Physical Oceanography: Planning for a Major Experiment

The oceans are still largely a mystery to man. Compared to his understanding of the atmosphere and of the earth's crust on which he lives, his knowledge of oceanic phenomena is limited to descriptions of a few major features. Yet changes in oceanic circulation are believed to have important influences on commercial fisheries, on both regional and global climatic conditions, and on the ability of the ocean to absorb a growing burden of man-made pollutants. To describe and then to predict the major oceanic flows and other phenomena—the "weather" of the fluid that covers three-fourths of the globe to depths of several kilometers —is the work of physical oceanographers. A major step toward that goal will be the first Mid-Ocean Dynamic Experiment (MODE), scheduled for next spring in a part of the Sargasso Sea off Bermuda. This 4-month experiment, whose detailed planning is now under way, marks the beginning of large-scale cooperative oceanographic research and illustrates both recent progress and recurring problems in studying the sea.

The mid-ocean phenomena that the MODE experiment is designed to elucidate are not well known. Early studies of ocean circulations focused on the major current systems—the Gulf Stream off the eastern United States and the Kuroshio current off Japan, for example—that are found near the continental boundaries of the oceans. Simplified models of the ocean circulation were able to show how prevailing wind patterns over the Atlantic, for example, would result in an intense localized current such as the Gulf Stream. The mid-ocean regions were assumed, in these early models, to be essentially quiescent with only a small mean flow; but what few observations of the currents in the interior of the oceans have been made show large fluctuations that tend to obscure any mean flow that might be present. To some oceanographers, the evidence is suggestive more of oscillatory or episodic motions than of any regular flow pattern.

The question of whether the ocean has in fact an identifiable mean or average circulation, and if so, what it is, is important for a number of practical reasons. Attempts to predict the ocean's influence on climate or the ultimate distribution of pollutants will depend on some model of the dynamics and thermodynamics of the oceans. A number of exploratory theoretical models have been constructed to explain temperature and salinity patterns of the oceans and to predict the behavior of some of the major current systems. More recently, numerical models that attempt to predict the behavior of the flow within an ocean basin in more detail have been designed. Both theoretical and numerical models, however, have been for the most part based on the assumption that the transport of heat and salt in the ocean is a relatively homogeneous process, which most oceanographers now believe to be incorrect. Furthermore these models have generally dealt only with the gross features of the circulation, because, in most instances, the appropriate assumptions for describing medium-scale phenomena (comparable to the meteorological phenomena that appear on a weather map of the atmosphere) are not known.

Newly Discovered Complexities

Phenomena in the oceans are harder to observe than comparable atmospheric features, because the ocean is opaque to everything but sound, and are often uniquely complex. One example of such complexity was the discovery several years ago of the tendency, under certain conditions, for seawater to form discrete steps in temperature and salinity rather than smooth gradients, a phenomenon known as microstructure. In laboratory experiments, long vertical columns of salty water—salt fingers—have been observed moving downward while neighboring columns of less salty water move upward, a phenomenon attributable to the differing rates at which salt and heat can diffuse through water. Salt fingers have not been observed in the ocean, although conditions under which they are believed to occur are known to exist in many of the tropical oceans.

Other examples of microstructure have been observed in the oceans, however. In the region where hot salty water from the Mediterranean flows out over the cooler, less saline water of the Atlantic, the distribution of temperature and salt shows a staircase pattern rather than the smooth vertical gradient that would have been expected in a simple diffusion process. Steps about every 10 meters with changes of about 0.2°C and 30 parts per million of salt have been observed; since both heat and salt are important in determining the density of seawater, the variations in both quantities are significant.

Although several explanations of the staircase phenomenon have been advanced, there is no general agreement as to its cause. Some oceanographers believe that microstructure plays an important role in controlling the diffusion of heat and salt downward in the ocean; the existence of such inhomogeneities within the ocean makes it much harder to realistically model diffusion processes on a larger scale within the sea.

To build better models, however, oceanographers need more information. The MODE experiment is the most ambitious attempt yet to obtain some systematic information about medium-scale motions in the sea. The experiment will involve three U.S. oceanographic ships and one British research vessel, a fixed array of current meters and temperature recording instruments moored to 16 different positions on the bottom, and a variety of other moored, free-floating, and airborne instruments. Measurements will be concentrated in a 190-kilometer square located about 500 kilometers southwest of Bermuda. The major objective of the experiment, which is to run from March to June, 1973, is to determine empirically the dominant motions and density fluctuations that occur below the surface of the ocean over distances of 10 to 200 kilometers and from a day to a month. By mapping current and temperature, the oceanographers hope to prepare the first equivalent of a weather map for a region of the ocean and hence to begin to understand the dynamical processes involved. This first MODE experiment is designed largely to ascertain what phenomena exist, so that later and more comprehensive experiments can be designed to test specific hypotheses and to determine how the mid-ocean phenomena interact with the general circulation of the sea.

Current meters are the basic means of measuring velocity in the ocean. More than 50 of these expensive instruments will be placed at three different depths on the cables of buoys moored to the sea bottom. Most available current meters are not able to record both current speed and direction instantaneously, but provide averages of these quantities independently. New current meters being developed for the MODE experiment will measure average velocity directly, thus providing more complete information. Also attached to the buoy cables will be recently developed temperature sensors that are self-contained units capable of recording large amounts of data. Shipboard instruments will also measure temperature and density.

The availability of complementary data from several types of instruments and of overlapping data on some properties will provide a relatively unique situation in oceanographic research, which is more commonly based on the uncorroborated results of a single instrument. The MODE experiment will thus allow different instruments to be compared and their effectiveness to be evaluated. Two different types of bottom-mounted pressure gauges will be deployed. Several types of free-fall devices and airborne probes will measure the velocity profile or the net transport of water past the experimental site. Two different means of measuring bottom currents will be employed.

One of the more important objectives of the MODE experiment is to look for and study large eddies in the sea motions. A number of large (6-meter) floats that are free-floating and hence able to move with such eddies will be used. To enable the tracking of the floats, they are equipped to emit precisely timed signals that can be picked up by hydrophones. The signals travel within a layer of the ocean that traps sound and thus propagates the signals like an acoustic wave guide. The hydrophone listening stations are part of a little-used network that was originally built for locating the impact point of missiles in the Atlantic test range, but they are also ideal for following the course of the MODE floats. As long as the floats are within range of the island-based listening stations, the location of the floats can be tracked to within a kilometer. The floats are constructed to be neutrally buoyant, so that they will remain close to a given density level (not quite the same as constant depth because of density fluctuations), and they also carry pressure recorders and devices for measuring the vertical velocity. The floats will provide some real-time information on currents during the experiment, while the current meters and many other instruments record their data for analysis only after the experiment.

Two separate arrays of buoys with current meters and temperature sensors are to be set out, one over a flat-bottomed area and the other over a region of moderate bottom topography. Much of the ocean floor is far from flat, and oceanographers increasingly believe that the bottom topography has important effects on the dynamics of the ocean. A detailed topographic map of the sea floor under the experimental areas is to be obtained. The scarcity of such information and the difficulties of doing oceanographic research are well exemplified by the efforts of the MODE team to find a suitable site for deploying the buoy arrays. One site tentatively chosen for preliminary work on the basis of available topographic charts turned out to have a much rougher bottom than expected—sea mounts higher than 1000 meters and a series of ridges with elevations of 500 meters or more, possibly too high for the kind of experiments envisioned in MODE. Most deep-sea charts are made on the basis of widely spaced samples of the topographic features rather than complete maps, and their navigational accuracy is often far less than that needed for positioning buoys in a tight array. As a result, very little can be taken for granted about a particular experimental area until it has been surveyed again in detail; the presence of the sea mounts convinced the MODE team to consider moving their experimental site elsewhere.

Theoretical Studies

In addition to providing heretofore unavailable observations and testing a variety of oceanographic instruments, the MODE experiment will also have a major impact on theoretical work in oceanography. Theoreticians are participating extensively in the planning of the experiment, and with this impetus have begun to focus their attention on what one participant described as "more realistic models." The problem facing the theoreticians is to decide, given the limited number of observations that will be available, how to gain the most information about dynamic processes in the ocean. To this end an unusually elaborate effort, including a 6-week planning session this coming summer, is being undertaken.

The necessity for detailed theoretical work in advance of the experiment is due to the variety of dynamic processes that conceivably may be important in the mid-ocean and to the inherent difficulties of oceanographic research. Measurements typically have lots of noise in them, and it is often not clear how to construct an accurate three-dimensional map of temperature, salinity, and current velocity from a few data points taken at differing times and even, in the case of the free-floating instruments, at different locations. Without careful preliminary resolution of these problems, the experimental data might well be of little value.

By analogy with the atmosphere, many oceanographers expect that eddies may be an important type of phenomena within the sea, but wave motions and catastrophic processes (such as the sudden sinking of a mass of cold water) may also be involved. Each hypothetical process might suggest a somewhat different experiment, so theoretical and numerical simulations of the experiment are being conducted with models of many such processes. By considering the results of a series of models, theoreticians hope to optimize the design of the actual experiment. The models will also provide guides to interpret the data once the experiment is over.

Compared with other large-scale geophysical experiments, the MODE experiment is being conducted so far with a minimum of organizational problems, although the real test will be the effectiveness of the experiment itself. Nonetheless, the planning for the experiment is proceeding with seemingly efficient cooperation between observational and theoretical groups, made up of scientists from more than 15 university and oceanographic institutions, under the guidance of a scientific council headed by Henry Stommel of the Massachusetts Institute of Technology and Allan Robinson of Harvard. The initial MODE experiment, even if it fulfills its early promise, will still leave many questions unanswered about how the ocean works. But the experiment will begin to provide the necessary information about the ocean that man will need to exploit its resources intelligently, and the planning effort for the experiment is already providing a new and broader conceptual framework for physical oceanography.

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