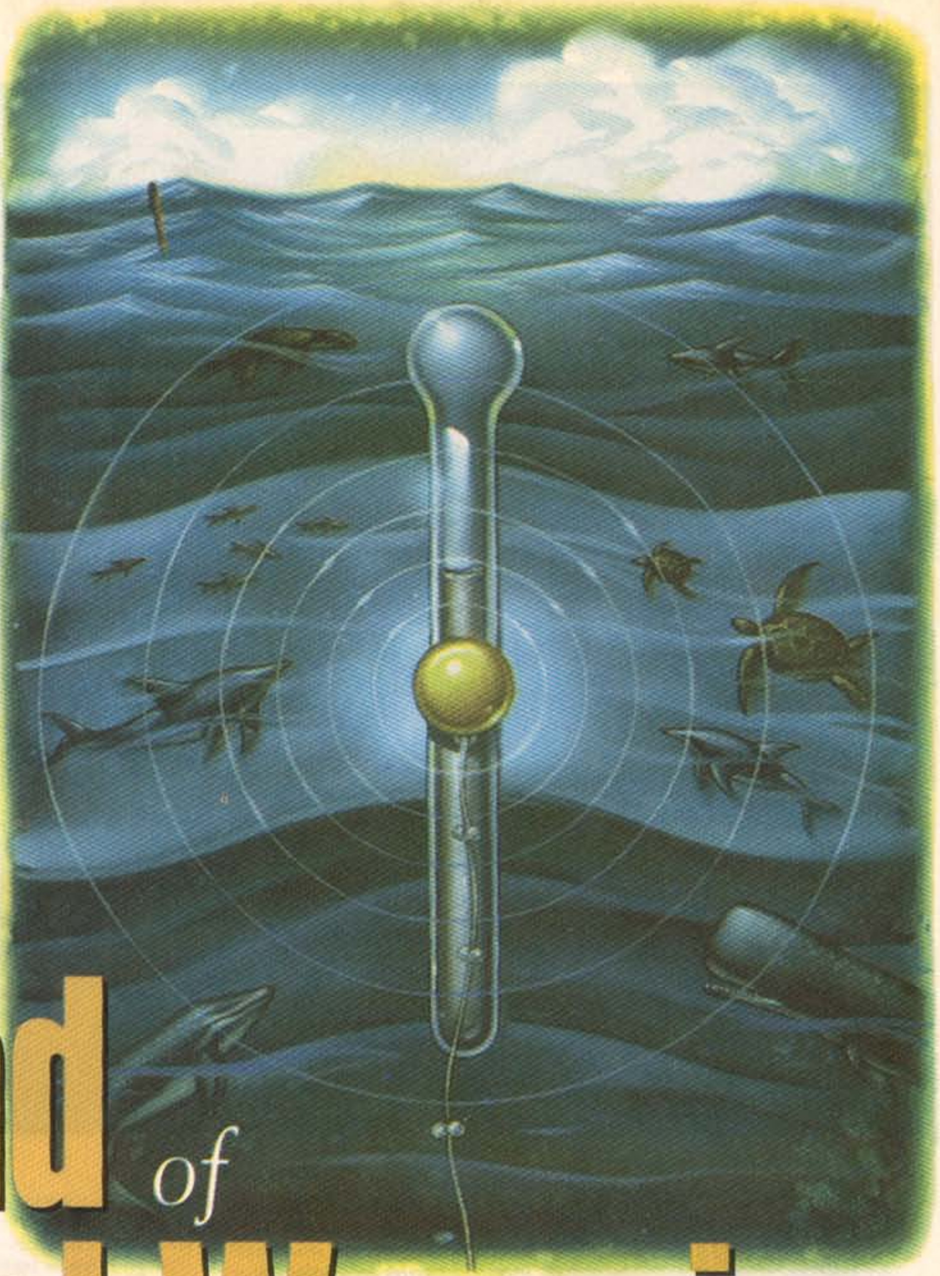
Cold War spy technology could become the world's largest ocean thermometer to measure global warming. But will the residents object?



GARY HENRIE

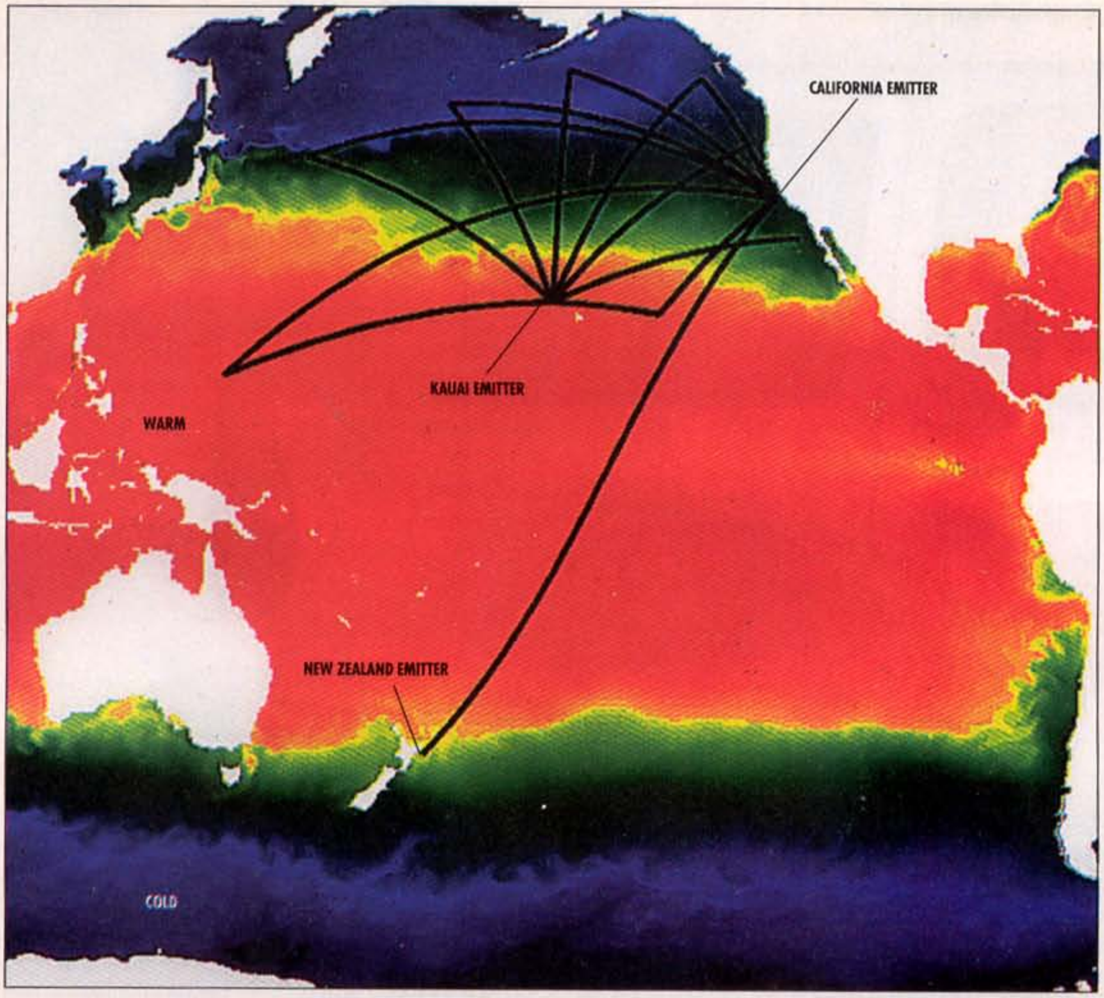
The Sound of Global Warming

BY STUART F. BROWN

A program that uses sound waves to measure ocean temperatures could improve global climate models but may be scrapped if whales and sea lions don't like it.

The Scripps Institution of Oceanography in La Jolla, Calif., hopes to inaugurate a $35 million program to measure temperatures beneath the surface of the Pacific Ocean. Knowing whether ocean temperatures are rising or falling over time would greatly increase the accuracy of computer models designed to predict climate change.

But the Scripps program—called the acoustic thermometry of ocean climate (ATOC)—uses low-frequency sound waves to determine ocean temperature. This has some marine mammal experts and environmentalists concerned because sea creatures such as blue whales, elephant seals, and sea lions either have hearing ranges that can detect ATOC sound waves or occasionally dive to depths where the sound-generating devices would operate. "This sound will travel though more than a quarter of the whole Pacific," says whale biolo-



Underwater microphones in the Pacific Ocean will measure average deep-water temperatures by clocking the travel time of sound from submerged emitters off California and Hawaii. Colors indicate local temperatures.

The U.S. Navy was quick to realize the implications of Ewing's work. It developed sound fixing and ranging (SOFAR), a method that uses hydrophones, or submerged microphones, to pick up noises underwater. For example, the noise of vibrating machinery aboard Soviet submarines was detected from one thousand miles away by SOFAR monitoring of the oceanic sound channel. "SOFAR was a mainstay of U.S. security during the Cold War," says Munk. "This method was our main source of information about one of Russia's most threatening activities."

Curiously, a Soviet scientist had independently discovered the sound channel in a 1946 experiment, but for some reason the Soviet navy didn't capitalize on the findings. Soviet strategy changed abruptly in the 1970s, when spies revealed the success of SOFAR. Much quieter Soviet submarines were soon in service.

gist Linda Weilgart of Dalhousie University in Nova Scotia, who triggered the controversy in a flurry of Internet exchanges last year. "You've got to be sure you're not affecting the long-term welfare of marine mammals, such as fertility rates, growth, and mortality" before going ahead with the program, she says.

The controversy over the Scripps ATOC program is especially ironic, since it pits animal-protection advocates such as the Sierra Club and the Natural Resources Defense Council against scientists who believe the program could help us learn more about one of the biggest mysteries of the environment—global warming. The ocean plays a bigger part in global climate than most people realize. "Most of the heat that powers the climate is stored in the seas," says oceanographer Walter Munk, the project's principal investigator. "You won't get the atmospheric climate prediction straight unless you get the ocean climate prediction straight."

Measurements of ocean-surface temperatures can be made by satellites, but their radar or infrared instruments are only capable of sensing the top few millimeters of water. Deep waters, which contain most of the ocean's heat, can also be sampled by oceanographic research ships dispensing sensing instruments. This process is expensive, however, for the amount of data gathered. ATOC's proponents argue that acoustic thermography's ability to sense the average temperature of an immense volume of water makes it the most practical method.

Using sound waves to measure water temperature has its origins in a 1944 experiment by Maurice Ewing of Columbia University, who discovered a natural "channel" in the sea that could carry sound waves across vast distances. This sound channel, at a depth of about 2,800 feet, is a seam of medium-temperature water that's isolated by a layer of warmer surface water above, and a layer of cooler, deep water below. The thermal and pressure barriers on either side of the middle-depth layer act as a wave guide, keeping certain sound frequencies bouncing between its two "walls" [see diagram]. Ewing's original experiment proved this when an underwater explosion was detected 900 miles away.

By the late 1970s, Munk was pioneering the techniques that would lead to acoustic thermography. He performed acoustic tomography experiments, using multiple sound emitters and receivers to produce three-dimensional temperature maps of areas of the sea. The method exploited a natural phenomenon: Sound travels faster in warm water than it does in cold water. Therefore, the average temperature of the water can be determined by clocking the travel time of low-frequency sound from its source to a receiver. For example, water warmer by a mere five one-thousandths of a degree decreases sound travel time across a 6,000-mile path by 150 milliseconds.

In 1991, Munk led a test program which showed that an underwater sound source exploiting the sound channel could be broadcast over great distances. A signal transmitted underwater from Heard Island in the southern Indian Ocean near Antarctica was detected by sensors 11,000 miles away. This experiment opened the door for ATOC, which uses a pair of sound emitters and an array of sensors to measure temperatures across vast areas of the Pacific.

ATOC sound emitters produce low grumbles of 75 hertz that are transmitted in coded 27-second sequences and are repeated 43 times for a total of about 20 minutes. The coding identifies the signal, which weakens and becomes buried in the ocean's random noise before it arrives at a receiver. Repetition provides replacements for individual signals that may be canceled out by background noise en route. Each chunk is tagged with its exact departure time. Computers then correlate clearly received chunks of different sequences into a precise measurement of sound travel time.

"Actually detecting climate change in the oceans will take at least a decade, and 20 years would be even better," says ATOC program manager Andrew Forbes. "If you only measure for five years, you may find yourself tracking a trend that is just riding on the back of an El Niño," Forbes says. "So you have to get beyond those known periodicities in the ocean and atmosphere and measure at least a couple of normal cycles."

The mission plan calls for one sound source to be anchored in the waters at Pioneer Seamount off central California, and another to be placed eight miles off the north shore of Kauai, Hawaii. An assortment of acoustic receiving devices located 3,000 to 6,000 miles distant will collect sound waves and convert them into average temperature measurements along 18 paths through the Pacific. The Navy has agreed to allow researchers access to part of its once-secret network of submarine-detecting hydrophones.

Once the ATOC network is established in the Pacific, the equipment will gather temperature measurements for 24 months. Forbes hopes the early insights gained into the thermal characteristics of the Pacific will lead to the development of a long-term acoustic thermometry network monitoring large ocean areas, particularly in the Atlantic, where major flows of cold, polar bottom water enter the global ocean.

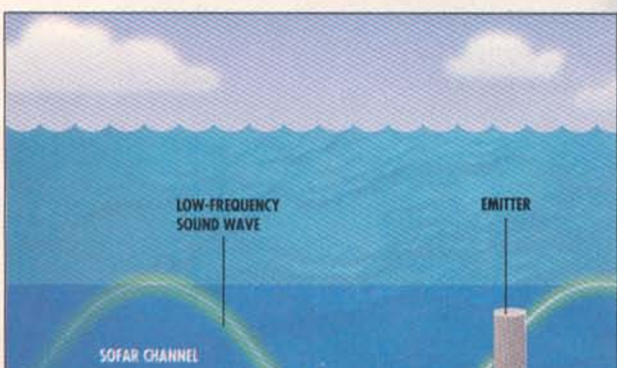
But the entire program hinges on the outcome of a six-month test aimed at determining if ATOC sound sources harm marine mammals. If federal and state permits are issued—perhaps as early as this summer—researchers will gradually bring the omnidirectional sound emitters up to full power for 20-minute transmissions for four-day periods, alternating with week-long periods of silence. Time-depth recorders will be attached to marine mammals in the neighborhood, and their swimming speeds and patterns, along with heart and respiratory rates, will be monitored.

Sound intensity from the ATOC microphones, which at 195 decibels roughly equals the noise of a large container ship at close range, diminishes rapidly as it radiates. At 2,700 feet from the source, the sound level decreases to 136 decibels, the equivalent of breaking waves, according to program officials. "We don't expect to see distress in these animals," says Daniel Costa, a marine biologist at University of California, Santa Cruz, who is heading the $2.9 million study on the effects of ATOC sound waves on sea mammals. "What we expect to see, if anything, is that the animals would express annoyance and avoid the site."

Program managers at Scripps have given the marine mammal group control of the sound emitters and the authority to modify or halt the entire program if they detect harm to sea life. Ocean temperature measurements will begin only if the system is found to be safe.

Still, marine biologist Christopher Clark, head of the ATOC marine mammal study, is embittered by the controversy. He feels that opposition to the program is grounded in emotion rather than scientific fact. "This is environmental activism gone completely astray," Clark says. "They should be focusing on the real acoustic pollution in the sea, which is the barrage of noise from supertankers and other shipping traffic."

If ATOC clears regulatory hurdles, Walter Munk and his acoustic oceanographers will transform a Cold War submarine snooping technique into the biggest thermometer in the sea. Scripps scientists plan to share data with researchers at NASA's Jet Propulsion Laboratory, who are now receiving ocean surface-height measurements from the orbiting *Topex-Poseidon* spacecraft. "The satellite altimetry gives you the temperature of the upper oceans, because when they are warmer the water level is higher," Walter Munk explains. "With ATOC, we get the temperature structure of the interior ocean. We will use these two views to help produce a good climate-prediction model, which we think does not now exist."



ROB SCHUSTER

An ATOC emitter generates low-frequency sound that becomes trapped in the ocean's middle layer and travels vast distances.