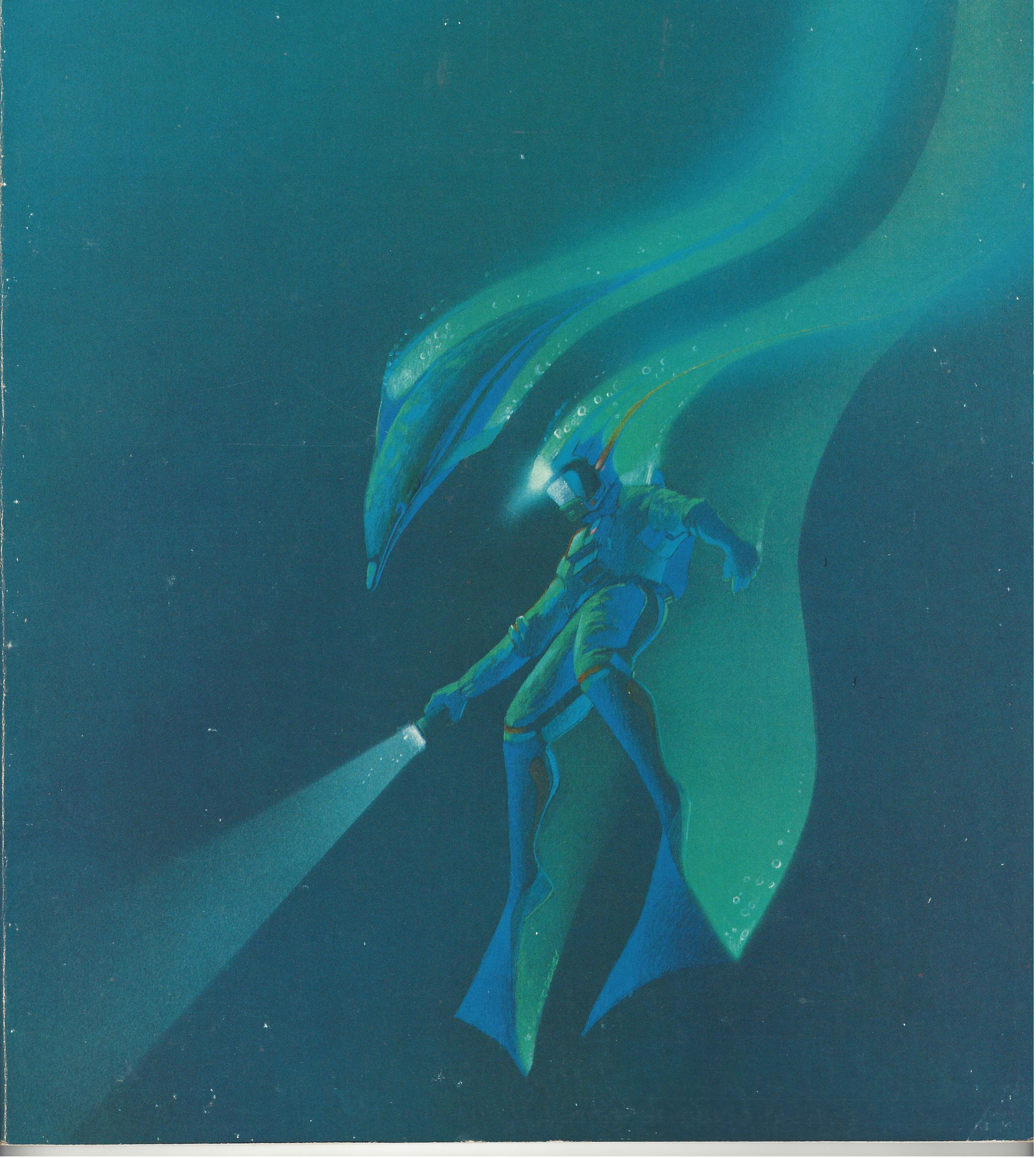
NUMBER 2, 1983

# Oceans

A PUBLICATION OF THE OCEANIC SOCIETY



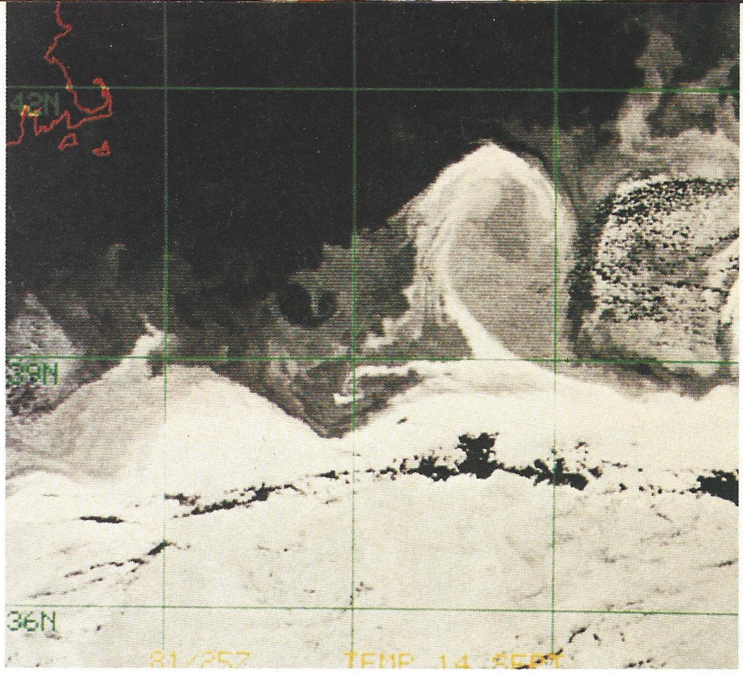
# SEAS FROM SPACE

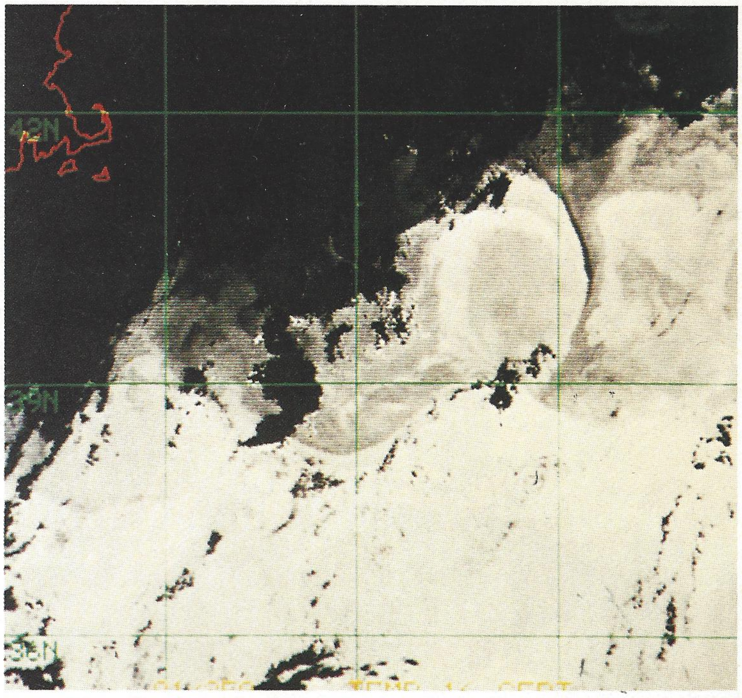
Despite the immense distances, satellite imagery is now supplying us with copious details about the oceans, including sea height (within centimeters), internal currents, and the topography of the seabed.

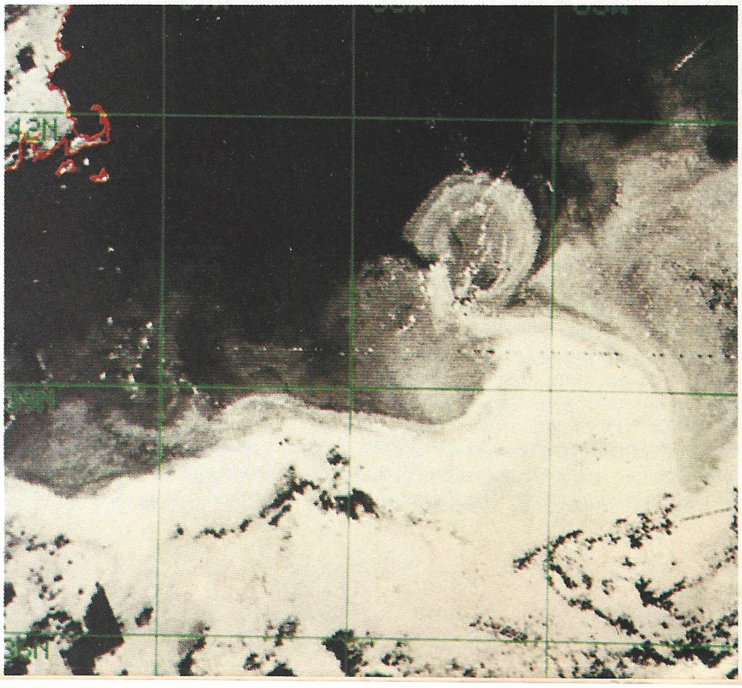
by Payson R. Stevens

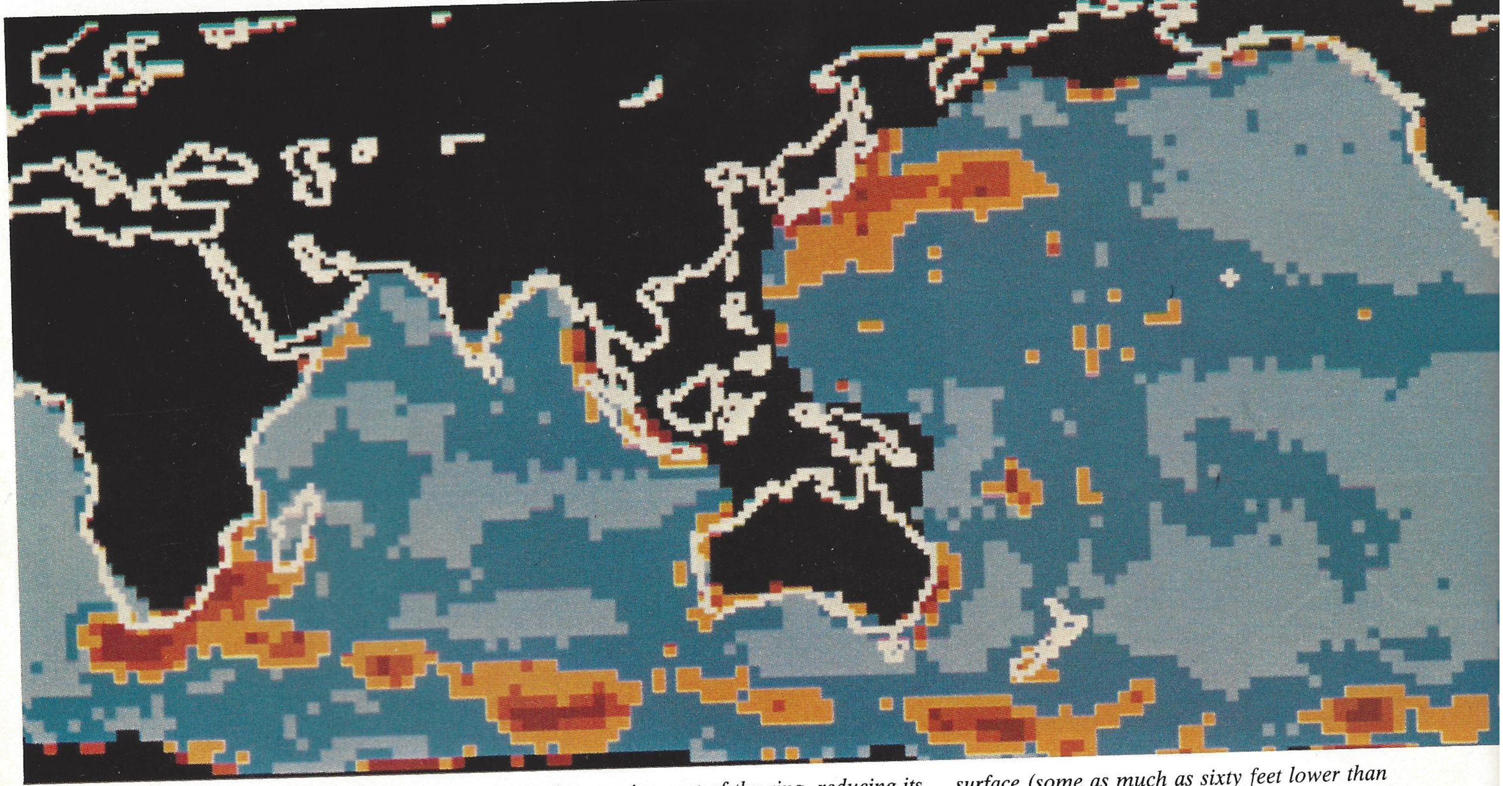
A NEW GALLERY of artistic ocean imagery is evolving, and scientists are generating its works. They use satellites as their brushes, computers for canvas, and statistics for paints. The satellites gather the images; the computers are often used to add arbitrary colors. No longer are scientists restricted to peeking at global atmospheric and sea-surface patterns through the keyhole of surfacebound instrumentation. Satellite data is expanding our knowledge of the oceans.

A variety of orbital ocean-sensing instruments have become available over the last decade. Their names—like the radar altimeter, the color scanner, the radar scatterometer, the scanning multi-channel microwave radiometer (SMMR), the synthetic aperture radar (SAR), and the infrared radiometer (IR)—give little hint of their complicated abilities. (For a more detailed catalog



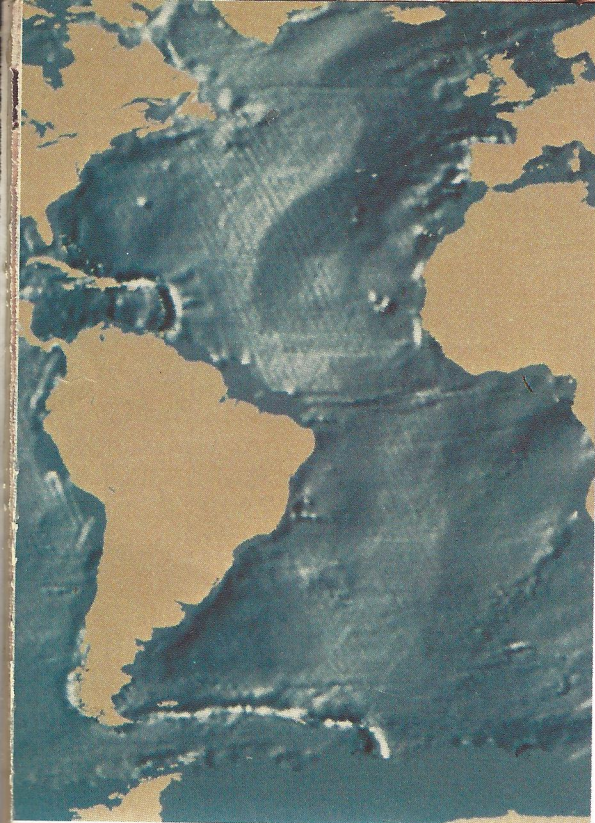



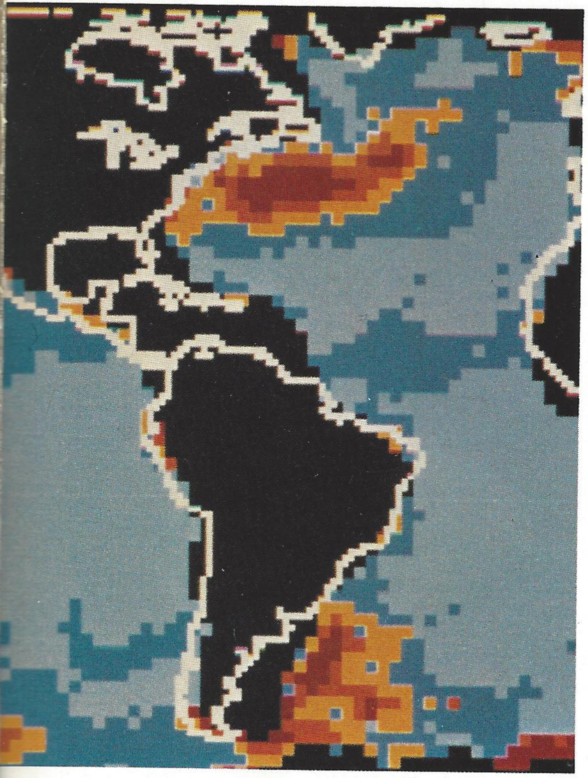


*Page 3: A Gulf Stream meander, picked up by the* Nimbus-7 *advanced very high resolution radiometer. This time-motion sequence shows the evolution of a warm core ring northeast of the Gulf Stream during a two-week period. Light regions correspond to warmer water; dark regions to colder water. The rings are about 120 miles in diameter. From top to bottom, streamers off the Gulf Stream are first pulled into the ring front and move clockwise around the ring. Two days later the meander is directly south of the ring. In another eleven days the meanders are seen taking a piece out of the ring, reducing its diameter by half. These interactions show how warmer water can mix with and help homogenize cooler Atlantic slope water. [O. B. Brown, R. H. Evans, J. W. Brown, University of Miami]*

*Top: A bas-relief of the oceans. Constant differences in the level of the sea surface were measured by the* Seasat *altimeter over a three-month period in 1978. Extremes in the seabed topography affect the earth's gravity field (called the geoid), which in turn produces an actual ocean surface topography. Sharp depressions on the surface (some as much as sixty feet lower than relatively nearby waters) are located above deep ocean trenches east of Japan, south of Alaska, east of Puerto Rico, and east of New Zealand. Comprehensive satellite images such as this one are revamping scientists' view of the seabed. [M. Parke, T. Dixon, K. Hussey, Jet Propulsion Laboratory]*

*Bottom: Just as gravity causes constant differences in the ocean surface (as in the image at top), so too does moving water vary the sea level temporarily. The* Seasat *altimeter shows the*





*maximum heights (red-orange) generated by meanders and eddies of five major western boundary currents: the Gulf Stream, the Kuroshio Current (Japan), Agulhas Current (South Africa), Falkland/Brazil confluence (South America), and the Antarctic Circumpolar Current. For the month-long period recorded, the image indicates a relatively small variability over vast regions of the world's oceans—usually only a matter of inches. [R. Cheney, J. Marsh, B. Beckley, NASA/Goddard Space Flight Center]*

of these sensors, see OCEANS, Vol. 12, No. 3.) The National Aeronautics and Space Administration (NASA), in concert with the National Oceanic and Atmospheric Administration (NOAA) and the navy, has funded research to develop satellite techniques and to evaluate their usefulness for observing the oceans. Says Dr. Stan Wilson, chief of NASA's Oceanic Processes Branch: "An incredibly diverse talent mix is working in this new field, including oceanographers, electrical and mechanical engineers, physicists, biologists, and computer engineers. For the first time we have demonstrated the technical capability to observe globally various features of our planet's oceans—such as sea-ice cover, ocean surface temperatures, plankton abundance, wind, waves, and currents—from space. The prospect is within our reach to make these observations and simultaneously link them to ship and buoy measurements, and begin to understand how the global ocean works."

Ocean sensors have been aboard six satellites (starting with NIMBUS-5 in 1972) and include SEASAT, which was the first satellite completely dedicated to oceanographic studies in 1978. A proof-of-concept mission, SEASAT demonstrated the feasibility of microwave techniques for ocean research before a power failure ended data transmissions after only three months. But NIMBUS-7 has been operating continuously since 1978, well beyond its one-year design life.

The cumulative data from these numerous sensors provide oceanographers with an emerging portrait of our water planet, which includes global maps on the variability of ocean currents, surface temperatures, surface wind speeds, water vapor in the atmosphere, and percent cloud cover. And on a regional scale, programs are being developed to measure solar radiation and oceanic productivity. Internal waves and underlying topographic features, such as shoals, can be clearly seen with SAR. Time-motion series can reveal and track the evolution of features such as warm core rings in the Gulf Stream. The color scanner can give estimates for chlorophyll concentrations. These relate to ocean productivity and show promise in helping fishermen. The extent of annual sea-ice cover (using SAR and SMMR) in both polar regions can be seen and has implications for weather, climate, and ship operations. Major bathymetric features, such as mid-ocean ridges and trenches, are reflected by their gravitational pull on the sea surface, and are revealed by the radar altimeter.

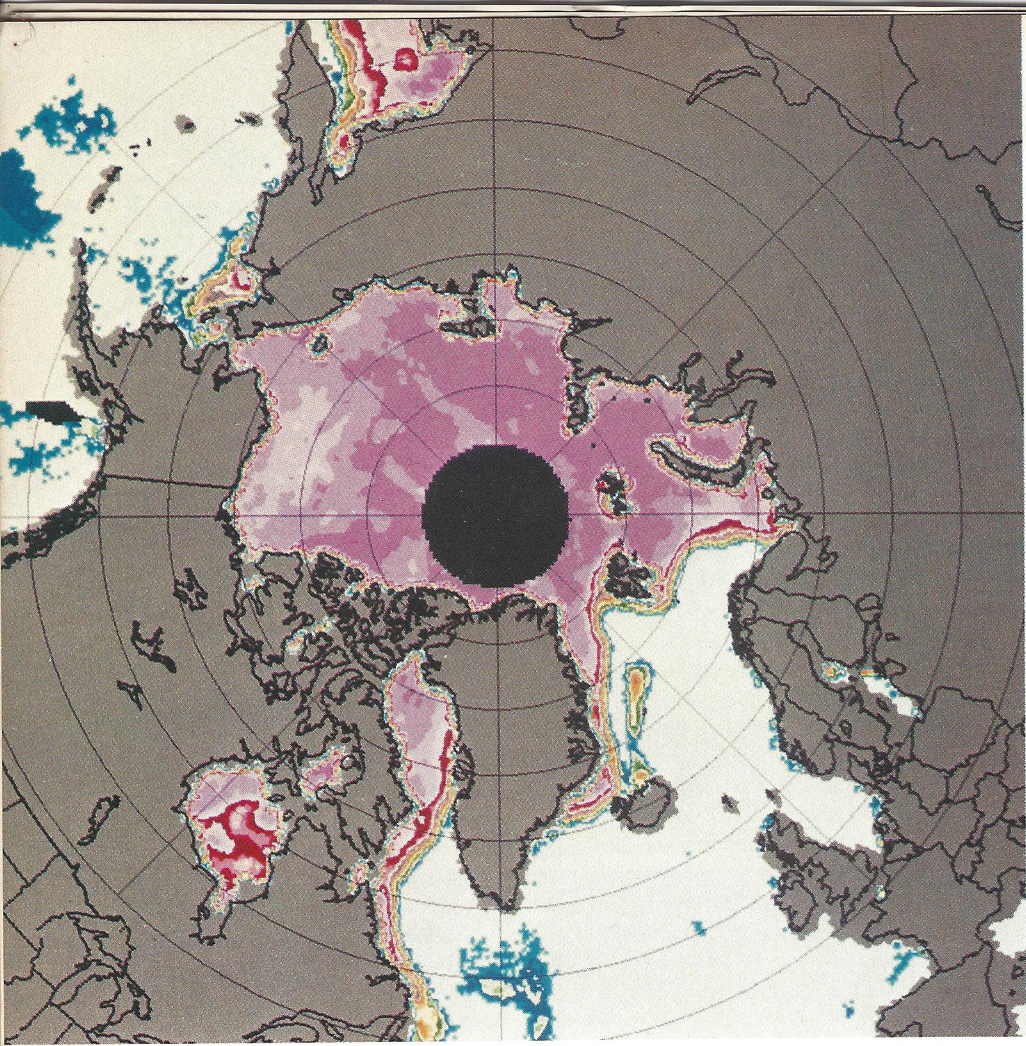
In effect, remote sensing can focus on the ocean's winds, waves, currents, ice, and thermal and optical properties, from which biological productivity can be derived. Its practical applications lead to improved marine forecasts for transportation, fisheries, coastal protection, pollution, deep-ocean mining, search and rescue, naval operations, climate, mapping, and defense.

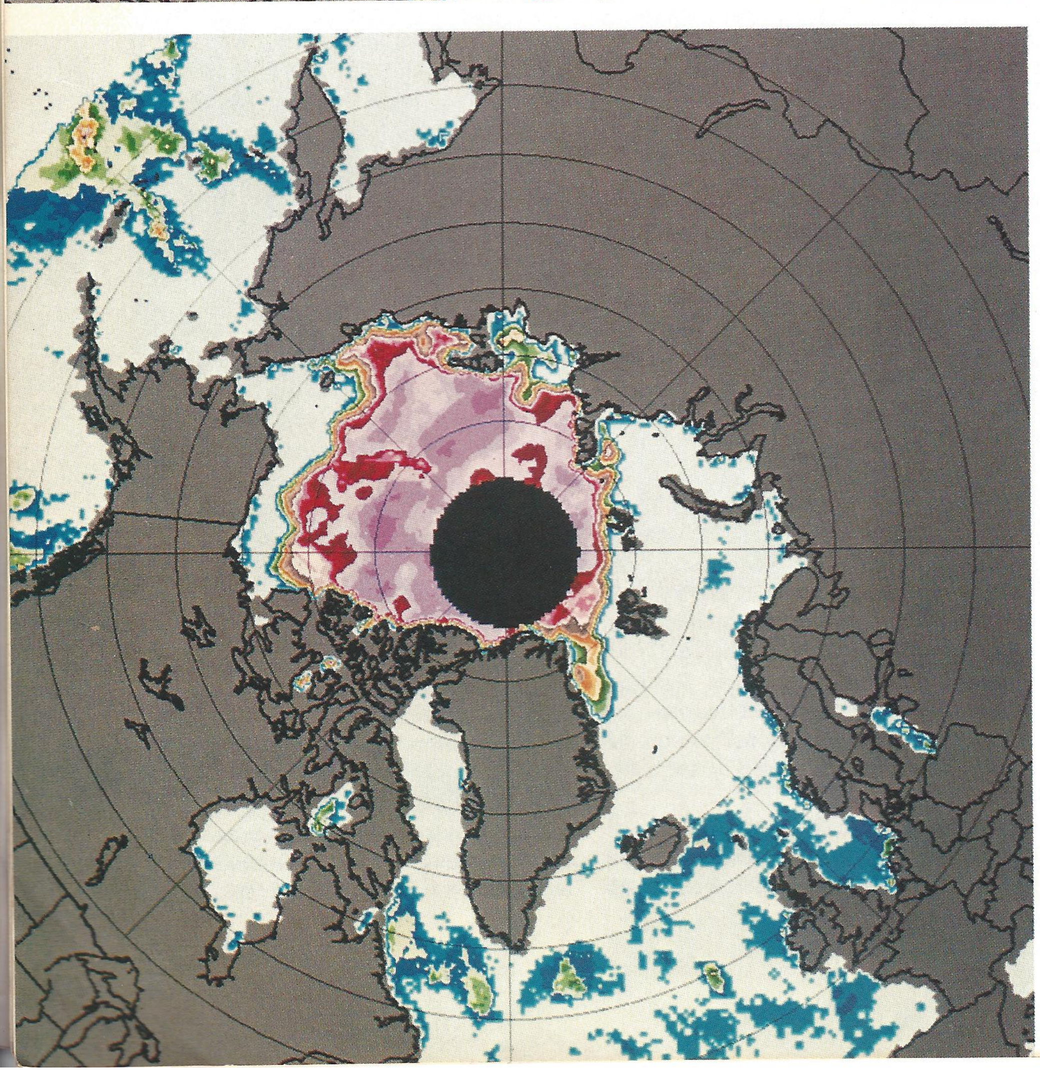
Satellite sensors, however, do not give us the whole oceanographic picture. They cannot actually penetrate into the ocean water column, nor can they measure important variables such as salinity, oxygen, and heat transport. But they can operate in conjunction with surface research vessels, which can "sea-truth" (or correlate) the satellite data to actual sampling. Recently, experiments funded by the National Science Foundation and NASA were carried out in the Gulf Stream. Known as the Warm Core Rings Program, it joined the efforts of two satellites and four research vessels over five cruise periods between September 1981 and September 1982.

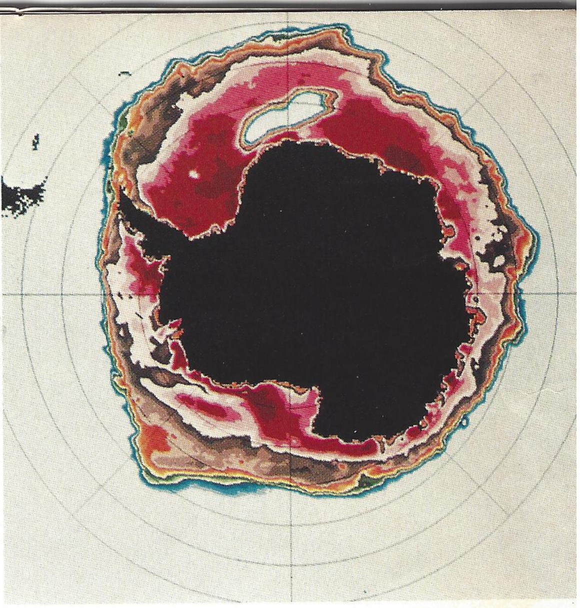
A warm core ring is a large eddy formed when a meander of the Gulf Stream pinches off and migrates into coastal waters. Rotating in a clockwise fashion, these rings present a semienclosed ecosystem of warm, nutrient-poor Sargasso Sea water trapped in a region of cool, productive coastal waters. As such they present a natural experiment to study the physical effects and biological responses of an isolated community. The effect of these rings on shelf-slope water exchange is critical and could have a major impact on important fishery grounds, such as those off Georges Banks.

Warm core rings are easily detected by the ocean color scanner (they have low chlorophyll concentrations) and the infrared and microwave radiometers (rings have higher temperatures). Two satellites containing such instruments relayed information to ships, making *in situ* measurements in the Warm Core Rings Program. This information enabled ships to orient themselves within oceanic features and to observe visually aspects of these events. Rings may also move fifteen to twenty miles per day. Thus satellite images enabled the research vessels to locate themselves in rings without spending expensive ship time in efforts to find out where the rings had moved. This program successfully showed how, with a dual approach using both ocean-sensing satellites and research vessels, oceanographers can now begin to see the forest from the trees.

The enormous volume of data generated by these sensors has created its own problem. The information to be analyzed is orders of magnitudes greater than the amounts generated by traditional oceanography. The data from the short-lived SEASAT is still being analyzed over four years after its demise,



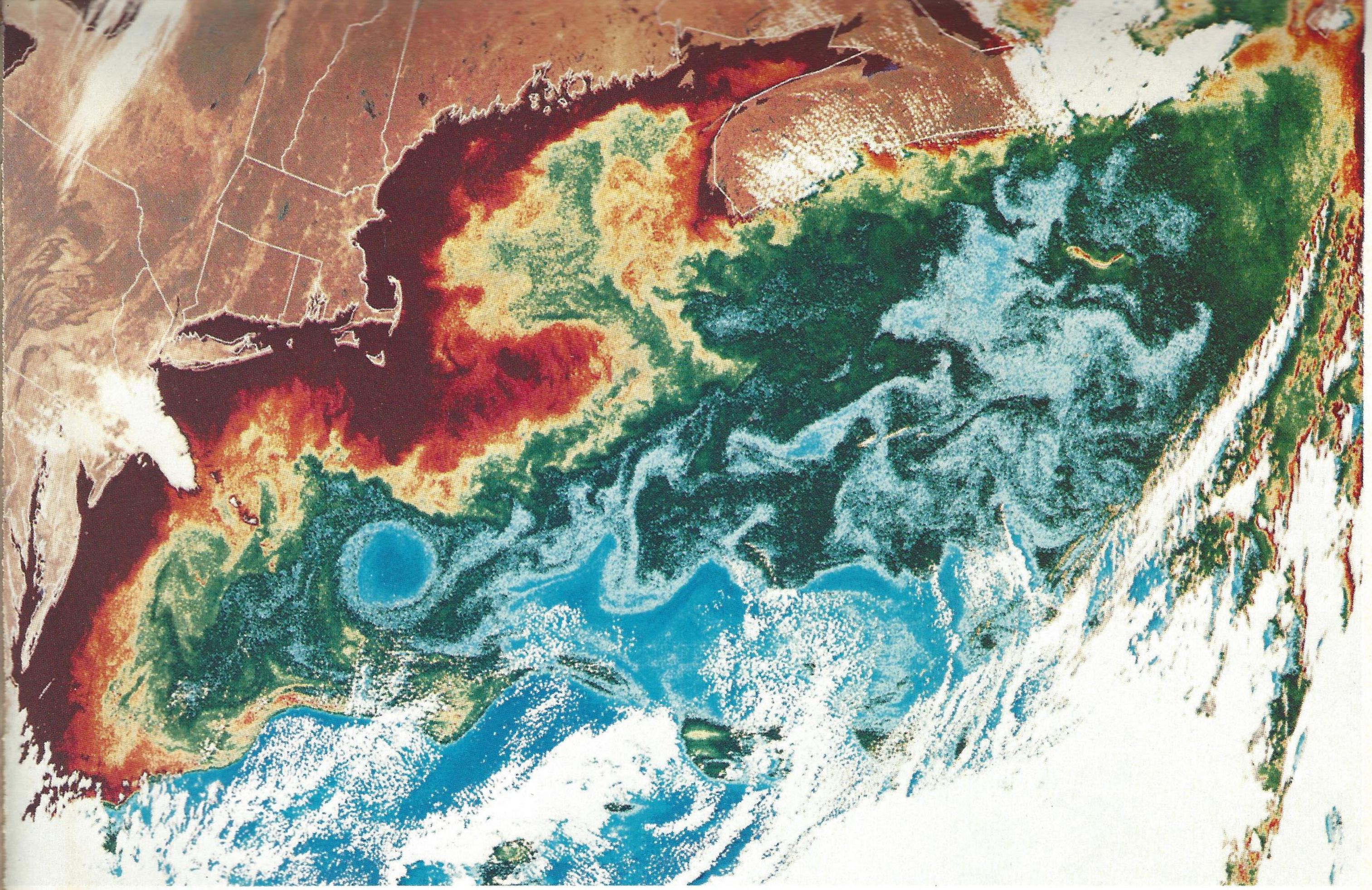


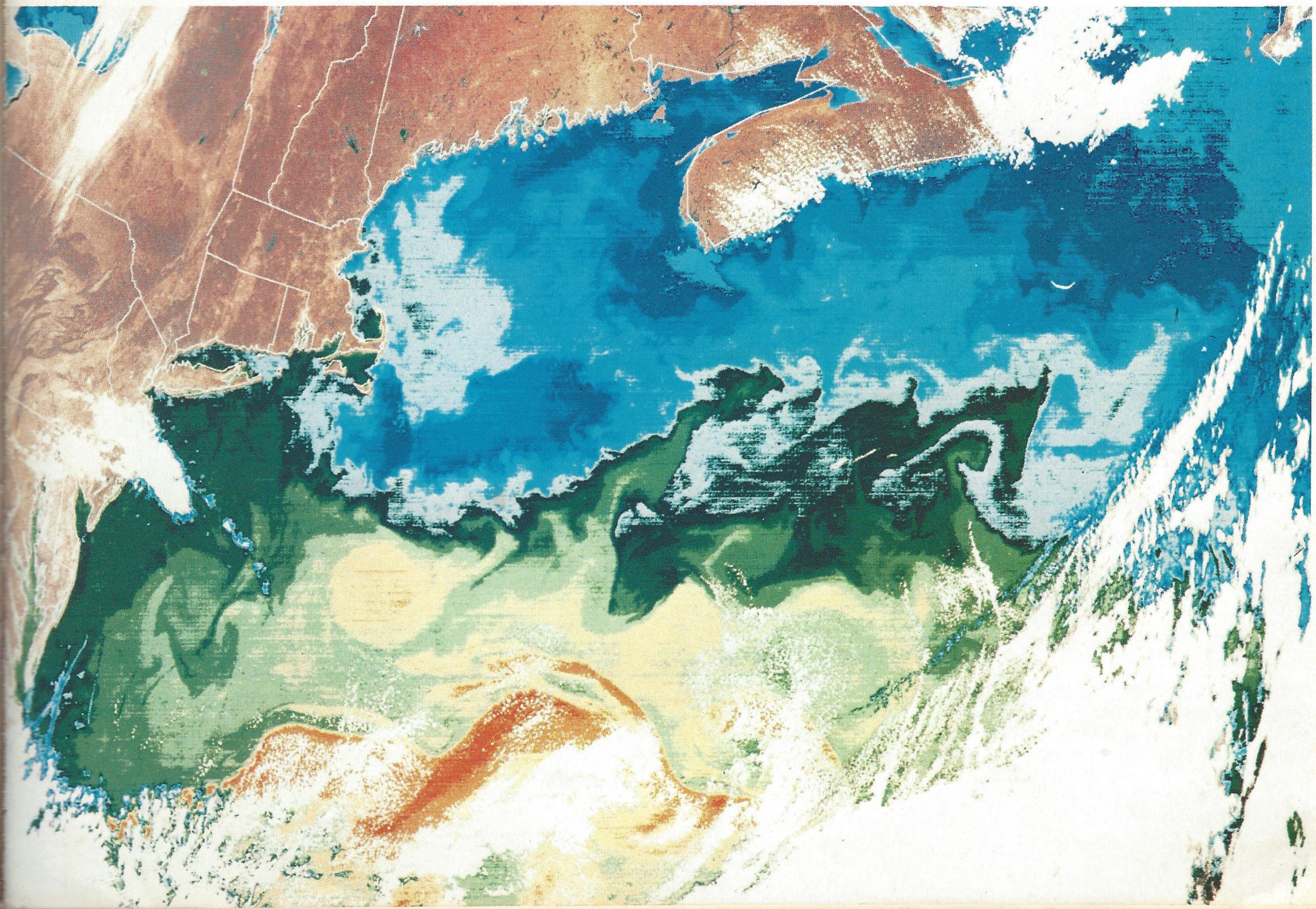


*Above: The winter sea-ice concentration around Antarctica, as pictured by the* Nimbus-7 *microwave radiometer. During winter, the ice covers an area seven times greater than during summer. The high coastal concentrations (red shades) become more sparse with increasing distance from shore (blue shades). An interesting but unexplained winter feature that often recurs annually is the open, ice-free region (light blue patch at top center), which is called by a Russian word—polynya. The Antarctic continent is the black region in the center; the southern tip of South America is at left. [J. Zwally, NASA/Goddard Space Flight Center, Ice Section]*

*Left, top and bottom: A comparison of the Arctic Ocean's basin of sea ice in late winter and fall, respectively. The* Nimbus-7 *scanning multichannel microwave radiometer shows the ice cover extending over the Bering Sea and Hudson Bay. The ice edge off the Newfoundland coast is somewhat constrained because of the Gulf Stream's warmer water. Note the clearly defined large band of ice that has separated from the main pack north of Iceland. The fall image shows the main sea ice confined to the Beaufort Sea northwest of Greenland. The bluish patches in the warmer ocean are false ice readings caused by severe weather, and the dark disc at the polar region indicates a lack of data that the sensor sub-orbital track does not cover. [D. J. Cavalieri, P. Gloersen, NASA/Goddard Space Flight Center]*

*Right, top and bottom: The Gulf Stream, through the instruments of the* Nimbus-7 *coastal zone color scanner (CZCS). False color imagery in the upper photo depicts concentrations of chlorophyll contained in phytoplankton (marine plants) off the Atlantic seaboard. The CZCS detects certain wavelengths of light absorbed by the chlorophyll in the plants, which indicates the water's productivity. The dark brown strips along the coast show the highest concentrations. The deep blue feathering offshore reflects the low productivity of the Gulf Stream as it mixes and moves north toward Nova Scotia. The swirling blue circle is a warm core ring surrounded by colder, more productive water. Southeast of Cape Cod is a dark red and orange tongue of the plant- and fish-rich Georges Bank. Cloud cover appears as the white along the bottom. At bottom is the same shot using the infrared channel. Yellow-red corresponds to warmer water, blue to cooler water. Such comparisons are useful because they show that many of the features seen with the chlorophyll CZCS have identifiable thermal counterparts. [*Nimbus-7 *Coastal Zone Color Scanner Experiment Team]*





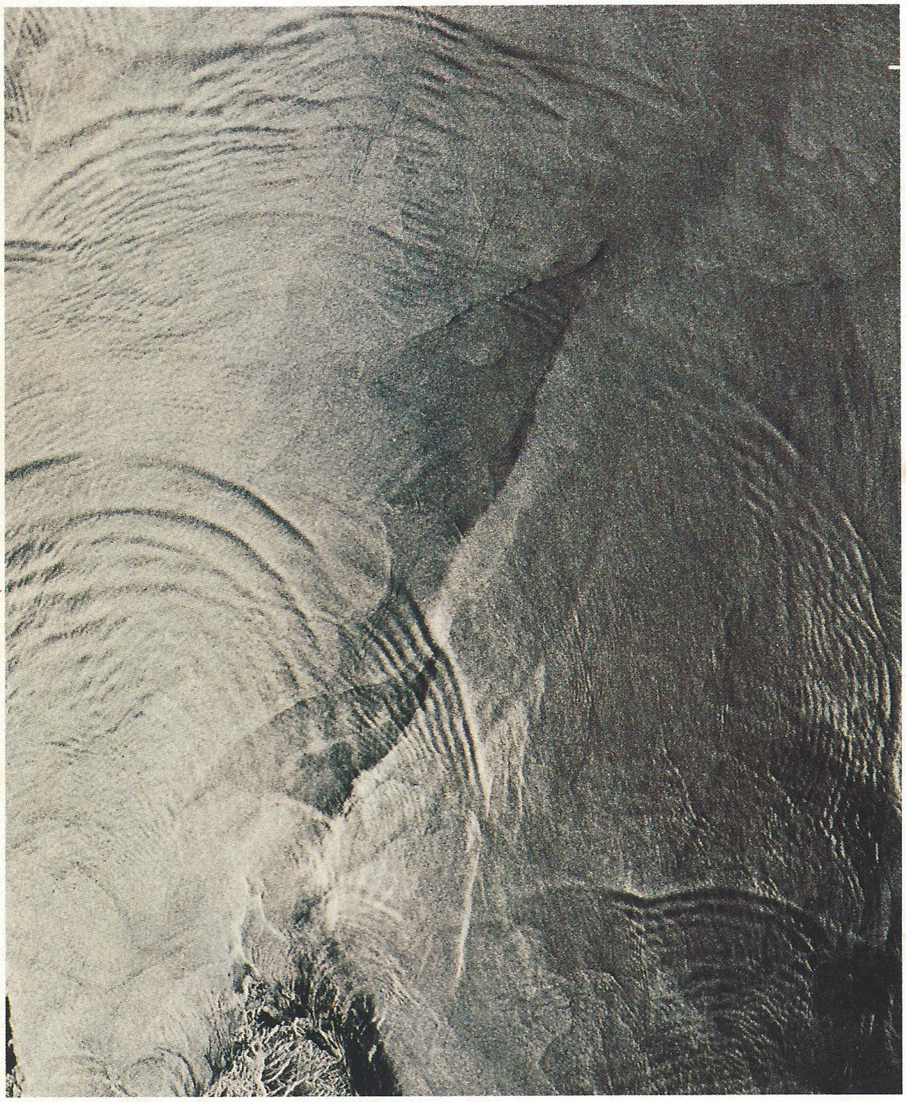
which highlights the enormity of the problem. For example, a standard oceanographic procedure called CTD (measuring conductivity and temperature versus depth) generates 26 million bits of raw data in three hours; whereas the NIMBUS-7 color scanner can generate 182 million bits of raw data in *four* minutes! (As computer programs become faster, future sensors will be streamlined for near real-time applications.)

Satellite sensors can revolutionize aspects of oceanography. The field is on the threshold of major advances in the study of the ocean and atmosphere as a complete system. Largely as a direct result of U.S. efforts, new tools and technologies have been established for satellite oceanography, and other countries are following suit. But, at present, the United States is not committed to a national program to provide spaceborne observations of the oceans.

Says Dr. Wilson: "If the U.S. is to capitalize on its investment and thereby maintain a competitive position internationally, it's absolutely necessary for various ocean-related agencies, academic institutions, industry and the navy to work together to develop a strong program. This cooperation is particularly necessary during the current austere fiscal environment, as no one group can afford to go it alone."

The brief annotated gallery on these pages indicates the range of information found in these images. For those who study the oceans, they are an elegant and compelling example of the wealth of details revealed by satellite oceanography.

*Payson R. Stevens is a biologist and head of InterNetwork, Inc., a science/media consulting group in Del Mar, California. He is also currently doing fisheries research at Scripps Institution of Oceanography.*



*In the Gulf of California, Baja Mexico, a* SEASAT *synthetic aperture radar image shows the northern tip of an island at bottom left. The pronounced concentric bands are internal waves, which are entirely within the sea and rarely reach the surface, although the satellite's sensors pick up their surface expressions. [L. L. Fu, Jet Propulsion Laboratory]*