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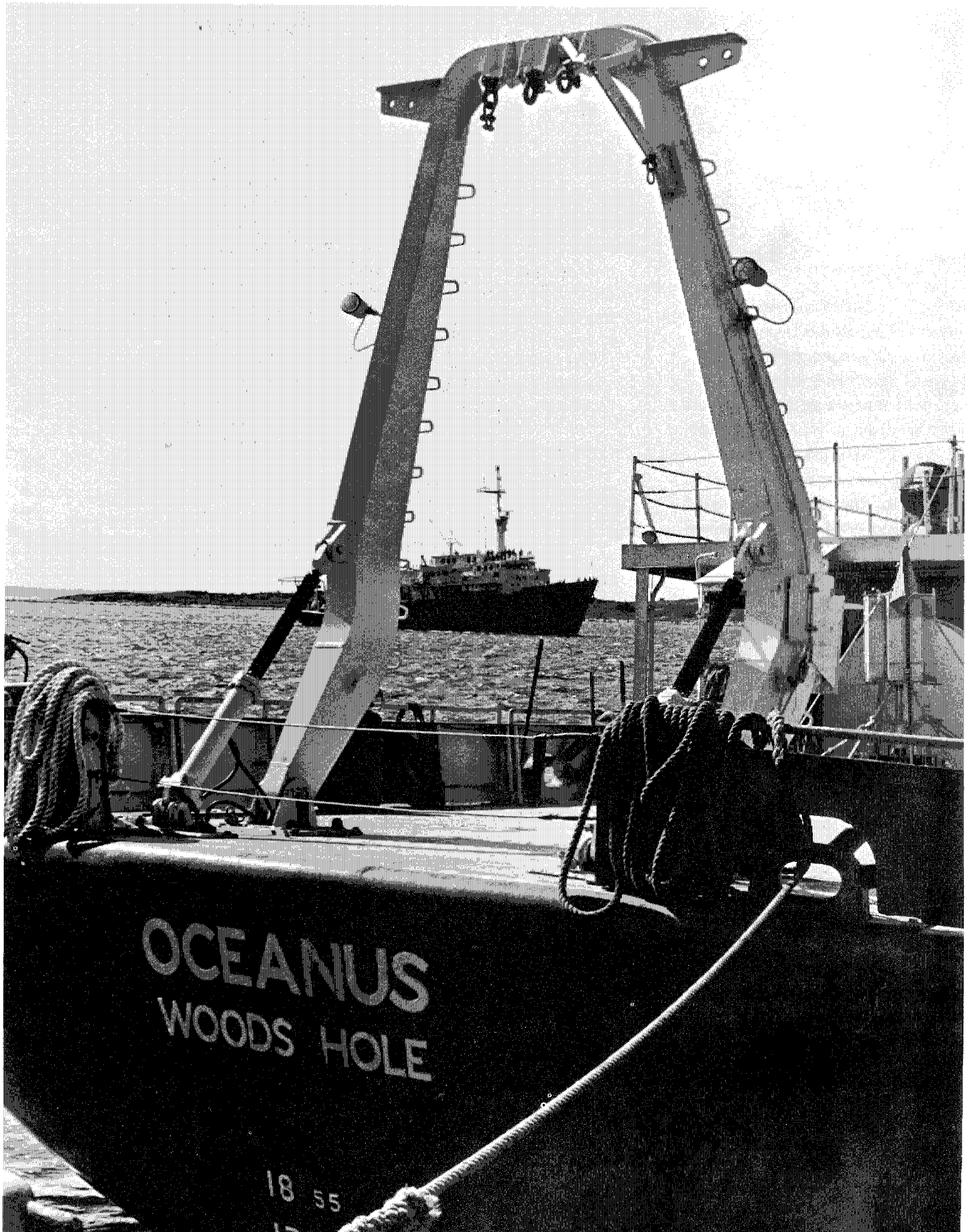
Cover:
R/V *Knorr* undertook a seven-month voyage in 1981 for the Transient Tracers in the Ocean program. The ship departed Woods Hole for this work in April and followed a zigzag track across the Atlantic with port calls at Bermuda, the Azores, Scotland, Iceland, Newfoundland, and back to Woods Hole in late October. The cover photo shows the ship silhouetted against an iceberg off Greenland. It was taken by *Knorr* First Mate Richard Bowen. The Transient Tracers program is a continuation and expansion of work begun in the early 1970s in the Geochemical Ocean Sections Study. These projects have employed the changes that take place with time in chemical species such as carbon-14 and helium-3 produced during nuclear tests in the late 1950s and early 1960s. Determination of the distribution of the elements 20 or more years after their entry into the ocean provides a measure of ocean mixing on these time scales. Their movements also provide an analog for distribution of fossil-fuel produced carbon dioxide.

Annual Report 1981:
Vicky Cullen, *Editor & Designer*
Reynolds-DeWalt Printing, Inc., *Printer*
Typesetting Service Corp., *Typographer*

1981 Annual Report

Photos by Shelley Lauzon



Atlantis II returns to Woods Hole in October of 1981 to join *Oceanus* in home port.

Director's Comments

A consistent and beneficial relationship with industry is woven through most of the history of the Institution. In view of current trends in government funding, it is clear that we, along with other academic institutions, must reassess and strengthen our industrial associations.

The focal point of our interaction with industry in recent times has been our highly successful ten-year-old Ocean Industry Program (OIP). The program evolved in response to enquiries from oil companies concerning underway seismic reflection data acquired by Geology and Geophysics staff members. Their regional mapping approach provided data that ideally complemented oil industry methodologies, which were more concerned with intense exploration over relatively small areas. Since OIP's inception, eighteen petroleum companies have participated, and there are currently fourteen members. The scope of services provided OIP member companies has grown in response to their needs and to the emergence of new technology. At present, we host two meetings each year and encourage a program of visits by our scientific staff to the member companies.

One of the primary reasons for the success of this program is its natural and synergistic fit into the mainstream of the Institution's activities. OIP has not required any special type of organization within the scientific departments and is administered by a very small management staff.

The Ocean Industry Program provides an ideal model on which to base future activities with industry – it is easily manageable, meets an industrial need, and creates the mutually productive dialogue that will play an increasingly important role in the Institution's dealings with industry. We have already made initiatives in other areas by holding meetings on topics such as ocean technology and energy. It is hoped that these forums will assist us in formulating additional programs for other sectors of industry and help us to define areas where the Institution can offer its resources to industry through sponsored research. While we do not expect such activities to cause a major change in our total yearly budget, we do feel that they will expose us to new challenges and promote a significant increase in the unrestricted income that is so important to the Institution in developing its own initiatives.

I am confident that there are several areas where the Institution possesses expertise which could be valuable to industry, especially as the search for marine resources moves into deeper water where industrial activities will be increasingly exposed to the vagaries of the marine environment. The solutions to many of the problems industry will face lie within scientific research such as that done in this Institution. This is indicated by the numerous outside consulting arrangements with which our scientists have collaborated with industry on an individual basis.

We must be sensitive to the issues common to all academic institutions concerning the availability of results to both the scientific community and the general public. While respecting industry's needs for proprietary research, we must adhere to the primary purpose of the Institution, promotion of the knowledge and understanding that will help assure the wise use of the oceans.

The other significant check that will ensure the integrity of future relations with industry is our adherence to the principle of the tenure system. Although it can create restraints in our activities, it plays an important role in the maintenance of our high standards. By adherence to this system, we will guarantee that although our work may have benefits of an applied nature, it will still have scientific justification. These same high standards are reflected in our technical staff, who are closely integrated into our present system. They are not only an invaluable element in the scientific achievements of the Institution but also a major asset in formulating future programs with industry. We can thus continue to accomplish our scientific missions without altering the basic principles upon which the Institution operates.

As changes occur in the general funding of science, we will have to consider additional mechanisms to cope with them. I am confident that the Institution will continue to adapt with the same resilience demonstrated in previous eras of major change, which, in retrospect, have had a strengthening rather than weakening effect on us.

John H. Steele
Director

Areas of Interest

Biology

The broad aim of biological oceanographers is to study the temporal and spatial distributions of populations of marine organisms and their interactions with each other and their environment. The work is predominantly ecological in nature and provides the basic information required to understand how the ocean works biologically. Among the research interests of Institution biologists are microbiology, planktonology, benthic biology, physiology, animal behavior, and aquaculture. Work on marine pollution includes research on the effects of drilling muds and hydrocarbons. The "patchy" distribution of many marine animals is under investigation as are the physiological adaptations of deep sea organisms to sparseness of food, low temperatures, and high pressures. Answers to questions about the food supply in the oceans are sought in studies of particles falling from the surface waters through the water column to the bottom of the sea, in upwelling areas where deep nutrient-rich waters replace surface waters that are driven offshore by prevailing winds, and in laboratory experiments that complement field investigations. The use of sound by marine animals and their sensitivity to electrical fields are being studied. Other work concentrates on salt marsh ecology and conservation, and there are research projects on aquaculture and waste water recycling and on the productivity of a salmon river in Canada.

Chemistry

Chemical oceanographers are concerned with the composition of the ocean environment. They seek to understand the processes that have brought seawater and sediments to their present composition and that contribute to the observed variability. They also seek understanding of the extent to which the environment may be changed by both natural and man-made phenomena operating on a variety of time scales. Input from rivers and reactions at the air-sea, seawater-sediment boundaries and seawater-volcanic rock interaction at spreading centers are under investigation as chemists consider the processes taking place at major ocean boundaries. Some critical questions in chemical oceanography revolve around transformations in particles as they fall from the surface waters to the bottom of the water column. The genesis and composition of the oceanic crust and its interaction with seawater is important to a general understanding of the oceanic system. Work on the fluxes of organic carbon includes determination of the amount of organic carbon produced in surface waters, the distribution, nature, and biogeochemistry of specific organic compounds in the marine environment, and studies of processes responsible for formation and diagenesis of organic matter in sediments. While studying radioactive isotopes in the ocean whether as a natural occurence or as a form of pollution, chemists are also finding the known decay rates of the isotopes useful as indicators for studying rates of water circulation and of biological and chemical processes that change the composition of seawater.

Geology & Geophysics

The tectonic, volcanic, and sedimentation processes that determine the shape and underlying structure of the sea floor are studied by marine geologists and geophysicists. The structure, evolution, and dynamics of the oceanic crust and lithosphere are investigated by applying the principles of structural geology to direct and remote observations of the seabed, by petrologic and geochemical analyses of rock samples, and by various geophysical methods, including seismology, gravity, magnetism, and geothermal measurements. Special attention is given to the divergent plate boundaries where concentrated heat flow fuels a major hydrothermal circulation system and where rocks originating deep in the earth are brought up to the sea floor in transform faults and in the axes of mid-ocean ridges. Detailed studies are being made of rifted continental margins and marginal basins and of the convergent plate margins where oceanic crust sinks beneath continents or island arcs creating deep sea trenches and the major belts of earthquake and volcanic activity. Research on particulate flux, carbonate and silicate dissolution, and other processes involved in the transport of biogenic material to the sea floor is vigorously pursued. The results are essential to a better understanding of the fossil record which reveals historical changes in climate and oceanic environment caused by the shifting of continents and oceans over the earth's surface through geologic time. Also important to the deciphering of the fossil record and to the understanding of sea floor morphology is the study of sediment dynamics, including slumping, turbidity currents, and the sculpting of abyssal sediments by deep sea currents. Research activity is focused also in the shallower areas of the oceans where marine geologists study the processes that determine the shape and structure of continental shelves and slopes and processes that shape the coastal zone.

Ocean Engineering

Engineering and technology form the background for all but the simplest observing system and as a result the Ocean Engineering Department has a wide spread of interests at the Institution. Interacting a great deal with members of other departments, Ocean Engineering staff are carrying out research and developing instrumentation in almost every field of oceanography. Current measurements on time and space scales of hundreds of kilometers and days down to millimeters and milliseconds are an important part of the work. Mechanical, electrical, acoustical, and optical engineering as well as signal processing are needed to accomplish and interpret these measurements. Some of the measurements relate to the complex effects of waves and currents over large areas. Structures, pressure cases, moorings, and electronic data handling and processing circuits are all developed as part of these programs. The use of unmanned instruments and of *Alvin* to observe the depths of the oceans, in particular recently at ridge systems, has been a large effort involving members from all disciplines of the oceanographic community. Satellites may well become an important source of ocean observations and use of them is being planned in several different ways. Data handling and processing for the Institution is the main interest of the Information Center, with better and faster methods the constant goal. The propagation of sound through the ocean and its bottom still presents challenging problems in acoustics to members of the department, in studies of the ocean bottom and the thermal structure of the ocean.

Physical Oceanography

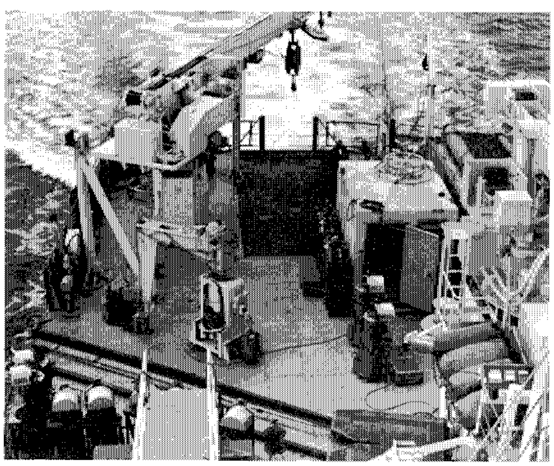
Ocean currents, their driving forces, and their interactions are the major interests of physical oceanographers. Such properties as variations in temperature, salinity, pressure, and large and small scale motions of the waters are measured with a variety of instruments lowered from ships, moored in place, or set to drift with the currents. Their data are plotted and analyzed toward an understanding of why and how the waters move as they do. Exchanges of energy between air and sea present important questions as one affects the other and their interaction becomes part of the world climate. Effects of bottom and coastal topography on ocean circulation systems are under investigation, and the technology of extended-period measurement is constantly upgraded so that trends can be followed. Large and small current systems are modeled toward the ultimate goal of understanding the structure and movement of the world's oceans and the interaction of the sea with its boundaries.

Marine Policy & Ocean Management

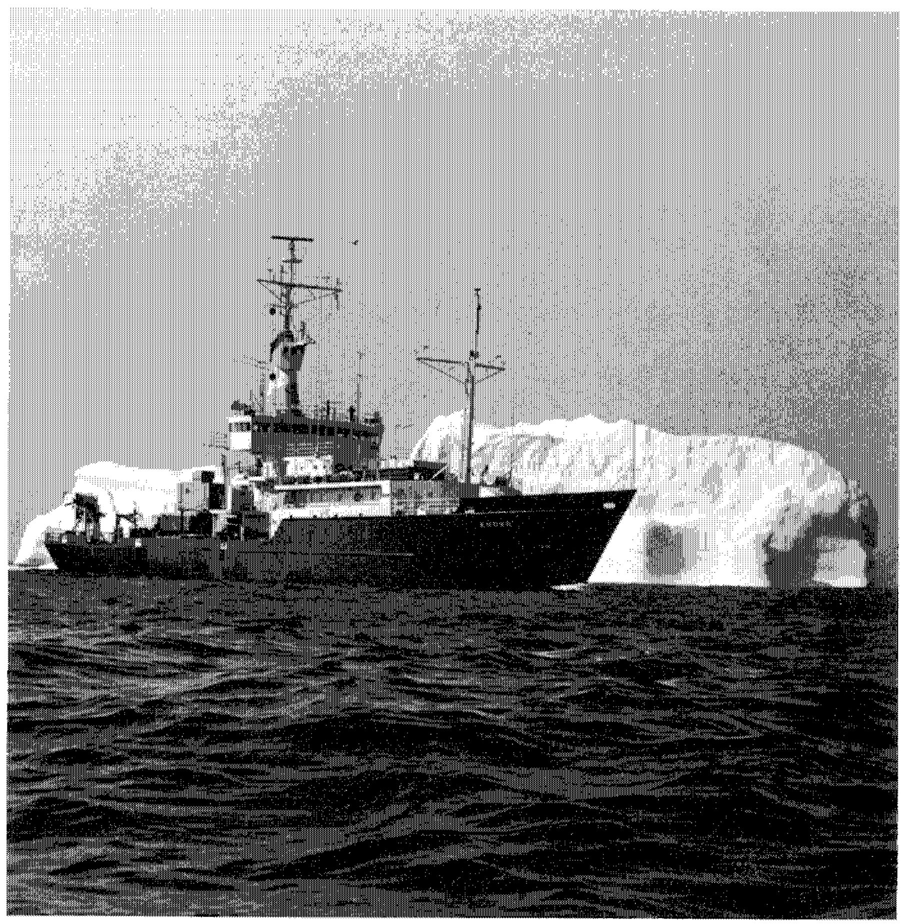
The Marine Policy and Ocean Management Program supports research by marine and social scientists on the social, economic, and political aspects of problems generated by man's use of the sea. The Program supports a small marine policy staff and offers advanced fellowships to individuals from such fields as anthropology, economics, international affairs, law, political science, and the marine sciences who are interested in applying their training and experience to marine policy and ocean management questions. The Program also sponsors lectures, workshops, and seminars on policy-related subjects. Present research in the Program focuses on: coastal zone management and pollution issues, fisheries management, marine mining and cooperative international marine policy.

Photos by William Jenkins

Knorr First Mate Dick Bowen views iceberg in the Labrador Sea during Transient Tracers cruise.



Knorr's fantail setup for Transient Tracers voyage.



Knorr passes iceberg during Transient Tracers cruise.

Reports on Research

In the science report for this year we again emphasize one aspect of the Institution's work, but, in contrast to previous reports where we have concentrated on specific areas of science, we will review a technique, modeling, that is common to all of the disciplines involved in oceanography and is the speciality of one of our newest ventures, the Center for the Analysis of Marine Systems (CAMS).

Modeling is the attempt to reproduce, in the laboratory, one or more of the complex sets of observations that have been collected from the ocean. There are three basic approaches to modeling studies.

The first attempts to use our knowledge of the laws of basic sciences (physics, chemistry, etc.) to build a framework of mathematical equations that may be used to stimulate the complex processes operating in the ocean. Solutions to these equations give predictions that may be close approximations of the real data or may be far different, depending upon the assumptions used to construct the equations and the methods of solution. If the predictions are very different from reality, we must go back and examine the basic assumptions and methods. This approach to theoretical modeling starts with assumptions about the primary processes that may affect the distribution of the property to be predicted. For example, the earth's rotation, wind stress on the surface, and boundary friction are three of the factors that are primary to the construction of models of ocean circulation. The next step involves applying these primary processes in a manner that is consistent with their strengths and variability in nature, e.g., the Coriolis force applied to the ocean's fluid by the earth's rotation varies with latitude. The final step involves solving equations which may or may not have known solutions; a substantial fraction of some modeling studies entails the finding of solutions to some very complicated equations. In many cases the solutions are so difficult to find that we resort to the power of modern computers to "bulldoze" our way through the successive approximations to the actual solution. In the contributions that follow, those of Haidvogel, Jenkins, Spencer, Pedlosky, Stephen, and Bowin are examples of this approach to the modeling of various physical, chemical, and geophysical ocean properties.

The second approach is exemplified in the contributions of Caswell, Schouten and Denham, and Leschine. In these, the basic science foundation is so little understood that it is impossible to derive fundamental equations that describe very complex biological, geological, sociological, and economic properties. Despite this problem, we have enough information to describe an event or property by the probability of its occurrence in given circumstances. With such information, it is possible to explore the structure of an environment and make some predictions of events and circumstances.

The third approach is contained in the articles by Grassle and Whitehead. Here the attempt is to reproduce physically the natural environment on a scale that can be viewed in the laboratory. Establishing experiments such as these is a difficult task because it is necessary not only that the important natural processes or forces have been included but also that, in reducing the environment to a laboratory scale, all of the properties have been scaled correctly. This demands a sophisticated knowledge of the basic physics, chemistry, and biology.

All of the modeling studies that we employ can be criticized because, however complex they are to execute, they do not match the complexity of the real ocean. However, in many instances, important insights into ocean phenomena may be gained from simple models that produce only a caricature of reality. Also, all models that are wrong are not always useless:

Nature and nature's laws lay hid in
night:
God said, "Let Newton be!" and all
was light."

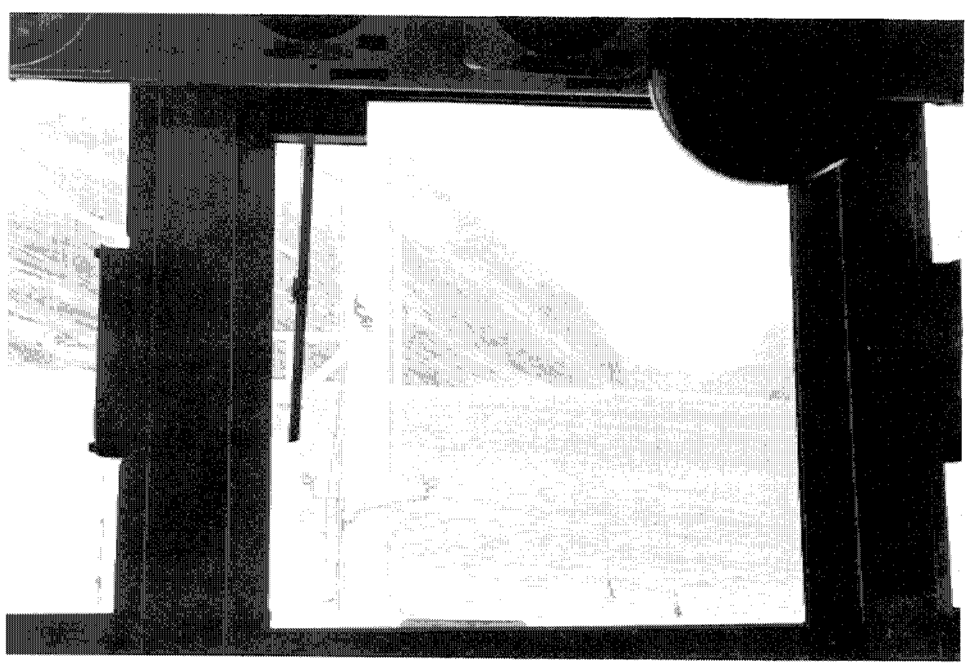
Alexander Pope
(Epitaph on Newton)

It did not last: the Devil howling "Ho!
Let Einstein be!" restored the status
quo."

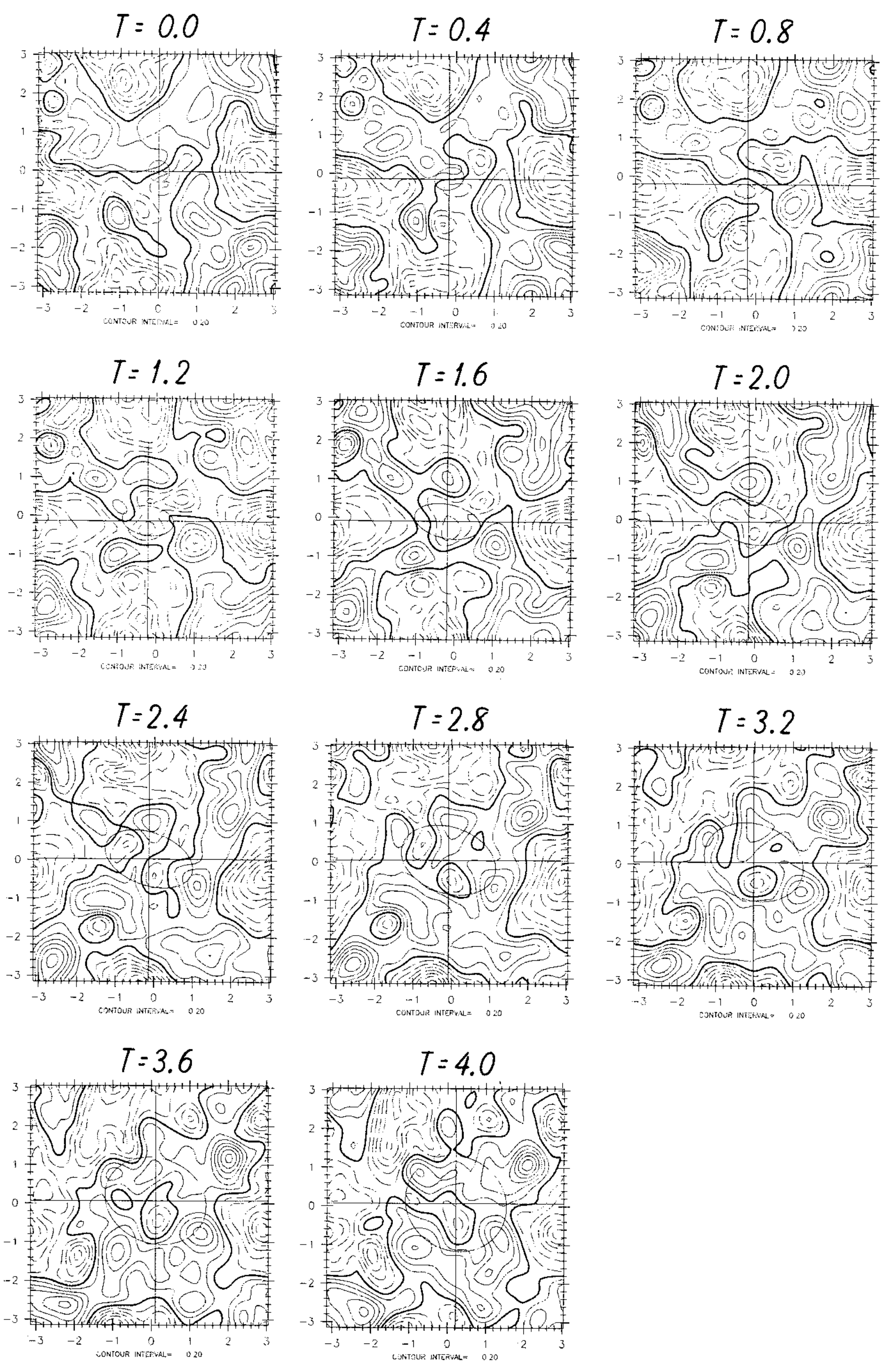
Sir John Collings Squire

Who can doubt that Newtonian physics is still a powerful model even in the face of being upstaged by Einstein. Perhaps the most sage comment comes from Alfred North Whitehead who said: *Seek simplicity, and distrust it.*

Derek Spencer
Associate Director for Research



View from the bridge of the R/V *Knorr* as the ship transits Prins Christians Sund at the southern tip of Greenland.



This sequence of streamfunction contour maps shows the temporal evolution of the simulated depth-independent flow field in a 1,000-square-kilometer region of the mid-ocean. Each successive map is separated from the next by about one week in simulated time, and the average velocity at a point is approximately 10 centimeters per second. The streamfunction contour interval is $3x10^7$ $cm^2/sec.$ in all the maps.

MODELS OF TRACER DISPERSAL IN THE OCEAN

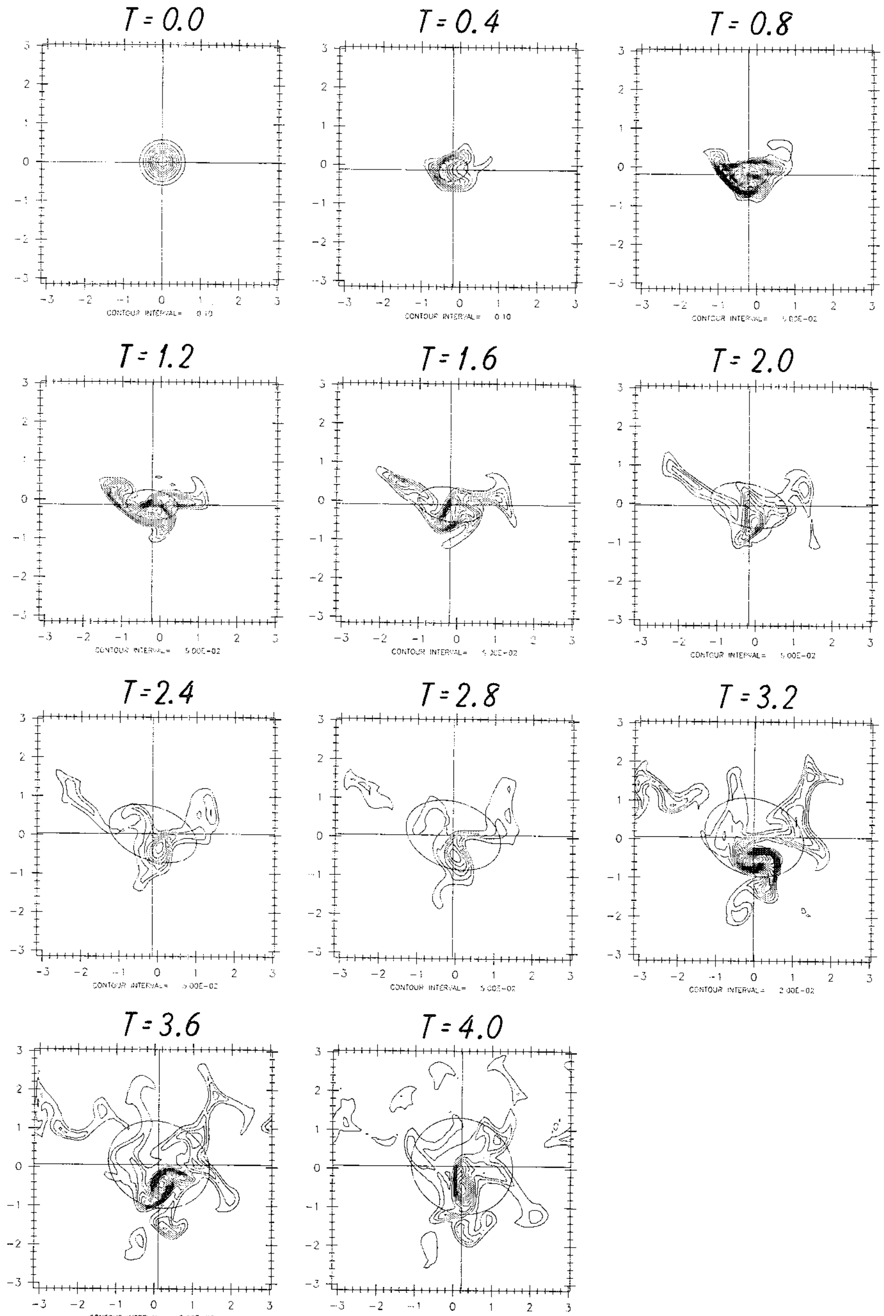
Dale Haidvogel

One of the most wide-ranging problems facing oceanographers today – having important application to physical, geochemical and biological, as well as societal, concerns – is the description of the processes by which dynamically inactive dissolved or suspended materials are redistributed and dispersed by ocean circulation. Such substances, often referred to as tracers, include naturally-occurring and anthropogenic chemical tracers (oxygen, tritium), biological nutrients and organisms (phytoplankton, fish larvae), and pollutants or waste materials either accidentally or intentionally released into the oceans (oil, nuclear waste).

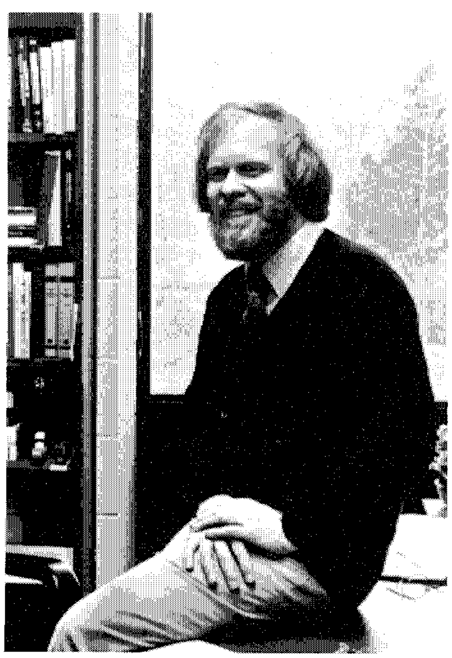
Particularly with regard to these latter materials, we need to know the answer to the following question. Given an initial distribution of tracer at some specific oceanic location, together with our knowledge of the ocean circulation (including currents, waves, and eddies on all scales), what will be the future distribution of the tracer as a function of time? For instance, the quantities of interest might be average properties of the tracer field, such as the movement of its center of mass or the breadth of the distribution about this center, or more detailed properties of the field such as its streakiness. Unfortunately, our present knowledge of the ocean circulation, even on its largest scales, is incomplete. Although field experiments are presently being planned to simultaneously measure flow fields and tracer dispersal at a few selected oceanic sites, we are far from being able to answer the general question posed above. (In fact, geochemists and physical oceanographers must often use the observed distributions of ocean tracers and knowledge of their source functions to infer the details of the large-scale ocean circulation itself. See, for example, the following discussion by Bill Jenkins.)

Fortunately, the use of theoretical and numerical models does provide a means of systematically measuring and characterizing tracer dispersal as a function of the strength and dominant scale of the circulation in which the tracer is embedded. With support from the Center for the Analysis of Marine Systems, Tom Keffer and I have begun a modeling study of this type. Using a mathematical model of the depth-integrated mid-ocean circulation – "the barotropic potential vorticity equation" – and choosing particular values for the associated oceanic environmental parameters, we begin by simulating a space/time series of mid-ocean streamfunction maps. Such a set of simulated flow field maps, generated from the mathematical model on the Woods Hole VAX-11/780 computer system, is shown in the figure at left.

Having generated this reference velocity field, we introduce an isolated spot of tracer into the ocean at some specific space/time location. Using the time-series of velocity fields provided by the circulation model, the evolution of the tracer spot can be determined. (The basis of this step is another mathematical model called the "advection-diffusion equation.") A time-history of the tracer distribution is thereby produced (see figure right). Since the ocean circulation – and our model of it! – is often quite turbulent or chaotic in nature, tracer spots released at different points may evolve quite differently. In order to determine the expected, or average, behavior of the tracer for the given flow



A small circular blob of tracer, approximately 100 kilometers in diameter, is released in the center of the first frame. Subsequent maps, separated by about one week in simulated time, show how the tracer is advected, dispersed, and fragmented by the oceanic circulation field shown in the figure opposite. The "cross-hairs" and inscribed ellipse, also superimposed on the other figure, show the location of the center of mass and the second moment of the tracer field, respectively. (The latter quantity is a gross measure of how far the tracer has spread away from the center of mass.) The tracer contour interval is indicated below each map.



Vicky Cullen

Dale Haidvogel

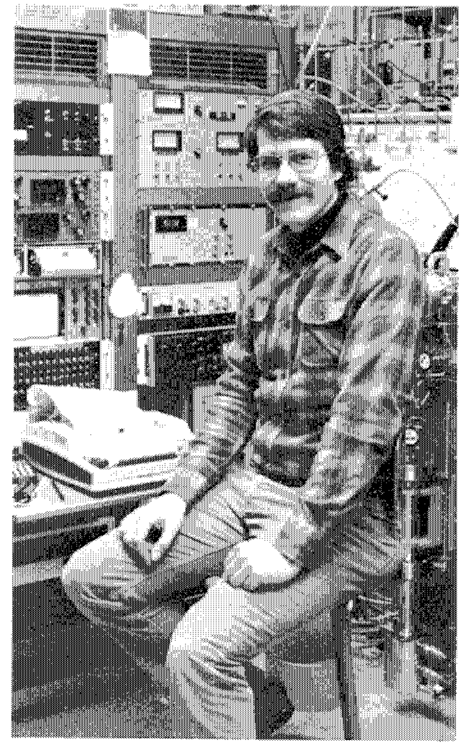
field, we must build up an ensemble – that is, a sequence – of independent tracer releases. Using computer models of the kind described here, it is possible not only to accumulate such a sequence of tracer release simulations for a given velocity field, but also to vary independently the character of the flow field. As a result, we are beginning to deduce with some statistical confidence the average properties of the tracer dispersal process over a wide range of oceanic conditions.

Using theoretical and model results like these as input, direct field observations of tracer dispersal from an implanted, isolated spot are being planned for the near future. One such proposed effort, the Deep Ocean Tracer Release Experiment (DOTREX), will involve investigators from England and the United States including several participants from Woods Hole.

CHEMISTRY AND OCEAN PHYSICS

William Jenkins

As mankind's activities increasingly influence the environment, we find a pressing need to understand the complex and often delicately balanced world that surrounds us. This is particularly true for the oceans, since they play a pivotal role both in climate and in the large-scale geochemical and biological systems of our planet. Learning about the rates, magnitude, and mechanisms of chemical and physical transport in the oceans is of prime importance for many activities: exploitation of oceans as a resource (both for food and minerals), deliberate disposal of wastes (e.g., chemicals and radioactivity), and the uncontrolled dispersal of pollutants such as fossil fuel carbon dioxide (CO_2). This last problem is an extremely important challenge to modern oceanography. The unrestrained burning of the fossil fuels is releasing substantial amounts of carbon dioxide and other substances into the air. Whereas many of these pollutants are felt on local and regional scales (for example, acid rain), the carbon dioxide released will affect us on a global scale: its absorption of infrared radiation will alter the climate balance of the entire earth, changing patterns of precipitation and temperature. Ultimately the bulk of this fossil fuel carbon dioxide will be adsorbed by the oceans. In fact, it appears about half of the CO_2 already released has already been taken up; but the question of how much more will be taken up, and how rapidly, remains to be answered. The rate at which the CO_2 is taken up is largely limited by how rapidly the CO_2-laden waters are transported from the ocean surface to deeper layers. But these transport processes are themselves driven and controlled by the climate which will be affected by the CO_2. This, coupled with the fact that these processes cannot readily be measured in any direct way (due to their "statistical" nature), makes the problem particularly acute.


Vicky Cullen

Bill Jenkins

Fortunately, the problem can also hold the key to its own solution. We have also released other substances into the environment which travel much the same pathways as carbon dioxide will into the oceans, so that by observing their passage we can make predictions about CO_2. Inasmuch as the nature and behavior of these transient tracers are varied and may differ somewhat from CO_2 in subtle ways, it behooves us to look at as many of them as possible. (They are called "transient" because their distribution is changing in time, and "tracers" because they are found in *trace* amounts once dispersed.) In a sense, the unique characteristics and mode of release of each of these tracers serve to highlight different processes in the oceans so that we can separate individual parts from the com-

Some of the Participating Institutions in the Transient Tracers in the Ocean Program

Lamont Doherty Geological Observatory (Columbia University.)
Massachusetts Institute of Technology
Princeton University
Scripps Institution of Oceanography
University of Miami (RSMAS)
University of North Carolina
University of Washington - NOAA (PMEL)
Woods Hole Oceanographic Institution

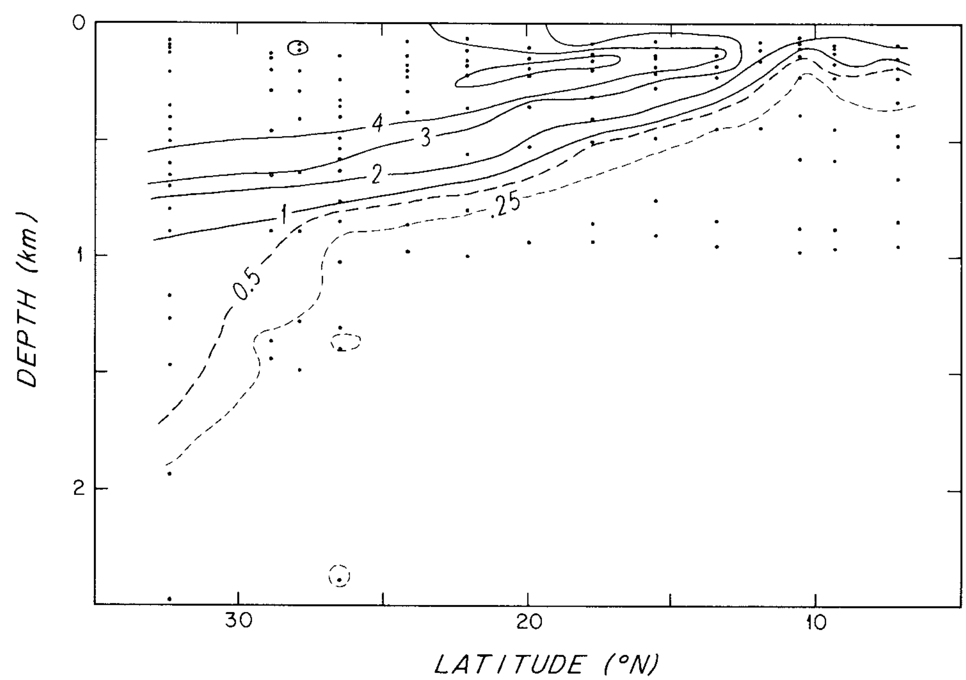
plexity of the whole. In the end we would like to construct a "model" or mathematical description which satisfactorily explains all the tracer patterns we see and allows us to predict with confidence the future of the CO_2 problem.

In recognizing the power of this approach and the dire need for pursuing this goal, the Department of Energy and the National Science Foundation are jointly sponsoring a major oceanographic program called Transient Tracers in the Ocean. Although the program is a multi-institutional, national effort (see table) it was coordinated here at Woods Hole Oceanographic Institution by Dr. Peter Brewer. After a test cruise in late 1980, the major field work was embarked on this year as a seven-month, 16,000-mile cruise aboard the R/V *Knorr*. During this intensive effort about 250 stations were occupied for geochemical sampling, and many thousands of analyses were performed. More important, however, were the additional thousands of samples returned to laboratories ashore for what will be several years of careful, difficult measurements of exotic and extremely rare substances. The second table summarizes some of these tracers.

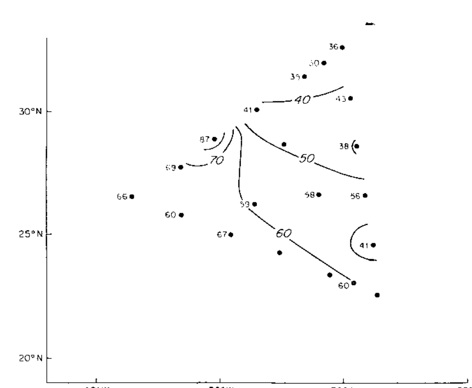
The data eventually obtained from these measurements will prove vital in verifying and refining our knowledge of ocean transport processes. Meanwhile, we are learning much from what observations already have been made for some of these tracers. A particularly useful tool is the combination of nuclear weapons-produced tritium (radioactive hydrogen, ^3H, half-life 12.45 years) and its stable, inert daughter, ^3He. A very graphic outline of how chemicals move in the ocean can be seen in the penetration of this tritium southwards toward the equator in the Atlantic (see upper figure). The intermediate tongue of tritium-rich water is seen penetrating southward below northward flowing tritium-poor southern surface water and deeper uncontaminated water. What is even more informative, though, is to track the flow of water as the daughter of the isotope, ^3He, builds up. This provides us with a visible clock to measure the subsurface velocities because we know not only the rate at which the ^3He is produced, but also that it is not altered by chemical or biological processes. The figure at right shows a plan view of this "tritiugenic" ^3He in a 1,000-kilometer wide triangular study area in the North Atlantic (see "The Beta Spiral" by Henry Stommel in the 1980 Annual Report). The clear and gradual increase of tritium toward the southwest gives us a measure of the direction and the speed of the flow – here about 1 centimeter per second or about 300 kilometers per year. These kinds of measurements can, in turn, be used to estimate rates of chemical or biological reaction in the marine envi-

Some of the Tracers Measured in the Transient Tracers in the Ocean Program

Element	Comments
Oxygen, salinity and nutrients	Measured in the ships
CO_2, alkalinity, pH	Measured in the ships
Trichlorofluoromethane ("freon 11")	Measured in the ships From spray cans, refrigerants
^{14}C	Bomb-testing produced, half-life about 5,000 years, follows CO_2
^3H (Tritium)	From bomb tests, half life 12.5 years
^3He	Daughter of tritium
^{85}Kr, ^{137}Cs, ^{90}Sr	From nuclear fuel reprocessing
^{39}Ar	Natural tracer (requires 1,000 liters of water), half-life about 300 years



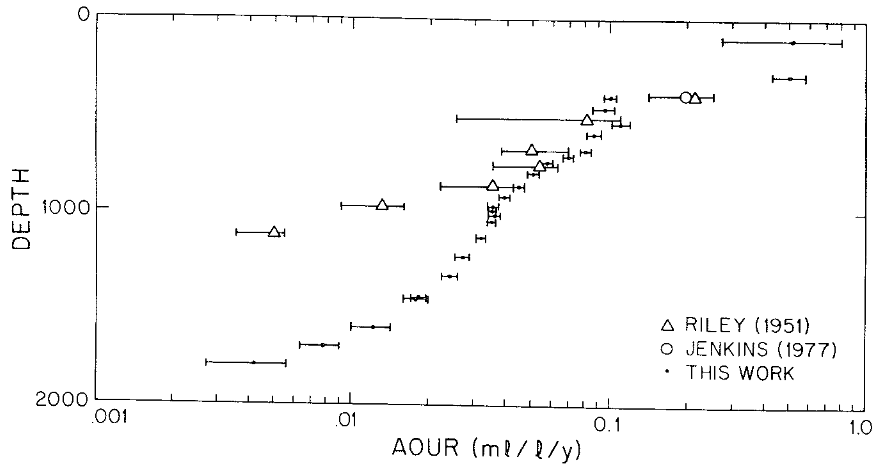
Note in this tritium plot along 38° West in the North Atlantic Ocean the upward and southward penetration of a tongue of high tritium at a few hundred meters depth.



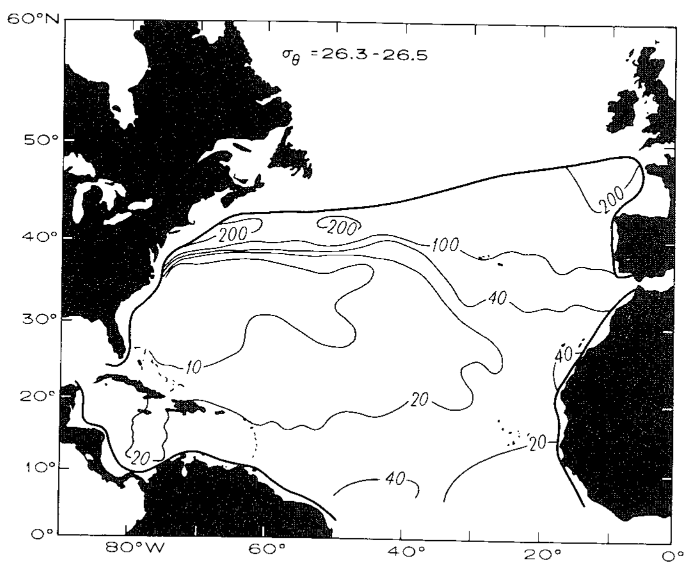
Excess helium-3 is shown on a density level in the eastern subtropical Atlantic. As the water drifts from the northeast to the southwest, helium-3 builds up from the decay of tritium, providing us with a means of dating the water's passage and measuring its velocity.

ronment. For example, the penetration of tritium and ^3He into the Sargasso Sea coupled with oxygen saturation anomalies allows an estimate of oxygen utilization rates (see figure at right).

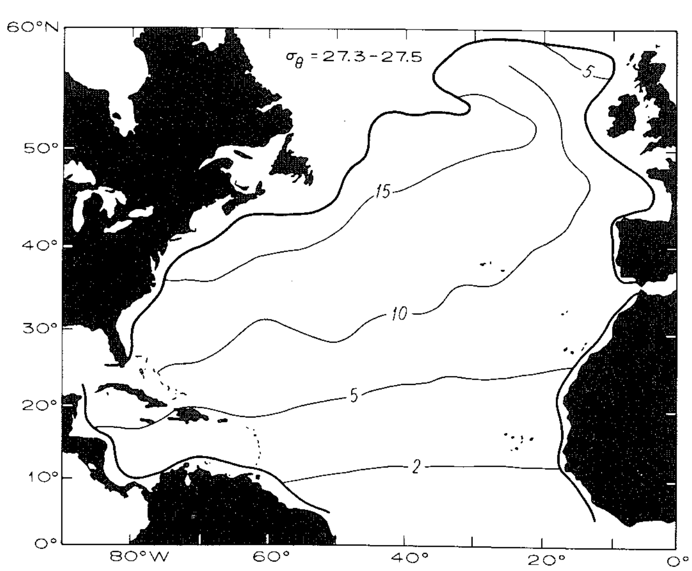
The above are just a few examples of the powerful tools and techniques that are available through the study of transient tracers in the ocean. As we follow the progress of these tracers, as we obtain more data and open new doors by measuring new tracers, we learn much about the rates and natures of the processes at work. Our ultimate goal of a complete and quantitative understanding of these processes is still distant, but over the next few years many important strides will be made.



The apparent oxygen utilization rate (AOUR) is shown as a function of depth in the Sargasso Sea. The dating of water masses by transient tracers allows us to estimate the rate at which oxygen is consumed in the sea by biological processes.



In this chart of the potential vorticity of the North Atlantic, the curves are the idealized flow paths in the upper few hundred meters. The clockwise circulation is driven predominantly by wind.



This is a similar chart of flow paths at depths greater than those of the wind-gyre. Here paths can be seen connecting the cold-water formation areas of the far north to the deep ocean beneath the wind-gyre.

'TRACING' THE OCEAN CIRCULATION

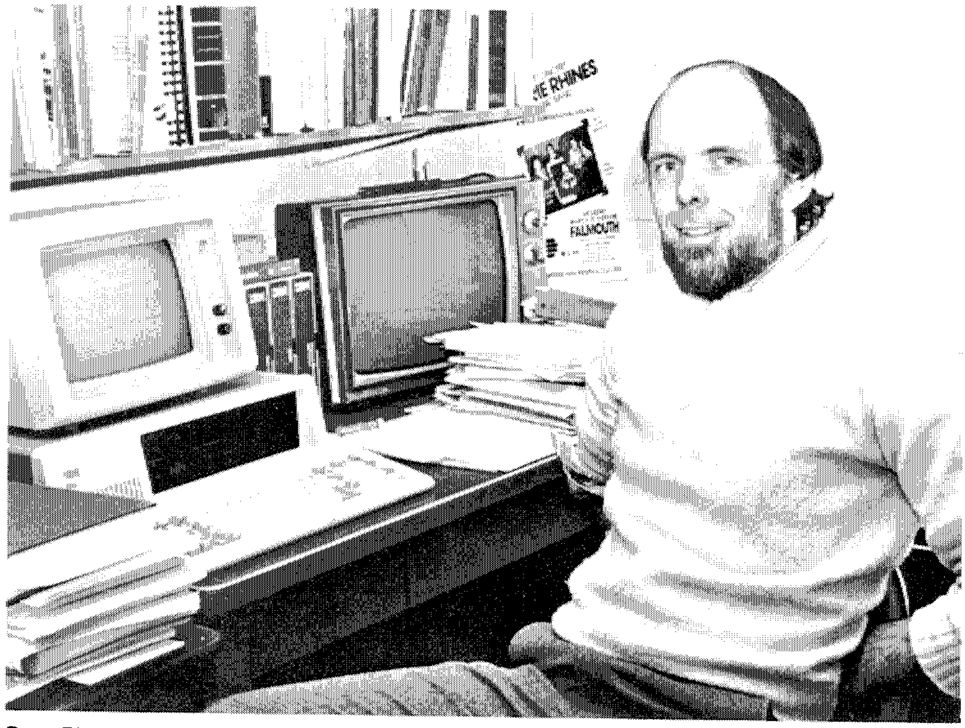
Peter Rhines

In searching for general principles that govern the ocean circulation, the scientists Hans Ertel and Carl-Gustaf Rossby in the 1940s came across a quantity called potential vorticity. Unlike most dynamical quantities – momentum, velocity, or pressure, say – the potential vorticity of a given patch of seawater remains nearly constant along its track. We can make charts of potential vorticity and interpret them as road maps for the large-scale circulation. In the mean, water should move along curves on these maps corresponding to constant values of potential vorticity. If the curves bend too sharply or if the speed of the flow is too great, the water may run off the path. Winds, cooling at the sea surface, and small-scale turbulence all may modify this principle, but the simple patterns (see figures left) do seem to relate strongly to the directions of flow. In the top few hundred meters of water we see closed circuits suggesting gyres of flow, and deeper down there appear great open pathways running from north to south. These latter relate to the 'ventilation' of the deep sea from high latitudes, where surface waters are forced to sink by severe winter weather.

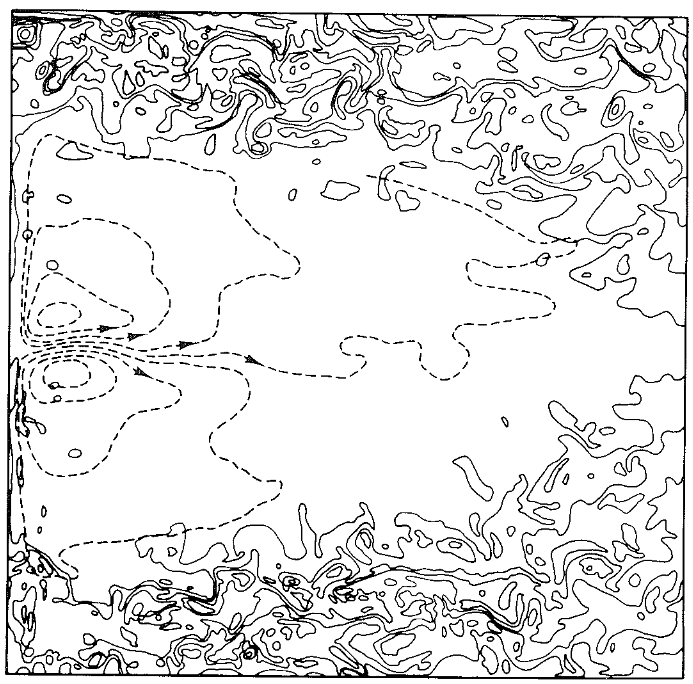
What determines potential vorticity? One contribution is from the Earth's rotation, which has a powerful hold on the circulation. Another is the height of a water parcel which may change as it moves about. If the sea were to move very slowly, the pathways of constant potential vorticity would simply be circles of latitude. Because the continents stand in the way of these paths, the only conclusion can be that the water must come completely to rest. This seeming paradox yields a useful prediction: in order to circulate at all, the oceans must develop sufficient speed that their height changes can bend these paths away from latitude circles (very much as we find them in the figures).

These sentiments can be turned into a mathematical theory of the circulation. William Young, a WHOI/MIT graduate student, and I have found that the theory yields a strange prediction: this key quantity, potential vorticity, can be spun round so intensely by the circulation that it mixes to a single uniform value within a region like the Sargasso Sea. We confided this result to computer modeler William Holland at the National Center for Atmospheric Research, who found that this "expulsion" of potential vorticity from a wind gyre actually occurs in computer simulations (see figure at right). Similar regions of uniform potential vorticity also appear in our maps of the oceans.

An important tool in studies of ocean circulation is trace chemistry. Like potential vorticity, dilute but measurable chemical compounds mark the water so that it can be observed and followed. Carbon dioxide from fossil fuels, freon from refrigerators, and nuclear debris from bomb tests are ingested through the sea surface and enter the serpentine circulation. For example, William Jenkins and I recently found the deep boundary current at the floor of the Sargasso Sea to be tainted with tritium from nuclear weapons tests. It could only have entered the ocean at its surface, some 4,000 kilometers to the north. Major observational studies like the *Knorr's* seven-month North Atlantic transient tracer survey of this past year thus have a dual role: to enable us to follow specific pollutants of concern to society and to help understand the basic physics of the circulation. To help with the clearly interdisciplinary nature of this problem, the WHOI Center for Analysis of Marine Systems (CAMS) has undertaken a multi-year program on transport and exchange in the seas. An important event took place in March 1981, when more than 40 oceanographers from the U.S. and Europe met at CAMS to discuss both theory and observations of the seemingly endless list of chemical tracers.


Vicky Cullen

Peter Rhines



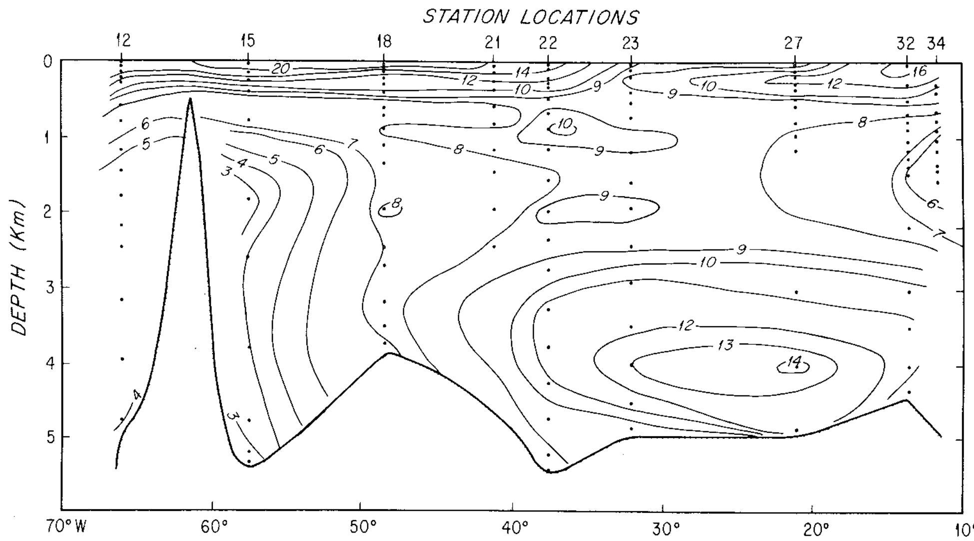
Accurate maps of potential vorticity would show chaotic stirring by ocean eddies, as well as the large-scale variation shown in the first figure. Here, a computer simulation by William Holland of the National Center for Atmospheric Research shows the eddy stirring at the edges of the wind-driven gyres, while inside the wind-gyres the potential vorticity has mixed to a uniform value. The time-averaged circulation follows the dashed curves. The "Gulf Stream" jet separates from the western wall of this idealized square ocean.

MODELING CHEMICAL DISTRIBUTIONS IN THE OCEAN

Derek Spencer

The chemicals that constitute the ocean are many and varied. Almost all of the elements known to man have been detected in seawater, a few in quite high concentrations, e.g., sodium at 10 parts per thousand, but most at concentrations less than one part in one billion and many at less than one part in one trillion. These concentration differences are due to a number of factors but principally to the differing reactivities of the elements. In general, those that are not reactive have long residence times dissolved in the ocean and consequently high concentrations. Those that are highly reactive tend to be removed from the ocean only a short time after they have been introduced and the removal processes, which are both biologically and chemically mediated, are of considerable interest to oceanographers. Many pollutant materials are reactive, and their behavior in the ocean can be predicted from the behavior of similar reactive natural substances.

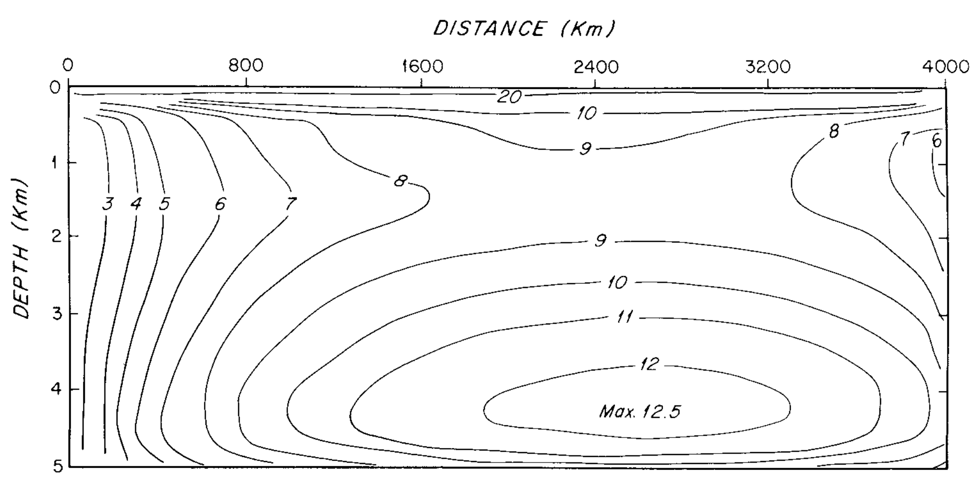
In the annual report of last year, Michael Bacon discussed the behavior of a natural radioisotope, lead-210, which is produced continually in the ocean by the radioactive decay of another isotope, radium-226. Radium, which is an element like barium, is not too reactive and consequently has rather a long residence time. In contrast lead is highly reactive and an atom of lead-210, after it is produced, spends only about 50 years, on the average, in the ocean before it is removed. Until recently, it was believed that the principal removal mechanisms for reactive heavy metals like lead were solely by biological uptake in the surface ocean and by adsorption on settling particles at depth. As Bacon showed, there are aspects of the distribution of lead-210 that cannot be easily explained simply by these two processes. We now believe that there is a significant flux of lead-210 into the ocean boundaries that is driven by chemical cycling processes taking place within the upper regions of the sediment.



Distribution of lead-210 in a transatlantic section.

The first figure shows the section of lead-210, across the tropical North Atlantic, Bacon used to illustrate that the concentrations of this isotope decrease everywhere as the slope and deep ocean boundaries are approached. The increased concentrations at the surface are due to the fact that in the radioactive decay chain from radium-226 to lead-210 there is another isotope, called radon-222, which is a gas and which has a half life of only 3.5 days. As the radium in the continents decays, it produces radon which diffuses very quickly in the atmosphere over the ocean where decay to lead takes place producing a flux of lead-210 to the ocean surface. In the ocean, the diffusive processes are much slower and except in special circumstances the existence of the intermediate isotope does not affect the distribution of lead-210 that is derived from the decay of radium-226 in the ocean.

Several questions occur if lead-210 is being removed at the boundary. Two of the most important are: How much needs to be removed to produce a dis-



Calculated model lead-210 distributions on a hypothetical transatlantic section assuming fluxes into the side and bottom boundaries.

tribution similar to that observed in the first figure? Is the amount removed consistent with what may be found in ocean sediments? These questions can be addressed by attempting to model the distribution of lead-210.

One of the simplest models that can be applied assumes that the slice of the ocean, shown in the first figure, may be considered a two-dimensional ocean in which there are no currents and the water mixes purely by diffusion. It also assumes that in any place on the section, the gain of lead-210 (by diffusion from elsewhere, by production from radium-226, or by atmospheric flux) is equal to the loss of lead-210 (by diffusion to elsewhere, by radioactive decay, by biological uptake in the surface layers, by adsorption on particles at depth, and by fluxes into the boundaries). These statements can be formulated into a mathematical equation which may be solved using computers. The second figure is the result of one such solution produced by using ocean mixing rates and atmospheric fluxes determined by others and experimenting with suitable values for the in situ and boundary removal rates until a satisfactory fit could be found. The model predicts the major features of the data shown in the first figure. It also predicts boundary fluxes that are much larger at the continental slopes than at the deep ocean floor. Recent data has confirmed that major differences in the fluxes of lead-210 to slope and abyssal regions actually exist and the magnitude of the fluxes is similar to those predicted by the model.

Although such models are useful tools for gaining insight into the feasibility of certain processes, we must be constantly aware that the real ocean is not as simplistic as they depict. The models are not necessarily unique, and other assumptions or approaches could produce results that may be equal or more satisfactory when all aspects of the ocean are considered. Another major limitation of these models is that they tell us nothing about the actual physics, chemistry, or biology of the mechanisms that the ocean uses.

Vicky Cullen

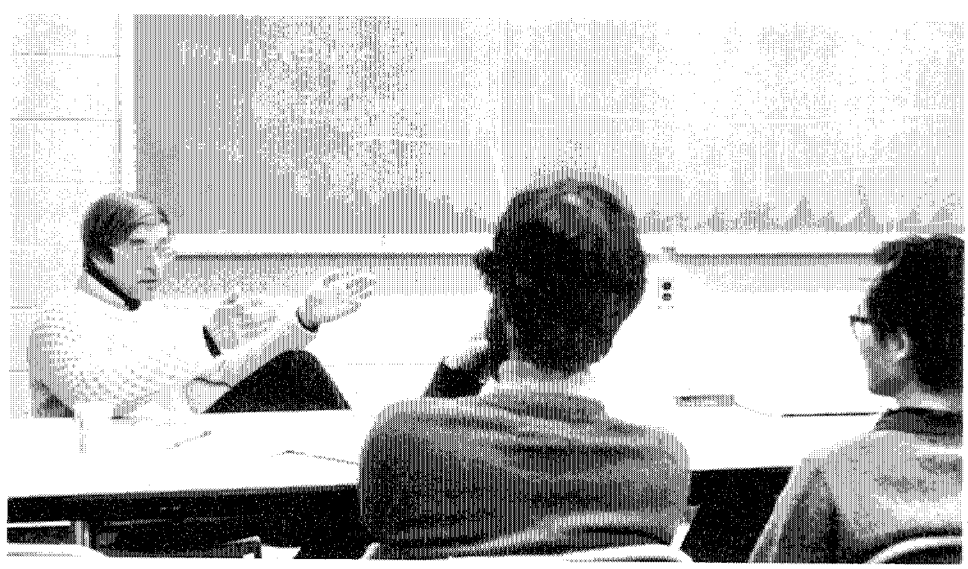
Derek Spencer

MATHEMATICAL THEORY OF FINITE AMPLITUDE BAROCLINIC WAVES

Joseph Pedlosky

In our mental picture of the ocean, large parts of it are dominated by transient eddies and current meanders. In a general way, we understand that the cause of the unsteadiness can, in large part, be attributed to the hydrodynamic instability of the intense oceanic currents and, to a lesser and unknown extent, to the instability of the gentler mid-ocean flow itself. In any oceanic current whose velocity is not uniform with depth, the effect of the earth's rotation is to tilt the ocean's density surfaces within the current so that they slope in a direction perpendicular to the direction of the flow. These tilts in the density surfaces represent a store of gravitational potential energy, and eddies can grow, feeding on the potential energy by an instability process which tends, on average, to level out the tilts in the density surfaces. This instability which feeds on the available potential energy of the otherwise steady flow is called baroclinic instability. The theory of baroclinic instability is one of the basic building blocks used to construct our conceptual image of the dynamic ocean, and yet it is fair to say that the basic dynamics of the instability is incompletely understood. Although a considerable body of theory exists to explain the initial development of a very small perturbation flow caused by the instability, our understanding of the perturbation dynamics becomes shakier as the instabiltity causes the originally infinitesimal perturbation to grow to a substantial and finite amplitude.

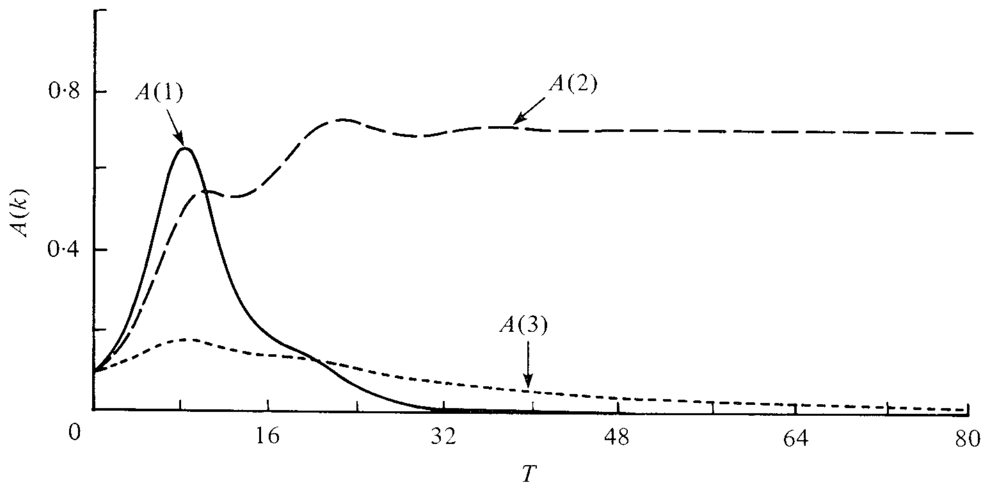
I have tried to understand the dynamics of finite amplitude perturbations by



Vicky Cullen

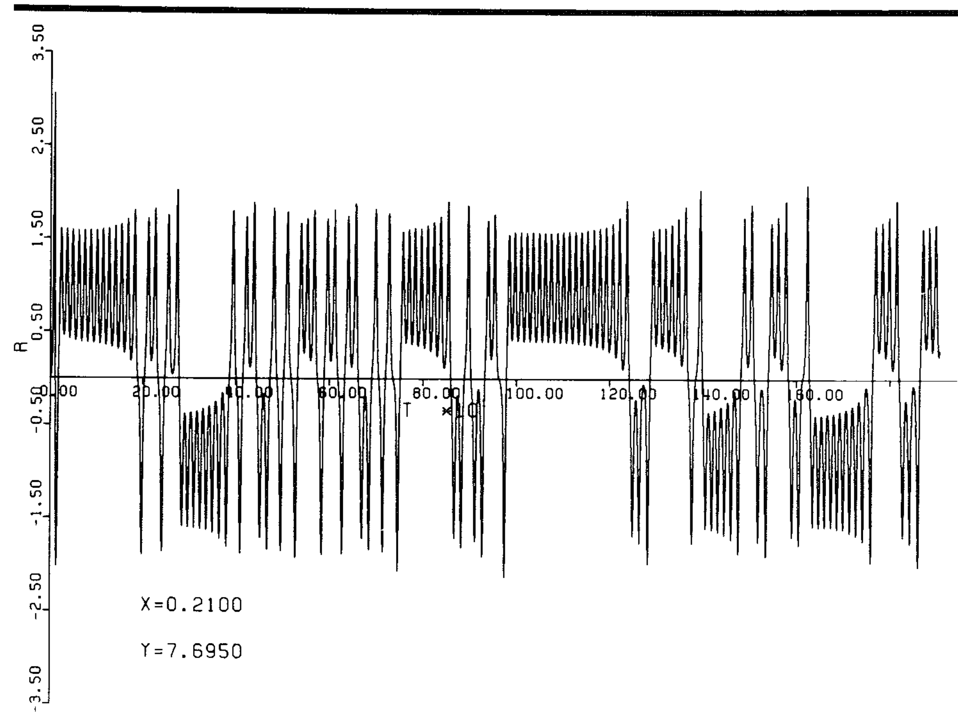
Joe Pedlosky teaches "Instabilities and Turbulence in Geophysical Systems."

formulating mathematical theories for the development in time of the perturbations in idealized currents which are just intense enough to be above the threshold of instability. The theories then predict the emergence of wavelike perturbations to the flow, and the chief object of the theory is to describe how the amplitude of the wave perturbation evolves with time. As each wave grows, it tends to reduce the potential energy available for further growth so that eventually this nonlinear feedback of the wave on the current will tend to choke off further growth. This much is intuitively obvious and requires no special theoretical argument. There are, however, some rather more surprising predictions of the theory. One thing we would like our instability theory to predict is the horizontal wavelength (i.e., the lateral size) of the perturbation we should expect to observe. Since the growth rate of an initially small disturbance depends strongly on its wavelength, the conventional wisdom of linear theory suggests that we should observe waves whose lengths correspond to the maximum growth rate. However, the nonlinear theory suggests otherwise. The results of the theory (upper figure) predict that the most unstable wave will not generally survive a competition of several waves for the potential energy stored in the current. Although it may grow the fastest and initially may dominate the wave response, it peaks at an amplitude small enough so that energy is left for a more slowly growing wave but one more efficient in extracting the maximum amount of energy from the current. As this more voracious feeder grows, it leaves no energy source for the first wave, which then decays due to frictional dissipation. The result is a perturbation field dominated by a wave whose wavelength is much larger than the one predicted by the linear theory applicable to infinitesimal waves.



Plot shows the development with time of the amplitudes of three waves of different wavelengths embedded simultaneously in an unstable flow. Initially, all three waves have the same amplitude. The most unstable wave, $A(1)$, grows fastest, but after reaching a peak inexorably declines and is replaced by a slower growing wave, $A(2)$.

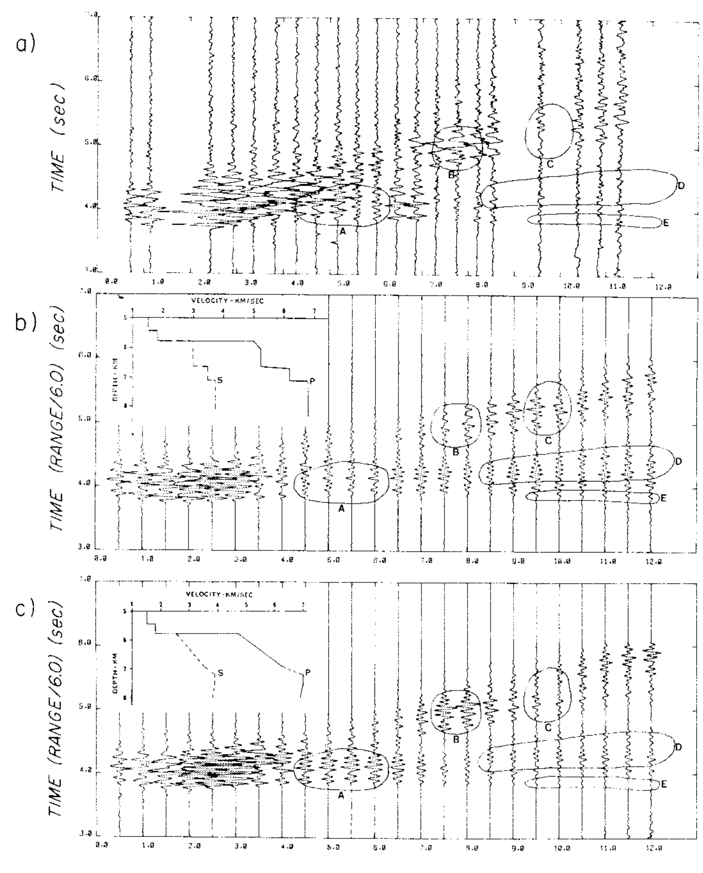
In the example shown in the upper figure, the surviving wave reached a state of steady amplitude, i.e., it was a propagating wave whose overall intensity remained fixed with time as the extraction of potential energy by the wave exactly balances frictional dissipation within the wave. This case typically occurs when the wave dissipation is large enough. For a wave whose configuration is such that dissipation is much smaller, the final wave amplitude need not be steady. Instead, the wave amplitude may well grow, reach a maximum, and then *decay*, temporarily returning energy to the current until a minimum amplitude (sometimes vanishing) is achieved and the process repeats. This pulsation of the amplitude may be completely periodic or, in some especially interesting circumstances, the time history of the wave predicted by the theory may have an apparently chaotic behavior with time (see lower figure) where no periodicities are apparent.



The time history of the amplitude of an unstable baroclinic wave is shown. Its interaction with the current produces an apparently chaotic, random behavior although the governing physics is perfectly deterministic.

SYNTHETIC SEISMOGRAM TECHNIQUES

Ralph Stephen



This is an example of a typical amplitude interpretation of an observed seismogram (top). Each trace is a plot of the amplitude of the sound as a function of time for a particular range. The compressional (P) and shear (S) velocity profiles for the synthetic seismograms (middle and bottom) are shown in the upper left hand corner of each diagram. Regions of significant amplitude behavior have been circled. Since the lower synthetic seismogram matches the observed data best, we conclude that the oceanic crust in this area (Western Atlantic) consists of gradually increasing velocity material rather than discrete layers of material.

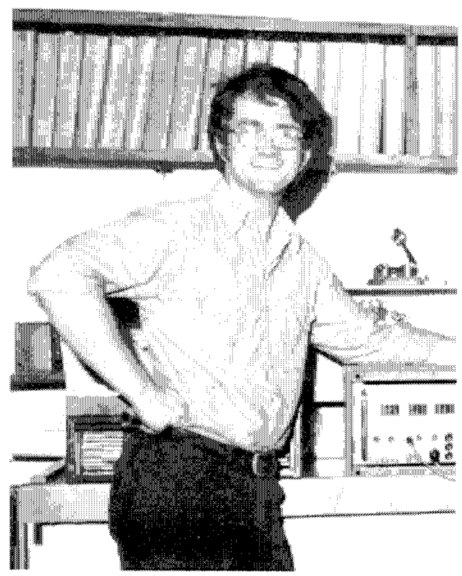
Synthetic seismogram techniques have played a major role in determining the structure of the earth beneath the oceans. The work at WHOI concentrates primarily on modeling seismic wave propagation from explosive or air gun sources to radio sonobuoys, ocean bottom hydrophones, or borehole geophones. By applying synthetic seismogram analysis, it is possible to study the amplitude and phase of the sound as well as its travel time.

Because of the complexity of the elastic wave equation, it is generally impossible to invert the observed seismograms directly to an earth model. The common procedure for interpretation is to generate the synthetic seismograms corresponding to a postulated geological model and to compare these with the observed data. The trial-and-error process continues until a "good" fit is obtained. This procedure was used in the early seventies to demonstrate that oceanic crust did not consist of constant velocity layers but rather of layers with varying velocity gradients.

The new insights in seismology had counterparts in the geological interpretation. The old model of constant velocity layers encouraged geologists to think in terms of constant material layers, and the rock type of each layer was hotly debated. However, with the improved insight of gradients in the crust, the effect of cracks and fractures became a key issue. The velocity structure may not be dominantly affected by rock type but rather by porosity. The increase of velocity with depth in the crust may simply reflect decreased porosity which is a consequence of the increasing overburden pressure. Drilling is the only means of establishing what rock types actually exist in situ in the crust. Furthermore, particle motion analysis of three-component borehole seismometer data indicates that the fractures in oceanic crust have a preferred alignment which causes seismic anisotropy.

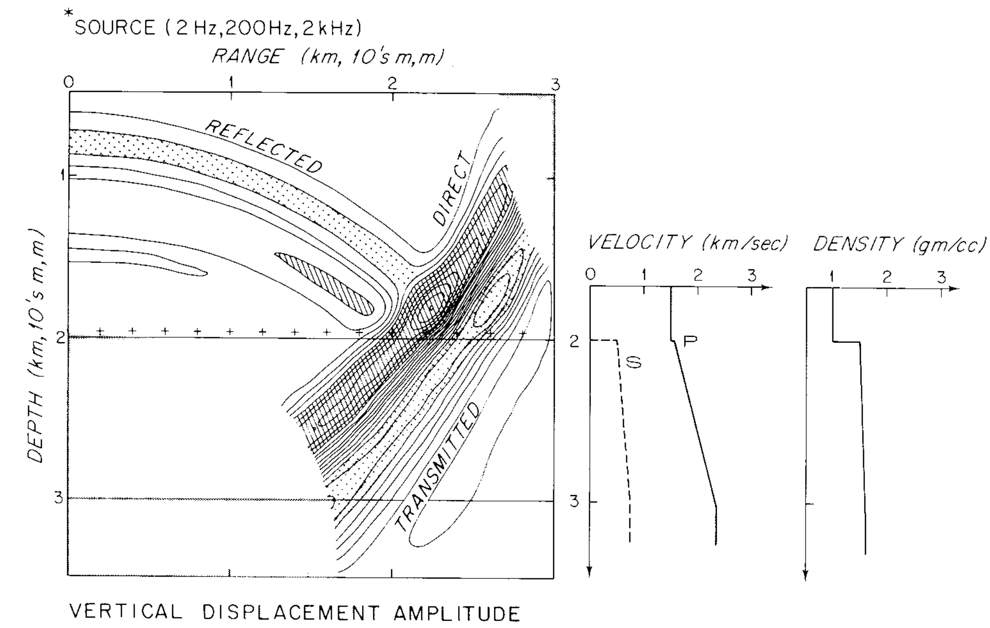
Synthetic seismogram analysis has also been applied to the study of shear waves in oceanic crust. Since water flows, it will not support shear waves, and explosive charges or air guns in the water column are pure compressional sources. It is tempting to assume that, with both sources and receivers in the water, only compressional waves need be considered in an interpretation. This is not the case. Under certain circumstances shear waves can be generated when the incident compressional wave hits the water/basement or sediment/basement interface and shear waves incident on this interface from below can convert back into compressional waves. The shear wave behavior in the basement affects the compressional wave amplitudes. It is necessary, therefore, to consider both compressional and shear wave velocity structures when interpreting a marine seismogram.

Until recently, synthetic seismogram methods assumed that the earth was laterally homogeneous (e.g., the reflectivity method). This assumption clearly



Deep Sea Drilling Project

Ralph Stephen



This contour plot of the amplitude of a sound wave serves as a "snapshot" in time. Reflected, direct, and transmitted waves due to interaction with the sea floor (+++++) are labeled. This picture, generated by a finite difference method, applies to high frequency sources (2kHz) over short distances (meters) or low frequency sources (2Hz) over long distances (kilometers). The gray, unlabeled regions are areas where the calculations are incorrect. Finite difference seismograms are a promising technique for studying seismic wave propagation through rough sea floor structures.

breaks down in studies of propagation in regions with rugged topography and strong lateral velocity gradients such as the continental margins, the mid-ocean ridges, and subduction zones. We have been developing synthetic seismogram techniques, based on the finite difference method, which are suitable for studying these structures. These methods are conceptually straightforward but require substantial computing facilities such as the VAX-11/780.

Before applying any synthetic seismogram technique, it is wise to confirm the accuracy of the solutions. This provides a check not only on the basic theory and approximations but also on errors and discrepancies in the actual code. Because of the complexity of the physical process, it is difficult to know from observation whether the results are correct, and the only viable approach is to compare results generated by fundamentally different schemes for the same model. We have compared the results of finite difference and reflectivity codes and obtained good agreement. (The reflectivity method is an established technique suitable for laterally homogeneous models only.) The next step is to apply the finite difference method to the interpretation of field data from the Rivera Ocean Seismic Experiment and the Bermuda Oblique Seismic Experiment.

As techniques are developed for carrying out rigorous inversions from the observed data to the velocity structure of the earth, synthetic seismograms will play an important role in generating ideal data sets for testing purposes. Clearly the inversion techniques must be consistent with the physical and mathematical theory of elastic wave propagation before they can be applied with confidence to the real data.

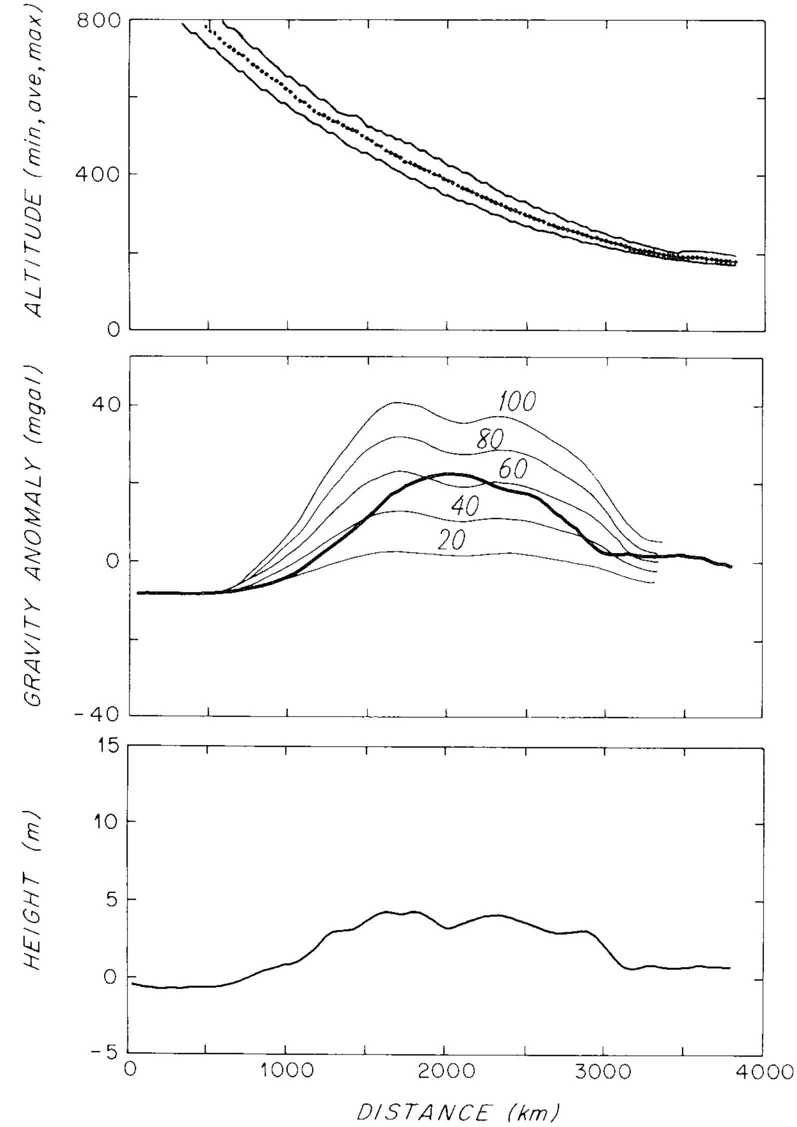
The process of science can be considered simply as observation and explanation. The understanding necessary to explain seismic wave propagation in the earth is provided by synthetic seismogram techniques.

GRAVITATIONAL MODELS

Carl Bowin

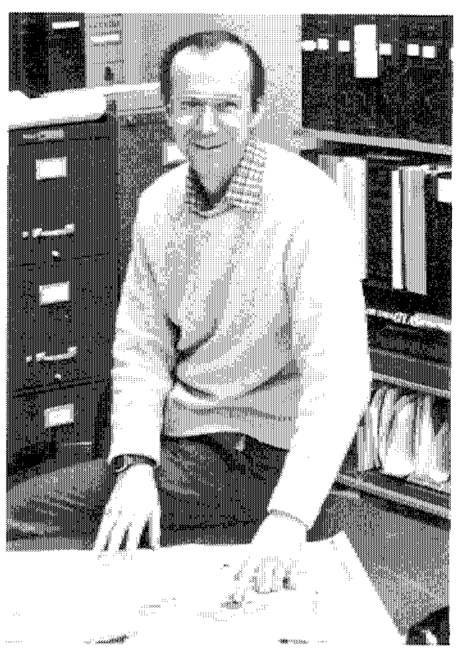
Gravity anomalies indicate irregularities in the distribution of mass within the earth. Topography is the irregularity in shape of the outer surface of the solid part of the earth. There can be large gravity anomalies where the topographic features are small, and, conversely, small gravity anomalies where topographic features are large. The relationship between gravity anomalies and topography is dependent on the distribution and magnitude of mass anomalies at depth within the earth as well as the mass due to the topography itself. This distribution of mass anomalies, in turn, is dependent upon the processes that created the features and the physical properties of the crust. Determination of the gravity anomaly over a topographic feature, then, can provide information on the nature of the distribution of mass irregularities beneath the topographic feature, and is a powerful way to study the structure of a planetary body. Development in the past few years of analytical techniques for quantifying the transfer function between topography and its gravity field has allowed more precise analysis of the structure of the earth.

If a gravity anomaly is small over a large topographic high, then there must be a mass deficiency at depth that offsets (compensates) the topographic mass excess at the surface. Such a condition is referred to as isostasy in which there is an inferred depth beneath the surface at which equal pressure is attained. Thus, for features in isostatic equilibrium, a mass deficiency (lower density material) occurs beneath regions with high topography; and a mass excess (higher density material) will occur beneath regions of topographic depressions. Within the earth for features having widths greater than about 200 kilometers this accommodation is largely achieved through undulations of the Mohorovicic discontinuity (commonly called the Moho) which is the boundary between the crust and mantle of the earth. Mantle material of high density rises closer to



Profiles are shown across Aphrodite along 85° E longitude on the planet Venus. The bottom profile shows the topography obtained from Pioneer Venus Radar Mapper data. The bold line in the center profile is the gravity anomaly obtained from Line-of-sight Doppler tracking data. The thin lines are predicted gravity profiles at 300 kilometers altitude above the Venusian surface calculated with the assumption of Airy isostasy for the topography. The predicted gravity curves are labeled with the assumed crustal thickness (in kilometers) used in each calculation. The uppermost profiles show the range and average of the Pioneer Venus gravity observations. A crustal thickness of about 60 kilometers matches best to the observed gravity measurements.

sea level (to about 10 kilometers depth) beneath the deep ocean basins of the world to compensate for the thickness of water which has low density relative to the crust of continents. Conversely, the Moho descends to great depths (40 to 60 kilometers) beneath high mountain ranges. The depth to Moho



Vicky Cullen

Carl Bowin

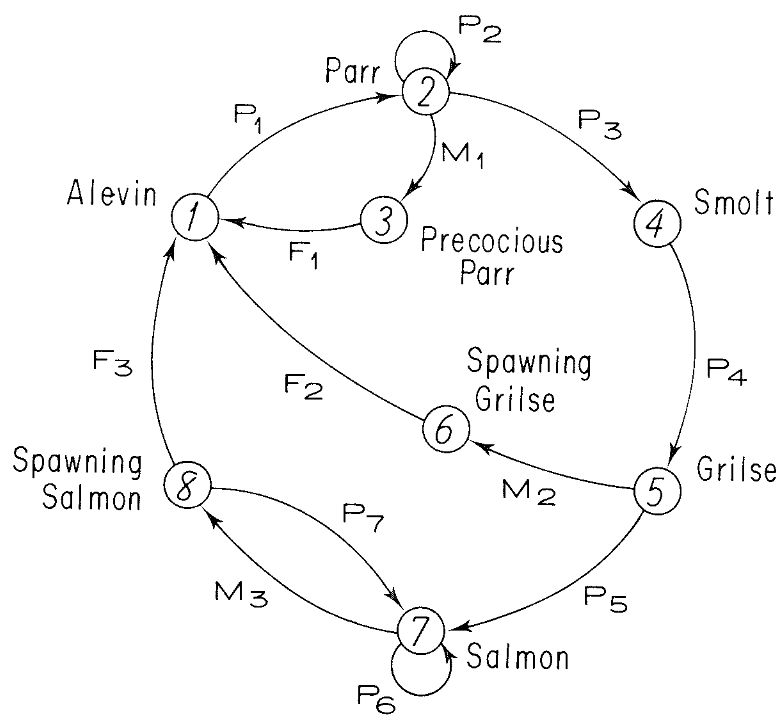
beneath continental plains of low elevation is close to 30 kilometers.

The transfer function is a model for the response of the earth's crust to a load placed on it. The load can be either an excess, such as a volcanic pile created during the birth and growth of a volcano, or a deficiency, such as occurred in the formation of the Grand Canyon in Arizona. With this technique, theoretical response functions can be calculated, converted into spatial filters, and applied to digitized topographic data. The result of applying (convolving) the spatial filter to topography is a predicted gravity anomaly that would be observed if the crust had that type of response function (see figure). The difference between the predicted gravity anomaly and the observed free-air anomaly is a measure of how likely it is that the earth is similar or not to a particular model. These results have demonstrated that ocean topographic features that have widths less than about 200 kilometers have response functions most nearly like those of a thin elastic plate lying upon an easily deformable mantle. The thickness of the elastic plate appears to range from just a few kilometers (2 to 5 kilometers) at the crests of ocean ridges where new ocean crust is being formed today to tens of kilometers where the crust of the ocean is old (more than 80 million years old). Thus the oceanic lithosphere becomes stronger with age as it cools and acts like an increasingly thicker elastic plate.

These techniques can also be applied to other planetary bodies. For example, the gravity anomaly over the western Aphrodite highlands region on Venus is greater than that which occurs over an earth feature of similar large size. Comparison of predicted gravity anomalies obtained by applying filters to the Pioneer Venus topography data (from the Radar Mapper) with the gravity anomalies determined from tracking the spacecraft suggests that gravity anomalies are greater in that region because the crust of Venus is thicker. At that location it is about 60 kilometers thick, roughly twice the thickness of the earth's continental crust. Thus, another clue is provided toward understanding why planets developed the way they have, and why the earth came to be the way we find it.

MODELING POPULATION DYNAMICS

Hal Caswell



In this life cycle graph for the Atlantic salmon, *Salmo salar,* major survival probabilities are denoted by Ps, maturation events by Ms, and fecundities by Fs. Future refinements of this graph will distinguish males and females and will include the possibility of repeat reproduction by precocious juvenile salmon.

The key to understanding population dynamics is the life cycle of the individual organism. Whether a local population increases or decreases, becomes extinct or persists, is ultimately determined by the environmental factors which govern its survival, growth, maturation, reproduction, and senescence. In the science of demography (the term is usually used in the context of human populations but applies equally well to other animals and to plants) researchers gather information on the stages of the life cycle, and the transitions between those stages, and try to deduce the implications for population growth.

Demographic theory was developed with the human life cycle in mind. In fact, A. J. Lotka, who single-handedly developed much of its theoretical basis early in this century, spent much of his career in the employ of a life insurance company. But the life cycle of humans (and most birds and mammals) is unusually simple. An individual is born, follows a relatively fixed growth schedule to reach maturity at a fixed age, reproduces sexually at a rate which is a well-defined function of age, and eventually dies. Such a life cycle can be completely described by two functions: the survivorship function l(x), which gives the probability of survival to age x, and the maternity function m(x), which gives the average number of offspring per individual aged x. Lotka showed how these functions could be combined to obtain the rate of growth (or decline) of the population, its eventual age distribution, the reproductive value of each age, and other aspects of the population's dynamics.

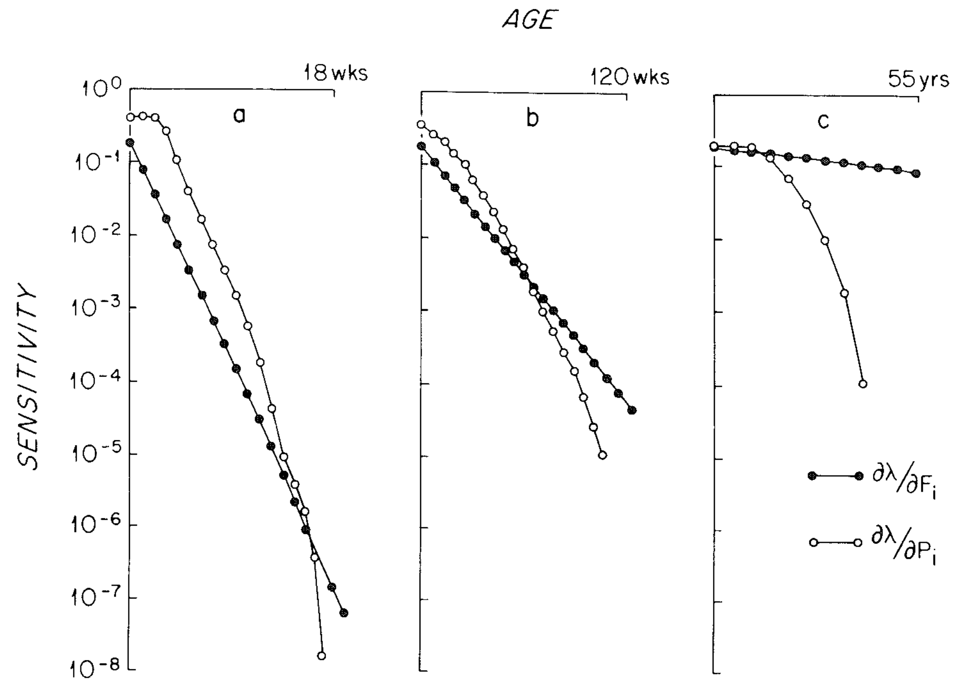
Unfortunately, the life cycles of some species are too complex for this theory to apply unmodified. Fish, trees, and many herbaceous plants, for example, have such plastic growth rates that the age of an individual tells us nothing about its survival or potential reproduction, though its size reveals a lot. Insects, copepods, cladocerans, and other arthropods go through a series of developmental stages or instars, the duration of which is markedly affected by the environment (especially temperature). Age tells little or nothing about the onset of maturity, but instar number may tell a great deal. Many organisms reproduce both sexually and vegetatively, and the offspring may be very different. It is not possible to calculate a single maternity function for such multiple modes of reproduction. Many organisms spend different parts of their life cycles in very different environments, in which they may experience very different survival probabilities.

A truly general demographic theory must be able to analyze life cycles in which individuals are grouped not only by age, but by size, developmental stage, spatial location, sex, or other factors. My research over the past several years has focused on this problem, and such life cycles can now be analyzed in detail, using techniques of matrix algebra. We are now beginning to apply this methodology to populations of Atlantic salmon (*Salmo salar*) at the WHOI Matamek Research Station. The salmon life cycle is diagrammed in the figure above. The construction of such life cycle graphs is the first stage in the analysis. Eventually we will obtain the consequences of such a life cycle for population growth, structure, and stability.

This sort of information is of obvious value for management, control, and harvesting applications since these decisions must be based on predictions of what the population will do in the absence of any intervention, but it has deeper, evolutionary implications, as well. Biologists often distinguish between proximate and ultimate factors in explaining phenomena. Proximate explanations of population dynamics focus on the environmental factors determining the values of survival probabilities, growth and reproduction rates, etc. Ultimate explanations seek evolutionary reasons for the pattern of the life cycle itself. Why do some organisms live for millennia, others for days? Why do some reproduce only once (e.g., Pacific salmon, periodical cicadas) while others reproduce repeatedly? Why do some produce huge numbers of tiny offspring while others produce only a few large offspring? Why do some reproduce sexually, others asexually? The list could go on and on, for the diversity of types of life cycles is truly enormous. To what extent is it possible to explain this diversity in evolutionary terms?

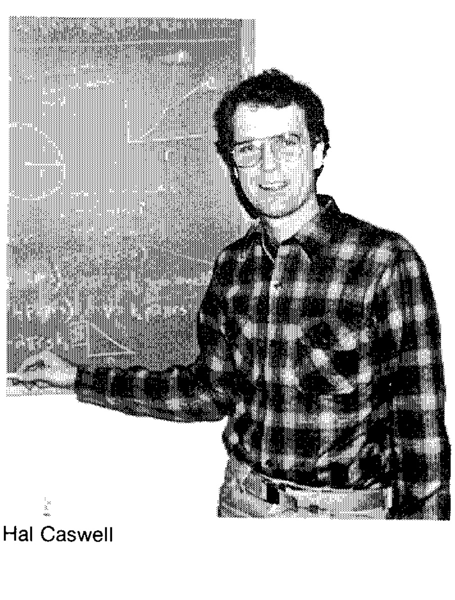
To predict the outcome of evolutionary pressures on the life cycle, we need a connection between demography and natural selection. This connection is provided by the notion of fitness. Fitness is a measure of the rate at which a genotype propagates itself into future generations; genotypes with higher fitness will increase in frequency over time. Population genetics theory measures fitness by the rate of population growth (λ) obtained from the life cycle graph. The evolutionary effect of possible life history shifts is given by their effect on λ. The more positive the effect, the more strongly the shift is favored by selection, and vice versa.

This fitness sensitivity has been worked out for general, complex life cycles. We have found that it can be expressed simply in terms of the matrices corresponding to the life cycle graph. Our results have shown that λ is much more sensitive to some life history alterations than to others. In age-classified life cycle models, for example, there may be six to seven orders of magnitude difference between the effect of changes in survival or fecundity at the beginning and the end of the life cycle (see figure at right).



The sensitivity of population growth rate (λ) to changes in age-specific fecundities (F_i) and survival probabilities (P_i) for three populations: (a) a laboratory population of the flour beetle *Calandra oryzae*, (b) a laboratory population of the vole *Microtus orcadensis*, (c) the human population of the United States as of 1965. Note the different age scales on the three graphs.

Our current work is focusing on application and extension of these results. It may even be possible for evolutionary changes to intrude into the realm of resource management. Atlantic salmon stocks are currently under heavy fishing pressure on the high seas. There has recently been an increasing incidence of precocious maturation of male parr (juvenile salmon) in some populations. These males reproduce without going to sea at all. They sacrifice some fitness by losing growth and fecundity, but they also miss out on considerable pre-reproductive mortality. It is known that precocious maturation has a genetic basis; is it possible that this is a genuinely evolutionary life history shift? If so, it is of considerable importance for the future of this fishery. An analysis of this life cycle can suggest conditions under which such a shift would be favored by selection.



Vicky Cullen

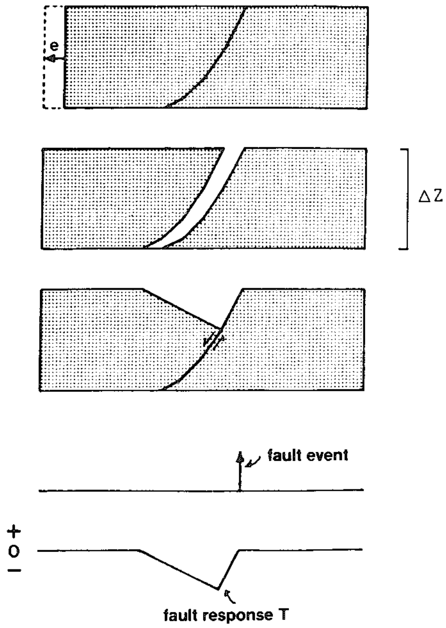
Hal Caswell

MODELING OF SEA-FLOOR TOPOGRAPHY

Hans Schouten
and Charles Denham

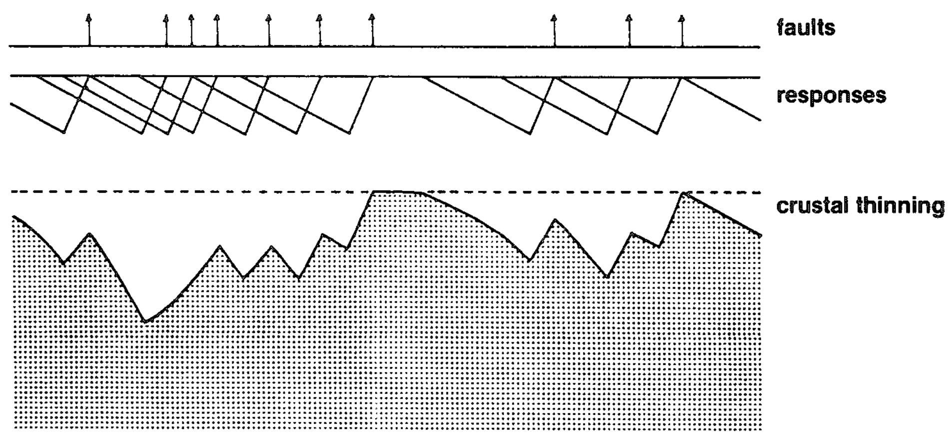
The topography of the oceanic crust is generated at the mid-ocean spreading center principally by the irregular accumulation of volcanic lava flows, followed by extensional faulting and tilting as the material moves laterally in the sea-floor spreading process. These latter "tectonic" forces account for most of the topographic relief that is seen by echosounding depth-recorders in deep ocean areas. If the tectonic mechanism were consistent over long periods of geological time, then a bathymetric profile would consist of the superposition of numerous similar-looking geometrical shapes that we call "faulting responses" or "thinning responses" (see figures at right). We have been studying the bathymetry of the Atlantic mid-ocean ridge near the FAMOUS area (36.5° N latitude) to discover the average faulting response for the region. The purpose is to characterize the tectonic faulting mechanism by a few statistical parameters that can be related to the type of spreading center under study. In particular, we want to know if fast-spreading centers (e.g., Pacific) produce a significantly different kind of topography than do slow-spreading centers (e.g., Atlantic).

We have discovered that the characteristics of the FAMOUS (French-American Mid-Ocean Undersea Study) area topography can be described by a mere three numbers. This "inverse wavelet" accounts for 99 percent of the statistical character of the region as determined by a method in time-series analysis called "least-squares inverse-filtering." The technique uses the autocorrelation (a measure of how well part of a curve resembles other parts of the same curve) of the topography as the principal data. The inverse-wavelet contains information on the slopes and sizes of



Schematic representation shows the response of the thin, brittle oceanic crust in a spreading center to a fault event that results in an extension (e); this can be represented by a fault-response function (T).

Sea-floor topography formed by a random process of normal faulting in the brittle oceanic crust can be characterized by a fault distribution with a certain fault density and a unit fault-response function. In this schematic representation, the fault distribution has caused a number of individual fault responses which add up to the area between the dashed line and the faulted brittle crust, i.e., crustal thinning.

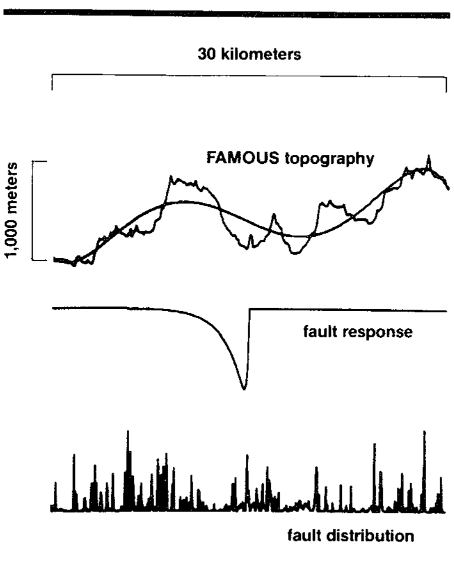


Hans Schouten and Chuck Denham.

the fault planes and fault blocks. Especially, it gives us an estimate as to how much thinning has occurred in the oceanic crust as a result of geological faulting. From that, we can derive how much lateral stretching has accompanied the process.

In the FAMOUS area (see figure below), the rough topography (upper, shown with best-fitting fifth-order polynomial curve) is actually composed of the superposition of simple fault shapes (middle), whose locations and magnitudes (lower) are detected by inverse-filtering the residual FAMOUS topographic data (5th order curve removed). Our next step will be to perform the same analysis on young Pacific (fast-spreading) topography, to see if there is any statistical difference in the shapes, sizes, and frequency of faulting, in comparison with young Atlantic (slow-spreading) topography.

If topography and spreading-rate are related, then the one can be used to estimate the other on a global basis. In older, sediment-covered crust, for example, the spreading-rate may be a helpful characterization of the crustal roughness which cannot be seen by echosounders, but which is important to low-frequency soundwave propagation beneath the seafloor.



This figure shows an example of FAMOUS area topography (upper), its fault-response curve (middle), and the result of inverse-filtering to detect the locations and magnitudes of the faults.

THE ROLE OF MODELING IN MARINE POLICY

Thomas Leschine

Research in marine policy is often directed at fostering the development of efficient and equitable ways of using marine resources. The distinguishing characteristic of much policy research, as a result, is consideration of the requirements for decision making and resource management within the context of the investigation itself.

Such consideration can be either explicit, as when the researcher attempts to solve (or at least contribute to the solution of) some particular resource management problem, or implicit, as when the researcher attempts to provide information about a resource and its use that will be helpful to those charged with managing it. When modeling is involved in a policy investigation, this differentiation of research intents can lead to the development of models which fall correspondingly into one of two types: prescriptive models, which are oriented toward problem solving, and descriptive models, which aim to describe the structure and function of resource systems, perhaps including the broader dimensions of the socioeconomic system relevant to exploitation or protection. Prescriptive models may seek to determine not just *a* solution to a resource management problem, but the "optimal" solution, framed in terms of the best course of action a resource manager can take given the regulatory, social, economic, and physical constraints imposed by the problem's context.

A great many modeling techniques have applicability to policy investigations. Among them are the linear and dynamic programming methods of economics and optimal control theory, respectively, and the methods of ecosystem simulation modeling which have been developed by quantitative ecologists. The programming methods are optimization techniques, while simulation models tend to be more descriptively oriented. Some approaches employ elements from several techniques to create a series of submodels which can be applied to problem analysis. Thus, policy oriented models vary in the extent to which the "decision" under consideration is explicit in the model itself. What is apparent, though, is that policy problems are often complex and multifaceted, a fact which seems both to invite and to confound the application of modeling to policy studies.

In marine policy, modeling has probably had its widest application in the fields of pollution and fisheries management. Models aimed at forecasting the fate and effects of pollutants in coastal waters have been developed both for studies of short-term events, such as oil spills, and for longer term management problems, such as the pollution of estuaries in highly developed areas. Modeling is frequently used in studies related to power plant siting in coastal areas, as well.

Models applied to fishery management questions evolved from classical models of the dynamics of naturally growing populations. For the most part, these models have remained fairly spare in structure and in degree of computational complexity. Until fairly recently, most such models focused on the behavior of single species populations, with rather simplistic assumptions about the nature of the underlying environment and the behavior of the economic or harvesting sector.

The models used in pollution studies, on the other hand, have often tended toward the opposite extreme. Many have evolved from the large-scale ecosystem simulation modeling efforts of the past 15 years, particularly in the field of aquatic ecology. Such models generally aim at predicting the pollution levels which result from various combinations of pollutant inputs and initial environmental conditions. Some interesting attempts have been made recently to link models of physical or ecological systems to innovative models of the "social value systems" thought to influence policy decision making. These linkages aim to define problem solutions which are simultaneously politically and technically feasible.

Whatever the approach, modeling probably succeeds best in policy research when its goals are modest. Models which try to include too much detail may miss their intended audience if they exceed the conceptual grasp of the decision maker. The salient features of complex human social systems may defy capture in "physics-like" models, and the important and subjective aspects of real world decision making may elude the researcher bent on optimization, which requires that all model inputs be quantified in some way. The true costs and benefits to society of various proposed solutions to management problems may also be extremely difficult to quantify. Inevitably, the researcher's understanding of important physical, biological, or other processes in the real world system which defines the policy problem is limited. The resultant uncertainties cast doubt upon the value of any model's predictions.

The goal of the modeler should be to provide sensible advice for decision making. What do resource managers, who almost always work under some degree of uncertainty, really need to know to minimize the possibility of serious error? What are the limitations of the model being used, and are some attributes of its behavior unlikely to be accurate reflections of the real world system's behavior? The modeler hoping to make a meaningful contribution to policy studies should keep fundamental questions such as these in mind at every stage of model development.


Vicky Cullen

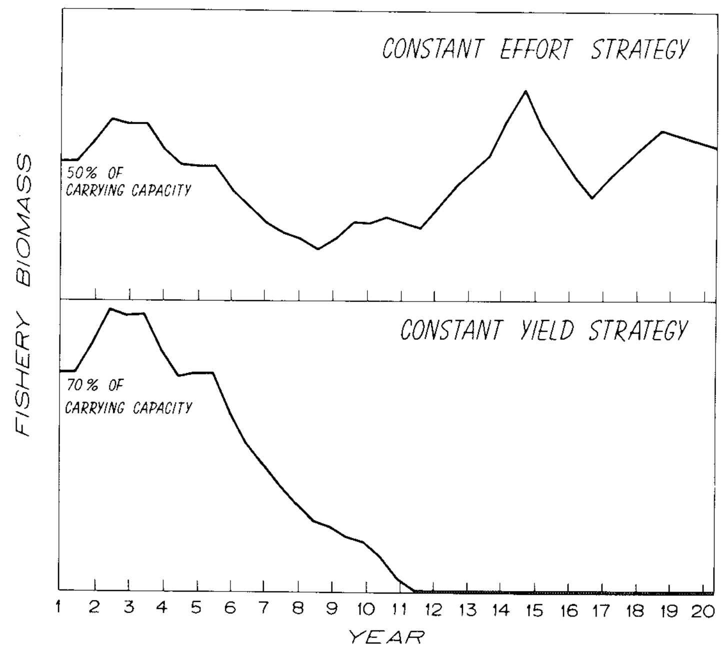
Tom Leschine

This figure shows the results of computer simulations in which a hypothetical single species fishery is managed, in the face of uncertain information about the state of the environment, in two different ways. Environmental variations, which are unpredictable and uncontrollable by the fishery's managers, cause the rate of recruitment of new stock to the fishery to vary randomly as much as 50 percent above or below the mean rate. The same random sequence of good and bad recruitment years is applied to each of two fishing strategies over the 20-year simulation runs shown.

In the "constant effort" fishery, biomass is harvested each year as a fixed proportion of the previous year's standing stock. The effort exerted in the model run (top graph) is that needed to capture the fishery's maximum sustainable yield (MSY), a yield which, were the environment to remain constant, could be maintained indefinitely at the same level. In such an environment, the standing stock biomass would likewise remain constant, in stable equilibrium with recruitment, natural mortality, and fish capture processes. All this is predicted by the model. The evident fluctuations in standing stock are thus due to the environmental changes, with the fishery's actual yield fluctuating proportionately.

If the effects of random environmental variation are ignored, then the policy shift to a direct quota or "constant yield" system of management is subtle and seemingly safe. For this strategy, the goal is to achieve the same catch year after year by adjusting the level of effort, if necessary. In the second model run (bottom graph) this policy is adopted, with the quota level set at 25 percent less than MSY as an additional margin of safety. Initially the result is a proportionately higher standing stock in the fishery, a beneficial change. The stock increases rapidly, but the manager's joy is short-lived; the bad recruitment years, which lead to low yields and 20-year-low standing stocks (in years 8-9) under the "constant effort" strategy, lead to a collapse of the fishery (in years 11-12) under the "constant yield" strategy.

The advice for the policy maker is not so much that quota systems are dangerous as it is that natural environmental variability can affect policy outcomes in surprising ways. Management policies can indeed affect the resilience of the system being managed, especially if they tend either to damp or to amplify natural variability. Although the model used here leaves out many important details, it may have the virtue of matching the advice it yields in terms of level of its complexity. The fishery's managers, of course, would like to know more and the modeler would like to say more. Each can, but at the expense of increasing the complexity of the model as well as the cost of providing the information the model requires. Such dilemmas are common when modeling is applied to policy analysis.



THE MERL EXPERIMENT

J. Frederick Grassle

Large ecosystem enclosures or "mesocosms" permit ecologists to experiment with replicated segments of nature. With support from the Environmental Protection Agency, a series of tanks at the Marine Ecosystem Research Laboratory (MERL) at the University of Rhode Island has been used by biologists and chemists from several institutions to study the functioning of nine (and more recently 12) replicated ecosystems derived from Narragansett Bay. Fiberglass tanks 1.8 meters in diameter and 5.5 meters high, with bottoms consisting of pans of sediment containing the intact benthic community from the Bay, are used as experimental enclosures. The water column is pumped from the Bay and is maintained with a twice daily pulsed inflow of seawater so that the turnover time for all the water in each tank is 30 days.

A small group from the Woods Hole Oceanographic Institution and the Marine Biological Laboratory have examined the tank benthic populations in a series of experiments. Although most of the components of the ecosystem have been studied by the staff of URI, this discussion centers on our work on the benthos.

Our first concern was whether the systems would replicate and remain similar to the natural ecosystem in the Bay. Despite predictions to the contrary, the animal communities and their functioning remained remarkably similar to the Bay and similar between replicate tanks. Temporal variation in productivity and nutrients followed that in the Bay.

The first experiments were designed to bridge the gap between laboratory studies of #2 fuel oil toxicity for single species of organisms and the effects observed on whole communities following spills in the natural environment. Previous studies had looked at only a portion of a marine ecosystem and were not able to examine the effects of low level chronic discharge. Our first experiment showed effects of chronic water column levels of #2 fuel oil averaging 190 parts per billion, and the second experiment demonstrated similar effects at 90 parts per billion under conditions where the controls were even more similar to the Bay. Most of the benthic populations declined soon after the initial biweekly additions and remained low for a year following the cessation of additions. The most common species increased to normal levels during the last month of the experiment, 13 months after the last oil addition. Although most populations declined, the reduction in the benthic forms resulted in an increased population of one small snail species (*Cylichnella*). We think this is the result of a simple food chain established in the absence of the normal bottom community: In the tanks receiving oil, the concentration of primary producers in the form of diatoms increases on the bottom. A one-celled animal belonging to the Foraminifera feeds on these tiny plants, and the snail is a specialized predator on Foraminifera.

Studies of the bottom-dwelling animals also helped our understanding of the processes in the water column. One problem was to explain the increases in phytoplankton in the tanks receiving #2 fuel oil. The first thought was that reductions in the numbers of zooplankton grazers were responsible, but when we calculated the capacity of the benthos to filter out the phytoplankton, it was many times that of the zooplankton. Reductions in the numbers of benthic filter-feeders as a result of the #2 fuel oil additions allowed maintenance of high densities of phytoplankton in the water column as well as allowing the bottom-living diatoms to grow.

Our latest series of experiments demonstrates the tight coupling of water column production and benthic production. Additions of nutrients (nitrate, phosphate, and silicate) to the water column at six different concentrations have resulted in a graded increase in the benthic populations. Interactions in the water column are not entirely linear, but the end result appears to be a direct relationship between the amount of nutrients added and the amount of food reaching the bottom. Though results from this experiment are not complete, it appears that it will provide an even clearer demonstration of the utility of large contained microcosms for understanding marine ecosystems.

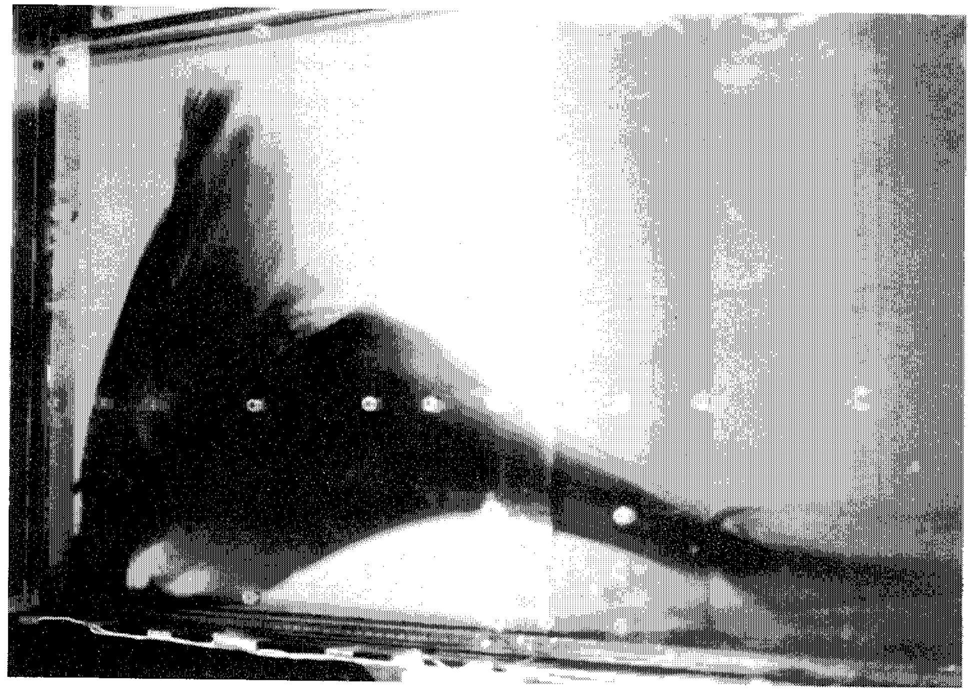
The experiment is continuing, enabling us to correlate the effects of more than one year's eutrophication on a shallow coastal marine community, independent of the inputs of other pollutants.

Eric Klos, URI

Fred Grassle and Candace Oviatt (URI) shovel Narragansett Bay sediment for MERL tank ecosystems.

LABORATORY EXPERIMENTS IN FLUID DYNAMICS

J. A. Whitehead, Jr.



J. A. Whitehead, Jr.

This model of the continental shelf in winter has had a dye injected in the lower lefthand corner. On the left, a number of light patches indicate that cells of cold water are penetrating into the slightly denser dye on the shelf. This cold water is spreading out toward the right and pulling the dye over the edge of the shelf break and down into the deep ocean on the right as a density current. A hydraulic jump on the bottom is revealed by a sudden widening of wisps of dye on the right.

Laboratory experiments in fluid dynamics are usually conducted in conjunction with either theoretical studies or field observations. Their purpose is to provide data pertinent to ideas about the dynamics of some flow of importance to earth, ocean, or planetary science. Since each experiment is individually fabricated, it is not normally conducted if answers are obtainable by numerical computations, theoretical analyses, or feasible field programs. However, there are plenty of problems beyond the scope of these methods, and the fluid dynamics laboratories at the Woods Hole Oceanographic Institution average six to eight experiments per year.

There are basically two types of laboratory experiments. The first can be called modeling (the subject of this issue) and is directed toward understanding some flow phenomenon on the earth or some other planet. However, there is a second class of experiment which is directed toward basic fluid mechanics – just trying to understand why a fluid flow behaves the way it does. These help us to understand the earth because the flow patterns studied under such clean conditions are often encountered in nature.

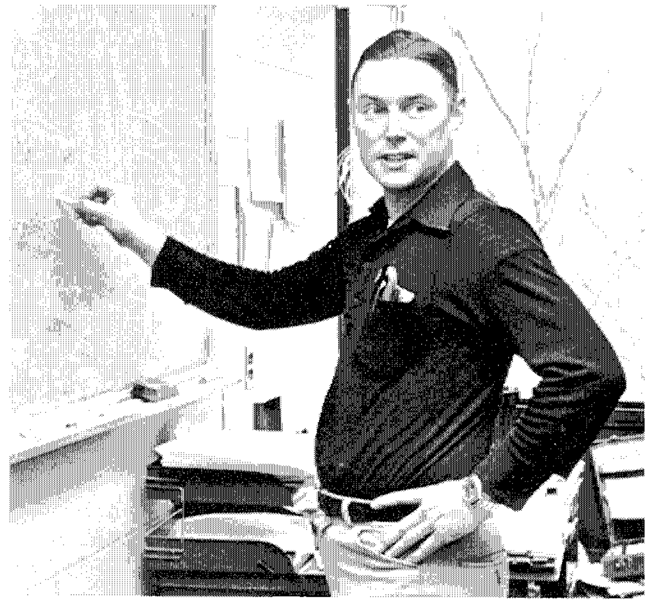
One modeling study concerns the formation of the world ocean's deepest water. This takes place in polar regions, principally in the Weddell Sea off Antarctica, in the Labrador Sea, and in the Norwegian Sea. The process of deep water formation has received considerable attention as an oceanographic problem for the past few years. However, the oceanographic observations have been sparse due to a number of problems including severe and dangerous weather, ice, lack of sufficient instrumentation, and the randomness of sinking events in location and time. Laboratory experiments which may clarify the dynamics and behavior of such sinking events are therefore potentially very useful.

A recently completed laboratory study concerned a model of a continental shelf during formation of deep water. The "shelf" was adjacent to a deep "ocean," connected by a "shelf break" with a steep slope. The deep ocean was exposed to a metal offshore sidewall which was maintained at a constant hot temperature by a heater and a thermostat. The shelf, slope, and ocean were all cooled by a lid containing chilled water. This differs from models of bays in lakes studied by civil engineers in that the entire system was placed on a rotating turntable to duplicate the effect of the earth's rotation. The complex bottom configuration also differentiates these experiments from numerical and analytical models of cooled oceans of uniform depth.

It was observed that the fluid rose upward at the heated offshore wall and flowed toward the shelf, curving toward its right due to rotation. Cooling of the warm flowing water from above created roll-like convection cells aligned in the direction of flow. After the water passed over the shelf, sinking regions formed of the densest water in the experiment developed near the coast. This dense water spread away from its formation region across the shelf, spilled off the shelf break as a gravity current, and plunged to the bottom of the model ocean.

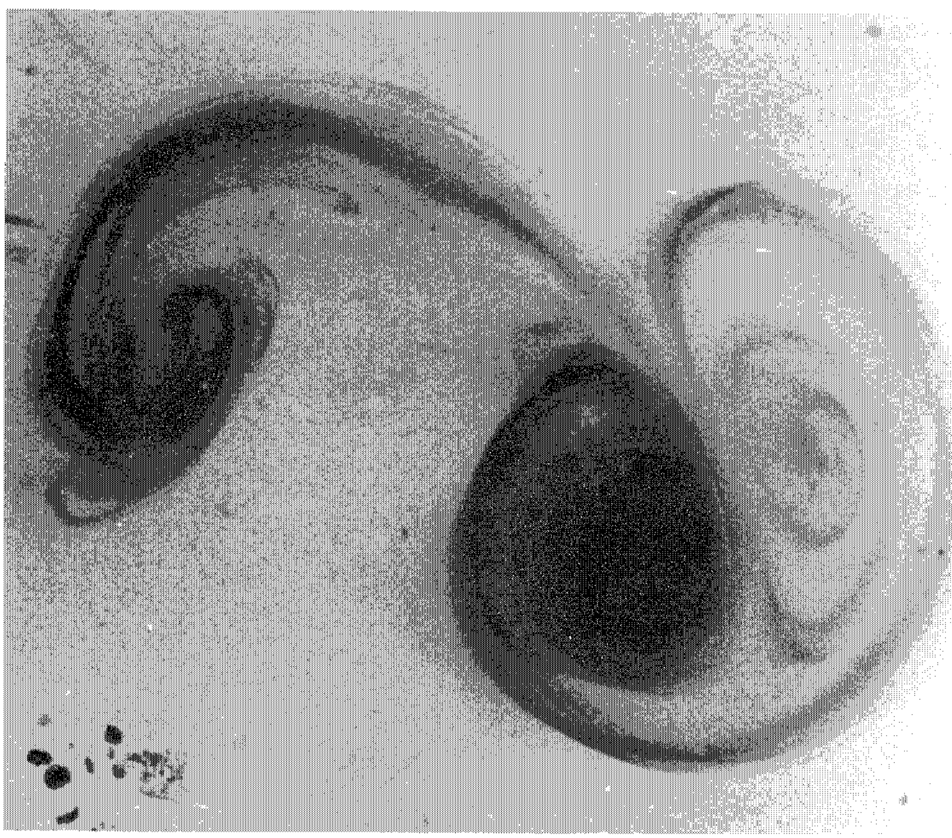
Measurements of the temperature and flow field allow us to test theoretical predictions of the velocity and temperature patterns. Those that are confirmed can be used to speculate upon the flow and thermal field in sinking regions of the oceans with somewhat more confidence than before. The laboratory-generated flows also indicate what locations are most likely to possess important flows on such shelves and thus they can be used in planning future field work.

Another project considered fundamental issues in fluid dynamics. The name "modon" was first coined by theoretician Melvin Stern of the University of Rhode Island for some mathematical solutions he found for a particular set of equations which are believed to be important in mid-ocean. The flows corresponding to these solutions are isolated pairs of vortices or eddies. Many modonlike solutions have now been discovered. These vortex pairs are easily created in the laboratory by impulsively squirting jets of water into a rotating fluid. The resulting modons are being studied with dye and particle tracers to determine whether any of the theoretical predictions can be confirmed and to determine evolutionary behavior as they age, something difficult to obtain theoretically. It is still not known whether modons exist in the real ocean as they do in our laboratory ocean, though occasional ocean eddies appearing in infrared images from satellites look like them. This evidence is, however, very indirect and more work will need to be done to detect real ocean modons. The fact that they are so easy to produce in the laboratory can be used as evidence that they might be there.



Vicky Cullen

Jack Whitehead



Robert Frazel

This "modon" or dipolar eddy on a beta-plane was generated on a two-meter turntable. The source of this eddy is on the left and is simply a turbulent jet of dyed fluid left on for 20 seconds. The eddy has a cyclonic gyre to the right and an anticyclonic eddy to the left. A cyclonic eddy whose origin is poorly understood has been shed on the far left.

1981 DEGREE RECIPIENTS
Massachusetts Institute of Technology/ Woods Hole Oceanographic Institution Joint Program in Oceanography/ Oceanographic Engineering

Doctor of Philosophy

ROBERT F. ANDERSON
B.S., University of Washington
Special Field: Chemical Oceanography
Dissertation: *The Marine Geochemistry of Thorium and Protactinium*

ROBERT L. BINDER
B.A., University of Pennsylvania
Special Field: Biological Oceanography
Dissertation: *Xenobiotic Monooxygenase Activity and the Response to Inducers of Cytochrome P-450 During Embryonic and Larval Development of Fish*

ROBERT W. COLLIER
S.B., Massachusetts Institute of Technology
Special Field: Chemical Oceanography
Dissertation: *Trace Element Geochemistry of Marine Biogenic Particulate Matter*

JOHN CROWE
B.S., Columbia University
Special Field: Marine Geophysics
Dissertation: *Mechanisms of Heat Transport Through the Floor of the Equatorial Pacific Ocean*

RUSSELL L. CUHEL
B.A., University of California, San Diego
Special Field: Biological Oceanography
Dissertation: *Assimilatory Sulfur Metabolism in Marine Microorganisms*

NEAL R. PETTIGREW
A.B., Dartmouth College
M.S., Louisiana State University
Special Field: Physical Oceanography
Dissertation: *The Dynamics and Kinematics of the Coastal Boundary Layer off Long Island*

WILLIAM R. YOUNG
B.Sc., Australian National University
Special Field: Physical Oceanography
Dissertation: *The Vertical Structure of the Wind-Driven Circulation*

Doctor of Science

PETER D. E. GOREAU
B.Sc., University of Bristol, United Kingdom
Special Field: Marine Geology
Dissertation: *The Tectonic Evolution of the North Central Caribbean Plate Margin*

SAMUEL W. SMITH, JR.
B.S., Florida Atlantic University
S.M., Massachusetts Institute of Technology
Special Field: Oceanographic Engineering
Dissertation: *Analysis of the Cathodic Behavior of Aluminum in Natural Seawater by Surface Chemistry*

Ocean Engineer

MICHAEL J. BRIGGS
B.S., University of Texas, Austin
M.S., University of Southern California
Special Field: Oceanographic Engineering
Dissertation: *Multichannel Maximum Entrophy Method of Spectral Analysis Applied to Offshore Structures*

Dean's Comments

During 1981 we saw the implementation of recommendations of the Joint Program Review, which was completed in late 1980. Specifically, there has been established at the Massachusetts Institute of Technology a Joint Program Office under the direction of John G. Sclater, with a full-time administrative assistant, Mary Athanis. Prof. Sclater, who reports directly to Associate Provost Frank Perkins, also serves on the Educational Council at WHOI, and, as Dean, I have joined the MIT Council on Graduate School Policy. A major reorganization of the Joint Program faculty committees has also taken place, something we feel will lead to a more balanced program. Our "jointness" continues to strengthen.

Certain trends in our Joint Program recruiting efforts were evident this year. They included a modest increase in total applications over the previous year; a significant increase in geology and geophysics applicants; a drop in number and percentage of biology applicants to only 38 percent of the total pool; admission offers to a record high of 30 percent of all applicants, significantly higher than our 10-year average of 17 percent and a record low 53 percent acceptance rate (our 10-year average acceptance rate of 64 percent is still the highest among our competition). Within the total enrollment of 91 graduate students there has been a gradual shift in distribution to a larger engineering program and a smaller biological program while all other disciplines are staying close to recent averages.

The 1981 graduates bring the alumni total to 127. An increasing percentage of our graduates is being hired by industry (up to 20 percent from less than 15 percent three years ago) with the largest percentage (57 percent) employed in academic institutions. However, we see a strong trend toward wider distribution among the other research-oriented laboratories, both private and federal. We are pleased that despite the generally bad climate for some areas of professional scientific work, our graduates are finding jobs in their chosen fields.

Our Postdoctoral Scholarship Program of six to eight one-year fellowships awarded annually continues to be a success. We attract a very strong applicant pool every year and this past year was no exception. This year, for the first time, there was a jointly appointed and funded Postdoctoral Scholar with the Ecosystems Center at the Marine Biological Laboratory, and we look forward to further collaboration with our neighbors in Woods Hole.

A superb applicant pool and generous support from our Associates made it possible to award 20 Summer Student Fellowships in 1981. Again, this program of opportunities for the aspiring undergraduate marine scientist confirmed our belief that the best way to learn about research is to do it.

We also continue our Minority Traineeship Program but have not been encouraged by the present funding climate for such programs. We provide support for this effort in order to give college students from minority groups an opportunity to learn more about a career they might not otherwise have considered. This year we were able to fund four trainees for 12 weeks each.

Our single biggest concern has been, and will continue in the coming year to be, how to attract bright science majors into the marine sciences. We see some very good prospects in our Summer Student Fellowship Program for undergraduates, and we have been successful in attracting students from that program into our graduate school, but generally these are students who have already decided on a marine science career.

We know from our discussions with the other major oceanographic schools (at two deans' retreats) that the problem is nationwide. We also know that industry, especially petroleum, is diverting talent away from graduate education with attractive salaries.

We have seen one effective process for turning young scientists toward a particular field, the almost too-successful results of the superb publicity about marine biology by the naturalist Jacques Cousteau. Our applicant pool and that of most of the other major oceanographic institutions over the past 10 years has been, on average, 55 percent biological science students. This is the first year that we have seen a significant drop in biologically trained applicants. We feel this is directly due to the tightening job market.

It is generally true that the first science exposure a child has is to biology, and a large percentage of science-oriented children stay in that field throughout their college careers. We believe the majority of secondary school science teachers were trained as biologists. Do secondary schools and high schools over-emphasize (over-promise) the importance of the future of biology at the expense of other scientific fields such as the physical sciences or engineering?

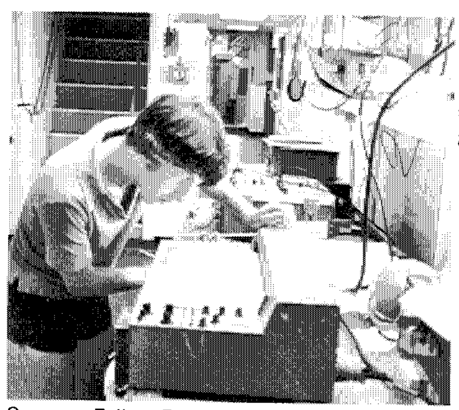
Recruiting efforts can sometimes be effective if we can convince undergraduate professors that there are valuable opportunities in fields other than their own specific fields. But recruiting on a one-to-one basis is not very cost-effective, especially in this time of tight budgets.

A preliminary study of the total applicant pool of the major oceanographic institutions suggests that, for example, there may be fewer than 100 students applying to the 11 major physical oceanography programs! Does this mean that only 100 undergraduate students are considering careers in this field when national statistics show that there are 90,000-plus students graduating with bachelor's or first-professional degrees in the physical sciences, math, and engineering each year?

It has been suggested that we need a Cousteau (or Carl Sagan)type personality to sell the excitement of discovery in the physical sciences. How can we portray the almost overwhelming excitement of discovering a pattern in our data that yields new insight into a natural process that has global implications such as effects on climate or on the genesis of sea floor rocks?

During the coming year we will be concentrating on several projects designed to increase the pool of physical science and engineering students interested in the oceans. This continues to be my major concern. We have an incredible opportunity to provide challenging and stimulating careers to those who are driven by the basic question - *why*?

Charles D. Hollister
Dean of Graduate Studies


Shelley Lauzon

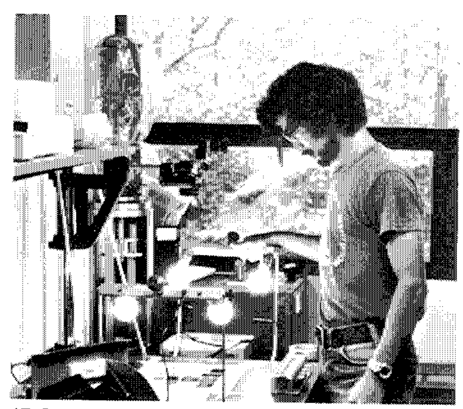
Summer Fellow Peter Haynes on *Oceanus*.


Vicky Cullen

Jerry Cheney, JP Student in Biology.


Shelley Lauzon

Dean Hollister and JP Student Steve Swift.


Shelley Lauzon

JP Student Kozo Takahashi and photo setup.

Ashore & Afloat

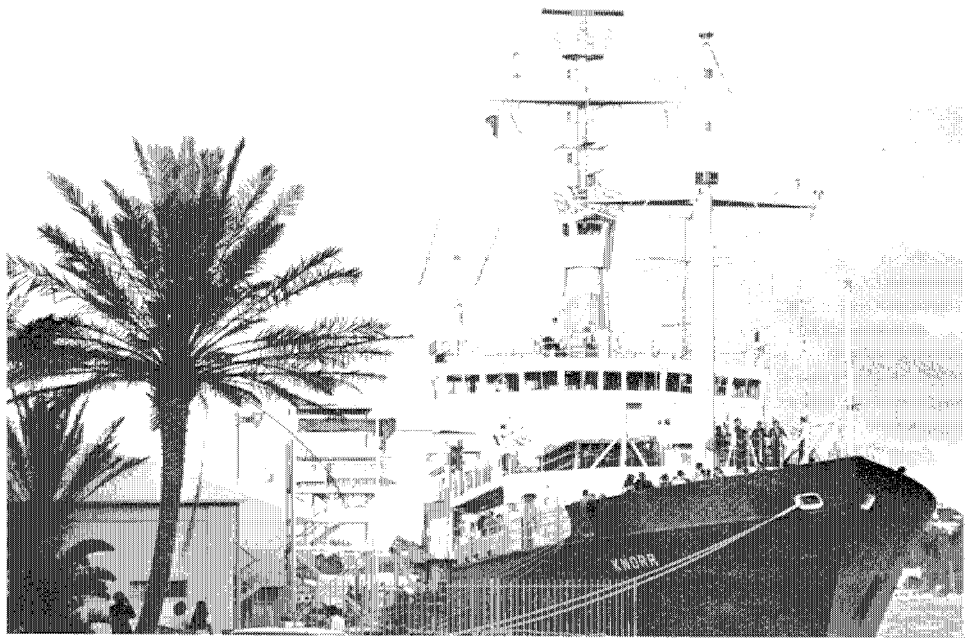
The need for new funding sources and the importance of the Institution's financial and scientific independence were discussed by Director John H. Steele at the winter meeting of the Corporation 14 January at Boston's Copley Plaza Hotel. Provost Arthur E. Maxwell reported on plans for the Ocean Margin Drilling Program and joined with Geology and Geophysics Department Chairman John I. Ewing in a review of the progress of the Joint Oceanographic Institutes for Deep Earth Sampling (JOIDES) program.

A construction permit was issued to the Institution in February for a 10,000 square-foot steel frame building on the Quissett Campus. Construction of the Coastal Experimental Laboratory began in the spring and progressed quickly through the summer months. The laboratory is the first building of the Coastal Research Center and was dedicated at the annual Associates Day of Science in October. Occupants were expected to move into the building in early 1982.

Associate Scientist John W. Farrington was named director of the Coastal Research Center in October, succeeding Senior Scientist John H. Ryther who left the Institution for a position at the University of Florida. Farrington had served as chairman of the Center's Planning Committee and was replaced in that post by Associate Scientist William D. Grant.

A Falmouth High School junior, Daniel Webb, son of Senior Research Specialist Douglas C. Webb, received the Institution's $750 college scholarship for a physics project he entered in the Falmouth Science Fair 14 March.

Senior Scientist Holger W. Jannasch addressed 110 Associates at the annual spring dinner 30 March at Boston's Museum of Science. In April, former



Vicky Cullen

A reception was held aboard R/V *Knorr* during a port call in Bermuda in May.

Ambassador at Large and Special Representative of the President to the Law of the Sea Conference Elliot Richardson spoke on a national ocean policy to 100 Associates and guests at the Union League Club in New York.

Spring whale watching cruises sponsored by the Associates Program attracted 200 Associates for three cruises in May. Narration was provided by Senior Research Specialist William A. Watkins and Research Assistant Karen E. Moore.

More than 300 guests attended an open house aboard R/V *Knorr* during the vessel's visit to Bermuda in May. Members of the island's Assembly and Senate, the Governor and Prime Minister, the American Consul General, friends from the Bermuda Biological Station, and U.S. residents visited the ship at the main dock in Hamilton.

Twenty-one staff members made presentations to the Office of Naval Research (ONR) in Bay St. Louis, Mississippi, in May seeking research support for fiscal year 1981. ONR awarded $2.1 million for Institution research projects.

Members of the National Science Board visited the Institution 18 June during a Woods Hole meeting. Tours of the facilities included dockside presentations on recent DSRV *Alvin* research programs, the Warm Core Rings Experiment, the Long Term Upper Ocean Study (LOTUS), and the Large Aperture Seismic Experiment (LASE).

The following day, 59 Trustees and Corporation Members attended the Annual Meeting of the Corporation and heard Associate Scientist Joel C. Goldman's science presentation on "Have We Underestimated the Magnitude of Biological Production in the Oceans?" Director Steele reported on accomplishments of the Ocean Industry Program and discussed ways to expand industry support and interaction. Later in the day, Associate Director for Research Derek W. Spencer spoke to 250 Trustees, Corporation Members, and Associates on "Radioactivity in the Oceans." Retiring Corporation Treasurer Edwin D. Brooks, Jr., was honored at the Associates Dinner that evening for his 31 years of service to the Institution. Also honored for her 25 years of service to ocean science was new Associate Mary Johrde, who retired in 1981 as head of the National Science Foundation's Office for Oceanographic Facilities and Support.

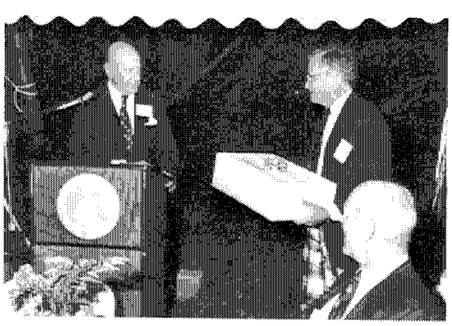

Frank Medeiros

Mel Briscoe and Peter Wiebe described their work to National Science Board visitors on a June visit.

Karen Moore

A spring whale watch was a popular Associates' event in 1981.

Among the many visitors to the Institution during 1981 were members of a National Academy of Sciences committee, chaired by Director John Steele, which met in Woods Hole in March to review Antarctic marine ecosystem research and propose new research directions. A six-member Sea Grant team visited the Institution in the spring; staff and graduate student presentations for continuing and proposed research resulted in an award of $715,000, somewhat less than in previous years due to federal cutbacks. Eighty military and civilian personnel from 14 Latin American nations attending the Inter-American Defense College in Washington visited Woods Hole in May to learn about Institution research programs and tour *Alvin* and *Lulu*. Fifty investigators in marine ecology and fisheries management gathered for a four-day meeting in June organized by the Institution's Coastal Research Center and the National Marine Fisheries Service laboratory in Woods Hole. Members of the international Group of Experts on the Scientific Aspects of Marine Pollution reviewed the present knowledge on ocean dumping at a five-day meeting. The quarterly meeting of the Trustees and Executive Committee of the University Corporation for Atmospheric Research (UCAR) was held in Woods Hole in July; Senior Scientist Peter B. Rhines and Director John Steele are the Institution representatives to UCAR. In August, the Advisory Council of the University-National Oceanographic Laboratory System (UNOLS) met in Woods Hole for the first time; Associate Director for Research Derek Spencer was elected chairman. "Technological Advances and Third World Countries" was the theme of a one-day seminar in September sponsored by the Institution and the International Federation of Institutes of Advanced Study, of which WHOI is a member. Representatives of 16 New England utility companies attended a two-day Corporate Associates Program seminar in November to hear presentations on current Institution research relevant to power companies. Semi-annual presentations were organized for the Institution's Ocean Industry Program and the Naval War College's Naval Staff Course for Foreign Officers.



Frank Medeiros

A gift to Ned Brooks, standing right, at the June Associates' dinner honored his 31 years as Treasurer.

Activities of the Coastal Research Center, established in 1980, got underway during the year with the selection of three major projects for initial focus. A scientific study of Georges Bank and a review of existing knowledge on that area will be published in a book entitled "Georges Bank and Its Surroundings: Book and Atlas." Senior Scientist Richard H. Backus is general editor of the text. Studies in Buzzards Bay continued through the year on the assimilative capacity of the coastal zone for waste disposal, and plans were made for further studies on marsh/bay interaction and the physical oceanography of the bay. Instrumentation needed for coastal research was the subject of continuing discussions and led to preliminary design plans for a small experimental multipurpose flume.

Senior Scientist Peter B. Rhines was one of 60 elected to the National Academy of Sciences "in recognition of distinguished and continuing achievements in original research." Senior Scientist Howard L. Sanders was one of 453 elected a Fellow of the American Association for the Advancement of Science (AAAS) for his efforts "on behalf of the advancement of science or its applications."

Senior Scientist Peter G. Brewer accepted a two-year appointment in November as program director for geochemistry at the National Science Foundation in Washington.

Corporation President Paul M. Fye was one of eight named by Governor Edward King to the Board of Trustees of the Massachusetts Maritime Academy.

Marine Policy Fellow Daniel P. Finn was one of a group of experts invited by the United Nations Environment Programme to visit eight African nations in the fall to explore the prospects for improved management of marine resources through national and regional action.

Senior Scientists George D. Grice and Howard L. Sanders traveled for two weeks in the People's Republic of China in June lecturing at various laboratories

Vicky Cullen

The new Coastal Experimental Laboratory was dedicated at the October Associates' Day of Science.

and exploring the possibilities of establishing collaborative research programs. Assistant Scientist Donald M. Anderson spent several weeks in Japan in early fall lecturing on red tide, a significant problem for that nation's large aquaculture programs.

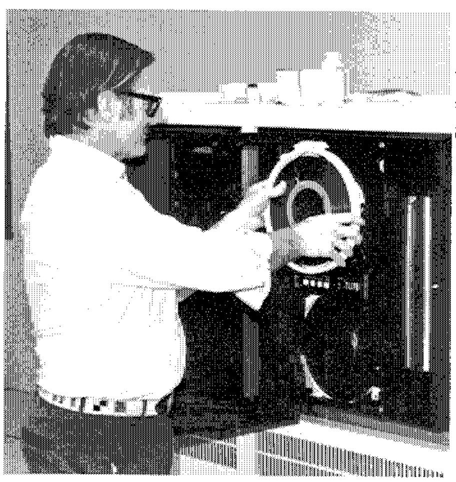
On 1 October Biology Department Chairman George Grice assumed the new position of Associate Director for Scientific Operations, with overall supervision of scientific operations and facilities. Senior Scientist Ralph F. Vaccaro was named Acting Biology Department Chairman.

Senior Scientist Nicholas P. Fofonoff succeeded Senior Scientist Valentine Worthington 1 November as chairman of the Physical Oceanography Department. Worthington had been department chairman since 1974 and retired in early 1982. Fofonoff had previously served as department chairman from 1967 to 1971.

More than 1,000 spectators lined the Great Harbor waterfront 23 August to watch 15 entries vie for first place in the second annual "Anything But a Boat Regatta." Institution Welder Douglas T. Grosch crossed the finish line ahead of the field in "R/V General Jeb Stuart," two 55-gallon drums welded together with coring tube liners as flotation. A sea monster named Dreagan delighted the crowd but failed to scare off competitors.

Bluegrass was the theme of the Employee Picnic 23 August on the Fenno House grounds. More than 250 enjoyed square dancing and games.

Shelley Lauzon



IPC Manager Skip Little puts a disc in the new VAX-11/780 installed in the Clark Laboratory.

Newly appointed Administrator of the National Oceanic and Atmospheric Administration (NOAA) John V. Byrne presented the fourteenth J. Seward Johnson Marine Policy Lecture 17 September on "NOAA's Role in a National Ocean Policy."

Three scientific meetings were held in the fall, attracting hundreds of scientists from around the world to Woods Hole. Senior Scientist Stanley W. Watson was chairman of the International Conference on Endotoxin Standards and LAL Use with Parenteral Drugs 21-24 September. The 69th statutory meeting of the International Council for the Exploration of the Sea (ICES) 3-14 October brought more than 300 scientists and representatives from 18 nations together. This meeting of ICES, the world's largest marine science organization, was the first held in the United States. The Third International Ocean Disposal Symposium 12-16 October brought several hundred researchers to the village to dis-

Shelley Lauzon

NOAA Administrator John Byrne talks with Susan Peterson after his Johnson Lecture.

George E. Conway
1 January 1934 – 15 June 1981

George E. Conway, Controller, passed away after a brief illness on 15 June 1981 at the age of 47. He had served in the Army, completed his education at Bentley College where he majored in accounting and finance, and worked as an auditor and accounting consultant for the William E. Hays Company of Boston before joining the Institution in June of 1962. His responsibilities grew with the Institution through the 1960s, and he was named Controller in 1973.

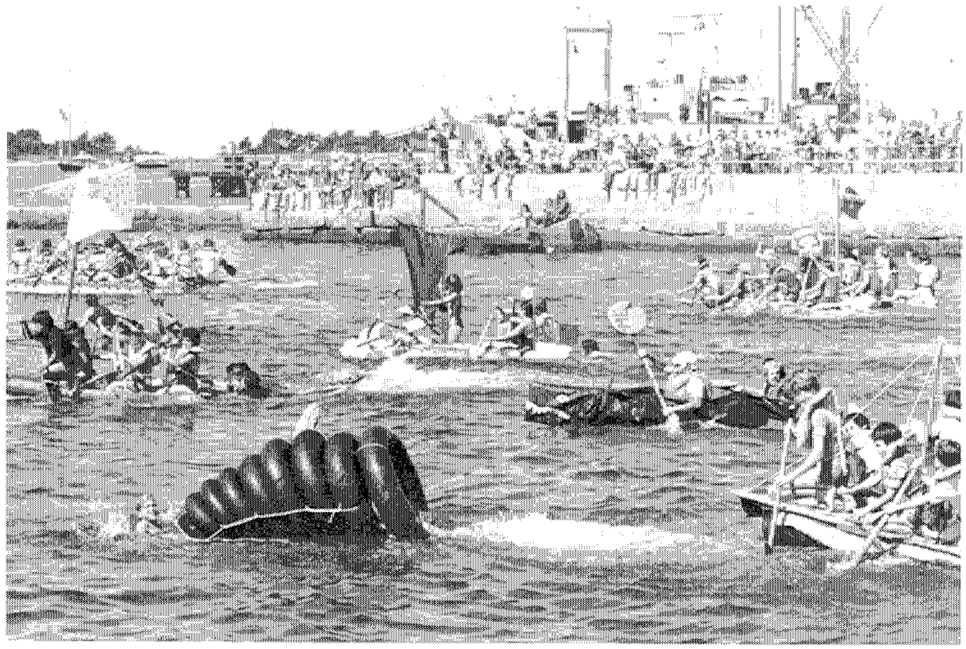
As steward of Institution funds, he was familiar with the operation of ships, shops, and all departments of the Institution, as well as the intricacies of dealing with the U.S. Government. George was involved with the fiscal problems (and solutions) associated with the growth of the Institution from an annual budget of $8,000,000 to more than $36,000,000, an endowment fund from $4,000,000 to nearly $45,000,000, and plant fund assets from $7,000,000 to $32,000,000. Of greater importance, however, was his evolution as an authority on the multi-fiscal complexities associated with operating the Institution.

George's community spirit extended to service as treasurer of the Falmouth Jaycees, and he was a Falmouth Hospital corporation member. The WHOI softball team benefited from his enthusiastic participation, and he was well known around Woods Hole as an inveterate noontime walker.

Underlying George's many achievements was a composite of his personal characteristics, including but certainly not limited to honesty, reliability, dedication, and knowledge of the "Woods Hole way." He was well respected by the Institution staff, whom he was always willing to help. He possessed an uncanny ability to deal with numbers as demonstrated by his analytical techniques and wisdom so evident in past budget projections when compared to actual data. For those of us who worked with George, it was both a pleasure and learning experience for which we are all deeply grateful.

George is sorely missed and his memory will remain forever in our hearts.

R. David Rudden



Shelley Lauzon

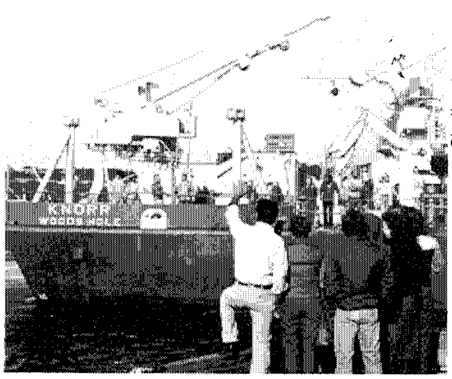
The second "Anything But a Boat" regatta brought a variety of strange craft to Great Harbor.

cuss scientific and environmental issues related to ocean waste disposal. Some 100 papers were presented at the meeting, sponsored by NOAA's Office of Marine Pollution Assessment.

"Ocean Pollution '81: The North Atlantic" was held 19-23 October in Halifax, Nova Scotia. The international scientific conference on chemical contamination of the North Atlantic Ocean was cosponsored by the Institution and the Bedford Institute of Oceanography; Associate Scientist John Farrington was conference cochairman.

DSRV *Alvin* and R/V *Lulu* returned to Woods Hole 17 February from winter dives in the Bahamas to begin a five-month overhaul during which new buoyancy material was added to the sub. The vessels headed south in July and spent the remainder of the year in the Pacific off Panama and Mexico largely for hydrothermal vent studies.

Chemical, geological, and physical oceanographic studies occupied R/V *Atlantis II* much of the year. The ship ventured into the Pacific for a few months in the spring, returning to the Atlantic for a four-month cruise to Spain and the Canary Islands. The ship arrived in Woods Hole 7 October and began a year-long maintenance and overhaul period to continue the mid-life refit and habitability upgrading begun in 1980.



Shelley Lauzon

R/V *Knorr* comes home in October following 7-month Transient Tracers in the Ocean voyage.

Vicky Cullen

George Grice was named Associate Director for Scientific Operations in October 1981.

R/V *Knorr* spent seven months of 1981 engaged in chemical and physical oceanographic studies for the Transient Tracers in the Ocean Program (TTO) in the North Atlantic. The multi-institutional effort is built upon a continuation of the GEOSECS program undertaken in the early 1970s.

The Institution employed its first female engineer during the summer when Kathleen Hoard, a graduate of the State University of New York Maritime College, served aboard R/V *Knorr* for part of the TTO cruise.

Three hundred Associates and guests attended the annual Associates Day of Science 9 October. Morning presentations focused on the deep ocean and were followed by the dedication of the Coastal Experimental Laboratory of the Coastal Research Center. Visitors toured Quissett Campus facilities and went aboard R/V *Knorr*, which had just returned from the seven-month TTO Atlantic cruise.

The west wing of the Clark Laboratory first floor was renovated in the fall and a new computer facility installed. The Institution's second VAX-11/780 computer was put into operation in early November. Together with a smaller VAX-11/750 computer purchased during the summer for administrative data processing, it has replaced the Sigma 7 computer in Shiverick. The Sigma 7 had provided central computer facilities for the Institution since 1968 and was sold at year's end to Andrews University in Michigan.

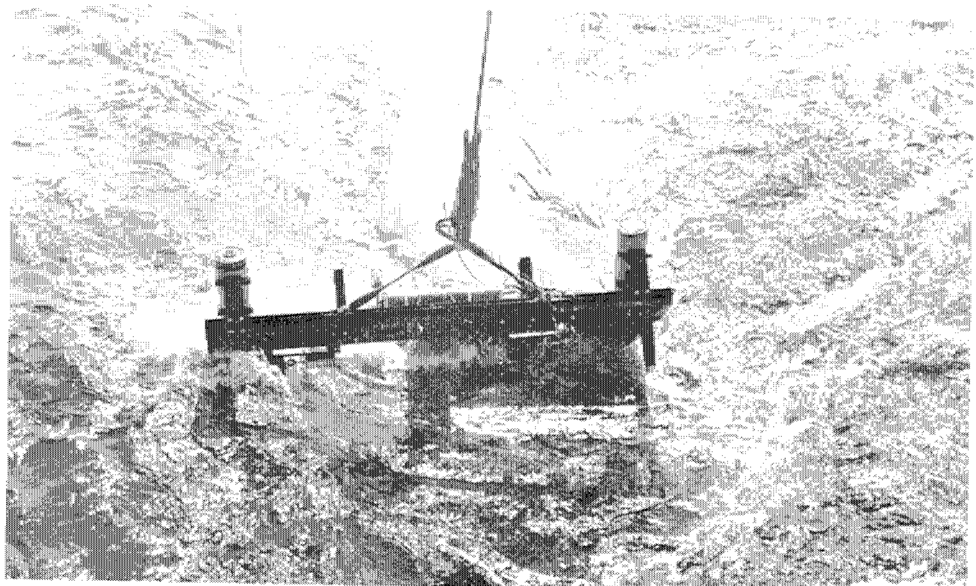
A new Controller and a new Development Director were appointed late in the year. Gary B. Walker, formerly corporate manager of budgets and financial services with Sanders Associates of Nashua, NH, was expected to assume his new post in early January 1982, filling the vacancy left by the summer death of George Conway. Paul Dudley Hart succeeded John L. Heyl as Development Director in November. Heyl assumed a vice presidential position at Maine's Bowdoin College. Hart has had considerable experience in industrial consulting and managed the support contract for the USNS *Eltanin* in the National Science Foundation's U.S. Antarctic Research Program.

Thirty-year pins were presented 18 December to Senior Research Assistant Edward H. Chute, Mechanical Shop Supervisor Robert G. Weeks, Research Associate Geoffrey G. Whitney, Jr., and Research Specialist Warren E. Witzell. Senior Scientist John Ryther received his pin at a farewell party in October. Eight retirees with 173 years of service to the Institution were also honored.

Provost Arthur E. Maxwell was honored 22 December at a farewell party. He became director 1 January 1982 of the Institute for Geophysics at the University of Texas at Austin.

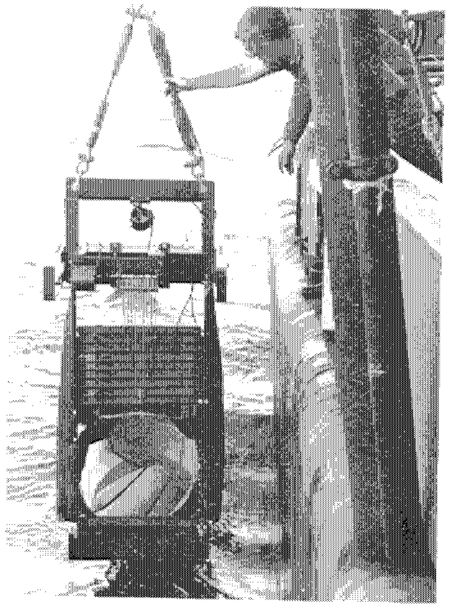
The UNOLS Office, located at the Institution since that organization's founding in 1971, was transferred at the end of the year to the University of Washington.

Two Quissett Campus buildings were renamed in the fall for Institution research vessels. Building B, better known as U.S. Geological Survey (USGS) headquarters, is now the Gosnold Laboratory. The Data and Earth Sampling Center (DESC), whose occupants now reside in the McLean Laboratory next door, has been leased to USGS and is now the Crawford Laboratory.



A Multiple Opening Closing Net/Environmental Sensing System (MOCNESS) is under tow on *AII*-110.

Photos by Peter Wiebe on *Atlantis II* #110



Al Morton launches a smaller MOCNESS.

Many hands haul in a water sampling system.

Mark Brzezinski of Oregon State tends apparatus for studies of silica uptake by phytoplankton.

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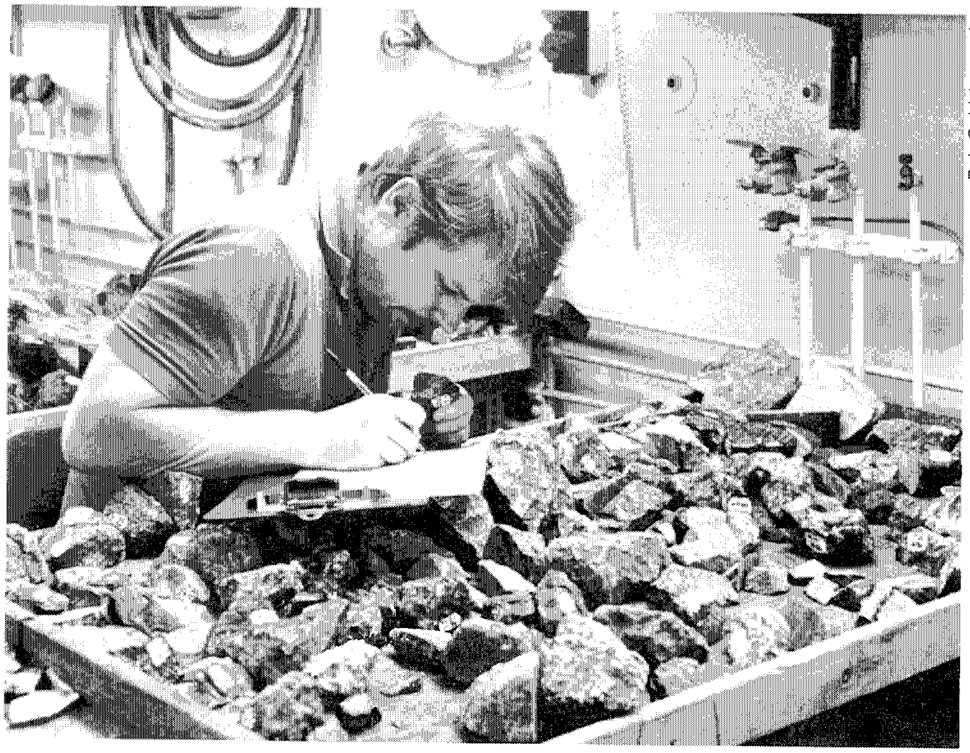
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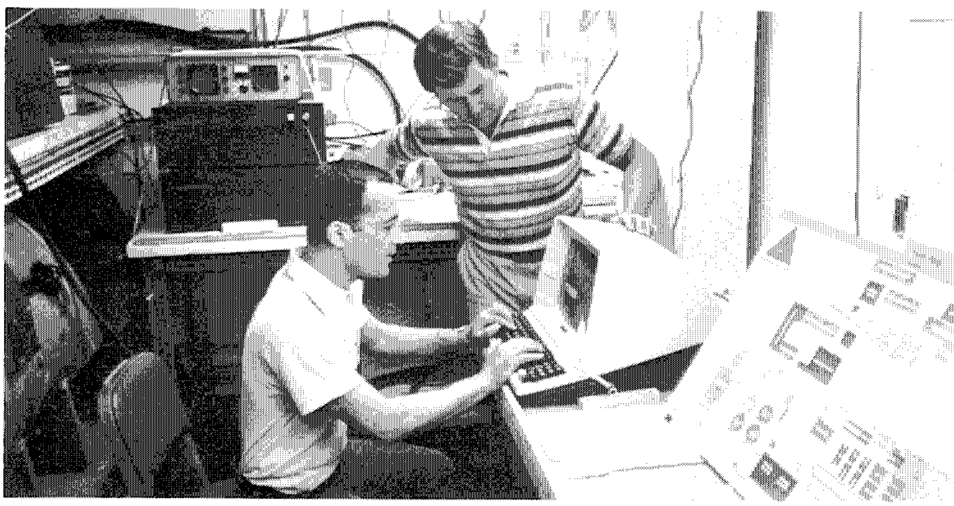
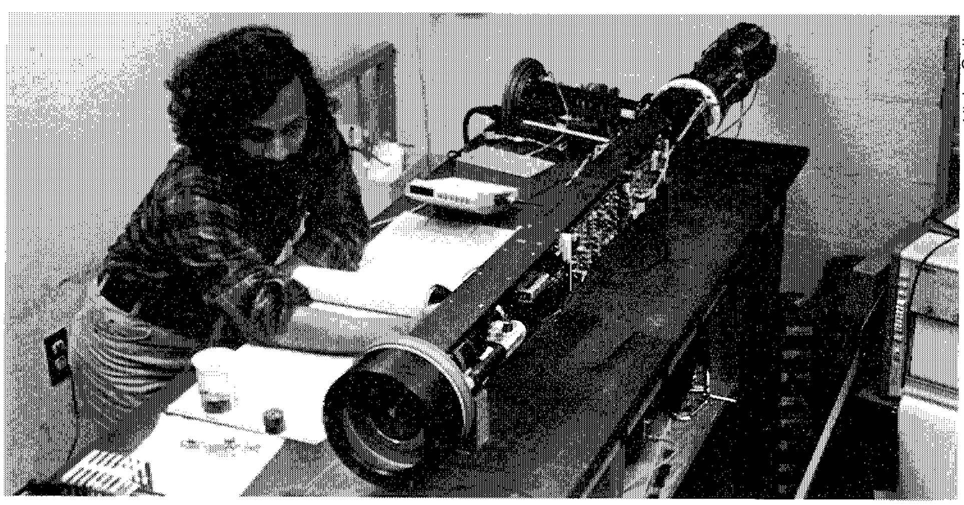


Shelley Lauzon

Bob Spindel, seated, and Paul Boutin are at the ocean acoustic tomography computer on *Oceanus*.



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Yogi Agrawal works with laser-Doppler velocimeter.

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# Disability Leave of Absence
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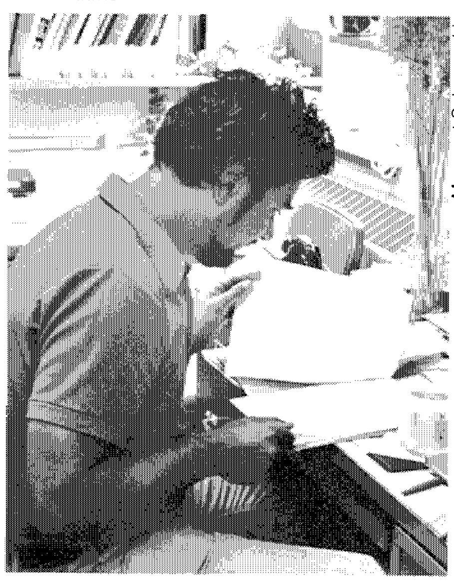
Bill Watkins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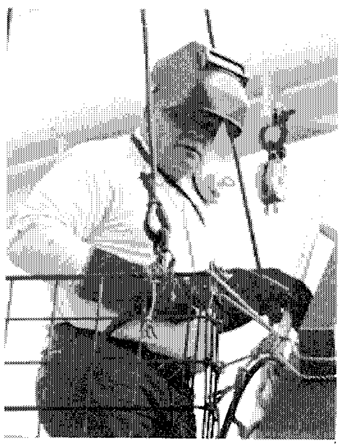

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Joseph A. Guzaj
David L. Hayden
Alfred C. Henser
Henry P. Hirschel
Albert C. Jefferson
+John P. Kamataris
J. Kevin Kay
+Annie M. Krueger
Tomas M. A. Macedo
+John W. Martin, Jr.
David H. Megathlin
Harry E. Oakes
Conrad H. Ocampo
Peter P. O'Reilly
Michael Palmieri, Jr.
+Angel Perez
George E. Pierce
#Samuel F. Pierce
Harry Rougas
Terrence R. Schieding
Anthony Senna, Jr.
Thomas C. Sheeran
+Ernest G. Smith, Jr.
+Harry H. Stanton
John K. Sweet, Jr.
William L. Sylvia, Jr.
Frank D. Tibbetts
Steven F. Tomkiewicz
+Herman Wagner
Joseph Warecki
Ernest C. Wegman, Jr.
Charles W. White

#Disability Leave of Absence
+Leave of Absence

Fellows, Students, & Visitors

MIT/WHOI Joint Graduate Program 1981-82

Vernon L. Asper
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University of British Columbia, Canada

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University of Cincinnati

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Massachusetts Institute of Technology

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University of Rhode Island

Josko A. Catipovic
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Jerry Cheney
Lamar University

Teresa K. Chereskin
University of Wisconsin

Ching-Sang Chiu
Northeastern University

Ka Hou Chu
University of California, Berkeley

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University of York, United Kingdom

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University College of North Wales, United Kingdom

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Michael F. Cook
Texas A&M University

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École National du Genie Rural des Eaux et des Forets, France

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Sophie Wacongne
Université Pierre et Marie Curie, France

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Australian National University, Australia

Victor Zlotnicki
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+ Leave of Absence

Marine Policy and Ocean Management Research Fellows 1981-82

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University of Rhode Island

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Marquette University

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University of California, Santa Barbara

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University of California, Santa Barbara

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Gary L. Taghon
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Kozo Takahashi
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Stanford University

Beth Chertock
Pomona College

Alistair J. Harding
Cambridge University, United Kingdom

Mary A. Hinkley
College of the Holy Cross

Kelly L. Kenison
Reed College

Shelley Lauzon

Summer Fellows Ken Brown, left, and Alistair Harding

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Sarah A. Little
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Manchester University, United Kingdom
Cambridge University, United Kingdom

Stephen R. Rintoul
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Kim A. Waldron
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Minority Trainees in Oceanography

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Allison A. Chun
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Colby College

Andrea Y. Provan
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Edward Rosa-Molinar
Tuskegee Institute

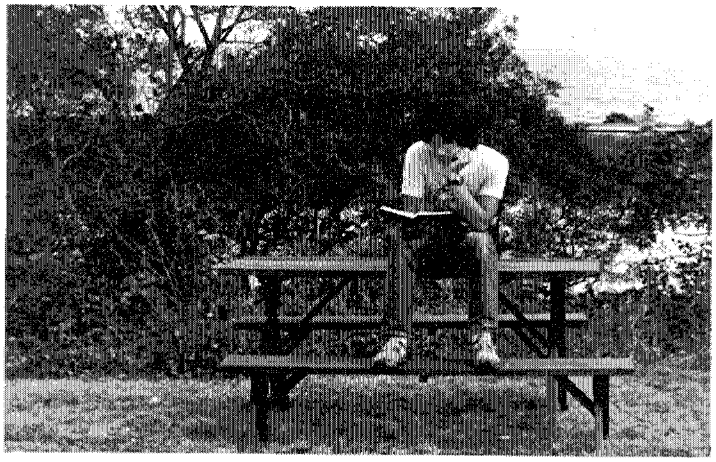
Geophysical Fluid Dynamics Summer Seminar

Fellows:

Christopher S. Bretherton
Massachusetts Institute of Technology

Fausto Cattaneo
University of Cambridge, England

Pierre H. Coullet
École Normale Supérieure, France



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Rodman Taylor

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Shelley Lauzon

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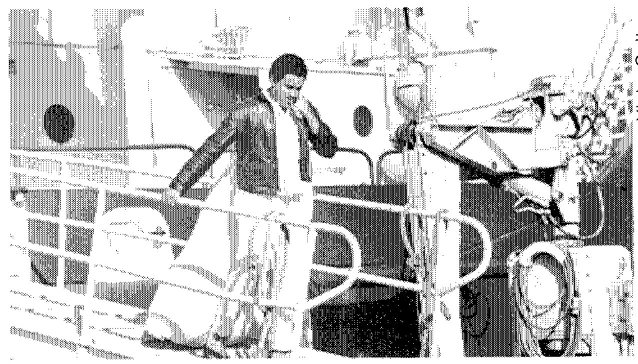
Voyage Statistics

Peter Wiebe

Oceanus Master Paul Howland in ship's main lab.

Peter Wiebe

Ordinary Seaman Steve Cotter mans *Oceanus* winch.



Vicky Cullen

Oceanus Messman Tony Senna lends a hand with *Knorr* laundry.

R/V Atlantis II

Total Nautical Miles for 1981 – 28,850 miles
Total Days at Sea – 199 days

Voyage	Cruise Period	Principal Objectives, Area of Operations	Ports of Call (Destination)	Chief Scientist
108-Ia	12 Feb-18 Feb	Geological studies of proposed crustal thermal anomaly associated with the Bermuda Rise	Miami	Sclater (MIT)
108-Ib	23 Feb-28 Feb	Continuation of the crustal thermal anomaly studies associated with the Bermuda Rise	Cristobal, Panama	Broda
108-II	2 Mar-6 Mar	Recovery of PARFLUX P2 mooring, hydrocasts and plankton tows in the Eastern Pacific	Balboa, Panama	Honjo
108-III	9 Mar-8 Apr	Determination of the concentrations of organic and inorganic material in the atmosphere and sea surface and fluxes across the sea-air interface for the Sea-Air Exchange Program (SEAREX)	Callao, Peru	Gagosian
108-IV	12 Apr-13 May	Chemical studies of the existence of fluid flow through sediments, flow cell characteristics, and relationship to basement physiography	Balboa, Panama	Sayles
108-V	19 May-30 May	Continuation of crustal thermal anomaly studies associated with the Bermuda Rise	Woods Hole	Sclater (MIT)
109-I	10 Jun-9 Jul	Large scale circulation studies of the North Atlantic and its climatological consequences	Cadiz, Spain	Wunsch (MIT)
109-II	15 Jul-8 Aug	CTD measurements for beta-spiral calculations in the North Atlantic, Canary Basin	Las Palmas, Canary Islands	Stommel
109-III	12 Aug-9 Sep	Large scale circulation studies of the North Atlantic and its climatological consequences	Woods Hole	Roemmich
110	17 Sep- 7 Oct	Physical, chemical, and biological studies for the Warm Core Rings Experiment in the western North Atlantic	Woods Hole	Wiebe

R/V Knorr

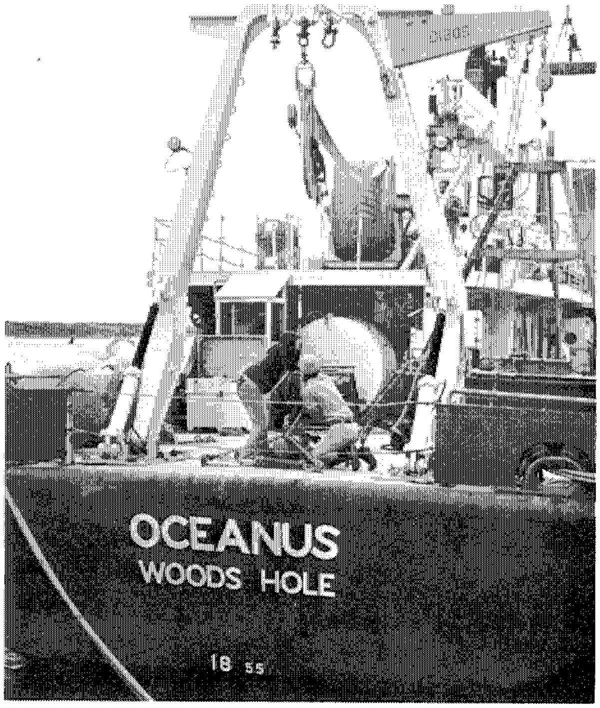
Total Nautical Miles for 1981 – 27,431 miles
Total Days at Sea – 216 days

Voyage	Cruise Period	Principal Objectives, Area of Operations	Ports of Call (Destination)	Chief Scientist
86	12 Jan-13 Jan	From shipyard in Jersey City, New Jersey	Woods Hole	
87	25 Feb-4 Mar	Hydrographic observations in the Long Term Upper Ocean Study (LOTUS) operating area at 34°N,70°W	Woods Hole	Weller
88	6 Mar-20 Mar	Determination of the production and fate of phytoplankton in the plume of the Hudson River	Woods Hole	Malone (Brookhaven)
89-I	1 Apr-13 Apr	Chemical and physical oceanographic studies for the Transient Tracers in the Ocean Program (TTO) in the western North Atlantic, Continental Shelf	Freeport, Bahamas	Brewer
89-II	16 Apr-10 May	TTO Program in the western North Atlantic	St. George, Bermuda	Sarmiento (Princeton)
89-III	16 May-14 Jun	TTO Program in the eastern North Atlantic	Ponta Delgada, Azores	Armi (SIO)
89-IV	19 Jun-15 Jul	TTO Program in the eastern North Atlantic	Greenock, Scotland	Broecker (LDGO)
89-V	21 Jul-16 Aug	TTO Program in the Norwegian and Greenland Seas	Reykjavik, Iceland	Takahashi (LDGO)
89-VI	21 Aug-17 Sep	TTO Program in the Labrador Sea	St. John's Newfoundland	Jenkins/Rhines
89-VII	23 Sep-19 Oct	TTO Program in the western North Atlantic	Woods Hole	Brewer
90	3 Nov-12 Nov	Chemical studies in the western North Atlantic	Woods Hole	Sayles
91	17 Nov-18 Nov 29 Dec-29 Dec	To shipyard From shipyard	Boston Woods Hole	

R/V Oceanus

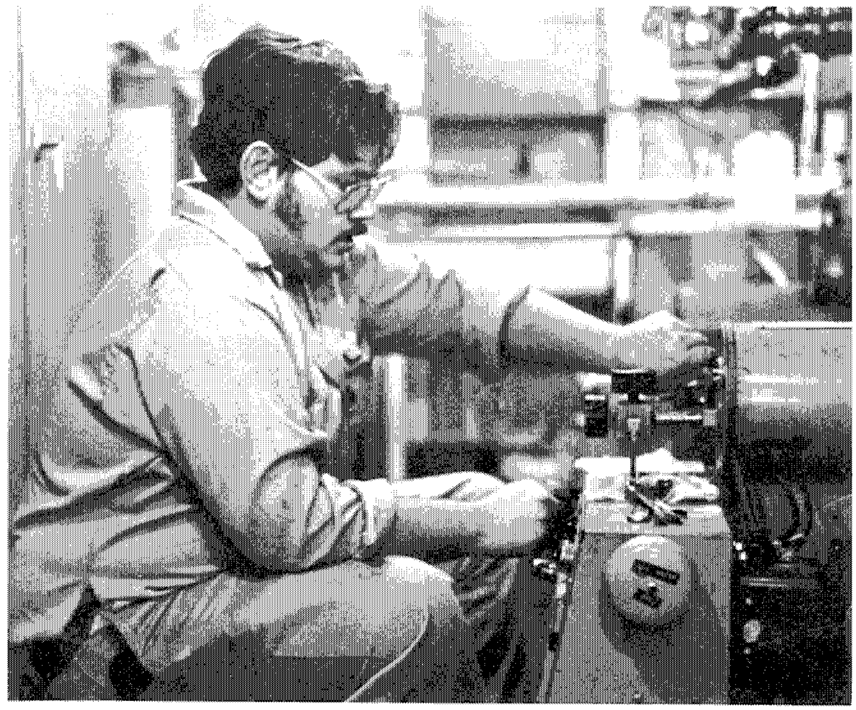
Total Nautical Miles for 1981 - 28,905 miles
Total Days at Sea - 225 days

Voyage	Cruise Period	Principal Objectives, Area of Operations	Ports of Call (Destination)	Chief Scientist
91	16 Jan-22 Jan	Hydrographic studies and deployment of bottom mounted instrument packages in Lydonia Canyon	Woods Hole	Butman (USGS)
92-I	30 Jan-8 Feb	Deployment of mooring array for the Acoustic Tomography Experiment in the vicinity of 26°N,70°W	Miami	Spindel
92-II	11 Feb-21 Feb	Continuation of mooring array deployment for Acoustic Tomography Experiment	Miami	Spindel
92-III	26 Feb-4 Mar	Continuation of mooring deployment for Acoustic Tomography Experiment	San Juan, Puerto Rico	Heinmiller (MIT)
92-IV	8 Mar-20 Mar	Collection of microbiological samples and gravity cores, deployment and recovery of free-fall tripods for incubation experiments in the Puerto Rican Trench, deployment of tripod at Deep Ocean Station #2	Woods Hole	Wirsen
93	26 Mar-3 Apr	Collection of microbiological and surface samples, recovery of tripod at Deep Ocean Station #2	Woods Hole	Copeland (MBL)
94	6 Apr-7 Apr	Zooplankton sampling for studies of life histories of key slope water species south of Cape Cod	Woods Hole	Wiebe
95	23 Apr-6 May	Recovery and deployment of current meter and tripod moorings in the Lydonia Canyon area	Woods Hole	Butman (USGS)
96	11 May-21 May	Deployment of moorings for LOTUS, testing of acoustic doppler current profiler	Woods Hole	Briscoe



Shelley Lauzon

Oceanus is unloaded at pierside in Woods Hole.



Richard Boudreau

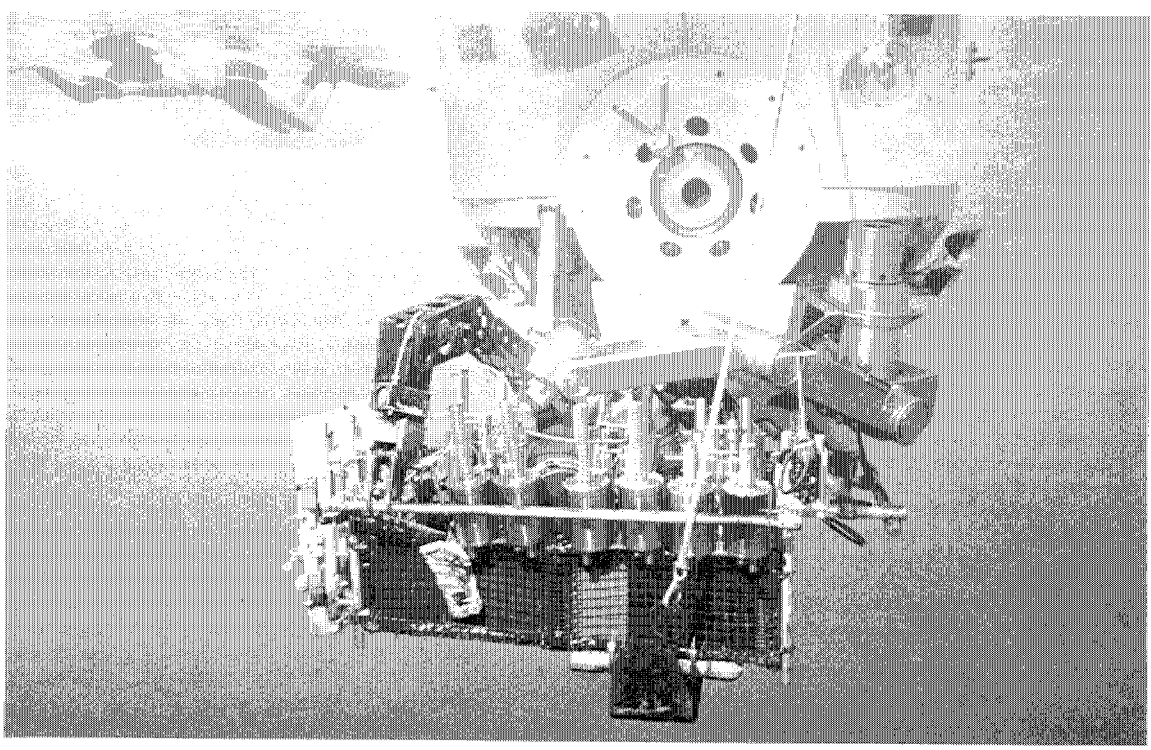
Second Assistant Engineer Bob Baker is at work in the *Atlantis II* machine shop.

97	21 May-22 May 28 May-29 May	To shipyard From shipyard	Jersey City, NJ Woods Hole	
98	29 May-30 May	Continuation of key slope water species sampling south of Cape Cod	Woods Hole	Wiebe
99	3 Jun-16 Jun	Testing hydrophone array for Large Aperture Seismic Experiment (LASE)	Woods Hole	Ewing
100	22 Jun-3 Jul	Biological sample collection and culturing near Bermuda in the Sargasso Sea	Woods Hole	Brand
101-I	10 Jul-24 Jul	Recovery and resetting a net of autonomous listening stations, deployment of SOFAR floats	Ponta Delgada, Azores	Valdes
101-II	26 Jul-10 Aug	Continuation of recovery and resetting net of autonomous listening stations, deployment of SOFAR floats	Woods Hole	Valdes
102	18 Aug-1 Sep	Recovery of Acoustic Tomography Experiment mooring array	Woods Hole	Spindel
103	10 Sep-18 Sep	Recovery of LOTUS moorings at 34°N,70°W	Woods Hole	Weller
104	25 Sep-2 Oct	Recovery and deployment of current meter and tripod moorings near Lydonia Canyon	Woods Hole	Butman (USGS)
105	7 Oct-23 Oct	Determination of the concentration, distribution, and contribution to primary productivity of cyanobacteria in the Sargasso Sea	Woods Hole	Watson
106	27 Oct-28 Oct	Continuation of key slope water species sampling south of Cape Cod	Woods Hole	Wiebe
107	30 Oct-5 Nov	Collection of microbiological samples, recovery of free-fall sediment coring tripod	Woods Hole	Wirsen
108	9 Nov-20 Nov	Collection of sediment and biological samples for the Georges Bank Sediment and Organism Monitoring Program	Woods Hole	Rawson (LDGO)
109	23 Nov-24 Nov	Continuation of key slope water species sampling south of Cape Cod	Woods Hole	Wiebe
110	30 Nov-8 Dec	Engineering tests on prototype bottom-mounted current profiler (POPUP)	Woods Hole	Luyten
111	11 Dec-15 Dec	Continuation of key slope water species sampling south of Cape Cod	Woods Hole	Wiebe

DSRV Alvin and R/V Lulu

Total Nautical Miles for 1981 – 11,014 miles
Total Days at Sea – 155 days
Total Dives – 82

Voyage	Cruise Period	Principal Objectives, Area of Operations	Ports of Call (Destination)	Chief Scientist
107-VII	8 Jan-9 Jan	3 dives to train builders' crew for Japanese submersible *Shinkai 2000*	St. Croix, Virgin Islands	Keach (IMI)
107-VIII	10 Jan-13 Jan	4 dives for recovery of test equipment	St. Croix	Sobel (NAVELEX)
107-IXa	15 Jan-21 Jan	6 dives to test large area imaging system	St. Croix	Ballard
107-IXb	22 Jan-22 Jan	1 training dive for Manganese Nodule Project	St. Croix	Weiss (SIO)
107-Xa	28 Jan-28 Jan	1 dive for recovery of test equipment	St. Croix	Williams (NFWTF)
107-Xb	30 Jan-1 Feb	3 dives for work on eel grass production and export from the St. Croix insular shelf	St. Croix	Hubbard (Fairleigh Dickinson)
107-XI	6 Feb-17 Feb	Transit from St. Croix	Woods Hole	
		1 test dive at end of overhaul period		
109	30 Jun-4 Jul	2 dives for *Alvin* recertification	Woods Hole	Donnelly
110	7 Jul-21 Jul	13 dives for baseline studies in sedimentary biology for offshore drilling management	Woods Hole	Hecker (LDGO)
111-I	25 Jul-8 Aug	Transit from Woods Hole	Balboa, Panama	
111-II	13 Aug-2 Sep	10 dives on the Carnegie Ridge for geological and hydrothermal deposit studies	Balboa	Malahoff (NOAA)
111-III	5 Sep-13 Sep	5 dives in the Panama Basin for investigations of animal/sediment relationships	Balboa	Grassle
111-IV	21 Sep-5 Oct	9 dives in the Panama Basin for benthic metabolism studies	Puntarenas, Costa Rica	Smith (SIO)
111-V	10 Oct-27 Oct	4 dives for observation of bottom lander and sample collection for the Manganese Nodule Project	Manzanillo, Mexico	Murray (UWA)
111-VI	9 Nov-25 Nov	13 dives in high temperature vents at 21°N on the East Pacific Rise	Mazatlan, Mexico	Edmond (MIT)
111-VII	4 Dec-13 Dec	7 dives for investigations of marine snow	Mazatlan	Alldredge (USCB)


Rod Catanach

DSRV *Alvin* begins East Pacific Rise descent carrying titanium water samplers to hot vent site.

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In Memoriam

Henry Burr Steinbach
7 Oct. 1905-21 Dec. 1981

H. Burr Steinbach served as the first full-time Dean of the Graduate Education Program from 1968 to 1973. He was elected to the Corporation in 1959 and became an Honorary Member in 1976 and an Honorary Trustee in 1977. He was also a Member of the Marine Biological Laboratory Corporation and served from 1966 to 1968 as Director and President.

He completed a bachelor's degree at the University of Michigan, a master's degree at Brown University, and a Ph.D. at the University of Pennsylvania. During his career as a renowned cell physiologist, Dr. Steinbach held faculty positions at the University of Chicago, the University of Minnesota, Columbia University, and Washington University. He served as Assistant Director of the National Science Foundation for one year and was a visiting professor at the University of Hawaii and National Taiwan University. He was advisor to a long list of scientific groups including the Institution's Marine Policy Program.

Part of Paul Fye's tribute to Burr Steinbach at a January 1982 meeting of the Educational Assembly follows:

As Dean, Burr brought just the right talent and experience to the newly created job – research biologist, department chairman at the University of Chicago, and MBL Director. His unique personality ideally matched the challenge. Patience, informality, and ingenuity were all his style. Most important of all was his boundless enthusiasm for good science and undiluted optimism for young people. Right up to the end of his life he showed remarkable indomitable spirit – always smiling and of good cheer despite increasing disability in recent years from amyotrophic lateral sclerosis. Unable to speak for more than the last year, he dashed off notes and questions, continuing to keep up with his interests. I remember so many happy things about him. For example, when I offered him a Dean's office in the so-called "executive wing," he politely refused. Instead he selected a location somewhat removed so that no student would ever be intimidated about going to see him. The legacy Dr. Steinbach has left is one of high standards, great courage, true humility, love and care for all he came in contact with. We are all better for having known him.

Edwin A. Link
16 Jul. 1904-7 Sep. 1981

An active participant in Institution affairs, Edwin A. Link became an Associate in 1960, a life Associate in 1962, and he was elected a Member of the Corporation and Trustee in 1964. He became an Honorary Trustee in 1974 and an Honorary Member in 1975.

A pioneer aviator, he was coinventor with his brother of the Link trainer used to train some 500,000 pilots during World War II. Link was president and founder of Link Aviation, which was acquired by General Precision, and he served as executive committee chairman of that company's Link Division from 1959 to 1964. With John Perry, he developed a lock-out submarine, and with J. Seward Johnson he established the Harbor Branch Foundation in Ft. Pierce, Florida. Considerable cooperative work has been done by this Institution and the Harbor Branch Foundation.

Though he left school to work in his father's factory, the Link Piano Co., Link eventually received several honorary doctorates as well as many other awards including the Lindbergh Award for achievements in science and technology combined with the preservation of the natural environment.

Philip H. Handler
13 Aug. 1917-24 Dec. 1981

Dr. Philip H. Handler had been a member of the Corporation since 1970. During a distinguished career in biochemistry, which included work on the nutritional causes of diseases and development of an important advance in the treatment of burns during World War II, Dr. Handler became an increasingly important spokesman for American science. He was appointed to the National Science Board in 1962, elected chairman of the board in 1966, and he was elected president of the National Academy of Sciences in 1968. Dr. Frank Press, who succeeded him at the National Academy last June, noted that under Dr. Handler's leadership the Academy's role in public service had been greatly enhanced.

He completed an undergraduate degree in chemistry at the College of the City of New York at 18, earned a Ph.D. in biochemistry at the University of Illinois, and then joined the Duke University faculty, eventually becoming chairman of the Department of Biochemistry.

Dr. Handler served as advisor to many government and scientific bodies. He was a member of the President's Science Advisory Committee from 1964 to 1967. Last October President Reagan awarded him the National Medal of Science.

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Financial Statements

Highlights:

The Institution's total operating revenue increased 16% in 1981 to $37,961,310 compared with a 6% increase and total revenues in 1980 of $32,814,404. Excess current unrestricted funds of $1,000,000 were transferred to Unexpended Plant Funds.

Funding for sponsored programs was derived from the following sources:

	1981	*1980*	*Increase (Decrease)*
National Science Foundation:			
Science Projects	$ 9,014,000	$ 7,739,000	16.5%
Facilities Projects	7,858,000	6,271,000	25.3%
Office of Naval Research	7,311,000	7,044,000	3.8%
Department of Energy	1,022,000	1,206,000	(15.3%)
National Oceanic & Atmospheric Administration	1,881,000	1,361,000	38.2%
Other Government	2,739,000	2,507,000	9.2%
Restricted Endowment Income	313,000	350,000	(10.6%)
Other Restricted Gifts, Grants, and Contracts	3,034,000	1,966,000	54.3%
	$33,172,000	$28,444,000	16.6%
Other statistics of interest are:			
Full-time Equivalent Employees	813	780	4.2%
Total Compensation (including Overtime & Benefits)	$20,141,000	$17,888,000	12.6%
Retirement Trust Contribution	1,873,000	1,880,000	(.4%)
Endowment Income (net)	2,372,000	1,965,000	20.7%
Additions to Endowment Principal	782,000	1,054,000	(25.8%)
Endowment Principal (year-end at market value)	42,371,000	41,954,000	1.0%

Gifts and grants from private sources including the 1,334 Institution Associates totaled $2,845,000 in 1981 of which $1,929,000 was restricted as follows:

Addition to Endowment Principal	$ 539,000
Laboratory Construction	400,000
Marine Policy & Ocean Management	350,000
Benthonic Foraminifera Studies	120,000
Education Program	55,000
Center for Analysis of Marine Systems	325,000
Coastal Studies Center	40,000
Other Research Programs	100,000
	$1,929,000

Funds availed of in support of the Education Program were derived principally from endowment income received in 1981 totaling $1,216,000. In addition to other funds restricted for education, unrestricted funds of $273,000 were availed of for the Education Program. Research contracts and grants provided student support in the amount of $406,000.

Your attention is invited to the Financial Statements and the notes accompanying them, audited by Coopers & Lybrand.

Joseph Kiebala, Jr.
Assistant Director for Finance & Administration
Kenneth S. Safe, Jr.
Treasurer
Gary B. Walker
Controller

Report of the Certified Public Accountants

To the Board of Trustees of Woods Hole Oceanographic Institution:

We have examined the balance sheets of Woods Hole Oceanographic Institution as of December 31, 1981 and 1980, and the related statements of changes in fund balances, and of current fund revenues, expenses and transfers for the years then ended. Our examinations were made in accordance with generally accepted auditing standards and, accordingly, included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the financial statements referred to above present fairly the financial position of Woods Hole Oceanographic Institution as of December 31, 1981 and 1980, the changes in its fund balances, and its current fund revenues, expenses and transfers for the years then ended, in conformity with generally accepted accounting principles applied on a consistent basis.

Coopers & Lybrand

Boston, Massachusetts
March 24, 1982

BALANCE SHEETS, December 31, 1981 and 1980

ASSETS	1981	1980
Current Fund Assets (Note A):		
Cash	$ 1,235,688	$ 1,740,108
Short-term investments, at cost which approximates market	6,965,520	5,050,000
Reimbursable costs:		
Billed	1,958,498	2,501,154
Unbilled	991,278	1,448,127
Other receivables	111,086	194,924
Inventories	611,766	532,911
Deferred charges and prepaid expenses	211,335	301,055
Deferred research expense	849,764	74,039
Due (to) plant fund	(3,732,278)	(3,647,365)
Due (to)/from endowment and similar funds	5,768	(3,043)
	9,208,425	**8,191,910**
Endowment and Similar Fund Assets (Notes A and B):		
Investments, at market	38,342,580	39,656,470
Cash and cash equivalents	4,034,464	2,294,778
Due (to)/from current fund	(5,768)	3,043
	42,371,276	**41,954,291**
Annuity Fund Assets (Note A):		
Investments, at market (cost $71,729 in 1981 and $70,513 in 1980)	83,124	87,713
Cash	2,338	2,573
	85,462	**90,286**
Plant Fund Assets (Note A):		
Land, buildings and improvements	18,471,506	17,257,421
Vessels and dock facilities	7,362,401	7,362,401
Laboratory and other equipment	3,691,554	2,881,719
	29,525,461	27,501,541
Less accumulated depreciation	10,242,165	9,360,268
	19,283,296	**18,141,273**
Due from current fund	3,732,278	3,647,365
	23,015,574	**21,788,638**
	$74,680,737	**$72,025,125**
LIABILITIES AND FUND BALANCES		
Current Fund Liabilities and Balances:		
Accounts payable and other accrued expenses	$ 2,173,826	$ 746,536
Accrued salaries and related liabilities	1,151,832	1,412,881
Deferred subscription revenue	118,065	107,064
Unexpended balances of restricted funds	2,397,113	2,814,826
Unrestricted balances designated for:		
Income and salary stabilization	2,487,168	2,288,368
Ocean industry program	264,797	218,259
Unrestricted current funds	454,647	207,200
Fiftieth Anniversary Fund	160,977	396,776
Total unrestricted balances	3,367,589	3,110,603
	9,208,425	**8,191,910**
Endowment and Similar Fund Liabilities and Balances:		
Endowment:		
Income restricted	25,577,009	25,052,059
Income unrestricted	3,228,246	3,234,866
Term endowment	3,939,117	3,970,510
Quasi-endowment:		
Restricted	6,238,368	6,281,323
Unrestricted	3,388,536	3,415,533
	42,371,276	**41,954,291**
Annuity Fund Liabilities and Balance:		
Annuities payable	25,292	26,651
Fund balance	60,170	63,635
	85,462	**90,286**
Plant Fund Balances:		
Invested in plant	19,283,296	18,141,273
Unexpended:		
Restricted	755,892	1,090,000
Unrestricted	2,976,386	2,557,365
Total unexpended balances	3,732,278	3,647,365
	23,015,574	**21,788,638**
	$74,680,737	**$72,025,125**

The accompanying notes are an integral part of the financial statements.

Statement of Current Fund Revenues, Expenses and Transfers for the years ended December 31, 1981 and 1980

	1981	1980
Revenues		
Sponsored research:		
Government	$29,029,942	$26,625,841
Nongovernment	4,142,360	1,817,921
	33,172,302	28,443,762
Education funds availed of	1,300,753	1,215,885
Total restricted	34,473,055	29,659,647
Unrestricted:		
Fees	311,264	375,997
Endowment and similar fund income	596,400	522,985
Gifts	916,003	934,431
Tuition	470,932	336,606
Investment income	887,132	614,154
Oceanus subscriptions	209,545	204,949
Other	96,979	165,635
Total unrestricted	3,488,255	3,154,757
Total revenues	**37,961,310**	**32,814,404**
Expenses and Transfers		
Sponsored research:		
Salaries and fringe benefits	10,145,935	8,705,149
Ships and submersibles	7,218,272	6,555,716
Materials and equipment	4,264,553	3,623,029
Subcontracts	1,219,275	964,845
Laboratory cost	1,837,220	1,556,735
Other	4,842,483	3,876,035
General and administrative	3,644,564	3,162,253
	33,172,302	28,443,762
Education:		
Faculty expense	324,006	290,393
Student expense	667,827	496,739
Postdoctoral programs	276,451	228,850
Other expense	165,756	242,078
General and administrative	140,086	132,325
	1,574,126	1,390,385
Unsponsored research	609,919	663,501
Oceanus magazine	281,320	255,598
Other activities	485,074	397,084
General and administrative	94,172	115,159
	1,470,485	1,431,342
Total expenses	**36,216,913**	**31,265,489**
Nonmandatory transfers:		
To plant fund, unexpended	1,000,000	1,290,000
Total expenses and nonmandatory transfers	**37,216,913**	**32,555,489**
Net increase in unrestricted current fund	**$ 744,397**	**$ 258,915**
Designated for:		
Income and salary stabilization	198,800	174,328
Ocean industry program	46,537	(9,748)
Unrestricted current funds	247,447	(115,341)
Fiftieth Anniversary Fund	251,613	209,676
	$ 744,397	**$ 258,915**

The accompanying notes are an integral part of the financial statements.

Statement of Changes in Fund Balances for the years ended December 31, 1981 and 1980

	Current Fund					Plant Fund		
1981	Restricted	Unrestricted	Total	Endowment and Similar Funds	Annuity Fund	Invested in Plant	Unexpended	Total Funds
Increases:								
Gifts, grants and contracts:								
Government	$29,029,942		$29,029,942					$29,029,942
Nongovernment	3,127,279	$ 916,003	4,043,282	$ 539,349			$ 400,000	4,982,631
Endowment and similar funds investment income (Note D)	1,775,935	596,400	2,372,335					2,372,335
Net increase in realized and unrealized appreciation			—	(365,184)				(365,184)
Other	122,630	1,975,852	2,098,482		$(3,465)		(150,000)	1,945,017
Total increases	34,055,786	3,488,255	37,544,041	174,165	(3,465)		250,000	37,964,741
Decreases:								
Expenditures (including $624,465 of funded depreciation)	(34,473,055)	(1,743,858)	(36,216,913)				624,465	(35,592,448)
Depreciation (Note A)			—			$ (892,564)		(892,564)
Total decreases	(34,473,055)	(1,743,858)	(36,216,913)			(892,564)	624,465	(36,485,012)
Net change before transfers	(417,269)	1,744,397	1,327,128	174,165	(3,465)	(892,564)	874,465	1,479,729
Transfers – additions (deductions):								
Current revenues to plant fund		(1,000,000)	(1,000,000)				1,000,000	—
Fiftieth Anniversary to endowment and similar funds		(242,376)	(242,376)	242,376				—
Fiftieth Anniversary to plant fund		(245,035)	(245,035)				245,035	—
Plant asset additions			—			2,035,438	(2,035,438)	—
Other	(444)		(444)	444		(851)	851	—
Total transfers	(444)	(1,487,411)	(1,487,855)	242,820		2,034,587	(789,552)	—
Change in fund balance for the year	(417,713)	256,986	(160,727)	416,985	(3,465)	1,142,023	84,913	1,479,729
Fund balance, December 31, 1980	2,814,826	3,110,603	5,925,429	41,954,291	63,635	18,141,273	3,647,365	69,731,993
Fund balance, December 31, 1981	$ 2,397,113	$3,367,589	$ 5,764,702	$42,371,276	$60,170	$19,283,296	$3,732,278	$71,211,722
1980								
Increases:								
Gifts, grants and contracts:								
Government	$26,625,841		$26,625,841					$26,625,841
Nongovernment	2,285,817	$ 934,781	3,220,598	$ 828,518			$ 504,645	4,553,761
Endowment and similar funds investment income (Note D)	1,442,388	522,985	1,965,373					1,965,373
Net increase in realized and unrealized appreciation			—	4,443,257				4,443,257
Other	95,349	1,697,341	1,792,690		$14,325			1,807,015
Total increases	30,449,395	3,155,107	33,604,502	5,271,775	14,325		504,645	39,395,247
Decreases:								
Expenditures (including $594,458 of funded depreciation)	(29,659,647)	(1,605,843)	(31,265,490)				594,458	(30,671,032)
Depreciation (Note A)			—			$ (856,272)		(856,272)
Total decreases	(29,659,647)	(1,605,843)	(31,265,490)			(856,272)	594,458	(31,527,304)
Net change before transfers	789,748	1,549,264	2,339,012	5,271,775	14,325	(856,272)	1,099,103	7,867,943
Transfers – additions (deductions):								
Current revenues to plant fund		(1,290,000)	(1,290,000)				1,290,000	—
Restricted to unrestricted funds	(36,375)	36,375	—					—
Fiftieth Anniversary to endowment and similar funds		(225,107)	(225,107)	225,107				—
Plant asset additions			—			1,597,499	(1,597,499)	—
Other	(455)		(455)	455				—
Total transfers	(36,830)	(1,478,732)	(1,515,562)	225,562		1,597,499	(307,499)	—
Change in fund balance for the year	752,918	70,532	823,450	5,497,337	14,325	741,227	791,604	7,867,943
Fund balance, December 31, 1979	2,061,908	3,040,071	5,101,979	36,456,954	49,310	17,400,046	2,855,761	61,864,050
Fund balance, December 31, 1980	$ 2,814,826	$3,110,603	$ 5,925,429	$41,954,291	$63,635	$18,141,273	$3,647,365	$69,731,993

The accompanying notes are an integral part of the financial statements.

A. Summary of Significant Accounting Policies:

Fund Accounting
In order to comply with the internal designations and external restrictions placed on the use of the resources available to the Institution, the accounts are maintained in accordance with the principles of fund accounting. This procedure classifies resources into various funds in accordance with their specified activities or objectives.

Investments
Investments in securities are stated at market value determined as follows: securities traded on a national securities exchange are valued at the last reported sales price on the last business day of the year; securities traded in the over-the-counter market and listed securities for which no sales prices were reported on that day are valued at closing bid prices. Investments for which a readily determinable market value cannot be established are stated at a nominal value of $1; income from such investments is not significant.
Net investment income is distributed to all funds in the year received and for pooled investments, income is distributed on the unit method. Unrestricted investment income is recognized as revenue when received and restricted investment income is recognized as revenue when it is expended for its stated purpose. Realized and unrealized gains and losses are attributed to the principal balance of the funds involved.
The Institution follows the accrual basis of accounting except that endowment and similar fund investment income is recorded on a cash basis. The difference between such basis and the accrual basis does not have a material effect on the determination of investment income earned on a year-to-year basis.

Contracts and Grants
Revenues associated with contracts and grants are recognized as related costs are incurred. Beginning with fiscal 1978, the Institution has negotiated with the government fixed rates for the recovery of certain indirect costs. Such recoveries are subject to carryforward provisions that provide for an adjustment to be included in negotiation of future fixed rates.

Gifts
Gifts are recorded in the applicable funds when received. Noncash gifts are generally recorded at market value on the date of gift although certain noncash gifts for which a readily determinable market value cannot be established are recorded at a nominal value of $1 until such time as the value becomes known. Unrestricted gifts are recognized as revenue when received and restricted gifts are recognized as revenue as they are expended for their stated purposes.

Plant
Plant assets are stated at cost. Depreciation is provided at annual rates of 2% to 5% on buildings, 3⅓% on Atlantis II and 5% to 33⅓% on equipment. Depreciation expense on Institution-purchased plant assets amounting to $624,465 in 1981 and $594,458 in 1980 has been charged to operating expenses. Depreciation on certain government funded facilities (Atlantis II, Laboratory for Marine Science and the dock facility, amounting to $261,814 in each year) is accounted for as a direct reduction of the plant asset and invested in plant fund. Title to the research vessel Atlantis II is contingent upon its continued use for oceanographic research.
The Institution consolidates available cash from the plant fund with other cash in the current fund for investment.

Annuity Funds
On the date of receipt of annuity fund gifts, the actuarially computed value of the future payments to annuitants is recorded as a liability and any excess amount of the gift is credited to the fund balance. The actuarial values of the liabilities are recomputed annually.

Reclassification of 1980 Balances
Certain balances in the 1980 financial statements have been reclassified to conform with the 1981 presentation.

B. Endowment and Similar Fund Investments:

The cost and market value of investments held at December 31, 1981 and 1980 are as follows:

	December 31, 1981		December 31, 1980	
	Cost	*Market*	*Cost*	*Market*
Government and government agencies	$10,469,136	$10,396,270	$ 6,174,890	$ 5,263,750
Corporate	4,791,653	4,459,624	6,419,492	5,387,940
Convertible debt	260,625	237,500	—	—
Common stocks	19,292,646	23,107,670	21,986,116	28,864,047
Real estate	45,501	45,501	39,733	39,733
Fiduciary Trust Co. Fund	100,000	96,015	100,000	101,000
Total investments	**$34,959,561**	**$38,342,580**	**$34,720,231**	**$39,656,470**

C. Pooled Investment Units:

On January 1, 1981, the Institution combined all endowment and similar fund investments into a single pool of investments. The conversion of the three funds (previously reported as Pool A, Pool B, and Separately Invested) was effected by assigning fund shares to each fund based on the total market value of investments held at December 31, 1980 and the pooled unit value of investments held in Pool A at that date.
The value of a pooled investment unit at December 31, 1981 was $.9672 as compared to the unit value of $.9749 upon conversion at January 1, 1981. The pooled investment income per unit at December 31, 1981 was $.0542.

D. Endowment and Similar Fund Income:

Income of endowment and similar funds consisted of the following:

	1981	1980
Dividends	$1,018,483	$1,059,791
Interest	1,472,841	972,031
Other	2,994	2,994
	2,494,318	2,034,816
Investment management costs	(121,983)	(69,443)
Net investment income	$2,372,335	$1,965,373

E. Retirement Plan:

The Institution has a noncontributory defined benefit trusteed retirement plan covering substantially all full-time employees. The Institution's policy is to fund pension cost accrued which includes amortization of prior service costs over a 30-year period. Retirement plan costs charged to operating expense amounted to $2,045,000 in 1981 and $2,011,000 in 1980, including $172,000 and $131,000, respectively, relating to expenses of the retirement trust. As of the most recent valuation date (January 1, 1981), the comparison of accumulated plan benefits and plan net assets is as follows:

Actuarial present value of accumulated plan benefits:	
Vested	$15,386,694
Nonvested	321,223
Total actuarial present value of accumulated plan benefits	$15,707,917
Net assets available for plan benefits	$16,785,727

The assumed rate of return used in determining the actuarial present value of accumulated plan benefits was six and one-half percent compounded annually.

Vicky Cullen

Atlantis II Voyage 542 comes home to Woods Hole.

Shelley Lauzon

Jim Craddock and Steve Ames look ashore
at the end of Gulf Stream ring cruise on *Atlantis II*.

Shelley Lauzon

Roger Mann handles *Asterias* lines.