CICOR

Cooperative Institute for Climate and Ocean Research

Dr. Robert A. Weller, CICOR Director

Annual Progress Report

July 1, 2003 - June 30, 2004

submitted to

National Oceanic and Atmospheric Administration
Ocean and Atmospheric Research (OAR)

September 2004

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CICOR

(Cooperative Institute for Climate and Ocean Research)

CICOR is a Cooperative Institute between National Oceanic and Atmospheric Administration (NOAA) and the Woods Hole Oceanographic Institution (WHOI).

The research activities of CICOR are organized around three themes:

- the coastal ocean and near shore processes,
- the ocean's participation in climate and climate variability and
- marine ecosystem processes analysis.

These theme areas, each of which has significant implications for human society, are interrelated and scientific progress will require collaborations 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 the observational systems.

CICOR has been in existence for six years. During the first 3-year Cooperative Agreement it assisted WHOI Scientists with 26 funded projects totaling a budget of $5,817,000. For the first three years of the present 5-year Cooperative Agreement, projects were funded with a budget of over $18,000,000. The program development fees covered three post-docs and one graduate student, along with short term visitors, whose work fell under the three CICOR Themes, Ocean's Participation in Climate, Coastal Oceanography and Near-Shore Processes and Marine Ecosystem Processes.

For more information
http://www.whoi.edu/science/cicor

CICOR
Cooperative Institute for Climate and Ocean Research
Annual Report 2004
Administrative Summary
Robert A. Weller, CICOR Director

CICOR is a Cooperative Institute between the National Oceanic and Atmospheric Administration (NOAA) and the Woods Hole Oceanographic Institution (WHOI). CICOR's specific research themes are the coastal ocean and near-shore processes, the ocean's participation in climate and climate variability, and marine ecosystem processes analysis. CICOR brings to NOAA research excellence in oceanographic research and marine policy and access to research ships and submersibles, remotely operated and autonomous vehicles, and state of the art ocean observing systems. CICOR supports education and outreach activities. One graduate student and two Postdoctoral Scholars, one A CICOR Postdoctoral Scholar and one a CICOR Minority Postdoctoral Scholar, are typically provided with support each year. CICOR staff participated in outreach activities including the state ocean science bowl, known as the Blue Lobster Bowl, and in the annual science fair of Falmouth High School. A CICOR research cruise this year had two teachers, one a middle school teacher from San Marcos, CA and one a middle school teacher from Arica, Chile, on board as part of the NOAA Teacher-at-Sea program; and the link between CICOR and the San Marcos school continues under a new grant obtained by that teacher. CICOR stimulates interaction with the external community by supporting visitors to WHOI and interaction with NOAA laboratories by offering travel support for WHOI investigators who wish to visit those labs to explore possible collaborative research. An example of a visit supported in part by CICOR was the visit of Dr. Jorge Corredor and his graduate student to CICOR in August. Dr. Corredor is a oceanographer at the University of Puerto Rico who has established a time series station in the Caribbean to study coupled biological and physical oceanographic variability, and the goal of the visit was to explore synergy between that and similar work at WHOI and lay the groundwork for future collaboration.

For the period of July 2003 to July 2004, CICOR served as the lead NOAA OAR Joint Institute. During this period Weller represented the Joint Institutes at the NOAA Senior Research Council. A major activity organized by CICOR and Dr. John Cortinas of OAR was the meeting of Joint Institutes with NOAA OAR staff in Silver Spring in April (?) 2004. These meetings have been held roughly every four years; but the reorganization of NOAA, including the development of goal teams that span the NOAA line offices and the recent evolution of priorities for the Federal budget motivated strong interest by the Joint Institutes in a more regular dialog with OAR. In the future, these meetings will be held every year and will include a new emphasis on coordination of the government relations staff of the Joint Institutes. Discussion at the Silver Spring meeting led to plans to achieve greater involvement of the Joint Institutes in the planning process at NOAA. Subsequent to the meeting the Joint Institutes have established an Executive Council of Directors, including the immediate past, present, and next lead Joint Institute Directors; Weller now serves on this group. Another outcome of the meeting was the decision by the Joint Institutes to host workshops to plan future research activities in areas of key interest to OAR and to populate these workshops with both NOAA and external researchers in order to stimulating interaction between the external community and NOAA OAR during the planning process. CICOR is taking the lead on developing the first workshop; one focused on developing plans that link research on climate variability, fisheries, and marine policy in the Northeast. CICOR hosted meetings of the CICOR Fellows and the CICOR Executive Board in May.

In 2004, a number of important research activities and results came from NOAA-funded research done in CICOR:

• establishment of the third Ocean Reference Station, well-instrumented surface moorings to document and quantify variability in surface meteorology, air-sea fluxes, and upper ocean variability, to examine the ocean's role in climate, and to stimulate development of improved atmospheric, oceanic, and coupled models, north of Hawaii by Weller and Plueddemann. The Hawaii site joins those in the Northwest Tropical Atlantic (NTAS) and under the persistent stratus clouds off northern Chile (STRATUS).

• installation of a high quality automated meteorological package (AutoIMET) on a container ship in the Atlantic. This is done in collaboration with NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML).

• analysis of observations collected earlier at Georges Bank, leading to a new understanding tidal flows around the Bank, which are an important by poorly modeled component of the advection governing physical and biological variability there

• results in the past year on the synthesis of data collected earlier at Georges Bank also included a conceptual model for the microbial food web there and findings about the interannual variability of cod and haddock larvae there; this latter work finds the variability of these species on the Bank to be sensitive to weather and climate, so that wind-driven transport and changes in hydrography associated with the North Atlantic Oscillation (NAO) need to be considered as well as changes in predation. Other related work used data from the California Current System to examine the relation between climate change and ecosystem change

• new field observations to support development of improved capability to predict plankton blooms in the Gulf of Maine were obtained on *RV Oceanus* in May

• improved understanding of two key regions of the eastern Pacific, the equatorial Cold Tongue and ITCZ complex (CTIC) and the persistent stratus clouds off northern Chile; in the CTIC time series of air-sea exchanges and upper ocean variability at two locations along 125°W (10°N and 3°S) provided new insight into the processes that controlled the evolution of sea surface temperature (SST) during the strong 1997-1998 ENSO event; in the stratus region, the mooring data has provided the first accurate time-series observations of the air-sea fluxes, allowed the first quantification of the local heat budget in the upper ocean there, and pointed to the role of ocean processes in maintaining the cool SSTs found under the stratus clouds

• research findings of the carbon cycle came from a study of the storage and transport of CO_2 in the Atlantic and a study of carbon dynamics in North American boreal forest regrowth

- two efforts focused on fisheries, with one study quantifying the relation between fish processing in the Northeast and fish harvesting and the second providing an analysis of fishing vessel accidents in the region

- improvements have been made to the processing and visualization of multibeam sonar that has the potential to provide efficient and effective means to estimate abundance and biomass of fish

- a program is underway to attach tags to sperm whales in the North Atlantic in order to document their behavior, including the amount of time they spend at the surface

Funding to CICOR from NOAA is categorized as falling into four Tasks, Task I ($551,554 or 6.4% of the total in 2004) supports administration, education, and support for visitors to and from CICOR and outreach activities; Task II is research funding with explicit participation by a NOAA investigator ($365,712, 4.2%); Task III is research that is in support of NOAA's strategic goals and funds work done by WHOI or other academic investigators without NOAA scientists as co-principal investigators ($6,923,315, 79.8%), and Task IV is support for use of WHOI research vessels and submersibles by NOAA and other NOAA-funded investigators ($840,258, 9.7%). The bulk of the NOAA funds come from the Office of Oceanic and Atmospheric Research ($7,318,539, 44.2%) and the Office of Global Programs ($6,680,305, 40.4%) with additional funds from the National Marine Fisheries Service, the National Ocean Service and the NOAA Arctic Program.

CICOR Annual Accomplishments 2003-2004

Jul 2003	"In the Spotlight" NOAA Web Joint Program Student Tom Farrar summarizes Pan American Climate Study (PACS)
Oct 2003	Teacher at Sea Program Stratus Cruise R/V Reville
Mar 2004	Hot Item on NOAA web "Two New Cooperative Institutes join existing 11 Joint and Cooperative Institutes" Hot Item on NOAA web "Breck Owens, CICOR PI, accepts NOPP Trophy for Argo Project" Falmouth High School Science Fair, Falmouth, MA Emilia Sogin "Bioremediation"
April 2004	JI Directors and Administrators Meeting, Silver Spring, MD CICOR Lead JI/CI
May 2004	CICOR Executive Board Meeting, Woods Hole, MA CICOR Fellow Meeting, Woods Hole, MA
June 2004	Tom Farrar presents PACS scientific talk to local Falmouth High School Students

Personnel for CICOR Annual Summary Report July 1, 2003 – June 30, 2004

Task I Support

Employees	**Appt. Dates**
Bob Weller, CICOR Director	1999-

Task I and Development Costs Support Post-Docs and Joint Program Students

Post-Doc	**CICOR Theme**	**Appt. Dates**	**Advisor(s)**
Nicolas Scott	Coastal/Climate	2004-	John Trowbridge Jim Edson
Ruoying He	Coastal/Climate	2003-2004	Dennis McGillicuddy Bob Beardsley
Amy Baco-Taylor	Marine Ecosystem Proc.	2002-2003	Tim Shank
Livui Giosan	Climate/Coastal	2001-2003	Lloyd Keigwin
Jim Lerczak	Coastal/Near-Surface Proc.	2000-2002	Dave Chapman, Carin Ashjian
Fiamma Straneo	Climate/Climate Variability	1999-2002	Bob Pickard

Graduate Student	**CICOR Theme**	**Appt. Dates**	**Advisor**
Rob Jennings	Marine Ecosystems	2000-	Lauren Mullineaux
Steve Fries	Coastal/Near-Surface Proc.	2000-2001	Jim Ledwell

Summary of Accomplishment
Ruoying He – CICOR Post-Doc 2003 - 2004

Ruoying He arrived at WHOI in September 2003 as CICOR 5th postdoctoral scholar. Since then he has been working on two main research projects. The first project is on the Gulf of Maine coastal circulation and harmful algal transport. This work is a part of the MERHAB (Monitoring and Event Response for Harmful Algal Blooms) project led by Dennis McGillicuddy (WHOI AOPE), Don Anderson and Bruce Keafer (WHOI BO). Ruoying participated in the MERHAB 2003 field survey in the Gulf of Maine where they collected a wonderful set of *in-situ* measurements of physical and biogeochemical variables. He then implemented and tested an adjoint data assimilative ocean model that assimilates coastal sea levels and currents to hindcast the circulation and material transports. Exciting research findings on the utility of data assimilative ocean model and on mechanisms controlling water exchange and transport processes were presented in several scientific meetings and seminars. A paper documenting detailed scientific results is to be submitted for the refereed journal publication. MERHAB 2004 field survey was just completed this summer. With two years *in-situ* measurements, Ruoying is working on another paper focusing on the inter-annual variability of the Gulf of Maine circulation and transport and will submit it for publication shortly. The second research project Ruoying is involved in is the southeast Atlantic coastal ocean observing system. This is a collaborative study with other investigators from University of Miami (UM), Skidaway Institute of Oceanography (SKIO), University of South Carolina (USC), and University of North Carolina (UNC). Ruoying has played an important role in data analyses of surface wind fields and satellite observations, and real time numerical model nowcast and forecast of coastal circulation. Several journal publications have been produced out of this work. Ruoying will start on September 1st as an assistant scientist in WHOI APOE department. Listed below is a short list of Ruoying's research activities so far in 2004.

Journal Publication

He, R., D. J. McGillicuddy, K. W. Smith, D. R. Lynch, C. A. Stock, and J. P. Manning, 2004, Adjoint data assimilation model hindcast of the Gulf of Maine coastal circulation and material transport. *To be submitted*

He, R., Y. Liu and R. H. Weisberg (2004), Coastal ocean wind fields gauged against the performance of an ocean circulation model. *Geophysical Research Letters,* Vol. 31, 14, 14303, doi:10.1029/2003GL019261

Weisberg, R. H., **R. He**, G. Kirkpatrick, F. Muller-Karger, J. J. Walsh (2004), Coastal Ocean Circulation influences on remotely sensed optical properties. *Oceanography*, 17, 68-75

Book Chapter

Weisberg, R. H., **R. He**, Y. Liu, and J. Virmani (2004), West Florida shelf circulation on synoptic, seasonal and inter-annual time scales, *Physical Oceanography in the Gulf of Mexico*, *in review*

Seminar and Presentation

He, R., Shelf and deep ocean interactions, Case studies on the West Florida Shelf. WHOI. December 9, 2003

He, R., Shelf and deep ocean interactions, Case studies on the West Florida Shelf. Marine Science Department, University of Connecticut, February 26, 2004

He, R., Observation and Data Assimilative Model Hindcast of the Coastal Circulation in the Gulf of Maine. Regional Associate for Research on the Gulf of Maine, July 15, 2004

He, R., Understanding and quantifying the deep ocean influence on the coastal ocean, WHOI, July 27, 2004

Research Proposal

Coastal Water Connectivity and Material Transport; PI: **R. He**, submitted to *NSF OCE* 2004 August Panel Review

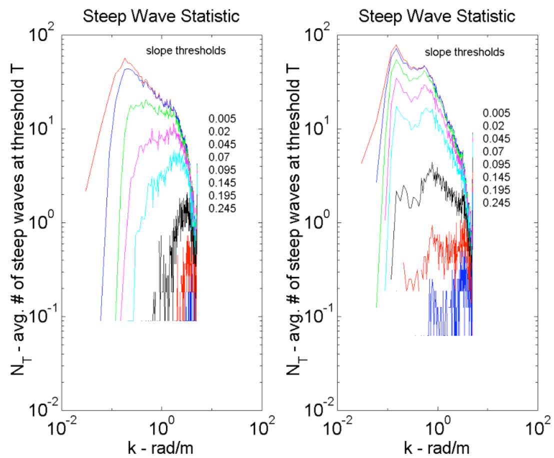
Summary of Accomplishment
Nicholas Scott – CICOR Post-Doc 2003 - 2004

Comprehension of the statistical distribution of steep and breaking surface waves is crucial to the understanding of such issues as the air-sea momentum flux and the air-sea gas exchange. My work, begun in January 2004 and funded by CICOR, is aimed at understanding the distribution of steep surface waves that are part of steep wave groups on the ocean surface. This is accomplished through the use of a new signal processing algorithm based on wavelet analysis. This methodology is applied to open ocean wave height data acquired from wave gauges during the Flux, Etat de la mer et Teledection en Condition de fetch variable (FETCH) experiment (1998) and the Adverse Weather Experiment (1998). Both experiments were air-sea interaction studies which employed the use of the Air-Sea Interaction Spar (ASIS) buoy, a spar-buoy designed specifically for the measurement of directional wave spectra and meteorological parameters.

Wavelet analysis of ocean surface wave data yields a quantity dubbed the steep wave statistic. The steep wave statistic, $N_T(k,\theta)$, is simply the number of steep wave crests at wave slope threshold T, wavenumber k, and angle θ It is calculated via a two part process. First the wavelet transform is used to not only detect local steep wave events which pass over a wave gauge array but also to find their scale. These events are tallied up according to wavenumber, angle, and wave slope threshold to yield the statistic.

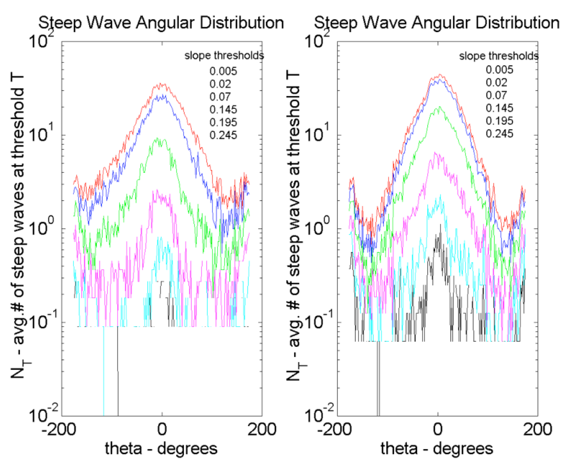
Results from the analysis of wave gauge measurements of the surface wave field from the Adverse Weather experiment and the FETCH experiment are shown in Figure 1. The figure shows N_T, the average number of steep wave events at wave slope threshold T versus wavenumber k. The wave slope thresholds are listed in black with increasing wave slope threshold from top to bottom corresponding to each of the curves of decreasing mean value for N_T. The figure shows that high wave slope crests appear over a wide range of wavenumbers for both the low wind case and the high wind case. Figures 1a and 1b show that at low wave slope thresholds, a larger amount of steep waves at low wavenumbers exists than at high wavenumbers. As the wave slope threshold is increased, the trend changes with the number of steep waves increasing with wavenumber, over a large portion of the wavenumber range. These curves point to the importance of the small-scale steep waves in characterizing the wave field.

Comparison of Figure 1a to Figure 1b shows that the trend at high wave slope thresholds is modulated in the case of high wind with the slope of the curves being gentler than in the previous case. This may be due to the presence of very steep and breaking waves in the wave field which occur at high wind speeds.



a) b)

Figure 1: Steep wave statistic, N_T vs. k at different wave slope thresholds T. Increasing values of the wave slope thresholds from top to bottom correspond to each of the curves of decreasing mean values of N_T . a) Adverse Weather Experiment case. Mean wind speed at 6 meters above ocean surface, U_6 = 6m/s. b) FETCH experiment case. U_6 = 15 m/s.



a) b)

Figure 2: Steep wave statistic, N_T vs. θ at different wave slope thresholds T. Increasing values of the wave slope thresholds from top to bottom correspond to each of the curves of decreasing mean values of N_T . Mean wind direction at θ =0. a) Adverse Weather Experiment case. Mean wind speed at 6 meters above ocean surface, U_6 = 6m/s. b) FETCH experiment case. U_6 = 15 m/s.

Directionality analysis of the waves was also performed. Figure 2 depicts the steep wave angular distribution, N_T for two different experiments as a function of angle, θ where the direction of the wind is at zero degrees. The plots show that irrespective of wave slope threshold, most of the steep waves move in the mean wind direction. This is qualitatively consistent with other observations.

The complete form of this work is in preparation for publication in Elsevier Scientific's Applied Ocean Research.

Summary Report July 1, 2003 to June 30, 2004
CICOR Joint Program Student Rob Jennings, Biology Dept.

The majority of 2003-2004 has been spent on three main goals. The first was finishing the analysis of and writing up the project I began in Ken Halanych's lab my second year. In this study, I sequenced two complete mitochondrial genomes, one from the hydrothermal vent tubeworm *Riftia pachyptila* and the other from the shallow water bamboo worm *Clymenella torquata*. The order of the 37 mitochondrial genes in the genome, as well as the gene sequences, provided multiple datasets to test current hypotheses of annelid phylogeny (most notably, that polychaetes are not monophyletic but include oligochaetes and hiridineans) and of the relationships between annelids and other lophotrochozoan phyla (mollusks, brachiopods, and sipunculans). The data clearly show that Oligochaeta and Hirudinea fall within the Polychaeta, in support of recent single-gene analyses, developmental evidence, and some morphological re-investigations. There is also support for the recent hypothesis that Sipunculans are closely related to, or perhaps even part of Annelids. In June of 2004 I submitted this work for publication to Molecular Biology and Evolution[1].

The second focus of this past year has been finishing the analysis and writing of my population genetics study of the bamboo worm *Clymenella torquata*. I finished analyzing the patterns of genetic diversity in samples collected in 2002 from the Bay of Fundy, Maine, Rhode Island, Long Island, New Jersey, and five sites on Cape Cod. The data reveal marked differences in genetic diversity, with low diversity in northern sites and higher diversity in southern sites. Note the dominance of the red haplotype (genetic signature) in northern sites, and its decline to the south as other genetic types increase in frequency (Figure 1). This pattern indicates that melting of the Pleistocene ice sheets has played an important part in slowly opening up northern sites for recolonization by *C. torquata*. There is also at least one distinct break in the genetic structure of *C. torquata*, located roughly between Rhode Island and Long Island. The Cape Cod populations seem to be a "hybrid zone" of mixed northern and southern genetic types, with some haplotypes found only on the Cape. The Cape Cod Canal may also be an important bypass around the peninsula, as some sites near Buzzards Bay show a closer resemblance to sites north of the Cape than to other Cape sites. This chapter will be ready for publication by mid-fall, and was presented at the CICOR Board of Directors meeting at WHOI in spring 2004[2].

I also completed a small side-project in which I looked at the genetic signal in new recruits of *C. torquata*. As molecular techniques (particularly those designed to work with tiny amounts of tissue) improve, many researchers are looking to larvae and newly settled young to examine how genetic diversity changes throughout the life of the organism. In particular, I was curious to what extent the genetic diversity present in the initial pool of migrating larvae might be masked or eroded by the severe post-settlement mortality that often affects soft-bottom invertebrates. To this end, I collected a sample of juvenile *C. torquata* as soon after settlement as I could detect them. Consistent with the extremely low levels of gene flow seen from adult populations, all the juveniles from which gene sequences could be obtained matched common Barnstable Harbor adult sequences, indicating that there probably are not larvae coming from other sources that are killed off before they can be sampled as adults. It would be interesting to repeat such an experiment on an organism that has higher dispersal capabilities.

This project has led to the development of my third dissertation chapter, a theoretical model. The model aims to add to existing population genetics models by explicitly including the high post-settlement mortality that was the motivation for the *C. torquata* juvenile project. The notion of "genetic drift" is certainly not new, in which the genetic makeup of a population can change in the absence of selection because population sizes are finite and recruits are "sampled" from the total pool of larvae delivered to a site. However, it has never been explicitly modeled in genetics by incorporating the often severe post-settlement mortality (often upwards of 80%) experienced by many soft-bottom dwelling invertebrates. I hope that analysis of this model will demonstrate that such severe post-settlement mortality has effects on the genetic makeup of populations even in the absence of selection, and can influence our measurement of gene flow and dispersal.

[1]Jennings, R.M., and K.M. Halanych. Mitochondrial Genomes of *Clymenella torquata* (Maldanidae) and *Riftia pachyptila* (Siboglinidae): Evidence for Conserved Gene Order in Annelida. submitted to Molecular Biology and Evolution June 2004.

[2]Jennings, R.M., and K.M. Halanych. "Population Genetics of the Annelid *Clymenella torquata*: The imprint of recent glacial history, the effect of Cape Cod and its Canal on local dispersal, and implications for local population biology and management." Presented at the CICOR Board of Directors meeting, May 2004.

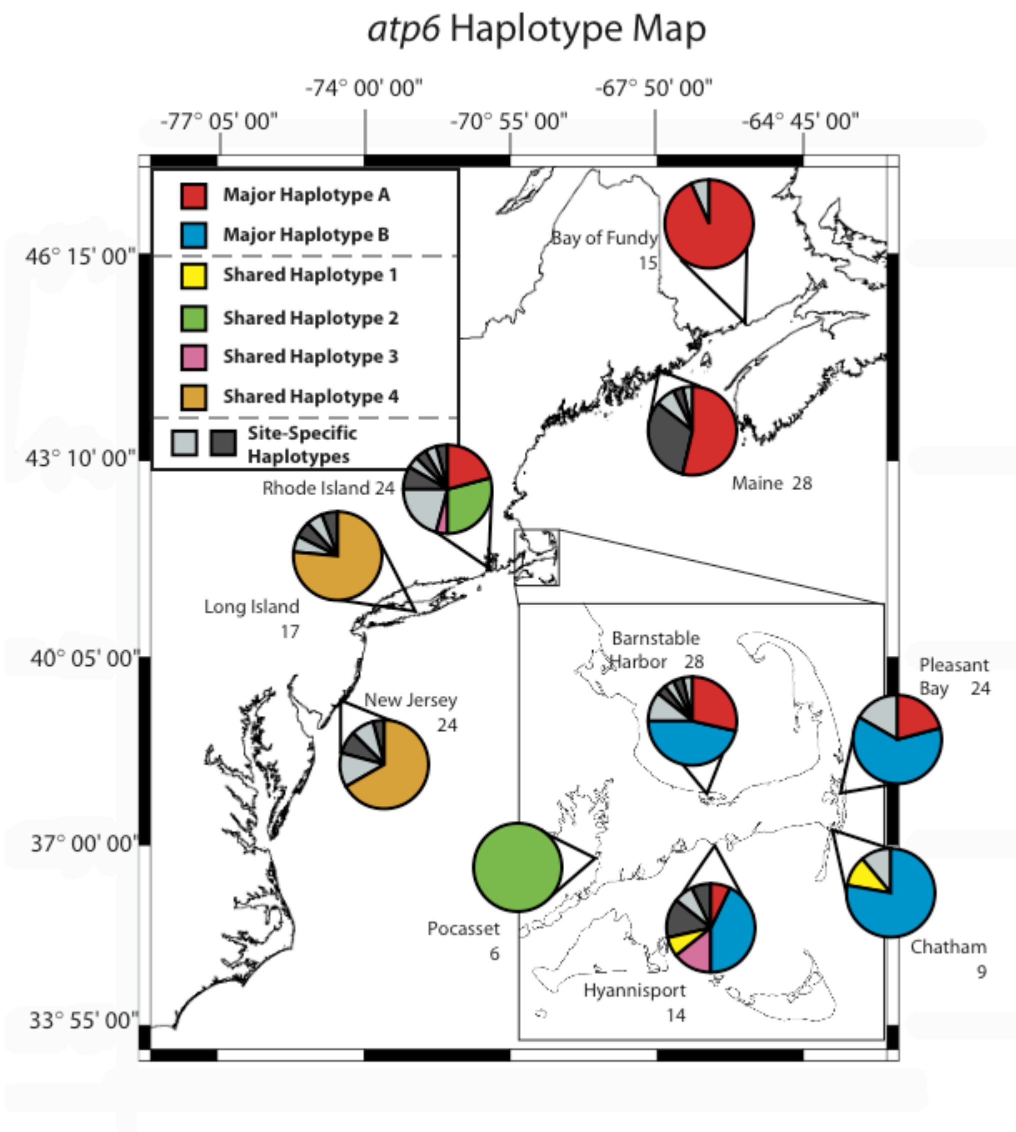


Figure 1. Patterns of genetic diversity in samples collected in 2002 from the Bay of Fundy, Maine, Rhode Island, Long Island, New Jersey, and five sites on Cape Cod.

CICOR Visitors

Professor Jorge Corredor, Professor of Chemical Oceanography
Ramon Lopez Rosada
University of Puerto Rico
Lajas PR 00667-0908

Prof. Jorge Corredor and his student Ramon Lopez Rosada, visited Bob Weller and Tom Farrar, both in the Physical Oceanography Department, on July 28-30, at Woods Hole Oceanographic Institution.

The visit allowed for discussions of future collaborations between WHOI and U. Puerto Rico staff on time series observations and studies of coupled biological and physical oceanographic variability in the Caribbean.

Prof. Corredor gave a seminar titled "Meso-scale Physical Forcing of Phytoplankton Biogeochemistry in the Eastern Caribbean".

Both Prof. Corredor and Ramon Lopez visited several other scientists while they were here, including
Peter Wiebe, Senior Scientist, Biology Department
Maureen Conte, Associate Scientist, Marine Chemistry & Geochemistry Department
Heidi Sosik, Associate Scientist, Biology Department
Rob Olsen, Senior Scientist, Biology Department
Dave Fratantoni, Associate Scientist, Physical Oceanography Department

CICOR Outreach
November 2003

NOAA Teachers-at-Sea Program
http://www.ogp.noaa.gov/ootas/index.html.

In November 2003, Bob Weller's NOAA funded project Stratus "Long-term Evolution and Coupling of the Boundary Layers in the Stratus Deck Regions of the Eastern Pacific" included a 16 day cruise to recover and deploy a surface mooring. Scripps Institution of Oceanography ship the R/V Roger Revelle sailed from Manta, Ecuador and docked in Arica, Chile.

Stratus hosted two teachers as part of NOAA's Teachers-at-Sea program. Debra Brice is a middle school science teacher in San Diego at San Marcos Middle School, and Viviana Zamorano is also a middle school science teacher at Escuela America in Arica, Chile. During the cruise, the teachers assisted with science operations including mooring deployments and recoveries. The teachers also hosted web broadcasts, wrote daily logs, took photos, and interviewed science members and crew. This information was used to communicate with their own classrooms as well as those of other land-based teachers. They were assisted with the video and web-based communications by John Kermond, also of NOAA.

CICOR Outreach
March 2004

Falmouth High School Science Fair, Falmouth, MA

"CICOR Outstanding Project in the Marine Sciences" is awarded every year to a local high school student. A Savings Bond and a certificate are presented with the hope that they will encourage the student to maintain their interest in marine science during their school years. CICOR is proud to have the opportunity to recognize the scientific potential of the youth of the local community

This year's recipient was Emilia Sogin with a project titled
"Bioremediation: The microbial breakdown of diesel fuel in seawater."

Abstract
The research was conducted in order to find out how bacteria, already exisitng in Vineyard Sound could degrade oil. However, before I started by project, I knew that there needs to be some influence on the microbes because they were so dormant from the cold weather. Therefore, I used a nutrient solution to stimulate the microbes in one set of my samples. Thus I was comparing how efficient the bacteria would degrade diesel. This has some very promising results, because this information may be a new lead in the development of the clean up of oil spills. In order to measure my results, I used a gas chromatograph, which is a machine that measures how much of certain compounds are still present in the sample. This information would then lead me to the answer of my question, whether or not there was bioremediation taking place.

My results gave me several different answers. First of all, nutrients are necessary in order for the bacteria to start munching on the diesel compounds. Furthermore, I learned that bacteria eat in specific order of compounds, first the n-alkenes, then the branched alkenes and finally the UCM compounds. The more complex compounds, such as the UCM compounds are eaten last because their structural shape dictates the eating rate of the bacteria. In conclusion, I learned that an oil spill may be able to be cleaned up through the use of bioremediation, however it is necessary to have some sort of stimulants to jump start the degrading process.

CICOR NOAA Outreach Web

NOAA Home Web Page – "in the Spotlight…"
http://www.noaa.oar

"Where the trade winds meet: air-sea coupling in the inter-tropical convergence zone"
J. Tom Farrer, WHOI Joint Program Student
Bob Weller, WHOI Senior Scientist and CICOR Director

NOAA Internal Web Page – "Hot Items"

"Two New Cooperative Institutes join existing 11 Joint and Cooperative Institutes"
Bob Weller, CICOR March 15, 2004

"Breck Owens, CICOR PI, accepts NOPP Trophy for Argo Project"
Bob Weller, CICOR March 25, 2004

2004 NOAA Progress Report

A Northwest Tropical Atlantic Station for Flux Measurement (NTAS)

NOAA Award No: NA17RJ1223
July 1, 2003 to June 30, 2004

PI: Albert J. Plueddemann
Woods Hole Oceanographic Institution
Woods Hole, MA 02543-1541
Phone: 508-289-2789, email: aplueddemann@whoi.edu

Program Manager: Michael Johnson, NOAA OCO

Related NOAA Strategic Plan Goals: Goal 2 (80%) – Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond and Goal 3 (20%) – Serve Society's Needs for Weather and Water Information.

Background: The Northwest Tropical Atlantic Station (NTAS) project for air-sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong SST anomalies and the likelihood of significant air-sea interaction on seasonal to decadal time scales. The strategy is to maintain a meteorological measurement station at approximately 15 N, 51 W through successive (annual) turn-arounds of a surface mooring. Redundant meteorological systems measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

Objectives: NTAS has two primary science objectives. First, to determine the air-sea fluxes of heat, moisture and momentum in the northwest tropical Atlantic using high-quality, in-situ meteorological measurements from a moored buoy. Second, to compare the in-situ fluxes to those available from operational models and satellites, identify the flux components with the largest discrepancies, and investigate the reasons for the discrepancies. An ancillary objective is to compute the local (one-dimensional) oceanic budgets of heat and momentum and determine the degree to which these budgets are locally balanced.

Accomplishments: Three Air-Sea Interaction Meteorology (ASIMET) systems were calibrated, assembled and tested. Two systems, comprised of the best performing sensors, were mounted on a three-meter discus buoy in preparation for deployment. The previous year's mooring (NTAS-3, deployed 15 February 2003) was replaced by the new mooring (NTAS-4) on 21 February 2004 during a mooring turn-around cruise on the NOAA ship Ron Brown. The period between deployment and recovery was dedicated to an intercomparison of the two systems, with the shipboard system as an independent benchmark. The NTAS-3 sensors are undergoing post-calibration and a cruise report is in preparation. Post-processed, hourly meteorological data from the NTAS-1 and 2 deployments, and uncorrected hourly data from NTAS-3 are available on-line from the Upper Ocean Processes (UOP) group web site (http://uop.whoi.edu/ntas). Complete, but uncorrected, data from the NTAS-3 deployment and 20 weeks of data from NTAS-4 are also available.

The first three deployment years have been very successful, with 100% data return of meteorological variables needed for bulk flux estimation. Figure 1 shows the annual cycle at the NTAS site as depicted by selected meteorological variables averaged over 1 week on a 13 month time base. Spring (MAM) is characterized by SST increasing from its annual minimum and very low levels of precipitation. Summer (JJA) is characterized by steady northeast winds at 6-8 m/s and continuing increases in SST. Episodic precipitation begins in late summer. Fall (SON) is characterized by reduced solar radiation, SST decreasing from its annual maximum, persistent precipitation, and variable winds. By mid winter (DJF), solar radiation begins to increase, precipitation decreases, and winds become steadier. Monthly averages show a clear tendency for strong precipitation to be associated with SST above 27°C, a characteristic of the Inter-Tropical Convergence Zone (ITCZ) system.

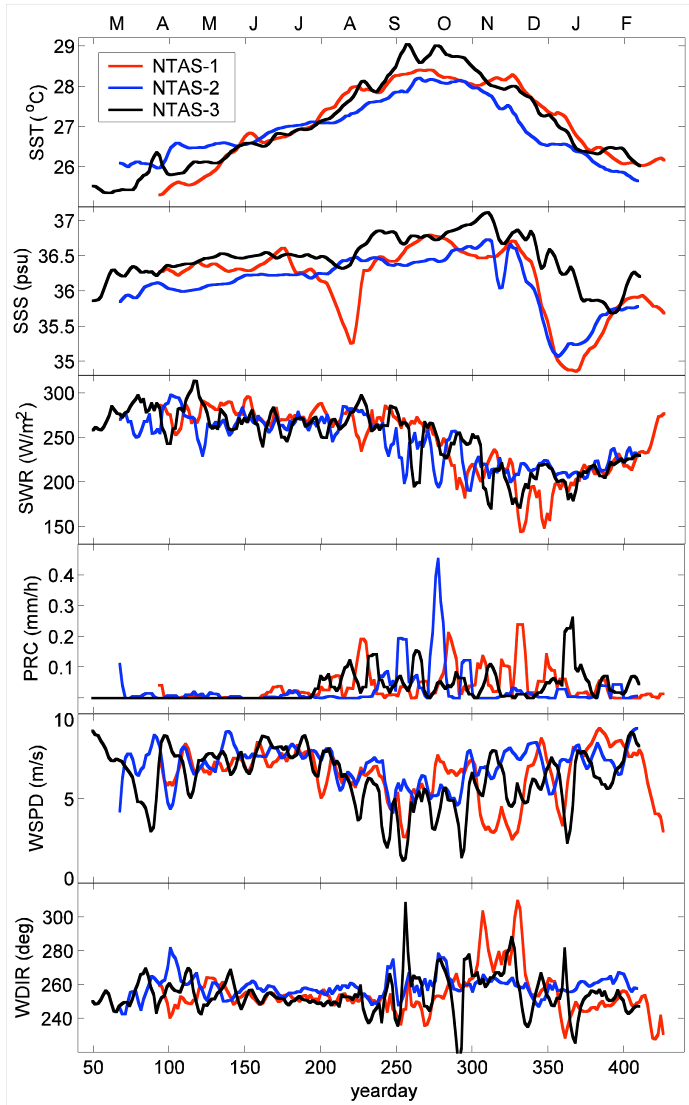


Figure 1. The annual cycle of surface meteorology at the NTAS site as depicted by selected meteorological variables averaged over 1 week on a 13 month time base. Sea surface temperature (SST), sea surface salinity (SSS), downwelling shortwave radiation (SWR), precipitation rate (PRC), wind speed (WSPD) and wind direction (WDIR) are shown for deployments in 2001 (NTAS-1, red), 2002 (NTAS-2, blue) and 2003 (NTAS-3, black).

Initial comparisons of the NTAS 1 and 2 fluxes with gridded products (Fig. 2) indicate a variety of issues for further investigation. European Centre for Medium Range Weather Forecasts (ECMWF) fluxes were from the output of the operational forecast model. National Centers for Environmental Prediction (NCEP) fluxes included both the first (NCEP-1) and second (NCEP-2) reanalysis. The Southampton Oceanography Centre

(SOC) climatology is based on ship reports from 1980-1993. It is clear that the two-year mean net heat flux is significantly underestimated by the three models (mean differences are 4-5 times larger than the expected error of about 10 W/m^2 from the buoy data). For ECMWF and NCEP-1 this is due to overestimation of latent heat losses and underestimation of shortwave gains. NCEP-2 shows a dramatic improvement in shortwave flux relative to NCEP-1, but still has a large net heat flux error due to substantial overestimation of latent heat losses. As a result, the amplitude of the annual cycle and the timing of positive to negative heat flux transitions are poorly reproduced by the models. In addition, all three models indicate a negative two-year mean net heat flux, whereas the observed value is +40 W/m2. Interestingly, the climatological net heat flux is a better match to the observations than any of the models.

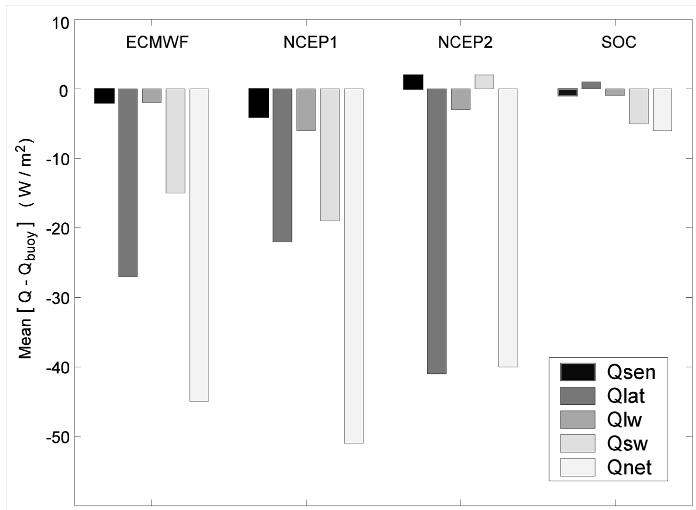


Figure 2. Mean differences between heat flux components from gridded products and the NTAS buoy for a two year period beginning in March 2001. The NTAS fluxes were computed using the TOGA COARE bulk flux algorithm (2.6b), whereas the NWP models and the SOC climatology use their own flux algorithms. The grid point nearest the NTAS site was used for comparison.

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Web site: http://uop.whoi.edu/ntas

2004 NOAA Progress Report

Air-Sea Interaction in the Eastern Tropical Pacific ITCZ/Cold Tongue Complex.

NOAA Grant: NA17RJ1223
July 1, 2003 to June 30, 2004

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NOAA Program Manager: Mike Patterson, Office of Global Programs

Related NOAA Strategic Plan Goal: Goal 2- Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

As part of the NOAA funded Pan American Climate Study (PACS), two surface moorings were deployed on 125º W, one at 3° S (cold tongue) and one at 10° N near the northernmost climatological position of the Inter-Tropical Convergence Zone (ITCZ). Each surface buoy carried two complete sets of meteorological sensors (wind velocity, air and sea temperature, incoming shortwave radiation and incoming longwave radiation, humidity, barometric pressure, precipitation, surface currents), and the heat, mass; and momentum fluxes have been computed using state-of-the-art bulk formulae (Fairall et al., 1996). The mooring lines carried temperature, conductivity, and velocity sensors to observe upper ocean variability in the upper 200 m. The data from the northern mooring returned the first accurate and complete time series of the air-sea fluxes of heat, freshwater, and momentum in the eastern Pacific warm pool beneath the northernmost climatological position of the Inter-Tropical Convergence Zone (ITCZ). This data set is also unique because it spans the strong El Niño event of 1997-98 and the onset of the subsequent La Niña. The data set was the focal point for the thesis work of an MIT/WHOI graduate student (Farrar, 2003), who has recently defended the thesis and is currently preparing results for publication under the supervision of Weller.

The effort was aimed at quantifying the relative importance of various physical processes in the evolution of upper ocean thermal structure and sea surface temperature at the mooring site. Drawing on the surface and subsurface mooring observations and remotely sensed wind and sea surface altimetry, the analysis showed that horizontal advection was of secondary importance in producing the observed thermal evolution (Farrar, 2003; Farrar and Weller, 2004). Instead, the most important factors in upper ocean thermal evolution were surface heat and momentum fluxes, vertical advection associated with Ekman pumping, and episodic vertical mixing across the thermocline associated with enhancement of the vertical shear by the large-scale geostrophic flow field. Vertical mixing was particularly important at the site during the transition of the tropical Pacific from El Niño to La Niña conditions. These findings yield insight into the factors affecting SST in the eastern Pacific warm pool, as the observed thermal evolution at the mooring site was representative of a much larger pattern of variability that has been shown to be a reliable precursor to ENSO phase transitions (c.f. Meinen and McPhaden, 2000, 2001; Alory and Delcroix, 2002).

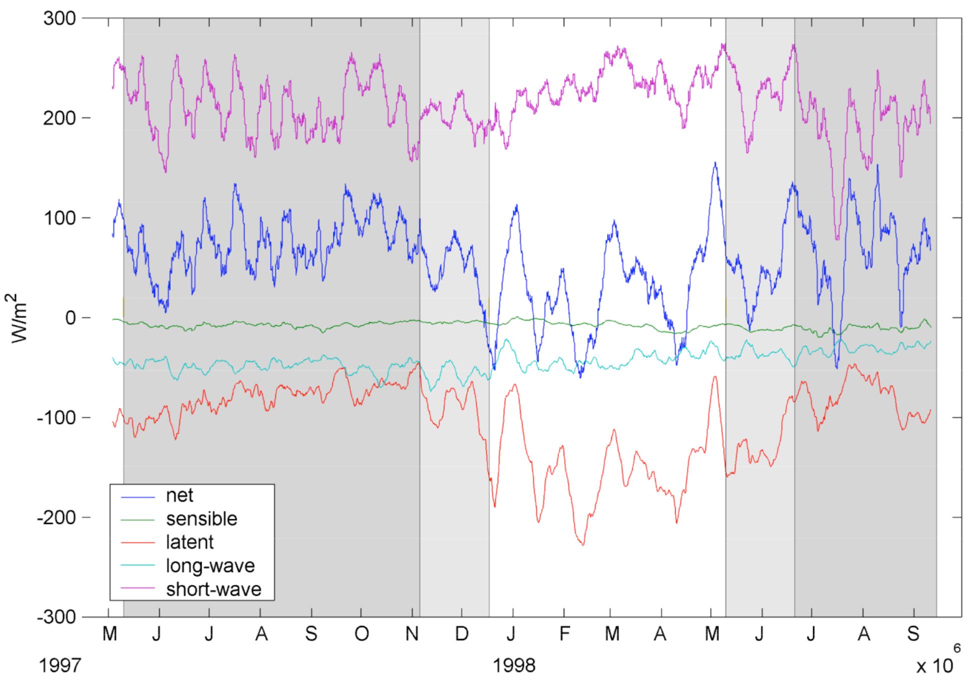

Figure 1. Heat flux component time series at 10°N. Times when the ITCZ was present are shaded.

Another important focus of this effort was to quantify the local air-sea fluxes of heat, freshwater, and momentum and to assess the importance of various timescales (from diurnal to seasonal) in the variability of these fluxes. This work led to several significant results. Climatological maps of cloud cover show the ITCZ as a band of clouds that might be expected to significantly reduce the solar heat flux. However, the observations indicate that the net heat flux was larger when the ITCZ was over the mooring site (Figure 1). While the solar heat flux was appreciably reduced during ITCZ conditions, the larger net heat flux was due to a relatively low evaporative heat loss from the sea surface during ITCZ conditions. This decreased evaporative heat loss is associated with reduced mean wind speeds and increased relative humidity during ITCZ conditions. At shorter timescales (2 to 30 days), there were also important differences between the ITCZ and non-ITCZ seasons. During ITCZ conditions, most of the 2 to 30 day variability in the net heat flux was due to variations in solar heat flux, while during non-ITCZ conditions, most of the 2 to 30 day variability in net heat flux was due to variations in latent heat flux.

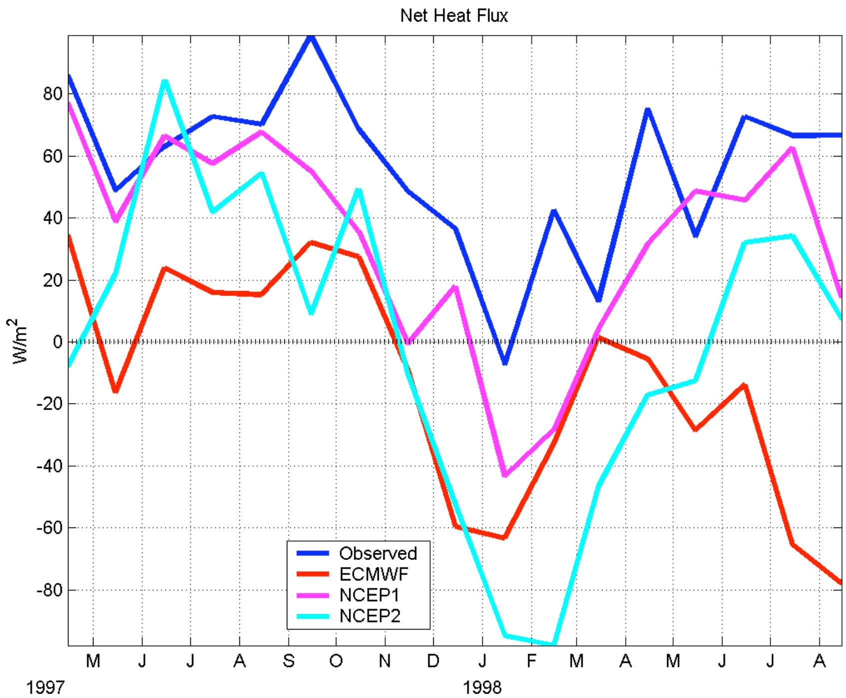

Figure 2. Observed monthly mean net heat flux (blue line) at 10°N, 125°W, along with the net heat flux from the ECMWF operational model and the NCEP 1 and 2 reanalysis products.

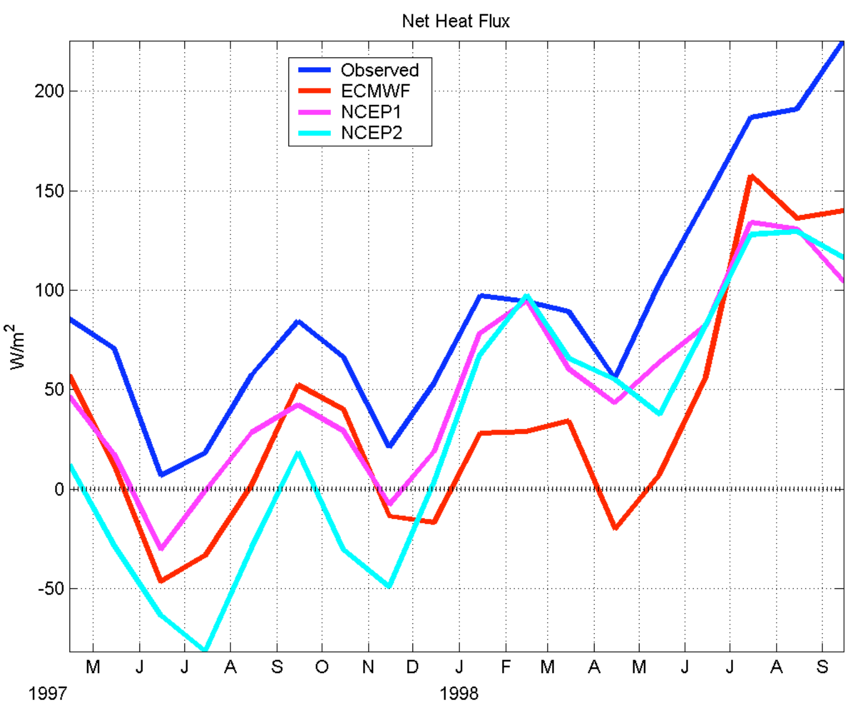

Figure 3. Observed monthly mean net heat flux (blue line) at 3°S, 125°W, along with the net heat flux from the ECMWF operational model and the NCEP 1 and 2 reanalysis products.

In order to address the goal of improving the simulation and prediction of sea surface temperature in the eastern tropical Pacific, a quantity known to be important to weather and climate over the Americas, Farrar and Weller have compared the high quality meteorological data from the buoy to surface fields commonly used to force ocean models (Farrar et al., 2004). The comparison focused on the reanalysis fields from the National Center for Environmental Prediction (NCEP1 and NCEP2; Kalnay et al., 1996; Kanamitsu et al., 2002) and on the operational model of the European Centre for Medium Range Weather Forecasting (ECMWF). A comparison of the monthly mean net heat flux in the observations to that in the three model products is shown in Figures 2 and 3. The models do a fair job of representing many of the qualitative features of the observed heat and momentum fluxes, such as the ENSO signal. For example, all three flux products showed the observed qualitative increase in heat flux to the equatorial cold tongue (3 ºS) as the tropical Pacific transitioned from El Nino to La Nina around May 1998. However, all of the models exhibit significant errors in the net heat flux to the ocean. The errors are comparable in size to the observed net heat flux. For example, at the 10 ºN site, the NCEP 2 monthly mean heat flux was of the wrong sign for 7 of 17 months, and the ECMWF product had the wrong sign for 9 of 17 months. Clearly, accurate simulation of SST requires that the heat flux be of the right sign. There are other errors that could have significant effects on long term oceanic simulations. For example, the equatorial cold tongue at the 3 ºS site was especially strong during May-Sept 1998 due to La Nina. All three model flux products had time mean heat fluxes that were roughly 70 W/m^2 too low during this period. The observed depth of the main thermocline during that time averaged 43 m, so the heat flux errors are large enough to cause an error of more than -4 ºC in the mixed layer temperature over the 5 month period.

Continuing progress will allow for the completion of the analysis of the data collected at 125°W during 1997-1998 in conjunction with preparation of a Ph. D. Thesis. The effort will first shift to examining the surface forcing, upper ocean dynamics, and evolution of the thermal structure at 3°S. With that complete, we will use remote sensing and TAO data in conjunction with the upper ocean observations and air-sea fluxes from the two mooring sites to extend the effort to identify the important physical processes that drive the evolution of SST and upper ocean thermal structure over the broader region spanning the equatorial cold tongue and in the eastern Pacific warm pool during the El Niño and La Niña events of 1997-98.

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2004 NOAA Progress Report

Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic

NOAA Grant: NA17RJ1223
July 1, 2003 to June 30, 2004

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NOAA Program Manager: Michael Johnson, NOAA/OGP

Related NOAA Strategic Plan Goals: Goal 2 – Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond and Goal -Serve Society's needs for Weather and Water Information.

This is the summary technical report for the period 1 July 2003 to 30 June, 2004 on a program to implement one high-density XBT line with TSG and IMET Instrumentation in the tropical Atlantic.

1. Project Goals – Year 3.

The Year 3 tasks were to install the system on the VOS specified by NOAA-SEAS for NOAA-AOML. Six months later the system will to be turned around using the second system. These goals were delayed from Year 2.

2. Description of Work – Year 3.

Ship selection for the Atlantic VOS was made late in 2003. AutoIMET systems were installed in June 2003 and December 2003 on the Pacific ships as part of a companion project.

January 2004. A survey of the SeaLand Express was carried out by Frank Bahr in Newport News, VA in preparation for the AutoIMET system installation.

March 2004. The AutoIMET system was installed on the SeaLand Express in Elizsabeth, NJ by Frank Bahr, Craig Marquette, Alan Gordon and Dave Hosom. The time in port was short and the weather was nasty. Steve Cook and Jim Farrington of NOAA helped with the AutoIMET installation and did the new NOAA SEAS 2000 installation on the bridge. The system was operating well with the exception of SST.

April 2004. Frank Bahr and Dave Hosom attended the OCO Workshop and the HRMM Workshop in Silver Spring MD and presented a poster on the combined Atlantic and Pacific VOS programs.

May 2004. Frank Bahr visited the ship in Elizabeth NJ to trouble shoot the SST system. The SST sensor (SeaBird 48) self records one minute data but was not being transmitted via the HullCom (acoustic modem) to the logger on the bow mast. The "Local" and "Remote" HullCom units were re-located to try to get a better acoustic path. The system was still not working properly. The SST and HullCom units were removed from the ship and returned to WHOI. The units were tested and WHOI and found to be operating properly, pointing to the acoustic path as the problem. It is possible to re-locate the "Remote" HullCom so that the acoustic path is very short by using a 100 foot long cable between the "Remote" HullCom and the SBE48. This will be installed in June.

June 2004. Frank Bahr and Laura Hutto reinstalled the SST and HullCom units on the SeaLand Express in Elizabeth NJ. There are reports of high wind "spikes" in the data, therefore a new WND module will be taken to the ship as well as a new IMET GPS to monitor "real wind" in post processing. The "real wind" currently is calculated in the NOAA SEAS 2000 system using the SEAS GPS data.

Success will be monitored via the SEAS data.

The system will be turned around in Baltimore MD in September 2004. The data will be processed and be available on the web.

2004 NOAA Progress Report

Long-term evolution and coupling of the boundary layers in the stratus deck regions of the eastern Pacific

Grant: NA17RJ1223
July 1, 2003 to June 30, 2004

Program Manager: Mike Patterson, OGP

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Related NOAA Strategic Plan Goal: Goal 2 – Understanding Climate Variability and Change to Enhance Society's Ability to Plan and Respond.

Background and Objectives

The primary purpose of this grant is to further our understanding of the processes that create and maintain the large stratocumulus cloud decks, and associated cool upper ocean, that are located off of the western coast of South America. To study the processes in the region, a mooring consisting of a surface buoy with an IMET system and a subsurface wire instrumented with temperature, conductivity, and velocity sensors has been deployed at 20°S, 85°W since October 2000. This mooring was originally provided as part of the enhanced monitoring effort of the East Pacific Investigation of Climate (EPIC) and is now an Ocean Reference Station and Surface Flux Reference Station (funded by NOAA Climate Observation program). A post-doctoral investigator (Keir Colbo) was hired in May 2003 to work full-time on this project.

The four locations where the Trade Winds blow off of the continents onto the ocean (Baja California, Peru-Chile, Namibia and the Azores) are regions of strong upwelling. Offshore and downwind of all these locations are situated large semi-permanent stratocumulus cloud decks. Global coupled computer models have had a difficult time in representing these regions. In particular, they tend to have oceans that are too warm, and through feedback mechanisms, this leads to insufficient cloud cover, which feeds back onto the ocean and causes it to further warm.

The main data products analyzed consist of the high temporal resolution (1 minute) surface meteorology from the buoy, and the high temporal and spatial resolution subsurface instrumentation located in the upper 400m of the water column. However, to place the mooring in the broader context of the region we also use publicly available data sets of satellite derived sea surface temperature (SST) and sea surface wind vector, drifter derived surface velocity and temperature, and historical subsurface CTD and XBT profiles.

Data Quality

Before proceeding with the analysis it is necessary to perform a thorough investigation of the data so as to identify, and hopefully correct for, possible observational errors. The data quality and return of all the Stratus deployments has been very high with two exceptions. In the second year the RDI Acoustic Doppler Current Profiler (ADCP) failed after half a year due to a fault with the instrument that caused excessive battery use. In the third year, many of the upper ocean Vector Measuring Current Meters (VMCMs) were fouled by fishing line leaving incomplete records.

It is also important to ascertain the accuracy of the measured variables. The oceanographic instruments are sufficiently common, and of sufficient quality, that the expected errors are both known and small. The surface meteorological instruments are not nearly as common, and thus we need to expend more effort on examining the accuracy. Although some of these instruments have been examined individually, there has been little consideration of the errors of the derived products (e.g. heat flux components). Additionally, most previous studies have considered only the functioning of the instrument in laboratory conditions.

To address these issues we are preparing a paper that deals in depth with the accuracy of the meteorological sensors. This includes an examination of many separate sources of error, such as; limitations in the precision of the instrument, errors in the calibration methods, drifts in the calibration constants with time, and a host of operational issues (e.g. buoy motion effects). The results of this analysis will be defensible error bars for all the meteorological and derived variables. These error bars are key for the proper interpretation of the data, and for its use as part of a long-term climate record.

Some preliminary results for the longwave sensor are listed below as an example. In interpreting the accuracy error bars it is important to realize that we are reporting absolute accuracy. Thus the instantaneous error in the chart represents the maximum expected deviation between the measurement and the truth. It does not represent the point-to-point noise in the readings since many of the sources of error vary slowly with respect to our sampling interval. For example, solar heating effects may cause the longwave radiation sensor to read 2 W/m^2 high in the morning and 2W/m^2 low in the evening, but have very little effect on the point-to-point noise.

	Precision	Lab. Cal	Cal. Drift	Field Error	Total
Longwave Radiation (Eppley PIR)	Dome: 0.1K Case: 0.1K Thermopile: 10 microV	Coeff.: 2 W/m^2 Noise: 0.5 W/m^2	2 W/m^2	Tilt Error: 2 W/m^2 T Grad.: 4 W/m^2 Spray: <1 W/m^2	Instant: 10 W/m^2 Day: 6 W/m^2 Annual: 5 W/m^2

Scientific Results

The science has been divided into several different areas, initially focusing on the ocean and atmosphere separately. The primary oceanic question is "What maintains the cold SST underneath the stratus cloud decks?" This question can be resolved by quantifying all the elements of the heat and salt budgets. Although it is important to understand the high frequency variability of the forcing, we initially concentrate on annual heat and salt budgets. There are two reasons for this choice. The first is that there is frontal activity in the area that introduces an unknowable advective signature into the data. By averaging over a time scale that is long compared to the frontal activity we hopefully eliminate its importance. Secondly, we are reasonably comfortable in assuming that there is no net heat or salt input over the annual cycle, as we do not observe a trend in annual mean upper ocean temperatures or salinities, which allows an additional constraint on our calculations.

<u>Annual Ocean Heat and Salt Budgets</u>
The annually integrated heat budget is a balance between a number of terms: Surface fluxes, Advection due to Ekman transport, Advection due to geostrophic transport, Convergence of the Ekman transport, Vertical Diffusion, and Eddy flux divergences. Budgets are often formed by estimating the known terms and then setting the unknown terms to be equal to the residual. We have attempted the harder problem of estimating all the terms, and using the closure of the annual budget as an additional check.

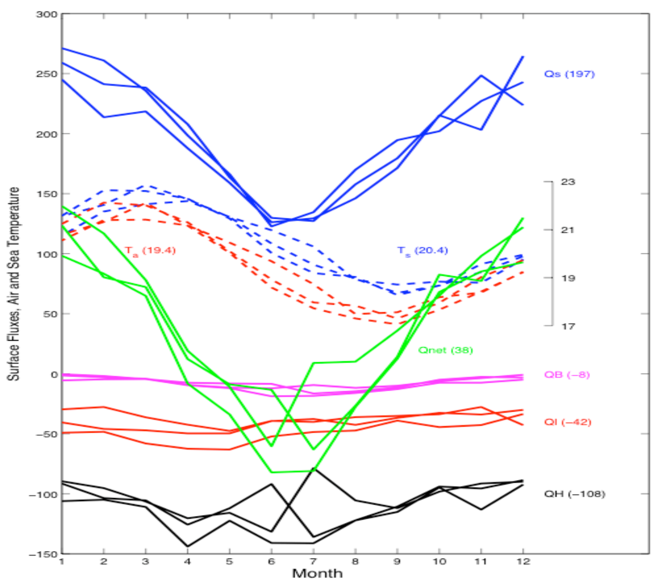

Figure 1: The monthly averaged components of the surface heat flux

The surface fluxes are calculated using bulk formulae from the mooring measurements of surface meteorology (Figure 1). Note that the variability is influenced by different processes in different seasons (clouds, via radiation, in austral summer; wind in austral winter). Ekman advection is calculated from a combination of satellite data (QuikScat for winds, and Reynolds or TMI for SST) (Figure 2).
Note the somewhat surprising result that there is little direct advection of cold water into the stratus cloud deck region, and that it is negligible at the mooring site. Geostrophic advection is calculated through a combination of mooring measured velocity and historical atlases of ocean climatology. The convergence of the Ekman transport is calculated from QuikScat winds and the resulting heat flux is determined by choosing a vertical profile for the Ekman pumping velocity. Vertical diffusion has been made negligible by choosing a suitably deep depth of integration. Finally the eddy flux divergence is estimated in a number of ways. The most reliable method is through a combination of surface drifter inferred diffusivity combined with historical climatology of subsurface temperature. However, we also tried a novel method of calculating the eddy correlation terms and their divergence directly from satellite data, using Topex/Poseidon sea surface height fields to estimate the geostrophic velocity anomaly.

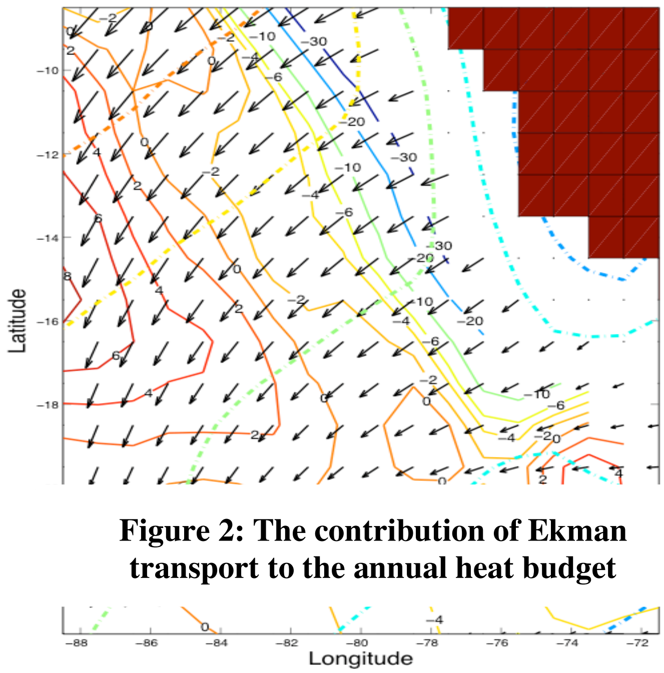

Figure 2: The contribution of Ekman transport to the annual heat budget

Combining all these separately derived components, we are able to approximately balance the annual heat budget. We find that the strong sources of heat from surface fluxes and the convergence of the Ekman transport are balanced by the large-scale gyre bringing cool water northward and by an important eddy flux of cool water from onshore.

Additionally, we can perform the above calculations for salt and arrive at an entirely independent check on the various components of advection, diffusion and eddy flux. We find that the salt budget is very similar to the heat budget with the exception that the large-scale gyre circulation plays a more important role. These results are being prepared for publication (Colbo and Weller, 2004).

<u>Meteorology Results</u>

The project began under EPIC with the intent of obtaining observations to determine whether or not the Peru-Chile stratus deck region was different from stratus deck regions off California and near the Azores, where previous field observations had been conducted. Toward this end, each cruise to the 20°S, 85°W site has been made with additional observations aimed at collecting surface meteorological and atmospheric observations and remote sensing imagery in a region surrounding the mooring have also been archived. The most extensive of these efforts came in October 2001, when the second phase of the EPIC2001 process study was devoted to studying the stratus deck region near the mooring. Collaborative analyses are underway with M. Cronin at NOAA PMEL, Chris Fairall at NOAA ETL, and investigators at the University of Washington, including S. Yuter and C. Bretherton. The surface meteorological observations are telemetered via satellite, but not put on the Global Telecommunication System (GTS), so they are not used by the numerical weather prediction centers when they initialize their models. Instead, we exchange our data via FTP with ECMWF and NCEP, obtaining from them the operational model data at the grid point nearest to the mooring.

Work to date has noted that the stratus deck region off northern Chile is different from other stratus deck regions previously studied (Bretherton *et al.*, 2004), with strong diurnal modulation of the atmospheric mixed layer. The present hypothesis is that there is a subsidence wave generated by the Andes that is the source of this diurnal modulation. Work is underway to use the first three years of surface mooring data to characterize the surface meteorology at the site, and publication of these results is planned for next year.

Flux Comparisons

The three years of high quality bulk fluxes, supported by the ship-buoy comparisons and the error study described above, have given us a very solid foundation for a quantitative description of the air-sea exchanges of heat, freshwater, and momentum under the northern Chile stratus. The surface radiation data were analyzed together with the radiation data collected by M. Cronin from mooring maintained along 95°W during EPIC, and this work (Cronin *et al.,* 2004) will soon be submitted for publication.

We are also working to write up the results of comparing our observed fluxes with the operational and reanalysis fluxes from NCEP and ECMWF and with the climatological values for this region. Because coupled models show sensitivity to how the optical properties of the stratus clouds are prescribed, we are interested in model parameterizations of stratus cloud properties and are participating in and providing data for the cloud parameterization CPT (Climate Process Team) headed by C. Bretherton.

Publications:

Bretherton, C. S., T. Uttal, C. W. Fairall, S. Yuter, R. Weller, D. Baumgardner, K. Comstock, R. Wood, and G. Raga, 2004: The EPIC 2001 stratocumulus study. *Bull. Amer. Meteor. Soc.*, accepted.

Colbo, K, and R. A. Weller, 2004. The variability and heat budget of the upper ocean under the Chile-Peru stratus, in preparation.

Cronin, M. F., N. A. Bond, C. Fairall, and R. A. Weller, 2004. Surface cloud forcing in the east Pacific stratus deck/cold tongue/ITCZ complex, for submission to *J. Climate*.

2004 NOAA Progress Report

U.S. Program in Marine Biotoxins and Harmful Algae

NOAA Grant: NA17RJ1223
July 1, 2003 to June 30, 2004

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Related NOAA Strategic Plan Goal: Goal 1 – Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management.

The following summary lists activities conducted by the National Office during the third year of this cooperative agreement:

International Activities:
International Council for the Exploration of the Sea (ICES) National Coordinating Center for Exchange of Information on Harmful Algal Blooms. Compiled reports of all HAB events in U.S. for the year 2003 for ICES Coordinating Center for Exchange of Information on HABs. This is the only compilation of US HAB incidents.

Attended ICES Working Group on HAB Dynamics meeting in Calvi, Corsica and presented summary of U.S. bloom events. Gave a presentation on *Alexandrium* Bloom Dynamics in the Gulf of Maine,

Collated and prepared maps for all U.S. HAB events for inclusion in a "global and visual overview of harmful events for the preceding 10 years". This is an ICES GIS effort, and now is an annual activity. Examples of these maps are included on the US National HAB web page.

Served as a depository and North American distribution center for the Proceedings of the *9th International Conference on Harmful Algal Blooms* and the *8th International Conference on Toxic Marine Algae* (published by IOC). Also distributed copies of *Monitoring and Management Strategies for Harmful Algal Blooms in Coastal Waters* (published by APEC and IOC). Handled payments and mailings for all requests for these books.

Assisted with editing and publishing the Proceedings from the *Second International Conference on Harmful Algae Management and Mitigation* (HAMM) held in Qingdao, China November 12-16, 2001.

Maintenance and updating of the internet listserver for ISSHA (The International Society for the Study of Harmful Algae).

National:
Directed and organized the *Second Symposium on Harmful Marine Algae in the U.S.* which was held December 9-13, 2003 in Woods Hole. This involved planning the scientific program; soliciting and compiling abstracts for oral presentations and posters; organizing discussion sessions; obtaining funding for travel awards for students and Postdocs, reviewing applications and making subsequent awards. Abstracts from the meeting were published recently in *Harmful Algae*.

Coordinated the venue for the 3rd U.S. HAB Symposium, scheduled for 2005, by soliciting volunteers willing to serve as hosts, collecting and disseminating descriptions of the possible venue sites, and conducting a vote of the U.S. HAB community. Assisting with planning the Symposium to be held in Monterey, California, including efforts to secure funding for student travel awards and meeting support.

The National Office has a major role in the ongoing revision of the *US. National Plan for Marine Biotoxins and Harmful Algae*. Over the past several months, significant time has been devoted to writing and editing the final workshop report.

Administration of a Rapid Response Program for HAB Events in the U.S. in cooperation with CSCOR administrators. This involves advertising availability of funds to the HAB community as well as accepting requests for funds and administering their dispersal. The National Office works with NOAA Program Managers to decide who receives funds and how much will be needed in each case. Additionally, we make arrangements and process travel associated with these rapid response activities as well as other budget issues, including vessel charters, equipment rental, etc.

Briefing before the House Science Committee, "Coastal Nutrient Pollution and Harmful Algal Blooms", September 24, 2003.

Testimony before the Subcommittee on Fisheries Conservation, Wildlife and Oceans, U.S. House of Representatives Hearing on H.R. 1856, the Harmful Algal Bloom and Hypoxia Research Amendments Act of 2003, February 26, 2004.

Distributed copies of *National Plan*, *ECOHAB*, *Economic Impacts* and other reports.

Meetings and many presentations on national HAB issues at universities, meetings, workshops, and symposia. This involves considerable travel, preparation, and follow-up.

Many discussions and meetings with federal agencies and others in Washington, DC to continue development and funding of the U.S. HAB program.

World Wide Web homepage – www.whoi.edu/redtide - continually expanding contents and updating information to include reports of HAB outbreaks, recent publications, funding opportunities, etc. This home page also generates numerous requests for additional information, photos, or references, which require personal attention.

Participate in press briefings organized by Sea Grant and other organizations. Present HAB issues from National perspective.

Responded to numerous newspaper and journalist inquiries. In order to ensure that HAB issues are presented correctly, and that they remain "visible" to the general public and to the federal officials, considerable time needs to be spent on interviews and other interactions with journalists.

Maintenance of a central repository for pictures and videos that can be distributed to the public and the media.

Publications:

D. M. Anderson, Guest Editor. 2004. Second Symposium on Harmful Marine Algae in the US, Woods Hole, MA, 9-13, December 2003. Harmful Algae 3 (3): 1-271.

Kleindinst, J.L. and D.M. Anderson. 2004. Internet-based communication tools for dissemination of information on harmful algal blooms (HABs), in: *Harmful Algae Management and Mitigation*, Hall, S., S. Etheridge, D. Anderson, J. Kleindinst, M. Zhu, and Y. Zou, (Eds.). In press.

Harmful Algae Management and Mitigation. 2004. Hall, S., Etheridge, S., Anderson, D., Kleindinst, J., Zhu, M., and Zou, Y. (Eds.), Asia-Pacific Economic Cooperation (Singapore): APEC Publication #204-MR-04.2, In press.

2004 NOAA Progress Report

Analysis of the 1999 Georges Bank Tidal Mixing Front Moored Array Data

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Program Manager: Dr. Lisa Dilling, NOAA Office of Global Programs

Related NOAA Strategic Plan Goal: Goal 1 - Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management.

Here we summarize the data processing and analyses of the data from the 1999 Georges Bank tidal mixing front mooring array conducted this past year by R. Beardsley and J. Lerczak and supported by the CICOR grant entitled "Analysis of the 1999 Georges Bank Tidal Mixing Front Moored Array Data." We summarize the results that were presented at the U.S. GLOBEC Georges Bank Science Meeting in November 2003 and at the AGU Ocean Sciences Meeting in January 2004. Finally, we outline the work that we plan to complete in the final year of this CICOR grant.

Data processing: While most of the processing of the acoustic Doppler current profiler (ADCP), temperature, salinity, and pressure data from the moored arrays was completed in the previous year (July 2002 to June 2003), inconsistencies in the orientation of the ADCP currents were identified this past year, and corrected current time series were generated. For the spring and summer deployments, both the orientation of the M_2 current ellipse of the vertically-averaged currents and the orientation of the vertically-averaged, sub-tidal currents varied from mooring to mooring by 10^o to 20^o with no obvious trend (Figures 1a and 1c). We attribute this variability in orientation across the mooring array to slight errors in the ADCP compass calibrations. Deviations in orientation were larger during the summer deployment than the spring. This may be because the ADCP compasses were not recalibrated during the spring to summer turn-around cruise.

The misalignment of the ADCPs was corrected by rotating the currents from each ADCP in order to minimize the deviations of the alignment of the tidal ellipse and the low-pass current relative to the mean orientation of the tidal ellipses and low-pass currents, respectively, of all moorings. After rotating the currents, deviations in alignment were significantly reduced (standard deviation = 1.1^o; Figures 1b and 1d).

Time series of processed currents, temperature, salinity, and pressure interpolated onto a common time base, and stored as MATLAB files were provided to Ron Schlitz (NMFS/NEFSC).

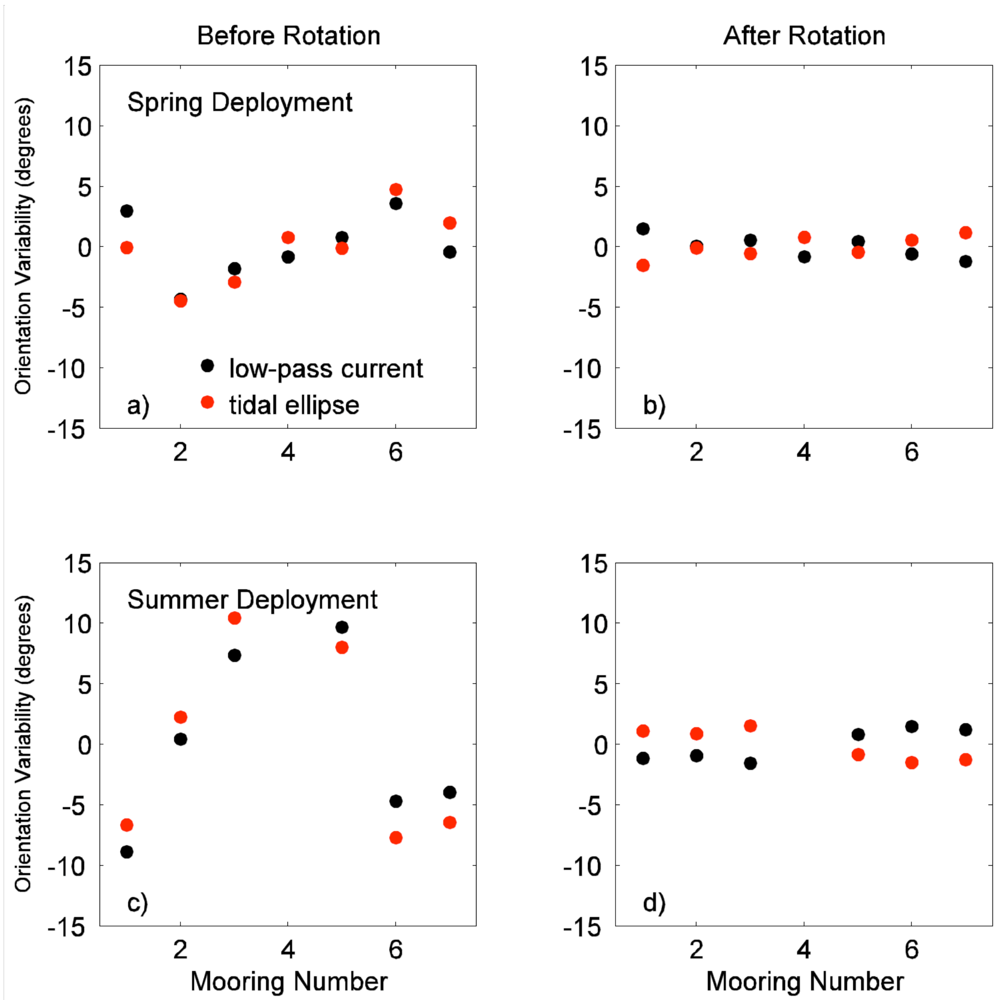

Figure 1. Variability of the M_2 tidal ellipse orientation (red circles) and the low-pass current orientation (black circles) for the vertically-averaged currents from the ADCPs during the spring and summer deployments of the tidal mixing front mooring arrays. The mooring number increases with off-bank distance. The left panels show the variability of the raw ADCP data. The right panels show the variability after the deviation at each mooring has been removed.

Outline of data analyses and results presented at meetings: Results from analyses of the tidal front mixing array were presented by Lerczak at the U.S. GLOBEC Georges Bank Science Meeting in November 2003 and at the AGU Ocean Sciences Meeting in January 2004. The emphasis of these presentations was on the cross-bank structure of the subtidal current and density fields and on the momentum balances which drive the subtidal, cross-bank and along-bank flows. To our knowledge, this represents the first attempt to directly measure the amplitude and structure of nonlinear tidal Reynolds stresses in the vicinity of a TMF. The key results from these analyses are:

• Vertically-averaged, subtidal flow is predominantly in the along-bank direction, clockwise around Georges Bank, with an amplitude as large as 25 cm/s (Figure 2a). When stratification is weak (before day 120), the current is intermittent and varies significantly in amplitude. During the summer, when stratification is strong, the along-isobath flow is less intermittent and has an average amplitude of about 10 cm/s.
• Vertical shear in the subtidal, along-isobath currents increases significantly from spring to summer with the increase in stratification (Figure 3a). This shear is predominantly in geostrophic balance.
• Cross-bank, tidal Reynolds stress (tidal average of the nonlinear terms vu_y and vv_y) are dominant terms in momentum budgets. The vertical structure and amplitude of the tidal Reynolds stress varies with stratification. For example, the vv_y term is vertically uniform when stratification is weak and has a mode two structure when stratification is strong. This term may be important in driving the subtidal, cross-bank flow in the vicinity of the TMF.
• The TMF is apparent in the structure of the density field in the vicinity of the array, but not all the time. During the summer (after day 170), the stratification is stronger off-bank than on-bank (Figure 4a), indicative of the presence of the TMF. This cross-bank variation of stratification is intermittent, at times during the summer being large (pink shaded region in Figure 4) while at other times during the summer being small (e.g., day 202). The presence of the front is also apparent the vertical structure of the cross-bank density gradient (Figure 4b). At the surface water tends to be denser on-bank than off-bank. However, near the bottom, off-bank water tends to be denser than on-bank. The vertically-averaged density tends to be higher off-bank than off bank. This is consistent with the structure of a TMF, for which mixing of the water column is more efficient on-bank of the front and less so off-bank of the front. We believe the short period (~5 to 10 days) variations in stratification and cross-bank density gradient are due to the cross-bank advection of the TMF in the vicinity of the mooring array. To confirm this we will determine the variations in the location of the TMF over the spring and summer of 1999 using satellite AVHRR data in collaboration with Jim Bisagni (UMass-Dartmouth).

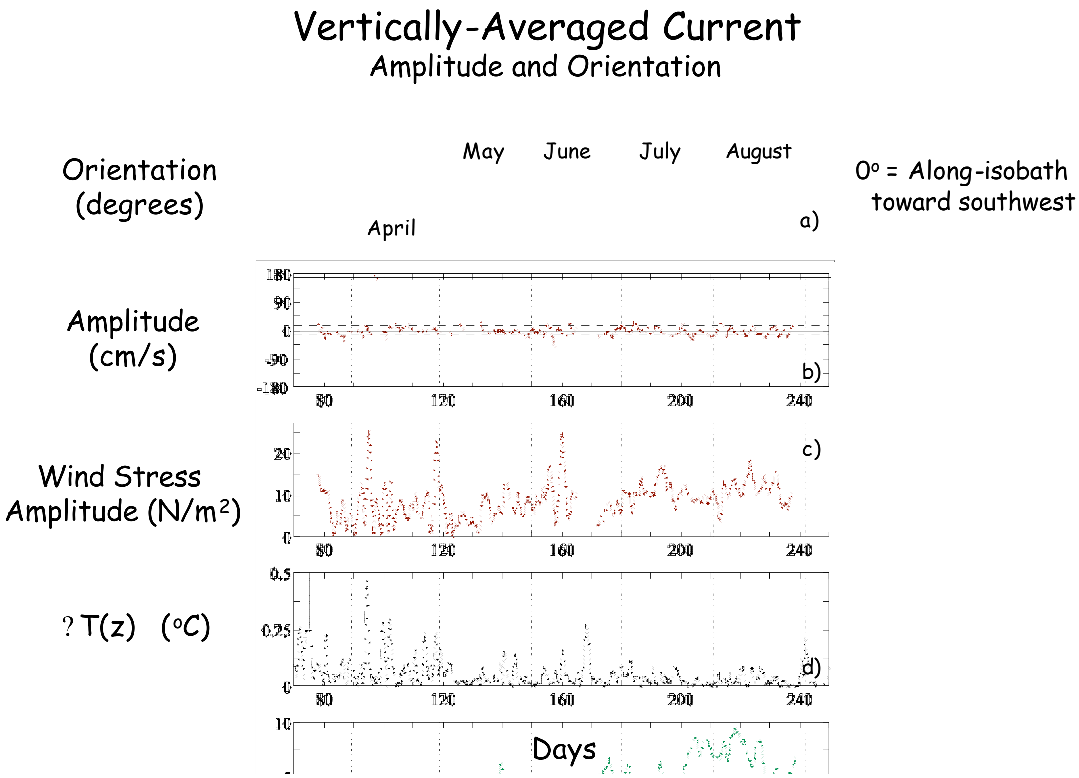

Figure 2. a) Orientation of the vertically-averaged, sub-tidal currents during the 1999 tidal mixing (TMF) front mooring array deployment. An orientation of 0° indicates flow along isobaths in the clockwise direction around the Georges Bank. The horizontal dashed lines indicate +/- 15°. The orientation is not shown when the current amplitude is less than 5 cm/s. b) Amplitude of the vertically-averaged, sub-tidal currents. c) Amplitude of the low-pass (sub-tidal) wind stress measured at NDBC buoy 44011. d) Top-to-bottom temperature difference at the TMF study site.

Vertical Shear in Along-Isobath Currents

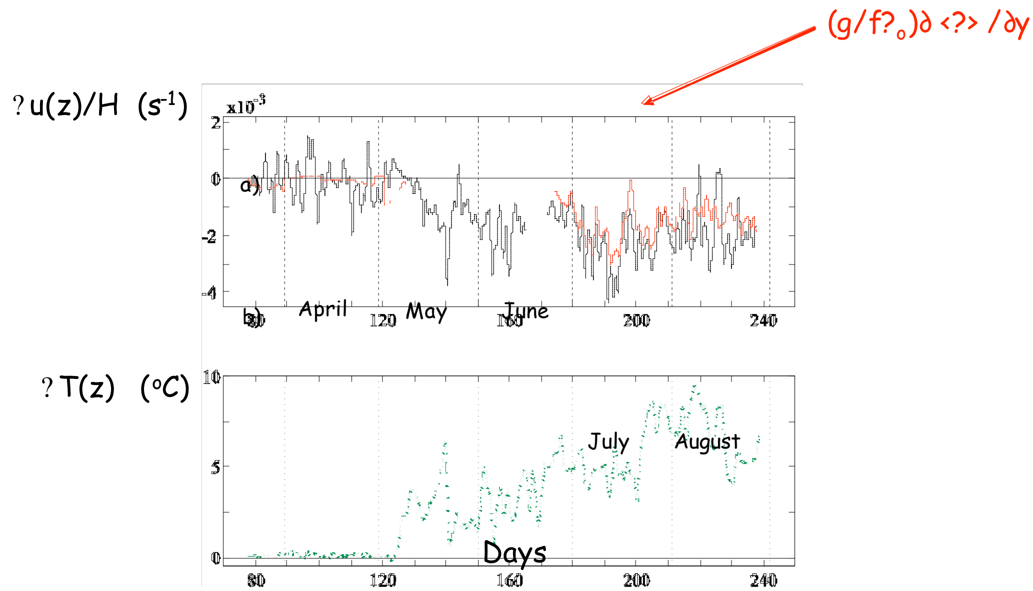

Figure 3. a) Vertically-averaged, vertical shear of the sub-tidal, along-isobath currents (black line). Vertically-averaged geostrophic shear (red line) estimated from the vertical temperature strings from moorings that spanned the mooring at which the shear estimate was made. b) Stratification (top-to-bottom) temperature difference.

Stratification and Cross-Bank Density Gradient

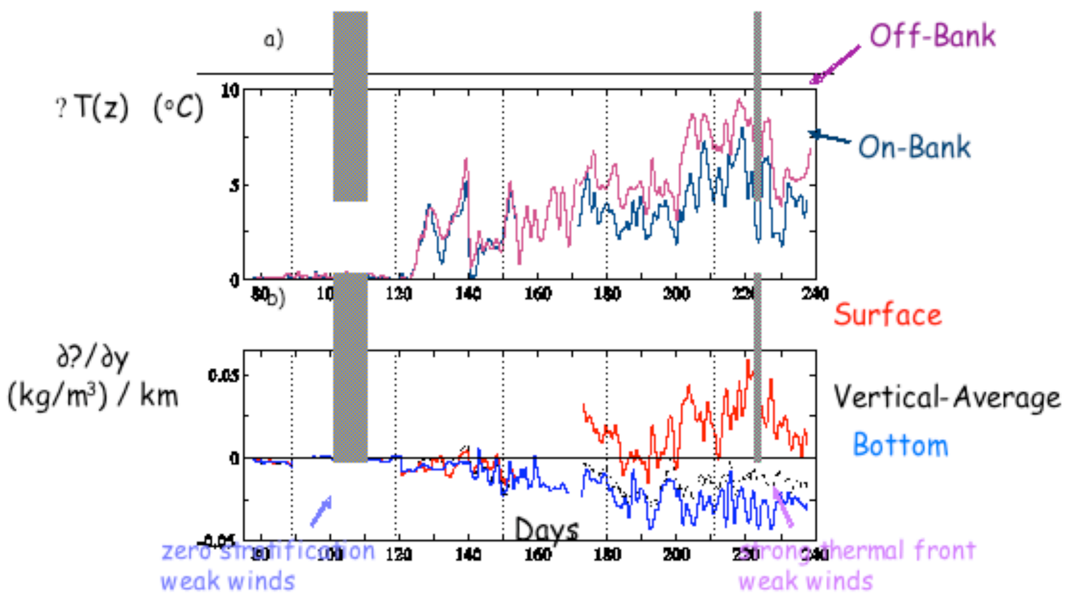

Figure 4. a) Stratification (top-to-bottom) temperature difference at the off-bank-most (red line) and on-bank-most (dark blue line) moorings of the TMF array. During the summer (after day 170) the off-bank mooring tends to be more stratified than the on-bank mooring. b) Cross-bank density gradient near the surface (red line), the bottom (blue line) and vertically-averaged (black line). During the summer months (after day 170), surface water tends to get denser towards the bank, while bottom water tends to get less dense. The vertically-averaged density decreases towards the bank. This cross-bank density structure is the result of more complete vertical mixing at the on-bank mooring than further offshore and is consistent with the presence of a tidal mixing front in the vicinity of the mooring array.

Future work: In the upcoming year, Lerczak and Beardsley will complete and submit a manuscript detailing the structure and variability of the density and sub-tidal current field as observed by the mooring array. The emphasis of this paper will be on our estimates of the momentum terms which drive the subtidal circulation in the vicinity of the TMF. In particular, we will compare our measurements of the tidal Reynolds stress terms for different levels of stratification to those predicted by analytical theory and those obtained from numerical models (e.g., the FVCOM simulations of the Gulf of Maine conducted by C. Chen, UMass-Dartmouth). Lerczak is working with J. Bisagni (UMass-Dartmouth) to compare the temporal variations in the location and strength of the TMF as observed in the mooring array data with satellite sea surface temperature measurements. We will also collaborate with C. Chen and R. Schlitz to make detailed comparisons of the structure of the TMF circulation, stratification and fluxes as determined from the mooring array data and those produced by the FVCOM model. Finally, we will provide support and assist in data analysis for R. Schlitz's study of the structure of tidal currents in the vicinity of the mooring array.

***References*:**

Lerczak, J., R. Schlitz, S. Lentz, and R. Beardsley. 2003. Sub-Tidal Circulation at the Tidal Mixing Front: Analysis of the Moored Instrument Array. Presentation at the U.S. Globec Georges Bank Science Meeting. 18-20 November 2003, Rhode Island.

Lerczak, J. A., R. J. Schlitz, R. C. Beardsley. 2003. The seasonally-varying, sub-tidal structure of the tidal mixing front on the southern flank of Georges Bank. *Eos Trans. AGU, 84*(52), Ocean Sci. Meet. Suppl., Abstract OS51J-09.

2004 NOAA Progress Report

Patterns of Energy Flow and Utilization on Georges Bank

NOAA Grant: NA17RJ1223
July 1, 2003 to June 30, 2004

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Related NOAA Strategic Plan Goals: Goal 1 –Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management.
Goal 2 – Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond.

Accomplishments
(1) Linear network analysis: This work has focused on the lower trophic levels (the microbial loop. See Fogarty and Stockhausen for upper level analysis) Previous methods (ECOPATH and "inverse" techniques) appear inadequate for these components – especially in relation to ecologically acceptable optimization criteria. We have developed alternative criteria and have carried out comparisons for microbial food webs. These methods have been developed for the Georges Bank microbial ecosystem. We shall use data from other investigators for applications in year three. A paper is about to be submitted:
"Reconstructing food web flows in linear marine ecosystems: optimizing for resilience."
Andrew Beet, Ann Milligan, John Steele and Andrew Solow

(2) Non-linear modeling: work continues, and is used in a review:
" Functional Diversity and Stability in Coastal Ecosystems"
Steele, J.H. and Collie, J.S., (in press)
The Sea, Vol 13, (eds Robinson and Brink)

Other relevant publications:
J. H. Steele and P. Hoagland. Are fisheries sustainable? Fisheries Research. (2003) 64. 1-3

Editor (with R. Harris) *Regime Shifts in the ocean*
(Special Issue, Progress in Oceanography, Vol 60 Nos 2-4)

Steele, J. H. Regime shifts in the ocean, reconciling theory and observation. Progress in Oceanography, 60, (2004) 135-141

Relevant Talks ; JHS (2003-4)

March: Resolving Ecosystem Complexity
(Paris, IOC Symposium)
May: Marine Time Series; Regime shifts or Rorshach tests?
(Southampton Oceanography Centre)

2004 NOAA Progress Report

U.S. GLOBEC: Integration and Synthesis of Georges Bank Broad-Scale Survey Results

NOAA Grant: NA17RJ1223
July 1, 2003 to June 30, 2004

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E. Durbin, R. Campbell, & B. Sullivan-Watts (URI)

NMFS/NEFSC
D. Mountain, J. Green, P. Berrien

Program Manager: Dr. Phil Taylor,
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Related NOAA Strategic Plan Goal: Goal 1 – Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management.

Collaborators:
The following projects are being carried out as part of the U.S. GLOBEC Northwest Atlantic/Georges Bank Synthesis Project and the investigators are collaborators on this project.

Project title: The Physical Oceanography of Georges Bank and Its Impact on Biology.
Investigators: Bob Beardsley (WHOI), Ken Brink (WHOI), Dick Limeburner (WHOI), Jim Churchill (WHOI), Jim Ledwell (WHOI), Changsheng Chen (UMassD), Jim Bisagni (UMassD), Charles Flagg (BNL), Ron Schlitz (NMFS/NEFSC) .

Project title: Zooplankton Population Dynamics on Georges Bank: Model and Data Synthesis.
Investigators: Peter Franks (SIO), James Pringle (UNH), Changsheng Chen (UMassD), Ted Durbin (URI), Wendy Gentleman (UW)

Project title: Patterns of Energy Flow and Utilization on Georges Bank
Investigators: Dian Gifford (URI), John Steele (WHOI), Michael Fogarty (NMFS/NEFSC), Michael E. Sieracki (BLOS), Jim Bisagni (UmassD)

Project title: Tidal Front Mixing and Exchange on Georges Bank: Controls on the Production of Phytoplankton, Zooplankton and Larval Fishes.
Investigators: Bob Houghton (LDEO), Dave Townsend (UME), Changsheng, Chen (UMassD), R. Gregory Lough (NMFS/NEFSC), Lew Incze (USME)

Activities/Findings:
This project is a collaboration between fourteen investigators from five universities and one federal laboratory. The funding for this project has been split between NOAA via NMFS, NOAA via CICOR, and NSF. Funds for the CIRCOR portion of the project were received in September 2002 and the funds from NSF were received in March 2003. The mismatch in arrival of the funding prevented some investigators from spending much time on the project to date. This report is a summary of what the investigators as a group have accomplished this past year.

The principal objective of this project is to utilize the very comprehensive U.S. GLOBEC broad-scale data sets that now exist to address two overarching questions:

1) What controls inter-annual variability in the abundance of the target species (cod and haddock larvae, *Calanus finmarchicus*, and *Pseudocalanus* spp) on Georges Bank (e.g., bottom up or top down biological processes, or physical advective processes)?
2) How are these processes likely to be influenced by climate variability?

The project involves work in two coordinated efforts.

1) Data completion and data management
2) Data analysis, integration, and interpretation
    A. Hydrographic-biological Relationships
    B. Integration of Rate Processes and Broad-Scale-Distribution Data Sets
    C. Building climatology using objective mapping or kriging
    D. Modeling

The focus in during the first two years has been on integrating the broad-scale data sets within themselves. The project PIs have participated in three workshops to coordinate data analyses and inter-comparisons. The first occurred in July 2002 and the results of that meeting are summarized in the "Report of the U.S. GLOBEC Georges Bank Phase IV Synthesis - Startup Planning Meeting 11-12 July 2002, Woods Hole, MA". This meeting was attended by nearly all of the PIs involved in the five phase IV synthesis projects. A second meeting was held of the PIs associated in this project in November 2002. This meeting was held back to back with a meeting of the Physical Oceanography group and investigators from both projects attended most of both group's sessions. One outcome of the November meeting was the tentative agreement of a grid of station positions to which biological and physical data would be used to "objectively map" the broad-scale data to create a master set of biological and physical data in a uniform framework. A working group was established to fine-tune the stations and it met in

January 2003 to finalize the station grid. This station grid has been circulated to all of the project PIs for use in their data mapping efforts and is posted on the GLOBEC database as the "broad-scale grid" (http://globec.whoi.edu/jg/dir/globec/gb/).

A second all investigator science meeting took place at Whispering Pines Conference Center, University of Rhode Island, Rhode Island on November 18 - 20, 2003. The meeting goals were:
1) to enable scientific investigators to share results of the first year of synthesis work, 2) to provide a forum for the integration and synthesis of findings among the groups, and 3) to prepare for national and international meetings.
A number of the PIs in the project participated in the ICES/PICES/GLOBEC sponsored Symposium on Zooplankton Ecology titled "The Role of Zooplankton in Global Ecosystem Dynamics: Comparative studies from World Oceans", which took place in Gijon, Spain between 19-23 May 2003.

Several investigators presented papers on the broad-scale synthesis work at the ICES Annual Meeting in Tallin, Estonia between

In early 2004 there were two National Meetings in which presentations about the broad-scale work were made. The first was the American Geophysical Union, 2004 Ocean Sciences Meeting, Portland, Oregon in January 26-30. At this meeting there were multiple special sessions devoted to U.S. GLOBEC program presentations. The second was the TOS/ASLO Meeting in Hawaii from 15-20 February 2004 where several broad-scale papers were presented.

The Third US GLOBEC Northwest Atlantic/Georges Bank Phase IV Science Meeting was held from 21 to 25 June 2004 at the Salve Regina University's Conference facility in Newport, Rhode Island. The primary goal was to bring together the US GLOBEC Georges Bank Phase IV-funded and other science investigators to review the current research progress and continue efforts to synthesize and analyze the results to date. In addition there was planning for a third special collection of papers to be published in DSR-II.

Summary of work to date
The following is a summary of the work that has been completed over the past two years.

Broad-scale egg samples for both cod and haddock have been processed to consider possible maternal influence on egg viability by D. Mountain and colleagues. Since increased egg size may reflect better condition and overall viability, the diameters of 50 eggs for each species were measured for each year. No indication was found that interannual variation in egg calculated mortality rates was related to variation in egg size. A model using climatological currents plus an added wind-driven was used to investigate the transport of eggs on the Bank. The results suggest that the interannual variation in egg mortality was caused by interannual variation in the wind-driven transport of eggs off the Bank. This result was presented at the 2003 ICES Annual Science Conference in Tallinn, Estonia. An analysis of early larval mortality in each year has indicated that the mortality for both cod and haddock was very low for eggs hatched from late February to late March in 1998. The larval growth rates also were somewhat higher during this period in 1998 compared to the same period in other years. The cause of the higher growth and lower mortality is still being investigated.

The zooplankton a 1 m^2 MOCNESS and a zooplankton pump data sets are in the process of analysis by T. Durban and colleagues. A comparison of data from the two sampling systems has been carried out to determine which is the appropriate source of data for subsequent analysis.

Maps are presently being prepared of zooplankton taxa on Georges Bank. For each taxon these include 5-year mean abundance for each month, the abundance for each month, and the deviation during each month from the five year mean. Data are being gridded onto the standard broad-scale survey Grid. These gridded data are being saved and will be made available to other investigators through the Georges Bank GLOBEC website. The maps will be placed on our GLOBEC website: http://globec.gso.uri.edu:9000/pls/globec/globec.home. A list of gridded data and maps is given below. A technical report will be completed containing these maps and data. Analysis of five-year mean climatologies for the dominant copepods show interesting spatial and temporal patterns that can be related to the differing life history strategies. Several manuscripts are in preparation and should be completed later this year. Some preliminary results were presented at the zooplankton production symposium in Gijon and at the ASLO/TOS meeting in Honolulu.

A predation group workshop was held in RI during November 2003 to discuss mortality estimates of *Calanus finmarchicas* determined from the broad-scale survey data by Mark Ohman, and estimates of predation potential by the dominant invertebrate predators based on their in situ abundance. This meeting was attended by E. Durbin, M. Casas, R. Campbell, B. Sullivan, L. Madin, E. Horgan, S. Bollens, M. Ohman and J. Runge.

Zooplankton data have been provided to a number of investigators including Dennis McGillicuddy, Changshen Chen, Jeff Runge, Larry Buckley, and Wendy Gentleman.

J. Runge and colleagues are working on the synthesis of estimates of reproductive rates of *Calanus finmarchicus* and *Pseudocalanus* spp. from broad-scale surveys and their applications to understanding of population dynamics of these target species. The data on reproductive index, female abundance and water column egg production (eggs m^{-2} d^{-1}) have been compiled for each broad-scale cruise and plotted using OAX objective analysis, but have not yet been plotted on the standard broad-scale survey grid. The broad-scale egg production data were used in the calculation of *C. finmarchicus* Georges Bank egg-N2 mortality rates published with M. Ohman, E. Durbin and others (Ohman et al. 2004). Among the Georges Bank Broad-scale Survey findings is a significant relationship between egg-N2 mortality and abundance of adult *Calanus* females, indicating density-dependent control of recruitment processes in *Calanus* populations on the Bank. Further work, still unpublished, by Ohman, Runge, and Durbin shows a seasonal pattern in egg-N2 mortality; the number of eggs lost m^{-2} increases dramatically in May and June over the 5- year series of broad-scale surveys. This pattern correlates well with the observed increase in abundance of potential predators on *Calanus* eggs, including *Calanus* stage CV and females, hydroids and adult stages of Metridia. These results form a basis for further collaboration with the predation group on sources of mortality of *Calanus* on the Bank. The estimation of *Pseudocalanus* egg production from broad-scale samples is proving more problematical. B. Niehoff has published a study of gonad morphology and oocyte development in *Pseudocalanus* from Georges Bank broad-scale surveys (with assistance from earlier GLOBEC grants to J.R. and E. D.), but there is at present no reliable gonadal index for accurately predicting egg production from preserved samples (Niehoff, 2003, Mar. Biol. 143: 759-768).

J. Runge and colleagues continue to develop a paper that compares growth rates of cod larvae in 1995 and 1998 using estimates of prey from the broad-scale cruises and the most recent trophodynamic model developed by Lough et al. (in review, Fisheries Oceanography). Prey concentrations and consequently the estimated growth rates of cod larvae in April, 1998 were considerably higher than during the broad-scale cruise in April, 1995. This study can serve as a template for analysis of growth rates of cod larvae across all broad-scale cruises. The paper was initially presented at the Zooplankton Production Symposium in Gijon, Spain in 2003. It was decided to hold publication until the trophodynamic model of Lough et al. is accepted.

Finally, J. Runge has used a portion of support from the grant to complete the writing a chapter on developments in coupled physical-biological models for description of secondary production and fish recruitment processes in the coastal ocean. The chapter discusses the GLOBEC Georges Bank program as a case history on a regional application of the coupled models.

Broad-scale biovolume analyses and comparison to bioacoustic data collected and the synthesis of the Gulf of Maine net tow and acoustics data collected during 1997,1998, and 1999 are being conducted by P. Wiebe, J. Green, and colleagues. The work on this project has coincided with work on a closely related project involving the processes controlling the recruitment of *Calanus finmarchicus* populations in the Gulf of Maine. The last cruises on this project also took place in 1999 and the work up of the samples and the analyses of the data have been going on in parallel. Some of this work has been carried out with Karen Fisher (who completed her Ph.D. thesis while working on the broad-scale project). The kriging technique and a newly developed wavelet/fractal interpolation scheme has been applied to the acoustic data sets obtained on the broad-scale cruises. These data will enable seasonal and the year to year variations in acoustic backscattering and the environmental data that were collected on Georges Bank surveys to be compared. The broad-scale zooplankton biovolume data collected with the Bongo nets by J. Green are being compared with the acoustic data. In addition as described below, the Gulf of Maine acoustics data will be compared with those collected on Georges Bank.

A series of cruises lead by C. Greene were conducted in the autumns of 1997, 1998, and 1999 to survey diapausing populations of Calanus finmarchicus and their predators in Wilkinson, Jordan, and Georges Basins (Gulf of Maine) as part of the U.S. GLOBEC Georges Bank program. The sampling was done with the BIO-Optical Multi-frequency Acoustical and Physical Environmental Recorder or BIOMAPER-II, a towed system consisting of a multi-frequency sonar, a Video Plankton Recorder (VPR), a bio-optical sensor package, and an environmental sensor package (CTD). It was towyoed along survey track-lines in each of the basins to collect acoustic data, video images, and environmental data between the surface and bottom. In addition, a 1-m^2 MOCNESS was towed obliquely from near-bottom to the surface at stations in each basin, sampling eight depth intervals for biomass, taxonomic analyses, and species counts. During the three years, a dramatic change in the hydrography took place in the Gulf of Maine that lagged by about two years after the precipitous drop in the NAO index that occurred in 1996. Colder and fresher water of Labrador Sea origin was present throughout much of 1998. Coincidently, the autumn diapausing *C. finmarchicus* abundance was much lower and there were also extraordinary numbers of a large predatory siphonophore. Despite the lower *Calanus* abundance in 1998, overall zooplankton biomass levels were comparable among the three years. This comprehensive data set may enable the issue of far-field (principally NAO driven changes in hydrography) and near-field effects (predator/prey relationships) on the plankton community in the Gulf of Maine basins to be evaluated. A report of this work was presented at the September 2003 ICES Annual Science Conference in Tallinn, Estonia and at the January 2004 AGU Ocean Science Meeting in Portland, Oregon.

An adjoint data assimilation approach has been used by D. McGillicuddy and X. Li to quantify the time-space-stage specified physical and biological controls on *Calanus finmarchicus* N3 to C6 stages over Georges Bank and its surrounding regions. The mean seasonal cycle of vertically integrated distributions, from five years of the GLOBEC Georges Bank Broad-Scale Surveys between January and June, was assimilated into a coupled physical-biological with climatological circulation. Large seasonal and spatial variabilities are present in the inferred supply sources, mortality rates, computed molting fluxes and physical transports. Partially recovered off-bank initial conditions show that the deep basins in the Gulf of Maine, and the Scotian Shelf are possible major off-bank source regions of early stage nauplii, C5 and C6 in January. In the growing season from January to April, inferred sources of young nauplii N3 are mainly confined on Georges Bank, especially on the Northeast Peak. These on-bank sources of young nauplii N3 are able to populate the bank with nauplii in late winter, becoming copepodids in spring. Large mortality rates of stages n4-C2 between January - February are the main regulators to limit the population increase rates. In the meantime, advection and mixing processes transport this species from source regions on Georges Bank to surrounding waters in the Gulf of Maine, the continental slope and South Atlantic Bight. Between April - May, the population dynamics on the bank are driven my molting from lower to higher stages. Between May - June, abundances of copepodids drop sharply on Georges Bank, especially on the Crest. Large mortality rates are mainly responsible for the population decline. In addition, down-stream transport of advection and down-gradient transport of turbulent mixing enforce the June decline. Mortality rates of N4 to C2 are large between January - March and May - June. Mortality rates of C5 and C6 are large between April - June. *Calanus finmarchicus* are most vulnerable to death at stages N6 and C1, but most unlikely to die at stages C3 and C4. When they mature to adults, their mortality rates are large between April - June.

In related work, A. Bucklin and D. McGillicuddy have continued work on Bank-wide patterns of distribution and abundance of two species of *Pseudocalanus, P. moultoni*, and *P. newmani*. The objectives include: 1) integrative data analysis, to compare patterns among all target species and any other taxa that are abundant and/or ecologically important; 2) application of numerical, coupled biological / physical models to the *Pseudocalanus* spp. distributional data to infer processes from the patterns; and 3) synthesis of the patterns and processes of all species to examine the role of each species in the Georges Bank ecosystem.

1) Data completion and data management: Analysis of samples from 1999 Broad-scale cruises, including all three vertical strata, is now complete. Full analysis of 1998 Broad-scale samples, beginning with the surface stratum (0-15m), is underway. All data will be posted to the U.S. GLOBEC data and information management system.

2) Data analysis, integration, and interpretation: The depth-integrated data are being objectively analyzed and mapped by D.J. McGillicuddy. Adjoint numerical models are being used to infer the biological sources and sinks implied by the observed changes in abundance between monthly surveys and the flow during the intervening periods. The depth-stratified data are being kriged and mapped to the Georges Bank "standard grid" by P. Wiebe. This latter analysis will allow us to examine how month-to-month patterns of vertical distributions differ between the species and among the five regions of the Bank and, in turn, how these differences impact differential patterns of transport and retention of the species on the Bank.

The Bank-wide patterns determined from 1999 Broad-scale cruises are being compared to a 1999 analysis of the distribution and abundance of the two species across a tidal-mixing front on Georges Bank, and to continuing observations of the two species in near-shore waters of western Gulf of Maine. These studies suggest that water column stratification and stratified flow may differentially impact the two *Pseudocalanus* spp. Alternatively, the species may actively respond in some way that generates different vertical distributions with respect to turbulence, stratified flow, and other micro-habitat conditions. Small-scale processes and patterns may thus play a significant role is determining patterns of species' distribution on larger spatial (i.e., mesoscale) and longer temporal (i.e., seasonal) scales.

Presentations about *Pseudocalanus* spp. on Georges Bank were made at national and international meetings during 2003 and 2004; a summary paper of the 1999 mapping and modeling is planned for submission to the special issue of Deep-Sea Research.

Integration and synthesis of the nutrients and chlorophyll data are being carried out by D. Townsend in collaboration with Maura Thomas. Ongoing effort involves re-plotting and re-contouring the data sets on phytoplankton chlorophyll and nutrient distributions on Georges Bank to fit the Standard Grid. Preliminary budgets have now being constructed, which include some of the organic nitrogen and carbon measures.

Since funds became available in early 2003, the predation group lead by L. Madin has been focusing efforts on organizing the 10-m^2 MOCNESS data into an access database and undertaking basic data reduction and manipulation to display the distribution and abundances of the major macrozooplankton and micronekton predators. We have been examining the relationship between these biota and various environmental conditions, especially hydrography and Slope Water intrusions. This work has resulted in two manuscripts (Stoltz et al., in revision and Brown et al., in revision). Also begun are various multivariate analyses to examine overall community structure within the Georges Bank macrozooplankton and micronekton. The results of this work were presented at the

GLOBEC special session at AGU in Portland, OR in January 2004. Finally, the integration of the distribution and abundance data described above with various rate process data derived from GLOBEC process cruises and the literature will allow the predation group (Madin, Bollens, Sullivan et al.) to generate broad-scale distributions of specific predation mortality rates for each target (prey) taxon.

Future Work:

In the immediate future, the project PIs will be finishing the production of data reports and the preparation of manuscripts to be submitted for the special Deep-Sea Research volume now in the early stages of being prepared.

Journal Publications:

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Niehoff, B and J. A. Runge. Accepted . A revised methodology for prediction of egg production of the marine planktonic copepod, *Calanus finmarchicus*, from preserved samples. J. Plank. Research.

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Perry, R.I., H.P. Batchelder, S. Chiba, E. Durbin, W. Greve, D.L. Mackas, H.M. Verheye. Submitted. Identifying global asynchronies in marine zooplankton populations: issues and opportunities. ICES Journal of Marine Science.

Runge, J.A., P.J.S. Franks, W.C. Gentleman, B.A. Megrey, K. A. Rose, F.E.Werner and B. Zakardjian. Accepted. Diagnosis and prediction of variability in secondary production and fish recruitment processes: developments in physical-biological modelling. *The Sea*. Vol. 13: The Global Coastal Ocean: Multi-Scale Interdisciplinary Processes. A.R. Robinson and K. Brink, eds.

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Stoltz, G. S., S. M. Bollens, H. Brown, L. P. Madin, and E. Horgan. In Revision. The distribution and population biology of the ctenophore *Pleurobrachia pileus* on Georges Bank, Northwest Atlantic. Mar. Biol.

Townsend, D.W., A.C. Thomas, L.M. Mayer, M. Thomas and J. Quinlan. 2003. Oceanography of the Northwest Atlantic Continental Shelf Waters. The Sea. Vol. 14. Harvard Univ. Press. (In Review).

Papers Presented/abstracts:

Bailey, M.A., B.R. Curran, J.A. Dijkstra, E.M. Rodrigues, C.A. Manning, J.G. Beaudet, and A. Bucklin (2003) Species-specific PCR discrimination of cryptic copepod species on Georges Bank (NW Atlantic). Poster presentation at the UNH Undergraduate Research Conference, Durham NH (May, 2003).

Bollens, S.M., D. S. Gewant, H. Brown, L. P. Madin, and E. F. Horgan. Variation in the Community Structure of Macrozooplankton and Micronekton on Georges Bank, in

Relation to Environmental Conditions. American Geophysical Union/Ocean Sciences meeting, Portland, OR, January, 2004.

Bucklin, D.J. McGillicuddy, and C.A.Manning (2003) Biological-physical processes determining *Pseudocalanus* spp. (Crustacea; Copepoda) distribution and abundance on Georges Bank in the Northwest Atlantic. ICES Annual Science Conference, Report ASC 2003 P:36 (Abstract)

Bucklin, A., D.J. McGillicuddy, M.A. Bailey and B.J. Curran (2003) SS-PCR discrimination of morphologically cryptic, ecologically distinct species: seasonal evolution of *Pseudocalanus* spp. on Georges Bank (Poster presentation at Third International Zooplankton Production Conference, Gijon Spain (May, 2003).

Bucklin, A., D.J. McGillicuddy, C.A. Manning, and P.H. Wiebe. Population dynamics of cryptic species of *Pseudocalanu*s in the Northwest Atlantic: biological and physical coupling at small- to mesoscales. AGU Ocean Sciences Meeting, Portland OR (25-29 January 2004)

Durbin, E., M. Casas. Spatial variations in abundance of zooplankton on Georges Bank. 3rd International Zooplankton Production Symposium. May-20-23, 3003. Gijon, Spain.

Durbin, E.G., Casas, M.C. Spatial variability of copepods on Georges Bank Are controlled by physical processes and life history characteristics. ASLO/TOS meeting. February 2004. Honolulu, Hawaii.

Fisher, K., P.H. Wiebe, and D. Chu. 2004. Developing a wavelet-based feature classification of Georges Bank high frequency acoustic backscatter based on a system developed for high-velocity fluid instability measurements. American Geophysical Union, 2004 Ocean Sciences Meeting, Portland, Oregon. January 26-30.)OS51H-09). Eos. Trans. AGU: 84(52) page OS178.

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Wiebe, P, H., M.F. Baumgartner, D. Mountain, M.C. Benfield, C.H. Greene, A.C. Lavery, N. Copley, and G.L. Lawson. 2004. Variation in the size of the overwintering population of *Calanus finmarchicus* in the Gulf of Maine during 1997, 1998, and 1999: Driven by changes in NAO forced advection or local predator and competitor fields? American Geophysical Union, 2004 Ocean Sciences Meeting, Portland, Oregon. January 26-30. (OS21B-03) Eos. Trans. AGU: 84(52) page OS16.

Web Sites:
The principal web site through which data and information from this project can be accessed is:
http://globec.whoi.edu

2004 NOAA Progress report

Variations in Oceanic CO2 Concentration, Transport and Divergence in the Atlantic

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Related NOAA Strategic Goal: Goal 2 - Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond.

NOTE: This project is funded 50% through NOAA/CICOR and 50% through NSF

1. A Comparison of the actual accomplishments compared to the objectives established for the period. We are now in the middle of the second year of this project:

a) YR 1 Objective: Assembling the data, and reformatting them for use within the local data archives.

We have nearly completed our quality controlled, 2-dbar data base of one-time hydrographic lines from WHPO. We now have 25 lines. 16 of them include the carbon parameters (total inorganic carbon, alkalinity and anthropogenic carbon) from GLODAP.

b) YR 1 Objective: Handling with crossover points: We have obtained some software from G. Johnsons and have worked out a system of adjusting the sections to minimize issues arising from crossovers. This system will need to be reapplied as new data is included.

c) YR 1 Objective: Produce Objectively mapped, gridded data sets of repeat data which can be mapped and differenced. We have done this for some, but not yet all the available repeat sections.

d) YR 1 Objective: Select layer definitions and reference levels. Twenty one neutral density layers to use in the inverse model have been defined. Reference levels are being chosen as sections are included.

e) YR 2 Objective: Perform basic analysis of reference level choice. This work is also ongoing as sections are included.

f) YR 2 Objective: Build upon basic models. We have begun with a 1997-1998

North Atlantic model (between 24N and 59N). After some effort to determine reasonable geostrophic reference surfaces, it was decided to reference all the data north of 24N to mean estimates of absolute velocity from floats. These data were obtained through B. Owens, K. Lavendar and P. Furey. Float displacements coming from a variety of subsurface float types (ALACE, BOBBER, P-ALACE, RAFOS, and SOFAR) were used to estimate the geostrophic pressure at 700 dbar through optimal interpolation which was then used to reference the hydrographic thermal wind to get an initial estimate of the absolute velocity fields.

g) YR 2 Objective: Analyze the effect of initial estimates of solution and data covariance. This work is ongoing.

h) YR 2 Objective: Begin interpretation of the results, focusing on the CO_2 transport and storage. The North Atlantic model has produced the interesting result of very strong south transport of TIC and a relatively small transport of anthropogenic carbon across 47N (Figures 1 and 2).

Initial investigation suggests that unlike latitudes to the north and south in which the overturning circulation cell dominates and controls magnitude of the southward transport of TIC, at 47N there is a large horizontal component to the circulation concentrated in the western basin in the region of the North Atlantic Current and recirculation. It was this region which initial prompted us to use the float data for referencing the geostrophic velocity fields as it contains isopycnals which slope nearly vertically from the surface to the bottom. The next step of the analysis will be to look at some of the other transects across 47N. Not all of them include TIC, however, the strong horizontal component is clear in the transport of other properties as well. The work and advice of R.Lumpkin will be extremely helpful here as he has worked in detail with these 47N data sets.

Combining the results we do have with the Takahashi's (2003) CO_2 air/sea exchange estimates suggest that today's uptake of carbon is spread over a greater region within the North Atlantic than pre-industrially, but that today both the uptake and outgassing are weaker. Another step we will take in our analysis is to compute air/sea exchange of carbon as an output of the model, see how these values compare with Takahashi's and also what they suggest about storage in the region.

We are also presently collaborating with Lynne Talley at Scripps to get a better handle on the geostrophic reference surface velocities and and circulation across the A24 transect.

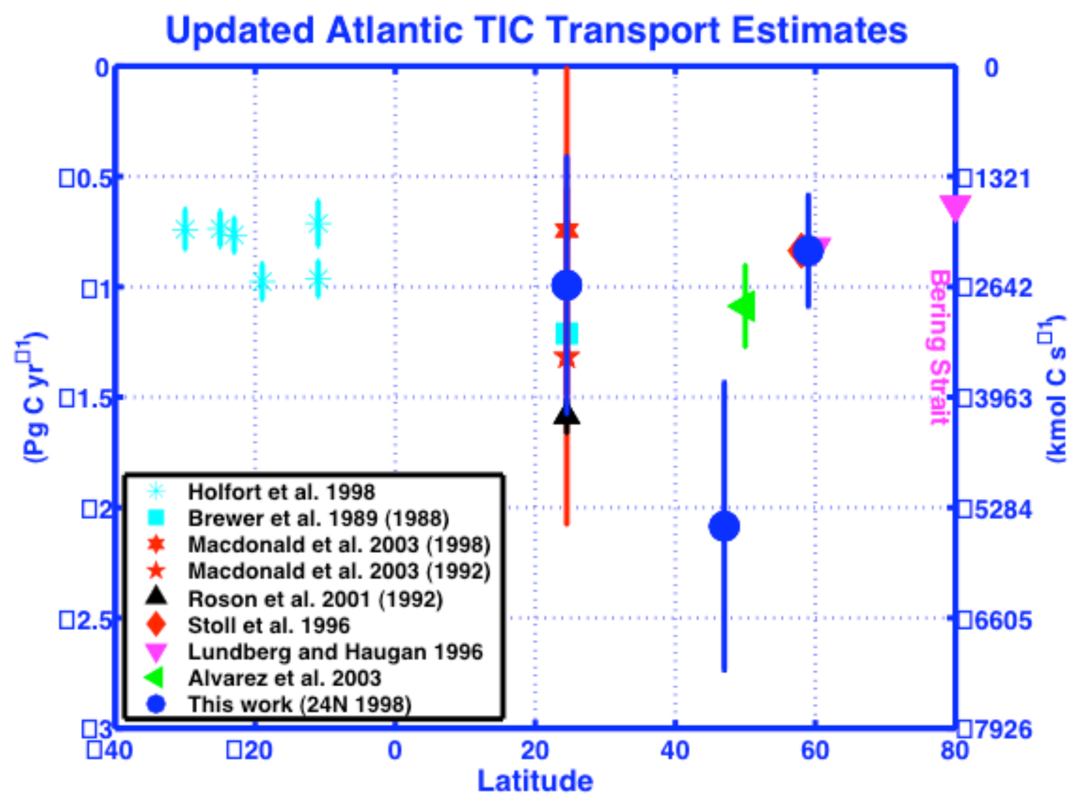

Figure 1:Carbon transport as a function of latitude in the Atlantic showing southward transport consistent with previous estimates at both 24N and 57N where overturning dominates, and very strong south transport estimate at 47N where there is a strong horizontal component to the circulation. (PgC/yr)

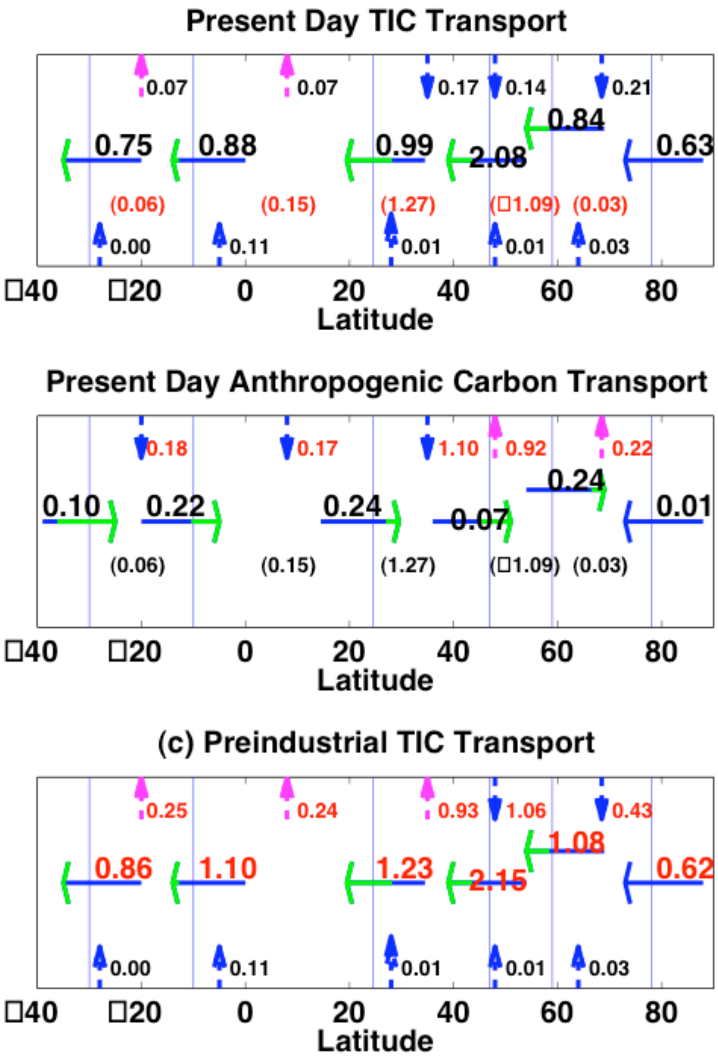

Figure 2: Comparison of a present day TIC transport estimate to a pre-industrial estimate showing less uptake of today over more of the North Atlantic. (a) Estimates of present day total inorganic carbon transport (solid blue arrow) from the present work at 24N, 47N and 57N, air/sea exchange (pink dashed arrows) from monthly pCO2 values (Takahashi et al. 2003) combined with gas exchange wind speed relationships using the monthly average and second moment to take the wind speed variability into account (Wanninkhof et al. 2001), river input (blue dashed arrows) based on the river discharge estimates of Perry et al. (1996), taking the inorganic carbon concentration within the rivers to be order 1000 umol/kg and assuming burial, respiration and outgassing of organic carbon occurs close to the ocean boundaries (Wallace, 2001; Aumont et al., 2001) and finally storage (in parentheses) which is computed as the residual of the other terms. The transport values across 10S and 30S are from Holfort et al.(1998). Those across 78N are from Lundberg and Haugan (1996).(b) The same for present day anthropogenic carbon. Each air/sea flux estimate is the residual of the other values in the particular box.(c) The same for the pre-industrial Atlantic Ocean. The green portions of the oceanic transport arrows indicate the estimated uncertainty where available. Units are (PgC/yr).

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Combining the results we do have with the Takahashi's (2003) CO2 air/sea exchange estimates suggest that today's uptake of carbon is spread over a greater region within the North Atlantic than pre-industrially, but that today both the uptake and outgassing are weaker. Another step we will take in our analysis is to compute air/sea exchange of carbon as an output of the model, see how these values compare with Takahashi's and also what they suggest about storage in the region.

We are also presently collaborating with Lynne Talley at Scripps to get a better handle on the geostrophic reference surface velocities and and circulation across the A24 transect.

j) Through our subcontract to the University of Miami, Dennis Hansell has been analyzing the available North Atlantic DOC data. We have published the manuscript listed below (Hansell et al., 2004). We are looking to extend this analysis to nitrates.

As we have funding through the NSF for our first year through 9/31/04, other tasks still at hand for this year are

k) To finish getting all the available data through the reformatting, quality control and cross-over adjustment phases in the processing. We have about 75% of the data complete and are on the verge of producing a full Atlantic model. Most of the data which still needs to be processed are repeat transects.

l) To continue producing objectively mapped, gridded data sets which can be mapped and differenced as repeat sections are quality controlled. This work is being done as we make our way through the data sets.

m) To perform the further analysis on the North Atlantic model suggested above.

2. The reasons for slippage if established objectives were not met.

A number of the year 1 and year 2 objectives are still ongoing. One reason is simply that we do not need all available data to go onto the next step, but another reason is that the quality control of the data has taken more effort than we original thought it would. Some time (and money) were lost when G. Packard who was helping with this effort left WHOI to work elsewhere. We were able to partly re-mediate the problem by hiring another tech person part-time using NSF funds to set up the cross-over adjustment system. However, it did not make sense to put another effort into retraining someone else to help with the quality control. So it is taking longer to complete. Looking ahead, it is possible that we will need to request more times and or funds, partly because of this slippage and partly because of the unforeseen increase in costs of salary and overhead.

3. Publications:

YEAR 1:

Macdonald, A. M., 2003, Oceanic CO2 Transport, Divergence and Air/Sea Exchange in the North Atlantic, CARINA conference, poster.

Also presented at the NSF NACP PI Meeting in May of 2003.

Macdonald A. M., M. O'Neil Baringer, R. Wanninkhof, K. Lee and D. W. R. Wallace, 2003, A 1998-1992 comparison of inorganic carbon and its transport across 24.5 N in the Atlantic, Deep Sea Research II, 50, 3041-3064.

YEAR 2:

J. Toole, A. Macdonald, R.Curry and participants of the 2003 North Atlantic survey of the U.S. CLIVAR/CO2 Repeat Hydrography Program, Decadal-timescale evolution of the North Atlantic Ocean, Poster for CLIVAR Meeting, Baltimore, MD 2004.

Macdonald, A. M. 2004, North Atlantic CO2 Transport and Divergence, invited talk, EGU Nice France. Also given as a presentation at the CICOR Cooperative Institute for Climate and Ocean Research, Executive Board Meeting May, 2004.

Hansell. D. A., Ducklow H. W., Macdonald, A. M. and M. O'Neil Baringer, 2004, Metabolic poise in the North Atlantic Ocean diagnosed from organic matter transports, Liminology and Oceanography, 49, 1084-1094.

2004 NOAA Progress Report

Ocean Reference Stations

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Related NOAA Strategic Plan Goal: Goal 2 - Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Overview

The goal of this project is to maintain long-term surface moorings, known as Ocean Reference Stations, as part of the integrated ocean observing system. The scientific rational for these Ocean Reference Stations is to collect long time series of accurate observations of surface meteorology, air-sea fluxes, and upper ocean variability in regions of key interest to climate studies and to use those data to quantify air-sea exchanges of heat, freshwater, and momentum, to describe upper ocean variability and describe the local response to atmospheric forcing, to motivate and guide improvement to atmospheric, oceanic, and coupled models, to calibrate and guide improvement to remote sensing products and capabilities, and to provide anchor point for the development of new, basin scale fields of the air-sea fluxes. Model, satellite, and climatological fields of surface meteorology and air-sea fluxes have large errors; high quality, in-situ time series are the essential data needed to improve our understanding of atmosphere-ocean coupling and to build more accurate global fields of air-sea fluxes.

Under this effort three sites will be maintained: the site at 20°S, 85°W under the stratus cloud deck off northern Chile (Stratus), the Northwest Tropical Atlantic Station (NTAS) at 15°N, 51°W, and a site north of Hawaii near the Hawaii Ocean Timeseries (HOT) site. The Stratus and NTAS sites have already having had surface moorings deployed and serviced annually under NOAA OGP support; they will transition to long-term Ocean Reference Stations under this effort. The Hawaii site will be a new Ocean Reference Station site to be done in collaboration with investigators that have made shipboard and moored observations in that region in recent years. In the management of the **Ocean Reference Stations** project, four tasks have been identified. First, there is the engineering, oversight, and data management (**Task I**); work in this area is underway and progress reported below. Second, the maintenance of the Stratus site (**Task II**), also with work underway and progress reported below. Third, the maintenance of the NTAS site (**Task III**), which is now covered under a grant to Plueddemann, but will in FY2005 shift to support as one of the operational Ocean Reference Stations. Fourth, the establishment of the third Ocean Reference Station, planned for Hawaii (**Task IV**); groundwork for this has begun and is reported below. Progress on each of the Tasks is reported in more detail below.

Progress

Task I Engineering, oversight and data:

Construction of new buoy for use at the Ocean Reference Stations is complete. These new buoys replace the 15-20 year old hulls presently used which are degrading (corrosion of the welded aluminum) and are expensive to ship as they do not fit inside a sea container like the new hulls. Acquisition of four meteorological sensor systems to be used to support the three sites is complete; these were tested and burned-in this year, then integrated with the new tower tops and tested again. Data processing continues on schedule.

The oversight task coordinates the common data tasks for the three sites. Oceanographic (velocity, temperature, salinity) and surface meteorological data (wind speed and direction, air and sea surface temperature, rain, incoming shortwave and longwave, relative humidity, and barometric pressure) are processed and stored on disks attached to our workstations. Telemetered data are made available via an FTP server and a website with download capability. We maintain a public access archive of Upper Ocean Processes Group data from mooring deployments.

We have advanced the schedule for building and testing the hardware for the Hawaii site; we will deploy there because an acceleration of funds was granted.

Task II Stratus Site:

The stratus surface mooring was deployed first under the previous grant (under the Pan American Climate Studies) in October 2000. It was recovered and redeployed from the NOAA Ship *Ron Brown* in October 2001. This mooring was recovered using the *RV Melville* (Puerto Caldera, Costa Rica to Arica, Chile) in October 2002 and a new mooring deployed at the same site. In-situ comparisons of the ship's and both buoys' meteorological sensors were carried out. During the deployments, hourly-averaged surface meteorology was available from the buoy in near real time via Service ARGOS and a WHOI ftp site. Data exchanges were made with ECMWF, NCEP and others to examine numerical weather prediction model performance and examine air-sea fluxes under the stratus clouds. The telemetered meteorological data are also available via the website maintained for this site (http://uop.whoi.edu/stratus). Internally recorded 1-minute meteorological data as well as the oceanographic data, which are only internally recorded, were downloaded from the recovered instrumentation. Data recovery was good (estimated to be 90%), post-calibrations are being done, and data files have been shared with colleagues. Preliminary cruise reports are filed with the State Department soon after the cruise; final documentation that goes to foreign observers and the State Department includes copies of the underway data and a final cruise report. Telemetry from the buoy presently deployed indicates that it is on station and both meteorological systems are functioning well.

Work this year included down-cruising hardware and instruments recovered in November 2003 on RV *Roger Revelle*, doing post-calibrations, data processing, writing cruise and data reports, preparing the mooring and instrumentation for the deployment in December 2004 on board the NOAA Ship *Ronald H. Brown*, starting in Arica, Chile and ending in Valparaiso, Chile, and coordinating that cruise. This year we also deployed a DART mooring for NOAA/PMEL and the Chilean Navy (SHOA). The cruise work was carried out aboard the R/V *Roger Revelle* of the Scripps Institution of Oceanography (SIO). The Stratus 2003 cruise constituted Leg 3 of the Dana expedition of the R/V *Revelle* and began in Manta, Ecuador, on November 10, 2003 and ended on November 26, 2003 in Arica, Chile.

However, the planning and observational preparation for the cruise began many months before. During the spring of 2003 instruments were gathered and placed on the mooring for testing. This testing of the instrumentation while mounted on the buoy, and exposed outdoors, is important for the proper gauging of accuracy and reliability. This on-going burn-in period typically lasts three or more months. In September of 2003, members of the UOP group met the R/V *Revelle* in San Diego at the Scripps Institution of Oceanography (SIO) piers to load and prepare equipment. The *Revelle* then cruised from San Diego along the Pacific coast of Mexico and Central America, eventually pulling into port in Ecuador on November 6, 2003.

On the buoy we measure air temperature, sea surface temperature, relative humidity, incoming shortwave and longwave radiation, wind speed and direction, rain rate, and barometric pressure. On the mooring line the instrumentation is concentrated in the upper 300m, temperature, salinity, and velocity. During the deployment, high data rate (up to 1 sample per minute) data are stored in each instrument. Hourly-averaged surface meteorology is telemetered via Service ARGOS. The internally recorded data goes through processing, has calibration information applied, and is subject to preliminary analyses before being made publicly available on our website. In the interim, preliminary versions are made available upon request.

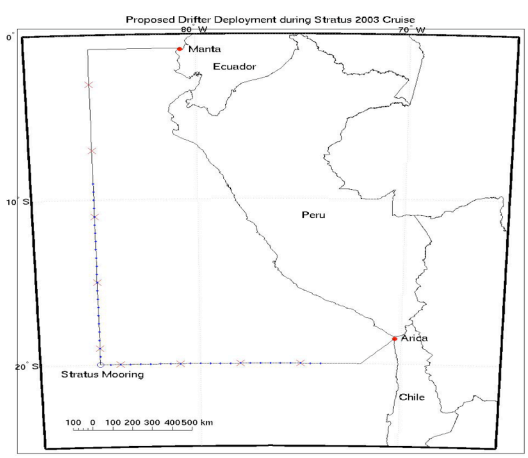

Figure II-1. Cruise track for RV *Revelle* in November 2003 during cruise to service the Stratus site. Forty-five surface drifters and nine Argo floats were deployed.

The Stratus 3 mooring was recovered on November 17th with no undue problems. The old mooring is traditionally recovered first so as to assess any problems that may have arisen, and to hence make last minute changes on the new mooring. Although in the previous two years there had been no evidence of problems with fishing at the mooring, the subsurface instrumentation from the upper part of the recovered Stratus 3 mooring was heavily fouled with long-line fishing gear. As a consequence, additional acoustic current meters were moved to the upper water column, in case the prop based current meters on Stratus 4 were similarly fouled. The Stratus 4 mooring was deployed on November 20th.

Both before the recovery of the old buoy and after the deployment of the new buoy time was spent comparing the buoy data with shipboard measurements. Because of the importance of establishing and documenting the accuracy of the meteorological and air-sea flux records collected by the Stratus moorings, extensive shipboard meteorological and air-sea flux instrumentation was installed on the *Revelle* and operated by Chris Fairall from the NOAA Environmental Technology Laboratory in Boulder, CO.

The Environmental Technology Laboratory (ETL) air-sea flux and cloud group conducted measurements of fluxes and near-surface bulk meteorology during the fall field program to recover the WHOI Ocean Reference Station buoy at 20 S Latitude 85 W Longitude. The ETL flux system was installed initially in San Diego in September 2003 and brought back into full operation in Manta, Ecuador, in early November 2003. The air-sea flux system consists of a fast turbulence system with ship motion corrections, a mean T/RH sensor, solar and IR radiometers, a near surface sea surface temperature sensor, a Particle Measurement Systems (PMS) Lasair-II aerosol spectrometer, and an optical rain gauge.

ETL also operated three remote systems: a Vaisala CT-25K cloud base ceilometer, a 35 GHz vertically pointed Doppler cloud radar, and a 20.6 - 31.65 GHz microwave radiometer. ETL has an integrated system in a seatainer that includes a Doppler Ka-band cloud radar (MMCR) and a microwave radiometer. The system can be used to deduce profiles of cloud droplet size, number concentration, liquid water concentration etc. in stratus clouds. If drizzle (i.e., droplets of radius greater than about 50 μm) are present in significant amounts, then the microphysical properties of the drizzle can be obtained from the first three moments of the Doppler spectrum. The radar is extremely sensitive and can detect most tropical cirrus and fair weather cumulus clouds. The Doppler capability can also be used to measure in-cloud vertical velocity statistics.

Marine aerosol concentrations and the processes that produce and remove the aerosols in the southeast Pacific have rarely been studied. During the Stratus 2003 research mission, the Texas A&M University (TAMU) Aerosol Research Group was given a unique opportunity to deploy two instruments to study a large spectrum of aerosol diameters from 12-nm to 15-μm. A Tandem Differential Mobility Analyzer (TDMA) investigated aerosols diameters up to 800-nm, while an Aerodynamic Particle Sizer (APS) model 3321 produced by TSI looked at the remaining aerosols up to 15-μm. The data collected will allow for a better understanding of the marine aerosol's chemical composition and distribution in this region of the world. The R/V *Revelle* also carried out routine underway oceanographic and meteorological observations.

The Stratus 4 cruise carried out additional activities in support of ocean observing projects by Ecuador and Chile. In answer to a request from the Ecuadorian Navy Institute of Oceanography (INOCAR), the surface buoy, SeaBird MicroCats and steel cable from the upper part of an Ecuadorian surface mooring located near 2°S, 84°W were recovered and transferred to an Ecuadorian Navy vessel on *Revelle*'s outbound passage from Manta, Ecuador. The sensor set on the surface buoy had been vandalized, and INOCAR was at that moment unable to affect a recovery of the mooring, which was not equipped with an acoustic release.

On the passage east from the Stratus Ocean Reference Site, a day of ship time was dedicated to doing a bottom survey and deploying a tsunami-warning buoy for the Chilean Navy Hydrographic and Oceanographic Service (SHOA). During the cruise staff from the NOAA Pacific Marine Environmental Laboratory (PMEL) and National Data Buoy Center (NDBC) were on board to provide training for four people from SHOA who participated in the cruise.

To further support ground-truthing of satellite data and increased understanding of the ocean in the eastern South Pacific, 45 drogue surface drifters and 9 profiling ARGO floats were deployed in the South Pacific from the Revelle along the cruise track.

The cruise also hosted two teachers as part of NOAA's Teachers-at-Sea program. Debra Brice is a middle school science teacher in San Diego at San Marcos Middle School, and Viviana Zamorano is also a middle school science teacher at Escuela America in Arica, Chile. During the cruise, the teachers assisted with science operations including mooring deployments and recoveries. The teachers also hosted web broadcasts, wrote daily logs, took photos, and interviewed science members and crew. This information was used to communicate with their own classrooms as well as those of other land-based teachers. They were assisted with the video and web-based communications by John Kermond, also of NOAA. All of their video, pictures, and logs are available at http://www.ogp.noaa.gov/ootas/index.html.

Hourly surface meteorological data are archived at WHOI, arriving within hours of when it was observed. These data are exchanged in near real time with ECMWF and NCEP; they in turn provide operational data at the grid point nearest the model. It is also shared with the Chilean Navy (SHOA). The same data are shared with CLIVAR investigators, especially modelers interested in the Stratus region, with VAMOS investigators in the U.S. and in South America. It is also sent to Peter Glecker at PCMDI for use in the SURFA project. This meteorological data are used to access the realism of operational atmospheric models in the stratus region. Once per minute as well as hourly surface meteorological time series are provided to the EPIC and VEPIC investigator communities (including Sandra Yuter, Chris Bretherton, Meghan Cronin). The surface meteorological data have been made available to the satellite community (including radiation – Langley, winds – Remote Sensing Systems and JPL, SST – Dick Reynolds, all variables – the SEAFLUX project). The oceanographic data are being used by Weller and a Postdoctoral Investigator at WHOI to investigate air-sea coupling and upper ocean variability under the stratus deck. In parallel it will be compared with ocean models results (with Ragu Murtugudde, Univ. of Maryland). The initial archive is that maintained by the Upper Ocean Processes Group at WHOI, which maintains a public access server of their mooring data. We are working with the International Time Series Science Team to develop a number of sites that will maintain as many records of time series stations as can be collected to facilitate access to such data. The work includes comprehensive comparison of ship and buoy meteorological sensors (Fig. II-2), which is critical to determining and demonstrating the accuracy of the moored sensors.

Figure II-2: The Stratus buoy with RV Melville in the background, taken during comparison of ship meteorological sensors (mounted on the tower on the bow) and buoy sensors.

The first two years of data from the Stratus ORS buoy have provided the first, accurate in-situ record of surface meteorology (Fig II-3) and air-sea fluxes (Fig II-4) under the stratus clouds, and there has been great interest in how the in-situ data compares to model and climatological data. Note that these figures provide documentation of significant biases in the reanalysis and climatological fields; the annual means are compared in Fig. II-5. Figure II-5 also points to greater year-to-year variability in the observations than in the model.

Another unique achievement of the Stratus mooring is the collection of the first record of upper ocean variability under the stratus clouds (Fig. II-6). Because these data have coincident surface forcing, work is underway to diagnose the local heat budget and assess the role of local air-sea interaction in maintaining the sea surface temperature under the stratus deck. Evidence of locally-wind driven flow to the southwest, off to the left of the wind, is apparent in the current meter data (Fig. II-7). Work is underway to quantify the extent to which this offshore flow carries cool water upwelled along the coast out under the stratus cloud deck. It has been found local atmospheric heating of the ocean drives diurnal heating on low wind days and a strong seasonal cycle and also that another, non-one-dimensional process such as horizontal advection is needed to remove some of the heat from the atmosphere.

Task III NTAS Site:

The Ocean Reference Station grant will take over support for NTAS in 2005. At present NTAS is funded under its own grant, but managed by Al Plueddemann as an element of the Ocean Reference Station project.

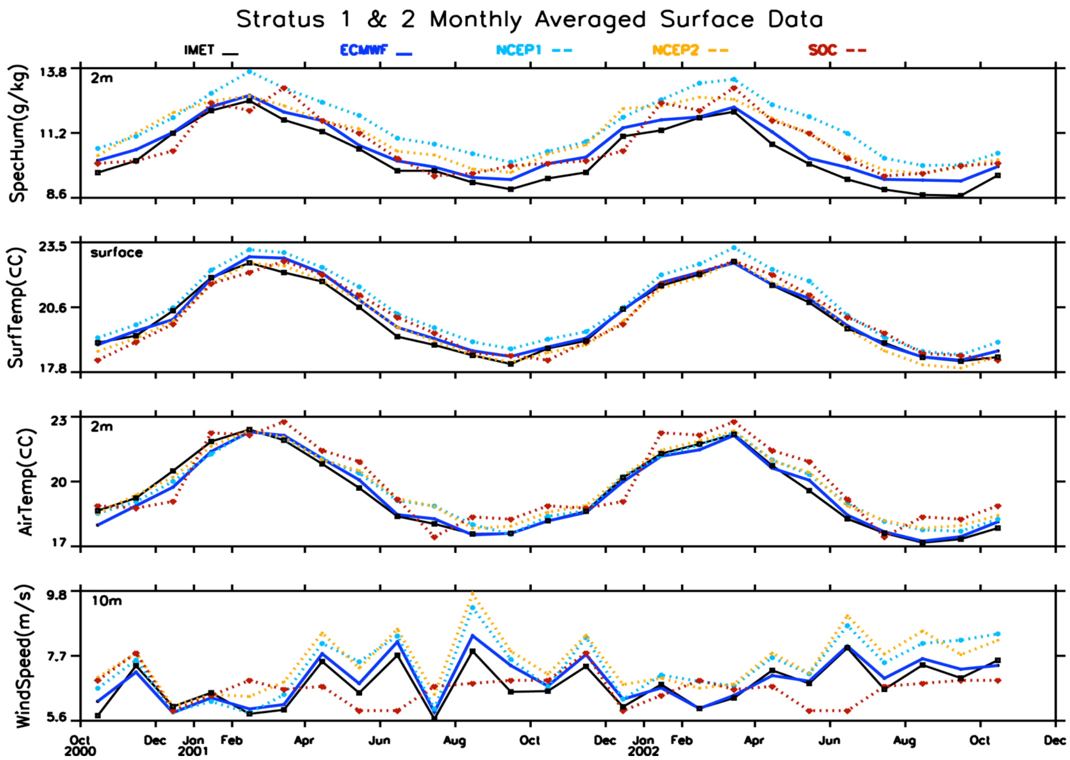

Figure II-3: Comparison of stratus buoy meteorological data with atmospheric model reanalyses (ECMWF ERA-15, NCEP1, and NCEP2) and COADS climatologies.

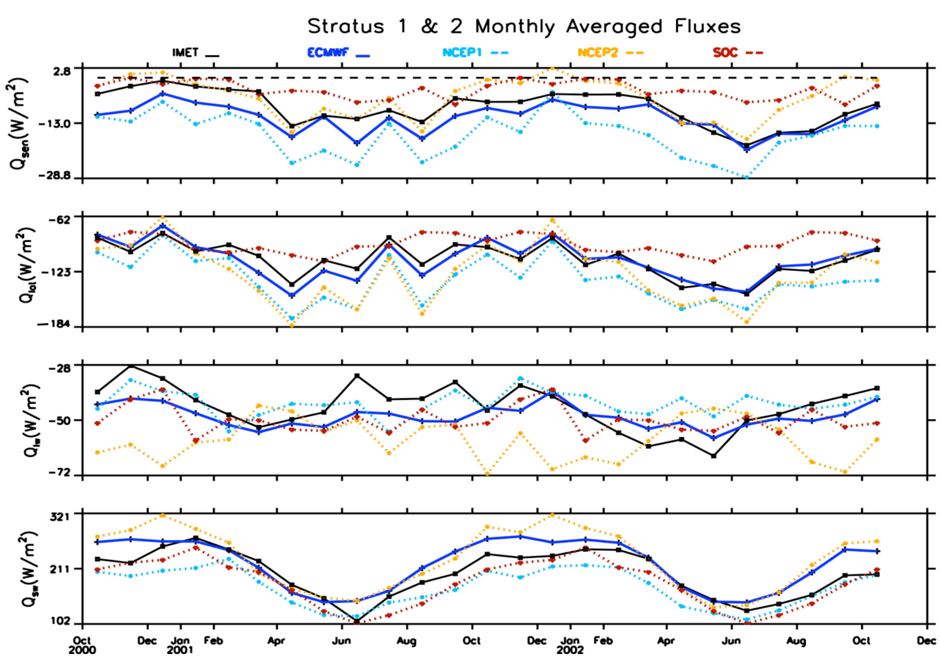

Figure II-4 Comparison of the air-sea fluxes at the Stratus buoy for two years with reanalysis and climatological data as in Fig. II-2.

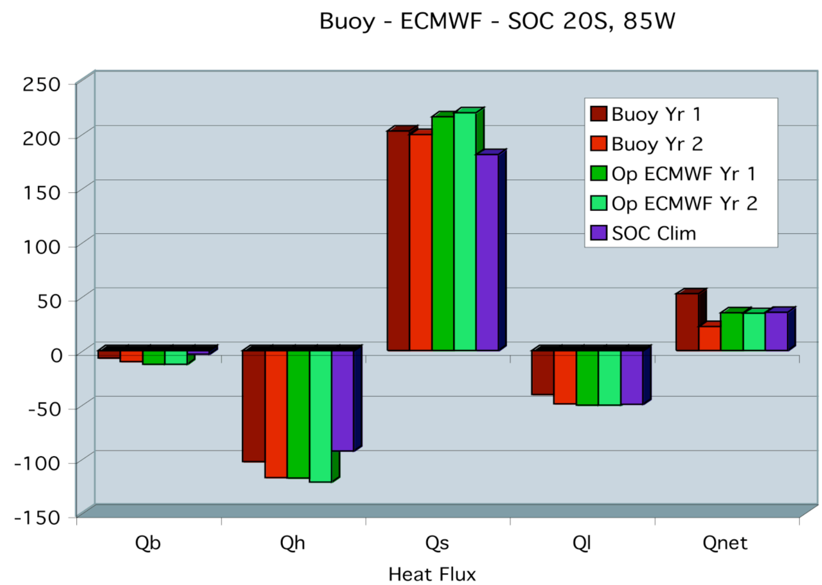

Figure II-5: Comparison of annual means of the heat flux components (sensible – Q_b, latent – Q_h, shortwave – Q_s, longwave – Q_l, and net heat – Q_{net}) for the first two years of data from the Stratus buoy with operational ECMWF model and SOC climatological heat fluxes.

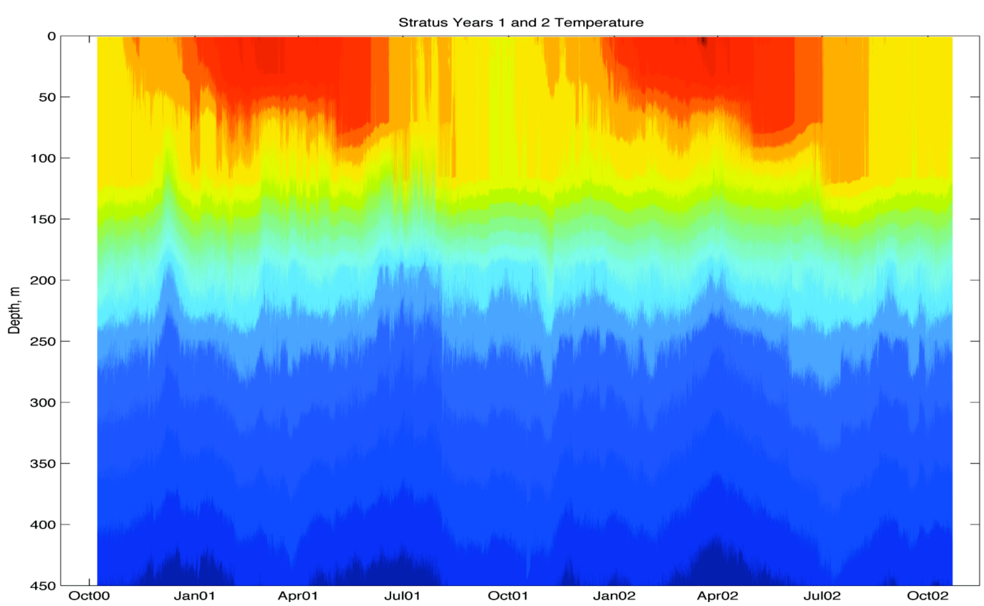

Figure II-6: Two years of temperature data from the upper 450 m at Stratus site.

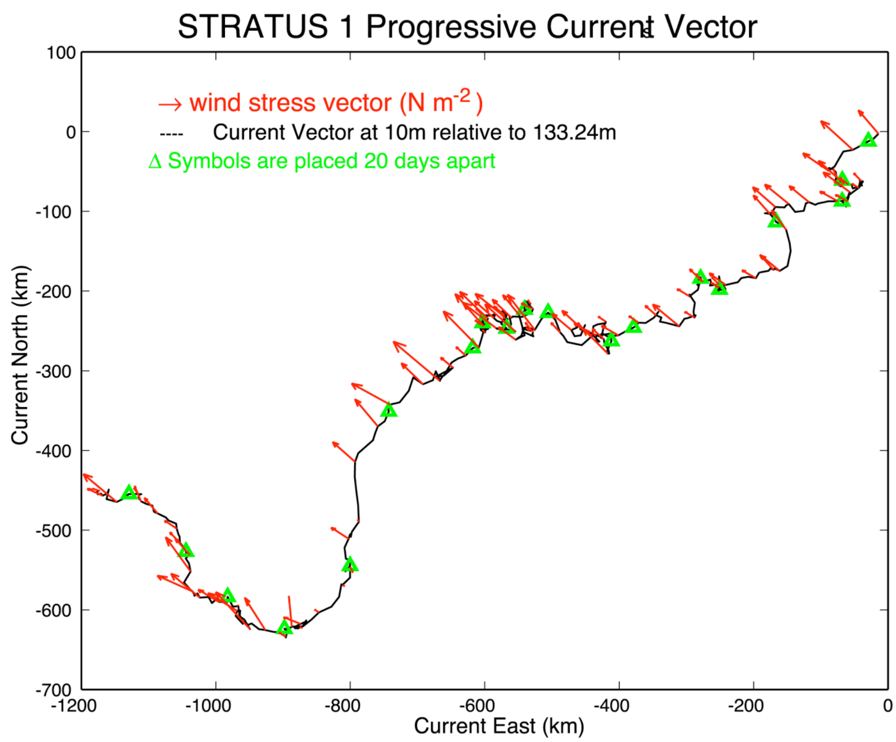

Figure II-7. The progressive vector diagram for the flow at 10 m relative to that at 133 m is plotted in black. Green triangles are spaced 20 days apart. Weekly-averaged wind stress vectors are shown as red arrows. The southeast Trades drive flow to the southwest in the upper ocean.

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Bretherton, C. S., T. Uttal, C. W. Fairall, S. Yuter, R. Weller, D. Baumgardner, K. Comstock, R. Wood, and G. Raga, 2004: The EPIC 2001 stratocumulus study. *Bull. Amer. Meteor. Soc.* in press.

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Hutto, Lara, Robert A. Weller, Jeff Lord, James Ryder, Alice Stuart-Menteth, Nancy Galbraith, Paul Bouchard, Jenny Maturana, Oscar Pizarro, and Jaime Letelier, 2003. Long-Term Evolution of the Coupled Boundary Layers (Stratus) Mooring Recovery and Deployment Cruise Report R/V *Melville*. Technical Report, WHOI-2003-02, UOP-2003-01.

Lucas, Lisan E., Bryan S. Way, Robert A. Weller, Paul R. Bouchard, William M. Ostrom, Albert S. Fischer, Carlos F. Moffat, Wolfgang Schneider, Melanie R. Fewings, 2001. Long-Term Evolution and Coupling of the Boundary Layers in the Stratus Deck Regions of the Eastern Pacific (STRATUS). Technical Report, WHOI-2001-04, UOP-2001-01.

Vallée, Charlotte, Kelan Huang, Robert Weller, 2002. Long-Term Evolution and Coupling of the Boundary Layers in the Stratus Deck Regions of the Eastern Pacific (STRATUS) Data Report. Technical Report, WHOI-2002-06, UOP-2002-03.

Vallée, Charlotte, Robert A. Weller, Paul R. Bouchard, William M. Ostrom, Jeff Lord, Jason Gobat, Mark Pritchard, Toby Westberry, Jeff Hare, Taneil Uttal, Sandra Yuter, David Rivas, Darrel Baumgardner, Brandi McCarty, Jonathon Shannahoff, M.A. Walsh, Frank Bahr, 2002. Long-Term Evolution of the Coupled Boundary Layers (STRATUS) Mooring Recovery and Deployment Cruise Report, NOAA Research Vessel *R H Brown*, Cruise RB-01-08, 9 October – 25 October 2001. Technical Report, WHOI-2002-02, UOP-2002-01.

Task IV Hawaii Site:

In this first year of this project an effort we identified occupation of a site near the Hawaii Ocean Timeseries Site as one that would have high value to the integrated ocean observing system and also that could be maintained without requiring funding beyond that outlined in the present budgets for this project. These criteria are being met by deployment of a surface mooring equipped with two ASIMET meteorological systems at the HOT site, just north of Hawaii, in collaboration including Roger Lukas at the University of Hawaii. The logistics of cruises in and out of Hawaii are affordable and convenient, as some gear could be left there, reducing cost. Further, the heritage of prior observations at that site points to the value of an Ocean Reference Station there. Lukas and colleagues were funded by NSF add oceanographic instrumentation to the mooring, and we applied for an add task to accelerate occupation of this site. We are shipping now for an August 2004 deployment and have worked under Task I to have the hardware for this site ready to meet that date.

The deployment would represent the establishment of a long time series moored perspective at the Hawaii site where a program of sampling from frequently repeated cruises has begun to build an understanding of the physical variability and of the interaction between physics, biology, and chemistry. It is expected that establishment of an Ocean Reference Site at this Hawaii location will accelerate progress toward understanding multidisciplinary science at the site, provide a key anchor site for developing air-sea flux fields in the Pacific, and provide a new regime in which to examine atmospheric, oceanic, and coupled model performance as well as the performance of remote sensing methods. Examination of the performance of models and remote sensing will lead to improvements in products and predictions.

2004 Progress Report

The Argo Float Program

NOAA Grant - NA17J1223
July 1, 2003 to June 30, 2004

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Program Manager: Steve Piotrowicz, NOAA/OAR

Related NOAA Strategic Plan Goal: Goal 2 – Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond.

Objectives
This grant covers WHOI's contribution to phase III of the Argo float program. The activities carried out in the third year of this grant include manufacturing of floats for the Argo array, quality-control of the data, and contributions scientific management of both the Argo Float program and Global Ocean Data Assimilation Experiment (GODAE). Further analyses of the data from an array of over 200 floats from the northern North Atlantic are being carried out to investigate the seasonally varying heat and salt content for the region as a demonstration of the types of analyses that can also be applied to the Argo float array.

Status
During the third year of this grant, we have further progress towards getting back on schedule for deploying floats. We have significantly streamlined the manufacturing of SOLO floats at WHOI, including a reorganization of the duties within the operations group and added a junior technician to the group. Improved collaboration and coordination with the Instrument Development Group at Scripps has smoothed out the delivery of parts. The redesigned SOLO float has a failure rate that is less than 3% at 1 year which means that we should be able to meet the design specifications for the Argo float array.

Over the past 12 months a total of 147 floats have been manufactured and deployed, primarily in the Atlantic Ocean. Although our coordination with AOML to deploy these floats primarily from VOS cruises has developed so that we can anticipate cruises and make deliveries on a timely basis, there continue to be occasional problems. For example, on one VOS cruise the floats were to be deployed by the ship's crew rather than the normal practice of having an AOML technician on board and three floats were launched without turning them on. We have modified the software in the floats so that they can now be turned on up to 60 days prior to launch and they will only start their mission after detecting a pressure increase of 50 dBars. Fortunately, this problem was detected before all the floats on that cruise were deployed.

A problem also developed with the antenna used to get GPS positions on the floats that were designed to use the ORBCOMM communications system. As a result, we suspended use of this variety of floats and have gone back to solely using the Argo satellite system, with its vastly reduced bandwidth. The problem with the antenna has been diagnosed and we expect to deploy a reduced number of ORBCOMM equipped floats over the next year.

Software has been completed so that the SEASCAN controller can be used with either a FSI or Seabird CTD. The mix of CTDs has been approximately 60% FSI and 40% Seabirds and we have not detected any significant difference in their performance.

As part of our effort to demonstrate the utility of the Argo float program, we completed in the previous year a manuscript describing the circulation of the Subpolar North Atlantic Ocean using profiling floats (Lavender, Owens, and Davis, 2003). During the present year, we have started an analysis of these same floats looking at the seasonal variation in heat and salt content in the upper one kilometer of the ocean. This work has been difficult because of significant drift in the conductivity measurements due to a bio-fouling agent that was used in the early floats that ablated over time at a non-uniform rate. We have completed the preliminary maps and are just starting to analyze them.

Owens has continued to spend some time involved with the International Argo Steering Team, the Argo Advisory panel and as co-chair of the US GODAE Steering Team.

In summary, the WHOI contribution to the Argo Float Program has significantly accelerated and improved the performance of the floats.

References

Lavender, K. L., W. B. Owens, and R. E. Davis, 2003. The Mid-depth Circulation of the Subpolar North Atlantic Ocean as Measured by Subsurface Floats, Deep-Sea Research, (accepted).

2004 NOAA Progress Report

GLOBEC Target Species: Interactions with Top Trophic Levels

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NOAA Program Manager: Elizabeth Turner, U.S. GLOBEC Program Manager,
NOAA Center for Sponsored Coastal Ocean Research

Related NOAA Strategic Plan Goal:
Goal 1 – Protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management.
Goal 2 – Understand climate variability and change to enhance society's ability to plan and respond

The goal of GLOBEC is to understand and predict how marine species respond to global climate change. Among the uncertainties in a warmer global climate is the extent to which upwelling will increase or decrease in specific boundary current systems, such as the California Current System, and consequently affect the productivity and community structure and function. Our interdisciplinary research, as part of the U.S. GLOBEC Northeast Pacific program, assists NOAA with Strategic Plan Goals 1 and 2 (above) to analyze top trophic levels (i.e., marine mammals and seabirds) in the northern California Current System (CCS) relative to mid-trophic levels and bio-physical coupling in the system. Among our objectives is to develop predictive bio-physical models of mammal and seabird occurrence patterns in order to improve our understanding of the mechanisms involved in ecosystem change, thus to improve predictability and management of living marine resources important to coastal communities.

Analyses of the coupled bio-physical data sets for two process cruises in the northern CCS during spring and summer 2000 have been completed (Tynan et al. 2004, Ainley et al. 2004). We have examined the correspondence between cross-shelf and along-shelf variation in physical forcing, oceanographic features, productivity, prey fields (as represented by acoustic backscatter at 4 frequencies), and cetacean and seabird occurrence patterns. Occurrence patterns of cetaceans and densities of seabirds were compared with hydrographic and ecological variables (e.g., sea surface temperature, sea surface salinity, thermocline depth, halocline depth, chlorophyll maximum, distance to the shoreward edge of the upwelling front, distance to the center of the equatorward jet, and acoustic backscatter at 38, 120, 200 and 420 kHz) derived from instruments on a towed undulating array (SeaSoar) and a four-frequency bioacoustic system. Using a multiple logistic regression model, 60.2% and 94.4% of the variation in occurrence patterns of humpback whales *Megaptera novaeangliae* during late spring and summer, respectively, were explained. That humpbacks occurred in regions of highest abundance of Pacific sardine *Sardinops sagax*, high densities of euphausiids, and the highest catch of juvenile salmon (Figure 1) suggests that whales were responding to a cascade of trophic dynamics enhanced by flow-topography interactions and the strong upwelling signature at a submarine bank and off Cape Blanco (Tynan et al. 2004). The percentage of variation in occurrence patterns explained by our logistic regression models for four species of cetacean (humpback whale, Pacific white-sided dolphin *Lagenorhynchus obliquidens*, Dall's porpoise *Phocoenoides dalli*, and harbor porpoise *Phocoena phocoena*) are among the highest ever achieved, and are likely a result of the concurrent acquisition of fine-scale oceanographic data with the cetacean survey data, as well a result of predator knowledge of the system (Tynan et al. 2004). In the multiple regression models for distributions of 12 species of seabirds, the most important explanatory variables (among 14 initially included in each model) were distance to the upwelling–derived frontal features (center and edge of the coastal jet, and an abrupt, inshore temperature gradient), sea surface salinity, acoustic backscatter representing various sizes of prey, and chlorophyll maximum (Ainley et al. 2004).

Our analyses of cetacean and seabird distributions in the northern CCS show the importance of the alongshore upwelling front, position of the coastal jet, vertically integrated backscatter at specific frequencies (i.e., prey), and the chlorophyll maximum to resolve top trophic distributions. Processes important to top trophic levels include flow-topography interactions between the upwelling front and jet with bottom topography at a submarine bank and at a large coastal promontory on the eastern boundary current circulation. Enhanced mesoscale variability (e.g. strong meanders) in the system also improved our ability to explain the occurrence patterns for some species (i.e. Dall's porpoise). The responses of cetaceans and seabirds to biophysical processes in the northern California Current upwelling system are both seasonally and spatially specific. Results of these analyses provide the framework for further development of predictive biophysical models of top predator occurrence in the California Current System. This research therefore assists in the protection and management of coastal resources through ecosystem-based management. In addition, by examining the influence of upwelling dynamics and circulation on occurrence patterns of top predators, this research contributes to our understanding of the effects of climate variability on the northern California Current ecosystem.

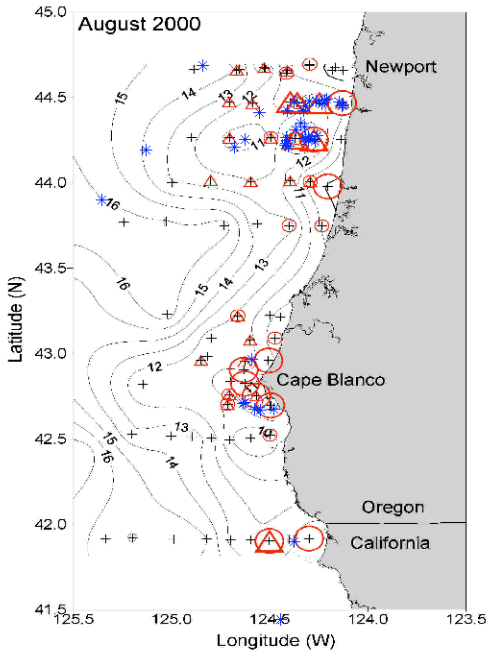

Figure 1. The correspondence of humpback whale *Megaptera novaeangliae* sightings (blue stars) overlaid on catch distribution for juvenile coho *Oncorhynchus kisutch* (red triangles) and juvenile chinook salmon *O. tshawytscha* (red circles) from surface trawls (catch data courtesy of R. Brodeur, NOAA) conducted during August 2000. Catch data is overlaid on surface temperature contours. The size of triangles and circles is proportional to the size of the catch: smaller symbols represent catch of 1 to 5 salmon; larger symbols represent catch of 6 to 150 salmon. Plus signs are stations where no salmon were caught. The correspondence between humpback whales and regions of higher salmon abundance (near a submarine bank, Heceta Bank, and off Cape Blanco) is clear. Figure 1 is reproduced from Tynan et al. (2004).

Publications:

Tynan, C.T., D.G. Ainley, J.A. Barth, T.J. Cowles, S.D. Pierce, L.B. Spear. 2004. Cetacean distributions relative to ocean processes in the northern California Current System. *Deep-Sea Research Part II* (in press). Contribution Number 483 of the U.S. GLOBEC program; WHOI Contribution Number 11035.

Ainley, D.G., L. B. Spear, C.T. Tynan, J.A. Barth, S.D. Pierce, R.G. Ford, T.J. Cowles. 2004. Physical and biological variables affecting seabird distributions during the upwelling season of the northern California Current. *Deep-Sea Research Part II* (in press). Contribution Number 438 of the U.S. GLOBEC program.

Presentations of Research:

September 25, 2003 – Eastern Pacific Ocean Conference, Catalina Island, CA, 'Cetacean Distributions Relative to Ocean Processes in the Northern California Current System: A GLOBEC Study', Eastern Pacific Ocean Conference (EPOC), September 24-27, 2003, Wrigley Marine Science Center, Catalina Island, CA; speaker

October 2, 2003 - WHOI Biology Dept., Seminar Series, 'Cetacean Distributions Relative to Ocean Processes in the Northern California Current System: A GLOBEC Study'

Invited, November 3, 2003, – Old Dominion University, Physical Oceanography Dept., 'Toward Predictive Biophysical Models of Cetacean Occurrence Patterns in the California Current System

Invited 'Science Talk', November 6, 2003 – US GLOBEC SSC, National Academy, 'Toward Predictive Biophysical Models of Cetacean Occurrence Patterns'

AGU Ocean Sciences, January 26-30, 2004, Portland Oregon, C. Tynan and R. Brodeur (Session Chairs), Session OS21J 'Understanding the Physical and Biological Coupling of Marine Population Dynamics: Higher Trophic Levels in the Northeastern Pacific'; talk entitled 'Toward Predictive Biophysical Models of Cetacean Occurrence Patterns in the California Current System'

US GLOBEC Northeast Pacific Program, PI Meeting, January 30- February 1, 2004, Portland Oregon; participation in planning for synthesis, US GLOBEC NEP Phase III CCS

2004 NOAA Progress Report

Carbon Dynamics of North American Boreal Forest Regrowth Using AVHRR

NOAA Grant NA17RJ1223
April 2003 – March 2004

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Related NOAA Strategic Plan Goal: Goal 2 - Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond.

This project is focused on the analysis of North American boreal forest carbon dynamics, including net primary production (NPP) and net ecosystem production (NEP). There are several aspects to the project, including: (i) time series analysis of NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery on a 10-day interval over the past two decades, (ii) estimation of biophysical attributes of the vegetation, including canopy light harvesting as it relates to photosynthesis over large areas, (iii) use of the image data, along with ancillary data sets, to drive models of carbon exchange in burned and regenerating areas, (iv) collection and analysis of field data sets to calibrate and validate the results. The data sets that we produce and the analyses that we conduct have direct relevance to the research objectives of NOAA's Climate and Global Change Program, and the USGCRP North American Carbon Program.

Work in this first year of the project was initiated upon receipt of funding, through WHOI-CICOR in August 2003, and builds upon previous work. We have focused primarily on items i and iv thus far, and have designed and drafted www pages which will be released soon (www.whrc.org). The AVHRR data time series, at 64 km^2 spatial resolution (GAC), was processed and corrected for the effects of satellite orbital drift between platforms. Temporal compositing of the AVHRR data (to 10-day intervals) helped to further reduce the atmospheric effects and had other advantages in that it reduced the influence of large view angles, low sun angles, and cloudy conditions. At the same time, compositing the data produces images that are a complex mosaic of values obtained from multiple dates within the time period, thus are less directly comparable to instantaneous ground measurements.

The surface radiance values were corrected to top of atmosphere reflectance, accounting for variations in earth-sun distance and in-band irradiances between sensors, and then used to calculate the normalized difference reflectance index (NDVI). The entire data set was then converted to estimates of the fraction of incident photosynthetically active radiation (PAR) intercepted by vegetation (i.e., Fpar), based on simple linear transforms of the NDVI. These data were then analyzed across a wide range of burned areas across boreal North America (figure 1).

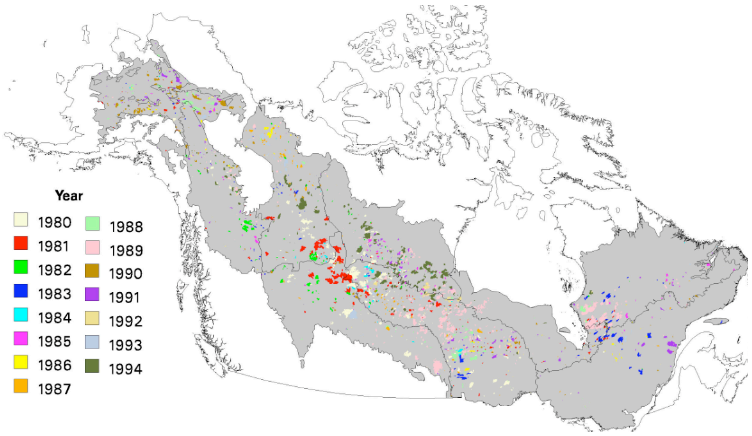

Figure 1. *North America fire locations (1980-1994) from Canadian and Alaska Fire Service (produced by B.Stocks). We are working with finer detail information than that depicted here.*

Previous work based on AVHRR analysis of fire scars used a single pixel, located in the center of a fire, to assess vegetation recovery. Because of the complexity of fire behavior, however, we know some areas within a fire will burn more or less intensely than others, and this can have a tremendous impact on the rate of vegetation recovery, and associated carbon sequestration (Kasischke et al., 2004). Moreover, differences in fire intensity determine not only the amount but also the type of vegetation that colonizes or regenerates in an area (figure 2). To capture this type of spatial variation in fire and associated vegetation regrowth, we have explored different approaches of intersecting the information in the AVHRR images with the fire boundaries depicted in figure 1. We settled on a method of internally buffering the fire polygons (by 8 km) in order to ensure that the AVHRR pixels are fully contained within the boundary (Figure 3). This has the effect of capturing a larger area of the fire, from which we can calculate various statistics associated with spatial variability in regrowth.

Figure 2. *Vegetation cover following fire in interior Alaskan boreal forest, near Delta Junction. This area burned intensely in August of 1994, consuming much of the organic soil mat and resulting in dense aspen regrowth*

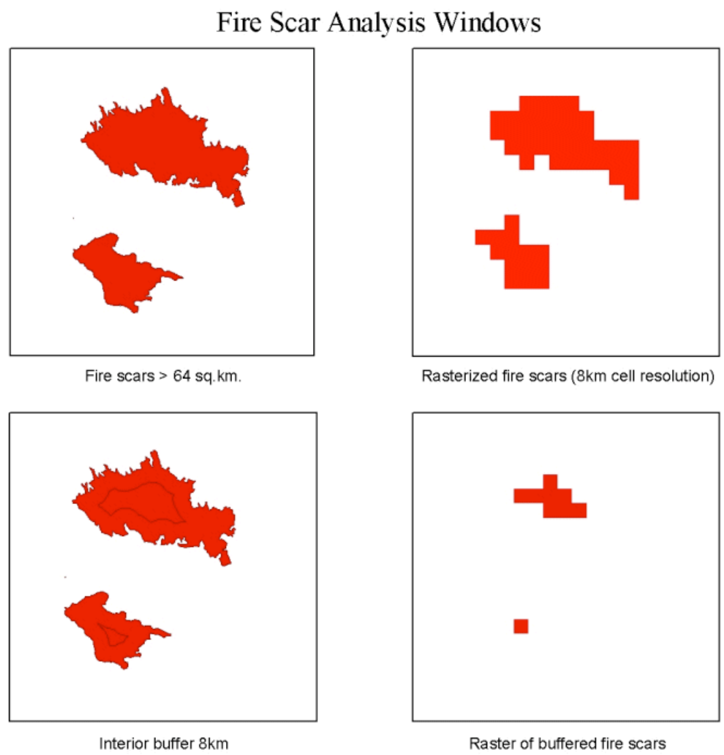

***Figure 3**. Buffering of fire polygons to capture spatial variability in fire behavior and vegetation regrowth patterns.*

As of result of the buffering process, many fires were not of adequate size to contain multiple AVHRR pixels, thus the overall sample size of fires we have to work with was much reduced. We found, for example, that the number of usable grid cells in 1989 fires (an episodic fire year) fell from 1247 to just 105 – although an additional 128 single-pixel fires were still usable (figure 4).

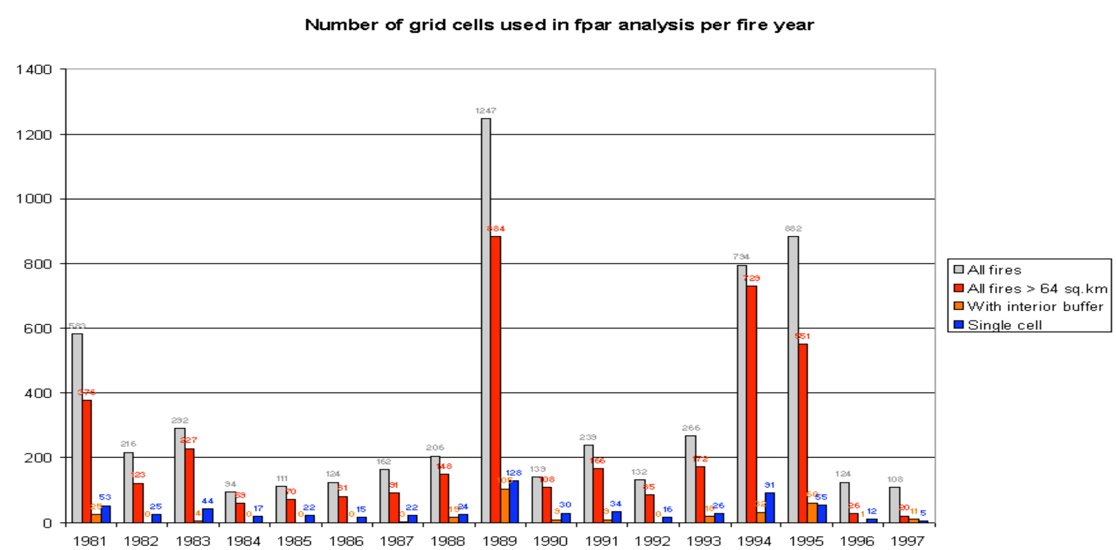

***Figure 4**. Sample size of fires occurring between 1981 – 1997, showing the reduction in sample size as fire edges were buffered to ensure AVHRR pixels were fully contained within the fire boundary.*

Once the buffered fire scar areas were defined, we extracted the mean *Fpar* values from each, and analyzed the behavior of the time series. We are exploring various time series analysis methods, but simple anomaly analysis reveals the interannual variability of the vegetation recovery. Regeneration from fires that burned in 1981 shows the gradual increase in canopy light harvesting (Fpar) as vegetation density and stature increase through time (Figure 5). We are now examining these results in the context of interannual climate variability.

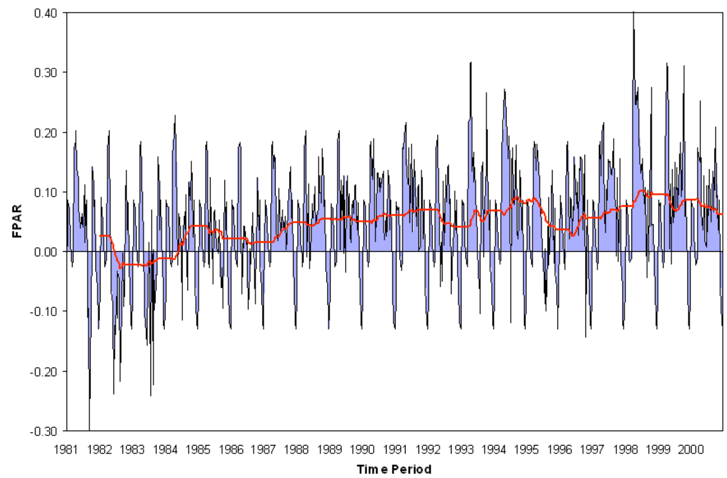

***Figure 5**. Time series of AVHRR Fpar anomalies (blue) between 1981 – 2000, for all fires that occurred in 1981. The graph shows both the seasonal variation in Fpar as well as the gradual trend towards increased light interception through time as the vegetation recovers. The solid red line indicates the 10-day mean Fpar over the 20 year period (i.e., 20 years * 36 intervals per year = 720 values).*

The other aspect of the project on which we made substantial progress is the field measurement activities in the Delta Junction region of interior Alaska. We are collaborating with others who are measuring soil and vegetation properties, including canopy towers with instruments that measure CO_2 and energy fluxes. Our continuous measurements of canopy Fpar have not yet been fully processed for the 2003 data set, pending sensor calibrations, but an example for the previous growing season shows the highly variable nature of canopy transmission, independent of the intensity of the incident PAR (figure 6). We examining this data set not only for analyses of temporal variation in light harvesting for photosynthesis, and to improve the estimates from satellite observations, but also to assess the spatial variation resulting from a combination of canopy structure and solar geometry. Our indirect estimation of leaf area index (LAI) from handheld instruments at 34 sites in the study area (Hyer and Goetz, in press) demonstrated the effect of a variety of measurement conditions, and the relative performance of different instruments for this purpose. The continuously operating PAR cell data will allow us to substantially improve upon that analysis. Finally, the data set, used in conjunction with the CO_2 flux measurements, will allow us to quantify the variations in efficiency of light use absorbed by the canopy for carbon sequestration.

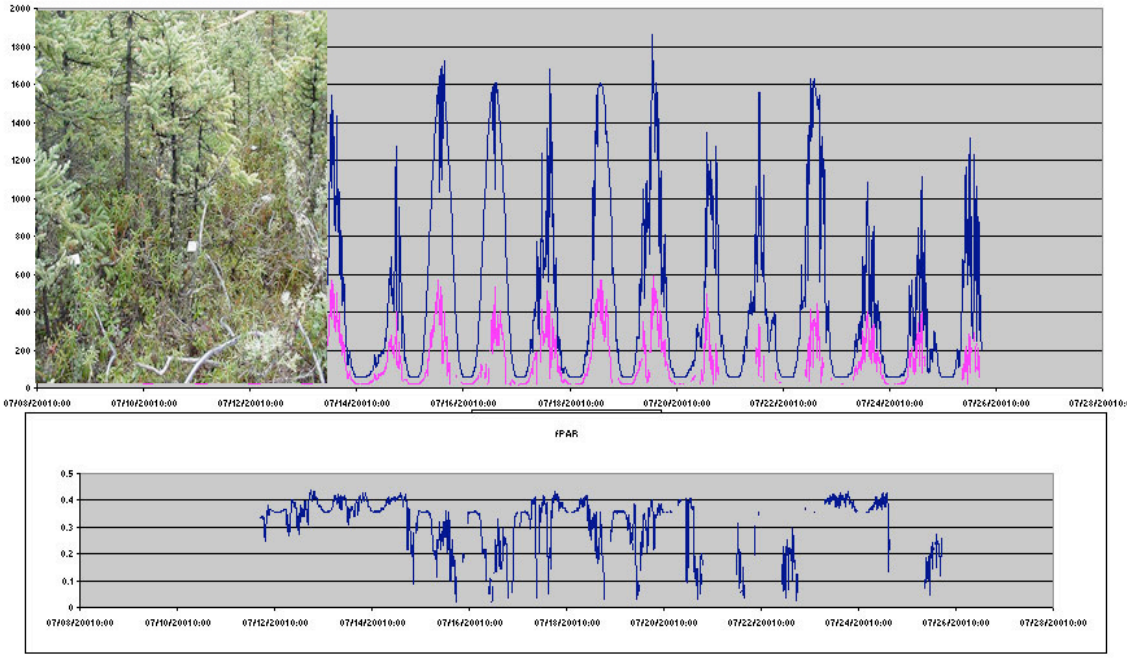

***Figure 6**. Temporal variation in incident PAR above and below canopy (top graph), and canopy Fpar (lower graph), in sparse spruce regrowth. Fpar data were collected using an array of solar cells arranged beneath the canopy (inset) and above-canopy sensors, averaging measurements at 10-minute intervals over this 2-week period in mid-July.*

Publications

Hyer, E., and S. J. Goetz. 2004. Comparison and sensitivity analysis of instruments and radiometric methods for LAI estimation: assessments from a boreal forest site. *Agricultural and Forest Meteorology* 122 (3/4):157-174.

Kasischke, E. S., S. J. Goetz, M. Hansen, M. Ozdogan, J. Rogan, S. L. Ustin, and C. E. Woodcock. 2004. Temperate and Boreal Forests. Pages 147-238 *in* S. L. Ustin, editor. Remote Sensing for Natural Resource Management and Environmental Monitoring. co-published by John Wiley & Sons and American Society of Photogrammetry and Remote Sensing, Hoboken, NJ.

Presentations

Remote Sensing and Modeling of Boreal Forest Regrowth Dynamics (May 2004), IBFRA Conference - Climate-Disturbance Interactions in Boreal Forest Ecosystems, Fairbanks, Alaska.

Measuring and Modeling Light Harvesting by Boreal Forest Regrowth (Dec 2003), AGU Fall Conference, San Francisco.

2004 NOAA Progress Report

Dr. Dennis McGillicuddy's Study of: Alexandrium Bloom Transport: Observation and Models

NOAA Grant: NA17RJ1223
July 1, 2003 to June 30, 2004

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NOAA Program Manager: Kenric E. Osgood

Related NOAA Strategic Plan Goal: See Chief Scientist report

During the period July 1, 2003 – June 30, 2004, one cruise on *R/V Oceanus* was funded. Dr. Dennis McGillicuddy was the Chief Scientist for this cruise.

May 18 – 28, 2003 11 NOAA/CICOR days

Project Summary:

The overall objective of this proposed project was to obtain field data on A. fundyense cell distribution and local hydrodynamics and to interpret those data using existing numerical models and data products from GoMOOS to determine if they can be used to provide short-term forecasts of bloom transport. Specific tasks are to: 1) collect field data in the western Gulf of Maine at temporal and spatial scales suitable for resolving A. fundyense distributions within the area covered by a CODAR array; 2) use CODAR and acoustic Doppler Current Profile (ADCP) measurements to estimate surface water velocities; 3) assimilate velocity observations into existing physical/biological coupled model; 4) seed the hindcast simulation with passive particles to assess transport of A. fundyense; 5) compare observed and predicted A. fundyense distribution s with PSP toxicity records; 6) test a conceptual model of the interactions between the western end of the EMCC, the Jordan Basin gyre, and A. fundyense using the observations of surface velocity and A. fundyense abundance; and 7) assess future needs for transitioning these predictive tools to meet management needs.

See the Chief Scientist report for the results.

2004 NOAA Progress Report

An Analysis of Fishing Vessel Accidents in Fishing Areas off the Northeastern United States

NOAA Grant: NA17RJ1223
July 1, 2003 to June 30, 2004

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Related NOAA Strategic Plan Goal: Goal 1 - Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management.

This is a collaborative research between the WHOI Marine Policy Center and the NMFS Northeast Fisheries Science Center. The study is related to the CICOR theme area Coastal Ocean and Near-Shore Processes (CICOR Task II). We understand that research in this theme area is extremely broad, including issues related to fisheries management. In this project, we examine the effects of change fishery management regulations on fishing vessel safety.

Commercial fishing is one of the least safe occupations. In 1996, the US commercial fishing fatality rate was 16 fisher deaths per 10,000 workers, a rate 16 times higher than that for fire and police protective service occupations. Between 1984 and 1998, 2,074 US commercial fishing vessel accidents resulted in total loss of vessel. The annual property, injury, and other costs of US commercial fishing vessel accidents are estimated to be over $240 million, more than three times the comparable cost of tanker accidents. Determinants of the probability of a fishing vessel accident may be used to improve both fishing vessel safety and fisheries regulations. However, quantitative analyses of long-term fishing vessel accident probabilities have been limited by lack of data.

The study investigates both fishing vessel accident probability and vessel trip probability for the northeastern United States using logit regression and daily data from 1981 to 2000. The results indicate that accident probability is affected by weather conditions, vessel locations, time of year, and vessel characteristics. Changes in fishery management in 1994 have not resulted in a general increase in accident probability but may have contributed to a higher accident rate in the Gulf of Maine over the 1994-2000 study period. Although higher economic returns induces more vessels to go fishing, this is not associated with an increase in accidents.

The vessel accident and vessel trip probability models developed in the study are important building blocks in the development and assessment of management options related to fishing vessel safety. The vessel accident probability model describes the relationship between the expected accident rate and a set of variables important in the design and assessment of fisheries management regulations. Spatial variables (e.g., location and distance to shore) are useful for management decisions related to fishing area closures and zoning. Similarly, seasonal and weather variables provide important information for the timing of fishing regulations. These variables may be used by the Coast Guard to improve allocation of search and rescue and response capabilities.

The management approach historically applied in many U.S. fisheries has contributed to overcapacity, excessive harvesting of fish stocks, and an environment in which fishermen may find it difficult to operate at high levels of safety. To improve safety in the commercial fishing industry, management measures must address fishing vessel safety regulation and enforcement, as well as resource conservation. Some considerations that may improve safety at sea include involving the harvesting sector at early stages of the management plan development process, giving more flexibility to boats in bad weather during limited fishing periods, revising crew size limits to reduce fatigue and alternative forms of rights-based management.

Paper Resulted from This Research:

Jin, D. and E. Thunberg. 2004. An analysis of fishing vessel accidents in fishing areas off the northeastern United States. *Accident Analysis and Prevention*, Submitted.

2004 NOAA Progress Report

Sperm Whales in the North Atlantic - DTAG Effort

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Related NOAA Strategic Plan Goal: Goal 1 - Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Summary

The MMS funded 'Sperm Whales in the North Atlantic' study was a cooperative effort between the Northeast Fisheries Science Center (NEFSC) of the National Marine Fisheries Service and the Woods Hole Oceanographic Institution (WHOI). The study built upon on-going survey work in the North Atlantic by NEFSC and a multi-year tag-based controlled exposure project in the Gulf of Mexico (the SWSS project) by WHOI. The goals in combining these two methodologies were:

1. to obtain baseline data on the behavior of sperm whales in the North Atlantic to compare against data from the Gulf of Mexico and the Mediterranean.
2. to assess the potential of the North Atlantic study area for controlled exposure experiments similar to those carried out in the Gulf of Mexico under the SWSS program.
3. to estimate the surface presence of sperm whales to improve survey-based population estimates.

The study centered on a cruise onboard the NOAA R/V Delaware in July 2003. A total of 12 sperm whales were tagged during the 4 week cruise yielding a substantial data set spanning both deep foraging and socializing. These tag recordings represent the first acquisition of sound and movement data from sperm whales in the North Atlantic. Visual and acoustic surveys were performed whenever weather permitted throughout the cruise and visual focal follows were made when tags were deployed. Complimentary data products included physical oceanographic measurements and skin and fecal samples from tagged and neighboring whales. The tag data set from the cruise has been examined using techniques developed on the SWSS program to parameterize foraging and social behaviors. The data set has also been integrated into a combined data set covering the Gulf of Mexico, North Atlantic and Mediterranean seas to enable comparative analyses. We find that the North Atlantic whales follow a foraging and socializing cycle similar to the Gulf of Mexico whales but dive significantly deeper to forage. Foraging largely occurs at 700-1100 m but a small amount of food may be taken as shallow as 300 m. A wide range of codas are produced but even fairly closely located groups appear to prefer distinct codas. Two factors make the study area undesirable for future controlled

exposure trials with an air-gun source. First, an unusually high rate of breaching, possibly associated with tag attachment, limited the longevity of the tag. The maximum attachment duration of 6 hours in the study area compares unfavorably with 16 hours in the Gulf of Mexico and Mediterranean. Secondly, low frequency impulsive sounds from underwater explosions in a Navy test range were frequently heard and would provide a pre-exposure condition amongst whales in a large surrounding region.

Contents

1. Methods

The data collection systems and methodologies used for the DTAG component of the Delaware cruise were based on those developed for the SWSS'02 and '03 cruises. Detailed descriptions may be found in the reports to MMS for those cruises and only an overview is presented here. Focus here is on the tag-related data collection; the visual survey method is detailed in a companion report from NEFSC.

1.1 DTAG

The DTAG was developed by WHOI principal investigators in 1999 with funding from ONR and WHOI endowment. Details on its design are in Johnson and Tyack (J. Oceanic Eng., Jan. 2003). This non-invasive tag records the sounds heard, and made, by the tagged whale together with its depth and orientation (i.e., pitch, roll, and heading), in a synchronized fashion throughout the dive cycle. The tag records data digitally for between 10 and 24 hours, depending on sampling rate, with enough resolution to track individual fluke strokes and is sensitive enough to record sounds from distant whales and ships. A new version of the DTAG, called DTAG-2, was used in the Delaware cruise and in the SWSS'03 cruise preceding it. This device has more recording capacity and a higher audio sampling rate and resolution than the original version. It is also one half the size and weight (300g in air). The improved recording capacity is achieved using a loss-less compression algorithm to increase the storage efficiency of the audio data. This algorithm gives a consistent compression factor of between 3 and 4 (i.e., the effective memory capacity is 3-4 times the nominal value). With the 3GByte memories used on the 2003 DTAG-2s, it is possible to record 96 kHz, 16 bit audio for over 16 hours. The sensitivity of the DTAGs used in the SWSS'03 and Delaware cruises was approximately -193 dB re μPa (this is also the clipping level or loudest sound level accurately recorded by the tag).

The DTAG is housed in a plastic fairing and is attached to the whale with a set of four small suction cups. The tag has a low profile on the whale as exemplified by Fig. 1 to minimize the risk of tag removal by conspecific rubbing. The tag has been successfully deployed on more than 60 sperm whales, 25 pilot whales and 5 beaked whales, among other species, with deployment durations of up to 30 hours. In the SWSS'03 cruise in the Gulf of Mexico immediately prior to the Delaware cruise, tag attachments of up to 17 hours with an 8 hour average were achieved with the new tag. The tag has a VHF beacon which broadcasts a signal in the 2m band (148-150 MHz) every second for tracking and recovery of the tag. Data is off-loaded from the tag via an infra-red interface. The tag battery can be recharged while data is off-loading maximizing the availability of the device.

Figure 1. The DTAG deployed on a sperm whale in the North Atlantic.

1.2 Tagging Method:

Operations in the field are typically run from a research vessel with a high flying bridge for visual observations. Once whales are located and the research vessel has moved close to the animals, a rigid-hulled inflatable boat (RHIB) is deployed with a 3 or 4-person tagging team to attach DTAGs to whales. On the RHIB, a directional hydrophone is used to locate and close on sperm whales. Visual and acoustic observers on the research vessel support the tagging effort by providing surfacing positions and acoustic bearings of whales to the RHIB team. A 46' cantilevered pole, made of carbon fiber, is used to deliver the tag allowing the approach vessel to remain well behind the flukes of the target animal. Intensive visual and acoustic observations from a nearby research vessel record the social and geographical context of the whales' behavior, before, during, and after tagging. After attaching a tag, the length of the whale is measured using photogrammetry and photographs of the fluke and other distinguishing features are taken for photo-identification. Whether a tag is attached or not, no more than three approaches are made to any individual or tight group of whales in keeping with the requirements of the NMFS permit issued to Peter Tyack. After each approach, the whale's surfacing location is inspected to search for feces or skin, and a data sheet is filled out detailing the position, approach number and response of the whale. Once a whale has been tagged and photographed, the RHIB either returns to the research vessel or attempts to tag another whale. No more than three whales are tagged at a time.

1.3 Visual and Acoustic Data Acquisition

Continuous visual and acoustic observation is critical not only to locate and close on sperm whales but also to provide a context for the data collected by the DTAG. Visual observations while following a tagged whale (i.e., during a focal follow) provide a surface track for the tagged whale, anchoring the movement data collected on the DTAG into a geographic frame. Visual and acoustic observations can also define the group size and distance between whales, important data for understanding the social behavior of the tagged whale. Acoustic tracking is also essential to stay with a tagged whale overnight or during bad weather.

For visual observations, we use high-power ('Big Eye') binoculars, mounted on tripods on the flying bridge of the research vessel. These are arranged to give a close-to 360 degree view. The visual and acoustics data are entered into logging software which also interfaces with the ship's navigation network to precisely locate each observation. Real-time displays of all the visual and acoustic contacts are maintained in both the acoustics laboratory and on the flying bridge to help the two teams communicate.

During the search phase of operations, sperm whales are located using visual and acoustic techniques. Visual observers scan for whales using the Big-Eye binoculars, and acoustic observers attempt to detect and locate sperm whales by listening for their vocalizations on a towed hydrophone array. Once whales are detected, the research vessel is steered toward the whales, and visual observers record the numbers and distribution of the group of animals. The acoustic observers commence to track submerged whales in preparation for tagging and record array signals to multi-channel audio recorders.

2. Cruise Summary

The field effort took place between the 7th and 31st of July, 2003, on board the R/V Delaware. Both WHOI and NEFSC personnel participated in the cruise. The WHOI group of 7 included a tagging engineer, acoustic observers, and visual observers. WHOI also supplied a 24' RHIB for tagging, a towed hydrophone array, and the visual and acoustic data collection hardware and software. The tag boat was a fiberglass-hulled Novurania, called the 'Balena', owned by the tagging group at WHOI. The Balena, has two counter-rotating 4-stroke Yamaha 110 hp outboard motors chosen for their low acoustic noise. The Balena was stowed on the aft deck of the Ewing and lowered over the starboard side using the main crane. The tight fit of the Balena on the deck made deployment difficult especially given the persistent roll of the R/V Delaware. However, there were no incidents during deployment or operation of the small boat. The Balena was captained by Wayne Hoggard from Southeast Fisheries Science Center, an expert boat operator with experience of approaching sperm whales gained during the MMS-funded SWAMP trials. DTAGs were delivered using the cantilever-pole method and Mark Johnson operated this system. The other tag-boat crew, Natacha Aguilar de Soto and Peter Madsen, performed the duties of acoustic tracking, permit data fulfillment and video camera operation. All approaches were made under a NMFS permit granted to Peter Tyack which lists Mark Johnson as a co-worker. In addition to tagging, the Balena crew took video for photo-identification and sizing of whales. Fecal samples were collected from diving whales and skin samples were preserved from recovered tags. As radio tracking of tags from the Delaware was impacted by strong interference, the Balena assisted with radio tracking of tagged whales and in recovering tags. Night time recoveries of tags were achieved fairly efficiently from the Delaware although this required that the acoustic array be winched in.

Two hydrophone arrays were carried onboard the Delaware for acoustic tracking. The WHOI-supplied three-element hydrophone array was built for the SWSS program and deployed from the Delaware as a streaming array (i.e., without a depressor) using a mechanical capstan. The array was used throughout the experiment and performed well. Two software systems were used in parallel for acoustic tracking. The first, Rainbow Click from the International Fund for Animal Welfare (IFAW), provided reliable bearing estimates for distant sperm whales. The other program, developed by Walter Zimmer of the SACLANTCEN NATO Undersea Research Center in La Spezia, Italy, was most effective for close whales and was used during focal follows. Sound from the array was recorded continuously on an Alesis hard-drive recorder at a sampling-rate of 48 kHz while tracking and 96 kHz during focal follows. Acoustic observations were logged using custom software also developed by Zimmer. Sound samples were acquired digitally using Logger software from IFAW. A staff of 4 observers operated the hydrophone array providing 24 hour coverage throughout the cruise except in high sea states and during high speed transits. A summary of the tracklines covered by acoustic watches is shown in Fig. 3 indicating also where sperm whales were heard.

Visual observations were made from the flying bridge of the Delaware and conformed to one of two protocols. While sperm whales were not present, the visual effort was led by NEFSC in a survey study. When sperm whales were located, the visual effort operated in a focal follow mode, using a protocol and data logging system developed under the SWSS program. The data logger combined navigation and observation information into a database and provided a real-time display for both the visual and acoustic personnel. The software for this system was developed cooperatively by WHOI and SACLANTCEN and was managed by Marilena Quero of WHOI. The visual data collection effort operated well throughout the campaign with the results summarized in Fig. 2.

A total of 12 tags were delivered in 7 operational days with sperm whales with the results given in Table 1. Weather was the main limiting factor: only about 45% of available at-sea days had sufficiently good weather for tagging. Considering that on many of the bad weather days sperm whales were located and tracked by the Delaware, the encounter rate of whales was excellent. Overall, we found the whales straightforward to approach - comparable to the most successful year in the Gulf of Mexico. 24 approaches were required to deliver 12 tags and only on one day of tagging attempts were we unable to deliver a tag. On a majority of days we delivered 2 or more tags. A summary of time expenditure on the cruise is given below.

Total cruise days	26

Comprising:	Lost to bad weather	11
	Successful tagging	6
	In-transit or dock-side	6
	Good weather but no sperm whales	2
	Unsuccessful tagging	1

With two exceptions, the attachment durations were fairly short (1.0-6.4 hours, see Table 2). This was, in part, due to a large number of breaches: 5 out of 12 tagged whales breached, in most cases ending the attachment. Similar high breaching rates were seen on the SWAMP'01 trial in the Gulf of Mexico whereas in other years, in the same area, few breaches were seen. It is not yet clear whether this was in response to the tag and, if so, what leads to this sort of heightened sensitivity. A high percentage (75%) of tags yielded skin samples. Two tags failed to yield a data-set: one was not recovered due to poor weather and a possible failed VHF transmitter. A second tag had a battery failure during deployment and did not record. The cause of this problem has now been identified and rectified in the design. A third tag remained attached for less than a minute due to a breach.

Despite the short attachments, we sampled each of the usual behavioral modes of sperm whales: foraging dives, socializing, resting, and traveling. The set of 18 deep dives provides a strong initial baseline for estimates of foraging success and energy expenditure using metrics developed in the SWAMP and SWSS programs. In addition to sperm whale vocalizations, the tags recorded sounds from other nearby odontocetes including pilot whales, bottlenose dolphins and spotted dolphins. The sounds of passing vessels and explosions from a distant naval exercise were also collected.

Overall we found the study area to be an exceptionally good site for sperm whale tagging. However the potential for poor weather and few long attachments make the area less attractive for controlled exposure experiments. Any such experiments would also need to examine the extent to which frequent naval exercises may have pre-exposed the population to impulsive sounds.

Table 1. **DTAG Data Sets for the Delaware cruise, North Atlantic, July 2003**

Date	Time	ID	Tag id	Record time / carry time (hours)	# of full deep dives	Sampling Rate, kHz	Skin/Fecal sample	Comments
7/16/03	10:44:17	sw197a	202	2.1 / 2.1	2	96	S	
7/16/03	12:01:41	sw197b	209	2.4 / 2.4	2	96	S	Breached off
7/20/03	11:42:10	sw201a	202	3.7 / 3.7	0	96	S	Breached off
7/20/03	15:15:13	sw201b	207	3.2 / 3.2	2	96	-	
7/21/03	12:10:59	sw202a	202	1.0 / 1.0	1	96	S	Breached off
7/21/03	12:55:43	sw202b	209	2.0 / 2.0	0	96	S	
7/25/03	11:59:02	sw206a	202	3.8 / 3.8	4	96	S	
7/25/03	-	sw206b	205	0 / 6.3	-	96	F	Battery failure
7/25/03	13:12:45	sw206c	209	2.6 / 2.6	3	96	S	
7/26/03	11:28:00	sw207a	202	6.4 / 6.4	4	96	S	
7/26/03	-	sw207b	209	0 / ?	-	96	S,F	Lost at sea
7/31/03	-	sw212a	13	0 / 0	0	32	-	Breached off

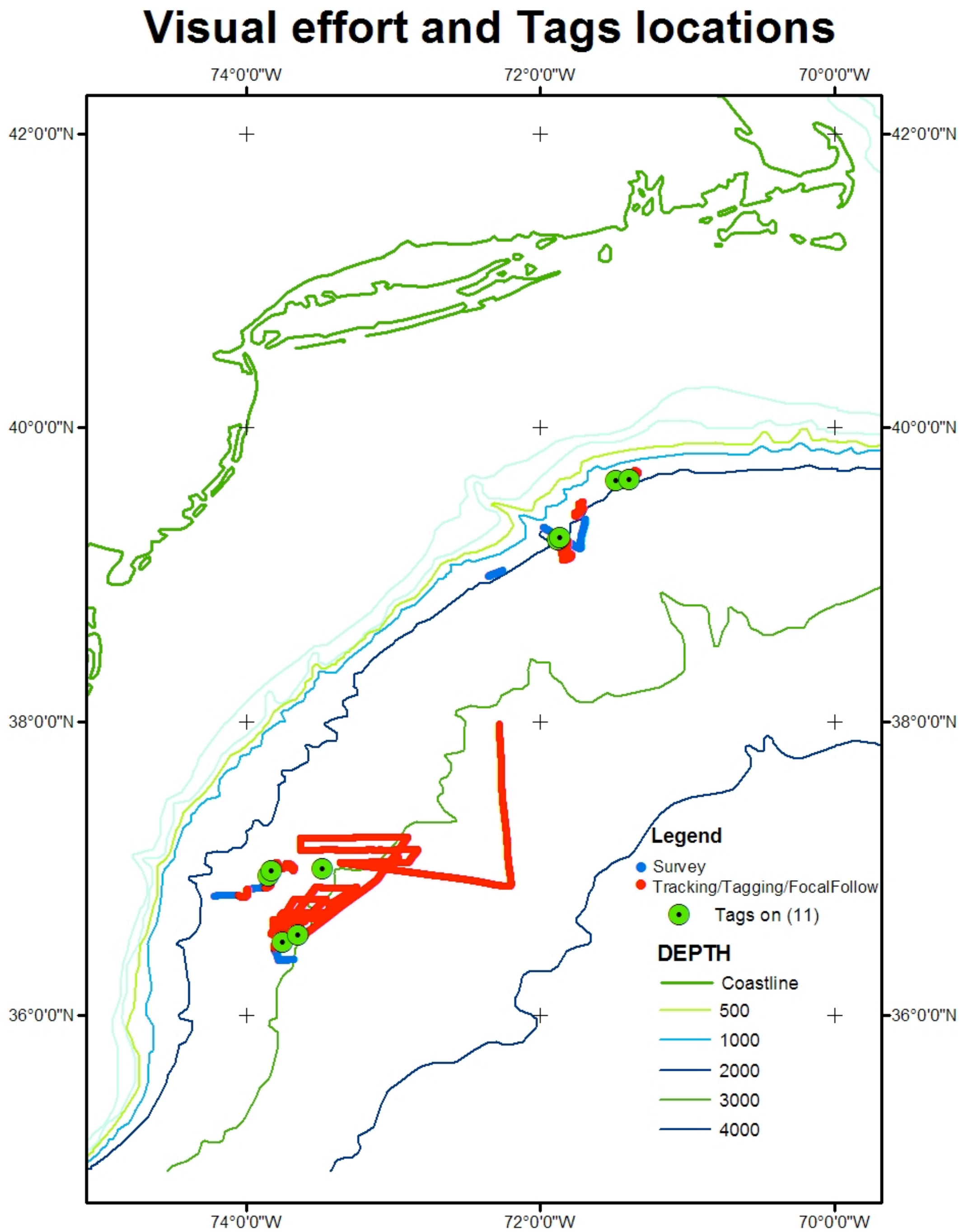

Figure 2. Visual survey and focal follow tracklines for the Delaware cruise

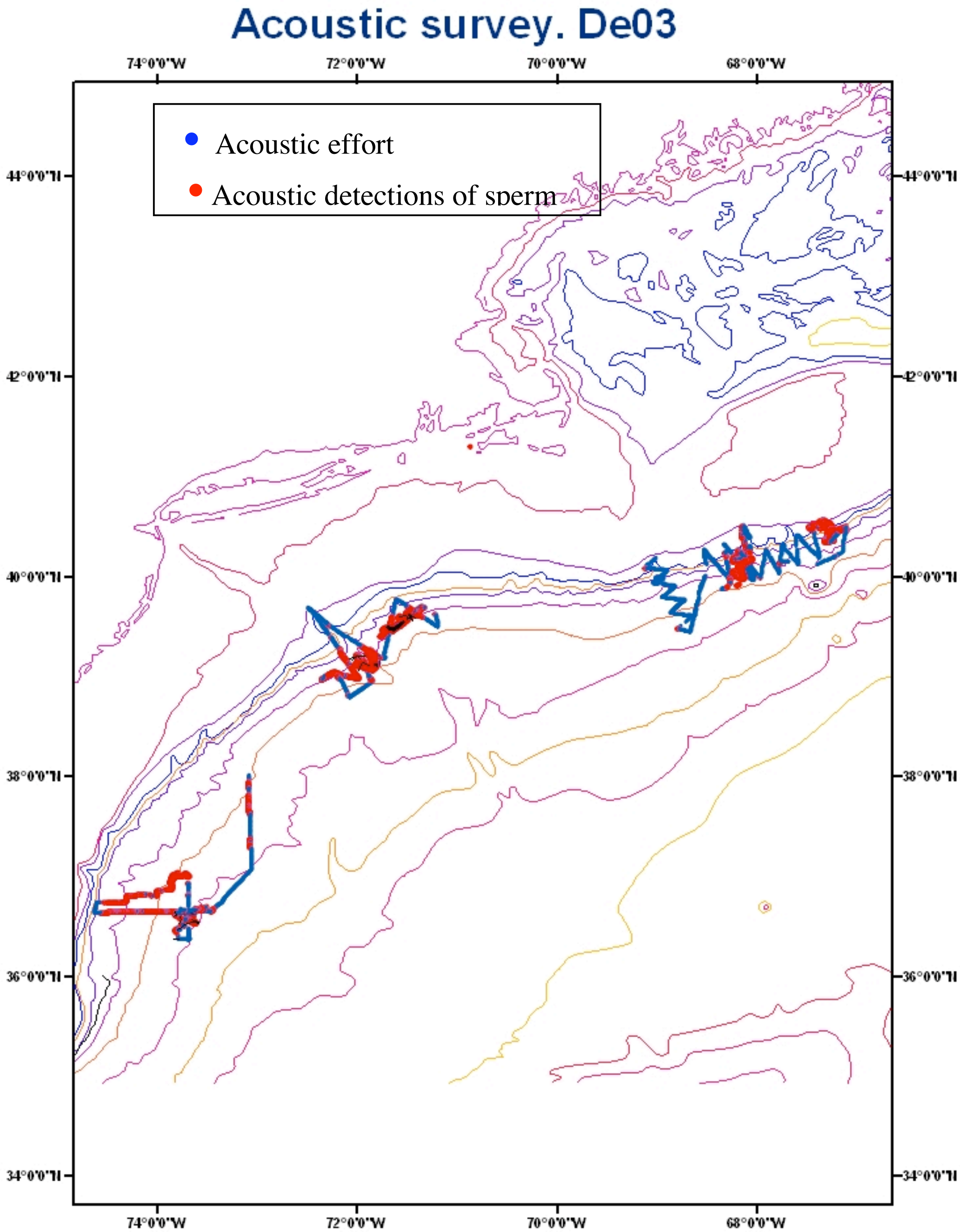

Figure 3. Acoustic survey tracklines for the Delaware cruise

3. Data Summary

As shown in Table 1, a total of 12 DTAGs were deployed yielding 9 data sets. These were complimented by visual sightings and ship-board acoustic recordings. A full copy of all data was provided to NEFSC at the end of the Delaware cruise for archiving. The procedure for quality assurance, archiving and handling each data source is described in the following.

DTAG Data: The tag data comprises two streams: the audio recording and the sensor stream. Sound from the tag is archived to a sequence of audio files in WAV format. The sampling rate for all tags except sw212a was 96kHz and the resolution was 16 bits. The data in the WAV files corresponds to the raw analog acquisition: a magnitude of 32768 corresponds to a full-scale input on the analog-to-digital converter. The frequency range of the audio acquisition was from about 100Hz to 46kHz with a flat response from 400Hz to 45kHz. The format for audio data as stored on the tag contains a built-in quality check with regularly spaced repeated samples and cyclic-redundancy error checking. The sensor data from the tag is archived in a sequence of 12-channel WAV format files. Each channel corresponds to a physical sensor channel, namely: accelerometer x, y, and z axes, magnetometer x, y and z axes, depth, temperature, and 4 variables related to engineering variables within the tag. The sampling rate of each sensor channel is 50Hz. The raw tag data is archived on CDs in WHOI's marine mammal center managed by Research Associate Amanda Hansen. The large WAV files are available on hard drives or can be regenerated from the raw data files on any PC. Sensor data are analyzed as described in Johnson and Tyack (2003) which also describes methods for quality assurance. Acoustic records are completely audited to produce a catalog of sounds produced by the tagged whale as well as other natural and man-made sounds recorded by the tag.

Permit Data/Close Observations from RHIB: During close approaches of the RHIB to whales, a range of data is collected for permit compliance, and for sizing and identifying individuals. These data include tagging location, reaction of the whale to tagging, tag placement, videogrammetry, and fluke identification photography. Visual observations are recorded on data sheets. Data sheets are copied in the field for archival and a copy is maintained in the WHOI marine mammal laboratory. Video recordings are streamed into a computer using FireWire and back-ups made on CD. Fluke-shots and other images are extracted as high-quality bit-map images and contributed to local identification catalogues where they exist. A description of each whale approach is generated for reporting purposes to NMFS.

Visual Data: The SACLANT-WHOI visual data collection system acquires ship location and heading at one second intervals and stores this along with visual observations in a Microsoft Access format database. The visual observation data include the range and bearing from the ship to a whale and the aspect (i.e., the heading) of the whale. This data is used to produce a surface track of focal whales (see, for example, Fig. 4) and to correct the dead-reckoned track derived from the tag data. Other visual data recorded include the species location and number of other species as well as the environmental conditions. Locations of whales sighted through the Big-Eye binoculars are determined from their relative bearing and reticle number. The standard algorithm is used to convert reticle number to range, based on the height from the water-line to the binoculars. The visual database is checked daily during the cruise to ensure that group ID's are correct, and that focal whales were correctly identified. The database is archived on CDs held at the WHOI marine mammal lab. After the cruise, surfacing locations of whales are plotted in MATLAB or Arcview and integrated with positions of the observation-boat.

Acoustic Data: Acoustic data comprises recordings made on the Alesis recorders, audio samples taken with Logger, and observations recorded with AcLogger. The recordings were backed up using external hard drives and these copies are maintained in the WHOI marine mammal lab. The start and end time of each recording is listed on a data sheet and the disks are sampled to check the recording quality. The AcLogger database was stored in Microsoft Access format and was periodically archived to CD during the cruise. A final copy is kept in the marine mammal lab. The acoustic recordings are used in after-the-fact data analysis for passive tracking and to link acoustic activity to sounds recorded on the tag.

Skin and fecal samples: Feces and sloughed skin material are occasionally collected during close approaches to whales using a dip-net or small plankton tow-net. Skin is also sometimes found on the DTAG suction cups after tag recovery. Anticipating this, the suction cups are sterilized before each deployment. The location and ID of the animal from which the material was collected are recorded on data sheets. A total of 9 skin samples and 2 fecal samples were collected from tags or during tagging on the Delaware cruise. Skin samples were stored in vials of DMSO during the cruise and then split for analysis by two separate laboratories. One set of samples was sent to Dan Englehaupt at the University of Durham to determine gender and relatedness. Dan has processed samples collected with DTAGs from the Gulf of Mexico and the Mediterranean and will examine relatedness of the North Atlantic whales with these populations. The other set of samples was analyzed at the NMFS laboratories to compare against samples from previous biopsy efforts in the North Atlantic. For samples with substantial material, excess material will be added to a library of genetic material maintained by NMFS. Fecal samples were first checked for skin which was removed and handled as above. Filtered fecal material was frozen and then taken by NEFSC for analysis.

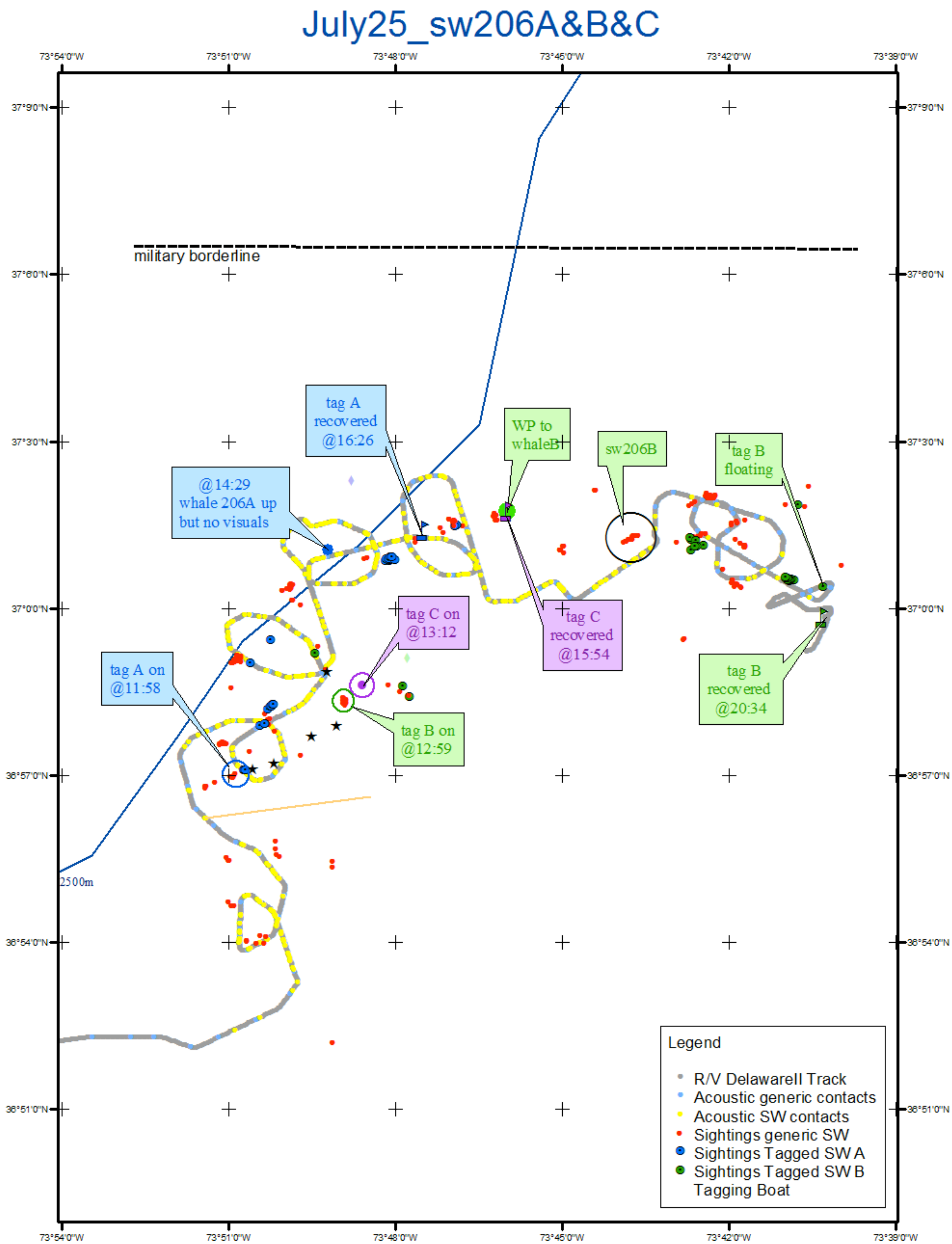

Figure 4. Example visual observation chart produced by the SACLANT-WHOI system

4. Data Analysis

Analysis of the tag and supporting data proceeds in two phases. The first phase consists of low level auditing of the data. In this phase, the sensor data is calibrated based on laboratory and field calibration values and checked for quality. The data from the orientation sensors (magnetometer and accelerometer) must also be corrected for the tag position on the whale which is estimated from visual sightings of whale aspect (i.e., compass heading) during surfacings as well as photographs and video taken from the tag boat. The tag position is then refined iteratively in order to maximize the consistency of the data. This technique, developed under the SWSS program, takes advantage of the fact that, in normal diving behavior, a sperm whale has a zero mean pitch and roll while at the surface and does not roll during the initial few seconds of a steep (i.e., non-social) dive. This method can also be used to detect a change in placement of the tag due to sliding. The end result is an accurate time series of the whale orientation parameterized by the Euler angles pitch, roll, and yaw. The accelerometer used to determine pitch and roll is inherently sensitive to sudden changes of movement as well as orientation and these give rise to an error in the orientation estimate. Fortunately the occasional episodes with strong dynamics due to sharp acceleration or turning can be readily identified in the data and flagged as inaccurate. The final step in the sensor data preparation is to combine the visual tracks with the DTAG pitch and roll time series to produce a dead-reckoned 3-dimensional track of the whale.

The initial processing of the audio data from the tag involves careful listening of the entire recording by expert listeners. A data sheet is used to record every vocalization from the tagged whale and other nearby whales as well as sounds from movement, vessels etc. Key features are entered into a database. These include creaks (fast click sequences associated with foraging), codas (stereotypical click sequences associated with socializing), and the start and end of regular clicking in each dive. The audio data is also inspected for echoes from the sea floor to determine the altitude of the whale.

The second phase of data analysis is to examine the meta-data products produced in the first phase, described above, to determine behavioral states, estimate foraging efficiency, look for evidence of foraging specialization, and to examine social interactions. The same low-level processing has also been performed for tag data acquired during the SWSS and Mediterranean studies. The resulting meta-data has a well-defined format facilitating comparisons between data sets and so the analytic value of the North Atlantic tag data will extend well beyond the time frame of the current project.

We are in the process of preparing a paper based on the North Atlantic data and present here an overview of the two main behavioral states represented in the data: foraging and socializing.

4.1 Dive behavior

The North Atlantic tags recorded normal sequences of deep and shallow dives. We distinguish the deep, typically U-shaped, foraging dives and their accompanying brief surface interval from extended near-surface periods as shown in Fig. 5. Table 2 summarizes the North Atlantic data set in terms of the dive parameters in Fig. 5. The dive times and descent/ascent rates are typical of sperm whales in our other study areas (see

Table 3). Dives were on average deeper than in the Gulf of Mexico: four of seven deep-diving whales in the North Atlantic dove below 1000m with a deepest dive depth of 1186m. This is more representative of diving behavior recorded from isolated large males in the Mediterranean where dives to 1250m have been recorded. According to the published bathymetry, the water depth at the North Atlantic tagging locations was between 1500m and 3000m. No bottom echoes have been found in the tag audio data indicating that the whales are at least 500m above the bottom and suggesting that the tagged whales were foraging in the mid-water column, like those in the Mediterranean deep water. In comparison, whales tagged in the Gulf of Mexico and in the Gulf of Genova in the Mediterranean often dove close to the bottom at a depth of between 600 and 1000m.

The tag audio recording was typical of that recorded in the Gulf of Mexico. Deep dives contained regular clicking with interspersed creaks while codas were common in shallow dives and during the near-surface portion of deep dives. The following sections describe the occurrence of sounds in these two dive classes in more detail.

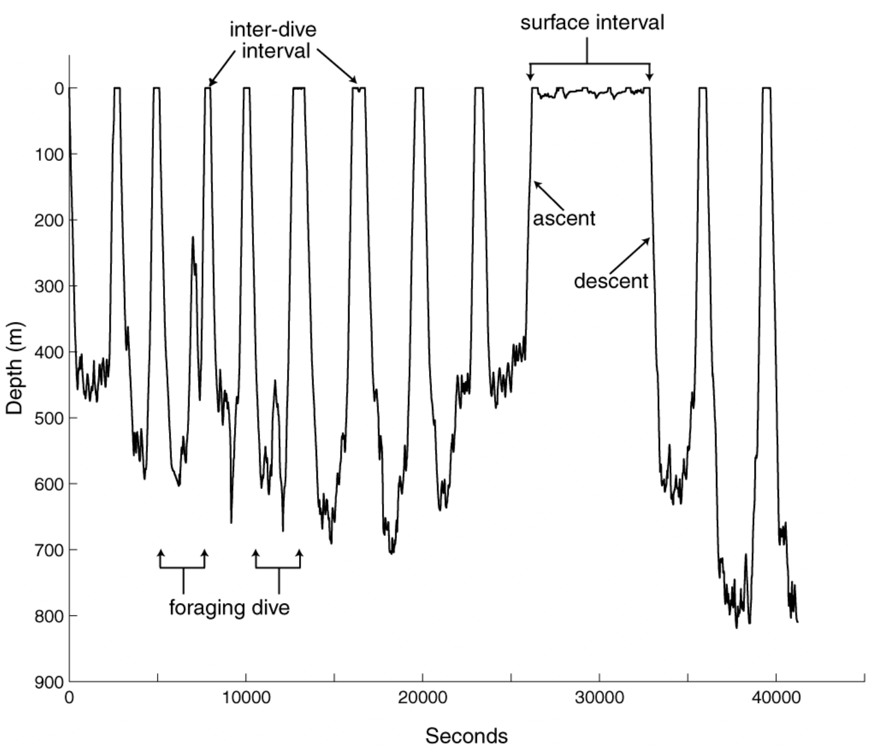

Figure 5. Typical elements in a normal dive profile.

Table 2. Dives recorded by DTAG during the Delaware cruise

Whale	**# Full dives**	Dive duration (min)	**Surface time** (min)	**Descent rate** (m/sec)	**Ascent rate** (m/sec)	**Max depth** (m)
197A	2	53	26	1.3	1.5	720
		50		1.1	1.2	821
197B	2	42	73	0.98	1.2	816
		40		1.1	1.0	986
201A	0	-	221	-	-	49
201B	2	55	72	1.3	1.4	970
		55		1.2	1.2	1186
202A	1	39	21	1.1	1.5	920
202B	0	-	120	-	-	17
206A	4	41	39	1.3	1.3	952
		42		1.1	2.2	942
		40		1.4	1.7	927
		39		0.9	2.0	1016
206C	3	47	31	0.9	1.4	976
		43		1.6	1.3	947
		43		1.0	1.6	1040
207A	4	45	194	1.2	1.4	891
		43		1.1	1.4	915
		46		0.9	1.7	1013
		41		1.3	1.1	871

Table 3. Average duration and depth of dive features recorded in the North Atlantic**.**

Duration (min)	Foraging Dive			Inter-Dive Interval	Surface Interval
	Total	Descent	Ascent		
North Atlantic	44.6	24.4	20.2	7.1	70.0
Gulf of Mexico	44.7	22.2	22.4	8.2	63.7
Mediterranean	40.3	24.4	19.3	9.7	57.5
Depth (m)	Foraging Dive Average Maximum Depth			Inter-Dive Interval	Surface Interval
North Atlantic	933.9			1.15	5.6
Gulf of Mexico	638.7			0.45	4.6
Mediterranean	797.3			0.34	4.9

4.2 Foraging Behavior

Table 4 lists the key acoustic features of the deep foraging dives recorded in the North Atlantic. Regular clicks start at normal depths, but some animals keep clicking on the ascent (see especially sw03_201b) which is highly unusual. Looking at the depth distribution of whales from the three study sites, shown in Fig. 6, it appears that the North

Atlantic whales spend comparatively less time at the maximum dive depths and rather more at intermediate depths. This is in agreement with the observation that the North Atlantic profiles are somewhat more V-shaped than those seen elsewhere. Some example dive profiles are shown in Figs. 7-12 with acoustic features superimposed. Creaks also occur over a much broader depth range than normal in our other study sites. Although the majority of creaks still occur near the base of the dive, the occasional shallow creaks and continued clicking through the ascent may indicate opportunistic foraging at shallower depths perhaps taking advantage of dispersed layers of prey. This represents a point of difference with Gulf of Mexico and Mediterranean data in which foraging appears to be limited to the base of the dive or to several distinct deep layers. Sperm whales, although primarily teutophagus, are known to also eat fish. In future work, we plan to examine fisheries information for the North Atlantic to identify possible meso-pelagic prey species.

Table 4. Regular clicks and buzzes recorded by DTAG

Whale	Dive	Regular clicks start (m)	Regular clicks stop (m)	# Buzzes/dive	Buzz depth
197A	1	130	527	20	537-720
	2	147	508	17	636-803
197B	1	154	640	8	653-816
	2	130	587	7	613-917
201A					
201B	1	253	157	32	225-975
	2	110	483	30	583-1192
202A	1	340	628	18	598-923
202B					
206A	1	370	483	23	589-954
	2	225	652	29	657-952
206C	1	86	543	27	635-986
	2	342	673	29	675-923
	3	339	649	30	543-1032
207A	1	378	503	29	743-893
	2	331	339	25	415-918
	3	317	461	32	501-873
	4	373	461	18	461-596

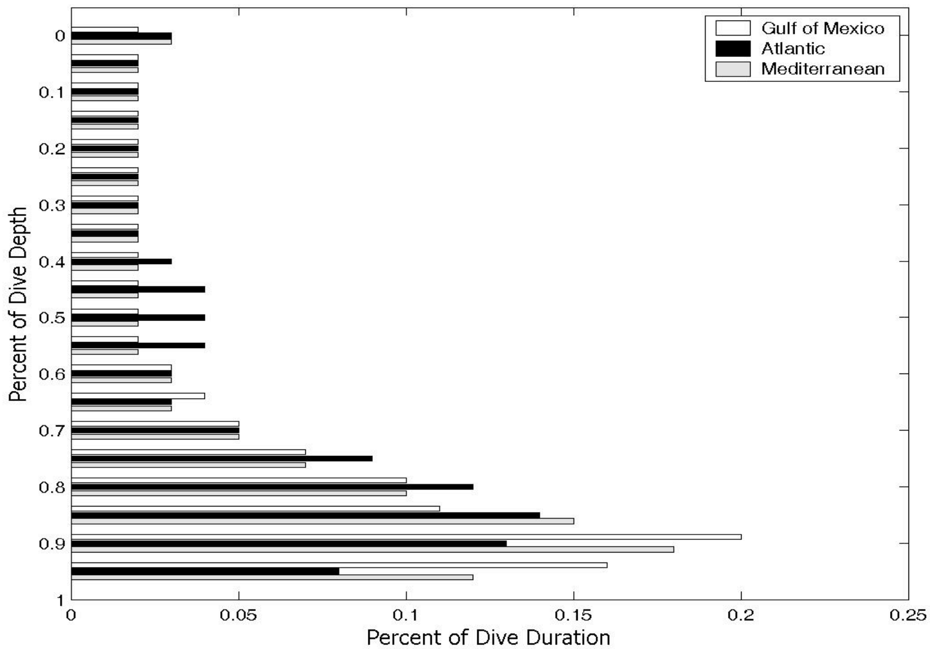

Figure 6. Average normalized foraging dive profile for sperm whales in the Gulf of Mexico, the Atlantic, and the Mediterranean.

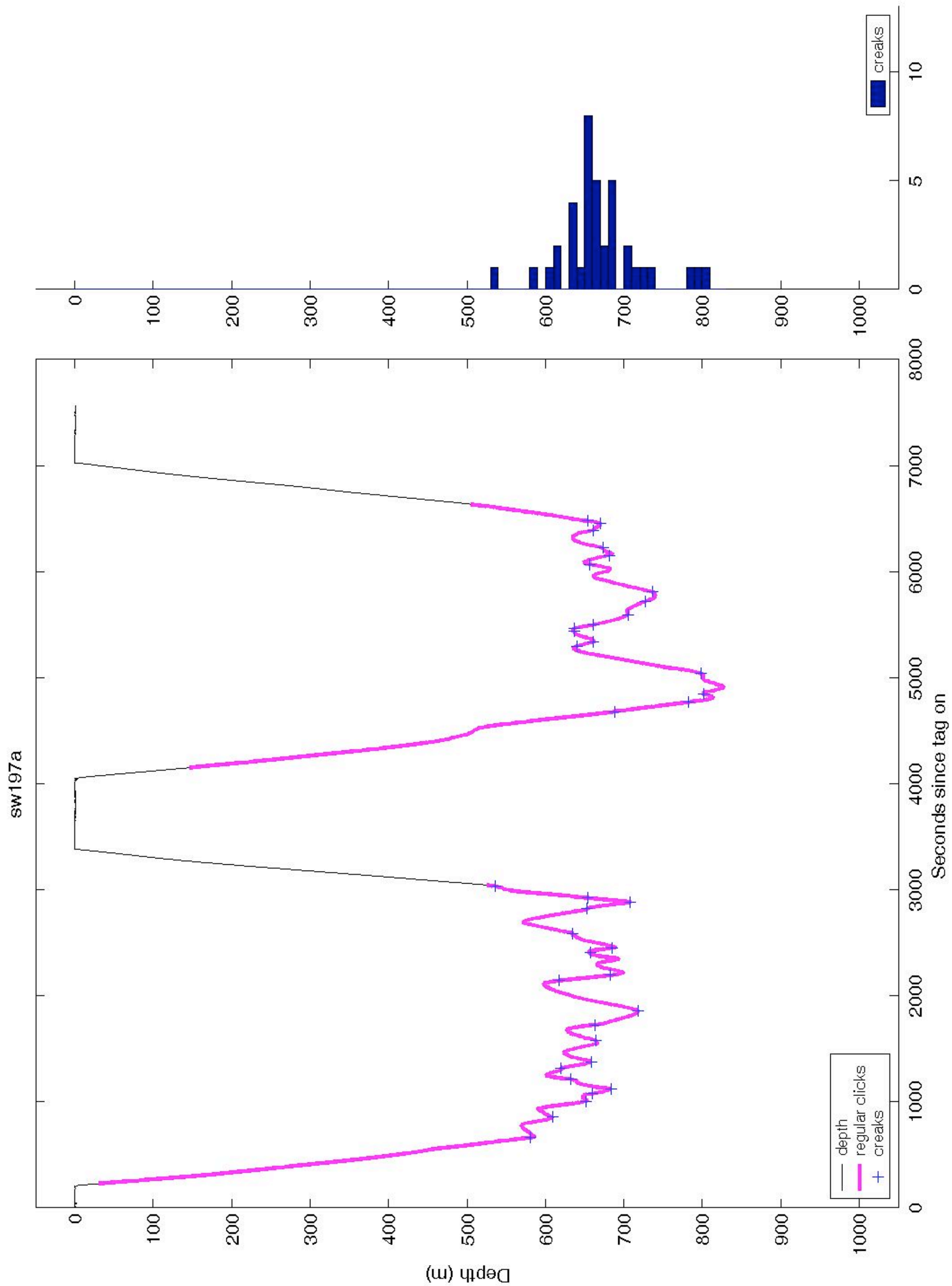

Figure 7. Dive profile indicating sound events for sw03_197a

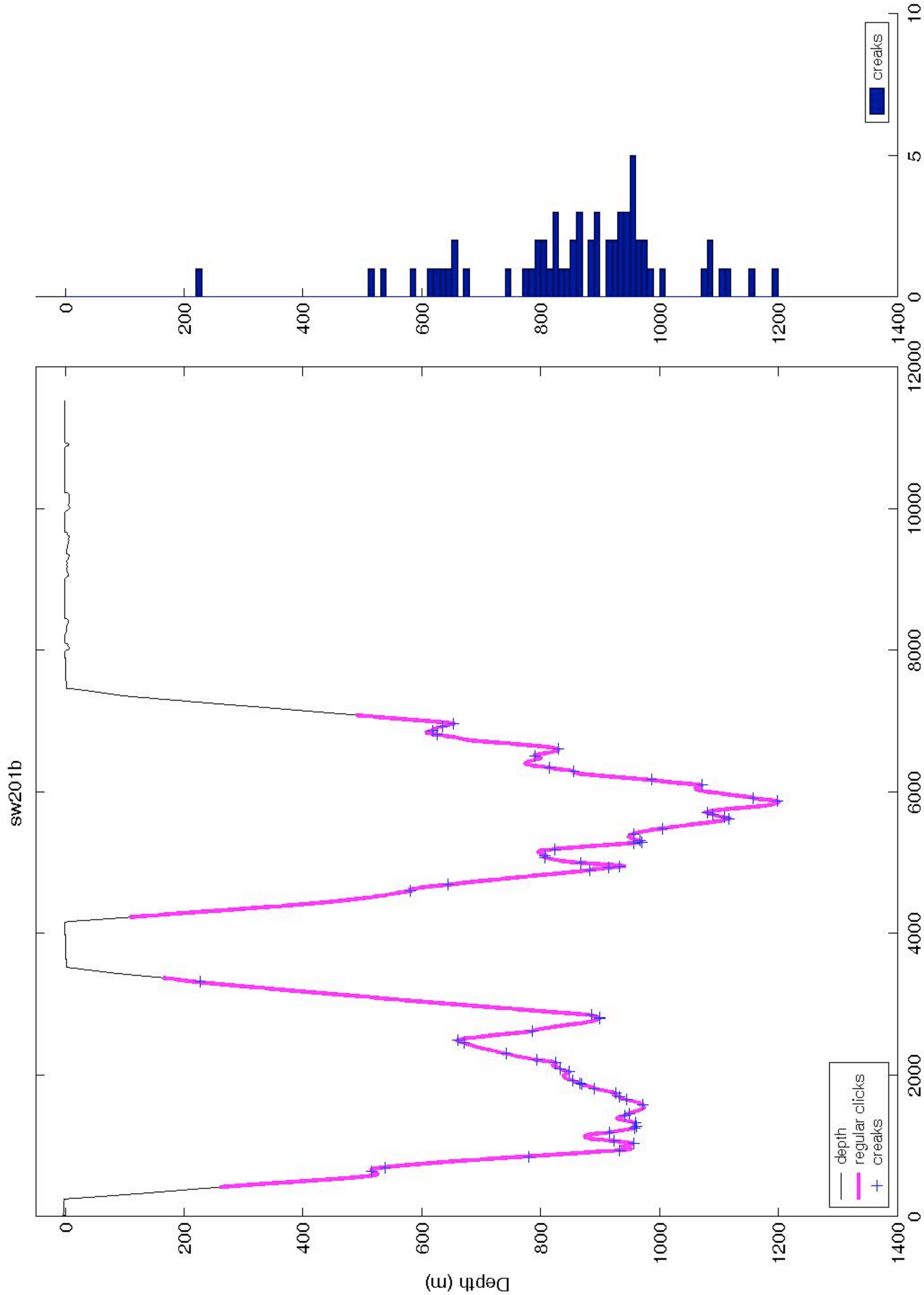

Figure 8. Dive profile indicating sound events for sw03_201b

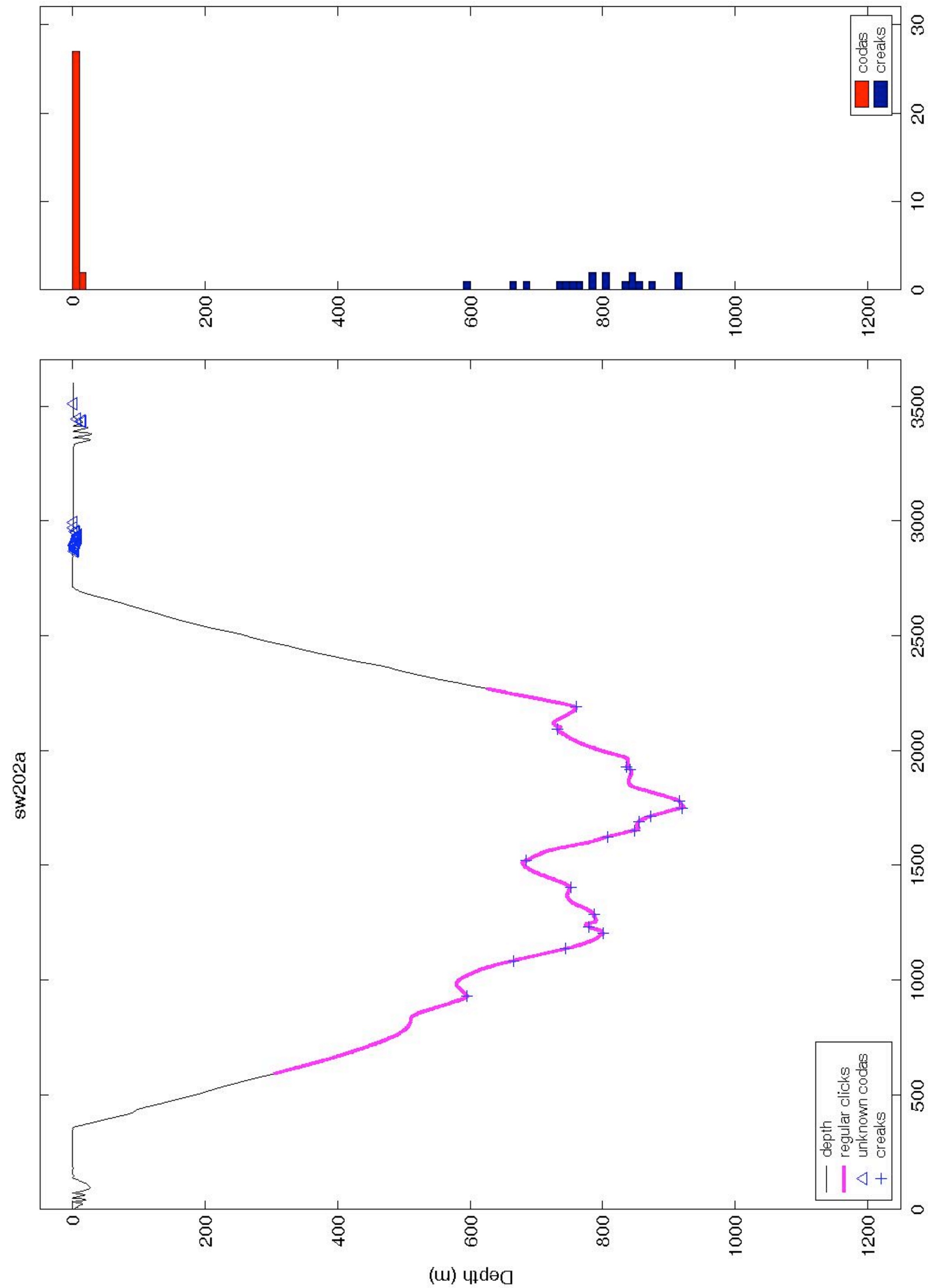

Figure 9. Dive profile indicating sound events for sw03_202a

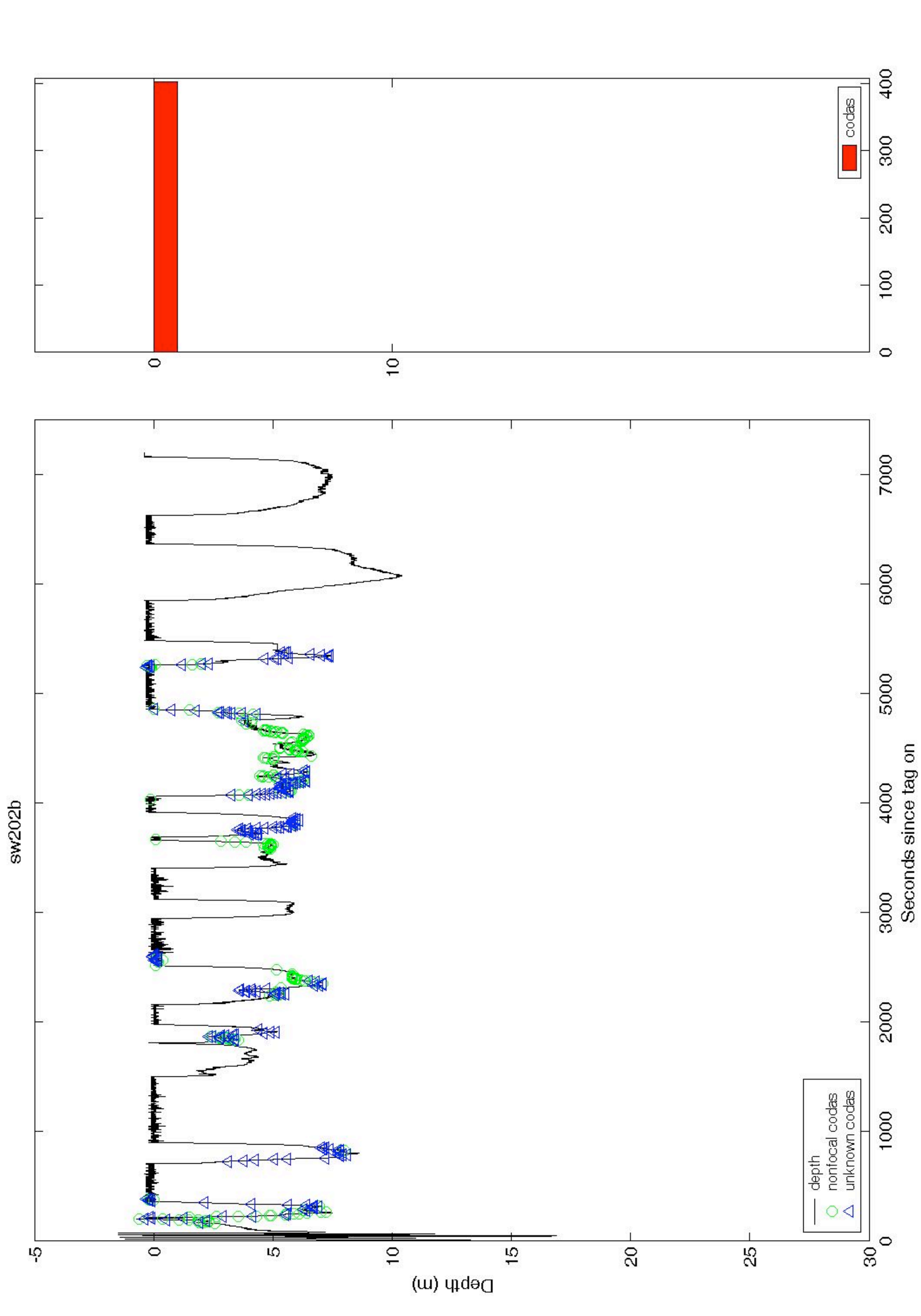

Figure 10. Dive profile indicating sound events for sw03_202b

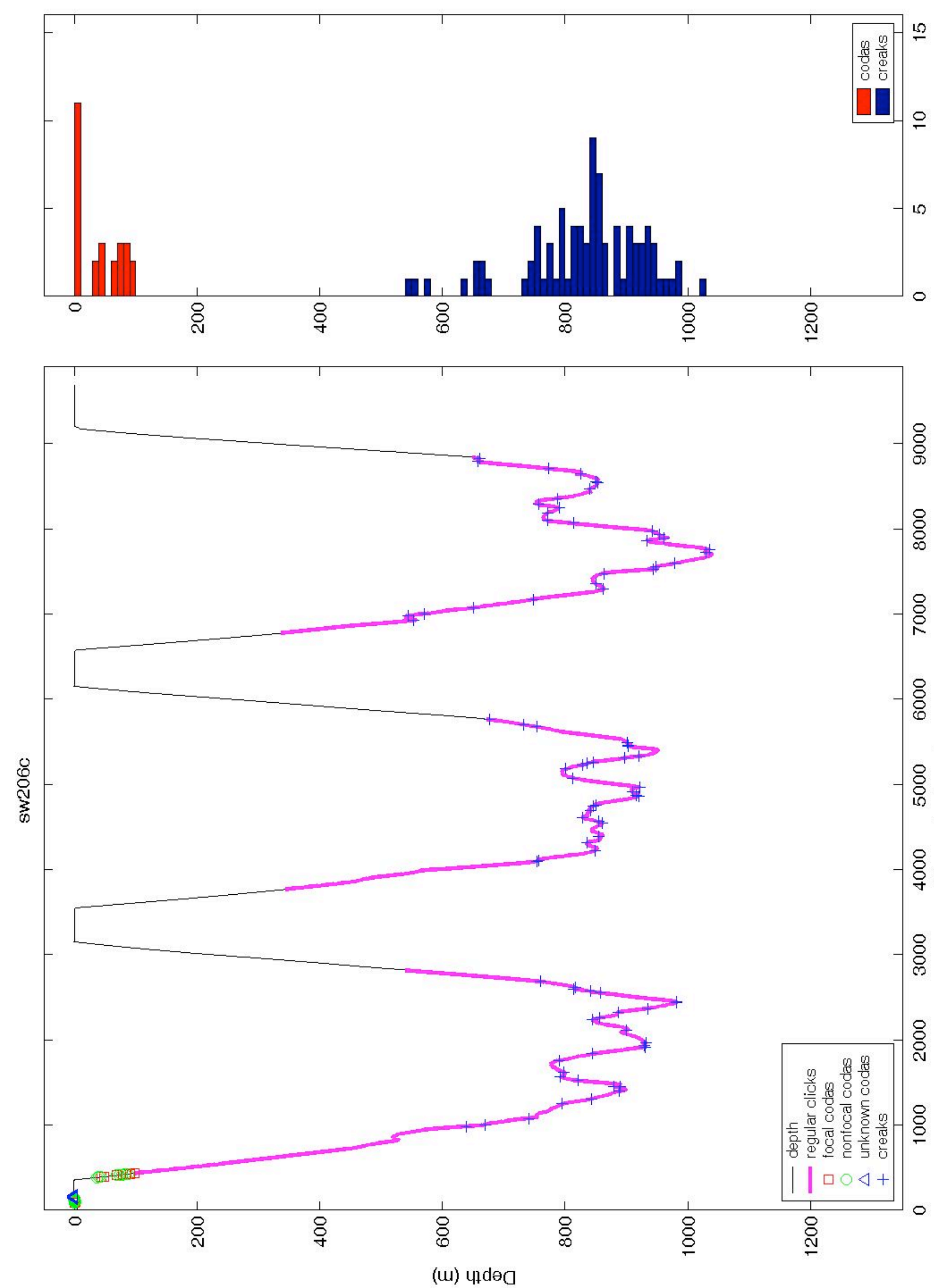

Figure 11. Dive profile indicating sound events for sw03_206c

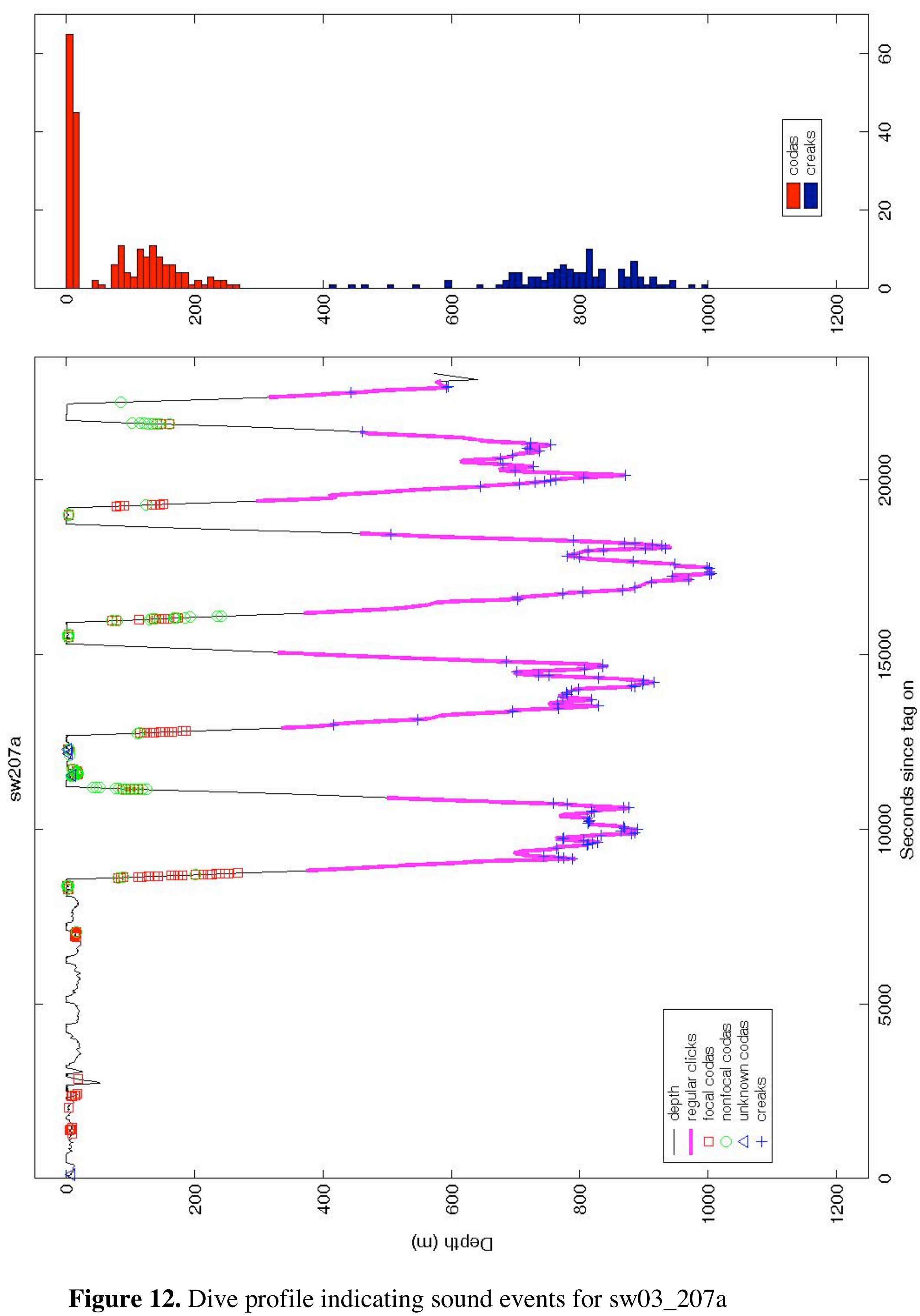

Figure 12. Dive profile indicating sound events for sw03_207a

4.3 Social Behavior

As shown in Figs. 7-12, codas (stereotypical click patterns) were often heard near the surface. Codas were made both by deep-diving whales during the descent and ascent, and by whales performing shallow dives. A number of tag recordings made on the Delaware cruise contained extended periods with shallow (<50m) dives and many codas. Codas are considered strong indicators of social behavior and were frequently accompanied, in the tag recordings, by sounds from other nearby conspecifics (usually also codas) and rubbing sounds from body contact. Out of the nine DTAG recordings, four contained codas (see Table 5). Although it can be difficult to judge if a particular sound was made by the tagged whale or another nearby, codas were identified in two recordings that were unambiguously produced by the tagged whale. On average, there were 121 codas on a given tag, with 45 being assigned to the tagged whale.

Table 5. **Codas recorded on DTAGs during the Delaware cruise**

Data set	Tagged whale	Untagged whale	Unknown
202A	0	0	29
202B	0	201	224
206C	17	20	4
207A	118	85	4

Figs. 13-14 show the depth histogram of coda production in the three study sites divided according to whether the coda was produced by the tagged (focal) whale or the untagged (nonfocal) whale. Whales in the North Atlantic tended to produce most of their codas in the shallowest part of the foraging dive (i.e., at the very beginning and end of the dive). No codas were recorded below 300 m. In the Gulf of Mexico, whales tended to produce codas throughout the upper 50% of their foraging dives. Most codas were produced above 300 m, although two whales produced codas between 300 m and 400 m. Tagged whales in the Mediterranean produced codas at up to 70% of their maximum dive depth, far deeper than in the other two regions. Three Mediterranean whales produced codas between 500 m and 700 m.

Figure 14 shows the depths at which codas from an untagged whale were recorded by the tag. This figure has a similar form to Figure 13, indicating that focal sperm whales tend to produce codas when they hear them from other animals and that other animals respond to codas produced by the focal whale.

Figures 15-18 show the average number of codas produced by tagged and untagged whales during foraging dive descents (Figure 15), ascents (Figure 16), inter-dive intervals (Figure 17), and surface intervals (Figure 18). Although codas were produced and heard during all phases of the dive cycle, by far the most codas were produced during surface intervals. However animals tend to spend less of their day in the surface behavioral mode than in foraging dives, and so the low number of codas produced in each foraging dive still represent a significant portion of the total coda count. Codas were rarely produced during inter-dive intervals, i.e., between foraging dives.

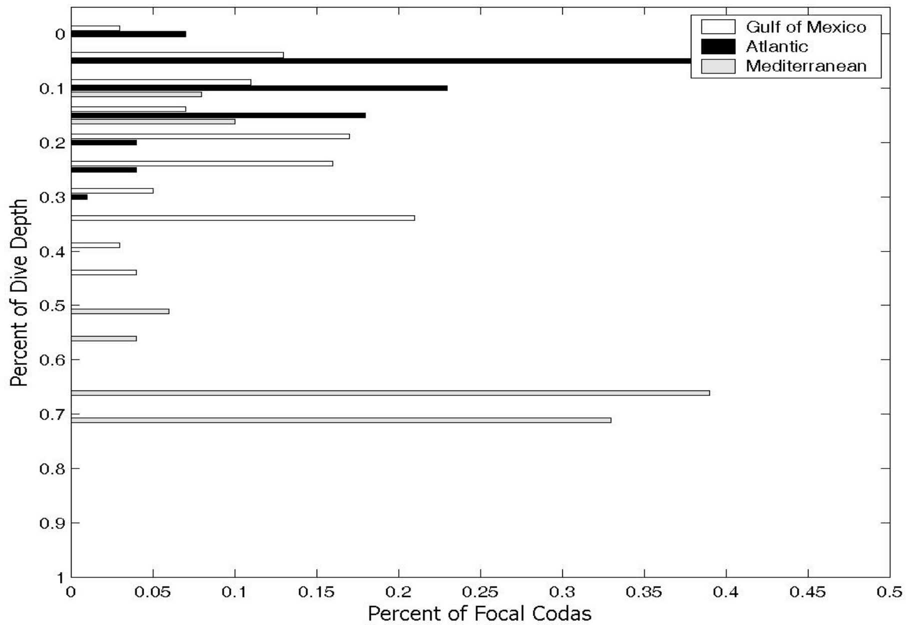

Figure 13. Depth occurrence of codas normalized by dive depth produced by tagged sperm whales in the Gulf of Mexico, the Atlantic, and the Mediterranean.

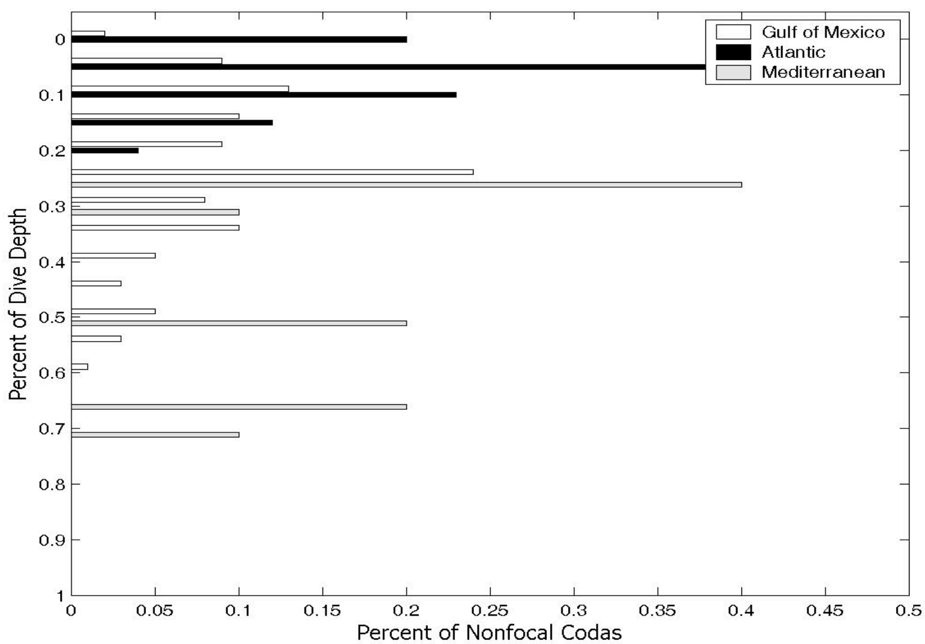

Figure 14. Depth occurrence of codas normalized by dive depth produced by untagged sperm whales in the Gulf of Mexico, the Atlantic, and the Mediterranean.

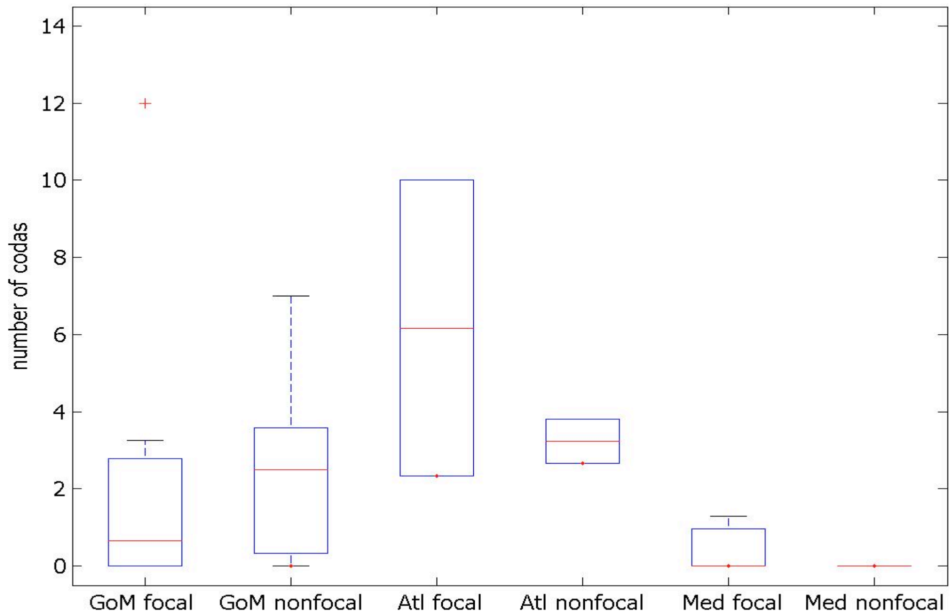

Figure 15. Average number of codas produced and heard per animal per descent in the Gulf of Mexico, Atlantic, and Mediterranean. The box has lines at the lower quartile, median, and upper quartile.

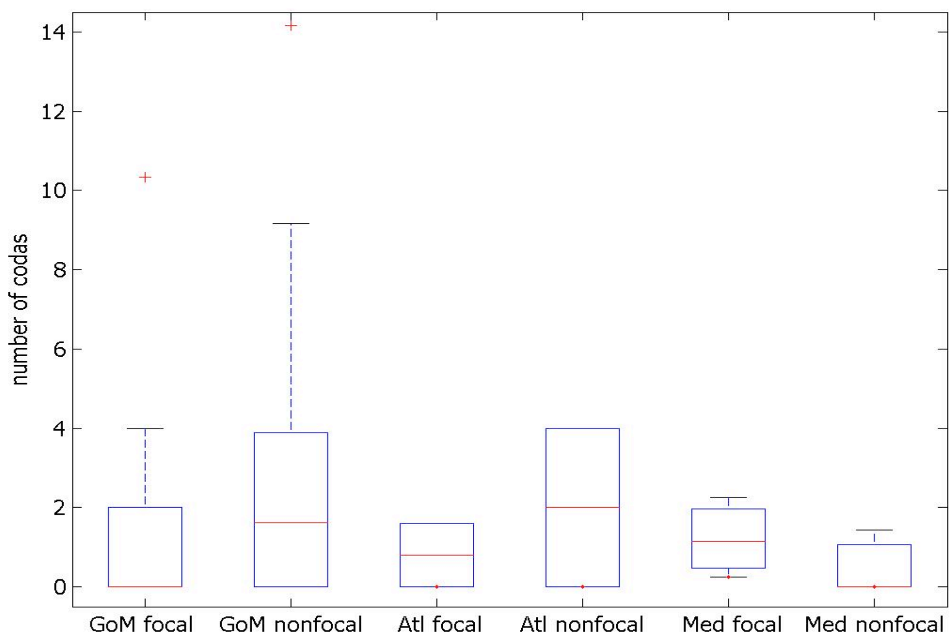

Figure 16. Average number of codas produced and heard per animal per ascent in the Gulf of Mexico, Atlantic, and Mediterranean.

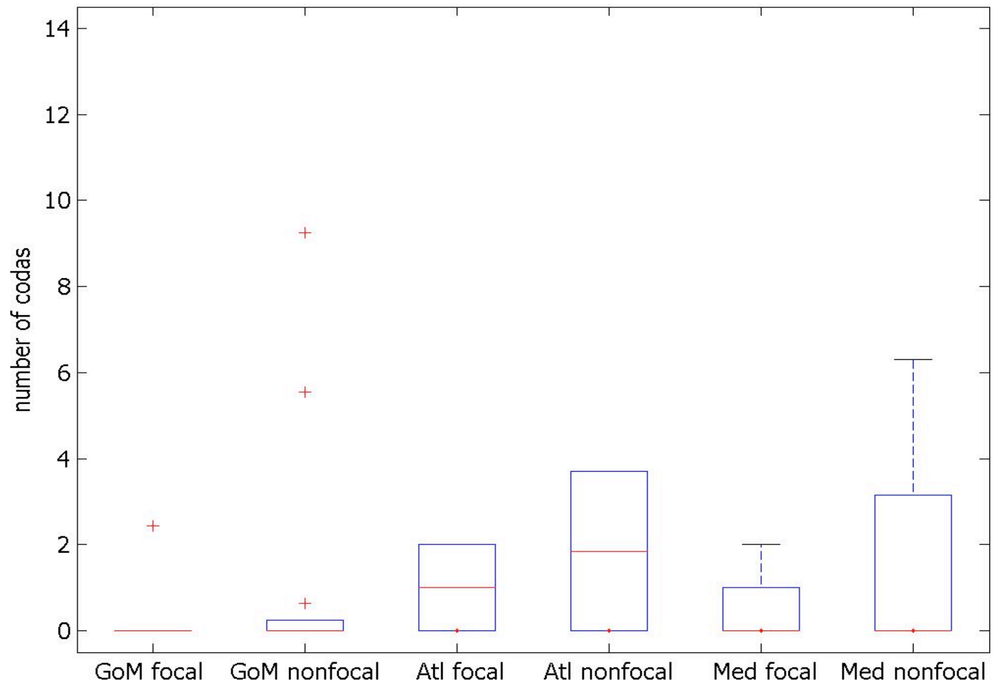

Figure 17. Average number of codas produced and heard per animal per inter-dive interval in the Gulf of Mexico, Atlantic, and Mediterranean.

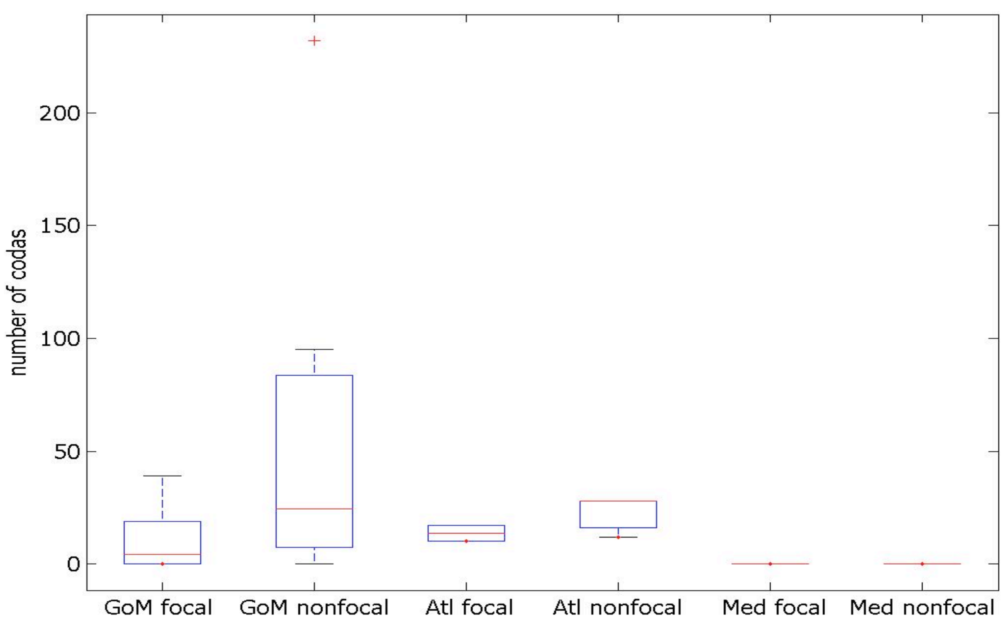

Figure 18. Average number of codas produced and heard per animal per surface interval in the Gulf of Mexico, Atlantic, and Mediterranean.

Codas have previously been described as being produced primarily by animals tightly aggregated at the surface and during surface intervals. The data presented here demonstrate that codas are produced by animals during the descent and ascent portions of foraging dives as well, and are even produced at considerable depth (>500 m in the Mediterranean). This suggests that codas may be used generally by animals to maintain contact at all times, not just when at the surface.

The specific pattern of clicks in a coda has long been thought to indicate group allegiance or correspond to geographic location. Table 6 lists the numbers of distinct coda types recorded by tags in the North Atlantic. Although a wide variety of codas were heard, a majority of codas were of types 1 to 6. Nine, eight, and two click codas were common to two or more of the tag recordings, while all other codas types were only heard on a single tag recording. Tagged and untagged whales on the same tag recording seem to produce similar types of codas but whales tagged on adjacent days in close geographic proximity such as 206c and 207a do not seem to use similar coda types. This may reflect a diverse population in the North Atlantic or broad repertoire of codas. Work is continuing to compare coda usage between the three study sites.

Table 6. Numbers of different types of codas produced by the tagged or focal whale (F) and non-focal whales (NF) in the Atlantic for three of four tags containing codas.

Coda	sw03_206c		sw03_207a		sw03_202b	
Type	F	NF	F	NF	F	NF
1+4+1			52	58		
2			26	21		6
9	2	12	1			16
2+3+1			26			
8	11	3				1
5+1			9	3		
10	1					3
6		2				
1+3+1			1	1		
11		2				
5		1				
2+1						1
7	1					
4+2			1			
1+4				1		
8+1	1					
1+3+2						1
1+4+2			1			
2+4+1			1			
10+1	1					

Acknowledgements

Wayne Hoggard, Walter Zimmer, Debi Palka, Matt Grund, Alex Shorter, Kira Barton, Tom Hurst, Dan Englehaupt, crew and science party of the R/V Delaware.

Publications

A paper describing the coda results is currently in preparation by S. Watwood.

Publications and presentations drawing on this work:

Miller P.J.O., Johnson M., Tyack P.L., "Sperm whale behaviour is consistent with use of rapid echolocation click buzzes “creaks” in prey capture", Proc. Royal Soc, in press.

Tyack P.L., Johnson M., Madsen P.T., "Echolocation in wild toothed whales", 147th meeting Ac. Soc. Am., NY, May, 2004.

Miller P.J.O., Johnson M.P., Tyack P.L., Terray E.A., "Swimming gaits, passive drag, and buoyancy of diving sperm whales (*Physeter macrocephalus*)", J Exp Biol., 207(Pt 11):1953-1967. May, 2004.

Miller, P.J.O., Johnson, M., Tyack, P.L., Terray E.A., "Swimming gaits, passive drag, and buoyancy of diving sperm whales (Physeter Macrocephalus)", European Research on Cetaceans 18th, Sweden, 2004.
Madsen, P.T., Johnson, M., Tyack, P., "Biomechanics and dynamics of the sperm whale sound generator with implications for foraging", European Research on Cetaceans 18th, Sweden, 2004.

2004 NOAA Progress Report

Processing and Visualization of Multi-beam Sonar Data

NOAA Grant: NA17RJ1223
July 1, 2003 to June 30, 2004

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Related NOAA Strategic Plan Goal: Goal 1 - Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management

Summary

Precise, accurate, and efficient estimates of the abundance/biomass of standing fish stocks will provide valuable information for better understanding the marine ecosystem processes.

Split-beam echo sounders have been used routinely as primary acoustic survey systems and have provided quantitative information on the abundance and biomass of fish stocks. Multi-beam sonar systems have been used primarily in seafloor bathymetry surveys and not until recently are used in fisheries acoustic surveys. Although the multi-beam sonar systems have a great potential to provide quantitative 3-D images of fish schools and a much more efficient way to estimate the abundance of the fish stocks accurately, there are no standardized quantitative data processing and visualization techniques available. The primary objectives of the proposed work are to streamline the procedures of quantitative multi-beam sonar data processing techniques and to develop a suite of GUI-based software for data processing and visualization.

Due to the unexpected delays of actual funding availability (about three months) and the availability of the multibeam sonar system (SM2000/ 90 kHz) provided by the Northwest Fisheries Science Center (NOAA) for sonar calibration experiment, I have only finished about 65-70% of the proposed research work and expect to finish the project completely early next year.

Accomplishments:

The proposed research consists of three major components: (1) multibeam sonar system calibration experiment; (2) development of the theory and techniques for quantitative multibeam sonar data processing; and (3) development of a GUI-base Matlab software package for implementing the quantitative multibeam sonar data processing. During the past year, several components of the project have been accomplished:
1. *Multibeam sonar calibration experiment* (100% accomplished):

From March 5 to March 29, 2004, the experiment was conducted in the sea-well on Iselin Dock at the Woods Hole Oceanographic Institution (WHOI) using the facilities developed under the other projects (NSF OCE-0002664 and NOAA NA97OG0241). The sonar system was SM2000/90 kHz provided by the Northwest Fisheries Science Center, NOAA (Fig. 1). The sonar calibration data include:
(a,) 2-D farfield (23 m) and near field (12 m) directivity measurements;
(b.) Time-Varied-Gain (TVG) measurement from 0-50 dB;
(c,) Pulse duration influence on quantitative measurements such as on target strength (TS) measurement;
(d.) Transmit power setting on quantitative measurements;
(e.) Stability and variability measurement.

Figure 1. Calibration facilities on Iselin Dock, WHOI (a) and the multibeam sonar head (b).

2. *Theory and techniques to quantify the acoustic sonar data* (90 % accomplished):

To quantitatively estimate biomass and/or abundance of the marine animals such as fish school from the raw multibeam sonar data, several necessary aspects need to be addressed. These include:
(a.) Development of formulae to determine the conversion factor from the raw acoustic data to target strength, taking into account TVG, transmit power, and pulse duration settings;
(b.) Development of formulae to determine the 3-dB beam width (θ_{bw}) for each of the 128 beam, spanning from –45 deg to 45 deg (Fig. 2), which will be used for determining the equivalent beam angle ψ or its logarithmic equivalence $\Psi = 10\log_{10}\psi$, a crucial parameter in quantitative biomass or abundance estimates.
(c.) Processing raw sonar calibration data to obtain 2-D sonar directivity pattern (Fig. 3).

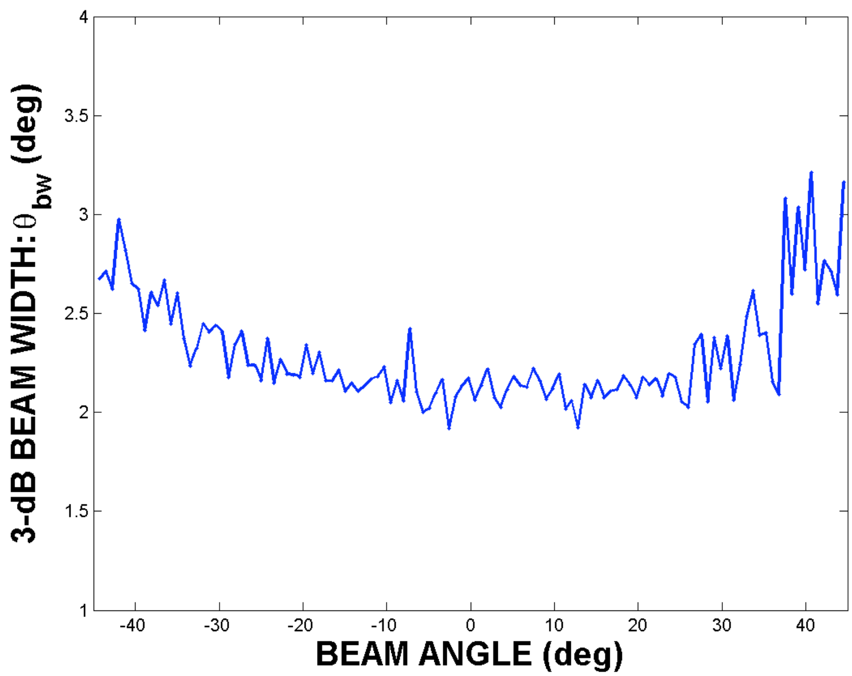

Figure 2. Equivalent beam angles of the SM2000/90 kHz numtibeam sonar.

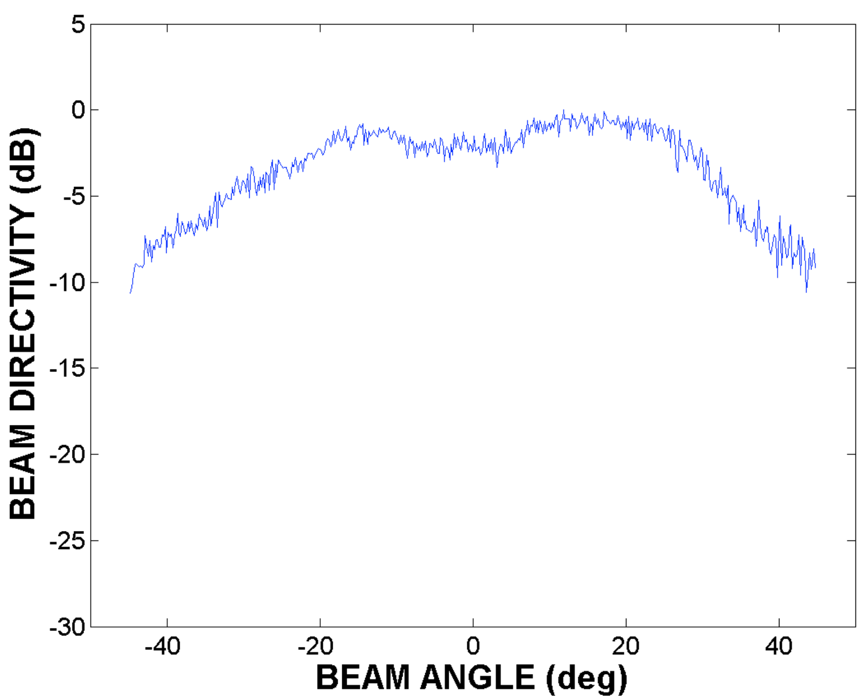

Figure 3. Beam directivity pattern of the SM2000/90 kHz sonar in the equatorial plane.

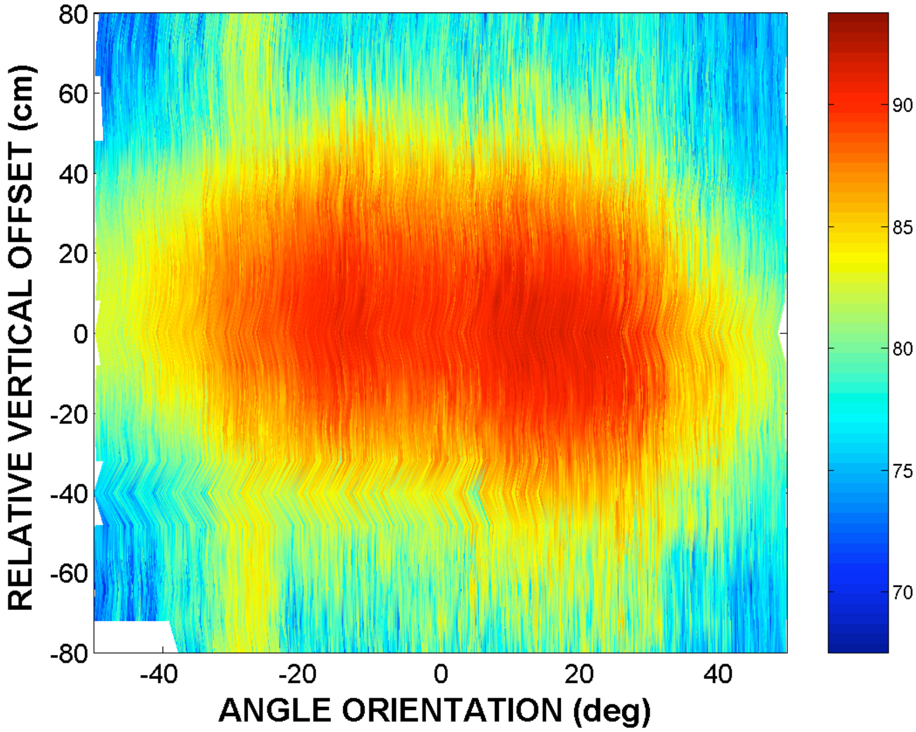

Figure 4. 2-D directivity pattern of SM2000/90 kHz multibeam sonar, measured at 23 m range.

3. *GraphicUserInterface(GUI) based Matlab software* (60 % accomplished):
The software has been developed specifically for Kongsberg Simrad SM2000 multibeam sonar system and can be easily extended to other multibeam sonar systems such as Reson Seabat 8000 series. The software has a Graphic User Interface (GUI) with multi-layer menu-driven operation options (Fig. 5). The major features of the software include:
(a.) User defined sonar system configuration with options of default sonar configurations of commonly used SM2000 systems;
(b.) Capability of processing raw and beamformed data;
(c.)Bottom detection algorithm;
(d.)Target tracking capability;
(e.)Flexible visualization options;

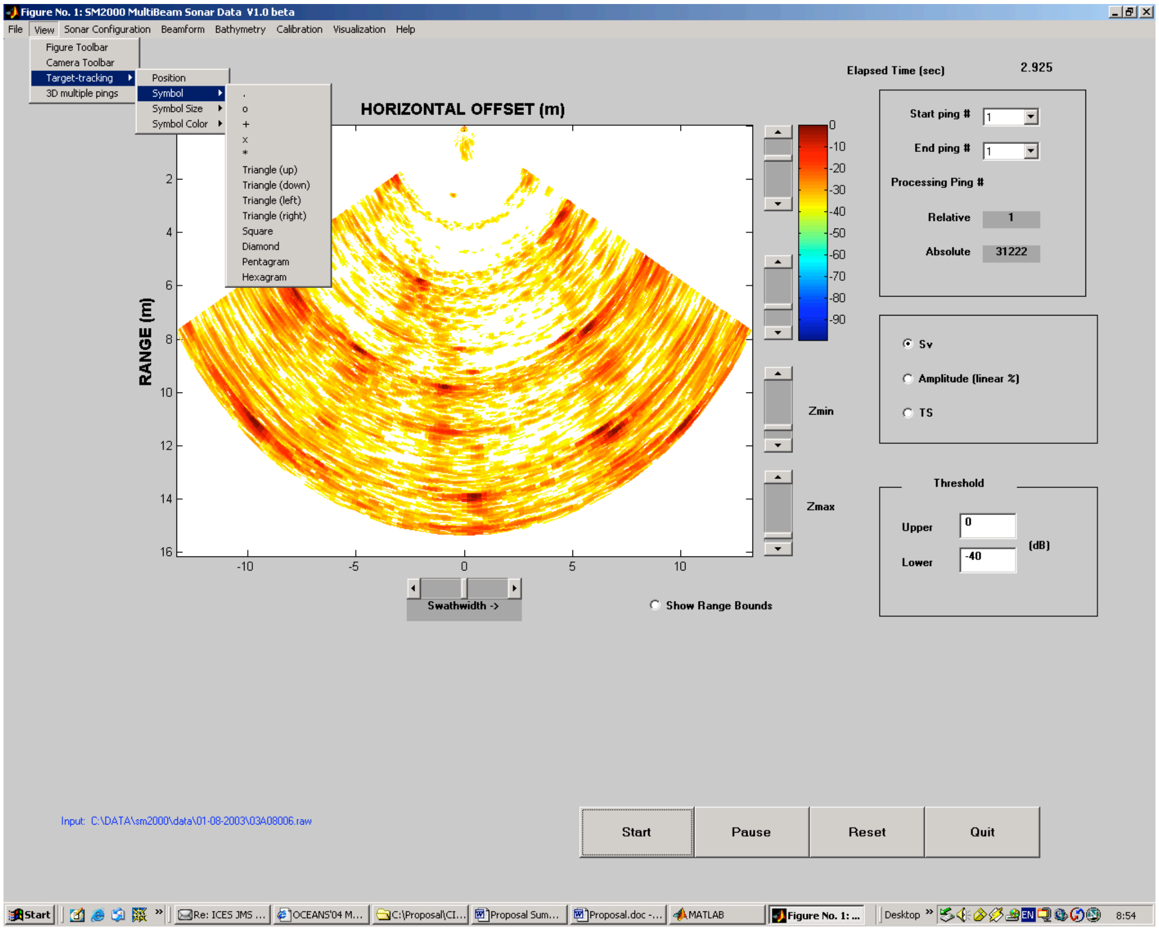

Figure 5. Graphic User Interface (GUI) of the Quantitative Multi-Beam Sonar Processing (QMBSP) software.

<u>Tasks to be completed:</u>

As described previously, due to the unexpected delays of actual funding availability and the sonar calibration experiment, I have only finished about 70% of the proposed research work and expect to finish the project completely early next year. The tasks that have not been completed but will be completed include:

1. Development of the theory and technique of computing the echo integration by taking into account the angular dependence of the targets;

2. Completion of sonar calibration data processing (influence of TVG, transmit power, etc.);

3. Enhancement and Refinement of the GUI based Matlab software, enabling more features including: (a) 3-D visualization ability, (b) More options

4. Final project report and paper writing. The papers will be submitted to scientific journals.

Publications Resulting From the Proposed Research:

Hufnagle, L.C. Jr., D. Chu, K.G. Foote, T.R. Hammar, J. M. Jech. Calibrating a 90-kHz multibeam sonar: illustrating protocols. Submitted to the OCEANS'04 MTS/IEEE/-TECHNO-OCEAN'04, Kobe, Japan.

Jech, J. M. , K.G. Foote, D. Chu, and L.C. Hufnagle, Jr. Comparing two 38-kHz scientific echo sounders. To be submitted to ICES Journal of Marine Science.

2004 NOAA Progress Report

An Analysis of the Relationship between Fish Harvesting and Processing Sectors

NOAA Grant: NA17RJ1223
July 1, 2003 to June 30, 2004

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Related NOAA Strategic Plan Goal: Goal 1 - Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management.

Project Summary:

This is a collaborative research between the WHOI Marine Policy Center and the NMFS Northeast Fisheries Science Center. The study is related to the CICOR theme area Coastal Ocean and Near-Shore Processes (CICOR Task II). We understand that research in this theme area is extremely broad, including issues related to fisheries management. In this project, we examine the effects of changing marine resource conditions on the coastal economy.

The commercial fisheries of the Gulf of Maine and Georges Bank are among the most important in the Nation. New Bedford, Portland, Point Judith, and Gloucester rank among the top-grossing fishing ports in the United States, and more than $692 million worth of fresh and partially processed fish was landed in New England in 2002. However, commercial landings of finfish and shellfish in New England have declined over the last fifty years from over one billion pounds in 1950 to 575 million pounds in 2002. Commercial landings of the traditional mainstay species of Atlantic cod, haddock, and yellowtail flounder have declined much more substantially as these stocks have been overfished for much of the time.

The fish-harvesting sector is linked tightly to an intricate network of onshore wholesaling, processing, and retail trade businesses. Together, the commercial fish harvesting and processing sectors in New England employ more than 16,000 people, and the annual total output value from these sectors exceeds $1.5 billion. An economic input-output analysis indicates that every $1 million increase in the sales of fish harvests leads to $1.4 million in economic impacts capturing direct, indirect and induced effects in economic sectors that both supply the fishing industry and purchase its products.

An analysis of all of the potential economic gains that could result from rebuilt fish stocks is critical. Clearly, the revenue from commercial fishing could be much higher if all of the groundfish resources were rebuilt. The economic gains might not be limited to only the harvesting sector. For example, the downstream processing sector might also grow as a consequence of rebuilt groundfish stocks. To date, however, the relationship between the harvesting and processing sectors has not been examined through a carefully designed empirical analysis.

The objective of this study was to develop a characterization of the relationship between fish harvesting and processing in New England. The characterization should enable improved assessment of the economic growth in the processing sector due to rebuilding of groundfish stocks. The hypothesis that economic output from the New England processing sector is not related to changes in the supply of fish from local harvests is the focus of the study. If this hypothesis is rejected, then the economic ramifications of low resource levels may have been and continue to be deeper and more widespread than is currently appreciated. Further, the relationship between the output from the fish processing sector and fish imports is examined.

The study results suggest that output from the fish processing sector is jointly determined by local fish landings and fish imports. The level of imports is an important factor in the management of fish processors. Local landings were found to *Granger-cause* processing in several cases, implying that past resource conditions indeed affected present processing output. In contrast, no significant causality was found between processing and landings. Given the low abundance stock condition during the study period, one would not expect processing to drive harvest.

A unidirectional causality was also found from processing to imports: processors import more fish when local landings decline. All identified *Granger causalities* in the study existed only at aggregate (all species) level, suggesting that the cause and effect relationship is weak at the individual species level. This is due to inter-species substitution as well as substitution among different raw fish suppliers (*e.g.*, local landings versus imports).

The study findings indicate that firms in the fish processing sector optimize their business operations over multiple species and multiple supply sources. Although an increase in local fish landings generally leads to an expanded seafood processing sector, the interaction may be complex, due to various substitution effects. A clearer understanding of these substitution effects will improve assessment of the economic gains accruing from rebuilding fisheries in New England.

Paper Resulted from This Research:

Jin, D., P. Hoagland and E. Thunberg. 2004. An analysis of the relationship between fish harvesting and processing sectors in New England. *Marine Resource Economics*, Submitted.

References from CICOR Annual Summary Reports

	JI Lead Author			NOAA Lead Author		
	FY01	FY02	FY03	FY01	FY02	FY03
Peer-reviewed	26	40	37	0	0	0
Non peer-reviewed	0	23	15	0	0	0