Tracking Ocean

A CTD rosette is deployed in the Southern Ocean from the Russian research vessel *Akademic Ioffe* as part of an international effort during the World Ocean Circulation Experiment (WOCE).

Pathways:

WOCE researcher Lynne Talley of Scripps in the laboratory aboard R/V *Roger Revelle*.

Research Career
Follows World Ocean Circulation

From shore, the power and energy of the ocean are obvious in its crashing waves and flowing tides, but these events give little evidence of the colossal motions that circulate ocean water around the planet.

Physical oceanographers at Scripps, in collaboration with an international network of institutions and agencies, have been participating in the World Ocean Circulation Experiment (WOCE) since the early 1980s. This program is the most extensive attempt ever undertaken to document and understand ocean circulation.

WOCE was designed as a major component of UNESCO's World Climate Research Program and involves scientists and institutions from more than 30 nations. The field stage of the program took place between 1991 and 1998, when research ships, in situ instruments, satellites, and powerful computer systems were used to compile comprehensive ocean circulation data—basin by basin. Because the interaction between the atmosphere and the oceans drives Earth's climate, an understanding of ocean circulation is necessary for scientists to uncover why, how, and how quickly global climate is changing.

BY PAIGE JENNINGS

Many researchers will spend the next several years synthesizing and analyzing the data to develop more accurate computer-driven climate-prediction models. Scripps is not currently involved in WOCE model development, but many of the data are already being used by Scripps scientists, including physical oceanographer Lynne Talley, for a variety of WOCE observational and experimental projects.

Talley, a Scripps professor and an expert on the circulation of intermediate ocean waters, has participated in WOCE for more than 14 years as a program strategist, administrator, and principal investigator. For many years Talley was a member of the steering committee for U.S. WOCE activities, which were mostly funded by the National Science Foundation. In 1998 she joined the International WOCE Steering Committee.

"I got involved with WOCE in 1985, and will be with it until it ends in 2007," said Talley. "Because I started out in it pretty young, my research has been shaped by it." This is evident from the stacks, cabinets, and plastic trash cans used to hold copious ocean data, research papers, and rolled up circulation maps in almost every corner of her office.

WOCE has kept her busy. Over the last decade Talley has spent more than seven months at sea, attended meetings around the world, and participated in approximately five WOCE-related projects. This hectic schedule is indicative of the WOCE effort, which condensed the equivalent of decades of data gathering into less than one decade. With growing attention being given to the effects of global climate change on the environment and on human life, it has been necessary to work quickly.

Because the ocean captures the Sun's heat and transports that heat great distances before releasing it back to the atmosphere, the complex movements

Continued on page 24

Pancake ice in the Southern Ocean as seen from aboard R/V *Palmer,* used by the National Science Foundation's Antarctic Program. **Inset,** The large-volume water sampling device known as a Gerard barrel is deployed from Woods Hole Oceanographic Institution's R/V *Knorr* in the Southern Ocean. WOCE is a multi-institutional effort to collect data in all the world's oceans.

Clearinghouse for a World of Ocean Data

The most-detailed data set of oceanographic information in existence was generated during more than 500 cruises for the World Ocean Circulation Experiment (WOCE) Hydrographic Program between 1991 and 1998.

All of these data, collected by more than 100 researchers from around the world, are compiled at one location, the WOCE Hydrographic Program Office (WHPO). In 1997, that office moved from Woods Hole Oceanographic Institution to Scripps.

When the office was established, staff members at Woods Hole developed procedures for accepting and processing data and wrote users' manuals. All of the groundwork was completed and data had begun to arrive by the time the office was transferred to Scripps. Maintaining a continuous flow of data in and out—while moving boxes and tapes full of data and setting up the new office—was important, as there is much work to complete in a short time span. Funding for the office ends in 2001.

"We didn't want to reinvent what Woods Hole had done," said Jim Swift, Scripps physical oceanographer and WHPO director. "We also didn't want to impede the data users by changing the procedures and policies."

All of the hydrographic data, mostly from CTD (conductivity, which denotes salinity/temperature/depth) instruments and water-sampling bottles, are sent to the office, ideally in the proper WOCE format. But, according to Swift, the data often must be cleaned up before being made available for use by scientists. "We not only deal with the data, we also work with information about the data—gathering methods, problems that might have occurred during the gathering, and administrative details, such as knowing how to contact the data provider."

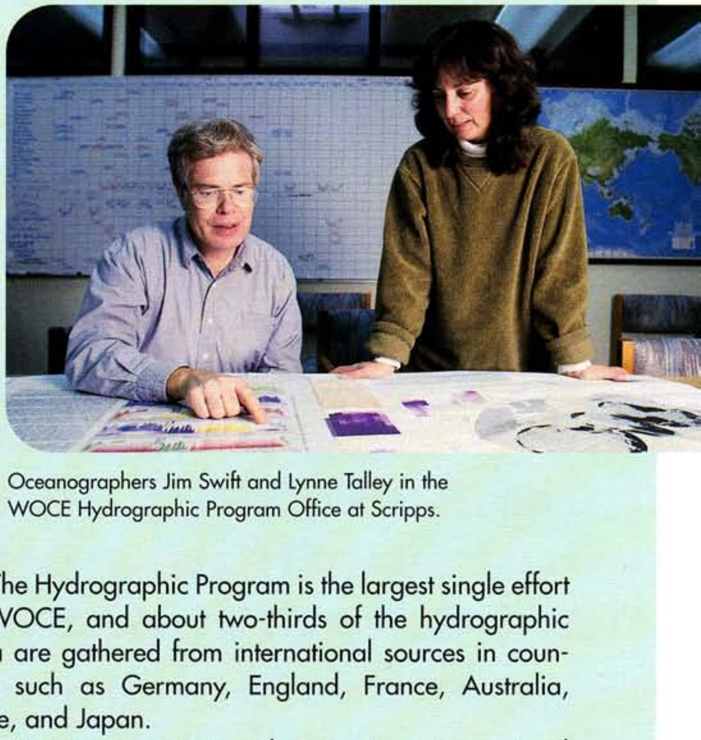
Swift's group spends a lot of time chasing down this information; they do what is necessary to help scientists get the data in a usable format.

"The role of our office is to have something that everyone can read," said Swift. The cleaned-up and organized data are separated into two categories: public and nonpublic.

Providers, for any reason, can specify that their data are not yet free for public use. This might happen because they are still verifying results or are using the data for a specific project. In the WHPO, the nonpublic data are processed and encrypted, but the decryption passwords are not released without the providers' permission.

When data sets are made public—as all WOCE data will be—they are available free of charge via the WHPO Web site (http://whpo.ucsd.edu/) and on CD-ROM. For Swift, getting the information to the user in the highest quality possible is of primary importance.

"We have a good relationship with all of our data providers, especially from the international community. My role is to help the process along; to let them know that we are not bad guys, so it is okay to send us their data," said Swift.



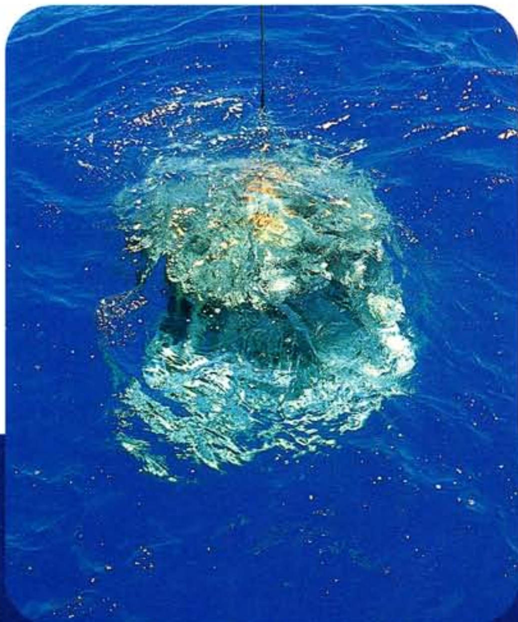
Oceanographers Jim Swift and Lynne Talley in the WOCE Hydrographic Program Office at Scripps.

The Hydrographic Program is the largest single effort in WOCE, and about two-thirds of the hydrographic data are gathered from international sources in countries such as Germany, England, France, Australia, Chile, and Japan.

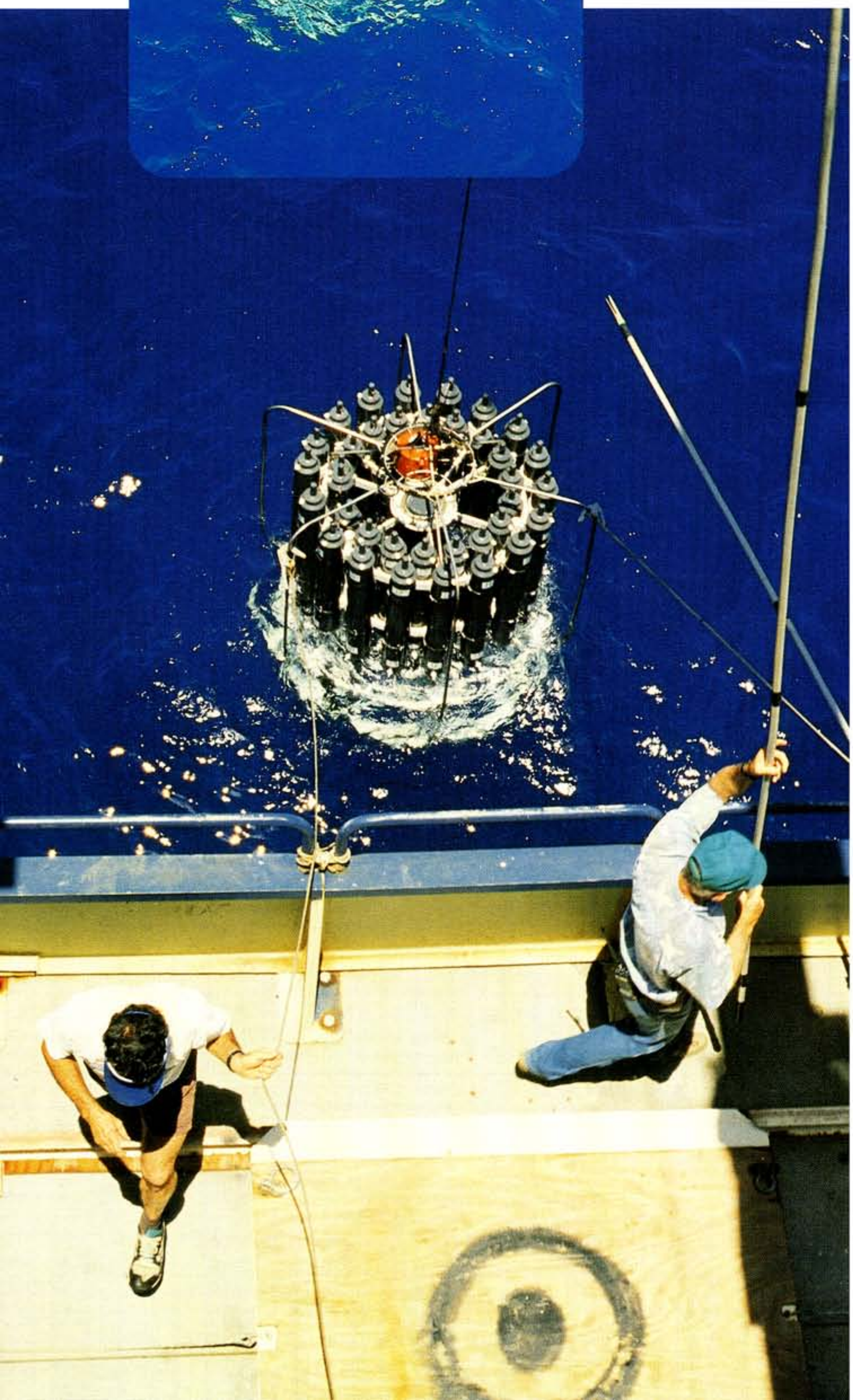
"We are very conscious that ours is an international office, even though our funding comes from the National Science Foundation," said Swift. "This program is neat because it is internationally sanctioned."

For example, explained Swift, a researcher working in a country where it is difficult to get funding may need a new sampling instrument to provide the quality of data required by WOCE standards. Because of the structure and strength of WOCE, that researcher should have a better chance of getting the funding for that instrument. Swift believes that oceanography conducted in the future will reflect the improvements instigated by WOCE.

According to Swift, "We are helping the world to get its data together."



Fundamental to understanding ocean circulation, CTDs—here being cast in the tropical Indian Ocean—are used to measure seawater salinity and temperature at various depths.



of the ocean are a primary factor in scientists' quest to understand global climate change. To build accurate computer models that depict climate change, scientists must couple atmospheric data with oceanographic data. These efforts are at the heart of why WOCE was conceived.

"There are two big goals in the program," commented Talley from her Scripps office. "One is to gather data with which to improve models for climate study and prediction; the second is to determine the representativeness of the data. Concerning the second goal, we basically want to know how the WOCE period—the 1990s—fits into long-term climate. Was the water warm, cold, or salty compared to the decade or two before or after the 1990s?"

Talley works with the raw hydrographic data gathered during WOCE. Approximately 35,000 CTD instrument casts—deployed and retrieved along ship transects in every ocean basin—provide a rich description of conductivity (which denotes salinity), temperature, and depth. Identifying these properties is key to determining how, where, and when currents move.

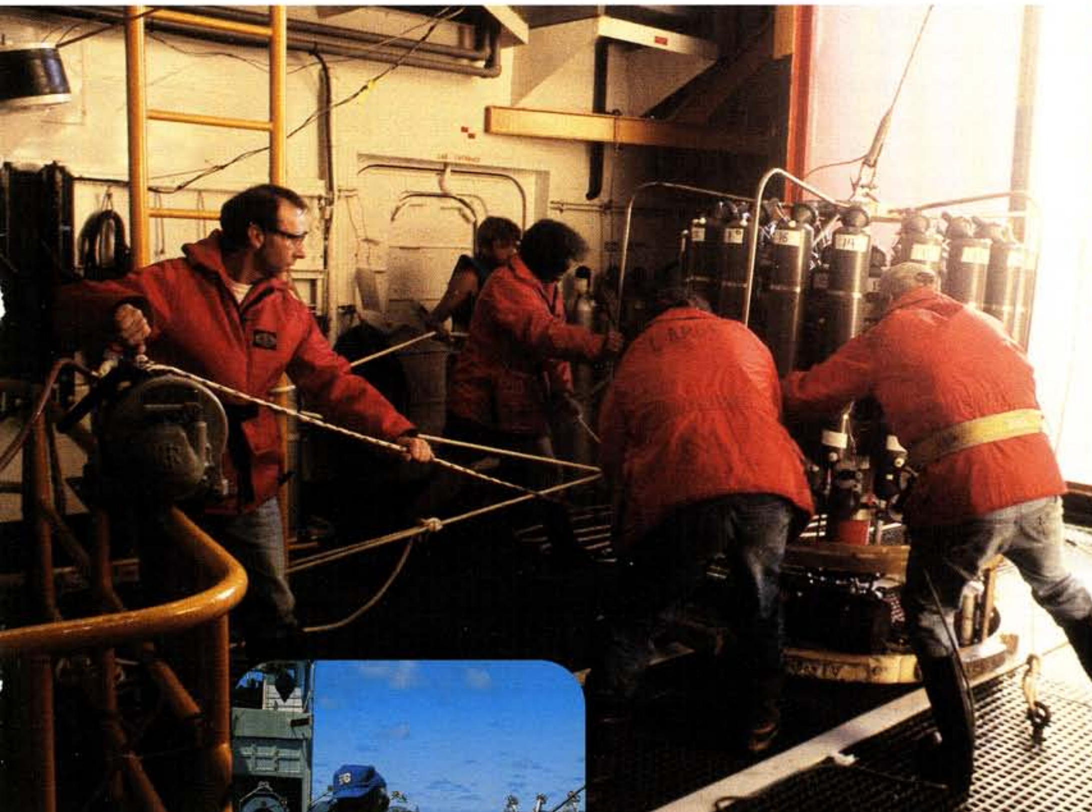
"We have really big, really rich data sets," explained Talley, "and there is a lot to say that's new about the ocean, just from these observations."

The data have been close at hand since 1997, when Scripps took over the operation of the WOCE Hydrographic Program Office from Woods Hole Oceanographic Institution. Talley advises the office, which is directed by Scripps physical oceanographer James Swift. The office is responsible for acquiring, archiving, and distributing all of the CTD and water-sample data gathered during WOCE.

One project—on which she is working with colleagues at Scripps, Woods Hole, NOAA, and in Hobart, Tasmania—is to map the circulation field of the entire Pacific Ocean, which covers more than 165 million square kilometers (63.7 million square miles).

The ocean is so vast and its movements happen on so many scales of size and time, that Talley says there are always new things to discover about circulation.

Approximately 5,000 CTD casts were made along crisscrossing transects in the Pacific. To begin plotting the circulation field, Paul Robbins, a Scripps postgraduate researcher, is using



Left, A CTD rosette is wrestled into the hangar of R/V *Palmer* in heavy weather. **Above,** An expendable current meter is deployed in icy Antarctic waters during the same cruise. **Inset,** In warmer latitudes, Scripps technician Jim Wells handles a submersible data-transmitting device in the tropical Pacific Ocean.

these data to segment the Pacific into 50 hypothetical boxes—each one created where transects have crossed and "boxed in" a section of the ocean. By looking at the data at the edges of these boxes, Talley and her colleagues will be able to determine circulation.

"We know that as much water as goes into a box has to come out," explained Talley. By comparing the fluxes in temperature, salinity, and water pressure along each side of the box, the researchers know where the water came in, and where it left. Box by box, from the ocean surface to the seafloor, the complex circulation patterns will begin to be revealed.

To start the mapping process some initial assumptions about Pacific circulation must be made. "We felt that as a group, because we had all worked so hard with the first observations, we would have the best first guess," said Talley.

As a part of that first guess, they are comparing the findings from the preliminary boxes to a Pacific circulation map worked out several years ago by renowned Scripps oceanographer Joseph Reid.

"Joe did his circulation map with very little WOCE data, so we'll see if we need to improve on his map. If there are improvements, they might come from the fact that we have higher resolution data along lines," said Talley.

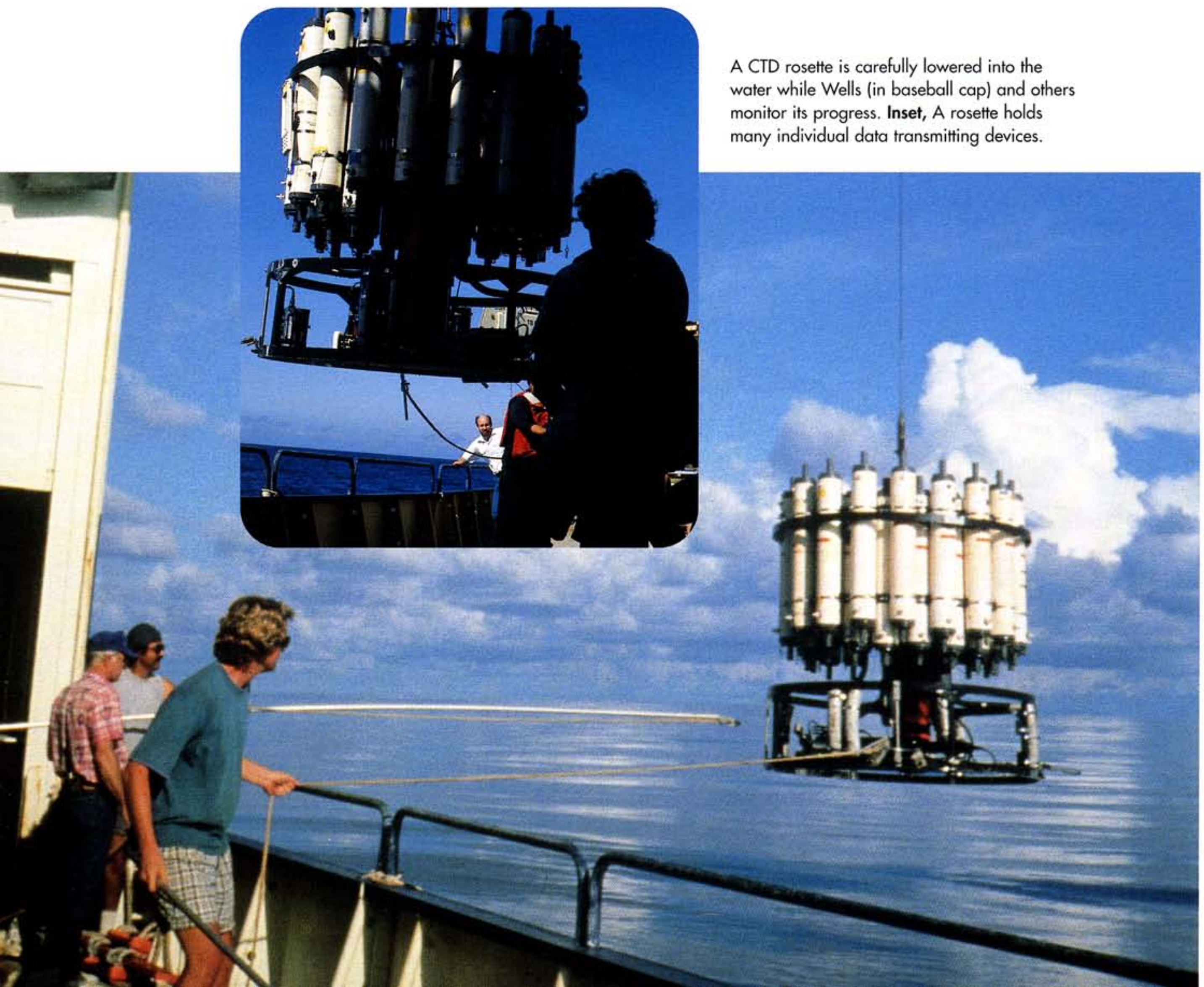
In many of the WOCE projects, including the mapping of the Pacific Ocean, Talley is involved with looking at circulation at all ocean depths. But she still finds time to focus on the topic of most interest to her, intermediate ocean waters.

Intermediate waters are formed in different places and are distinct from deep waters. Found between approximately 500 and 1,500 meters (1,640 and 4,920 ft) deep, intermediate waters originate in the Labrador Sea in the North Atlantic, in the Sea of Okhotsk in the northwest Pacific, and off Chile near the Drake Passage. Often, according to Talley, when physical oceanographers describe processes in the deep ocean, they don't make a distinction between intermediate and deep water. She thinks it's about time they did.

"I think there has been more focus than needed on deep water without considering how it really divides into deep and intermediate waters. They are separate and each one has its own processes."

In 1998 she began working with Scripps physical oceanographer Daniel Rudnick on a project, not associated with WOCE, to study the formation of intermediate water in the Sea of Okhotsk—a marginal sea that lies north of Japan and east of Russia, between 50° and 60°N. It is in this body of cold water that intermediate water is formed for the North Pacific.

"Sea ice forms in the winter, almost covering the sea, and it all melts in the summer," explained Talley. "As ice forms, the salt in



A CTD rosette is carefully lowered into the water while Wells (in baseball cap) and others monitor its progress. **Inset,** A rosette holds many individual data transmitting devices.

Lynne Talley and colleague Dan Rudnick inspect a new bottom lander during preparations at Scripps. Containing data-collecting instrument packages, four such landers—essentially protective shields—will be deployed on the continental shelf of the Sea of Okhotsk this summer.

the ice collects in pockets and drips out the bottom. This makes the water under the ice saltier and heavier. This briny, dense water then flows off the continental shelf in plumes and enters the nearby ocean or marginal sea basin. It usually sinks some way down—in the Sea of Okhotsk it sinks down a few hundred meters."

The seasonal feeding by this new dense water helps renew the intermediate layer of the North Pacific. A similar process in the Antarctic leads to the formation of deep water in the Southern Ocean.

To measure the formation of sea ice through the winter and to quantify how much water is flowing off the shelf, Rudnick will deploy four "bottom landers" this summer that will rest on the shelf north and west of the island of Sakhalin, off the coast of Siberia. Each bottom lander is equipped with an Acoustic Doppler Current Profiler to record the velocity of the dense water as it flows over the shelf, and a device, known as a microcat, that will measure temperature and salinity.

"We hope to discover the properties of the dense shelf water and to estimate the quantity of water that is formed by measuring its transport before it leaves the shelf," said Talley.

Talley and Rudnick obtained funding for the Sea of Okhotsk project from the National Science Foundation, and they are working jointly with scientists in Japan and Russia. According to Talley, this project is part of the Japanese arm of CLIVAR (Climate Variability and Predictability)—a large-scale international program planned as part of the World Climate Research Programme to follow on the heels of WOCE. The general goals of CLIVAR, which will build on the knowledge gained from WOCE, are to determine climate variability and predictability on seasonal to 100-year timescales, to identify the physical processes and man-made causes responsible for climate change, and to develop modeling and predictive capabilities.

The U.S. arm of CLIVAR, which is in the early planning stages, will involve many scientists at Scripps, including Talley. Most likely, this will mean more international travel, conferences, and sea time. But for Talley, it's all about going where the science is.