COOPERATIVE AGREEMENT PROPOSAL

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NATIONAL OCEANIC AND ATMOSTPHERIC ADMINISTRATION

From

THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

For the Support of the

COOPERATIVE INSTITUTE FOR CLIMATE AND OCEAN RESEARCH (CICOR)

INSTITUTION:	The Woods Hole Oceanographic Institution
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COOPERATIVE INSTITUTE FOR CLIMATE AND OCEAN RESEARCH (CICOR)

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1 July 2001–30 June 2006

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I. INTRODUCTION

The Woods Hole Oceanographic Institution (WHOI) proposes to continue the association with the National Atmospheric and Oceanic Administration (NOAA) through the Cooperative Institute for Climate and Ocean Research (CICOR). The purpose of CICOR is to provide a unified structure that will facilitate a variety of research and educational programs that can be carried out in collaboration with NOAA. The continuation of CICOR will advance climate and oceanographic research and build links between WHOI and NOAA in a number of ways. First, participation in NOAA research and planning as a Joint Institute significantly enhances the engagement of WHOI scientists with NOAA programs. Second, contact and collaboration between individual WHOI and NOAA scientists will be enhanced through existing and future joint projects and through a Visiting Scientist Program. Third, through collaborative research under CICOR, the Institution's substantial observational and technological research-and-development capabilities will be made available to the NOAA research community. Fourth, CICOR will support graduate and post-graduate positions chosen specifically to enhance scientific collaboration between WHOI and NOAA. This proposal outlines some of the possible research and educational activities that may fall under this cooperative institute.

The primary mission of the WHOI is to advance through research and education the fundamental understanding of oceanographic processes and the interaction of these processes with other components of the Earth system. Hallmarks of Institutional efforts have been the development and deployment of state-of-the-art observational technology in support of analysis and modeling, a rich and diverse expertise in the many facets of the ocean sciences, including marine policy, and excellent collaboration and connectivity to many national and international institutions and programs. The Institution has had long-standing relationships with other research organizations in Woods Hole. These include the Northeast Fisheries Science Center (NEFSC) of the National Marine Fisheries Service and the U.S. Geological Survey. Existing cooperative agreements with both organizations facilitate joint research, as well as sharing computing and research platforms. The Institution, in support of NOAA's mission to describe and predict changes in the earth's environment and to conserve and manage wisely the nation's coastal and marine resources, also participates in NOAA's research initiatives, including the ECOHAB program on harmful algal blooms, the Georges Bank GLOBEC program, and the studies of climate variability supported by the Office of Global Programs. A number of these activities are described later in this proposal. Scientists at the Institution have ties to colleagues and research

activities at other NOAA laboratories, especially GLERL, AOML, ETL, and PMEL, and to sister Joint Institutes, particularly CILER, JIMO, JIMAR, JISAO, and CIMAS.

The activities of CICOR will be organized around three broad themes: Coastal Ocean and Near-Shore Processes; The Ocean's Participation in Climate and Climate Variability; and Marine Ecosystem Processes Analysis. These areas will encompass most of the current collaborations between WHOI and NOAA scientists and other institutional participation in NOAA programs. These theme areas, each of which has significant implications for human society, are interrelated and scientific progress will require collaboration by scientists within and between disciplines. In each case, progress will depend on a combination of fundamental process studies, the development and deployment of technological systems for sustained observation, and the development of predictive models that are based on an understanding of the underlying processes and that assimilate information from observational systems. Integration across the themes provides a basis for consideration of how multiple modes of variability, such as in physical climate, population dynamics, and ocean bottom morphology, combine and interact to be expressed at a point as well as over a region or an ocean basin. CICOR will work to foster this integration in the research done at WHOI and in collaboration with NOAA scientists.

WHOI brings significant strengths to this effort. At present there is considerable discussion about the role of academic institutions in carrying out long-term or sustained observations. Projects under CICOR place WHOI and NOAA investigators in the forefront of our nascent national ocean observing systems, and WHOI's technical expertise and commitment to fieldwork help sustain those projects. As our understanding of the ocean grows, we must use that knowledge effectively by also understanding the social and economic impacts of change and of improved predictability. Scientists in WHOI's Marine Policy program provide the expertise to do so. Communication with the public is essential if we are to realize and demonstrate the value of what we learn. CICOR will sustain outreach efforts to benefit marine science and NOAA's programs.

The scope of the research activities envisioned under CICOR is outlined below for each of the three themes. The continuation of this cooperative institute will provide an opportunity to efficiently and effectively consolidate the technology and scientific expertise necessary to undertake these projects and programs, to effectively partner with NOAA colleagues, and to contribute to the research thrusts of NOAA's Oceanic and Atmospheric Research (OAR) division.

II. RESEARCH THEMES

The WHOI/NOAA Cooperative Institute on Climate and Ocean Research will conduct research that enhances NOAA's mission to describe and predict changes in the Earth's environment and to conserve and manage wisely the Nation's coastal and marine resources. CICOR research activities fall within three Research Themes.

A. COASTAL OCEAN AND NEAR-SHORE PROCESSES

The coastal ocean is a critical region from several perspectives. It is energetic, with the wind, waves, and currents giving rise to coastal and estuarine transports of sediments, nutrients,

contaminants, and species. Air-sea exchanges and aerosol production are enhanced by the waves. At the same time, it is where much of man's impact on the ocean as well as man's interaction with the ocean occurs. We have created dumpsites and introduced contaminants into the coastal ocean, but this is where we also fish and work toward establishing aquaculture.

Research under CICOR on the coastal ocean and near-shore processes is extremely broad, including scientific research on fundamental processes of biology, physical oceanography and sediment and sand transport, as well as the effects of contaminants and the changing environment upon the ecosystems and the habitats for marine mammals, fish and humans. In areas where there is a sufficient understanding of the physical processes to make meaningful predictions of the response to changes in atmospheric forcing, it may now be possible to develop predictive models for the occurrence of Harmful Algal Blooms, the response of the Georges Bank fisheries and other similar phenomena. The common theme in all of this research is that finding the solution to problems requires the bringing together of basic understanding of processes in several fields—an interdisciplinary effort. The development of a predictive capability requires a sustained effort to make meaningful observations of phenomena on scales comparable to the physical variability, and incorporation of the critical data into models. Making these observations on appropriate spatial and temporal scales requires new technology, so there is a substantial focus on developing and exploiting acoustic technology, as well as recent advances in chemical and biological sensors.

One research area that illustrates the breadth of the Coastal and Near-shore research theme is Aquaculture. Aquaculture studies have played a large role in the WHOI Biology Department. Our principal facility for work of this type, the Environmental Systems Laboratory (ESL), was conceived and built as a unique, large-scale marine research laboratory by Dr. John Ryther in 1970. Under Ryther's direction, the laboratory saw about 12 years of large scale basic research on phytoplankton and macroalgae physiology, nutrient dynamics, and trophic energy transfer through marine food chains. Large ponds were used to culture phytoplankton using sewage as a nutrient source, and the phytoplankton supported cultures of shellfish in concrete raceways. In the 1980's, ESL was used by the Howard Hughes Medical Institute for large-scale culturing of biomedically-important invertebrates. During the last decade, researchers at WHOI have used ESL for culturing a variety of species, and for work in marine toxicology, invertebrate and vertebrate physiology and zooplankton ecology. The Shore Laboratory, located near ESL, has also supported aquaculture related work. This included a pilot-scale hatchery for scallops, conducted by a private company, and research on rearing larvae of quahogs. At present most of the aquaculture effort at WHOI is related to culturing bivalve molluscs, but there is considerable research on the basic biology of larval invertebrates and fishes that is very relevant to aquaculture.

Many of the research programs under the coastal theme are currently supported by NOAA and involve substantial collaborations with NOAA scientists, either within focused large international programs, like ECOHAB and GLOBEC, or in one-to-one relationships between NOAA and CICOR researchers. We look forward to enhancing the collaborations within NOAA for research in the coastal ocean and on near-shore processes.

B. THE OCEAN'S PARTICIPATION IN CLIMATE AND CLIMATE VARIABILITY

Beyond the coastal ocean, the broad expanse (close to 70% of the earth's surface) and large potential reservoir of the ocean for heat, freshwater, CO_2, and other constituents dictate that the ocean must be considered as a key element of the climate system. To understand the ocean's role, we need to observe, understand, and model how it stores and transports these constituents and exchanges them with the atmosphere, the land, and the polar regions.

The Arctic Ocean plays a significant role in the global climate system through direct influences on the surface heat budget and the North Atlantic thermohaline circulation, and via links to the atmospheric circulation patterns in the Northern Hemisphere.

Over the past twenty-five years, there has been a growing recognition of the critical role of sub-basin-scale oceanographic processes in the dynamics of the overall climate system. The timescales on which these processes operate and interact range from seasonal to millenial and beyond. Sustained observational studies and process experiments can provide important information about relatively high frequency processes. For information about longer frequency processes, physical oceanographers have turned increasingly to paleoceanographers. This information is needed to understand oceanographic and climate variability on long time scales. The analysis of high-resolution proxy records such as corals, ice cores, and sedimentary records can also be used to bridge the so-called spectral gap between the instrumental climate record and lower resolution geological records.

Potential CICOR projects within this theme include observational programs, process experiments, and modeling. The observational programs can be divided in turn into three types: retrospective analyses, broad-scale surveys, and more narrowly focused observational studies. Retrospective analyses include the development and analysis of proxy records and the application of new methods to the re-analysis of existing data. Broad-scale surveys will use state-of-the-art observational technology to provide high quality spatial time series of multivariate oceanographic and atmospheric measurements; their goal is to characterize an ocean basin. Focused observational studies, which bridge the gap between broad-scale surveys and process experiments, involve concentrated observations of a region of a basin of particular climatic significance. An example is the Tropical Atmosphere Ocean (TAO) observing array currently in place in the Pacific.

Process experiments are also of three types: measurement calibration, model validation, and parameterization experiments. Measurement calibration experiments are used to improve estimates of key quantities. For example, *in-situ* measurements of the air-sea heat exchange can be used to improve the estimation of overall heat flux based on bulk properties by providing regional values of key parameters. Model validation experiments are aimed at assessing the ability of large-scale numerical models to represent key oceanographic processes. Some of these processes are not explicitly resolved in such models and must be incorporated through parameterizations. Parameterization experiments are designed to improve these representations.

Models provide the means to examine the ocean processes involved in climate and climate variability, to assimilate sparse observations in a dynamically consistent way, and to make pre-

dictions about future climate change. Paleoceanographic records have great value as benchmarks for models, and a particular thrust under this theme will be to foster interaction between WHOI paleoceanographers and modelers at GFDL.

C. MARINE ECOSYSTEM PROCESSES ANALYSIS

This theme encompasses a broad range of community and ecosystem level studies, many of which are concerned with the interaction of biological composition and structure with physical, chemical or geological characteristics of the environment. Research on the species composition, trophic structure, and evolutionary history of a variety of marine ecosystems has long been a central strength of the WHOI. In more recent years, there has been greater emphasis on the processes of ecosystem function—fluxes of energy and materials, growth of individuals and populations, competitive and predatory interactions, succession of species and populations. Environments studied have ranged from coastal estuaries and salt marshes to offshore shelf and bank regions, to the oceanic water column, the abyssal sea floor and the hydrothermal vents of ocean ridges.

One area of research under this theme would be fisheries and essential fish habitat. Cooperative efforts in fisheries research have a long history at WHOI, including collaborative agreements with the Northeast Fisheries Sciences Center in support of research, facilities, and infrastructure (library, computer facilities), and many individual contacts and collaborations between scientists. Since the early 1990s, the GLOBEC Northwest Atlantic program on Georges Bank has provided a framework for unprecedented collaboration between WHOI physicists, biologists and engineers and fisheries scientists from NOAA/NMFS and other institutions. WHOI brings expertise in organismal biology, mathematical modeling, physical-biological interactions, sampling techniques, engineering, and economic/policy analysis to bear on current vexing problems in fishery research and management. This should be an especially fruitful area of research within CICOR because of the physical proximity and excellent intellectual connections with the Northeast Fisheries Science Center in Woods Hole, as well as increasing collaboration with NMFS labs in Gloucester, Milford and Sandy Hook.

The National Habitat Program recently established in NMFS represents NOAA's most concerted effort to date to conserve, restore and create essential habitat for a variety of marine and freshwater species of ecological and economic importance. A program of this scope requires new basic research in many areas to understand the natural functioning of habitats, help determine needed restoration, and evaluate results. WHOI scientists have conducted research on the physical and biological nature of various types of habitat, including salt marshes, coastal subtidal regions, and offshore banks and basins such as the Gulf of Maine. While not originally directed toward habitat preservation or restoration efforts, this research provides a great reservoir of information for new collaborative efforts under the National Habitat Program.

Historically, benthic ecology at WHOI has included research in the deep-sea, at hydrothermal vent sites, and in coastal waters of Cape Cod. This is another area of research under the theme of Marine Ecosystem Processes Analysis. Currently we have a strong interdisciplinary interest in larval ecology, with investigators working on aspects of transport, settlement, survival and

metamorphosis of larval stages of benthic organisms from a variety of habitats. Much of this research includes both fieldwork and laboratory studies using the advanced facilities of the Rinehart Coastal Research Center. Since the discovery of hydrothermal vents by WHOI scientists in the 1970s, our biologists have been in the forefront of investigations on the ecology, physiology, life history and evolution of the vent organisms. This continues with research on larval distribution, colonization, community succession and phylogeny. There is also a long history and much current research at WHOI on geology, geophysics and chemistry of hydrothermal vents, and many future biological studies will be interdisciplinary collaborations with researchers in these fields.

Aquatic toxicology, which encompasses investigations concerning the role of natural or man-made substances on the health and survival of organisms, populations and ecosystems in marine and freshwater environments, is another area of research in the Ecosystem theme. It is practical to include pathogenic organisms among these substances since in many cases their effects are due to anthropogenic introduction or disturbance, and the field and laboratory methods to investigate harmful effects from chemical or biological stressors are often similar. Approaches to the study of toxicology include epidemiological studies, ecosystem monitoring, chemical, microbiological, or molecular characterization of stressors, biochemical and molecular analysis of the modes of action of stressors, and possible mechanisms for reversal or remediation of toxic effects. Current aquatic toxicology research areas at WHOI that might be supported by CICOR in the future include: mechanisms of action and induction of biochemical responses, enzyme induction as a monitoring tool, population responses to contamination, and endocrine disruption in seabirds.

Another area included in this theme is Marine Mammal Research. NOAA has the responsibility, under the Endangered Species Act and the Marine Mammal Protection Act, for monitoring populations of marine mammals in U.S. waters, and regulating the adverse impact of human activities upon those mammals. WHOI has strong and broad expertise in marine mammal research, with expertise and interests ranging from the physiology and behavior of individuals to the dynamics of populations. Studies at all of these levels are crucial for many NOAA management priorities including stock assessment, measurement of chemical, acoustic, and nutritional habitat quality, and regulation of incidental mortality from vessel collisions and gear entrapment. Some of the research activities that might be included in CICOR are discussed in the research sections.

III. DISCUSSION OF TASKS

This proposal for the WHOI/NOAA Cooperative Institute on Climate and Ocean Research is organized by Tasks, described below.

TASK I:

This task provides support for the administrative activities of CICOR. As such, support is requested for the Director and staff, post-doctoral scholars associated with research in CICOR, fellowships for graduate students with interests in climate and related studies associated with

research in CICOR and a visiting scientist program to develop and enhance research in CICOR. The budget also includes support for meetings of the CICOR Council of Fellows and the Executive Board, and for various Outreach activities, like the website and newsletters.

The CICOR Post-Doctoral Scholar program is closely associated with the WHOI program. This is a highly competitive program in which the Scholars are selected by an Institution-wide Fellowship Committee from a pool of 100–170 applicants. The ranking is based upon academic records, research promise and relevance of scientific interests to those of the Institution Staff and CICOR research themes. Applicants are solicited through a special advertisement (see Appendix I) but are reviewed as part of the larger Institution process. The CICOR has supported a Postdoctoral Scholar for the past two years.

We propose to further develop the CICOR Visiting Scientist program to enable scientists from other institutions and from NOAA Laboratories to visit and conduct research at the Institution, participating in collaborative programs with CICOR Fellows. This can be particularly helpful in the analysis of data and the incorporation of new techniques or technology into CICOR research programs. The visitors will be selected by the CICOR Director in consultation with the Council of Fellows. Each visitor will stay for approximately 1-2 weeks, and CICOR will provide for travel and living expenses.

TASK II:

The research effort in Task II consists of those proposals and programs that actively involve NOAA scientists as collaborators.

TASK III:

The research efforts in Task III consists of proposals and currently funded programs supported by NOAA through the OAR, OGP, NMFS, and other external funding offices in NOAA, and are therefore directed toward NOAA's strategic goals. We encourage active collaboration with NOAA staff but none is required under this Task.

TASK IV: FACILITIES - MARINE OPERATIONS

Task IV will include proposals for various facilities, such as UNOLS ships, submersibles, and unmanned vehicles that will be used in support of NOAA's mission and cooperative research.

IV. PROPOSED RESEARCH

This section of the proposal describes some of the research projects that could be supported under Tasks II, III, and IV of the CICOR cooperative agreement. They are not meant to be exclusive, but to give a flavor of the sorts of things that could be accomplished under each Theme of CICOR.

TASK II:

Some of the research projects that could be funded under Task II for each of the CICOR Themes are described below. While both Task II and Task III involve research under CICOR's three themes, Task II projects are distinguished by having direct involvement of NOAA scientists in the work. The present and/or possible future NOAA partners are listed in brackets after the WHOI investigators involved in each project.

A. COASTAL AND NEAR-SHORE PROCESSES

1. Estuarine and Coastal Transport Mechanisms and Models—*Rocky Geyer and John Trowbridge [Tom Gross (NOAA/NOS)]*

The protection and management of coastal and estuarine resources requires understanding and prediction of physical transport processes. Eutrophication, hypoxia, harmful algal blooms and contaminant transport are all strongly influenced by the physical transport and mixing processes in coastal environments. Three-dimensional models are now capable of simulating many of the hydrodynamic and ecological processes, and increasingly complex models are being relied upon as management tools. Yet there are key physical processes that are not adequately understood or parameterized in models, on which the model predictions and management decisions may sensitively depend. Bottom stress, vertical mixing and horizontal dispersion are particularly important processes with respect to water quality, sediment and contaminant transport modeling, yet these are some of the most difficult processes to simulate in numerical models. WHOI's coastal oceanographers have made considerable progress in understanding the underlying physical processes, and the focus is beginning to shift toward their influence on water quality, sediment and contaminant transport, and harmful algal blooms.

We propose an interdisciplinary program of field observations and modeling to address the rates of vertical mixing and horizontal dispersion in estuarine and near-shore coastal environments, with particular attention to the factors influencing the transport and fate of sediment, organic carbon, and other biogeochemical fluxes. The field effort will include estuarine and coastal environments in the U.S. northeast, selected for logistical, scientific and programmatic considerations. Potential sites include the New York Bight and Hudson River estuary, the New Jersey inner shelf, and the continental shelf south of Cape Cod. The research plan would include new approaches to resolving bottom stress and turbulent mixing, using high-resolution acoustic velocimeters and microstructure sensors as well as conventional moored instrumentation. Additional measurements related to sediment transport and biogeochemical transport processes will be incorporated into the field effort as appropriate for the different efforts. The principal objective of the field studies will be to quantify vertical, turbulent fluxes and horizontal dispersion in coastal and estuarine environments, and then to develop and refine the parameterizations of these fluxes for inclusion into numerical models.

The numerical modeling component of this program will pursue a rigorous examination of turbulence closure as well as sub-gridscale transport parameterizations, using the observational sites as test-beds. The general approach will be to develop 3-dimensional, limited domain models that represent the important transport mechanisms at the field sites. The emphasis of the

modeling will be on quantifying the transport processes. The modeling will be coordinated with ongoing predictive modeling efforts by NOAA at various scales, from the estuarine scales exemplified by the PORTS models to the regional modeling efforts such as the East Coast Ocean Forecast System (ECOFS).

2. **Coastal Physical Observational Methods and Sustained Measurements—***Bob Beardsley, Ken Brink, Jim Irish, Steve Lentz, Dick Limeburner [David Mountain, Michael Fogarty, Michael Sissenwine (NMFS/NEFSC)]*

One of the main objectives of the ongoing Georges Bank GLOBEC effort is to gain a sufficient understanding of the system to allow us to define a compact set of measurements that will expedite improved long-term assessments of the state of the biological system. For example, we anticipate, based on results now being analyzed, that the timing of the onset of stratification in spring will provide useful input for estimating that year's biological productivity. We propose to build on GLOBEC results (the Georges Bank field program ends in 1999) to define what physical and biological long-term measurements will provide the most impact for predicting recruitment, and at the most reasonable cost. For both of the seagoing components below, the first order of business will be to work together with NOAA NMFS personnel and other GLOBEC investigators (including biological oceanographers and numerical modelers) to define the critical long-term measurements. We will then begin to implement these programs (again, in cooperation with NOAA Northeast Fisheries Center personnel). In order to maintain continuity, we will put in place a provisional long-term effort, with the understanding that it could be modified in the first few years due to improved insights from a deeper analysis of the GLOBEC data. Further, we anticipate that the measurements made here could have a substantial benefit for other NOAA activities, such as the ongoing Coastal Ocean Prediction efforts (NOS) and for Coastal Hazards efforts.

Moored Measurements: Recent improvements in moored instrumentation (to measure atmospheric and oceanographic variables) and mooring design allow the efficient collection of *in-situ* data to describe the coastal environment on long time scales.

In particular, we seek to implement a new moored capability to measure accurately, routinely and over 6-month periods all parameters needed to estimate the surface wind stress and heat flux, and ocean properties such as currents, temperature, conductivity (salinity), fluorescence, beam transmission, and up-and down-welling light. This long-term measurement program will focus on the ocean environment and its variability, and will complement the existing NOAA network of moored environmental buoys, which at present focus only on collecting surface weather data.

A better knowledge of the surface forcing and the coastal ocean response is needed to help understand observed fluctuations in the ecosystem (e.g., interannual variations in the coastal ocean water properties, especially temperature and salinity, primary and secondary production, commercial fisheries) and predict future changes in the ecosystem. While the environmental information to be collected through this sustained measurement effort will clearly benefit basic research on processes important to the local ecosystem, these data will be of immediate use as input into coastal ocean prediction programs now being developed by NOAA (NOS) and other agencies.

We tentatively propose a three-phase program for sustained physical measurements in the northeast U.S. shelf region (Mid-Atlantic Bight/Georges Bank/Gulf of Maine). First, add sensors to existing NDBC environmental buoys to measure the full suite of air-sea variables needed to estimate the surface wind stress and heat flux components. Second, deploy oceanographic instrumentation at these sites to provide water column profile measurements of currents and key water properties. Third, augment this array with additional combined meteorological/ oceanographic moorings to obtain an along-isobath array that spans the outer stretch of this shelf region. In all phases, this work will be done in collaboration with NOAA scientists interested in sustained coastal measurements in this shelf region. This plan is, of course, subject to some modification in response to a more detailed understanding of GLOBEC results.

Historical Analysis: We have found that the historical record is patchy. Often, for example, a biological record will exist, but that a physical record needed for interpretation either does not exist, or is not available. We thus propose to work with NOAA scientists to identify and put into modern digital format existing long multi-year time series of key ocean variables which would contribute to any study of interannual and decadal variability in the coastal ocean. Examples of existing data sets still in only hand-written format include meteorological and oceanic measurements taken between 1956 and 1972 from the lightships, e.g., Georges Bank Tower, Nantucket, and Ambrose. As scientific and public interest in coastal ocean climate and its impact on fisheries, etc., increases, we need to find these existing unique data sets and convert them into useful formats.

Lagrangian Observations: As part of the U.S. GLOBEC Northwest Atlantic/Georges Bank program, satellite-tracked drifters have been released over Georges Bank in an effort to examine the near-surface flow in this shelf region, and in particular to study the flow of water onto, off of and around Georges Bank. These drifters utilize ARGOS for tracking, typically obtaining 4-6 fixes per day with an accuracy of ±1 km per fix. The drifters eventually exit the shelf to the southwest and enter the slope water where their trajectory data are incorporated into the WOCE Atlantic drifter data archive. Recent improvements in drifter design, specifically the addition of GPS tracking, yielding hourly fixes with an accuracy of $<\pm 50$ m, allow resolution of tidal currents and related phenomena.

We propose to continue the deployment of drifters over Georges Bank using the new GPS-tracked drifters. The primary objective of this effort is to observe the Lagrangian flow over the bank during the January-July period critical for larval fish (cod and haddock) survival. These new measurements, when combined with the 1995-1999 Lagrangian drifter data being collected in U.S. GLOBEC, will provide a key long-term time series to be used to identify and understand interannual variability in the physical environment and its impact on the recruitment of key fish populations on the Bank.

3. **Energy and Momentum Transfer in the Coastal Zone—***Jim Edson, Wade McGillis and John Trowbridge [James Wilczak And Chris Fairall (NOAA/ETL)]*

Oceanographers and meteorologists have long relied on simple models of shear-induced momentum transports. However, there is an ever-increasing amount of evidence that the structure of the near surface atmospheric turbulence and the mechanism of momentum transfer are

significantly modified by the presence of surface waves and change rapidly with height. Unfortunately, despite many past experimental and theoretical studies, we have not been able to explain this wind-wave coupling mechanism to a satisfactory level. Most studies have also failed to properly include the effect of wind variability and to properly account for differences between the mean wind direction and the propagating wave field. This is particularly true in regions where the wind-wave or swell field is diffracted in coastal waters (i.e., shoaling). Beneath the air-sea interface, large-scale coherent structures generated through wave-current interaction and small-scale intermittent turbulence generated by wave-breaking also invalidate these simple momentum transport models. These simple models also fail in the bottom boundary layer due to, e.g., the oscillating flow. These wave-induced processes are clearly interrelated such that the momentum transport across the air-sea interface and through the water column is a strongly coupled process.

The main objectives of this proposal are to improve our understanding of the detailed mechanism of momentum and energy flux from wind to surface waves (from largest swells to short wind waves of order 10 cm) in coastal areas, to study turbulent energy and momentum transfer from surface waves to near-surface currents, and to investigate how the energy dissipation at the bottom can influence the evolution of surface waves. We propose to accomplish these objectives by deploying a vertical array of instruments that spans both sides of the air-sea interface. These instruments would provide detailed information on the mean, wave induced, and turbulent motions on both sides; as well as the wave field itself. We would also attempt to quantify the horizontal variability of the wave field (i.e., to estimate the radiation stress divergence) using a spatial array of pressure sensors. Collocation allows us to address the complete vertical coupling mechanism in the air-surface-water-bottom system without relying on traditional statistical parameterization of these processes.

4. **An Investigation of Coastal Marine Aerosols—***Jim Edson and Wade McGillis [Fairall and Grund* (NOAA/ETL); *Katsaros* (NOAA/AOML)*]*

The generation, evolution, and transport of aerosols through the coastal atmospheric boundary layer is an unexplored subject. The generation of sea salt aerosols results in a droplet boundary layer that directly influences the near surface energy budget, the optical properties of the near-shore region (e.g., through the generation of marine haze), and its chemical composition. The processes that form a droplet boundary layer can be broken down into three major components: (1) the production of spray at the sea surface as film, jet, splash, and spume droplets; (2) their transport through the ABL by turbulence and advection; and (3) their interaction with the scalar fields and consequent evaporation or condensation.

The effects of inhomogeneity and enhanced production in and adjacent to the surf zone on these processes require new measurement and modeling technologies to explain. To meet this requirement we have recently developed higher-order closure models that, for the first time, are able to characterize droplet evolution and transport in such flows. These models can now be extended to account for the inhomogeneous boundary conditions found in coastal areas. Additionally, new fast-pulse scanning Doppler lidars developed by NOAA/ETL permits determining the two-dimensional flow with the necessary temporal and spatial resolution for this problem.

We propose a field/modeling program around these existing tools to provide the necessary measurements to improve our understanding of the fundamental physics and the effects these droplets have on the energy budget and optical properties. The measurements made during the field experiment will be used to specify boundary conditions in 2-D 2nd~order closure numerical models that include droplet dynamics. These boundary conditions include the droplet source function, oceanic and land surface properties, and the mean and turbulence profiles at the entrance and outflow regions. Our higher order closure models would then be run to obtain the 2-D flow field and predictions of the internal boundary layers. These results would then be compared with measurements to evaluate model performance in predicting the momentum, thermal, and droplet boundary layers. The results from these evaluations will be used to test existing IBL parameterizations, dry deposition models, and equations describing sea spray evaporation.

5. **Harmful Algal Blooms—***Don Anderson [Gregory Doucette, Patricia Tester (NOAA/NOS), Kevin Sellner (NOAA/COP)]*

Over the last several decades, the United States has experienced an escalating and worrisome trend in the incidence of problems associated with harmful and toxic algae. Impacts include mass mortalities of wild and fanned fish and shellfish, human illness and death from contaminated shellfish or fish, death of marine mammals, seabirds, and other animals, and alteration of marine habitats or trophic structure. Formerly only a few regions were affected by harmful algal blooms (HABs) in scattered locations, but now virtually every coastal state is threatened, in many cases over large geographic areas and by more than one harmful or toxic species (Anderson, 1995). It is still a matter of debate as to the causes behind this expansion, with possible explanations ranging from natural mechanisms of species dispersal to a host of human-related phenomena such as nutrient enrichment, climatic shifts, or transport of algal species via ship ballast water (Anderson, 1989; Smayda, 1989; Hallegraeff, 1993). Whatever the reasons, virtually all coastal regions of the United States are now subject to an unprecedented variety and frequency of HAB events. The United States is not alone in this respect, as nations throughout the world are faced with a bewildering array of toxic or harmful species and impacts and disturbing trends of increasing incidence.

HABs are highly visible and important coastal problems with many oceanographic, ecological, and meteorological linkages that fit perfectly within NOAA's mission. Ecosystem and fisheries impacts from HABs are significant, and considerable national and international effort is needed to address the issues. Through CICOR, ongoing and future activities will be supported that fall into the general categories of observation, modeling and prediction, technology development, and societal impacts.

Planned Future Research:

U.S. National Office for Marine Biotoxins and Harmful Algal Blooms. The activities of the National Office have expanded in parallel with the interest of NOAA, congress, the public, and the media. With ECOHAB and other interagency NAB initiatives underway in the U.S., and new NAB programs being implemented internationally, it is clear that the National Office will remain an important resource for the duration of this CICOR proposal and beyond. Nationally, the need to communicate the science of HABs to various constituencies will continue, and this

involves frequent participation at workshops, conferences, and symposia. Support is also needed to maintain and update a heavily used WWW home page on HABs. This web page will be expanded considerably now that it has been shown to be an effective outreach tool. New items of international interest include ongoing efforts to design and implement an international ECOHAB program, working with SCQR, the IOC, and several agencies such as NSF, NASA, and NOAA COP, as well as an APEC program designed to bring 21 Pacific-rim countries (including the U.S.) into full agreement on regulations and standard methods for monitoring and analysis of seafood contaminated by NAB toxins. Working group activities within ICES, IOC, WESTPAC, TAT and SCOR will continue as well. Funds for the National Office are provided by the NMFS (now NOS) Southeast Fisheries Science Center in Charleston SC and from the NOAA Coastal Ocean Program, and the Biological Oceanography Program at NSF. The original grant and subsequent renewals have been processed through NSF, even though the bulk of the funds come from NOAA programs. This represents a situation where funding logistics would be greatly facilitated through the CICOR Joint Institute.

Rapid Response. All too frequently, areas of the U.S. with no prior history of toxicity will unexpectedly experience blooms of new or known harmful algal species. The outbreak of *Pfiesteria-like* organisms in Chesapeake Bay in 1997 is one example. The resulting confusion and misinformation often results in unnecessary economic losses and inadequate documentation of the environmental conditions prevailing at the time. The need for a national rapid response capability is clear, but this is difficult to arrange financially or logistically given the variability in space and time inherent in HAB phenomena. Funds need to be freely available for distribution to teams of experts who can converge on a site as soon as possible after notification. This is typically not possible with government agencies, but could be facilitated through the National Office and the Joint Institute, both in the selection and coordination of national experts and in the transfer of funds to the rapid response teams.

North Atlantic Oscillation and HABs. This year, "El Niño" demonstrated the far-reaching effects of mesoscale meteorological and oceanographic phenomena. In the northeast, a similar atmospheric forcing called the North Atlantic Oscillation (NAO) has been identified which also affects many physical and biological phenomena over a wide region. In this project element, WHOI scientists will explore the potential linkages between the NAO and patterns of shellfish toxicity caused by certain HAB species. Red tides have caused toxic outbreaks for many years throughout the U.S. and Canada, and long-term datasets exist which go back 40-50 years. In Western Europe, records are available of shellfish toxicity over the last 20 years. In some of these areas, toxicity varies dramatically, sometimes in a cyclical pattern. Since HABs are controlled by a variety of oceanographic and atmospheric variables, including temperature, rainfall, wind, and sunlight, we hypothesize that the interannual variations in toxicity relate to large-scale forcings such as those associated with the NAO. To explore this, data will be collected from agencies that monitor shellfish toxicity in both North America and Europe. The data will then be analyzed for relationships with the NAO index. From a policy standpoint, there is great potential for developing an understanding of these phenomena and a predictive capability that have far-reaching benefits to the fisheries industry and to the general public.

HAB Bloom Dynamics and Coastal Processes. This program element consists of the ECOHAB-GOM project, funded by NOAA COP and NSF. That project will investigate *Alexan-*

drium bloom dynamics in two major regions of the Gulf of Maine - one dominated by a buoyant plume of riverine water, and the other by a high salinity coastal current accompanied by large tidal forcings. The project is funded for 5 years, beginning in 1997, and will involve 14 investigators from 9 institutions. There are many opportunities for NOAA scientists to work on this project, and such collaborations would be facilitated by the existence of CICOR.

Management, Mitigation, and Control. For all natural disasters, detection and prediction are essential if the impacts from the phenomena are to be minimized. This is true for HABs as well, and as a result, numerous monitoring programs have been established in U. S. coastal waters in an effort to provide either advance warning of outbreaks or to delineate areas that require harvest restrictions. This monitoring is conducted for both NAB species and for their toxins. The latter has become quite expensive in recent times due to the proliferation of toxins and the number of potentially affected resources. There is thus an urgent need to improve monitoring procedures, especially through the development of new assay technologies that can reduce costs and increase throughput. Several NOAA laboratories, such as the NOS facility in Charleston SC, are actively involved in a new class of assays that are a very effective alternative to the chemical and animal-based tests now in use. At WHOI, molecular probes are being developed which can "tag" an HAB species exclusively, rendering it easily visible under the microscope and potentially detectable in an automated assay. The current state of the art is that there are numerous probes under development for a wide array of NAB species, but field applications of this new technology are few. Work is needed to test and validate these new tools.

Another management tool that requires further development for HABs is satellite remote sensing. Remote sensing has great potential as a tool to assist in monitoring the development and movement of HAB phenomena over larger spatial and shorter time scales than those accessible through ship-based sampling. Thus far, it has not been fully utilized in this regard. The NOAA Coast Watch Program is actively involved in attempts to detect and track red tides, and WHOI scientists have applied this technology in field programs as well. This is clearly an area where interactions and collaborations between WHOI and NOAA will be frequent.

In an offshoot of remote sensing technology, automated buoys will someday be searching for HAB cells or their toxins while simultaneously measuring the physical and optical characteristics of the water column to provide the complementary information needed to make "algal forecasts" of impending toxicity. The expertise in NOAA laboratories, combined with the skills in biology and engineering at WHOI can bring us one step closer to this vision.

A final element under this category involves efforts to directly manipulate algal blooms - to destroy or remove the cells before they can cause harm. This is an area of HAB science that has received little attention thus far (Anderson, 1997), but it is an important avenue to pursue. A variety of potential control strategies have promise, such as biological control using natural parasites, viruses, or bacteria, or even flocculation of bloom organisms using clay. WHOI is exploring these controversial but important issues in several ways. Biologist Dave Caron is investigating the potential of protozoan grazers as control agents for brown tide blooms, and Don Anderson is using clay to scavenge HAB cells from the water column. NOAA's responsibilities as steward of the oceans suggests that it will soon become involved in HAB mitigation and control projects, and a number of those can be conducted through WHOI laboratories.

Modeling and Prediction: The prediction of HAB outbreaks will require models, which account for both the growth and behavior of the toxic algal species, as well as the movement and dynamics of the surrounding water. However, large-scale models of NAB population dynamics are at a very early stage of development. The growth and accumulation of individual harmful algal species in a mixed planktonic assemblage are exceedingly complex processes involving an array of chemical, physical, and biological interactions. Our level of knowledge about each of the many HAB species varies significantly, and even the best-studied remain poorly characterized with respect to bloom or population dynamics. The end result is that despite the proven utility of models in many oceanographic disciplines, there are no predictive models of population development, transport, and toxin accumulation for any of the major harmful algal species in the United States. Several are under development, including one in the ECOHAB-GOM program described above, but there is thus a clear need to increase efforts to formulate realistic physical models for regions subject to HAB events, and to incorporate biological behavior and population dynamics into those simulations.

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B. THE OCEAN'S PARTICIPATION IN CLIMATE AND CLIMATE VARIABILITY

1. Eulerian Observatories in GOOS (Global Ocean Observing System)—*Bob Weller, John Toole, Nelson Hogg, Mike McCartney, [McPhaden and Cronin (PMEL), Molinari (AOML)]*

The fluxes of heat, freshwater, and momentum across the sea surface determine the circulation and property distributions of the oceans. In turn, those same fluxes are the means by which the ocean introduces variability into the atmosphere. Both fluids also transport heat and freshwater. However, the ocean, with its large heat capacity, dominates the ocean-atmosphere heat storage and has tremendous potential to introduce variability into the atmosphere. In order to understand the role of the ocean in climate we need to have accurate measures of the exchanges across the air-sea interface, of the evolution of ocean properties in response to the surface forcing, and the oceanic transports of heat and freshwater. To make a major contribution

to achieving these goals, we propose a network of Eulerian observatories as part of the Global Ocean Observing System (GOOS). At sites selected by their importance in identified or hypothesized climate phenomenon these observatories will provide long-term measurements of the air-sea fluxes and of the vertical structure of ocean temperature, salinity, and velocity. Recent technological advances have given us the capability to make accurate surface flux measurements and to cost-effectively collect temperature, salinity, and velocity over the entire water column. With these observatories we will collect the time series in diverse and data sparse environments needed as anchor sites for accurate global air-sea flux fields, to observe change in the ocean's interior, and to quantify oceanic transports. The work to be done includes installation and maintenance of the observatories, further development of the technology, establishment of collaborations to sustain these observatories, and analysis and archiving of the data collected from them.

2. **Measuring The Labrador Sea Water (LSW) Transient In The Subtropical/Tropical North Atlantic—***Mike McCartney, Ruth Curry [R. Fine (RSMAS), T. Chereskin (SIO); R. Molinari (AOML)]*

The time series of hydrography at station S near Bermuda and station B in the Labrador Basin has revealed a 6-year time-lagged arrival of water mass variability signals generated in the Labrador Basin at the base of the subtropical gyre's thermocline (Curry, McCartney and Joyce, 1998). These signals are generated by the accumulated impact of decadal variability of the warm to cold-water transformation of the upper limb of the thermohaline overturning circulation. That circulation is responsible for the delivery of over 1 petawatt of heat to the atmosphere above the subtropical and subpolar North Atlantic. The southward flowing cold limb of that same overturning circulation thus is observed as feeding back to alter the stratification in the intermediate depth range of the Gulf Stream in about 6 years. We have additional evidence showing that off Abaco the delay is somewhat longer, about 10 years (Molinari et al., 1998). The time delays are for the most part revealed through relatively small amplitude "wiggles" of water mass properties being lag-correlated. Comparisons of these data and the basin scale data sets of the WOCE program reveal that we are in the midst of a much larger "main event" in this history of variability. The relatively high NAO index of the past 25 years culminated 1988–1995 in extremely high index states—the highest in a 140+ year record. The associated atmospheric forcing anomalies created a very cold and dense variety of Labrador Sea Water, which is flushing through the cold limb of the thermohaline overturning circulation with time delays similar to what is mentioned above. Its arrival in the Gulf Stream region may be linked to the very strong baroclinic transport of that current in the early-mid 1990's. Its arrival at Bermuda has reversed the preceding extended period of warning at mid-depth, a warming that sometimes has been included with evidence of global warming. Our previous work indicates the geography we can expect for the continuation of the western intensified southward invasion of LSW.

We propose to mount an expedition to the area of the southwestern subtropical and tropical North Atlantic where the southern edge of the LSW invasion will likely be towards the end of the century. This continues the documentation of the extraordinary thermohaline anomaly, particularly focusing of the evolving potential vorticity distribution and its feedbacks to thermocline circulation.

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3. **Atmosphere—Ocean Coupling In The Eastern Tropical Pacific—***Bob Weller [D. Rogers (SIO/CORC), M McPhaden, M Cronin and W Kessler (NOAA/PMEL), and R. Wiesberg (USF)]*

Anomalous sea surface temperatures in the eastern tropical Pacific have, as evidenced by the present El Niño, the ability to perturb the atmosphere and alter weather and climate in remote locations, including North and South America. One of the strongest, regular features of the sea surface temperature field in this region is the annual appearance of cool water extending out from the west coast of South America westward along and south of the equator. The difficulties we have at present in simulating the annual evolution of this cold tongue in state-of-the-art coupled ocean-atmosphere models suggest that we have not yet achieved a good understanding of atmosphere-ocean coupling in the eastern tropical Pacific. Further, the coupled models exhibit considerable sensitivity to changes in the parameterization of the stratus deck region. Thus, we have concern that we do not yet have the basic understanding of the coupled ocean-atmosphere system in the eastern tropical Pacific required for development of the capability to make reliable seasonal to interannual predictions of both this region and of the remote regions influenced by its variability. Several coordinated studies will address these concerns in the next few years included PACS (Pan American Climate Studies), VAMOS (Variability of American Monsoon System), BECS (Basin Extended Climate Study), EPOCS (Eastern Pacific Oceanography Climate Study). We plan to participate in these programs by fielding surface and subsurface moorings in the eastern Pacific between 125°W and 80°W and off the coasts of Peru and Chili to observe the air-sea interaction and upper ocean variability. In addition, we would collaborate with PMEL to provide IMET sensors for enhanced monitoring on the TAO moorings and by supporting VOS observations in this region.

4. **Surface Flux Parameterizations And Air-Sea Interaction Process Studies—***Bob Weller, Jim Edson [J. M Hemsely* (NOAA/NDBC), *M McPhadden* (NOAA/PMEL) *and M Cronin* (NOAA)]

An accurate description of the exchange of momentum, heat, fresh water and gasses at the air-sea interface is essential to further our understanding of the coupled atmosphere-ocean system. In order to improve the predictability and modeling of both regional and global processes, we propose to identify and address physical processes in the coupled marine boundary layer that are poorly sampled, understood or parameterized. A regional example would be the coastal ocean response to hurricanes. As large winds interact with a fetch limited wave field, the exchange of momentum across the sea surface is uncertain and surface drag and moisture exchange coefficients are not validated. Examples of climate processes include: (1) global warming due to greenhouse gasses, where the air-sea gas flux parameterizations play an

important role but have not been validated over a broad range for forcing conditions, and (2) El Niño, where the surface heat and moisture fluxes play a key role in setting large scale atmosphere and ocean circulations but still have large uncertainties. We would design and carry out air-sea interaction field study experiments that would be focused on observing these and other specific processes and quantifying the exchanges between and variability in the atmospheric and oceanic boundary layers. The goal is to address specific processes that may have a large impact on predictability and improve our understanding and parameterization of these processes. The work to be completed includes deployment of air-sea interaction buoys, supplementing existing observing buoys and ships with IMET sensors to provide complete flux observations in poorly sampled regions, developing new technologies to improve our measurement capabilities and shipboard work for observations that can not be made remotely.

5. **Monitoring the Thermal And Salinity Fields of the Tropical North Atlantic—***Ray Schmitt [R. Molinari (AOML)]*

An array of ~120 profiling floats is proposed for the tropical North Atlantic (3-21°N). These floats would report temperature and salinity profiles to 1500 m depth and provide a measure of horizontal velocity from their observed displacements. The floats would have a 10-day cycle time and an expected life of 3 years, thus ~40 floats per year would be deployed. The array would meet the sampling requirements for the Array for Real Time Geostrophy (ARGO), thus providing information on the baroclinic velocity structure to complement the barotropic information derived from satellite altimetry. A special focus for this array would be on the upper ocean heat and fresh water budgets. The very intense hydrologic cycle of the tropics provides strong signals in the salinity field that will be used to develop quantitative estimates of the fresh water fluxes for comparison with climatological, forecasting and satellite-based flux estimates. River runoff will be incorporated into the analysis as well. The data will be quality controlled and made available in near-real time, for use in weather and climate forecasting.

6. **Propagation Of Climate Signals By The DWBC—***Bob Pickart [Molinari and Johns (NOAA)]*

This is a three-year analysis effort using historical hydrography along the western boundary of the North and South Atlantic. In phase I, we essentially collect every hydrographic (Bottle and CTD) section ever taken across the DWBC, from the Denmark Strait to the Antarctic Circumpolar Current. This includes temperature, salinity, oxygen, and (where available) CFC data. In phase II, all of these sections are re-gridded onto a standard coordinate system in which the ordinate is depth (or density) and the abscissa is bottom depth. This allows every section to be put on the same grid, removing problems otherwise arising from varying bottom slope or lateral orientation of sections (note that stations on ridges need to be omitted). Mean lateral maps and vertical sections will be constructed to investigate the alongstream evolution and pathway of the DWBC. In phase III, EOF analyses will be performed to reveal the dominant inter-annual and decadal variability, including complex EOFs to investigate propagation of climate signals. The different layers and water-mass constituents of the DWBC will be considered. We envision this study as providing important information on the role of the MOC's deep limb in the climate system, including pathways, time-scales, and modification of water-masses. It will also shed light on the impact of the equator on the progression of waters in the MOC.

7. **Joint Air-Sea Monsoon Investigation—***Bob Weller, Jim Edson, [C. Fairall (NOAA/ETL), M. McPhaden and M. Cronin (PMEL)]*

The tropical eastern Indian Ocean is characterized by some of the warmest sea surface temperatures and strongest atmospheric convection found on earth. Air-sea exchanges of heat and freshwater there play a critical role in driving the Austral-Asian Monsoon and in introducing interannual variability into that system. However, the eastern tropical Indian Ocean is such a data sparse region that we have only very limited knowledge of the air-sea fluxes in that region. Thus there is little basis for describing, understanding, and appropriately modeling the processes that couple oceanic and atmospheric variability in that region. We propose to deploy surface moorings and participate in cruises in the eastern tropical Indian Ocean to obtain accurate estimates of the air-sea fluxes and to make coincident observations of the variability of the upper ocean. This would be done during the cooperative Joint Air-Sea Monsoon Investigation () and in collaboration with NOAA/ETL and NOAA/PMEL.

8. **Eastern Boundary Current Transport Into The Labrador Sea—***Bob Pickart [R. Molinari and E. Johns* (NOAA)*]*

The combination of the West Greenland and Irminger Currents represents the upper-layer "rim-current" system that enters the Labrador Sea. As a source of fresh and salty water, respectively, these currents play a major role in the convection cycle of the Labrador Sea on a variety of time scales, from seasonal to decadal. Yet their transports have not been quantified by direct measurement. We would propose to measure the boundary current inflow into the Labrador Sea using a moored array that extends from the shelfbreak to the deep slope. A two-year array will determine the mean and seasonally varying components, and provide the beginnings of an interannual monitoring program. The West Greenland Current is a source of the low-salinity cap over the Labrador Sea, which tends to inhibit convection, yet provides a source of fresh water to the LSW when convection does occur. The salty Irminger water, advected around the perimeter of the Labrador Sea, also impacts convection, particularly near the boundary. It is important to determine the flux of these water masses into the Labrador Sea, including detection of climate anomalies, and hence help quantify the impact of the wind-driven circulation on the convection process.

The moored array will consist of upward-looking ADCPs at the shallowest level, and conventional VACMs on the slope. Temperature/Salinity sensors will be included at all depths above 1200 m to measure the freshwater flux. A two-year array is proposed, with a mid-deployment turnaround; all cruises will be staged from St. Johns, Newfoundland and will include hydrography. The overall program is three years in duration, with the final year designated for analysis (some subset of the instrumentation may be left in the water for longer term monitoring).

9. Developing A Collaboration Between The WHOI Paleoceanography Group and The NOAA/Geophysical Fluid Dynamics Laboratory (GFDL)—*Delia Oppo [Tony Broccoli and Isaac Held* (NOAA/GFDL)*]*

As part of CICOR, we propose to develop formal interactions between the WHOI Paleoceanography Group and the NOAA/GFDL (Princeton University) to collaborate on modeling experiments of mutual interest. Our first theme is to explore, on both orbital and millennial times scales, the influence of extratropical climate on tropical climate on the one hand, and the influence of tropical climate on extra-tropical climate, on the other hand. Improvements in coupled ocean-atmosphere general circulation models (OAGCMs) are on the horizon. These improvements will make the models much more suitable for addressing issues related to climate variability, both past and future. Thus, this is the time to begin a dialogue with modelers about the kinds of experiments that would help us test hypotheses we have developed from the geologic records.

10. Carbon Cycle And Gas Exchange—*Nelson Frew [R. Feely and R. Wanninkhof (NOAA)]*

The Earth's climate system is highly complex and human impact on the climate is even more complex. Global warming is one of the important issues today. The oceans play an important role in regulating the earth's climate by continuously exchanging heat and greenhouse gases with the atmosphere. The ocean's capacity for CO_2 is not only regulated by air-sea interactions, but also by the complex interactions of ocean circulation dynamics and biological activities in the upper water column. Over the past few years, many studies have further demonstrated the important role of the organic carbon in the oceanic carbon cycle. The results suggest that transport of carbon in the dissolved organic form is a significant process (Carlson et al., 1994; Guo et al., 1995).

The atmosphere/ocean interface is one of the largest and most important interfaces on earth. Exchange of heat and gases across the atmosphere/ocean interface regulates our climate. These exchange processes, operating over a range of time scales, also significantly affect the ocean's carbon cycle. Seasonal weather patterns affect the physical structure of the upper ocean and upper ocean mixing, which regulates the supply of nutrients into the euphotic zone and primary production (Aebischer et al., 1990). Large-scale atmospheric systems such as ENSO and the NAO affect the mean state of the atmosphere-ocean climate system on annual to multiyear time-scales and also affect the frequency and magnitude of regional and short-lived atmospheric fluctuations such as storms and hurricanes (Dickson et al., 1996). The interactions among these processes on different time-scales—episodic, seasonal, interannual—is poorly understood in terms of the effects on ocean biogeochemistry. However, it is becoming increasingly apparent that the nature of high frequency variability in atmospheric forcing significantly influences the overall mean productivity (Taylor and Stephens, 1980) and also material export to the deep ocean (Conte et al., 1998).

The scientific objective of this proposal is to improve the quantification of the flux of carbon across the air-sea interface through a combination of field studies, data analysis, and modeling. We propose to work in collaboration with NOAA scientists Drs. R. Feely and R. Wanninkhof to investigate:

The Transfer Velocity of CO_2 Gas Across the Air-Sea Interface: The air-sea interaction group at WHOI would be extremely interested in collaborations with NOAA in investigating processes in the marine boundary layer, particularly with a focus on understanding and parameterizing air-sea gas exchange. The group (Drs. N. Frew, W. McGillis, E. Bock, J. Edson and J. Dacey) has broad expertise and interests in remote sensing of gas transfer, microlayer chemistry, turbulence, small-scale waves and micrometeorology. We are anxious to participate in a proposed Equatorial Pacific cruise, complementing the planned CO_2 exchange measurements with a variety of underway measurements of trace gas profiles and fluxes, wave spectra (small gravity-capillary and long waves), surface films, near-surface turbulence and atmospheric forcing. Joint participation would greatly enhance intercomparison and calibration of different flux estimate methods, and provide ground truthing for model estimates using satellite data.

In addition to field studies and global extrapolations using remote sensing products, continued studies in controlled environments will improve parameterization of gas exchange with surface turbulence indicators such as wave slope. In addition to using the established facilities at WHOI, we'll also utilize the new large linear wind-wave tank in Miami to perform experiments with seawater. This tank will be equipped to accommodate remote sensing tools.

The Temporal Variation of the Difference of Partial Pressure of CO_2 Between the Sea-Surface Water and the Atmosphere and the Temporal Variation of the Organic and Inorganic Carbon in the Upper Ocean Through Observations: We plan to outfit NOAA, WHOI, and selected volunteer observing ships, following regular meridional routes, with underway measurement devices to continually measure the surface seawater properties along the cruise tracks. The measurable properties include partial pressure of CO_2 in the atmosphere and in seawater, seawater fluorescence, total CO_2 (TCO_2) and total organic carbon (TOC) in seawater. The challenges of this work include the simplification and automation of current instrumentation for underway measurements of TCO_2 and TOC, and the improvement of the algorithms used to collect and merge these data sets with the ship's data (sea surface temperature, salinity, position, atmospheric pressure, etc.). The pCO_2 data will be further added to the international pCO_2 database initiated by the Joint JOC-JGOFS Ocean CO_2 Advisory Panel. This coherent global database of surface ocean pCO_2 is being assembled at the Carbon Dioxide Information and Analysis Center (CDIAC).

The Temporal Variation of the Organic and Inorganic Carbon in the Upper Ocean on a Global Scale Through Interpolation and Multi-Parameter Analysis of the Measured Data Sets: Over the past few years we have demonstrated that multi-parameter analysis can be used to interpolate the oceanic total CO_2 field throughout the water column (Goyet and Davis, 1997; Goyet et al., 1997). We plan to further develop these algorithms to address the temporal variations of carbon in the upper ocean. Multi-parameter analysis can also be used to quantify the contribution of different water masses to the observations. We plan to use this approach to quantify the influence of the different processes, physical, chemical and biological, on the observed variations of TCO_2 in the ocean. These algorithms will also be used as boundary conditions in models to assess seasonal and interannual variation in carbon fluxes.

The Transport of Carbon in the Ocean: On a global scale, the ocean is absorbing approximately 2±0.8 Pg C per year (Denman, 1996). Using three-dimensional models we plan to investigate where and how this carbon is stored and transported in the ocean.

At WHOI, we have introduced the oceanic carbon cycle in the ocean general circulation model MOM-2.2. This model can be used at different resolutions to investigate the transport of carbon in the ocean. It can also be used to investigate the response of the ocean to different scenarios of CO_2 increase in the atmosphere. We plan to integrate the observations and the knowledge gained from the multi-parameter approach into the global ocean carbon model. The results of the model are expected to provide improved insights on the global scale of the temporal variations of the ocean CO_2 source and sink areas and to provide good estimates of the fluxes of carbon across the air-sea interface and within the ocean.

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11. Arctic Air-Sea-Ice Interaction and Global Climate—*Andrey Proshutinsky and Cecilie Mauritzen [K. Naugolnykh (NOAA/ETL), J. Overland (NOAA/PMEL), M. Baringer and R. Molanari (NOAA/AOML)]*

The key hypothesis guiding this work is that the Arctic Ocean and ice are active components of the global system in decadal and longer scale climate variability. Analysis of atmospheric conditions and analysis and monitoring of selected ocean and ice parameters at particular locations in the Arctic will help us understand the influence of the Arctic Ocean on the global thermohaline circulation, the resulting global heat balance, and the climate of North America.

We have formulated a set of scientific questions which can be resolved in cooperation with NOAA scientists: Are changes in the arctic driven from the top down (stratospheric forcing) or from the bottom up (ocean-ice forcing)? Can the Arctic Ocean stratification or circulation change enough to release Atlantic Water heat to the surface and cause ice-free conditions in the summer? Can one predict local and regional impacts of climate change based on observations and modeling of larger scale variability?

Below are examples of the types of projects that might be undertaken. These are meant to be representative, but not exclusive.

Arctic Atmosphere And Ocean Oscillations: It has been speculated for over a century that variability in environmental parameters such as atmospheric pressure and temperature, ice conditions and ocean currents can be described by an oscillating system. If the period and magnitude of the oscillations were discernible, we would be able to predict future changes. The major goal of this project would be to understand relationships among oscillations in environmental parameters as a first step in answering one of the basic arctic questions: Are changes in the arctic driven from the top down (stratospheric forcing) or from the bottom up (ocean-ice forcing)?

There are two oscillatory modes in the Arctic that are of interest. First, there is an atmospheric oscillation in the first Empirical Orthogonal Function (EOF) of monthly-mean wintertime pressure records, with a coherent signal evident from the earth's surface up to the troposphere. The signal involves a "seesaw" in pressure between the Arctic basin and the surrounding land mass. The long-term trend in the EOF time series shows a deepening of the polar vortex, with implications that include possible reversal of the Beaufort Gyre, enhanced cooling and deep convection in the Greenland Sea, and changes in precipitation patterns over Eurasia. The second oscillatory mode, detectible from 1946 to the present in a coupled ice-ocean model, involves similarly phased, oscillating patterns over the Arctic region in both the atmosphere and the ocean. Positive and negative polarities in multi-year mean atmospheric states drive two ocean circulation regimes. This coupled atmosphere-ocean mode differs from the atmospheric mode described above. Recent sea level pressure data suggest that the ocean-atmosphere system will shift, or has already shifted, from its present cyclonic state to an anti-cyclonic state similar to that seen previously. Both oscillations have existed for at least 50 years and have important implications for ice distribution, freshwater export and heat fluxes.

Arctic Heat Storage And Exchange: This project would have the goal of quantifying the storage of heat within the Arctic basin and the major pathways of heat exchange between Arctic and subarctic oceans. The Atlantic Inflow to the Arctic represents the northernmost warm limb of the global thermohaline circulation, and its heat content is re-distributed within the Arctic Ocean. Since heat stored in the Arctic basin is variable, it is necessary to monitor both interior heat content and the heat fluxes associated with exchange through major pathways such as Fram Strait, the Barents Sea and the Bering Sea. Acoustical thermometry is an ideal method of making integral heat content measurements on basin scales and could be combined with conventional techniques to provide a monitoring system for detecting the high latitude signature of global climate change. This project is representative of observational, theoretical and empirical studies to answer the second scientific question: Can the Arctic Ocean stratification or circulation change enough to release Atlantic Water heat to the surface and cause ice-free conditions in the summer?

Data Reconstruction For Climate Change And Modeling Studies: Observations and modeling results demonstrate that the recent history of the Arctic is characterized by significant changes in ocean circulation, a descending trend in summer ice cover, a significant decrease in Arctic sea level pressure, and changes of the North Atlantic Oscillation (NAO) index. To understand the origin of these changes, they need to be placed in the perspective of the record for at least the past hundred years. Before 1942-1946, most data sets do not cover the central arctic and the Arctic Ocean. Relatively good quality observations at high latitudes exist in quantity only after 1978 when satellite measurements and surface ice buoys (International Arctic Buoy Program) began coverage of the polar regions. Therefore, the major goal of this project would be data reconstruction for the Arctic region using different approaches, assumptions and physical relationships.

C. MARINE ECOSYSTEM PROCESSES ANALYSIS

1. **Transition of GLOBEC Results To Management On Georges Bank—***Peter Wiebe, Cabell Davis, Jim Irish [David Mountain, Michael Fogarty, Michael Sissenwine (NMFS/ NEFSC)]*

A major goal of the GLOBEC Georges Bank program is to provide scientists and managers in NMFS and/or COP with information and tools to assist with monitoring and management of the fishery in the future. Essential components of this transition are a comprehensive physical biological model, which can assimilate new data (see b) and generate realistic seasonal and spatial distributions of key parameters and species, information on specific organisms and properties to be monitored as indicators of larger scale processes, and the instrumentation, moorings and data structures to provide continued monitoring of the Bank. This effort would be strongly collaborative with NOAA NMFS and COP.

2. **Data Collection By Fishermen For Monitoring And Modeling—***Peter Wiebe and Bob Groman [Ann Bucklin (UNH Sea Grant)]*

Commercial fishermen clearly have a major stake in the recovery of New England fisheries like Georges Bank, and constitute a significant resource of knowledge and labor to assist in the continued monitoring of the ecosystem and the fishery. A current National Ocean

Partnership Program proposal involving WHOI and NOAA Sea Grant would establish a program to provide commercial fishing boats with environmental monitoring sensors that could telemeter data on meteorological, hydrographic and biological conditions to a central point, for inclusion in assimilative models of the Georges Bank ecosystem. Real time synoptic data and model forecasts obtained by this cooperative, would be incorporated into the GLOBEC database structure, and be freely available on the Internet for use by any individual, program or agency for such purposes as research, education, assessment, management, marketing, or regulation. Implementation and expansion of this program could be collaborative with NOAA/NMFS, Sea Grant, Environmental Information Services (EIS), NODC, and other programs.

3. **Primary Measures of Hearing in Large Marine Vertebrates**— *Darlene Ketten [Phil Clapham,* (NMFS/NEFSC)*, Ken Balcomb,* (NOAA)*]*

At the moment, there is a virtual data vacuum on hearing abilities in a wide range of larger marine vertebrates. In particular, we lack comprehensive audiograms for cetaceans, turtles, and seabirds. The lack of basic hearing information on these animals is crippling our regulatory agencies and impeding the development of, on one hand, effective acoustic deterrents (AHDs) that could reduce by-catch and, on the other, of lower frequency sonic devices (LSDs) for long-range detection of target species that would improve fisheries yields. Because of the geographic coincidence of WHOI researchers and students with expertise in sensory systems with the range of captive animals at New England Aquarium and NMFS facilities coupled with the rate and species diversity of strandings in this region, we have a unique opportunity to develop a coordinated, multi-modality program for measuring basic hearing abilities in North Atlantic cetaceans, pinnipeds, sea turtles, and common sea birds. Species available at New England Aquarium and at the NMFS facility in Woods Hole; e.g., turtles and seals, will be tested both behaviourally and with non-invasive electrophysiologic auditory evoked potential (AEP/ABR) methods. These data will be used to provide a basic audiogram; i.e., frequency vs. sensitivity curve, for each captive species tested and will provide a metric for determining the relationship of behaviorally significant hearing responses to AEP/ABR results. Following this hearing calibration study, AEP/ABR responses from live stranded animals will be obtained opportunistically using a recently developed portable ABR system that is battery powered and therefore transportable to a stranding site. With this combined approach, we anticipate being able to provide the first direct hearing curves for baleen whales as well as for three species of marine turtle and marine birds. These data will also substantially enhance the database for smaller odontocetes and pinnipeds.

4. **Advanced High Frequency Acoustic Methods For Zooplankton Research—***Peter Wiebe and Tim Stanton [Gregory Lough, Michael Fogarty, Bill Michaels, (NMFS/NEFSC)]*

Food chain dynamics and fish recruitment are inextricably linked in ways that are still poorly understood. Fisheries management has in the past been based largely on stock size estimates derived from fish catch statistics and assessments of the existing stocks from resource assessment cruises. Little regard has been paid to the environmental conditions under which the stock was living or the ecological forces affecting the production, growth, and survival of the eggs and larval forms of the commercial stocks because of the difficulty in linking recruitment success to environmental conditions. We are now entering an era where our ability to measure the physical and biological environmental conditions and relate these conditions to the early life history of important fish is vastly improving. It is now feasible to use underwater remote sensing

techniques (acoustical and optical) to survey large ocean areas for zooplankton standing crop and taxonomic composition and to relate these findings to the physical structure of the environment. The incorporation of these techniques into environmental status cruises will enable the patterns of distribution and abundance of zooplankton to be readily developed. In addition, these data will provide valuable input into models designed to provide insight into coupling between physics and biology. The goal of this project will be to take feasible, but untested strategies for conducting zooplankton surveys in coastal regimes using the new technologies and develop them into bonafide applied science survey tools.

Most fisheries acoustics systems have not been designed to map zooplankton, but they have instead been focused on surveying populations of adult fish. The lower frequencies (12 kHz to 70 kHz) used in fish surveys only produce data useful for zooplankton investigations when used in concert with higher frequencies appropriate to zooplankton (120 kHz to 1000 kHz). With the development of advanced systems such as BIOMAPER-II (a system that has integrated multi-frequency acoustics and optics sensors, and can be tow-yoed off the side of a ship), zooplankton can be surveyed quantitatively. To effectively use the field data, however, the analysis tools must include theoretical models appropriate for the organisms responsible for the volume backscattering at particular frequencies. In addition to BIOMAPER-II, we have extensive laboratory capability to measure acoustic scattering properties of live zooplankton and have been developing advanced acoustic scattering models for quantitative interpretation of acoustic surveys.

We propose to work with NOAA/NMFS personnel and to use BIOMAPER-II to develop better strategies to map zooplankton in regions that are relevant to the NOAA/NMFS mission. Concurrent with that work, we will continue our laboratory studies of acoustic scattering properties of zooplankton and development of scattering models, especially for larval fish of commercially important species living in New England waters. We will develop the processing tools, which will use the combination of survey work and new scattering models to produce accurate estimates of the temporal and spatial variability of zooplankton in relation to the marine environment.

5. **A Data Assimilative Ecosystem Approach To Modeling Recruitment Variability In Fish Populations—***Dennis McGillicuddy [Jim Manning, David Mountain, Gregory Lough (NMFS)]*

It has been recognized for some time that fluctuations in recruitment profoundly impact fish stock variability. The ability to understand (and eventually predict) factors, which control this process, would therefore be enormously valuable for fisheries management. An outstanding opportunity exists in the Gulf of Maine/Georges Bank region to develop an ecosystem-based approach to this problem. The circulation is well-described (Beardsley et al., 1997), and is realistically represented in hydrodynamic models (Lynch et al., 1996). Coupled physical-biological models have shown great utility in the study of various trophic levels: Franks and Chen (1996) investigated the role of the tidal mixing front on George's Bank in nutrient supply and phytoplankton production; Davis (1984) examined the combined influences of circulation and population dynamics in creating observed patterns in zooplankton abundance; Werner et al. (1996) used a trophodynamic model to simulate larval fish being advected through a prey field.

Although the major conceptual elements of an integrated ecosystem model (from nutrients to fish) have been established, they have yet to be dynamically linked together. The various data sets collected during the U.S. GLOBEC Georges Bank Program, in addition to other ancillary sources such as SeaWiFS ocean color, offer an extremely powerful context in which to do so. Recent advances in modeling have demonstrated the ability to construct realistic circulation hindcasts (Lynch et al., 1998), and the capability to' assimilate biological data (McGillicuddy et al., submitted). Synthesis of observations through both forward and inverse modeling techniques should lead to a better understanding of the underlying ecosystem controls on fish populations. At present, a team of investigators from WHOI, Dartmouth College, and a host of other institutions are currently working on various aspects of these problems under the auspices of the U.S. GLOBEC. Strengthened ties with NOAA fisheries scientists and managers via the CICOR program would greatly facilitate progress toward the goal of integrated ecosystem understanding.

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6. **Technology For Survey And Assessment—***Peter Wiebe, Tim Stanton, Ken Foote, Scott Gallager, and Heidi Sosik [Wendy Gabriel, Tom Azarovitz, (NMFS)]*

WHOI innovation and experience in development of advanced acoustic, optical and other instruments, used in towed, moored, or profiling modes will continue, finding application for a wide range of fisheries related problems. Future partnerships with NMFS would be expected in this area. In addition to underwater instruments, further development of satellite imagery and its

analysis for assessment of environmental properties, primary production, etc., will be a fruitful area for cooperative research between WHOI and NOAA satellite programs.

7. **Early Life History of Fishes—***Scott Gallager [Greg Lough, Laurence Buckley (NMFS)]*

Laboratory and pilot-scale studies on culture techniques, feeding, growth and behavior of larval stages of economically important fish species will continue to be an important element for understanding survival and recruitment in natural fisheries. Continuation of current research efforts within the GLOBEC program could extend to other species, probably in collaboration with NMFS labs at Sandy Hook or Narragansett.

8. **Trans-Atlantic Ocean Observatory—***Peter Wiebe and Larry Madin [Ambrose Jearld (NMFS)]*

With the development of monitoring and telemetry technology and of real-time assimilative models like that under construction in GLOBEC, it will become possible to establish observing stations to monitor stocks of cod or other economically important fishes, and their food resources across their entire North Atlantic range. Such a system, of moored and profiling instruments for physical parameters, primary production and distribution of zooplankton and fishes tied by satellite telemetry to shore monitoring stations, could be a central component of the proposed Global Ocean Observing System (GOOS). It would also contribute significantly to future global scale efforts to characterize and quantify the distribution of fishes and other marine organisms in the world ocean. A program of this nature would have collaborative ties to many NOAA agencies including NMFS, NOS, NESDIS.

9. **The Effects of Fishing Activity on Benthic Processes and the Environment Benthic Processes and Fisheries—***John Trowbridge and Jim Churchill [Fred Serchuk, Wendy Gabriel, Steve Murawski, Ken Sherman (NMFS)]*

Recent research conducted as part of the U.S. GLOBEC Northwest Atlantic/Georges Bank program has begun to clarify the importance of the benthic environment on the early life stages of cod and haddock, two key commercial fish. Spawning is preferentially done over rough substrate (especially the gravel and coarser bottom on the Northeast Peak of the Bank), while bottom trawling may produce a source of hydroids for the rest of the water column where they can prey on larval cod and haddock. Over much of the New England shelf including Georges Bank, most of the sediment resuspension that occurs during winter is due to storms, while that in summer is due primarily to fishing activity, especially bottom trawling. This can directly effect light penetration through the water column, influencing primary productivity, the location of zooplankton, which prey on the phytoplankton, and the light levels needed for larval cod and haddock to feed and survive.

Past research on fisheries on Georges Bank and the surrounding areas has generally ignored the role of benthic processes in the early life stages of larval fish for several reasons. First, the basic understanding of benthic processes was quite limited, and experimental approaches and observational methods quite crude. Second, there was little appreciation of the relative importance of benthic processes on the early life stages. Third, the degree of benthic

habitat alteration by human activity and its effect on the rest of the environment was largely unstudied.

As part of its mandate to supply scientific information for use in fisheries management, NOAA has a growing need for better understanding of benthic processes and how they are effected by fishing activity. In particular, critical management decisions to (a) close or open specific regions for fishing and/or (b) limit or modify different types of fishing and fishing gear within specific areas need a better understanding of the bottom environment, the processes which govern it, and the complex roles of the benthic environment on different fisheries.

Fortunately, much has been learned in the 1990's about benthic processes on continental shelves, and the basic state of understanding is much improved. This project seeks support for WHOI scientists to work with NMFS collegues to conduct research to better understand a) the effects of active fishing on the bottom environment, b) the recovery of the bottom environment following a cessation of fishing through closure, and c) the role(s) benthic processes and both natural and man-induced changes in the bottom play in the different fisheries.

We propose a series of field, laboratory and modeling studies to investigate the effect of fishing activity on near-bottom flow, sediment concentration and optics fields, and the resulting impact on life histories of commercially important species and their predators. The field studies will include measurements of velocity and turbulence, optical and acoustic measurements that provide indirect information about suspended sediments, and biological sampling of the seafloor and water column. Laboratory studies will address, in a process-based manner to the extent possible in an artificial setting, the effect on fauna of a disturbed sea floor and elevated water-column concentrations of suspended sediment. The modeling studies will be used to place the field and laboratory observations in a broader context.

TASK III

Some of the research projects that could be funded under Task III for each of the CICOR Themes are described below. Both Task II and Task III involve research under CICOR's three themes; Task III projects are distinguished from Task II by being efforts conducted primarily by WHOI principal investigators.

A. COASTAL AND NEAR-SHORE PROCESSES

1. Nearshore Hydrodynamics, Sediment Transport, And Topographical Evolution— *John Trowbridge*

The nearshore, defined as the region where forcing by surface waves dominates hydrodynamics and sediment transport, is one of the most dynamic parts of the ocean. Wave-induced oscillatory velocities often reach 1 m/s, and the wave-driven alongshore current typically has a comparable magnitude. Topographical changes, both on seasonal time scales and within a single severe storm, are measured in meters.

Nearshore processes are of crucial societal importance. Engineers and planners have long been concerned with coastal protection, particularly in heavily populated areas where wave attack, set-up and shoreline erosion threaten coastal structures. Rapid topographical evolution in shallow coastal channels and tidal inlets threatens roads and bridges, influences the flushing characteristics of inland waterways, and produces constantly changing challenges to navigation.

The scientific community concerned with nearshore hydrodynamics has made impressive advancements in the past two decades. In research programs centered on intensive oceanic measurements, workers in this field have developed and verified models of nearshore wave propagation and the alongshore current, documented and described the variety of fluid motions that occur in the nearshore, and established empirical relationships between wave forcing and important but hard-to-predict quantities such as mean set-up and amplitude of swash oscillations. More recently, the nearshore hydrodynamics community has begun to focus on difficult measurement problems, such as the wave boundary layer, and difficult conceptual and modeling problems, such as the generation of low-frequency oscillations by incident waves.

In spite of its practical importance, scientific progress on nearshore sand transport and topographical evolution has been exceedingly slow. The complex interactions between fluid motions and sediment particles present extremely difficult conceptual and measurement problems. As a result, predictive ability remains poor, and engineers and planners are forced to make important decisions regarding nearshore sand transport on the basis on empirical, poorly constrained models.

The time is ripe, however, for rapid scientific progress on nearshore sand transport and topographical changes. Modern navigation and data acquisition capabilities have recently made mapping of nearshore topography and observation of topographical evolution possible at a scale never previously contemplated. Acoustical measurements can now image the bottom at scales ranging from centimeters to meters, and acoustic techniques have the potential to measure both fluid motions and sediment response within a centimeter of the sea floor, where the bulk of sediment transport likely occurs.

We propose an intensive research program aimed at a fundamental scientific understanding of nearshore sediment transport and topographical evolution. The program will consist of a field component and a modeling component. In the field component, advanced measurement techniques will be used to make incisive observations that reveal, under a variety of different conditions, the structure and dynamics of nearshore flow and sediment transport fields. The modeling component will range from detailed representations of the complex physics of flow-sediment interactions, at one extreme, to large-scale simulations, on the other, which are based on cruder but still physically based parameterizations of subgrid scale processes and are capable of providing predictions ranging up to years or decades. Both components will capitalize on the astonishing variety of nearshore environments that are offered by Cape Cod, and both components will capitalize on WHOI's combined expertise in fluid dynamics, sediment transport, and geology.

2. **Inflow of the Labrador Current into the Subtropical North Atlantic—***Bob Pickart and Glen Gawarkiewicz*

The main branch of the Labrador Current transports water of sub-polar and arctic origin equatorward along the shelfbreak of the Labrador and Newfoundland basins. It represents a portion of the sub-polar western boundary current, and is subject to both wind and buoyancy forcing. Upon reaching the Grand Banks of Newfoundland, part of the current retroflects and turns northward inshore of the North Atlantic Current. It is unknown, however, what portion of the current is diverted, since some of the transport clearly continues equatorward as a shelfbreak current. It is of fundamental importance to determine this equatorward throughput, as it represents a major contribution to the mass/salt balance of the Canadian and US continental shelves. Furthermore, because the Labrador Current responds to NAO forcing it is important to document the variability of the flow. This variability will have a large impact on the shelf/slope system and associated ecosystem, and may influence the convection over the slope depending on how much low salinity water is carried offshore.

We propose a simple moored array to measure the inflow of the Labrador Current at 52°W over a three-year period. This will result in the first direct measurement of the mean transport into the subtropical domain, and. provide valuable information on the variability from seasonal to inter-annual time scales. Five upward-looking ADCPs with T/S sensors will be moored at 10km spacing across the shelfbreak (located at the bottom or at 300m, whichever is deeper). This will enable study of the two-dimensional structure of the jet as well. We envision all work being done on coastal vessels staged from a nearby Canadian port.

3. **Real-Time Current and Flux Measurements for the Nearshore—***Albert Williams 3rd*

Wave, tidal current, and wind generated flow vary locally and temporally in the nearshore influenced by-depth, local and offshore storms, and topography. These flows may move sediment shoreward, offshore, alongshore, or may build bars, erode structures, fill dredged channels, deposit or remove beaches and generally impact human occupation of the shore. Studies of the processes responsible for sediment flux require as input, forcing functions in the form of currents and waves. This in turn requires current sensors that work reliably and accurately in a near surface wave field. The sensor, MAVS (Modular Acoustic Velocity Sensor, developed under NSF support), is such a current meter, designed to have good cosine response in the vertical as well as excellent response characteristics for flow in 3 dimensions. Using magnetometers to rotate each instantaneous velocity measurement into earth coordinates and averaging these to reduce the noise of the magnetometers provides flow information useful to parameterize the conditions during sediment erosion or deposition. Coupled with an optical sensor of suspended sediment concentration, a flux measurement can be made to further provide information about conditions affecting erosion and deposition.

Current flow and sediment flux measurements are needed during storms and during all stages of tide. Real time return of information during such events from sites as shallow as 2 meters to as far offshore as 10 km and as deep as 30 m can be used to trigger sampling on the beach or on a bar. Two routes to provide real time data from the MAVS current meter are being developed in another program: direct wire link ashore (shallow site) and SeaNet radio link from a surface buoy. In each case, the data link from the sensor to the transmitter is a cable with

RS485 communications. The transmitter is a wireless LAN radio transmitter with receiver on one of four towers in the Nantucket Sound/Martha's Vineyard area with return to WHOI for entry into a website. Thus the data are available in nearly real time via web.

The elements of the research program that are new to this program are the physical coupling to the transmitters, the mooring or cable connection ashore, and the coupling to scientific users. Previous work will have solved the problem of getting the information from the transmitter to the website via wireless LAN transmitter. This program will deploy approximately seven MAVS current meters, three with OBS sensors to obtain flux estimates. Deployment times between servicing will be 6 weeks initially, extending to three months with experience. In year one, the moorings, cable laying, and technical problems of interfacing the instruments to the cable will be resolved. One MAVS instrument with interface electronics and wireless LAN will be acquired in the first year for these demonstrations. In year two, six more systems will be acquired with three OBS or equivalent optical sensors for flux measurements. Initial deployments of 6 weeks will be extended to 3 months during the second year. In the third year, the coupling to science will be tightened with siting, depth, frequency of sampling, and additional sensors or alternate sensors selected by scientific members of CICOR. Collaborative studies of sediment transport in storms, under extreme tides, over bars, and in channels will be undertaken.

4. **Extension Services to Cape Cod Aquaculture Ventures—***Dale Leavitt*

The decline of traditional fisheries in the New England region has increased the economic importance of new aquaculture ventures, for both fin and shellfish. On Cape Cod, shellfish aquaculture, particularly of quahogs and oysters, is beginning to develop, but these species are subject to diseases, which may limit their productivity or marketability. An important function of extension services through WHOI Sea Grant and CICOR will be assistance with introduction and development of alternative species (e.g., surf clam, sea and bay scallop, razor clam) to diversity the industry and make it less susceptible to catastrophic disease problems.

5. **Culture, Energetics and Physiology of Larval Stages of Aquaculture Species—***Scott Gallager*

The development of species for aquaculture use requires research on the early life stages to understand nutritional requirements, growth rates and behavior. The facilities of the ESL and Shore Lab at WHOI are will suited to research- and pilot-scale rearing studies on larval and juvenile stages of prospective aquaculture species.

6. **Engineering Development for Offshore Aquaculture Installations—***Dale Leavitt, Walter Paul*

Due to concerns about near-shore impacts of large aquaculture installations, future expansion may be further offshore. This requires considerable new engineering to design robust, workable and cost-effective structures to contain or support finfish or shellfish cultures. WHOI has begun work in this area with the collaborative project between engineers and biologists on mussel culture at the WHOI Buoy Farm. The expertise of our AOP&E Department in offshore

structures and mooring systems could be invaluable for designing the next generation of aquaculture facilities.

7. **Applications of Remote Sensing to Monitor Offshore Aquaculture—***Heidi Sosik and Chris von Alt*

The greater difficulty of access to offshore aquaculture means that new remote sensing technologies, including satellite observation, new in-situ sensors and moored or profiling instruments will be needed to monitor conditions at offshore aquaculture installations. Examples would include nutrient and phytoplankton stocks, monitored by ocean color, *in-situ* nutrient analyzers, fluorometers or flow-cytomoters, all technology currently in development at WHOI. Newer methods for monitoring abundance, growth rates or condition of cultured species would also be valuable. Autonomous observing systems and vehicles supporting a variety of sensors and reporting via fiber cable or satellite link are all strong areas of research at WHOI.

8. **Technology for Land-Based or Recirculating Aquaculture Facilities—***Carl Wirsen*

An alternative location for new aquaculture installations may be land-based facilities, in some cases as a way to re-use existing warehouse or factory buildings. There are significant engineering and biological challenges in creating effective and economically viable closed culture systems on a large scale. These include design of tanks and water supply systems and control of waste products, possibly by microbiological methods. WHOI expertise in engineering, microbiology and biotechnology would be extremely valuable in solving these kinds of problems.

9. **Coastal Ocean Observations and Observatories—***Ken Brink, Rocky Geyer, Wade McGillis, and Jim Edson*

The ability to make advances in oceanography depends critically on the ability to make measurements, and this is especially so in the coastal ocean. The problem here is challenging for several reasons. One is simply that this is a hostile setting for making measurements, especially where the net water depth is less than around 20m so that waves cause substantial problems. Further, the coastal environment is extremely anisotropic: things vary differently in the alongshore and cross-shelf directions. All variables are extremely non-stationary on seasonal time scales, where the entire nature of the water column can change (unlike the tropical or subtropical deep ocean, where only a fraction of the water column is strongly affected on these time scales). Finally, interdisciplinary issues are particularly acute in the coastal environment, making the development of non-physical sensors that can sample compatibly with physical technologies especially pressing.

WHOI is tackling these issues on a number of levels. We are among the leaders in developing moorings that can endure on the inner shelf. We are developing an observatory off Martha's Vineyard that will enable diverse year-around measurements in real time and that are capable of capturing rare and extreme events. Finally, we are working on developing new non-physical sensors that will mesh with physical data sets, and enable the development and evaluation of interdisciplinary models. These activities all represent long-term efforts that require repeated improvements and evaluations. These efforts are directly pertinent to CICOR science

themes and represent appropriate places for building cooperation between WHOI and NOAA scientists and engineers.

B. THE OCEAN'S PARTICIPATION IN CLIMATE AND CLIMATE VARIABILITY

1. Station W: A Slope Water Time Series of Hydrography and Air-Sea Fluxes—*Mike McCartney, John Toole, Bob Weller, Ruth Curry and George Tupper*

We propose to establish the inaugural Station, W (39°N, 70°W), of a global set of Eulerian Observatories. Station W is to be located in the slope water north of the Gulf Stream, a site selected for its importance for climate research in the mid-latitude North Atlantic climate system. It also offers logistical convenience, allowing it to serve in parallel as a development and test site for additional technology evolution for the Eulerian Observatories, and it has a history of a variety of past measurements allowing backwards extrapolation of climatic data time series to combine with the new forward time series.

A moored profiler mooring will provide a high time resolution time series of hydrography and ocean currents from near seafloor to near sea surface. A surface mooring will have 2 sets of IMET sensors, 20 inductive Microcats in the upper 250 meters, and a downward looking ADCP, will provide accurate measurements of air-sea heat flux and wind stress, and estimates of fresh water flux, and further upper ocean measurements. The Station W hydrography will characterize the evolution of the subpolar water masses being delivered to the Gulf Stream by the deep western boundary current, an oceanic feedback pathway linking surface subpolar forcing to the mid-depth Gulf Stream, a pathway observed to involve time lags of order 6 years. It will also characterize the variability of upper ocean heat content on the slope-water side of the Gulf Stream. Station W lies in the northern side of the lozenge of the largest oceanic heating of the atmosphere in the North Atlantic (indeed, in the world ocean). The annual average atmospheric heating is estimated at about 150 watts per square meter, with a large seasonal range exceeding 650 watts per square meter. These bulk formula-based estimates will be much improved by the planned direct measurement of fluxes at Station W, and by their impact on redefining the regional parameters of the bulk formulas themselves. They will provide a coupled data set of atmospheric forcing of the seasonal mixed layer and the annual march of the mixed layer.

While Station W will have much value in isolation, by pairing it with other time series data we anticipate considerable enhancement of value. For example, by pairing with the existing Station S near Bermuda we will estimate the time series of net eastward baroclinic transport between the stations. A pairing of Station S with Station Bravo in the Labrador Sea has already been used to demonstrate that the net baroclinic transport of the subpolar—subtropical gyres varies by +1-15% on decadal time scales. How much of this is Gulf Stream variability and how much is variability of subpolar currents? Is there a seasonal component to the variability? By combining Stations W and S data with measures of thermal structure between the two sites (XBT, Palace and hydrographic station data, and altimetric height) can we link the Gulf Stream baroclinic transport variability with the variabilities of temperature transport by the Gulf Stream, of oceanic heating of the atmosphere, and of storage of heat in the upper ocean.

We will support Station W and the studies of the Gulf Stream with a hydrographic section program taking advantage of the logistical proximity of Station W and Bermuda. Four times a year, including the annual mooring turnaround cruise, a hydrographic section will be made from the shelf break across the continental slope and the Station W mooring site out to the 3500 in isobath. This will accomplish two things. First, it will provide data for assessing the drift of the moored salinity measurements. Second, it will measure the baroclinic flow and water masses of the deep western boundary current and northern part of the slope water, to develop a regional context for the higher time resolution Station W site at the edge of the deep current. One of the four sections per year will be extended from the sections' normal offshore terminus across the Gulf Stream system to Bermuda. This will provide an indication of the interannual evolution of the lateral structure of baroclinic transport and water mass distribution, including the deep Gulf Stream and adjacent recirculations' baroclinicity changes and the accumulated results of the mixing between the deep western boundary current water measured at Station W and the subtropical gyre waters measured at Station S. It will also guide the estimation of upper ocean temperature transport using the Station W and S combined with altimetric measurements and the lower time resolution Palace and XBT data between the two sites. The once annual longer cruise will be run in late winter/early spring to simultaneously assess the field of intermediate depth convection in the slope water and the Sargasso sea, and the maximal upstream retraction of the Gulf Stream warm core, all setting the winter SST distribution. That annual cruise will take 12 days (round trip Woods Hole). The other three cruises are 4 days duration (round trip Woods Hole). One of the four cruises per year will be 1 day longer than these estimates to allow for the mooring turnaround. In the future, as inexpensive subsurface moorings are developed, we anticipate using them to instrument the intermediate and deep water on the line connecting Stations W and S.

2. **Accurate Global Air-Sea Flux Fields for GOOS—***Bob Weller, Dave Hosom, [P. Taylor and S. Josey (SOC, U.K.)]*

Developing accurate global fields of the air-sea fluxes has been identified by the Ocean Observing System Development Panel (OOSDP) as being among the highest priority elements of a Global Ocean Observing System (GOOS). We have developed a strategy to achieve this goal. There are two observational components. One is the Volunteer Observing Ship (VOS) fleet, and the other is surface moorings equipped with IMET sensors deployed at select global locations. The VOS provide the broad spatial coverage needed for global mapping. The time series from the surface moorings provide high quality anchor points within the VOS fields and are the basis for developing regionally specific sets of bulk formulae to be used to compute the air-sea fluxes. The work we propose here is ongoing use of the *in-situ* data from both the VOS and the surface moorings to prepare the global surface meteorological and air-sea flux fields, ongoing studies of how to improve the buoy and ship systems, and observing system simulation experiment to provide guidance to operational activities within GOOS that collect surface meteorological and sea surface temperature data.

3. **Mentorship of High Quality Surface Meteorological and Air-Sea Flux Observations on U.S. Academic and NOAA Research Vessels—***Bob Weller, Dave Hosom, Dick Payne*

Improved Metrological (IMET) systems have been installed on the academic research fleet (UNOLS) and on R/V Ron Brown (NOAA). These systems are capable of high quality observations; and because the research fleet often works in remote, data sparse regions of the world's oceans, these ships are potentially an important element of GOOS. To ensure that the quality of the data from these ships is maintained and that their data is supplied to GOOS, we propose to mentor these IMET installations. To do this, we would provide ongoing technical support to the ship operators, quality control near-real time and delayed mode data sets, recommend and oversee repairs and calibrations, and process, edit, and submit to GOOS archives the data from these vessels.

4. **Implementation of Observing Systems on VOS For GOOS—***Dave Hosom, Bob Weller, Dick Payne*

The volume of calibrations required by the 50 ship VOS fleet that has been proposed and the fleet expansion envisioned for following years is not feasible with our present facilities. Effort is aimed at acquiring equipment necessary to automate our calibrations while maintaining or improving our accuracy standards and developing acquisition and processing software. In following years, we will fine-tune the systems while doing the initial calibrations for the 50-ship fleet. In addition we will continue our evaluation of new sensors.

5. **A Numerical Study of the Linkage Between Tthe North Atlantic Oscillation and Climate Changes in the Tropical and Subtropical Atlantic Ocean—***Jiayan Yang*

The Meridional Overturning Circulation (MOC) is driven partly by the formation of the North Atlantic Deep Water (NADW), whose formation rate and property are strongly influenced by climate changes in the subpolar basin. In fact, observations show that the layer thickness of Labrador Sea water bears strong imprints of the North Atlantic Oscillation (NAO), a leading signal in decadal time-scale climate changes in the Atlantic. Since the MOC is a main mechanism for poleward heat transport in the Atlantic Ocean, its variation is likely to alter the balance of heat fluxes in the downstream regions in the subtropical and tropical oceans. We propose to use a three-dimensional numerical model to study how NAO affects lower-latitude ocean through MOC teleconnections.

6. **Profiling Palace Floats for the Northern North Atlantic—***Breck Owens*

We propose to continue the investigation of the seasonal to interannual variability of the heat and salt (freshwater) content of the sub-tropical and sub-polar North Atlantic using profiling autonomous (PALACE) floats. The deployment of an additional 50 floats per year in the northern North Atlantic will enable us to extend the coverage initiated during the Atlantic Climate and Circulation Experiment (ACCE). In combination with other float data from deployments funded under separate NOAA and NSF contracts and with the XBT Volunteer Observing System, we will be able to monitor and map out the depth of the mixed layer and its temperature and salinity over most of the North Atlantic. In collaboration with colleagues at MIT we will assimilate this data together with altimetry to provide estimates of the large-scale

patterns of air-sea heat and freshwater fluxes. The float positions will also provide estimates of the mean circulation and eddy variability at a nominal depth of 600 m.

The data from these floats will be transmitted on the GTS system so that it can also be incorporated into the National Climate Center seasonal predictions for the North Atlantic. Taken in total, the continued coverage of the North Atlantic from 1997 to 2002 will be used to evaluate the feasibility of the proposed global Array for Real-time Geostrophic Oceanography (ARGO), which is planned to start in 2000. This data stream has been designated as one of the significant contributions to the Global Ocean Data Assimilation Experiment (GODAE).

7. **Design Studies for the Atlantic Climate Variability Experiment—***Mike McCartney, Nelson Hogg, Terry Joyce, Breck Owens, John Toole, Bob Weller [Marshall, Stammer, Wunsch (MIT), Visbeck (LDEO), Niiler (SIO)]*

The Atlantic Climate Variability Experiment is element of the U.S contribution to the international CLIVAR. It is to be a coordinated program of sustained measurements, process experiments, data interpretation, theory and modeling directed towards improving the description and physical interpretation of the Atlantic Ocean's participation in climate variability on time scales from seasonal through millennial. There are many candidates for sustained measurements and process experiments that if feasible could be well designed and produce significant progress in understanding climatically phenomenon and processes in the ocean and at the air-sea interface. We propose to undertake feasibility and experimental design studies for some of the more complex candidates. These will utilize existing data sets and model simulations to move from concept to feasibility decision and sampling design. Here are examples of measurements and experiments that ACVE might include:

a. Constraining the flow of heat in the climate system by simultaneous estimates of air-sea heat exchange by three methods: bulk aerodynamical formula, as a residue term in the heat budget of the atmosphere above the ocean (divergence of atmospheric heat transport after allowance for top of atmosphere radiation imbalance), and as a residue term for the heat budget of the ocean (divergence of oceanic heat transport). The mutual improvement of all three methods brought about by such an experiment is directed to the goal of accurately quantifying the variability of heat flow in the climate system by so called natural modes of climate variability and detection of possible global warming signals.

b. What is the best sampling plan for oceanic meridional heat transport given the mesoscale variability, the regional seasonality, and the likely structure of circulation, and what are the trade-offs between the errors and the costs? How well does a pair of hydrographic stations at the ends of a basin crossing line, combined with a variety of sea-surface and upper ocean measurements, constrain the meridional overturning circulation and associated fluxes of heat, fresh water and other climatically relevant properties?

c. What program is needed to allow a quantitative description of the subsurface fields accompanying the propagating recurrent winter SST anomalies observed crossing the mid-latitude North Atlantic? Are the operational network measurements adequate, or are enhancements or directed experiments needed? Are there signals in existing data or in numerical simulations that can guide an economic measurement strategy? Are there process experiments

needed to better understand the entrainment process in the seasonally modulated warm to cold water transformation underlying the propagation pathway?

d. Subduction: This process links atmospheric wind- and buoyancy-forcing to the restratification of the subtropical and tropical thermoclines, and thus to the redistribution of sub-surface circulation. Can we design an experiment to validate the representation of this process that occurs in numerical climate simulations?

e. Do existing oceanic data and or models suggest "modes" of basin scale circulation and transport changes that can guide a sparse sampling network design?

The transition from tropics to subtropics is a critical area for SST anomalies, as it is the formation area for hurricanes, and an area of outcropping of isopycnals that descend southwards to define the equatorial upper ocean thermocline. It is the site of the maximum fresh water transport, and has a large seasonal cycle of wind and buoyancy forcing. The wind forced Ekman flow and the distribution of geostrophic flow from hydrography indicate a strongly spiraling layered upper ocean circulation. Can an array of moored profilers and other measurements describe the mean circulation and the mean seasonality of that circulation, and interactively improve the modeling of the linkage between the tropical Atlantic and the Mid-latitudes?

8. The Response of the Upper Ocean to Atmospheric Forcing in the Northwestern Corner of the Subtropical Gyre in the North Atlantic—*Amy Bower*

The highest buoyancy fluxes into the ocean in the North Atlantic occur in a narrow band in the northwestern corner of the subtropical gyre. This band is aligned with the mean path of the Gulf Stream, and results from strong evaporative cooling when cold, dry continental air flows over the warm surface waters during winter. These cold air outbreaks are episodic and their number and intensity vary interannually. Cooling during outbreak events is the first step in the transformation of warm, light surface water to colder, denser deep and intermediate waters along the upper limb of the Meridional Overturning Circulation, and as such has an important effect on the subsequent evolution of surface water properties.

We propose a process-oriented study of the effect of cold air outbreaks on the upper ocean in the northwestern North Atlantic. The primary objective of the research is to directly observe the changes in stratification and heat content in the upper several hundred meters along fluid particle pathways in the Gulf Stream and North Atlantic Current. This will be accomplished by deploying profiling floats that will drift submerged in the upper several hundred meters and periodically surface to obtain a vertical temperature profile and a position fix. The floats will be launched sequentially at regular intervals during winter from a ship of opportunity steaming between New York and Bermuda. Interannual variations will be characterized by repeating the deployment strategy for three winters. The floats will drift with the currents for at least one year, and therefore will observe the complete seasonal cycle along each float track.

9. WFDAC: The WOCE-CLIVAR Subsurface Float Data Assembly Center—*Phil Richardson and Chris Wooding*

We propose to continue the WOCE-CLIVAR subsurface float data assembly center (WFDAC) for another *5* years until the WOCE float data have been assembled and made available to the oceanographic community. Over 2000 floats have been launched during WOCE and they are becoming available in larger numbers. Previously we assembled earlier historical float data.

10. Ocean Circulation and Variability in the North Atlantic Current and Subpolar Gyre from Satellite Altimetry—*Dave Fratantoni and Phil Richardson*

The Atlantic Climate Change Experiment (ACCE) is a 4-year oceanographic program to determine the circulation and variability in the North Atlantic. Oceanographic observations during this experiment include hydrographic sections, subsurface floats, and surface drifters. We propose to augment these measurements with satellite altimeter data to examine the surface circulation of the North Atlantic Current and the subpolar gyre. In cooperation with Robert Cheney of the NOAA Laboratory for Satellite Altimetry, we will compile a hydrographic, surface drifter, and shipdrift climatology and evaluate numerical model simulations in an effort to determine the long-term mean dynamic topography and to assess upper-ocean variability.

11. Holocene Paleoclimate Studies with Centennial Resolution —*Lloyd Keigwin*

A full understanding of climate change over past millennia and into the coming century requires proxy data from geological samples of the ocean. The argument is simple. Instrumental observations of atmosphere and ocean properties are short; quality data are limited to the past 100 yrs at best, yet it is axiomatic that variance in climate increases with length of timescale. There are special locations on the seafloor where proxy data such as oxygen isotope ratios in carbonates can be used to reconstruct past ocean temperatures and salinities. In the nearshore environment, geologists have at their disposal mollusk shells and corals which accrete calcium carbonate in annual bands, and in the deep ocean sediment cores and solitary corals contain records of climate and ocean change on decadal to millennial timescales. This project will exploit many such locations around the North Atlantic by mapping patterns of climatic variability using geochemical techniques. It will begin by evaluating the suitability of existing samples and then continue by targeting new locations with a month long expedition at sea. One of our overriding goals will be to determine the ocean's role in climate change on the century timescale. Recent studies of the North Atlantic Oscillation have made predictions about ocean ventilation on decadal timescales, and recent geological studies have found an opposite response on millennial timescales. It will be particularly rewarding to work at the century timescale, the very timescale on which human influence is probably occurring.

12. Modeling the Ocean Climate—*Mike Spall, Sonya Legg, Xin Huang, Jiayan Yang and Glen Gawarkiewicz*

We will examine the sensitivity of the simulated ocean climate and its variability to small and mesoscale processes and their parameterization, and to variations in the surface forcing conditions (wind stress, heat flux, and freshwater flux). Numerical models of the ocean are essential tools for understanding the ocean climate and its variability, and for predicting future changes in

the ocean climate. Large-scale numerical simulations run for many tens or hundreds of years must necessarily be at coarse resolution; therefore physical processes acting below the grid scale (e.g., mesoscale variability, microstructure) must be approximated through parameterization. Unresolved mixing processes play an important role in modifying the ocean stratification, and thereby affecting circulation; for example by communicating atmospheric fluxes to the ocean interior (e.g., oceanic convection), controlling the abyssal diapycnal mixing (e.g., internal wave dissipation, double diffusion), and modifying the inflows from marginal seas (entrainment in overflows). Similarly, parameterizations of the fluxes of heat, freshwater and momentum across the air-sea interface and into the oceanic mixed layer, and the physics of ice formation are necessary to evaluate the response of the ocean to atmospheric climate variability, and the feedbacks of the ocean on the atmosphere.

We propose to combine our expertise in study of these small and mesoscale processes, their parameterization, and modeling of the large-scale ocean to quantify the sensitivity of the large-scale ocean climate and its variability on time-scales from decades to millennia to the unresolved processes and their parameterization and surface forcing variability. We will refine existing parameterizations to account for new features recently understood through high-resolution simulation and observation, and develop parameterizations where none currently exist through explicit simulations of the relevant processes. These parameterizations will be implemented in both idealized and realistic geometry general circulation models (using for example the GFDL MOM code, or Miami Isopycnal Coordinate Ocean Model). Our focus will be on the sensitivity of the large-scale ocean climate and its variability on decadal and longer timescales to the representation of the unresolved processes. Our goal is to develop models that are capable of realistically simulating important climate processes in the ocean. We will use these models to examine mechanisms by which climate anomalies are propagated from the sea-surface through the oceanic interior, and study the phenomena that lead to interannual and interdecadal climate variability in the oceans (e.g., ENSO and NAO) including pathways of interaction between physical processes on different scales.

The modeling studies outlined above will be carried out in close collaboration with scientists working on observational aspects of low frequency climate variability both at WHOI and NOAA. Comparisons will be made with existing climate records such as SST, SSH, atmospheric pressure and storm track anomalies (such as characterized by the NAO index), ice cover, and hydrographic data. A key role of the models in this context is to provide a dynamically consistent means of interpolating the observed data in both space and time. Sensitivity studies will be carried out to distinguish between forced and natural internal modes of variability. Key regions and quantities that yield robust signatures of the climate state and the propagation of climate anomalies will be identified in the model studies. Such an understanding will aid in designing observational networks and developing long-term monitoring strategies (i.e., what, where, and how often to observe).

13. Influence of Atmospheric Processes on the Ocean's Carbon—*Maureen Conte*

The atmosphere is a major source of particulate carbon and many other elements to the ocean (Duce et. al., 1992). The atmospheric delivery of terrestrial organic carbon to the oceans is thought to be of the same order of magnitude as riverine inputs (Buat Ménard et al., 1989).

Some dust-borne elements may function as essential micronutrients that enhance plankton productivity and/or alter species composition. For example, it has been hypothesized that the airborne Fe flux may control nitrogen fixation rates in oligotrophic regions (Martin et al., 1991), and that flux ratios of micronutrient elements such as Zn and Co may control phytoplankton species composition (Sunda and Huntsman, 1995*)*. These changes may, in turn, alter the earth's radiative balance and climate by altering DMS production and formation of cloud condensation nuclei (Charlson et al., 1992). The atmosphere is the primary source of many pollutants to the oceans. Some of these anthropogenically-derived metals (e.g., Pb, Hg, Cu, Se) and organic compounds (e.g., PAH, PCB) may have a deleterious effect on plankton productivity.

Aeolian fluxes of particulate carbon and dust-derived elements to the oceans are intimately tied to basin-scale climatic variables such as rainfall, atmospheric circulation and wind strength which affect the terrestrial biota, aridity and wind-driven material transport. The North Atlantic, by virtue of its proximity to the continents and pollution sources, is particularly impacted by aeolian-derived constituents, both natural and anthropogenic. The delivery of airborne materials to the surface Atlantic varies significantly over seasonal and interannual timescales due to changes in basin-scale climate and meteorological patterns (Prospero and Ness, 1986, Moulin et al., 1997) and also due to secular changes in anthropogenic emissions (Huang et al., 1996). Yet, the effects, both positive and negative, of this large atmospheric input on upper ocean productivity and ecosystem functioning are largely unknown.

The sinking flux of biogenically-derived material to the deep ocean controls biogeochemical cycling of carbon and many other elements that are involved in biological systems. In addition, biological scavenging also acts to incorporate nonbiogenic materials in sinking particles (Deuser et al., 1981, 1983), and hence constitutes a major removal mechanism for mineral components such as dust and anthropogenic pollutants. Particle export to the deep ocean appears to be tightly coupled to upper ocean productivity, which in turn is significantly coupled to atmospheric processes.

Climatic change is likely to significantly alter meteorological forcing patterns and also aeolian fluxes to the western North Atlantic. We have very little understanding of how these changes might impact the oceanic productivity and carbon cycling. There is an urgent need to predict the future effects of anthropogenic climate change on ocean functioning and to interpret the oceanic sedimentary record in terms of past climate change. This demands that we have a better understanding of the interrelationships among atmospheric forcing, upper ocean productivity, and sedimentation patterns in the deep ocean. Sustained observations have been and will continue to be essential to identifying causal relationships and the interactions among processes occurring on different time-scales.

The broad objective of this research is to improve our knowledge of the linkages between atmospheric processes, upper ocean biology and material fluxes to the deep ocean. The proposed work focuses on time-series studies of atmosphere/ocean interactions in the western North Atlantic, and builds upon the existing wealth of time-series measurements at Bermuda and established collaborations among the BATS, OFP and BTM program PIs. We plan to concentrate our efforts in two broad areas:

Weather, Aerosols and Upper Ocean Biogeochemistry: We will continue the current measurements of atmospheric fluxes of organic carbon compounds (both natural and anthropogenic) and key inorganic elements to the surface ocean as well as standard meteorological variables (e.g., temperature, wind speed and direction, humidity, rainfall) at Bermuda. These measurements will be made at the air sampling tower facility at Tudor Hill (the AEROCE site). They will be coincident with measurements of upper ocean physics and biogeochemistry (BATS, BTM programs) and particle flux (OFP program). These new measurements will augment and lengthen existing time series of coincident atmosphere/ocean observations at Bermuda. This research would also utilize NOAA weather products and satellite data (SEAWIFS). The aim is to understand how interannual variations in meteorological patterns in the North Atlantic affect atmospheric fluxes to the western North Atlantic, and how these in term affect upper ocean biology and particle flux. For example, can the observed variability in particle flux be related to NAO status and/or variability in atmospherically-forced mixing events? The synthesis of these datasets would help determine the causal linkages and interrelationships among atmospheric processes, ocean productivity and carbon cycling.

Development of Molecular Proxies for Paleoclimate Studies of the North Atlantic: The ongoing OFP time-series has generated an unprecented 20+-year record of sedimentation patterns in the deep Sargasso Sea. Resident within the collected material are chemical signals of material sources (both natural and anthropogenic), upper ocean ecosystem structure, climatic indicators (e.g., aeolian inputs) as well as clues to processes controlling the particle flux. We will make detailed analyses of key trace constituents of sediment trap material, and correlate their flux patterns to upper ocean processes. These proxies can be used to probe deep moored particle flux time-series to provide crucial information on ocean functioning in the absence, of significantly more costly and labor intensive shipboard measurement programs. These proxies will also be used to decipher the century to millennial scale record of Atlantic climate variability, which is preserved in sediments of the nearby Bermuda Rise. This area is a major focus of the NOAA Atlantic Climate Change Program.

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14. Aerosol and Trace Gas Sensors: Autonomous Buoy-Mounted Systems—*Ed Sholkovitz*

Aerosols play substantial roles in the earth's radiation balance and climate and atmospheric chemistry and are involved in important biological and chemical processes in the oceans. The deposition of dust from the continents is thought to enhance biological productivity in the oceans, the production of non-seasalt sulfate from ocean sources influences the formation clouds, and the injection of seasalt aerosols can affect the removal of ozone in the troposphere. Hence, sampling of aerosols near the ocean-atmosphere boundary and in the marine boundary layer (MBL) is important with respect to understanding short and long term changes in climate, atmospheric chemistry and ocean productivity.

Certain marine phytoplanktons release gaseous dimethylsulfide (DMS) that is transported across the ocean/atmosphere boundary to the marine boundary layer where atmospheric chemical reactions convert DM5 to NSS particles. This combination of biology, biogeochemistry, physical transport and atmospheric chemistry leads to the oceans being the major source of NSS aerosols that affect climate as they are important in the formation of clouds. The quantitative relationship between phytoplankton productivity and DMS emissions to the marine boundary layer remains elusive. Ozone plays a central role in the atmospheric chemistry of the MBL including that of oxidizing DM5 through OH production.

Areas of research that can be addressed with aerosol and trace gas data from buoys are:

(a) Environmental: Directly determining the off shore transport of contaminants to ocean, estuaries and lakes. Removal of ozone from the MBL.

(b) Oceanic: Effect of mineral dust on the ocean's trace element composition and biological productivity vis-à-vis the Fe Hypothesis.

(c) Climate Forcing: Sulfur Cycle (Production of NSS from DMS).

(d) Radiation Balance: Role of anthropogenic mineral aerosols on the Earth's climate.

(e) Marine Meteorology: Production and transport of sea spray and seasalt droplets under different wind and wave conditions.

(f) Optics: Attenuation of electromagnetic radiation above the ocean.

Why use a buoy? The episodic nature and large variability in aerosols concentrations and fluxes are difficult to capture in any systematic fashion using ships or aircraft. Shipboard measurement inevitably misses many important events. Buoys can stay on station in strategic regions for 3-6 months, thus providing a less expensive and alternative platform for long-term time-series research and monitoring programs and for short-term field experiments. Having buoy-mounted samplers and sensors remotely controlled from shore would open up new research possibilities. Sampling could be event-based, that is based on satellite pictures of outbreaks of dust and biomass burning from the continents, increased biological productivity or volcanic eruptions.

The central theme and long-term scientific objective of this proposal is the application of buoy-mounted sensors to important oceanic and atmospheric problems involving aerosols and trace gases. While the focus of this proposal is on technology, the scientific questions being addressed are fundamental in nature.

15. Arctic Air-Sea-Ice Interaction and Global Climate—*Andrey Proshutinsky, Jiayan Yang, Cecilie Mauritzen, Al Plueddemann*

The Arctic is a unique region where interactions between ocean, atmosphere and ice contribute to complex processes which are linked to global atmosphere and ocean circulation and ultimately to global climate variability. Climate models have shown that the Arctic has a particularly high sensitivity to climate change due to several feedback mechanisms that are poorly understood at present. In fact, our knowledge of the Arctic system and its variability today and in the past is still very limited. Observations and modeling results demonstrate that the recent history of the Arctic is characterized by: a significant change in the ocean circulation (first detected in the early 1990s); a decrease in summer ice cover (over the past 20 years); changes in meridional exchange between the North Atlantic and Polar regions (especially pronounced since about 1950); significant warming of the core of the Atlantic Water; changes in the freshwater flux out of the Arctic Ocean; and a significant decrease of sea level pressure and increase of sea level. We propose observational and numerical modeling projects that will seek to elucidate the principal processes of air-sea-ice interaction in the Arctic and determine the links between Arctic processes and changes in the global atmosphere and ocean circulation on interannual to decadal time scales.

Below are examples of the types of projects that might be undertaken. These are meant to be representative, but not exclusive.

Variability of Thermohaline Circulation and Freshwater Storage: The Arctic Ocean is strongly salt-stratified, with about 45,800 km^3 and 12,200 km^3 of fresh water stored in the Canadian and Eurasian Basins, respectively. The freshwater storage results in a persistent salinity anomaly (minimum salinity at depths from 5 m through 400 m) in the center of the Beaufort Gyre that drives the thermohaline circulation of the Arctic Ocean anticyclonically. The origin of such a freshwater distribution has not been discussed and explained previously. Many 3-D ocean models fail to properly reproduce this salinity anomaly in their multi-year runs. The freshwater budget of the Arctic Ocean and freshwater output to the North Atlantic depend significantly on the intensity of this salinity anomaly, the direction of the thermohaline circulation, and availability of fresh water from the Beaufort Gyre. The fundamental questions for this project would be: What is the mechanism for accumulation of fresh water in the center of the Beaufort Gyre? Is this fresh water transported to the North Atlantic and what are the conditions that influence its rate of transport? What is the primary driver of the Arctic Ocean circulation, thermohaline or wind-driven forcing? How does the wind-driven circulation change the thermohaline structure and resultant circulation seasonally, annually, and decadally?

Pathways and Fate of Atlantic Water in the Arctic: The Atlantic Inflow to the Arctic represents the northernmost warm limb of the global thermohaline circulation, and its heat content is distributed in the Arctic Ocean. The fast spreading to the Arctic interior of the dramatic Atlantic Water heating in the 1990's demonstrated that the heat distribution occurs on a short time scale. An observational study would be undertaken to determine the pathways and fate of the Atlantic Water in the Arctic. The main questions to be addressed are: what are the driving mechanisms behind the oceanic exchange between the North Atlantic and the Arctic; how does the Atlantic Water fill the intermediate layers of the Arctic; will a change in the inflow conditions or in the interior circulation of the Atlantic Water impact the sea ice cover above?

Investigation of Arctic Ocean Sea Level Rise: Tide-gauge stations in the Kara, Laptev, East-Siberian and Chukchi Seas have recorded Arctic sea level change from the 1950s through 1990s. Over this 40-year period, most of these stations show a significant sea level rise. Sea level rise is one of the manifestations of warming in the Arctic, and has important and specific consequences such as increases in coastal erosion and thawing of permafrost. Observational data analysis in combination with comparison from numerical models will provide the basis for this research. The project would seek to further our understanding of the Arctic climate system by (1) identifying links among atmospheric, hydrologic, cryospheric and oceanic processes, (2) quantifying the regional and temporal variability of relevant processes in terms of sea level response, and (3) determining the relative importance of each factor influencing sea level change under global warming conditions.

Sea-Ice Variability and Upper Ocean Processes: Satellite observation has shown that the aerial coverage of sea ice in summer has been decreasing by about 2.5% per decade since the advent of satellite-borne observations in the 1970s, and rather rapidly since the early 1990s. One of the key processes that may have played a role in this variability is the change of hydrographic structure in the upper layer. Observations indicate that the Arctic halocline has thinned in the recent decade, and such a change may have affected the exchange between the mixed layer and the warmer water beneath it. Preliminary analyses indicate that synoptic scale storms may produce sufficient mixing to penetrate through the halocline. Such mixing events can result in

warming the mixed layer and subsequent changes of sea-ice concentration. Surface wind fields from numerical weather prediction models, *in-situ* observations from drifting buoys, and an ocean mixed layer model could be used to examine the overall impact of such storm-driven mixing in the heat budget of the Arctic mixed layer. Basin scale analyses of atmosphere-ocean-ice heat flux could be done with the benefit of multi-sensor satellite data (surface temperature, albedo, cloud fraction, ice concentration) and used to identify key factors (e.g., albedo) that are important for the overall atmosphere-ocean-ice heat flux.

Ventilation of the Halocline by Boundary Processes: The Arctic halocline is presumed to be ventilated by exchange with water originating on the Arctic shelves. The problem is made difficult by the fact that the dynamics of dense water formation on the shelf or upper slope are intimately coupled to the dynamics of western boundary currents in general. Thus, in order to fully understand the issue of high latitude shelf/slope exchange, it is necessary to consider various components of the system simultaneously, from the shelf to the deep ocean. Specific areas of interest are the role of the ambient shelf-break circulation and deep slope currents in driving cross-slope exchange between shelf and basin. Two issues seem to be of particular importance in enabling the boundary to communicate with the open ocean: variable topography and deep slope currents. Along-slope variations in bathymetry may impact the dynamics of the shelf-break jet, inducing secondary circulations that span the entire water column. This in turn influences the stability characteristics of the jet, and may lead to eddy formation and cross-slope exchange. Variability of deep slope currents may couple with the shelf-break circulation in forming boundary eddies that subsequently populate the interior.

16. Synthesis of Coordinated Changes in the Ocean-Ice-Atmosphere System of the Northern North Atlantic—*Cecilia Mauritzen*

Fundamental changes in the state of the North Atlantic system are occurring, on timescales ranging from annual to decadal and even longer. We know that the North Atlantic Ocean is responsible for a significant proportion of the poleward heat transport within the climate system, and thus contributes to maintaining the climatic conditions of northern Europe. Thus a basic question in climate research is: "Is there variability in the northward heat transport, and, if so, what is the chain of events that leads to this variability?"

The strongest decadal-scale signal detected in the North Atlantic is that of the North Atlantic Oscillation (NAO). NAO technically tracks the atmospheric pressure difference between Iceland and the Azores, and it is found to have a strong impact on ocean and ice conditions in the northern North Atlantic and even in the arctic regions. There is also evidence to suggest that other interannual/decadal scale climate signals may be present, notably the El Niño/Southern Oscillation (ENSO) in the northern hemisphere sea ice cover.

The strength of the meridional overturning cell (MOC), which carries the heat northwards, is related to the rate of dense water formation as well as to the rate of entrainment and change in volume of water masses. The rate of dense water formation is related to the atmospheric conditions (surface cooling, E-P, etc.), freshwater fluxes associated with ice transport, and to the surface densities of the ocean. The task is to create time series associated with these parameters, by considering the North Atlantic as a set of boxes to which numbers are to be

attached and on which budget calculations can be performed. The goal is to establish, using all available data, which time scales of variability can be detected in the system and which time scales are coordinated in all three media, and then to synthesize this information into a set of hypotheses, consistent with the dynamical constraints of the system, to explain the interplay between ice, ocean and atmosphere in creating such variability.

C. MARINE ECOSYSTEM PROCESSES ANALYSIS

1. Trace Element Markers for Dispersal of Larval Clams—*Lauren Mullineaux*

A new research project is underway to investigate the use of naturally occurring trace metals in shells of juvenile clams as markers of the specific location where the clams settled. A mechanism to trace the geographic origin of clams collected from the field would be a powerful tool for understanding dispersal of populations at the post-larval stage. This capability would enable resource managers to understand where important source regions are, how much exchange occurs among populations and how far individuals from polluted areas are transported.

2. Evolution and Phylogeny of Hydrothermal Vent Fauna—*Ken Halanych*

The origin of the uniquely adapted fauna of the hydrothermal vent communities is uncertain. There is debate over whether these species are of ancient or recent origin, and whether they were originally deep-sea species that adapted to a chemosynthetic regime, or shallow, chemosynthetic species that adapted to the deep sea. Molecular methods for determining phylogenetic relationships will be powerful tools for understanding the relationships of the vent fauna to other species in the ocean.

3. Dispersion and Recruitment of Coastal Benthic Populations—*Jesus Pineda*

There are opportunities for continuing work on dispersal of planktonic larvae by mesoscale physical forces, and the role of climate variations, such as El Niño, in changing patterns of dispersal and recruitment of nearshore species. The research involves biology, physical oceanography, climatology and modeling studies, with likely collaboration with NOAA Global Climate programs, and NOS.

4. Dumpsites—*J. Farrington*

Biogeochemistry and Biological Effects of Petrochemicals, Petroleum, Trace Metals, and Radionuclides of Environmental Concern in the Oceans: The Institution has had a leading role from the 1950s to the present in understanding the input, fate, and effects of chemicals of environmental concern (e.g., petrochemicals, radionuclides, trace metals) when deliberately or inadvertently discharged to the oceans as a result of human activities; directly from land or ships, and indirectly from land by way of the atmosphere. Institution scientists contributed to early understanding of the global distribution and transport to ocean depths of radionuclides from atmospheric nuclear weapons tests in the late 1950s and during the 1960s. At the same time research concerned with sewage and chemical waste disposal to coastal areas (e.g., the New York Bight) was sounding the alarm about promiscuous use of the oceans for waste disposal.

Pioneering research on the fate and effects of oil spills was accomplished at the Institution in the late 1960s and early 1970s, forming the basis for research at WHOI, and in collaborations with colleagues at other academic institutions and federal government agencies, that continue to the present for inputs, fates and effects of petroleum chemicals in the oceans from all sources. Similar research on other types of chemicals of environmental concern such as polychlorinated biphenyls and similar petrochemicals, persistent pesticides, various trace metals and transuranic radionuclides contributed significantly to the firm scientific basis for reduction or elimination of discharges of several of these chemicals to the oceans:

WHOI scientists conducting biogeochemical research were major contributors in the 1970s and early 1980s to the design and testing of a prototype monitoring program "Mussel Watch", and then implementation in the 1980s of the NOAA Status and Trends Program for monitoring chemical contaminants in surface sediments and bivalve organisms and selected other organisms in the nation's coastal areas. Concurrently, Institution biologists began pioneering efforts that continue to the present advancing understanding of sublethal, chronic effects of chemicals of environmental concern at sub-cellular, cellular, organismal, population, community, and ecosystem levels of organization. Some of this research was in collaboration with NOAA's Northwest Fisheries Center-Seattle research efforts. Other aspects were conducted with funding from programs m NOAA concerned with ocean dumping, and from the Sea Grant program. Recent (1990s) study areas have included the Deep Water Dumpsite 106 off the New York and New Jersey coasts on the continental slope, the New Bedford Harbor (Massachusetts) Super-fund Site (PCB Pollution), Boston Harbor (Massachusetts), Massachusetts Bay and the Gulf of Maine.

Biogeochemistry of Petrochemicals and Trace Metals in the Continental Margin and Deep Ocean: Sewage sludge from the New York area was dumped for several years into surface waters at Deep Water Dump Site 106 off the coast of New Jersey and New York in the continental slope area. Scientists from WHOI collaborated with colleagues from Rutgers University, the University of Maryland, State University of New York at Stony Brook, Bristol University in the United Kingdom, Tokyo University of Agriculture and Technology in Japan, the United States Geological Survey, Woods Hole, NOAA researchers, and scientists from NOAA and other government contractors to study the fate and effects of these sewage discharges. Petrochemical tracers such as the linear alkyl benzenes (LABS) from household and industrial detergent inputs to sludge, silver to aluminum ratios, and Chlostridium (bacteria in sludge) were measured in surface sediments sampled carefully by DSV Alvin. These analyses unequivocally documented the arrival and accumulation of sludge particles in the continental slope surface sediments approximately 2,000 meters below the surface water dumpsite in a pattern of deposition consistent with predicted particle movement in the overlying and near bottom waters. Analyses of stable isotope ratios of carbon, nitrogen and sulfur in sludge particles and in benthic animals demonstrated that the animals fed on significant amounts of sludge organic matter once it was deposited to the area.

Sludge dumping ceased in the early 1990s, a few years after it began. However, the biogeochemical "experiment" in the surface sediments and benthos of the dumpsite region continues. Much valuable information can be gained about fundamental biogeochemical processes by following the fate of the tracer chemicals introduced to the surface sediments and

benthos. This is a unique experiment in progress in the continental slope area. We know of no other similar "experiment" in the world's continental slope and rise areas.

In addition to the fundamental understanding of biogeochemical processes, there is another important aspect to this research. Oil tankers and bulk cargo ships carrying chemical cargoes and oil tankers have sunk in deep waters and it is likely that accidents of this type will happen in the future despite the best efforts at prevention. The technology and research approaches used at Deep Water Dumpsite 106 have proved the capability for assessing and monitoring these types of accidents for accumulations of chemicals in surface sediments and benthos and are valuable to wise, effective management of resources in Exclusive Economic Zones and valuable open ocean, deep sea habitats.

Coupling of recent ocean bottom survey and mapping techniques using towed sonar and camera systems and ROVs, such as those deployed and proved by WHOI Deep Submergence Laboratory scientists and engineers in the recent expedition to the Derbyshire site, with ROV mounted sediment and biota sampling systems, and development of more efficient chemical/biochemical sampling and sensor systems would provide a much improved and more efficient capability. In addition, development of AUVs with chemical sensors and moored chemical sensor arrays would provide an efficient capability to assess and monitor such accidents for accumulation of chemicals in surface sediments and benthos in deep waters over long periods of time.

Fate and Effects of Chemicals in Urban Harbor Sediments: Marine chemists and biologists at WHOI have been studying the long-term fate, biological availability, and effects of industrial organic chemicals, petroleum and combustion product polynuclear aromatic compounds, and trace metals accumulated in urban harbor sediments since the early 1970s. Initially this involved research in analytical chemistry methodology followed closely by documentation of the accumulations in the sediments as a result of human activities. Then questions about the long term fate and effects were posed and are subjects of ongoing research. Some harbors such as New Bedford Harbor have such severe chemical contamination/pollution that they have been designated as EPA Superfund sites.

As the inputs of chemicals from human and industrial waste streams are reduced, the surface sediments in these harbors are a real and potential continuing source of chemical contamination and adverse effects on valuable living resources in coastal and estuarine areas. In addition, chemically contaminated sediments are building up in present and planned navigation channels. Dredging of these channels to allow for continued international maritime-based trade is adversely impacted by uncertainties surrounding the safe dredging and disposal of dredge spoils.

We envision a collaborative effort between WHOI biologists and marine chemists and colleagues in NOAA laboratories (e.g., the Great Lakes Research Laboratory and the Northwest Fisheries Laboratory, Seattle) in research on the crucial questions surrounding bioavailability of chemicals in the sediments, biological effects, and bioremediation research.

5. Fish Target Strength Measurements and Modeling in Support of Acoustic Surveys of Fish—*Tim Stanton*

Acoustic surveys of fish schools are routinely performed by many NOAA vessels. The surveys can produce high resolution, high speed, synoptic information over the entire water column of distributions of fish. A critical element of the survey effort is to relate the acoustic echo levels to meaningful biological quantities such as animal length and numerical density. The combination of these two quantities results in estimates of the total tonnage of various fish stocks. Accurate estimates of tonnage have both commercial and ecological importance.

Relating the echo level to the important biological quantities involves development of acoustic scattering (target strength) models. While there are adequate models for some animals, others are inadequate and some do not exist. This lack of models limits the degree to which acoustics can be used to quantitatively survey the animals. Development of accurate models requires extensive controlled measurements of acoustic scattering by the animals. At WHOI, we have developed a pulse-echo laboratory for making acoustic scattering measurements of live animals and have amassed ten years of experience using the setup, mostly with macrozooplankton (and in one case, fish). The computer-automated system is fully operational and is routinely used to perform measurements over a wide range of acoustic frequencies and angles of orientation.

We propose to develop target strength models of fish relevant to the NOAA mission. The development will make use of the extensive capabilities of our acoustic pulse-echo laboratory. We will perform acoustic scattering measurements of live fish over a wide range of frequencies and all angles of orientation. These measurements will include (but not be limited to) frequencies that NOAA vessels use such as 38 kflz and 120 kHz. The data will serve as a basis for physics-based scattering models that can be used to predict a wider range of animal sizes than those involved in the experiment.

The measurements will follow procedures that have been refined over many years in our laboratory. Each fish used in the measurement will be live since it is well known that the acoustical properties of the fish change once the animals die. The individual fish will be suspended in the acoustic beam with an arrangement of acoustically transparent tethers. The animal will be sufficiently constrained so that controlled measurements of target strength versus angle of orientation can be performed. The tether will be suspended from a framework that is rigidly attached to our computer-controlled stepper motor. After each ping is transmitted and recorded, the animal is rotated a precise amount until the next ping is transmitted. The sequence is repeated until all target strength data are collected for that particular frequency. The procedure is repeated for the other acoustic frequencies. The suite of target strength data will initially be compared with existing mathematical acoustic scattering models. Certain parameters that are normally determined empirically will be tuned according to the data to obtain a best fit. If the best fit to these data does not provide satisfactory agreement with the data, then a new model will be developed. Once a satisfactory model has been completed, we will make the model available to NOAA scientists for interpretation of their acoustic surveys of fish.

6. Quiet Fish Survey System—*Tim Stanton*

Fish schools are routinely surveyed by many NOAA vessels. Whether the sampling device is a net or acoustic system, a major problem in the surveys is the fact that the ships radiate a significant amount of noise. This noise can cause the fish to avoid the ship. As a result, the fish may be grossly under sampled in the survey, thus invalidating the survey.

We propose to solve this problem by constructing a quiet fish survey system that could be deployed by a NOAA vessel and accurately survey the fish without disturbing them. The system would be composed of an Autonomous Underwater Vehicle (AUV) with an autonomous acoustic echo sounder mounted on it. AUVs are inherently much quieter than a full size ship and could survey a region populated by fish without disturbing them. Use of the device would first involve the ship traveling to the survey site. The AUV would then be deployed into the region containing the population of fish and perform a preprogrammed survey of the area. During the survey, the echo sounder would repeatedly ping and record the echoes from the animals (in a manner similar to what ship-board echo sounders do). After the survey is completed, the AUV would return to the ship via use of a navigation transponder and be retrieved. Once the AUV is onboard the ship, the data are extracted from the AUV and the system is returned to the water with fresh batteries for the next survey.

Use of this quiet fish survey system would solve a longstanding problem that scientists have had in surveying fish, regardless of what sampling technology they used. Furthermore, it is low risk as the construction of the system would involve configuration of existing technology that is residing at WHOI. The system would consist of the autonomous underwater vehicle REMUS **(R**emote **E**nvironment **M**easurement **U**nit**S)** with an acoustic echo sounder system mounted on it. The REMUS system, which has already been successfully built and tested by WHOI engineers, is small enough (6 feet long) so that it can easily be deployed by any NOAA vessel with no special handling requirements. Echo sounder electronics have already been successfully built and tested in the field with a REMUS system.

The project would involve first assembling a REMUS from existing plans and integrating the necessary subsystems into it (including autonomous echo sounder electronics, navigation sensors, and CTD; all from existing plans). The completed system would then be tested in local waters at WHOI. Tests would include implementing various survey tracks as well as calibration of the acoustic system. Once tests are completed, the system would be deployed at sea to survey fish populations. The deployments would be performed in collaboration with NOAA scientists.

7. Marine Mammal Population Dynamics—*Hal Caswell*

Understanding the dynamics of marine mammal populations is essential to management of these species. NOAA is mandated by law to assess annually the status of all populations of marine mammals in U.S. waters, and to formulate regulations based on the results of those assessments. The analysis of marine mammal population dynamics raises challenging problems in fundamental population biology. Researchers in the Mathematical Ecology program at WHOI have made important contributions to population dynamics theory, and have recently begun to apply these models to marine mammals.

Individual organisms experience rates of birth, survival, development, growth, and reproduction. On the one hand, these rates reflect the environment of the individual, and all the natural and anthropogenic factors that determine it. On the other, they determine the changes in abundance, distribution, and structure of the population from one year to the next. To study marine mammal population dynamics requires, first, ways to extract estimates of the vital rates from data on individuals. Then those rates must be incorporated into population models that can project the future behavior of the population under a variety of environmental scenarios. These models can be used to compare effects of different management strategies, and to evaluate the effects of model assumptions. Because all population data are imperfect, it is important to assess the sensitivity of the conclusions to uncertainty.

We are interested in exploring all these steps. For example, an increasing number of programs in the U.S. and abroad maintain photographic identification databases on individual whales. WHOI researchers have developed methods to extract demographic data from such databases and incorporate it into population models (Brault and Caswell, 1993, Caswell et al., 1998a). These methods have proven to be powerful tools, but there is still no general theory for estimating parameters from catalog sighting data. We are also interested in exploring aspects of the model (e.g., nonlinearity, environmental and demographic stochasticity) that are seldom examined. In collaboration with some NOAA scientists, we have recently developed a method for uncertainty analysis and applied it to incidental mortality of harbor porpoise (Caswell et al., 1998b), and would like to extend the results.

Our specific research interests in marine mammal population dynamics include, but are not limited to, the following:

(i) Development of generally applicable methods for extracting demographic information from photographic identification catalogues.

(ii) Exploring the relationship between Monte Carlo methods for uncertainty analysis and Bayesian methods for parameter estimation.

(iii) Exploring the effects of small population size on stage-structured population models (the demographic stochasticity problem, central to population viability analysis for very small populations).

(iv) Evaluating the effects of environmental stochasticity on population viability analysis and on the stock assessment procedures mandated by the Marine Mammal Protection Act.

(iv) Developing detailed demographic comparisons between the North Atlantic right whale, which is recovering extremely slowly (or, if recent results are correctly, not at all) and the South Atlantic right whale, which is recovering much more rapidly. The goal of this study would be to pinpoint the critical points in the life cycle responsible for the situation in the North Atlantic.

References:

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8. Aquatic Toxicology—*John Stegeman, Mark Hahn, and Judy McDowell*

Aquatic toxicology research that could be done includes:

Mechanisms of Action and Induction of Biochemical Responses: There is a long history of research here on the mechanisms by which different categories of pollutants (hydrocarbons, PCBs, metals, etc.) are taken up by animal tissues, how they affect the physiology and biochemistry of different organisms, and what responses are induced in the organism that either ameliorate the effect, or lead to other harmful consequences. Much of the work has centered around a family of enzymes, Cytochrome P45 Os, which are almost universally involved in metabolizing and detoxifying foreign chemicals, and on receptor molecules, which are specific to classes of pollutants such as aromatic hydrocarbons. The mechanisms of action of these enzymes and receptors, and their characteristics in different species are being investigated at the biochemical and molecular genetic level.

Enzyme Induction as a Monitoring Tool: As a result of the research described above, it is possible to assay levels of cytochrome P450 enzymes as an index of exposure to particular pollutants. Methods like this are extremely valuable because they are less expensive than chemical analyses, are often a better indicator of actual exposure than measurements of pollutants directly in the environment, and they provide a sensitive measure of incipient biological effects. This approach is currently being developed for a variety of animals, including fish, birds and marine mammals.

Population Responses to Contamination: Pollutants often produce sub-lethal effects on growth or reproduction that can have impacts at the population level. Long term effects on populations in polluted areas can be assessed via changes in reproductive output or other life history parameters, in comparison with unpolluted control populations. Combined effects of chemical and pathogenic stressors may occur, and can be incorporated into population models.

Endocrine Disruption in Seabirds: Abnormal reproductive development in the endangered Roseate tern has been correlated with feeding in contaminated areas such as New Bedford Harbor. It is thought that PCBs and other chlorinated compounds act as chemical mimics of hormones, thereby causing reproductive abnormalities. Using chemical, biochemical, and immunohistochemical methods as well as cell culture bioassays, researchers measure exposure of

the birds to a variety of environmental contaminants and assess the relationship between reproductive abnormalities and concentration of -specific contaminants.

9. Studies of the Role of Body Condition and Nutrient Limitation on Reproductive Success in Endangered Species, such as Right Whales—*Michael Moore*

Ship-strikes and gear entanglement only account for about half the population growth failure in northern right whales. Compared to southern right whales, more northern females never calve and those that do have a prolonged calving interval. Inbreeding, chemical exposure and nutritional limitation may all be significant. Using ultrasound at sea we are testing the hypothesis that blubber thickness is predictive of the compromised reproductive success in northern right whales. Preliminary data support this hypothesis. We are now developing our system further to measure lipid content acoustically. What will then be practical is a long term monitoring project of body blubber thickness and lipid content in right whales of known reproductive history. This will have direct relevance to current Large Whale Implementation Team efforts, as the relative significance of physical trauma and habitat quality will be better understood.

10. Analysis of Critical Feeding Habitat of Northern Right Whales Using High Resolution Video Plankton Recorder Analysis—*Cabell Davis, Scott Gallager, Carin Ashjian*

Eastern Cape Cod Bay is a principal feeding ground for the northern right whale. The whales enter the bay during the winter/spring period to feed on dense patches of the copepods Calanus and Psedocalanus. The formation and persistence of these patches is critical for successful foraging of the whales, since the background concentrations of the copepods is insufficient to meet the whales metabolic needs. It is hypothesized that these patches typically form in tidally driven convergent regions due to the downwelling flow interacting with the surface-keeping behavior of the copepods. Although these patches appear to be predictable in location (due to the association of the convergence with bottom topography), they are ephemeral due to variability in wind forcing, which can dissipate the patches. The whales then must feed during the temporal windows when the patches are present. Understanding the timing and duration of copepod patch formation and persistence in association with the response time and foraging behavior of the whales will provide critical information on the factors controlling foraging success of the whales. In collaboration with Dr. C. Mayo of the Center for Coastal Studies, we propose to conduct a series of short rapid response cruises from a small research vessel (e.g., *Asterias)* to the right whale feeding grounds off Provincetown, MA. We will conduct local surveys of the area using the Video Plankton Recorder to obtain high-resolution distributional information on the copepod species in real time. These surveys will be done during calm periods immediately following strong wind events to measure the timing of patch formation. The sampling will be continued through the calm periods to measure the influence of tidally driven convergence on patch maintenance and into the initial phase of strong wind forcing to measure time scales of patch dissipation. The surveys will be conducted during the winter spring period for three consecutive years to determine the role of inter-annual variability on copepod patch formation. Sampling will be done in concert with observations of right whale foraging.

11. Development of Tag Systems for Collection of Acoustic, Behavioral, and Physiological Data from Marine Mammals—*Peter Tyack and Mark Johnson*

Tyack's lab and the Acoustic Systems Group in the Department of Applied Ocean Physics and Engineering at WHOI have been developing a method that is crucial for behavioral studies on the effects of noise on marine mammals that would provide useful data on risk factors involved in vessel collision and net entanglement. This involves the development of a tag that can record sounds heard at the animal. These sounds include the animal's own vocalizations, as well as ambient noise. Acoustic records from similar tags developed for seals also detect heart beat and breathing sounds. Other sensors included in these tags measure depth, water temperature, speed, pitch, roll, and heading of the animal. Sensors and attachments have been successfully tested on elephant seals, bottlenose dolphins, and right whales. After these successful pilot projects, we now need to design, build and deploy a miniaturized fully digital recording tag optimized for attachment to most marine mammals. We anticipate a three-year program, involving design and construction of a prototype in the first year, followed by two years of testing and building more refined models.

12. Behavioral Studies on the Impacts of Anthropogenic Ocean Noise on Marine Mammals—*Peter Tyack*

Acoustic recording tags are particularly powerful tools for studying behavioral responses to noise, because the same tag can measure the noise stimulus at the whale, while also measuring behavioral and physiological responses. This approach is particularly important for pelagic or deep-diving animals that are difficult to follow from above the sea surface. Species such as beaked whales and sperm whales are a high priority for studying noise-induced behavioral disruption. Funding for such a high priority project would involve one year for cruise preparation and two years with one 3–4 week cruise each year.

13. Model Assessments of Acoustic Trauma Incidence in Marine Mammals—*Darlene Ketten, Peter Tyack, and William Watkins*

Noise is a significant, unavoidable component of virtually every human marine endeavour, including shipping, research, military activities, fisheries, and recreation. Considering the breadth and magnitude of man-made noise in the sea, it is reasonable to assume that many if not all anthropogenic noise sources can have a significant adverse impact on marine animals. Because marine mammals are especially dependent upon hearing and in many cases are endangered, the concern over noise impacts on these animals is particularly acute. However, at the moment, we do not know whether manmade noise is indeed hazardous or whether it is largely irrelevant in the context of large-scale natural ambient noise in the oceans. The fundamental issues are: 1) how is the ambient noise spectrum changing in oceanic habitats as a result of human activities, and 2) do areas of high ambient noise coincide with species of marine mammals such that there is a significant risk of auditory or behavioral impact? To address these questions we need to review recent ambient noise data throughout the oceans in terms of its implication for auditory trauma and behavioral disruption. The noise data exist but, to date, they have not been integrated with information and estimates of impact on marine mammals. This requires several areas of expertise; i.e., familiarity with the mechanisms involved in acoustic trauma, familiarity with the hearing abilities and acoustic behavior of marine mammals, famil-

iarity with behavioral disruption due to noise stimuli, an understanding of relevant differences in marine vs. aerial ears, and access to regionally specific ambient noise data. We propose to combine the existing data sets and to develop a virtual map of the current marine noise floor vs. marine mammal hearing and vocalization acoustic parameters and population distributions. The resulting combined data set will be analyzed to identify "acoustic hotspots" where auditorially fragile species appear to coincide with acoustic activities with a substantial potential to damage hearing or disrupt key behaviors.

14. Behavioral and Auditory Factors in N.E. Regional Net Entanglements—*Peter Tyack and Darlene Ketten*

Another high priority marine mammal issue for the NE region concerns the entanglement of harbor porpoises in fishing nets. Little is known about how harbor porpoises detect or avoid obstacles such as nets. Tags that document movement patterns during a dive, as well as patterns of echolocation, will help to resolve these questions. Studies of tagged porpoises near nets will help in the development of effective measures to reduce this take. Postmortem analyses and comparisons of animals taken from nets with and without acoustic deterrents will allow us to determine also whether hearing impairments are a factor in entanglement and what percentage of the population is therefore likely to become entangled regardless of AHD use. The budget would support possible work with captive porpoises in a facility designed for rehabilitation and release of stranded porpoises as well as with fieldwork on wild animals. Audiometric tests of the stranded animals undergoing rehabilitation will focus on determining peak sensitivities and the slope of porpoise hearing curves in order to assist in the design of AHDs that are perceptible but unlikely to induce acoustic trauma. Behavioral work with these animals will similarly focus on determining frequencies that are socially or otherwise functionally significant, as in echolocation, and therefore important to consider as potential maskers or behavioral disruptors. Research on echolocation in captive harbor porpoises may also improve the design of AHDs that only ping when porpoises are echolocating nearby, or may improve the design of nets that are better targets for porpoise sonar.

15. Real-Time Acoustic Detection of the Calls of Right Whales for Input to the Right Whale Early Warning System—*Peter Tyack and Mark Johnson*

Human-induced mortality of right whales from collisions with ships and net entanglement account for about one third of total right whale mortality, and this excess mortality may inhibit the recovery of this highly endangered population. Efforts to reduce mortality from vessel collision have focused on Early Warning Systems (EWS) to alert vessels operating in waters near right whales. These Early Warning Systems need not locate and track each individual whale, but they must identify areas roughly 10 nmi x 10 nmi where whales are located. The primary methods used for locating whales have involved aerial surveys, which are estimated to have approx. 50-65% chance of sighting a right whale during an overflight. This sighting rate is low enough that other supplementary methods for locating whales are required for the EWS to significantly reduce the risk of collision.

Acoustic detection of calling whales, using a real-time coastal observational networks, is a promising option for supplementing whale sightings in the Early Warning System. This system would need to be capable of detecting and locating whale calls continuously 24 hr/day

within an area of roughly 10 km x 10 km. Calling rates of right whales are not well documented for their feeding or breeding areas, but as long as one whale within an aggregation called occasionally, this would suffice to identify whale areas. The calls of balaenid bowhead whales can be detected and classified with very high reliability. We would propose to develop an automatic system for detecting, classifying, and locating right whale calls. This acoustic whale detector would be integrated with real time telemetry capabilities of the coastal observation network, allowing data on the detections of whale calls to be available on a real-time basis for use by the EWS and other interested parties.

TASK IV

WHOI's Marine Operations efforts consist of several groups that are actively involved with NOAA research in littoral zones and the world's oceans. Participation in NOAA research includes the following activities:

A. SHIP OPERATIONS

WHOI Ship Operations provides competent sea worthy, ocean going platforms outfitted with state of the art navigation, positioning and data acquisitions systems, including SeaBeam multibeam bathymetry, sub-bottom profilers, Acoustic Doppler Current Profilers (ADCP), as well as hydrographic trawl winches and .680 wires. The ships are manned by experienced, dedicated crews who are committed to contributing to the scientific investigation. WHOI operates the Research Vessels *Atlantis*, *Knorr* and *Oceanus*, and the 46 ft. coastal research vessel *Asterias*. In addition there is a fleet of small boats designed to be useful for NOAA work in coastal estuaries, rivers and bays. A new SWATH vessel is being developed by WHOI that will provide improved, safe, stable and affordable year-round access for research in the New York Bight, Gulf of Maine, Georges Bank, and other coastal and near-shore areas. The new platforms and technologies will be available to NOAA researchers at the National Marine Fisheries Service, Northeast Fisheries Center (NMFS/NEFC) in Woods Hole and to NOAA researchers around the country. WHOI has long been a partner with NOAA and other federal agencies in advancing and improving the tools with which and from which to conduct oceanographic measurements and observations. This work includes platform design, acoustic sensing and quieting; mooring systems design, development, construction, deployment and recovery; ship board and ship deployed instrumentation of all types; and ship conversion and modernization. We have collaborated with NOAA in the past on these efforts and expect to continue to do so.

B. SUBMERSIBLE OPERATIONS

WHOI operates the National Deep Submergence Facility (NDSF) that has its oversight in a Memorandum of Agreement signed by NOAA/NURP, the National Science Foundation and the Office of Naval Research. The NDSF consists of both **h**uman **o**ccupied and **r**emotely **o**perated **v**ehicles (HOV's and ROV's). The submersible *Alvin* has accomplished more scientific research dives than any other HOV submersible in the world. *Alvin* is rated to a depth of 4,500 meters and is fully instrumented with a suite of sampling, data logging and camera options available for in-situ observations. The engineering staff of the *Alvin* Group can assist NOAA researchers in modifying existing or constructing new equipment to exploit the capabilities of the vehicle. The

ROV's and tethered vehicles in the National Facility consist of the ROV's *Jason-Medea*, *Argo* and the DSL 120 towed sonar. The tethered vehicles operated by the WHOI Deep Submergence Laboratory are capable of a wide variety of imaging tasks, and offer unparalleled digital processing capabilities. The NDSF is a major asset available to NOAA researchers both within and outside NURP. This research would include the NOAA Vents Program, research at ocean dumpsites; research associated with NOAA's Marine Sanctuary Program; marine mammal research; sewage outfall systems; post-earthquake coastal margin disruption assessment and so forth.

Other Institution facilities may be required to support cooperative research and may be funded through this Task as well as supporting other UNOLS facilities through subcontracts when they are required to support NOAA research.

V. PERSONNEL

CICOR is a respected and valued center of research within the Woods Hole Oceanographic Institution (WHOI) but does not have the authority to hire personnel. All personnel associated with CICOR have an appointment in one of the 5 scientific departments or the Marine Policy Center of WHOI or are affiliated with another university, research institution, or NOAA lab. These latter fellows are generally supported by a subcontract from WHOI.

Dr. Robert Weller, a Senior Scientist in the Physical Oceanography department, is currently the Director of CICOR. He receives support from the Task I funds of the cooperative agreement and from both institution unrestricted and overhead funds. Nancy Brink, Senior Research Assistant in the Physical Oceanography department is the Office manager for CICOR, devoting approximately ¼ of her time to the task. Claire Reid, Executive Assistant to the Director of Research is the Joint Institute Administrator and is fully supported by overhead.

In addition to the Administrative staff of CICOR, the following people were Principal Investigators or provided research assistance on individual scientific projects funded through the previous (July 1998–October 2000) cooperative agreement to CICOR.

NAME	TITLE	DEPARTMENT
SCIENTIFIC STAFF:		
McCartney, Michael	Senior Scientist	Physical Oceanography
Owens, W. Breckner	Senior Scientist	Physical Oceanography
Richardson, Phillip	Senior Scientist	Physical Oceanography
Stanton, Timothy	Senior Scientist	Applied Ocean Physics & Engineering
Tyack, Peter	Senior Scientist	Biology
Weller, Robert	Senior Scientist	Physical Oceanography
Wiebe, Peter	Senior Scientist	Biology
Anderson, Steven	Associate Scientist	Physical Oceanography
Edson, James	Associate Scientist	Applied Ocean Physics & Engineering
McGillicuddy, Dennis	Associate Scientist	Applied Ocean Physics & Engineering
McGillis, Wade	Associate Scientist	Applied Ocean Physics & Engineering
Plueddemann, Albert	Associate Scientist	Physical Oceanography

Yang, Jiayan	Associate Scientist	Physical Oceanography
Fratantoni, David	Assistant Scientist	Physical Oceanography
Lersczk, James	Post-doctoral Scholar	Biology
Straneo, Fiamma	Post-doctoral Scholar	Physical Oceanography
TECHNICAL STAFF		
Hosom, David	Principal Engineer	Physical Oceanography
Curry, Ruth	Research Specialist	Physical Oceanography
Manganini, Steven	Research Specialist	Geology & Geophysics
Terray, Gene	Research Specialist	Applied Ocean Physics & Engineering
Eastwood, Robert	Research Engineer	Applied Ocean Physics & Engineering
Johnson, Mark	Research Engineer	Applied Ocean Physics & Engineering
Peters, Donald	Research Engineer	Applied Ocean Physics & Engineering
Chu, Dezhang	Research Associate	Applied Ocean Physics & Engineering
Cohen, Anne	Research Associate	Geology & Geophysics
Hammar, Terence	Research Associate	Applied Ocean Physics & Engineering
Wooding, Christine	Research Associate	Physical Oceanography
Chandler, Cynthia	Info. Systems Associate	Marine Chemistry & Geochemistry
Galbraith, Nancy	Info. Systems Associate	Physical Oceanography
DEPARTMENT ASSISTANT		
Billings, Andrew	Engineering Assistant	Applied Ocean Physics & Engineering
Bouchard, Paul	Engineering Assistant	Applied Ocean Physics & Engineering
Costello, Larry	Engineering Assistant	Physical Oceanography
Dunn, James	Engineering Assistant	Applied Ocean Physics & Engineering
Hurst, Thomas	Engineering Assistant	Applied Ocean Physics & Engineering
Johnson, Craig	Engineering Assistant	Applied Ocean Physics & Engineering
Lord, Jeffrey	Engineering Assistant	Applied Ocean Physics & Engineering
Murphy, Stephen	Engineering Assistant	Applied Ocean Physics & Engineering
Ostrom, William	Engineering Assistant	Physical Oceanography
Reese, John	Engineering Assistant	Physical Oceanography
Ryder, James	Engineering Assistant	Applied Ocean Physics & Engineering
Way, Bryan	Engineering Assistant	Physical Oceanography
Biassoni, Nicoletta	Research Assistant	Biology
Brink, Nancy	Research Assistant	Physical Oceanography
Butler, Mari	Research Assistant	Biology
Copley, Nancy	Research Assistant	Biology
Fischer, Albert	Research Assistant	Physical Oceanography
McKenna, Sean	Research Assistant	Applied Ocean Physics & Engineering
Sisson, John	Research Assistant	Applied Ocean Physics & Engineering
Chausse, Dolores	Admin. Professional	Applied Ocean Physics & Engineering
Franklin, Gloria	Admin. Professional	Applied Ocean Physics & Engineering
Gaffron, Barbara	Admin. Professional	Physical Oceanography
Hurst, Sheila	Admin. Professional	Applied Ocean Physics & Engineering
Lucas, Mary Ann	Admin. Professional	Physical Oceanography
Tucci, Mary Jane	Admin. Professional	Biology

VI. PERFORMANCE MEASURES

CICOR research will be reported in scientific journals, the CICOR Annual Report, and in other special CICOR Technical Reports. CICOR staff and visitors will present papers at numerous seminars, conferences and scientific meetings in the United States and abroad. In

addition, CICOR embraces the need to cooperate with NOAA's NESDIS data centers in the timely submission of marine data to these centers. WHOI supported this by providing facilities for the NESDIS/NODC Northeast Regional Liaison Officer for 20 years.

VII. BUDGETS

While the budgets presented below cover the entire period of this five-year proposal, it is recognized that proposals are individually reviewed and funded on the basis of 12-month, or shorter, funding project periods. The budgets herein are severable in that each research task supports research personnel and associated costs based on the duration of the five-year proposal. Further, because the proposal separately funds the administrative costs on an annual basis and separately funds the research proposals, should future funding not be available, work can be stopped in a timely fashion. Since the cooperative agreement operates on a research exchange basis, Administrative offices can be closed and results of research conducted with the funds under this agreement (to the point when funding is no longer available of being severed) will be documented and submitted to NOAA as the Institute's product unless other specific arrangements are made.

5-YEAR SUMMARY BUDGET

TASK I BUDGET JUSTIFICATION

This task provides support for the administrative activities of CICOR. As such, 2 months of support in each year is requested for the Director. Additional support for the Director, and other staff of CICOR, is provided by the Woods Hole Oceanographic Institution from the overhead pool and Institution unrestricted funds. Benefits, a direct cost to all projects, are calculated as a percent of salary costs using our projected CY2001 rate. This is subject to change as new rates are negotiated.

Travel funds are requested for the Director and the Joint Institute Administrator to attend the various NOAA meetings. These costs are based on prior experience with similar projects. They include airfare, per diem for lodgings and meals, ground transportation and other allowable costs and are estimated to be $1,000 per trip. Travel is also requested in support of the Visiting Scientist program to enable scientists from other institutions to visit and conduct research at the Institution, participating in collaborative programs with CICOR Fellows or for Fellows to visit NOAA labs. The visitors will be selected by the CICOR Director, in consultation with the Council of Fellows. Each visitor will stay for approximately 1-2 weeks and CICOR will provide for travel and living expenses. The budget projects costs of $1000 per week and we expect to have 4 weeks of visits each year.

The CICOR Post-Doctoral Scholar program is closely associated with the WHOI program. Costs for a Post-Doctoral Scholar include the stipend, a portion of the cost of health insurance and a small fund for the Scholar's discretionary use in the conduct of his/her research.

In addition we request a small amount of funds to be used for the operating expenses of the CICOR office, including telephone charges and mailing and reproduction costs for the newsletter as well as assistance with web-site maintenance.

The indirect costs are calculated on Salary and Benefits only, not on modified total direct cost. This is in accordance with OMB Circular A-122. The overhead rates used are those that the Woods Hole Oceanographic Institution is proposing to use for the life of this CICOR cooperative agreement: 44% for Laboratory Costs and 30% for General and Administrative Costs. Although the rates for WHOI have not yet been negotiated with our cognizant agency, the Office of Naval Research (ONR), we expect that they will be higher than what is proposed here. In accordance with government regulation, the difference between the CICOR rates and rates approved by the ONR will be covered by the Institution's unrestricted funds.

TASK I BUDGET

TASK II BUDGET JUSTIFICATION

The research effort in Task II consists of those proposals and programs that actively involve NOAA scientists as collaborators. Task II projects funded through the last cooperative agreement were approximately 14% of the total dollars received. The dollars budgeted in each category - personnel, travel, equipment, etc. - are based on the patterns of spending for the total previous cooperative agreement. The estimated amount of Contractual charges is also based on past experience and represents those funds that may be awarded to co-principal investigators at other academic and research institutions. Benefits, a direct cost to all projects, are calculated as a percent of salary costs using our projected CY2001 rate. This is subject to change as new rates are negotiated. The Other Costs category includes miscellaneous costs such as graphic services, publication costs, repair and maintenance, graduate student support, vessel charters and ship use, insurance, etc.

The indirect costs are calculated on Salary and Benefits only, not on modified total direct cost. This is in accordance with OMB Circular A-122. The overhead rates used are those that the Woods Hole Oceanographic Institution is proposing to use for the life of this CICOR cooperative agreement: 44% for Laboratory Costs and 30% for General and Administrative Costs. Although the rates for WHOI have not yet been negotiated with our cognizant agency, the Office of Naval Research (ONR), we expect that they will be higher than what is proposed here. In accordance with government regulation, the difference between the CICOR rates and rates approved by the ONR will be covered by the Institution's unrestricted funds.

TASK II BUDGET

TASK III BUDGET JUSTIFICATION

The research efforts in Task III consists of proposals and currently funded programs supported by NOAA through the OAR, OGP, NMFS, and other external funding offices in NOAA, and are therefore directed toward NOAA's strategic goals. We encourage active collaboration with NOAA staff but none is required under this Task. Task III projects funded through the last cooperative agreement were approximately 77% of the total dollars received. The dollars budgeted in each category—personnel, travel, equipment, etc.—are based on the patterns of spending for the total previous cooperative agreement. The estimated amount of Contractual charges is also based on past experience and represents those funds that may be awarded to co-principal investigators at other academic and research institutions. Benefits, a direct cost to all projects, are calculated as a percent of salary costs using our projected CY2001 rate. This is subject to change as new rates are negotiated. The Other Costs category includes miscellaneous costs such as graphic services, publication costs, repair and maintenance, graduate student support, vessel charters and ship use, insurance, etc.

The indirect costs are calculated on Salary and Benefits only, not on modified total direct cost. This is in accordance with OMB Circular A-122. The overhead rates used are those that the Woods Hole Oceanographic Institution is proposing to use for the life of this CICOR cooperative agreement: 44% for Laboratory Costs and 30% for General and Administrative Costs. Although the rates for WHOI have not yet been negotiated with our cognizant agency, the Office of Naval Research (ONR), we expect that they will be higher than what is proposed here. In accordance with government regulation, the difference between the CICOR rates and rates approved by the ONR will be covered by the Institution’s unrestricted funds.

TASK III BUDGET

TASK IV BUDGET JUSTIFICATION

Task IV will include proposals for various facilities, such as UNOLS ships, submersibles, and unmanned vehicles that will be used in support of NOAA's mission and cooperative research. Task IV projects were approximately 8% of the previous cooperative agreement. All funds were either for the cost of shiptime or other facilities at WHOI or were subcontracted to other academic and research institutions in support of their ships and facilities.

TASK IV BUDGET

APPENDIX I

SOLICITATION FOR POSTDOCTORAL SCHOLAR FELLOWSHIP—2001–2002

APPENDIX II

COOPERATIVE INSTITUTE FOR CLIMATE AND OCEAN RESEARCH (CICOR) TIMELINE AND ACCOMPLISHMENTS

1997–1999

March 1997	Meeting at WHOI with ERL and AOML, GLERL, OGP, NMFS to begin work on the CICOR MOA
Sept 1997	ERL retreat
Feb 1998	Draft MOA
May 1998	CICOR cooperative agreement proposal submitted to ERL
August 1998	CICOR established
Nov 1998	CIASTA Review, Reno, Nevada
Jan 1999	JI Directors meet at AMS
Feb 1999	WHOI CICOR office remodeled
Feb 1999	Massachusetts Ocean Sciences Bowl
March 1999	EUROGOOS meeting in Rome
April 1999	JI Directors and Administrators meet at NOAA, Silver Spring, MD
April 1999	First CICOR Postdoctoral Scholar selected from over 100 applicants
April 1999	CICOR web site published
April 1999	Regional GOOS effort—CICOR/CIMAS/JIMO
April 1999	OAR GOOS discussion
May 1999	CICOR Executive Board Meeting
May 1999	OAR Retreat
June 1999	First visiting scientists invited
July 1999	Chair, Executive Board, CICOR Director, and WHOI Grants and Contracts Manager visit OGP
September 1999	CICOR Fellows selected
November 1999	NEOOS (North East Ocean Observing Systems) organizational Meeting at Rutgers CICOR-sponsored Post-Doc Dr. Fiammetta Straneo arrives First Issue of *The Bridge*, CICOR's newsletter sent out (copy attached)
December 1999	Dr. Fei-Fei Jin, University of Hawaii, First CICOR Visiting Scientist

2000–>

February 2000	Fellows Meeting to Discuss Proposal Themes and Elect Council Vote for Chairman of Council of Fellows CICOR sponsors SeaOrbiter Presentation
March 2000	Joint Institute Administrator's Workshop - Long Beach, CA
May 2000	Bob Weller visits JIMAR Dr. Mark Cane, LMGO Visiting Scientist Eric Hintsa, MC&G visits AOML Second Issue of The Bridge sent out (copy attached)
June 2000	Presentation to NOAA Outreach people
September 2000	Informal Review Dr. Jim Lerczak, Second CICOR Post-Doc arrives Fellow Submissions for proposal due (September 15, 2000)
November 2000	Submit 2001-2006 Umbrella Proposal to NOAA

APPENDIX III

MAJOR PUBLICATIONS RESULTING FROM CICOR COOPERATIVE AGREEMENT (JULY 1998–AUGUST 2000)

Bucklin, A., M. Guarnieri, D. J. McGillicuddy, and R. S. Hill, in press. Spring-summer evolution of Pseudocalanus spp. abundance on Georges Bank based on molecular discrimination of P. moultoni and P. newmani. **Deep-Sea Research II**.

Curry, R.G., M.S. McCartney, and T.M. Joyce, 1998. Oceanic Transport of Subpolar Climate Signals to Mid-Depth Subtropical Waters. **Nature**, 391: 575-577.

McCartney, M.S., 1997. Is the Ocean at the Helm? **Nature**, 388: 521-522.

McGillicuddy, D. J., D. R. Lynch, P. Wiebe, J. Runge, E. G. Durbin, W. C. Gentleman, and C. S. Davis, in press. Evaluating the synopticity of the U.S. Globec Georges Bank Broad-scale sampling pattern with Observational System Simulation Experiments. **Deep-Sea Research II**.

Molinari, R.L., R.A. Fine, W.D. Wilson, R.G. Curry, J. Abell, and M.S. McCartney, 1998. The Arrival of Recently Formed Labrador Sea Water in the Deep Western Boundary Current at 26.5°N. **Geophysical Research Letters**, 25: 2249-2252.

Paillet, J., M. Arhan, and M.S. McCartney, 1998. The spreading of Labrador Sea Water in the eastern North Atlantic. **Journal of Geophysical Research**, 103: 10223-10239.

WOCE Data Products Committee, 2000: WOCE Global Data, Version 2.0, **WOCE International Project Office**, WOCE Report No.171/00, Southampton, UK.

Yang, J., 1999: A Linkage Between Decadal Climate Variations In The Labrador Sea and The Tropical Atlantic Ocean. **Geophysical Research Letters**, Vol. 26, No. 8, 1023-1026.

Books and Other One-Time Publications:

Johnson, M., D. P. Nowacek, P. L. Tyack, 2000. On the vocalization behavior of northern right whales and the practicality of remote acoustic detection. Abstract, **Right Whale Consortium Meeting**, Boston 26-27 Oct 2000.

McCartney, M.S., 1997. The North Atlantic Atmosphere-Ocean Oscillation. In: 1997 U.S. WOCE Report, **U.S. WOCE Implementation Report Number 9**, U.S. WOCE Office, College Station, TX. pp 55-60.

Nowacek, DP, Johnson, M, Shorter A and PL Tyack. 2000. Right whale diving behavior and approaches by vessels: early insights into ship strikes. Abstract, **Right Whale Consortium Meeting**, Boston 26-27 Oct 2000.

Parks, S., 2000. Characterization of acoustic advertisement of the North Atlantic Right Whale. Abstract, **Right Whale Consortium Meeting**, Boston 26-27 Oct 2000.

Schmitt, R. W. and E. T. Montgomery, 2000. Salinity: The missing piece of the climate puzzle. **Backscatter**, 11 (3), 4-11.

Tyack, P. L., Nowacek, D. P., Parks, S, and Johnson, M., 2000. Studying risk factors for vessel collision using controlled exposures of noise to tagged right whales. Abstract, **Right Whale Consortium Meeting**, Boston 26-27 Oct 2000.

WOCE Data Products Committee, 1998. WOCE Global Data, Version 1.0. CD-ROM: Subsurface Floats. **WOCE International Project Office**, WOCE Report No. 158/98, Southampton, U.K.

WOCE Data Products Committee, 2000: WOCE Global Data, Version 2.0, **WOCE International Project Office**, WOCE Report No.171/00, Southampton, UK. 121 pp.

Papers Using Data from CICOR Right Whale Project:

Brown, S, Gillespie, D., Lewis T. Mathews J., McLanaghan R, and Moscrop A., 2000. Right Whale Passive Acoustic Research conducted by the International Fund for Animal Welfare, 1999-2000. Abstract, **Right Whale Consortium Meeting**, Boston 26-27 Oct 2000.

Jin, X., R. X. Huang, J. Yang, 1999: Centennial oscillation in an ocean-ice coupled model. **Advances in Atmospheric Sciences**, Vol.16(3), 323-342.

Roemmich, D. and W. B. Owens. The Argo Project: Global ocean observations for understanding and prediction of climate variability. **Oceanography**, Vol. 13, no. 2, 45-50.

Yang, J., and J. D. Neelin, 1997: Interdecadal variability in a coupled sea-ice and thermohaline circulation system. **Journal of Climate**, Vol. 10, 3059-3076.

Yang, J., and J. D. Neelin, 1997: Sea-ice interaction and the stability of the thermohaline circulation. **Atmosphere—Ocean**, Vol. 35, 433-469.

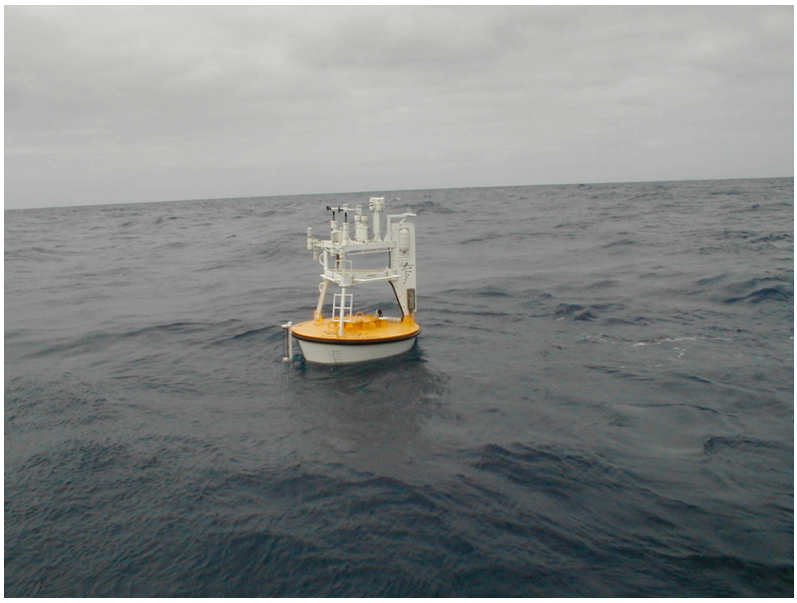
Yang, J., 1999: A Linkage for Decadal Climate Variations in Labrador Sea and tropical Atlantic Ocean. **Geophysical Research Letters**, 1023-1026.

APPENDIX IV

NOAA ADMINISTRATOR'S WEEKLY REPORT

In October, under support from NOAA OGP coming through CICOR, Bob Weller began a 3-year long study of the region of the eastern Pacific off the coast of Chile. This area of the ocean is typically covered by stratus clouds, and that cloud cover is believed to play an important role in governing how the ocean and atmosphere exchange heat in the eastern Pacific. Experiments with coupled ocean-atmosphere models indicate that model results, such as surface wind fields over the Pacific, are very sensitive to how the stratus clouds and the regulation of the air-sea heat exchanges by the clouds are parameterized in these models. To develop a better understanding of air-sea coupling under the stratus deck and to examine the performance of models in this region, Weller deployed a well-instrumented surface mooring 800 nm west of northern Chile. The mooring collects accurate observations of air-sea heat, freshwater, and momentum fluxes and time series observations of the evolution of the vertical structure of the upper ocean temperature, salinity, and velocity fields.

The mooring deployment in October marked the beginning of several collaborations. The surface meteorology and air-sea flux data are being shared with numerical weather prediction centers and investigators at WHOI and the modeling centers will use the buoy data, which are not included in the model fields, to examine the performance of the models. In addition, the cruise was done in collaboration with Chilean oceanographers. Staff from the Chilean Navy Hydrographic and Oceanographic Service, which is interested in deploying their own moorings, participated. Staff and students from the University of Concepcion obtained XBT and CTD sections along 20 deg S on the way out to the mooring site and on the way back into to port at Arica, Chile. They are interested in the vertical structure of the ocean properties, including nutrients and oxygen, across the Peru and Chile basins. Continuation of these collaborations is hoped for during the three annual cruises that remain.



APPENDIX V

"THE BRIDGE"—CICOR NEWSLETTERS

Download copies at: http://www.whoi.edu/science/cicor/communications/cicor_bridge.html