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APL's INDEPENDENT RESEARCH AND DEVELOPMENT THRUST IN OCEANOGRAPHY

Advances in satellite sensors, ocean instrumentation, and computer technology have opened up a new era in ocean research, promising rapid growth in the scientific understanding of the sea and the application of this new knowledge to the solution of both civil and military problems. As part of a coordinated, multiyear research and development plan, APL scientists and engineers are laying a foundation for future contributions in the fields of satellite oceanography, tactical oceanography, and Chesapeake Bay research.

INTRODUCTION

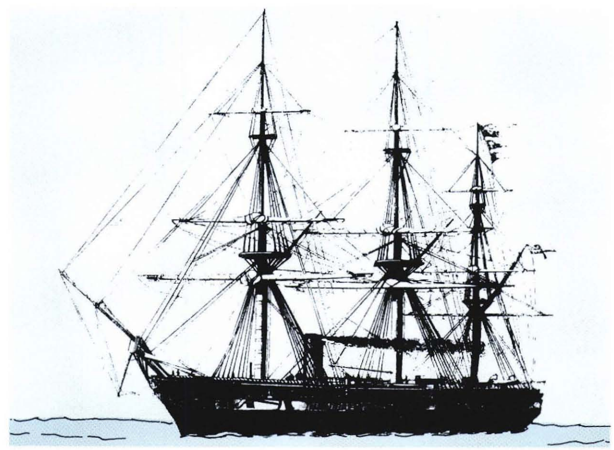
When APL, in 1983, incorporated the concept of Thrust Areas into its independent research and development (IR&D) program, it was only natural that ocean science and technology should be among the first areas chosen for special emphasis. One would be hard pressed to think of a more suitable topic for an organization committed to solving problems for the U.S. Navy. However, the ocean is an almost boundless subject, one that does not fit between the covers of a few research reports or inside the walls of a single institution. What part of ocean research should APL prepare to undertake? And why one part and not another?

In this article we will show how we answered those questions and, midway into our 3-year research program, will give a view of where we are in our investigations and where we hope to go. Before we begin, though, it will help to get a sense of position and direction if we stand back and look at our starting point in relation to larger events in man's attempt to understand and use the sea.

DEVELOPMENTS IN OCEAN RESEARCH

The systematic, scientific study of the ocean began scarcely more than 100 years ago when the steam corvette, HMS *Challenger*, left Portsmouth, England, on the morning of December 21, 1872. A little in the manner of Captain Kirk and Mr. Spock, who command the fictional Starship *Enterprise,* Captain George S. Nares and science officer Charles Wyville Thompson led the *Challenger* on a 3½ year mission into a world full of strange phenomena and alien life forms. This remarkable first voyage set the pattern for the era of "great expeditions" in oceanography, characterized by the collection of voluminous amounts of oceanographic information during long excursions by ships of single nations.

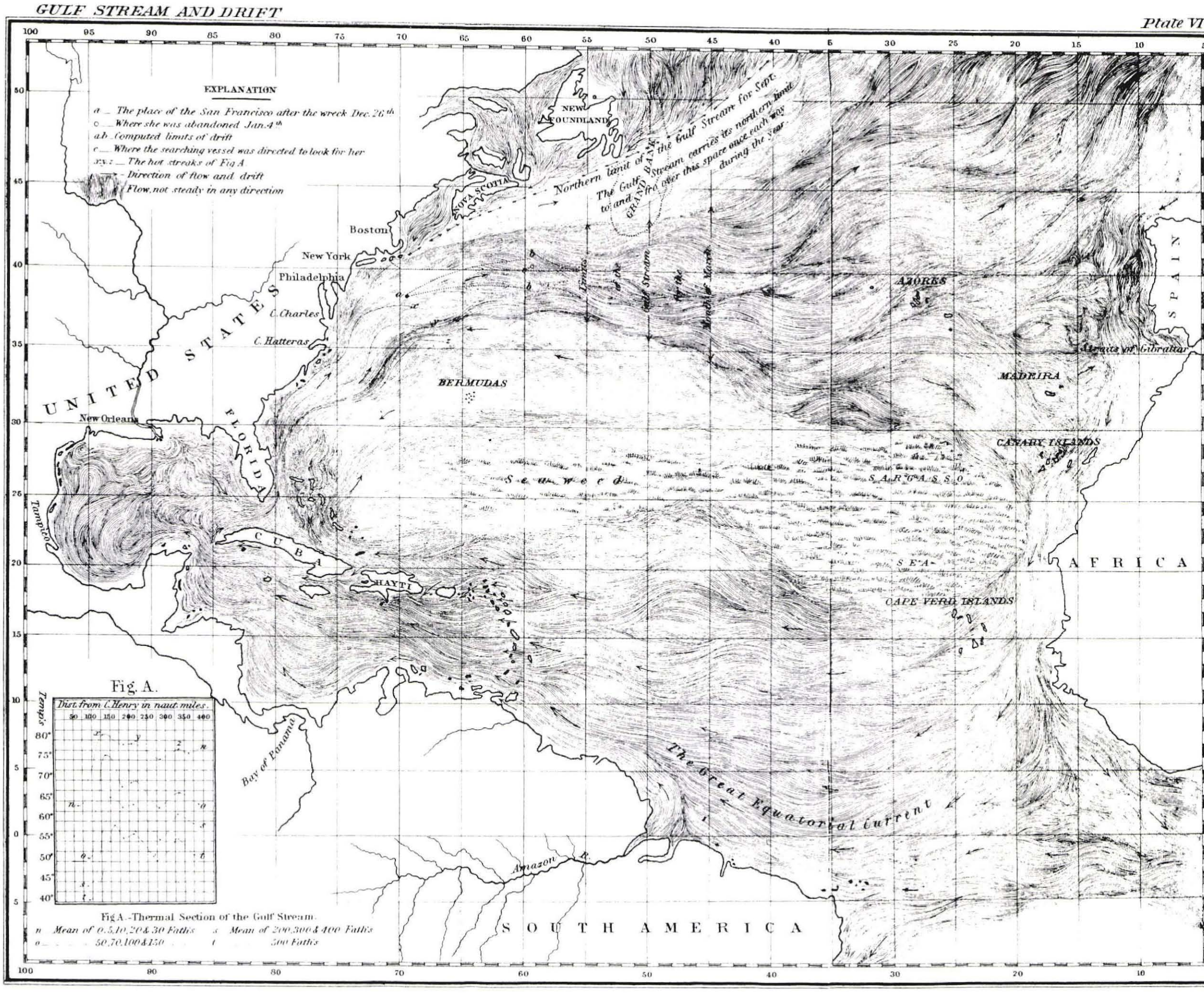
By today's standards, the measurement techniques used by oceanographers of that era were crude. Many times, instruments did not work at all, and, more often than not, an investigator had only the vaguest idea about the location of his ship, the depth of his sampling equipment, or even what he was trying to measure. He considered an experiment a great success if the ocean gave back his instrument.



The voyage of HMS *Challenger* covered over 68,000 nautical miles, and the scientific company established 362 observation stations where measurements of ocean depth, currents, and temperature distributions were made. Many water samples and specimens of marine organisms were also collected at these stations. Temperature soundings, consisting of 10 to 20 temperature measurements at various depths, were made using the most modern device of the day—a Miller-Casella mercury thermometer—that could measure temperature to within 0.1 degree celsius while under great pressure. It took 45 minutes for the sounding line to reach 3000 fathoms.

Blessed with hindsight, we now know that the physical measurements made during those years were too widely spaced in time and geographic location to reveal much about the dynamics of the ocean. But they were a start, and much was learned.

By the end of the Second World War, it had become clear to everyone that the study of the ocean was too big and too important an undertaking for any individual nation, and machinery was set up for international cooperation in ocean research. The International Geophysical Year, 1957-58, marked the beginning of



Matthew Fontaine Maury, the first Oceanographer of the Navy, invited all shipmasters to send him observations of oceanographic and meteorological interest for the purpose of preparing charts of winds and currents. This chart of the Gulf Stream appeared in Maury's classic book, *The Physical Geography of the Sea,* published in 1855. Maury's charts revolutionized ocean navigation, shortening the passage between some ports by as much as 2 months.

the era of "international programs" that continued in an impressive series of multinational projects through the International Decade of Ocean Exploration, 1970–80. These research programs, perhaps exemplified by the Mid-Ocean Dynamics Experiment in 1975, tended to be regional rather than global in scope, and scientists made full use of improvements in sensors, pressure vessels, and electronics to obtain high-resolution data from instruments that were towed, dropped, or left free to drift.

During that period, subsurface ocean weather was discovered and we had our first glimpse of the global ocean from space. These achievements, combined with very rapid developments in microelectronics and computer technology, set the stage for the emergence of the next, and latest, era of ocean research.

The era of global observation can be considered to have started on June 27, 1978, with the launching of Seasat, the first U.S. satellite dedicated exclusively to oceanographic studies. Seasat ceased operation after only about 100 days in orbit, but while it was operational it provided the first worldwide maps of ocean current variations, surface wind speed, surface temperature, and wave height.

On the strength of those results, ocean scientists began to think in terms of global-scale research. Their thoughts were emboldened by continued improvements in the sensitivity, coverage, and reliability of in situ ocean instruments, now capable of being linked by satellites. They were also encouraged by sustained progress in computer technology, which promised an ability to store and process incredible amounts of data and made large computational models of the ocean conceivable for the first time.

Oceanographers are now planning a World Ocean Circulation Experiment, to be conducted from 1988–93 as part of the World Climate Research Program, that will rely heavily on satellite measurement techniques. And, for the 1990s and beyond, an Earth Observing System is being proposed to study climate, water and energy cycles, and geophysical processes from various space platforms, including NASA's Space Station. In a companion article in this issue, L. F. McGoldrick describes some of these plans in detail.

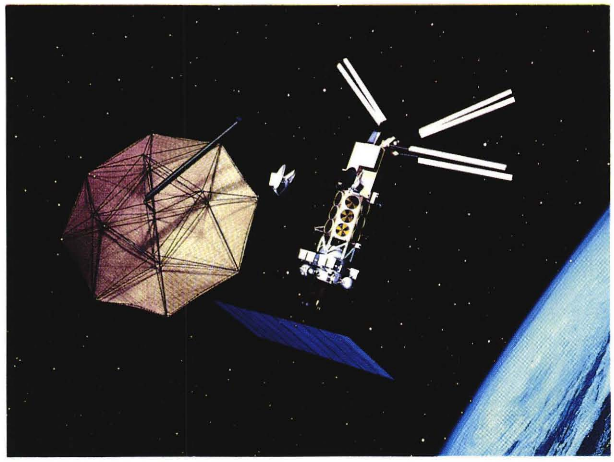
In this new era, the historical curve that plots the slow progress in ocean research is clearly beginning to break sharply upward.

DEVELOPMENTS IN NAVAL APPLICATIONS

Tactical oceanography—the use of knowledge about the ocean for military purposes—has a much longer history than scientific ocean research. The study of the subject probably got underway a few days after a clever and adventurous soul first rode a floating log across some prehistoric river. Sixteenth-century corsairs knew exactly where to wait for the winds and currents to bring their next victim, knowledge they unhappily shared with naval escorts. And modern navies, in addition to still being limited by wind, waves, fog, and ice, found that, as their technological means improved, they had to learn more and more about the ocean in order to understand, for example, why a sonar that operated perfectly in the morning went stone deaf in the afternoon.

Fortunately, the U.S. Navy has always been a leader in oceanographic research and development. Captain Matthew Fontaine Maury revolutionized ocean navigation in 1852 by developing the first systematic charts of ocean currents, and, a century later, the Navy was first to use electronic computers to help in the preparation of ocean forecasts. But staying in the lead in the present age of global missions, sophisticated sensors, and long-range weapons means that increasingly detailed information about the ocean is needed over very broad areas, and on demand. So the Navy is about to enter a new era of its own with the deployment in 1989 of the Navy Remote Ocean Sensing System (NROSS), the first U.S. Navy oceanographic satellite.

Other major initiatives in naval oceanographic research were announced in 1984 by the Secretary of the Navy and the Chief of Naval Operations. In his policy statement, Secretary of the Navy John Lehman called for "a major reinvigoration of Navy efforts in oceanography." He instructed the Navy to ensure a leadership role in the development of ocean computer models and in the operational use of remotely sensed ocean data, and he asked for the construction of new deep-ocean research platforms.



Sensors aboard the NROSS satellite will measure surface winds and temperatures and survey the topography of the sea surface and ice fields. Among the applications, this information will be the basis for a shipboard antisubmarine-warfare acoustic prediction model to be incorporated in a Tactical Environment Support System. NROSS data will also be used in the World Ocean Circulation Experiment.

DEVELOPING A PLAN

To discover where APL might fit in this overall scheme, John R. Apel, in late 1982, formed an Ocean Program Committee "to explore means and opportunities for augmenting oceanographic programs." For 6 months, this committee examined strengths, weaknesses, opportunities, and problems and worked to develop a long-range view of APL's potential role in ocean research.

Committee members were not surprised to find from their survey that the Laboratory had a strong record of accomplishment in ocean technology, as well as a solid base of trained people and technical resources. APL scientists and engineers had dramatically improved ocean navigation by inventing the Transit satellite navigation system, they had developed the GEOS-3 spacecraft, designed and built the altimeter for Seasat, and made advances in the analysis of satellite data. Moveover, for two decades, they had carried out a long list of applied oceanographic research and instrumentation development programs for the Navy—not to mention environmental assessments for the State of Maryland and ocean energy studies for the U.S. Department of Energy.

The committee reported that APL had the potential for making unique and significant contributions in three general areas:

1. *Satellite oceanography,* because APL builds satellites and satellite sensors, understands the space environment, and has the resources and knowledge to collect and analyze large amounts of satellite data;
2. *Tactical oceanography,* because the Laboratory is unmatched by traditional oceanographic research and development institutions in its closeness to the "blue suit" Navy, its comprehensive understanding of all types of Navy systems, and its years of experience at sea learning how weapons and sensors are affected by the environment;
3. *Chesapeake Bay research,* because the Bay is a troubled and nearby national resource, and APL has the ability to help.

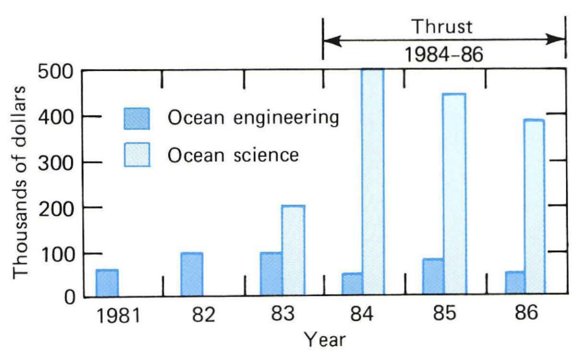
The committee took on the job of suggesting a strategy for investing IR&D funds to support general long-range objectives in the three areas, and one of the principal factors it examined was opportunity. The members saw, for example, that the Laboratory, in its role as the Navy's manager for the Geosat program, was in an excellent position to contribute to the scientific study of the ocean using data from the satellite's altimeter, an instrument designed by APL engineers to map the shape of the earth and its oceans with high precision. They also recognized opportunities to attach low-cost research components to major seagoing projects with little interference and to support collaborative studies of the Chesapeake Bay at a time when the efforts to save it were just beginning. The committee also hoped, of course, that the Laboratory could be made ready to participate in the international ocean research programs planned for the late 1980s and 1990s and in programs connected to the development and use of NROSS.

IMPLEMENTING A PROGRAM

When the area of ocean science and technology became one of the first thrust areas in the APL IR&D program, the findings of the Ocean Program Committee were used to define several 3-year goals. First, during this period we wanted to emphasize projects of high scientific merit as opposed to engineering development projects. However, in the second place we wanted this emphasis to occur in a manner that would take advantage of specific opportunities and would prepare APL for future roles in satellite oceanography, tactical oceanography, and Chesapeake Bay research, in accordance with long-range objectives. Last, we wanted to fill technological gaps, especially in numerical ocean modeling.

As research proposals were received, they were evaluated both from the standpoint of their technical merit and their correspondence with the goals just mentioned. Related proposals were combined and integrated into four major project areas so that, ultimately, four teams of investigators were working in a unified manner with common purpose. At this time, the research program has run a little past the halfway mark. Over the course of the 3-year thrust period, almost $1.5 million will have been invested in ocean research.

In addition to the IR&D thrust efforts, the Laboratory is engaged in several contract ocean research activities, as well as a long-range program of research in ocean science in the Milton S. Eisenhower Research Center. Much of this work is focused on the study of the interaction between subsurface and surface wave fields, as described elsewhere in this issue in the articles by Apel, Gasparovic, and Thompson.



IR&D funding in ocean science and technology at APL.

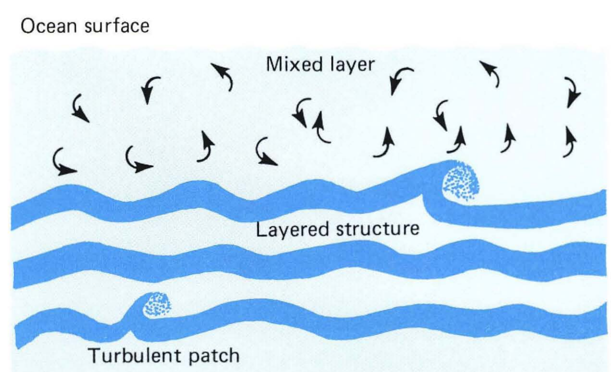
The nature of the ocean phenomena under study in the IR&D thrust program, their scientific and tactical significance, and the efforts and plans of the APL research teams investigating the phenomena are sketched very briefly in the following sections. Only simple, broad strokes are used, but perhaps the descriptions will suffice to illustrate the importance and quality of the efforts.

The Origin of Small-Scale Variations in the Ocean

Not long ago, the interior of the ocean was thought to be a fairly peaceful place, changing only gradually from point to point and from moment to moment. But high-resolution measurements made during the last several decades have taught us that properties such as temperature and salinity actually change quite sharply with depth across a large number of horizontal layers, some less than a meter thick. These layers undulate slowly up and down, some moving in step, others coming closer together and then moving farther apart, as packets of internal waves propagate through the body of the ocean, seemingly coming from every direction. We also know that this underlying pattern is often disrupted by energetic and extensive patches of turbulence that appear suddenly here and there, even far below the surface.

Ocean finestructure and microstructure are important subjects for scientists trying to understand how the ocean manages to move matter and energy from one depth to another or how ocean fronts (boundaries between masses of water with different characteristics) are maintained. They are also important to the engineers who attempt to develop underwater communications and sensor systems. Variations in the environment over distances of 100 meters or less cause troublesome fluctuations in the transmission of high-frequency sonar signals and can limit the ability to produce images of underwater objects.

At the moment, the origin and nature of this small-scale activity in the ocean are not well understood.

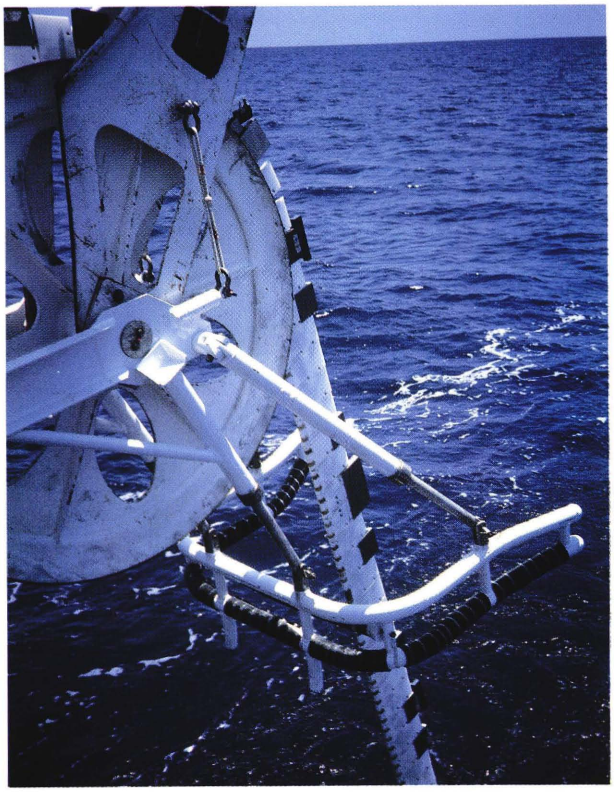


Small-scale ocean activity. The ocean is discretely layered, which, coupled with the very active nature of these layers, sometimes produces turbulence at great depth.

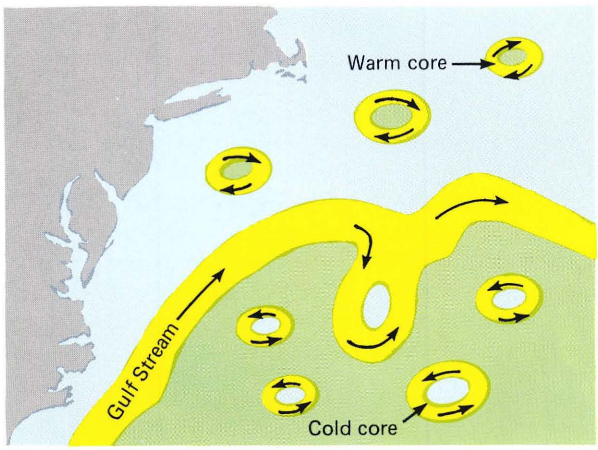
Speculation about its sources abounds, but facts are scarce. One of several purposes of current APL research is to investigate various ways in which one source might be distinguished from another experimentally.

Measurements of ocean finestructure and microstructure were made as part of the IR&D thrust during the fall of 1984 in the Gulf Stream and Sargasso Sea east of Florida as an adjunct to a U.S. Navy project. This piggyback arrangement allowed the research team to use a unique, high-resolution, towed oceanographic chain, consisting of a vertical string of several hundred closely spaced, highly accurate, sensitive sensors for measuring temperature and salinity. (Some aspects of the analysis of these measurements are described in Refs. 1 and 2.) Because the sensors were closely spaced in the vertical direction and also were able to respond rapidly to changes in the direction in which they were being towed, their signals produced a high-resolution two-dimensional image of small-scale variations in temperature and salinity as the chain sliced through the ocean. The results are analogous to viewing a full TV picture instead of a sequence of unrelated single scans across the middle of the screen, as one would see using earlier towed instruments or dropsondes. From a scientific standpoint, the ability to observe ocean activity with such high resolution in both vertical and horizontal dimensions is a major development, one that already shows promise of giving insight into the origin and distribution of ocean finestructure and microstructure.

A great deal more about the ocean is to be learned from these data. The Office of Naval Research, recognizing the importance of the work, plans to support further analyses by APL scientists in the near future. At the same time, the IR&D effort will turn to the question of whether or not the patterns of small-scale variation found in the experiments could significantly alter high-frequency acoustic transmission or, inversely, whether or not the processes that produce them might be studied using high-frequency acoustic remote sensing methods.



Hundreds of miniature sensors, many spaced only 10 centimeters apart, comprise the "wet end" of APL's modern oceanographic chain. Temperature changes in the range of a few tens of microdegrees celsius can be measured. Experimental information is received at a rate of over 22,000 data values per second.



Most mesoscale eddies in the North Atlantic are produced by unstable meanders in the Gulf Stream. If a meander develops toward the east, the resulting eddy traps cold Atlantic water in its core and it rotates counterclockwise. Meanders that occur toward the west produce eddies that have warm shelf water in their cores and they rotate clockwise.

The Weather Beneath the Ocean Surface

If it were possible to photograph large water currents, a time-lapse motion picture of the ocean would be dramatic. Sharply defined and fast-moving streams would be seen flowing along continental boundaries and, in a cascade of explosive instabilities, they would send large eddies of water hundreds of kilometers in diameter spinning into the surrounding body of the sea. Almost all of the action in the scene would be associated with these mesoscale motions, which account for all but a few percent of the ocean's kinetic energy and comprise the subsurface weather. Viewed at true speed, the lifetime of one of these ocean "storms" would be about 100 days.

The idea of taking a "photograph" of subsurface weather systems is not at all farfetched if one uses a satellite altimeter as a camera. An altimeter determines the distance to the earth by measuring the time it takes for a radar pulse to travel to the surface and back again, and state-of-the-art instruments, like the one aboard Geosat, can measure altitude to within a few centimeters. Measurements of distance can be used to visualize mesoscale features because ocean currents produce small elevations and depressions in the sea surface. For example, the sea surface at the southeastern edge of the Gulf Stream is more than 3 feet higher than the level at its northwestern edge, 60 miles away.

If the satellite's position is known accurately, an image of the perturbations in the ocean's shape caused by mesoscale currents can be assembled over the course of many orbits as the trace of the satellite's path wraps around the earth, one revolution after another. A reasonably sharp image can be obtained if the "shutter stays open" only a fraction of the roughly 100 days associated with the movement of the subsurface weather pattern. Studies at NASA and elsewhere have shown that a single satellite can cover most of the world's oceans in a closely spaced pattern in about 10 days.

The contours of ocean height that result from altimeter measurements are analogous to atmospheric highs and lows common to newspaper weather maps and TV weather reports. This kind of information is important for a number of reasons. Ocean variability, over the course of a few years, can significantly influence the world's climate, and climatic fluctuations have been known to produce widespread and dramatic effects. Mesoscale currents, fronts, and eddies also have major influences on the propagation of sound in the ocean. Much of the mystery surrounding aberrations in intermediate and long-range acoustic transmission can be attributed to a lack of understanding of the subsurface weather.

If the observation of subsurface weather systems from a satellite sounds easy, it is not. A large number of error sources—uncertainties in the satellite orbit, the contributions of tides and surface waves, anomalies in the transmission of the radar signal through the atmosphere, and inaccuracies in describing the true figure of the earth (the geoid)—need to be understood and their effects removed. Otherwise, the total error can overwhelm the variations that one hopes to see.

Supported by the IR&D program, ocean scientists at APL have now joined researchers at the Naval Ocean Research and Development Activity, NASA, and the National Oceanic and Atmospheric Administration, and elsewhere in trying to understand and eliminate these errors. The APL team had the distinction of obtaining the first oceanographic information from the Geosat satellite.

Predicting ocean weather is even more difficult than observing it. Satellite altimetry serves a role analogous to a network of barometers in the atmosphere: it can only provide information on the pressure field at the surface. Subsurface motions and the distributions of temperature and salinity with depth also influence the dynamic evolution of mesoscale systems, but they cannot be measured from a satellite. The satellite data must be augmented by in situ measurements to provide the missing information. The two are then interrelated and projected into the future using large numerical models, much as atmospheric weather is predicted today.

Part of the research at APL on mesoscale processes is devoted to developing an advanced computer model to predict the evolution of ocean fronts and eddies and to learning how to get the most value from satellite data for the purposes of starting and updating computations. While the new model is under development, data assimilation methods are being studied in cooperation with Harvard University, using an approximate model developed by Allan Robinson and his associates.

Several collaborations of APL scientists with researchers at other organizations are being arranged. APL scientists have their eyes fixed on future programs associated with both naval applications and the World Ocean Circulation Experiment.

Ocean Winds and Waves Viewed from Space

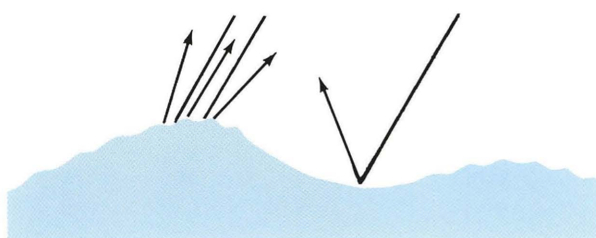
Storms at sea can be awesome and dangerous. If a strong wind blows in more or less the same direction over a distance of 500-600 miles, ocean waves can grow to be monsters over 30 feet high, with crests traveling nearly 45 miles an hour. Waves of this size would easily wash over most buildings in a fraction of a second, with amplitude to spare.

It is rare today for a ship to sail blindly into 30-foot seas, although sudden, malevolent turns in the weather still occasionally send seamen and their cargo to the bottom. Encountering waves about 10 feet high, however, is not uncommon. According to studies of merchant ship logs, amplitudes of 10 feet or more are experienced perhaps as much as 25 percent of the time.

At a height of 10 feet, ocean waves can still be troublesome, sickening passengers, increasing travel time and shipping costs, and considerably diminishing the operational effectiveness of navies. Timely forecasts of the state of the sea over the entire globe is clearly a goal worth pursuing, and large-scale observations of the forces applied by the wind are also important in understanding the general circulation of the ocean, and hence the world's climate.

The IR&D thrust in ocean science and technology cannot be credited with starting a new effort in this research area at APL, as it can in the others. When the IR&D initiative began, the study from space of ocean waves was already a going concern at APL. References 3 and 4 describe some of the early work connected with the Seasat mission, and, in this issue, Beal gives an up-to-date historical account of satellite oceanography at APL.

The emphasis supplied by the IR&D program has led, nevertheless, to significant technical advancements and to a broadened ability to study and understand

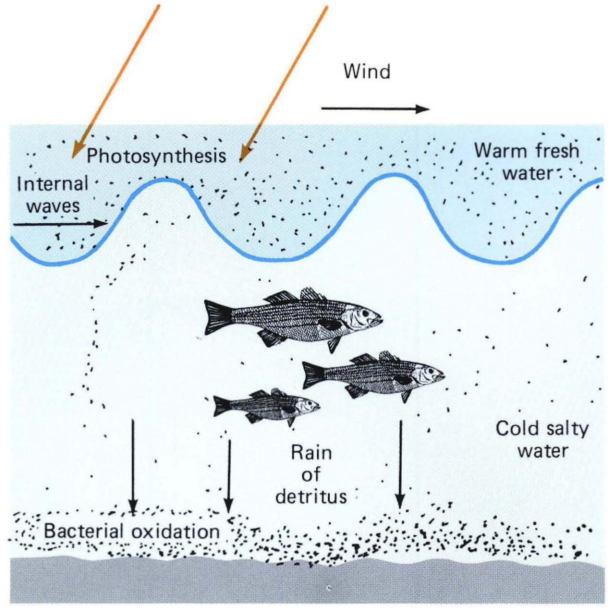


Radar imaging of ocean waves. One reason that waves can be seen by spaceborne radar is the difference in backscattered radiation caused by the modulation of small waves that ride on larger ones.

ocean winds and waves measured with satellite instruments. For example, with IR&D funding, the research team has shown, somewhat to its own surprise, that a synthetic aperture radar (a particular kind of imaging radar that can photograph the ocean surface through clouds from very high altitude) can be used to characterize not only the surface wave field but the surface wind speed and direction as well. They have used this result to put together the first complete wind field history of a tropical storm from satellite data.

The IR&D investment has also been used to place in operation a large computer model for analyzing and predicting wind-waves over global expanses of the ocean. The code, named SAIL (Sea Air Interaction Laboratory), was originally developed in a joint effort by the National Oceanic and Atmospheric Administration and Oceanweather, Inc., and APL researchers have now started complementing their analyses of satellite observations with this new tool.

The team is already looking beyond NROSS to future generations of smart oceanographic satellites from which information about the state of the ocean might be reported instantaneously using high-speed on-board computers of special design.



Oxygen balance in the Chesapeake Bay. The inhibition of vertical exchange by stratification and the decay of phytoplankton contribute to anoxia in the Bay.

Internal Waves and Oxygen in the Chesapeake Bay

In the spring, fresh water from abundant rainfalls and melting mountain snows swell the tributaries flowing into the Chesapeake Bay. When this water reaches the Bay, it spreads in a layer above the heavier ocean water moving northward along the bottom.

The large difference in density between the warm, fresh surface water and the cold, salty water beneath it acts as a strong barrier to vertical exchange. In many respects these two water masses remain separate worlds. The nutrient-rich upper layer, warmed by the sun and aerated by the wind, makes a fertile environment for the growth of aquatic plants and animals. Phytoplankton—microscopic plants that float and drift with the water—flourish in great numbers.

In the darkness of the deeper water, plant life is more inhibited, but animals still move freely, continually consuming dissolved oxygen that cannot be replenished easily by vertical mixing or photosynthesis. As the phytoplankton die above and settle to the bottom, even larger amounts of oxygen are used up by the bacteria that produce decay. Over a period of a few months, a serious depletion of dissolved oxygen in this lower layer can occur. In some parts of the Bay, the oxygen near the bottom may disappear completely—a condition called anoxia.

In the abstract, the occurrence of anoxia is a complex and delicate problem in ecological balance. For the animal life struggling to survive along the bottom, the problem is a matter of finding the next breath—as it is, in a different sense, for Bay watermen. Experts believe that the seasonal decline in oxygen level is related to a decrease in the numbers of crabs, striped bass (rockfish), and oysters. The Environmental Protection Agency reported several years ago, at the end of a 5-year study, that episodes of anoxia in the Bay were becoming more widespread each year.

With funding from the IR&D program, APL oceanographers arranged a collaboration with biologists from the Homewood Campus of Johns Hopkins, the Chesapeake Bay Institute, and the University of Delaware who were set to study the biochemical aspects of anoxia under a grant from the National Science Foundation. This new interdisciplinary research team conducted its first field experiments during the last two weeks of May 1984. Team members made continuous 24-hour, high-resolution biochemical and physical oceanographic measurements at four locations just south of the Bay Bridge and near the Patuxent River outflow. The results of the experiments were reported in Ref. 5.

What they found surprised many people. Giant internal waves, some over 20 feet high, were observed to propagate along the interface between the upper and lower layers. Waves of this magnitude may have a major influence on the vertical transport of oxygen and can strongly affect the amount of sunlight available for photosynthesis to plant species trapped beneath the upper layer. This discovery also has important implications for anyone who makes measurements in the Bay, whether for scientific or environmental monitoring purposes. Given the large vertical motions that were found, a simple strategy of gathering samples at one or two depths, and at random times, may not always produce representative results.

The research team returned to the Bay last spring, but the large internal waves apparently did not. Season-to-season and interseasonal variations could be important pieces of the anoxia puzzle, and the team hopes to continue its investigation over a number of yearly cycles under the sponsorship of the National Science Foundation.

SOME FINAL REMARKS

Measured against its set goals, the IR&D thrust in ocean science and technology has to be considered a success. The four projects we have reviewed deal with subjects of considerable scientific importance, and nearly 20 journal articles or conference papers have been published, or are being prepared for publication, by research team members. The first three projects have great potential for naval tactical applications; two of them are in the field of satellite oceanography and use numerical ocean modeling as a component. The fourth project makes an innovative contribution to the study of the Chesapeake Bay.

We began this article with a look back in time, and I demonstrated that man's need to understand the ocean has always far exceeded his ability to study it. But at last technology seems to be gaining ground. In the decades just before the *Challenger* voyage, a sounding at a depth of a few thousand meters required more than an hour of backbreaking work by a hundred men just to haul in the line against its tremendous weight and resistance. Those few hard-earned pieces of information should be contrasted to the 100 million bits of data collected each second by Seasat to get a sense of the progress that is under way.

Almost no one argues about whether or not there is a future in ocean research. Few doubt the need to understand climate or question the dominance in antisubmarine warfare to be gained by understanding and exploiting subsurface ocean weather. Given a start and a long-range commitment, APL scientists and engineers will no doubt continue to do their part to contribute to the understanding of the ocean in the years to come.

REFERENCES

[1] D. C. Dubbel, "The Reduction in Finestructure Contamination of Internal Wave Estimates from a Towed Thermistor Chain," *Johns Hopkins APL Tech. Dig.* **6**, 186-202 (1985).

[2] H. C. Schoeberlein, "A Statistical Analysis of Patches of Oceanic Small-Scale Activity," *Johns Hopkins APL Tech. Dig.* **6**, 194-202 (1985).

[3] C. C. Kilgus, "A First Look at the Potential of Remote Sensing of the Ocean," *APL Tech. Dig.* **16**, 2-7 (1977).

[4] J. L. MacArthur, "The Seasat Radar Altimeter," *APL Tech. Dig.* **16**, 8-14 (1977).

[5] C. C. Sarabun, A. Brandt, M. A. Tyler, and G. D. Smith, "Biological Transport, Internal Waves, and Mixing in the Chesapeake Bay," *Johns Hopkins APL Tech. Dig.* **6**, 227-235 (1986).

ACKNOWLEDGMENTS—In this summary article it was not possible to point out individual achievements. Yet it must be obvious that the success of the IR&D program in Ocean Science and Technology is due entirely to competent and enthusiastic researchers. The research teams consist of A. B. Fraser, D. C. Wenstrand, D. C. Dubbel, D. P. Vasholz, S. A. Mack, H. C. Schoeberlein (the Small-Scale Processes Project team); J. Calman, C. E. Schemm, L. F. McGoldrick, E. B. Dobson, R. S. Hirsh (the Mesoscale Processes Project team); R. C. Beal, T. W. Gerling, D. E. Irvine, F. M. Monaldo (the Global Wind Wave Project team); and C. S. Sarabun, A. Brandt, J. E. Hopkins (the Chesapeake Bay Project team).

The accomplishments of these researchers have appeared, or soon will appear, in the archival technical literature, tangible evidence of their efforts. But a wise and obviously experienced poet once observed that there are no statues of committees. While a statue is somewhat beyond the writer's means, the contributions of the Ocean Science and Technology Thrust Area Panel in helping to define goals, develop a program architecture, and review proposals are most gratefully acknowledged. This panel was composed of J. R. Apel, G. D. Smith, R. F. Gasparovic, D. M. Silver, G. M. Starken, R. C. Beal, L. F. McGoldrick, L. C. Kohlenstein, and W. H. Avery.

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