Ocean and Climate Change Institute

2007 Annual Report

Message from the OCCI Director Terry Joyce

Photo by Dave Gray, WHOI

During the past year, it has been interesting for us to follow the increase in press and public awareness about climate change centered on global warming. This is an important scientific and societal problem, certainly deserving of the attention it is getting. Sometimes forgotten, however, is the rest of the climate problem: what happened naturally in the past or is happening naturally at present, and why. Having the answers to these questions is essential, before we can make accurate projections about the future.

Unusual weather this winter around the US has had folks scratching their heads. Clearly, there is more to learn about climate beyond the effects of global warming. The Ocean and Climate Change Institute (OCCI) has been supporting studies directed towards determining the difference between human-induced and natural climate change.

Before the end of the winter of 2006/2007, we hope to complete a series of articles written by OCCI-sponsored scientists for the general public on ongoing climate research at WHOI. These have been appearing as they are completed under the *Oceanus* byline on the Web. A print issue will collect all of these climate-related articles this spring. In this annual report, we focus on three new projects that you won't see in the *Oceanus* articles.

In the first project, Mary-Louise Timmermans tries to understand why there is a body of dense, salty water in the Arctic Ocean's deep Canada Basin. In our present climate, there is no way this water can either enter the basin from the outside (since it is not present elsewhere in the Arctic Ocean) or form at the surface and sink. So it is a bit of a puzzle to explain the existence of this deep Arctic water mass. Clearly, it must have formed under a different climate than the present. What kind of a climate and when this might have occurred are issues being addressed.

The second project report, by Steve Jayne, discusses the beginning of a partnership between modelers and physical oceanographers at MIT, WHOI, NASA and Scripps. The goal of this partnership is to work towards a better estimation of the present state of the ocean using the best available models and oceanographic data sets.

In meteorology, observational data such as air temperature, humidity, and barometric pressure are ingested into numerical models, which generate weather forecasts. The best forecasts are produced with the most reliable initial data. Errors in data ultimately prevent forecasts from being extended more than several days. Ocean prediction also requires accurate estimation of the present ocean state. Thus, better use of ocean data in models is central to this project, which is supported jointly by OCCI and MIT.

The third report is about sea level rise and fall and the fidelity of the coral record in telling us what happened in the past. The methodology uses radioactive isotopic records contained in the skeletons of fossil corals. The fossil period of interest is one that occurred before the onset of the last ice age. The sea level at the height of the last interglacial maximum was higher than today, and we can expect similar higher sea levels in our immediate future. Bill Thompson's efforts have centered in the tropical western Atlantic Ocean. Results show that sea level change can occur more rapidly than previously thought, which is certainly relevant to the present, as we watch the accelerated melting of the Greenland ice sheet. —Terry Joyce

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Arctic Ocean Circulation and Climate Change

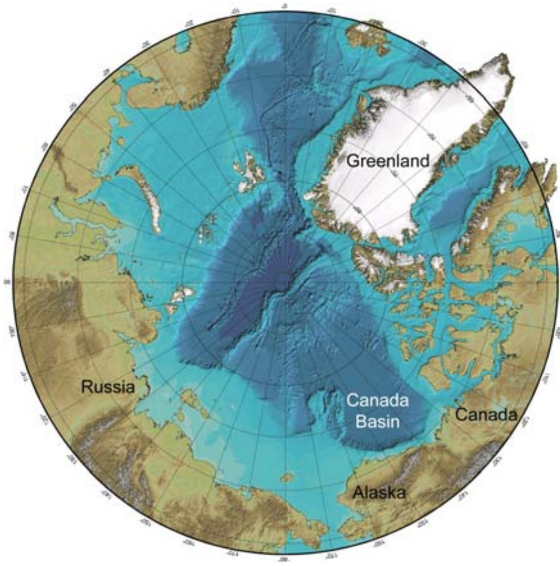
The Deep Arctic Ocean as an Indicator of Climatic Shifts

The water in the deep Canada Basin is the saltiest and most dense water in the entire Arctic Ocean. Recent studies have shown that this deep water has been isolated from shallower waters of the Canada Basin for at least the past 500 years. This prompts the following questions of key climatic importance: Did a climate shift in the past cause an end to new influxes of dense water to the deep Canada Basin? If so, how?

The Canada Basin deep water most likely originated when very salty (and, hence, dense) water was expelled by ice formation at the surface and sank to the deep. When water freezes at the surface of the ocean, the resulting sea ice is essentially fresh and buoyant. The salt is concentrated in surface waters under the ice, and since salt water is heavier than fresh water, it begins to sink. In the present climate, adequate volumes of surface water dense enough to reach the deep are not generated by ice formation, so the Canada Basin deep water remains isolated from the surface water.

In a different climate regime, the capacity for extensive new ice growth in the wintertime could re-start deep water renewal, as large quantities of salty water are produced during ice formation. Such a climate regime would require less permanent ice cover in the Arctic and more open water – i.e., in a world changed by global warming.

Map of the Arctic Ocean indicating location of the Canada Basin



The specific conditions that led to the shut-off of deep renewal have not been determined, nor do we have a complete understanding of what future Arctic climate conditions might lead to new influxes of shallower waters to the deep.

My research investigates the relationships between ice growth and deep-water renewal, with the aim of understanding how the present-day properties of the Arctic deep water can provide insight into past Arctic climate patterns and recent climate transitions. Using hypothetical ice cover scenarios and contemporary observations, I have been able to quantify the depth to which dense water sinks and determine the conditions necessary for surface water to become sufficiently dense to sink all the way into the deep basin.

With OCCI funding, I am collaborating with colleagues at the National Center for Atmospheric Research on computer climate models. We are identifying changes to the deep water that are caused by reducing the summer sea ice to an extent characteristic of future global warming scenarios. The modeling will aid in the interpretation of field observations and provide a basis for understanding how deep-water renewal events can be used as indicators of a shifting Arctic climate.

—Mary-Louise Timmermans

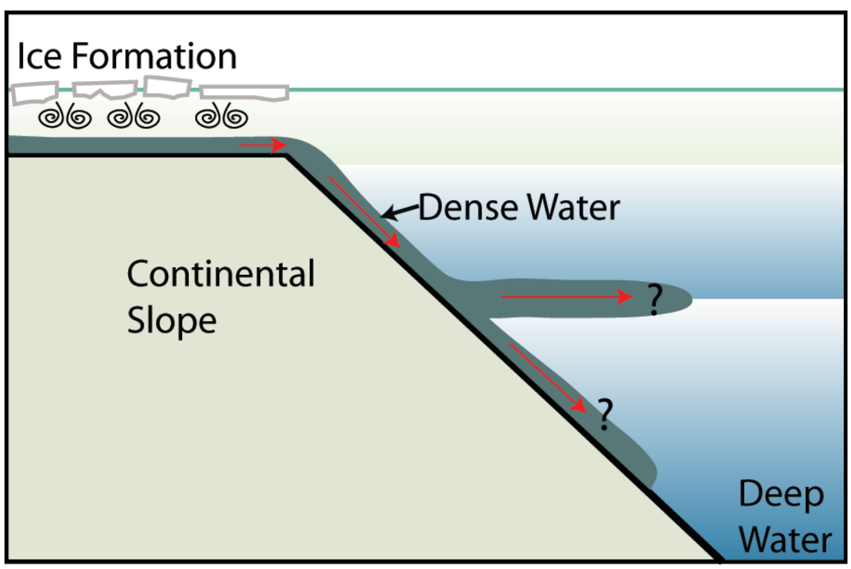


Illustration by M-L Timmermans

Dense salty water (red arrows) is expelled upon ice formation on the continental shelf. The dense water flows down the continental slope. Large volumes of dense, salty water are required for it to reach the deep Canada Basin. At present, adequate volumes of surface water dense enough to reach the deep are not generated by ice formation. What may happen in a warmer climate regime, when there is less ice cover, is the focus of this investigation.

Synthesis of Ocean Observations and Numerical Models

Estimating the Circulation and Climate of the Ocean

Scientists at Woods Hole Oceanographic Institution have been engaged in a large, multi-institutional collaborative project called, ECCO: Estimating the Circulation and Climate of the Ocean. The ECCO project involves the cooperation of computer scientists and oceanographers at the Massachusetts Institute of Technology, NASA's Jet Propulsion Lab, Scripps Institution of Oceanography and WHOI.

The main task of the project is to combine a numerical simulation of the global ocean circulation with existing observational data — including data from ship-based surveys, satellite observations, and measurements from ocean floats — to obtain best estimates of ever changing ocean circulation. The purpose of the ECCO project is ultimately to provide a tool for studying large-scale ocean dynamics, designing observational programs, and examining the ocean's role in climate variability.

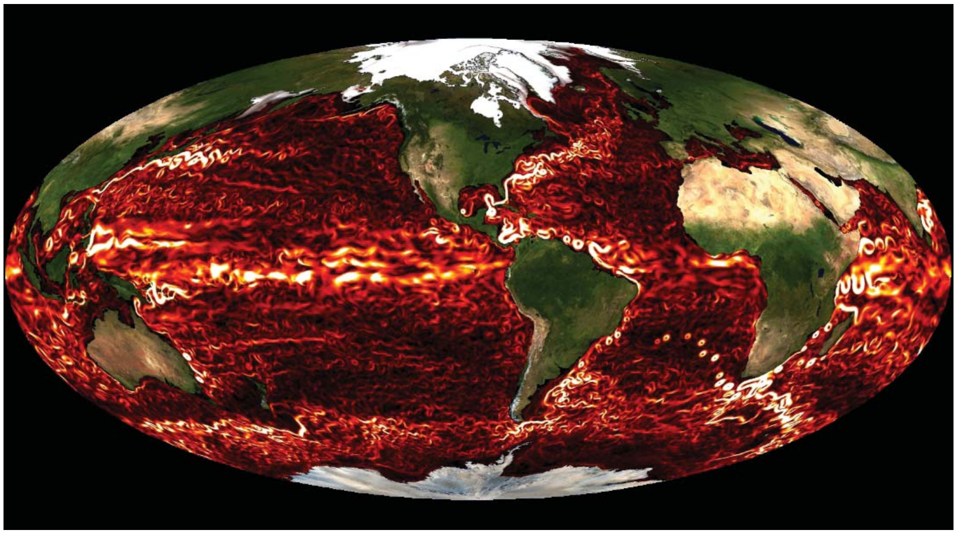
In order to achieve these goals, ECCO needs to evolve from its current experimental status to that of a practical and operational tool for oceanography. Just as reliable weather predictions require good estimates of the present atmospheric state, future ocean prediction will require good estimates of the ocean state.

In many cases, numerical ocean models provide detailed simulations that are visually beautiful yet are inaccurate when compared to real observations. Much of the ECCO project has been devoted to the technical development of mathematical and computational means of combining observational data with an ocean circulation model, while less effort has been spent on evaluating the model's accuracy.

Since one of WHOI's greatest strengths lies in its seagoing and observational work, it is the role of WHOI scientists involved in this project to evaluate the integrity of the ECCO results. A number of observational oceanographers have datasets in hand that can be used to test the reliability of the ECCO ocean-state estimates. Scientific interests within the group are very broad and range in geographic focus from the Arctic to the Antarctic, the Southern Ocean to the tropical oceans, and the Atlantic to the Pacific. Expertise includes research on the dynamics of currents, ocean-atmosphere effects, sea-ice interactions, and other physical properties of the oceans around the globe. Observational data from WHOI scientists are being entered into the model to determine its accuracy. Verifying the correctness of such detailed simulations requires the analysis of vast amounts of model output and data, and represents one of the most significant problems in oceanography today.

With OCCI support, the WHOI team will help to ground-truth the ECCO model simulations and ultimately enable more realistic estimates of global ocean currents. Many observational programs already underway at WHOI could benefit from interactions with the ECCO project. ECCO simulations can help fill data gaps and provide a broader context within which to place observations made in various regions throughout the world oceans.

—Steven Jayne



Snapshot from an ocean numerical model of the speed of Earth's ocean surface currents. (Continents are shown in brown, green and tan; ice caps in white and gray.) Fastest current speeds are in white and yellow, while quieter regions are in red and black. The major ocean currents can be seen including: the Gulf Stream coursing through the Gulf of Mexico along the coast of Florida, up the east coast of the US and out into the Atlantic; the Kuroshio along the east coast of China and Japan; the Agulhas Retroflection and its associated rings off of South Africa; and the equatorial current systems, to name just a few. Running numerical ocean models is very time consuming, even on the world's largest supercomputers. Verifying the correctness of such detailed simulations requires the analysis of vast amounts of model output and data, and represents one of the most significant problems in oceanography today. (Image courtesy of Chris Hill, MIT.)

Sea Level and Climate Change

Rising Sea Levels – How much, how fast?

Increasing levels of greenhouse gases in the atmosphere and the warming of Earth's climate prompt concerns about rising sea levels due to melting of the polar ice caps. This leads to an urgent question: How much and how fast could sea levels rise?

Tremendous amounts of water are stored in ice, and if all the ice in Greenland and Antarctica were to melt completely, it would raise sea level by more than 200 feet. Although large parts of the Antarctic ice sheets are not expected to melt in the foreseeable future, melting even a small fraction of the existing land ice would have a dramatic impact on heavily populated coastal areas.

The historical record shows that global sea level has risen at a rate of one-half foot per century over the last fifty years and one whole foot per century over the last ten years. Although it is not yet certain that the recent acceleration in sea level rise is a long-term trend, the unexpectedly rapid loss of land ice over the past few years surprises glacial geologists.

Much of what we know about the history of sea level over the last several hundred thousand years comes from fossil coral reefs that once grew near the sea surface. Fossil coral reefs now located nearly 400 feet below modern sea level tell us that sea level was dramatically lower twenty thousand years ago, when great ice sheets extended as far south as Cape Cod, Long Island, and much of the northern US.

Corals can be dated using chemical techniques that measure the decay

Fossil corals on Great Inagua Island, Bahamas. Live corals of this variety grow just below the sea surface, so scientists use corals to date sea-level changes over long periods of time. The above photo shows several generations of corals from the last interglacial period (around 122,000 years ago, the most recent time in Earth's history when climate was as warm as it is today). In the photo below, remnants of the last interglacial coral reef sit about 5 feet above modern seal level at Devil's Point, on Great Inagua Island, Bahamas. Consensus among scientists is that sea level has risen about 8 inches over the last 100 years. The highest estimates of future sea level rise suggest an increased sea level of nearly 3 feet by 2100. These sorts of changes (3 feet in 100 years) occurred several times approximately 122,000 years ago, when the climate was similar to today and thought to have been relatively stable. This implies that sea levels may be more sensitive to climate change than has previously been appreciated. Photo credits: (top) H. Allen Curran, Smith College; (bottom) Bill Thompson, WHOI.

Sea Level and Climate Change (continued)

of uranium incorporated into coral skeletons from seawater during growth. As the coral skeletons age, the ratios between the "daughter" or decayed uranium isotopes change, leaving a record of time passing. This technique has been used by climate scientists for decades.

Over the last 30 years, however, there has been a growing realization that most coral ages obtained using the uranium isotope method are unreliable. We have learned that, during the natural course of decay, uranium isotope atoms actually move from place to place. Because of this unexpected mobility of the isotopes used for coral dating, the resolution of sea level studies has been compromised. Both the paucity of reliable data, and the erroneous ages that are accepted lead to a confused and distorted picture of sea level history.

My research has focused on developing more accurate equations for calculating coral ages, based on my insights into the causes and consequences of this isotope mobility. I have developed a new method that produces more accurate coral ages and helps me to compile a much more detailed history of sea level change.

The Ocean and Climate Change Institute provided funding for me to take a detailed look at sea level change during the Last Interglacial Period, about 122 thousand years ago, the most recent time when Earth's climate was as warm as it is today. In July of 2005, I spent a month at the Bellairs Research Institute of McGill University on the island of Barbados, mapping and sampling fossil corals from the last interglacial period at several locations. January and March of 2006 saw a similar round of fieldwork, sampling fossil coral reefs on the Bahamas Islands of San Salvador and Great Inagua, in collaboration with colleagues at Smith College, Wooster College of Ohio, and the Gerace Research Center in San Salvador, Bahamas. Using my new method, we have dated about a third of the nearly 300 fossil corals collected, using isotope ratios measured at the WHOI Plasma Mass Spectrometry facility.

The results from these three different Caribbean Islands are consistent, suggesting that sea levels during the last interglacial period varied by ten feet over intervals of a few thousand years. Rates of change exceed three feet per century – a significant change on a human timescale. This contrasts sharply with the prevailing view that sea level has remained relatively constant for at least ten thousand years.

The implication of these results is that today's sea level is not such a stable feature of the landscape, and that melting rates of continental ice may be more sensitive to small changes in climate than previously thought. These results have helped to leverage a commitment from the National Science Foundation to continue this work. –Bill Thompson

OCCI-Sponsored Graduate Student Research

Photo by Anne Cohen, WHOI.

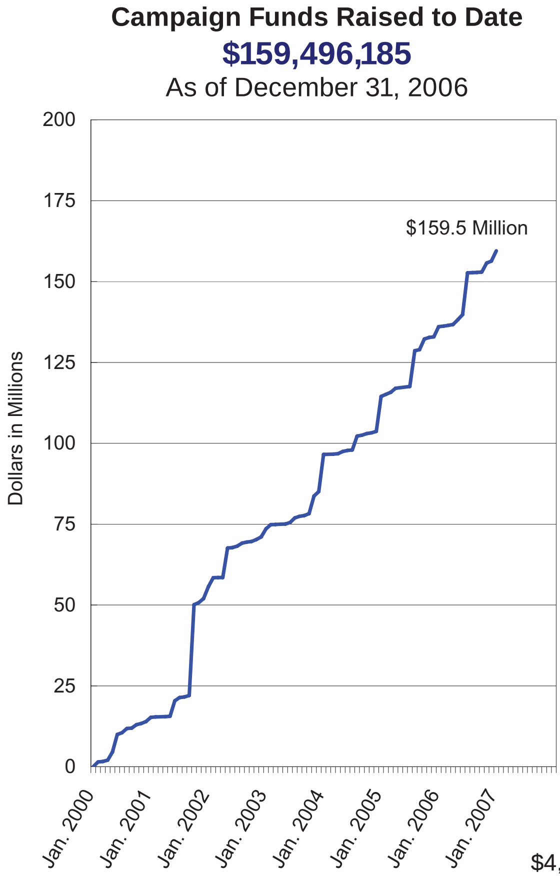
Nathalie Goodkin is a fifth-year graduate student in the MIT/WHOI Joint Program in Oceanography. Advised by WHOI scientists Konrad Hughen and Bill Curry, Nathalie is analyzing corals to understand changes in sea surface temperatures.

Using a two hundred twenty-five-year-old coral from the south shore of Bermuda, Nathalie employs chemical techniques to reconstruct monthly changes in ocean temperatures. Wintertime sea surface temperatures at Bermuda reflect a climate pattern called the North Atlantic Oscillation (NAO). The NAO strongly influences Northern Hemisphere weather, and global warming may be affecting this system. Nathalie and her collaborators are analyzing a long-lived coral that provides a record of the NAO from the Little Ice Age to modern day, allowing them to evaluate variability during both cold and warm periods in the modern era.

Left: Nathalie Goodkin and WHOI Engineer, Peter Landry with a giant brain coral, which has been sliced in half for analysis. Because corals are slow growing over their long life-spans, they provide monthly resolution records over several centuries.

Financial Information

Campaign Progress



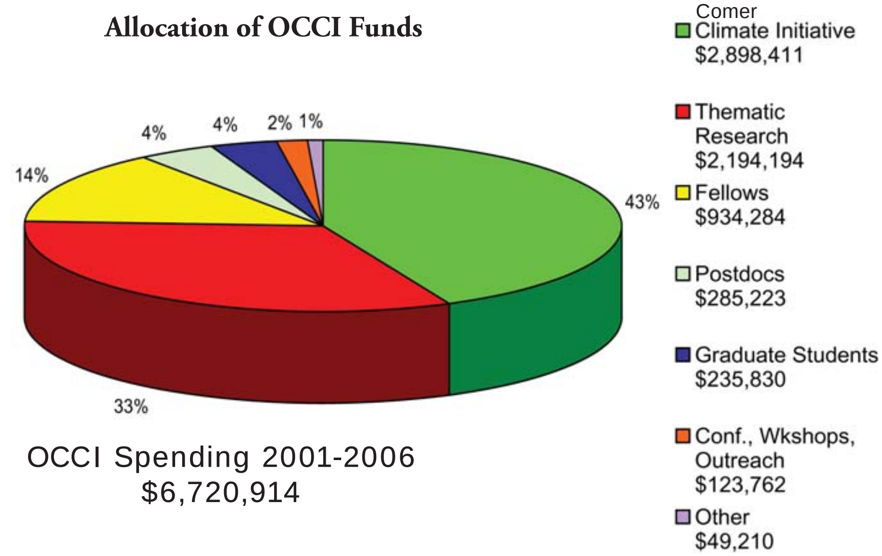
We are pleased to announce that 2006 was the second best year of WHOI's Depth of Leadership campaign.

During 2006, funds raised for the campaign totalled $23.5 million, bringing the cumulative campaign funds raised to $159.5 million. Only in 2001 (when we had a $28 million anonymous gift) were the figures higher.

This success derives primarily from the commitment of WHOI's Board and Corporation members and the dedicated work of the Campaign Committee.

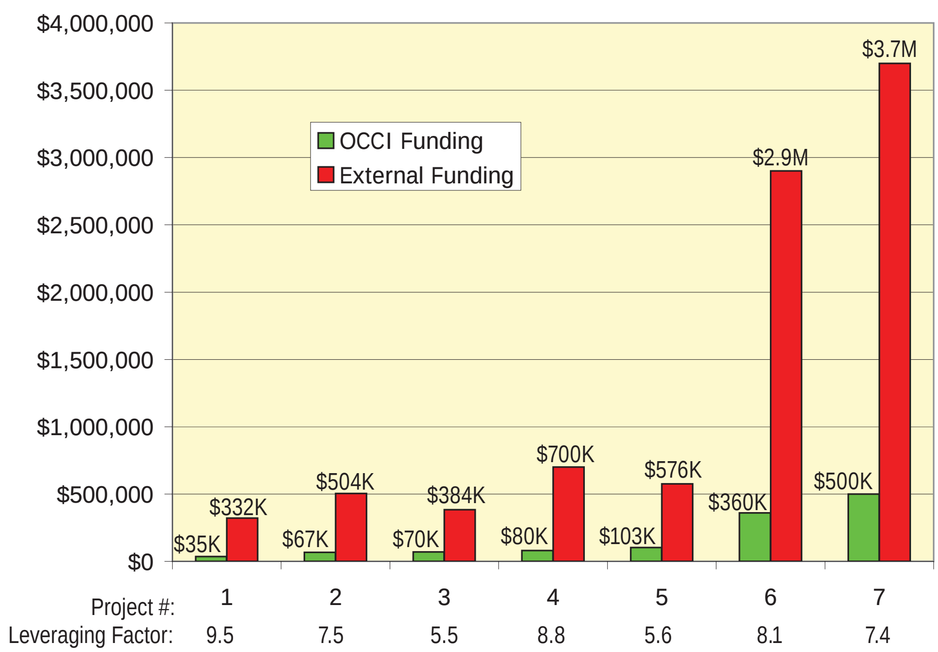
We are deeply grateful to all those who have contributed to the campaign already and look forward to another great year in 2007.

Allocation of OCCI Funds



Over the past six years, the OCCI has supported over sixty research projects, comprising 76% of the budget. In addition, OCCI supported ten research fellows; six postdoctoral scholars; two graduate students; five conferences, forums or workshops; a visiting lecture series; a sundry of small discretionary grants; and funds for outreach and educational projects such as graphic animations and WHOI's Dive and Discover Web site.

OCCI Leveraging



Numerous OCCI-funded projects have leveraged additional federal dollars. The chart above shows a sample set of seven projects that range in OCCI investment from $35K to $500K, bringing in federal grants ranging from $332K to $3.7M. Leveraging factors range from 5.5 to 9.5, with an average leveraging factor of 7.5.