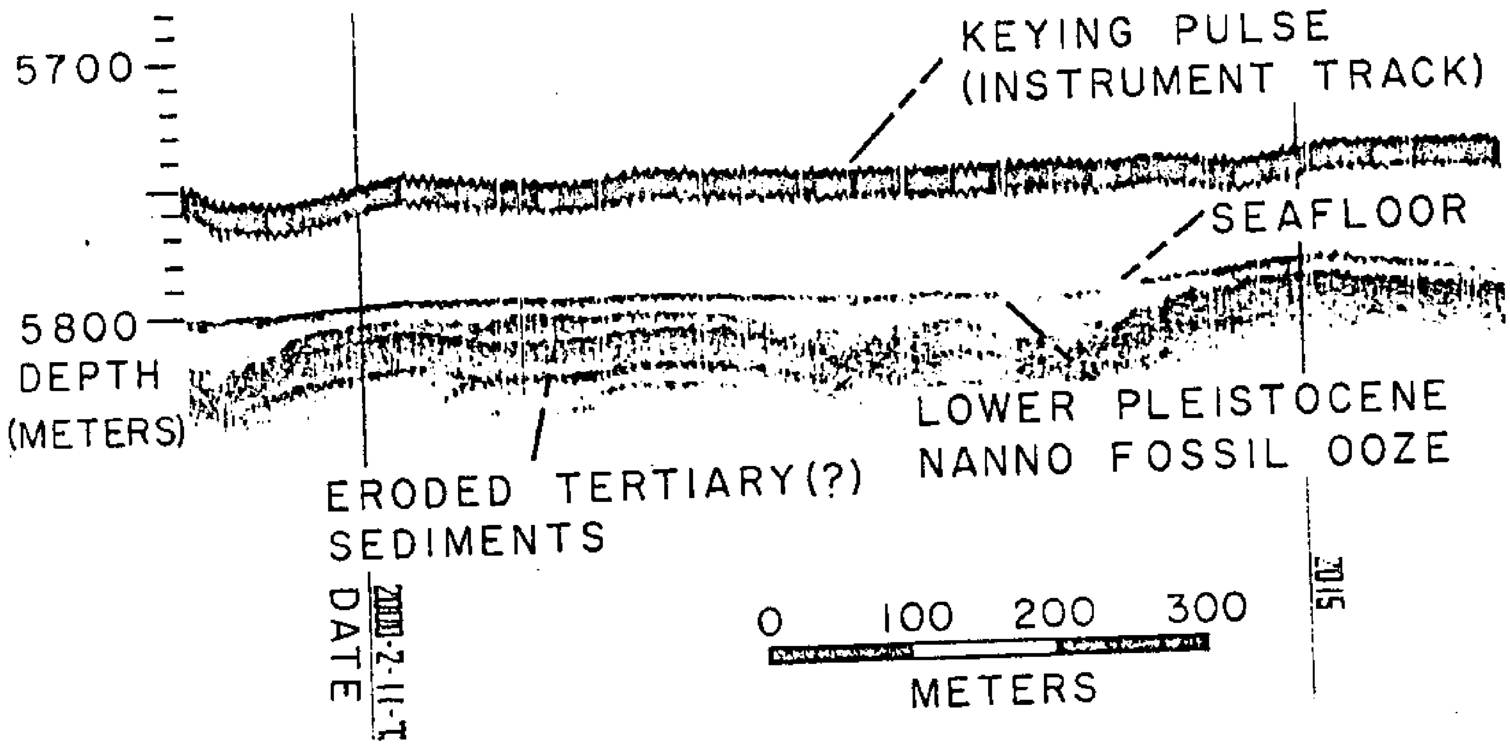

KEYING PULSE
(INSTRUMENT TRACK)
SEAFLOOR
5700
5800
DEPTH
(METERS)
LOWER PLEISTOCENE
NANNO FOSSIL OOZE
ERODED TERTIARY(?)
SEDIMENTS
DATE
0 100 200 300
METERS

Figure 15

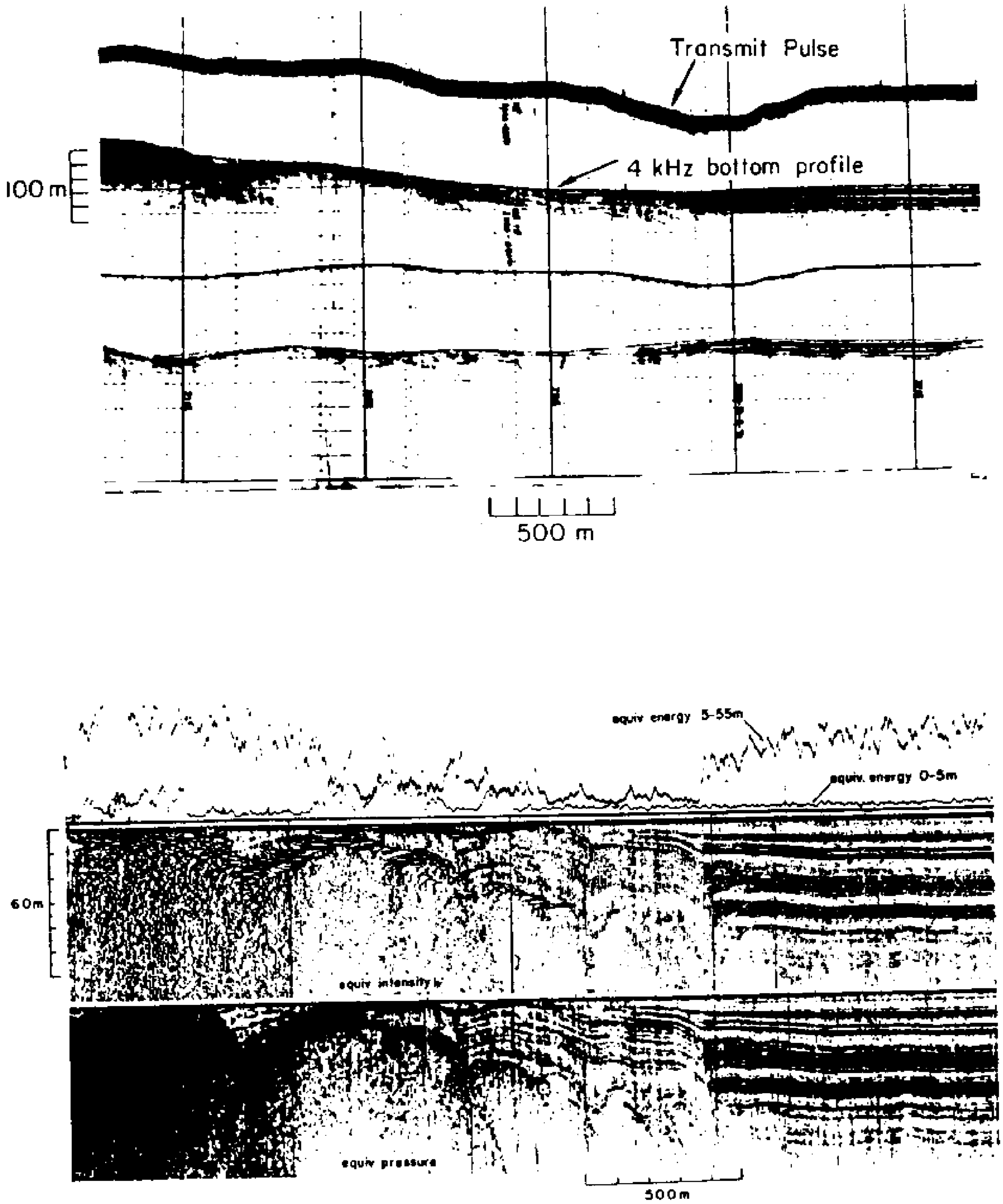

Transmit Pulse
4 kHz bottom profile
100 m
500 m
equiv energy 5-55m
equiv. energy 0-5m
60m
equiv intensity
equiv pressure
500m

Figure 16

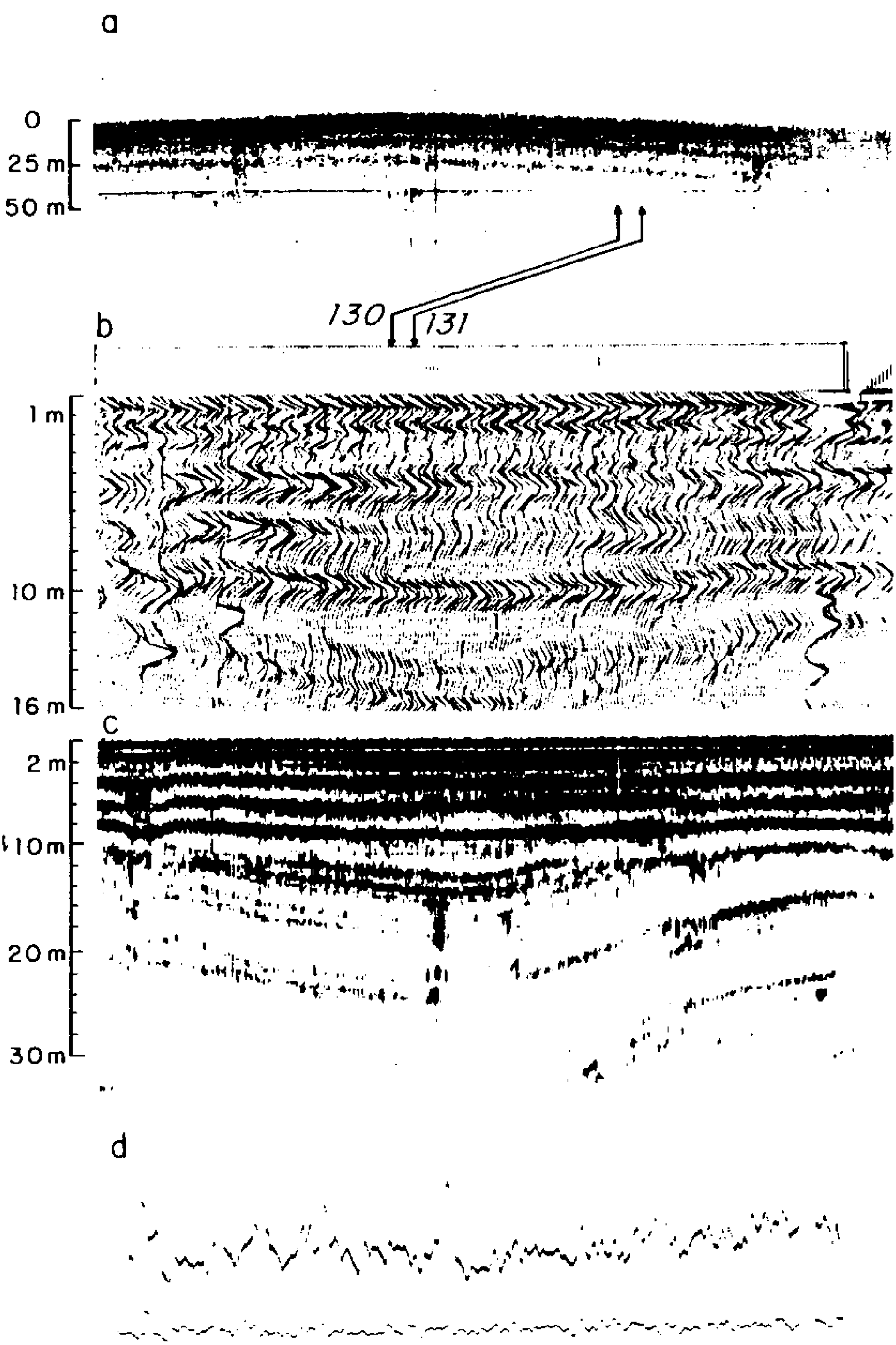


Figure 17

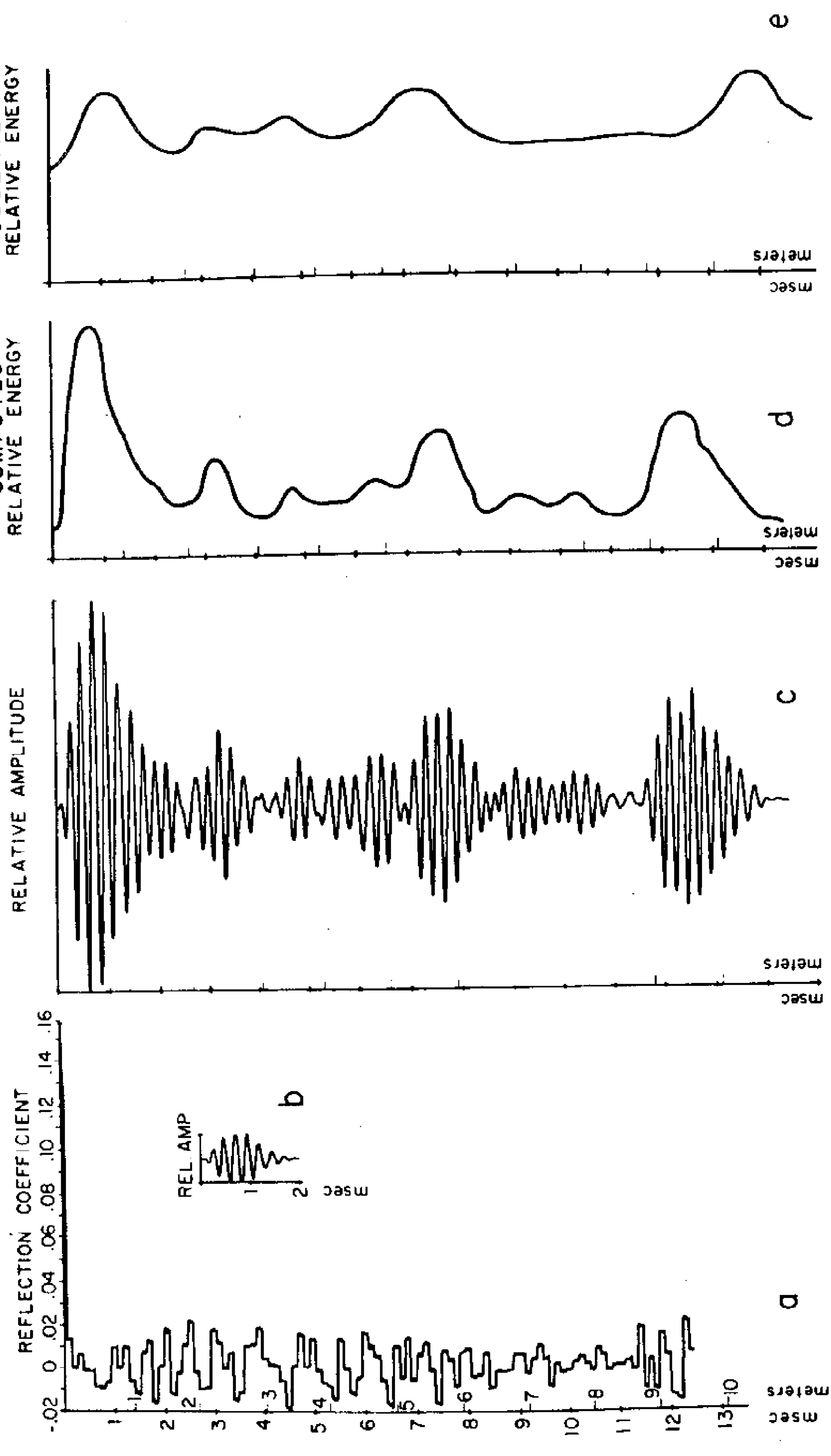

OBSERVED
RELATIVE ENERGY
COMPUTED
RELATIVE ENERGY
RELATIVE AMPLITUDE
REFLECTION COEFFICIENT
REL AMP
msec
meters
a
b
c
d
e

Figure 18

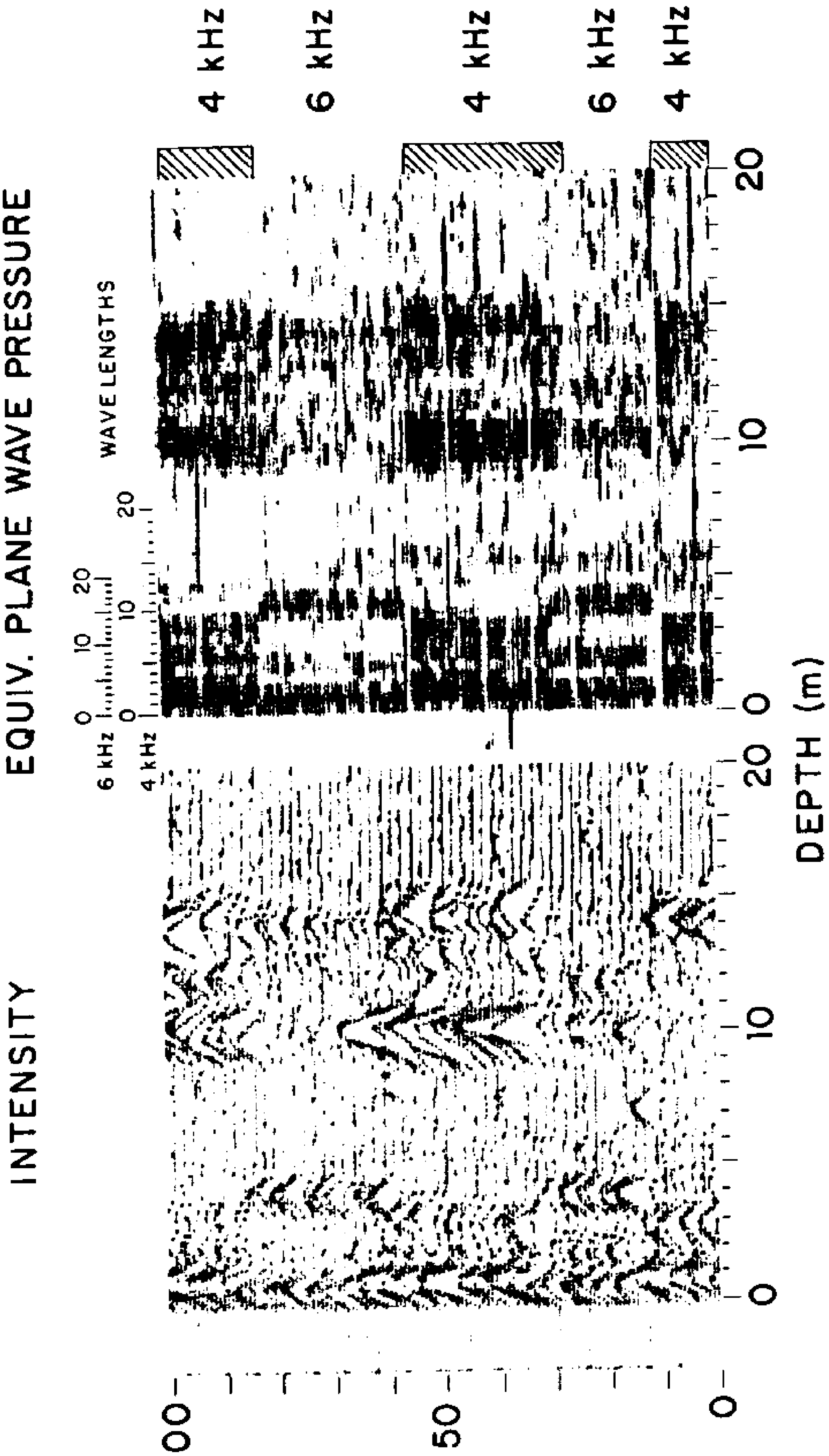
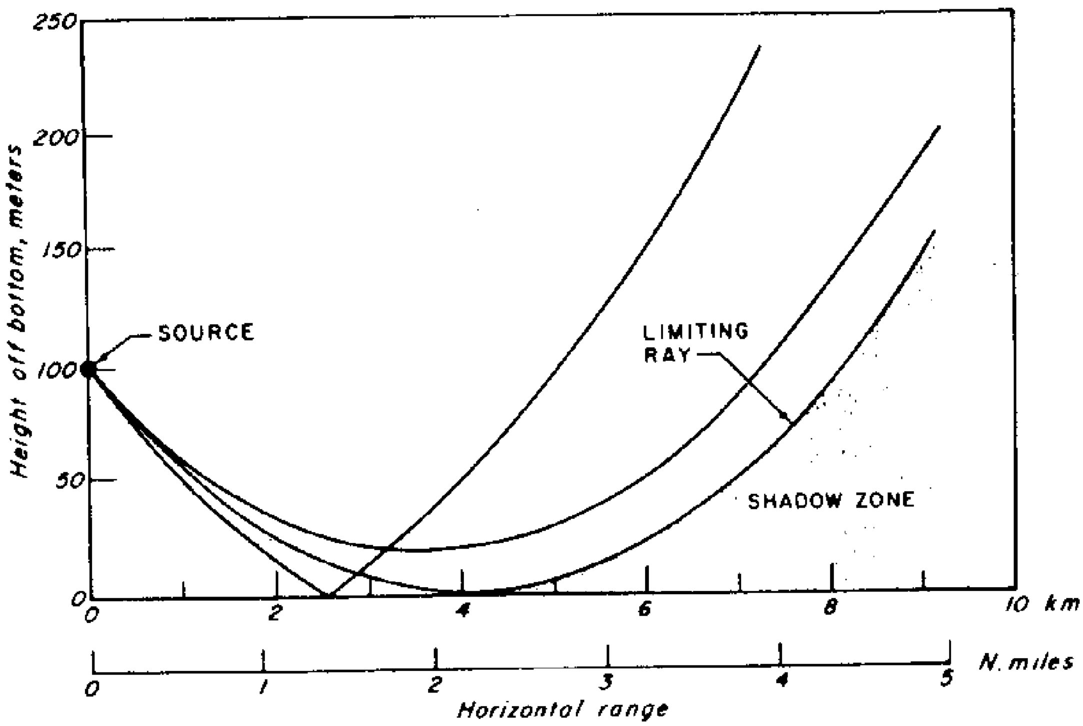

INTENSITY
EQUIV. PLANE WAVE PRESSURE
WAVELENGTHS
4 kHz
6 kHz
4 kHz
6 kHz
4 kHz
DEPTH (m)
DISTANCE (m)

Figure 19



250
200
150
100
50
0
Height off bottom, meters
SOURCE
LIMITING
RAY
SHADOW ZONE
0
2
4
6
8
10 km
0
1
2
3
4
5
N. miles
Horizontal range

Figure 20

OARS Paper #12

REMOTE ACOUSTIC SENSING OF OCEANIC FLUID AND BIOLOGICAL PROCESSES

This contribution was delivered as an invited paper at a NOAA workshop:

Ocean Acoustic Remote Sensing Workshop
Mayflower Park Hotel
Seattle, Washington

January 21-24, 1980

by Marshall H. Orr

Abstract

A short outline of the present research activities in high frequency remote acoustic sensing is presented, followed by a general description of the results of the high frequency acoustic remote sensing program at the Woods Hole Oceanographic Institution. Illustrations of the type of fluid and biological processes detected during the first three years of the program are included.

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

W.H.O.I. Technical Memorandum 80-2

Introduction

Remote acoustic sensing of atmospheric fluid processes has, during the past 15 years, developed into an active research discipline. There are a large number of applied and basic atmospheric research groups[1] using the acoustic technique in both the monostatic and bistatic modes of operation. These groups study both fluid and biological processes. In contrast, the number of researchers actively using or evaluating the use of high frequency remote acoustic sensing to study oceanic fluid processes is quite limited. They are divided among several groups in the United States and Canada[2-13]. Some activity in the Soviet Union also results in an occasional publication[14]. The potential for using high frequency acoustics as a remote sensor for small-scale fluid processes in the ocean has been recognized since at least the mid-1950's[15-18]. Although a few people actively pursued the potential, the oceanographic community has not adopted the technique as a tool. This lack of interest may be due to the discipline's past preoccupation with trying to understand oceanic circulation on a mesoscale and also the uncertainty in interpreting the acoustic records without complementary in situ data.

As an indication of the diversity of the high frequency remote acoustic sensing research groups' oceanic activities, a list of their respective interests follows. Lloyd Regier[2] (Scripps) and Bob Hill[2] (NRL) are independently modifying and evaluating the use of an Ametek, Straza Doppler Shear Measurement acoustic system with the aim of measuring the water column shear from a moving ship in the upper 100-200 m of the ocean. John Pijanowski[4] (NOAA, National Ocean Survey) is evaluating a Thomson/CSF Doppler current meter, to be used in the same manner as the Ametek, Straza instrument. In addition, J. Edward[5] (General Electric) is developing a system (Quo Vadis) which is being adapted to measure shear using a correlation technique. The acoustic Doppler and correlation systems are in a developmental and evaluation stage and are not yet used routinely in oceanographic experiments to measure shear.

Tom Kaye (NOSC), while at Scripps MPL, was involved in experiments to evaluate the use of acoustic systems in a monostatic pulsed backscattering mode to detect thermal structure and internal wave activity in the water column. Both an 8 kHz[6] array on a submersible barge and an 87 kHz transducer[7] mounted on FLIP were used during the experiments. The general conclusions of the work were that acoustic systems can be used to detect internal waves from biological scatterers and that thermal microstructure in the ocean environment can be detected. The acoustic detection of thermal microstructure was thought to be limited by biological backscattering contamination.

Rob Pinkel[8] (Scripps MPL) has used a narrow beam 87 kHz transducer aboard FLIP in a Doppler range gated mode to look horizontally outward to detect internal waves. He is replacing the 87 kHz unit with a three-axis narrow beam high power transducer system which operates over the 65-90 kHz range. With this system, he has achieved the ability to measure Doppler signals at a range in excess of 1 km. The three-axis system will be used to measure, among other things, the isotropy and frequency vs. wavenumber dependence of the internal wave fields in the immediate area of FLIP.

John Proni[9] (NOAA, AMOL) has been using a towed two frequency (20, 200 kHz) acoustic system to perform remote acoustic sensing of the ocean. He has detected internal waves and interleaving water masses. He also uses his system to study the dispersion of particulates released during the ocean disposal of dredge spoils, sewage sludge, and industrial chemical wastes. Dr. Proni is presenting a talk at this workshop, hence his work will not be elaborated upon.

David Farmer (Institute of Ocean Sciences, Canada) and J.D. Smith[10] (University of Washington) have been using commercially available fathometer systems in conjunction with standard oceanographic instrumentation to study fluid processes associated with a tidal flow across a sill in Knight Inlet, British Columbia. The fluid system is two-layer with fresh water over salt water. Their acoustic data is quite striking, revealing internal waves, shear instabilities, and hydraulic jumps in the vicinity of the sill.

My research[11-13] has used a four-frequency towed acoustic system operated in a monostatic pulsed mode to study a variety of fluid and, on occasion, biological processes in the estuary, shelf, and open ocean. The acoustic system[19] was developed at the Woods Hole Oceanographic Institution and has been used to study:

(1) sewage sludge and particulate distribution in Boston Harbor,

(2) fluid processes such as internal waves, shear instabilities, air-sea interactions, shelf-slope frontal zone, interleaving water masses, and hydraulic jumps across sills, and

(3) the seasonal dispersion properties of particulates released or formed during industrial chemical and sewage sludge disposal at Deep Water Dumpsite 106 (DWD 106). The research has been conducted in Boston Harbor, Massachusetts Bay, on the eastern continental shelf, in Puget Sound, and in the open ocean.

Experimental Considerations

The acoustic system operates simultaneously on four frequencies, selectable from the following frequencies or bandwidths: 15-45 kHz, 78 kHz, 200 kHz, 357 kHz, and 520 kHz. Any frequencies in the 5-800 kHz band can be utilized if the transducers are available. There is a dead band at 455 kHz $\pm$ 20 kHz. A four-frequency operating system was chosen to allow the remote determination of the dominant backscattering mechanism which allows one to detect a particular fluid process. Theoretical considerations[13,20,21,22,23] indicate that the dominant mechanisms anticipated for the oceanic environment are:

(1) backscattering from laminae or isotropic temperature fluctuations which are developed during turbulent mixing events,

(2) backscattering from temperature steps or gradients, and

(3) backscattering from particulate distributions (either animate or inanimate) associated with varying water masses. For example,

nearly neutrally buoyant particles, when falling through the water column, could have a tendency to collect at density discontinuities associated with temperature steps in the water column. Consequently, an acoustic backscattering system would be able to map the location of the density step and associated thermal step and the step's response to internal wave activity and mixing processes.

The wavelength dependence for each of the above backscattering mechanisms is:

	Wavelength Dependence
(1) for turbulent mixing areas	
(a) isotropic temperature fluctuations	$\lambda^{-1/3}$
(b) laminae temperature fluctuations	λ^{-2}
(2) for thermal gradients	λ^{2}
(3) for particulate backscattering	λ^{-4}

The target strength of the backscattering from each of the above mechanisms (using numbers for temperature fluctuations, thermal gradients, and particle concentrations which are representative of oceanic conditions) varies from greater than -60 dB to less than -130 dB. This entire backscattering target strength range is detectable with high frequency acoustic systems. It is, however, detectable with a range dependence. The -60 dB target strengths should be detectable to ranges in excess of 100 m depending upon the characteristics of the high frequency acoustic backscattering system being used.

The variability of the backscattered pressure signal as a function of backscattering mechanism is shown in Figure 1. This figure indicates that an acoustic system operating over the frequency range of 20 to 600 kHz should be able to identify which of the above backscattering mechanisms is the source of the backscattered acoustic energy provided only one backscattering mechanism is operational at a particular time.

It has been of concern that the dominant interference to the detection of fluid processes by physical backscattering mechanisms may come from biological scatterers which range in size from less than 1 mm to greater than meters. This is the case in many situations; not, however, to the detriment of using acoustics as a remote sensor of fluid processes. If the biological scatterers are neutrally buoyant as in the case of small phyto- and zooplankton, they act as acoustically detectable passive tracers whose motion mirrors the motion of the water column and the variability of water mass type. When the biology responds to strong thermal or density structure in the water column and group themselves near these features, the ability to acoustically detect short period internal waves or interleaving water masses is often striking. These are situations, as illustrated later in this paper, where the biology can respond to events in a nonpassive manner.

Results

The remainder of the paper will be used to illustrate and discuss the types of phenomena which have been detected with the W.H.O.I. high frequency acoustic backscattering system. Some of the data has been previously published; a great majority is being prepared for publication. The data will illustrate the ability of the acoustic systems to detect a variety of fluid processes and to detect the vertical and horizontal dispersion of particulates in the open ocean. The illustrations will progress from the estuary zone to the open ocean.

Boston Harbor. The particle distribution in Boston Harbor has been studied for the past two years with the object of determining the distribution of particle concentrations in and outside the harbor.[24] Large quantities of particles originate from the release of sewage sludge from the Deer Island municipal waste treatment plant's settling tanks. The release occurs at the beginning of ebb tide. The acoustic system has been used as part of this study to detect the particles at release to determine both the areal extent (in the vertical and horizontal) of the plume and the tidal variability of the particle burden at 24-hour anchor stations. The acoustic system has been quite helpful in determining the particle depth distribution and areal extent of the plume such that water samples could be obtained from areas of highest particle contrast. Mixing mechanisms at the salt water interface which exists near the harbor entrance have also been identified. Figure 2 is representative of the acoustic records obtained near the Deer Island outfall. It shows a plume of materials rising from the outfall and the particle distribution in the immediate vicinity of the outfall. During surveys of the particle distribution in Boston Harbor, the acoustic system has discovered previously unknown locations where broken sewage pipes were releasing material into the harbor.

Massachusetts Bay. Short period internal waves are known to propagate through Massachusetts Bay. They are generated on the incoming tide by the propagation of a lee wave[12] across Stellwagen Bank, as shown in Figure 3. The acoustic system was used during an interdisciplinary experiment to detect the internal wave field and to remotely determine the biological response to its passage.

A typical record taken over Stellwagen Bank during the passage of the lee wave is shown in Figure 4. The backscattered signal (200 kHz, monostatic pulsed mode) is reflected from a region of high shear and turbulent mixing (arrow 1). Temperature records obtained with a CTD (arrow 2) showed a high variability when the heavy acoustic scattering areas came to the CTD's depth of deployment. The acoustic records show areas of distinct shear instabilities (arrow 3) and the development of "cats eye" type turbulent mixing areas (arrow 4). The acoustic backscattering is from temperature fluctuations caused by mixing in a high shear zone. Atmospheric acoustics researchers[25] have concluded that the same backscattering mechanism allows detection of mixing events in the first 1-3 km of the atmosphere.

The distinction between biological scattering and backscattering from high shear areas is brought out in Figure 5. An internal wave field (wavelength $\sim$ 200 m) propagating through Massachusetts Bay is shown.

Two backscattering mechanisms allow the detection of the internal wave: (1) backscattering from particulates (arrow 1) which, in this case, are biological organisms, zooplankton, which appear to respond to the short period internal wave field as passive traces on the water column, and (2) backscattering from temperature fluctuations which develop in an area of high shear (arrow 2). Note that the heavy acoustic scattering area which marks the discontinuity between the mixed layer and the temperature gradient below it does not appear until the vertical displacement of the water column is near its maximum. At this point the diffuse but narrow in vertical extent scattering appears and becomes more intense as one proceeds to the rear of the lobe. The acoustic system is detecting a mixing area and it is believed that the intensity of the signal is proportional to both the energy dissipation rates and the cell size of the dissipation.

One of the goals of the research program has been to obtain collaborative and simultaneous data from free fall CTD fine and microstructure devices such that acoustic backscattering levels can be compared to theoretically predicted backscattering levels using structure factors determined from the in situ measurements. Also, the threshold levels, in terms of dissipation rates, at which the turbulence can be acoustically detected need to be determined. With proper calibration, the acoustic systems could be used to remotely estimate dissipation rates. This goal is proving elusive due to the transient nature of the turbulence and the difficulties of placing in situ measuring instruments into the areas of mixing at the same time acoustic records are being obtained.

In several instances during the Massachusetts Bay experiment, large scale Kelvin-Helmholtz shear instabilities were detected in association with the internal wave fields. The most spectacular event is shown in Figure 6. The diagonal lines are caused by acoustic backscattering from a yo-yo CTD which was being lowered and raised from a drifting research vessel. The density profiles calculated from the CTD[12] measurements are overlain on the acoustic records. The data was taken in the first lobe of an internal wave field which was passing the drifting ship. The downthrust of the internal wave was seen as the vertical displacement of point scatterers (arrow 1). The increase in a diffuse acoustic backscattering (arrow 2) started near the base of the mixed layer. The density profile becomes quite ragged as the diffuse acoustic backscattering area takes on the characteristic form of (Kelvin-Helmholtz) shear instabilities. Note the strong density inversions (arrow 3) corresponding to the regions where the cold dense water below the mixed layer has been thrust into the mixed layer water. The large scale shear instabilities (arrow 4) are being revealed by the presence of small scale shear instabilities (arrow 5) which evidently have large enough temperature variability and the correct cell size ($\sim$ 3.5 mm) for backscattering of a 200 kHz pulse (λ = 7.5 mm).

An example of short period internal wave breakdown as it approached shallow water is displayed in Figure 7. The symmetric wave field outlined by the high scattering areas associated with shear near the mixed layer boundary is seen to break down in the fourth lobe (arrow 2) into an area of heavy mixing which appears to be caused by large-scale instabilities overrunning one another (arrow 3). In addition, an area where an entire lobe (arrow 4) is overturning is outlined. This overturning has the potential of forming interleaving water masses as the cold water in the lobe is thrust over the warm water in the mixed layer. Indeed, such a sequence (Figure 8, arrow 1) was observed in another Massachusetts Bay internal wave train ,where layered acoustic scattering zones were detected as an internal wave field ,broke down. Unfortunately, no XBT data was obtained during the acoustic observations to confirm the magnitude of the temperature variability associated with layered structure.

Interleaving Water Masses. The acoustic systems have detected interleaving water masses and internal waves both on the outer continental shelf and in the open ocean. The open ocean data appears to be dominated by acoustic backscattering from biological organisms (particulates) whose neutral or nearly neutral buoyancy allows them to act as passive tracers of water mass motion. As an example of interleaving water mass detection with a 200 kHz acoustic system, data obtained in April 1978 at Deep Water Dumpsite 106 (depths > 1700 m, Figure 9) are displayed. An XBT taken on the same day as the acoustic record, XBT #54, is shown in Figure 10. Warm water (arrow 1) overlays a layer of cold water (arrow 2) followed by a layer of warm water (arrow 3) (Figure 10). The three layers of water are clearly distinguishable in the acoustic record as pointed to by arrows 1', 2', and 3' (Figure 11).

Internal Wave Spectra. During the JASIN experiment (Joint Air-Sea Interaction Experiment), July-September 1978, acoustic data were obtained during box tows which involved other ships moving in formation with appropriate navigation. One (the ATLANTIS II) carried Clayton Paulson's (Oregon State University) thermistor string. The internal wave spectra (energy density vs. wavenumber) calculated from the digitized acoustic records obtained during one of the box tows is shown in Figure 12. This spectrumis being intercompared with the towed thermistor string data of Paulson's to determine the accuracy of the acoustic data. The main point to notice in the spectra is the sharp cut-off at a wavelength at 1 km and the relatively high energy density for the experiment area. A rough intercomparison with Paulson's data indicates that the acoustic data has the right appearance and the energy density is of the same order of magnitude; more detailed intercomparison remains to be performed. Similar experiments have been performed with the Naval Research Laboratoty (NRL) thermistor string group. In that case, the data were taken from the same ship, thus cross-correlation between the acoustic time series of the vertical displacement of the scattering surfaces and vertical displacement of the isothermal surfaces detected by the thermistor chain will be able to be calculated. This information will be used to further determine the utility of using remote acoustic sensing systems to detect fluid processes in the ocean. Acoustic data taken in a variety of places in the world's oceans are presently being digitized to determine the variability of the internal wave energy density spectra as a function of geographic location.

At this point, a small but representative portion of my work in fluid processes has been covered.

Ocean Dumping of Industrial Chemical Wastes. The NOAA Ocean Dumping Program has been studying the impact of the disposal of industrial chemical wastes at DWD 106 for the past several years. A significant problem in studying wastes in the open ocean is to determine the position of the waste field, its horizontal and vertical distribution as a function of time, and the effects of shear on the dispersion of the plumes such that meaningful chemical and biological samples can be obtained both within and outside the contaminated water column. If the industrial chemical wastes either form or have particles associated with them, acoustic systems can be used to trace the particle dispersion such that the plume can be tracked and water samples, etc. can be taken from depths which correspond to the distribution of the waste fields.

Acoustic data has been taken during the past three years, and indicates that the vertical distribution of the waste fields is seasonally dependent. That is, during the summer months there exists a sharp seasonal thermocline in the top 10-20 m of the water column which acts as an effective barrier to the penetration of the particulate phase of the waste field. During the winter months, the mixed layer is 100-120 m in thickness and consequently the particulate phase of the wastes are distributed throughout this portion of the ocean in discrete patches. During the springtime, the shallow seasonal thermocline is being re-established and the penetration of the particulate phase of the waste field is effectively limited by the density discontinuities. These characteristics are exhibited in the acoustic data obtained during summer, winter, and springtime water conditions (Figures 13-15). Both the summertime (Figure 13) and the springtime water conditions (Figure 14) are characterized by the shallow seasonal thermocline (arrow 1) and particle distributions which are limited in their vertical distribution (arrow 2). The wintertime condition (Figure 15) has a deep mixed layer (arrow 1) and the corresponding wider vertical distribution of the particles (arrow 2). An analog trace of the backscattered acoustic pressure signal (Figure 16) indicates the variable distribution of the particles within a small plume which ranges from 90-110 m in vertical depth. These analog records are being digitized to determine dispersion rates; however, the problem is not easily solved due to the need for precise navigation and the ability to monitor a plume for extended periods.

The effects of shear on the horizontal and vertical distribution of sewage sludge particles is shown in Figure 17. Note the asymmetric distribution of particles in the plume due to the effects of shear. The water sampling ambiguities without acoustic guidance should be apparent. To be able to measure shear in the water column over small vertical segments ($\sim$ 1-3 m) is necessary such that intelligent planning for ocean dumping sampling may be made on board ship. A good candidate for these shear measurements is either the acoustic Doppler and correlation systems mentioned earlier or Tom Sanford's (Univ. Washington) expendable shear probes.

Biological Interaction. The study of biological interaction with fluid processes such as internal waves indicates, as previously discussed, that the biology which is detected most readily with the 200 kHz acoustic systems responds as a passive tracer to the water motion. The biology detected with the 200 kHz systems has on occasion, however, exhibited marked mobility in predator-prey interactions[27]. These predator-prey interactions have been observed both in Massachusetts Bay and Puget Sound. They are rarely observed, but interesting.

The Puget Sound data obtained during June 1979 (Figure 18) shows several scattering layers (arrow 1) which were detected for significant periods of time. They are seen to exhibit internal motions (arrow 2).

On two occasions the scattering layer was observed to move vertically (arrow 2) to avoid a dense school of heavy scatterers (predators) which were moving through the area (arrow 3). This active predator-prey interaction suggests that biological mechanisms for the avoidance of oceanographic instrumentation (nets) could also exist, as has been suspected by many biologists. Again in Puget Sound, the active evasion of Dr. Michael Gregg's (Univ. Washington) microstructure measuring free fall vehicle was observed on two successive drops (Figure 19). The backscattering from the vehicle (arrow 2) can be seen to begin at the same time that the backscattering layer (arrow 1) dissociates (arrow 3). Before the vehicle returns to the surface, the scatterers return to their original configuration. The vehicle happened to fall in the beam of the acoustic system. It did not return to the surface in the beam, hence the scatterers were not seen to disperse during the vehicle's ascent.

The potential of using acoustic systems to evaluate fish stock and zooplankton biomass has been recognized by the European community[28] and active research and applied programs in that community are both assessing and actively using the technique. The U.S. program, especially on the east coast, is very small and funded at low levels. One of the problem areas in using the acoustic systems has been in the stock assessment of demersal fish. Many of the acoustic systems used have not been able to resolve demersal fish which reside close to the bottom from the bottom due to the use of broad beam width transducers and/or long acoustic pulse lengths. With the W.H.O.I. acoustic system operating at 200 kHz with a narrow beam and short pulse length, we have been able to easily resolve demersal fish a few centimeters from the ocean bottom[29] (Figure 20) in 80 m of water. The potential of remotely sensing fish stocks for scientific assessment and commercial catching exists and should be vigorously pursued in this country, with individual programs on both the east and west coasts. At present there are small programs on the west coast[30-33], in the Great Lakes[34,35], and on the east coast[36]. The greatest concentration of activity appears to be on the west coast.

Conclusion

A short outline of the research programs and objectives of those groups who are actively involved in the use or evaluation of high frequency acoustic backscattering as a remote sensor of fluid processes has been presented. A general overview of the results of my research program has been presented to illustrate or call attention to the potential of using high frequency acoustic backscattering systems in the study of:

- I. A variety of fluid processes:
  - A. internal waves
  - B. fronts
  - C. mixing
  - D. interleaving water masses
- II. Particulate distributions:
  - A. natural in estuary, shelf, and open ocean environment
  - B. manmade in estuary, shelf, and open ocean environment
    1. dredge spoils
    2. industrial chemical wastes
    3. sewage sludge

III. Biology
  A. fish stock assessment
  B. zooplankton biomass
  C. predator-prey interactions
  D. biological avoidance of oceanographic instrumentation
  E. biological response to fluid processes

High frequency acoustic backscattering techniques have the potential for becoming a valuable tool in oceanographic research. They will be able to work in both a complementary and a stand-alone format. The technique, if applied, should not be done in the black box format common to the use of XBT's or CTD's. Dedicated research groups individually addressing all or one of the research areas listed above must be formed and staffed with individuals (scientists, engineers, and technicians) capable of understanding the physical processes (fluid dynamics) to be studied and the technical capabilities and limitations of the instruments being used. The groups should have not only superior acoustic systems but also high resolution CTD's and shear measuring devices available to them. The open ocean data acquisition with these systems is done in a continuously varying environment and one must be ever alert and have the depth of knowledge as indicated above to allow anticipation of the fluid processes occurring in the research area and to anticipate the necessary alteration of the research instruments' configuration to take advantage of the varying oceanic conditions. If research using high frequency acoustic systems as a remote sensor is attempted in the black box format, i.e., giving an instrument with a few knobs to turn to a technician or uneducated scientist, the technique in all likelihood will lead to extreme frustration and eventual abandonment by the oceanographic community.

Acknowledgements

The W.H.O.I. acoustic system has been designed by Frederick R. Hess and, under his guidance, constructed and maintained by Brian Bardsley and Donald Crowell. Data reduction and analysis has been performed by Lincoln Baxter II and Stanley Bergstrom. Susan Smith has prepared this manuscript. Support for the work described in this text has come from the Naval Oceanographic Research and Development Agency, the National Oceanic and Atmospheric Administration Ocean Dumping Program, the National Oceanic and Atmospheric Administration Sea Grant Program, and the National Science Foundation.

Bibliography

1. A partial list of those groups involved in atmospheric work may be obtained from J. Acoust. Soc. Am., 66, S, 1979. Several sessions of the 98th Meeting of the American Acoustical Society were devoted to remote acoustic sensing of the atmosphere.

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3. Bob Hill at the Naval Research Laboratory is evaluating an Amatek Straza Doppler system to measure shear.

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Figure Captions

Figure 1. Plot of pressure amplitude vs. frequency for four backscattering mechanisms which are considered to be important to the detection of oceanic fluid processes.

Figure 2. Acoustic record (200 kHz) of particles rising from the Deer Island outfall and their distribution throughout the water column in the immediate vicinity. Arrow 1 points to the outfall, the dark areas near the surface are the result of backscattering from the particles in the water. Particles falling out of the plume can be seen in the area of arrow 2.

Figure 3. Temporal development of a short period internal wave field in Massachusetts Bay. The figure and identification of the generation mechanism are from Dr. Melbourne Briscoe[12]. (A) The outflowing tide across Stellwagen Bank produces a lee wave which is held in position until the tide slacks, (B). At that time, the lee wave propagates westward across Stellwagen Bank forming a short period internal wave which then propagates across Massachusetts Bay (C,D).

Figure 4. Acoustic record (200 kHz) of a short period internal wave forming from a lee wave propagating across Stellwagen Bank. The acoustic backscattering from arrow 1 is thought to be from temperature fluctuations in the vicinity of a high shear zone created during the passage of the lee wave. Note the formation of shear instabilities (arrow 2) and cats eye-like structure (arrow 3). The horizontal line was caused by backscattering from a CTD (arrow 4) held at constant depth during the lee wave passage.

Figure 5. A 200 kHz acoustic record of an internal wave packet observed at the position marked * in Figure 1. The period of the waves are Doppler shifted by the ship's speed of about 2.5 knots (128 cm s^{-1}) as it travelled from the rear to the front of the packet parallel to the packet's propagation direction (240^{o}; left to right in figure). The seasonal thermocline is displaced by 30 m (arrow 1) and the stratified point scatterers (zooplankton) at 30 to 40 m are displaced more than 20 m (arrows 2 and 3). The heavy acoustic backscattering in the vicinity of arrow 4 and extending in an oscillatory pattern throughout the figure is caused by turbulent mixing near the thermocline. The asymmetry of the wave field, with narrow troughs and broad crests, is determined by the depth of the mixed layer. Similar asymmetrical waves have been observed acoustically in the lower atmosphere. The heavy scattering near 75 m is probably caused by euphausiid and mysid shrimp. The oscillations in bottom depth (arrows 5 and 6) are due to variations in the travel time of the sound pulses resulting

from the thermal structure of the waves; that is, the water column above arrow 6 is mostly cold (slower speed of sound).

Figure 6. The 200 kHz acoustic record of overturning instabilities associated with the internal wave packet (propagating from right to left) at site A (Figure 1) between 11:30 and 11:41 LT. 30 August 1977. This portion shows two overturning events; the direction of overturning (left to right) is opposite that of packet propagation. Superimposed are the corroborating density profiles obtained by repeated vertical casts of the CTD. The instrument's path is seen as the oblique traces.

Figure 7. A short period internal wave breaking down as it approached shallow water on the western side of Massachusetts Bay. The internal wave field is travelling to the left in the figure with the first lobe noted with arrow 1. The fourth peak (arrow 2) of the internal wave field is seen to be breaking down. The acoustic record indicates that nearly 15 m of the water column is undergoing mixing. Shear instabilities (arrow 3) can be seen in the area of heavy mixing. A second region (arrow 4) reveals an entire lobe of the internal wave field in a classical breaking wave configuration. This configuration would suggest the possibility of the formation of interleaving water masses as a result of the overturn (see the next figure).

Figure 8. The formation of interleaving acoustic scattering areas (arrow 1) in the area of internal wave breakdown in western Massachusetts Bay. This is a process often mentioned in the theoretical internal wave literature, here shown clearly by the acoustic backscattering technique.

Figure 9. Chart showing the position of DWD 106 as referenced to the east coast of the United States of America.

Figure 10. An XBT sequence indicating the thermal structure of the springtime water at DWD 106. Of particular interest is XBT #54. The layered structure in the water column is noted by the arrows 1, 2, and 3.

Figure 11. An acoustic record taken at DWD 106 during a chemical waste disposal monitoring operation. The particulate phase of the chemical waste can be seen distributed in the first 15 m of the water column and on the first density interface, see arrows 1, 2, and 3. The interleaving water masses followed during the experiment and described in the text are illustrated by the arrows 1', 2', and 3'. Note the internal waves and the lack of vertical coherency between the layer at 25-30 m in depth and the layer at 7-15 m in depth.

Figure 12. Energy density spectra vs. wavenumber calculated from nine hours of acoustic backscattering data obtained during a box tow at the JASIN (Joint Air-Sea Interaction) experiment site on September 3, 1978. The acoustic backscattering surface was displaced on occasion by as much as 20 m and appeared to outline the vertical displacement of the base of the mixed layer.

Figure 13. Summertime 200 kHz acoustic backscattering record showing the base of the seasonal mixed layer as outlined by particles from a duPont acid iron waste field (arrow 2). Note that a small number of particles are outlining a second density gradient (arrow 3). The entire waste field was being perturbed by a cynoidal internal wave during the data acquisition period. The internal wave was being Doppler shifted by a moving vessel. The difficulty in sampling the water column as a result of the varied spatial distribution of the waste, the thinnest of the particle layers, and the influence of the internal wave field on the particle distribution should be apparent.

Figure 14. A multilayered springtime water mass similar to that previously discussed in Figure 11. In this case the penetration of particulates released during an industrial chemical waste disposal operation was limited by the first density discontinuity (arrow 1). Note the shallow penetration of the waste plumes over a period of more than one hour following the release of the waste.

Figure 15. Vertical dispersion of a chemical waste plume in wintertime water conditions. The depth of the mixed layer was from 80-120 m during the experiment period. In this case, arrow 1, the waste plume was observed to be distributed over the first 75 m of the water column, or nearly 5 times as deep as during the spring and summer month data previously described.

Figure 16. A representative data set of analog acoustic signals backscattered from a particle cloud during the wintertime water conditions (depth range 75-110 m). The amplitude of the acoustic signal, i.e., the amount of horizontal offset to the right, is representative of the number of particles in the cloud. Note that the amplitude is quite variable for the 12 sec of data shown in the figure. The difficulty of sampling the cloud with ship-launched equipment in the horizontal and vertical should not be underestimated. Even though the acoustics can readily detect the particles, in this case a cloud approximately 50 m in width, the chances of positioning a ship over the cloud a second time with Loran C without knowing water shear are very small.

Figure 17. An example of the effects of shear on the horizontal dispersion of sewage sludge. Two crossings nearly perpendicular to a barge disposal track acoustically detected the particle plume to a depth of 60 m. At a depth of 15 m the shape of the sinking particle plume was distorted by shear in the water column. This effect was noted during both crossings of the waste plume.

Figure 18. A 200 kHz record of backscattering from biological layers (arrow 2). Schools of predators (arrow 3, 200 kHz record), see 20 kHz record (arrow 1'), were detected in the water column. In the vicinity of the predators, the layers of zooplankton are seen to actively move in the vertical in what is interpreted to be active predator-prey interactions. The scattering voids in the vicinity of the predators (arrow 2) are conspicuous.

Figure 19. A 350 kHz acoustic backscattering record showing a layered scattering zone (arrow 1). A free fall oceanographic instrument (M. Gregg, U. Washington) was released and, at a depth of approximately 16 m (arrow 2), was acoustically detected as it drifted beneath the acoustic transducer. At the same time, the acoustic scattering layer disappeared (arrow 3), having moved away from the descending instrument package. Once the package was a safe distance away, the scatterers returned to the layer structure (arrow 3). It is believed that the scatterers, as observed with the acoustic system, were moving away from the instrument when it was detected above them. The similarity in the scattering void area as observed in this record and Figure 18 should be noted.

Figure 20. High speed recording of 200 kHz data showing individual demersal fish to within 10 cm of the ocean floor (arrow 2). The presence of scatterers closer than 10 cm to the bottom are observed in the record (arrow 3). The easily resolved fish 2 m from the ocean floor are indicated (arrow 1).

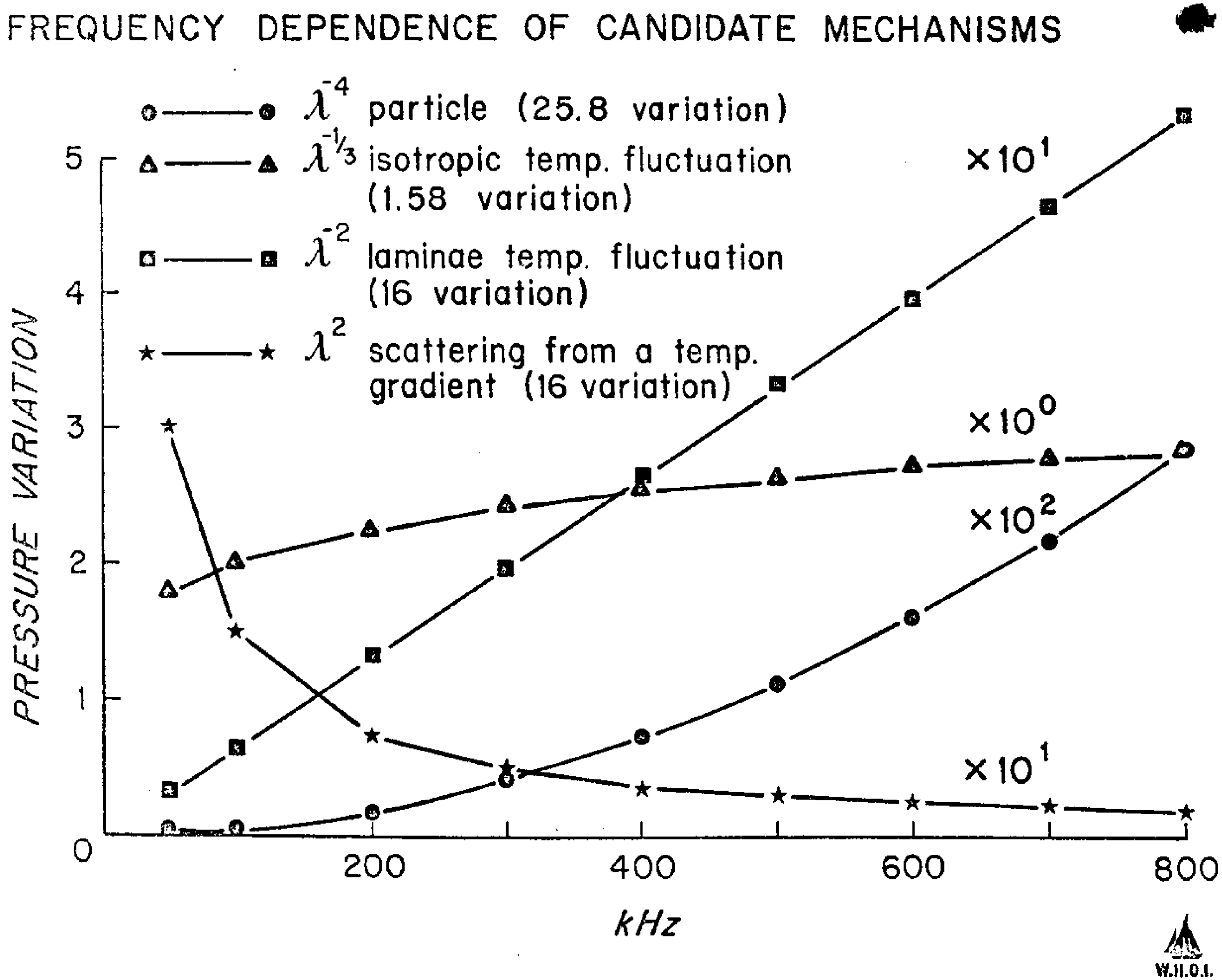

FREQUENCY DEPENDENCE OF CANDIDATE MECHANISMS
λ^{-4} particle (25.8 variation)
$\lambda^{-1/3}$ isotropic temp. fluctuation (1.58 variation)
λ^{-2} laminae temp. fluctuation (16 variation)
λ^{2} scattering from a temp. gradient (16 variation)
×10^1
×10^0
×10^2
×10^1
PRESSURE VARIATION
0
1
2
3
4
5
200
400
600
800
kHz
W.H.O.I.
ORR

Fig. 1

Fig. 2

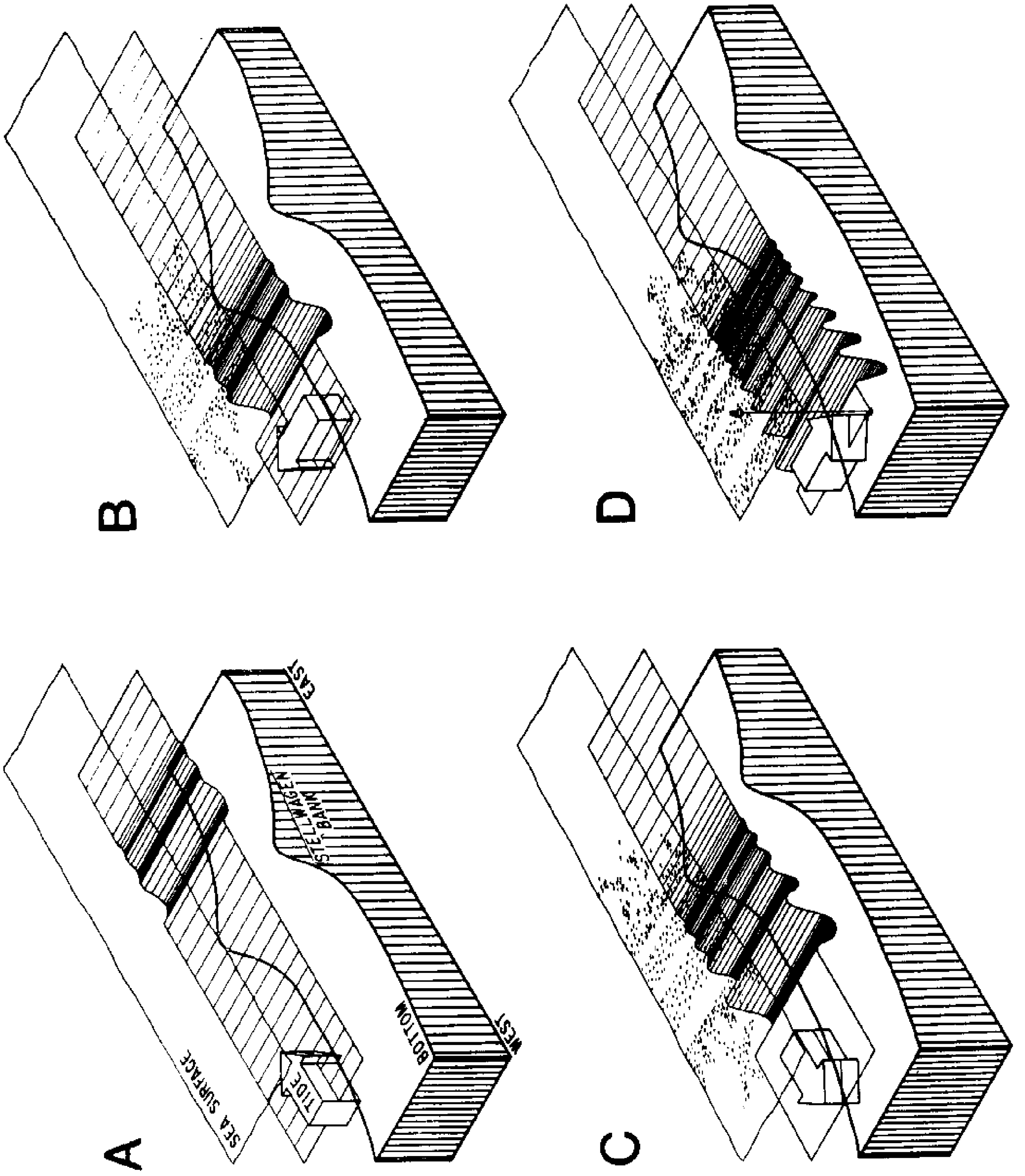


Fig. 3

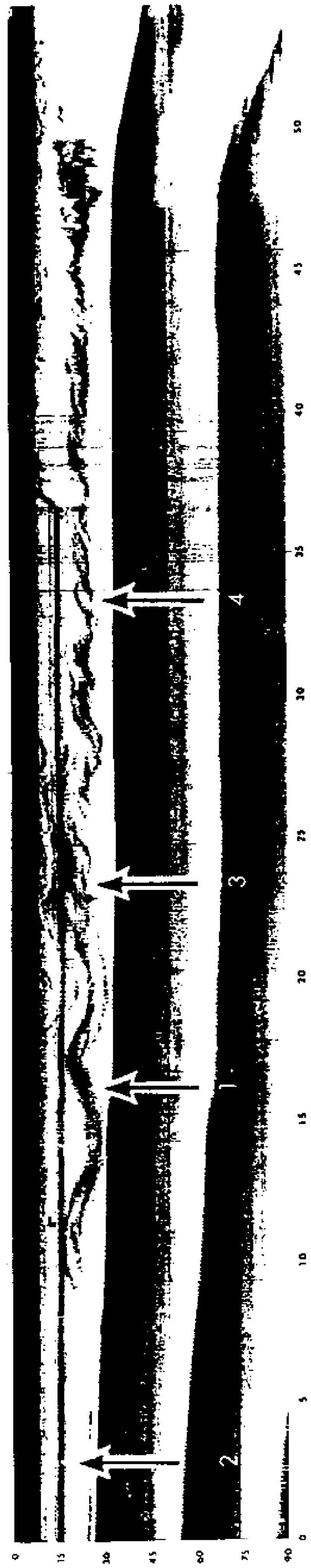


Fig. 4

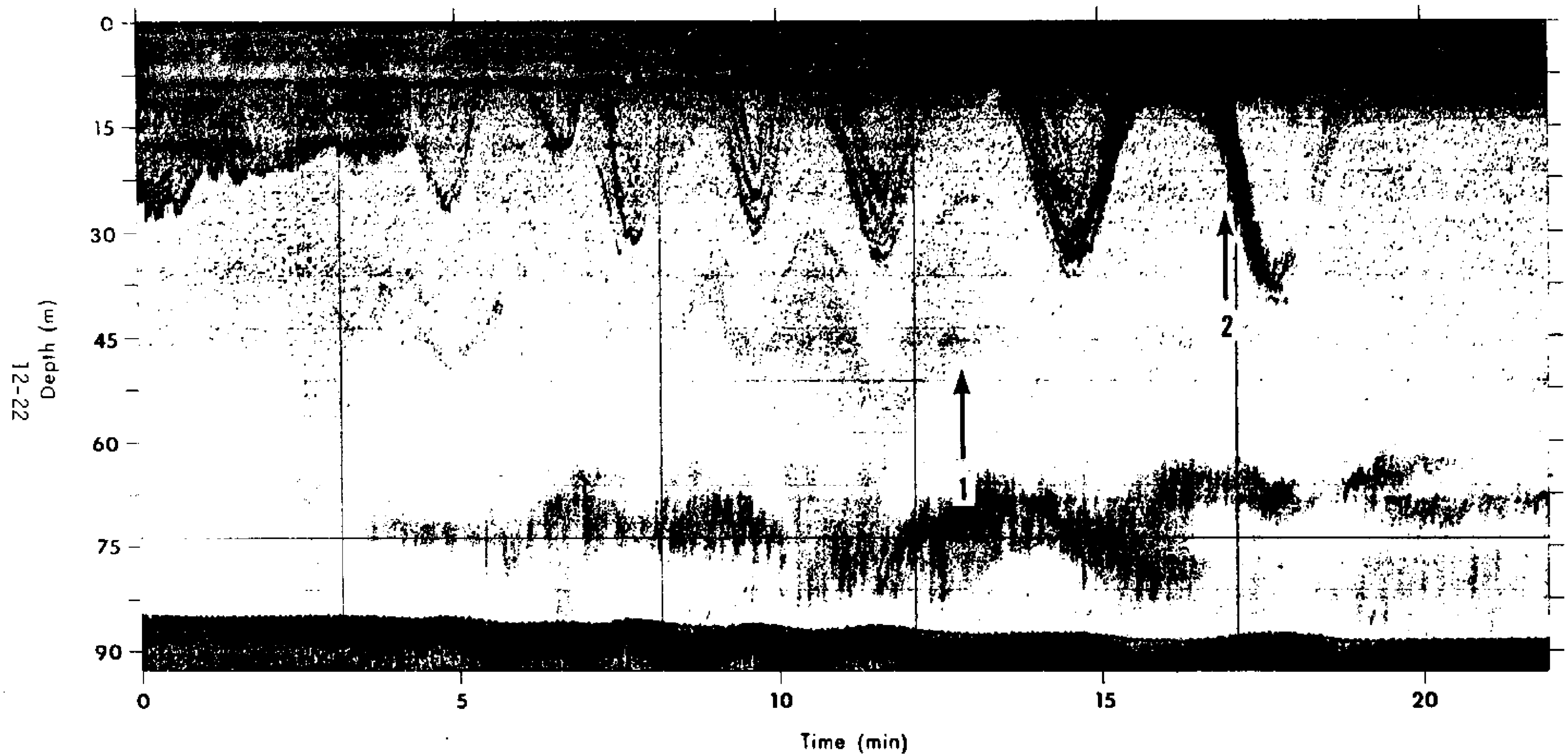


Fig. 5

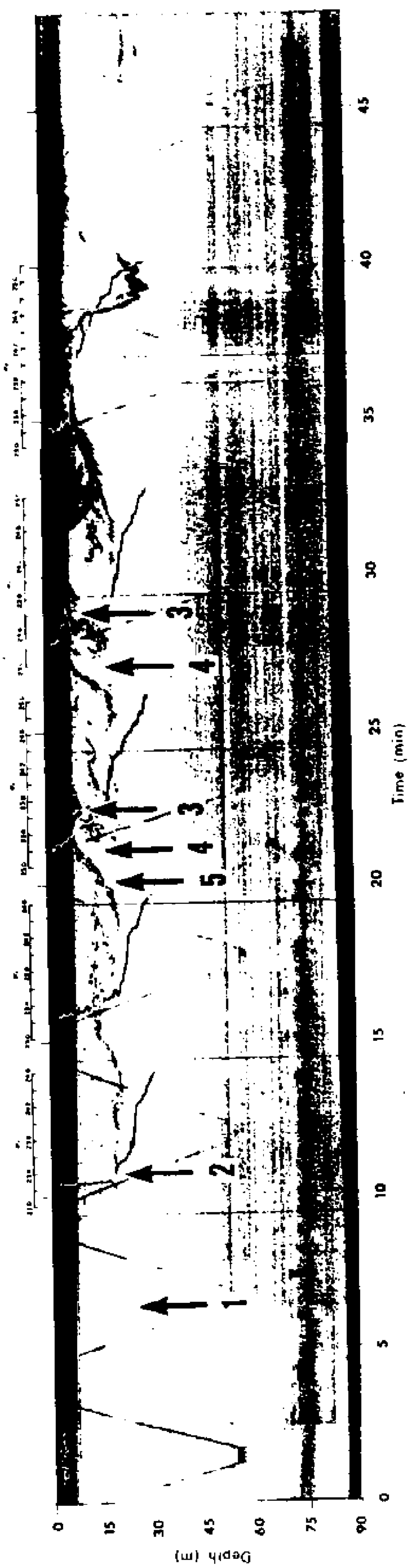


Fig. 6

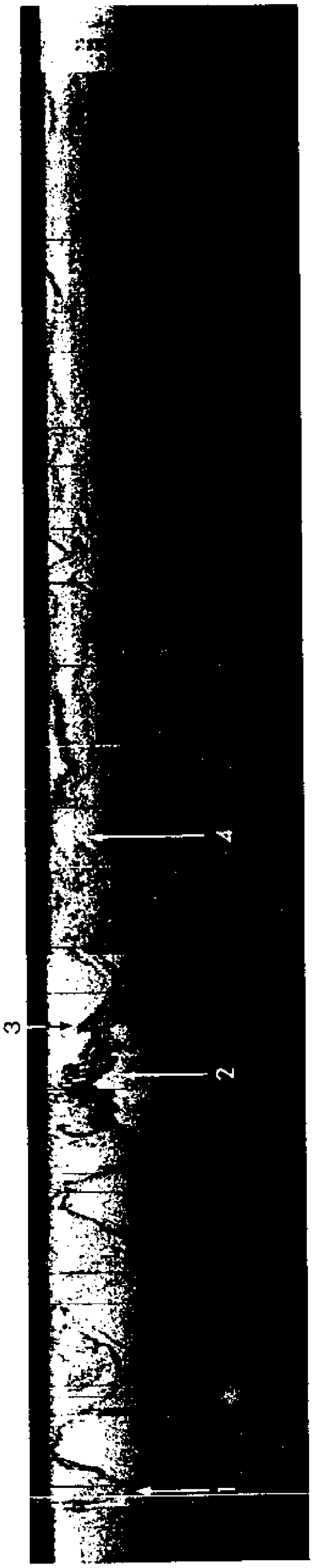


Fig. 7

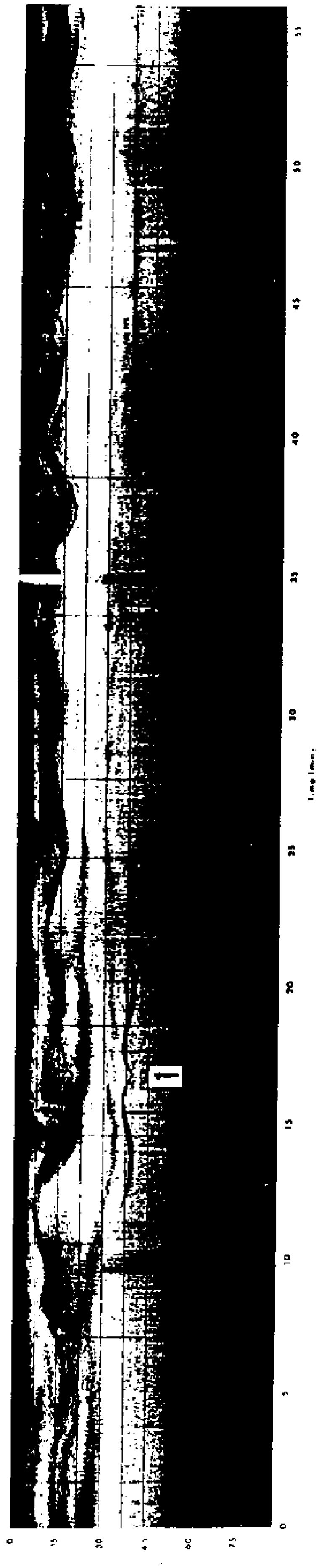


Fig. 8

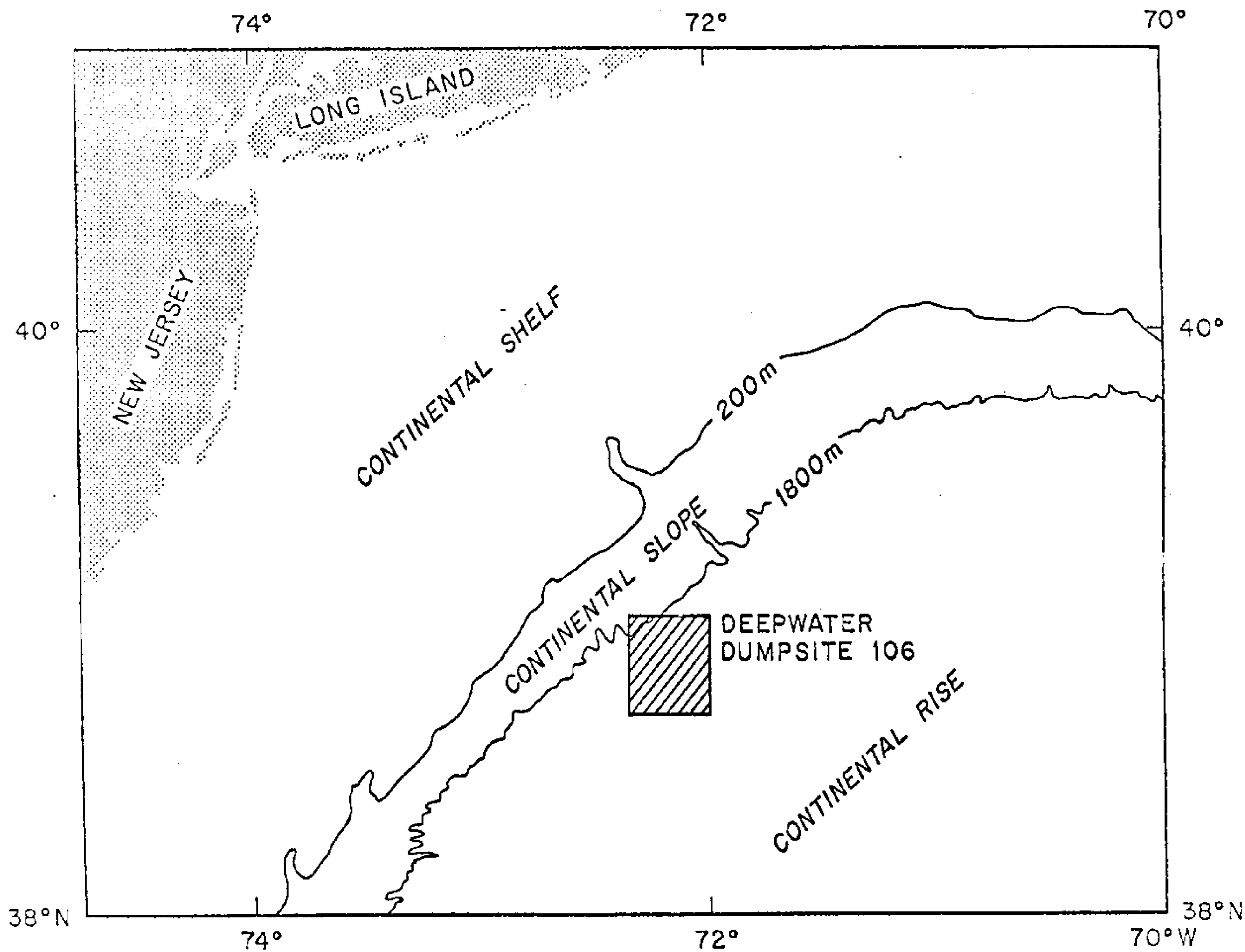
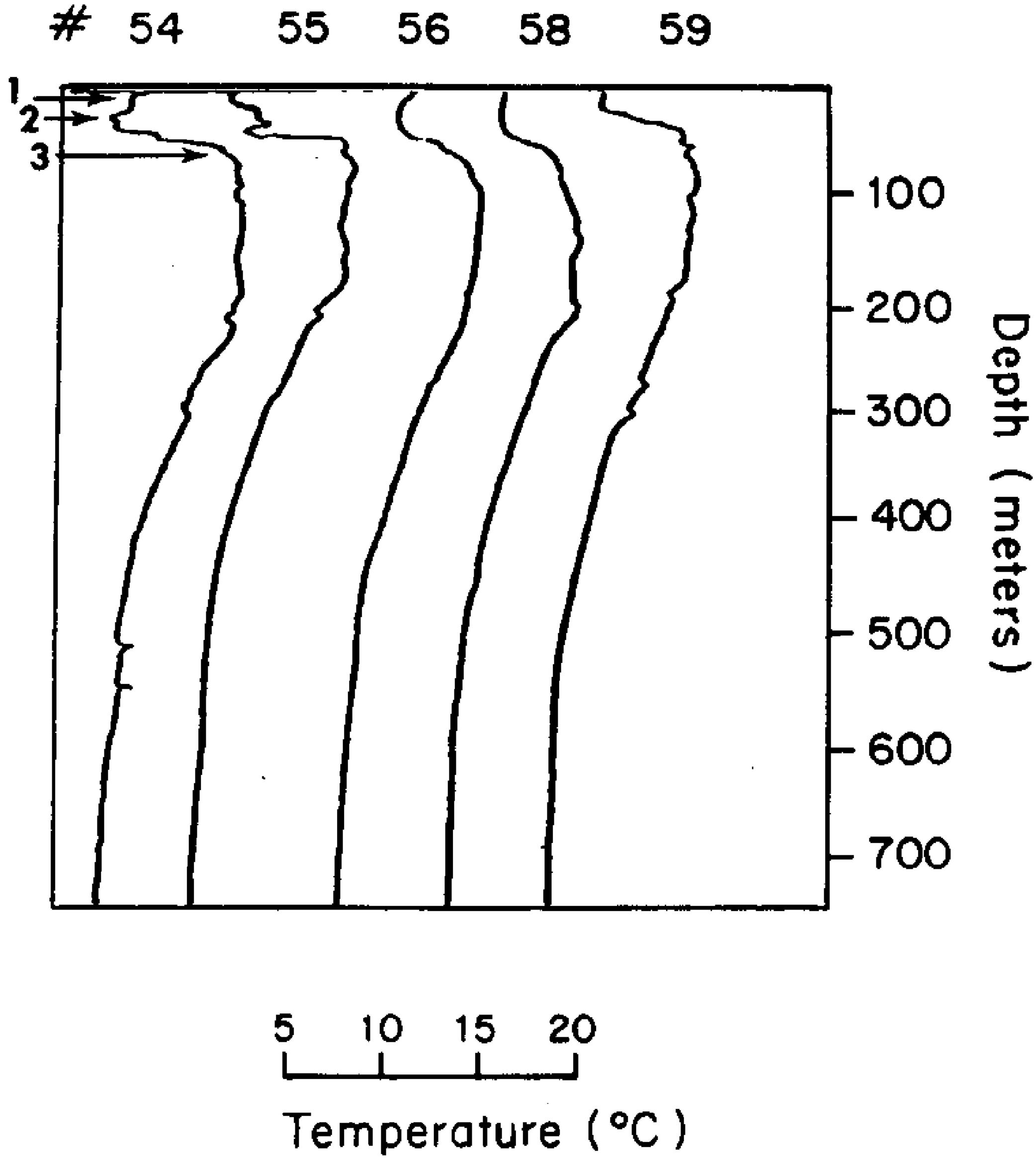

74°
72°
70°
40°
38°N
70°W
LONG ISLAND
NEW JERSEY
CONTINENTAL SHELF
CONTINENTAL SLOPE
CONTINENTAL RISE
200m
1800m
DEEPWATER
DUMPSITE 106

Fig. 9



At 600 meter depth
all traces read approximately
5°C

#54 = April 10	2330Z		#58 = April 11	0828Z
#55 = April 11	0350Z		#59 = April 11	1735Z
#56 = April 11	0612Z			

Fig. 10

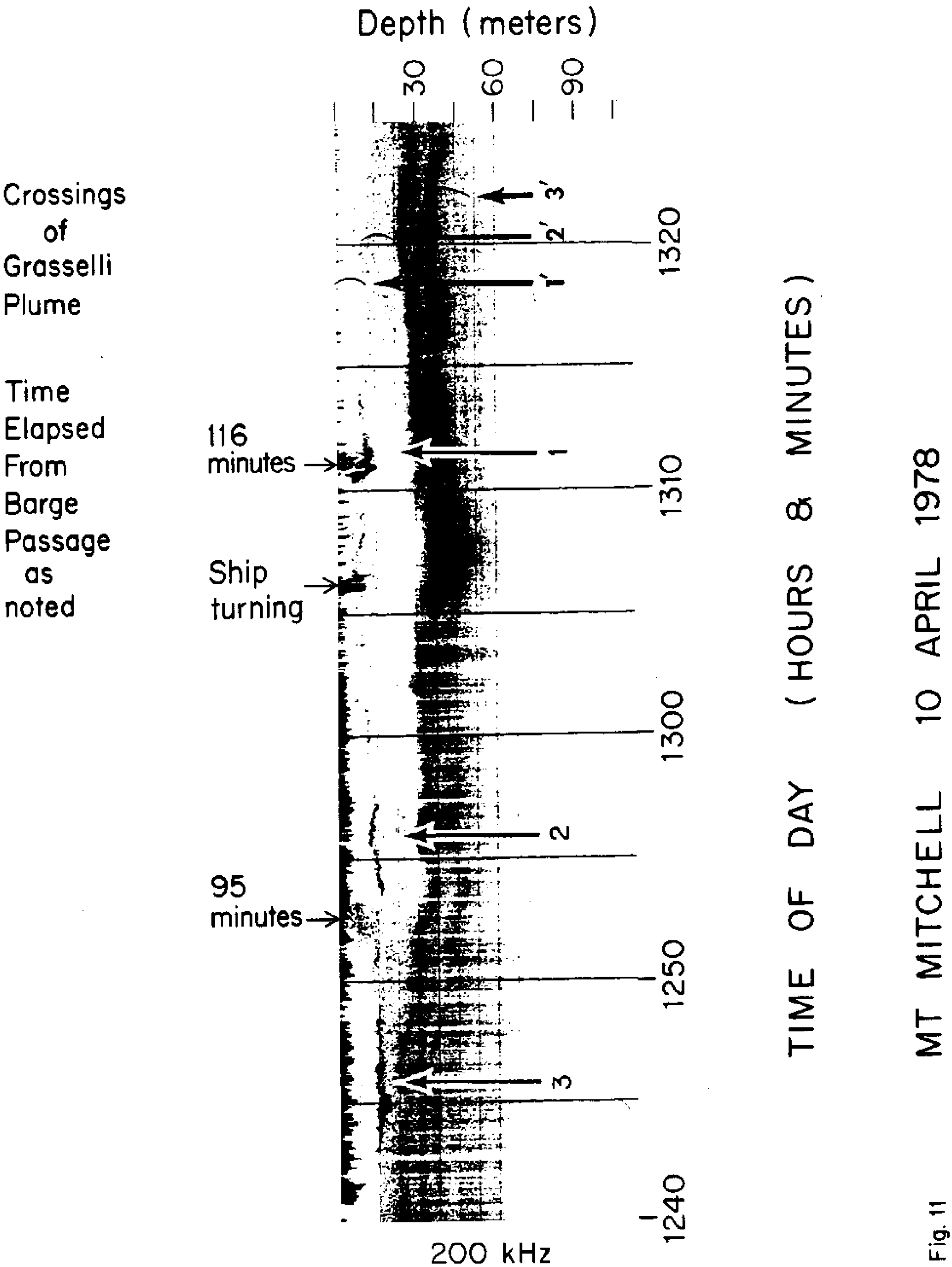
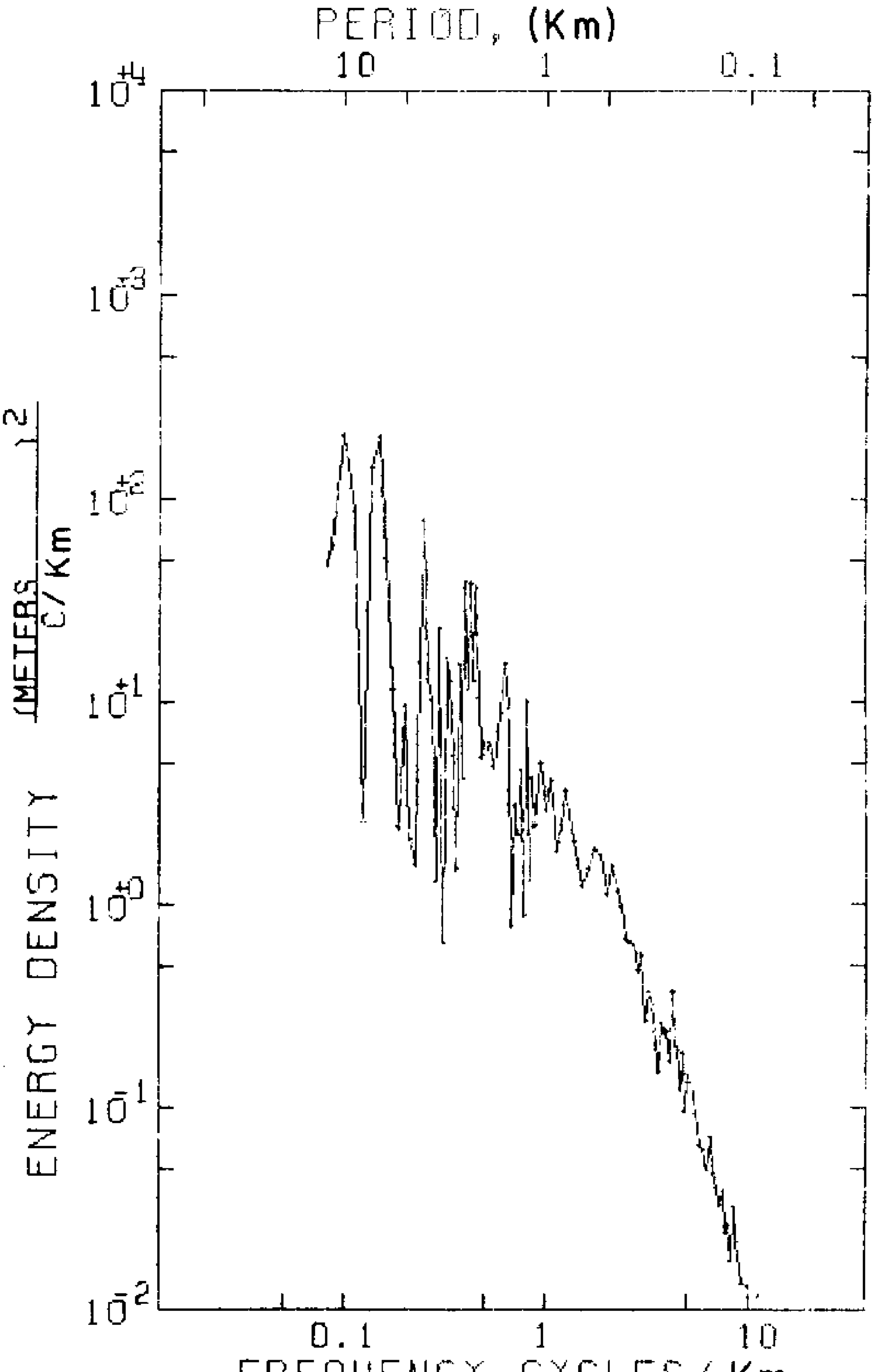

Depth (meters)
30
60
90
Crossings of Grasselli Plume
Time Elapsed From Barge Passage as noted
116 minutes
Ship turning
95 minutes
1'
2'
3'
1
2
3
1320
1310
1300
1250
1240
200 kHz
TIME OF DAY (HOURS & MINUTES)
MT MITCHELL 10 APRIL 1978

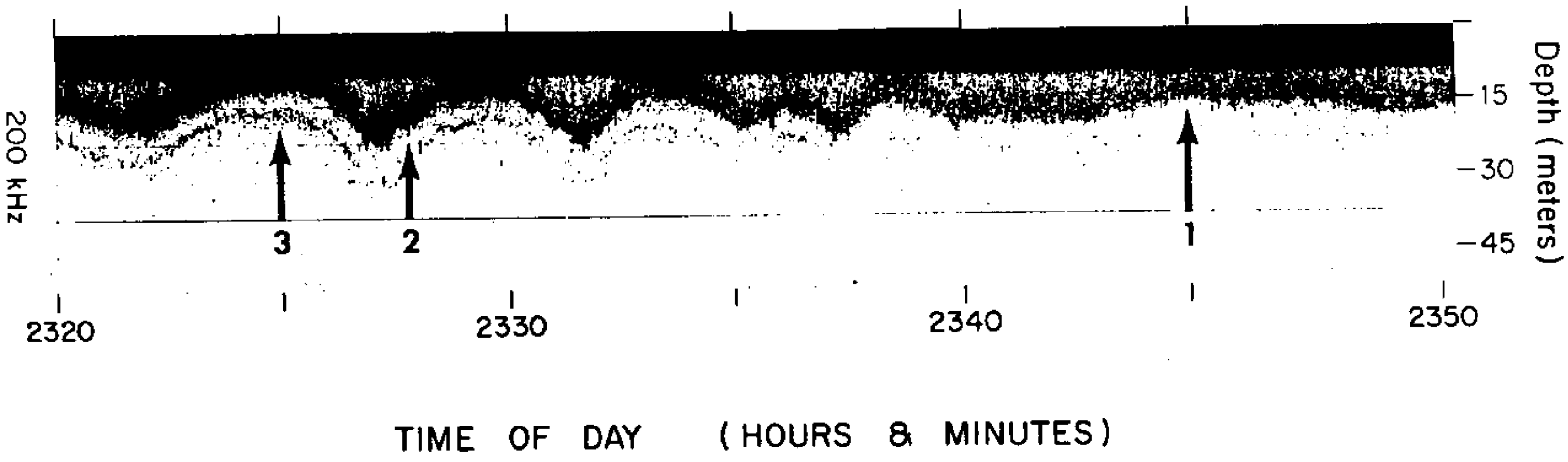
Fig. 11



JASIN W.H.O.I.
ORR

Fig. 12

SEPT. 3, 1978



ALBATROSS IV 26 July 1977 Edge Moor Waste

riding an internal wave

480 minutes after barge passage

Fig. 13

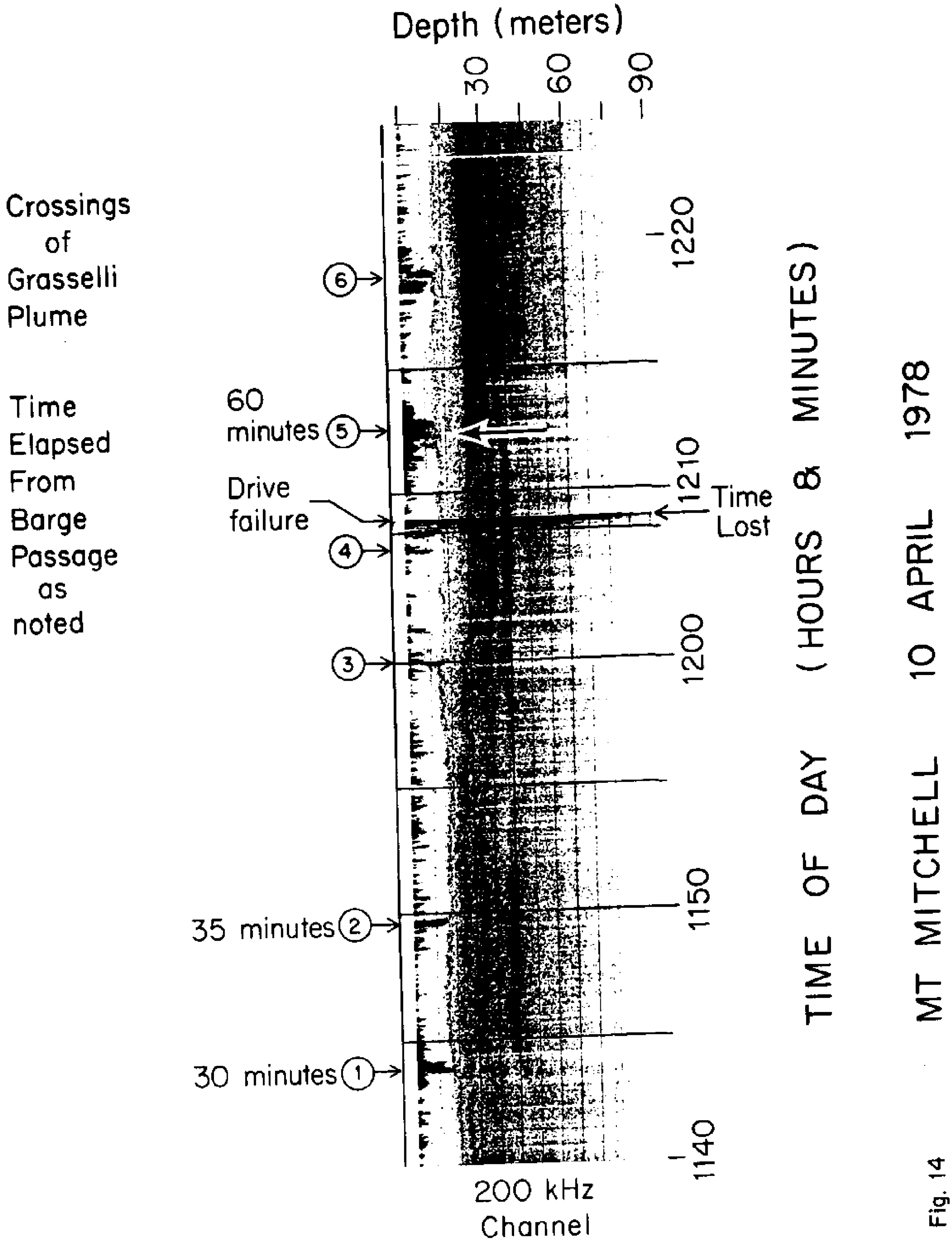

Crossings of Grasselli Plume
Time Elapsed From Barge Passage as noted
Depth (meters)
30
60
90
60 minutes
Drive failure
Time Lost
30 minutes
35 minutes
1220
1210
1200
1150
1140
200 kHz Channel
TIME OF DAY (HOURS & MINUTES)
MT MITCHELL 10 APRIL 1978

Fig. 14

ALBATROSS IV 2 FEB 1978

Edge Moor Waste
about 6.6 hours after barge passage

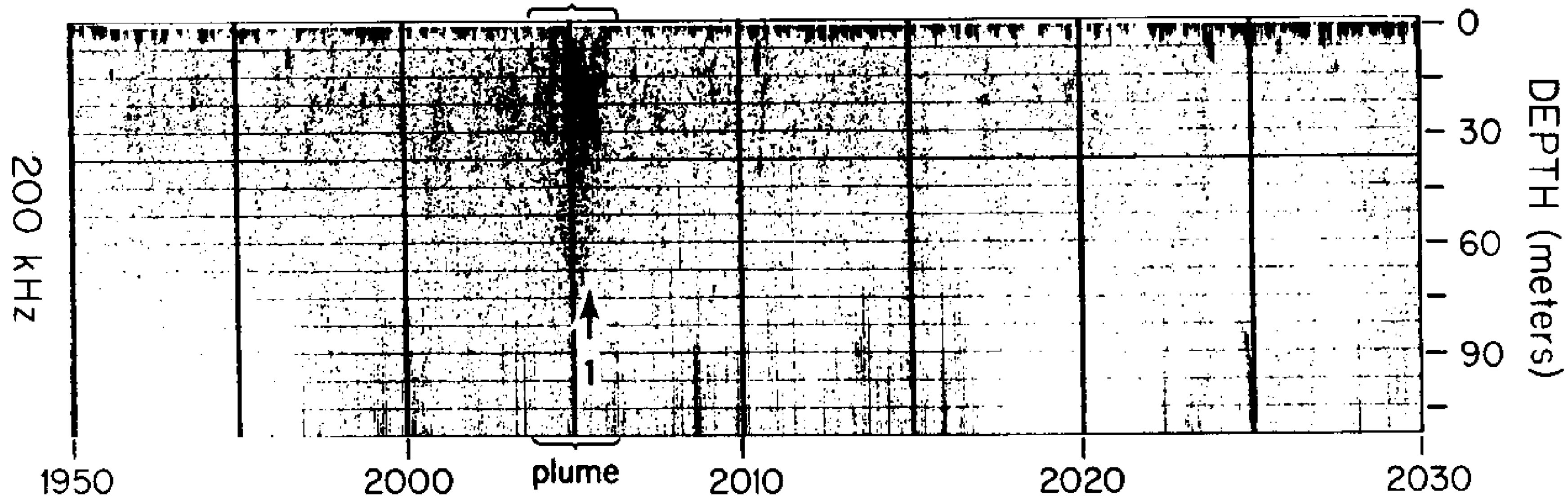


Fig. 15

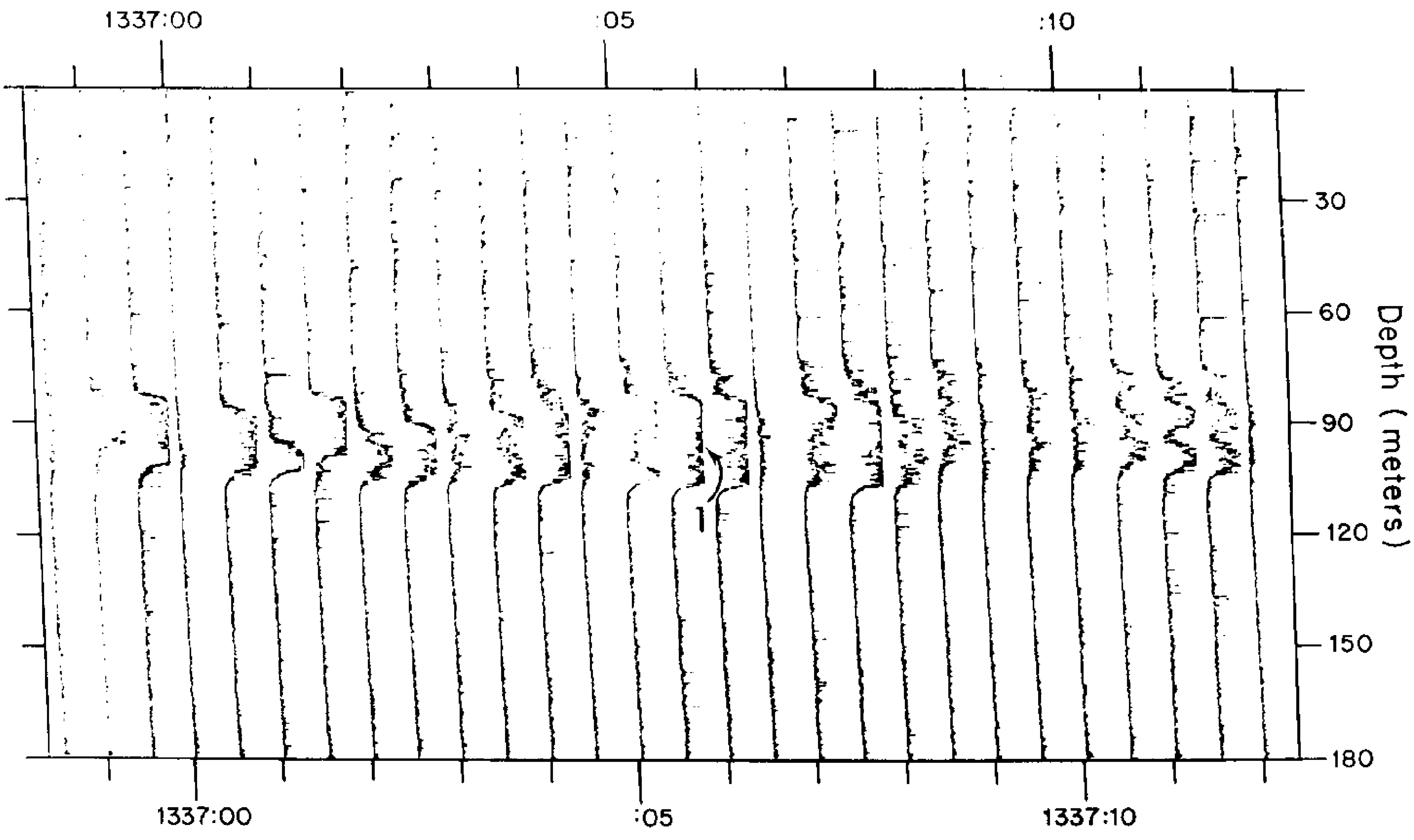


Fig. 16 ALBATROSS IV 2 Feb 1978 Edge Moor Waste

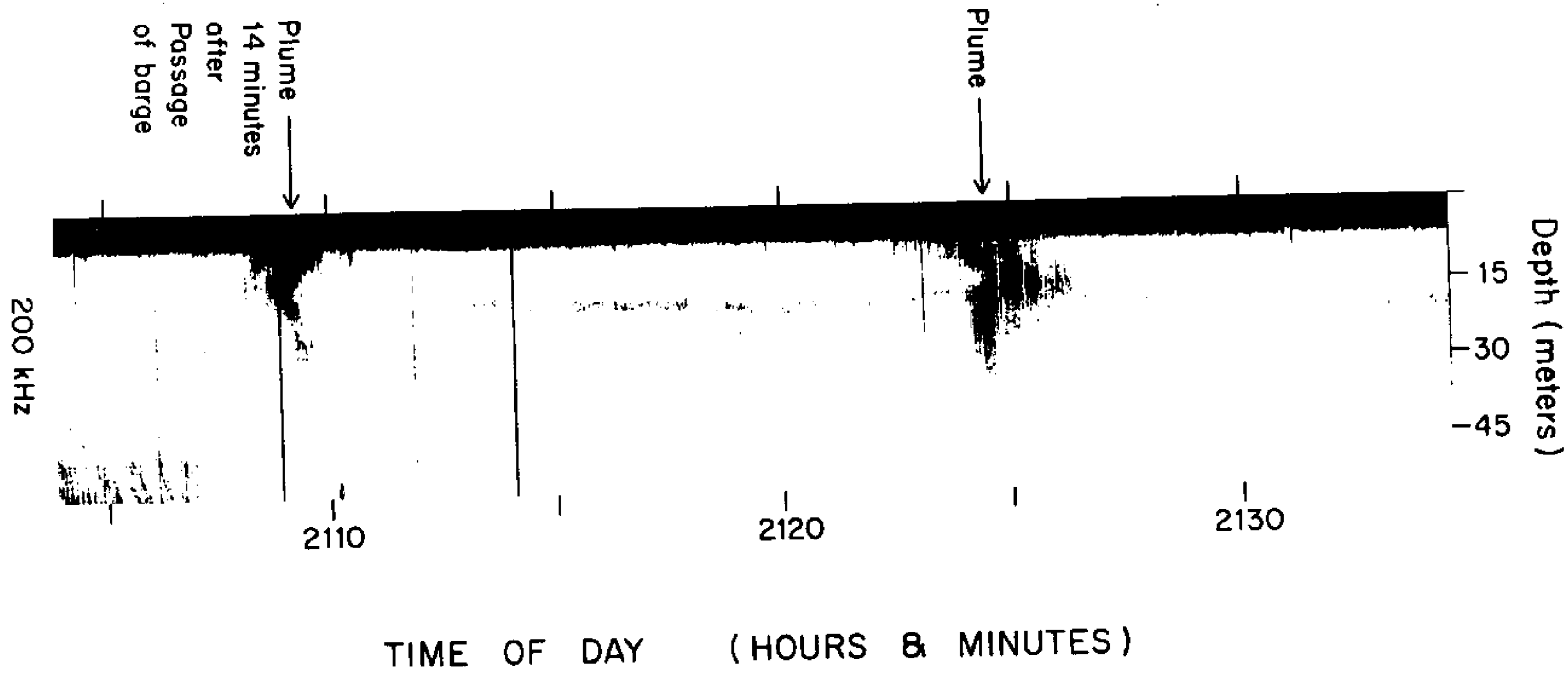
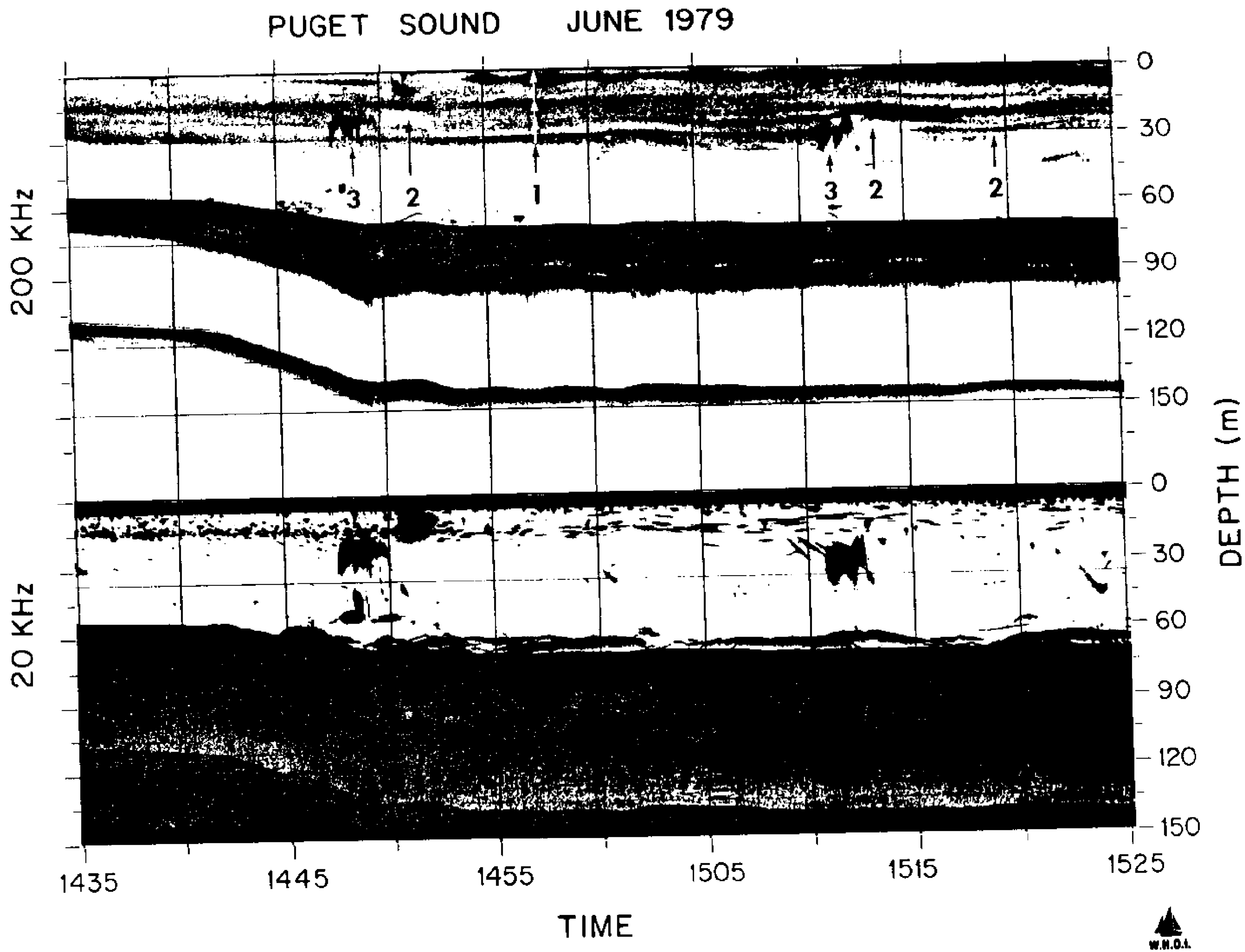
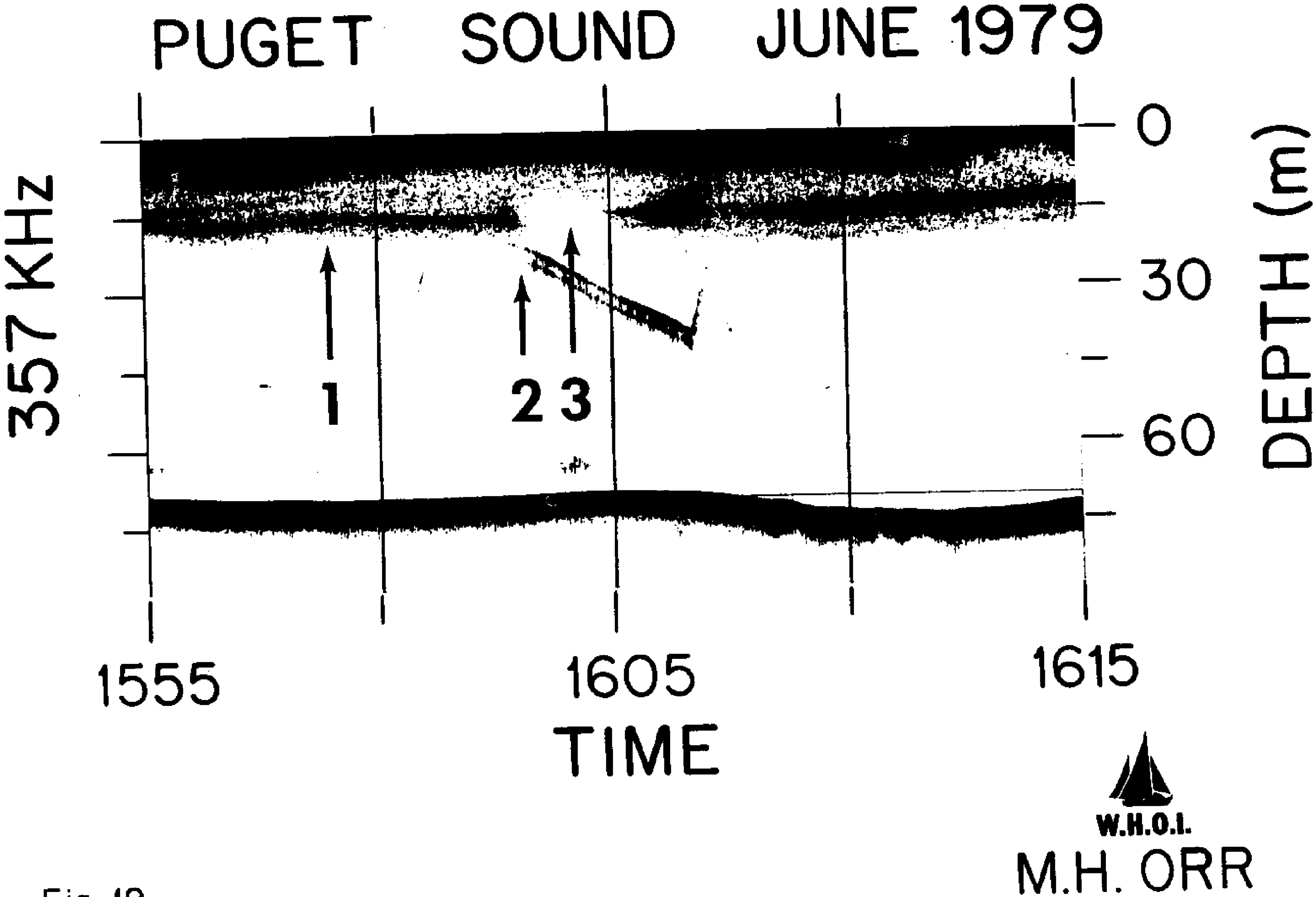


Fig. 17 PEIRCE 23 July 1977 Sewage Sludge Dump



PUGET SOUND JUNE 1979
200 KHz
20 KHz
DEPTH (m)
0
30
60
90
120
150
3
2
1
3
2
2
1435
1445
1455
1505
1515
1525
TIME
W.H.O.I.
M.H.ORR

Fig. 18



PUGET SOUND JUNE 1979
357 KHz
0
30
60
DEPTH (m)
1
2 3
1555
1605
1615
TIME
W.H.O.I.
M.H. ORR

Fig. 19

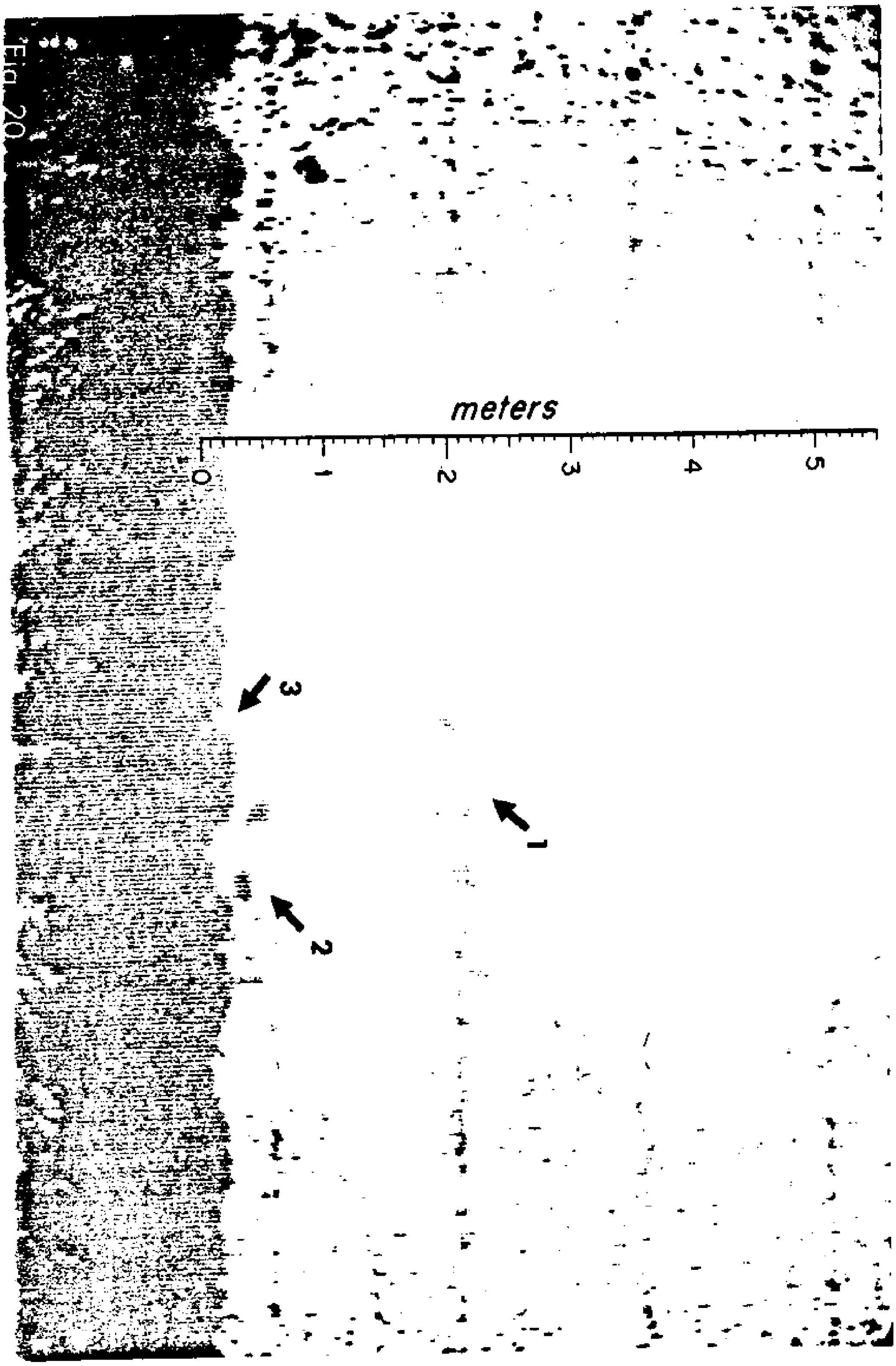


Fig. 20

OARS Paper # 13

ESTIMATION OF WIND SPEED AND STRESS AT THE SEA SURFACE FROM AMBIENT NOISE MEASUREMENTS

by D. Randolph Watts
University of Rhode Island

Knowledge of the wind speed and stress is of central importance to studies of oceanic response to atmospheric forcing. Either the wind stress magnitude or the vectorial wind stress is an essential parameter in such diverse subjects as surface exchange processes of heat and dissolved substances, the deepening of the wind mixed layer, the generation of surface waves and the wind-driven circulation. Direct estimation of the wind stress requires detailed measurement of the structure of the wind field above the surface, or of the turbulent dissipation. Wind stress is expressible as a quadratic function of the wind velocity with a drag coefficient subject to uncertainties due to surface roughness and air stability. Wind speed observations over the ocean from ships may be "fair weather biased," and wind stress is considerably underestimated by the square of the mean wind speed.

We have been working on a novel way of monitoring the winds over the ocean by measuring the acoustic ambient noise level from the safety of the ocean bottom. For many years acousticians have known that ambient noise levels increase with increasing surface agitation. Wenz (1962) reviews the knowledge of ambient noise in the ocean. Figure 1 is from his work, showing noise spectral level as a function of acoustic frequency. The two principal contributions are from shipping noise and from a wind-induced surface source. Additional intermittent sources are from biologically generated noise and from rainfall. At frequencies above 2 kHz distant shipping noise is relatively unimportant and wind dominates the spectrum. Above 30 kHz thermal noise of molecular agitation can overwhelm the levels generated at low wind speeds.

In the band 2 to 20 kHz where the principal source is the wind generated surface noise, the spectra decrease with increasing frequency with a slope of about -17 dB/decade, and the spectral levels shift with increasing wind speed as described by Knudsen (1936). The mechanism by which the sound is produced remains poorly understood. Whitecaps and spray must create noise at sea states where they exist, however ambient noise levels increase steadily also with lower wind speeds, from below 1 knot to 8 knots, where whitecaps are absent.

Three suggested mechanisms that could generate the observed spectra are (i) wave motion alone near the surface (Marsh, 1963), (ii) generation by capillary patches ("cats paws") on the sea surface (Kuo, 1968), and (iii) the excitation of small bubbles near the surface which then radiate efficiently at their natural acoustic frequencies (Wenz, 1962). Later investigations have shown that the noise level correlates better with wind speed than with wave height (Perrone, 1969).

The inversely posed problem, namely of deducing wind speed from measurements of ambient noise level, is partially solved by Shaw, Watts and Rossby (1978). We found in observations during MODE good correlation between surface wind speed and ambient noise level at 5 kHz, despite the relatively low quality surface wind data obtained by ships in the region. The logarithm of the wind speed was found to vary linearly with noise spectral level, as had been earlier observed by Piggott (1964) and Crouch and Burt (1972). A sample calculation of wind stress from an assumed drag coefficient was presented, and we presented the hypothesis that the noise generation should be directly related to the wind stress being applied to the sea surface rather than to the wind speed. In that paper we also called attention to the fact that precipitation is known to generate high levels of noise in the ocean (Heindsmann, Smith and Arneson, 1955). The spectrum is nearly "white" in the 2 to 30 kHz range and can exceed the wind noise levels, particularly at high frequencies. The spectral level rises with increasing precipitation rate (Franz, 1959). Thus the "red" wind-generated noise is distinguishable from the "white" rain-generated noise by monitoring more than one frequency.

Recently David Evans and I have collaborated at URI to build an ambient noise instrument package which may be simply deployed on any mooring. (We have called the instrument WOTAN, for Weather Observation through Ambient Noise.) The measurement technique is quite simple: the noise voltages from a sensitive omnidirectional broadband hydrophone are amplified and passed through narrow band filters ($\pm 7\frac{1}{2}\%\ f_c$). The center frequencies, 4.3, 8.0, and 14.5 kHz are chosen to span the range of interest and to avoid active pinger frequencies typically employed for Swallow float tracking, depth sounding, and other man-made sounds. The logarithm of the rectified signal is taken electronically to deal with the wide dynamic range of noise levels which may be encountered. Each channel is then voltage-to-frequency converted, counted and recorded on a digital cassette recorder. Much of the electronics was designed by Mr. Winfield Hill of Sea Data Corp., which also produces the recorder.

We build two WOTANs for deployment in the JASIN experiment northwest of Scotland. They were placed on a Kiel Inst. f. Meersk. mooring and Woods Hole mooring, which had a vector averaging wind recorder (VAWR) at the surface. The instruments measured the average noise spectral level (NSL) every two minutes at the above three frequencies and recorded the results on cassette tapes. The WOTAN on the Kiel mooring functioned perfectly, however the one on the WHOI mooring failed in one track of the tape recorder shortly after deployment. The record obtained was at a depth of 1500 m in water 2200 m deep.

In processing these data we first applied the calibration of Shaw, et al.* to produce wind records shown in Figure 2 for comparison with directly measured winds by the VAWR on Woods Hole's mooring, 5 km distant. These essentially raw records illustrate good and bad portions peculiar to this record. Note first the relatively clean portion of data from 10-18 August. Here the full range of observed winds, 0.1 to 12 m/s is tracked well at all time scales. With the initial calibration there are small differences in the magnitudes of the winds produced by the different acoustic frequencies, which are resolved below.

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*adjusted for the Knudsen -17 dB/decade slope

The initial spike on 9 July represents noise during launch by R/V Meteor. The Meteor returned to keep a station 1 km from the mooring from 23 July to 6 August and performed yo-yo CTD work. This unfortunately created considerable noise. Commencing 10 August there was a 5 day port call during which most of the JASIN ships were absent from the region. During this period the best agreement is obtained with the VAWR winds. The Meteor also worked near the WOTAN mooring 22-25 August. Except for the influences of locally generated man-made noise, the records are visually very coherent with the wind speed record. Even during the noisy period the envelope of minimum noise/wind estimates agrees with the directly measured winds, i.e. the ship could only add noise, but was occasionally quiet. On a normal remote deployment of a WOTAN, this problem would not exist.

The clean portion of the records from 10-14 August is used now to refine the empirical linear relationship between the NSL and the log of the observed wind speed. Figure 3 shows the 14.5 kHz channel digital counts ($\propto$ NSL) plotted vs log (VAWR wind). The noise levels are consistent with the Knudsen spectra with regard to their dependence upon acoustic frequency and wind speed. The best fit linear relationship for each channel is then used to refine the acoustically deduced winds and plot them versus those observed (Fig. 4). A wind record may thus be produced equally well from any one of the channels. Work is in progress on an algorithm which utilizes data from the three frequencies to check the relative NSL's for consistency with a wind-generated origin in order to edit points and produce more faithful wind records.

At this point however the results already indicate that the wind speeds agree within ± 2.5 m/s or better from 3 to 12 m/s. The relationship improves at higher wind speeds, and had higher winds existed, should extend without problem. (For comparison the specifications for the SEASAT scatterometer are ± 5 m/s above 5 m/s.)

A sample spectrum of the WOTAN winds from the clean period before 23 July is shown in Figure 5. We see the same levels and slope (-5/3) with increasing frequency as in spectra from the VAWR. This figure also illustrates the advantage of a continuous measurement to study the statistical properties of the wind above the sea, i.e. a subsampled (non-time-averaged) wind record would suffer significant aliasing in the highest octaves it attempts to resolve.

Another advantage of the acoustic wind measurement over point measurements is the intrinsic spatial averaging resulting from a distributed noise source. For the JASIN deployment Figure 6 depicts the sound speed profile and the refracted ray paths which reach the instrument at 1500 m. Accounting for the appropriate absorption losses, and integrating over each annular source region, we find that the 14.5 kHz noise originates within approximately a 6 km radius of the instrument, the 8 kHz noise respectively within about 12 km, and the 4.3 kHz noise arrives almost evenly distributed out to the refraction limit of 16 km (see inset above the ray diagram).

The Knudsen spectra are generally taken as guidelines which are expected to vary in absolute level by about 5 db depending upon geographic area, depth of the water and of the hydrophone, proximity to the coast, and seasonal changes in stratification. NSL's can be expected to be 5 to 10 dB higher in coastal waters for a given wind speed and frequency. There is no clear indication of any variation with depth in deep water; works that have suggested such dependence have made their measurements non-simultaneously and/or at a varying distance from shallow waters. Very few papers deal with noise frequencies above 3 kHz.

Therefore in new locations and depths the acoustic determination of wind records must be empirically calibrated against some direct wind observations. A small seasonal variation in this "calibration," which we expect to be $<$ 1 or 2 dB at 4 kHz and nil at 14 kHz, can be compensated for by source area/attenuation integrations such as were illustrated above.

Kevin Kolodzy at URI is examining how well the wind velocity (speed and <u>direction</u>) can be determined by combining WOTAN and synoptic surface pressure charts during the records in JASIN. Angular variability in the wind fortunately varies on a longer time scale than speed, so in principle this should work on geostrophic time scales applying a small ageostrophic correction as in Willett and Sanders (1959). We are also interested in testing some methods by which it may be possible to determine direction acoustically.

Altogether, the acoustic method of monitoring surface winds over the ocean offers several advantages. The instruments are relatively simple and inexpensive and sit in the safety of the ocean bottom for long periods unattended. The continuous time series allows one to obtain unbiased statistics regarding the wind field; in particular the average wind stress may be properly determined from $\langle v^2 \rangle$ rather than $\langle v \rangle^2$.

List of Figures

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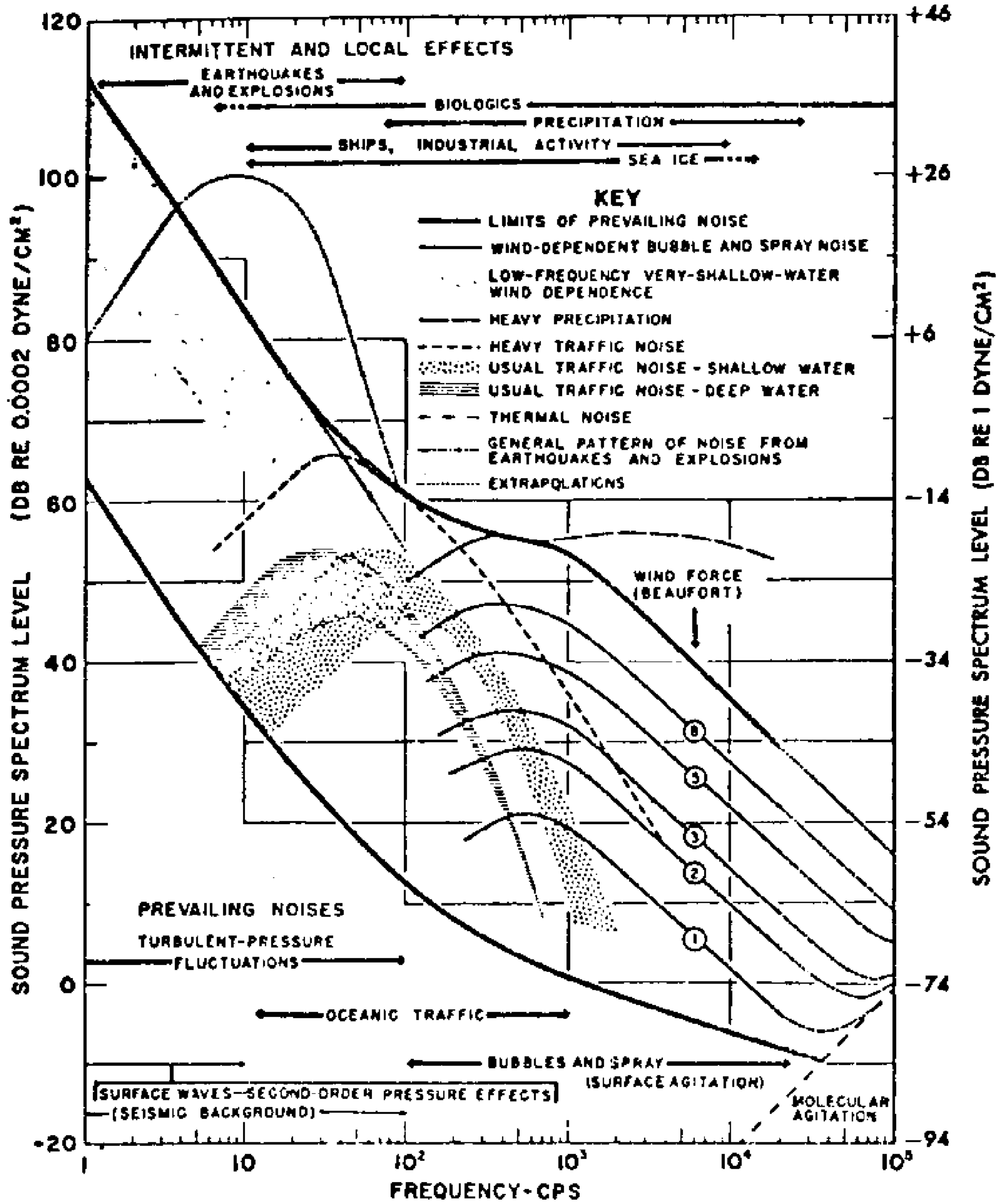


FIGURE 10.—Composite of Ambient Ocean Noise Spectra (Wenz, 1962)

Figure 1

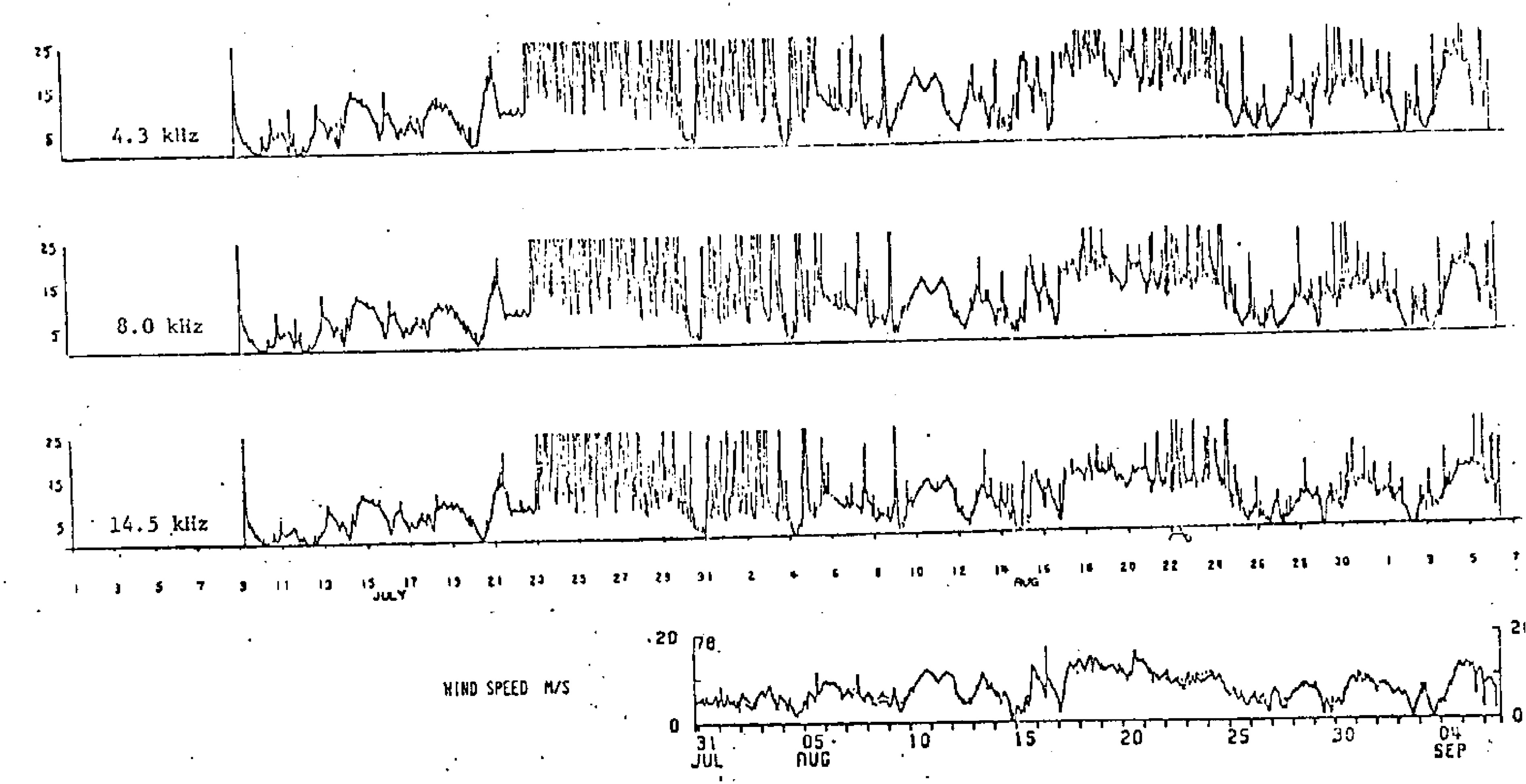
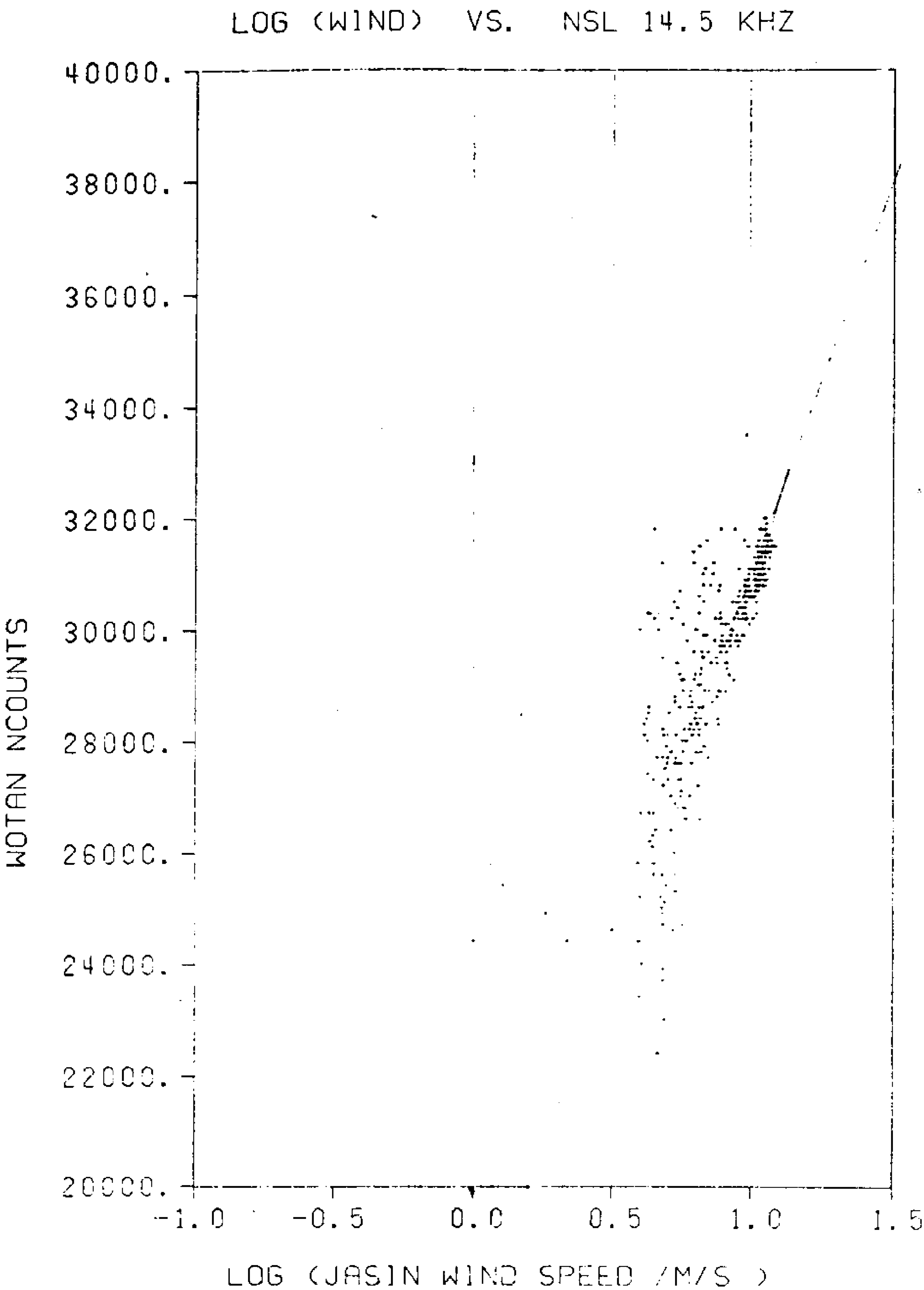

WIND SPEED M/S
4.3 kHz
8.0 kHz
14.5 kHz
25
15
5
JULY
AUG
WIND SPEED M/S
.20
78
0
21
31
JUL
05
AUG
10
15
20
25
30
04
SEP

Figure 2



LOG (WIND) VS. NSL 14.5 KHZ
40000.
38000.
36000.
34000.
32000.
30000.
28000.
26000.
24000.
22000.
20000.
WOTAN NCOUNTS
-1.0
-0.5
0.0
0.5
1.0
1.5
LOG (JASIN WIND SPEED /M/S)

Figure 3

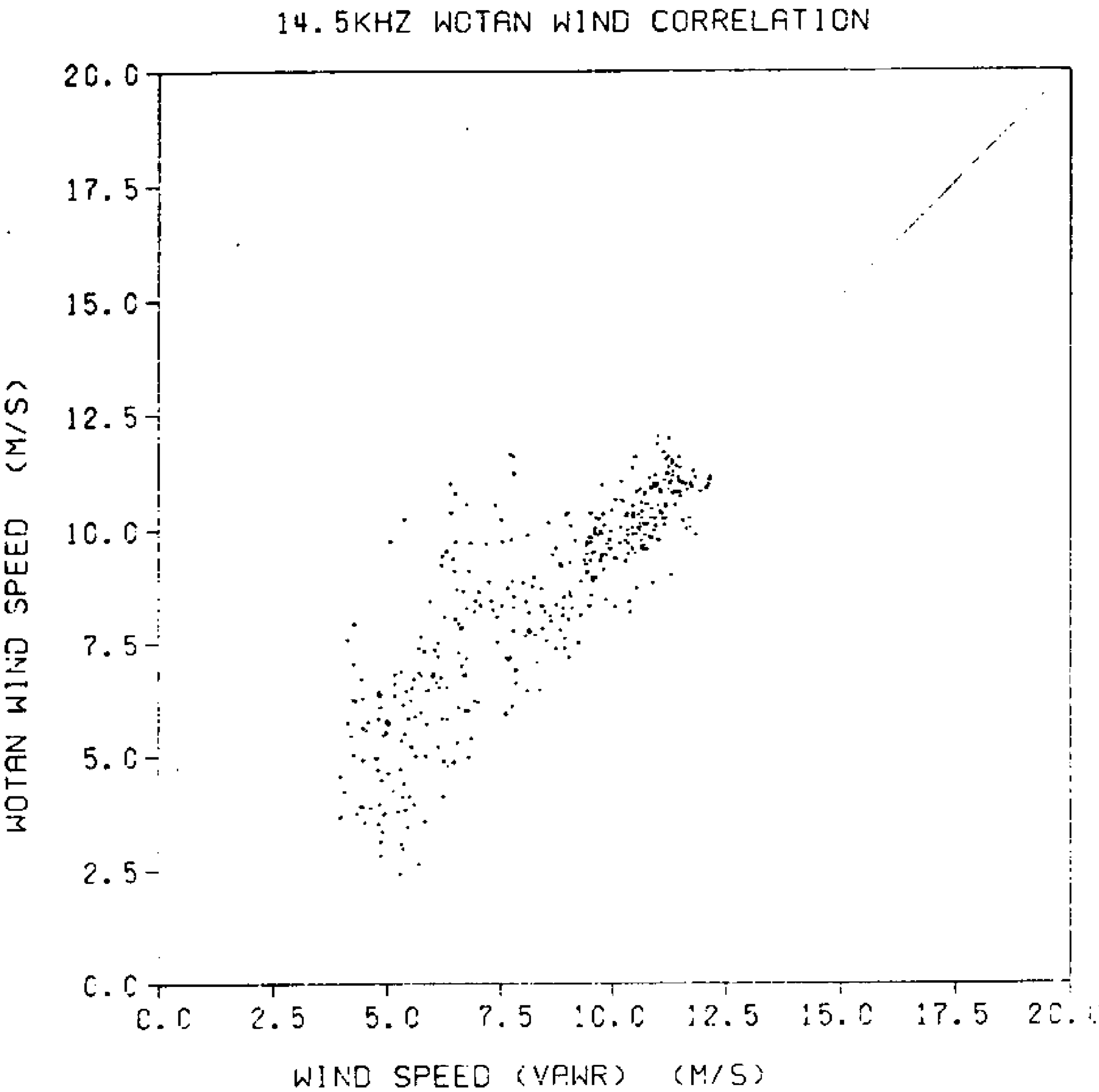
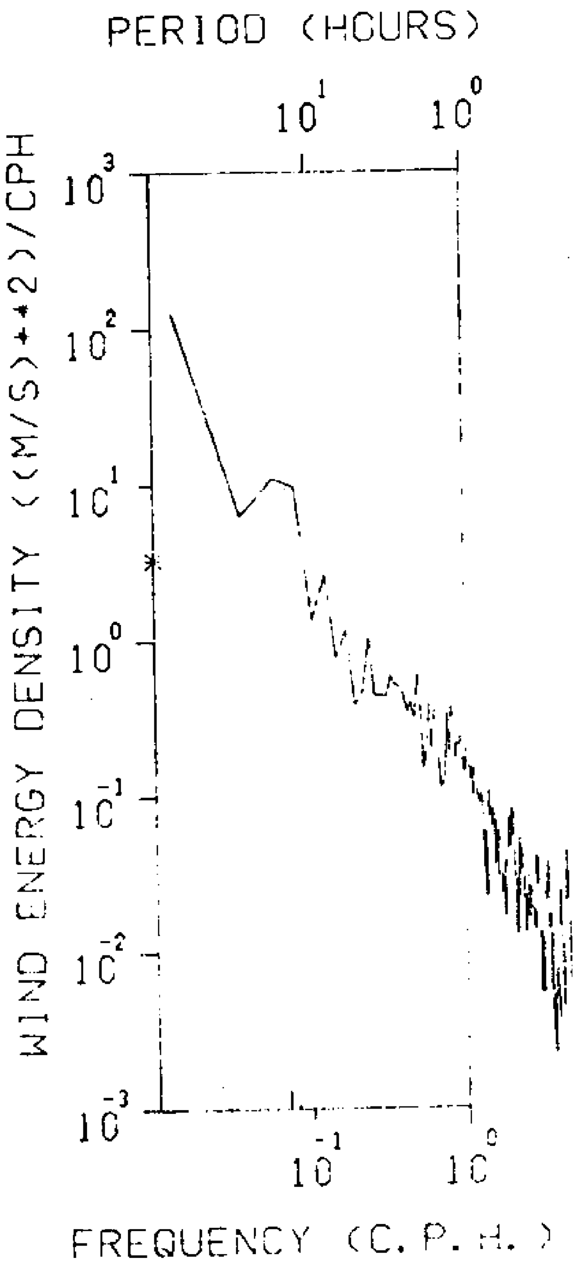

14.5KHZ WOTAN WIND CORRELATION
WOTAN WIND SPEED (M/S)
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
WIND SPEED (VAWR) (M/S)

Figure 4



PERIOD (HOURS)
10^1
10^0
WIND ENERGY DENSITY ((M/S)**2)/CPH
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-1
10^0
FREQUENCY (C.P.H.)

Figure 5

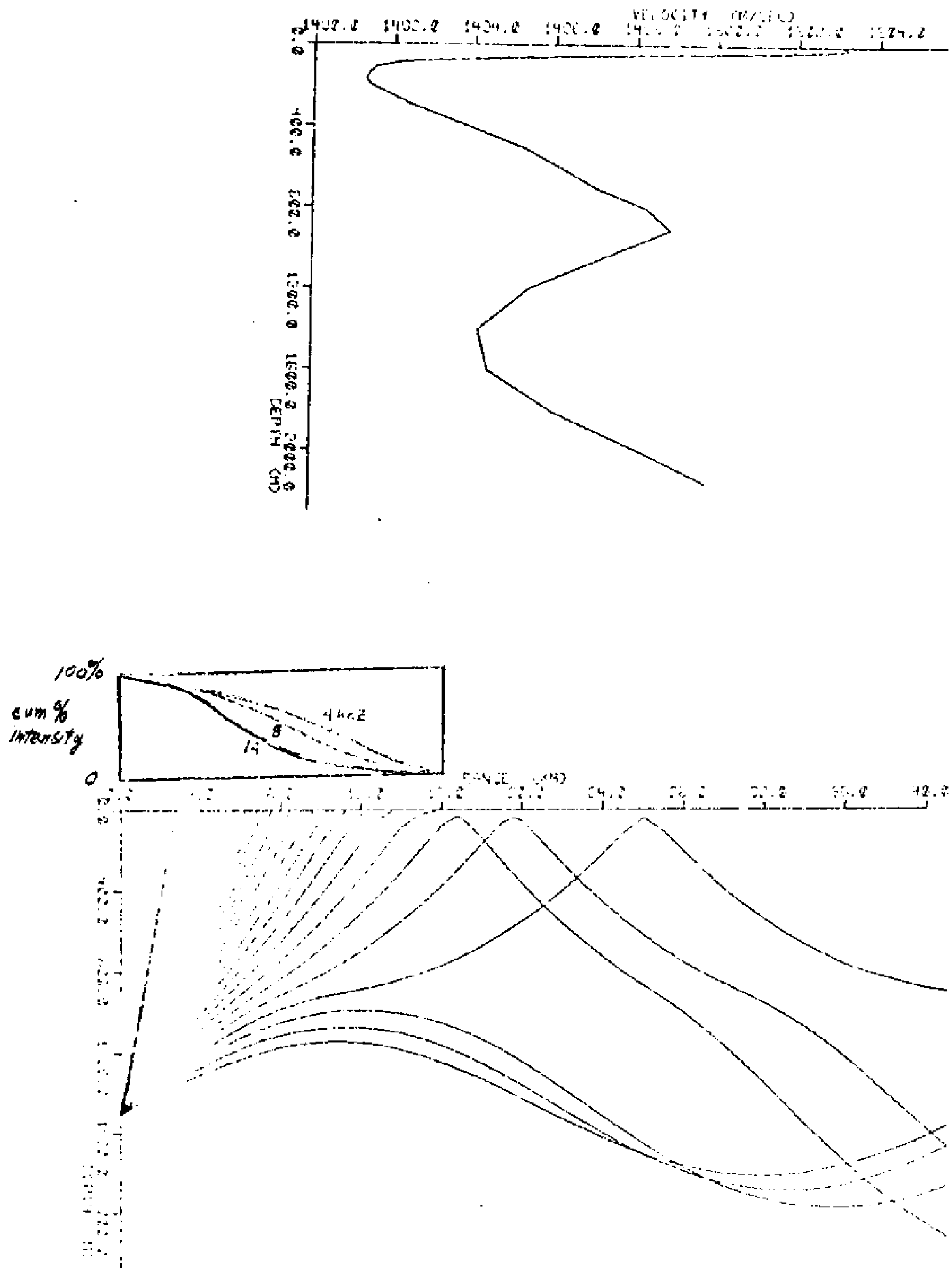


Figure 6

Report on Atmospheric Remote Sensing, with a Special Emphasis on Acoustic Echosounding

by

C. Gordon Little
Wave Propagation Laboratory/NOAA

Introduction

The organizers of this workshop have suggested that a summary of some of the things we in the Wave Propagation Laboratory have learned in the process of developing an atmospheric remote sensing program might be helpful to you. I hope that this is true.

The Wave Propagation Laboratory was set up in 1967 in recognition of a basic fact of geophysics. In geophysics, the nature and scope of the research you can perform, and of the services you can provide are determined by the observational data sets you can obtain.

In other words, if you have the right data sets, i.e., the relevant parameters can all be measured on the right time and space scales, then the research can advance rapidly, and the services can be accurate and timely. But if you do not have the right data set--i.e., you can't measure the right parameters, or you can't measure them on the right time and space scales--then the research progress is halted, and the services will be inadequate or irrelevant.

The next point is that since we are dealing with three-dimensional fluids containing processes of very many scales, the data sets that we must be able to obtain must be three-dimensional. Further, such data sets will be terribly expensive to obtain and often impracticable to obtain by in situ sensors. Recognizing this situation then, the Wave Propagation Laboratory was set up in 1967 to explore the potential for remotely sensing the parameters of the atmosphere and the ocean.

The potential advantages of remotely sensing ocean and atmospheric parameters are many. These include the facts that the data are conceptually available:

in one, two, or three spatial dimensions,

without the use of towers, balloons, or aircraft,

with excellent continuity in space and time,

with excellent resolution in space and time,

over a wide range of parameters,

as spatial averages, and,

using systems which may be readily automated.

In attempting to summarize the status of progress in realizing the above advantages of remote sensing of atmospheric parameters, let me first list the primary measurements that are required for atmospheric research and services. Basically, we are concerned with several levels of data. The simplest data sets to acquire are those at the surface. A second level of complexity occurs when we attempt to provide vertical profiles of the parameter. Maximum complexity occurs when we try to obtain the full three-dimensional field of the parameter. In each case--surface data, vertical profiles, and three-dimensional fields--it is important to recognize that we may be concerned only with the mean value of the parameter, or we may also wish to know the strength of the fluctuations of the parameter, or we may wish to know the vertical flux of the parameter. In other words, we may be interested in, for example, the wind speed, or we may be interested in the fluctuation of the wind speed, (i.e., the turbulence), or we may be concerned with the vertical flux of momentum. For each of the three primary meteorological parameters of winds, temperature, and humidity then we need (for research purposes at least) to be able to obtain the surface values of the mean, fluctuating, and vertical fluxes; the vertical profiles of each of these three aspects of the parameter, and the full three-dimensional fields of each of the three aspects.

The next three tables summarize the current status of ground-based remote sensing for wind, temperature, and humidity, respectively. In the case of wind we see that we are able to measure remotely, in some cases by redundant techniques, the surface value of mean wind speed and direction by optical scintillations; vertical profiles of the mean, fluctuating, and flux components; and the full three-dimensional field of the mean wind speed and direction, and of the intensity of turbulence.

For temperature, less progress has been made. The surface values can be measured by optical time of flight or optical scintillation techniques, and we have some ability to measure the vertical profiles; unfortunately, at this time, and indeed for the foreseeable future, we do not have the ability to measure the full three-dimensional fields of temperature, temperature fluctuation, and heat flux.

Our ability to measure the humidity parameter is even less. There we have an ability to measure path-averaged values of the mean humidity near the surface using differential absorption, and we have some ability to measure the vertical profile of humidity by microwave radiometric approaches. But again, we do not have the ability to measure the full three-dimensional field of either the mean value, the fluctuating component, or the flux. The status of remote sensing of precipitation is summarized in Table 4 and of remote sensing of clouds in Table 5.

I have chosen two areas of atmospheric remote sensing for discussion in somewhat greater detail. These are respectively, optical scintillation and acoustic echosounding techniques. They are chosen because acoustic analogues seem to me likely to have some application or relevance to ocean remote sensing.

Figure 1 is a photograph of a laser beam incident upon a sheet of paper after it has propagated some several hundred meters or even a few kilometers in the free atmosphere. Note that the distribution of light is highly variable in position; photographs taken just a few milliseconds apart show that the pattern of light is highly variable both in space and time. This pattern is, of course, the product of propagating light through a medium whose refractive index is a fluctuating quantity, primarily due to slight fluctuations of temperature associated with mechanical turbulence. These scintillations have been studied over the years by our Optical Sensor Applications group, under the leadership of Mr. R. S. Lawrence, and including Dr. Stephen F. Clifford and Dr. Reginald Hill who are with us today. Over the years, this group has learned how to predict and interpret these scintillation phenomena, and using this understanding how to design and construct remote sensing techniques capable of extracting meteorologically significant information. One might assume that an irregular fluctuating pattern such as indicated in Figure 1 contains very little information on the medium through which the light has passed. This group, however, has shown that the intensity of the fluctuations is directly related to the path-averaged intensity of the fluctuations in refractive index and therefore to the intensity of the atmospheric temperature fluctuations. Since these are empirically related to the vertical heat flux, measurement of the intensity of the scintillation has provided a simple, low-integration-time method of measuring vertical heat flux. By studying the intensity of the scintillations as a function of their spatial size, they are able to derive information on the distribution along the optical path of the intensity of these temperature irregularities. By looking at the time delay between the arrival of scintillations at two closely spaced apertures in the scintillation pattern, they have shown that it is possible to deduce the path-averaged transverse wind speed. The use of two such systems at approximately orthogonal directions permits the derivation not only of averaged wind speed but also average direction. By using three or more such transverse wind measuring paths in a closed circuit, they are able to measure the convergence or divergence of air in the plane incorporating the paths. On a single path, looking at the differences in transverse wind speed for irregularities of different sizes, they are able to derive information on the profile of transverse wind speed as a function of position along the path.

The above discussion relates to scintillations observed during clear air conditions; the group has also shown that under rain or hail conditions it is possible to derive the path-averaged rainfall rate, and the path-averaged drop-size distribution. Similarly, nearly all the above work makes use of manmade light sources, either an incandescent lamp or a laser beam. These authors, however, have shown that such a manmade source is not required and that the scintillations of natural scenes containing adequate contrast, can be used to measure transverse wind speed.

Thus, it is possible from a full understanding of the propagation theory of optical waves through a turbulent medium to derive considerable information on the properties of that medium. This enables me to make a point that I very much wish to stress, namely, that remote sensing requires an accurate model and understanding of the basic propagation theory on which it is based. The reason that this group has been able to extract so much information from the scintillation pattern is that they and others have built up a very full understanding of the propagation of optical signals through a turbulent medium. Propagation theory provides the fundamental base on which all remote sensing must build and I would strongly urge that this workshop recognize this fact both in its deliberations and its recommendations.

The next and closing area that I wish to speak to briefly relates to our use of acoustic waves in the atmosphere. Basically, over the past ten years we have shown that acoustic waves can be used, in an inverted sonar-type echosounding mode, in the atmosphere to measure the structure of the atmosphere, profiles of velocity, profiles of mechanical turbulence and dissipation rate, and the depth of the atmospheric mixing layer. Thermal plumes and atmospheric gravity waves are readily identified and studied by these acoustic echosounding techniques. By now scores of groups around the world are using acoustic methods of probing the atmosphere for both research and operational purposes. Later this week you will hear from Ted Brown of the Wave Propagation Laboratory of some new work he is doing to develop an interferometric method of measuring atmospheric temperature profiles in the lowest hundreds of meters of the atmosphere. We feel that we have made considerable progress in understanding how to use acoustic waves for remote sensing purposes in the atmosphere and look forward to participating in this workshop on oceanic remote sensing by acoustic techniques.

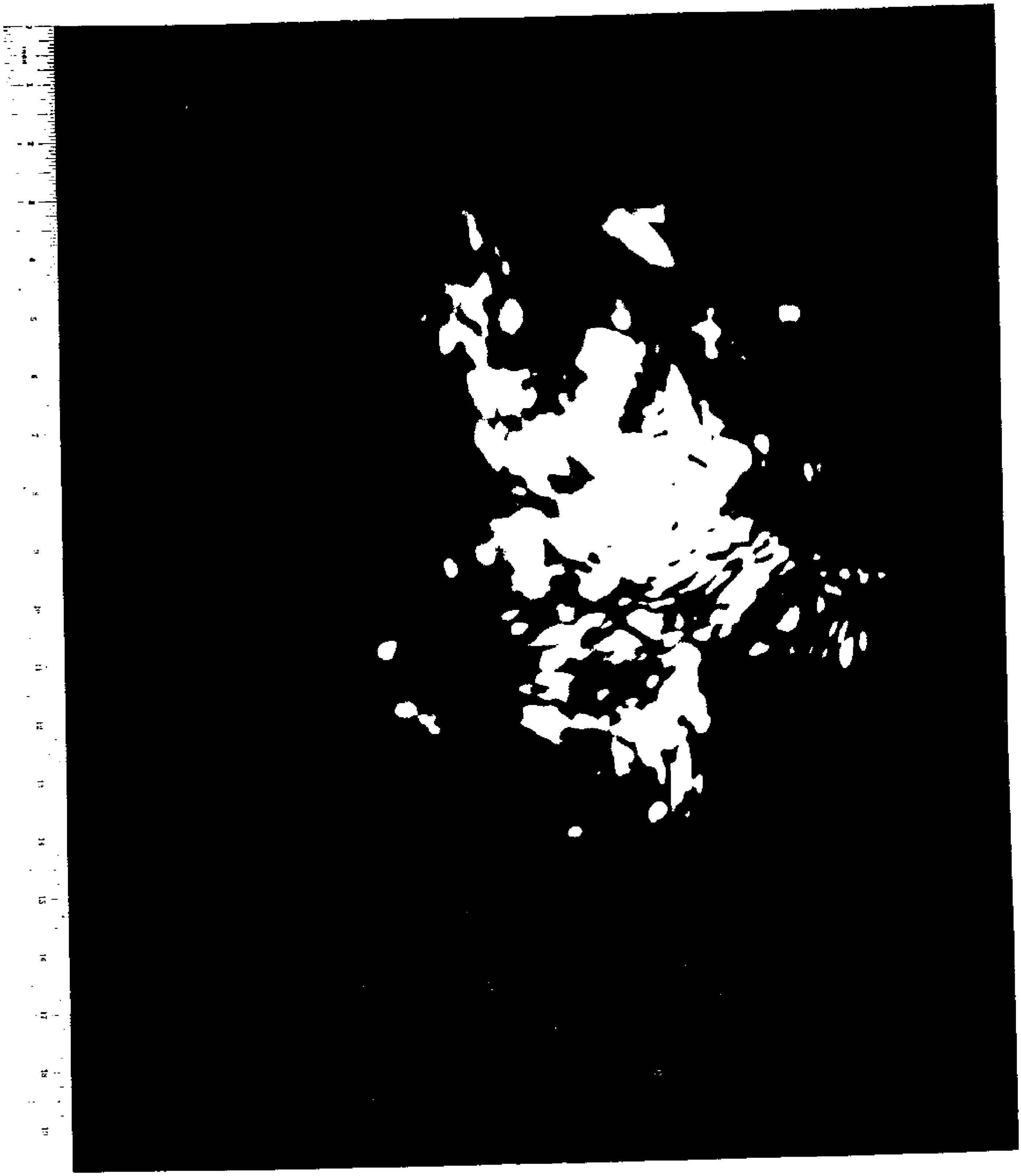


Figure 1

Table 1

STATUS OF REMOTE MEASUREMENT OF WIND

Type of Measurement	Demonstrated Techniques
Surface values	
Mean	Optical scintillations
C_V	---
Momentum flux	---
Vertical profiles	
Mean	Microwave, acoustic, IR Doppler
C_V	Microwave, acoustic Doppler
Momentum flux	Microwave Doppler
3-D field	
Mean	Microwave Doppler
C_V	Microwave Doppler
Momentum flux	---

Table 2

STATUS OF REMOTE MEASUREMENT OF TEMPERATURE

Type of Measurement	Demonstrated Techniques
Surface value	
Mean	Optical time-of-flight
C_T	Optical scintillation
Heat flux	Optical scintillation
Vertical profiles	
Mean	Microwave radiometry
C_T	Acoustic sounding
Heat flux	---
3-D field	
Mean	---
C_T	---
Heat flux	---

Table 3

STATUS OF REMOTE MEASUREMENT OF HUMIDITY

Type of Measurement	Demonstrated Techniques
Surface values	
Mean	Differential absorption
C_e	---
Moisture flux	---
Vertical profiles	
Mean	Microwave radiometry
C_e	---
Moisture flux	---
3-D field	
Mean	---
C_e	---
Moisture flux	---

Table 4

STATUS OF REMOTE SENSING OF PRECIPITATION

Type of Measurement	Demonstrated Techniques
Surface values	
Mean rainfall rate	Optical scintillation Microwave absorption Microwave radar
Drop-size distribution	Optical scintillation
Vertical integral	
Liquid water	2λ microwave radiometer
3-D field	Microwave radar
Phase identification	Polarized lidar
(Ice/water)	Polarized radar

Table 5

STATUS OF REMOTE SENSING OF CLOUDS

Type of Measurement	Demonstrated Techniques
Phase identification	Polarized lidar
Integrated liquid water	2λ microwave radiometer
Base height	Lidar
3-D distribution	
Cloud particles	Lidar/8mm radar
Median diameter, Liquid water	Proposed matched 3cm/8mm radars

OARS Paper #15

ATMOSPHERIC AND OCEANIC ACOUSTIC REMOTE SENSING ANALOGIES

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1. INTRODUCTION. Acoustic remote sensing denotes the use of sound waves for detection and measurement. In "active" remote sensing the observer originates the sound; in "passive" remote sensing the sound occurs naturally. We call active remote sensing systems "monostatic" if the locations of the transmitter and receiver coincide; and "bistatic," in other cases. The interactions of the transmitted sound with the medium of propagation produce changes in the received sound. These changes form the raw data for the remote sensing process.

Both air and (sea) water represent normal fluids and, with the exception of surface tension, both share similar, though quantitatively different, physical properties. If we avoid the ground or the sea surface, wave propagation in the atmosphere and oceans should undergo the same physical phenomena, including reflection, refraction, diffraction, scattering, interference, and (in case of motion) the Doppler effect. Thus, we can easily construct naive analogies between atmospheric and oceanic acoustics.

In 1635 Gassendi made the first measurement of the speed of sound in the atmosphere using his own pulse to time the delay between the noise and the flash of a musket. Atmospheric acoustic remote sensing began in 1704 with the research of Derham.[1] Derham invented an improved timing mechanism (which he called an "automaton") and, then, proceeded to study every influence on sound propagation that he could imagine, including the effects of wind, topography, geographic location, diurnal and seasonal variations, and atmospheric conditions. He devised a classification for wind speeds, invented a method for measuring winds by observing the motion of chaff (real chaff, not the metallic fibers used today in Doppler radar studies), and demonstrated a quantitative relation between winds and changes in sound speeds. He first noted the scattering of sound from clean air but, at this early period, could only guess at the physical mechanism. In addition, he made a "systems analysis" of the technique he called "echometry"--range finding, or the measurement of distances by timing echo delays--and applied the techniques to a measurement of the width of the Thames river (projected attempts to measure the width of the English Channel and the Straits of Gibraltar failed due to the outbreak of a war).

In 1827 Colladon and Sturm made the first measurement of sound in water. Apparently, the first application of oceanic acoustic remote sensing occurred just after the sinking of the Titanic. During the period 1912-1914, Richardson, Fessenden, and Hunt separately obtained[2] patents on various kinds of "echometers." The inventors, and others, demonstrated the usefulness of the echometer for determining the underwater distance to icebergs and, later, to schools of fish. In 1957, as part of the Symposium on Naval Hydraulics, Batchelor[3] derived the correct equation for the scattering of sound by turbulence, and by fluctuations in an arbitrary "passive additive," such as salinity or temperature. Apparently, Batchelor's paper had little or no impact on the naval or oceanographic communities. However, over a decade later, the result found an application in assisting in the correction of an error in Tatarskii's[4] atmospheric scattering cross-section.

The earliest acoustic remote sensing techniques, sketched above, relied on the phenomenon of reflection. In 1968 McAllister[5] constructed the prototype of all later "echosondes," an instrument which depended, instead, on scattering (in this case, scattering caused by atmospheric temperature fluctuations). In 1969 Little[6] analyzed and developed the theory underlying the operation of the echosonde, and initiated much of the research on modified forms, such as the bistatic echosonde (also sensitive to turbulent velocity fluctuations) and the Doppler echosonde (for remote sensing of wind fields). In 1975 Fisher and Squier[7], and Proni and Apel[8] adapted the echosonde for studies in the ocean, particularly for the study of internal waves, in the first case, and for study of both internal waves and dispersal of oceanic pollutants, in the second. For the atmospheric acoustic remote sensing field, Brown and Hall[9] have reviewed the rapid progress made over the last decade. Despite a few disappointments, the rate of progress has been such as to require a period of consolidation and evaluation before the field could catch its breath and move in new directions (we will discuss one of these--the temperature remote-sensing echometer--later in the talk).

The above brief history of the field of acoustic remote sensing may strike some as a frivolous diversion. But, in fact, we have the serious purpose of exhibiting and emphasizing the weak and random nature of what, for brevity, we can call the air-sea interaction, that is, the air (science)--sea (science) interaction. Many of the techniques recently developed for the atmosphere have considerable potential for oceanic remote sensing. Without a doubt, oceanic researchers have gained insights and information that would have similar value in the atmospheric field. Therefore, development of a NOAA policy for strengthening this "air-sea" interaction, and for encouraging cooperative research between atmospheric remote sensing groups and oceanographic groups, both within NOAA and in other research institutions (such as the Scripps Institution of Oceanography and the Woods Hole Oceanographic Institute) would bring valuable returns to the research communities.

2. STRUCTURES AND SCALES. The Introduction suggested that we can easily construct analogies between wave phenomena in the atmosphere and oceans. The real problem that needs study lies with the differences and failures in the analogies due to quantitative changes in structures and scales. But, this implies that an analysis actually covering the subject promised by the title must include almost all of atmospheric and oceanic science. Clearly, we must cut the problem down to manageable size and, even then, consider the proposed ocean tomography experiment: the plan of the experiment envisages ringing a roughly 1000 km diameter section of ocean with sound sources and hydrophones in order to detect, measure,

and track oceanic gyres (and other structures) of approximately 100 km diameter. An analogous experiment in the atmosphere would require ringing an entire continent about 10,000 km in diameter with low-frequency or infrasound sources and receivers to obtain similar information on atmospheric cyclones and anticyclones approximately 1000 km in diameter. Probably, one could show such an experiment in the atmosphere to be physically unsound. And, even neglecting the complaints of the few hundred million people within the ring, the cost would make the experiment absurd. Thus, an experiment feasible in one case becomes unfeasible in the other due to the change in scale.

From the point of view of overall spatial and temporal averages, both the atmosphere and the oceans represent stable fluid layers. Thus, the global averaged Väisälä frequency N, given by $N^2 = -(g/\rho)(d\rho_0/dz)$ with ρ_0 the potential density, g the acceleration of gravity, and z the vertical coordinate, represents a key factor in appropriate scales. For the atmosphere, $N_{atmos} \approx \sqrt{g/H} \approx g/c \approx 10^{-2}\ s^{-1}$, where H is the scale height and c the speed of sound. For the oceans, a rough calculation gives $N_{ocean} \approx N_{atmos} \sqrt{\rho_{atmos} / \rho_{ocean}} \approx 10^{-3}\ s^{-1}$. Thus, the overall frequencies of the two fluid bodies differ by a factor of ten. We can use the Rossby deformation radius given by Rhines[10] as $L_R = ND/f$, with D the layer depth and f the Coriolis parameter, as a horizontal length scale. Since the depth of the ocean ($\approx$ 6 km at some points) roughly equals the scale height of the atmosphere, the horizontal scales of Coriolis-influenced atmospheric and oceanic structures must also differ by a factor of ten. At mid-latitudes in the atmosphere $L_R \approx 10^{-2} \times 10/10^{-4} \approx 1000$ km and, in the ocean $L_r \approx 100$ km.

Any fluid moving with respect to a solid boundary develops a boundary layer of some thickness h within which conditions at the surface directly influence the fluid structure. In the atmosphere, the atmospheric boundary layer (ABL) has undergone intensive study over the last ten to twenty years. In the ocean, the benthic boundary layer (BBL), a turbulent layer just above the ocean bottom, represents the true analogue of the ABL. Pedlosky[11] has shown that, for a quasi-geostrophic fluid with a maximum horizontal velocity U, $fL/NH \approx U/NH \approx 1$ and thus, in our analogue, the ratio N/U should be a constant. But, this implies that the friction velocity u_* (defined by the shear stress at the boundary) should depend linearly on N. Thus, for average values with the same surface roughness $u_{*ocean} \approx 0.1\ u_{*atmos}$. For the BBL, $u_* \approx 0.1\ m\ s^{-1}$ and, for the ABL $u_* \approx 1.0\ m\ s^{-1}$, represent typical maximum values. The thickness h of a neutral boundary layer approximately satisfies the relation $h = \alpha u_*/f$. For the atmosphere, Wyngaard[12] gives $\alpha \approx 0.25$, and, for the ocean, Wimbush and Munk[13] have suggested $\alpha \approx 0.4$. If we also introduce the N-dependent correction function obtained by Weatherly and Martin[14] the respective approximate stable boundary layer thicknesses become $h_{BBL} \approx 10$ m and $h_{ABL} \approx 100$ m.

The above analyses suggest that comparisons of active remote sensing in the atmosphere and the oceans should restrict attention to a maximum scale between the typical boundary layer thickness h and a scale considerably less--say, a factor of 100--than the Rossby deformation radius L_R; that is, for the ocean, scales between 0.01 km and 1.0 km, and for the atmosphere, scales between 0.1 km and 10 km. In the ocean, such a restriction permits consideration of remote sensing in the oceanic mixed layer (typically 100 m thick) or even down to the thermocline. In the atmosphere, the range includes the unstable ABL, where thermal plumes increase h to anywhere from 1.0 to 3.0 km. (We remark that, although "plumes" of other types exist in the ocean, atmospheric thermal plumes have no oceanic analogue except, perhaps, over hot vents in the deep ocean floor.) In passing, we note that acoustic remote sensing provides measurements of the thickness of the ABL, and could do so for the BBL and the oceanic mixed layer, as well.

3. WINDS AND CURRENTS. Design of systems for wind measurements began within a few years of the construction of the first monostatic echosondes. The most obvious method for such measurements applies the Doppler effect, with either multiply-pointing monostatic echosondes, or sets of bistatic echosondes aimed at a single scattering volume. NOAA's Wave Propagation Laboratory recently sponsored an international intercomparison, and comparison against anemometers on the 300 m tower at the Boulder Atmospheric Observatory. This intercomparison showed that--at least for the best instruments--Doppler echosondes can provide 3-dimensional wind field profiles of very satisfactory accuracy, and can extend the profiles up to as much as 1 km in altitude. Figure 1 sketches the geometry of the WPL bistatic system; Figure 2 shows a scatter plot of the comparison with tower instruments. Figure 3 shows results from an identical system deployed in a valley near The Geysers (a geothermal power plant) to assist DOE in a study of the ABL in rugged terrain. We note that the WPL system has a cost advantage over older designs using FFT data processing, an improvement obtained by substituting a complex covariance method that lies within the capacity of an inexpensive microprocessor.

For the ocean in or just below the surface layer, Pinkel[15] has built a rotatable monostatic Doppler echosonde that can provide a 2-dimensional plot of horizontal ocean currents. Peynaud and Pijanowski[16] recently reported encouraging results on the more difficult task of making acoustic Doppler current measurements in the surface layer from a moving ship. With the JANUS configuration for the acoustic beams (used both for the current measurements and the corrections for ship motions), they obtained profiles to 100 m depths with 3 m resolution. We note that, if measurements of currents in, or just above the BBL should have value, either in oceanography (perhaps measuring density currents from polar seas), or in ocean pollution studies (perhaps, the dispersal of tritium), construction of a Doppler echosonde for the purpose lies within the present state of the art.

Correlation methods provide alternatives to the use of the Doppler effect. Some of such techniques can measure average velocities of large-scale flows, when small spatial resolutions become unnecessary or undesirable. The earliest correlation attempt compared the intensity patterns of two vertically-pointing monostatic echosondes spaced less than 50 m apart. Lawrence, Ochs, and Clifford[17] developed a much more sophisticated approach that allows greater accuracy as well as the measurement of large-scale flows. A single "line-of-sight" beam (horizontal for near-surface winds) traverses the flow. The instrument correlates the outputs of two spaced detectors at varying time delays and, then, relates the slope of the resulting curve at zero delay to the path-averaged wind. A triangle with optical, rather than acoustic, beams has operated at the Boulder Atmospheric Observatory for about a year and measured both components of the horizontal near-surface wind. We expect a cooperative program soon that will carry out a similar experiment with a single acoustic beam in the ocean. For measurements of profiles of speed, alone, Zhou and Qu[18] of the Institute of Atmospheric Physics, Academia Sinica in Beijing (Peking) have developed an alternative scheme--using a single, vertically-pointing monostatic echosonde--that correlates the returns from successive pairs of pulses, with a variable, small altitude difference taking the place of a time delay. Though inherently less precise, the technique may find an application in measuring wind speed profiles in an urban environment that would not permit any of the previous configurations.

4. TEMPERATURE PROFILES. Temperature represents one of the most important meteorological variables. Temperature variations and the flow of heat in surface and sub-surface currents may play a major role in the air-sea interaction and, thus, in climatology. Monin, Kamenkovich, and Kort[19] remark that the temperature field is the most important of the oceanological fields studied in fisheries-related oceanology. Despite the success of the echosonde in observing geophysical turbulence, winds, and ocean currents, no practical extension of acoustic remote sensing to measurement of temperatures and temperature profiles has appeared feasible until now. Other non-acoustic remote sensing methods have limitations in geometry or resolution. The importance of temperature observations in geophysics thus forces the continued use of costly and intermittent devices, such as radiosondes in the atmosphere or XBT's in the ocean.

In 1976, Brown, Little, and Wright[20] conducted an experiment that combined the scattering of sound (as in an echosonde) with the formation of 3-dimensional fringes in space by constructive interference of properly-spaced sources (as in a Young's interferometer). Recently Brown[21] described an acoustic remote sensing thermometer, for which he reclaimed the old designation of echometer, that combines the principles of the above experiment with techniques that include curve fitting of pulse envelopes and measurement of the mean phase within pulses. Preliminary results indicate that the echometer may provide temperature measurements to within, in the atmosphere, a few tenths, and in the ocean, a few hundredths of a degree Kelvin, to range up to about 500 meters, and with spatial resolutions of about 10 m, in the atmosphere, or about 1 m, in the ocean.

Figure 4 sketches the geometry of a possible mounting of an echometer on a ship. In actuality, wind or current produces an additional effect--much like a sonic anemometer--that, for correction, or simultaneous measurement--requires a symmetric arrangement. Figure 5 shows the configurations under evaluation for the atmospheric tests. The following two Figures show some of the promising results achieved with the echometer, to date. Figure 6 compares the relative temperature changes measured with the echometer at an altitude of about 50 m, to the temperatures given by a thermometer on a nearby 10 m mast, late in a sunny morning, with developed thermal plumes moving through the array at, from about 1 to 3 m s^{-1}. Figure 7 compares echometer measurements at about 500 m altitude with thermometer values at the top of the 300 m BAO tower (also at about 300 m horizontal distance), and shows a period of late afternoon cooling. Just as in the oceanic mixed layer the variances of temperature fluctuations decrease with depth, in the atmospheric boundary layer variances decrease with increasing altitude. Such altitude effects plus the separations in location would appear to account for the differences in measurement between echometer and thermometer.

5. CONCLUSIONS. Adoption of a NOAA policy for strengthening interchange between atmospheric and oceanic acoustic remote sensing groups, and of supporting cooperative research programs, would lead to much greater progress in both fields. For one example, application of the scintillation method for measuring average values of large-scale flows could find immediate use in measuring total mass currents through ocean channels and straits. For a second, the continued development of the echometer for use both in the atmosphere and the oceans could lead to the capability of simultaneous measurement of depth profiles of temperature, current, and heat flow.

Any such interchange based on the analogues between atmospheric and oceanic acoustic remote sensing, however, should take special care to analyze the differences between the two applications--differences that might suggest alternative approaches or major changes in parameters. For example, tracking of pulse envelopes probably leads to sufficient accuracy for the high-frequency echometer measurements of temperature and currents in the ocean. But, with practical operating frequencies for the atmosphere, suitable accuracy requires the addition of techniques for determining the mean phase of the scattered sound. Such techniques probably would not bring further increases in accuracy in the ocean, however, since the preponderant part of the returns appears due to incoherent scattering from nekton, bubbles, and particles, rather than the coherent scattering from a continuous field of turbulent fluctuations in the atmosphere.

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FIGURE CAPTIONS

1. Bistatic Doppler echosonde geometry.
2. Doppler echosonde-tower wind comparisons.
3. Doppler echosonde winds in rough terrain.
4. Echometer geometry for oceanic temperatures.
5. Echometer test configurations.
6. Echometer measurements of thermal plumes in late morning.
7. Echometer temperatures during late afternoon cooling.

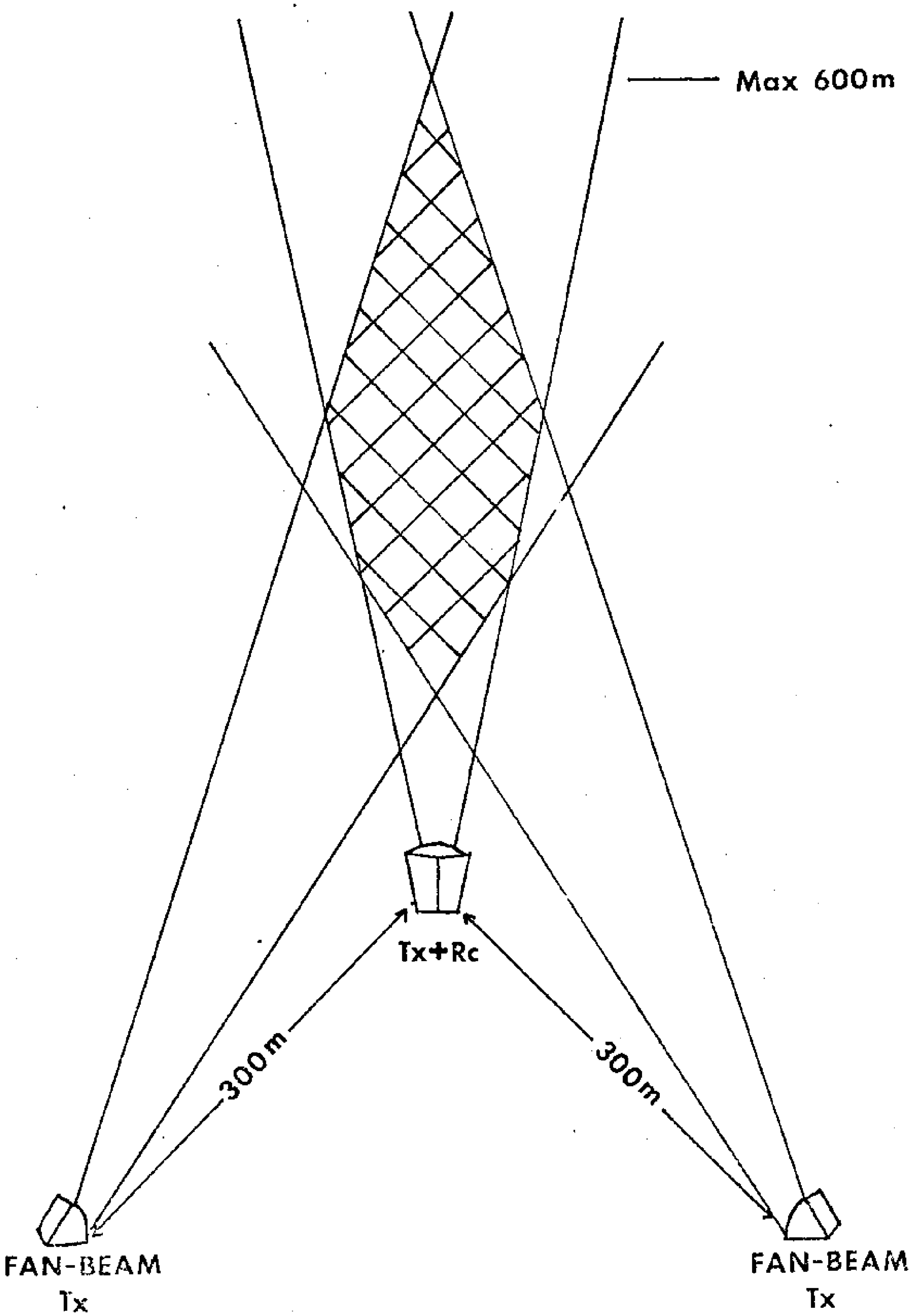


FIGURE 1

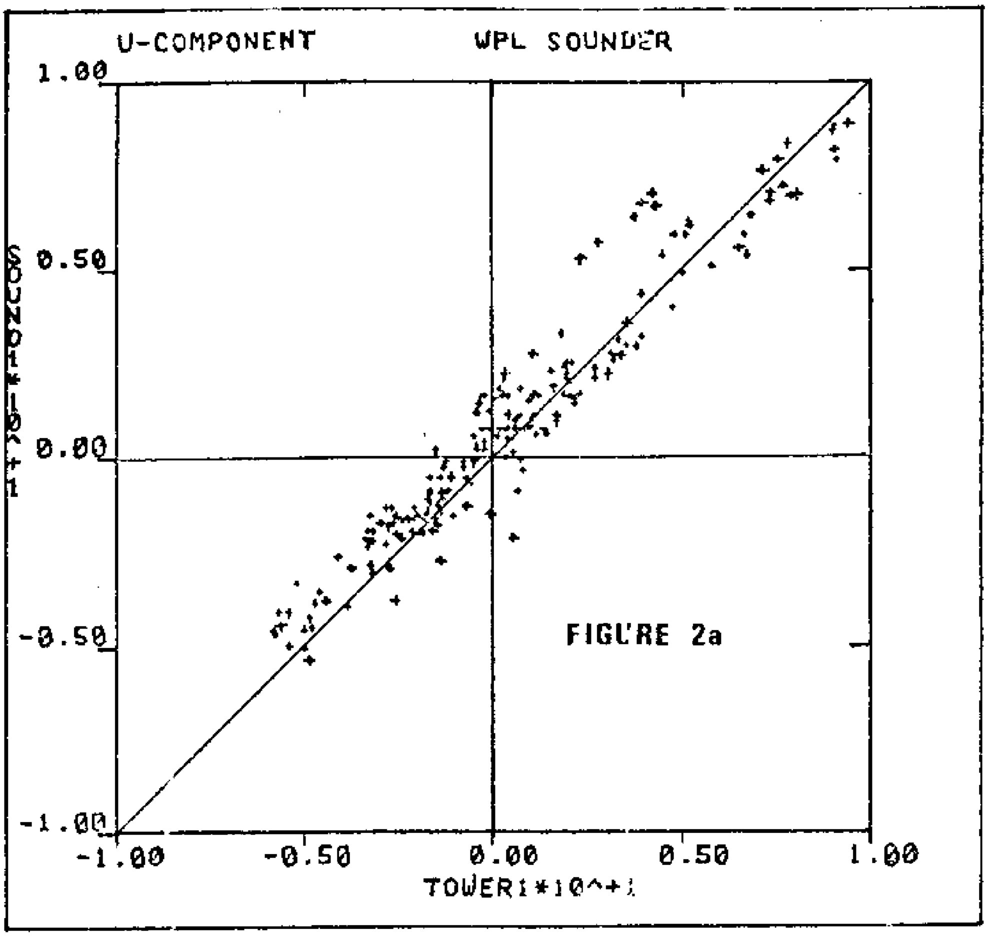


FIGURE 2a

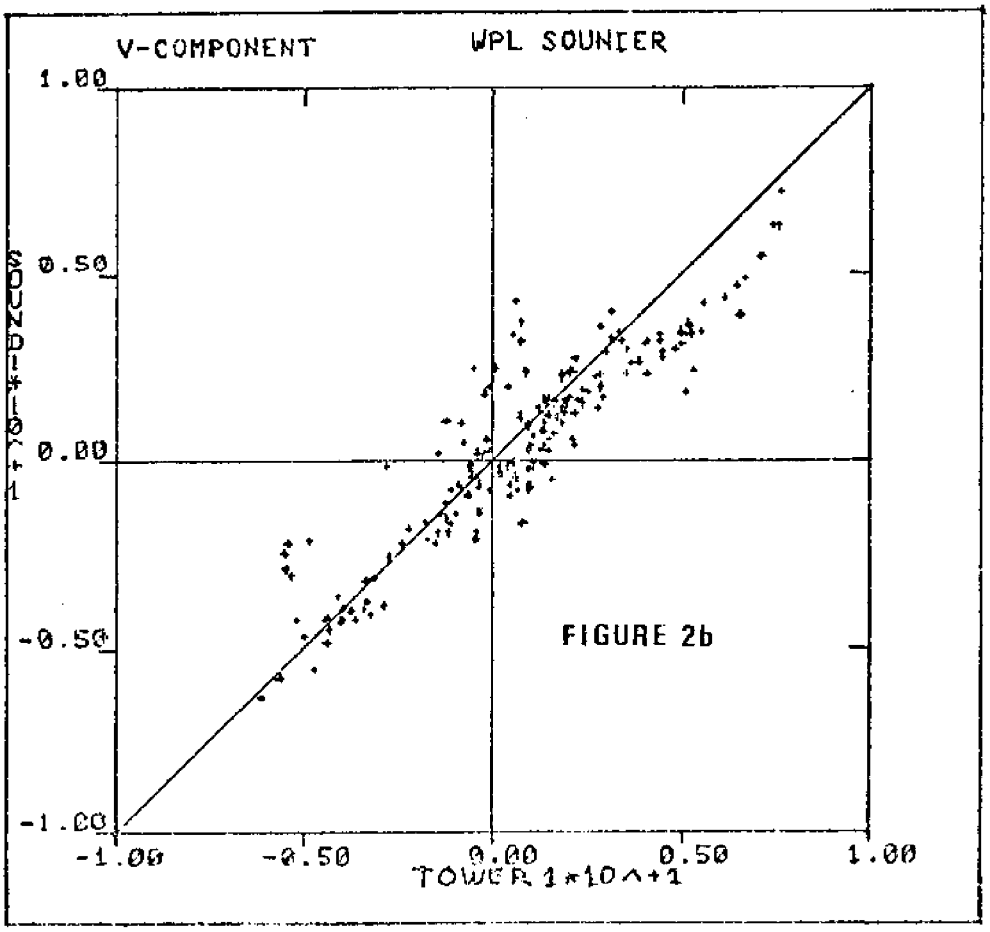


FIGURE 2b

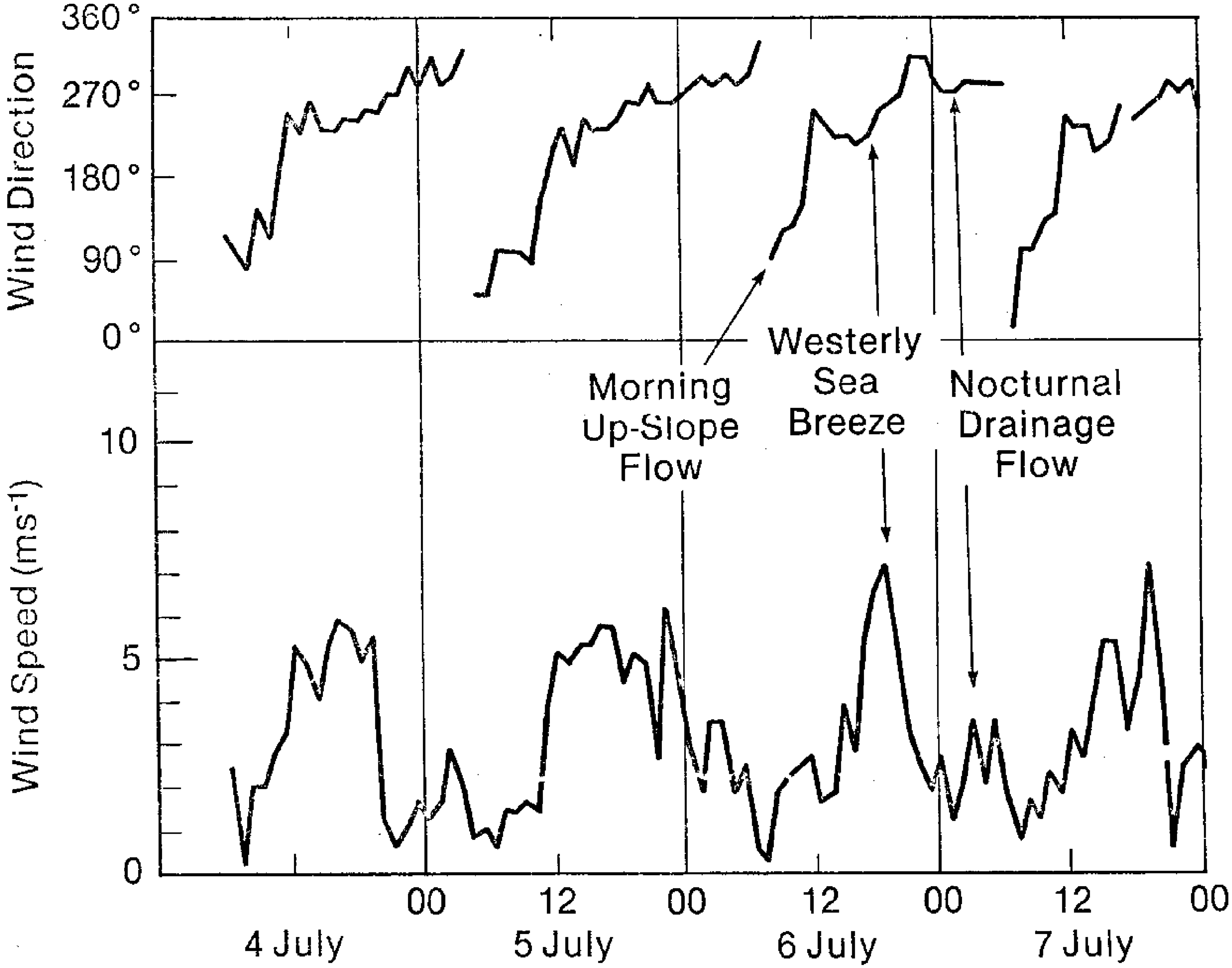
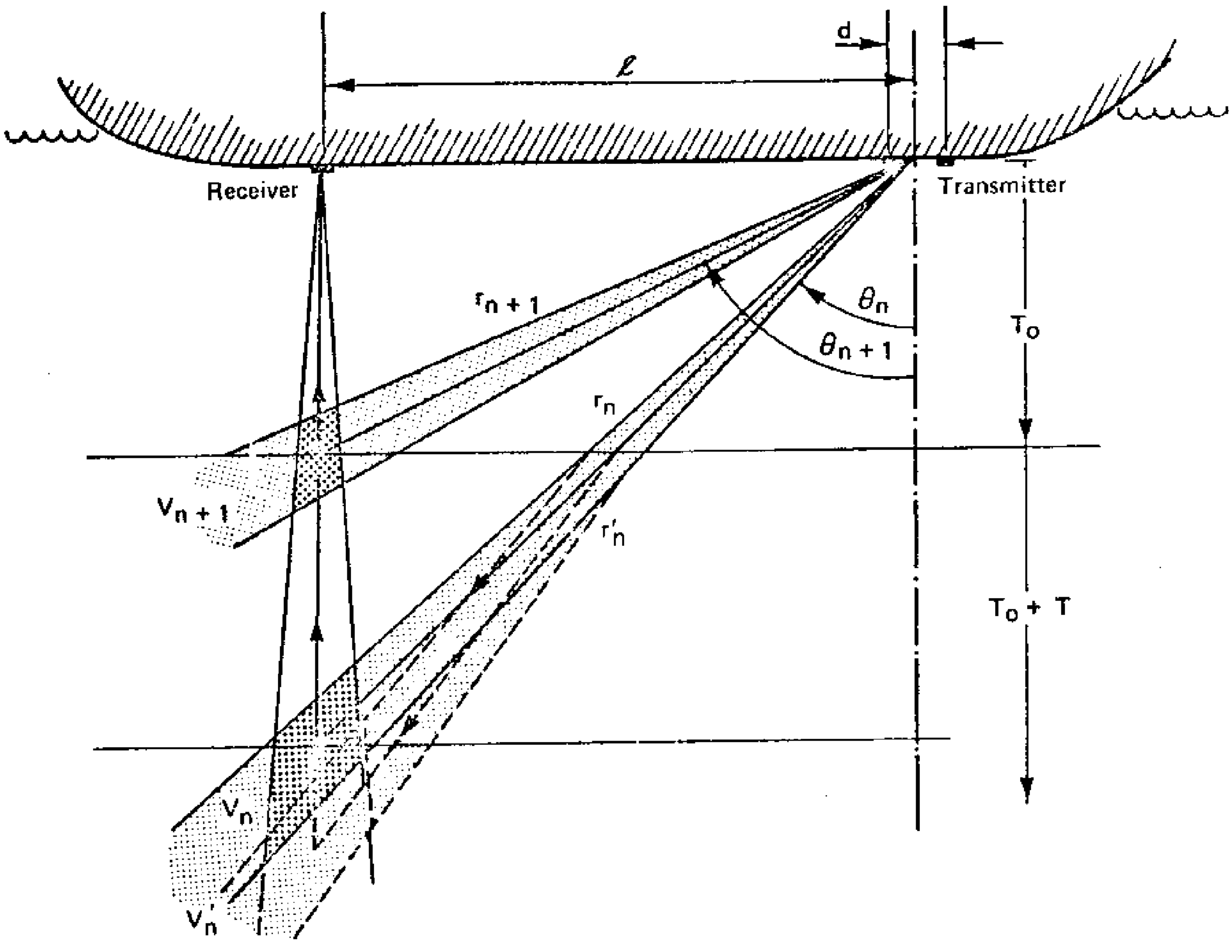

Wind Direction
360°
270°
180°
90°
0°
Wind Speed (ms-1)
10
5
0
Morning
Up-Slope
Flow
Westerly
Sea
Breeze
Nocturnal
Drainage
Flow
00
12
00
12
00
12
00
4 July
5 July
6 July
7 July

FIGURE 3



Echometer Geometry

Edmund H. Brown

FIGURE 4

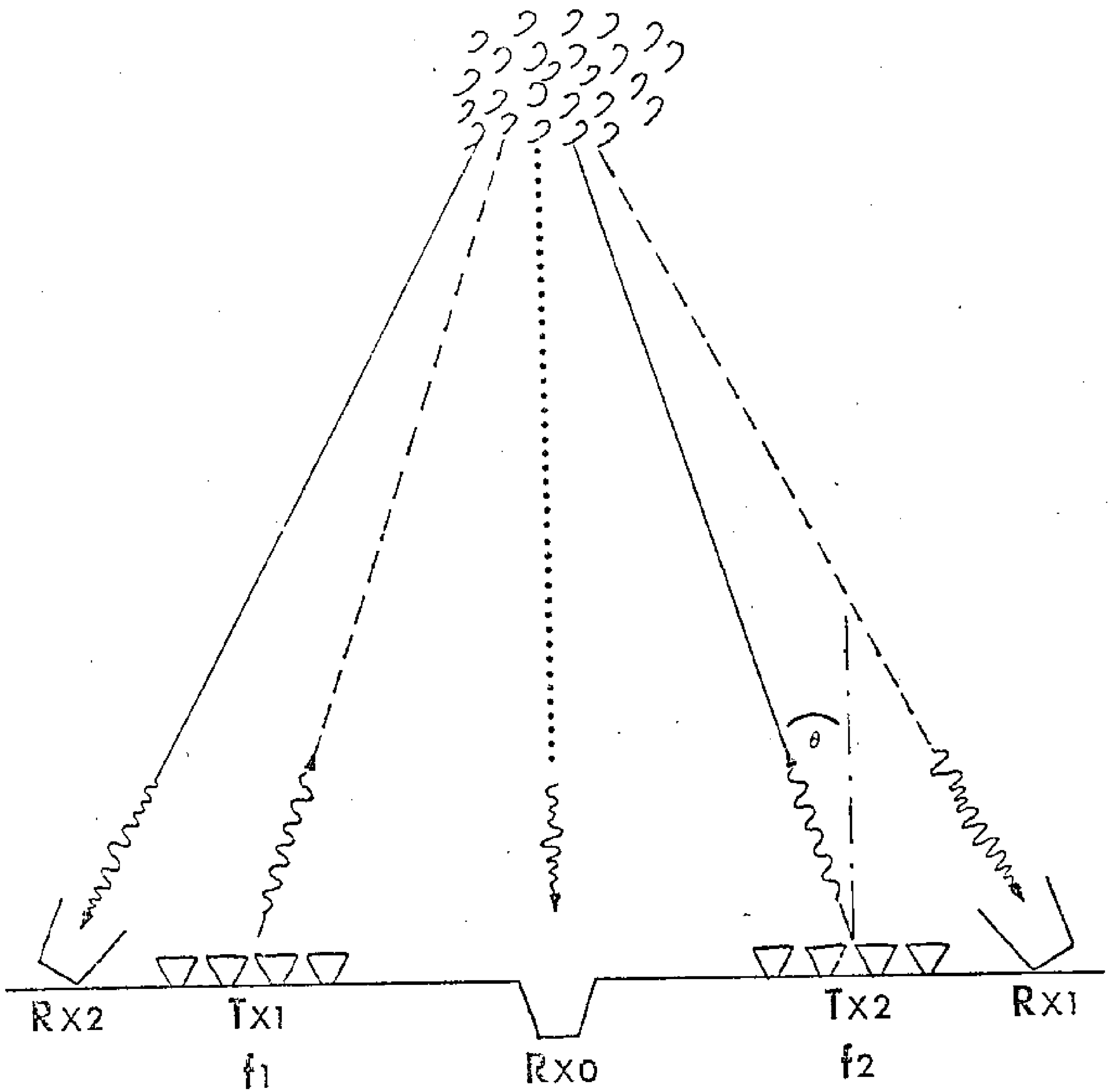


FIGURE 5 Echometer Configurations

FIGURE 6

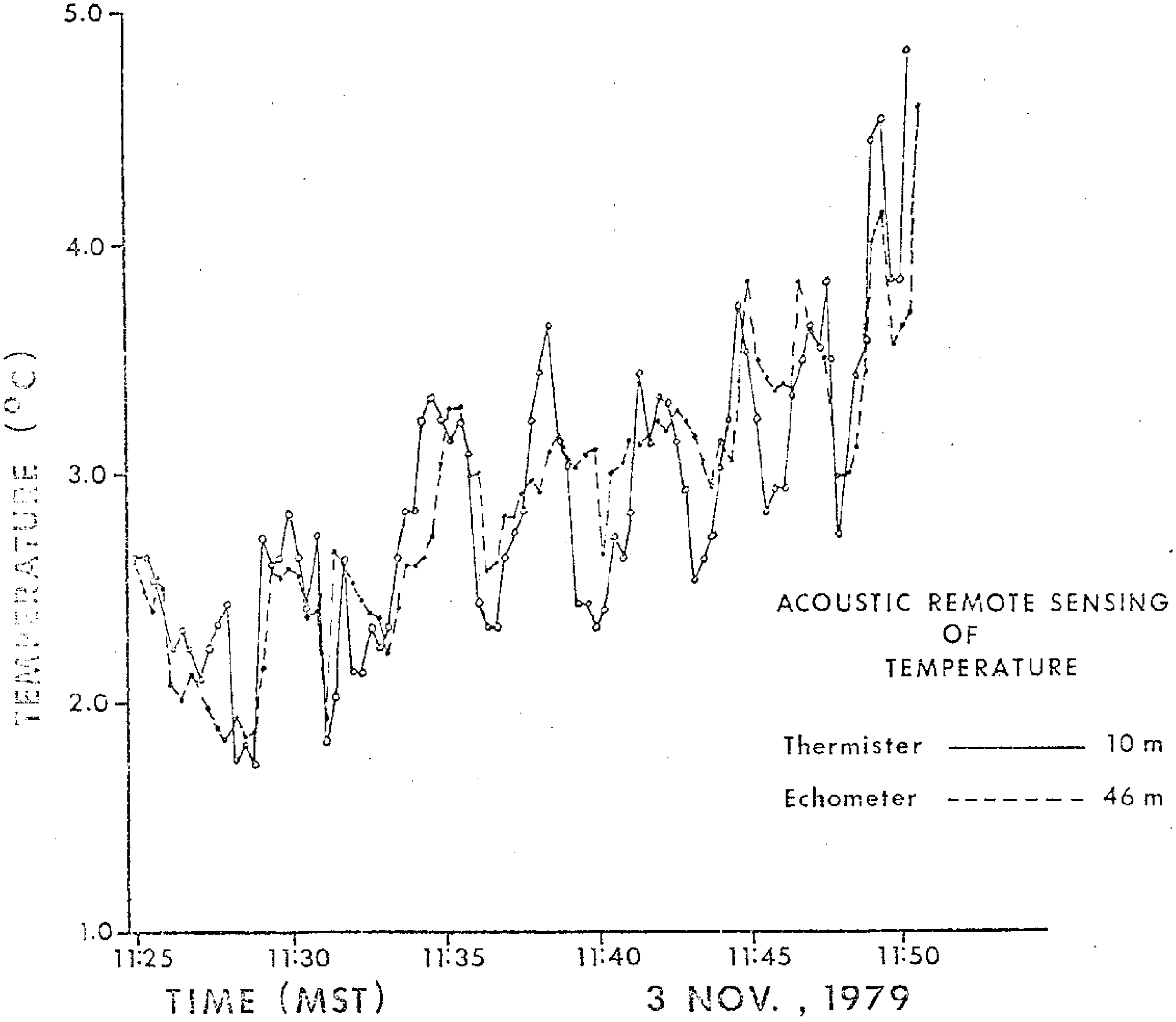
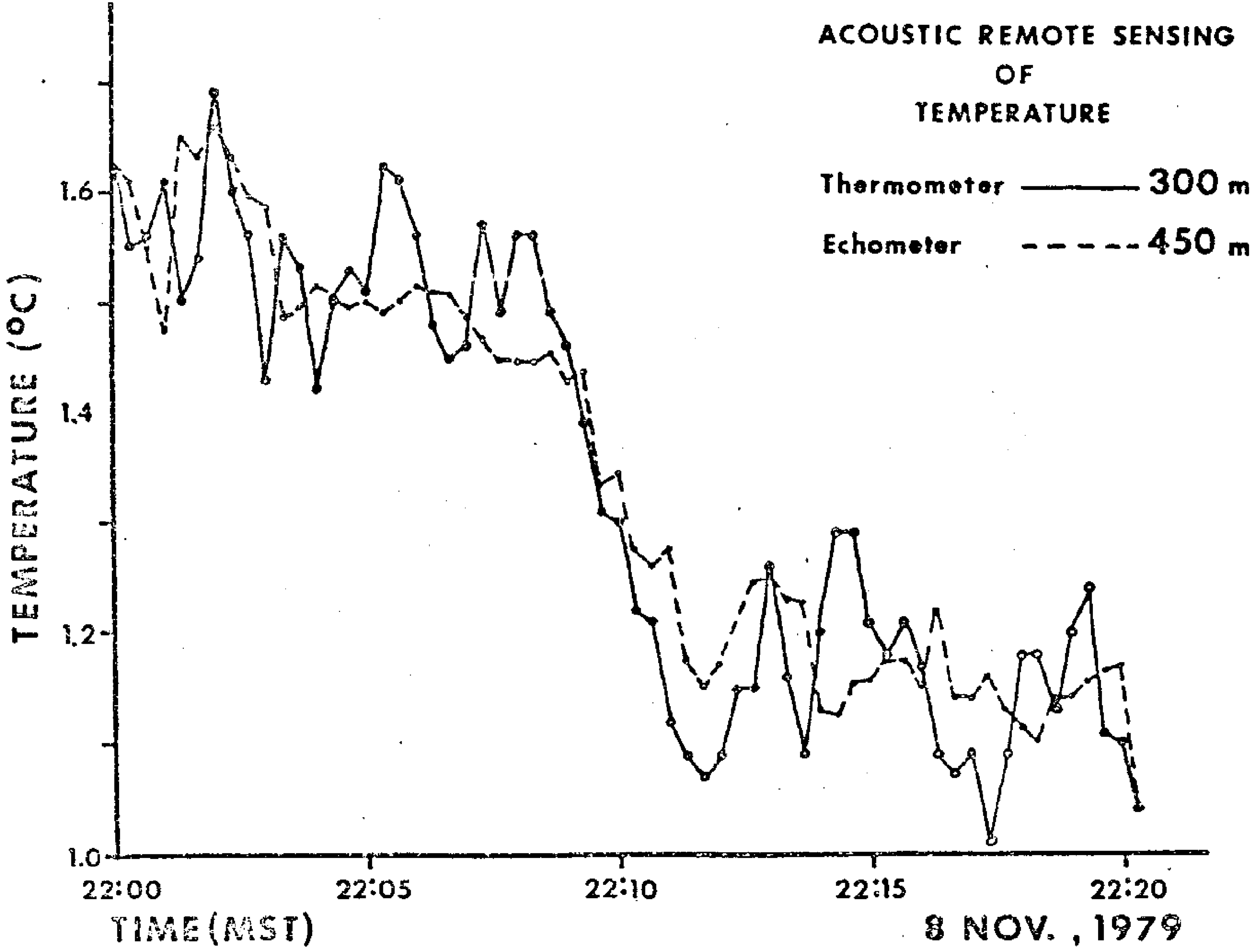

5.0
4.0
3.0
2.0
1.0
TEMPERATURE (°C)
11:25
11:30
11:35
11:40
11:45
11:50
TIME (MST)
3 NOV., 1979
ACOUSTIC REMOTE SENSING
OF
TEMPERATURE
Thermister 10 m
Echometer 46 m

FIGURE 7



ACOUSTIC REMOTE SENSING
OF
TEMPERATURE
Thermometer 300 m
Echometer 450 m
TEMPERATURE (°C)
1.6
1.4
1.2
1.0
22:00
22:05
22:10
22:15
22:20
TIME (MST)
8 NOV., 1979

OARS Paper #16

OCEAN ACOUSTIC REMOTE SENSING: WORKSHOP OVERVIEW AND REMARKS

by Morris Schulkin, Program Chairman
Applied Physics Laboratory - University of Washington

1. Introduction

The nature of my remarks is such as to touch base with other activities of NOAA which must be considered in the proceedings of this present NOAA Ocean Acoustic Remote Sensing (OARS) Workshop. In addition I plan to cover a technical overview of the subject matter of this workshop from a different point of view in an attempt to fill gaps in the presentations and at the same time tie things together in some cohesive framework.

First, this Workshop grew out of a recommendation of a previous NOAA Oceanic (Electromagnetic) Remote Sensing Workshop held in Estes Park, Colorado in August 1979. The use of acoustic remote sensing in the ocean is not a new subject--nor has a small amount of money been spent in its development. However, with the advent of satellite and other means of remote monitoring of the ocean surface, man now has an opportunity to obtain a synoptic view of the entire ocean-atmosphere system. In principle, ocean acoustic remote sensing systems can monitor happenings inside the ocean, on almost any size and time scale, which may then be related to the sea-surface and atmospheric dynamics picture as required or desired. The Action Summary (Reference 1) prepared by the first Workshop should be considered in preparing a proposed plan of action to implement our conclusions and recommendations. The makeup of our Working Groups is such that each Group has one member who attended the previous Workshop.

A second point of contact with other NOAA activities is the NOAA responsibility to supply products and services relating to the oceans and atmosphere for user groups--government, industry, commerce, and the public (see Table 1). These products and services require observation and measurement systems in the context of our Workshop Group names:

- o Climate and Weather
- o Fisheries
- o Ocean Services
- o Pollution

One of the tasks of this Workshop is to consider the options that are available at this time in working toward the establishment of an operational "integrated ocean oriented observing system." (See Ref. 2).

I now intend to fill some gaps in our technical coverage and to attempt to provide a cohesive technical framework using a topical breakdown such as: ocean chemical acoustics, ocean bioacoustics, ocean geoacoustics and what I call ocean dynacoustics--the acoustics related to ocean dynamics.

Table 1: <u>SOME NATIONAL NEEDS FOR OCEAN MONITORING</u>

<u>CUSTOMERS</u>: GOVERNMENT, INDUSTRY, COMMERCE, AND PUBLIC

<u>USES</u>:

A. OFFSHORE OIL AND GAS

B. MARINE TRANSPORTATION

C. COMMERCIAL MARINE FISHERIES

D. MARINE RECREATION

E. MARINE CONSTRUCTION

F. COASTAL COMMUNITIES

<u>OCEAN OBSERVATION AND MEASUREMENT REQUIREMENTS</u>

A. FISHERIES INFORMATION SERVICES

B. PREDICTION OF WEATHER AND CLIMATE

C. POLLUTION MONITORING AND CONTROL

D. OCEAN MAPPING AND CHARTING; TIDES AND CURRENTS

E. OCEAN ENGINEERING SUPPORT SERVICES

2. Ocean Chemical Acoustics

In the ocean there is acoustic absorption due to ionic relaxations (Figure 2-1) (Ref. 3).[a] Depending on temperature, salinity and pressure, magnesium sulphate has a relaxation frequency in the 50 kHz region which causes absorption. Boric acid has a relaxation frequency in the 1 kHz region which is strongly dependent on temperature and pH. There are large regional differences in this low frequency absorption due mainly to differences in pH at the sound channel axis. This absorption process is thus related to the carbon cycle in the ocean. The ocean is a sink for CO_2 so that monitoring the pH in some way is quite important.

Dissolved gasses in the ocean are not known to have a direct acoustic effect. But under conditions of supersaturation, wave breaking, and photosynthesis and life processes, bubbles are released which have profound acoustical effects--including scattering, absorption and sound speed reduction.

Sodium chloride, the predominant salt in sea water, actually inhibits acoustic absorption. However by contributing strongly to the conductivity of sea water, it helps to make the ocean impervious to the transmission of radio waves up to about 100 MHz (Figure 2-2). This is one reason why we are here today.

Light does penetrate down to about 200 m which is the photic zone crucial to photosynthesis and life in the ocean. Figure 2-3 shows provinces of optical visibility for the North Atlantic as measured by the use of Secchi disks (Ref. 4). There are different reasons for this variability involving life-related and mineral-related particulates. The dominant acoustical characteristics of particulates are scattering with amplitude and phase variability and attenuation as a byproduct. One of the criteria used in interpreting acoustical scattering data is to distinguish between bubble type and dense body (with respect to seawater) scattering characteristics.

3. Marine Bioacoustics

The basic differences in the scattering properties of bubbles and dense bodies are shown in Figure 3-1 (Ref. 5). Note three points: (1) the bubble scatters about 10^3 times more strongly than the geometrical cross section, (2) the bubble will have maximum response at a frequency about 1/100 of that of a dense body the same size, (3) the scattering is resonant and sharp for a bubble compared with a dense body. There is considerable damping introduced by the fish tissue surrounding biological bubbles (swim bladders), thus broadening and lowering the associated resonance peak. Thus fish schools can attenuate sound waves considerably.

The phenomenon of the deep scattering layer (DSL) is shown in Figure 3-2 (Ref. 6). The acoustical properties of the DSL were discovered using depth sounders at 12 kHz. The scattering layers are light-sensitive

[a] The figure numbers on the figures drawn from different sources do not correspond, in general, to the figure numbers in this paper.

ecological systems involving plankton and swim bladder fish. The DSL exhibits a diurnal rise toward the sea surface after sunset and a descent to depth after sunrise. In Figure 3-3, we show the nature of the acoustical frequency dependence of the scattering as a function of diurnal and seasonal effects in the Mediterranean as measured by column scattering strengths. These are the scattering measures obtained by using explosive charges to cover relatively large volumes of the ocean. Column scattering strength is the integrated scattering coefficient (acoustical scattering cross section per unit volume) expressed in dB over a water column of unit cross section. Note that winter night and summer day are highest and lowest respectively.

The combined bubble and heavy body scattering cross section of a single swim bladder fish is shown in Figure 3-4 a, b as a function of fish length and acoustic wavelength (Ref. 7).

Figure 3-5 shows how the incoherent target strength of a fish school depends on the value for a single fish in terms of sonar and geometrical parameters (Ref. 8). Using Doppler sonar, fish school speed with respect to the ship may be obtained along with tail-beat frequency data, from which the average size of an individual fish in the school may be derived (Ref. 9). Direct fish sampling surveys (net hauls) are also required with the sonar information for unambiguous data interpretation. Specific sonar systems have been used for counting and assessing fish stocks in restricted places such as streams and lakes.

The emission of unique sound spectra by fish furnishes another technique of identification through passive or listening sonar. The sound of ecological formations may well be useful for fisheries studies. Playback of such sounds may even be useful in fish stock control. Figure 3-6 shows sound spectra for croakers and other fish (Ref. 10). Porpoise sounds are well known. Since porpoises are also found with tuna schools, the possibility arises of fish school monitoring and even possible control. Another well-known biological signal is the 20 Hz emissions of baleen whales. These 20 Hz signals are relatively narrow and intense, and are apparently optimal for communications over thousands of kilometers.

4. Marine Geoacoustics

A dramatic geoacoustical signature, along with the whale signals shown in Figure 4-1, is that of a seaquake of magnitude 6.2 on the open-ended Richter scale (Ref. 11).

The signal at bearing angle -28° shown in Figure 4-2 is from a rumbling underwater volcano. This figure was kindly supplied by NRL in a report on the development of a wide-area (10^6 nmi^2) hydrographic reconnaissance system (Ref. 12). A towed low-frequency receiving array and 50 lb. signal charges are used. On-line processing is being developed for the system. In NRL's TOPO ONE experiment isolated uncharted seamounts, seen as highlights to the right side of Fig. 4-3, were found by this method and verified by the New Zealand Navy. Figure 4-3 shows the final processed product map produced by averaging 20 single shot maps. The scale of the longitude-latitude grid is 1° x 1°.

The standard technique used for seismic reflection and refraction profiling is shown in Figure 4-4 (Ref. 13). Note the subbottom profiling possible. The main use of the higher frequency 12 kHz depth-sounder is to map the bathymetry of the ocean bottom. Penetration of the ocean bottom sediments down to about 200 m below the interface is often possible using 3.5 kHz or lower frequency sound. Figure 4-5 (Ref. 13) shows, for a cross section of the North Atlantic, how seismic profiles may be plotted together with bathymetry. This type of chart is useful for determining where in the ocean basins nuclear waste containers should best be dumped for sinking into the sediments and ultimately being covered by continued sedimentation.

A great number of studies and measurements have been involved in learning about the acoustical properties of ocean bottoms and sediments. Bottom loss (dB) has also been used to distinguish different types of bottoms. Figure 4-6 shows loss vs. grazing angle calculated as a function of porosity (Ref. 14). At high porosity ($>$ 60%) the bottom sediment is sound-slow compared with seawater and leads to a lossy angle of intromission. Less porous bottoms have low loss up to the critical angle and higher loss beyond. Figure 4-7 shows the plot of sound speed vs. porosity illustrating the sound-slow and sound-fast principle (Ref. 15).

5. Sea Surface Dynamical Scales

The synoptic measurement of the oceans- and atmosphere-system obtained by electromagnetic and ocean acoustic remote sensing should match at the sea surface. Sea surface dynamical scales are relatively well known. A spectral energy sketch of these waves is shown in Figure 5-1 (Ref. 16). There should be discrete spectral lines in the range 8 to 12 seconds due to swell. Swell waves are low-frequency, narrow-band gravity waves that have outrun the wind.

Figure 5-2 (Ref. 17) shows the extent of other dynamical ocean surface features including their vertical elevations above sea level. It also shows the altimeter accuracy and precision required to measure these phenomena from satellites, such as SEASAT. SEASAT demonstrated a 10 cm accuracy. The lateral dimensions of the phenomena listed gives an indication of the length of the acoustic path required to measure these features extended below the surface.

A plot of Wyrtki's dynamic surface topography is shown in Figure 5-3 (Ref. 18). This should be measurable by satellite altimetry. The spacing between dynamic height contours gives a measure of current strength of the quasistationary current systems of the oceans.

Considerable work, both theoretical and experimental, has been carried out on sea surface scattering including the directional spectrum (Ref. 19). Sonar measurements compare favorably with the radar measurements of the same wavelength. In addition surface currents and water transport can be measured by various acoustic techniques.

Figure 5-4 (Ref. 20) shows sea surface scattering measurements as a function of grazing angle and wind speed, at an acoustic frequency of 60 kHz at Key West, Florida. The data show a sharp drop-off below 5° grazing angle. The leveling-off of scattering strength shown in the figure is thought to be due to layers of bubbles just below the surface. Another low frequency acoustical property now receiving attention and shown in Figure 5-5 a, b (Ref. 19b; Ref. 21) is the wind-related ambient noise levels between about 1 Hz and 20 Hz. These have been ascribed to wind-induced turbulence and current shears deeper in the water.

6. Ocean Dynacoustics

(a) Ocean Dynamical Scales

Ozmidov (Figure 6-1) (Ref. 22) distinguishes three horizontal range-scale regions of energy input into the oceans: (1) atmospheric pressure and wind systems at about 1000 km with a response of ocean circulation and synoptic currents; (2) inertial and tidal energy input at about 10 km with a response of internal waves and tidal currents; and (3) wind and local solar heating at about 10 m involving sea surface gravity waves, induced h.f. internal waves, local currents, and fine-structure layering and microstructure mixing. The smallest scale is that of molecular viscosity and diffusion.

Each external energy-fed region of the spectrum is followed by a continuous turbulent breakdown region which may be described statistically as, for example, in Figure 6-1. Here the energy spectral density, the ordinate, shows the size scale decay as following the 5/3 power law of isotropic turbulence. There is some question regarding the adequacy of this decay law for the anisotropic structures that occur at this scale. Figure 6-2 (Ref. 23) shows an energy spectrum obtained for the mesoscale-synoptic region described in terms of temperature variance. A square law appears to hold from 500 km down to 50 km. These spectra were obtained from the data shown in Figure 6-3c. Changes in the relatively stable features shown in the figure, the in-ocean weather, are expected to be measured by the Munk-Wunsch tomography experiment.

In Figure 6-4 (Ref. 24), there is shown a set of acoustic variability data over the fixed-source, fixed-receiver path between Eleuthera and Bermuda, 1260 km long. Two-day means of transmission loss data taken over a 5-month time period show a 20 dB excursion. The nature of the statistical distributions of transmission loss is also shown. There is about a 7 dB standard deviation. Acoustic changes in phase (travel time) and amplitude are expected to depend on current and temperature changes.

A square law of turbulent decay also appears in the progressive internal wave region between the inertial frequency and the Brunt-Vaisala buoyancy frequency. Figure 6-5 (Ref. 25) shows such behavior in the vicinity of Cobb Seamount where the spectral variable is time in hours. Acoustic phase measurements made by Ewart over a 17 km path between Cobb and another seamount are plotted in Figure 6-6 (Ref. 26). The dashed line shows how well the theoretical calculations of Desaubies fit the data, using a modified Garrett-Munk spectrum.

Two types of internal waves are shown in Figure 6-7 (Ref. 27). The longer period waves are progressive and driven by tidal forces. The shorter period "waves" apparently appear to be oscillations on layers, which eventually break up by being over-driven or by a process called a Kelvin-Helmholtz shear instability. Figure 6-8 (Ref. 28) shows the short-period type internal waves as observed on FLIP by F. Fisher. The waves are shown up by particulate scatterers in the ocean.

Layers of the order of tens of meters down to 1 meter occur in the finestructure region of the turbulent decay spectrum. Figure 6-9 (Ref. 29) shows a temperature vs. depth profile obtained by Gregg, in which the shaded region was studied in more detail (Fig. 6-10). The fluctuations in the plot are evidences of finestructure activity. In the detailed stippled section, (enlarged in Figure 6-10), there is a thermocline, with much thermal activity as shown by the wiggles on the temperature gradient plot. If the temperature gradient is squared and the average taken, the activity of the finestructure is really brought out. The ratio of the mean square temperature gradient to the square of the mean temperature gradient is called the Cox Number. The Cox Number measures the heat flow and is equal to the ratio of the eddy thermal conductivity to the molecular thermal conductivity. The statistical distribution of the temperature variation for finestructure plotted as a function of inverse time (frequency) follows a 5/2 power law as shown in Figure 6-11 (Ref. 25). Features shorter than a meter are called microstructure.

The nature of the fluidic processes in the finestructure and microstructure regions are brought out in Figure 6-12 (Ref. 30) and 6-13 (Ref. 31). Figure 6-12 shows the sort of configurations that occur in the finestructure region as brought out by particulate scattering. Figure 6-13 shows the results of a new technique for distinguishing between layered scattering and point scattering.

7. Conclusion

In conclusion, I would like to restate the objectives of the Workshop. The technical and programmatic presentations which you have listened to up to this point must be related to these objectives.

Objectives of OARS Workshop

1. Document current NOAA activities that utilize OARS techniques.

2. Review the state of the art in OARS and the prospects and trends in future development.

3. Identify the needs and opportunities in OARS development that are important to major NOAA programs.

4. Identify priorities and document a "needs and opportunities" prospectus that may guide future initiatives in research and development, operations and services.

5. Determine the opportunities for scientific cooperation within NOAA and between NOAA and the Navy in OARS research and development.

6. Recommend action to implement the workshop conclusions.

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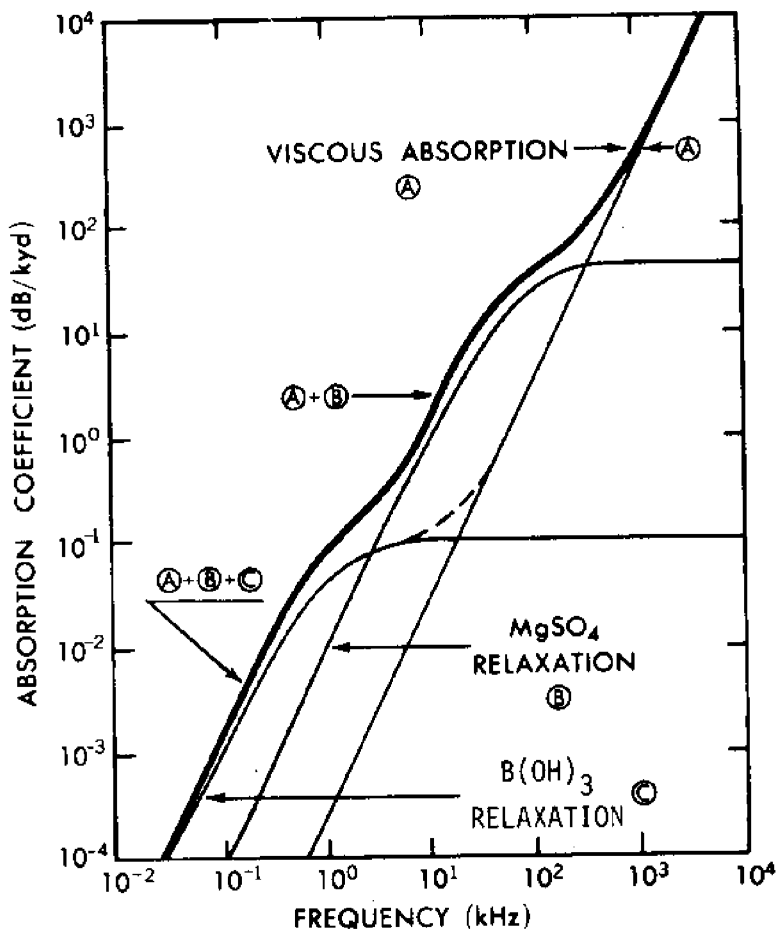
Figures (OARS Overview-Morris Schulkin)



$B(OH)_3$ RELAXATION		$MgSO_4$ RELAXATION		VISCOUS ABSORPTION

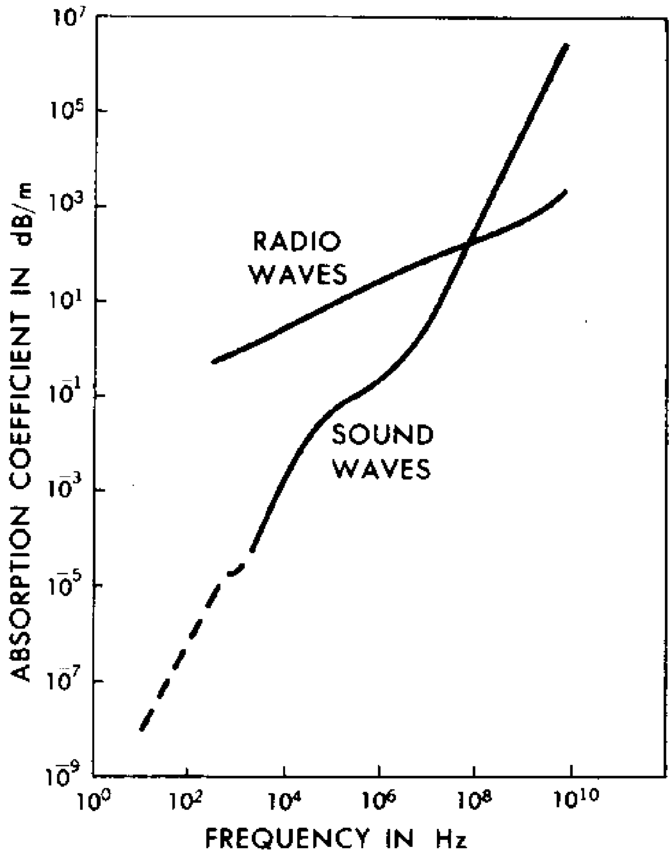
$$a = \frac{0.1f^2}{1+f^2} + \frac{40f^2}{4100+f^2} + 0.000275f^2$$

a = ATTENUATION IN dB/kyd

f = FREQUENCY IN kHz

Figure 2-1. Absorption of Sound in Seawater (adapted from Thorp, 1967)

FIGURE 4-4. ABSORPTION OF WAVES IN SEAWATER.



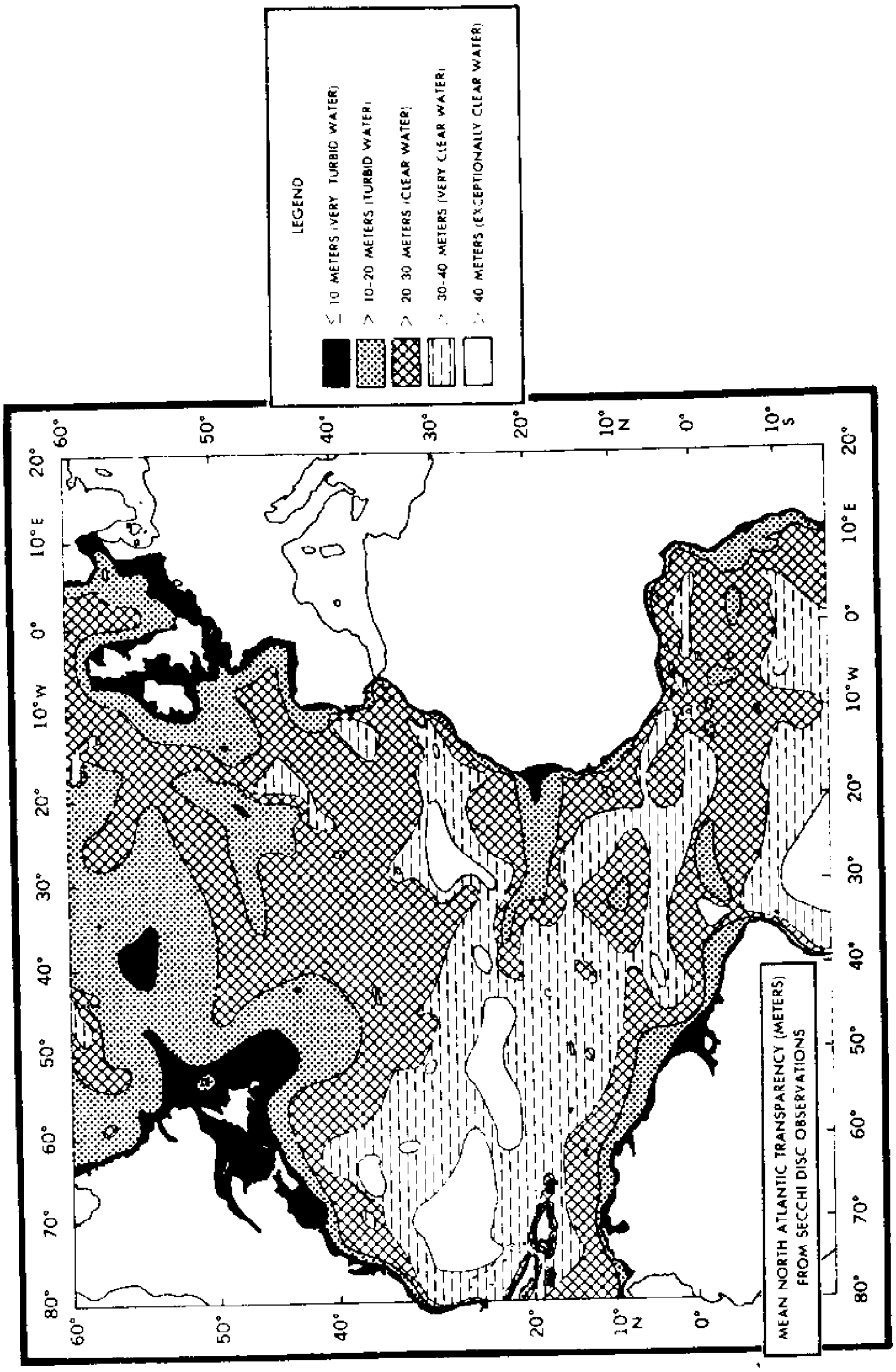
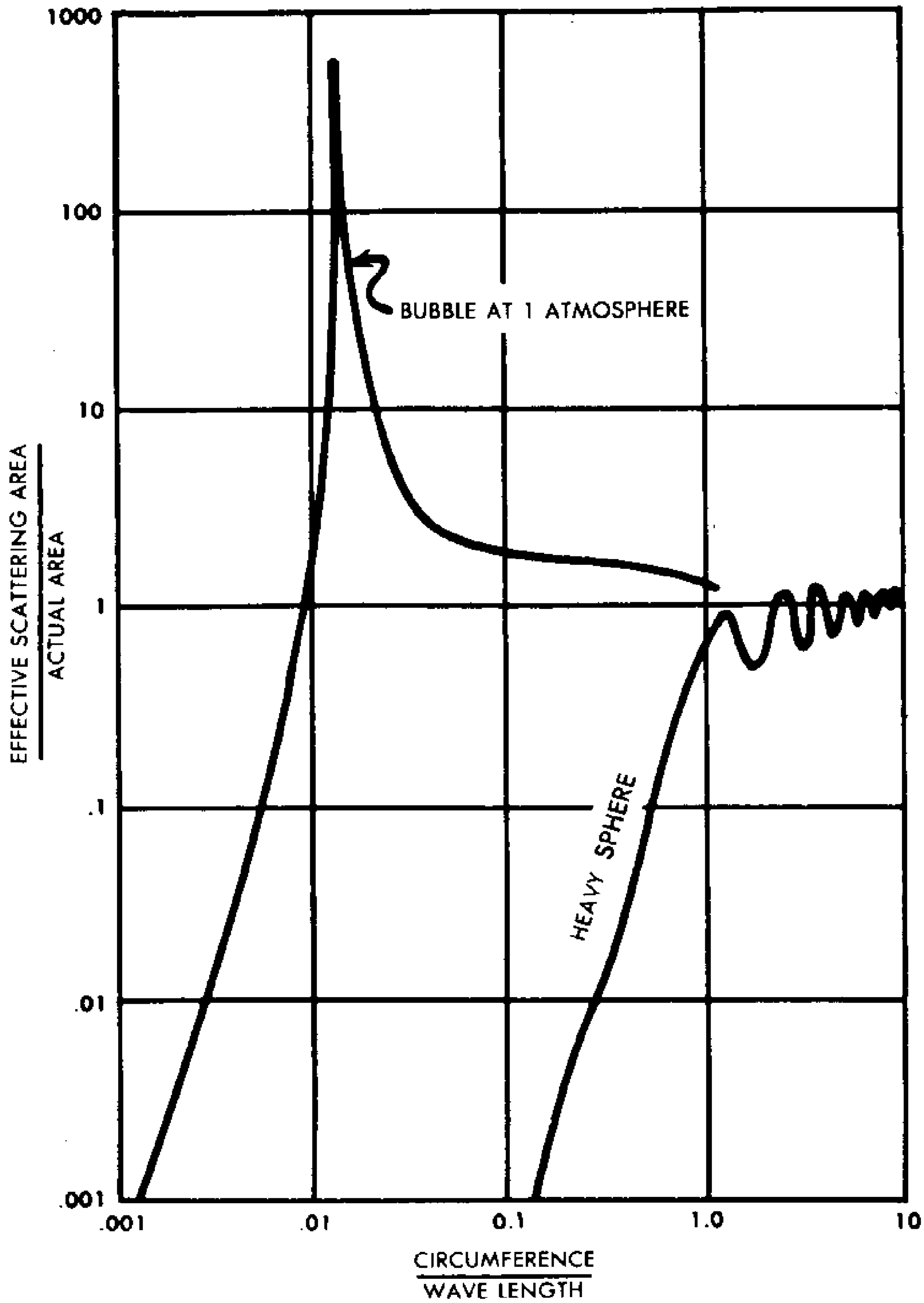
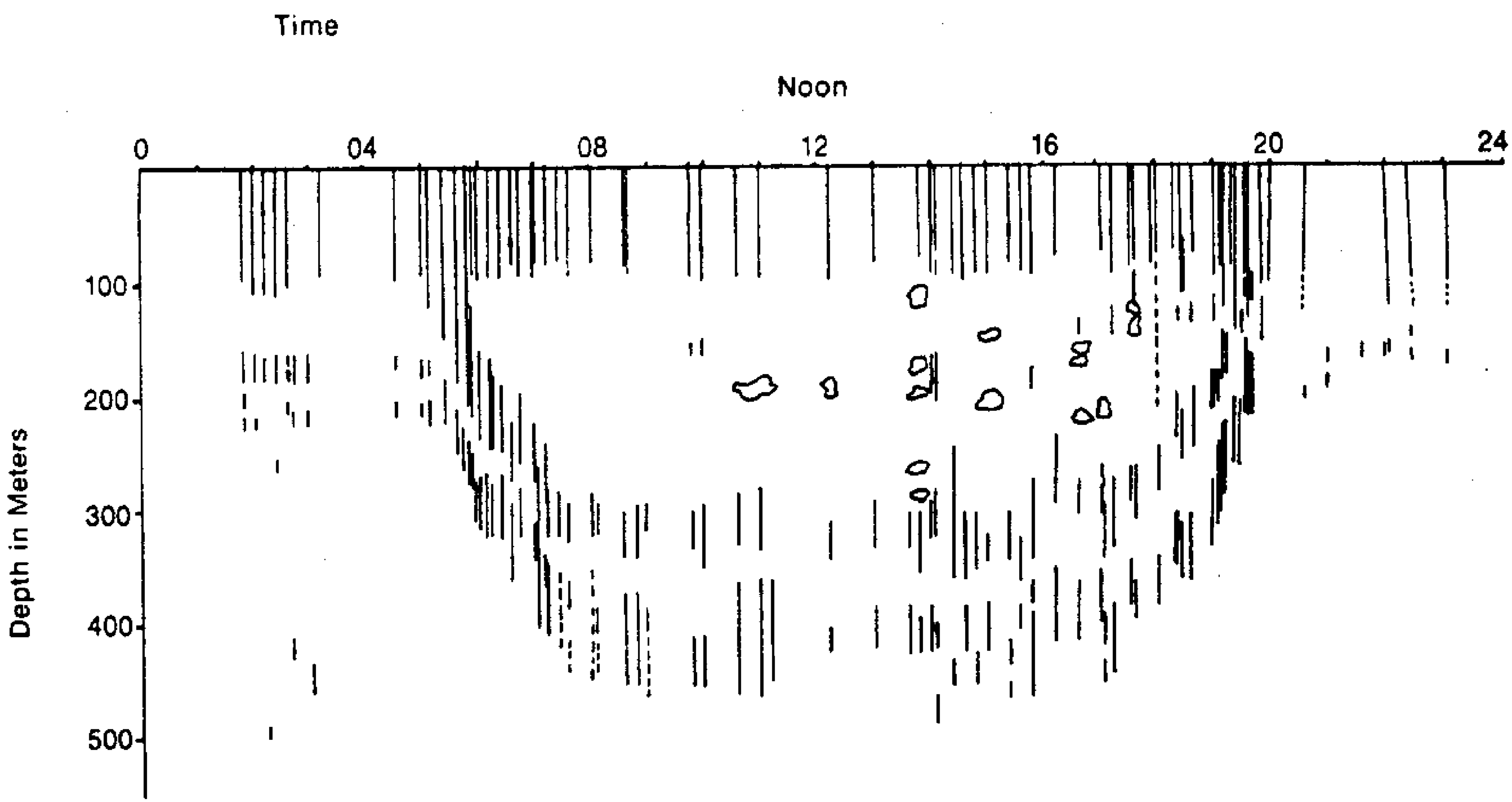


FIGURE 3-2. TRANSPARENCY CHART OF THE NORTH ATLANTIC OCEAN.
(ADAPTED FROM M.A. FREDERICK, U.S. NAVAL POSTGRADUATE SCHOOL, 1970.)

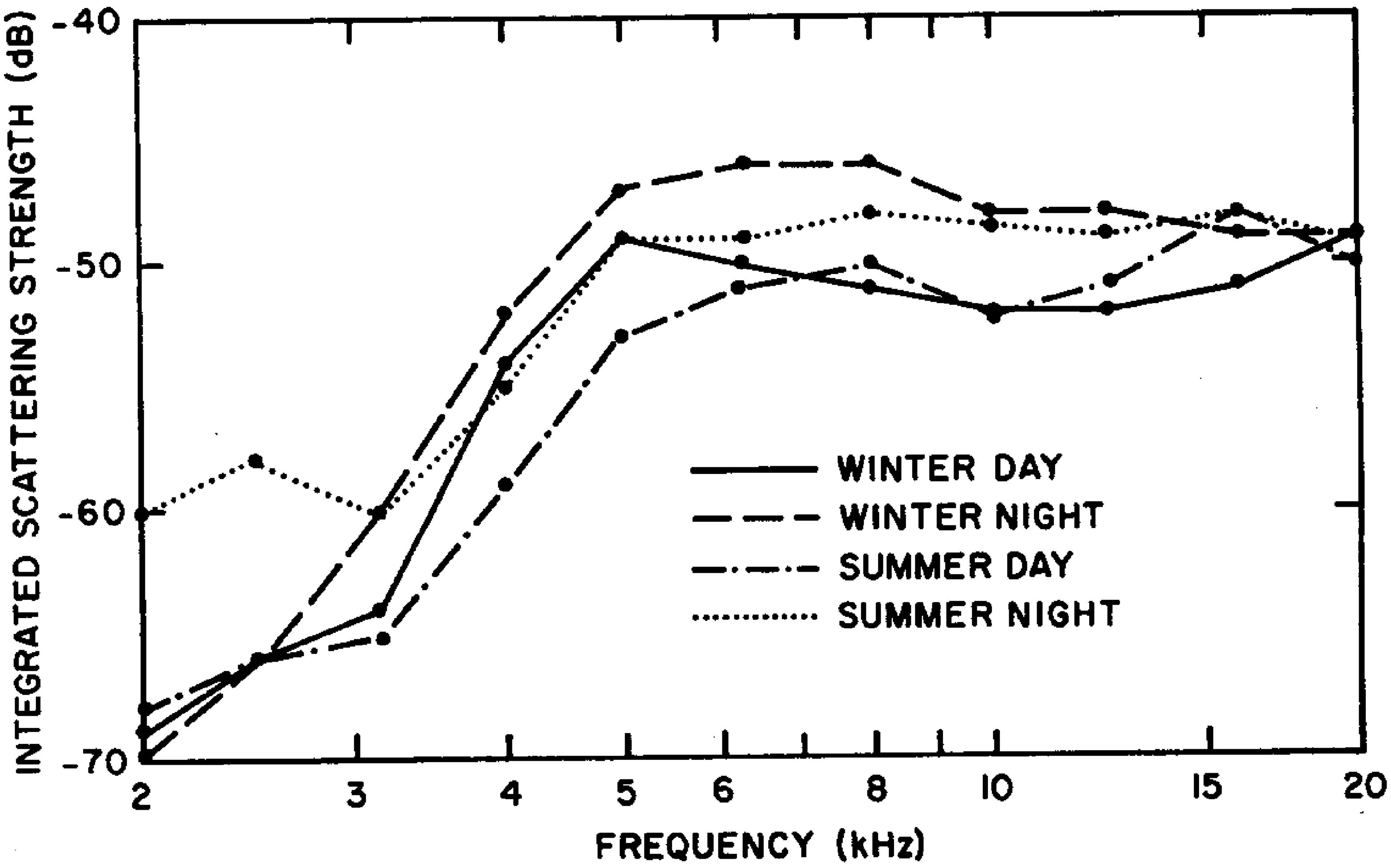
FIGURE 3-5. VARIATION OF EFFECTIVE SCATTERING AREA WITH WAVELENGTH FOR SMALL SOLID PARTICLES AND BUBBLES. (NAVAL OCEANOGRAPHIC OFFICE, 1966)





(b)

Figure 7.4.1*b*. The 24 hour 30 kHz DSL pattern (vertical migration) observed at the mouth of the Gulf of California, 28°N, during July 1969. A number of patchy echoes are indicated at a depth of about 200 m between 1030 and 1700 hours local time. (Dunlap, 1970.)



INTEGRATED SCATTERING STRENGTH AS A FUNCTION OF FREQUENCY, SEASON, AND TIME OF DAY FOR STATION 3 IN THE MEDITERRANEAN.

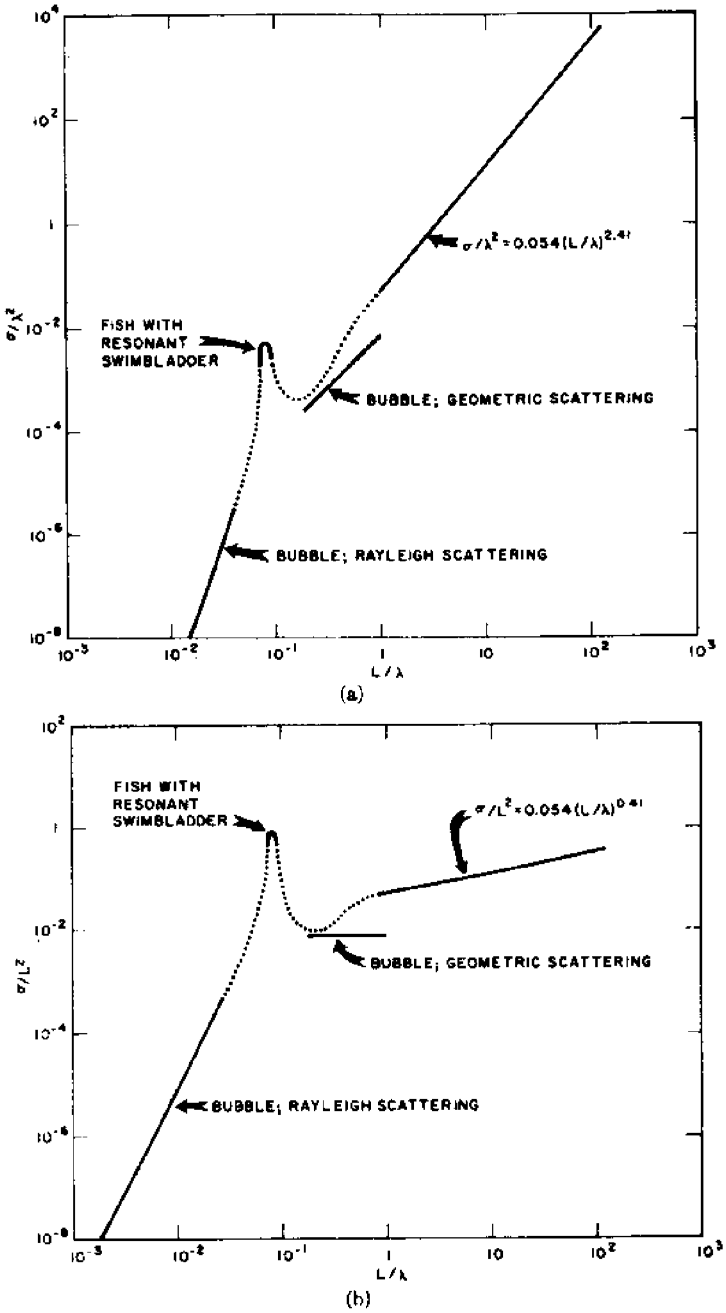


Fig 6. Estimated maximum side-aspect acoustic cross section of an individual bladder fish for all values of $L/\lambda \leq 100$, assuming $D = 20$ ft, $Q = 5$, and $R/L = 1/20$.
(a) σ/λ^2 as a function of L/λ. (b) σ/L^2 as a function of L/λ.
(from R. H. Love, JASA Vol. 46(3), 1969)

FIGURE 3-5

A. Target Strength (Incoherent) of Fish School

$$TS = TS_i + 10 \log D + 10 \log V' - A \qquad \text{dB}$$

TS is school target strength (incoherent component)

TS_i is individual school member target strength

D is schooling density in fish/m^3

V' is volume of school sampled by sound cone

A is attenuation due to school scattering and absorption

B. Fish Speed vs Length and Tailbeat (Bainbridge's Relation)

$$v = \frac{L}{4} (3F - 4) \qquad \text{m/s}$$

v = swimming speed (m/s)

L = total length (m)

F = tailbeat frequency (Hz)

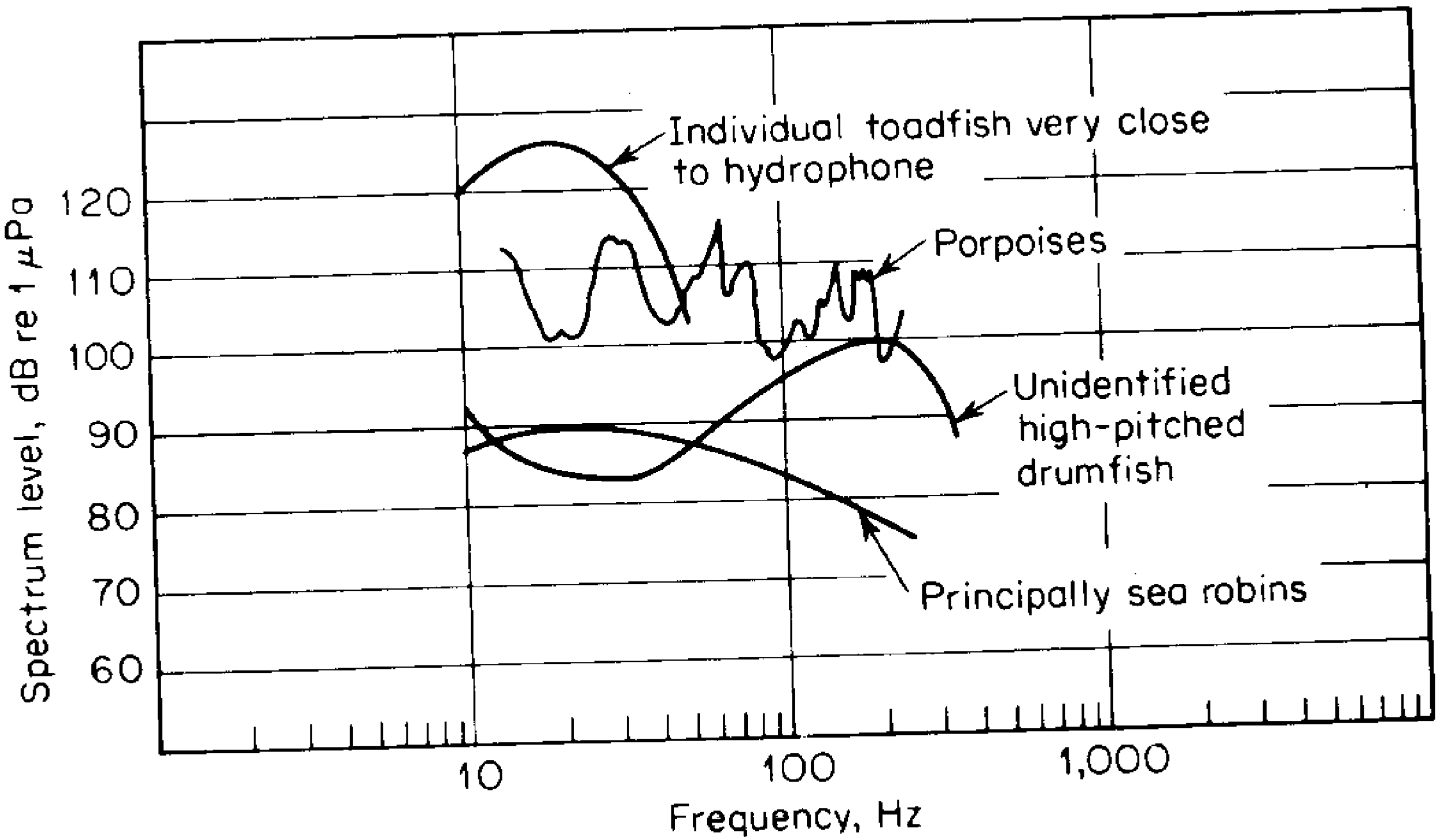


Figure 7.9 Sample spectra of the noise made by marine animals as observed at sea. (from Knudsen, et al., Underwater Ambient Noise, J. Mar. Res., 7:410, 1948, In Urick, 2nd ed. <u>Principles of Underwater Sound</u>)

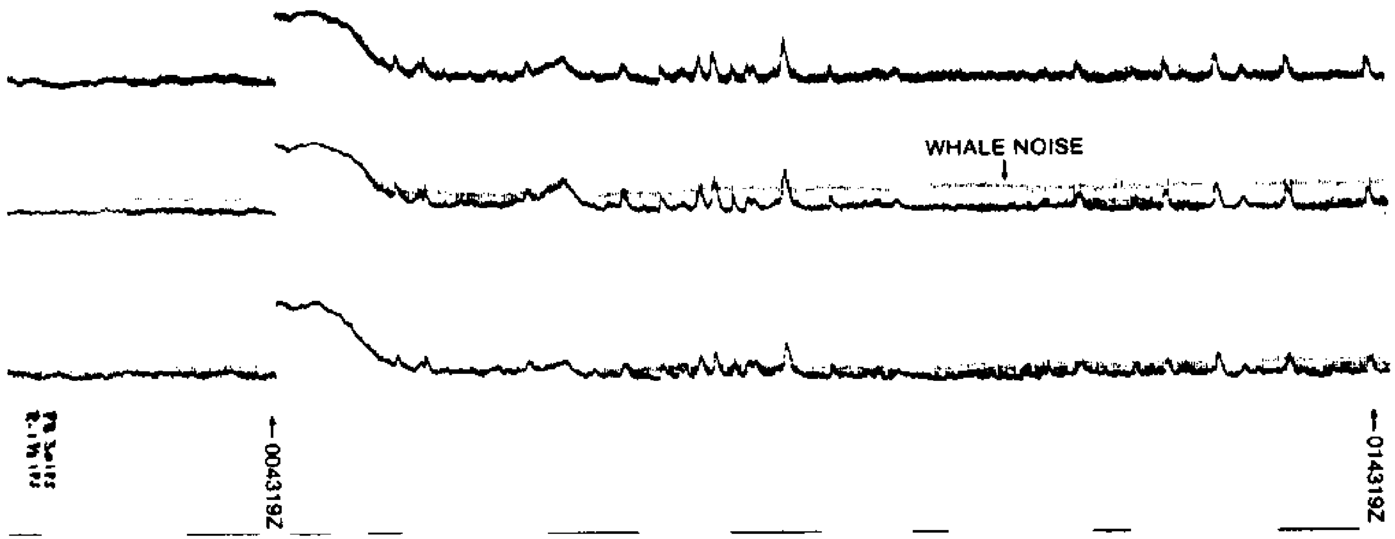


Fig. 4-1. Hydrophone signals showing whale noise near several of the hydrophones before and after the major quake. This time of year (March) corresponds to whale migration from South to North. The seaquake did not appear to perturb the whales. These whale signals are observed as tones at 20 Hz and are emitted at a rate of approximately 5 per minute. (from NUSC Tech. Newsletter, Vol. III (5) May 1978, "Earthquake! -- overloads systems in Bermuda," contributed by A. D. Arneson.

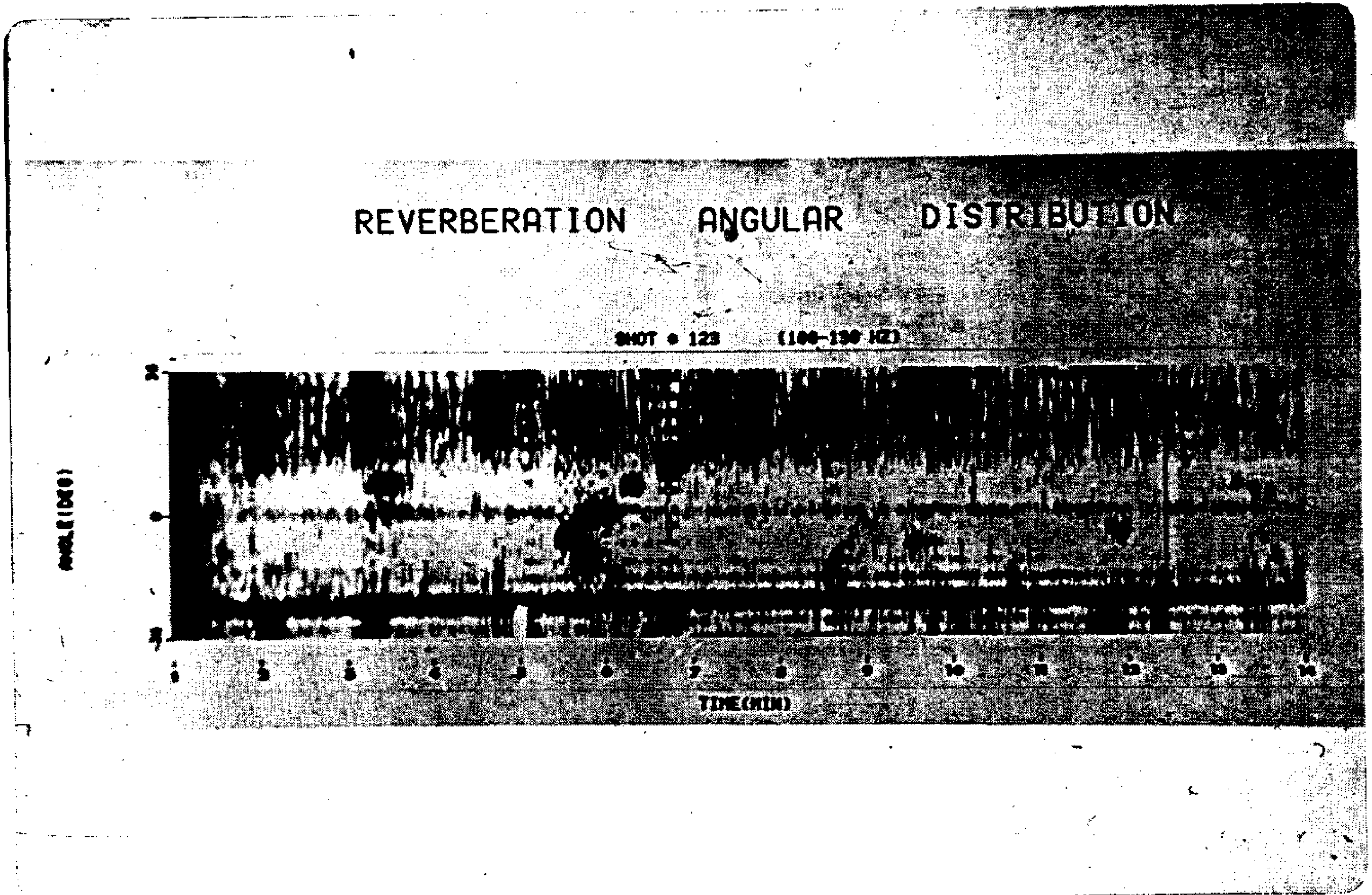


Figure 4-2. Topographic Reconnaissance: Reverberation Angular Distribution--Rumbling Volcano at -38° Bearing. (from Ref. 12)

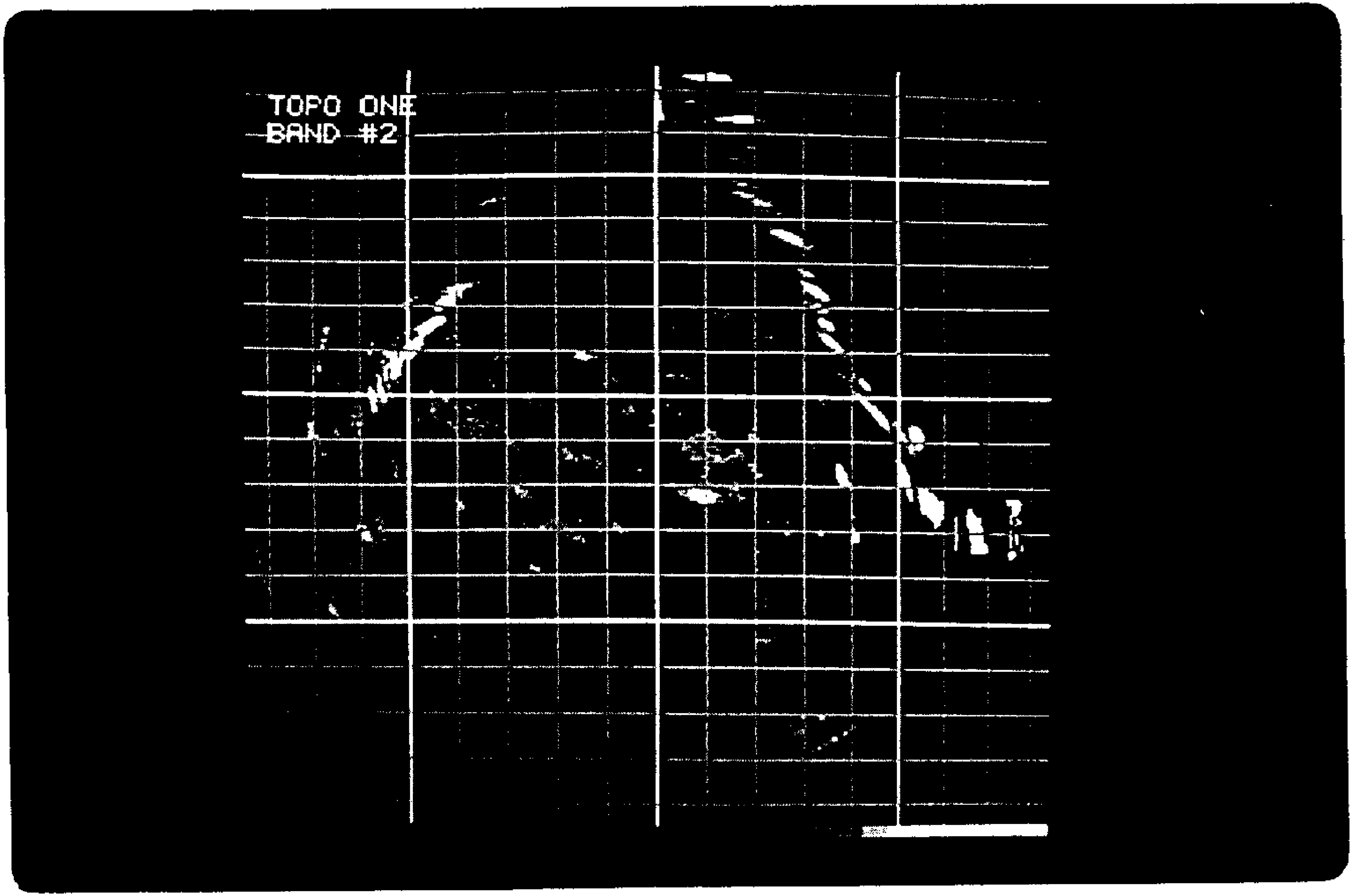


Figure 4-3. Topographic Reconnaissance: Discovery of Seamount Character of Louisville Ridge, New Zealand. (from Ref. 12)

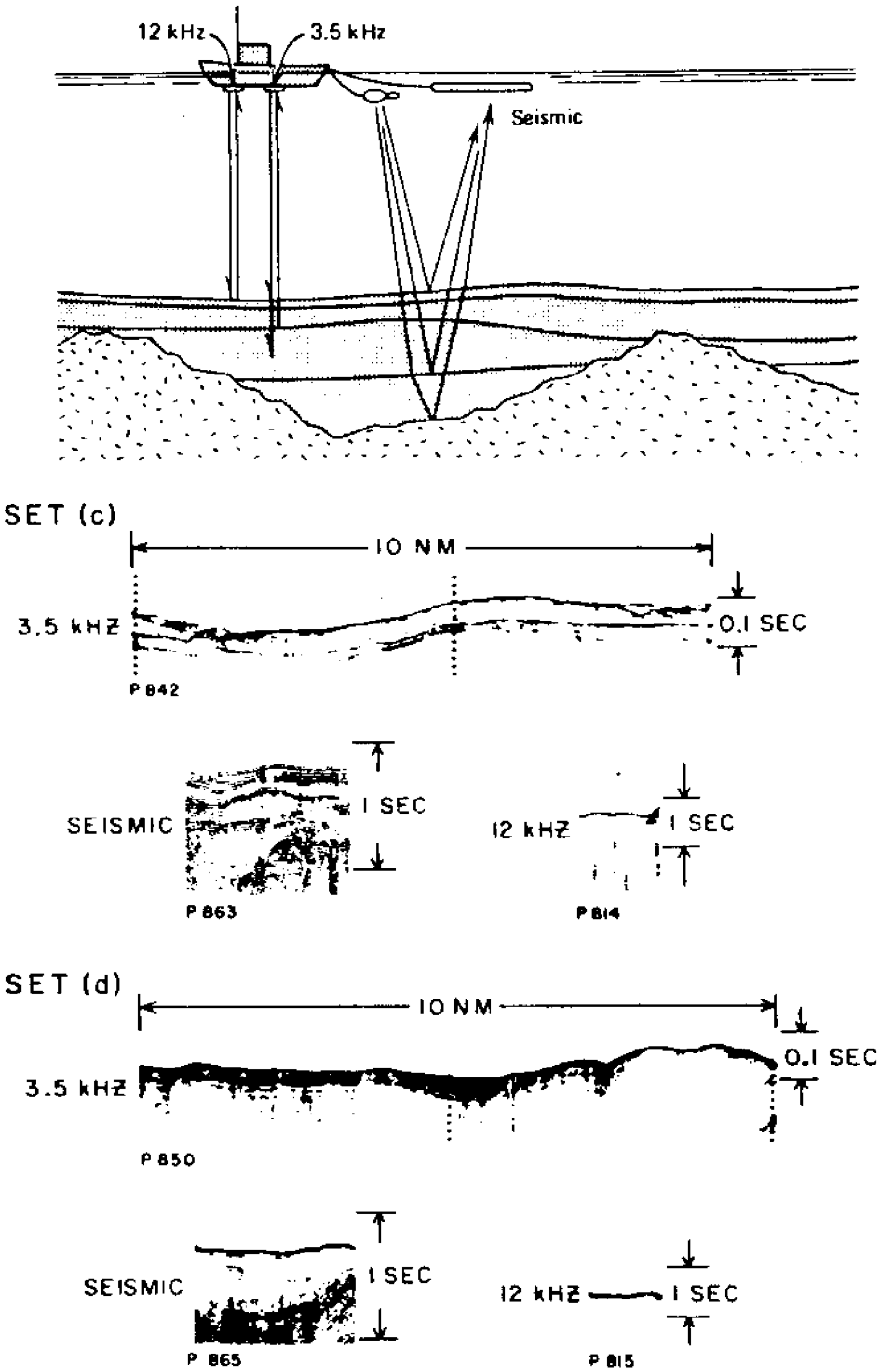


Figure 8.4.5. Echo sounding arrangement and seismic profiling records, taken along same profiles, for different frequencies. Seismic data are at about 25 Hz. Set (c) is for a smoothly rolling bottom. Sub bottom reflections appear on 3.5 kHz and seismic traces. Set (d) is for a slightly rough bottom. The 3.5 kHz signals are scattered by small features on the bottom. The bottom appears to be smooth for the seismic signal (60 m wavelength). (Lowrie and Escowitz, 1969.)

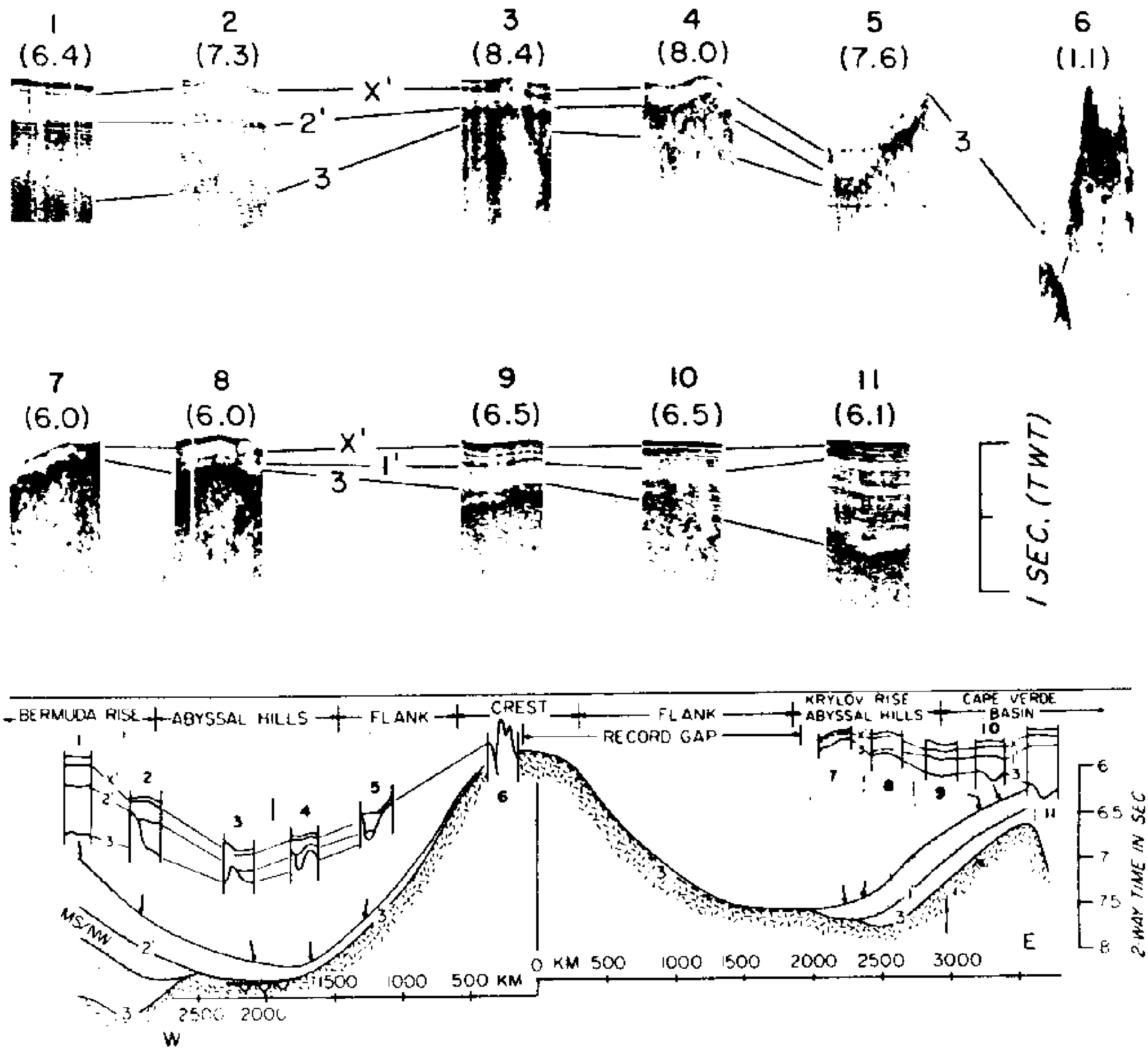


Figure 8.4.8. Transatlantic seismic profiles. Sections are aligned on returns from water-sediment interface. Two-way travel time from surface to bottom is given in parenthesis. Line drawings of corresponding seismic profile sections are shown for possible correlations of subbottom reflectors x, x', y, y', z, 1, 1', 2, 2', and 3 (acoustic basement). (Lowrie and Escowitz, 1969.)

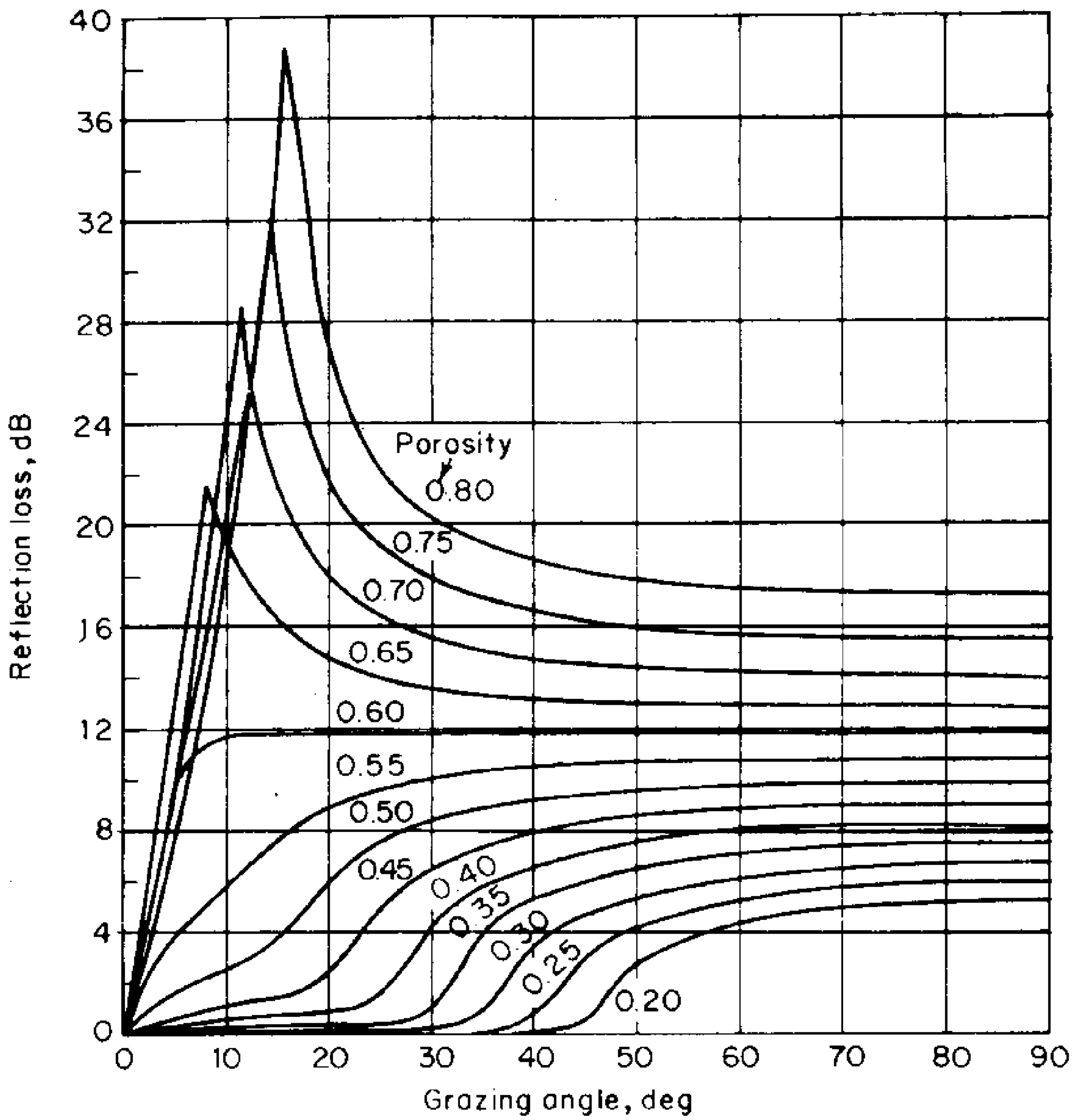


Figure 5.28 Computer curves of reflection loss as a function of grazing angle for a number of porosities. The high peak losses for high values of porosity are seldom found in field data. Approximate porosity values are: coarse clay, 0.81; medium silt, 0.63; fine sand, 0.45; very coarse sand, 0.27. (In Urick 2nd ed. Principles of Underwater Sound)

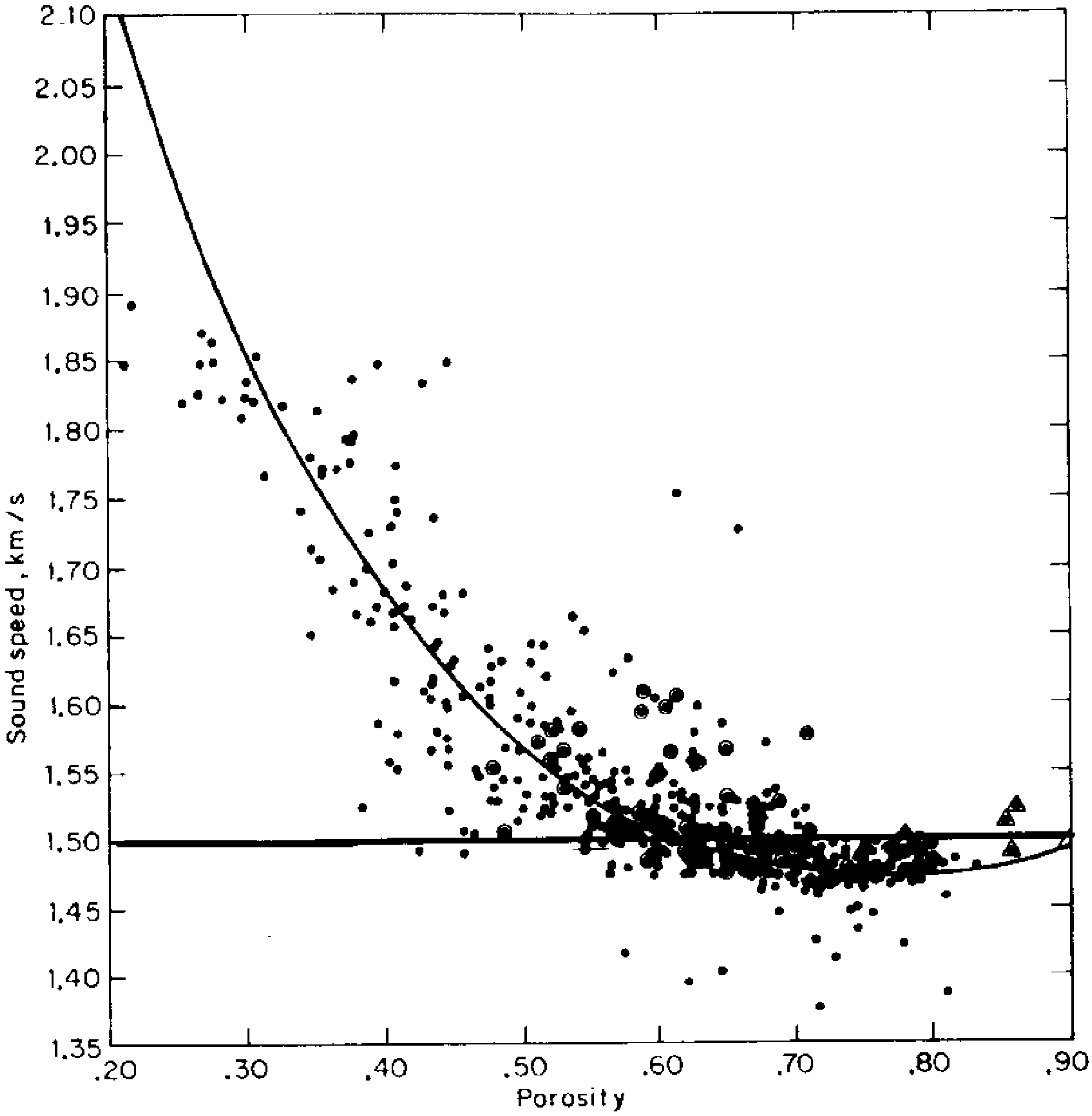


Figure 5.27 Sound speed versus porosity from measurements made on core samples. The curve shows Wood's equation (Wood, A Textbook of Sound, Macmillan, New York, 1941) for a mixture of noninteracting solid particles in water. (from B. C. Schreiber, "Sound Velocity in Deep Sea Sediments, J. Mar. Res., 73:1259, 1968, In Urick 2nd ed. Principles of Underwater Sound)

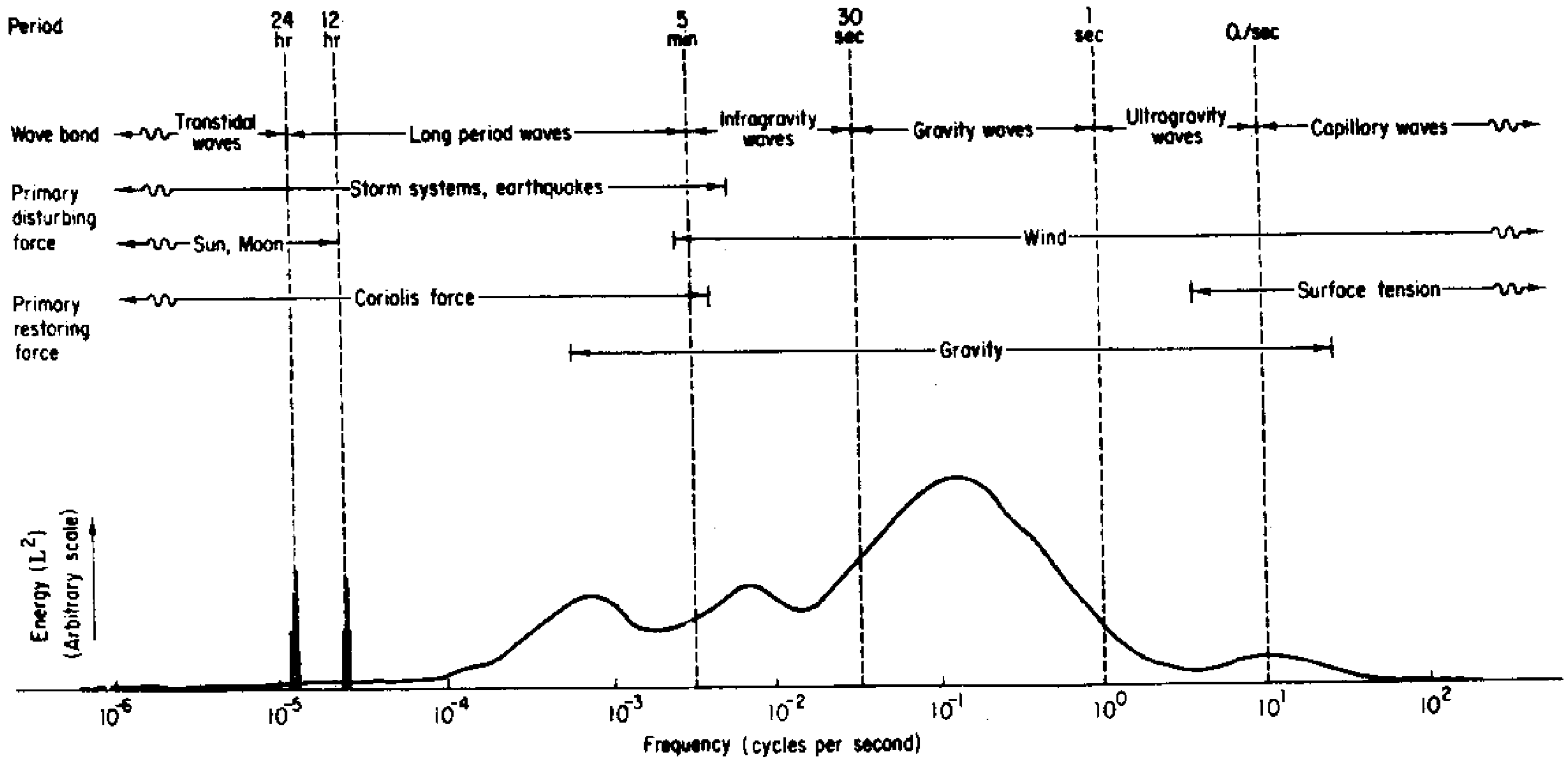


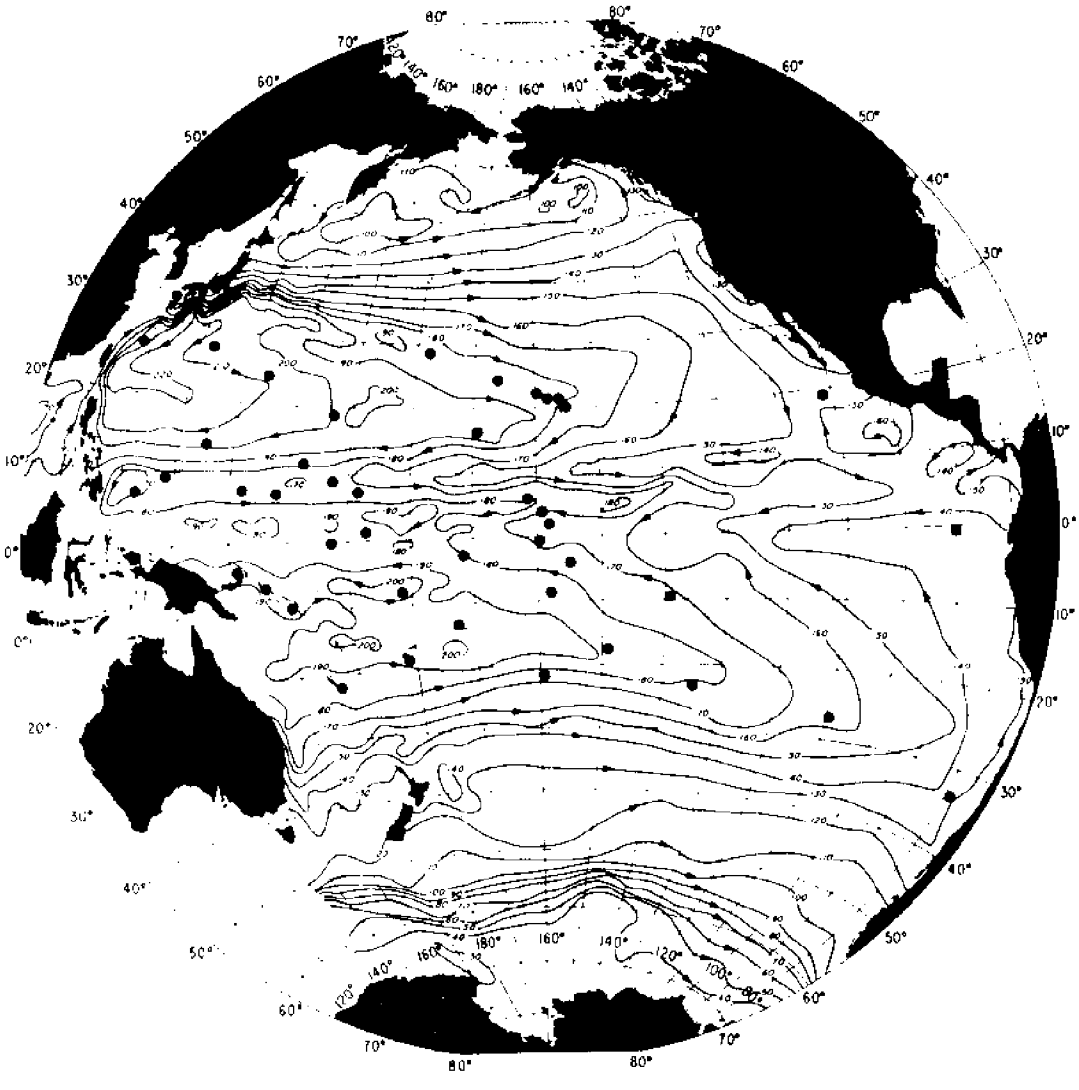
Figure 1.2-1 Schematic (and fanciful) representation of the energy contained in the surface waves of the oceans--in fact, a guess at the power spectrum. (from B. Kinsman, Wind Waves, Prentice-Hall, 1965)

OCEAN DYNAMICAL SYSTEMS AND REQUIRED SATELLITE ALTIMETER CAPABILITY.

	SCALES OF PROCESSES				REQUIRED ALTIMETER CAPABILITY			INVESTIGATED BY THE OTHER WORKING GROUPS			
	RANGE	LENGTH SCALE	TIME SCALE	SPEED/ VELOCITY	VERTICAL RESOLUTION	HORIZONTAL RESOLUTION	FREQUENCY OF COVERAGE	GEOID AND ZERO FREQUENCY	TIDE	ORBIT	MEASUREMENT TECHNIQUES
SEAMOUNTS AND TRENCHES	10 m	100 km	$>10^3$ years	0	1.0 m	10 km		O.K.	O.K.	O.K.	O.K.
EDDIES - STATISTICS - TRACKINGS (Middle Latitude)	50 cm	100 km	2 years (Decay)	2 m/sec Velocity 2 km/day Transport	±10 cm	10 km	1 week	O.K.	Not Required	Not Required	Several Satellites Satellite with Multi-beam Altimeter
GENERAL BASIN WIDE CIRCULATION (Position and Strength Variations)	1 m	5000 km	2-10 years	2 m/sec	±5 cm	50 km	1 mo.	10 cm or better Global Geoid	5 cm	5-10 cm	Intersecting Orbit
WESTERN BOUNDARY - CURRENT - POSITION & STRENGTH VARIATION	1 m 50 cm	100 km Wide 400 km Meander	1 week 20 days	2 m/sec 10 km/day	±10 cm	10 km	1 week	10 cm Local Geoid	None	None	Several Satellites Satellite with Multi-beam Altimeter
EASTERN BOUNDARY CURRENTS	20 cm	300 km	10 days	20 cm/sec	±5 cm	10 km	1 week	10 cm Local Geoid	None	10 cm	Improved Altimeter to ±5 cm
ANTARCTIC AND CIRCUMPOLAR CURRENTS	1.2 m	500 km	20 days	1 m/sec	±10 cm	20 km	1 week	10 cm Local Geoid	None	10 cm	70° Inclination
SEA STATE	10 m	100 km	1/2 day			10 km	Concurrent with Height	None	None	None	None
UPWELLING CURVATURE CHANGE	20 cm 1 m	100 km	1 week	1 m/sec	±5 cm ±10 cm	±10 km	1 week	10 cm Local Geoid	None	10 cm	Improved Altimeter to ±5 cm
EQUATORIAL CURRENT - EDDIES - CURRENT	40 cm 15 cm	200 km 1200 km	20 days 35 days	1 m/sec 40 km/day	±5 cm	20 km 50 km	1 week	10 cm Local Geoid	None	10 cm	Improved Altimeter to ±5 cm

(from Ref. 17)

MEAN DYNAMIC TOPOGRAPHY--PACIFIC OCEAN;
CONTOURS ARE DYNAMIC CENTIMETERS //1000 DECIBAR LEVEL



(from Ref. 18)

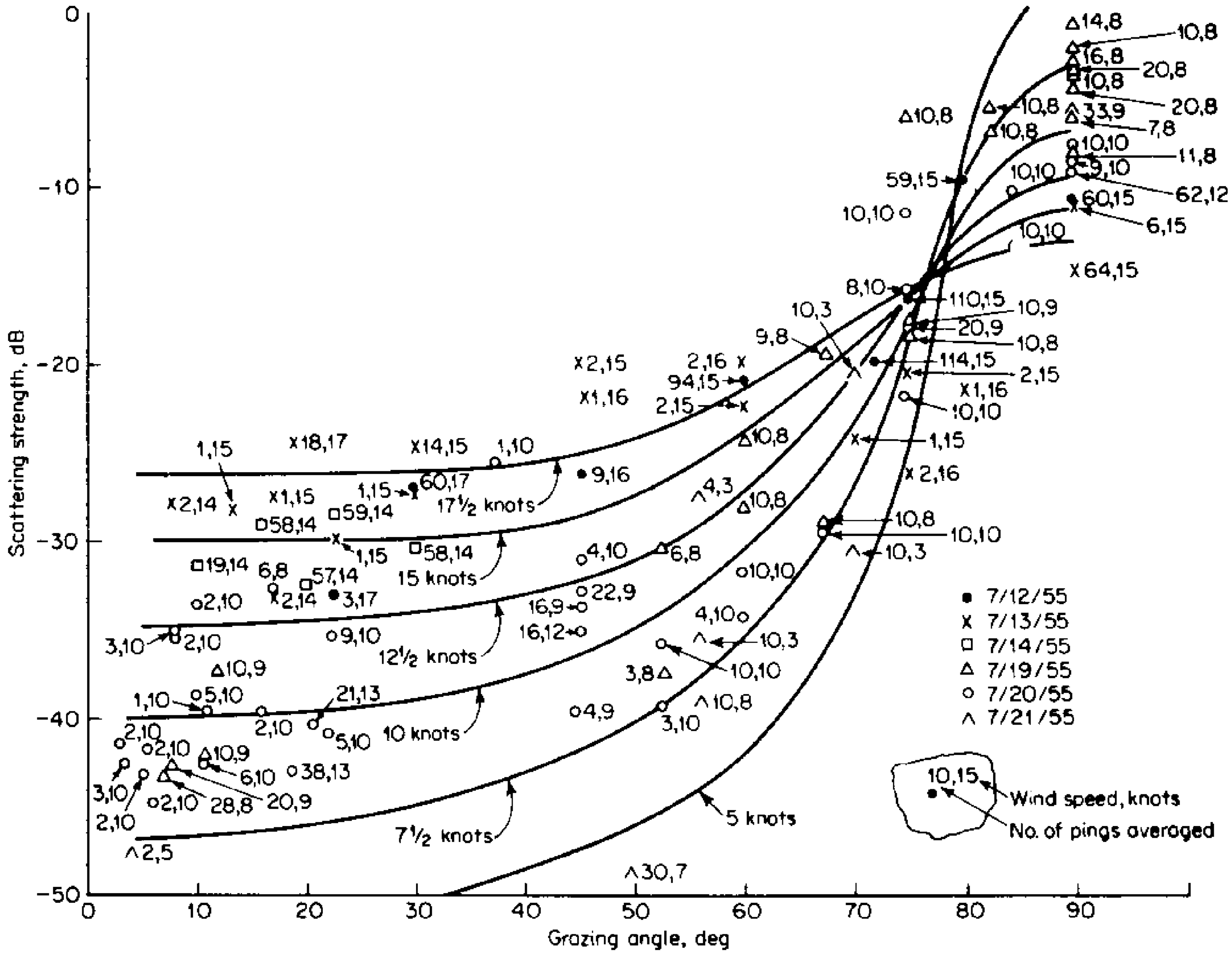


Fig. 8.17. Variation of sea-surface scattering strength at 60 kHz with angle at different wind speeds off Key West, Florida. Plotted points show the number of pulses averaged and the wind speed for individual determinations. (from Ref. 20)

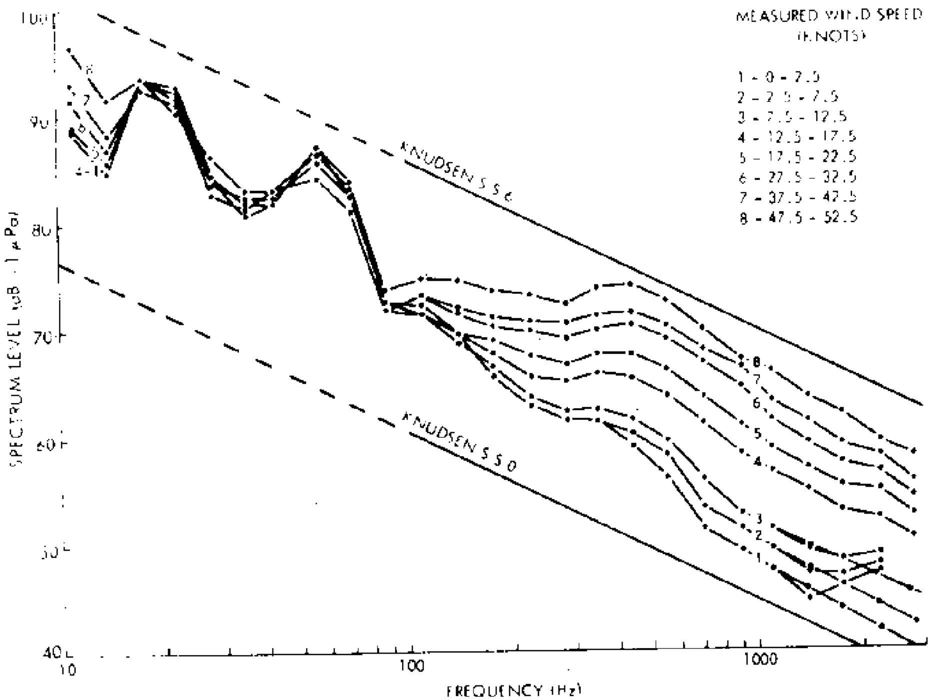


Fig. 2. Ambient noise spectra grouped by wind speed, Bermuda, 14,000 ft (from R. L. Martin and A. J. Perrone, Geographical Variation of Ambient Noise in the Ocean for the Frequency Range from 1 Hz to 5 kHz, In International Workshop on Low-Frequency Propagation and Noise, Vol. 2, Woods Hole, Mass., 14-19 October 1974 (1977)

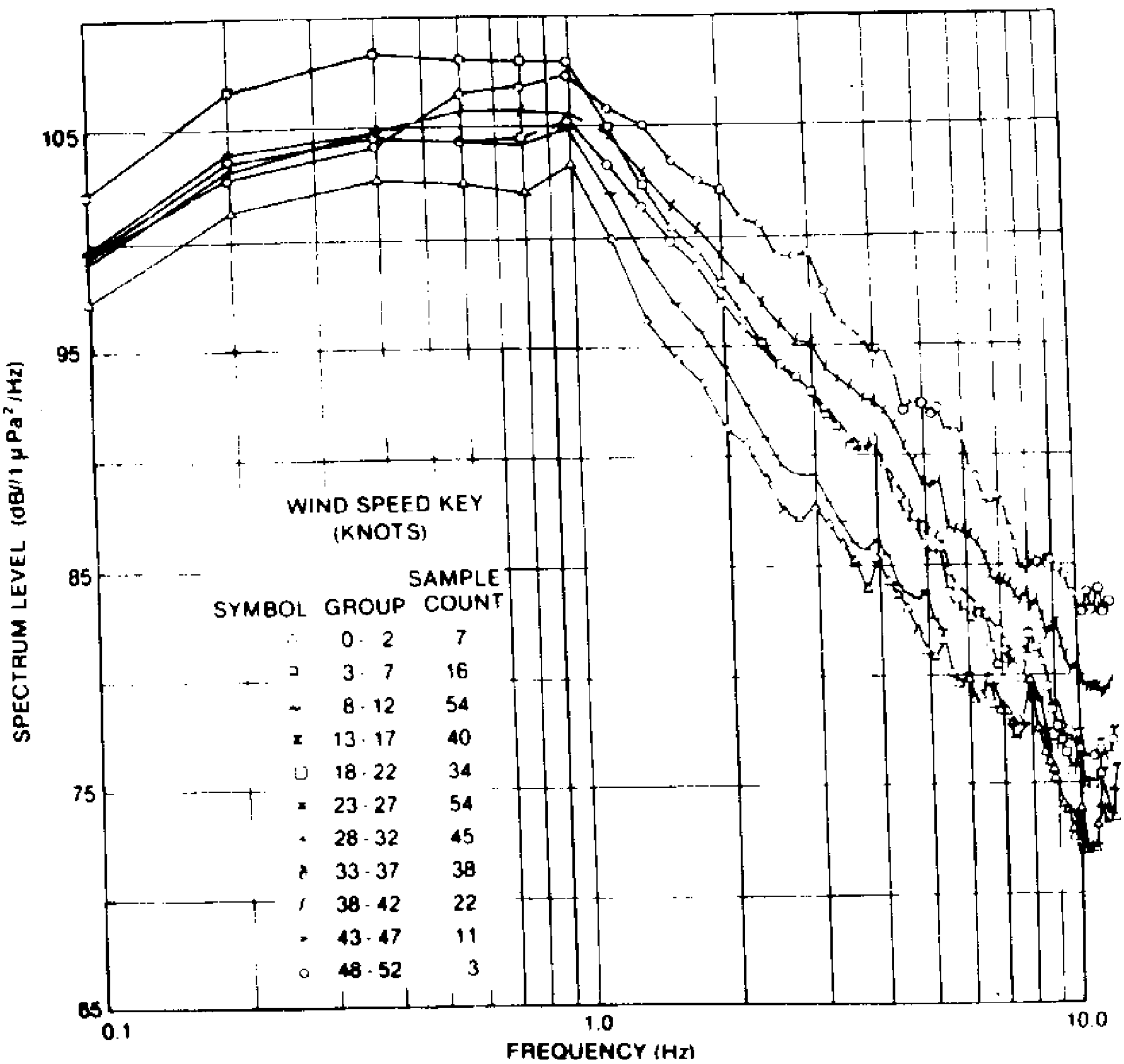


Figure 2. Ambient noise spectrum versus windspeed groups; Bermuda, 1966, water depth 900 m (2600 ft). (from Nai-Chyuan Yen and A. J. Perrone, NUSC Tech. Rpt 5833, 13 February 1979)

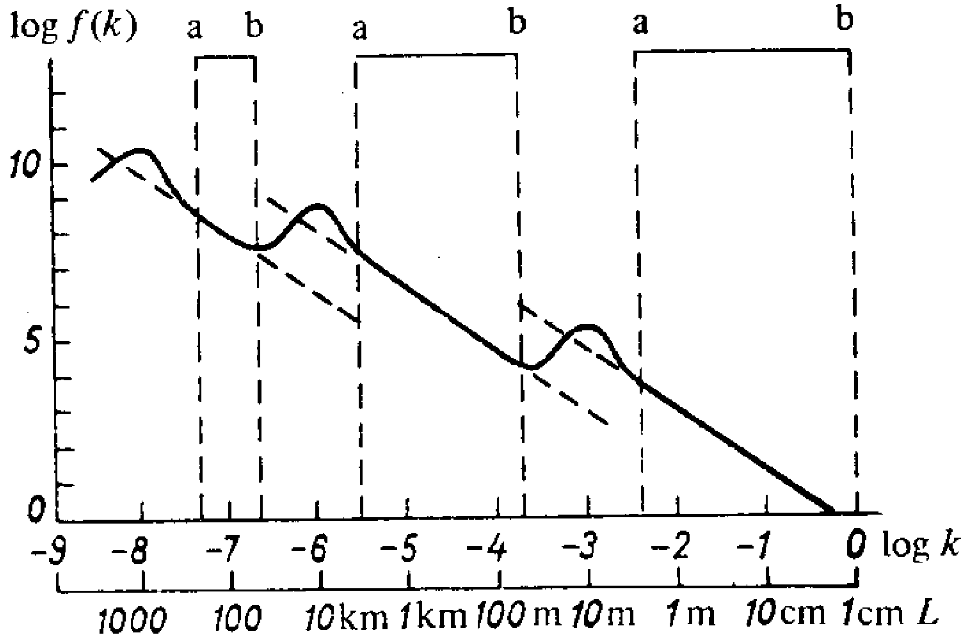
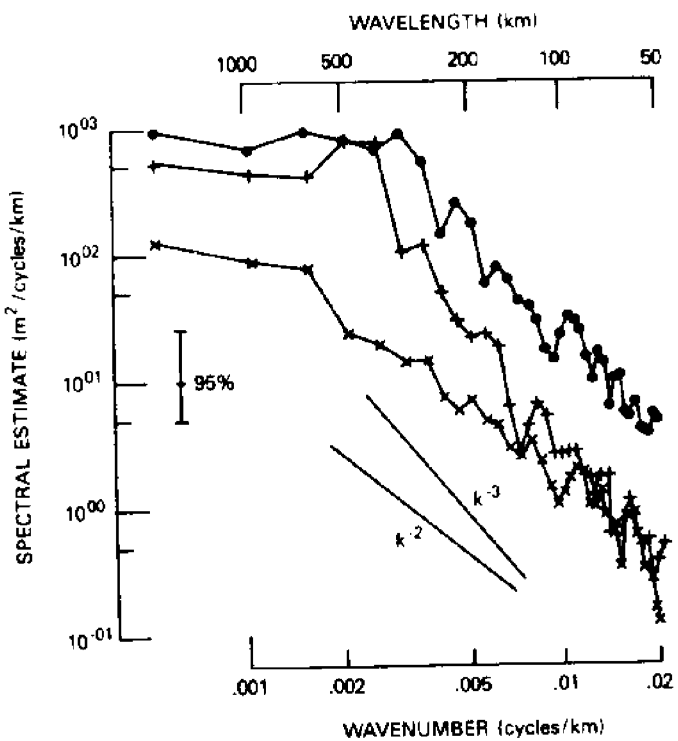


Fig. 1-2-1. Schematic kinetic-energy spectrum of ocean motions (after Ozmidov [3]). *a-b* -- Zones in which the 5/3 law is satisfied.

SPECTRA OF ISOTHERM DISPLACEMENT IN MAIN THERMOCLINE.



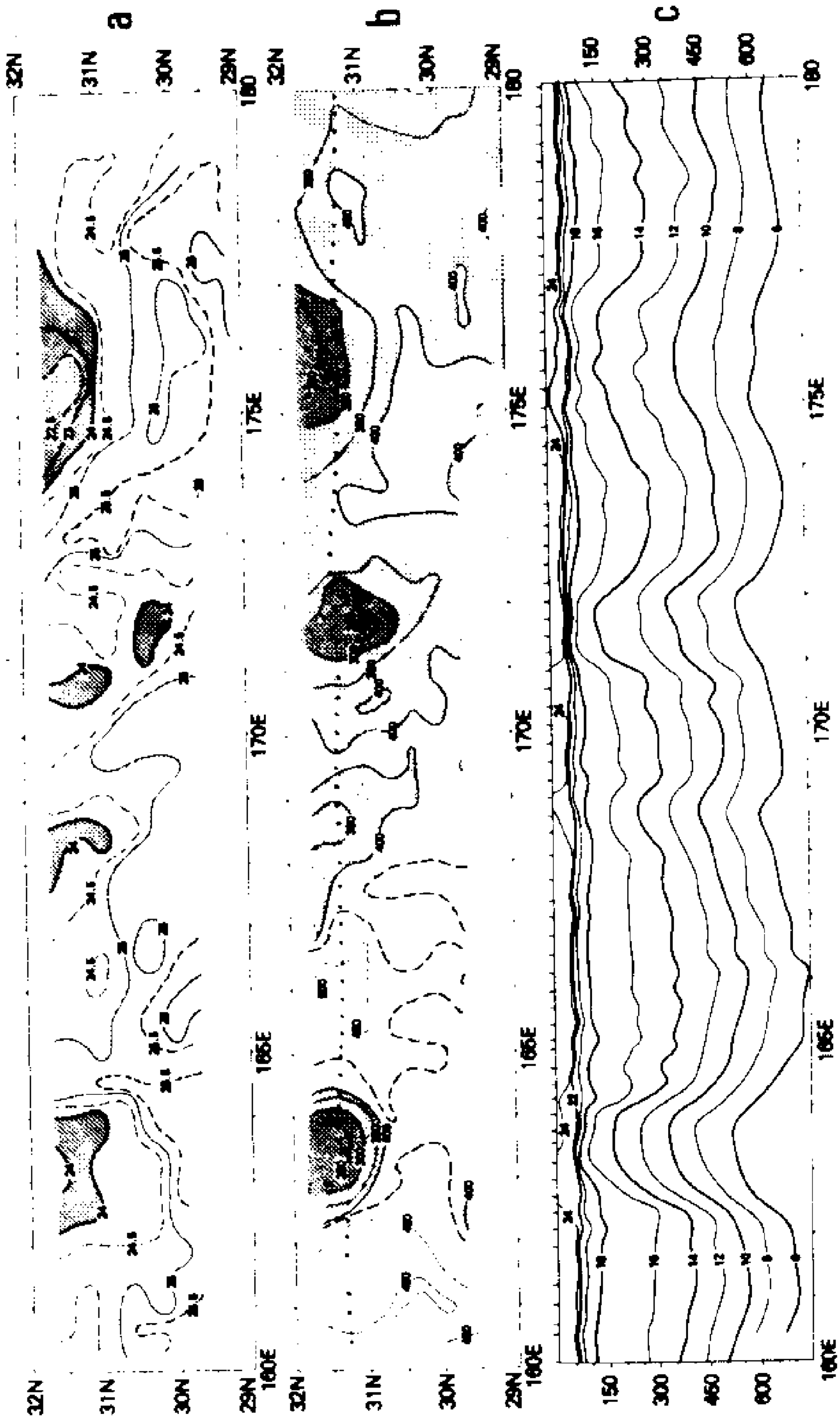
x = 12°C isotherm for three ships 29-30.5°N

\+ = 12°C isotherm for three ships 30.5-32°N

● = 10°C isotherm for six ships 36-38°N

(from Ref. 23)

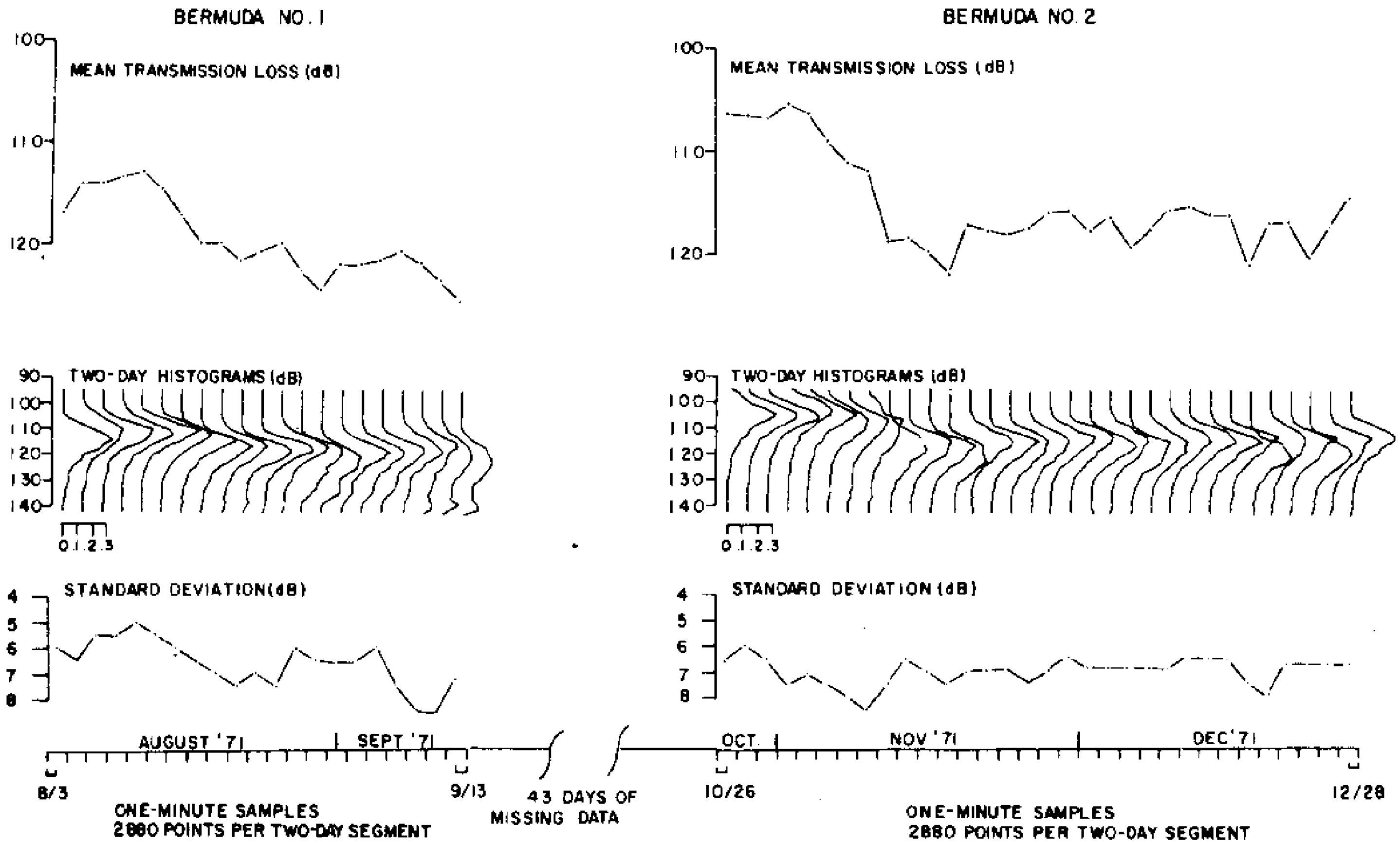
Fig. 6-3



a SURFACE TEMPERATURE IN DEGREES CELSIUS: **b** DEPTH OF THE 12°C ISOTHERM IN METERS: **c** VERTICAL TEMPERATURE SECTION, IN DEGREES CELSIUS AND METERS, TAKEN ALONG THE HEAVIER DOTTED TRACK IN **b** ABOVE: DATA FOR **a**, **b**, AND **c** WERE TAKEN BETWEEN 3 AND 6 NOVEMBER 1975.

(from Ref. 23)

A TIME-DEPENDENT STATISTICAL CHARACTERIZATION OF THE BURMUDA AMPLITUDE DATA OVER A 5-MONTH PERIOD. EACH DATA POINT FOR THE MEAN AND STANDARD DEVIATION AND EACH HISTOGRAM COVER 2 DAYS (2880 POINTS) OF AMPLITUDE DATA.



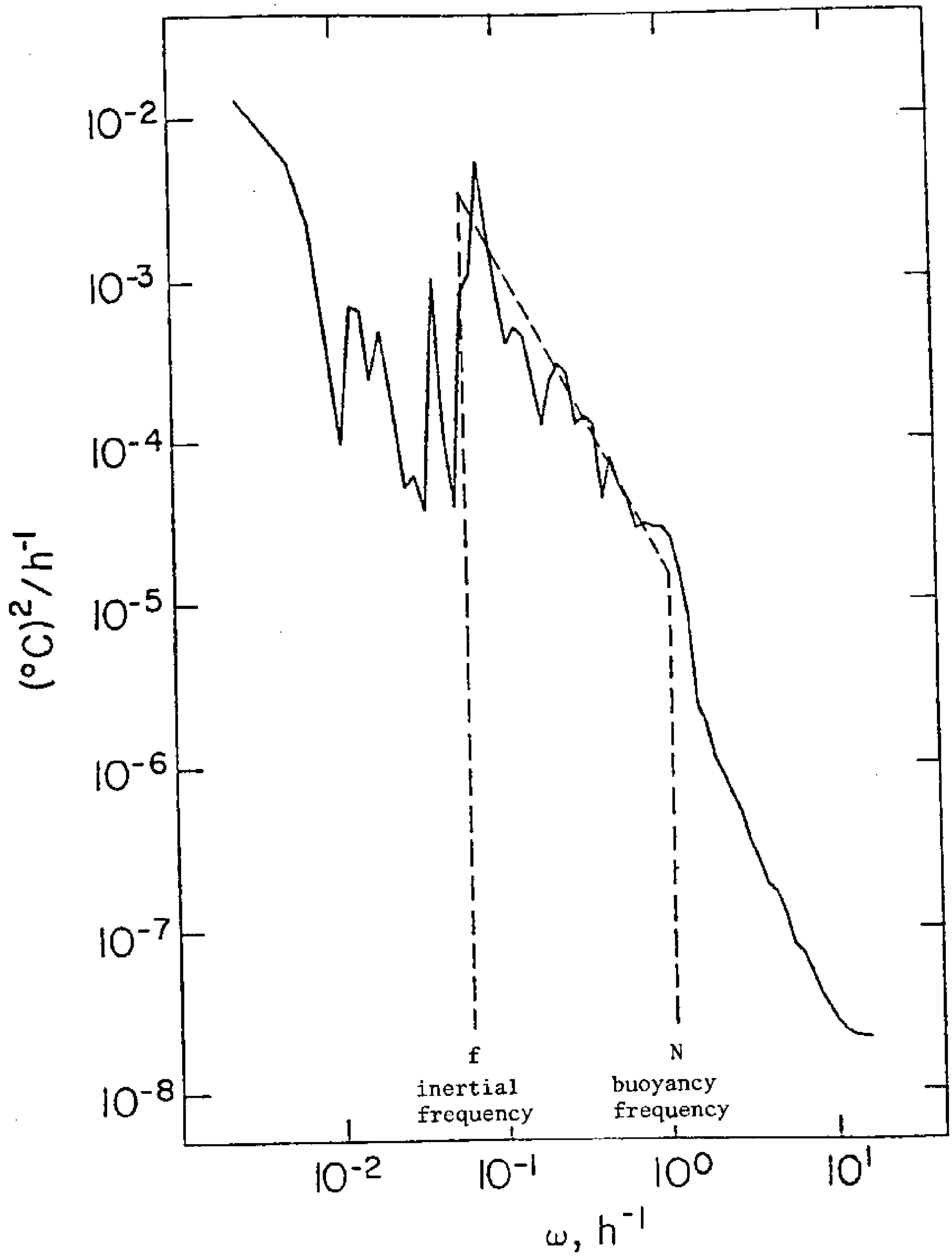


Fig. 4.1.2. Moored temperature spectrum (MS) measured by sensor T6 at 1203 m. The fit to the modified internal wave model is also plotted. (from M.D. Levine, "Statistical Description of Internal Waves and Temperature Fine Structure in the Deep Ocean", University of Washington Ph.D. Thesis, Seattle, 1979.)

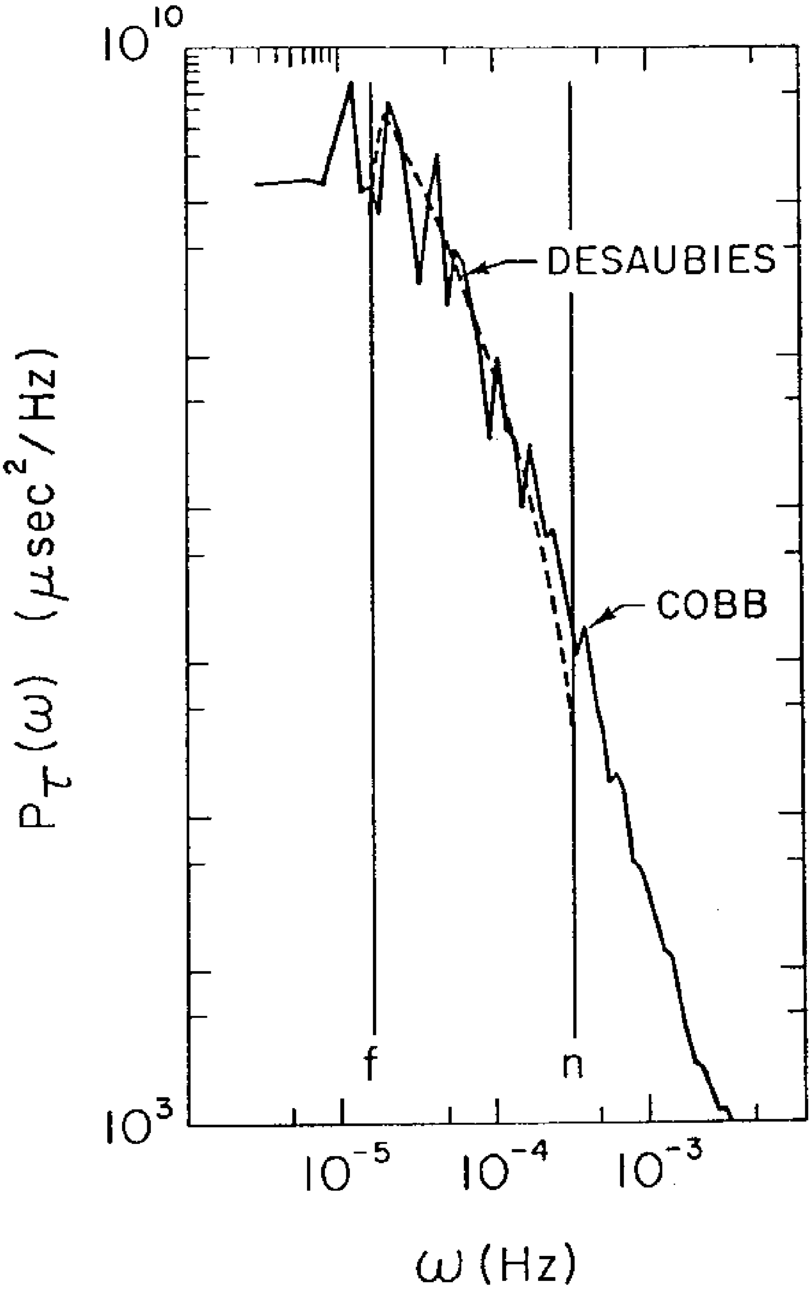


Figure 3. Comparison between the theoretical and the measured phase spectrum. (Courtesy of T. Ewart)

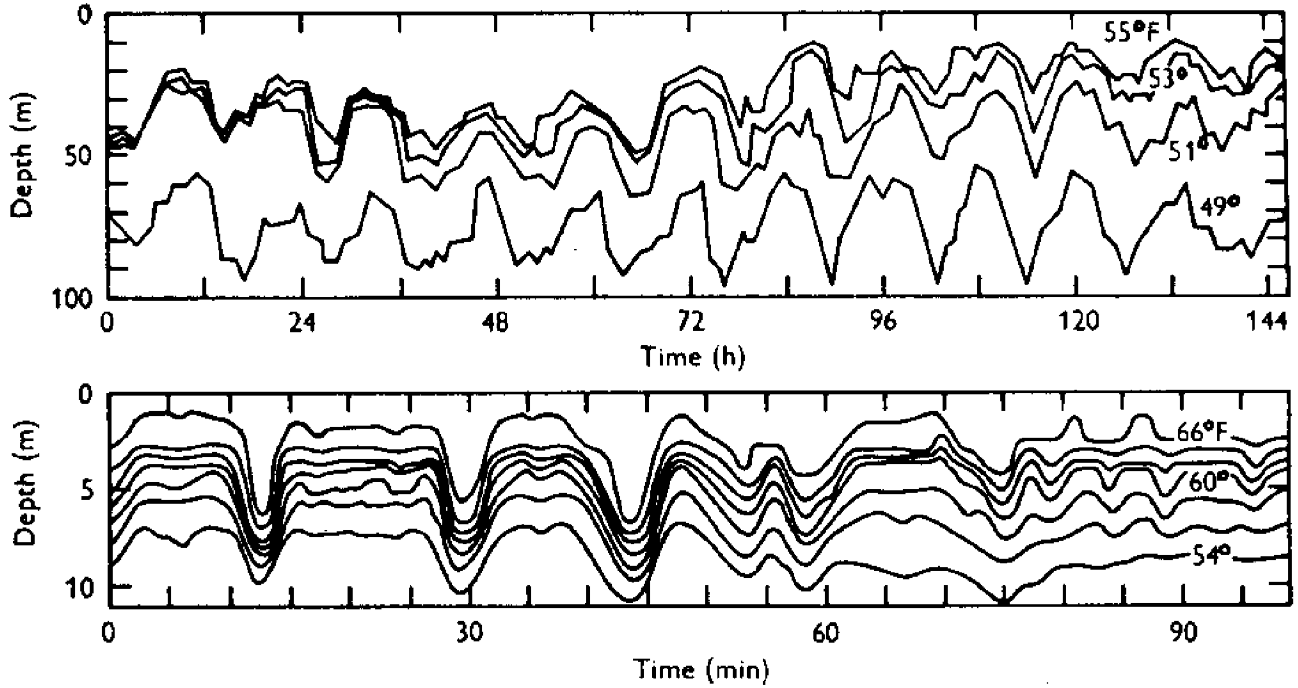


Figure 1.3.3. Isotherms in internal wave motions. (*Top*) dominant component with tidal frequency and amplitude about 15 m. (*Bottom*) Oscillations in a shallow thermocline with a considerably higher dominant frequency. (Phillips, 1966.)

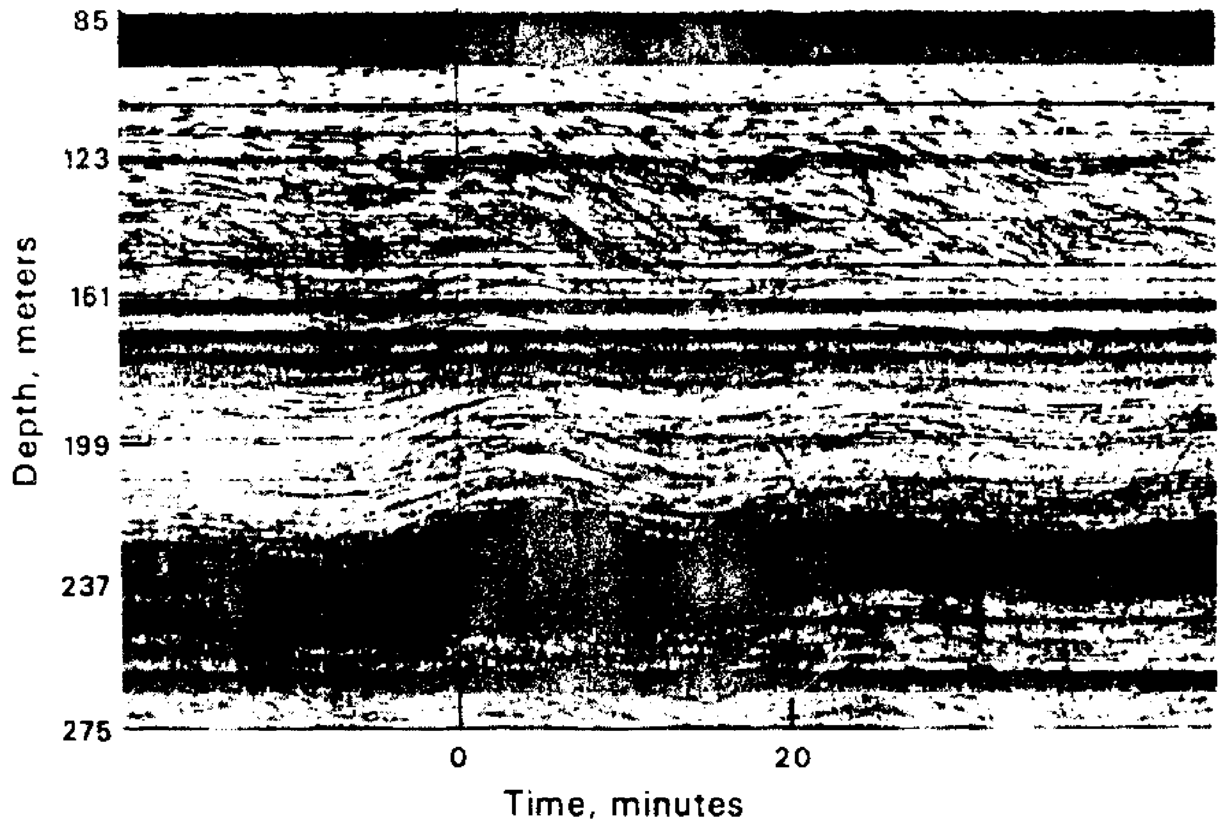


Figure 7.4.6. Internal waves. The observations were made from FLIP (floating instrument platform) in water 3600 m deep at 31°N, 120°W. The data were taken with a 6.6 ms pulse at 87.5 kHz. The echo sounder beam was 3 dB down at ±0.5°. Photograph courtesy of F. H. Fisher, Marine Physical Laboratory, University of California, San Diego. (Fisher, 1975.)

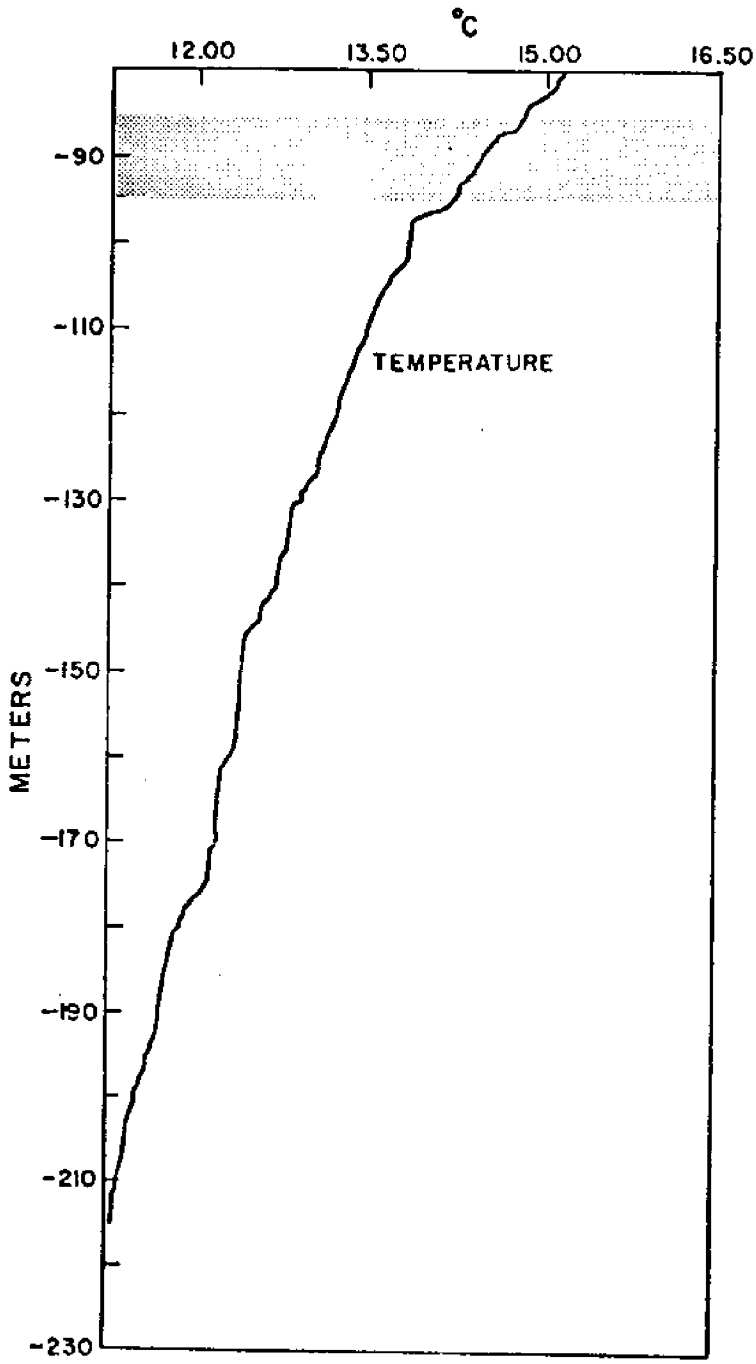


Figure 6-9. Finestructure in a Temperature vs Depth Profile. (from Ref. 29)

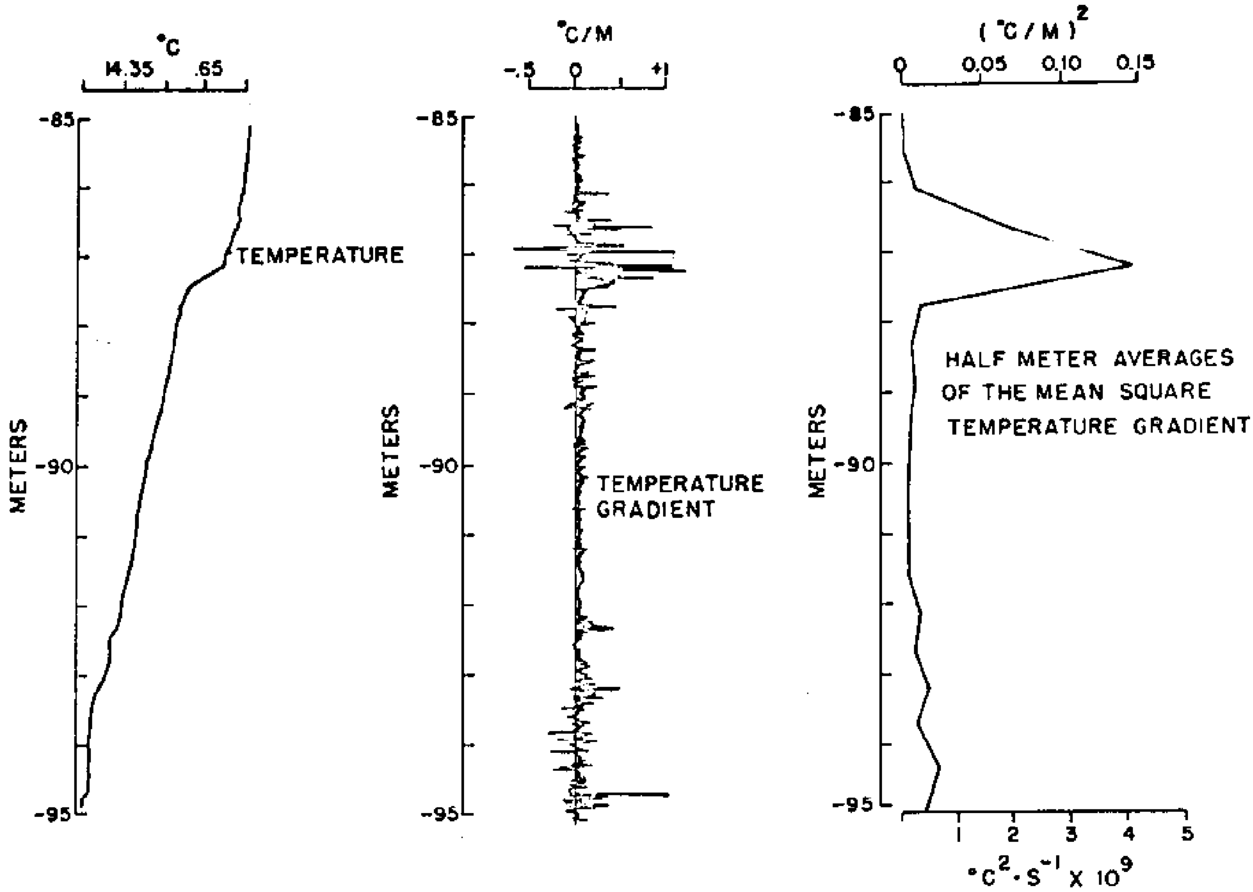


Figure 6-10. Detail of a Thermocline Portion of Finestructure -- Temperature Gradient and its Square also Shown.

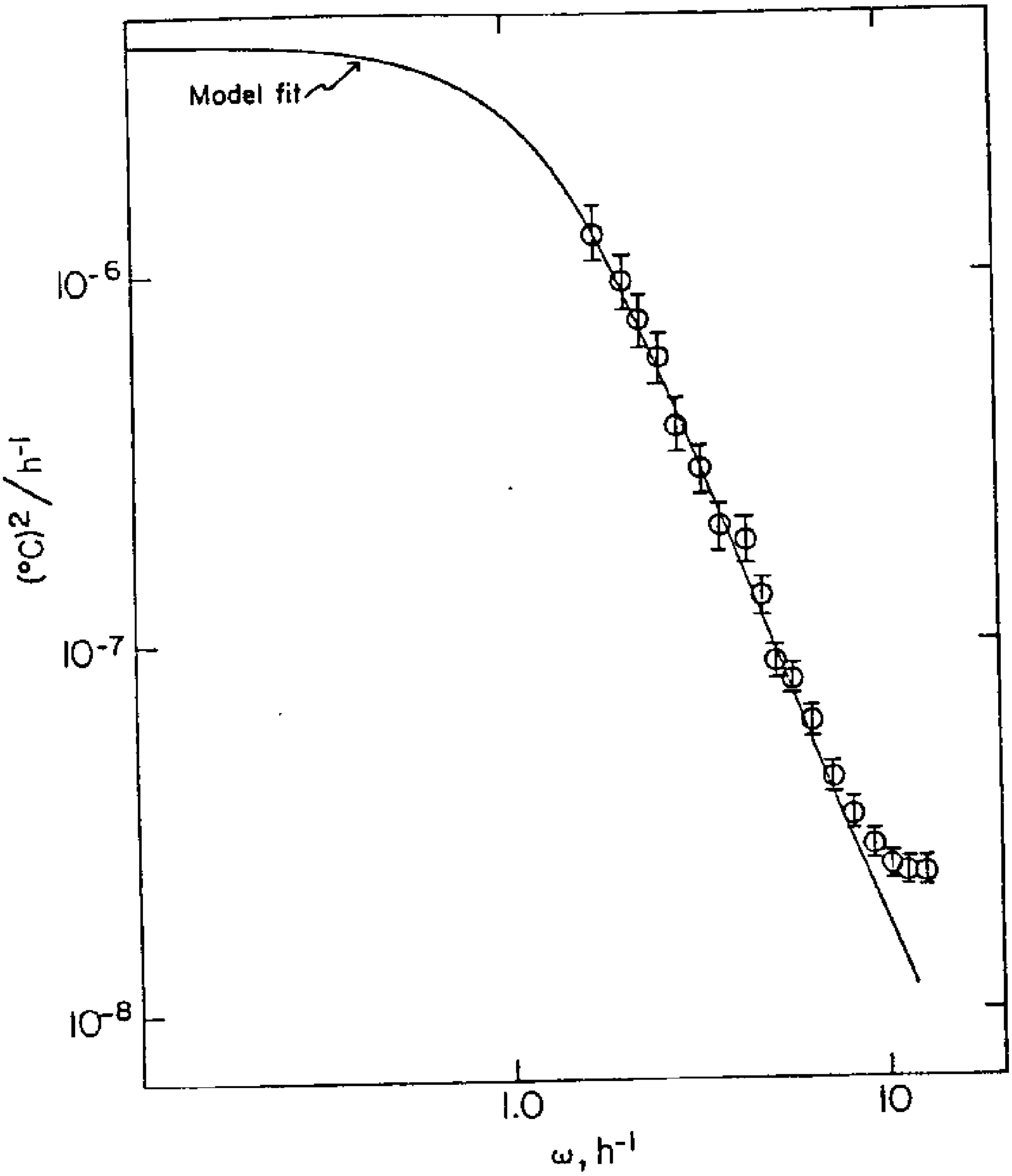


Fig. 4.2.2. Fit of theoretical FSMS curve to high frequency portion of MS T6 by adjusting C^2. Data are plotted as circles with 95% confidence limits. (from M.D. Levine, "Statistical Description of Internal Waves and Temperature Fine Structure in the Deep Ocean", Univ. of Wash. Ph.D. Thesis, Seattle, 1979.)

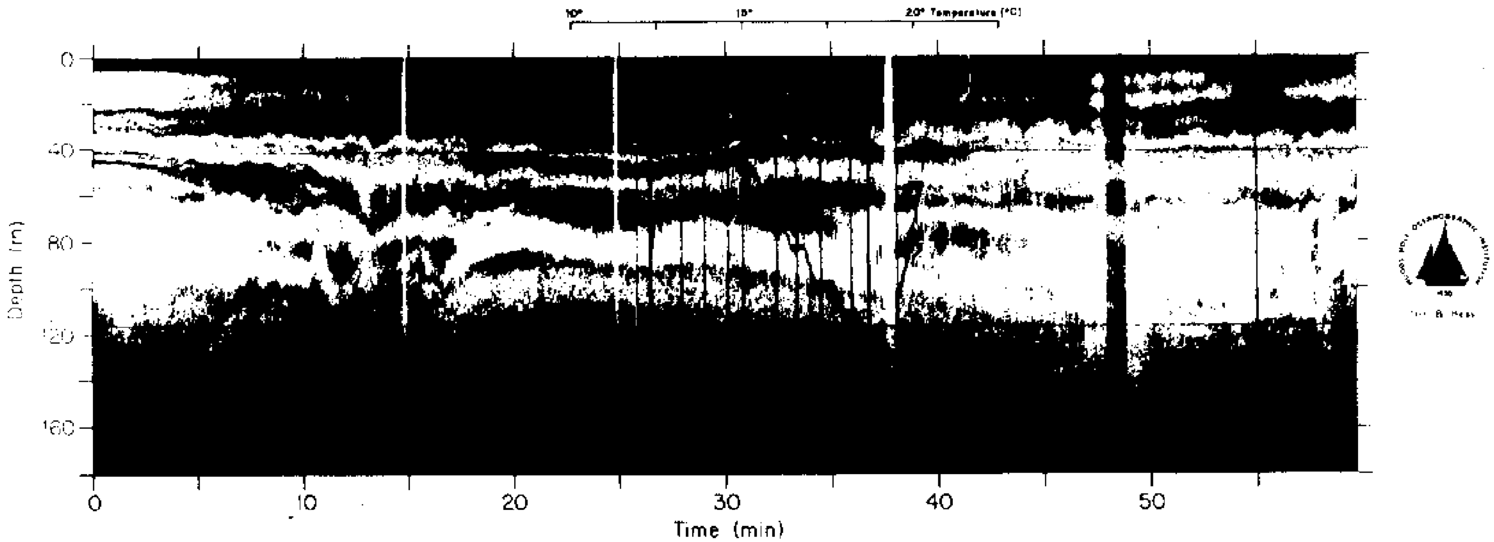


Figure 5. Various water masses at work in Hudson Canyon, including a lenticular, low-scattering intrusion running down the axis of the canyon. (from F. R. Hess and M. H. Orr, Woods Hole Tech. Rpt. WHOI-79-76, October 1979)

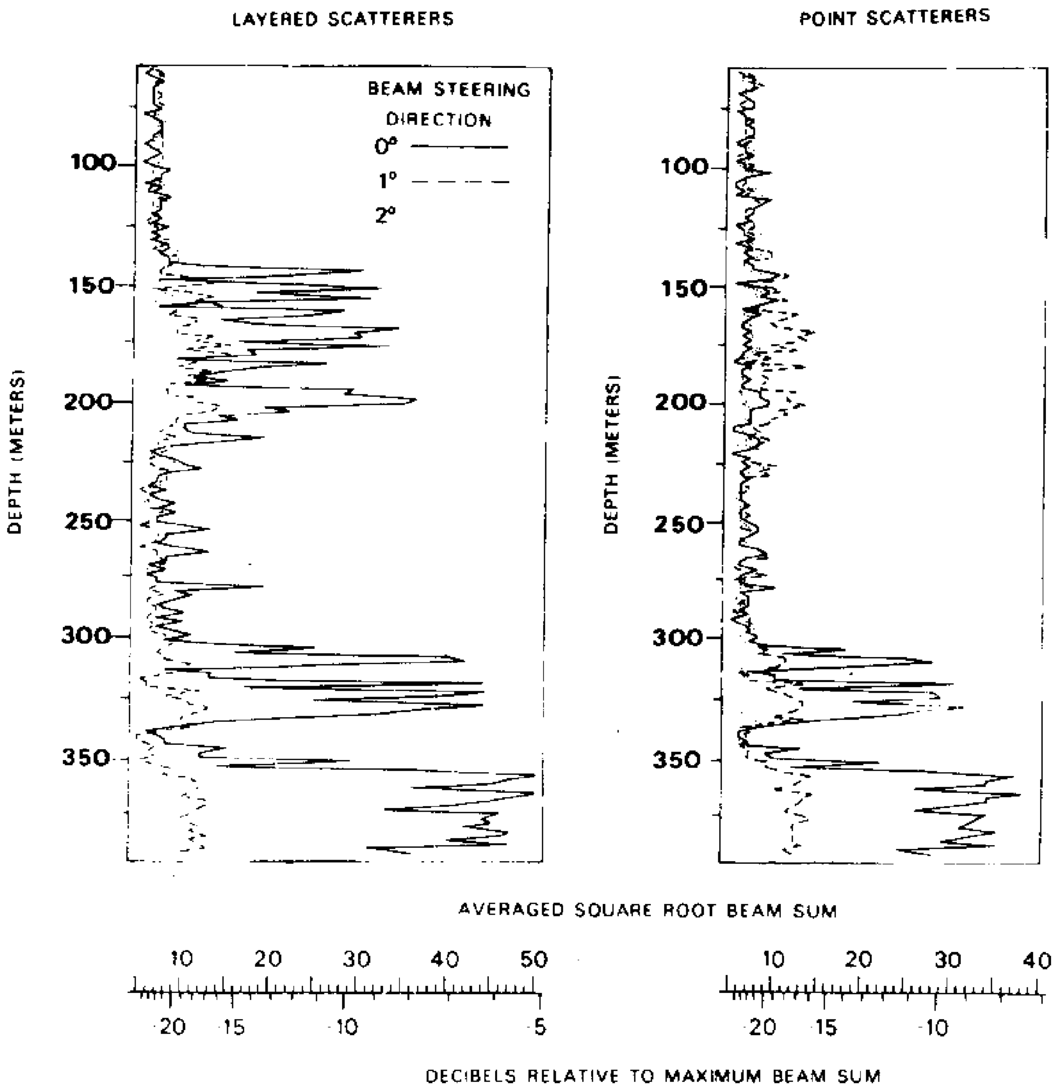


Fig. 9. Beamformer output averaged over 50 consecutive pings for three steering directions and both focusing modes. (from Kaye, G.T., and V.C. Anderson, J. Acoust. Soc. Am. 66 (3), Sept. 1979)

Bibliographic Overview of Ocean Acoustic Remote Sensing (OARS)

Prepared for OARS Workshop
January 21-25, 1980
Seattle, Washington

U.S. DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary

National Oceanic and Atmospheric Administration
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FOREWORD

This document was prepared using the online bibliographic search capabilities available at NOAA's Library and Information Services Division in Rockville, MD. Computer-produced copy was edited to select only the most relevant material.

Over 100 databases are available for online search in this and many other locations in the nation. Properly used, these databases can measurably shorten the amount of time needed to research a question, to prepare a bibliography, or to check a point of information. As an example, the entire National Technical Information Service database alone contains well over half a million citations, with about 5000 added each month. Databases now exist on almost any subject.

These powerful research tools are, however, still only tools. Their successful use depends on the ability of the requester to communicate and the skill of the search analyst in interpreting the request and conducting the search. A successfully completed search may require several interactions between requester and analyst, and analyst and computer.

The search strategy used to retrieve the material from which this document was produced is explained in some detail in the appendices.

Carolyn P. Brown; Chief, User Services Branch

A COMMENT

This document contains 100 bibliographic references to "overview-type" papers on Ocean-Acoustic-Remote-Sensing (OARS). In addition, references are provided to 15 contemporary textbooks on Ocean Acoustics. This bibliography was obtained entirely using computer (on-line) search methods and is, as such, a demonstration of the power, as well as the limitations of such methods. The methodology developed to conduct the search, as well as the specific search strategy are discussed in Appendix A. Described in Appendix B are the computer-readable data bases used in this search and containing more than nine million searchable citations.

Many excellent articles, very relevant to OARS, are not included here simply because they are not "overview-type" papers -- however, it is likely that the included set contains references to most of the relevant work. Due to the press of time, we have alphabetized the listing but have not categorized it in any other way, and it is likely that we have not picked up all the errors and typos. We have, however, used word-processing and if warranted, will republish the document in an upgraded form. In this regard, your suggestions and comments would be welcomed.

We have prepared this bibliography for use during and subsequent to the OARS Workshop. In addition, the OARS Committee has arranged to provide search services during the conduct of the Workshop itself, directly to the participants.

Barbara Roush..Secretary............NOS
Gary Adams.....Library Scientist...EDIS
Ronald New.....Systems Analyst......NOS

ACKER, WILLIAM C.

1977. Techniques for Measuring the Effects of Nuclear Power Plants on Local Fish. Published in Oceans '77 Conf. Rec., Annual Comb. Conf sponsored by the Marine Technology Society, and IEEE Counc. on Oceanic Eng, 3rd. (Available from IEEE, Piscataway, NJ, v. 1, p. 23C, 1-23C, 2.) Los Angeles, CA.

Acoustical equipment and techniques have been developed that are now being used to help assess the effects of coastal power plants on fish. The technique consists of acoustic assessment of fish abundance with a portable, towed assessment system and simultaneous measurement of the temperature at several depths in and around the thermal plume. When the acoustic-temperature measurements are used in conjunction with an acoustically directed sample fishing program, data on species composition can also be obtained.

ANDERSON, A. L.

1978. Ocean Acoustic Model Inputs/Sensitivity Published in EASCON '78, Arlington, VA, p. 228-34

Ocean acoustic models are useful tools for temporal and spatial extrapolation or interpolation of measurement results. The relationship between model input accuracy and model output accuracy is determined by the model's sensitivity to input variation (or error). A process of model comparison for relative accuracy determination and sensitivity assessment is termed model evaluation. Environmental inputs for ocean acoustic models, model sensitivity and model evaluation are discussed.

ANDERSON, VICTOR C.

1972. First Twenty Years of Acoustic Signal Processing J. Acoust. Soc. Am 51(2):1062-1065

In a review of the acoustic research of the past two decades it is shown how work on signal recognition evolved into a unified class of spatial and temporal processing techniques. Progress is shown in the areas of spectrum analysis, correlation, multiple beam forming, the fast Fourier transform, sequential detection, and adaptive beamforming.

ANDERSON, VICTOR C.

1975. Seeding the Field of Acoustical Signal Processing J. Acoust. Soc. Am 57(6):1269-1274.

A historical review is given of the contributions to the field of acoustical signal processing, and eventually in underwater research, that orginated with F. V. Hunt at the Harvard

Acoustics Research Laboratory. The culmination of these researches led to the present real-ocean investigation of a ship transit detector.

ANDREWS, F. A.

1967. Analytical Review of Lessons Learned from the H-bomb Sea Search off Spain-1
Published in Proceedings of U. S. Navy Symp. on Military Oceanography. 4th, p. 3-28. Washington, D. C.

The most significant search and identification lesson learned is the inadequacy of sonar in classification. Improved acoustic classification, and the integration of acoustic, magnetic anomaly, visual detection, and other detection means into one package are indicated. The most significant recovery lesson is the necessity for decoupling surface motion from attachment motion.

ANONYMOUS

1975. Underwater Sound-A Review, II
IEEE Trans. Sonics and Ultrason 22(5):291-332.

Particular attention is given to a system model for active and passive sonar operation, the signal waveforms, transmission and reception modes commonly used in echo ranging, the propagation effects, and reverberation mechanisms of the acoustic channel, the multidimensional aspects of conventional beamforming and the feasibility of adaptive control in an operational environment, the effectiveness of gain control receivers and hard clipping for dynamic range compression and normalization of acoustic data, the techniques presently employed for signal detection and parameter estimation - for video and aural presentation, and the dynamical system measured required for system performance evaluation.

ANONYMOUS

1978. New Underwater Potential Measuring System
Anti-Corros. Methods and Mater. 25(4), 15.

A new underwater cathodic protection, potential monitoring system has been developed by Metal and Pipeline Endurance Limited (MAPEL) which, they claim, enables rapid cost-effective checking of subsea anode installations without the need of physical examination by drivers or submersibles. MAPEL's underwater monitoring system eliminates the need for physical examination of cathodic stations by the use of seabed transponders and a single survey vessel. Savings on time, cost and equipment is considerable. Utilizing transponders located at one mile intervals on the seabed the system can interrogate two hundred miles of pipeline in only 48 hours. The system comprises two parts: 1. A shipborne surface interrogator unit, complete with either a towed or 'dunking' transducer. 2. A series of seabed potential-measuring transponders, each one having its own identification code, so that up to 1000 transponders can be used in any one system. All underwater components are designed for long-term maintenance free operation with transponder battery life of up to 10 years. Operating as an underwater data telemetry link the equipment can be used to transmit a potential value from the underwater cathodic protection system to the surface monitoring unit aboard the survey vessel. The surface unit which can be either mains or battery operated, contains the necessary circuitry to transmit a unique coded address signal to the selected seabed transponder. On receipt of this signal, the corresponding battery-powered transponder unit will activate, measure the potential between the reference half-cell and the underwater steel structure, as generated by the cathodic protection anode, process the potential and then acoustically telemeter the value to the surface. This reply signal is then processed by the seaborne equipment to produce a digital display of the measured potential. At the same time the specific address code of the underwater transponder is displayed for identification purposes.

APPELL, G. F.

1977. Performance Assessment of Advanced Ocean Current Sensors Published in Oceans '77. 3. Annual Combined Conference, MTS/IEEE Los Angeles, CA

Significant progress has recently been made towards the development of advanced ocean current measuring sensors. The new technology for measuring ocean currents has shown improved time response characteristics and high accuracy measurement in a three- dimensional flow pattern while at the same time minimizing hydrodynamic distortions caused by the system's presence in a fluctuating flow field. The Test and Evaluation Laboratory (T&EL) of the Office of Marine Technology of NOAA has a continuing laboratory test program to assess the performance of newly-developed marine sensors and to assist manufacturers and the marine community in the development testing of sensors which may have application for present or future NOAA measurement programs. Under this program, evaluation tests have been performed on several new electromagnetic and acoustic-type current measuring sensors. Tests conducted are concerned with the steady flow and dynamic (fluctuating velocity vector) response characteristics of the sensors in a system configuration. This paper will discuss evaluation test results obtained to date, problems encountered, and plans for future work. A discussion on the state-of-the-art in new current measuring sensor technology, including remote sensors, will also be presented.

ARASE, E. M. and T. ARASE

1974. Underwater Ambient Noise
Acoust and Vib Prog., v 1, p. 191, 193-236.

The present knowledge of ambient noise research and some outstanding problems are summarized. The characteristics of the measured noise are given and accounted for in terms of the underlying mechanisms. For example, for the noise spectra, the contributory effects of the surface wind, ship traffic, etc., are examined. For noise directionality as measured by arrays or by two- element correlators, the distribution of the noise sources that might account for the measured directionality is given. Amplitude and level statistics do not yield to this approach at present. Under-ice noise is discussed briefly.

AYRES, A. and T. CALKINS

1977. Acoustic Position Measurement Systems
Published in Oceans '77, 3rd Annual Combined Conference MTS/ IEEE, Los Angeles, CA.

Progress made over the past 2 decades in acoustic measurement technology is finding important application in dynamically positioning drill ships for offshore oil exploration. This paper quickly traces the history of this technology, examines in general terms the basic underwater tracking problem, describes approaches taken to its solution, and identifies the factors which affect the designer's choice of systems. Comparisons are made between the basic types of tracking systems and between the conventional and newly developed signal processing techniques.

BARNARD, G. R.

1967. A Summary on Reflection and Scattering of Acoustic Waves from Model Surfaces, NTIS Report No. AD-A046 840/5ST.

These studies have included both analytical and experimental investigations, with the experimental work being done in a laboratory tank which has provisions for precise control of the parameters of the experiment. Full-scale experiments at sea are expensive and time consuming, and particular aspects of reflection theory are often obscured by sea or bottom conditions that cannot be controlled. The small-scale experiments in the acoustic tank with model surfaces provide information rapidly and accurately to compare with mathematical models. These mathematical models can then be used to predict the reflection and scattering of sound by the ocean boundaries for full-scale conditions.

BELL, D. L.; et al

1973. Progress in the use of Acoustics to Classify Marine Sediments

Published in Ocean '73, IEEE International Conference on Engineering
in the Ocean Environment, Seattle, Washington, p. 354-9.

The authors review progress and describes a prototype towed array measurement system which provides fundamental data concerning near-surface sediments. They give generalized results of field tests and indicate parameters giving consistent measurements.

BIRDSALL, T. G.

1973. Automatic Fixed Site Propagation Tests (Underwater Acoustics). Published in Proceedings of the NATO Advanced Study Institute on Signal Processing, Loughborough, Leics., England, 299-309.

The author reviews long duration oceanic underwater acoustic propagation tests, generalities and details. He discusses purposes, hardware and software and initial analysis. The use of minicomputers is suggested.

BOBBER, ROBERT H.

1973. Underwater Sound Reference Division and 32 Years of Sonar Calibration and Standards. Rep. NRL Prog., p. 1-5.

The Underwater Sound Reference Division is a focal point in the Navy for standardization in the science and technology of underwater sound measurements. Its research and development program is aimed at expanding the state of the art and providing Navy in-house expertise. Reference calibration measurements in a large complex of specialized facilities and calibrated standard transducers are available to all naval facilities and contractors in support of undersea warfare programs.

BRENDEN, B. B.

1975. Acoustical Holography
J. Phys. E (GB) 8(11):885-6.

The most striking thing about acoustical holography is the variety of hologram detector schemes that have been investigated. The various detection schemes yield a variety of imaging devices which are contributing benefits in the fields of medical diagnosis, industrial testing, undersea search and geological exploration. The two most persistently successful detectors have been the liquid surface which provides instantaneous real-time imaging at framing rates in excess of 100 frames/s and scanned piezoelectric receivers which have been used extensively for pressure vessel inspection.

BRISCOE, MELBOURNE G.

1976. Internal Waves in the Ocean
The Reviews of Geophysics and Space Physics 13(3):591-645, 1975.

Progress in measuring, describing, and understanding oceanic internal gravity waves during the quadrennium 1971-1974 is reviewed. Emphasis is given to trends in techniques and ideas that hold promise for the future. An extensive bibliography is provided.

BROWN, C. L. and A. L. BROOKS

1974. A Summary Report of Progress in the Ocean Acre Program
Report No. NUSC-TR-4643, Published by Naval Underwater Systems Centr, New London, CT.

The Ocean Acre program is a long-term, multidiscipline research project designed to study the acoustic and biological characteristics of the Deep Scattering Layer(s) (DSL) in a one-degree quadrangle (the 'Acre') of open ocean water located near Bermuda. During the fourteen cruises in the area, more than 300 fish species from 80 families were collected. Approximately 90% of these specimens belong to the following four families: Myctophidae, melamphaidae, sternoptychidae, and gonostomatidae. Acoustic measurements taken at discrete frequencies from 1.3 to 15.5 kHz showed that the scattering strengths and depths of the DSL remained fairly constant from day to day and night to night. A mathematical model has been developed that provides a computer printout of scattering strengths and resonant frequencies. A comprehensive bibliography and a listing of the various research investigations being carried out with Ocean Acre material follow the test.

BROWNING, D. G. and A. C. KIBBLEWHITE

1978. Oceanographic Mapping by Use of Low-Frequency Acoustic Attenuation Measurements
Journal of the Acoustical Society of America 64(1):75.

It is well known that low frequency sound waves can travel long distances in the ocean via the deep ocean channel (SOFAR propagation) and thus sample a large region. At low frequencies two attenuation mechanisms are domenant; a chemical absorption process due to boron, and scattering from oceanographic inhomogeneities. Hence attenuation can be related to the physical and chemical properties of the medium, and a characteristic attenuation can be attributed to a specific water mass. Data from long range propagation experiments in the Pacific Ocean is analyzed to determine the extent of particular water masses and to locate their boundaries (fronts).

CESTONE, J. A., et al.

1977. Latest Highlights in Acoustic Underwater Navigation. Navigation 24(1):7-39.

The objective is to report the latest developments in acoustic underwater navigation. The prime area of concern will be accuracy: first, in the establishment of a transponder navigation field and new techniques for survey of that field; and second, in the determination and study of multipath propagation to limit range errors. Results of in-situ tests to determine characteristics of both interrogation signals and reply signals are presented.

CESTONE, J. A.; et al

1977. Recent Developments in Acoustic Underwater Navigation J. Navig. (GB) 30(2):246-80.

Acoustic transponders are employed in underwater navigation in situations in which a high degree of accuracy is required. The survey techniques described are designed to yield adequate accuracy for local navigation to proceed with minimum ship time in situ. Subsequent refinements in the survey may be computed later, utilizing data obtained while navigating during the operation. The paper confines itself to systems in which the round-trip travel time is measured between a common interrogator to a transponder and a receiver located at the interrogator.

CHEN, YUNG MING and DAR SUN TSIEN

1977. A Numerical Algorithm for Remote Sensing of Ocean Density Profiles by Acoustic Pulses
Published by Numerical Computation Corp., Stony Brook, NY
Report No. NCC-1

An iterative algorithm for solving nonlinear inverse problems in remote sensing of ocean density profiles by acoustic pulses is developed. The basic idea of this new algorithm is that first, the original pulse problem in the time-domain is reduced to a continuous wave problem in frequency-domain and then the nonlinear inverse problem in frequency-domain is solved by a hybrid of a Newton-like iterative method, Backus and Gilbert linear inversion technique, and the finite difference method. This new computational algorithm is tested by numerical simulations with given data from ten different frequencies and is found to give excellent results.

CHESTERMAN, W. D.

1974. The Ocean Floor (A Review)
Contemp. Phys. (GB) 15(6):501-16

In the last decade there have been extensive advances in the use of sonar systems for the mapping of the sea floor. Different sediment types can now be delineated and displayed in analogue form for subsequent mapping and analysis. Acoustic sensors in the side-scan sonar mode can now be used from ships at normal hydrographic survey speeds over the whole continental shelf. Research effort at the University of Bath has led to the development of systems which are now widely used for cable survey problems and for studying the transport of sediment in coastal waters.

CLARK, J. G.

1976. Acoustic Sensing of Large-Scale Ocean Dynamic Processes
J. Acoust. Soc. Am 59(1):S57

In recent years relationships have been established between fixed-system acoustic transmission fluctuation and ocean dynamic processes on space scales of tens and hundreds of kilometers. In this context, tide-driven processes have been studied in some detail, transport-related variations in the dynamic structure of the Gulf Stream have been studied, and investigations in progress include preliminary attempts to relate acoustic phase fluctuations in the time scale of several months to Rossby waves and/or deep ocean eddies. These results will be reviewed, and the most deep-ocean experimental conclusions compared with MODE and OWEX findings. The viewpoint taken throughout is that environmental information is being extracted from a "noise background" in the sound-speed field a major component of which is the internal wave continuum. Measurement problems due to multipath effects will be discussed.

CORELL, ROBERT W.; et al

1973. The Science and Technology of Utilizing the Bottom Resources of the Continental Shelf
Published by New Hampshire University, Durham, Sea Grant Program Report No. UNH-SG-102

The report covers a university/industry research and development project with two major thrusts: (1) to develop effective technologies to acoustically classify and assess the coastal sea floor and subbottom sediment for both physical and engineering properties, and (2) to study from a broad perspective the technical, ecological, legal and economic understandings essential to a responsible exploration and use of a country's continental shelf bottom resources. The report summarizes the objectives and accompishments for the second year and discusses these results in the context of a five-year research and development effort.

CRON, BENJAMIN F.

1970. A Review of the Statistical Properties of the Ocean Surface
NTIS Report No. NUSC/NL-TM-2211-128-70

This study reviews the work on ocean surface statistics and some new approaches are considered. A brief discussion of some similarities between ocean surface statistics and underwater sound noise fields is included. The author outlines the method for obtaining the equation showing the relation between the spatial-temporal correlation and the directional wave spectrum. Methods of measuring the spatial-temporal correlation of the surface are mentioned along with the equations, and special cases of this correlation are considered. The most important one (i.e., the simplest to measure) is the temporal correlation at a point on the surface. The Fourier Transform of this correlation leads to the power spectrum of the Neumann-Pierson type. Finally, a method of obtaining cross spectra between pairs of a linear array of elements is discussed and similarities between this method and the underwater sound problem of obtaining the directionality of ambient noise is mentioned.

DAN, BHUPINDER SINGH and F. A. ANDREWS

1971. A Literature Survey on the Subject of the Use of Acoustics in Fish Catching and Fish Study. Report no. 71-7, Catholic Univ. of America, Washington DC, Inst. of Ocean Science and Engineering.

The paper traces the history of the use of acoustics in fish catching and fish study and briefly describes the present state of the art, gives a comprehensive bibliography of the relevant papers and books, and presents summaries of some of the significant papers. It also lists the problems to be solved.

DERR, V. E.

1972. Applications of Remote Sensing Techniques to Buoy-Based Environmenbtal Data Gathering
Published by National Oceanic and Atmospheric Administration, Boulder, CO, Wave Propagation Lab., Report No. NOAA-TM-ERL-WPL-7

The different remote sensing concepts are tabulated in broad categories of Acoustic echo-sounding, Lidar, Radar, and Passive techniques respectively, with each subcategory of atmospheric and ocean remote sensing. For each technique, the parameters to be measured are identified. Each concept is then evaluated numerically according to the importance of the parameter(s) being measured, and the estimated probability that the system could work successfully in the buoy environment, and the absence of any other existing measurement system capable of measuring the parameter.

DONN, WILLIAM L.

1971. Final Report and Summary of Results
Final Report, Lamont-Doherty Geological Observatory, Palisades, NY

The report summarizes the results of studies of (1) acoustic-gravity waves which included the neutral atmosphere and ionospheric effects; (2) coupling between gravity waves and the sea surface; and (3) infrasound from artificial and natural sources including rocket infrasound at short and long range, sound from Apollo rockets in space, coupling of infrasound to seismic waves in the ground and infrasound from natural sources. The report also presents a bibliography of the results.

DYSON, FREEMAN; WALTER MUNK; BERNARD ZETLER

1976. Interpretation of Multipath Scintillations Eleuthera to Bermuda in Terms of Internal Waves and Tides. J. Acoust. Soc. Am. 59(5):1121-1133.

In underwater experiments on acoustic transmission, some statistical properties of random vector fields are compared with measured cw transmissions between Eleuthera (Bahamas) and Bermuda. Rate-of-phase and intensity spectra due to time-varying multipath interference are shown to depend essentially on a single parameter nu**2, interpreted as the mean-square rate-of-phase for any typical single path. Observed 406-Hz phase and intensities are consistent with 1/nu equals 270 and 357 sec for Eleuthera to Bermuda and for Eleuthera to midstation transmissions. This result is compared to 192 and 286 sec, respectively, for a ray-geometric calculation using an internal wave model based on oceanographic observations. The role of internal tides is mentioned.

EL-HAWARY, F. M. and W. J. VETTER

1977. Estimation of Subsurface Layer Parameters by use of a Multiple Reflection Model for Layered Media.
OEIC, St. John's, Newfoundland, v.2, p. 1087-1109.

An important aspect relating to diverse activities in the ocean is some knowledge of the properties and geometry of the underwater sediments and rock formations. This paper reports on work in progress which is concerned with the determination of geometry of subsurface sediment layers and rock strata. Use is made of a multiple-reflection model which gives a mathematical description for the effects of layered media on the response to impulsive type acoustic excitations in the water. The parameters of the model are propagation delays and reflection/transmission coefficients at the boundaries between layers. The method is intended for use with impulsive type source signals. The procedure involves extremum detection on a sequentially updated residual correlation function which derives from the cross-correlation of source signal and received signal. The procedure generates estimates for the return pulse sequence. It is shown that the estimates for return pulse factors are very nearly minimum variance estimates. A-priori information can be utilized, and estimation error variances are generated for the parameters. Test results are given for a simulated return pulse sequence, and in incomplete form for a real field record.

EMMANUEL, C. B.; et al

1973. A Feasibility Study for the Remote Measurement of Underwater Currents Using Acoustic Doppler Techniques
Published by National Oceanic and Atmospheric Administration, Boulder, Colorado, Wave Propagation Lab, Report No. NOAA-TR-ERL-278; WPL-25

A need exists for the remote measurement of water currents in the estuarine, coastal, and open ocean environments. Remote sensing techniques such as the measurement of the Doppler shift of acoustic waves scattered by irregularities embedded in water, offer an attractive alternative. Based on available information on the concentration and size distribution of scatterers, an attempt is made to estimate the scattering cross section for some typical scatterers. In particular, the scattering characteristics of suspended particulate and organic matter, gas bubbles, and temperature and current velocity fluctuations are examined. The effects of transmission losses and ambient noise on the signal-to-noise ratio of the returned signal are evaluated. The results are used to ascertain the feasibility of acoustic Doppler techniques to measure water currents for ranges of up to 100 m with a varying pulse length resolution of 0.3 to 3 m. This resolution and additional noise considerations necessitate the use of frequencies of the order of several hundred kHz. It is shown that a pulse Doppler current measuring system is feasible.

ESSEN, H. H.

1979. Theoretical Investigations on Acoustic Remote-Sensing of Ocean Surface-Waves
Journal of Geophysics-Zeitschrift Fur Geophysik 45(2):183-198.

Some aspects of acoustic remote sensing in the ocean are discussed with application to surface waves. Bragg scattering is assumed for the physical mechanism of modulating the acoustic carrier. The frequencies necessary for that mechanism are in the range of some 100 Hz. It is shown that the variance spectrum of the modulated slowly varing acoustic amplitude is the appropriate quantity for deriving the relevant statistical properties of surface waves. For remote sensing the relationship between the measured acoustic and unknown surface-wave spectrum is described by a transfer function. Theoretical transfer functions are computed for CW (continuous wave) measurements over long ranges in shallow water. A mode- and a ray-propagation model are considered and the numerical results are compared. The transfer function depends strongly on the angular distribution of surface waves, which usually is unknown. If, on the other hand, both the 1-dimensional acoustic and waveheight spectrum are measured simultaneously these values can be used to determine the angular-distribution function. The necessary assumptions for this method are discussed and a simple model is presented which allows the application of matrix inversion.

EVERETT, JOHN T.; et al

1973. Ocean 73. Published in Proceedings of IEEE Int Conf on Eng in the Ocean Environ. 4th, Seattle, WA.

Following is a continuation of the list of titles and authors: Underwater Acoustic Activities of the National Marine Fisheries Service, by John T. Everett. Research on the Luring of Fish Schools by Utilizing Underwater Acoustical Equipment, by Yoshinobu Maniwa, Yoshimi Hatakeyama, and Hisaju Motegi. Bound on the Variance of Fish Abundance Estimates Obtained from Acoustic Echoes, by John E. Ehrenberg and Dean W. Lytle. Acoustical Bottom-Mounted Fish Enumeration Systems, by William C. Acker. Acoustical Sensing and Assessment of Bristol Bay Sockeye Salmon, by Gary Lord. Application of Acoustics to the Assessment of the Pacific Hake Population in Port Susan, Washington, 1969-1973, by Richard E. Thorne. Systematic Approach to Fishery Planning, by Fred L. Offensend.

FISHER, F. H.; V. P. SIMMONS

1975. Discovery of Boric Acid as Cause of Low Frequency Sound Absorption in the Ocean. Published in IEEE Conference on Eng. in the Ocean Environ. and Marine Technology Society Annual Meeting. 11th, p. 21-24. San Diego, CA. (Pub. by IEEE 75 CHO 995-1 OEC, New York, NY).

Laboratory measurements of sound absorption using the resonator technique have confirmed that sound absorption in sea water is about ten times greater than the predicted value and that it is due to boric acid. In conjunction with the acoustic measurements done in a 200 liter spherical glass resonator, the relaxation frequency of the boric acid was measured using the temperature-jump technique for chemical kinetic studies. A three-state chemical reaction is required for a quantitative explanation of the observed absorption and relaxation frequency. Besides providing confirmation of effect discovered by long-range propagation work at sea, it has revealed a new aspect of boron chemistry. Graphs and equations show data.

FORD, E.

1978. Sub-sea Extraction of Offshore Oil
Holland Shipbuld., 26(12):63-64.

Faced with rising costs of offshore production platforms and below-sea pipelines, companies are looking for alternative methods for extracting oil, especially in deeper water where platforms become increasingly expensive and even technically impracticable at some of the great depths now envisaged. One such alternative is the sub-sea completion system (SCS) in which the oil well terminates at the seabed instead of on a production platform. After processing to stabilize it, the oil can then be brought to the surface to a loading and storage spar or directed to shore through a pipeline. Two basic SCS systems have been proposed; both are at an advanced stage of development. In one, any necessary maintenance can be carried out by divers. In the other, which is known as the 'one atmosphere' system, any necessary work can be carried out in the sub-sea structure itself to which technicians can be transferred from a transfer bell and work in shortsleeve conditions. 'One atmosphere' systems may come into their own when oil is being extracted from water depths of over 300 m. During the installation of an SCS, and for subsequent maintenance, there is a need for vehicles from which work can be carried out below water. The latest British development in the field is Consub 2. This is a more powerful version of Consub 1, built in 1974, and is to be used for work on the seabed as well as for surveying and detailed inspection and monitoring of offshore installations. A manned type of submersible vehicle, will play an important part in SCS operations, from initial survey work, through construction to subsequent inspection. Two main types are available - the P-Class and the L-Class. P-Class ranges in size from 7.5 tonnes to 13.6 tonnes displacement and contains all the necessary equipment for navigation/surveillance, underwater work and crew safety. Recently developed is a new type of high power, undersea ultrasonic beacon which can operate as an acoustic marker as part of an acoustic measuring system at depths down to 1000 m. Known as MAPS (Marconi Acoustic Positioning System), the device delivers signals which are monitored by a ship and used to measure its position.

GAILLARD, ROBERT J.; et al

1970. United States Coast Guard Oceanographic Sensor Study. Volume I. State-of-the-Art of Oceanographic and Meteorological Sensors, Tutorial Discussion
Repot no. TI-59009-1a, Texas Instruments Inc., Dallas Services Group.

Task 1, in two volumes, evaluates the state-of-the art of oceanographic and meteorological sensors. Instruments for the measurement of a number of oceanographic parameters from different platforms are evaluated with respect to the operational requirements laid down by the United States Coast Guard. Conclusions are drawn relevant to these requirements -- i.e., what measurements with specified accuracies can be accomplished from specific platforms, what may be accomplished during the next 5 years, and what is beyond the 5-year state of the art.

GILMORE, MONT

1977. Recording River and Reservoir Water Depth. Civ. Eng. 47(4):65-66.

At the Kerr Reservoir on the Roanoke River in Virginia and North Carolina, reservoir bottom was surveyed before reservoir filling and twice thereafter, to determine rate of siltation. The post-filling surveys offer an illustration of the progress being made in hydrographic surveying. In both cases, sound-type (sonar) water depth sensors were used. Improvements were made in the latest resurvey: a narrower-beam signal gave accurate measurements at greater depth of water. Computer programs enabled automatically calculating increase in siltation.

GOPAL, R.;et al

1978. Acoustic Monitoring Instrumentation for Pressurized Water Reactors. ISA Trans. 17(3):71-80.

Special instrumentation considerations for nuclear plants are discussed, the principles of acoustic emission and leak monitoring are reviewed, and a prototype acoustic monitoring system is described. A large measure of work is currently directed toward learning to interpret the detected signals. Results of recent shop, plant and laboratory examinations are presented.

GOULD, W. J.

1977. Measurement of Currents in the Open Sea Published in Wormley, Eng. (Surrey) Institute of Oceanographic Sciences, Report 54, 55 pp.

Techniques of current measurements are reviewed. Failings of existing meters are indicated, and desirable developments considered. The variability of the currents is discussed briefly, particularly as it affects measurement. Data sources known to the Marine Information and Advisory Service of IOS were collated to develop an inventory of current observations in the shelf seas around the UK and in the Northeast Atlantic. There are severe instrumental problems in the measurement of currents if substantial wave orbital velocities are present. Velocities are probably systematically overestimated. The geographical coverage of current observations is poor in the shallow seas and worse in open ocean. The availability of good data in the near surface zone is very poor. For future measurements of currents to be of maximum value potential users should define their requirements for data products and accuracy. Present understanding of open ocean circulation suggests that observations at each locality extending over 2-3 yr. may be needed for a description of the variability of the current there. In shallow water extended geographical coverage is required to adequately describe variability due to variations in the bottom depth to improve the value and relevance of numerical models. The development of new sensors for the measurement of currents should be supported. A concurrent study should be made of the dynamics of surface and subsurface moorings to determine the best platforms for deployment of the new sensors. Consideration should be given to supporting a development program for remote aocoustic tracking stations moored in deep water in the Northeast Atlantic.

HARAN, MICHAEL E.

1979. Visualization and Measurement of Ultrasonic Wavefronts
Published in Proceedings IEEE, v. 67(4), p. 454-466.

The transmission of ultrasonic wavefronts through a medium and the reflection of these wavefronts from an object or interface depend upon the bulk mechanical properties of the medium or object. Measuring or visualizing the wavefront yields important information about various transmission media and objects under study and has found application in nondestructive evaluation, medical diagnosis, underwater imaging, and acoustic microscopy. This paper reviews the various methods by which ultrasonic wavefronts are detected, measured, and visualized. Special emphasis is placed on optical diffraction by ultrasound and optical interferometric detection of acoustic particle displacement. Shorter summaries are given of chemical, thermal, liquid crystal, electromechanical, and mechanical methods. The distinction between these methods is not always clear. For example, the displacement of an air/water interface by radiation force is a mechanical method even though the displacement may be recorded optically. Therefore, an attempt is made to distinguish between the physical effect of the wavefronts on the medium or measurement device as opposed to the process used to record that effect.

HAWKER, KENNETH E.; et al

1979. A Summary of the Results of a Study of Acoustic Interaction with the Sea Floor
Report No. ARL-TR-79-2, Texas Univ at Austin Applied Research Labs

This report summarizes the results of research carried out during 1978 on acoustics interaction with the sea floor. Major topics considered are propagation in a range variable environment by mode-mode coupling methods, bottom roughness (scattering) studies, and a number of sensitivity studies including the acoustical effects of sediment rigidity, Doppler broadening due to source motion, and the relationship between mode attenuation and bottom loss per bounce.

HECKMAN, DON B.

1974. Survey of Acoustic Navigation Techniques
Published in Proceedings of Appl. of Mar. Geod., Int. Symp., Columbus, Ohio, p. 187-196. Marine Technology Society, Washington,DC.

Acoustic navigation techniques, utilizing bottom moored acoustic references, (e.g., transponders or beacons) can provide very precise (1-10 m) relative positioning of both surface and subsurface objects. This precision relative positioning can be extended to the geodetic coordinates by integrating the acoustic system into a geodetically referenced navigation system such as NAVSAT. This paper is a tutorial treatment in which the subject is partitioned into two major topics. First is a discussion of the measurement of the geometric parameters required to determine position relative to an array of bottom moored references. This describes the basic terminology and principles employed in various techniques such as Range-Range, Range- Bearing, Doppler, Pulse-Doppler, etc. The relative merits and limitations of these techniques are also presented. The second major topic treated is that of solution techniques. That is, given that the appropriate geometric parameters can be measured to within a reasonably known accuracy, how is an acceptable mathematical solution effected given the raw geometric data.

HELDEBRANDT, K. E.; et al

1978. The Development and Testing of Current Meters for Long-Term Deployment on the Continental Shelf
Published in Oceans '78. 4th Annual Combined Conference MTS/IEEE Washington, D. C.

Measurements of ocean currents to support U. S. continental shelf construction and environmental projects have been established as a major user need. Regimes of interest range from the surface to 300 m and from concentrated, short-term measurements to sparse, long-term measurements of up to 3 years. The timeliness, reliability, and availability of the data are frequently more important to the user than absolute data accuracy. One of the more critical needs of the offshore industries is for measurements of current during design events, such as severe storms. Near-real-time data is also highly desirable during quieter periods to aid on-site construction and to permit timely environmental monitoring in coastal and estuary regions. The NOAA Data Buoy Office (NDBO) has initiated a development and test program to provide current measurement systems to meet these needs. NDBO's objective is to develop this capability using existing state-of-the-art current sensors and data buoys. A parallel effort is also underway to develop an underwater acoustic data link for long-term at-sea testing and operation of the current sensors. This paper presents an overview of the NDBO current meter development and test program, including the implementation plan, significant features of the hardware design, and the results of testing conducted to date.

HERSEY, J. B.

1977. A Chronicle of Man's Use of Ocean Acoustics Oceanus 20(2):8-21

The author traces the development of ocean acoustics from the Ancient Greeks through to the present. Much of the scientific research has been carried out in the last 3 centuries with greatest developments occurring in the last 60 years. In the course of research, the development of the thermocline in the ocean and its generation of the acoustic shadow was discovered. From the basic concept of detecting other ships and icebergs at sea came the echosounding of bottom topography and thence geophysical studies of sediment layers. In addition the theories of elastic wave propagation which evolved simultaneously gave rise to an understanding of the complexities of elastic waves generated by earthquakes in the earth and propagated in the outer layers of the earth. As an offshoot animal sounds were also investigated. An important aspect is the understanding of the influence of the ocean on sound propagation, and the precise measurement by sound of distance in the ocean. Industrial applications of echo ranging, such as the side scan technique have been used in fisheries operations for several years. The monitoring of industrial operations are likely to be advanced in the next decade, and as for the potential of ocean acoustics in science, the greatest use will probably be in assisting oceanographers to monitor ocean processes.

HOLLIDAY, D. V.

1976. Impact of Modern Acoustic Technology on the Scientific Assessment of Marine Life JASA 59 (Suppl. 1)

In recent years significant advances have been made in understanding the effects of the marine environment on the propagation and scattering of sound and in acoustical signal processing. A few of these developments have been used in the study of marine life. Several examples of the uses of underwater acoustics to study life in the sea are examined. Specific topics include studies of plankton and small nekton; investigations and assessments of commercial fish stocks; and studies of marine mammals.

HOLLISTER, C. D.

1976. Mid-Plate, Mid-Gyre Seabed Assessment Program for Nuclear Waste Disposal, Final Report
Woods Hole Oceanographic Institution, Mass. Department of Energy

Status of the following tasks is reported: acoustic experiments for lateral and vertical consistency determinations; design, fabricate, and interface core launch and recovery system for C. S. LONG LINES; field test Giant Piston Core (GPC) on Bermuda Rise with LONG LINES, summer of 1976; GPC cruise to MPG-1 in October 1976; core sample analysis and data synthesis for vertical consistency; and acoustic mapping of MPG-1 for horizontal consistency.

HORTON, CLAUDE W., SR.

1972. Review of Reverberation, Scattering, and Echo Structure
J. Acoust. Soc. Am 51(3):1049-1061.

Graphs and charts are used to summarize the nature of work during the past two decades in underwater acoustics in the areas of reverberation and scattering. Comparisons are made between results of measurements at sea, on models, and with theoretical calculations. Work on targets of simple geometric shape are reviewed.

HUETER, T. F.

1972. Twenty Years in Underwater Acoustics: Generation and Reception
J. Acoust. Soc. Am. 51(3):1025-1040.

A review of underwater transducer design during the past two decades indicates extensive research on advantages of using lower frequencies for detecting and localizing targets, and improvements in transducer sensitivity, power output, and depth of submersion. New concepts include hydroacoustic generation, use of compliant metal tubes for focusing and reflection, use of structural flexing modes for radiation, and free-flooded cavity structures as deep submergence sources.

IRELAND, L. C. and J. W. KANWISHER

1978. Underwater Acoustic Biotelemetry: Procedures for Obtaining Information on the Behavior and Physiology of Free-Swimming Aquatic Animals in Their Natural Environments
Academic Press, 24/28 Oval Road, London NW1 7DX, UK, p. 341-379

This review outlines the potential advantages and limitations of acoustic telemetry. Firstly the authors consider sound as a medium for underwater telemetry, emphasizing those characteristics of sound in water which must be taken into account in order to select efficient equipment for a given experimental situation. The use of acoustic telemetry and the construction of a sonic receiver, a directional hydrophone, and several types of acoustic transmitters are then described. In conclusion the authors speculate on possible future work with acoustic telemetry.

JAFFE, L. D.

1976. Applications of Aerospace Technology to Petroleum Exploration. Volume 1: Efforts and Results
Published by Jet Propulsion Lab., Calif. Inst. of Tech. Pasadena, Report No. NASA-CR-152694;JPL-DOC-5040-32-V-1

The feasibility of applying aerospace techniques to help solve significant problems in petroleum exploration is studied. Through contacts with petroleum industry and petroleum service industry, important petroleum exploration problems were identified. For each problem, areas of aerospace technology that might aid in its solution were also identified where possible. Topics selected for investigation include: seismic reflection systems; down-hole acoustic techniques; identification of geological analogies; drilling methods; remote geological sensing; and sea floor imaging and mapping. Specific areas of aerospace technology are applied to 21 concepts formulated from the topics of concern.

JONYS, C. K.

1976. Acoustic Measurement of Sediment Transport
Can Inland Waters Branch Sci Ser. n. 66,

The results of laboratory work, a theoretical feasibility study and a summary of the observations and analysis of a field investigation program are presented. Laboratory experiments are carried out to verify some acoustical aspects of impact noise in water for application in the development of a theoretical relationship between the noise generated by riverbed pebble collisions and bed-load transport rates. Underwater pebble noise is simulated by rolling ceramic balls on a bed of similar balls in a large laboratory flume. Sound is measured with stationary hydrophone located in the water about the pebble bed. Specific information is obtained on the interparticle collision frequency delineating the limit of transition from impact to continuous type of sound; the applicability of theoretical relationship in the determination of total sound pressure levels owing to impact sources; the acoustic directivity of pebble collision noise; the sound field characteristics surrounding pebble collision sources; the effect of pebble velocity on the generated sound pressure level; and the spectrum characteristics of the pebble collision generated noise. An idealized relationship is formulated between the rate of bed-load transport and the sound pressure level which is generated by interparticle collisions and measured with an omnidirectional hydrophone located at a finite distance above the riverbed. The transfer function shows the rate of bed-load transport to be dependent not only on the observed sound pressure level but also on at least six other variables that must be determined independently of the acoustic observations. In field experiments, underwater sound samples are recorded in two gravel-bearing rivers during periods with and without bed-load movement. Also, samples of artificially generated interparticle collision noise by different sizes of gravel pebbles are recorded. Flow velocities and bed-load transport are measured. The purpose of the observations is to obtain field data for the study of the feasibility of the acoustic method for bed-load measurement. The sound samples recorded in the field are analyzed for pressure spectrum in one-third octave bands between frequencies from 50 Hz to 30 kHz. The pressure spectra exhibit no distinguishing features for positive identification of pebble collision generated noise. The absence of the gravel noise component in the spectra is attributed to masking by high levels of background noise owing to turbulence below 550 Hz, and water droplets and air bubble sources above 500 Hz.

KIBBLEWHITE, A. C. and D. G. BROWNING

1978. Identification of Major Oceanographic Fronts by Long-Range Acoustic Propagation Measurements
Deep-Sea Research 25(11):1107-1118.

There is experimental evidence that different water conditions influence the transmission of LF sound to slightly different degrees. Attenuation and various signal parameters, particularly, are sensitive to ocean water properties, and in long- range acoustic experiments changes in transmission characteristics are observed that can be used to identify the boundaries between different oceanic water masses. Topics discussed include procedures used in long-range propagation experiments; the acoustical identification of ocean fronts; convergence zones; and signal travel times, signal structure, and signal duration.

KRISHNASWAMI, R.; et al

1977. Development of Acoustic Techniques for Assessment of Fish Stock Abundance. Published in Integrated Fisheries Project Silver Jubilee Celebrations Cochin, India. Souvenir, p. 117-126.

In this article the use of echo-detection in stock assessment is reviewed and the possibilities of using these techniques for stock assessment in Indian waters is discussed.

KRITZ, JACK

1973. Doppler Sonar Log for Water Speed Measurement
Published in Inst. of Navig., Natl. Mar. Meet., US Merchant Marine Academy, Kings Point, NY, p. 50-56.

Describes the development process of a new speed log using the doppler shift of scattered acoustic energy from the water mass. A short review of the sonar doppler art is given and the motivation for the program is developed. Design objectives are established. A parameter study is described and the selection of a 2-MHz carrier frequency with a 10-foot range gate is shown to best meet the design objectives. The final configuration is described. Test results and field experience are discussed.

LASKY, M.

1977. Review of Undersea Acoustics in 1950
J. Acoust. Soc. Am 61(2):283-97.

The paper includes lighthouse acoustic signalling, the development of early hydrophones, submarine detection devices developed during World War I, fathometers and ship location systems designed between the wars, and military oceanography, measurement technology and anti-submarine developments that took place during World War II. The paper contains a very large number of diagrams and photographs showing early equipment and early workers in the field.

LUEHRMANN, W. H.

1969. Seismic Profiling Systems
Oceanology Int 4(6):44-7.

Seismic systems specifically designed to provide continuous mapping of the geology below the floor of the oceans are reviewed. Generic information concerning the several categories of acoustic sound sources available and an identifying chart are provided. Other components discussed include detector or "streamer" cables, amplifier and signal processors, on-board displays, and both analog and digital magnetic recording systems.

MASTON, W. P.

1976. Sonics and Ultrasonics' Early History and Applications
IEEE Trans. Sonics and Ultrason 23(4):224-32.

The science of producing and transmitting sound waves in materials has become a flourishing art with many practical applications. Among the low-amplitude uses are underwater sound transmission for locating submarines, measuring the depth and detail of ocean bottoms, flaw detection in materials, delay lines for storing information and for performing many processing calculations, and many medical applications such as locating cancers and other imperfections in the human body. Ultrasound waves have been used in many physical investigations. When the amplitude of the sound wave becomes large, some nonlinear effects occur such as the production of cavities in liquids and fatigue in solids. These give rise to another series of applications such as ultrasonic cleaning, emulsification of liquids, machining of materials, and tests for fatigue in materials, particularly when a large number of cycles is required. Biological applications such as the destruction of bacteria and the use of focused ultrasound as a surgical knife are also possible. It is the purpose of this paper to give the historical background leading up to these applications and to discuss some of them in more detail.

MATHISEN, OLE A.

1975. Three Decades of Hydroacoustic Fish Stock Assessment MTS Journal Technical Notes 9(6):31-34.

The article discusses the advances made in the use of acoustic instrumentation. It gives a brief background history of the breakthroughs and improvements made over the last three decades. The first decade is from 1945-1955, the second is from 1955-1965, and the third is from 1965-1975. It concludes by commenting on future outlooks for this kind of instrumentation in marine environments.

McELROY, P. T.

1977. Acoustics in Marine Fisheries - An Underused Tool

Oceanus 20(2):59-66

This article summarizes the present scope of acoustic methods of detecting and catching fish. The author explains the physical basis of sound scattering by fish shoals, and discusses means by which the swimbladder resonant frequency may be used to identify species, and the Doppler shift employed to locate feeding or swimming fish. Advances in acoustic fishing technology in recent years are outlined for the major fishing countries. Among the areas deserving future investigation the author lists: (1) species identification by acoustic methods, (2) shoal density estimation, and (3) behavioural studies, including the response of fish to sound.

MEDWIN, H.

1977. Counting Bubbles Acoustically: A Review. Ultrasonics 15(1):7-13.

The acoustical resonance characteristics of bubbles are the key to their detection by backscatter, excess attenuation and sound speed dispersion in bubbly liquids. The linear, lumped-constant, behaviour of single bubbles is reviewed and formulated in terms of the physical constants of the medium liquid, the bubble gas and the interface between. Acoustical techniques for bubble counting are discussed using in-situ experiments at sea as an example.

MOOSE, P. H.; et al

1971. Electronic System and Data Processing Techniques for Estimating Fish Abundance
Published in Conference on Engineering in the Ocean Environment, San Diego, CA, by IEEE, New York.

Among the techniques employed to estimate the stock size of pelagic fishes, acoustics has proven to be the most versatile and cost effective method. Furthermore, modern digital data processing equipment is paving the way for accurate onboard estimates of fish densities thus providing for optimum utilization of ship time and scientific personnel. Echo integration is a method of estimating fish densities acoustically, which, unlike echo counting, improves with increasing density. A digital data acquisition and processing system (DDAPS) has been developed at the University of Washington to implement the integration technique in real time for two echo sounders and 10 depth strata simultaneously. The system, which includes a small GP computer, contains other important features such as an automatic bottom following facility.

MORSE, R. W.

1977. Acoustics and Submarine Warfare
Oceanus 20(2):67-75

The paper reviews the development of submarines since World War I. Initially their importance was underestimated, but German development of diesel engines with battery power improved efficiency. The importance of acoustics is emphasized throughout, with development from passive listening devices on escort ships through the discovery of piezoelectricity with vacuum-tube technology, to shipboard sonar using lower frequencies and long distance echo-ranging systems and homing torpedoes. Oceanographic research on vertical temp structure on which sonar relies heavily has also been important with the bathythermograph a key tool. Since 1945 the most profound change has been nuclear propulsion permitting high underwater speeds and practically unlimited range. Investigations into future response to challenge of nuclear submarines demonstrated increase in offensive capability rather than defensive. No particular system of anti-warfare measures has proved dominant but many vehicle types can be used in combination. In the development of ballistic missiles with nuclear warheads a new strategic role for submarines has been created, mainly as one of deferrence but it is apparent that national security is dependent on the development of underwater acoustics.

MUNK, W. H.; J. D. WOOD; W. BIRKEMEIER; C. G. LITTLE, and R. H. STEWART

1972. Remote Sensing of the Ocean.
Boundary-Layer Meteorology, v. 5, p. 201-209.

The authors consider the problem of remote sensing of the oceans in the context of atmospheric remote sensing. The principal interest is in remotely sensing the ocean from within the ocean.

MUNK, WALTER H. and PETER F. WORCESTER

1976. Remote Acoustical Sensing of Ocean Parameters
J. Acoust. Soc. Am 59(1):S57

We have conducted some measurements preliminary to the possible establishment of an environmental acoustic array off California. Some simultaneous two-way transmissions with sources and receivers at approximately 1 km depth and separated by 25 km will be discussed. For this geometry there exist essentially an upward path and a downward path; each has only a single turning point. At frequencies below a cycle per day we hope to use the array in a deterministic mode to study the drift of mesoscale eddies and intrusive features. At higher frequencies we expect to obtain information about the statistical properties of internal waves. Some preliminary results will be given.

MUNK, WALTER H. and GORDON O. WILLIAMS

1977. Acoustic Oceanography.
Nature 267(5614):774-778.

Measurements of ocean fine structure (with typical time scales of 15 min to 1 d, spacial scales of 10 to 100 m vertically and 1 to 10 km horizontally) are consistent with the measured variability in the transmission of acoustic signals through the ocean volume. The observations suggest that the statistics of acoustic fluctuations can be used to monitor the statistics of ocean fine structure. Further, fluctuations in the travel time are a measure largely of temperature fluctuations along the acoustic path, and the difference in reciprocal travel times is a measure of the component, along the path, of current shear. Such acoustic measurements give integrals along the paths, with the attendant advantages and disadvantages as compared with the traditional 'spot' measurement; precision promises to be comparable or better.

MURPHY, M. L. and W. R. COTTON

1978. <u>Recent Trends in Marine Data Acquisition Technology</u> Published in 40th Meeting of the European Association of Exploration Geophysicists, Dublin.

Marine data acquisition technology has gone through a transition from reconnaissance of large areas to detailed mapping of subsurface structures. The technological requirements to support this transition have provided advances in source/receiver configurations, hardware and software systems to improve consistency and advance the state-of-the-art marine data collection. This paper presents trends, developments and applications of segments of these technologies in the marine environment. Special emphasis will be devoted to configurable source/receiver arrays, marine streamer attitude sensing, source timing and integrated navigation and data logging systems. The trend toward increased accuracy in navigation is discussed as it is related to the trend toward increased spatial sampling. Methods and procedures for achieving increased spatial sampling are discussed as they apply to the marine environment. The paper concludes with a short discussion on future trends in data collection technology. Actual and model data are presented where applicable.

MURTY, T. S. and R. J. POLAVARAPU

1974. <u>Atmospheric Acoustic and Internal Gravity Waves and Their Relevance to Tsunami Prediction.</u> Published in International Union of Geodesy and Geophysics Tsunami Committee Meeting and Symposium Wellington, New Zealand.

The concept of earthquake magnitude developed by Richter in the 1930's proved to be useful in seismology, and similar attempts were made in developing a tsunami magnitude scale. However, experience showed that such a tsunami magnitude scale did not work in practice due to the great influence of local topography on tsunami magnitude. At the I.U.G.G. tsunami symposium held at Moscow in August 1971, the consensus of opinion was to abandon the tsunami magnitude scale and develop a tsunami energy scale which might be universally adaptable. It is proposed here that one of the possible approaches to this concept of a tsunami energy scale is to make use of the effects in the atmosphere caused by strong dip-slip earthquakes which are generally believed to be tsunamigenic owing to their predominant vertical faulting. However, to understand the type of wave motions generated in the atmosphere by tsunamigenic earthquakes, one has to determine the atmospheric acoustic-internal gravity wave spectrum due to various energy sources in addition to earthquakes: meteorological disturbances, atmospheric nuclear explosions, volcanic explosions, solar eclipses, sonic booms, rocket launches, etc. In this review paper, the spectrum due to these various perturbations was systematically examined and it appears that the atmospheric internal gravity waves in the 10- to 15-min. period range might be useful for tsunami energy estimation purposes.

NEWMAN, A. K.

1973. Computer Analysis of Oblique Acoustic Reflection for Ocean Sediment Identification
Published in Proceedings of the Offshore Technology Conference, Houston, TX, Paper No. OTC-1791, I-602-611.

Computer analysis of the acoustic-field-theoretic Green's function for a spherically spreading sound wave from a ball transducer over a semi-infinite viscoelastic Voigt model of the ocean sediment has obtained a substantial improvement in the technology of remote acoustic sediment identification. IBM 360-50 digital computer subroutines were prepared in Fortran IV to compute the value of the integral as various parameters were varied, to obtain the information and insight needed for the optimum system design for remote acoustic sensing of the ocean sedsiments. The preliminary investigations of the many possibilities made available by this approach have been good.

ORR, M. H. and F. R. HESS

1978. Remote-Sensing of Physical Processes in Ocean Using High-Frequency Acoustic Backscattering Systems
Journal of the Acoustical Society of America 64(1):S104.

High frequency acoustic backscattering systems are being used to remotely sense fluid processes in the oceanic environment. The systems are being used to detect and study short period internal waves, large scale Kelvin-Helmholtz instabilities, turbulence, interleaving water masses, frontal zones and variability of natural and man induced particle distributions. Graphic acoustic records will be presented demonstrating some of the results obtained to date.

ORR, MARSHALL and MICHAEL SCHOENBERG

1976. Acoustic Signatures from Deep Water Implosions of Spherical Cavities. J. Acoust. Soc. Am. 59(5):1155-1159.

Hollow glass spheres of various sizes have been preweakened to implode at ocean depths of approximately 3 km and sunk using chain weight. Acoustic signals generated from the implosion of these spheres have been analyzed. Pressure signatures, energy-density spectra, and total acoustic energy in the frequency band 96-5000 Hz are presented. The signatures of all the implosions have many features in common. Basically each consists of a low flat negative-pressure pulse followed by a sharp positive-pressure spike of roughly 0.2-msec duration. The efficiency of the conversion of available potential energy to radiated acoustic energy is approximately 18%. Total radiated acoustic energy for spheres of 43.2-cm diameter imploding at a 3-km depth is about 53 dB re 1 J. Preweakened glass spheres show promise as a tool in the study of the sedimentary structure of the ocean bottom due to the impulsive character of the signal that is radiated upon implosion.

ORR, MARSHALL H. and FREDERICK R. HESS

1978. Acoustic Monitoring of Industrial Chemical Waste Released at Deep Water Dump Site 106. J. Geophys. Res. 83(C12):6145-6154.

Some industrial chemical wastes form flocs or particles upon being introduced into seawater. High-frequency acoustic backscattering systems have been used to study the dispersion of the particulate phase of industrial chemical waste in a water column (depths of > 1500 m) with a sharp seasonal thermocline. The particles have been found to remain trapped for extended periods (at least 74 hours) in the mixed layer, to accumulate on the density structure found between the mixed layer and the seasonal thermocline, to accumulate on the density structure associated with the seasonal thermocline, and form a diffuse cloud in the main thermocline. The effluent phase of the chemical waste, which was tagged with rhodamine WT dye, has been found to remain in the vicinity of the particulate phase of the waste.

PARKER, W. R. and R. KIRBY

1977. Fine Sediment Studies Relevant to Dredging Practice and Control.. Published in Second International Symposium on Dredging Technology, Texas A&M University, College Station, TX, Volume 1.

Fine sediment arrives as mobile suspensions at sites from which it must be dredged. In highly turbid estuaries dense mobile suspensions are regularly produced as part of the natural circulation of fine sediment. In low turbidity estuaries their intermittent formation by storms, or during dredging and dumping operations, may be more important in relation to dredging problems. The evolution of mobile suspensions into static suspensions, and their subsequent consolidation, cause time dependent changes in density and acoustic properties which affect the nature of echosounder records from sites where static suspensions develop. Field observations and laboratory studies indicate that, in areas of mud sedimentation, definitions of sea bed altitude based only on echosounder records may be ambiguous unless the nature of what is acoustically identified is investigated by other means. The consequent problems of the definition of the sea are important for navigational purposes and for the specification and control of dredging operations. The range of practical dredging problems encountered if the top reflector on an echosounder record is the only criterion used to define the sea bed, and the potential hazard of using lower reflectors without additional information, suggest that techniques for measuring in situ, density, such as,-ray densimeters, are an essential supplement to echosounders.

PORTER, R.

1977. Acoustic Probing of Ocean Dynamics
Oceanus 20(2):30-38

In this review the author summarizes the physics of sound propagation in the sea, in relation to variables including temp, salinity, pressure, depth, currents, tides and internal gravity waves. Recent developments in acoustic measurement of ocean dynamics are described, including the SOFAR float program of MODE, and some other float-tracking experiments in the Gulf Stream, and the Woods Hole study on the influence of internal waves on the phase and amplitude of low frequency sound. Long baseline (up to 200 km) moored systems with up to 6-month data recording capability and tracked by fixed acoustic beacons will be easily handled by medium-sized research vessels and comparable in cost to existing direct-measurement systems. Such a system, under development by Scripps Institution of Oceanography, is described.

PRONI, J. R.; et al

1976. On the Use of Acoustics for Studying Suspended Oceanic Sediment and for Determining the Onset of the Shallow Thermocline
Deep-Sea Res. 23(9):831-7.

Acoustic observations of a low-density sediment flow originating from a dredge operating in the main Miami shipping channel have been made. The flow proceeded seaward along layered thermal gradients at the top of the shallow thermocline and at greater depths. Acoustic, thermal, salinity, chemical, and transmissivity measurements were made during summer and winter in 1974.

RISNESS, E. J.

1973. Acoustic Signal Processing in Fast Unmanned Underwater Vehicles
Published in Proceedings of the NATO Advanced Study Institute on Signal Processing, Loughborough Leics., England, p. 489-94.

The author reviews underwater acoustic communication and the acoustic constraints imposed by limited underwater vehicle size. Target detection and homing and the effect of self noise are discussed. Complex signal processing using microelectrons is considered.

ROSSBY, T.; D. WEBB

1970. Observing Abyssal Motions by Tracking Swallow Floats in the SOFAR Channel
Deep-Sea Res Oceanogr Abstr 17(2):359-365

An observational program, currently in progress, to study abyssal water motions in the western Sargasso Sea by tracking Swallow floats in the SOFAR Channel is described. The pertinent properties of the SOFAR Channel, such as the vertical trapping and the low rate of attenuation of acoustic energy, are discussed briefly. In particular it is shown that useful acoustic ranges in excess of 1000 km are possible for tracking Swallow floats. The signals from the float, which must be received by at least two hydrophones, are detected in 1 Hz wide bandpass filters and the output is recorded continuously in digital form. The time of arrival of the signals is determined from a visual display of the data. The first two experiments have clearly shown that transmission over these distances is feasible. The abrupt failure of both floats after only a few days is unexplained. Concern is raised about the possibility of biological attack on the floats.

SANDUSKY, L.; WILDE, P.

1978. Preliminary Bio-Ecologic Investigations at the OTEC Gulf of Mexico Site -29 degree N 88 degree W.
Published in Proceedings of the Ocean Therm Energy Convers Conf. 5th. (Available from NTIS (CONF-780236), Springfield, VA v. 1, p. III. 83-III, 103).

Bio-ecologic measurements important for environmental assessment of the impact of an operating Ocean Thermal Energy Conversion Plant have been initiated in July 1977 at the proposed Gulf of Mexico site off the coasts of Louisiana, Mississippi, Alabama, and Florida with physical oceanographic measurements on the OSS Researcher in a joint effort with the Atlantic Ocean Marine Laboratory (AOML) of the National Oceanic and Atmospheric Administration (NOAA). The measurements in July included 16 formal hydrocast stations of various depths to 1000 meters. Water was analyzed for trace metals, nutrients, and phytoplankton biomass as estimated by chlorophyll and ATP. Physical data was supplied by NOAA-AOML. In addition, two surface net casts were taken to obtain zooplankton at the site and two **1**4C bioassays were made to measure productivity. The Deep Scattering Layer (DSL) was monitored at the site by a continuously recording 12 KHZ depth sounder. Measurements in November were made from the RV Virginia Key (AOML). They included 4 hydrocasts, 6 net tows for zooplankton (samples analyzed by Gulf Coast Research Laboratory), 1 STD trace, 20 XBT's and one **1**4C phytoplankton bioassay.

SCARTON, H. A.; et al

1977. Review of the Acoustic Detection of Boiling in Nuclear

Reactors. Published in Winter Annual Meeting of ASME, Atlanta, Georgia, p. 109-123.

Boiling may or may not be a desired operating characteristic for the coolant of a nuclear reactor. In certain reactors such as the Liquid Metal Fast Breeder Reactor (LMFBR), coolant boiling is considered abnormal. In other reactors such as the Boiling Water Reactor (BWR), boiling is always present, but the character of the boiling becomes important. This paper presents a review of over 260 references on the physics of boiling, stressing acoustic monitoring techniques. Recent experimental results are examined for sodium boiling during LMFBR excursions and the characteristics of the physical acoustic signatures are identified.

SCHLANK, JOHN JAMES, JR.

1968. Sub-Bottom Sounding: A Survey for Naval Applications Master's thesis. Naval Postgraduate School, Monterey, CA

The sub-bottom profiling techniques have vastly improved over the last several years. Many commercial companies are presently engaged in the manufacture of either individual components or the entire system largely as a result of its applicability to petroleum exploration. New systems and innovations are developing at a rate whereby it is difficult to remain current. Interest in the technique has likewise increased within the Navy, and more than several research projects built around its use are currently receiving Navy funding. It was therefore deemed advisable that a survey of existing equipment characteristics and manufacturers be made to serve as a guide to potential Navy users as to the possible applications of this technique.

SCHULKIN, MORRIS

1975. Basic Acoustic Oceanography
Report no. NOO-RP-1, Naval Oceanographic Office, Washington, DC

A brief introduction is given of oceanography for acousticians. The main topics and related acoustical examples are: submarine geology (bottom acoustic loss); marine biology (the deep sound scattering layer); chemical and physical properties of seawater (sound speed and sound absorption); the steady state of the ocean (sound speed vs. depth structure and modes of sound propagation in the ocean); and waves in the ocean (sea surface loss and sea surface noise, and acoustic propagation and internal waves).

SMITH, PAUL F.

1969. Underwater Hearing in Man: I. Sensitivity
Report no. SMRL-569, Naval Submarine Medical Center, Groton, CT

Submarine Medical Research Lab

All available research on the underwater hearing sensitivity of man is reviewed. New data on the underwater hearing of divers with known AC and BC levels are presented. It is concluded that: man suffers a loss of sound pressure sensitivity upon immersion; underwater hearing sensitivity is frequency dependent with peak sensitivity being about 61 to 64 dB above .0002 decibels per square centimeter at 1 kiloHertz; air conduction auditory deficiencies are not reflected in underwater hearing levels unless the air conduction deficiencies are accompanied by bone conduction deficiencies; wet suit diving hoods reduce underwater sensitivity to sound by about 25 to 35 dB at frequencies of 1 kiloHertz and higher.

SMITH, WINCHELL

1974. <u>Experience in the United States of America with Acoustic Flowmeters.</u> Published in River Gauging by Ultrason and Electromagn Methods, Jt Symp., University of Reading, Berks, England, Session 3, 21 p.

This paper reviews the development of acoustic velocity metering (AVM) systems in the United States and discusses installations made by the US Geological Survey at four sites on large rivers in the Columbus River basin. The feasibility of the devices is demonstrated, and the calibration procedures are outlined. Problems which may limit the usefulness of AVM systems in some locations are outlined. Problems which may limit the usefulness of AVM systems in some locations are also described. These include refraction of acoustic transmissions by temperature gradients, attenuation of signals by entrenched air, and the attenuation of signals by suspended sediment.

SMITS, TALIVALDIS I.; et al

1975. <u>Assessment Report: Theoretical and Measured Performance Limits of Raytheon DE723M, Atlas AN1021 and Ross Surveyor Echo Sounders, Used on A Type 711 Survey Launch</u> Catholic Univer of America, Washington, D.C., Department of Electrical Engineering/Naval Oceanographic Office, Washington, D.C.

In depth sounding, the sonar is called upon to perform detection and estimation of the bottom. For both its detection and estimation performance analysis, a suitable signal-to-noise ratio at the input to the transducer (or at some other reference point) is needed, and thus will be focused upon in this sonar equation analysis. For, at any time after transmission of the sounding pulse if the input signal-to-noise ratio is above a certain 'detection threshold' (fulfilling a specified false alarm probability criterion), a decision will be made by the receiver system that the bottom was observed, and a depth measurement provided. This report discusses the theoretical depth measurement accuracy limit (assuming the bottom echo has been properly detected) imposed by additive noise, and considers the detection threshold depth limit imposed by the false alarms.

SPIESS, F. N.; LOWENSTEIN, C. D.; BOEGEMAN, D. F.

1978. Fine Grained Deep Ocean Survey Techniques. Published in Annual Proceedings of the Offshore Technology Conference. 10th, V. 2, Paper OTC 3135, p. 715-724. OTC, Dallas, Texas.

A deeply towed system for fine scale deep ocean surveys has been assembled. It consists of precision echo sounder, sub-bottom penetration sounder, side-looking sonar, cameras, TV, magnetometer and a variety of other specialized measurement and sampling devices all operated on a coaxial electrical/mechanical towing cable. Local navigation to 5 m precision is provided by an acoustic transponder system. Recent advances have included digital side-looking sonar, dual frequency sub-bottom penetration system, an advanced transponder/echo repeater and a delay device for maintaining navigation when local topography or refraction blank out sound paths to transponders.

STASKO, A. B., and D. G. PINCOCK

1977. Review of Underwater Biotelemetry, with Emphasis on Ultrasonic Technique Canada. Fisheries Research Board Journal 34(9):1261-1285.

Underwater biotelemetry includes studies of movements, behavior, and physiological functions of underwater animals, as well as environmental conditions surrounding them. In such studies data are received via signals from a transmitter on or in an animal. Ultrasonic signals were used in early work. More recently both ultrasonic and radio signals have been used. In the two decades since the 1st underwater biotelemetry studies in the mid-1950s, there have been considerable technical advances. Transmitters have become smaller, more powerful, and have longer operating life. Coding of individual transmitters has become more reliable and decoding more automated. Transmitters capable of sensing environmental, behavioral, and physiological factors from free-swimming animals have been built. Receiving systems ranging from small ones for tracking from canoes to large ones for oceangoing vessels have been developed. With this equipment f60 species of underwater animals have been studied. Various techniques of transmitter attachment have been developed and different methods of tracking explored. Underwater biotelemetry has been applied to studies of fish migration, orientation mechanisms, movement patterns at obstecology, behavior, and physiology of animals. The equipment needed for ultrasonic biotelemetry, methods of localization and transmission, and the biological implications of underwater telemetry are examined in detail.

STERNICK, LEON

1978. Velocity Determination by Doppler Sonar in Deep Water. Published in Proceedings of IEEE Position Locat and Navig Symp., San Diego, CA, by IEEE (Cat n. 78CH1414-2 AES), New York, NY, p. 265-271.

The purpose of this paper is to define principles of a highly accurate velocity sensor which depends upon the doppler shift of an acoustic signal transmitted from a moving platform and received as a result of backscatter from the ocean bottom. Basic principles are reviewed which show that the doppler shift from a point scatterer is determined at the interface between the projector and the medium at the time of transmission, and the receiver and the medium at the time of reception. The total doppler shift is the result of vehicle motions spaced apart by the round trip time of the acoustic signal. In deep water significant time elapses between transmission and reception and hence velocity can change appreciably.

STOCKTON, THOMAS R., and MILES W. MC LENNAN

1975. Acoustic Position Measurements, An Overview Published in Offshore Technology Conference, 7th, Houston, TX. V. 1, paper OTC 2172, p. 255-264.

There are two fundamental measurement modes depending on whether the emission time of the source ping is known. When the source time is known, the solution is in the form of intersecting spheres (spherical tracking). If the time of the ping is not known, the measurement problem is the equivalent of solving for the intersection of hyperbolodical surfaces (hyperbolic tracking). Position measurement uncertainties are due to inexact knowledge of hydrophone location, ping arrival time, and sound velocity. Each of these errors can have a random and/or bias component. The manner in which these errors are reflected into position measurement uncertainties is governed by geometry and the measurement mode. The basic concept is discussed, generalized equations are developed, and the affect upon the equations of simplified array patterns and simplifying approximations is examined. Finally, the inaccuracies imposed by each error source are discussed, and position error contour curves for typical measurement geometries are presented.

TARASOV, N. I.

1963. The Live Sounds of the Sea Trans. of mono. Zhivye Zvuky Morya, Moscow, 88p.

The sounds produced by marine animals, such as mammals, fishes and crustaceans, are analyzed with respect to frequencies, pitch and other sonar characteristics. The various types of sounds, mechanics of their production, their application by marine animals for communicative purposes and their utilization by men, notably with respect to fishing, are also discussed. In line with this, the past and present investigations and findings by the Soviet, American, Japanese, Polish and British scientists relative to the sounds produced by marine animals in seas, oceans and aquariums are described and evaluated.

TEILHAUD, S.

1978. Considerations on the Continuous Seismic Reflection in the Sea and its Use in Civil Engineering. (article in French) Bull. Liaison Lab. Ponts Chaussees 98:9-16.

Seismic sounding has developed considerably in the past few years, particularly in the field of oceanographic research and the oil industry where it has found its most important functions. Recently knowledge of river or coastal areas has been necessary for civil engineering studies and techniques have been developed for answering specific problems. However, the use of data and their interpretation has remained at a primary stage which has not demonstrated the possibilities of the method to the extent that this technique has been able to prove itself on a large scale. To remove any doubts and thus help eventual users, and in the light of past experiments, the different factors that must be considered to ensure the success of a seismic investigation are discussed. Problems include shallow depths of water and the different apparatus available and the conditions of their use. Finally, the potential of more rational and complete exploitation using magnetic measurements such as those used already in oceanography and the oil industry are considered.

TUCKER, M. J.

1975. Ocean Technology. Radio Electron Eng. 45(10):610-616

Trends in oceanographic instrumentation over the past 10 years have included the adoption of digital methods, the use of submersibles, precise underwater position fixing and the use of satellites, the latter however being very restricted. The development effort on large data buoys is discussed, and some important recent developments in acoustic techniques are presented. Outstanding problems in oceanographic instrumentation, in particular that of current measurements are dealt with.

WADE, GLEN; et al

1972. Acoustical Holography, Volume 4
Published in Proceedings of Acoust. Hologr., v 4., Int. Symp. 4th, Santa Barbara, CA.

The scope of the 37 papers comprising this volume is substantially broader than the term "acoustical holography" usually implies; it encompasses the whole area of visualization, detection, and recording of sound fields whether with long wavelengths, microwaves, or with extremely short sound wavelengths. The symposium papers appear each as a separate chapter. In general, the work reported deals mainly with experimental and theoretical developments in the above areas. This work has significant practial potential use in terms of seismic sensing, underwater imaging, non-destructive testing, real-time acoustic microscopy, and medical diagnosis. Following is a list of titles and authors: Real-Time Acoustical Imaging by Means of Liquid Surface Holography, by Byron B. Brenden. Progress Report on the Laser Scanned Acoustic Camera, by R. L. Whitman, M. Ahmed, and A. Korpel. Real-Time Reconstruction of Images from Hydroacoustic Holograms, by J. L. Weaver and G. C. Knollman. Practical High Resolution Acoustic Microscopy, by L. W. Kessler, P. R. Palermo, and A. Korpel. 1GHz Scanned Acoustic Microscope, by B. A. Auld, R. J. Gilbert, K. Hyllested, C. G. Roberts, and D. C. Webb.

WASSERMAN, L. P.

1972. Instrumentation for the 1980's: Evolution or Revolution Published in 8th Annual Conference and Exposition on Applications of Marine Technology to Human Needs, Washington, DC. Marine Technology Society.

Earliest marine instruments were of the 'rock-on-a-string' family. Sonar provided a quantum jump improvement along with acoustic data transmission television and the XBT are advances of the 1960's. Point sensors will be replaced by remote sensors which are better at continuous recording in all four dimensions. A revolutionary change will result in pressure tolerant, low power drain, disposable, reliable, ocean certified instruments for the 1980 decade.

WESTNEAT, A. S. and W. PORTER

1976. Acoustic Sediment Classification Involving Gas-Laden Soils Published in Proceedings of Offshore Technology Conference, 8th, v. 2, p. 961-966, OTC-2613, Dallas, TX

It has been demonstrated that acoustic echoes, returned from a multi-layered sea floor, are useful in identifying key properties of those sediments. The principal remotely measured classifiers in current use are sediment bulk density, intra-layer compressional wave velocity and attenuation rates. In typical marine sediments the successive underlying layers exhibit densities and velocities that usually increase with depth. In delta areas, as found in the Gulf of Mexico, however, this is not always the case due to the inclusion of biological gas in the soil, which may seriously affect its engineering properties. This paper reviews the concept of negative reflection coefficients resulting from underlying layers of lower impedance, presence of gas, and their impact on the prediction of physical soil parameters from acoustic probing. The mathematical implications are explored and examples of analyses of acoustic reconnaisance data, taken over delta soils, are shown.

WESTON, D. E.

1978. Shallow-Water Sound Propagation
Published in EASCON '78, 252-5, Arlington, VA, by IEEE, New York.

The scale of the sound propagation geometry for shallow water is compared with that for other propagation modes. This leads immediately to two well-known points: first the common necessity for a wave approach and the dependence on the number of normal modes effective in carrying the energy, and second the heavy penetration of the bottom and the need to know its properties. Progress in describing the mean acoustic transmission is briefly reviewed. Progress in understanding the variability in transmission is also treated--complicated because of the large numbers of different mechanisms which can act, but helped by the existence of a number of fixed measurement ranges. Sonar applications are illustrated by detections of whales and fish.

WILSON, JERRY C.; et al.

1973. Ocean 73. Published in Proceedings of IEEE Int Conf on Eng in the Ocean Environ. 4th, Seattle, WA.

Following is a continuation of the list of titles and authors: Remote Assessment of Sea Floor Sediments, by Jerry C. Wilson Measurement of In Situ Sound Speed During Sediment Coring, by D. J. Shirly, A. L. Anderson, and L. D. Hampton. "Acousticore", A New Concept in Acoustic Propsecting for Minerals and Preconstruction Surveying, by Hugh A. Wright and Paul R. Miles. Acoustipulse System Provides Improved Marine Geologic Engineering Information, by Conrad J. Johnson and Herman C. Sieck. Progress in the Use of Acoustics to Classify Marine Sediments, by D. L. Bell, W. J. Porter, and A. S. Westneat.

ZAKHAROV, L. N. and S. N. RZHEVKIN

1974. Phase-Gradient Measurements in Sound Fields
Sov. Phys. Acoust 20(3):241-245

New developments of methods and equipment for phase-gradient measurements in underwater sound fields are reviewed. The design of small-scale gradient hydrophones capable of measuring the components of the particle velocity and their phase differences with the sound pressure has resulted in the formulation and solution of a number of reciprocal underwater-acoustical problems calling for the determination of the acoustical and geometrical parameters of a source by means of phase-gradient measurements far from the source. A method is proposed for determining the strength of sources by measurement of the sound energy flux across a closed surface, as well as for determining the impedance and reflection coefficient of the bottom as a function of the frequency and angle of incidence. The feasibility of determining the coordinates of a sound source by phase-gradient measurements at a single point is demonstrated for the case in which the hydrophone dimensions are negligibly small in comparison with the wavelength. The spatial characteristics of sea noise in coastal zones are analyzed, and the causes of noise field asymmetry due to surf- generated noise are explained.

ZHUKOV, R. F.; et al

1973. Underwater Search Systems, Instruments, and Devices Trans. of Mono. Sistemy, Pribory i Ustroistva Pidvodnogo Poiska, Moscos, 182 p. Joint Publications Research Service, Arlington, VA

A study was made of the physical principles of constructing underwater search systems, their instruments and devices. Underwater search systems are described the operation of which is based on various physical principles, and methods of utilizing them. The description of the systems, instruments, devices, physical principles and the principles of the construction and operation of them and also methods of utilizing them and determining the efficiency are presented from foreign publications. There is a brief discussion of the principles of determining the efficiency of various underwater search systems. Examples are presented of the organization of underwater search operations -- the search for the sunken Affray, Thresher and Scorpion submarines, the American hydrogen bomb lost off the coast of Spain and other objects.

The following includes 15 references to contemporary textbooks on Underwater Acoustics obtained from the LIBCON/E data base.

ALBERS, V. M. (editor)
PY : 1970
TI : Underwater Sound
SNO: Benchmark Papers in Acoustics
IT : Underwater Acoustics
LC : 72-79141

ALBERS, V. M.
PY : 1969
TI : Underwater Acoustics Instrumentation
IT : Underwater Acoustics - Instruments
LC : 76-84217

ALBERS, V. M.
PY : 1965
TI : Underwater Acoustics Handbook II
IT : Underwater Acoustics
LC : 64-15069

ANDERSON, N. R. and B. J. ZAHURANCE (editors)
PY : 1977
TI : Oceanic Sound Scattering Prediction
SNO: Marine Science, v. 5
IT : 1. Underwater Acoustics
IT : 2. Sound-Waves - Scattering
IT : 3. Bioacoustics
IT : 4. Marine Biology
LC : 77-3445

BOBBER, R. J.
PY : 1970
TI : Underwater Electroacoustic Measurements
IT : 1. Underwater Acoustics
IT : 2. Electro-Acoustics
LC : 72-608304

CARUTHERS, J. W.
PY : 1977
TI : Fundamentals of Marine Acoustics
SNO: Elsevier Oceanography Series; 18
IT : Underwater Acoustics
LC: 77-4044

CLAY, C. S. and H. MEDWIN
PY : 1977
TI : Acoustical Oceanography: Principles and Applications
SNO: Ocean Engineering, a Wiley Series
IT : Underwater Acoustics
IT : Sea-water-Acoustic properties
IT : Oceanography
LC : 77-1133

COX, A. W.
PY : 1974
TI : Sonar and Underwater Sound
IT : 1. Sonar
IT : 2. Underwater Acoustics
IT : 3. Anti-Submarine Warfare
LC : 74-15547

HAMPTON, L. (editor)
PY : 1974
TI : Physics of Sound in Marine Sediments (Proceedings)
SNO: Marine Science, v. 1
IT : Marine Sediments - Acoustic Properties
LC : 74-8022

KELLER, J. B. and J. S. PAPADAKIS (editors)
PY : 1977
TI : Wave Propagation and Underwater Acoustics
SNO: Lecture Notes in Physics; v. 70
IT : Underwater Acoustics
LC : 77-18813

NATIONAL DEFENCE RESEARCH COMM.
PY : 1969
TI : Physics of Sound in the Sea
SNO: Documents on Modern Physics
IT : Underwater Acoustics
LC : 74-603914

NATIONAL RESEARCH COUNCIL (COMMITTEE on UNDERWATER TELECOMMUNICATION)
PY : 1970
TI : Present and Future Civil Uses of Underwater Sound
IT : Underwater Acoustics
LC : 76-606666

STERN, R. and B. M. BROWN
PY : 1970
TI : Underwater Acoustics
IT : Underwater Acoustics
LC : 78-109428

TUCKER, D. G. and B. K. GAZEY
PY : 1966
TI : Applied Underwater Acoustics
SNO: The Commonwealth and International Library, Physics Division
IT : Underwater Acoustics
LC : 66-18403

URICK, R. J.
PY : 1975
TI : Principles of Underwater Sound (2nd edition)
IT : Underwater Acoustics
LC : 75-17514

APPENDIX A - SEARCH METHODOLOGY

The specific search strategy to be discussed here was executed in the following data bases available on the Lockheed Information System called DIALOG: National Technical Information Service (NTIS), COMPENDEX, INSPEC, SCISEARCH, DISSERTATION ABSTRACTS, LIBCON/E, OCEANIC ABSTRACTS, and Aquatic Sciences and Fisheries Abstracts (ASFA). For a description of each data base see Appendix B.

The search strategy used to retrieve references of a review nature on ocean acoustic remote sensing (OARS) involved creating sets of key words representing four distinct concepts. Each set consisted of synonymous words or word roots which were merged together utilizing the boolean operator OR. As concepts were created, they were intersected with each other utilizing the boolean operator AND.

The four concepts that were identified as relevant to a search for review literature on OARS were ACOUSTIC, OCEAN, MEASUREMENT, and REVIEW. Remote as a concept was subordinated and subsumed in the MEASUREMENT concept because the word itself, or related phrases, has not been commonly used in the literature.

The synonyms used for each concept are shown in Figure 1. The symbol (?) is used to indicate truncation of a word root, and an asterisk (*) is used to indicate the AND boolean operator. Consecutive numbers are set numbers used as references when executing boolean operators in the software. The other numbers refer to the number of unique references in the data base being searched (in this case NTIS) which contain the word or word root somewhere in the searchable fields of the reference. NOTE: Searchable fields of a reference vary from data base to data base, though generally they include the title of the reference, the author's affiliation or corporate source, an abstract of the reference, and descriptors which are subject terms applied by indexers.

The four concepts in our specific search strategy are located in Sets 4, 11, 20, and 34. These sets are the result of the merging of terms with the OR boolean operator. Set 12 is the intersection of the ACOUSTIC and OCEAN concepts. Set 21 is the intersection of the ACOUSTIC, OCEAN, and MEASUREMENT concepts. The final set 35 is the intersection of all four concepts ACOUSTIC (20408 references) and OCEAN (83270 references) and MEASUREMENT (158525 references) and REVIEW (53941 references). Each of the 78 references in set 35 contains at least one of the words or word roots from each of the concept sets 4, 11, 20, and 34.

A major difficulty with computerized literature searching involves the retrieval of references which are not relevant to the objectives and/or subject of the search. Often, references known to be relevant to the subject being searched do not appear in the final set which is printed, while "garbage" references do. This can occur for a variety of reasons, chief being the computer's literal retrieval of character strings (to human beings, words) which have multiple meanings, connotations, and uses -- e.g., Sound, Marine, Sens? (Sense, Sensing, Sensitive,Sensitivity, etc.). Other reasons for not retrieving known relevant references include: the published date of the reference is earlier than the time frame covered by the data base; the source of the reference is not among the sources abstracted and indexed by the data base; the type of publication (technical report, journal, dissertation) is excluded in the data base, e.g., NTIS data base includes only technical report literature and not journal literature, while COMPENDEX includes all types of literature sources.

Figure 2 shows two references, one relevant and one not relevant, that were retrieved with the search strategy shown in Figure 1. The words or word roots from each concept which caused the references to be retrieved are circled.

In the specific search strategy, the word "sound" proved to be a term that allowed many irrelevant references to be retrieved, owing to its usage in geographical as well as acoustical senses. The REVIEW concept was deliberately kept broad to include terms which MIGHT have a review connotation, but which often do not (progress, summar?, latest develop?, recent develop?, potential develop?, and assessment). It was felt that by broadening this concept, the increase in irrelevant references would be tolerable given the small number of references expected in the final set coupled with the potential for retrieving additional relevant references.

The final set 35 of the search strategy is merely an attempt to edit with the computer the main subject set 21 which is the intersection of the ACOUSTIC, OCEAN, and MEASUREMENT concepts. The large number of references in the NTIS data base retrieved in the set (1603) contain many references that would be relevant to the objectives of OARS, but not to the special intent of the computerized search -- i.e., the retrieval of references of an "overview" nature. Any exhaustive computerized literature search strategy for OARS would stop with Set 21, or its equivalent. We can only hope that this "bibliographic overview" will prove to be valuable to you in broadening your perspective, or as a starting point for a more detailed literature search.

Set	Items	Description
1	10080	ACOUSTIC?
2	910	SONIC
3	13306	SOUND???? ?
4	20408	1 OR 2 OR 3
5	23461	OCEAN?
6	12511	SEA
7	54952	WATER? ?
8	746	UNDERSEA
9	6783	UNDERWATER
10	16054	MARINE
11	83270	5 OR 6 OR 7 OR 8 OR 9 OR 10
12	5146	4*11
13	48462	MEASUR?
14	11569	MONITOR?
15	12123	ESTIMAT?
16	71534	TEST? ?
17	7380	REMOT?
18	21600	DETECT?
19	16513	SENS?
20	158525	13 OR 14 OR 15 OR 16 OR 17 OR 18 or 19 or 20
21	1603	12*20
22	23584	REVIEW?
23	2124	STATE(3W)ART
24	13410	PROGRESS
25	895	OVERVIEW
26	6963	SUMMAR?
27	68	TUTORIAL
28	766	LITERATURE(2W)SURVEY?
29	144	LITERATURE(2W)SEARCH?
30	3	LATEST(W)DEVELOP?
31	460	RECENT(W)DEVELOP?
32	5	POTENTIAL(W)DEVELOP?
33	8302	ASSESSMENT
34	53941	22 OR 23 OR 24 OR 25 OR 26 OR 2
35	78	21*34

THE SPECIFIC SEARCH STRATEGY SHOWN HERE WAS EXECUTED ON THE NTIS DATA BASE. THE SEARCHER TYPES IN THE WORD OR WORD ROOT (?) ON A TYPEWRITER TERMINAL, AND THE SYSTEM RESPONDS WITH A SET NUMBER, THE NUMBER OF ITEMS RETRIEVED FOR THE INPUT WORD OR WORD ROOT, AND A DESCRIPTION OF THE WORD OR WORD ROOT ORIGINALLY INPUT FOR THE SEARCHER'S REFERENCE. SET NUMBERS ARE USED TO EXECUTE BOOLEAN LOGIC.

FIGURE 1

IRRELEVANT REFERENCE

Chemical and Geochemical Studies off the Coast of Washington. Report of Progress, September 1976--August 1977

Washington Univ., Seattle. Dept. of Oceanography.*Department of Energy. (6808000)
AUTHOR: Carpenter, R.
E12G5E4 Fld: 8J, 13B, 68D, 47C, 97R GRAI7813
1977 39p
Contract: EY-76-S-06-2225-024
Monitor: 18

Abstract: Progress is reported on a series of marine chemical and geochemical investigations involving both laboratory studies and field studies off the coast of Washington. Most of the field work the past few years has been on the Washington continental shelf, slope and the submarine canyons indenting the shelf north of the Columbia River. Our aim is to provide basic data required to characterize underlying chemical and physical processes and their rates which control the distributions, concentrations and ultimate fate of some of the potentially hazardous agents associated with fossil fuel and/or nuclear power production or transportation. The studies followed several main lines of investigation which are in various stages of completion: studies of the uptake and transfer of exp 210 Po, exp 210 Pb and related elements in the well defined surf zone ecosystem at Copalis Beach, Wa; field studies of the uptake and transport by zooplankton fecal pellets of exp 210 Po, exp 210 Pb and other trace inorganic and organic constituents in a well studied part of Puget Sound; studies of the behavior of exp 210 Po and exp 210 Pb in sediments off the coast of Washington and the application of the exp 210 Pb determinations in sediment cores to determine sediment accumulation rates for the past 100 years, the depth of the surface mixed layer, and a mixing coefficient for the surface sediments; and investigations of aliphatic and aromatic hydrocarbons in some of the same samples of organisms and sediment cores whose accumulation histories for the past 100 years have been determined with the lead-210 technique. (ERA citation 03:020079)

Descriptors: *Lead 210, *Polonium 210, North Pacific Ocean, Sediments, Washington, Age estimation, Aquatic ecosystems, Aquatic organisms, Chemical analysis, Coastal waters, Drill cores, Environmental transport, Geochemistry, Oceanography, Radionuclide kinetics, Sampling, Lead isotopes, Mass transfer, Polonium isotopes

Identifiers: ERDA/580500, ERDA/520200, ERDA/520301, Continental shelves, *Water pollution, Fossil fuels, Radioactive contaminants, Path of pollutants, Baseline measurements, Puget sound, NTISDE

RLO/2225/T24-20 NTIS Prices: PC A03/MF A01

RELEVANT REFERENCE

A Review of the Statistical Properties of the Ocean Surface *

Naval Underwater Systems Center New London Conn New London Lab (405916) *

Technical memo.
AUTHOR: Cron, Benjamin F.
D1715J1 Fld: 17A, 20A, DC GRAI7709
1 Jul 70 24p
Rept No: NUSC/NL-TM-2211-128-70
Project: ZR01101
Task: ZR0110101
Monitor: 18

Abstract: This study reviews the work on ocean surface statistics and some new approaches are considered. A brief discussion of some similarities between ocean surface statistics and underwater sound noise fields is included. The author outlines the method for obtaining the equation showing the relation between the spatial-temporal correlation and the directional wave spectrum. Methods of measuring the spatial-temporal correlation of the surface are mentioned along with the equations, and special cases of this correlation are considered. The most important one (i.e. the simplest to measure) is the temporal correlation at a point on the surface. The Fourier Transform of this correlation leads to the power spectrum of the Neumann-Pierson type. Finally, a method of obtaining cross spectra between pairs of a linear array of elements is discussed and similarities between this method and the underwater sound problem of obtaining the directionality of ambient noise is mentioned.

Descriptors: *Surface waves, *Sound transmission, *Ocean surface, Ocean waves, Sonar arrays, Statistical analysis, Ambient noise, Acoustic measurement, Spectrum analysis, Directional, Underwater sound, Ocean models, Power spectra, Height finding, Correlation techniques, Fourier transformation, Linear arrays *

Identifiers: Most Project-2, NTISDODXA *

AD-A035 899/4ST NTIS Prices: PC A02/MF A01

NOTE: THESE REFERENCES WERE RETRIEVED WITH THE SPECIFIC SEARCH STRATEGY EXECUTED IN THE NTIS DATA BASE. THE SEARCHABLE FIELDS (*) IN THIS DATA BASE ARE THE TITLE, CORPORATE SOURCE, DESCRIPTORS, AND IDENTIFIERS. ABSTRACTS ARE NOT SEARCHABLE. CIRCLED WORDS INDICATE HOW REFERENCES WERE RETRIEVED (ONLY ONE WORD PER CONCEPT CIRCLED FOR EXAMPLE).

FIGURE 2

APPENDIX B - SEARCHED DATA BASE DESCRIPTIONS

1. ASFA, AQUATIC SCIENCES AND FISHERIES ABSTRACTS

PRODUCER: Food and Agriculture Organization of the United Nations FAO, Rome, and the Intergovernmental Oceanographic Commission of UNESCO. (Maintained by NOAA).

DATES: January 1978 - present

AQUATIC SCIENCES AND FISHERIES ABSTRACTS (ASF) is a comprehensive data base on the science, technology, and management of marine and fresh-water environments. It includes related legal, political, and social topics. Information in the file is derived from international sources including books, periodicals, technical reports, and conference proceedings. Subjects included in the file are aquatic biology, oceanography, fisheries, and water pollution as well as other related topics. The online file begins with January 1978 and is updated approximately monthly. At some future date, the backfile to January 1975 will be made available on-line.

2. COMPENDEX; ENGINEERING INDEX

PRODUCER: Engineering Index, Inc.

DATES: 1970 - present

COMPENDEX is the on-line version of the publication, Engineering Index (monthly/annual), which provides worldwide coverage of engineering and technological literature. All fields of engineering are covered, including aerospace, civil, electrical, marine, mechanical, nuclear, and environmental.

3. COMPREHENSIVE DISSERTATION ABSTRACTS

PRODUCER: Xerox University Microfilms, Ann Arbor, MI

DATES: 1861 - present

COMPREHENSIVE DISSERTATION ABSTRACTS is a definitive subject, title, and author guide to virtually every American dissertation accepted at an accredited institution since 1861, when academic doctoral degrees were first granted in the United States. In addition, CDA serves to disseminate citations for thousands of Canadian dissertations and an increasing number of papers accepted in institutions abroad. Professional (e.g., M.D., L.L.D.) and honorary degrees are not included. All subject areas are covered.

4. INSPEC: Physics Abstracts; Electrical and Electronics

Abstracts; Computer and Control Abstracts

PRODUCER: Institution of Electrical Engineers, London

DATES: 1969 - present

INSPEC is the on-line version of the SCIENCE ABSTRACTS family of journals: PHYSICS ABSTRACTS, ELECTRICAL AND ELECTRONICS ABSTRACTS, and COMPUTER and CONTROL ABSTRACTS. The file provides worldwide coverage of all fields of physics, electrotechnology, computers, and control. The file contains more than 1 million citations compiled from journal articles, books, conference papers, patents, dissertations, and technical reports. Monthly updates add about 150,000 new records each year.

5. LIBCON/E

PRODUCER: 3M Library Systems

DATES: 1968 - present

LIBCON/E provides coverage of monographic literature cataloged by the Library of Congress. All subject areas of English-language materials are covered. In addition to monographic items, the file contains some cataloged nonprint materials. The file contains about 2 million records; weekly updates add about 200,000 new records per year.

6. NATIONAL TECHNICAL INFORMATION SERVICE BIBLIOGRAPHIC DATA FILE; NTIS; GOVERNMENT REPORTS ANNOUNCEMENTS; GRA

PRODUCER: National Technical Information Service

DATES: July 1964 - present

This multidisciplinary data base consists of reports resulting from government-sponsored activities. More than 240 Federal agencies and their contractors and grantees as well as some State and local government agencies regularly deposit their reports with NTIS. More than 650,000 citations including abstracts are currently included in the data base, and about 5,000 new items that appear in the printed Government Reports Announcements are added each month. In most cases, either hard copy or microfiche copy of cited reports may be obtained from NTIS. Abstracts of all NOAA publications and those produced under NOAA contracts and grants, including the National Sea Grant Program, should be found in the data base.

7. OCEANIC ABSTRACTS; OCEANIC; OA

PRODUCER: Data Courier, Inc.

DATES: 1964 - present

An on-line version of the publication Oceanic Abstracts (OA). The data base contains bibliographic citations to all items abstracted in OA. Abstracts are present for 1967 only. Oceanic Abstracts provides a comprehensive coverage of literature relating to oceans and estuaries in the subject areas of biology, geology, meteorology, oceanography, acoustics, optics, engineering, law, and coastal resources and planning. About 1,500 journal titles and 500 other source items are screened for relevant material each year, and 8,000 items are selected for inclusion. The data base is updated bimonthly.

8. SCISEARCH, SCIENCE CITATION INDEX

PRODUCER: Institute for Scientific Information

DATES: 1974 - present

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Working Group Reports

A.O CLIMATE AND WEATHER WORKING GROUP REPORT

CONTENTS

A.I Introduction

Ocean acoustic remote sensing is highly complementary to ocean remote sensing from satellite, which has received considerably more, and more well-organized, attention in that it offers great promise for providing subsurface data. The electromagnetic spectrum used in satellite remote sensing is limited to observations at or very near to the ocean surface. For the same reason, ocean acoustic remote sensing appears to be considerably more relevant for data collection required for climate research and prediction than for weather. It is quite generally accepted that subsurface oceanographic data are not essential data for short-term weather forecasting. There are, however, certain weather-related surface phenomena, such as wind waves, or wind stress, whose presence might be effectively observed far below the surface.

Ocean data for climate research and prediction can be grouped into two general categories: monitoring and geophysical "experiments." Much of what is presently known of the factors involved in climate variation is derived from empirical analyses of historical atmospheric, hydrologic, and oceanographic data sets. Statistical analyses of these data sets as they are improved are the best hope for successfully accurate seasonal and interannual climate prediction. On the other hand, improvement of skill in such forecasts, and the ability to make credible forecasts of climatic conditions in response to influences outside the range of recent historical experience, is critically dependent upon improvement of the state of the art of deterministic modeling of the coupled ocean/atmosphere/cryosphere system. This improvement cannot come from mathematics and computer technology alone, but rather from a balanced program of modeling and observations. Parameterization of many geophysical processes and testing of physical hypotheses in many cases cannot proceed from the necessarily sparse data sets that can be collected routinely through monitoring. More intensive sets of observations focused on specific objectives are required for this purpose. Experiments such as MODE, POLYMODE, GATE, FGGE, NORPAX, etc. demonstrate the pattern of such studies.

A.2 Status of Present OARS Applications

Up to the present, there has been no use of ocean acoustic remote sensing for systematic ocean monitoring for weather and climate, and only a few instances of their use in related geophysical experiments. Of the techniques discussed in Section A.4, the inverted echo sounder has been used in small numbers since 1973. It may now be considered a proven instrument. Shipboard doppler shear profilers and the WOTAN (Weather Observation Through Ambient Noise) have been tested at sea and show excellent promise for use in both long-term monitoring and special experiments. Preparations are now underway for the first serious test of ocean acoustic tomography. This test in itself will require a geophysical experiment of some considerable proportions. During the next decade, the most likely application for this technique is in special experiments. It is potentially attractive for sampling oceanographic processes in which the most energetic temporal and spatial variations are important. Depending upon associated cases, it may subsequently meet requirements for operational collection of this type of data.

A.3 Requirements

Because a considerable body of documents now exists on the subject of ocean monitoring for climate studies, and because there was reasonable agreement among the members of the Working Group on the kinds of ocean climate observation that are becoming critical, the discussion of requirements was limited. Reference is made particularly to the NOAA Climate Plan, the National Five-Year Climate Plan, and "An Ocean Climate Research Plan" (ERL).

Briefly, the requirements for physical oceanographic parameters in climate lie in the following areas:

o Sea Surface Temperature

In terms of relative priority, sea surface temperature is the key oceanic parameter to be monitored for shorter time scales, because it controls the transfer of thermal energy from the ocean to the atmosphere and therefore has a direct and immediate effect on the climate system.

o Upper Layer Heat Content

In order to understand and eventually to predict the large-scale, long-term variability of sea surface temperature, it is necessary to monitor the heat content of the upper "heat storage" layer of the ocean. In the context of these discussions, particular emphasis is placed on profiles of temperature and current through the mixed layer, and mapping of temperature (and current) fields.

o Wind Stress

Wind stress exerted upon the surface of the oceans is the major driving force that maintains the prevailing ocean currents which in turn play a significant role in the horizontal transport of heat energy from the tropics to the poles. It also generates the surface waves and swells that are responsible for downward mixing of heat that accumulates at the surface, thereby increasing the thickness of the heat-storage layer and making way for more heat to be stored. Wind stress therefore affects the amount and distribution of thermal energy in the ocean, and, because wind stress on the ocean determines surface roughness, it is fundamental to modeling air-sea interactions, particularly with regard to boundary layer heat transfer.

o Sea Level and Sea Surface Tomography

Sea level is a sensitive indicator of long-term global climate change, and measurements of local sea level (dynamic height) variability in the open ocean are extremely useful for monitoring climatically significant fluctuations of major ocean currents and upper layer heat content.

o Ocean Currents

As in the atmosphere, understanding and monitoring the general circulation of the ocean is an important step toward understanding and predicting the climate. Although the general circulation has been studied for many years, there is no definitive picture of the global movement of water, which to a large degree controls the flux of heat energy. (See also Upper Layer Heat Content.)

o Sea Ice

Sea ice is particularly sensitive to climatic conditions, varying over a year from almost total coverage of the Arctic Ocean in the cold months to about 60% coverage at the end of the summer. Nearly three-fourths of the incoming radiation from the sun is reflected by the ice, while only about one-tenth is reflected from open water. The remainder is absorbed. The ice cover thus drastically reduces heat exchange as well as mass exchange between ocean and atmosphere.

o Salinity

Salinity is a significant ocean climate variable in that it determines the freezing point of sea water and affects the density structure (hence circulation) of the ocean.

In focusing the discussions on the use of OARS for meeting these requirements, the Working Group found the most immediate promise in the areas of upper layer heat content and circulation (currents), sea level, and wind stress observations. Within the category of heat content and circulation, the combined acquisition of temperature and dynamic information received repeated and continued emphasis.

The Working Group also concluded, as noted in the introduction, that the applications of OARS to weather requirements were not extensive. The requirements for near-real-time data on wind velocity, sea state, and precipitation over ocean areas were the major weather applications highlighted in the discussions.

A.4 Promising OARS Techniques

Acoustic remote sensing techniques show considerable promise for ocean environmental applications. Tomography, if successful, will permit the mapping of sound speed and temperature structure over large ocean areas $(1000 \text{ km})^2$, and from the temperature field significant information can be derived about the flow. Several doppler shear profilers are under development which will ultimately make possible the rapid continuous absolute measurement of shear profiles in an upper ocean from surface ships or bottomed transducers. The echometer, proposed by the Wave Propagation Laboratory for atmospheric applications, should make possible the continuous measurement of temperature profiles in the upper ocean from surface ships or bottomed transducers, and the possibility exists for it obtaining the shear profile as well. The inverted echo sounder, currently in an advanced state of development, when calibrated initially using conventional techniques, can measure mean heat content in the water column, a quantity of considerable interest to the climate program.

The ocean-bottomed ambient noise measuring equipment WOTAN has operated successfully in the field for some time and can be used currently for estimating wind speed and mean wind stress, quantities obtained in the open ocean only with considerable difficulty. It shows promise for free and anchored buoy operations as well, although these would be new applications of the technology. The Wave Propagation Laboratory has also suggested the use of acoustic instrumentation for the measurement of directional ocean wave spectra although this concept again is not currently under development.

The discussion that follows provides considerably more information about these concepts, addressing current studies and plans, what institutions are involved, the potential for successful development (if not already demonstrated), development needs, and some development program milestones.

A.4.1 Ocean Acoustic Tomography (A Scheme for Large-Scale Monitoring)

Observations during the last two decades have demonstrated that most of the kinetic energy of the ocean circulation is associated with variability on a relatively small scale (the mesoscale) of order 100 km. Measuring this variability poses a formidable problem because of the small spatial scale compounded by the long ocean time scale of order 100 days. Ocean acoustic tomography is a potential technique to monitor the oceans by measuring acoustic transmissions between moorings over large distances of order several hundred kilometers. The procedure consists of measuring perturbations in travel time between a number of acoustic sources and receivers, and then inverting these perturbations in travel time to obtain the interior sound speed structure. The structure in the vertical is obtained because there exist many purely refracted ray paths for each source-receiver pair that sample different parts of the water column and therefore have different travel time perturbations. Because the number of pieces of information is the product of the number of sources, receivers, and resolvable multipath arrivals, the economics of the system is enhanced over usual spot measurements.

Dr. W. Munk of Scripps Institution of Oceanography, Dr. R. Spindel of Woods Hole Oceanographic Institution, Dr. C. Wunsch of Massachusetts Institute of Technology, and Dr. J. Birdsall of the University of Michigan are currently involved in a joint effort to test the feasibility of ocean acoustic tomography. Experiments conducted during 1978 and 1979 have demonstrated that the ocean multipath structure is stable at least over a period of a few months, that the ray paths can be adequately resolved using existing acoustic sources with approximately 20 Hz bandwidths, and that the travel time perturbations can be measured with 10 ms precision, which is more than adequate for monitoring mesoscale fluctuations. They are therefore proceeding with a full three-dimensional test that will take place in the Atlantic for a period of four months early in 1981. This experiment will provide concomitant acoustic and oceanographic observation adequate to address the first inversion problem of the temperature field, and to begin work on the second inversion problem of the flow field. Four source moorings and five receiver moorings will be installed to monitor a 300 km by 300 km area. NOAA (AOML) will play an important role in this experiment by conducting CTD surveys of the area at the beginning, middle, and end to provide conventional data for comparison with the acoustic data and will participate in other oceanographic aspects of the project. Analysis of the data from this experiment is expected to be completed within two years.

While the data analysis is proceeding, the investigators plan to explore the possibility of using two-way acoustic transmissions to monitor ocean currents, to examine techniques to obtain the data on shore in real time (e.g., by long-range acoustic telemetry or by satellite link), to study the feasibiity of building sufficiently stiff moorings to eliminate the need to track mooring motion, and perhaps to monitor the horizontal deflections of ray paths as a possible input to the acoustic inversion problem.

If the 1981 experiment is successful, an experiment to apply the technique to another oceanographic problem will be conducted in 1983. Possible candidate experiments include an equatorial experiment to monitor the undercurrent meanders (perhaps in conjunction with the Equatorial Pacific Ocean Climate Studies (EPOCS) work); an experiment to monitor the cold water overflow through the Denmark Straits; and an experiment to monitor the Gulf Stream recirculation. Personnel and equipment resources are probably sufficient to conduct this experiment.

In roughly 1985-86 an order of magnitude increase in experiment size to 1 megameter squared from the 0.1 megameter squared 1981 experiment is tentatively planned.

Ocean acoustic tomography has potential application to sampling and mapping of oceanographic sound velocity (temperature) and current structure in regions that by reason of size and spatial and temporal variability cannot be adequately sampled by means of conventional ship current meters or other methodology. Possible application includes conduct of special investigations of the dynamics of ocean circulation and heat flux. Its best application will probably require concomitant observation of sea level by altimetric satellite or other means of determining the absolute pressure or current fields. Such methodologies may be critical for a successful Atlantic heat flux determination.

A number of developmental needs have been identified and some are being addressed. Foremost among these are questions of determining the several sound paths with sufficient accuracy, the stability of these paths over periods of several months, and the accuracy with which the travel time data can be inverted to produce maps of sound velocity on temperature. Secondary problems concern the secondary inversion of the derived temperature data to obtain flow fields, and possible application of the method to oceanic regions which do not have a prominent sound channel.

Probable Milestones:

1981	1983	1985
300 km square experiment, 9 moorings for four months (MODE area)	Oceanographic experiment, use of technique for research, experiment with reciprocal transmissions	1000 km square deployment, 15-24 moorings for ocean circulation, heat transport

A.4.2 Shipboard Doppler Acoustic Current Profiler

Vertical profiles of current velocity over much of the world's oceans can be obtained at relatively low cost by employing ships of opportunity equipped with suitably modified doppler speed logs.

This instrument utilizes four high-frequency narrow acoustic beams, each inclined 30° to the vertical (fore, aft, port, and starboard) to obtain a high resolution profile of horizontal currents to a depth of 100 to 200 meters beneath the ship. Estimates of the horizontal velocity of successive layers in the water column are made by subtracting the doppler-shifted backscatter of each layer from the bottom return, thus giving a vertical profile of absolute horizontal current velocities.

In the deep ocean, where the bottom return is not available because of signal attenuation, the Global Positioning System may possibly serve as a means for providing a reference velocity. An alternative approach, known as the Parametric Array Doppler Sonar, obtains bottom returns even at extreme depths by mixing two high-frequency colinear beams to form a single acoustic beam that has the range capability of the low (beat) frequency with the narrow beam characteristics of the high primary frequencies.

At the present time several workers are experimenting with doppler units built by Ametek-Straza, including Lloyd Regier at Scripps and Bob Hill at NRL. John Pijanowski of NOAA/NOS is testing a unit built for NOAA by the French Company, Thompson C.S.F. None of these instruments is presently capable of providing absolute current profiles in deep water, although the Parametric Array Doppler Sonar can be modified for this purpose.

The disadvantage of the Doppler Acoustic Current Profiler is its dependence on scatterers in the water column for coherent doppler signals. Scatterers in sufficient concentrations are normally present only in the upper several hundred meters. However, this is the region of greatest interest (for climate purposes) since it is where most of the heat energy is stored and is also the region of greatest variability due to surface wind stress.

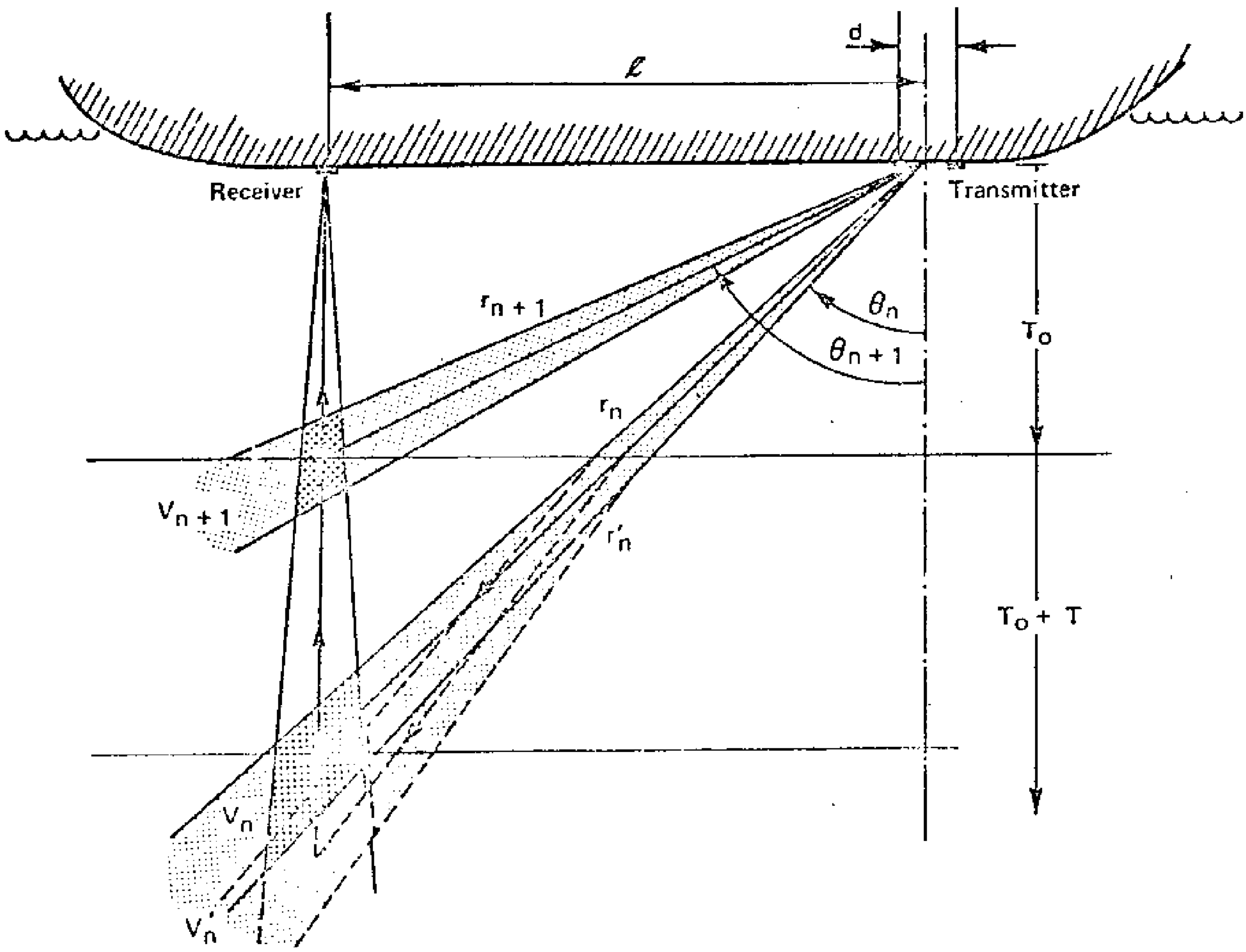
The advantage of the Doppler Acoustic Current Profiler is that it can operate unattended while the ship is underway; it can be integrated as part of the SEAS (Shipboard Environmental Data Acquisition System) system currently being developed for NOAA/NWS use aboard cooperative ships, and should be acceptable to commercial ship operators, since doppler speed logs are familiar navigational devices aboard modern ships. Indeed, the addition of an absolute current profiling capability would enhance a ship's navigation capabilities by providing a true velocity readout even in deep water, which present systems do not.

Suggested Milestones:

1981	1981	1983
Begin development of Acoustic Current Velocity Profiler.	Begin integration for shipboard applications.	Install experimental system aboard NOAA ship for field tests in conjunction with heat flux experiments.

A.4.3 Echometer

With reference to Figure 1, p. A-8, an echometer consists of a transmitting array or a pair of transmitting arrays combined with a single receiver for simultaneous correction and measurement of ocean current profiles. The transmitting arrays consist of two or more transducers spaced several wavelengths apart. Such a spaced array produces a directivity pattern that contains a number of beam-like constructive interference fringes. These 3-dimensional interference fringes act like sound channels through which the major part of the transmitted energy flows. Ordinarily, the axis of the transmitting arrays would be positioned pointing vertically downward. The various interference fringes, however, would be positioned at increasing angles inclined to the array axis. A narrow beam from the receiver would also point vertically downward from a point considerably distant--perhaps a whole ship length--from the transmitting array. The exact distance chosen would depend on the depth to which temperature and current profiles are desired. The receiver beam would intersect the transmitted fringes at a number of



Echometer Geometry

FIGURE 1

scattering volumes—volumes containing scatterers in the form of temperature fluctuations, velocity fluctuations, salt fluctuations, nekton and other biota or solid particles. The operating frequency chosen would depend on the kind of scatterers expected in a particular application. Sound traveling from the transmitting array along the beam-like fringes would be scattered into the narrow receiver beam and reach the receiver. The angle at which the fringes are located--and thus the total path length—depends on the value of the velocity of sound (with changes mainly due to changes in temperature) and to the component of the current along the array. Clearly, the velocity with which a pulse of sound traverses the path also depends on the temperature. With the echometer configuration these two effects combine in the same sense to give a maximum change in delay time per change in temperature. The delay time gives a path-averaged measure of temperature, in the absence of current. With ocean currents present, use of a symmetric arrangement of pulses traveling with opposite horizontal components gives two values of delay time such that the average of the two relates to the temperature, and the difference of the two relates to the component of the current. By using very many fringes, or by sweeping a few fringes over the depth range desired by varying frequency, a raw depth profile of temperature and current can be obtained. Then, as a final step, the raw profile can be converted to a true depth profile of temperature and current by mathematical inversion, based on Snell's law of refraction.

At the present time the basic feasibility of the echometer has been demonstrated in the atmosphere. Temperatures have been measured to heights of about 500 m and compared with measurement from a nearby meteorological tower. These compared favorably although the tower values were consistently lower. Program modifications to provide absolute path-integrated temperatures and wind are in progress and should be completed by mid-1980. Subsequently, the final step of hardware modifications to give a raw profile, followed by software to furnish the mathematical inversion of the profile and production of the desired true profile, will be undertaken. This work is being done by E.H. Brown and his staff at NOAA's Wave Propagation Laboratory (see OARS Paper #15).

Preliminary studies indicate that the principle of the temperature/current echometer is equally valid in the ocean as in the atmosphere. Such an echometer for ocean applications could be equally well mounted on a ship or buoy, or also, possibly, on the ocean bottom. Most of the challenges for such a modification would be engineering problems, and some—such as corrections for ship motion--would have the same solutions as needed for the ship-mounted doppler current meter. We would propose going slowly enough in such a development of an ocean echometer as to permit efficient responses to the differences in the ocean environment. One possible direction would be to form a joint program with the staff at Scripps Institution of Oceanography and modify some of their existing equipment—perhaps that using 87.5 kHz--to permit mounting on FLIP and performing a first ocean feasibility experiment. Such an experiment, "piggy-backed" on some other program, would cost on the order of $150 K. If successful, continuation of engineering development of the ocean system could rely heavily on the expertise being gained in the atmospheric experiments.

Proceeding with the development of a prototype ocean temperature/current depth profiler is estimated to take an additional two to three years and require approximately $500 K. Field testing might very well be handled by a NOAA oceanographic group or by some outside oceanographic institution.

Suggested Milestones

Complete Ocean Feasibility Experiment	January 1981
Complete Atmospheric Raw Profile Prototype	July 1981
Complete Total Prototype Atmospheric System	January 1982
Complete Total Prototype Oceanic System	January 1984

A.4.4 Inverted Echo Sounder (IES)

The IES is an ocean-bottom moored instrument which transmits and receives acoustic pings to measure the travel time to the ocean surface and back precisely. Variations in the travel time arise due to variations in the water depth caused by motion of the free surface, and due to changes in the sound speed associated with changes in the mean temperature in the water columns.

Instruments employing this technique were used in applications during the Mid-Ocean Dynamics Experiment (MODE) and subsequently in the Gulf Stream to monitor the depth of the main thermocline and the dynamic height through the main thermocline with an accuracy of 1 dynamic cm, i.e., comparable with the best standard hydrographic techniques (Watts and Rossby, 1977)[1]. In that same paper the technique is shown to be well suited for monitoring variation in the heat content in the water column. The instruments can operate in depths to 7000 m for up to a year. Details of the instrument design are summarized in Bitterman and Watts (1979)[2].

These instruments are presently being used by Watts of URI to study Gulf Stream meanders in an array designed to measure variability in the path and structure of the Gulf Stream as it leaves the continental margin off Cape Hatteras. Meanders grow and propagate downstream of this region; these experiments seek to test whether they may be linked to perturbation at the "inlet." (See Watts and Olson, 1978.)[3] Recently other IES's have been deployed by Miller (URI) and Katz (Lamont) in the equatorial Atlantic Ocean to study equatorially trapped modes of oscillation.

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[1] Watts, D. Randolph and H. Thomas Rossby (1977). "Measuring Dynamic Height with Inverted Echo Sounders in MODE." Jour. Physical Oceanog., Vol. 7, pp. 345-358.

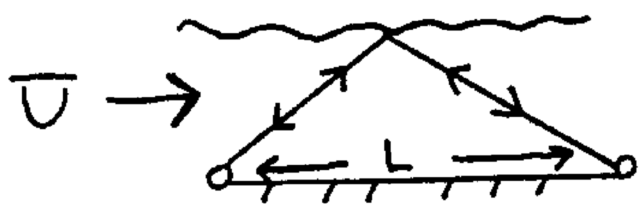
[2] Bitterman, David and D. Randolph Watts (1979). "The Inverted Echo Sounder." IEEE/MTS Oceans '79 Proceedings, pp. 302-311.

[3] Watts, D. Randolph and Donald B. Olson (1978). "Coalescence of a Gulf Stream Ring with the Gulf Stream off Cape Hatteras." Science, Vol. 202, pp. 971-972.

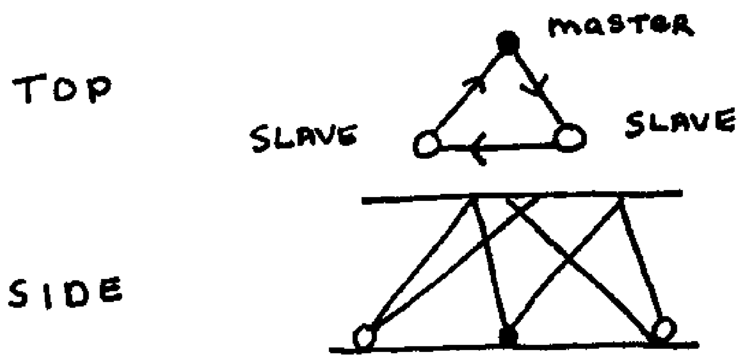
Nine additional instruments are presently under construction for deployment in the EPOCS experiment to monitor variation in the heat content of the water column and to study whether sea surface temperature anomalies in that region represent significant changes in ocean heat storage or are merely near-surface readjustments of heat distribution.

The technique of measuring acoustic travel time in the IES configuration holds promise for a number of applications beyond its presently demonstrated capability. These include:

1. Sing-around vorticity and heat flux observations. This technique would employ an arrangement of two IES's transmitting to each



other simultaneously over a short range in the presence of a mean current. In such a case the difference in the two travel times will be proportional to the vertically averaged current. Each travel time separately will change by an amount proportional to the heat content of the water column. This combined information on the integrated current profile and the water column heat content might successfully be related to heat transport by appropriate model assumptions and/or by supplemental hydrographic observations. The two instruments would require synchronous timing in this configuration, although an extension of the idea offers relief of that constraint. Three such IES's, two slaved to a master in a sing-around configuration with two-way transmission solves this problem and offers additionally the mean vorticity of the water column (by the circulation theorem).



2. Use with bottom pressure observations to determine free surface position (deepwater tide) and the depth of the thermocline. This marriage of techniques is both instrumentally feasible and scientifically desirable. The bottom pressure and changes in acoustic travel time are variables that can be expressed analytically in terms of free surface variations and internal water mass characteristics.

3. Observation of the shape of the return pulse from an IES, particularly the rising edge, to give sea state information in analogy with the satellite radar.

4. Monitoring of arctic ice sheet thickness during the winter, from the safety of the ocean bottom using an IES.

Suggested Milestones:

1980 Begin IES in EPOCS.

1981 Use of IES in tomography experiment for transmission across Gulf Stream; incorporate bottom pressure sensor in IES; begin in development of second generation (microprocessor) IES.

1983 Begin trial vorticity/heat flux application of IES.

1985 Use of IES to support calibration of satellite altimeter along lines across Gulf Stream during large-scale systems evaluations.

A.4.5 WOTAN (Weather Observation Through Ambient Noise)

Through the use of a passive acoustic receiver located on the ocean bottom or at mid-depth on a mooring, it has been demonstrated that measurements of wind speed and wind stress on the sea surface can be made by monitoring noise levels in the 4-20 kHz range. Accuracies of ± 2.5 m/s or better are possible, down to wind speeds of 2.5 m/s or lower. By using a range of frequencies it is also possible, in principle, to determine rate of precipitation.

Two prototypes of this instrument now exist. However, the present design is very simple and easily duplicated. At least one manufacturer may be interested in producing operational versions of the device. In addition to potential applications from fixed stations for weather observation and ocean/atmosphere research, the device may prove to be a candidate for wind observations from drifting buoys. At present, little is known of the full range of uses to which such systems might be applied. Extensive testing is now required in experiments that provide independent observations of wind stress, wave conditions, wind speed, and precipitation rate.

The development and application of WOTAN could also benefit greatly from a theoretical component to study the relationship between acoustic signals produced at the sea surface and the physical mechanisms thought to produce them.

Suggested Milestones:

1981 Initiate plan for research into WOTAN techniques.
Use in conjunction with acoustic tomography moorings.

1983 Test for use with drifting buoys as wind speed sensor.

1985 Use with satellite altimeter.
Expand drifter measurements.

A.4.6 Bottom-Based Acoustic Sounding (A Research Concept)

The previous discussions in this section of the report have focused on five highly promising acoustic techniques for application to climate and weather problems. These discussions contain an implicit emphasis on instrument development; in each case a systems level application of acoustic sensing techniques is advocated. In order to provide a unifying theme to our recommendations, and to underscore the need for a research component transcending just climate and weather as part of a development program in acoustic sensing, one additional area of emphasis is suggested.

It is proposed that the bottom-based acoustic sounding concept be broadened and investigated as a means of providing several types of data critical to ocean climate and weather programs. In such a program the travel time, the doppler, and the passive listening modes would be examined for their combined application to observations from fixed stations. The following parameters would be emphasized, initially for research purposes, later perhaps for operational uses:

Parameters	For use in basic and applied studies of:
$\sigma(z)$ profiles (scattering cross-section)	- ocean structure and processes. - ocean biota.
$u(z)$, $v(z)$ profiles by doppler or correlation	- ocean dynamics and heat transport.
phase depth (depth in acoustic wavelengths in the echo sounder mode)	- heat transport (together with the $u(z)$, $v(z)$ measurements).

Parameters	For use in basic and applied studies of:
surface wave directional spectra (by measurement of two-dimensional phase distribution across the sea floor)	- air-sea interaction, surface stress, acoustic noise, and as a direct services product.
passive acoustic noise measurements	- air-sea interaction, surface stress, acoustic noise due to surface agitation, and rain.

The only ocean work of this type of which the Working Group is aware is the Inverted Echo Sounder (IES) and Weather Observation Through Ambient Noise (WOTAN) programs of Randy Watts and colleagues of the University of Rhode Island. Atmospheric acoustic echosounding work to measure $\sigma(z)$ and u(z), v(z) profiles in the atmosphere is performed by several groups in the U.S., including NOAA's Wave Propagation Laboratory. The measurement of surface wave directional spectra from studies of the phase distribution of echoes from a vertically directed acoustic sounder is, we believe, a new idea. The potential applications of the measurement techniques developed through this research transcend climate alone. The addition of the echometer (E.H. Brown - WPL) might well permit the measurement of temperature profiles as well, thereby enhancing the heat transport measurement capabilities of the overall system.

Suggested Milestones:

At this stage of identification of the concept, level-of-effort estimates only are possible.

Phase I	Studies and analyses of each subsystem and optimum integration into a single system. Design tests of critical parameters or concepts (1 year).
Phase II	Test and evaluation of critical components of the system. Design prototype system (2 years).
Phase III	Test and evaluate the overall system prototype (2 years).

A.5 Recommendations

1. It was recognized that the field of acoustic tomography would benefit from a coordinated, interagency program that included a significant NOAA component. It is therefore recommended that:

- o NOAA continue participation in oceanographic aspects of development and testing of the technique. NOAA's potential roles include collection of conventional oceanographic data, work on inversion methodology, and investigation of regional oceanographic problems associated with the use of the technique.

- o NOAA initiate participation in acoustic aspects of the development. Possible tasks include investigation of long-term sound path stability, telemetry, and the application of acoustic phase on reciprocal transmission to special situations like variation of the Florida current. Cooperation with appropriate Navy interests, perhaps in joint use of island-based acoustic facilities, is also suggested.

- o NOAA address the question of designing simple moorings of sufficient stability and durability for use in tomographic arrays. NOAA has addressed similar needs in the past.

2. It is recommended that a doppler current shear profiler be developed for potential integration into an experimental shipboard package aboard one of the NOAA research ships. It is further recommended that the instrument be evaluated extensively in conjunction with NOAA's Heat Flux Experiment and other appropriate field experiments such as EPOCS and then considered for installation aboard cooperative ships as an integral part of the SEAS system.

3. The potential for simultaneous depth profiling of temperature, current, and horizontal heat flow are so rewarding that a program to further develop the echometer should be undertaken. It is recommended that:

- o NOAA undertake continued experimentation with the atmospheric version of the echometer aimed at translation of the information gained to application in the ocean, and that a cooperative ocean feasibility experiment be undertaken. If the latter is successful, full development and construction of an ocean echometer could follow immediately.

- o The feasibility experiment proposed above be carried out cooperatively with an experienced ocean remote sensing group with available equipment, such as Scripps Institution of Oceanography.

4. The inverted echo sounder has already demonstrated an ability to monitor changes in heat content of the water column. The concept could be expanded by using a small array of IES's to measure "sing-around" sound velocity, vorticity, and heat flux. Other possibilities include measurements of the IES pulse shape after scattering by the sea surface to derive information on sea state. It is recommended that:

- o NOAA, working with the University of Rhode Island and other groups, seek to expand the capabilities and use of the IES for climate research applications.

- o NOAA consider subsequent development of a second generation device for use in long-term monitoring applications.

5. The potential of WOTAN is exceedingly promising as an air-sea interaction research instrument, and also as an ocean climate monitoring device (for example, if deployed over large scales on drifting buoys). Accordingly, the following steps are recommended:

- o NOAA investigate development of a WOTAN suitable for deployment as part of an advanced drifting buoy sensor suit.

- o NOAA plan for development of WOTAN in both bottom-mounted and drifting buoy configurations, in conjunction with planned ocean research programs (e.g., EPOCS, Ocean Heat Flux, STREX) to supplement surface observations of wind and rainfall.

- o NOAA encourage evolution of this technique through a program of basic research into the mechanisms of ambient noise generation and their relationship to parameters such as sea state, wind stress, and precipitation.

6. Bottom-based acoustic sensors have already demonstrated the ability to monitor parameters such as heat content of the water column, wind stress, and rainfall rate. Other parameters potentially measurable by such sensors include current velocity profiles (as above), sea surface directional spectra, internal wave directional spectra, and profiles of acoustic back-scattering cross section. We recommend that:

- o NOAA undertake a multi-year research and development program cooperatively with universities and other agencies to explore and exploit the use of bottom-based acoustic sensors.

7. The Working Group noted that acoustic telemetry of data from a subsurface platform was found to be a common requirement in a wide variety of the development programs under consideration. It is, therefore, recommended that:

- o The requirements for acoustic telemetry for OARS be established, and the adequacy of current technology for meeting them be assessed.

- o NOAA undertake support of a modest program to develop the necessary capability.

8. Institutional and organizational matters addressed by the Working Group brought forth the following recommendations and observations beyond those contained implicitly in the items above:

- o The mix of program interests, development organizations, and acoustic experts achieved by this workshop should be continued and reinforced by periodic meetings such as this one.

- o A program in OARS for climate applications could be implemented through existing organizational mechanisms. The program is best focused through its technological strength and critical program needs rather than through organizational issues.

- o Coordination of individual NOAA efforts into an effective whole and the careful relating of NOAA programs to those of other agencies should be sought in implementing these OARS recommendations.

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B.0 FISHERIES WORKING GROUP REPORT

CONTENTS

B.1 Introduction

B.1.1 Ocean acoustic remote sensing (OARS) is essentially a 20th-century phenomenon which began with sounding to the bottom and detecting icebergs. For more than half the history of oceanic acoustics, fish-finding has been a major use of this technology. The use of OARS for fishery management purposes has been growing for only 20 years. The fundamental "transparency" of turbid and deep ocean regions to underwater sound guarantees that OARS techniques will grow as the method of choice for fishery management problems on several important stocks of fish. The prompt development of OARS techniques will require a long-lasting commitment. The growing role of NOAA in fishery management requires that NOAA take the lead in the U.S. for developing OARS technology for the purpose of maintaining the optimum sustainable yield of U.S. renewable fishery resources.

OARS techniques are very elaborate and specialized owing to the vast expenditure of talent and money in anti-submarine warfare (ASW) and seismic exploration of the seabed for oil deposits. The understanding of the OARS environment, research on signal processing, and acoustic system integration will materially aid NOAA in the development of OARS techniques.

B.1.2 Scope of OARS Fisheries Report

Several nations are involved in the development of OARS techniques for fishery problems and ten are listed in Table 1.1. The table lists 14 OARS procedures and the countries using these procedures on the high seas. While the U.S. would appear to lead technologically, the United Nations Food and Agriculture Organization leads in the application of OARS technology to fishery evaluation. NOAA's largest investment in fishery acoustics is a computerized dual beam echo integration system which is nearly operational in the Northern and Northeast Pacific.

NOAA has the lead research responsibility in support of more than 70 fishery management plans to be implemented by eight regional management councils extending from the North Pacific and Western Pacific to the centuries-old fishing grounds off the New England coast. By no means are all of these fisheries amenable to management or study by OARS techniques. Indeed, only 15 species or species groups are identified at this time as important candidate-species for quantitative OARS development work (Table 1.2). Of these, four are already being investigated with NOAA's developmental OARS system (digital echo integration). Other species may never need the intense space-time continuity offered by OARS techniques. Thus, we must remain aware that acoustic techniques will become an invaluable management tool but not a panacea for all fisheries problems.

Table 1.1. illustrates the diversity of acoustic equipment for fishery studies. The equipment should be developed in an orderly fashion based on the need and value of the fish resources and their inherent variability and danger of overfishing. OARS counting of single large fish is already fully developed. Quantitative digital echo integration is now nearly operational for layers of fish containing 1 to 10 fish per cubic meter. The chief problems which remain are identification of species and estimation of the biomass of pelagic schooling fishes.

B.1.3 Scope of This Report

This report represents the written deliberation of 17 of the leading U.S. scientists and engineers in the fields of fishery assessment, management of fishery research, physics of underwater and atmospheric sound, anti-submarine warfare (ASW), information science, and signal processing from academic, federal government, and industry laboratories. The group was assembled by the NOAA Assistant Adminstrators for Research and Development, Fisheries, and Oceanic and Atmospheric Services. The meetings were convened for four days after 3 months of preparation. This document is one, Fisheries, of four (Climate and Weather, Ocean Pollution, Ocean Services) and extends from deliberations on research management policy in NOAA and Fisheries to applied and fundamental research and development in OARS.

B.2 NOAA OARS Policy

B.2.1 The basis for meaningful advancement of OARS will require some technological risk for the term of about one decade. A stated NOAA policy on OARS would release inventiveness and technical creativity from NOAA research groups and permit establishment of effective ties to professors and graduate students of the top professional schools of this nation.

TABLE 1.1 - Summary Table of International Work in Fishery Acoustics by Oceanic Acoustic Remote Sensing (OARS) Techniques

	Echo Counting	Echo Integration	Echo Strength	Target Strength	Sonar Mapping	Trawl/Sonar Mapping/Aerial Survey	Low Frequency Towed Array (GLORIA)	Broad-band Source/Towed Array	Low Frequency Fixed Array	Sonic Tags/Tracking	Doppler Shift	Doppler Spread	High Frequency Profiles	Telemetering Buoy Uplooking Sounder	Sector Scanner
U.S.	X	X	X	X	X	X		X	X	X	X	X	X	X	
U.K.		X		X			X		X	X					X
Canada	X	X								X					
UN/FAO		X				X									
South Africa		X			X	X									
U.S.S.R.	X	X	X												
Norway	X	X													
Spain		X													
Japan	X														
Poland		X													

TABLE 1.2 - Fisheries Conservation and Management Act National Marine Fisheries Service Ocean Acoustic Remote Sensing Effort

CENTER	COUNCIL	CANDIDATE SPECIES OR GROUP	OCEANIC REGION
Northwest and Alaska Fisheries --Seattle	North Pacific	Herring Groundfish Groundfish Walleye Pollock	 East Bering Sea Gulf of Alaska
	Pacific Council	Pacific hake Rockfish	California Current California Current
Southwest Fisheries --La Jolla	Pacific Council	Anchovy Jack mackerel Pacific mackerel Pacific sardine	California Current California Current California Current California Current
	Western Pacific Council		
Southeast Fisheries --Miami	Caribbean Council		
	Gulf of Mexico Council		
	South Atlantic Council	Calico Scallop	
	No Council	Menhaden Coastal Pelagics	
Northeast Fisheries	Mid-Atlantic Council	Atlantic mackerel	
	New England Council	Atlantic Sea herring (juveniles)	

B.2.2 Significant progress in fisheries acoustics can probably be obtained with existing NOAA and NMFS personnel and technological and academic expenditures of less than 1% of the current NMFS budget on an annual basis. Benefits would accrue from increased effectiveness of ship time used for fishery management information. Another source of benefits of OARS application is that the inevitable collapse of some kinds of fish stocks could be discovered earlier and the consequences made less severe and less frequent. Such consequences would alleviate the idling of fisheries capital investment, unemployment, and importation of alternative sources of fish and protein. Another benefit would be the rapid fishing response to rapidly growing fish stocks, with consumer benefits in lower protein prices.

B.2.3 A NOAA policy statement on OARS could delimit the technological effort by resisting special interest demands. Also a policy could contain explicit requirements that Ocean Pollution, Ocean Services, Climate and Weather, and Fisheries avoid duplication of fundamental research necessary to implement OARS systems. A NOAA policy could designate liaison with Navy ASW and with NOAA/NESS, NOAA/MUST (Manned Undersea Science and Technology Office) to forestall duplication and waste.

B.2.4 Lastly, a NOAA policy could be cast to ensure a balanced program of environmental monitoring with Environmental Protection Agency (EPA) and Coast Guard and fisheries management.

B.2.5 Summary

A NOAA OARS development policy commitment to a balanced program of development of OARS for environmental assessment and fisheries management would release the creative talents of NOAA scientists and engineers and their colleagues in the universities and industry. An OARS policy would also delimit responsibilities and specify periodic technical oversight to secure advances in OARS with a minimum of technological risk.

1. The NOAA OARS/1980 Fisheries Working Group <u>concludes</u> that

   a. the national OARS policy should emphasize long-range budget commitments required to secure NOAA/OARS benefits;

   b. the OARS policy must be a balanced program of environmental assessment and fisheries management; and,

   c. the OARS policy must be coordinated with electromagnetic remote sensing in some phases.

2. The NOAA OARS/1980 Fisheries Working Group <u>recommends</u> that a NOAA national policy statement on OARS be issued in support of research on acoustic remote sensing in the ocean.

B.3 NOAA OARS Policy-Level Panel

B.3.1 Scope of Panel Action

1. The NOAA policy level panel would focus on those portions of OARS development that dealt with fundamental properties, e.g., wave propagation.

2. Another responsibility of the NOAA OARS panel would be the evaluation of technological progress and effectiveness of OARS within Fisheries, Ocean Pollution, Climate and Weather, and Ocean Services.

3. The OARS panel would foster liaison among NOAA agencies, with defense, international OARS, academic, and industrial laboratories.

B.3.2 The internal NOAA OARS panel would also assemble professional and technical expert panels at nodes and milestones in the NOAA OARS program. Lastly, the NOAA OARS panel could advise the NOAA Administration on the desirability of having a NOAA OARS Program Manager during critical phases in the long-term development of OARS technology.

B.3.3 The NOAA OARS/1980 Fisheries Working Group concludes that:

1. current research, development, and applications work occurs within several Main Line Components (MLC's) in NOAA;

2. the OARS/1980 Workshop demonstrated a community of interest in NOAA/OARS and includes our federal, academic, and industry colleagues; and

3. augmentation of research effort and effective planning is a likely outcome of regular intercommunication among OARS and other specialists within NOAA.

B.3.4. The OARS/1980 Fisheries Working Group recommends that a NOAA/OARS panel be formed to foster intercommunication among the programs in NOAA.

B.4 NMFS OARS Fisheries (F) Panel

B.4.1 Scope of Panel Action

One duty of the NMFS OARS/F Panel is to forward recommendations regarding studies of fundamental acoustic properties to the NOAA OARS panel for joint consideration with OARS/P, OARS/CW, and OARS/OS requirements in fundamental OARS advancement. OARS/F also selects representatives to the NOAA OARS Panel.

1. The primary duty of OARS/F is to foster the development of OARS systems to accomplish NMFS missions.

2. OARS/F will also evaluate needs and progress in regional OARS system developments and establish developmental priorities.

3. The OARS/F panel will also be responsible for maintaining liaison with international OARS efforts and offer and elicit cooperative development, especially where fish stocks common to U.S. and bordering countries require data of uniform derivation and quality for international joint management.

4. It can be anticipated that OARS/F and OARS/P may interact broadly in areas where fisheries cause pollution and pollution impacts fisheries.

B.4.2 OARS/F will assemble expert panels to review regional applications of OARS and set standards for verification of effectiveness of OARS/F regional and species OARS techniques in the context of fishery management.

B.4.3 The OARS/1980 Fisheries Working Group concludes that:

1. OARS programs exist in NMFS which have demonstrated good application potentials, but which require unified administrative and funding support.

2. Geographically varying differences in fish populations, environments, and needs for fishery management services preclude universal application of a specific OARS technique.

3. A focused and balanced national effort is needed within NMFS to insure that adequate attention is given to OARS potentials and requirements in NMFS research planning.

B.4.4 The OARS/1980 Fisheries Working Group therefore recommends that meetings of appropriate NMFS personnel be held to develop a plan for the application of OARS technology for NMFS missions, and that regular (at least annual) meetings be held thereafter to evaluate progress and to provide planning advice to NMFS Center Directors.

B.5 Applications of Accepted OARS/F Techniques

There are instances of OARS/F techniques where no further acoustical or electronic development seems necessary. There are also OARS/F techniques where needs for further development of a sub-system are not clear enough without consideration in the context of the fishery management system of which OARS/F is only a part. We select three examples.

B.5.1 Quantitative digital echo integration and fish counting can now be accomplished in a survey mode with an existing OARS/F development. For example, applications have been achieved during a survey of the stock of herring residing in open water off the Northern Washington-Southern Vancouver Island area. The total biomass of herring estimated during this survey, which was distributed within three major aggregations, amounted to about 205,000 metric tons (MT). The Canadian estimate of the expected return to the spawning grounds of the offshore component of the stock, based on a large series of spawning ground surveys, was about 180,000 MT, plus about 100,000 MT of juveniles that were not necessarily in the surveyed area. The excess biomass estimated by echo integration could be easily accounted for by mortality prior to their return to their spawning areas from 8 to 10 months after the survey. Offshore sampling indicated that few 1-year-old fish were in the survey area at the time of data collection. While this result supports the working capability of echo integration, a time series should be established to test the "robustness" of the estimates.

B.5.2 Automated sonar mapping is another method for monitoring stocks of schooled fish. In particular, the California Department of Fish and Game, with federal support, has monitored the northern anchovy for several years. They detected (Mais, 1974; Mais, in press) a threefold decline in the anchovy central stock from their surveys. Such surveys using sonar mapping, research pelagic trawls, and monitoring of the commercial catch have much to offer in the development of population predictive capability.

B.5.3 Even rudimentary acoustic techniques offer added information for the design and refinement of direct sampling. Sampling which requires expensive ship time and technical analysis can, in theory, be made much more efficient by formal allocation of sampling effort using OARS/F techniques.

B.5.4 The Fisheries Working Group of OARS/1980 recognizes the existence in each region of a limited number of key fishery management problems which are now amenable to generalized applications of OARS techniques. For example:

1. Quantitative Digital Echo Integration is in the advanced developmental/operational phase for single-species fisheries in the Northeast Pacific and Bering Sea;

2. Automated sonar mapping is available for schooling pelagic fishes in relatively deep water (greater than 50 meters);

3. Standard statistical techniques of double sampling allow OARS techniques to be used to allocate sampling of depth strata in ecosystems, fish aggregations and other localized phenomena in the oceans.

B.5.5 The Fisheries Working Group of OARS/1980 recommends that continued application of accepted OARS techniques such as echo integration and sonar mapping be emphasized: (1) to obtain the long-term acoustic monitoring/prediction information essential to effect fish stock management, and (2) to meet the need to better communicate the present and potential utility of acoustic techniques.

B.6 NMFS Specific Technical Developments of OARS/F

Virtually all the OARS/F techniques developed so far use quantitative amplitude (target strength) domain information to assess size and abundance of fish, layers, and schools. The motion of a fish school, the motion of the fish within the school, and the motion of fish body parts all yield information potentially useful for identifying the fish and assessing their behavior (i.e., feeding, migrating, escaping). The presence or absence of an air bladder is an important classification criterion and if the air bladder is present the resonance of the bladder and the distribution of resonance frequency in a school allows a useful estimate of fish size, an important population parameter.

B.6.1 Classification and sizing of acoustic targets may be accomplished by measuring acoustic resonance, doppler structure and in situ target strength. Experimental work with these methods has brought the techniques up to an engineering level which supports the implementation of prototype systems for field evaluation. Specific systems which should be considered for implementation are:

1. Wide band sparker/towed array systems tailored to anchovy year-class classification and school sizing.
2. High resolution doppler/range processing for high frequency (30-100 kHz) side-looking mapping sonars.
3. Calibrated dual beam sonars for quantitative acoustic target strength measurements.

B.6.2 Implementation of these systems should be followed by an extended program of data collection coordinated with biological sampling for species identification of observed acoustic targets.

1. Surveying coastal pelagic fish schools presents a problem for which acoustic techniques have a potential applicability. The shallow water environment introduces the complication of masking by bottom reverberation so that the deep water mapping system cannot be used effectively. Investigation of the use of MTI (moving target indicator) techniques which are used in the radar community for ground clutter rejection, or the use of highly directional sonar beams using either large

aperture or parametric transducers should point the way to the implementation of a shallow water fish school mapping system.

2. Larval Fish/Zooplankton Sampling

There are two current research approaches in this area: (1) Towed backscatter arrays (100-250 kHz) look vertically down and can sample the upper water column (<200 m) continuously. The net system position can be monitored continuously and located in relation to acoustic features (WHOI, AOML), (2) On the other hand higher frequency (> 1 MHz) systems can be used alone or in conjunction with pumps or nets to sample a smaller (<10 m^3) volume of water (UCSD, TRACOR). With such a system continous profiling of a water column is not possible nor can net location be continuously monitored. Furthermore, far greater resolution is attainable and the probability of sizing and discriminating targets is higher. Both types could and should be used to extend the sampling volume surveyed by traditional gear. These devices are in the developmental stage but considerable research has been done and we estimate that with active cooperation from current research groups they could be applied within three years.

B.6.3 "Holistic" description is useful on several scales of space and time of fishery ecosystems.

Fishery ecosystem studies require simultaneous measurements of environmental parameters as well as the different trophic levels on a multi-species basis. The monitoring of these parameters requires different time and area schedules. The basic statistical design approach to such problems is a nested sampling design. Extensive development of nested approaches using direct sampling, OARS, and electromagnetic remote sensing techniques can be done utilizing and adapting presently available technology. This development should provide the discipline for evaluation of the potential techniques and methods. While sampling design and evaluations is an ongoing project as newer technical tools become available, initial input to improved effectiveness of sampling should be possible within one year.

B.6.4 The Fisheries Working Group of OARS/1980 recognizes the existence in each region of a limited number of key fishery problems which are now amenable to specific technical development of OARS/F techniques. The economics of the operational use of these techniques should be evaluated as they are developed.

1. Identification, classification, or sizing of fish within school targets can be accomplished using acoustic resonance, doppler spread, and in situ target strength;

2. Coastal pelagic schooling fish should be studied using shallow water sonar mapping;

3. Abundance of larval fish and zooplankton could be determined using acoustic high-frequency depth profiling;

4. Fishery ecosystems could be observed on several scales of space and time using nested sampling strategies involving direct sampling, OARS, and electromagnetic remote sensing techniques; and therefore,

B.6.5 The Fisheries Working Group of OARS/1980 recommends that project plans for specific technical development of OARS techniques be prepared and included in the NMFS OARS plan for evaluation by Center Directors and preparation of budget initiatives for 1983.

B.7 NOAA/Navy Technological Cooperation

B.7.1 The Fisheries Working Group of OARS/1980 concludes that it is NOAA's responsibility to maintain a continuing program in research and development of OARS techniques and that much existing acoustic technology has not yet been attempted or evaluated in the context of fishery research. The applicable technology developed by the Navy is, as a matter of policy, unclassified and fully available as an information base for fisheries research. It is unrealistic, however, to assume that the Navy's implementation of the acoustic technology will satisfy NOAA needs in acoustic remote sensing.

B.7.2 Therefore, the NOAA OARS/1980 Workshop recommends that NOAA continually monitor Navy acoustic technology but emphasizes that NOAA/OARS must assume full responsibility for research and development of acoustic technology for fisheries and environmental monitoring problems.

B.8 Summary

To secure the benefits of lengthy, stable commitments to technological development NOAA should consider a NOAA policy on OARS to be implemented and monitored by a NOAA OARS panel and such outside review as is required. The panel should have representation from OARS/Fisheries, OARS/Pollution, OARS/Ocean Services and OARS/Climate and Weather. The panel should manage major NOAA-wide projects (acoustic tomography) and other fundamental advances in OARS/Science. The panel should delegate to OARS/F, etc. those matters of development, implementation, and regional allocation of effort. Both NOAA and NMFS level panels should foster inter- and intra-agency cooperation. Both should rely on academic and miltary OARS basic science and contract funded development and at times implementation. There are certain well-developed acoustic techniques such as echo integration, sonar mapping, and acoustically directed sample allocation whose further development depends on judicious trial applications within fishery management or research systems. There are also a few frequency-domain and high-frequency developments worth advancing to operational level. For these OARS/F techniques and fundamental NOAA OARS advances, NOAA should accept the positon of lead U.S. agency.

B.9 Conclusions and Recommendations

B.9.1 The NOAA OARS/F Working Group concludes that:

1. A national OARS policy could use strong independent oversight and long-range budget commitments required to secure NOAA/OARS benefits;
2. An OARS policy must be a balanced program of environmental assessment and fisheries management; and
3. The OARS policy must be coordinated with electromagnetic remote sensing in some phases.

Therefore, it is recommended that a NOAA national policy statement on OARS be issued in support of research on acoustic remote sensing in the ocean.

B.9.2 The NOAA OARS/F Working Group concludes that:

1. Current research, development, and applications work occurs within several MLC's in NOAA;
2. It demonstrated a community of interest in NOAA/OARS and includes our federal, academic, and industrial colleagues;
3. Augmentation of research effort and effective planning is a likely outcome of regular intercommunication among OARS and other specialists within NOAA.

Therefore, it is recommended that a NOAA/OARS panel be formed to foster intercommunication among the programs in NOAA.

B.9.3 The OARS/F Fisheries Working Group concludes that:

1. Some OARS programs exist in NMFS which have demonstrated application potential but require unified administrative and funding support;
2. Geographic differences in fish populations, environment, and needs for fishery management services preclude universal acceptability of specific OARS techniques; and,
3. A focused and balanced national effort is needed within NMFS to ensure that adequate attention is given to OARS potential and requirements in NMFS research planning.

Therefore, it is recommended that meeting of appropriate NMFS personnel be held to develop a plan for implementation of OARS for NMFS missions, and that regular (at least annual) meetings be held thereafter to evaluate progress and to provide planning advice to NMFS Center Directors.

B.9.4 The OARS/F Working Group recognizes the existence in each region of a limited number of key fishery management problems which are now amenable to generalized applications of OARS techniques. For example there are:

1. Quantitative digital echo integration which is in the advanced developmental/operational phase for single-species fisheries in the Northeast Pacific and Bering Sea;

2. Automated sonar mapping is available for schooling pelagic fishes in relatively deep water (greater than 50 meters); and,

3. Standard statistical techniques of double sampling allow OARS techniques to be used to allocate sampling of depth strata in ecosystems, fish aggregations and other localized phenomena in the oceans.

   It is recommended that continued application of accepted OARS techniques such as echo integration and sonar mapping be emphasized: (1) to obtain the long term acoustic monitoring/prediction information essential to effect fish stock management, and (2) to meet the need to better communicate the present and potential utility of acoustic techniques.

B.9.5 The OARS/F Working Group recognizes the existence in each region of a limited number of key fishery problems which are now amenable to specific technical development of OARS techniques. The economics of the operational use of these techniques should be evaluated as they are developed. For example:

1. Identification, classification, or sizing of fish within school targets can be accomplished using acoustic resonance, doppler spread, and in situ target strength;

2. Coastal pelagic schooling fish should be studied using shallow water sonar mapping;

3. Abundance of larval fish and zooplankton could be determined using acoustic high-frequency depth profiling;

4. Fishery ecosystems could be observed on several scales of space and time using nested sampling strategies involving direct sampling, OARS, and electromagnetic remote sensing techniques; and therefore,

   It is recommended that project plans for specific technical development of OARS techniques be prepared and included in the NMFS OARS plan for evaluation by Center Directors and preparation of budget initiatives for 1983.

B.9.6 NOAA/Navy Technology

1. The OARS/F Working Group concludes that it is NOAA's resonsibility to maintain a continuing program in research and development of OARS techniques and that much existing acoustic technology has not yet been attempted or evaluated in the context of fishery research. The applicable technology developed by the Navy is, as a matter of policy, unclassified and fully available as an information base for fisheries research. It is unrealistic, however, to assume that the Navy's implementation of the acoustic technology will satisfy NOAA needs in acoustic remote sensing.

   Therefore, it is recommended that NOAA continually monitor Navy acoustic technology but emphasizes that NOAA/OARS must assume full responsibility for research and development of acoustic technology for fisheries and environmental monitoring problems.

B.10 Summary of Recommendations

NOAA OARS/F Working Group recommends that:

B.10.1 A NOAA national policy statement on OARS be issued in support of research on acoustic remote sensing in the ocean.

B.10.2 A NOAA/OARS panel be formed to foster intercommunication among the programs in NOAA.

B.10.3 A meeting of appropriate NMFS personnel be held to develop a plan for implementation of OARS for NMFS and that regular (at least annual) meetings be held thereafter to evaluate progress and to provide planning advice to NMFS Center Directors.

B.10.4 Continued application of accepted OARS techniques such as echo integration and sonar mapping be emphasized (1) to obtain the long-term acoustic monitoring/prediction information essential to effect fish stock management, and (2) to meet the need to better communicate the present and potential utility of acoustic techniques.

B.10.5 Project plans for specific technical development of OARS techniques be prepared and included in the NMFS OARS plan for evaluation of Center Directors and preparation of budget initiatives for 1983.

B.10.6 NOAA continually monitor Navy acoustic technology but emphasizes that NOAA/OARS must assume full responsibility for research and development of acoustic technology for fisheries and environmental monitoring problems.

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C.0 OCEAN POLLUTION WORKING GROUP REPORT

CONTENTS

C.1 Introduction

Discharges into the ocean of waste material are made with the object of removing such materials from specific areas or confining them to specific dump sites. Acoustic monitoring of such activities has revealed, however, that in many cases the predicted fate of such discharged materials has been incorrect. Understanding the processes related to the functioning of the natural ocean system is thus a necessary element in the analysis and prediction of the fate and effects of these discharges. Acoustic techniques can play a vital role in this effort, particularly with respect to identifying and tracking discharged material, analyzing biological activity and determining water mass movement.

The Pollution Working Group has prepared a framework that illustrates categories of pollution disturbances that can affect the ocean system, has indicated the applicability of acoustic techniques to each of these and has identified recommendations aimed at improving NOAA's capability in these areas. (See Table 1, p. C-2.)

C.2 NOAA Responsibilities in Ocean Pollution

The basic NOAA responsibilities in monitoring ocean pollution are expressed in the following existing legislation: (a) Marine Protection Research and Sanctuaries Act of 1973, (b) Marine Mammals Act, (c) Fisheries Conservation Act, (d) Clean Water Act, (e) National Ocean Pollution Research and Development and Monitoring Planning Act of 1978, and (f) Coastal Zone legislation.

In the programs supporting this legislation, measurands include currents, particulate and chemical distributions, and temperature and density fields. Measurements of currents are required for dilution rate estimations and for flux measurements. Acoustic surveys provide synoptic measurements for concentration fields and currents. Ocean pollution surveys also require direct sampling as well as optical and acoustic remote sensing techniques. However, continued research and development are required for determining the best way of making these measurements with respect to volume of ocean covered in the shortest time.

Table 1:

POLLUTION MONITORING SYSTEM

	R&D*	SD&T**	P&D***
I. SYSTEM FUNCTIONING			
A. Water Mass Identification, Movement and Estuarian Outflow	X	X	
B. Adjective Field Determination			
1. Fluid Exchange Process	X		
C. Biological Dynamics			
1. Phytoplankton	X	X	
2. Zooplankton	X	X	
3. Nekton	X	X	
D. Particle Resuspension and Transport			
1. Seasonal Effects	X		
E. Flocculation	X		
II. SYSTEM DISTURBANCES			
A. Dumping			
1. Categories of Materials			
a. Sewage sludge		X	
b. Industrial waste		X	
c. Dredged material	X	X	
d. Nuclear waste	X		
e. Fly ash	X		
2. Site Selection			
a. Topography			X
b. Water mass movement	X		
c. Biological activity		X	
3. Monitoring			
a. Compliance		X	
b. Effects	X	X	X
4. Impacts (Research Problems)	X		
B. Discharges (Regulated)			
1. Categories of Materials			
a. Sewage sludge effluent		X	
b. Industrial waste		X	

* Research and Development
** System Development & Transition
*** Procurement & Deployment

	R&D	SD&T	P&D
c. Urban runoff		X	
d. Thermal waste	X	X	
e. Drilling muds		X	
f. Ocean mining		X	
2. Site Selection			
a. Bottom topography stability			X
b. Water mass movement	X		
c. Impacts		X	
3. Impacts	X		
4. Monitoring			
a. Compliance		X	
b. Effects		X	X
C. Discharge (Unregulated)			
1. Materials			
a. Petroleum			
1) Pipelines	X	X	
2) Ship accidents	X	X	
3) Blowouts	X	X	
a) Exploration			
b) Operational wells			
4) Deep water loading and unloading operations	X	X	
5) Natural seeps	X	X	
b. Hazardous substances			
1) PCB	X		
2) Ammonia	X		
3) Ketones	X		
4) Chlorine	X		
5) Pesticides (synthetic organics)	X		
6) Radioactive materials	X		
7) All previously identified substances in Paragraph II. B.		X	
2. Damage Assessment/Impact	X		
a. Environmental			
b. Socio-economic			
3. Monitoring		X	
D. Bottom Disturbances			
1. Mining operations			
a. Resuspension	X		

	R&D	SD&T	P&D
2. Dredging operations			
a. Resuspension	X		
3. Hydroscouring and trenching (pipeline)			
4. Facilities siting			
a. Platforms, etc.			
5. Ship traffic			
6. Fishing operations			
E. Other			
1. Artificial islands			
2. Floating reactors			
3. Noise Pollution			
F. Noise			

C.3 Present Uses of OARS Techniques

There are very few NOAA pollution monitoring programs currently using OARS techniques. These are: the AOML acoustics program under John Proni, the National Marine Fisheries research program under Mike Macauley, and the Woods Hole Oceanographic Institution program under Marshall Orr. This last program has been partially sponsored by NOAA.

Prime measurands in these three programs include the backscattered acoustic intensity field, concentration levels in space and time of total suspended material, and various chemical compounds and vertical profiles of various oceanographic parameters such as temperature, salinity, and current. The products required are a series of maps of the acoustic backscattered intensity field and the chemical concentration field for the purpose of obtaining the dilution rate of the material in question.

The following programs require the previous measurands and use OARS techniques to a minimal degree:

Outer Continental Shelf Development
Hazardous Material Spill Response
Resource Mining
Energy Utilization (e.g., Ocean Thermal Energy Conversion)
Waste Disposal (Marine Ecosystems Analysis Program)

C.4 Promising Uses of OARS Techniques

C.4.1 The following OARS techniques may not exist presently but could be expected to support measurement programs:

1. Fixed projector and fixed receivers to measure flux in closed channels, e.g., Hudson River.
2. Side scan or equivalent systems to provide 3-dimensional sensing.
3. Water current measurements utilizing the following techniques: doppler backscatter, correlation techniques, horizontal acoustic propagation paths, bottom-mounted transducers, reciprocal transmission.
4. Measurement of biota layers and their behavior.
5. Acoustic navigation within a survey area.
6. Backscatter for littoral transport measurements.

C.4.2 The following list presents several types of investigations wherein OARS techniques may augment existing approaches:

1. Moored projector and receivers to investigate and develop currents time series data in conjunction with existing current meters and sampling procedures (flux measurements).
2. Aids for direct sampling efforts.
3. Current measurements, via expendable transducer.
4. Backscatter and transmissometer studies.

5. Underwater navigation net in conjunction with other navigation techniques within survey area.
6. Volumetric current measurements to provide calibration checks for HF radar.
7. Measurement of surface oil slick thickness to complement EM mapping of an oil spill and also mapping of subsurface oil plumes.

C.5 Goals for OARS Implementation

C.5.1 General Goal. Set up an acoustic group which is responsive to NOAA and other agency needs with the following program elements:

1. Research and Development: (a) Determine general quantitative limits for the acoustic estimate of the concentration field distribution. (b) Carry out a research program to determine the basic physical and particulate properties of a given oceanic region which will then govern the evolution of an acoustic current meter system.

2. System Development and Application: (a) Develop a shallow water acoustical current meter. (b) Develop a 3-dimensional scanning system for a more complete mapping of a pollution event. (c) Develop an upward looking bottom-mounted, internally-recording acoustical system for both concentration field and current field measurements.

3. Procurement and Deployment: (a) Platform accommodating suite of personnel and instrumentation required for team approach.

C.5.2 Planning Elements

1. Facilities. Assuming that the general goal of the part 4.5.1 above and/or Recommendation 4.7, item 1 below is implemented, it follows that an acoustics engineering laboratory is required together with offices (perhaps 10) and a staging/storage area.

2. Personnel. It is estimated that 15 to 20 persons are required to adequately staff the recommended acoustics group for 4.5.1.

3. Time. If a currently extant acoustics group at Miami (AOML) is expanded to the pilot general acoustics group discussed in 4.5.1, a two-year time frame until operation is reasonable. If a totally new group is formed, a four-year time frame is reasonable (for start-up period).

4. Developmental and Operational Financial Cost. An annual budget of $750,000 to $1,000,000 in terms of FY 80 dollars appears reasonable to achieve these goals.

C.6 Policy and Problem Areas

C.6.1 Organization of OARS Effort. NOAA should establish an OARS research and development group under a principal acoustic scientist. This group should be funded from the Office of Marine Pollution Assessment (OMPA) with hardware support from the Office of Ocean Engineering. This formulation of a specific NOAA effort to use OARS techniques should not preclude individual agencies or laboratories from initiation and development of OARS programs to support in-house activities using state-of-the-art technology. In a short-term crisis situation, the R & D group would be directed by OMPA to respond cooperatively with other NOAA investigative effort.

C.6.2 Problem Areas. Scientific, technical, and administrative problem areas include:

1. Continuity in funding and qualified staffing levels within the existing NOAA personnel framework.

2. Establishment of confidence limits on the concentration levels within the acoustic field.

3. Rapidity with which an OARS survey of an event or program can be accomplished considering existing support levels.

4. Procurement of viable support for record cataloging, data management and reduction, and real time computer services.

C.7 Conclusions and Recommendations

It is concluded that the use of ocean acoustic remote sensing in pollution research and monitoring is increasing. The usefulness and importance of OARS in studying oil spills, dredge material discharge, sewage sludge discharge, and industrial waste discharge is now firmly established. NOAA should support acoustics research in this area because the requirements are extensive and the techniques must be improved and quantified with respect to volume coverage, pollutant type, and diffusion and dispersal properties. The demands placed on the acoustics group at AOML far exceed its resources in personnel and facilities.

In order to overcome deficiencies it is recommended that:

1. A panel be created within NOAA or an individual identified to coordinate acoustical activity. This individual or panel should report to high-level management, possibly to an Associate Administrator.

2. A second OARS workshop be convened in two years.

3. NOAA support research efforts to establish confidence limits in order to quantify acoustical estimates of a particulate field.

4. NOAA support research efforts to create a shallow water (< 100 m) oceanic current measurement system utilizing any or all of the following: (i) doppler backscatter, (ii) correlation and/or (iii) reciprocal path techniques.

Working Group
Pollution

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D.0 OCEAN SERVICES WORKING GROUP REPORT

CONTENTS

D.1 Introduction

The National Ocean Survey (NOS) and the National Data Buoy Office (NDBO) manage ocean platforms and instruments to collect oceanographic data needed: (a) for the production of oceanographic information products, (b) as input for special civil projects in the ocean, (c) to support their scientific researches, and (d) as indicators of pollution, storm signals, etc. Ocean Services, in the context of this working group effort, is defined as the collection of at-sea data in support of such needs as those stated above.

The group recognized that there are ocean service needs for which it is not obvious that the application of OARS techniques would be beneficial, and there are ocean service needs that are good candidates for OARS techniques. Indeed, active sonar, an OARS technique, is used for doing practically all of the depth sounding for nautical charts. Currently, all operational systems in NOS are single beam systems but analysis and experiments are being conducted with dual frequency, dual beam systems and single frequency multibeam systems which will enhance the efficiency of nautical chart production.

Other service missions which are necessary or may become necessary in the near future and which appear to represent sensible application of OARS techniques are:

1. Fishing Obstruction Charts
2. Clear Channel Determination
3. Bathymetric Maps
4. Current Surveys - Time Series
5. Real Time Current Information - Harbor/Channels
6. Sea Floor Geodesy

7. Periodic, Synoptic Temperature vs. Depth
8. Site Specific Surveys on the Sea Floor

Missions one through five above were deemed by the Working Group to have the highest priority based on immediacy and needs of the mission. The remaining three represent potential missions for the future with requirements as yet not well defined.

In keeping with the broad objectives of the workshop, the Working Group established the following objectives for its deliberations:

1. Select OARS techniques, applicable to oceanographic service missions, as candidates for inclusion in the OARS program.
2. Provide rationale for selection of above candidates.
3. For each of the above candidate techniques, recommend OARS program goals (for the next 5 years).
4. Estimate resource requirements to achieve the above OARS program goals.
5. Address NOAA policy issues that could influence the effectiveness of a NOAA/OARS program.

Sections D.2 and D.3 deal with items one through four above and Section D.4 deals with NOAA policy issues - item five. Section D.5 is a statement of conclusions and recommendations.

D.2 High Priority Missions

D.2.1 Fishing Obstruction Charts

1. Brief Description of Need

As a result of recent legislation, NOS is under mandate to produce fishing obstruction charts. Both natural and man-made obstructions must be charted by a date to be specified. After charts are produced, the government will be liable for claims by the commercial fishing industry for damage to nets and other equipment caused by obstructions not charted. The government will also be liable for claims of consequential damages (lost revenues) as a result of damage to equipment. New surveys and verification of damages due to uncharted obstruction will be required. The area coverage (over 800 thousand square nautical miles) is too great to survey before chart production. The present approach is to produce charts initially using all currently available information in order to meet publication requirements. It is presently contemplated that areas of major concern will be surveyed under contract. The wire drag technique would be very slow in areas of numerous obstructions. Verification of claims and the continuation of surveying will be required in as cost-effective an approach as possible. The strategy for survey and concept development should be considered in conjunction with the requirements for clear channel and bathymetric surveys (discussed elsewhere in this report) because of important similarities in requirements.

2. Requirements

a. The location and least depth of all obstructions or areas of numerous obstructions will probably be charted at a 1:80,000 scale.

b. Objects such as a pipe or wellhead, 1/3 meter diameter, projecting 2/3 meter from bottom, must be located. Underwater piling, rock outcrops, and other natural features which are likely obstructions must be indicated.

c. Depth of concern will be from 10 meters and 200 meters.

d. The effective coverage rate which appears feasible is 2 square nautical miles/hour with a detection probability of 80%.

e. False/real target ratio (false target alarm rate) may be a significant cost factor and as such should be considered in its system design.

f. Positional accuracy will be Loran C or better.

It is not intended that the entire area upwards of 800,000 square nautical miles will be systematically surveyed. The likely strategy will consider systematic survey over selected areas and survey to verify or follow up on reported obstructions and claims. Hence an effective survey rate of 2 square nautical miles per hour for each of several survey platforms may be adequate. A detection probability of 80%, or perhaps 90%, is also considered adequate because a failure to detect a particular obstruction does not necessarily result in a catastrophic loss. The cost of the attempt to approach 100% detection probability is likely to outweigh the benefits.

3. Concept

High frequency, high resolution sonars could be developed to meet this requirement. The mapping requirements are well matched to the resolution dimensions which can be achieved with side-looking sonars (SLS) and scanning mine-hunting sonars. The SLS systems are considerably simpler and inherently less costly than the horizontal scanning sonars and thus seem better adapted to use for this function. However, any development program should include a review of current mine-hunting sonars and sonar development programs in the U.S., U.K., and France which have the most significant and accessible activities in this field.

SLS systems, configured to operate in a towed mode from any of a number of NOAA or chartered ships could start by surveying, with Loran C or one of the shorter range systems (e.g., Raydist navigation) in primary fishing areas with full coverage; followed by thin coverage in areas with steep or irregular topography which probably have such extensive roughness as to be categorized in terms of large continuous areas of obstacles. The goal of two square miles per hour can be achieved with a properly developed multi-lane (multibeam) system. The principal operational problem to be faced by an idealized system is the existence of false targets. Since the principal ones will be biological they will present the greatest difficulty in the areas of most fishing activity. This problem will be addressed in the section titled Requirements for each mission.

4. Status

Operational commercially available SLS systems can detect targets of the specified minimum size; however, they lack the required area coverage rate. Simple systems with half a meter lateral resolution can cover only 750 m^2/sec* or 2.7 km^2/hr, substantially short of the target of 6.8 km^2/hr. A multibeam system*, of which one prototype has been built, could achieve this sweep rate using 3 beams. This would be primarily a development problem since the basic signal processing approach and environmental parameters are reasonably well known. Yaw compensation would be required. It would also be desirable to incorporate a doppler measurement capability for clearly defined targets to allow discrimination against some biological assemblages to reduce the number of false objects.

5. Program Goals

Analysis and concept formulation	FY 1981
Design development and fabrication	FY 1983
Technique development	FY 1982-1983
Operational	FY 1984
Cost from FY 1981 to FY 1983	$2 million

It recommended that a program be developed with the goals indicated above. It is estimated that $2 million would be required through technique development by the end of fiscal year 1983. This would include both the cost of in-house effort and contract effort.

D.2.2 Clear Channel Determinations

1. Brief Description of Need

The clearance and certification of clear navigation channels is presently done by wire drag operation. The increase in vessel drafts along with the designation of traffic lanes in previously uncertified areas has placed increased emphasis on more cost-effective techniques for clearing channels. Two types of areas

*See "Ocean Acoustic Remote Sensing of the Sea Floor," Fred N. Spiess, OARS Paper #11.

are important: the deep water of the West Coast and Alaska, where large bottom features in uncharted areas may exist; and the shallow water of the East Coast, Gulf off-shore, and harbor areas, where small objects may exist, e.g., pipes, pilings, and wrecks, as well as rocks and sand waves.

The deep water area is presently being addressed with the development of the bathymetric swath sonar system (BS^3) which will provide 100% coverage of the bottom and will locate and determine least-depth on all topographic features which project up to the operating depth of deep draft vessels in areas deeper than such features.

The shallow water clear channel areas of the Gulf, Atlantic coastal areas and harbors, presently being accomplished by wire drag, represent a more difficult detection problem than that discussed above. This is because both the natural and man-made obstructions of significance can reach to only two or three feet above the bottom and yet be of concern. The BOS'N BS^3 would not be adequate for such determination.

2. Requirements

Shallow water	20-40 meters
Obstacle size	2/3 m high, 1/3 m diameter
Probability of obstacle detection	99%
Channel width	200 m to 5 Km
Effective area coverage	3.5 sq.km/hr (1 sq.nm/hr)
Positional accuracy	3-10 meters

False/real target ratio is a significant relationship since all targets are investigated.

The above requirements are somewhat similar to the requirements for the fishing obstruction charting missions. One major exception is the more stringent probability of detection necessary for clear channel work. It is thought that a program of development or application engineering for a side-looking sonar for the fishing obstruction charting mission could probably be combined with one for this mission. This should be addressed in subsequent OARS program planning. OARS technology effort for the bathymetric mapping mission might possibly also be integrated into a program for the above two missions. The goals and budgetary estimate (on a stand-alone basis) for developing a system for the clear channel mission are given below:

3. Concept

Existing available swath echo sounding systems seem appropriate for locating pinnacles and the like in deeper water harbor approaches. In shallower water a side-looking sonar of the type implied under the Fishing Obstacle heading would provide appropriate coverage for location of discrete objects. The higher detection probability would be achieved by multiple sweeps of the area and by incorporating additional preformed beams. Given the greater importance of shallow water (< 50 m) this might well be a hull-mounted system.

Full bathymetric coverage is required in shallow water, where the swath width of existing downlooking multi-beam sounders has small lateral dimensions. An interferometer-type SLS adjunct* can, in principle, provide a much larger sweep width and is particularly well matched to the low-relief circumstances involved. This could give at least a 400 m swath in 30 m of water over a nearly horizontal sea floor.

4. Status

The corresponding section under fishing obstacles covers the situation with regard to detection of discrete objects. With regard to the SLS interferometer-type swath mapping sonar, one such has been built, with quite different requirements, by V. C. Anderson of the Marine Physical Laboratory (MPL, Scripps) and a more nearly equivalent one is under development for the MPL Deep Tow by Spiess*. Neither of these, however, has had to cope with the close presence of the sea surface. The problems associated with the discrete object detection are similar to those presented under fishing obstruction charting. In the case of the interferometer adjunct, the principal development would be the design of a transducer and associated signal processing to eliminate the interfering effects of the sea surface. Beyond that the primary concerns would be in selection of appropriate system parameters and construction of a prototype system. Consideration would have to be given to data storage and processing since the data rates would approach 100 soundings per second.

5. Program Goals

Analysis and concept formulation	FY 1981
Design, development, and tabulation	FY 1983
Technique development	FY 1982-FY 1983
Operational system acquisition and use	FY 1984

Cost $2 million through techniques development

*Ibid.

D.2.3 Bathymetric Mapping

1. Brief Description of Need

The present NOS bathymetric mapping program utilizes existing data collected for nautical charting. Manual processes are employed to analyze and draw the detailed contours for these maps which are used for base maps for various endeavors including those of the Bureau of Land Management (BLM). Requests for a significant amount of ship time and bathymetric surveys have been received during the '80s out to the 200-mile limit along the Alaska and Pacific coasts. There are four operational areas of concern:

a. Deep Ocean to 200 nmi

b. Pacific shallow water 40 m - 600 m depth

c. Atlantic and Gulf shallow water 10 m to 200 m depth

d. Coastal shorelines 0-10 meters depth

The Deep Ocean areas are being addressed with the development of the Sea Beam swath system. The Pacific shallow water system which utilized the BOS'N sensor is also under development and is expected to be operational in about a year. It is the BS^3 noted earlier. It is generally slow and hazardous to do bathymetric surveys in the coastal shoreline areas having depths under ten meters from boats using acoustic techniques. This is one of the reasons for the present effort in NOS to develop an airborne laser technique.

The largest area of concern for which a system does not exist but is of major concern is in East Coast and Gulf shallow water of 10-200 meters depth. This is also the most extensive shallow water area requiring fisheries obstruction charts. The survey platform therefore may possibly be the same.

2. Requirements

The shallow water East/Gulf Coast requirements are:

a. Surveying by small boats based on ships or shore-based small boat field parties. Boats are typically 25-35 feet long with 30 kn capability.

b. Water depth: 10 to 200 meters.

c. Accuracy: $\pm$ (.3 m + .005 depth)(3 sigma).

d. Swath angle: up to 160° to provide depth and reconnaissance data so as to minimize number of vessel track lines.

e. Survey of from flat to slightly undulating bottoms to very rough, jagged rock-outcropping and coral bottoms.

f. Resolution on bottom at a depth of 100 meters will be 10 meters.

g. Positional accuracy will be 3 to 10 meters.

3. Concept

Multiple-beam swath techniques have been used for bathymetric surveying by NOAA and the Navy. An interferometric concept, used in airborne side-scan radars, appears to offer enhanced resolution and efficiency relative to the multi-beam swath technique.

Basically two identical horizontal arrays are installed, one above the other, on each side of a vessel. The physical separation of the two interconnected horizontal arrays in the vertical plane gives rise to an interference pattern on reception. The greater the separation, the greater the number of interference lobes and the greater the resolution in the vertical plane. The problem is reduced on transmit by using only one of the two arrays.

4. Status

Basically, the technique is well understood and no unusual technological problems are foreseen in developing it for the above requirements.

It is recommended that a plan be prepared to achieve the goals given below.

5. Goals

The analysis and conceptual formulation and exploratory development should be accomplished in an initial phase since this technique appears to have a degree of development risk. This phase could logically be integrated with the clear channel and fisheries obstruction system concept development. The program might appear as follows:

<u>Phase I:</u>

Analysis and concept formulation	FY 1981
Exploration development	FY 1982

<u>Phase II:</u>

Design development and fabrication	FY 1983-FY 1984
Technique development	FY 1984-FY 1985
Operational use	FY 1986

Budgetary estimates (including in-house effort)

First phase	FY 1981-FY 1982	$1.5 M
Second phase	FY 1983-FY 1985	$4.0 M

D.2.4 Current Surveys - Time Series

1. Brief Description of Needs

The National Ocean Survey provides tables of currents for the estuaries and near shore areas surrounding the United States. This information is used for vessel navigation safety and by those conducting operational and scientific programs. At present the measurements of currents are made in situ by securing current meters to a mooring line extending from a surface buoy to an anchor. Unfortunately, the motion of the buoy is coupled into the current meter as noise, thus degrading the measurement and its accuracy. Analyses and tests conducted by WHOI, NOS and NDBO confirm this problem. Typically currents are measured in depths ranging from 10 m to 200 m. The number of current meters secured to the mooring varies as the depth, with up to three meters used at the greater depths.

A self-contained remote-sensing, bottom-mounted, multibeam-doppler sonar current measuring technique presently under development appears to provide the solution to the problem in that the unit will be located at the bottom, out of the turbulent surface regime. Survivability is an additional advantage realized, since the currents measuring system is located well under the keels of passing vessels.

2. Requirements

a. Vertical profiling of currents to 200 m depths

b. Speed Accuracy/Resolution of 0.1 kn/0.2 kn

c. Directional Accuracy/Resolution of 3°-5°/5°

d. Unattended operation for two months

e. Battery operation

f. Current Speed Range to 10 kn

3. Concept

Basically, the remote sensing concept envisioned for this application is a bottom-mounted three or four beam doppler technique. In principle, the technique is similar to the bottom tracking doppler navigation equipment presently installed aboard vessels. Conceptually, the technique proposed is an inverted bottom-mounted ship's navigational system using time-gating to measure doppler returns from predesignated layers in the water column. Since the doppler signals are returned from scatterers in the water column, the signal-to-noise ratio is dependent upon all scatterers including biota. However, noise generated by the dynamics at the surface is not coupled into the signal.

4. Status

To date, the concept has been demonstrated through experiments in controlled and open environments using a single beam system as well as with a four beam system mounted on a vessel.

The next phase, in the final process of development requires the development of a signal estimator. The signal estimator will be developed from results of experiments using a three or four beam system. Several experimental systems are available and, with minimum modification, can be used for conducting experiments in several typical estuaries.

Following the development of the signal estimators, specifications will be completed for the procurement of a prototype system for test and evaluation.

Following are estimated schedules and costs for completion of the work.

5. Program Goals

Develop Engineering Model	FY 1981-FY 1982
Experiments and Demonstrations	FY 1982
Operational	FY 1983
Cost of $400 K	FY 1981-FY 1982

D.2.5 Real-Time Currents Information for Safe Harbor/Channel Navigation

1. Brief Description of Needs

Studies conducted by the Coast Guard and the New York Port Authority have shown the desirability of providing real time currents, water levels and winds in harbors and ship navigation channels. Winds and water levels for the harbor and channels can be inferred from measurements made along the shoreline, whereas currents are desired at strategic locations. Unfortunately, moored current measuring systems are vulnerable to ship traffic.

A remote-sensing, bottom-mounted, multibeam-doppler sonar current measuring technique presently under development, appears to provide a solution to the problem.

2. Requirements

Although specific performance requirements have not as yet been established for the measurement of these currents, preliminary discussions seem to focus on the following:

a.	Vertical profiling of currents	Top 40'
b.	Provide currents to four depths	10', 20', 30', 40'
c.	Speed Accuracy/Resolution	0.1kn/0.2 kn
d.	Directional Accuracy/Resolution	3^{o}-5^{o}/5^{o}
e.	Unattended operation for one year	
f.	Power and signal cable trenched to shore	
g.	Current/Speed range	0-5 kn
h.	Deployment depths	$\leq$ 30 m

3. Concept

Basically, the remote sensing concept envisioned for this application is a bottom-mounted three or four beam doppler technique. In principle, the technique is similar to the bottom tracking doppler navigation equipment presently installed aboard vessels. Conceptually, the technique proposed is an inverted bottom-mounted ship navigational system using time-gating to measure doppler returns from predesignated layers in the water column. Since the doppler signals are returned from scatterers in the water column, the signal-to-noise ratio is dependent upon all scatterers including mobile biota. However, noise generated by the surface dynamics is not coupled into the signal.

4. Status

To date, the concept has been demonstrated through experiments in controlled and open environments with a single beam system.

The next phase, in the final process of development requires the determination of a signal estimator. The signal estimator will be developed from results of experiments using a three or four beam system. Several experimental systems are available and with minimum modification can be used for conducting experiments in several typical estuaries.

Following the development of the signal estimators, specifications will be completed for the procurement of a prototype system for test and evaluation.

Following are estimated schedules and costs for completion of the work.

5. Program Goals

Develop Engineering Model	FY 1981
Experiments and Demonstrations	FY 1982
Specifications, Procurement and Operation	FY 1983-on
Cost of $400 K	FY 1981-FY 1982

As can be seen in the previous section on time series current surveys for other applications, there is significant similarity in technical performance requirements. It will be seen that some of the effort in the above program will, therefore, be directly applicable to both sets of requirements.

D.3 Possible Future Missions

D.3.1 Sea Floor Geodesy

An area for system improvement appears in the geodetic (and related geological) context in which one desires to document gradual changes of sea floor geometry. This could be in coastal or slope areas where large-scale creeping and slumping may occur and in the vicinity of ocean spreading centers and transform faults. These can be documented using networks of transponders and appropriate trilateration approaches. Transponder designs have been formulated and bench tested which can control the response delay times to within a microsecond or better if necessary, thus eliminating this problem from contributing to uncertainty. Similarly it seems feasible to build sound velocity meters for use in survey areas to give reliable values of speed of sound to one part in 10^5 (about one cm/sec). With these two capabilities, it becomes possible to resolve motions of a few cm over distances as great as a few km, given careful design of the overall experiment and related computational methods. This would make it feasible to measure spreading rates directly at intermediate- and fast-spreading centers. In such situations, the full rate is from 5 to 20 cm per year and the region over which this builds up ranges from 2 to 10 km. In this context then, acoustic transponder techniques can become in themselves acoustic remote sensing instruments, providing measurement of geodynamic effects as they occur at the sea floor. This technique has the possibility of being extended to the measurement of accumulated earth stress and thus becoming a tool for earthquake prediction.

Other uses for such techniques are resource assessment, national and state geographic boundaries and subdivision of the bottom for ownership, zoning and resource exploitation purposes.

The Ocean Services Working Group considered this potential acoustic technique but was uncertain whether sea floor geodesy is a NOAA-assigned mission at present. Therefore, it is recommended that this concept be brought to the attention of the National Geodetic Survey, which has a better understanding of NOAA's present or prospective role in sea floor geodesy. Pending resolution of this issue, the technique described above should be reconsidered for possible inclusion in a NOAA/OARS program.

D.3.2 Periodic Synoptic Temperature vs. Depth Measurements

Temperature variations and the flow of heat in ocean surface and subsurface currents may play a major role in the air-sea interaction and, thus, in climatology. Monin, Kamenkovich and Kort (1977)[1] remark that the temperature field is the most important of the oceanological field studies in fisheries-related oceanology. Despite the success of the echosonde in observing geophysical turbulence, winds and ocean currents, no practical extension of acoustic remote sensing to measurement of temperatures and temperature profiles has appeared feasible until now. Other nonacoustic remote sensing methods have limitations in geometry or resolution. The importance of temperature observations in geophysics thus forces the continued use of costly and intermittent devices, such as radiosondes in the atmosphere or XBT's in the ocean. Some scientists would prefer to obtain a three-dimensional synoptic ocean temperature map which the XBT is not ideally suited to provide.

Such ocean temperature information is vital to the prediction of sonar system performance on a daily or more frequent basis. It is, therefore, of great interest to the Navy as well as the fishery biologist and climatologist.

Two acoustic approaches for obtaining temperature versus depth measurements were considered at this workshop by the Ocean Services Working Group. Since time was limited, other acoustic methods were not explored, but may exist.

One system suggested by Watts[2] at the OARS workshop plenary session was a bottom-mounted inverted echo sounder that measures

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[1] Variability of the Oceans, John J. Lumley, ed., 1977, John Wiley & Sons.

[2] OARS Paper #13, this volume.

the round-trip time from bottom to surface and back. Since temperature is the most important variable in the speed of sound, temperature changes from known profiles can be inferred. Since most of the temperature changes occur in the mixed layer, and this layer is of the most interest to the potential users of the information, experimentation with the technique might reveal means of extracting useful data about that portion of the water column. At best, however, one would have only an average temperature over that portion. The integrated sound velocity (therefore temperature) over the entire vertical depth may be of interest to some users. The effects of salinity and particulate matter may limit the technique somewhat. Further, bubbles will effect sound speed considerably and may present analysis limitations.

Brown[1] suggested an approach for obtaining a temperature versus depth profile, the preferred data set. In 1976, he and his associates conducted an experiment that combined the scattering of sound with the formation of three-dimensional fringes in space by constructive interference of properly spaced sources (as in a Young's interferometer). Recently Brown (1979) described an acoustic remote sensing thermometer, for which he reclaimed an old designation, echometer, that combines the principles of the above experiment with techniques that include curve fitting of pulse envelopes and measurement of the mean phase within pulses. Preliminary results indicate that the echometer may provide temperature measurements to within a few tenths of a degree Kelvin in the atmosphere and a few hundredths of a degree Kelvin in the ocean, out to ranges of about 500 meters. The spatial resolution is about 10 m in the atmosphere, and about 1 m in the ocean.

This system could be ship, buoy or possibly bottom-mounted.

The Ocean Services Working Group considered these approaches and concluded that while NOAA does have research missions which need temperature vs. depth information, remote acoustic techniques for such profiling are yet to be demonstrated. Development or applications engineering for ocean services applications should not yet be programmed. Present explanatory efforts should be continued and encouraged.

D.3.3 Site Specific Surveys/Sea Floor

A number of special task areas in which acoustic remote sensing could play a significant role were identified. These task areas are discussed as a group because of several common factors:

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[1] OARS Paper #15, this volume.

- o Each task requires detailed information about a specific location on or below the sea floor.
- o NOAA's role or responsibility for performing the task is not clearly defined.
- o Technology, acoustic or other, exists to perform the task, but requirements for improvement of existing technology or development of new technology are not known.

The specific tasks identified include: sea floor resource assessment, surveys of potential nuclear waste disposal sites, surveys of potential ocean thermal energy conversion (OTEC) sites, assessment of the environmental effects of marine mining, and determination of the physical structure of the subbottom. The primary requirement for each of these task areas is detailed bottom mapping—a requirement that has been and can be met by acoustic remote sensing, as well as by other means (e.g., optical). Most of the task areas also have related requirements, such as the need for precise current information, that can be met by acoustical techniques. Each of these task areas is discussed in more detail below; however, the discussion is limited to general comments and recommendations because NOAA's responsibilities are not well defined.

Resource Assessments (Sea Floor) - The primary sea floor resources considered are mineral resources (e.g., manganese nodules, sand, gravel). NOAA responsibilities for detailed sea floor resource assessments may be inferred from current mission statements. However, these inferred responsibilities do not provide sufficient justification for initiation of a specific acoustic program. Pending congressional legislation will assign responsibilities and authorizations for marine mining activities, and it is expected that NOAA will have an expanded role in this area. For this reason, further evaluation of the application of acoustic remote sensing to marine mineral resource assessment is recommended. This evaluation should be performed with NOAA's Marine Minerals Division.

Nuclear Waste Disposal Site Surveys - The disposal of nuclear waste in the seabed is an option under consideration by the Department of Energy (DOE). DOE has suggested closer cooperation between DOE and NOAA concerning current and future research and development activities in this area. DOE has a primary requirement for detailed mapping of the sea floor at potential nuclear waste disposal sites (water depth must be greater than 4,000 meters). Acoustic technology for such detailed mapping exists but the number of available systems for performing this task is limited because of the depth requirement. NOAA's responsibilities for providing detailed bottom mapping at these potential disposal sites is unclear. Senior management level DOE-NOAA discussions are being scheduled to address these questions, and internal NOAA discussions to evaluate alternative NOAA roles are in progress.

Acoustic remote sensing techniques can contribute significantly to the study of potential nuclear waste disposal sites but specific NOAA programs cannot be designed or initiated until NOAA's role is clarified.

OTEC Site Surveys - Surveys of potential OTEC sites include not only detailed bottom mapping, but extensive current and temperature mapping and determination of biological activity as well. These surveys, which could be aided by acoustical remote sensing, are required to determine the potential environmental impact of OTEC facilities and are currently the responsibility of DOE. Pending congressional legislation, however, would assign some of the responsibilities to NOAA. NOAA's role, with or without the legislative mandate, is presently under discussion by senior NOAA management. Until resolution of these policy issues, no specific acoustic remote sensing programs can be recommended with respect to these missions.

Environmental Impacts of Marine Mining - Although the final objective of environmental impact surveys is somewhat different from "resource assessment" surveys, the same or similar acoustical techniques could be applied. In this particular case, because the subject is environmental impacts of marine mining, comments concerning NOAA's responsibilities and specific program recommendations are the same as for "Resource Assessment," above.

Subbottom Physical Structure - Acoustic techniques exist for determination of the subbottom physical structure; however, the quantity and quality of acoustical measurements are not adequate for scientific or operational (e.g., siting of structures) purposes. Senior NOAA management is currently discusssing NOAA's future role in this task area. Specific technology improvement or technology development programs cannot be recommended until NOAA roles are defined.

It is recommended that NOAA's role with respect to the above missions be reviewed in about six months to formulate appropriate program goals vis-a-vis OARS techniques for inclusion in a NOAA OARS program.

D.4 Policy Issues

The Working Group recognized several policy issues which should be addressed to enhance the implementation of workshop recommendations. These policy issues fall into three broad categories: intra-agency relationships and communications; interagency relationships and communications; and NOAA "corporate"-level involvement in resources allocation for technology research and development.

1. Intra-Agency Relationships and Communications

Acoustic remote sensing cross-cuts all of NOAA, in terms of research in acoustic wave propagation in the sea, development of acoustic technology, operation of acoustic systems and use of data obtained by acoustical means. Prior to this workshop, acoustic program activities or needs in some parts of NOAA were not well known to other parts of NOAA. The complete and frank exchange of ideas and program information demonstrated the value of future meetings to address specific topics. The Ocean Services Working Group recommends that follow-on meetings be scheduled to continue the dialogue initiated at this workshop. These meetings should be scheduled on an annual basis for the next few years, but could probably be modified to every two or three years later.

2. Interagency Relationships and Communications

This issue addressed primarily NOAA-Navy relations. The U.S. Navy is, and will continue to be for the foreseeable future, the premier developer and user of ocean acoustics. For this reason, NOAA must establish closer relationships and better communications with the Navy to enhance the transfer of acoustic technology. Although a certain degree of unclassified technology and information is exchanged between NOAA and the Navy, these exchanges are generally limited to specific projects and depend largely on personal friendships. The workshop recommends that the Office of the Naval Deputy to NOAA be used to establish a close NOAA-Navy relationship at the senior management level. This closer relationship could be in the form of mutual briefings of ongoing acoustic activities and projected needs for both agencies. The participation of senior management personnel from both agencies in the encouragement and promotion of such arrangements is recommended.

Security classification as a barrier to NOAA exploitation of Navy developments was discussed. No clear approach to cope with this barrier emerged from the group's discussion. It was concluded, however, that more use of the Office of the Naval Deputy to NOAA should be made.

Another issue concerning interagency relationships is the balance between serving NOAA mission requirements and serving the requirements of other Federal agencies or the ocean community at large. The development or improvement of certain acoustic remote sensing techniques or systems may be of major benefit to another agency, but of limited value to NOAA activities. NOAA's responsibilities for this type of activity are unclear.

3. NOAA "Corporate"-Level Involvement

The group identified a major need for involvement of senior management if the recommendations of the workshop are to be successfully implemented. Because acoustic remote sensing activities cross-cut all of NOAA, it is inevitable that difficulties will arise concerning the priority of acoustic projects or the allocation of resources. These may best be resolved through an integrated planning, budgeting and resource allocation above the MLC (Main Line Component) level. This would require that an official above the MLC level, with broad scientific and technical background, but without a parochial view toward the interests of any MLC, be intimately involved in the resource allocation process. Perhaps the appropriate place for this function is the NOAA Science and Services Policy Group.

In addition, it is felt that, as a matter of policy, a percentage of the NOAA budget be designated for technology research and development subject to the above allocation process to achieve balanced technology programs responsive to NOAA's ocean services and scientific missions.

D.5 Conclusions and Recommendations

Based on economic analyses and results of technical work conducted to date by industry and NOS, it is recommended that the acoustic remote sensing development program for Ocean Services be completed as discussed in Section D.2 above.

The development of techniques required to provide the high-resolution sonars in support of the hydrographic missions (fishing obstruction detection, clear channel determination and bathymetric surveys) should be funded. United States and foreign technology must be addressed to assure use of prior work. It was also agreed that economic and alternative concept trade-off analyses must be conducted.

Many of the techniques applicable to the hydrographic mission are borrowed from airborne sidelook radar developments and are being extended to meet ocean acoustic requirements. It appears that, based on discussions of hydrographic requirements and possible techniques for meeting these needs, no fundamental physical limitations are foreseen.

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