Oceanography: A Closer Look at Gulf Stream Rings

Oceanographers have now come to realize that the oceans cannot be divided up into a few large pools of water having the same physical, chemical, and biological properties throughout. What investigators are finding as they space their observations more closely is that previously undetected phenomena, ranging in scale from a few millimeters to several hundred kilometers, are revealed.

Among the largest and most energetic entities are the rings, massive whirls that move across the open ocean in a profusion hardly suspected 20 years ago. Although rings have been observed in the North Atlantic since 1936, it is only recently that they have been the subject of intensive study. At any given time, more than a dozen rings may be drifting about the western North Atlantic. As a result of modest search efforts, such rings have also been found in other oceans. Besides being a major element of ocean circulation, rings may be important in studies of ocean pollution, naval submarine strategy, and marine biology.

Ring oceanographers have devoted most of their attention to those that form in the North Atlantic, and most information about rings has come from these studies. The rings of the North Atlantic are spawned by the Gulf Stream, the narrow ribbon of swiftly moving water that hugs the southeast coast of the United States before turning offshore near Cape Hatteras.

Benjamin Franklin's sketchy chart of the Gulf Stream was eventually succeeded by detailed observations that revealed a relatively narrow current that forms wandering loops—called meanders—after leaving the coastline. A ring is formed, as was first observed in 1950, when a meander pinches off, much as a river meanders and forms a cutoff and oxbow lake (Fig. 1). During the pinch-off, the meander fuses to form a generally circular ring of relatively rapid current (about 4 kilometers per hour). Such a ring is typically 150 to 300 kilometers across and extends downward 2500 to 3500 meters, almost to the ocean bottom.

Because the Gulf Stream separates the warmer Sargasso Sea on the south from the colder water to the north, the seawater in the core of the ring differs considerably from the water around it. A meander pinching off on the southern side encloses cold water and forms a cold-core ring in the warm Sargasso Sea. A meander to the northern side forms a warm-core ring in the cold water between the Gulf Stream and the coast. It is these differences in temperature that allow a ring to be readily located and tracked.

Philip Richardson of Woods Hole Oceanographic Institution and David Lai of the University of Rhode Island used a computer to search more than 50,000 separate records of the distribution of water temperature in relation to depth in the North Atlantic. They concluded that about 11 cold-core rings can be found south and east of the Gulf Stream at any one time and about three warm-core rings coexist north of it. Moreover, by linking water temperature records that had never been associated before, they were able to track 25 rings over a period of time.

Richardson and Lai found that warm-core rings moved westward and then southwestward at about 5 kilometers per day, as they followed a relatively narrow alley between the shallower water of the continental shelf and the Gulf Stream itself. Eventually, they are resorbed into the Gulf Stream off Cape Hatteras. Cold-core rings seem to move along less constrained paths, but they also tend to move toward the southwest at about 3 kilometers per day and many are resorbed off the east coast of Florida. Although approximately equal numbers of warm- and cold-core rings are spun off to opposite sides of the Gulf Stream, cold-core rings survive up to 2 to 3 years, while warm-core rings last less than a year because of the shorter distance available for travel.

Not all rings behave in such a predictable manner. An interdisciplinary team of marine scientists from Woods Hole, the University of Rhode Island, and Texas A & M University selected a 2-month-old cold-core ring last December for extended scrutiny. They dubbed it "Al." Al, already somewhat peanut-shaped, elongated further, producing two separate rings, Al and Art. Art moved off to the east while Al apparently merged with the Gulf Stream only to re-emerge and glance off a third ring named Bob, which the team was already studying. Ring Bob then raced away at the breakneck speed of 20 kilometers per day with the oceanographers in hot pursuit. At last report, it had encountered another ring and the Gulf Stream again.

Long-term studies of rings require that such gyrations be accurately tracked over months and even years. Two satellite methods have replaced the costly and localized coverage previously provided by surface ship surveys. Infrared-sensing satellites are producing periodic charts of ring positions for much of the western North Atlantic. Unfortunately, this approach is limited by the relatively rapid fading of the surface temperature differences between a ring and its surroundings and by the uniform heating of all surface waters during the summer months. To help alleviate these problems satellites are also used as tracking stations for signals broadcast from buoys that may remain in the center of rings for many months after emplacement from a ship or an airplane.

Predicting the behavior of individual rings is not possible with our present un-

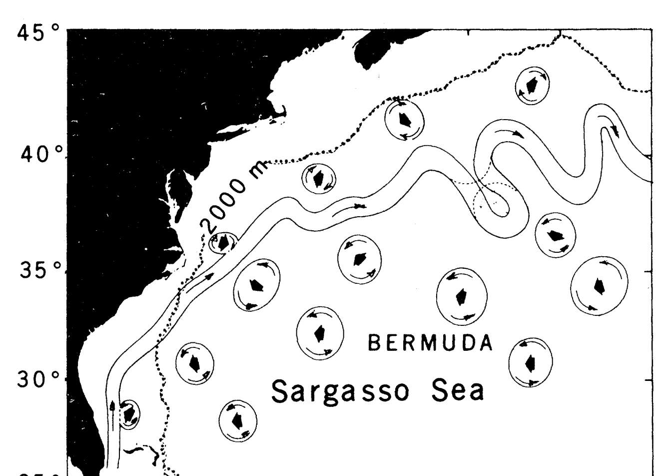

Fig. 1. A schematic representation of the path of the Gulf Stream and the distribution and movement of rings. It is an attempt to summarize a number of studies that were made at different times and that usually focused on a smaller region. [Source: P. L. Richardson, Woods Hole Oceanographic Institution]

derstanding of ocean physics; but progress is being made toward elucidating the processes that affect the formation and long-term movement of rings. For example, data from current meters tethered to the ocean bottom have suggested that part of the Gulf Stream flow returns quickly to the southwest in a tight clockwise circle. It is thought that the southwestward drift of cold-core rings may result from their being caught in this return flow.

Another approach is to program a computer to predict the future movements of ocean waters on the basis of assumptions concerning the driving forces (water temperature differences and the wind), the shape and bottom topography

Speaking of Science

Genetic Engineering: The Origin of the Long-Distance Rumor

Opponents of genetic engineering often cite the possibility that scientists may create a new pathogen of some kind by combining the genes of different species in one organism. The criticism is most often leveled at research on recombinant DNA, which is the most controversial technique for achieving gene transfer, but other procedures, such as cell uptake or fusion, can also be used to introduce new genes into cells.

A recent rumor has it that a cell-uptake experiment performed in New Zealand produced a strain of fungus that kills pine trees. Early this year, the rumor caused quite a furor in New Zealand, where the timber industry is of major importance, and the story is now spreading in this country. For instance, in a public forum on the genetic engineering of nitrogen fixation,* a few speakers alluded to the New Zealand experience, without giving any details, as an example of how a genetic engineering experiment could go awry.

But what actually happened in New Zealand? Was a "killer fungus" unleashed? The answer is no, according to Kenneth Giles, the investigator who did the research in question while he was with the Plant Physiology Division of the Department of Scientific and Industrial Research of New Zealand. Giles, who is now at Iowa State University, says that the New Zealand reports greatly exaggerated and misrepresented the results of his experiments, which were done in 1975. He may have produced a new pathogen—and it is not certain that he did—but the only pine "trees" that died were 10 seedlings, some 2 to 3 inches high, that he studied in the laboratory under conditions very unlike those in nature.

Giles did the experiment because he wanted to introduce the ability to fix nitrogen into a fungus species (*Rhizopogon* sp.) that is a normal symbiotic associate of pine (*Pinus radiata*) seedlings and young trees. The fungus grows in and around the roots and helps the plants absorb phosphate, which they need for growth. He hypothesized that a fungus that reduces atmospheric nitrogen to ammonia, which is also required by plants, might help the seedlings grow even better.

To achieve this goal, he first treated the fungal cells with an enzyme to digest away the cell walls, and then incubated the protoplasts thus formed with the bacteria in an appropriate culture medium. He hoped that after the bacteria became incorporated within the fungal cells they would continue to produce ammonia. Giles found that a very small percentage of the fungal cells did take up the bacteria and, consequently, acquired the ability to fix nitrogen in culture.

The next step was to determine whether the five strains of nitrogen-fixing fungi he isolated were still capable of associating with pine seedling roots and producing ammonia for the seedlings. Giles considered this experiment a success, even though the ten seedlings inoculated with one fungal strain died within a month. The other 40 remained healthy, and there was evidence that the fungi formed associations with most of them and fixed nitrogen.

Giles destroyed by autoclaving all preparations of the strain that appeared to have killed the seedlings because he thought that the containment facilities available to him were not adequate for studying a possible new pathogen. Nevertheless, he says that for several reasons it is very unlikely that any of the fungus could have escaped from the laboratory.

He grew the seedlings in sterile soil in jars with cotton stoppers and screw-top lids. Manipulations of the altered fungal strains were carried out in a laboratory that is always bathed in ultraviolet light when not in use. (Ultraviolet light kills microorganisms and its use in this way is a common precaution to prevent contamination of cell cultures.) Since the laboratory did not have a hood with a filtered exhaust, Giles performed the experiments with the hood fan off to prevent dispersal of the cells. Finally, the fungus used does not form spores in culture and could only spread by vegetative growth. In any event, Giles points out that the altered fungi grow very poorly compared to the wild strains and would not compete well with them under natural conditions.

Giles said that he himself called the material a pathogen when he presented the work at scientific meetings and also in a paper published in *Plant and Soil* in June of this year. He emphasizes, however, that even the wild fungus strain kills about 10 percent of very young pine seedlings in conditions similar to those he used for the experiments with the altered strain. He rather regrets that he destroyed all samples of the altered strain because it is now impossible to determine just how pathogenic it actually was.

Giles was dismayed by the sensational treatment accorded his research in New Zealand and does not want to see it used in a similar manner by opponents of genetic engineering in this country. Nevertheless, it may still become a part of the continuing debate here. One researcher has pointed out that Giles is an experienced and careful worker and no problems ensued; but if a less experienced worker were to inadvertently produce a pathogen and allow it to escape from the laboratory, the consequences might be great.

—J.L.M.

*Public Meeting on Genetic Engineering for Nitrogen Fixation held on 5 and 6 October 1977 at the National Academy of Sciences. The meeting was sponsored by the Research Applied to National Needs Program of the National Science Foundation.

of the ocean basin, and the principles of fluid motion. Within the limitations of the assumptions, the computer model can describe how the ocean evolves from a given set of starting conditions. Such general circulation modeling is being carried out by several groups. Within the last few years, increasingly realistic results have been generated, suggesting that the assumed data of the model more closely resemble what is happening in the actual ocean. The new results reproduce the meanderings of the Gulf Stream, the formation of rings, and their slow movement toward eventual resorption.

By changing or deleting a single factor in a model, its importance to the overall behavior of rings can be determined. William Holland of the National Center for Atmospheric Research has found that the shape of the ocean bottom as described in his model is essential to producing realistic movement of rings as they drift to the southwest. He thinks that this dependence suggests that a ring can interact with or "feel" the bottom under certain conditions and thus be nudged in a specific direction.

While theoreticians were finding that rings could be fit into a model of the North Atlantic, observational physical oceanographers were discovering that rings were associated with strong ocean currents throughout the world. The Kuroshio, a current off the east coast of Japan, is the North Pacific equivalent of the North Atlantic's Gulf Stream. Because of the rings' potential effect on coastal fisheries, Japanese researchers have had an active interest in warm-core rings spun off from the Kuroshio; but they doubted that cold-core rings survived long enough to be found in large numbers at any one time. Robert Cheney of the U.S. Naval Oceanographic Office conducted a combined air and surface search for Kuroshio rings in October 1976; he used expendable temperature-sensing devices to map the upper 300 meters of the ocean. On each of three flights, he found a different cold-core ring, some of them relatively old. Cheney concluded that the Kuroshio produces rings which are essentially the same as Gulf Stream rings.

Warm-core rings in the Gulf of Mexico have been recognized for some time. They apparently form when the Florida Current, which is actually the Gulf Stream before it passes through the Straits of Florida, loops up into the Gulf of Mexico.

The Antarctic Circumpolar Current, which completely encircles the Antarctic continent, also produces rings. While investigating the boundary between the cold water surrounding Antarctica and the warmer water to the north, researchers recently encountered, entirely by chance, two cold-core rings associated with this current. As in the case of the Gulf Stream, this boundary is associated with narrow bands of rapidly moving water. These currents, which are usually rendered in textbook charts as broad, straight arrows, have recently been shown to be a complex system of migrating meanders. Unlike the Gulf Stream, they are embedded in a larger area of turbulent activity, further complicating ring movement. Terrence Joyce and Steven Patterson of Woods Hole report that the ring that they observed in the Drake Passage, just south of Cape Horn, was smaller (about 110 kilometers) and rotated less rapidly (about 1.1 kilometers per hour) than the average Gulf Stream ring. This finding is in accordance with the higher latitude and slower speed of the Antarctic Circumpolar Current.

It now appears that rings are inevitable wherever narrow swift currents exist. Although meandering and ring formation were not really anticipated, from a theoretical point of view they are not very surprising to oceanographers. The observed longevity of rings is more difficult to explain.

Ring Dissipation

Unlike weather patterns, such as hurricanes, rings, once formed, have no external source of energy. A hurricane continuously draws in warm moist air from which it can extract large amounts of energy. Thus, the hurricane cannot only maintain itself but it can grow and intensify. A ring cannot grow. It can only maintain its circulation by drawing on the potential energy, which constitutes 95 percent of the ring's total energy, stored in the temperature difference between its core and its surroundings. It is slowly dying from the moment of birth.

The mechanism of the dissipation of a ring's energy is not yet clear. Internal friction may tend to draw water from outside into the core of the ring, leading to the eventual erasure of the temperature difference. Glenn Flierl of the Massachusetts Institute of Technology, who devised a computer model of a ring, suggests that while internal friction could be at work, the dominant process may be the leakage of energy from the ring in the form of very slow, long waves. Rings might thus contribute to other physical processes occurring at great distances from the ring itself.

The impact of rings on other properties of an ocean basin has been investigated in the Gulf of Mexico. Because rings derived from the Florida Current are saltier, warmer, and more energetic than the surrounding Gulf waters, they can make a net addition of salt, heat, and kinetic energy to the Gulf as a whole. Brady Elliot of Texas A & M has calculated that the amount of additional salt carried into the Gulf each year by rings approximately compensates for the fresh water entering from rivers. Paul Etter, also of Texas A & M, has made calculations for the heat content of the Gulf and found rings help to maintain the heat balance.

Rings are interesting not only for what they may add to a body of water but also for what they may take away. Deepwater dumpsite 106, which is 106 nautical miles (196 kilometers) southeast of New York City, was originally established as a munitions dumpsite some years ago when necessarily simplistic ideas of ocean circulation prevailed. It is currently an industrial chemical disposal area and the subject of a major oceanographic investigation. In a preliminary study of the hydrography of the area, James Bisagni of the National Marine Fisheries Service (Narragansett, R.I.) found that the dumpsite was wholly or partially occupied by warm-core rings about 20 percent of the time, raising the possibility that the rings pick up pollutants from the dumpsite. Approximately three rings per year spend about 3 weeks each in the area as they drift toward the southwest and resorption off Cape Hatteras. Rings on and off the dumpsite are being studied for possible biological and chemical changes resulting from dumping, but the investigation of the effects of rings on the dispersal of pollutants have not yet begun.

Rings may harbor not only pollutants but also submarines seeking refuge. Sound transmission in the sea is quite efficient and sound detection is the primary means used to track submarines. But seawater is not a uniform transmitting medium. Any variation in the temperature or salinity over the sound path will tend to bend and distort the sound. The U.S. Navy is becoming aware through studies of its own that the sharp temperature difference between a ring's core and its surroundings is likely to create a suitable pocket of distortion for any submarine wishing to complicate a search for it.

In addition to their significant physical characteristics, rings also carry with

(Continued on page 430)

(Continued from page 389)

them a distinct biological community which in many respects is alien to that outside the ring. These organisms, and their chemical and physical environment, are typical of the water mass from which the core of the ring was derived. In the case of a ring to the south of the Gulf Stream, the cold-water community in its core must attempt to cope with its slowly changing environment as the ring dissipates and gradually loses its identity.

The cold waters north of the Gulf Stream, having higher levels of essential nutrients than the warm Sargasso Sea, support larger amounts of plankton (microscopic plants and animals) and the larger animals that feed on the plankton. Marine biologists assume that the species indigenous to these cold waters are particularly well suited to some factor or combination of factors characteristic to those waters. Determining which factors are involved has proved difficult.

Some marine biologists think that rings offer an opportunity to simplify such investigations. By observing changes that occur in ring organisms as their environment becomes progressively more adverse, biologists hope to delineate those conditions that are most important to their success.

The most striking results to date are those of Peter Wiebe of Woods Hole concerning the shrimplike, 25-millimeter-long zooplankter *Nematoscelis megalops*. This organism has been considered to have a strict preference for cold water, although scattered reports of catches south of the Gulf Stream have been made. It now appears that most of those were chance catches from rings. Wiebe found that *N. megalops* moved to deeper and colder water as the core warmed, apparently in an attempt to maintain the temperature of its surroundings at about 10°C. It moved to greater depths even though it meant moving out of reach of its food supply, the smaller zooplankton in the warmer surface layer. Wiebe has observed the extinction of this "expatriated species" due to starvation.

The study of rings as a significant aspect of the ocean seems to have left its infancy, but it has not yet arrived at maturity. New instruments are being put to use, and large cooperative projects are being pursued. These should prove useful in exploring one of the increasing number of newly discovered oceanographic phenomena.

—RICHARD A. KERR

Personnel Placement

POSITIONS WANTED

Ph.D. **Biochemistry**; experience in enzymology, nucleic acids, cyclic nucleotides, radioimmunoassay, radio-receptor techniques. Publications. Drug industry experiences for 2 years. Seeks position in industry. Box 388, SCIENCE. X

Biochemist–Chemist. Ph.D. Broad research and teaching experience. Publications. Experience in neurochemistry, membranes, proteins, lipid biochemistry, enzymology. Research in diabetes and metabolism. Strong background in analytical methods and radioisotopes. On medical school faculty for last 6 years. Desires academic, hospital, industrial, or government position. Available immediately. Box 389, SCIENCE. X

Biochemist/Molecular Biologist, Ph.D., 1970. Nine years of experience in nucleic acid and nucleic acid enzymology research. Expertise in molecular biology of RNA tumor viruses. Publications. Desires position in university or industry. Box 390, SCIENCE. X

Clinical Chemist: Ph.D. biochemist seeks postdoctoral position in clinical chemistry to qualify for board exam. Box 391, SCIENCE. 10/28; 11/4

Electrophysiologist/Neurobiologist, M.D., publications, grants, teaching experience; seeks academic or research position. Box 392, SCIENCE. 10/28; 11/4, 11

Immunologist/Immunopharmacologist, Ph.D. 1963. Postdoctoral at NIH for 2 years; research chemist at VA hospital for 2 years; research associate in immunology for 3 years; senior immunologist in industrial research for 7 years. Looking for new, creative, challenging position in immunological research-industry/academia. Publications, supervisory experience. Interests: cellular/humoral immunology, immunopharmacology, immunodiagnostics, allergy, inflammation, transplantation immunity. Experience in in vitro and in vivo models of cellular and humoral immune responses for drug testing, inflammation, in lymphocyte separation and culture, and immunofluorescence. Box 393, SCIENCE. 10/28; 11/11

Lighthousekeeper, Ph.D. accomplished in realms of people (psychological counseling), things (currently marketeering for high-technology company), ideas (dissertation on quantum psychology). Cerebral hemispheres need exercise, peace of mind. Seeks science-oriented and/or product-oriented position. Box 394, SCIENCE. X

Mathematical Ecologist, Ph.D. Seven years as systems ecologist, Canadian IBP forest and lakes ecosystem studies. Three years in Africa, applied fisheries problems. Two years in Latin America, land-use problems. Extensive publications. University teaching experience. Seeks academic position fall 1978 at large or small university which values teaching environmental studies and would encourage continued interest in developing countries. Box 395, SCIENCE. X

Neurophysiologist/Behavior. M.S.; 2 years of experience in primate operant techniques, project administration and management, stereotaxic surgery and recording, and electrode implantation. Additional experience in physiology, abdominal and thoracic surgery, respiratory physiology, and cardiovascular physiology. Thesis topic: electrographic evaluation of the neurotoxicity of mirex (analog of Kepone). Seeks industrial, academic, or government position. R. E. Stevens, III, P.O. Box 1453, Texarkana, Texas 75501; telephone: 501-772-8998. X

Zoology M.S. 1976 (physiology emphasis). Broad background in physiology and biology. Desires research technician position in physiology or related laboratory. Willing to accept low salary in order to gain greater research experience. Plans to continue education. Presently in Southern California; open to any location. Box 396, SCIENCE. X

POSITIONS OPEN

DEPARTMENT OF OPHTHALMOLOGY OF WAYNE STATE UNIVERSITY

The department is seeking applications from **ACADEMIC OPHTHALMOLOGISTS** (M.D.), for appointments in neuro-ophthalmology and other academic subspecialties of ophthalmology. Demonstrated ability to perform basic and/or clinical research is essential. Please send curriculum vitae to: **Chairman, Department of Ophthalmology, Wayne State University School of Medicine, 540 East Canfield, Detroit, Michigan 48201.** *An Equal Opportunity/Affirmative Action Employer.*

ACADEMIC PATHOLOGISTS

Faculty positions are available in the Department of Pathology, University of California, San Francisco, for Board-certified or Board-eligible (anatomical pathology or anatomical and clinical pathology) pathologists with an interest in modern pathology. An area of expertise in skin, lymphoproliferative, or Ob-Gyn diseases is desired, but not essential, as well as interest in or evidence of investigative work. Rank and salary are negotiable. Please direct inquiries to: **Edward A. Smuckler, M.D., Ph.D., Professor and Chairman, Department of Pathology, University of California, San Francisco, California 94143.** *The University of California is an Equal Opportunity/Affirmative Action Employer and welcomes applications from women and minority group members as well as other qualified persons.*

ACADEMIC POSITION: Department of Chemistry of the University of Nebraska–Lincoln seeks to add one Ph.D. organic chemist as a tenure-track assistant professor beginning September 1978. The position involves teaching on both undergraduate and graduate levels, and the development of a high-quality research program. A curriculum vitae, including a list of publications, a brief account of research interests, three letters of recommendation, and copies of graduate and undergraduate transcripts should be sent to: **Professor C. J. Michejda or Professor R. D. Rieke, Department of Chemistry, University of Nebraska, Lincoln, Neb. 68588.** The closing date for applications is 15 December 1977. *University of Nebraska is an Affirmative Action/Equal Opportunity Employer.*

AQUATIC ECOLOGIST

The University of Wisconsin–Madison invites applications for the position of assistant professor beginning fall 1978. The Department of Zoology, Laboratory of Limnology, seeks applicants with strong experimental and quantitative interests in **stream ecology**. Responsibilities include an active research program and teaching in advanced and introductory courses. Postdoctoral experience is desired. Send curriculum vitae and names of four references to: **James F. Kitchell, Laboratory of Limnology, University of Wisconsin-Madison, Madison, Wis. 53706.** Applications must be received by 15 November. *An Equal Opportunity Employer.*

AQUATIC RESEARCH AND TEACHING: The State University College at Fredonia, N.Y., is looking for a Ph.D. biologist, chemist, or similar discipline to assume a 12-month appointment to begin 1 January 1978. This joint position between the College's Environmental Resources Center and either the Biology or Chemistry Department will be half-time research and half-time teaching each semester plus full-time research in the summer. The research will emphasize fishery biology and/or chemistry in western New York. Possibility of subsequent year reappointments. Salary: $14,500. Send letter describing research interests, résumé, and two letters of recommendation to: **Dr. Richard Mayer, Director, Environmental Resources Center, State University College, Fredonia, N.Y. 14063.** *An Equal Opportunity/Affirmative Action Employer.*

Two **ASSISTANT PROFESSOR APPOINTMENTS** in chemical engineering are now available. Appointments can be delayed until the fall of 1978. Selection will be based on potential and performance in teaching and research. The Ph.D. is required. Primary emphasis is on biochemical engineering and mathematical modeling; capabilities in other areas will be considered. Initiation research grants are available. New teaching and research facilities are in the advanced planning stage. Please send résumé and supporting information to:

Jerome S. Schultz, Chairman
Department of Chemical Engineering
The University of Michigan
Ann Arbor, Michigan 48109

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