CICOR

# Cooperative Institute for Climate and Ocean Research

of the Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

# Annual Progress Report

## July 1, 2006 - June 30, 2007

Dr. Robert A. Weller, Director

submitted to
National Oceanic and Atmostpheric Administration
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Please direct comments or request for copies to: cicor@whoi.edu

Robert A. Weller, Director, CICOR
Patricia White, CICOR Administrator

**On the cover:** Summer Student Fellow Amy Kidd and CICOR Postdoctoral Scholar Jeremiah Hackett examine a test tube containing genetic material for studies of toxic algae during the summer of 2006. Researchers at the Institution are working to unravel the very genes that make some algae toxic, while also teasing out why different species and sub-species bloom under different conditions. (Photo by Tom Kleindinst, WHOI)

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# Executive Summary

## CICOR
Cooperative Institute for Climate and Ocean Research
Annual Report 2006-07

**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.

Education and Outreach activities are key priorities for CICOR. This year CICOR has continued its support of graduate students postdoctoral scholars, Summer Student Fellows as well as its participation in a local science fair. It also continues its sponsorship of a multi-media Harmful Algal Bloom exhibit in the WHOI Exhibit Center, which along with the Information Center hosts over 30,000 visitors per year.

NOAA's Teacher At Sea program has continued to be an important component of CICOR outreach. Again this year a CICOR research cruise hosted a teacher. Brett Hoyt, a teacher from Billings Montana was on board NOAA Ship RONALD H. BROWN in the Fall of '06, while scientists conducted atmospheric research on the stratus cloud deck. They traveled from Miami, through the Panama Canal, and all the way to Chile.

CICOR continues to stimulate interaction with the external and international 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. For example, CICOR hosted a visit from Steve Ruberg, Group Leader for the Marine Instrumentation Lab at NOAA's Great Lakes Environmental Laboratory (GLERL) who discussed Real-Time Coastal Observatories Networking (ReCON) and the use of Microsensors and Off-Shore Ethernet Networking at two informal meetings on Thursday, May 31, 2007. CICOR also continues its contributions the OceanSITES Data and Steering Committees by maintaining its website and distributing the brochure which was produced in early 2006. CICOR also participated along with other CIs in the first CI Fair held at NOAA in February '07.

From an administrative perspective CICOR has had an unusual year. It was anticipated that CICOR would be re-competing its cooperative agreement in the summer of 2007, however, rather than a competition NOAA decided to offer a one-year extension until June 2009. The terms of the extension are currently under review with WHOI administration. Despite the delay with CICOR planning, the year was exciting in terms of NOAA/WHOI activity. Anticipation for the re-competition lead to a comprehensive assessment of WHOI scientists' ideas, which are likely to be of interest to NOAA. Also worth noting is the significant role WHOI scientists are playing in NOAA IOOS activity. Two related proposals that came through the CICOR office promise to develop cutting edge technology and practices for observatories for ecosystems and fisheries management as well as for data quality assurance and quality control.

## CICOR ANNUAL RESEARCH HIGHLIGHTS

- U.S. National Office for Marine Biotoxins and Harmful Algal Blooms - at the Woods Hole Oceanographic Institution directed by Don Anderson continues to play a critical role of communication and management both within the HAB community as well as for the general public. The Offices site remains one of the most often visited sites at the Institution. In cooperation with CSCOR, the National Office administers the Rapid Response Program for HAB events. This year it worked with NOAA Program Managers to distribute funding for the HAB events including this year's *Heterosigma* event in Washington State.

- Sandra Castro and William Emery's work has resulted in the submission of paper to Journal of Geophysical Research describing the results obtained in years 1-3 of their research on Multi-Sensor Improved SST (MISST) for GODAE. We just completed a round of revisions and have submitted the revised manuscript. The last two years of this project are devoted to understanding and characterizing uncertainty estimates in the presence of diurnal warming (DW). Diurnal warming of the ocean surface layer at low wind speeds and sufficient insolation can lead to significant and highly variable differences between the skin and subsurface temperatures. These differences represent a source of uncertainty in estimates of the subsurface temperature. This stage of the work explores whether improved accuracy can by achieved through retrieval of the skin temperature and explicit consideration of diurnal warming effects.

- Maureen Conte's research is progressing towards producing the first, direct quasi-hemisphere scale data on spatial and temporal variations in terrestrial photosynthetic discrimination of $CO_2$. The data will be used in conjunction with air mass trajectory analyses to improve current estimates of the magnitude and geographical pattern of carbon sinks. Results will additionally provide information on nonvolatile organic aerosols and spatial and temporal variability associated with changing air transport and temporal trends, and thus complement other atmospheric studies of long-range transport of continental emissions and their impact on regional atmospheric chemistry. These products are directly relevant to the NOAA CGCP goal of improving our ability to observe and understand changes in the global environment and the GCC focus on carbon fluxes.

- Cabell Davis and Qiao Hu had three major achievements this year in their work on developing an automated image analysis and pattern recognition system to automatically process digital images collected by SeaBed AUV and electronic observer monitoring system. They collected videos from electronic observer monitoring system, configured the Matlab interface to read video files, and developed a fish detection algorithm on the video files and tested the algorithm on one of the video files.

- Cabell Davis and Robert Beardsley completed a full 5-year run for the NPZD-FVCOM coupled model and can generate the seasonal evolution of 3D patterns in nutrients and phytoplankton that are consistent with the field data for th e U.S. GLOBEC NWA Georges Bank program. They used this model to conduct the first high-resolution N-budget for Georges Bank water column including scenarios of low-nutrient LSW intrusions (Ji et al., in press).

- Janet Fredericks is helping to bring to new levels the work of the QARTOD group dedicated to continuing multi-agency effort formed to address the quality assurance and quality control issues of the Integrated Ocean Observing System (IOOS) community. QARTOD IV was held at the Woods Hole Oceanographic Institution, June 2006. Related materials, including the QARTOD IV final report, are posted on the QARTOD website: http://qartod.org. Fredericks along with QARTOD colleagues have been granted an IOOS award to begin in early 2008 which will bring this important aspect of observatory science critical attention.

- Di Jin's analysis for NMFS on regulations in the NE Searfood Industry demonstrates the importance of taking a broader view of adjustment processes in fishing and fishing related industries rather than focusing solely, as is often the case, on changes in a single state or a single fishery. The general finding that fishing related marine sectors have largely stabilized in the Northeast region as a whole, but that some centers of marine activity are declining while others are being created is consistent with long term trends in landings of seafood products.

- Breck Owens' group pushed forward the development of the ARGO float technology and constructed and deployed ARGO floats in collaboration with partners at SIO, the University of Washington, and AOML. Over the past 12 months they have manufactured and deployed a total of 137 floats, primarily in the Atlantic Ocean.

The group has now developed a SOLO float that uses the Iridium Short Burst Data communications system. A second-generation version was first deployed in October 2006.

- Alison Macdonald and colleagues have developed an inverse box model of the Atlantic Ocean that is clarifying how carbon is taken in, stored, and transported by the Atlantic Ocean. During the past year significant progress has been made toward accumulating sufficient new data to make a post-TTO evaluation of the North Atlantic bomb $^{14}C$ inventory. In addition to those data which were included in GLODAP v.1.1, we have new results from two NOAA cruises (OACES93 on the A16N line and OACES98 on the A05/AR01 line) as well as German data from the A1 sections.
- Bob Pickart's research on the RUSALCA Herald Canyon project indicated that overall, relatively little mixing occurred over this large distance, indicating that the evolution of the dense water within Herald Canyon sets, to first order, the properties of the water that eventually ventilates the upper halocline. This demonstrates the importance of canyon dynamics in influencing both the water mass product, and where the water ultimately ends up in the Arctic basin.

- Hanu Sing's conference on Autonomous Underwater Vehicles (AUVs) facilitated a dialog between Autonomous Underwater Vehicle (AUV) developers, engineers and science users in June 2006. (AUVs) have, in the past decade, reached a high level of maturity in their application to marine geological, biological, chemical, and physical oceanographic problems. However, the broad scientific community had not been exposed to an up-to-date review of the relative merits of using different kinds of AUVs for different applications. The conference covered a range of subjects in order to best plan and propose a wide range of field research employing AUV technology, - not least in support of forthcoming Ocean Observatories Initiative (OOI) activities.

- James O'Brien, Shawn Smith and Mark Bourassa have continued development of the Shipboard Automated Meteorological and Oceanographic System (SAMOS) initiative which has resulted in an additional 10 vessels reporting for the period covered by this report. The SAMOS data quality evaluation system is now operational for both preliminary and research SAMOS data products. Many upgrades have been made to both our public access web site and our internal data base tools. Throughout the year, DAC personnel have been actively promoting the SAMOS Initiative through meetings and working groups

- Dennis McGuillicuddy led the second in a series Skill Assessment workshops for regional testbed projects entitled: Coupled Biological/Physical Models in the Coastal Ocean: Skill Assessment and Planning for Regional Testbed Projects. The workshop was held at the Friday Center in Chapel Hill NC, March 6-8, 2007.

- The NOAA-NSF funded multi-investigator US GLOBEC Georges Bank Broad-scale group led by Peter Wiebe completed preparation of the special Deep-Sea Research-II volume entitled "Deep-Sea Research II: Dynamics of Plankton and Larval Fish Populations on Georges Bank, the North Atlantic U.S. GLOBEC Study Site." this year with guest editing by Peter Wiebe, Bob Beardsley, David Mountain, and Greg Lough. The manuscripts have been submitted for publication and the volume should appear at the end of 2006. Of the seventeen manuscripts, four represent contributions from the broad-scale group.

- Tim Stanton's work for the NMFS addressed the limitations of traditional high frequency acoustic systems by using a novel broadband acoustic system spanning most of the frequency range, 1-100 kHz. The lower portion of this frequency range fills in the crucial "gap" missed by high frequency systems so that the difference in scattering characteristics between fish with swimbladders, fish without swimbladders, and large zooplankton can be determined unambiguously.

- Lisan Yu's production for the Atlantic Ocean of a new, improved air-sea flux product with daily and 1°x1° resolution, verified against high quality mooring and ship data. A series of the analysis study has been conducted to utilize the newly developed flux dataset to investigate climate variations of global heat flux fields, their relation to SST, and their implications for regional and global climate change. As a result, six papers have been submitted/accepted/published in peer-review journals during FY2006.

- Dave Hosom and Robert Weller's collection of high quality surface meterological data along long, cross-basin ship tracks using VOS. This data with its high spatial resolution together with the high time resolution Ocean Reference

Station data provides the means to investigate spatial as well as temporal variability, to quantify errors and biases in space as well as time, and to support the data assimilative synthesis of improved global flux fields by Lisan Yu.

- Robert Weller and Al Plueddemann's maintenance of the unique, high quality Ocean Reference Station time series surface moorings off northern Chile (20°S, 85°W), in the North Atlantic tradewinds (15°N, 51°W) and north of Hawaii continues as does their collaboration with modeling centers and other investigators in the use of this high quality, independent data to illuminate biases and other errors in climatologies, model-based fields, and in remotely-sensed products. The stratus project has been successful in elucidating the physical processes that maintain the observed cool surface waters of the Peru-Chile stratus region. Colbo and Weller (2007a) synthesized the mooring data with historical hydrographic and satellite data to show that the upper ocean heat and salt budgets had a large component that was contributed by the divergence of the "eddy" flux. This large transport of cool, fresh water from the coastal upwelling region to the deep ocean through the eddy field has not been noted before. It also helps explain the deficiencies observed in many global models of the region, which are not eddy resolving, and hence cannot adequately capture this important oceanic transport. Two significant accomplishments this year include the addition of real-time telemetry to the NTAS buoy and a strong the strong partnership with NDBC on the NTAS cruise.

- The U.S. GLOBEC synthesis project was a collaborative integrative effort that involved scientists from academic institutions and the NOAA/NEFSC working together in the analysis, synthesis, and publication of data collected during the U.S. GLOBEC Northwest Atlantic Georges Bank field years (1994-1999). It has been a very productive and successful partnership. The U.S. GLOBEC data and information web site (See http://globec.whoi.edu/) provides open access to the data collected by all of the U.S. GLOBEC modules and information about the Georges Bank program. It is frequently accessed not only by scientists, but also by educators, students, and managers. Two scientific investigator workshops to update program PIs on ongoing research were held for GLOBEC Phase IVb scientists were held this year.

- Tom Farrar's analyses of air-sea interaction and upper ocean variability at two sites spanning the eastern tropical Pacific cold tongue during the 1997-1998 ENSO event have uncovered compelling evidence of the link between the intraseasonal SSH and SST fluctuations there. Tom Farrar completed his Ph.D. thesis during the past year under Weller's supervision and manuscripts are being prepared for publication.

# CICOR – Administrative Overview

**(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).

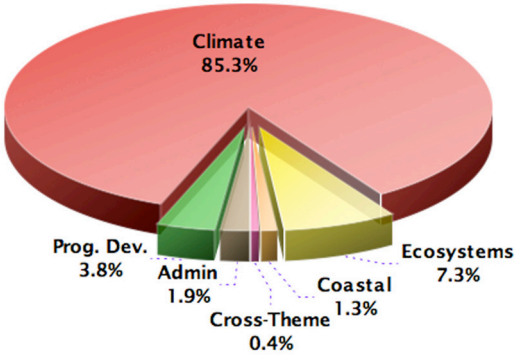
CICOR's primary mission is to facilitate and build interaction between NOAA and academia through sponsored research organized around three broad themes. CICOR's closest NOAA Research Laboratory is the Northeast Fisheries Science Center (NEFSC) of the National Marine Fisheries Service (NMFS), which is located near WHOI in Woods Hole, Massachusetts. Historically, the Great Lakes Environmental Research Laboratory (GLERL) was CICOR's formal partner within the NOAA OAR structure, but several years ago the cooperative institute has been partnered directly with the Climate Program Office within OAR. CICOR investigators also have research partnerships with other NOAA laboratories, including AOML (Atlantic Oceanographic and Meteorological Laboratory) in Miami, PMEL (Pacific Marine Environmental Laboratory) in Seattle, and the Environmental Technology Laboratory (ETL) in Boulder.

CICOR completed its first cooperative agreement with NOAA OAR, which lasted 3 years, in the summer of 2001. A new 5-year cooperative agreement was signed July 2001. In 2006, the agreement was extended until June, 2008. Another one-year extension until June '09 is currently being formalized. Under the cooperative agreement CICOR research is organized around three **science themes**. At the same time, for administrative purposes budgets are organized around four **tasks**.

CICOR's three research themes are:
- 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 requires collaborations by scientists within and between disciplines. In each case, progress depends 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.

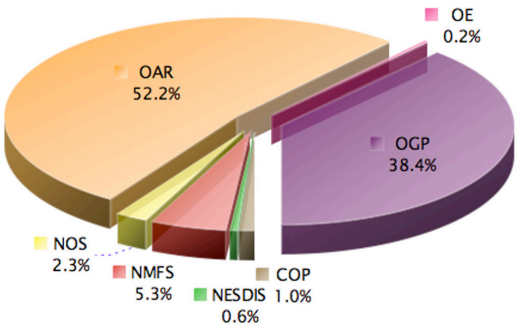
**2006-07 Funding by Theme**




CICOR has been in existence for nine years. During the first 3-year Cooperative Agreement it assisted WHOI Scientists with 26 funded projects totaling a budget of $5,817,000. The total amount funded for projects undertaken during the present 7-year Cooperative Agreement through May '07 is $32,618,166. For the reporting year July 2006 – June 2007, the total amount awarded for projects was $5,934,344.

The bulk of the NOAA funds come from the Office of Oceanic and Atmospheric Research and the new Climate Program Office (formally the Office of Global Programs and Arctic Program Office) with additional funds from the National Marine Fisheries Service, the National Ocean Service and the NOAA Arctic Program.

**2006-7 Funding By NOAA Office**




Funding to CICOR from NOAA is categorized as falling into four Tasks:

- **Task I**, with a total of $331,706 in 2006-7, included $110K for

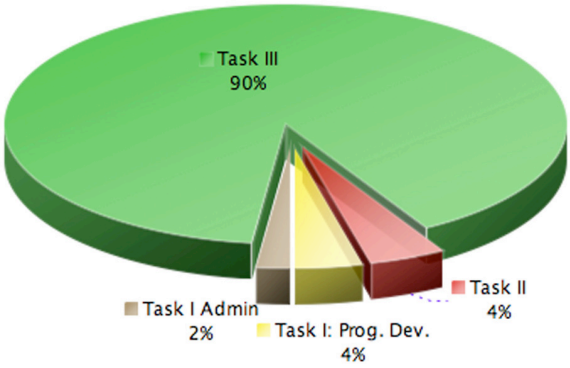
administration and $221.7K for supporting program development,. CICOR program development fees during this reporting year covered two post-docs, a graduate student, three summer student fellows, educational outreach, travel support for CICOR PIs and post-docs to attend meetings with NOAA personnel as well as support for short term visitors for seminars and workshops. For more information see the CICOR website: http://www.whoi.edu/science/cicor.

• **Task II** is research funding with explicit participation by a NOAA investigator ($256.3K);

• **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 ($5.2M), and

• **Task IV** is support for use of WHOI research vessels and submersibles by NOAA and other NOAA-funded investigators. (There was no Task IV support this year.)

**2006-07 Funding by Task**




It is important to bring to the reader's attention that CICOR is an administrative, planning, and facilitation structure serving NOAA, WHOI, and other external investigators funded by NOAA. CICOR investigators respond to NOAA Announcements of Opportunity, submit proposals, and if successful are awarded funds by NOAA through CICOR. The $110K base funds from NOAA OAR and the program development funds are devoted to Task I activities including education, outreach, and increasing engagement in planning and execution of NOAA research. That the principal mode of research is competitive grants funded in response to NOAA announcements is the context for how CICOR manages its science.

Although NOAA funds CICOR Research, the Woods Hole Oceanographic Institution contributes substantial fiscal and administrative support to the Institute. It does this in a number of significant ways, for example, by supplementing lower overhead rates, which are afforded CICOR research and by providing $100K for overhead support. The current cooperative agreement was proposed and awarded with indirect cost that were less than the 2001 overhead rates negotiated with our cognizant agency, ONR, with the exception that the rate would remain fixed at 44% and 30% of salaries (for lab and G&A respectively) for the duration of the five-year Cooperative Agreement. Since WHOI overhead rates have typically increased each year, the difference between the overhead rates on CICOR proposals and the WHOI rate continues to increase. (2001 WHOI Rates: WHOI however, is required to charge all grants and contracts regardless of funding agency the same overhead rate. This is accomplished by WHOI contributing from its unrestricted funds the difference in overhead on CICOR projects. CICOR's current cooperative agreement was extended two years from June 30, 2006 to June 30, 2008 with no increase or change to the overhead structure. As of May 2007, WHOI's contribution to overhead for the current cooperative agreement totals over $888,189, an average of $148,000 per year and over $196,000 in this reporting year. A change in the overhead rates for the anticipated one-year extension is currently being considered.

CICOR has had a Board of Fellows, however the Review process lead to the decision to restructure the Fellows for greater effectiveness. As a first step in this process appointed two Associate Directors, Kenneth Brink, Senior Scientist in the Physical Oceanography Department was appointed to organize coastal initiatives, and Jesús Pineda, Senior Scientist in the Biology Department for ecosystems research. The Associate Directors have worked with a new group of fellows to foster collaboration on a variety of problems of interest to NOAA between NOAA labs and WHOI researchers who have specific expertise in these areas.

# Personnel Summary

July 1, 2005 – June 30, 2006

Task I Support

| Employees | Appt. Dates |
|---|---|
| Bob Weller, CICOR Director | 1999 - present |
| Patricia White, CICOR Administrator | 2004 - present |

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

| Post-Doc | CICOR Theme | Appt. Dates | Advisor(s) |
|---|---|---|---|
| Ricardo De Pol Holz | Climate | 2006-2007 | Lloyd Keigwin |
| Jeremiah Hackett | Coastal & Ecosystems | 2005-2006 | Don Anderson |
| **Graduate Student** | **CICOR Theme** | **Appt. Dates** | **Advisor** |
| Carlos Moffat | Climate | 2005-2007 | Robert Beardsley |
| **Summer Student Fellows** | **CICOR Theme** | **Advisor** | |
| Tess Brandon | Climate Obs. | Al Plueddemann (PO) | |
| Orianna DeMassi | Climate Modeling | Steve Lenz (PO)) | |
| Carolyn Clarkin | Coastal: Marine Policy | Hauke Kite-Powell (MPC) | |
| **Guest Student** | **CICOR Theme** | **Advisor** | |
| Uriel Zajaczkovski | Climate | Bob Weller | |

# Personnel Support Overview:

Through CICOR NOAA supported 104 people in 2005-06: Twenty people were supported for half time or more eighty-four were supported for less than half time. (The summary below does not include summer student fellows or joint program students.)

| Personnel | | | | |
|---|---|---|---|---|
| Category | Number | B.S. | M.S. | Ph.D. |
| Research Scientist | 104 | 59 | 15 | 30 |
| Visiting Scientist | 0 | 0 | 0 | 0 |
| Postdoctoral Fellow | 4 | 0 | 0 | 4 |
| Research Support Staff | 56 | 40 | 16 | 0 |
| Administrative | 18 | 18 | 0 | 0 |
| Undergraduate Students | 0 | 0 | 0 | 0 |
| Graduate Students | 1 | 1 | 0 | 0 |
| Employees (< 50%) NOAA Funding | 84 | 47 | 14 | 23 |
| Total (≥50% support) | 20 | 11 | 2 | 7 |
| Obtained NOAA employment within the last year | NA | | | |

# CICOR Postdoctoral Scholar Summary Report

## Dr. Jeremiah D. Hackett – CICOR Postdoctoral Scholar 2005-2006

Dr. Hackett arrived at the Woods Hole Oceanographic Institution (WHOI) in September of 2005, after completing his Ph.D. in genetics at the University of Iowa. During his Ph.D. training, Dr. Hackett generated a genomic resource for the toxic dinoflagellate *Alexandrium tamarense* and used these data to address plastid evolution in dinoflagellates. Dr. Hackett's Ph.D. training provided him with a strong background in genomics, molecular biology and evolution. At WHOI, Dr. Hackett seeks to become familiar with the ecology and physiology of toxic dinoflagellates and apply genomic tools to investigate harmful algal bloom formation. Dr. Hackett's project at WHOI, in collaboration with faculty advisor Donald M. Anderson, was to use this genomic resource to investigate the ecology of harmful algal bloom formation and toxin production in *Alexandrium* species, which cause paralytic shellfish poisoning through the production of saxitoxin.

Dr. Hackett's primary project was to use the expressed sequence tag (EST) database that he generated in his Ph.D. to identify genes involved in nutrient utilization (i.e. nitrogen and phosphorus) and toxin production. The ESTs are partial sequences of expressed genes in *Alexandrium* are an efficient means for the discovery of genes involved in these processes. He then measured the expression of these genes in cultures of Alexandrium grown under nutrient stress. This work identified genes that may serve as markers for nutrient stress in natural toxic blooms. Samples from a natural bloom were also collected for gene expression analysis. The ultimate goal of this research was to identify a set of genes that can be used as markers of nutrient stress and toxin production to analyze how nutrient utilization influences the growth, sustenance, and decline of harmful algal blooms. Dr. Hackett hopes to use these markers as a diagnostic "tool kit" that can be used to monitor blooms and predict their severity and toxicity in the field.

Using bioinformatics tools, Dr. Hackett identified genes in Alexandrium involved in nitrogen (e.g. nitrate reductase, glutamine synthetase, urease) and phosphorus (alkaline phosphatase, phosphate transporters) utilization. The expression of these genes was tested on cultures of *Alexandrium* under nitrogen and phosphorus stress and compared to the nutrient replete condition using quantitative polymerase chain reaction (QPCR). These experiments confirmed that the expression of these genes responds to decreasing nutrient levels. Dr. Hackett also tested several genes that may be directly involved in toxin production, although clear candidates have yet to be identified. Dr. Hackett and colleagues from the Anderson lab collected samples of a toxic *Alexandrium* bloom from Salt Pond in Eastham, MA from April-June 2006. Candidate markers for nutrient stress were tested on these field samples.

Dr. Hackett also attempted to culture another harmful dinoflagellate, *Dinophysis*, which is the cause of diarrhetic shellfish poisoning (DSP). Research into the causes of has been hindered by the fact researchers are currently unable to keep this organism alive in culture. Previous work by Dr. Hackett and others, using molecular biology techniques, has shown that *Dinophysis* steals its chloroplast from another alga, a cryptophyte called *Teleaulax*. In an attempt to culture *Dinophysis*, Dr. Hackett isolated single cells of *Teleaulax* from Eel Pond in Woods Hole and confirmed the identity of these tiny algae using molecular markers. Dr. Hackett then isolated single cells of *Dinophysis* and is attempting to feed *Teleaulax* to *Dinophysis*. These experiments are on-going and are approaching a critical point (about 6 weeks from isolation) where we will know if *Dinophysis* can survive on this prey.

In 2006, Dr. Hackett was offered, and accepted, a faculty position as an assistant professor at the University of Arizona, Department of Ecology and Evolutionary Biology, in Tucson, AZ. He began his new position in January of 2007.

In the last year, Dr. Hackett has had three publications published or accepted, and an additional three submitted:

Hackett, J. D., Yoon, H. S., Bhattacharya, D. Genome Evolution in Dinoflagellates. 2006. In: Genome Evolution in the Algae. Bhattacharya, D. and Katz, L. eds. Oxford University Press.

Yoon, H. S., Hackett, J. D., Bhattacharya, D. In Press. A genomic and phylogenetic perspective on endosymbiosis and algal origin. Journal of Applied Phycology.

Hackett, J. D., Yoon, H. S., Butterfield, N. J., Sanderson, M. J., Bhattacharya, D. Accepted. Plastid endosymbiosis: Sources and timing of the major events. In: Evolution of Aquatic Photoautotrophs, Eds. Falkowski, P., and A. Knoll. Academic Press.

# CICOR Postdoctoral Scholar Summary Report

## Dr. Ricardo De Pol-Holz - CICOR Postdoctoral Scholar 2006-2008

Dr. De Pol-Holz arrived at the Woods Hole Oceanographic Institution (WHOI) in November of 2006, after completing his Ph.D. in Oceanography at the University of Concepcion, Chile. During his Ph.D. training, Dr. De Pol-Holz studied the biogeochemistry of nitrogen isotopes in the eastern South Pacific and used this information to asses the variability of the intensity of denitrification during the Late Quaternary. Dr. De Pol-Holz's Ph.D. training provided him with a strong background in stable isotope analysis, nitrogen biogeochemistry and Paleoclimatology. At WHOI, Dr. De Pol-Holz seeks to become familiar with radiocarbon techniques, and to assess the past variability of intermediate water mass ventilation in the South Pacific. Dr. De Pol-Holz's project at WHOI, in collaboration with faculty advisor Lloyd D. Keigwin, is to use paired radiocarbon analyses in benthic and planktonic foraminifera to investigate the deglacial changes in Antarctic Intermediate Water (AAIW) ventilation using cores from the Chile margin.

Dr. De Pol-Holz's primary project is to use the radiocarbon data to determine the apparent ventilation age of a selected depth range in the eastern South Pacific. The N isotope information that he generated in his Ph.D. provided the evidence that during the last deglaciation, there was a collapse in the ventilation of the South Pacific subsurface (onset of the modern Oxygen Minimum Zone) which it has been associated with changes in intermediate water formation. The radiocarbon data that is being analyzed at WHOI constitutes the first attempt to directly assess the changes in AAIW near its formation zone west of the Drake Passage. Dr. De Pol-Holz hopes that the radiocarbon data will confirm the growing evidence of the existence of a deep and radiocarbon depleted water reservoir in the Pacific and that it was its ventilation and the spread of its signal to other basins by way of AAIW formation, the responsible mechanism for the deglacial increase in $CO_2$ in the atmosphere.

Using stable isotope analysis on benthic foraminifera, Dr. De Pol-Holz will also try to identify hydrological changes that could have altered AAIW characteristics during the last glacial-interglacial transition (18,000-11,000 years ago). The methodology lies in the identification of peaks in abundance of selected species of benthic foraminifera like *Uvegerina peregrina*, *Cibicidoides sp.* and *Bulimina sp.* in several cores from intermediate depths along the Chilean margin. His preliminary results confirm the existence of such peaks, and the next step of stable isotope and radiocarbon analyses is about to begin.

CICOR sponsored Dr. De Pol-Holz's travel to one national conference in 2006, an international research trip and an advanced course in 2007. The first was the American Geophysical Union fall conference in San Francisco, CA in December, 2006. Coming from a marine biological background, this conference was an important opportunity for Dr. De Pol-Holz to learn about the latest research in the broad field of Paleoclimatology and network with the leaders in this field.

The second trip was a research visit to the University of Bremen, Germany. This trip gave Dr. De Pol-Holz the opportunity to collect samples from a set of sediment cores along the Chile margin that were taken previously by the GeoB department. During this trip, Dr. De Pol-Holz was invited to give three public presentations of his previous and present work at the University of Bremen, the Alfred Wegener Institute in Bremerhaven and the ifM-Geomar Institute in Kiel.

Dr. De Pol-Holz was a Co-PI on a proposal submitted to the National Science Foundation to continue with his work on radiocarbon analysis of benthic foraminifera in the eastern South Pacific. A panel will decide on this proposal in December 2007.
In the last year (2006-2007), Dr. Hackett has had two publications published, and an additional one submitted:

De Pol-Holz**,** R., R. Robinson, D. Hebbeln, D. M. Sigman and O. Ulloa. Controls of sedimentary N isotopes along the Chile margin. 2007. Submitted to *Deep-Sea Res II.*

De Pol-Holz, R., O. Ulloa, F. Lamy, L. Dezileau, P. Sabatierr, D. Hebbeln. Late Quaternary variability of

sedimentary nitrogen isotopes in the eastern South Pacific Ocean. 2007. *Paleoceanography,* 22, PA2207, doi:10.1029/2006PA001308.

De Pol-Holz, R., O. Ulloa, L. Dezileau, J. Kaiser, F. Lamy and D. Hebbeln. Melting of the Patagonian Ice Sheet and deglacial pertubations of the nitrogen cycle in the eastern South Pacific. 2006. *Geophysical Research Letters*, 33(4), L04704, doi:10.1029/2005GL024477.

# CICOR Joint Program Student Summary Report

*Graduate Student Research Assistants*
CICOR provides the framework at WHOI for coordinating NOAA-funded research, for building ties between WHOI investigators and colleagues at NOAA laboratories, and for developing cooperative NOAA-funded research at academic institutions in the northeastern United States. Graduate Student Researchers are associated with the research activities related to CICOR themes and funded through CICOR. Program development costs support the WHOI-NOAA Cooperative Institute for Climate and Ocean Research educational program. CICOR supported Carlos Moffat during the 2006-2007 reporting year. Carlos successfully defended his thesis in the summer of '07.

**Carlos Moffat**
Ph.D. Candidate, MIT/WHOI Joint Program in Physical Oceanography.

Brief Education background:
University of Concepción, Marine Biology, 1998

Advisor/WHOI lab or group:
Advisor(s): Dr. Robert C. Beardsley and Dr. Breck Owens, Physical Oceanography Department.


**PROJECT/FOCUS TITLE:**

My thesis research, titled 'Coastal Circulation on the west Antarctic Peninsula', is aimed at understanding the circulation of the coastal ocean of the shelf west of the Antarctic Peninsula, as part of the Southern Ocean Global Ocean Ecosystem Dynamics (SO GLOBEC) program.

As part of a multidisciplinary program, my research fits into a broader objective of describing the unique set of processes that contribute to the rich biological community found in the study region. For example, I am studying the Antarctic Peninsula Coastal Current (APCC), a buoyant coastal plume that we first described using the SO GLOBEC dataset. The APCC appears to be a dominant part of the coastal circulation in this area, and may play a critical role in help make the Marguerite Bay such a rich and productive ecosystem.

**RELATED NOAA STRATEGIC PLAN GOAL:**

Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

**ACTIVITY REPORT**

During the 2006, I examined the SO GLOBEC data set, which includes two broad-scale conductivity, temperature and depth (CTD) surveys and mooring observations. Previous studies had suggested the presence of a buoyant coastal current forming during the ice-free season along the coast of the Peninsula. By using the SO GLOBEC data set, I was able to provide a first description of this current, which we have named the Antarctic Peninsula Coastal Current (APCC).

The APCC is a strongly seasonal feature of the circulation, which seems to disappear during the winter months. While present, the APCC appears to transport a substantial proportion of the freshwater runoff from the land. Understanding the variability and dynamics of the APCC are therefore key to understanding the fate of the freshwater being lost from the Antarctic continent as the regional climate warms up. The cross-shelf gradients in density associated to the APCC are accompanied by gradients in biological properties like chlorophyll and plankton concentrations, suggesting that the APCC provides a favorable environment for biological production.

An initial version of these results were presented in February of 2006 at the Ocean Sciences conference at Hawaii and at the Antarctic Peninsula Climate Variability Workshop at Boulder, Colorado, and a final manuscript has been submitted to Deep Sea Research.

In the summer of 2007, I successfully defended my thesis, 'Coastal Circulation on the west Antarctic Peninsula'. After a visit back home in Chile, I will return this fall to WHOI as a Post Doctoral Investigator working with Bob Beardsley and Breck Owens on a numerical model study of the APCC dynamics and several other topics related to my thesis work.

# CICOR Summer Student Fellows

## Tess Brandon

Summer Student Fellow

Cornell University, Earth Systems Science, 2007

Advisers:
Al Plueddemann, Physical Oceanography
Rich Signell, USGS
Rocky Geyer, Applied Ocean Physics & Engineering

**PROJECT TITLE:**

Hydrodynamics of Tidal Flow Across A Submarine Sand Ridge

**PROJECT SUMMARY:**

The Middle Ground sand ridge runs along Vineyard Sound at a slight angle to the reversing tidal flow along the channel. This study sought to understand small-scale processes associated with the ridge by collection and analysis of *in situ* velocity data and comparison to a numerical model. Velocity time series from a mooring confirmed the expected dominance of the ebb tide on the north side of the ridge, and an observed mean flow of 5-10 cm/s in the direction of the ebb tide was confirmed by the model. The mean of the cube of the velocity, a proxy for sediment transport, was directed towards the ridge. Multiple spatial transects across the ridge at different stages of the tidal cycle were obtained using the Autonomous Underwater Vehicle (AUV) REMUS. The REMUS data showed strong, localized velocity shear near the ridge crest during the strongest currents. Cross-ridge shear in the model (which used relatively smooth bathymetry) was similar, but weaker and broader. Four potential processes for ridge formation and maintenance were evaluated based on the observations and model results.

This project was particularly worthwhile for me because of its combination of field and computer work. Collecting the REMUS transects involved planning field missions around several variables, including scientists' busy schedules and the tidal cycle in Vineyard Sound. Each mission was a learning experience in working with AUVs and in the realities of field work. The raw data then had to be processed, analyzed and visualized, which I did primarily using Matlab software. Although there is still work to be done on this project, it has taught me a great deal about the scientific process in physical oceanography.

# Carolyn Clarkin

Summer Student Fellow

Bucknell University, Political Science and Environmental Studies 2008

Advisor: Dr. Hauke Kite Powell, Marine Policy Center

**PROJECT:**

Economic Benefits of QuikSCAT Information for the Maritime Shipping Industry

**RELATED NOAA STRATEGIC PLAN GOAL:**

Goal 4. Support the Nation's commerce with information for safe, efficient, and environmentally sound transportation.

**SUMMARY OF ACCOMPLISHMENTS**

Hurricane force extratropical storms pose dangerous threats to life and property at sea. Prior to the availability of QuikSCAT ocean surface wind information in 2001, the occurrence of hurricane force extratropical storms were underestimated by the conventional ocean observing systems such as the Voluntary Observing Ship (VOS) program and moored buoys. The incorporation of QuikSCAT information into the National Oceanic and Atmospheric Administration's daily operations and forecasting has greatly reduced uncertainty on the frequency and geographic position of hurricane force extratropical storms. Consequently, wind warnings and forecasts for mariners engaged in commerce, transportation, and recreation are more accurate. The economic value of additional QuikSCAT information was estimated by modeling the likelihood that transits across the North Atlantic and North Pacific Oceans encounter hurricane force storms. The model simulates transits with four varying levels of information: no information or "blind", nowcast issued at both 12 and 6 hour intervals, and perfect forecast. Perfect forecasts yield the most substantial reduction in the percentage of transits encountering a storm, virtually by 100% for both the North Atlantic and North Pacific. Nowcasts issued at both hourly intervals yield some, but much less substantial reductions in the percentage of transits encountering storms, on average between 1 to 3%. The substantial difference between nowcast and perfect forecast results may be due to the currently oversimplified model. Nonetheless, reductions in the percentage of transits in storms reduce cargo liability costs and container replacement costs. Perfect forecasts may potentially yield $720 million in savings per year for the maritime container shipping industry alone. Further savings may be realized in the maritime tanker and dry bulk industries as well as other users of QuikSCAT information such as coastal communities.

# Orianna DeMasi

Summer Student Fellow

Western Connecticut State University
McGill University
B.S. Mathematics (2009)

Advisor: Steve Lentz, Physical Oceanography

**PROJECT:**

Understanding the Tides South of Martha's Vineyard.

**GOALS:**

Describe observed tidal features on the portion of the New England shelf south of Martha's Vineyard.

Try and fit a numerical model to predict sea level height and velocity in the region.

Learn about the dominate forces on the tide in this region.

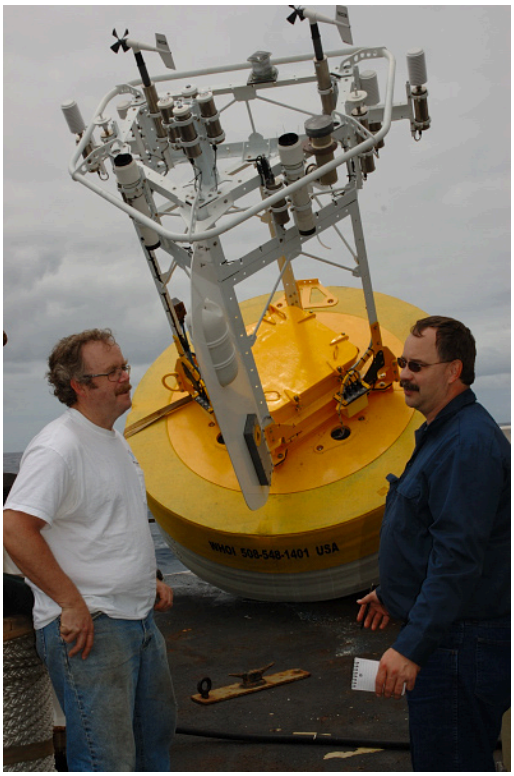
**OVERVIEW:**

This past summer I worked with Steve Lentz in the Physical Oceanography Department to determine the characteristics of the tides south of Martha's Vineyard. We looked at 5 sets of data that were collected over various time periods by pressure gauges and current meters from 13 moorings. The data includes a mooring on the 7m isobath, which is farther inshore than any previous tidal study has looked. I analyzed the data with T_tide in Matlab to extract maximum amplitudes and phases for the sea level, cross shelf velocity and along shelf velocity. The amplitudes and phases from the various studies were complied to give a comprehensive description of the tidal structure on the inner shelf and tidal variability across the shelf. We also worked on comparing the tidal observations a simple baroclinic model that assumes an along shelf pressure gradient. We found this model to be insufficient to model the complexities of the tides in the area. However the model was useful for learning about the predominate forces and momentum balances over this area of the continental shelf. We found a geostropic balance (Coriolis component and cross shelf pressure gradient dominant) for the cross shelf structure, minimal vertical transport, and the along shelf acceleration term to be of little significance. We also estimated nonlinear acceleration terms and a frictional bottom stress constant for the area.

# Teacher At Sea Program Involvement 2006-07

A strong education and outreach effort within CICOR is its involvement in the NOAA Teacher-at-Sea program (http://www.tas.noaa.gov/). In 2002, the STRATUS research cruise brought a NOAA Teacher-at-Sea for the first time to a non-NOAA vessel, in this case to the *R/V Roger Revelle*, chartered from UNOLS by NOAA for the STRATUS cruise. This Teacher-at-Sea was Debra Brice, from San Marcos, California. A Chilean counterpart, Vivianna Zamarano, a Chilean TAS from Arica, Chile (where the cruise ended) also participated in the cruise and interacted extensively with the science party while providing real time links to classrooms in the United States. Since 2002 there has been a NOAA Teacher at Sea on every Stratus cruise.

In 2006, the stratus cruise hosted Brett Hoyt from Montana. Mr. Hoyts' personal statement about the experience included:



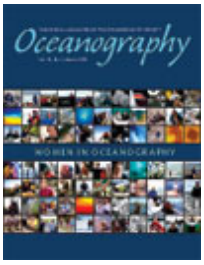

The Teacher at Sea's program goal is stated as "It is NOAA's desire that the logs, lesson plans, and workshops/presentations you create as a result of this experience will help foster a better understanding of our ocean planet among you, your students, and your colleagues."

I feel that with the support of NOAA, Woods Hole Institute, and CICOR that this mission statement has been fully achieved. I have been able to add "Ocean Awareness" to my student's view of the world. Because of my experience with TAS I am able to share real experiences which helps make science come alive for my students. I will be presenting a Teacher at Sea sectional at the upcoming statewide teacher convention and look forward to encouraging many other teachers to participate in this incredible experience. I have become a strong advocate for not only the TAS program but for NOAA and WHOI as well. I encourage my students to consider a career in science and use the above-mentioned institutions, in conjunction with my TAS photos, to highlight what real scientists doing real science actually look like.

The impact upon the students and professionals I work with will last years past the three short weeks of my TAS experience and has provided me with an experience of a lifetime.

When in port in Central and South America, the science party on these cruises to the Stratus Ocean Reference Station regularly participate in interviews with the local press. These dialogs typically cover both the involvement of participants from these countries in the research and questions about ENSO, which has a major impact on these countries. In association with obtaining clearance to sample in national waters, local observers are invited from the countries from which the ship sails and from which the ship docks at the end of the cruise. Additionally, as bunk and lab space is available and as ship time allows, these participants, which include researchers and their graduate students as well as members of the naval oceanographic services of these countries, are invited to participate in the research and carry out their own research projects.

Communication with and support for Stratus Teachers at Sea continues via the CICOR office. All Teachers at Sea associated with the Sratus cruise in the past and scheduled for 2007 have been given memberships to the Oceanography Society which includes a subscription to the publication, *Oceanography.* These teachers have also been given subscriptions to the WHOI publication, *Oceanus*.




# Annual CICOR Research Summaries

## U.S. Program in Marine Biotoxins and Harmful Algae

NOAA Cooperative Agreement No. NA17RJ1223 sub-points 09, 10, 11, 36 and 88
July 1, 2006 through June 30, 2007

**Dr. Donald Anderson**
Woods Hole Oceanographic Institution, Woods Hole, MA 02543
(508) 289-2351, danderson@whoi.edu

Program Manager: Dr. Quay Dortch, NOAA/NOS/CSCOR

Related NOAA Strategic Plan Goal:
Goal 1. Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.

**PROJECT OVERVIEW**

This project supports operation of the U.S. National Office for Marine Biotoxins and Harmful Algal Blooms - at the Woods Hole Oceanographic Institution. The Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) authorizes several components that constitute a National Program for Harmful Algal Bloom (HAB) Research. The National Program for Harmful Algal Bloom Research is currently implemented through two competitive extramural research programs of NOAA's Center for Sponsored Coastal Ocean Research (CSCOR), the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) and the Monitoring and Event Response for Harmful Algal Blooms (MERHAB). CSCOR has established the U. S. National Office for Harmful Algal Blooms to provide critical coordination and technical support capabilities that enhance the Nation's ability to respond to and manage the growing threat posed by HABs. It also provides liaison with the scientific community and related programs nationally and internationally.

**ACCOMPLISHMENTS**

Redesign of The Harmful Algae webpage (http://www.whoi.edu/redtide), which is a critical resource for the U.S. and global HAB community. This year, considerable effort was devoted to the complete redesign of this site – which will include significant new content as well, especially on freshwater HABs, which were previously not covered. The new website is scheduled to be launched this fall and we will continue to update the contents, with plans to add FAQs and information geared to students and educators.

Another activity in this regard is the maintenance of an e-mail distribution list for the U.S. HAB community. This list is used for announcing meetings, funding opportunities, and other issues of relevance to the broad group of those involved in U.S. HAB research, monitoring, and management. This list currently has over 450 members and we are frequently asked to coordinate communication among this group. We also continue to update and maintain a listserver for the International Society of the Study of Harmful Algae (ISSHA).

Another major focus during this past year has been the planning and organization of the 4th U.S. HAB Symposium, scheduled for October 29 – November 1, 2007 in Woods Hole, Massachusetts. We expect approximately 250 scientists, students and agency personnel to attend this symposium. Efforts include soliciting, collecting and compiling abstracts for oral presentations and posters; program development – topics for presentations and discussions sessions; conference site organization and arranging facilities; obtaining funding for travel awards for students and Postdocs, reviewing applications, and making and processing subsequent awards; We also created and maintain the website for the symposium (http://www.whoi.edu/sbl/liteSite.do?litesiteid=13352) and disseminated information to the US HAB community and other interested groups. This symposium is a major commitment of effort.

We also devoted significant time to the preparation of the report - *National Scientific Research, Development, Demonstration and Technology Transfer (RDDTT) Plan for Reducing Harmful Algal Bloom Impacts*. We organized and sponsored a four-day workshop for development of this report, which was held in June with approximately 50 participants. Numerous phone calls were held during the past year to coordinate the workshop and develop the report; significant time has been devoted to writing major sections and editing the entire report.

The National Office presently undertakes the unique role of compiling information on HAB events in the U.S. as the ICES *National Coordinating Center for Exchange of Information on Harmful Algal Blooms.* This involves annual efforts interacting with colleagues around the U.S. to compile reports of all national HAB events each year. These raw data are entered into standard forms and supplied to the ICES Science and Communications Center in Vigo, Spain for inclusion in the Harmful Algal Event Database (HAEDAT). A summary of the US bloom reports was given at the April 2007 ICES Working Group on Harmful Algal Bloom Dynamics, held in Riga, Latvia. National and international bloom reports are also provided to all U.S. network participants, as well as to other interested parties. This is the only compilation of U.S. HAB incidents. Additional efforts were undertaken this year to increase the representation of U.S. resource managers in this activity.

The National Office also administers 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. This year, events included: a *Heterosigma* event in Washington state.

The National Office is supporting the recently formed National HAB Committee (NHC) which is overseeing coordination and implementation of the new US National Plan for HABs. In November 2006, we organized the first meeting of this group; held in Cambridge, Maryland. We also developed a webpage for the NHC (http://www.whoi.edu/page.do?pid=13935); ran several conference calls; organized and ran the 2007 election for new members; set up ad hoc subcommittees; and will organize the second on-site meeting to be held in Woods Hole prior to the 4th US HAB symposium (October, 2007).

The National Office assists with the formulation of scientific agendas, arranging for financial and administrative support, and providing expert representation for national and international HAB workshops, symposia, and conferences. During the past year, these meetings have included: the 13th International Conference on Harmful Algal Blooms (Steering Committee member; Hong Kong, November 2008); North Pacific Marine Science Organization (PICES) annual and section meetings, the ICES (International Council for the Exploration of the Sea) working group on Harmful Algal Bloom Dynamics, the Fourth US HAB symposium (October 2007) and the RDDTT workshop (June 2007).

The National Office also organizes travel awards for participants at many of these meetings. For the past year, we assisted with participant travel to the Gordon Conference Satellite workshop on Mycotoxins and Phycotoxins, the IOC Phytoplankton course, the 4th US HAB symposium, and the 12th International HAB Conference on Harmful Algal Blooms.

The National Office participated in the 8th Intergovernmental Panel on HABs, convened by the Inergovernmental Oceanographic Commission. In addition to helping with the preparation of the US position paper and other documents, D. M. Anderson joined the US delegation in Paris for the meeting. There continue to be action items related to IPHAB VIII, and these are dealt with as they arise.

**PUBLICATIONS**

Anderson, D.M. Approaches to monitoring, control, and management of harmful algal blooms (HABs). *Proceedings of the International Conference on Coastal and Ocean Governance, East Asian Seas Congress 2006, Ocean & Coastal Management Journal* (under review).

Anderson, D.M. The expanding problem of harmful algal blooms: New technologies for monitoring, research and management. Proceedings of The Arabian Seas International Conference on Science and Technology of Aquaculture, Fisheries and Oceanography (submitted).

Heisler, J., P. Glibert, J. Burkholder, D. Anderson, W.Cochlan, W. Dennison, C. Gobler, Q. Dortch, C. Heil, E.Humphries, A. Lewitus, R. Magnien, H. Marshall, K. Sellner, D. Stockwell, D. Stoecker, and M. Suddleson. Eutrophication and harmful algal blooms: A scientific consensus. Harmful Algae (submitted).

SUMMARY OF INTERACTION WITH NOAA

The National Office works extensively with the NOS Center for Sponsored Coastal Ocean Research (CSCOR) program in Silver Spring, Maryland at many levels, including communicating to the US HAB community about funding possibilities; coordinating national conferences workshops and symposia; producing assessments and other reports as required by Congress, serving as US delegate to several international panels and working groups, and so forth. We also work with this program in administering rapid response funds for HAB events throughout the country.

**SUMMARY OF EDUCATION AND OUTREACH ACTIVITY**

As described under "Accomplishments", the National Office maintains a webpage, "Harmful Algae", http://www.whoi.edu/redtide. This website strives to serve as a comprehensive resource for a broad range of user groups, including scientists, managers, the general public, journalists and students. Although there are many HAB-related websites in the U.S., this is the only one that deals with the entire range of U.S. HAB problems and provides access to information on national HAB research programs. It is used as a central repository for information about HABs in the U.S. and every week, this site is one of the top 5 sites visited of all the WHOI websites. We receive numerous requests for specific information, images, etc. from individuals – particularly students and journalists.

The National Office is directly involved in numerous presentations that are given each year to various types of audiences – journalists, students, scientists, etc. A few of the presentations given during the past year are detailed below:

11/06 - Digital Video Conference on "Red Tides" with Egyptian academics and researchers from the Egyptian National Institute of Oceanography and Fisheries (NIOF). Discussion of recent research activities and took questions from 250 Egyptians participating in a one-day conference on Red Tides and HABs at the Bibliotheca Alexandrina. The discussion focused on methods of mitigating or suppressing Red Tides, computer modeling to predict their occurrence, and the potential dangers to human health, tourism and fish and shellfish production by Red Tides and HABs.

12/06 - Invited seminar, "Multidisciplinary approaches to monitoring, control, and management of harmful algal blooms (HABs)", The International Conference on Coastal and Ocean Governance, East Asian Seas Congress 2006, Haikou City, China.

02/07 - Keynote talk, "The expanding problem of harmful algal blooms: New technologies for monitoring, research and management", The Arabian Seas International Conference on Science and Technology of Aquaculture, Fisheries and Oceanography, Kuwait.

02/07 - Plenary / Keynote talk: "The ecology and oceanography of toxic *Alexandrium* blooms in the Gulf of Maine", The Arabian Seas International Conference on Science and Technology of Aquaculture, Fisheries and Oceanography, Kuwait.

02/07 - The expanding problem of red tides and harmful algal blooms: Impacts, trends, and linkages to eutrophication, SERC Evening Lecture Series, Edgewater, MD

02/07 - Invited presentation, "The 2005 and 2006 New England red tides: mechanisms, management challenges, and implications for future forecasting capabilities", NOAA, CSCOR, Silver Spring, MD

During this past year, we sponsored an undergraduate student from Northeastern University during her cooperative work program. Kathyrn Shaughnessy developed several new webpages sponsored by the National Office (the NHC page; Fourth US HAB symposium webpage, and the new Harmful Algae page). In so doing, she received training from the National Office in many areas of web design and publication as well as a basic introduction to harmful algae.

# Wind-Driven Transport Indices for Cod and Haddock Recruitment on Georges Bank

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 410
July 1, 2006 through June 30, 2007

**Dr. Philip Bogden**
GoMOOS (Gulf of Maine Ocean Observing System)
Tel: (207) 773-0423 E-mail: bogden@gomoos.org

Program Manager: David Mountain NOAA/NMFS/NEFSC

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.
Goal 3. Serve society's needs for weather and water information.
Goal 4. Support the Nation's commerce with information for safe, efficient, and environmentally sound transportation.

## PROJECT OVERVIEW

In February, GoMOOS development staff met with project manager David Mountain and James Manning of NOAA NEFSC to discuss how best to address the needs of the project. It was determined that the goals of the project could be met by tailoring the product to improve access to wind observations and predictions over the web. Additionally, GoMOOS learned through end user feedback and survey results that this type of information would be valuable to the greater Gulf of Maine community.

*Recent inquiry from a GoMOOS user:*

"I am sailing the Marblehead to Halifax ocean race this summer and would like to follow the winds over the course for the next few weeks. Is there a graphical product that estimates the current surface wind direction and velocity over that ocean area (Gulf of Maine plus east to Halifax) that I can conveniently access? Thanks for your help."

As a result of that discussion, the team decided to create a wind forecast product that would utilize available wind speed and direction predictions for a 48-hour forecast product on the GoMOOS website. Point forecasts would be extracted from the model data specific to the GoMOOS and NBDC buoy locations in the Gulf of Maine, as well as provide a forecast to observation comparison plot to gauge the accuracy of the forecast.

## ACCOMPLISHMENTS

To design the display, GoMOOS developers evaluated similar products available on sailing and airline websites for a layout and design approach that would be useful for displaying the large amount of data in a digestible format for a non-scientific user base. It was also determined that a design that incorporated the wave forecast model (WaveWatchIII) already in operation would make the best use of the visual space and give users a greater amount of information in one place. As part of the redesign, the wave forecast was also expanded to include primary direction in addition to wave height and period.

From a technical perspective, it was determined that the NOAA National Center for Environmental Protection (NCEP) model would be the best source for the wind and wave data. Working with James Manning, GoMOOS developers identified three NOAA OPeNDAP servers that provided the forecast. One server provided a forecast at hourly intervals, and the other two provided forecasts at 3-hour intervals. Initial testing revealed two modes of failure that were encountered with the servers:

1) The server was offline
2) The forecast on the server was not updated

Code was developed to extract the desired data from the wind forecast model. Code was also developed to discover and identify the server that was online and had the latest forecast. Additional challenges were encountered in extracting data from the OPeNDAP servers. In order to programmatically interact with the server, a Python package called PYDAP was utilized.

Data is stored on the GoMOOS server, and the product is updated twice daily. It is a fully automated process, but requires manual intervention in the event of failure to acquire the latest data due to server failure.

The Wind and Wave Forecast was completed in early June, and is available as a web-delivered product, available 24 hours, 7 days a week on the GoMOOS.org website at http://www.gomoos.org/waveforecasts/windwaveforecast.html. The user communities that will benefit from this product include mariners, fishermen, scientists, coastal managers, recreational boaters, sailors, surfers and educators.

## FIGURES AND IMAGES

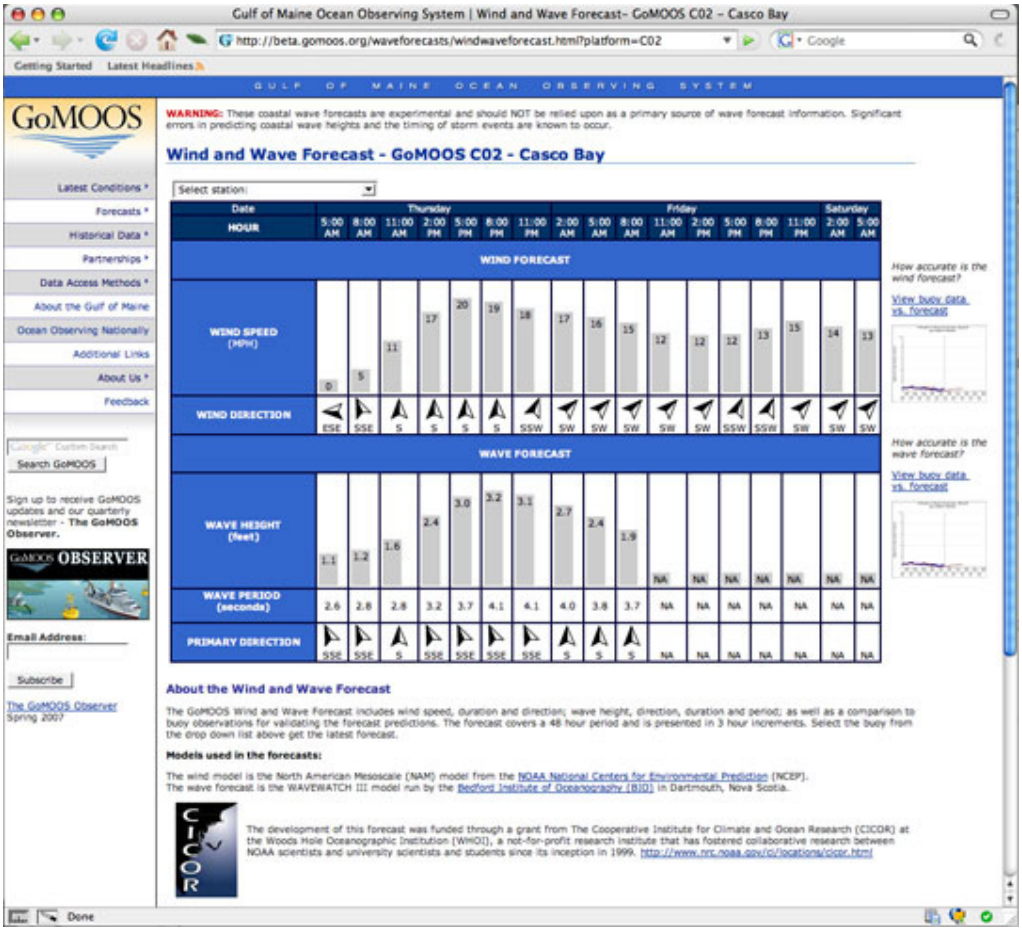



Figure 1. Screenshot of Wind and Wave Forecast

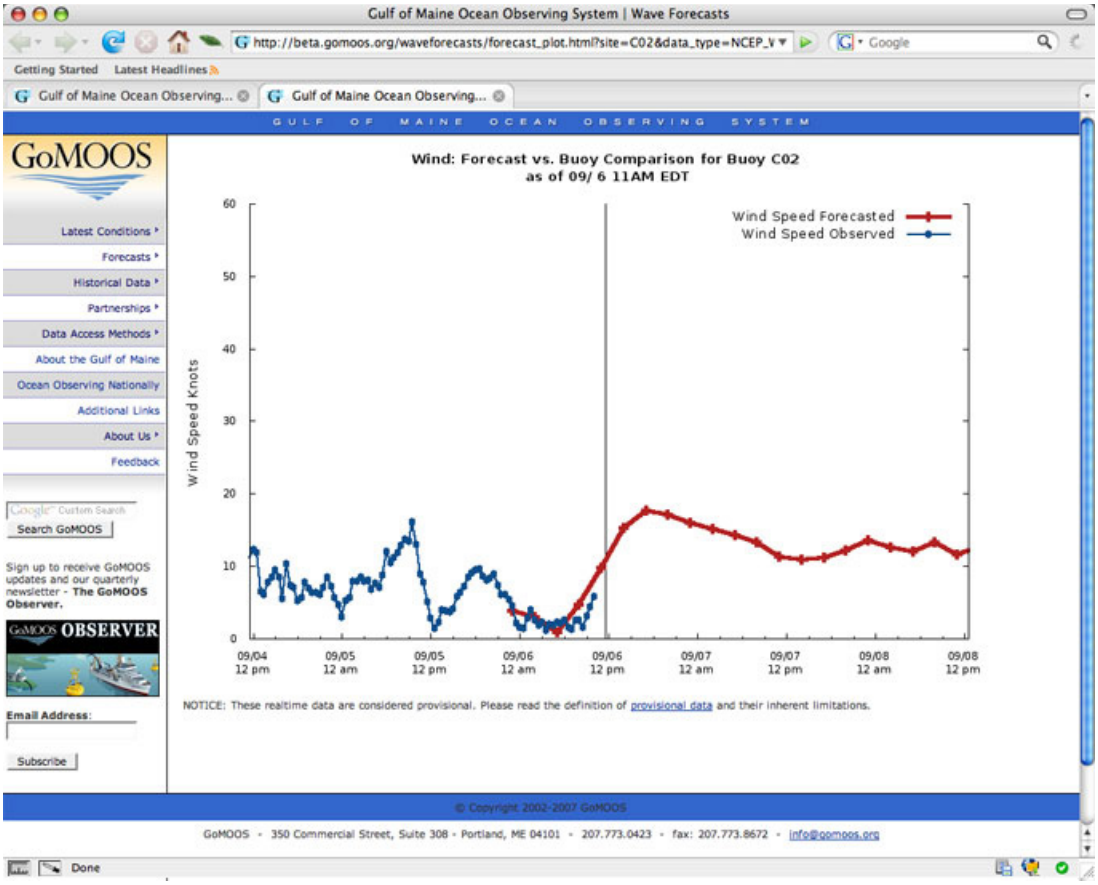



Figure 2. Screenshot of forecast to observation comparison plot.

## PUBLICATIONS

None

## SUMMARY OF INTERACTION WITH NOAA

GoMOOS worked closely with project manager Dr. David Mountain and James Manning on this project. Dr. Mountain provided guidance on addressing the specific objectives and needs of the project. James Manning provided guidance to the GoMOOS programming staff on access to OPeNDAP servers, and collaborated on the development of code for the forecast itself.

## SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

The Wind and Wave Forecast tool was integrated into the recent release of the upgraded GoMOOS.org website. The website was initially released in beta testing mode in July, and a panel of end users was enlisted to help with testing. Initial feedback on the Wind and Wave Forecast was very positive. The majority of users rated it Good or Excellent for ease of use, value of information presented and relevance to their needs.

Some feedback from the user testing:

“Good service and the Wind and Wave forecast looks like it will be very useful.”

“Wind-wave forecast: this would be very useful to me, I would probably use it on a daily basis.”

In September, the GoMOOS beta website became the operational website. The new wind and wave product is

highlighted as a new site feature and highlighted in our news update. We will be using our outreach tool – the GoMOOS Observer newsletter – to alert our user base of all the new features, including the Wind and Wave Forecast. Additionally, we will be reaching out to user groups (e.g. Fishermen's Forum in March) to alert them of these new products and services.

Additionally, it was determined that the wind forecast would be a useful first step in prototyping a product for our work with the NERACOOS (Northeastern Regional Association for Ocean Observing Systems). One of the products identified as a high priority for coastal managers was a tool to determine the likelihood of harmful algal bloom (HAB) formation given certain environmental conditions. Researchers at the University of Maine have discovered that a relationship exists between wind direction, duration and stress that can create downwelling conditions which appears to be favorable to the formation of HABs during the spring and summer months.

Using available NCEP wind forecast model and buoy gathered wind data; we can generate an alert when the HAB favorable conditions are detected in the forecast

Users (HAB managers, HAB scientists) can then log in to the HAB Potential Index Tool (Figure 3) to view the forecast and get more information.

The HAB Potential Index Tool would be a visual indication of forecast for the next 48 hours and would include observed conditions from the GoMOOS buoy array for accuracy. Alerts will be issued when observed data matches forecast data

The forecast was modified programmatically to detect upcoming conditions – wind speed, direction and duration. If the conditions are met, an alert is generated. We are working with HAB scientists to determine the exact conditions that will trigger the alert. The next step is to develop notification services so that end users (HAB managers) can be alerted via email or SMS text message that these conditions are likely to occur sometime in the next 48 hours.

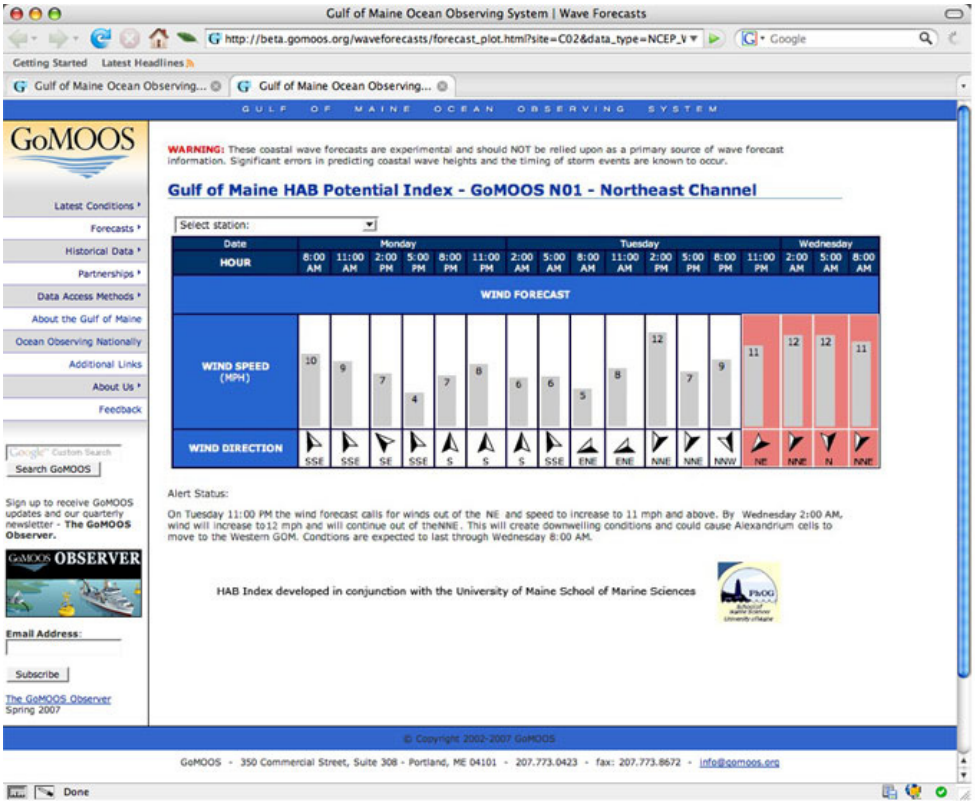



Figure 3. Screenshot HAB Potential Index Prototype.

# Multi-Sensor Improved SST (MISST) for GODAE

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 357
July 1, 2006 through June 30, 2007

**Dr. Sandra Castro and Dr. William Emery**
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Program Manager: Dr. Stan Wilson, NOAA/NESDIS

Related NOAA Strategic Plan Goal:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.
Goal 3. Serve society's needs for weather and water information.

## PROJECT OVERVIEW

The complementary nature of present infrared and microwave sea surface temperature (SST) products provides opportunities for combining the data, but significant differences among the products must first be understood and characterized. In this project we explore which environmental and sensor parameters contribute most to the uncertainty in existing infrared Advanced Very High Resolution Radiometer (AVHRR) and microwave Advanced Microwave Scanning Radiometer (AMSR-E) and Tropical Rainfall Mapping Mission Microwave Imager (TMI) SST products and present a method for specifying the errors in terms of available satellite-derived products.

Method: Collocations between the satellite retrievals and SST measurements from moored and drifting buoys are constructed and used to derive the error estimates. Multidimensional look-up tables are generated to provide the expected bias and standard deviation of individual retrievals as functions of various combinations of parameters influencing the differences between the products. Objective evaluations then determine what combinations are most effective in reducing these differences.

During the first three years of this project, we completed the derivation of error statistics for AVHRR, AMSR-E, and TMI as a function of satellite-derived sensor and environmental parameters. Bias adjustments derived from the satellite zenith angle, channel 4–5 brightness temperature difference, and SST for the infrared, and wind speed, water vapor content, and SST for the microwave products were the most effective single combinations of parameters in reducing the variability of differences both relative to the buoys and in gridded difference maps between the products. Further improvements are possible through inclusion of additional independent corrections based on the climatological SST anomaly and aerosol optical depth. These corrections enable reductions in the monthly rms difference between the products of as much as 42% and in differences with independent buoys of as much as 10%. The largest individual corrections were to AVHRR data in regions of low SST, but larger numbers of microwave retrievals were significantly changed by the adjustments.

The last two years of this project are devoted to understanding and characterizing uncertainty estimates in the presence of diurnal warming (DW). Diurnal warming of the ocean surface layer at low wind speeds and sufficient insolation can lead to significant and highly variable differences between the skin and subsurface temperatures. These differences represent a source of uncertainty in estimates of the subsurface temperature. This stage of the work explores whether improved accuracy can by achieved through retrieval of the skin temperature and explicit consideration of diurnal warming effects.

**ACCOMPLISHMENTS**

1. Based on our previous findings regarding the large biases in the AVHRR sensor for regions of cold SSTs (high latitudes), we are collaborating with Dr. Doug May of NAVO (the AVHRR operational agency and data provider) in order to understand the sources of the cold SST bias in the Navy retrieval algorithm. This is a global algorithm trained with buoy SST data, but since there is sparse buoy coverage at high latitudes, the algorithm fails to capture the unique characteristics of high latitudinal regions leading to the biases. To this end, we have extended the derivation of error statistics for the latest AVHRR sensor on board the NOAA-18 spacecraft. This required construction of a whole new set of satellite-buoy collocated matchups for the period from January 2006 (roughly the beginning of the N-18 AVHRR) through the present. Binned N-18 AVHRR SST – Buoy SST differences as a function of satellite SST are shown in Figure 1 for nighttime (top) and daytime (bottom). The figure reveals a persistent bias for cold SSTs present in the new sensor. This is an ongoing investigation and as such, we do not have a complete understanding as to what is causing the biases. We are required to keep a simpler approach than before based on what NAVO can likely implement operationally.

2. We have been participating in the Diurnal Variability Warming Group (DVWG), a working group within GHRSST-PP and its US counterpart, MISST. The objective of the DVWG is to provide a new consensus model for diurnal warming that can be used within the GHRSST project. Several physically-based models are currently being evaluated for their accuracy and suitability. Through collaborations with Dr. Gary Wick from NOAA/ ERSL, we are currently testing a version of the Kantha and Clayson second moment turbulence closure model (MODKC), as well as an enhanced version of the TOGA COARE warm layer model. For homogeneity in the runs, a comprehensive data set of has been put together consisting of direct measurements of radiative fluxes from SEVERI (MSG satellite) and forcing conditions from numerical weather prediction (NWP) model outputs over the Western Mediterranean Sea at a 0.1 degree resolution. This region was selected in agreement with other NOPP investigators as part of a collaborative study of different diurnal variability models and their associated uncertainties. Model runs are validated using radiometric skin SST measurements and corresponding subsurface temperatures. As part of our involvement in the DVWG, we are concentrating our validation efforts using skin data from the CIRIMS radiometer, provided by Dr. Andrew Jessup (University of Washington).

Specifically, we have addressed the following issues:
- Supplementing the CIRIMS radiometric skin SST data with corresponding environmental data needed to study diurnal warming predictions.
- Explicit evaluation of DW models using CIRIMS data (Figure 2).
- Comparison of temperature profiles from the MODKC model as computed from idealized forcing data (Figure 3).
- Comparison of modeled DW with observations from SEVERI on the Western Mediterranean grid (Figure 4).
- A problem identified is the performance of the MODKC at lower wind speeds. We are currently looking at different turbulence formulations to see if the problem could be solved (Figure 5).

3. Submission of paper to Journal of Geophysical Research describing the results obtained in years 1-3. We just completed a round of revisions and have submitted the revised manuscript.

## FIGURES AND IMAGES

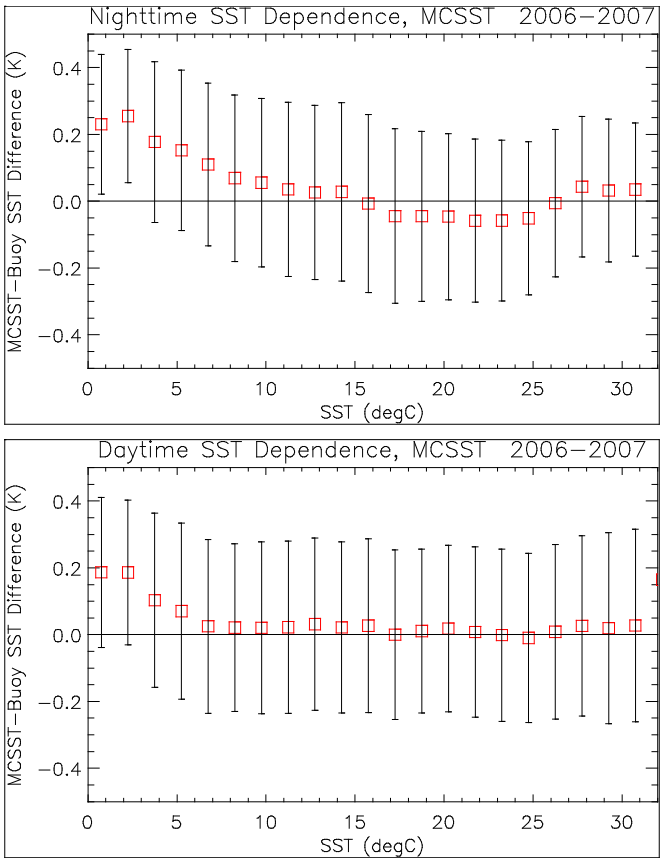


Figure 1. Derived dependence of the N-18 AVHRR SST retrieval error on SST for 2006-2007 based on comparisons with buoy observations. The top figure corresponds to nighttime and the bottom one to daytime observations. The symbols indicate the mean bias and the error bars represent one standard deviation of the observations showing variability of the observed differences.

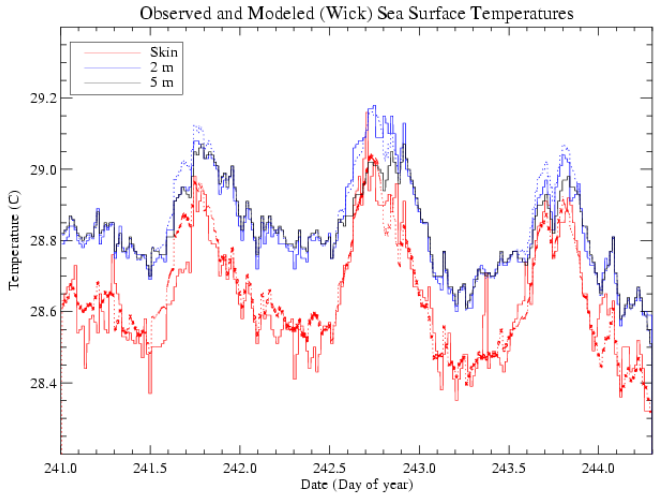


Figure 2. Agreement between DW observations and model outputs computed using full forcing data. The 3-day warming events (warming is through the entire 5-m water column) were captured during a 2003 NOAA cruise between St. Maarten and Florida on board the R/V Ronald Brown. Continuous lines correspond to observations and dotted lines are modeled outputs. Skin SST observations are from the CIRIMS radiometer, 2-m temperatures are from a through-the-hull sensor, and 5-m temperatures are from the R/V Brown's thermosalinograph.

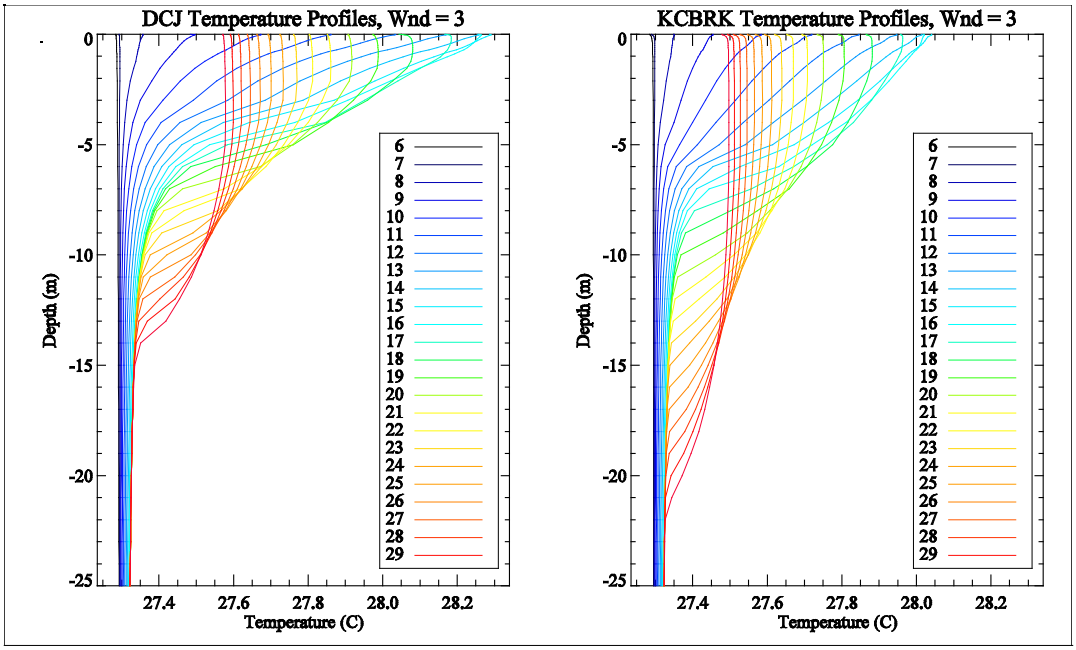


Figure 3. Comparison of temperature profiles on the 25-m depth water column obtained from the MODKC DW model under idealized forcing. Shown profiles correspond to a steady wind of 3 m/s and two different turbulence formulations: the baseline configuration (DCJ) and implementing a new compensation for turbulence due to breaking waves (KCBRK). Simulations expand over 36 hours. Profiles are color coded by hour of day. By introducing wave breaking, the warming decreases at the surface but penetrates deeper into the water column.

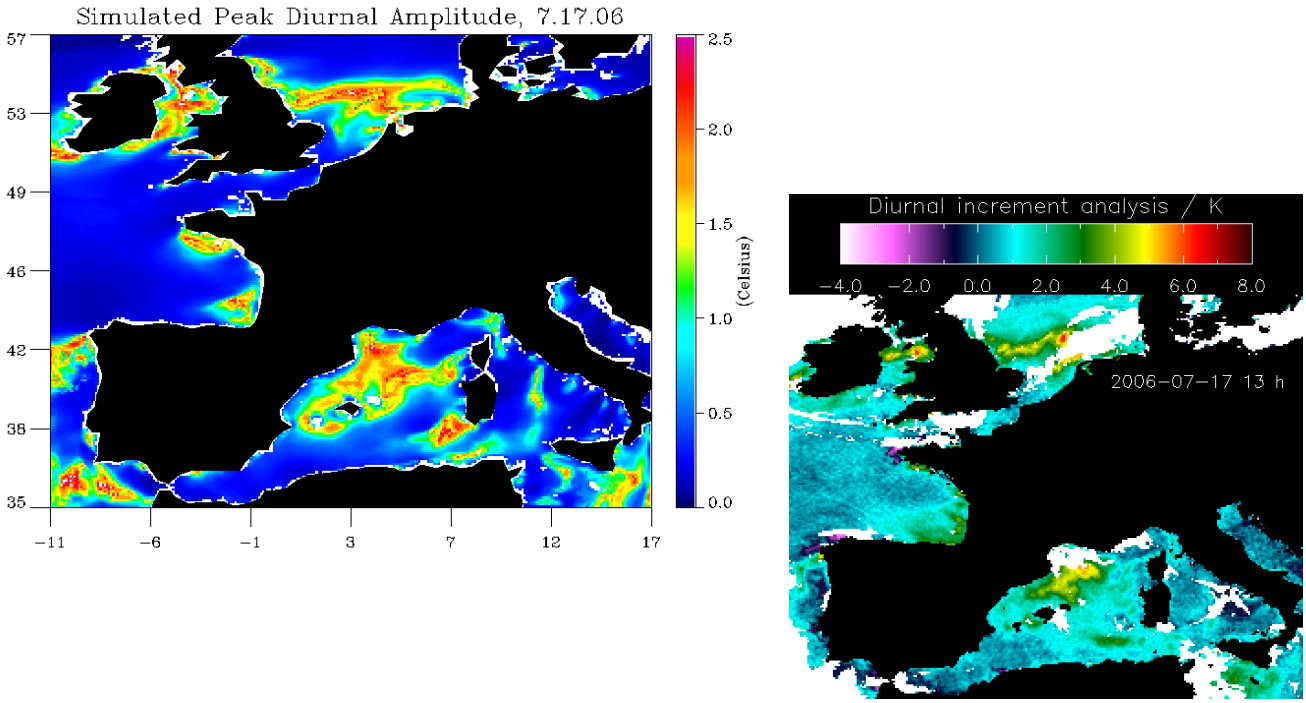


Figure 4. Regional application using modeled forcing data. Represented in the top panel are simulated peak diurnal amplitudes for one day using the MODKC model in conjunction with the KCBRK turbulence scheme run at 0.1-degree resolution on the Western Mediterranean Sea. Peak diurnal amplitudes were computed with respect to the foundation temperature. The model was forced with solar fluxes from SEVERI and turbulent fluxes from ECNWF modeled outputs. The bottom figure represents the corresponding diurnal warming estimated from SEVERI data. Even though there is a strong correlation between model and observations, the peak observed amplitudes are underestimated by the model.

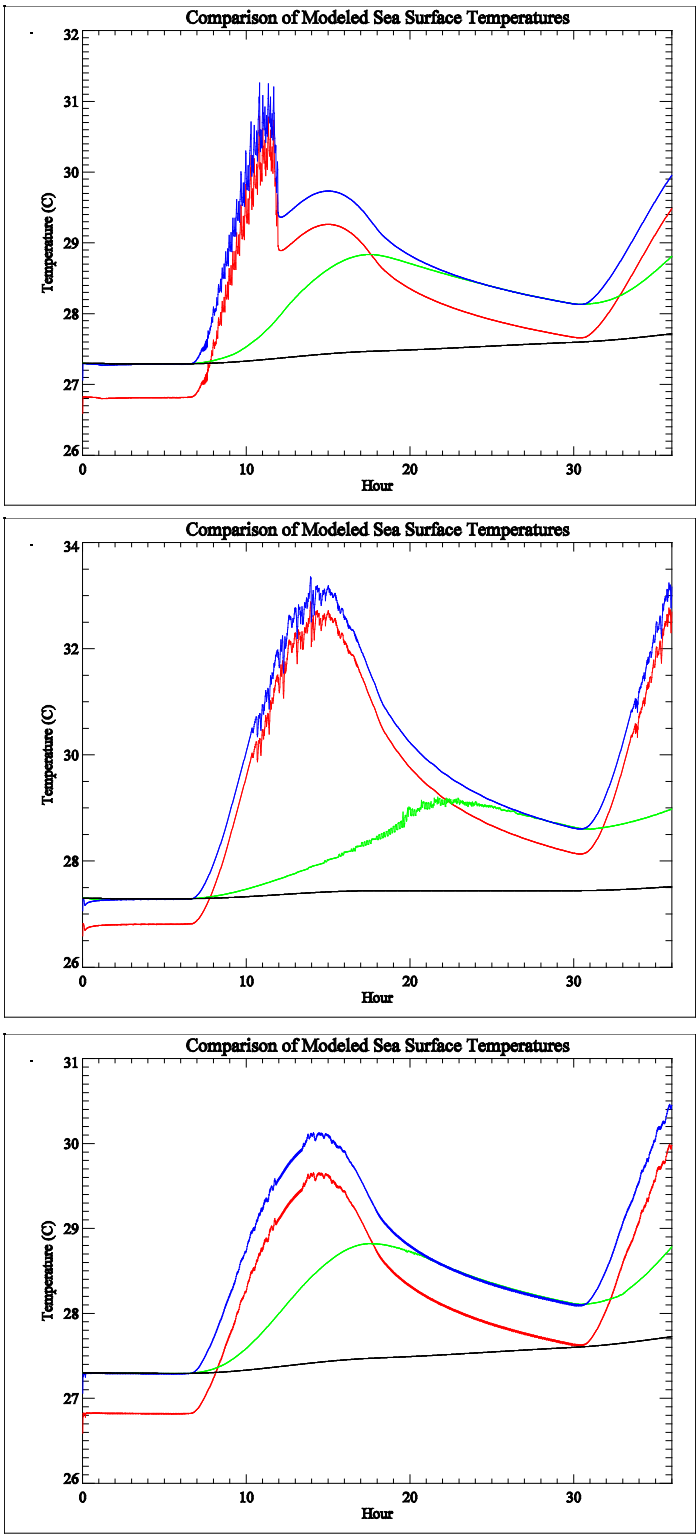


Figure 5. Timeseries of modeled SSTs (Red: skin SST; Blue: subskin; Green: subsurface temperature at 1m depth; Black: subsurface temperature at 5m-depth) obtained from running the MODKC model with different turbulence schemes. Model runs are for 36 hours under idealized surface conditions (Tropical atmosphere, 1 m/s wind speeds, 1000 W/m$^2$ insolation). Top pannel corresponds to the DCJ (baseline) turbulence scheme, the intermediate panel is the result of collaborations with Dr. Andrew Harris from NOAA/NESDIS/OAR, and bottom panel is for the KCBRK (enhanced turbulence due to wave breaking) scheme. The runs exemplify the different degrees of instability of the model at low wind speeds. The latter scheme represents our current best effort at improving the performance of the model at low wind speeds.

## PUBLICATIONS

Castro, Sandra L., Wick, Gary A., Jackson, Darren J., and Emery, William J. "Error Characterization of Infrared and Microwave Satellite Sea Surface Temperature Products for Merging and Analysis", *submitted to J. Geophys. Res.*, 2007.

## SUMMARY OF INTERACTION WITH NOAA

This work was done in close partnership with Dr. Gary Wick and Mr. Darren Jackson from NOAA/OAR/ESRL/PSD.

Additional project partners that we interacted with included scientists of the Office of Research and Applications within NOAA/NESDIS (Dr. Andy Harris and Ms. Eileen Maturi). Future planed impact studies incorporating our results will be conducted by NOAA/EMC within NESDIS.

## SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

Results were presented at the DVWG workshops held in Key Largo, FL in February 2007 and Melbourne, Australia in May 2007. The next DVWG will take place in Edinburgh, Scotland in September, 2007. We will present a related poster in the AMS/EUMETSAT and SEAFLUX meetings in Amsterdam, The Netherlands, following the DVWG workshop. We will be directly working with the NAVO group in Stennis in October 2007 to address the issues with the N-18 AVHRR sensor.

# Application of the Leaf Wax-aerosol Method to Assess Spatial and Temporal Patterns of Carbon Isotopic Fractionation of Atmospheric $Co_2$ by Terrestrial Photosynthesis

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 354
July 1, 2006 through June 30, 2007

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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.

## PROJECT OVERVIEW

Temporal and spatial variations in the concentration and isotopic composition of atmospheric carbon dioxide can be used to estimate the relative magnitudes of the terrestrial and oceanic carbon sinks. Although a powerful approach, sizeable uncertainties in model-derived estimates exist because of our relative lack of understanding of the extent and causes of variability in isotopic fractionation by terrestrial photosynthesis and respiration. An important model parameter is the terrestrial photosynthetic discrimination of $CO_2$ ($\Delta$), yet no satisfactory method exists to measure this on large spatial scales. Terrestrial biospheric discrimination of $CO_2$ ($\Delta$) reflects the integrated consequences of environmental and physiological factors on photosynthetic processes, and the extent to which $\Delta$ varies on global scales can significantly alter model conclusions.

The major goal of this study is to validate and refine a novel "biomarker"-based method I am developing that uses the carbon isotopic composition of higher plant-derived leaf waxes in aerosols to directly estimate $\Delta$ and its temporal variation on large spatial scales. The revised operational plan entails continuous bulk aerosol sampling at three strategically located sites (Bermuda, Barbados, French Guiana) that receive spatially integrated, well-mixed air masses from key regions representative of major ecosystems. This study will produce the first, direct quasi-hemisphere scale data on spatial and temporal variations in terrestrial photosynthetic discrimination of $CO_2$. The data will be used in conjunction with air mass trajectory analyses to improve current estimates of the magnitude and geographical pattern of carbon sinks. Results will additionally provide information on nonvolatile organic aerosols and spatial and temporal variability associated with changing air transport and temporal trends, and thus complement other atmospheric studies of long-range transport of continental emissions and their impact on regional atmospheric chemistry. These products are directly relevant to the NOAA CGCP goal of improving our ability to observe and understand changes in the global environment and the GCC focus on carbon fluxes.

**ACCOMPLISHMENTS**

I have established ongoing aerosol sampling programs on Bermuda (July 04-Aug 06), Barbados Apr 05-present) and French Guiana (Oct 06-present). Collections on Bermuda were made at the Tudor Hill tower (SW end of Bermuda). The open ocean air sector facilitates collection of North American air masses and in summer Northern African air masses. Collections on Barbados are made at the Univ. Miami Ragged Point tower on the eastern end of Barbados. Trade winds in Barbados bring North African air year-round. Sampling in French Guiana is being conducted at the Nouragues field station, a a remote camp located in the pristine, northeastern Amazon rainforest. The prevailing winds sampled at Nouragues blow across an essentially uninhabited region of the Amazon in French Guiana and northeastern Brazil. Sampling will continue in French Guiana until Sept 2007.

The methodology used for aerosol sampling at the Nouragues station is unique. The aerosol filter head has been mounted in a 30 meter tall rainforest canopy tree, with an extension to raise the sampler several meters above the crown (Fig. 1). The canopy platform itself is accessed using a rudimentary cabled walkway extending from the side of a steep hill, where the pump house is located. Our portable sampler is powered exclusively by Nouragues's solar panels and small hydroelectric generator, so there is no local signal contamination. This is the first time a continuous biogenic aerosol sampling campaign has been conducted in the remote Amazon and, as far as I am aware, it is the first time an aerosol sampler has been mounted in a tree and run using exclusively "clean" power generation.

1. First Accomplishment
Generated continuous time-series of bulk carbon and plant wax aerosol molecular and isotopic composition at Bermuda and Barbados. We have received about six months of samples from French Guiana and analysis of these samples is underway. Initial results are excellent, with good signal intensity.

Results to date from Bermuda and Barbados (and data from other continental sites) confirm the large regional scale of the wax aerosol "footprint". Seasonal variations observed in wax aerosol molecular composition and wax d13C in the Bermuda and Barbados samples reflect seasonality in the plant ecosystems sampled (e.g summer/fall increase in plant species having the C4 photosynthetic pathways, decreased C3 plant photosynthetic discrimination during the dry season) as well as seasonal changes in air mass trajectories. As previously observed at Bermuda (1995-1998 sampling campaign), there is minimal correlation between wax and dust loading indicating that waxes are not carried primarily as a component of the dust. This confirms that the long-range transport of plant waxes across the North Atlantic basin is largely independent of Saharan dust transport (although of course, both are carried by African air masses).

2. Second Accomplishment

Photosynthetic discrimination ($\Delta$), derived using the wax aerosol n-alcohol isotopic composition, ranges from 10 to 19.5 ‰ (Fig. 2a). These wax aerosol estimates of $\Delta$ are very consistent with modeled estimates of annual ecosystem discrimination, but importantly the wax aerosols uniquely provide information on temporal variability (shown for comparison in Fig 2b is the annual ecosystem discrimination from the model of Scholze et al., 2003).

At Bermuda, the new wax aerosol data agree well with wax aerosol data previously collected in 1995-1998, but there are also differences providing the first indications of inter-annual variability. The Barbados results are the first detailed seasonal data on the organic composition of biogenic aerosols originating from North Africa. Barbados wax aerosols are isotopically enriched relative to those at Bermuda (and other North American sampling sites), as predicted given the predominance of C4 vegetation in North Africa. At Barbados, there is a 6 per mil seasonal range in the photosynthetic discrimination. The wax aerosol molecular composition suggests that the wintertime minimum in discrimination (nearly a pure C4 plant signature) is caused by enhanced wax emissions during the seasonal burning of C4 cereal crop fields after harvesting, another indication of a major influence of biomass burning on emissions and long-range transport of continental organic carbon.

**FIGURES AND IMAGES**


Figure 1. Atmospheric sampling towers at Bermuda and Barbados, and portable aerosol sampler installation in Amazon rainforest canopy tree in French Guiana. Typical HiVol aerosol samplers are used for the tower sampling. Left photo shows mounting the sampler on the canopy platform and the cabled walkway in French Guiana. Vacuum hose leads to the pump house at the end of the walkway. Bottom right photo shows flagpole designed to raise and lower filter holders (located under rain shield in photo) to change the sample filters.

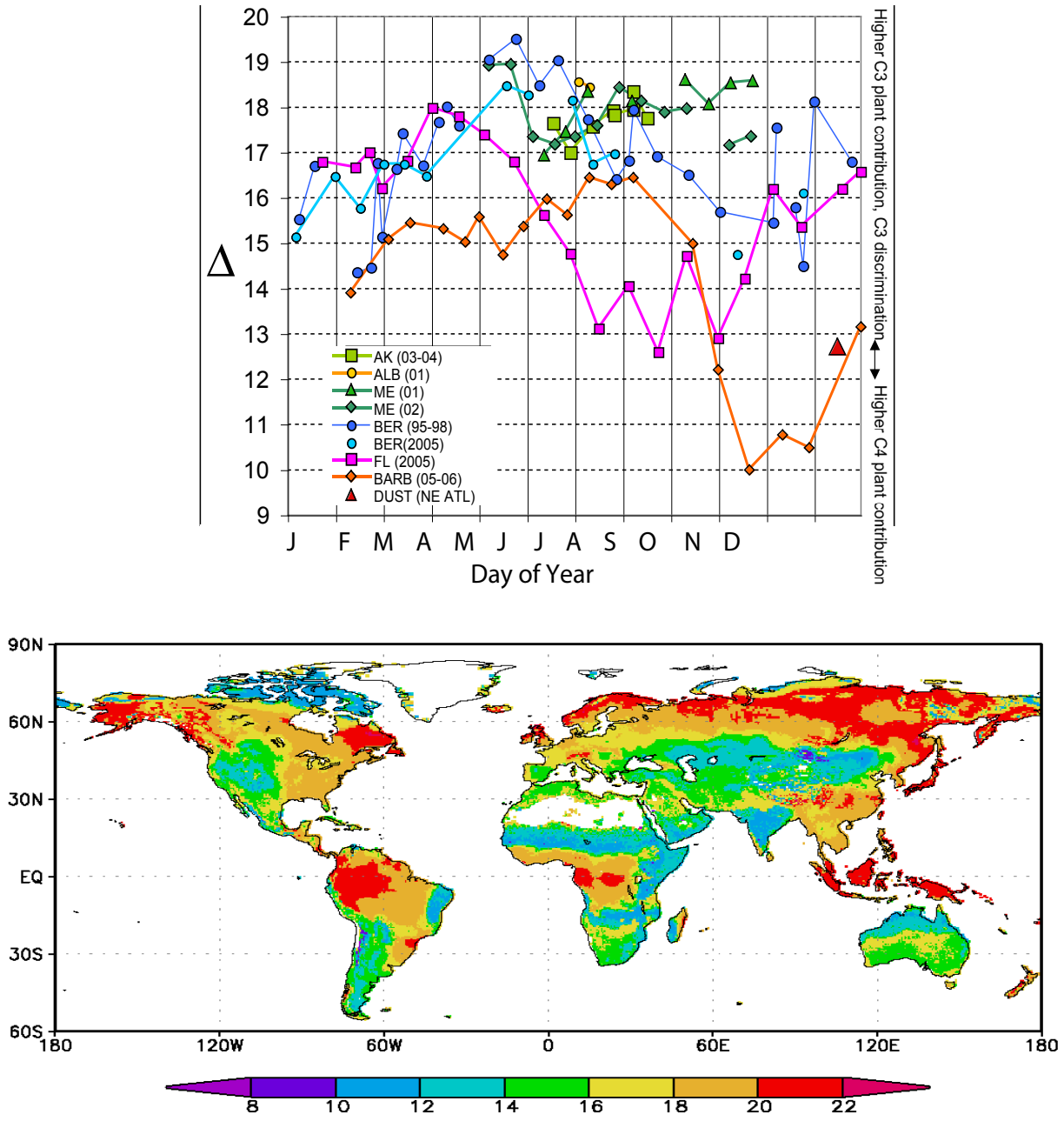


Figure 2. Upper panel: Seasonal patterns in wax aerosol-derived estimates of the terrestrial photosynthetic discrimination (Δ) of source vegetation in continental footprints of Bermuda and Barbados aerosols, and in wax aerosols collected at other North American continental locations. Legend: AK (Alaska tundra), ALB (Alberta, northern short grass C3 prairie), ME (Maine, sub-boreal forest/northern hardwoods), BER (Bermuda- predominately North America witha easterlies from Africa during summer/fall), FL (Florida- North America with southeasterlies in summer/fall), BARB (Barbados-easterlies from N. Africa year-round).
The seesaw variations observed in the Florida record (day 180-170) are caused by shifts in air mass trajectories from westerlies to south easterly flow (higher $\delta^{13}C$ ). At Barbados, the extremely low Δ estimates (day 275-350) correspond with the peak in the (C4) crop burning season in the subSahara.

Lower panel: For comparison, model results of annual ecosystem discrimination (Scholze et al. 2003. Geophys. Res. Lett., 30: 1097)

## PRESENTATIONS/PUBLICATIONS

Conte, M. H. and J. C. Weber. 2007. Large spatial-scale and temporal variability in carbon isotopic fractionation of atmospheric $CO_2$ by the terrestrial biosphere: A plant wax-aerosol proxy approach. NOAA Global Carbon Cycle PI Meeting, Silver Spring, Md., Sep 07.

Conte, M. H. 2007. Assessing large-scale regional and temporal patterns of terrestrial ecosystem discrimination using molecular tracers in continental aerosols. MBL Ecosystems Center Seminar Series, May 07.

Weber, J. C. and M. H. Conte. 2006. Spatial and Temporal Patterns in the Carbon Isotopic Signal of Leaf Wax Aerosols in Continental Air Masses: Linkages with Ecosystem Discrimination. Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract B21E-06.

Conte, M. H. and J. C. Weber. 2005. Quantification of Isotopic Fractionation of Atmospheric Carbon Dioxide by Terrestrial Photosynthesis Using the Carbon Isotopic Composition of Plant Wax Aerosols. Eos Trans. AGU, 86(52), Fall Meet. Suppl., Abstract B13B-02.

## SUMMARY OF INTERACTION WITH NOAA

The project uses the NOAA air trajectory model HYSPLIT to compute back air mass trajectories and establish the potential aerosol "footprint" of each sample.

Dr. Joe Prospero, the director of the NOAA/Univ. Miami collaborative institute, runs the Barbados tower facility and has assisted with logistical support for field activities there.

## SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

The project has sponsored undergraduate and high school students in my lab (Becky Clarkson, Brown University; Don Inglis, Mashpee High School; Rachel Franzblau, Ann Arbor Pioneer High School, Ann Arbor, Michigan). Their main activities have been general laboratory support, computer processing of the organic geochemical data generated by GC and GC-irMS, and use of the NOAA HYSPLIT model to compute back air mass trajectories. The HYSPLIT analyses in particular have given the students a much better appreciation of atmospheric circulation patterns and atmospheric modeling.

# U.S-GLOBEC: NWA Georges Bank—Processes Controlling Abundance of Dominant Copepod Species on Georges Bank

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 409
Dec 1, 2005 through June 30, 2008

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Program Manager: Dr. Elizabeth Turner, NOAA/NOS

Related NOAA Strategic Plan Goal:
Our research has implications that are relevant to NOAAs 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.
Goal 3. Serve society's needs for weather and water information.
Goal 4. Support the Nation's commerce with information for safe, efficient, and environmentally sound transportation.

## PROJECT OVERVIEW

A fundamental goal of Biological Oceanography is to understand how underlying biological-physical interactions determine abundance of marine organisms. For animal populations, it is well known that factors controlling survival during early life stages (i.e., recruitment) are strong determinants of adult population size, but understanding these processes has been difficult due to model and data limitations. Recent advances in numerical modeling, together with new 3D data sets, provide a unique opportunity to study in detail biological-physical processes controlling zooplankton population size. We are using an existing state-of-the-art biological/physical numerical model (FVCOM) together with the recently-processed large 3D data set from the Georges Bank GLOBEC program to conduct idealized and realistic numerical experiments that explore the detailed mechanisms of how local dynamics and remote forcing control lower food web dynamics and dominant zooplankton species in the Georges Bank-Gulf of Maine region. Remote forcing being studied include low-salinity surface water intrusions from the Scotian Shelf (due Arctic ice melt) and NAO-dependent intrusions of deep Warm Slope Water versus Labrador Slope Water through the Northeast Channel into the GB-GoM region. The effects of this remote forcing together with realistic local forcing (from tides, winds, heat flux, local advection and mixing) on nutrient-phytoplankton-microzooplankton-detritus (NPZD) dynamics and population dynamics of dominant copepod species are being studied. Self-sustainability of each species population on the bank itself and in the Gulf of Maine is being examined by controlling immigration from source regions. This modeling study is providing new insights into the role of local and large-scale processes controlling zooplankton abundance in the ocean. The modeled copepods include small species that are the dominant prey for larval cod and haddock in this region, thus providing critical information for concurrent larval fish modeling studies. This detailed, process-oriented, regional-scale modeling with boundary forcing lays the groundwork for integration with models of the entire ocean basin. The resulting model provides a powerful new tool for understanding how local and large-scale forcing interact to control plankton production in the sea.

## ACCOMPLISHMENTS

Although the start date for this project is listed as 12/1/2005, funds were not received at WHOI until late July 2006, and work did not begin until this time. Over the past year, we have made considerable progress toward our goals. We know from the broadscale survey data (Fig. 1) that copepods abundance increased during the GLOBEC years (1995-1999), and that this increase was associated with an intrusion of low salinity water from the Scotian Shelf, the latter being identified from oxygen isotope analysis to originate from the Labrador Sea. The low salinity water had higher chlorophyll concentration (Fig. 1C). The higher copepod concentrations also were associate with higher growth rate and survival of larval cod and haddock (Fig. 1D-E). We believe that the low-salinity water may have been caused by a melting Arctic (Fig. 2), which releases fresher water through the Canadian archipelago that continues on through the Labrador Sea and Scotian Shelf to the GB-GoM region. We hypothesize that this low salinity surface water causes an early spring phytoplankton bloom, leading to early growth of copepods and better feeding environment for larval fish on Georges Bank. In addition, we hypothesize that the NAO induced intrusion of nutrient-poor deep Labrador Slope Water into the GB-GOM through the Northeast Channel will lead to reduced nutrients on Georges Bank and reduced productivity (Fig. 3). To test these hypotheses on remote forcing, together with other hypotheses on local forcings and population sustainability, we developed a biological-physical model (Fig. 4), and are using it in idealized and realistic forcing scenarios. We have completed a full 5-year run for the NPZD-FVCOM coupled model and can generate the seasonal evolution of 3D patterns in nutrients and phytoplankton that are consistent with the field data. We have used this model to conduct the first high-resolution N-budget for Georges Bank water column including scenarios of low-nutrient LSW intrusions (Ji et al., in press). We also examined satellite and field collected data to determine the effects of low-salinity intrusions from the Scotian Shelf on the timing of the spring phytoplankton bloom (Ji et al., accepted). We have completed development of a new "mean-age" copepod population model that is concentration-based and minimizes the effects of artificial numerical diffusion. This development is significant as it allows for the use of concentration-based population models in complex 3D models. We completed a model run for the copepod Pseudocalanus for the first GLOBEC field year, 1995 (Fig. 6). During the next phase of this project we will complete the model runs for *Pseudocalanus* for 1995-1999 and will model the other dominant copepod species (*Calanus finmarchicus, Centropages typicus, Centropages hamatus*).

## FIGURES AND IMAGES

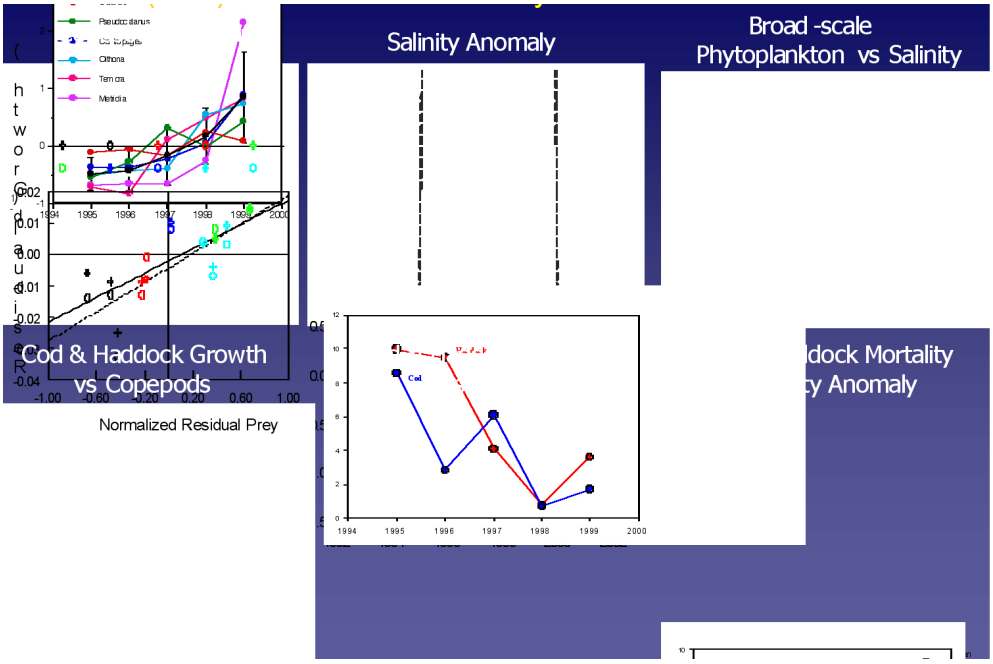


**Figure 1**. Broadscale survey results. A. Mean GB copepod abundance from 1995. B. Salinity anomaly 1992-2002 (dashed lines bracket GLOBEC years), C. phytoplankton vs salinity, D. larval fish growth vs prey abundance, E. larval fish mortality vs year, F. larval fish mortality vs salinity anomaly.

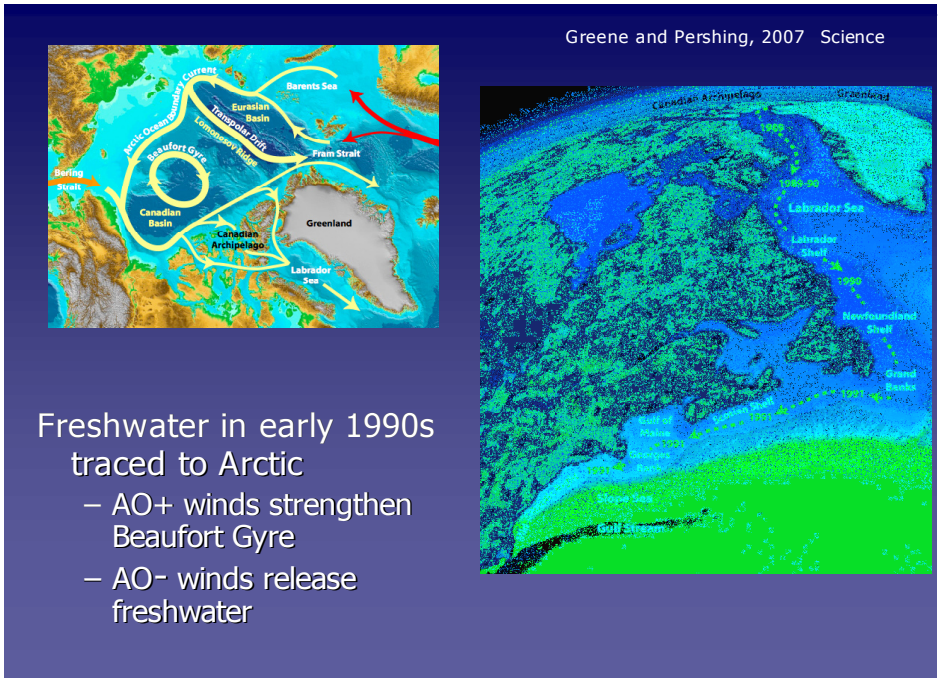


**Figure 2.** (Left Panel) The Arctic's Beaufort Gyre can accumulates or releases low-salinity melt water depending on the phase of the Arctic Oscillation. (Right Panel) The transit time for Arctic melt water to travel from Baffin Bay to the GB-GoM region is 2 years.

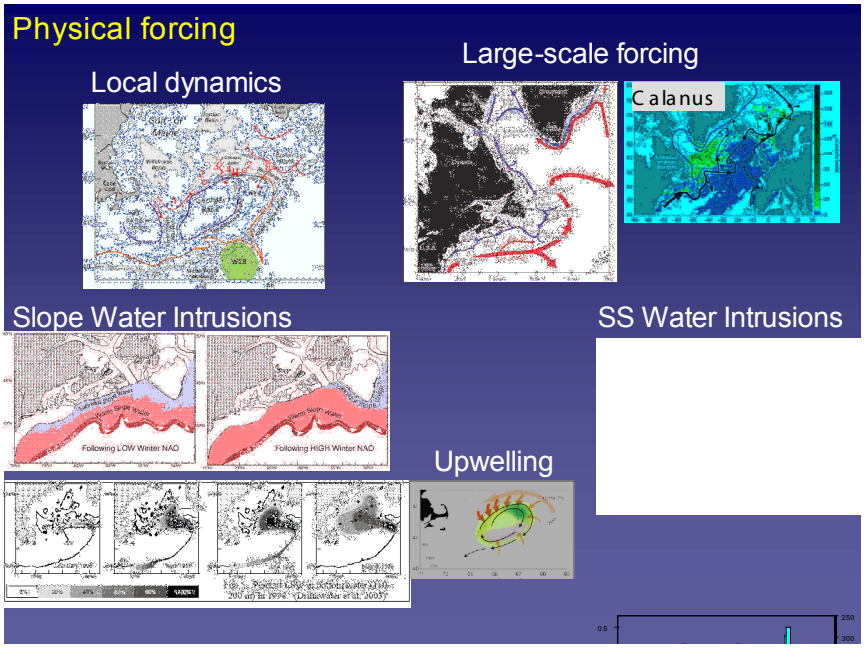


**Figure 3.** Local and remote forcing on plankton by hydrography, currents, and nutrient input into the GB-GoM region. (upper left) Local forcings include tides, winds, mean flows, and mixing. (other panels) Remote forcing include surface and deep intrusions of water from the Labrador Sea. Deep Labrador Slope Water is relatively poor in nitrate and its intrusion is NAO – related.

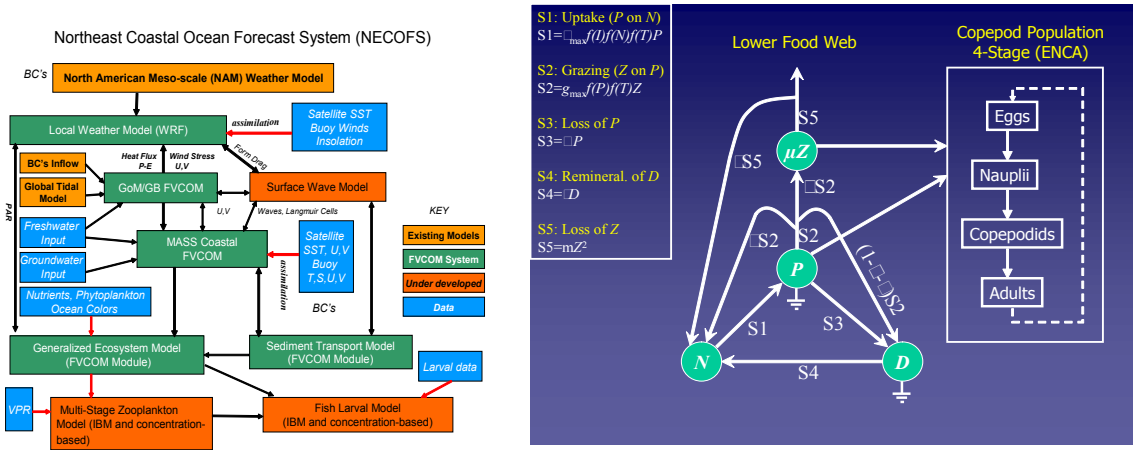


**Figure 4**. Model schematics for physical (left) and biological (right) models.

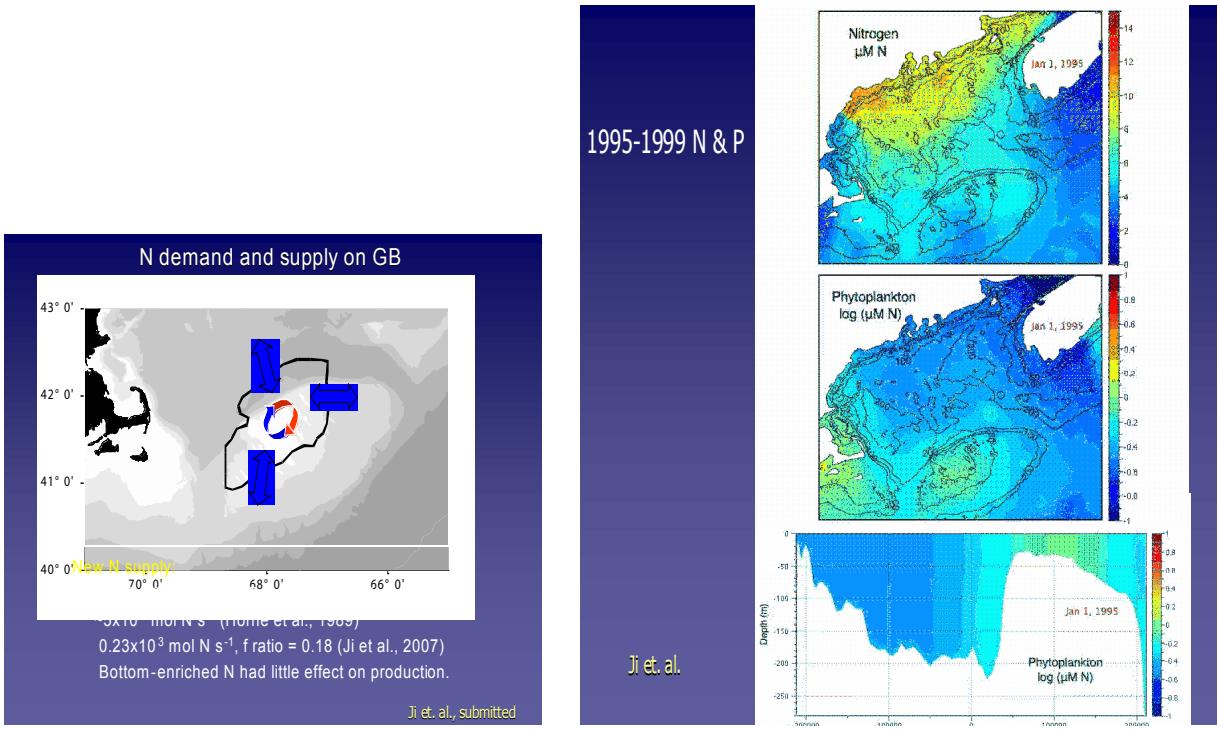


**Figure 5**. Example of 3D, NPZD-FVCOM output (right). This model was run through the GLOBEC years from 1995-1999. The model was used to compute the N-budget for Georges Bank (below) and effects of LSW intrusions.

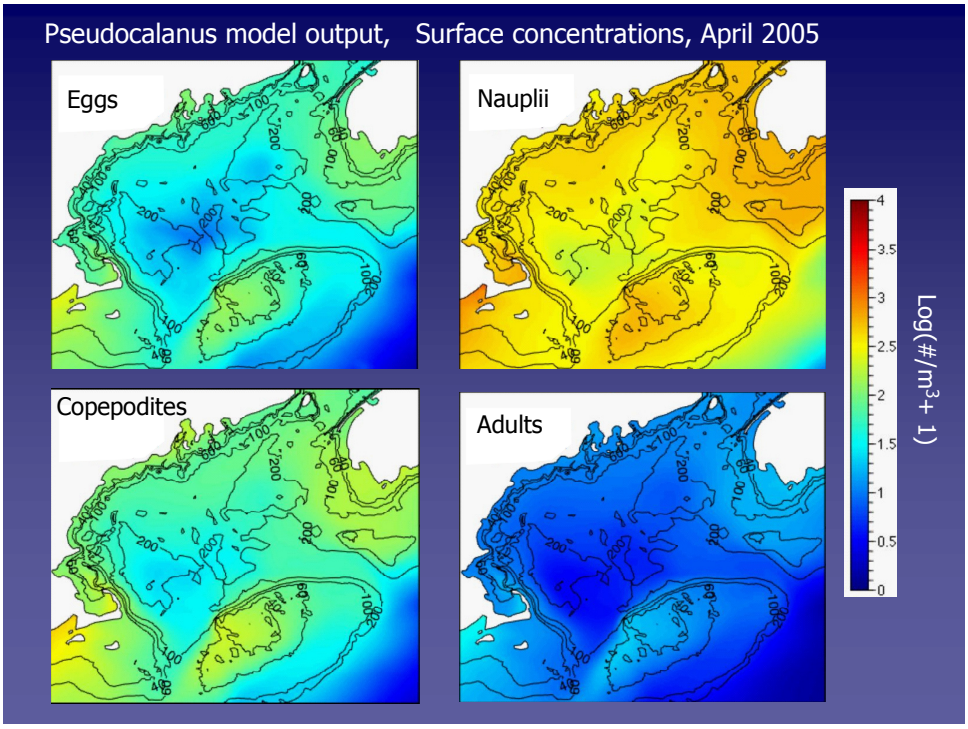


**Figure 6**. Example of copepod model output. The mean-age copepod model was coupled with the NPZD-FVCOM model and run during the first GLOBEC year, 1995. The model was able to reproduce the 3D distribution of *Pseudocalanus* observed in the field data.

## PUBLICATIONS

Hu, Q., C. Davis, and C. Petrik. A simplified age-stage model for copepod population dynamics. *Mar. Ecol. Prog. Ser.* (accepted with revision)
Hu, C., and C. S. Davis. Normal versus Gamma: Stochastic model of copepod molting process. *J. Plankton Res.* (accepted with revision)
Ji, R., C. Davis, C. Chen, R. Beardsley. Influence of local and external processes on the annual nitrogen cycle and primary productivity on Georges Bank: A 3-D biological-physical modeling study. *J. Mar. Systems* (in press)
Ji, R, C. Davis, C. Chen, D W Townsend, D G Mountain, R C Beardsley. Influence of ocean freshening on shelf phytoplankton dynamics. *Geophys. Res. Let.* (accepted)
Ji, R., P. J. S. Franks. 2007. Vertical migration of dinoflagellates: model analysis of strategies, growth, and vertical distribution patterns. *Mar. Ecol. Prog. Ser.*, 344, 49–61.

## SUMMARY OF INTERACTION WITH NOAA

Davis has made several presentations on the progress of this project to NOAA personnel on the US GLOBEC Scientific Steering committee at their semiannual meetings (10/2006 and 5/2007). He also presented part of this work during an overview presentation for the Pan-Regional GLOBEC meeting in Boulder, CO, 11/27-30/2006 and to Drs. Steve Murawski and Elizabeth Turner (NOAA) following the CAMEO meeting in Falmouth, MA (June 2007). Davis presented a portion of this work to the ICES WGZE meeting in Riga, Latvia (March 2007) and to the IMBER modeling meeting in Cadiz, Spain (March, 2007). Davis and Ji also presented this work at the Zooplankton Symposium in Hiroshima, Japan (May-June 2007) and at the Gordon Conference on Coastal Ocean Modeling in New London, NH June 2007 Chen and Ji also made presentations on their subcomponents of the project to NOAA personnel at national meetings and at the SSC meetings.

## SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

We have developed websites for the project for access by the educational (K-College) and public sectors:
http://www.whoi.edu/sbl/liteSite.do?litesiteid=5935
http://fvcom.smast.umassd.edu/research_projects/GB/index.html
Davis has made presentations on this project and GLOBEC NWA program in general to public audiences (e.g., business professionals at the Harvard Club breakfast, Dec 2006). Chen's lab at UMASSD SMAST is linked to the SEA LAB Marine Science Education Center, a part of the New Bedford public school system. As our research progresses we will work with SEA LAB and the NSF-funded Center for Ocean Sciences Education Excellence– New England (COSEE-NE) staff to disseminate this material to the larger educational community.

# Automatic Detection and Identification of Rockfish and their Habitats from Underwater Images Collected by the Seabed AUV and Video Observer Monitoring of Commercial Fishing Vessels

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 408
June 1, 2006 through May 31, 2007

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Program Manager: Dr. Elizabeth Clark, NOAA/NMFS etc.

Related NOAA Strategic Plan Goal:
Goal 1. Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.

## PROJECT OVERVIEW

The mission of this project is to develop an automated image analysis and pattern recognition system to automatically process digital images collected by SeaBed AUV and electronic observer monitoring system. The system includes two components: fish detection and fish classification. Fish detection is used to extract (segment) the fish image from the background. Fish classification is used to separate fish into different groups using supervised learning.

## ACCOMPLISHMENTS

We have three major achievements after releasing our first report. We collected videos from electronic observer monitoring system, configured the Matlab interface to read video files, and developed a fish detection algorithm on the video files and tested the algorithm on one of the video files

*1. Video Collecting*
We had regular email and phone exchanges with Howard McElderry at Archipelago Marine Research Ltd (AMR) and scientist Jonathan Cusick at Northwest Fisheries Science Center. We met Morgan Dyas from Archipelago Marine Research Ltd at Cape Cod Commercial Hook Fishermen's Association, Chatham, Massachusetts to check out the electronic monitoring systems and get high quality video files from electronic monitoring system. We exchange ideas with him and Richard Rees to make the electronic monitoring systems works better.

*2. Configure the Matlab interface to read video files*
After trying several options to read video files under Matlab environment, we ended up with using "mplayer" as the media player and Matlab wrapper files developed by Ashwin Thangali from Boston University under Linux

operation system. The configured system is able to read video files provided by Archipelago Marine Research Ltd on electronic monitoring system in Matlab interface. Since Matlab toolbox only provides to read raw AVI video files, it is non-trivial task to set the system up. Out of 4 video files provided by Archipelago Marine Research Ltd, I am able to read 2 of them under the Matlab environment. I suspect that the other two files are too big.

*3. Implement a fish detection algorithm on the video files:*
We developed a fish detection algorithm that includes the following 5 components (ref. Figure 1).
a. Background subtraction: The videos were turned on at the moment when the fishing activity began. There is a time interval between the start time of fishing activity and the first fish being caught. This time period is used to estimate the background image of fishing boat. The mean of first 2000 frames are calculated and subtracted from the consequent videos.
b. Segmentation: The background image is subtracted from all the video frames after first 2000 frames. The resulting video frames are transformed into gray-scale images. The global threshold value is calculated by Otsu's segmentation method. This threshold value is used to segment the frame into foreground and background image.
c. Optimal window selection: Due to the cluttered nature of fishing environment, it is desirable to only consider part of the video frame as region of interest. An optimal window is selected based on the visual inspection of the fishing activity videos. An optimal window is defined as a region of interest where it is best to separate the fish from the background.
d. Motion detection: The algorithm checks the overlap between the segmented blobs and the optimal window. If the overlapping blobs exceed certain size threshold, they are considered as fish. A bounding box is derived from the blob, and it is used as a mask. The masked region on the background subtracted image is saved out as tiff file with the frame number as part of the filename.
e. Fish count: The filenames are analyzed by a script and the frame numbers are recovered. If the difference between two consequent frame numbers is below a threshold, these two images are considered as the same fish.

*4. Test results:*
We tested the above algorithm on one of the video files named "Southern_Dawn_close_camera_view.dvi". There were 1655 files saved out as fish images. Out of these 1655 files, the fish count program counts 703 fishes. Most of them are false positives due to other moving components (such as fish line, porch, and waves) and high compression ratio. The example images are given in Figure 2.

## FIGURES AND IMAGES

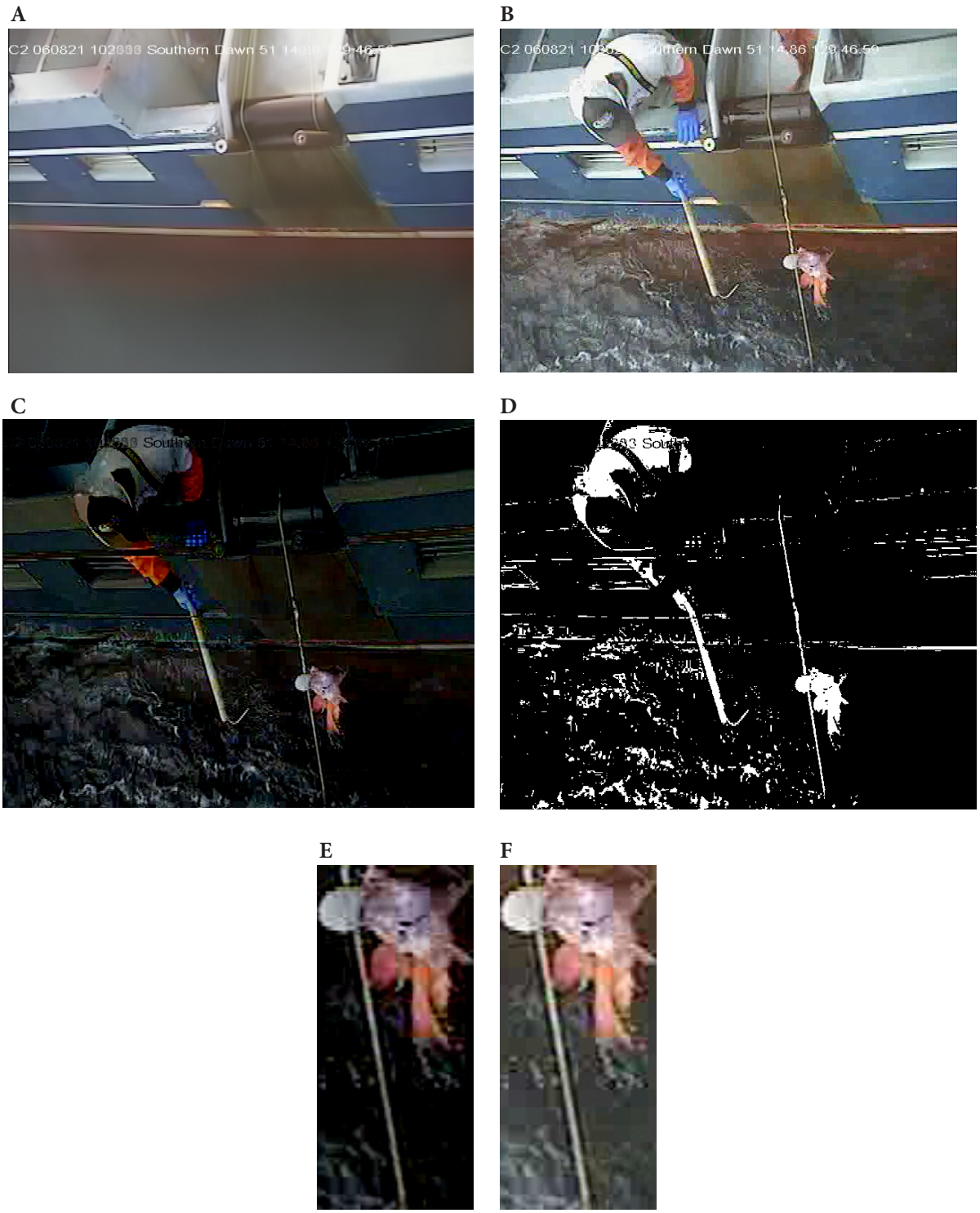


Figure 1. Fish detection results of electronic monitoring system. (A)background image, (B)original frame, (C) original frame with background subtracted, (D) segmented frame of (C), (E) fish extracted from background subtracted frame (C), (F) fish extracted from original frame (B)


Figure 2. Fish detection results of electronic monitoring system. (A)-(M) image gallery of automatic fish detection system.

## FUTURE DIRECTION

Although the above algorithm shows very some promising results, there are several hurdles need to be overcome before the system to be fully operational.

1. Probability of detection and probability of false alarm
The probability of detection and probability of false alarm need to be quantified. I optimized the parameters on the video file which did not have manual counting results. This step is relatively easy with corporation from AMR.

*2. Relative high false alarms*
Although I did not have detailed counts on the video file I investigated. My best estimate is that there are between 200 to 300 fishes caught on that video. This yields 2 out of 3 fishes detected are false alarms. There are two ways

to tackle this problem. First approach is to try to fine tune the free parameters in the system to further reduce false alarm rate. Second approach is to separate fish and non-fish with classification. Both approaches should be investigated.

3. A unified framework
Different fishing boats tend to have different camera settings. The optimal windows are very different from different video files. Furthermore, different videos have different image quality. A unified framework is need to process generic video files. Otherwise, minor human interference is needed.

*4. Multiple shots*
When the classification approach is used to separate the segmented images into different categories, strategies need to be developed to be able to take advantage of multiple shot of single fish. I suggest using classifier voting system.

5. *Image from original frame versus background subtracted frame*
In current version, the region of interest is saved out from background subtracted frames. It is very easy to switch to save out from original frames. A comparison is needed to compare the classification accuracy of images from original frames versus background subtracted frames.

6. Video image quality
The video image quality is fairly low as shown in Figure 2. It would be very helpful both the fish detection and fish classification to reduce the compression ratio. The tradeoff between video image quality and the fish classification accuracy needs to be investigated.

**SUMMARY OF INTERACTION WITH NOAA**

I exchanged emails and phone conversation with Dr. Cusick regarding what needs to be done on electronic observer monitoring system.

# Quality Assurance of Real Time Oceanographic Data (QARTOD) IV Support

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 392
April 1, 2006 through March 31, 2007

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Program Manager: Mr Mark Bushnell NOAA/NOS, etc.

Related NOAA Strategic Plan Goal:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.
Goal 3. Serve society's needs for weather and water information.

## PROJECT BACKGROUND

QARTOD is a continuing multi-agency effort formed to address the quality assurance and quality control issues of the Integrated Ocean Observing System (IOOS) community. The first workshop was held at the NOAA NDBC office in Bay St. Louis, MS in the winter of 2003. Over 80 participants attended with the primary task to develop minimum standards for calibration, QA/QC methods and metadata. The workshop resulted in a report which summarized the recommendations on these issues and on future workshops. QARTOD II (second workshop) was held February 28-March 2, 2005 in Norfolk, VA, and focused on QA/QC issues in HF radar measurements and wave and current measurements' unique calibration and metadata requirements. QARTOD III was held on November 2-4, 2005 at Scripps Institution of Oceanography, La Jolla, CA. It continued the work on waves and current measurements, as well as commencing work on CTD measurements and HF Radar. QARTOD IV was held at the Woods Hole Oceanographic Institution, June 21 - 23, 2006. Related materials, including the QARTOD IV final report, are posted on the QARTOD website: http://qartod.org.

## ACCOMPLISHMENTS

The QARTOD IV workshop addressed the challenges related to the collection, distribution and description of real-time ocean data. One of the primary challenges facing the oceanographic community will be the fast and accurate assessment of the quality of the data streaming from the IOOS partner systems. Operational data aggregation and assembly from distributed data sources will be essential to the ability to adequately describe and predict the physical, chemical and biological state of the coastal ocean. These activities demand a trustworthy and consistent quality description for every observation distributed as part of IOOS. The intent of QARTOD IV was to report on the recommended quality descriptions for parameters such as waves and currents and to develop guides to best practices to assure data quality.

The workshop focused participants into the following areas of interest: waves, in situ currents, CTD measurements and dissolved oxygen. The waves and currents groups reported on results from previous workshops on testing data quality and defining flags for real-time release of data. Efforts began at QARTOD IV to define best practices and shared resources for promoting quality assurance. The CTD group was reorganized and the dissolved oxygen group was newly formed. Metadata experts from the Oceans.US/DMAC guided each group towards the development of minimum standards in metadata within their particular area of focus.

A host of guest speakers presented other existing efforts promoting the development of national and international standards for QA/QC in real-time oceanographic data.

The workshop was funded by NOAA with support from Oceans.US and the WHOI CICOR office. Facilitators from NOAA NOS Special Projects Office provided support in organizing workshop materials and reporting the proceedings within each break out group.

With support from a pending RCOOS award (2008-2010) from the NOAA Coastal Services Center administered through the CICOR office, the results of the QARTOD IV workshop will be integrated into the developing standards of the Open Geospatial Consortium (OGC) Sensor Observations Service (SOS) framework. The QA/QC standards and services will be demonstrated by integration with the OOSTETHYS project (www.oostethys.org). The tools, vocabularies and guides will be made publicly available through the Marine Metadata Initiative web site (www.marinemetadata.org).

# Economic Impact of the 2005 Red Tide Event: A Spatial and Dynamic Analysis

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 399
June 1, 2006 through May 31, 2007

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Program Manager: Michael Jeck NOAA/NMFS

Related NOAA Strategic Plan Goal: Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.

## PROJECT OVERVIEW

Over the last several decades, harmful algal bloom (HAB) events have been observed in more locations than ever before throughout the United States. The 2005 bloom of *Alexandrium fundyense* was the most widespread and intense in New England waters since a similar event more than three decades ago. In this study, using historical data from the National Marine Fisheries Service, the Massachusetts Division of Marine Fisheries, and other sources, we develop estimates of the direct economic impacts of the 2005 event on commercial shellfish fisheries in Maine and Massachusetts. Results of our regression analyses suggest that the 2005 event had broad spatial and temporal effects on the shellfish market. In response to a supply shortage resulting from local closures, there was an increase in shellfish imports to New England during the red tide. Further, shellfish closures in Maine were the most likely cause of observable price changes on the Fulton Fish Market in New York.

## ACCOMPLISHMENTS/PROGRESS/STATUS

Existing impact assessments of HAB events are often rough estimates based on limited observation or hypothetical events. In most cases, we do not have a good understanding of the economic effects of red tide events. From a management perspective, however, it is important to measure the scale of the economic costs to society of HAB events.

We develop estimates of direct economic impacts of the 2005 event on commercial shellfish fisheries in Maine and Massachusetts using methods that are consistent with economic theory and data from NMFS, DMF, and other sources. Our results indicate that the low-end estimate for total direct impacts in Maine was $2.4 million including lost revenues in the softshell clam and mussel fisheries. The total direct impacts on commercial shellfish industry in Massachusetts may be as high as $18 million. However, because of serious data limitations, the estimated direct impact on Massachusetts harvesters should be viewed with caution. To improve estimates of HAB impacts in Massachusetts, it will be essential to construct a baseline of monthly shellfish landings so that HAB impact assessments may focus on the relevant months. For the same reason, daily data would further improve the precision

of our future estimates. We have shown that impact estimates are affected by baseline values of non-HAB years. An accurate impact estimate requires a relatively stable baseline using data from recent years.

We have identified two broader effects of the 2005 red tide event on shellfish market. First, the event led to an increase in shellfish imports to fill the supply-demand gap resulting from declines in local harvests. This implies that indirect impacts of a HAB-event on the seafood industries may be partially mitigated by rising supplies from alternative market channels. Second, we have shown that HAB impacts on softshell clam prices are spatially linked: the shellfish closures in Maine may result in price changes in New York.

Figures and Images

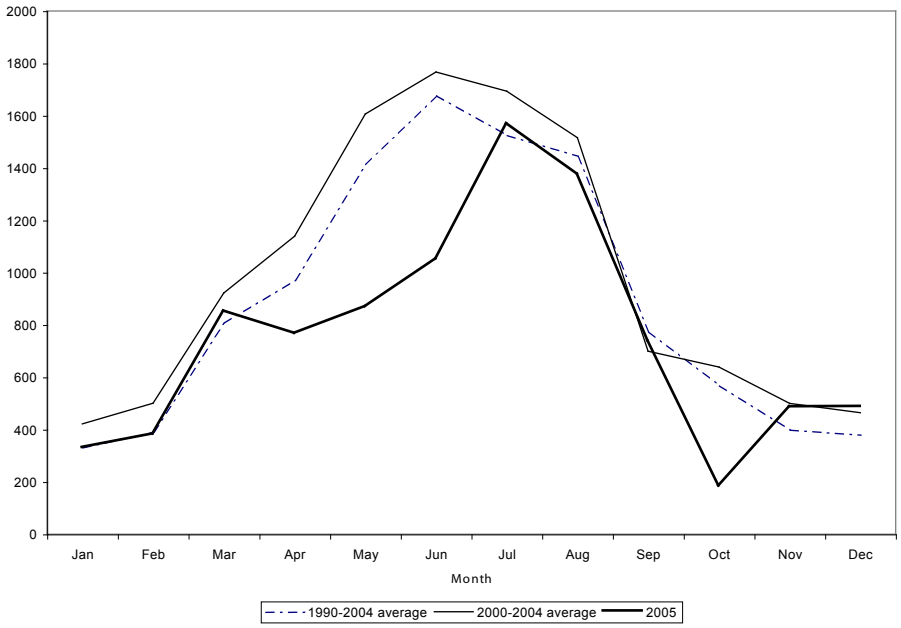


Figure 1. Monthly Softshell Clam Landings in Maine: Baseline *versus* 2005
The softshell clam peak harvest season is from May to August. Considerable declines in the quantity of landings occurred from April to August of 2005 with the largest drops of 737 thousand pounds (46%) and 715 thousand pounds (40%) in May and June, respectively.

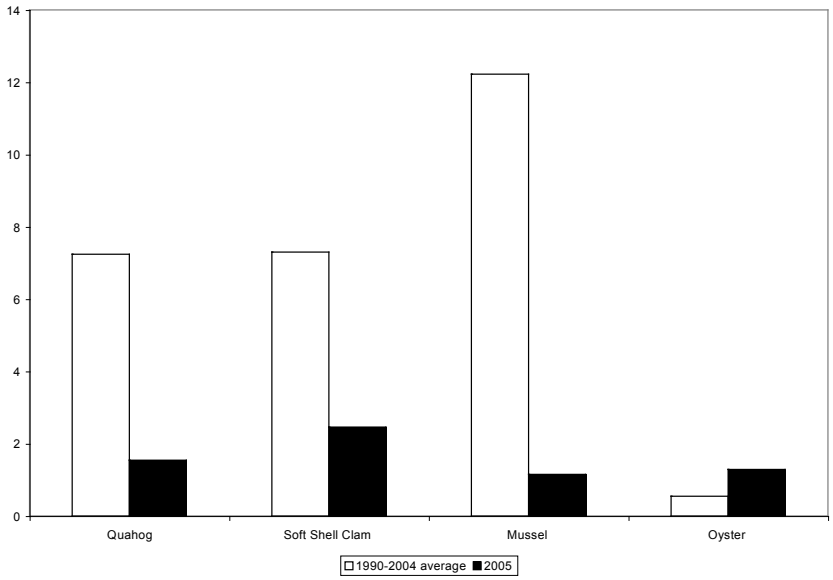


Figure 2. Changes in Annual Shellfish Landings in Massachusetts:
Baseline *versus* 2005

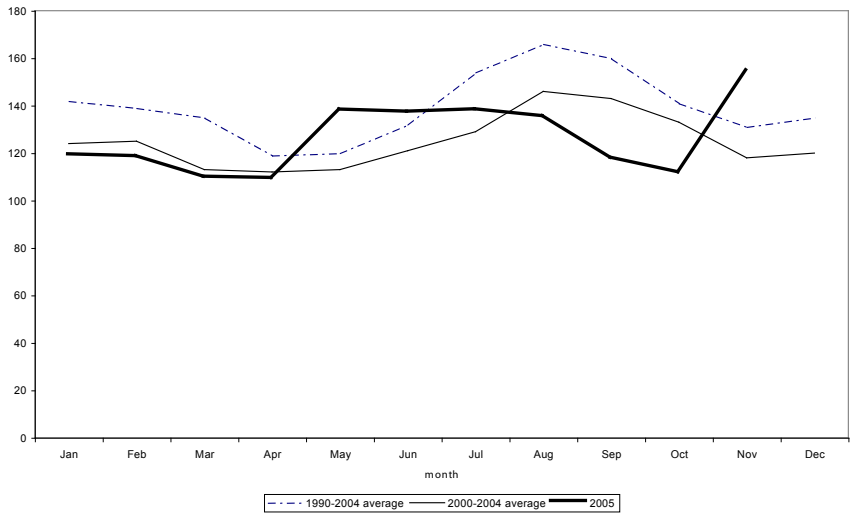


Figure 3. Softshell Clam Wholesale Prices on New York Fulton Fish Market: Baseline *versus* 2005

The price was higher than normal during the early stages of the red tide event (May and June), possibly due to supply shortages from Maine, and lower than normal during the later stage of the event (August through October), possibly because of consumer concerns of seafood quality resulting from negative media publicity. Another possible cause for the price drop is that when the New York market expected supply to be limited all summer, wholesalers switched to other sources to ensure a stable supply.

Publications

Jin, D., E. Thunberg and P. Hoagland. 2007. Economic impact of the 2005 red tide event on commercial shellfish fisheries in New England. *Ocean and Coastal Management*, Submitted.

Summary of Interaction with NOAA

This was a collaborative research project with NOAA. Eric Thunburg at the Social Sciences Branch of the Northeast Fisheries Science Center worked closely with Di Jin and Porter Hoagland at WHOI Marine Policy Center throughout the project.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

***Relevant presentations***:

Jin, D. 2006. "Economic Impact of the 2005 Red Tide Event: Project Description and Some Preliminary Results." Presented at the MIT Sea Grant Symposium on the *Alexandrium* Red Tide of 2005 in Cambridge, MA (April 18).

Hoagland, P. 2006. "The Public Policy of Harmful Algal Blooms." Presented at the 12th International Conference on Harmful Algae, Copenhagen, Denmark (4 September).

Hoagland, P. 2007. "Economic Impacts of Harmful Algal Blooms." Presented at the 2007 Gordon Research Conference on Mycotoxins and Phycotoxins, Colby College, Waterville, Me. (21 June).

Hoagland, P. 2007. "From Jubilees to Halos: Clarifying the Economic Effects of Harmful Algal Blooms (HABs) on Commercial Fisheries." Presented at the American Fisheries Society-Sea Grant Symposium "Mitigating Impacts of Natural Hazards on Fishery Ecosystems" at the 2007 AFS Annual Meeting, San Francisco, Calif. (5 September).

***Contributed to***:

Program Planning and Integration (PPI). 2007. *Economic Statistics for NOAA*. Washington: Office of the Chief Economist, NOAA, US Department of Commerce (DRAFT). [Section on HAB Impacts.]

# Marine Resource Endowment, Regulation and Geographic Concentration in New England Seafood Industries

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 398
July 1, 2006 through December 31, 2006

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Program Manager: Michael Jeck NOAA/NMFS

Related NOAA Strategic Plan Goal: Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.

## PROJECT OVERVIEW

The effect of fishery resource conditions and fishery regulation on fishing and fishing-related infrastructure has been a contentious issue in the Northeast region (coastal states from Maine to North Carolina) of the United States. In this paper we apply statistical models developed in the economic geography and location choice literature to examine the spatial distribution and changes in the relative importance of marine related sectors. These models were applied to employment data for the 1986 to 2004 time period obtained from County Business Patterns. Major adjustments to these data were required to account for data suppression and changes in industrial classification schemes. Findings demonstrate that (1) employment in marine fishing and fishing-related industries represent a small proportion of regional employment; (2) there was a slow declining trend in marine sector employment; (3) there were considerable spatial and temporal variations in employment changes in the marine sector; and (4) marine sectors are more geographically concentrated than other non-marine sectors, and that geographic concentration has been shifting over time.

## ACCOMPLISHMENTS/PROGRESS/STATUS

Examination of the spatial distribution and changes in marine related sectors over time indicates that (1) marine sector employment is a relatively small component of the regional economy; (2) there is a slow declining trend in employment in the marine sector; and (3) considerable spatial and temporal variations have occurred in marine sector employment.

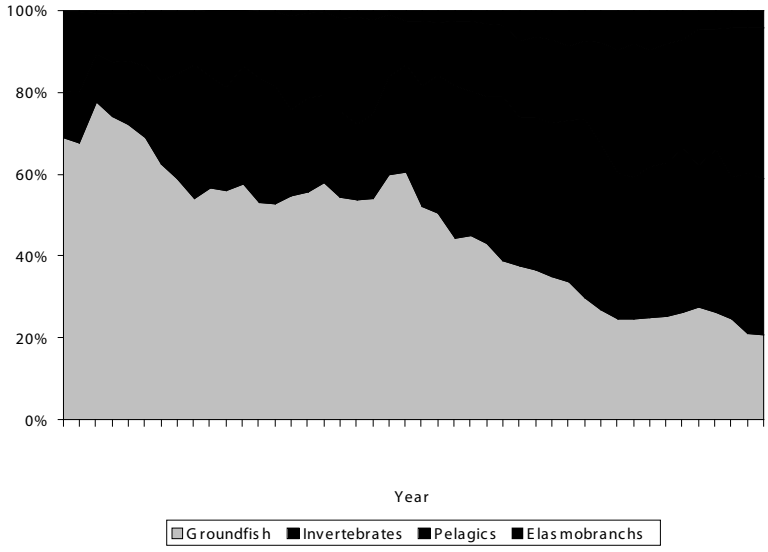
Our analysis of geographic concentration shows that marine industries are more concentrated than other industries due to natural (geographic) advantage, and that significant changes have occurred in the levels of agglomeration in different marine industries. While the level of concentration has been declining in the marine resource sectors (e.g., marine seafood and marine water transportation) over the longer run (1986-2004), a rising trend appears to be evident in more recent years (1998-2004). That is, systematic contraction in the marine resource sector (including marine fishing, marine seafood, and marine water transportation) has been less than one percent per year and the dispersion effect was quite strong (4.8%) between 1998 and 2004. This means that the declining trend in traditional marine resource industry centers has been halted, and has even been reversed in some marine sectors since the late 1990s. In the meantime, new centers are being created (as shown by the dispersion effect).

Our analysis demonstrates the importance of taking a broader view of adjustment processes in fishing and fishing related industries rather than focusing solely, as is often the case, on changes in a single state or a single fishery. The general finding that fishing related marine sectors have largely stabilized in the Northeast region as a whole, but that some centers of marine activity are declining while others are being created is consistent with long term trends in landings of seafood products. That is, aggregate landings have been relatively stable, while changes in the species composition of the catches has favored centers of fishing and fishing-related activity that harvest/process species on the rise while placing centers that harvest/process species on the decline at a competitive disadvantage. This perspective is particularly useful when examining the cumulative effects of resource or regulatory change. This broader context for analysis does not change the fact that depressed resource conditions and the regulatory environment designed to rebuild those resources may have localized effects.

Analysis of marine sector employment indicates that the fate of fishing and fishing-related sectors in Maine differs from that of most other states. Employment in the marine seafood sector in Maine declined by more than 8% per year during 1998 to 2004 whereas the marine seafood sector in all other New England states increased by at least 2% per year. The observed decline in marine seafood employment may have been offset by the general increase in ship/boat building in Maine but this too has differential effects throughout Maine since the ship/building sector tends to be highly concentrated whereas the marine seafood sector is less geographically concentrated. Thus, while marine-related employment in Maine communities in which ship/boat building is an important industry may have increased over time, marine-related employment in other coastal Maine communities has been declined. In fact, the general decline in marine seafood industries in Maine has prompted concerns over the loss of fishing and fishing-related infrastructure and waterfront access, especially over the prospect that conversion of waterfront land use will curtail Maine's ability to take advantage of increased supplies of seafood once fishery resources have recovered. Note that this concern is not unique to Maine as increasing coastal land values for non-marine dependent uses throughout the Northeast provide incentives for land owners to sell out when the income from seafood-related industries is not sufficient to keep land in its current use.

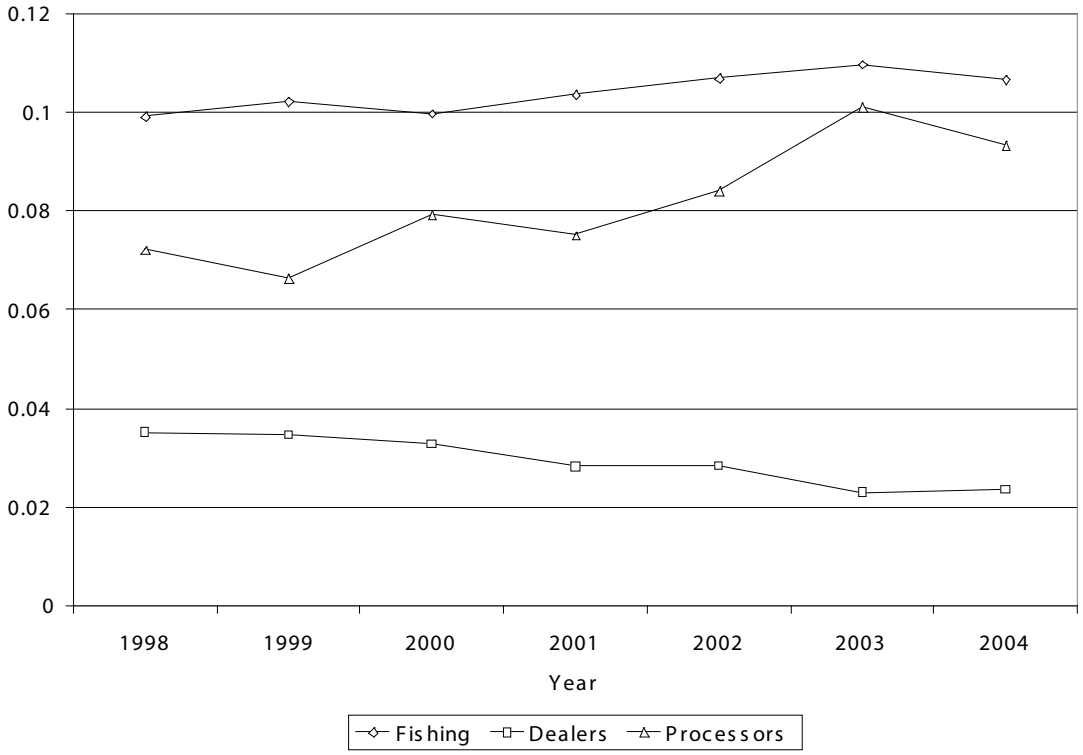
## FIGURES AND IMAGES

Figure 1. Domestic Landings Shares of Groundfish, Pelagics, Invertebrates, and Elasmobranchs (1962 to 2005)




In spite of the general decline in groundfish harvest, aggregate landings in the Northeast region began increasing in 1986 and have been at least 300 thousand mt in every year since 1987. These landings were achieved by shifting effort away from groundfish to other species. For example, invertebrates (lobsters, scallops, clams, and squids) increased from 18% of total landings in 1980 to 44% in 1994. Similarly, pelagics (principally Atlantic herring and Atlantic mackerel) which accounted for just over 10% of aggregate landings in 1983 now accounts for over 35% of total landings. Prior to 1990, elasmobranchs (dogfish and skates) were never more than 4% of total domestic landings. From 1990 to 1998 elasmobranchs accounted for about 10% of total landings, but higher exploitation of these stocks resulted in a 45% decline in their biomass index between 1990 and 2002.

Figure 2. Ellison-Glaeser Indices of Geographic Concentration for Selected Marine Sectors, 1986-2004




Seafood dealers and seafood processing accounted for at least 75% of the marine seafood sector. Agglomeration in these two disaggregated sectors moved in opposite directions during 1998 through 2004. Concentration in the seafood dealer sector was declining while concentration in the seafood processing sector was increasing. Agglomeration of the commercial fishing sector was higher than either the dealer or processing sector in 1998 and continued to increase through 2004.

**PUBLICATIONS**

Thunberg, E. and D. Jin. 2007. Geographic Concentration in Northeast Region Seafood Industries. *Journal of Environmental Economics and Management*, Submitted.

**SUMMARY OF INTERACTION WITH NOAA**

This was a collaborative research project with NOAA. Eric Thunburg at the Social Sciences Branch of the Northeast Fisheries Science Center worked closely with Di Jin at WHOI Marine Policy Center throughout the project.

**SUMMARY OF EDUCATION AND OUTREACH ACTIVITY**

The project has just completed. We will start presenting the results at relevant conferences.

# Assessment of Air-Sea $CO_2$ Exchange Rates in the World's Oceans Using Bomb $^{14}C$ Inventories Derived from the WOCE Global Survey

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 350
1 March 2004 - 28 February 2007

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Program Manager: Dr. Kathy Tedesco, NOAA/OAR/OGP/GCC

Related NOAA Strategic Plan Goal:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

## PROJECT OVERVIEW

Introduction:
Determining the spatial patterns and variability of carbon sources and sinks at global to regional scales, and documenting the fate of anthropogenic $CO_2$ in the atmosphere and ocean are main goals of the NOAA contribution to the U.S. Interagency Carbon Cycle Science Program (CCSP). Quantifying air-sea $CO_2$ exchange rates is critical to these goals because this exchange is the primary mechanism for $CO_2$ transfer between the atmospheric and oceanic carbon reservoirs. The ocean inventory of bomb-produced radiocarbon ($^{14}C$) is directly related to air-sea $CO_2$ exchange and thereby provides a powerful constraint on the exchange rates. The large amount of high-quality radiocarbon data collected during the WOCE program provides the opportunity to improve our estimate of these air-sea $CO_2$ exchange rates.

## PROJECT GOALS:

This project has three main objectives:
(1) To determine air-sea $CO_2$ exchange rates in the world oceans based on the bomb 14C distribution observed during the WOCE global survey in the 1990s,
(2) To re-evaluate the air-sea $CO_2$ exchange rates based upon the bomb $^{14}C$ inventory estimated from the 1970s-GEOSECS data using an improved method of separating natural $^{14}C$ from the observed $^{14}C$, and
(3) To use inverse methods to derive the air-sea $CO_2$ exchange rates from the WOCE era oceanic bomb $^{14}C$ distribution and ocean circulation.

## METHOD:

An improved method of separating natural $^{14}C$ from the observed $^{14}C$ distribution is being used to estimate the bomb $^{14}C$ distribution and inventory (Rubin and Key, 2002). The completion of this database was the focus of the first year of the project. During the second year the focus has turned to the lateral transport model analysis in

which the transport models developed by Broecker et al. (1985) are being used to assess the regional air-sea $CO_2$ exchange rates. Comparisons of regional $^{14}C$ inventory estimates derived from gas exchange rates related to both cubic and square of wind speed have been conducted. The existing inverse box model of the Pacific Ocean will be used to derive the air-sea exchange rate of $CO_2$ based on bomb $^{14}C$ distribution during the third year of the project.

**ACCOMPLISHMENTS**

Bomb $^{14}C$ database

The radiocarbon separation method devised by Rubin and Key (2002; referred to hereafter as the PALK method) is based on the strong linear relationship between potential alkalinity and measured radiocarbon in deep waters not yet contaminated by bomb-produced radiocarbon (Equation 1 and 2).

Natural $\Delta^{14}C = -59 - 0.962(PALK-2320)$
$PALK = (Alkalinity + Nitrate)*35/Salinity$

The PALK method is an adaptation of the silicate method published by Broecker et al. (1995) and was developed using the same GEOSECS data set. The regression statistics for the PALK method are marginally better than for the silicate method, but the important difference is that the PALK method does not show latitudinal bias. One problem with the PALK method is that many radiocarbon measurements do not have accompanying alkalinity measurements. In these cases some form of multiple-parameter linear regression (MLR) can be used to estimate alkalinity. Alternatively, for mid and low latitude samples the silicate method can be used after applying a minor calibration correction applied (Rubin and Key, 2002; Equation 4).

As part of the Global Ocean Data Analysis Project (GLODAP; work partially supported by this grant) most of the WOCE radiocarbon data as well as that from previous major expeditions were organized into a set of three data files – one for each ocean. All of the measured radiocarbon data were separated into bomb and natural components and then these data were used to produce objective global maps of the distributions at 33 depth layers. The objective gridding and the specific depth surfaces were chosen to match existing climatologies for temperature, salinity and nutrients. Both the maps and the data sets are available via the internet (http://cdiac.esd.ornl.gov/oceans/glodap/Glodap_home.htm) and are collectively known as GLODAP version 1.1 (Gv1.1). Preparation of the maps and data sets is described in Key et al. (2004). They also included global radiocarbon and bomb radiocarbon inventory estimates. The distribution of bomb $^{14}C$ inventory is shown in Fig. 1.

One of the major deficiencies of Gv1.1 was that the WOCE Atlantic Ocean radiocarbon data available at the time was insufficient to objectively map in that basin. Therefore, older radiocarbon data from the Transient Tracers in the Ocean (TTO) and South Atlantic Ventilation Experiment (SAVE) were used. Since release of Gv1.1 GLODAP work has continued (with support from this and other grants). We now have WOCE era data from three additional North Atlantic cruises (plus 2 in the Pacific and 2 in the Indian). The same separation method has been applied to these new data. Once these new results are merged with Gv1.1 we will attempt to remap the North Atlantic radiocarbon distributions. We emphasize attempt because the WOCE era North Atlantic data distribution is such that the mapping results may be unacceptable. In the South Atlantic Gv1.1 used SAVE radiocarbon data and we cannot improve on that since there are almost no WOCE era radiocarbon samples in that basin. Fortunately, SAVE was in the late 1980s and the time difference between that data and WOCE data is sufficiently short relative to the time scales of interest for this work.

No one has yet determined if the PALK method can be improved given the larger data set and the higher quality alkalinity data now available. Rubin and Key (2002) noted that slightly different regressions were obtained from the three oceans, but suggested that the simplicity of a single global regression out-weighted the minor differences. Investigations with the WOCE data show the same minor ocean to ocean differences in the PALK regressions. This is almost always the case for oceanographic regressions which are empirical rather than theory based: the smaller the region, the better the regression. Choosing regional fits, however, causes other significant problems; specifically, the regional functions have to be made consistent across region boundaries. Failure to eliminate boundary discontinuities can result in significant problems when using or interpreting the results (as noted in Key et al., 2004 regarding the Goyet et al. 2000, global alkalinity maps).

More interesting, and perhaps more significant depending upon the application, recent research by C. Sweeney and R. Key has shown that in Pacific deep and abyssal waters the PALK method produces bomb $^{14}C$ estimates that show an unexpected pattern. If the PALK method was perfect one would expect the estimated bomb $^{14}C$ values to decrease with depth to zero somewhere in the thermocline (based on tritium and CFC distributions) and scatter randomly about zero from that depth to the bottom (except in bottom water formation areas where one might expect small positive near-bottom values). In fact while the deep and abyssal values average to zero, there is a pattern. Estimated values near the oxygen minimum tend to be slightly negative while near bottom values are slightly positive. This pattern should not exist and certain types of inversion calculations (those based on individual sample results) that try to make use of all bomb $^{14}C$ estimates may be biased as a result. This potential bias is not expected to have any significant impact of the inventory-based models we will be using. Regardless, we will continue to investigate the issue. Early tests indicate that including AOU in a modified PALK equation can remove the bias in the Pacific, but side effects of this change and the applicability to other oceans is yet to be determined.

The GEOSECS data are too sparse to map objectively. Furthermore, Peacock (2004) convincingly demonstrated that the zonal averaging technique used by Broecker et al. (1995) to obtain a global bomb radiocarbon inventory was biased high by 10 to 25% due to the locations of the GEOSECS stations. In that work GEOSECS (and some WOCE) data were extrapolated globally using MLR (in silicate, temperature, oxygen, salinity, depth and latitude) and the natural component was estimated from global silicate climatologies. We are now using GEOSECS $^{14}C$ data along with the zonal averages of Peacock (2004) to represent the global distribution used re-assess the 1975 air-sea $CO_2$ exchange rates, The WOCE-era exchange rates are being computed from the WOCE $^{14}C$ dataset for 1994.

During the past year significant progress has been made toward accumulating sufficient new data to make a post-TTO evaluation of the North Atlantic bomb $^{14}C$ inventory. In addition to those data which were included in GLODAP v.1.1, we have new results from two NOAA cruises (OACES93 on the A16N line and OACES98 on the A05/AR01 line) as well as German data from the A1 sections. Surface results have been obtained from the NOAA reoccupation of A16N in 2003 and we will very soon have surface data from the re-occupations of A20 and A22 (measured, but not yet reported by NOSAMS). We are actively trying to track down results from line AR18 (around Iceland), but have as yet been unable to contact the persons responsible for this dataset. We have added the surface results from R. Nydal's group (posted at CDIAC) and a new atmospheric history record.

Re-mapping and integrating these values is extremely time consuming and labor intensive, therefore, this step will not be attempted until we have completed the "radiocarbon data search". Please note, this data search is not limited to cruises with radiocarbon data. Eventually the air-sea gas exchange rate derived from this work will be most useful in the analysis of anthropogenic $CO_2$. Therefore the data search bounds include all those cruises with carbon and/or tracer data. Thus far, 70 new cruises have been added to the database. Almost all of these are from European expeditions. Very few were included under the WOCE umbrella or otherwise reported to any national collection agency.

Figure 2 gives a hint of the information content of the combined data. On first inspection the data are simply "messy" with the only dominant signal being the significant increase between the 1950s and 1960s. Closer inspection and/or relatively simply analysis, however, shows previously identified and new trends in the data including:

1. The "M" shaped pattern with high values in the subtropical and subpolar gyres and lower values at the equator and high latitudes originally identified by the GEOSECS data for all measured decades
2. Significantly larger variance at any given latitude during the time frame of the maximum atmospheric signal (1960s and 1970s)
3. Significant longitudinal variance for a given latitude and time (WOCE data)
4. Muted signals at high southern latitudes
5. A steady decrease, on average, following the atmospheric maximum
6. Significantly more data than any previous compilation

Once these data are fully analyzed we expect to be able to re-analyze the currently accepted equilibration time (~10yrs) by examination of the lag time between the atmospheric and surface ocean values. The fact that we now have the beginning of a representative "time series" for the North Atlantic should place significant constraint on numerical ocean/atmospheric models.

**Lateral Transport Model**

Broecker et al., (1985) developed lateral transport models for the three major ocean basins to simulate the GEOSECS bomb $^{14}C$ distribution in the water column. With the WOCE radiocarbon data, this same model can be used to study the effect of regionally varying air-sea $CO_2$ exchange rates on the distribution of bomb $^{14}C$ in the oceans. To begin this task, we needed to reconstruct the lateral transport model developed by Broecker et al., (1985). We have successfully completed this task, and we have reproduced model results published in the original paper. We have produced a MatLab code to facilitate doing sensitivity studies for the three major oceans basins.

The next step was to summarize the revised bomb $^{14}C$ inventories based on separation of the natural and bomb $^{14}C$ components according to PALK method (Rubin and Key, 2002). The CO2 exchange rates given in Broecker et al (1985) were based on bomb $^{14}C$ inventories estimated from Tritium penetration depth and smooth natural $^{14}C$ profiles in the upper ocean. This yields different inventories from those derived from PALK-natural $^{14}C$ relationship as given in Rubin and Key (2002). The tasks completed in the 2nd year of the project included the re-evaluation of $CO_2$ exchange rates for three major oceans based on this revised 1975 inventory by Rubin and Key (2002) and the evaluation based on 1995 inventory using WOCE radiocarbon data.

Broecker et al (1985) assumed a uniform exchange rate for each basin, but for the re-evaluation, we are determining the sensitivity of the bomb $^{14}C$ inventories to specific $CO_2$ exchange rates for each of the 13 boxes (5 in the Atlantic, 5 in the Pacific Basins and 3 in the Indian) used in the Broecker model. The estimates are based on averaging the monthly gas exchange rates for each 4ox5o bin within the region of interest. The gas exchange values are calculated using the same input values (SST, SSS, P, U10) as is used in the $pCO_2$ climatology of Takahashi et al. (2002). Note, to account for the effect of variable winds on the quadratic relationship of gas exchange with wind speed the 2nd central moment of the monthly winds on 6-hour intervals from NCEP/NCAR re-analysis is used (Kalnay et al., 1996).

The three ocean basins have been divided into latitudinal zones with a prescribed circulation (Figure 3). Based on the gas exchange parameterization outlined above the estimated invasion rates are:

| | | |
|---|---|---|
| Atlantic | Antarctic | 25.80 (mol m-2yr-1) |
| | South temperate | 17.20 |
| | Equatorial | 11.67 |
| | North temperate | 12.40 |
| | Arctic | 21.32 |
| Pacific | Antarctic zone | 25.91 |
| | South temperate | 16.71 |
| | Equatorial | 8.84 |
| | North temperate | 13.74 |
| | Arctic | 22.40 |
| Indian | Antarctic | 29.76 |
| | South temperate | 19.26 |
| | Equatorial | 10.30 |

These air-sea $CO_2$ exchange values are used in the model to produce bomb $^{14}C$ distribution that are compared with those derived by Broecker et al. (1985, 1995). They used invasion rates of 22.3, 19.2 and 19.4 mol m-2yr-1 for the Atlantic, Pacific and Indian Ocean basins, respectively.

Using the prescribed model of oceanic meridional transport (Figure 3), estimates of the atmospheric bomb $^{14}C$ time history for each hemisphere and the equator (Figure 4), revised estimates of the zonal areas and the newly evaluated invasion rates, bomb $^{14}C$ inventories (Figure 5, left panel) and surface concentrations (Figure 5, right panel) have been calculated for both 1974 and 1994. It is seen that in general the basin wide constant invasion rate of Broecker et al. (1985) has a better fit with the inventory estimated by Peacock (2004) for 1974, while the re-determined invasion rates result in a better fit with inventory based on WOCE data for 1994. There are significant deviations of inventories from WOCE data for 1994 if a constant ocean basin wide invasion rate of Broecker et al.(1985) is used. For year 1974, the surface bomb $^{14}C$ concentrations predicted from using the constant invasion rates have a better fit

to the observed data than those derived from the re-determined different zonal invasion rates. However, for the year 1994, significant deviations of model results from the WOCE data are observed both for constant invasion rates and re-determined zonal invasion rates. This is an indication that the physical parameters in this simplified transport model, such as advection fluxes and vertical mixing rates (diffusivities) are inconsistent with the ocean dynamics. Hence, adjustments to physical parameters of this model are still needed.

For illustration of the direction of adjustments required, model results with reduced vertical mixing rates, or with the reduced upwelling and downwelling fluxes for the Atlantic Ocean (Figure 5) were considered. The left hand two panels are for the inventories, using either the constant zonal invasion rate of 22.3 mol m-2 yr-1 of Broecker et al. (1985) or the re-determined different zonal invasion rates. Similarly, the surface bomb $^{14}C$ concentrations are shown on the right hand side panels. It is shown that the model surface bomb $^{14}C$ concentrations are significantly lower than the observed values, especially in 1994. One of reasons could be that the vertical mixing rates are too fast in the model.

To test the effects of vertical mixing rates, the diffusivity in zones 2, 3, and 4 were reduced by half (Figure 6). This gives results with reducing the surface $^{14}C$ concentrations, but not significantly enough to match the observations. The reduced vertical mixing rates also reduce the inventory. Again, the reduced inventories do not significantly improve the model results to match with the observations in 1994. The effects of reduced upwelling flux (by 2 Sv) in zone 3 and downwelling flux in zone 4 are also shown. The surface concentration has increased slightly, but not enough to match the observations. However, the inventory has increased slightly in equatorial zone, but reduced in the north temperate zone. The magnitude of the changes is too small to explain the deviations of model results from the observations. Proper adjustments in vertical mixing rates and upwelling fluxes are necessary to assess the $CO_2$ invasion rates in the world's oceans using bomb $^{14}C$ data. In the Pacific and Atlantic Basins the box inverse model will help assess the direction of these adjustments.

**Inverse Modeling**

The final focus within this project was the inclusion of $^{14}C$ within existing inverse box models of the Atlantic and Pacific Basins. In the first year of the project, the background and bomb radio carbon data obtained from the GLODAP database were reformatted for use within the inverse system. The next step focused on the Pacific where most of the $^{14}C$ measurements were obtained along the long lines which have been used in the inverse model.
The original thought was to map these data both in the horizontal to fill in stations which did not include $^{14}C$ measurements and in the vertical to place $^{14}C$ on the 2 dbar pressure intervals used as input to the box models. The inverse models would then be run individually for the GEOSECS era and the WOCE era, making the assumption that the ocean circulation has not changed over that time period. However, large gaps in the data set make mapping problematic. Therefore, it was thought that a more useful direction, given the results of the lateral transport model, would be to use the circulation defined by the inverse box model in place of the lateral transport model. After some investigation, however, this route was also found to be problematic as the inverse model by definition includes mass imbalance in every box which integrated over time overwhelms the solution.
Given that the inverse portion of this project still has half it's available funding left (~2 man months), we have decided to instead use the results of the Pacific inverse model (spreading the mass imbalance over the full basin) as the basis for the lateral transport model, then to perform a variety of runs to determine sensitivity to the underlying circulation. If this method proves useful, we will then, look to recent circulation results provided in the literature from WOCE and CLIVAR analyses to use as the base circulation for lateral transport model in the other basins, and again perform multiple runs to determine sensitivity.
The results will be compared to the present lateral transport model results with the focus on determining those aspects of the 3-dimensional circulation which are of most importance to the inventory and surface concentration calculations. This effort will take place in the coming 6 months.

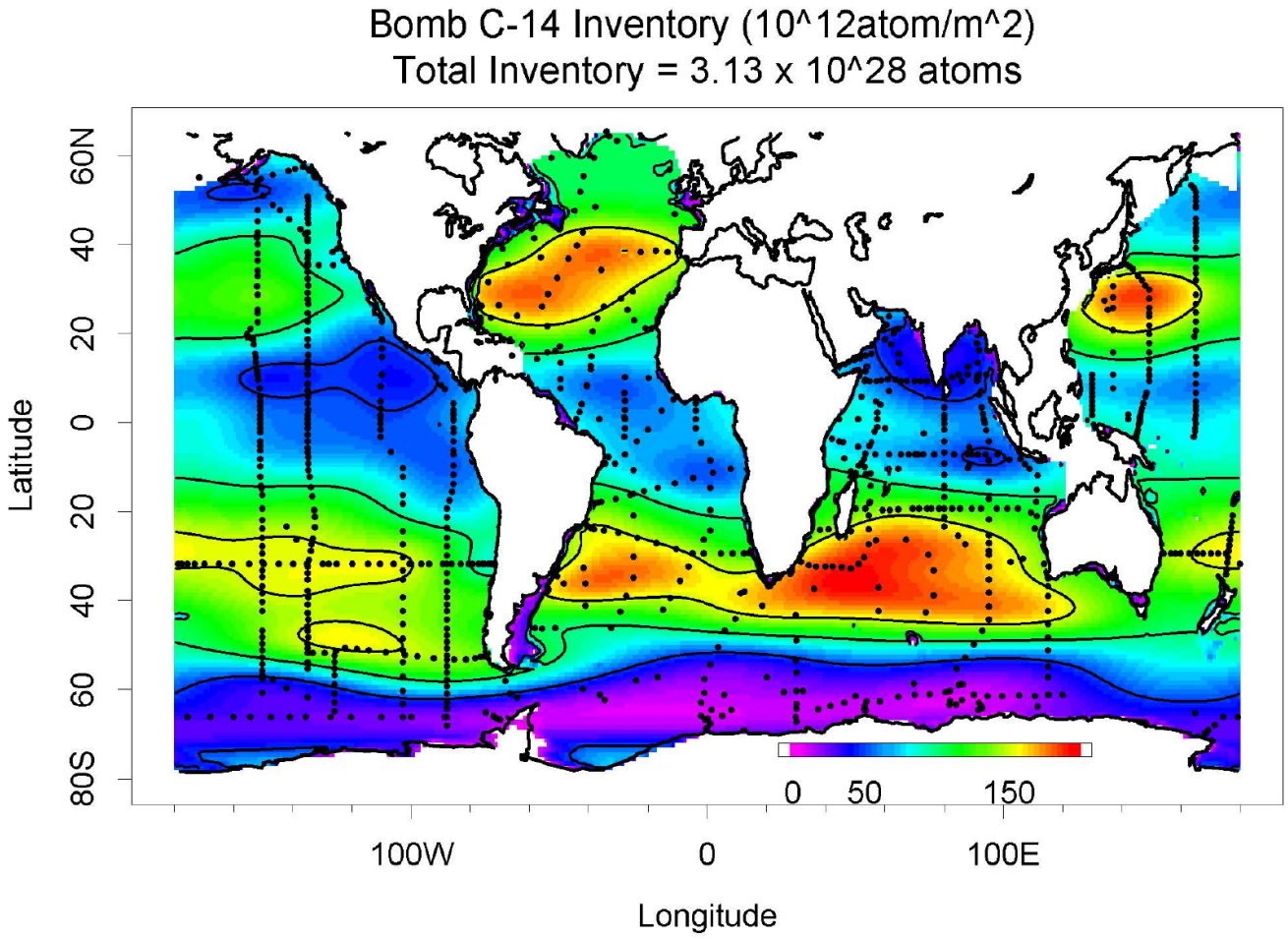


Fig. 1. Distribution of bomb $^{14}C$ inventory (1012 atom/m2) in the global oceans.
Surface Atlantic Ocean Measurements

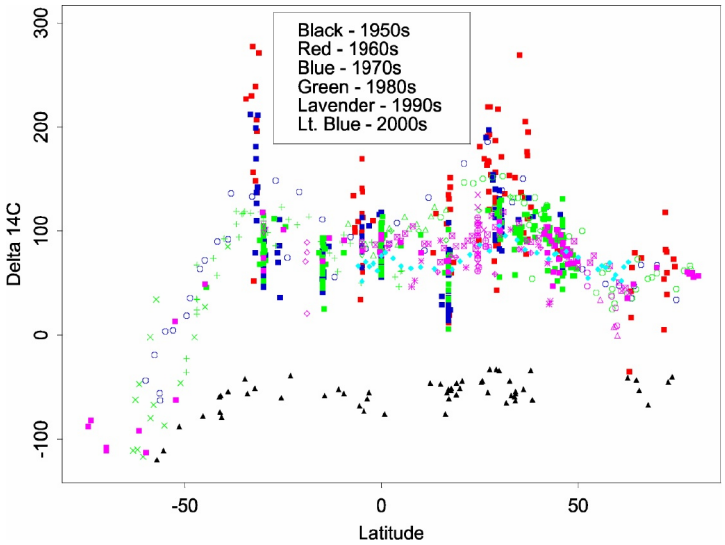


Fig. 2. Collected surface $\Delta^{14}C$ measurements (‰) in the Atlantic. Colors indicate the measurement decade and symbols indicate different expeditions within each decade.

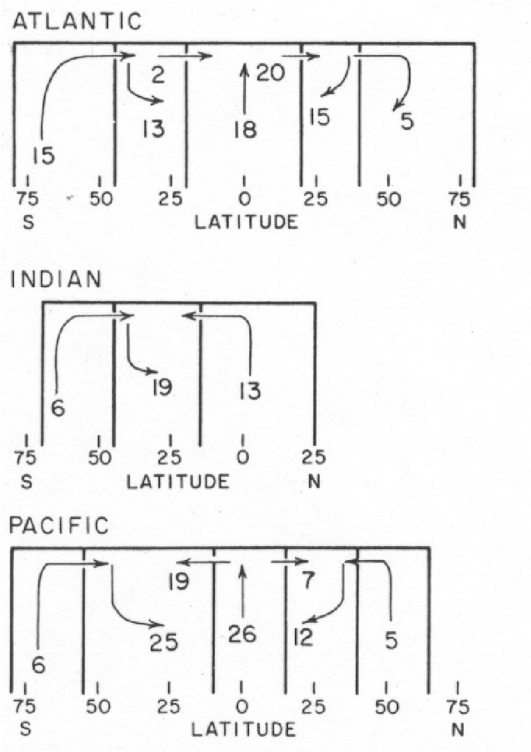


Figure 3. Transport model used to estimate the distribution of bomb 14C in the World Ocean.

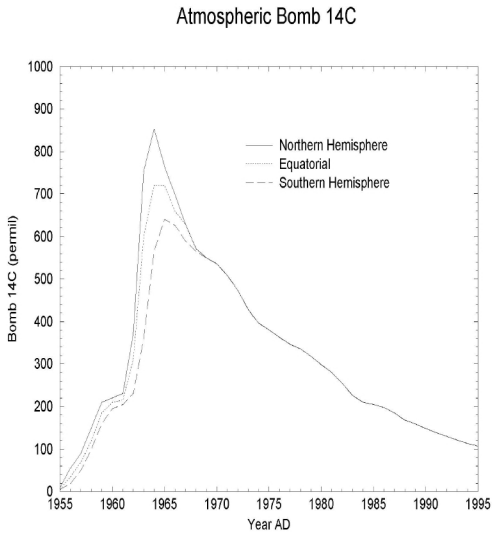


Figure 4. Atmospheric bomb 14C input function.

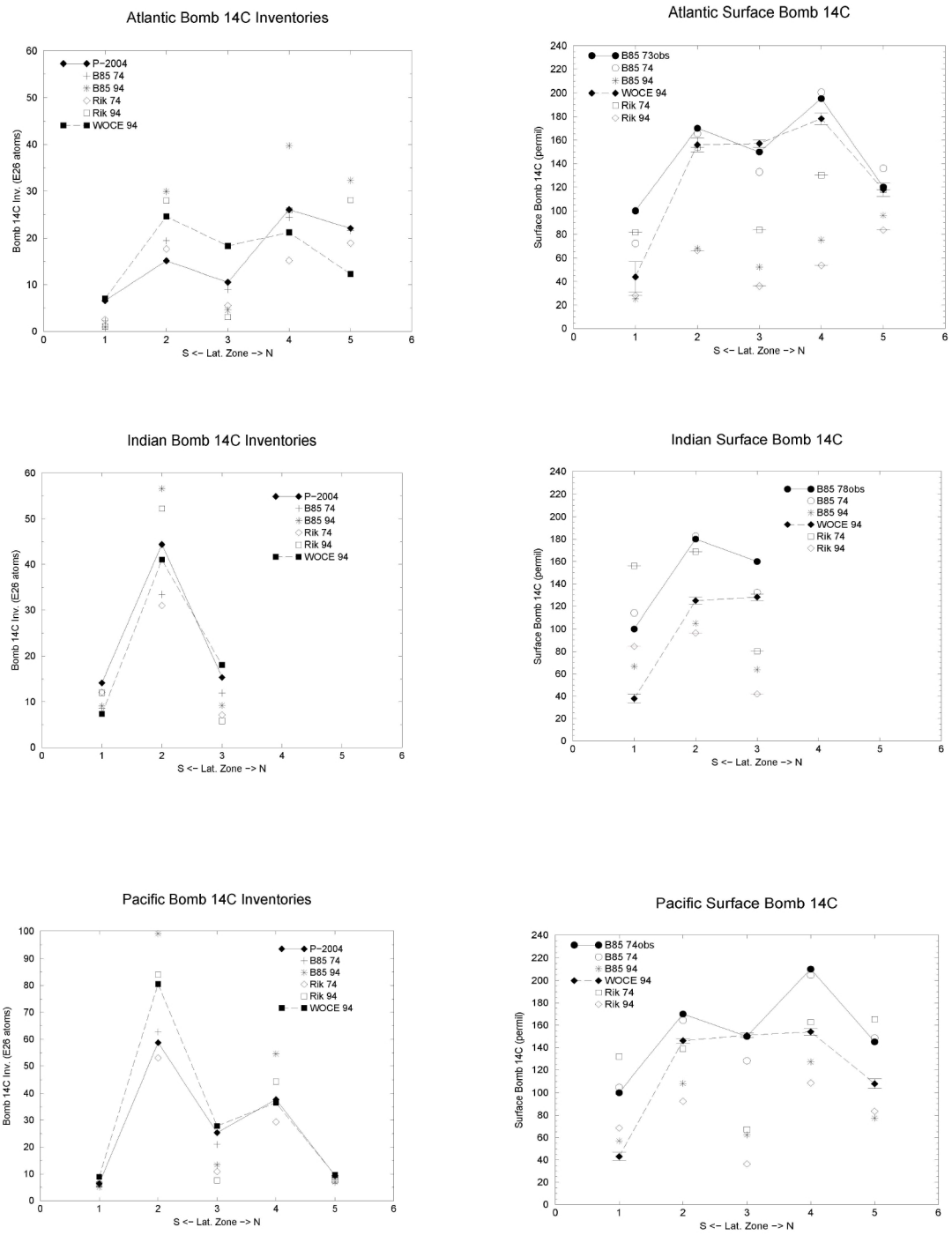


Figure 5. Model results for year 1974 (GEOSECS) and 1994 (WOCE) using re-calculated invasion rates (Rik 74 and 94) compare to those using Broecker et al.1985 (B85 74 and 94) constant ocean basin wide invasion rates. The solid symbols are observed values. Zone 1 = Antarctic, 2 = S. Temperate, 3 = Equatorial, 4 = N. Temperate, and 5 = Arctic as delineated in Figure 3.

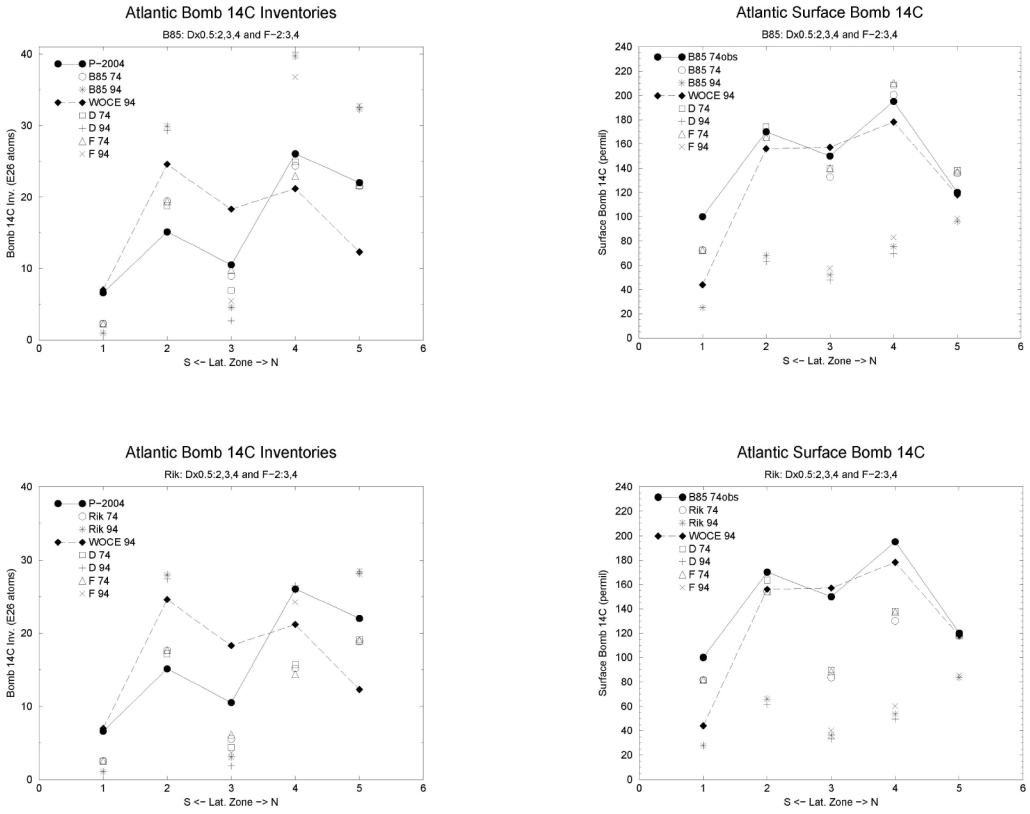


Figure 6. Model sensitivity tests for adjusting vertical diffusivity by 50% in zones 2, 3, and 4 in the Atlantic Ocean, and for adjusting fluxes in zones 3 and 4 by 2 Sv also in the Atlantic Ocean.

## PUBLICATIONS

Peng T.-H., R. Wanninkhof, R. Key and A. Macdonald. Assessment of the Air-Sea $CO_2$ Exchange Rates in the World's Oceans Using Bomb $^{14}C$ Inventories, poster ICDC7, Boulder, Colorado, 2005.

A. Macdonald, T.-H. Peng, R. Wanninkhof and R. Key, Ocean Bomb Radio-Carbon ($^{14}C$) GEOSECS-WOCE, WHOI seminar, Dec, 2005.

Web Links: (http://cdiac.esd.ornl.gov/oceans/glodap/Glodap_home.htm)

## REFERENCES

Broecker, W. S., T.-H. Peng, H. G. Ostlund, M. Stuiver. The distribution of bomb radiocarbon in the ocean, Journal of Geophysical Research, 90, 6953-6970, 1985.

Broecker, W.S., S. Sutherland, W. Smethie, T.-H. Peng, and G. Ostlund, Oceanic radiocarbon: separation of the natural and bomb components, Global Biogeochem. Cycles, 9, 263-288, 1995.

Goyet, C., R. Healy and J. Ryan, Global distribution of total inorganic carbon and total alkalinity below the deepest winter mixed layer depths, 28pp., ORNL/CDIAC-127, NDP-076, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN., 2000.

Kalnay, E., and et. al., The NCEP/NCAR 40-year reanalysis project, Bull. Am. Meteorol. Soc., 77, 437-471, 1996.

Key, R.M., A. Kozyr, C.L. Sabine, K. Lee, R. Wanninkhof, J. Bullister, R.A. Feely, F.

Millero, C. Mordy, T.-H. Peng, A global ocean carbon climatology: Results from Global Data Analysis Project (GLODAP), Global Biogeochem. Cycles, 18, GB4031, doi:10.1029/2004GB002247, 2004.
Peacock, S. Debate over the ocean bomb radiocarbon sink: Closing the gap. Global Biogeochem. Cycles, 18, doi:10.1029/2003GB002211, 2004.

Rubin, S. and R. M. Key, Separating natural and bomb-produced radiocarbon in the ocean: The potential alkalinity method, Global Biogeoche. Cycles, 16(4), doi: 10.1029/2001GB001432, 2002.

Takahashi, T.; Sutherland, S. G.; Sweeney, C.; Poisson, A. P.; Metzl, N.; Tilbrook, B.; Bates, N. R.; Wanninkhof, R.; Feely, R. A.; Sabine, C. L.; Olafsson, J.; Nojjiri, Y., Global sea-air $CO_2$ flux based on climatological surface ocean $pCO_2$, and seasonal biological and temperature effects. Deep-Sea Res. II, 49, 1601-1622, 2002.

## SUMMARY OF INTERACTION WITH NOAA

This project is a collaboration with NOAA-AOML PIs Tsung-Hung Peng and Rik Wanninkhof. Peng is the lead PI on the project and is for responsible for the lateral transport model results. I have worked with them in determining how the inverse model and it results can best be used to within the context of this project. I have converted the Peng's Fortran Atlantic lateral transport model to run in the Matlab. In November 2006 I participated in the NOAA Global Climate Change review panel. I will be attending the NOAA GCC PI meeting this September in MD.

## SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

Last fall I attended the New England Board of Higher Education Science Network as a panel member and mentor. I participated in the Learning Inovations Focus Group in Feb. 2007 and attended the organizational meeting of Falmouth Public Schools' Project SEpTeMber in December 2006. Beginning early this year, I developed a collaboration with a teacher at Falmouth Academy to begin a pilot program focused on having junior and senior high school students base their science fair projects on observations obtained from oceanographic cruises. I currently have 4 students: one who will obtain observations from a mooring cruise going out this September; two who will use data from a hydrographic cruise this October and another who will be taking advantage of a variety NOAA fishery's cruises occurring this fall.

# Coupled Biological/Physical Models in the Coastal Ocean: Skill Assessment and Planning for Regional Testbed Projects

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 77
July 1, 2004 through June 30, 2008

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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.
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

## PROJECT OVERVIEW

The goal of this project is to provide the scientific and technical basis for quantitative evaluation of coupled physical-biological models relevant to NOAA's Ecosystem Based Management activities.

We conducted an initial workshop in July, 2006 with practitioners drawn from carbon cycle, marine ecosystems, population dynamics, harmful algal bloom, and water quality modeling, as well as those interested in ecosystem-based management. Participants defined a set of papers to be composed for a refereed journal. A subset of participants planned a specific Model Intercomparison and Evaluation Project (MIEP). A second workshop in March, 2007 reconvened the participants to present the papers and synthesize the results. The MIEP working group prepared an implementation plan, and will contribute an accompanying paper.

## ACCOMPLISHMENTS

The second workshop for Skill Assessment for Coupled Biological/Physical Models of Marine Systems was held at the Friday Center in Chapel Hill NC, March 6-8, 2007. The attendance list is posted on the project web site.

Most of the contributing teams from Workshop 1 were represented. There were two workshop goals:
• synthesize and coordinate submissions to a special issue of the *Journal of Marine Systems* (JMS)
• compile recommendations for NOAA and other interested parties. The web site (http://www-nml.dartmouth.edu/Publications/internal_reports/NML-06-Skill ) will be maintained through project completion and holds the full record of workshops 1 and 2.

**JMS Volume**
The first 1.5 days were spent in plenary, as scheduled. These provided an update on progress of the papers in preparation and new results, many of which indicated significant and exciting cross-fertilization of ideas presented at the first workshop.
Three breakout sessions followed:
1. Data Assimilation

2. Metrics
3. Overview/outreach for a broader audience
Items 1 and 2 correspond to planned 'cross-cut' contributions to the JMS volume, and specific plans for coordinated completion of these manuscripts were committed to. Item 3 remains under discussion relative to audience and content. A fourth item 'Vocabulary' was suggested for discussion; participants did not elect discussion on this, with greater immediate interest in the above three topics. A cross-cut paper by editors on vocabulary was planned since the beginning as part of the front of the volume, and an early editors' draft has been available throughout both workshops. It was decided to defer to editors in advancing this piece toward completion and review. A fifth item 'Data Archive' was not pursued. The plenary presentations and working group reports are recorded with the conference record.

**Project timeline**
The schedule for volume completion begins with submission now, directly to the guest editors. The guest editors will arrange for review, revision, and acceptance of individual papers beginning as soon as they are received. Once all parts of the volume are individually accepted, they will be transmitted as a whole to JMS for electronic and paper publication. The date for this bulk completion is April 1 '08. It is anticipated that minimal delays will follow this deadline and all involved are committed to this date.

Commitments for ms submission were based on these good-faith estimates:

| # date | # submissions |
|---|---|
| April 1 | 6 |
| May 1 | 4 |
| June 1 | 4 |
| July 1 | 3 |
| Aug 1 | 2 |

The cross-cut papers (Vocab, DA, Metrics) generally fall in this window of time. Authors and editors believe these are realistic relative to April 1 '08 completion deadline.

**RECOMMENDATIONS FOR NOAA**

Ahead of the workshop, a set of nine questions (listed on the web site) were distributed as the basis of discussion on this topic, which took place during the final session of day 2.

Break-out groups were organized and conducted on day 3, in three areas:
1. HABs
2. Fisheries
3. Environment

Reports of these groups were made and are part of the conference record. Following the 3 breakout group presentations, the assembled workshop listed some common issues that emerged among them. Recommendations discussed included:

1. Facilitate access to real-time data streams. This would include networking, servers, and people.

2. Encourage ensemble modeling, specifically the use of an ensemble of *different* models.

3. Encourage the use of probabilistic model results – mean and variance – and the expression of this in simple ways to a general audience, backed by rigorous analysis. (The IPCC report is an example.)

4. Encourage the formalization of the prior – at the least, the mean and variance of all relevant quantities.

5. Always examine the posterior: a) the remaining misfit and b) the departure from the prior. There is information in both.

6. Recognize the importance of organizational structure. Encourage regional expertise in regional centers; and networking of these relative to technical and scientific generalities.
7. Do not separate data providers from modeling.

8. Similarly, do not separate physical modeling from biological modeling.

9. Encourage a blend of Government/University/Industrial activity.
10. Use the existing NOAA centers and cooperative programs to their fullest. There is much opportunity in these for cross-fertilization. Avoid new organizational structures if extant ones can be made to work.

The editors are composing a report to NOAA summarizing those recommendations.

**PUBLICATIONS**

As of August 29, 2007, 12 manuscripts have been submitted for publication. These are listed on a special issue web site: http://www.whoi.edu/sbl/liteSite.do?litesiteid=18052

**SUMMARY OF INTERACTION WITH NOAA**

There was active participation of NOAA scientists in the second workshop.

**SUMMARY OF EDUCATION AND OUTREACH ACTIVITY**

None yet.

# U.S. Research Vessel Surface Meteorology Data Assembly Center

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 356
July 1, 2006 through June 30, 2007

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Program Manager: Michael Johnson, NOAA/OCO

Related NOAA Strategic Plan Goals:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.
Goal 3. Serve society's needs for weather and water information.

## PROJECT OVERVIEW

The central activity of the U.S. Research Vessel Surface Meteorology Data Assembly Center (DAC) is the continued development of the Shipboard Automated Meteorological and Oceanographic System (SAMOS) initiative (http://samos.coaps.fsu.edu/). The SAMOS initiative focuses on improving the quality of and access to surface marine meteorological and oceanographic data collected *in-situ* by automated instrumentation on research and merchant vessels. Over the past year, the SAMOS DAC has (1) recruited 10 additional vessels to provide routine observations, (2) developed a research-quality data evaluation system, (3) expanded tools to display data quality, (4) improved user access to data, and (5) continued international liaison activities. In addition, the DAC continues delayed mode quality evaluation of observations from the *Ronald Brown* and *Ka'Imimoana*. The DAC activities focus primarily on NOAA Strategic Plan Goals 2 and 3 by providing high quality weather and near surface ocean data for use in validating satellite products, global air-sea flux analyses, and model fields.

The DAC was established at the Florida State University specifically to coordinate the collection, quality evaluation, distribution, and future archival of SAMOS data. A SAMOS is typically some form of a computerized data logging system that continuously records navigation (ship's position, course, speed, and heading), meteorological (winds, air temperature, pressure, moisture, rainfall, and radiation), and near ocean surface (sea temperature and salinity) parameters while the vessel is at sea. Measurements are recorded at high-temporal sampling rates (typically 1 minute or less). The DAC collaborated with the Woods Hole Oceanographic Institution (WHOI) to design a ship-to-shore-to-user data pathway for U.S. research vessel SAMOS data. In the past, the data flowed from ship to shore only in a delayed-mode with a 3 month to 2-year lag between collection and availability to the user community. The new vision supports automated data transmission from each ship to the DAC on a daily basis. A "preliminary" version of the SAMOS data is available soon after receipt by the DAC. The preliminary data have undergone common formatting, metadata enhancement, and automated quality control. Visual inspection and further scientific quality control are now operational and result in a "research" quality SAMOS product. Plans are being developed to further enhance distribution services for the quality-controlled data in formats that meet user needs. Data exchange agreements are in place with two national data archive centers to ensure that the original and quality

controlled data are maintained for future generations of scientists.

**ACCOMPLISHMENTS**

Over the past year our efforts have focused on the recruitment of additional vessels to the SAMOS initiative and the continued development of the data quality procedures. Recruitment resulted in an additional 10 vessels reporting for the period covered by this report. The SAMOS data quality evaluation system is now operational for both preliminary and research SAMOS data products. Many upgrades have been made to both our public access web site and our internal data base tools. Throughout the year, DAC personnel have been actively promoting the SAMOS Initiative through meetings and working groups, including the International Marine Technicians Symposium (INMARTECH) at WHOI in October 2006 and the 4th WMO/IOC JCOMM[1] Ship Observation Team (SOT) meeting in Geneva, Switzerland in April 2007. Finally, we continue our delayed mode data processing for the NOAA vessels *Ronald Brown* and *Ka'Imimoana*.

*1. 2. Vessel recruitment*

Recruitment of additional vessels to participate in the SAMOS Initiative was very successful during the reporting period. Ten new vessels were recruited (Table 1) in the past year. These vessels now routinely contribute SAMOS observations when they are at sea. Collaboration with NOAA's Office of Marine and Aviation Operations (OMAO) resulted in eight new recruitments. OMAO developed a SAMOS data transmission applet as part of the version 4.0 release of their scientific computing system (SCS). As the new SCS was installed in the fleet, the NOAA vessels began transmitting data to the DAC. In addition, Co-PI Smith attended the annual UNOLS RVTEC meeting and INMARTECH in October 2006 and had good conversations with several additional vessel operators. Most expressed interest in participating in SAMOS, but initiating new data transfers is still difficult in these times of tight operational budgets for research vessels.

Table 1: Ships transmitting observations to SAMOS DAC during the period July 1, 2006 - June 30, 2007.

| Vessel | Call Sign | Operator | Number of ship days of data |
|---|---|---|---|
| *Atlantis* | KAQP | WHOI | 290 |
| *Gordon Gunter* | WTEO | NOAA | 2 |
| *Healy* | NEPP | USCG | 6 |
| *Henry Bigelow* | WTDF | NOAA | 21 |
| *Hi'Ialakai* | WTEY | NOAA | 45 |
| *Ka'Imimoana* | WTEU | NOAA | 7 |
| *Knorr* | KCEJ | WHOI | 229 |
| *Lawrence Gould* | WCX7445 | NSF/Raytheon | 32 |
| *Miller Freeman* | WTDM | NOAA | 122 |
| *Nancy Foster* | WTER | NOAA | 74 |
| *Oscar Dyson* | WTEP | NOAA | 93 |
| *Ronald Brown* | WTEC | NOAA | 71 |
| | | | 992 |

*3. Daily SAMOS data processing*

Preliminary processing of SAMOS observations received via daily email messages from participating research vessels is now an operational activity at the DAC. During the reporting period, 992 days of shipboard meteorology data were processed for the 12 recruited vessels (see Table 1). Preliminary processing (Figure 1) starts once the data file arrives at the DAC as an attachment to an email. Each email attachment is unpacked, the data provided are verified that they conform to the format and parameters expected for the individual vessel, and finally the data are blended with vessel specific metadata and are converted to a common netCDF format. The data for each day are then passed through an automated quality evaluation program and data quality statistics are calculated prior

1 World Meteorological Organization/Intergovernmental Oceanographic Commission Joint Technical Commission for Oceanography and Marine Meteorology

to the file being posted for users on the SAMOS web and ftp sites. The entire process from arrival at the DAC to distribution of the preliminary data files is fully automated. Preliminary files appear on the data distribution site within 5 minutes of their arrival at the DAC (typically shortly after 0000 UTC).

A sample of the spatial distribution of data received, processed, and on-line for 1 January – 21 May 2007 is shown in Figure 2. Prior to 2007, the only two ships providing data were the *Knorr* and *Atlantis*. A rapid increase in vessels participating in SAMOS began in early 2007, leading to the present 12 recruited vessels (Table 1).

Each individual data file has been augmented with extensive metadata that is stored in a ship profile database. In addition, the shipboard database uses a strict version control to track individual data files received from their original email attachment to the final files released to the public (Figure 1). Individual data quality statistics are stored in the ship database and these can be accessed through the data availability link on the SAMOS web site (http://samos.coaps.fsu.edu/html/data_availability.php). A sample of data quality graphics for the *Knorr* is provided in Figure 3.

*4. Delayed-mode SAMOS processing*

The preliminary processing of SAMOS observations is fully operational (see 2 above). Due to data logging problems on the ship or communication dropouts, some data arrive several days after they were collected. Often the data are noted to be missing by the analyst at the DAC and arrive after the analyst notifies the vessel technician at sea. In addition, data for a single day may be fragmented and may arrive in multiple files attached to a single email. As a result, the DAC developed a method to merge multiple files for a single observing day into a combined, delayed-mode data file. This merged file undergoes additional automated and visual data quality evaluation and is then released as a "research-quality" SAMOS data file for the particular observation day (Figure 1).

The process to merge multiple files for a single observing day and the visual data quality evaluation are now operational. The merge program is designed to eliminate duplicate records from the files being merged. Duplicates are eliminated based on a series of rules that take into account the automated quality control applied to the preliminary data files. The merge process is fully automated and the merged files are tracked within the file-tracking database. Currently the merge occurs 10 calendar days after the observation day (when the preliminary data should arrive at the DAC). Using the database, the analyst can easily reference the original file pieces that were merged to create a single data file for each observation day. Once merged, a summary of the data quality flags on the new file is produced and stored in the database.

Each day, the data quality analyst at COAPS reviews the latest merged files and conducts a visual quality evaluation. The visual analysis is accomplished using SVIDAT, a graphical user interface developed by COAPS programmers. SVIDAT allows the analyst to review, add, or modify data quality flags on the merged files. Once the analyst is satisfied with the data quality, the file is saved and posted automatically to the SAMOS ftp and web sites. This process also updates all necessary tracking information in the ship database and creates the copies of the original, preliminary, and research quality files for delivery to the national archive centers.

*5. Continued delayed-mode evaluation of NOAA ship data*

The DAC continues to evaluate the quality of the meteorological observations collected by the NOAA vessels *Ronald Brown* and *Ka'Imimoana*. We have received data from the *Ronald Brown* for the period February – December 2006. These data have been converted to our internal netCDF format and are awaiting quality control. For the *Ka'Imimoana*, we have received data for the period September 2004 – August 2007. The data for September 2004 – December 2005 have completed visual quality inspection and their data quality report is being written. Data from January – September 2006 have been converted to our format and are awaiting visual quality control. The remaining *Ka'Imimoana* data are awaiting conversion and quality evaluation. We note that in 2007 both the *Ronald Brown* and *Ka'Imimoana* were recruited to the SAMOS initiative and will no longer be providing delayed-mode data to the DAC. The outstanding delayed-mode data for the *Ronald Brown* and *Ka'Imimoana* will be evaluated and released by mid-2008. Future data for these vessels are being processed as part of the SAMOS initiative.

*6. Public access to observations and metadata*

A web presence for SAMOS is accessible at: http://samos.coaps.fsu.edu/. The pages provide information on the SAMOS initiative as a whole, provides links to relevant literature, and access to past SAMOS workshops. Through these pages, the DAC provides access to the preliminary quality controlled data for all 12 ships currently recruited to the SAMOS initiative. A metadata portal allows users to access ship- and parameter-specific metadata along with digital photos and schematics of participating vessels. Both the metadata portal and data access are user searchable. Criteria include searches by vessel and the observation dates. The web site also provides access to desired SAMOS parameters, accuracy requirements, and training materials.

The data distribution system is under constant development. New in the reporting period is the "Data Availability" link under "Data Access". This new page provides the user with more options to select desired data than the older "Data Download" page. Through "Data Availability" users can select one or more ships and a time range to determine whether observations are available. The data are displayed graphically by day and each day is color-coded according to the overall quality of the days observations. The user can then select to download data of one or more ships and has the option of selecting only good quality or all available data. Drill down capacity allows the user to select a single day and ship from the graphic to display detailed data quality graphics (similar to Figure 3). A new metadata interface is being developed and plans call for the data to be accessible via a THREADS server at COAPS. These new tools will be added to the web site for users when testing is complete.

7. Liaison activities

The SAMOS DAC serves as the coordination office for the entire SAMOS initiative. In this capacity, DAC personnel facilitate U.S. and international collaborations on topics ranging from data accuracy, data acquisition and exchange, training activities, and data archival.

Foremost of these activities was participation by co-PI Smith at the International Marine Technicians Symposium (17-19 October 2006) at WHOI. The symposium provided an opportunity to introduce the activities of and plans for the SAMOS initiative to the international research vessel community. Throughout the week, Mr. Smith participated in dialogs with ship operators as part of the SAMOS vessel recruitment effort. Mr. Smith also visited one of the NOAA OMAO vessels in port at WHOI and received a demonstration of the NOAA OMAO SAMOS data applet in SCS 4.0. This meeting led directly to the recruitment of many of the NOAA vessels in 2007. The symposium was also the venue where the "A Guide to Making Climate Quality Meteorological and Flux Measurements at Sea" was first released to the technician and operator community. This guide was co-authored by Frank Bradley (CSIRO) and Chris Fairall (NOAA/ESRL) and was a collaborative effort between the WCRP Working Group on Surface Fluxes and the SAMOS initiative. Several scientists participating in SAMOS activities contributed to the guide.

Co-PI Smith also was invited to participate at the Fourth Session of the WMO/IOC JCOMM Ship Observation Team meeting in Geneva, Switzerland (16-21 April 2007). The SOT is responsible for overall coordination of the Voluntary Observing Ship (VOS) program and the meeting brought together VOS participants from many countries. Participants included several countries that are working towards full automation of their standard VOS meteorological reports. Mr. Smith presented the activities of the SAMOS initiative and had productive discussions with the VOS automation community. They were keenly interested in the SAMOS approach to data quality evaluation and long-term access to observations for future climate research.

DAC personnel attended other meetings throughout the year to promote both the stewardship of SAMOS data, but also the scientific application of these data.

## FIGURES AND IMAGES

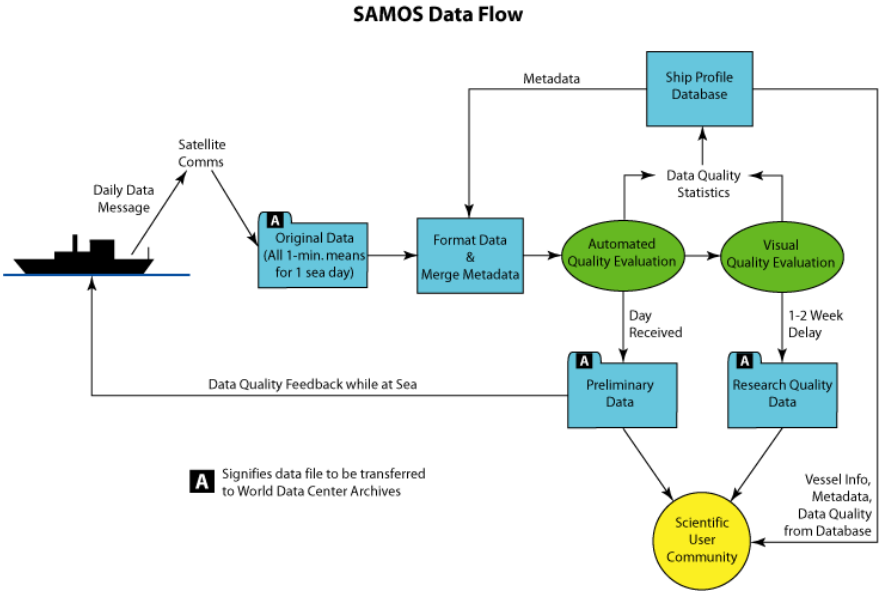


Figure 1. Operational data flow between research vessels at sea and the SAMOS DAC. Data transfers take advantage of 24/7 broadband satellite communications. Real-time data quality feedback to vessels at sea and their home institutions have proven successful to reduce the amount of poor quality data caused by sensor failures.

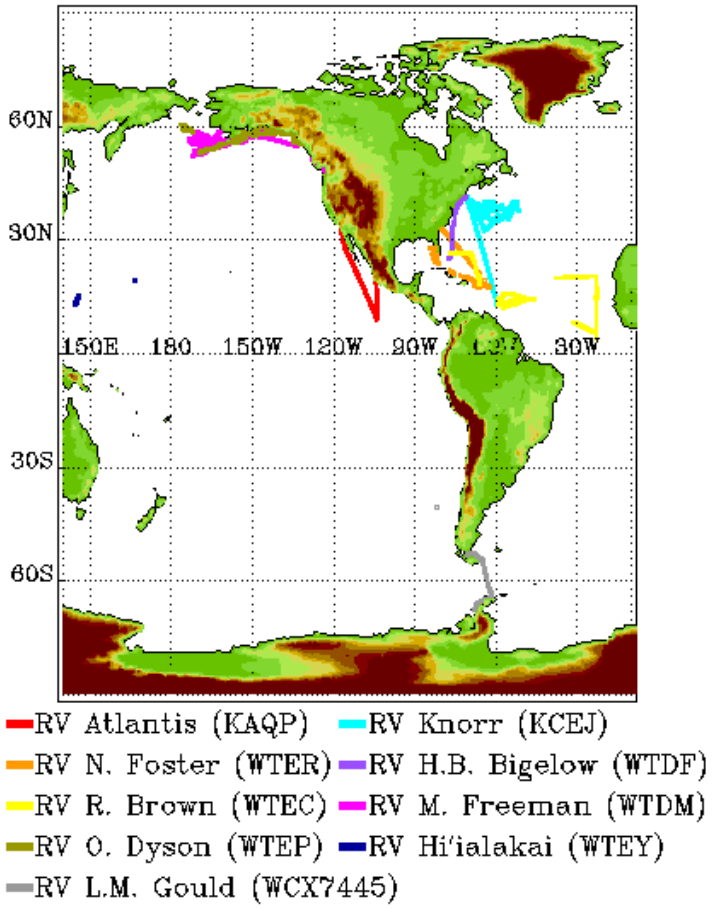


Figure 2: Cruise tracks for nine vessels submitting to the SAMOS DAC for the period 1 January – 21 May 2007.

(a)

(b)

(c)

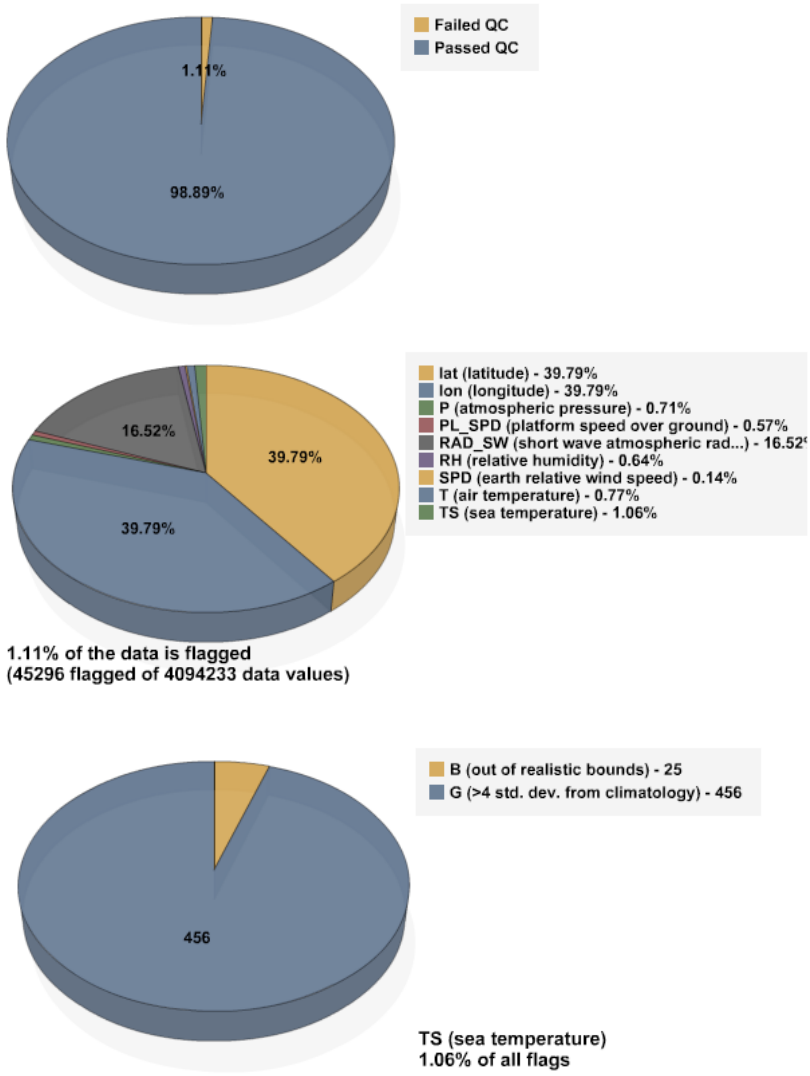


Figure 3: Data quality statistics for SAMOS observations received from the RV *Knorr* for the period 1 July 2006 – 30 June 2007. (a) Total percentage of data that passed or failed preliminary QC. (b) Breakdown by measured parameter of 1.11% of data that failed QC tests. (c) Flags applied to sea temperature (1.06% of the 45,296 values that failed QC tests).

## PUBLICATIONS

Refereed

Smith, S. R., 2006: A Partnership between Shipboard Oceanic and Atmospheric Data Programs. *EOS, Trans Amer. Geophys. Union*, **87**, 463, 466.

Technical reports

Smith, S. R., 2007: Shipboard Automated Meteorological and Oceanographic System (SAMOS) Initiative. Report for 4rd session of the JCOMM Ship Observation Team meeting, 16-21 April 2007, Geneva, Switzerland, 2 pp.

Smith, S. R., R. Keeley, and T. Delcroix, 2006: Report of the 1st Joint GOSUD/SAMOS Workshop. UCAR Joint Office for Science Support, Boulder, CO, USA, 63 pp. [Available from COAPS, The Florida State University, Tallahassee, FL 32306-2840].

Conference proceedings/presentations

Bourassa, M. A., and S. R. Smith, 2007: Improving air-sea flux estimation with a new wave-dependant

parameterization and high-quality research vessel observations. *ONR Progress Review – Southeast Region*, Tallahassee, FL, USA, 1-3 May 2007.
Smith, S. R., J. Rolph, and M. A. Bourassa, 2007: Progress of the Shipboard Automated Meteorological and Oceanographic System (SAMOS) Initiative Data Assembly Center. *Climate Observation Division 5th Annual System Review*, NOAA, Silver Spring, MD, USA, 5-7 June 2007.
Smith, S. R., 2007: The SAMOS Initiative. *4th session of the JCOMM Ship Observation Team*, Geneva, Switzerland, 16-21 April 2007, CDROM.
Josey, S. A. (presented by S. R. Smith), 2006: Evaluation of Air-Sea Fluxes. *2nd CLIVAR Global Synthesis and Observation Panel meeting*, La Jolla, CA, USA, 8 and 9 December 2006.
Smith, S. R., 2006: The SAMOS data assembly center. *International Marine Technicians Symposium*, Woods Hole, MA, USA, 17-19 October 2006.
Smith, S. R., F. Bradley, and C. Fairall, 2006: A guide to making climate quality meteorological and flux measurements at sea. *International Marine Technicians Symposium*, Woods Hole, MA, USA, 17-19 October 2006.

## SUMMARY OF INTERACTION WITH NOAA

The SAMOS initiative is a collaborative effort that encompasses a number of U.S. and international partners. The DAC routinely interacts with a number of NOAA facilities to achieve the goals of the initiative. Foremost is our routine participation in the annual system review of the NOAA Climate Observation Division (COD; formerly Office of Climate Observation). Through COD, we collaborate with other centers focusing on mooring, drifters, and other components of the ocean observing system.

We actively collaborate with several groups at the NOAA Earth System Research Laboratory (ESRL) in Boulder. Chris Fairall's group has been an active participant in the SAMOS initiative through both the development of the roving standard flux system (for onboard instrument comparisons) and the "A Guide to Making Climate Quality Meteorological and Flux Measurements at Sea". Through a collaboration with Scott Woodruff at ESRL (and Steve Worley at NCAR), the DAC has developed hourly sub-sets of WOCE era research vessel observations that are now available as a supplement to the International Comprehensive Ocean Atmosphere Data Set (ICOADS). This code is currently being modified to allow data received at the SAMOS DAC to be contributed to ICOADS.

We continue to have an ongoing and productive partnership with Office of Marine and Aviation Operations (OMAO). Through recent collaborations with Doug Perry, Tom Stepka, and Dennis Shields, the DAC has started receiving routine SAMOS transmissions from eight NOAA vessels. As a result, the former delayed-mode data transfers from the *Ronald Brown* and *Ka'Imimoana* are now fully automated through the SAMOS initiative.

We also continue to interact with the National Oceanographic Data Center (NODC) and the National Climatic Data Center. Through NODC, we plan to establish a routine archive for SAMOS observations. We plan to transfer SAMOS data to NCDC in support of the SURFA project, which will evaluate surface fluxes in operational numerical weather forecasting models.

## SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

The DAC does not presently participate in outreach activities. We do annually participate in the FSU Young Scholars Program (YSP). This year we hosted and directed the research activities of two high school students. The YSP students spend six weeks on the FSU campus taking classes and conducting directed research. We have been involved in the YSP program since 1998.

The SAMOS initiative has a number of educational goals. The focus of the training activities has been the production of a "A Guide to Making Climate Quality Meteorological and Flux Measurements at Sea". The handbook is aimed at the sea-going research community and ships' technical staff. Topics include information on preferred sensor location, calibration, in-situ comparisons, documentation, metadata, bulk flux methodology, and measurement error. Both hardcopy and digital versions of the handbook were produced by NOAA/ESRL and distributed at INMARTECH 2006.

# The Argo Float Program

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 304 & 305
July 1, 2004 through June 30, 2005

**Dr. Brechner Owens**
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Program Manager: Dr. 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.

## PROJECT BACKGROUND

The goal of the Argo float program is to have 3000 profiling floats reporting profiles of temperature and salinity on a 10-day cycle covering the global ocean. The program expects to reach this goal in October 2007. Once this coverage has been achieved the further objective is to sustain this array indefinitely. The US is expected to provide half the array and the WHOI component of the Argo float program that has been funded through CICOR represents approximately 15% of the array. The duration of present grant is 5 years, starting in July 2006.

The Argo float program was designed to provide data for a number of different usages. These range from real-time analyses by operational centers to high precision analyses by climate scientists to investigate decadal climate signals. This breadth has placed an extraordinary demand on both the performance of the instruments and on the infrastructure to process the data so that the data is distributed in a timely manner to real-time users and subjected to stringent quality control to provide a high-quality data set that will exponentially increase coverage and quantity of data available to construct ocean climatologies.

## OBJECTIVES

This grant covers WHOI's contribution to phase III of the Argo float program. The activities carried out in the final year of this grant include manufacturing of floats for the Argo array, quality-control of the data, and contributions scientific management of the Argo Float program. 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

Over the period from 1 July, 2006 to 30 June, 2007 a total of 137 floats have been manufactured and deployed, primarily in the Atlantic Ocean. 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, but there continue to be occasional problems. As compared to the deployments in other oceans, the relatively small size of the Atlantic requires that we only deploy 6-8 floats per VOS cruise and these cruises change on short notice which requires quick responses to these changes or that float leave the lab only to return later since the cruise has been canceled. This means that the time per float spent organizing for its delivery is higher than is the case when a cruise involves 30 or more floats as is the case in the Pacific and Indian Oceans. We have also arranged to deploy floats from research cruises on the R.V. Ron Brown in both the Atlantic and Pacific Oceans. We have also arranged, through

Raytheon Polr Services to deploy floats from the R.V. *Oden* in the Southern Ocean. An additional 10 floats have been loaded on the R.V. Nathaniel Palmer, but their deployment has been delayed due to a recent fire in the biological lab of the ship.

We have now developed a SOLO float that uses the Iridium Short Burst Data (SBD) communications system for data communications and GPS for positioning. Three floats were deployed in the Arctic Ocean under separate funding. A second-generation version was first deployed in October 2006. We are also working with the newest version of Iridium transmitter that is smaller and much lower power, but has a reduced message length. With this new transmitter, we are able to incorporate a continuous profile of dissolved oxygen with the same battery pack presently used for floats equipped with an Argos transmitter. This float has been deployed off Bermuda and is working well. These floats also use an antenna designed at WHOI that costs only slightly more than an Argos antenna. Using this version of the hardware and SBD communications minimizes the additional costs for Iridium compared to Argos equipped floats so that the additional costs give added lifetimes of the float and represent a net savings.

During the present year, an analysis of Argo float data identified that the WHOI FSI equipped floats had data that had a significantly cold bias. After extensive examination of the problem, it was determined that the error occurred because the FSI CTD was carrying out the bin averaging from the bottom of the profile, rather than from the sea surface downward. This error caused the pressure values to be incorrectly reported in the netcdf files. For approximately half of these floats, there is engineering data that will allow the data to be corrected unambiguously. For the other fraction, a least-squares procedure combined with a visual inspection has been developed to best estimate the pressures. This procedure will increase the pressure uncertainty to order 10 dbars. In the process of carefully screening the pressure data from the WHOI floats, a smaller error was found in the way that pressure was reported for the floats equipped with an SBE CTD. Procedures have been developed to correct all these incorrect pressures. At this time, the FSI CTD data that can be corrected unambiguously and the SBE CTD data have been corrected and the files at the global data centers corrected. WHOI is now working through the FSI data that requires manual inspection.

Owens has continued to work with A. Wong (U of Washington) to improve the procedures for calibration of the conductivity sensors against historical CTD data. We have implemented a piece-wise linear fitting procedure that chooses the statistically simplest model of the drift. This new procedure has been evaluated by the Argo community and has been accepted as the method to carry out the calibration of conductivity sensors.

Owens has continued to spend some time involved with the International Argo Steering Team and the Argo Advisory panel. This has included a meeting in Paris in March 2007.

In summary, the WHOI contribution to the Argo Float Program has continued significantly accelerated and improved the performance of the floats. Improvements in both the communications system and the calibration procedures have been implemented. A significant error in the data reported from these floats has been identified and the procedures to correct the data have been developed and implemented.

# Dynamics of the Flow of Pacific Water Through the Western Chukchi: Analysis of the 2004 RUSALCA Herald Canyon Hydrographic Data

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 371
June 1, 2005 through May 31, 2006 (Extended to ?)

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Program Manager: Dr. John Calder

Related NOAA Strategic Plan Goal:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

## PROJECT OVERVIEW

In summer 2004 the Russian icebreaker Khromov carried out the inaugural cruise of the Russia-US Long-term Census of the Arctic (RUSALCA) program. The expedition was a great success, consisting of multi-disciplinary sampling from Bering Strait northward into the Chukchi Sea. Part of the hydrographic component consisted of a detailed survey of the flow through Herald Canyon (Figure 1). This was the first time that the canyon had been sampled at high cross-stream resolution (station spacing less than the Rossby radius of deformation), enabling us to resolve fully the currents and water masses. Using the hydrographic and velocity data obtained from the survey, the dynamics of the flow of dense water through the canyon, and the potential impact that this has on the ventilation of the western Arctic, was investigated.

## ACCOMPLISHMENTS

The focus of the study was on the cold, dense winter-transformed Pacific water (< -1.6oC) that drains out of Herald Canyon and ultimately ventilates the upper halocline of the western Arctic Ocean. This water was likely formed the previous winter due to strong surface buoyancy loss over the Chukchi Sea, both before the onset of the ice, and during polynya events throughout the season. (Influx of winter water from the Bering Sea likely contributed as well.) During the RUSALCA survey the dense water was flowing northward through the canyon, entering the head of the canyon on the western side (Figure 2). A lateral view of the winter-transformed layer shows that this cold water switched to the eastern side of the canyon as it progressed northward (Figure 3). The consequences of this are huge, since it means that the newly-ventilated winter water entering the Arctic will flow to the east along the Chukchi shelfbreak rather than to the west along the East Siberian Sea. This in turn means that the water has a "direct route" to Fram Strait and the North Atlantic Ocean, where it can contribute to the global overturning circulation.

Why did the dense water cross to the eastern side of the canyon? The topography of the canyon is such that in addition to the lateral constriction (greatest near section 2) there is a local sill near section 3. Both of these features suggest that hydraulic control could be active, and one of the consequences of this is that the northward-flowing water should switch sides of the canyon.

There is indication in the hydrographic data that hydraulic adjustment was indeed active during the time of the survey. In Figure 3, the core of the dense layer transiting through the canyon has been marked with a symbol at each section, and these stations were used to construct a vertical section along the length of the canyon (Figure 4). Within the dense layer, which roughly corresponds to the magenta shading in Figure 4a, the deepest isopycnals ground as the water flows northward through the canyon. However, this trend reverses near the canyon mouth where the isopycnals abruptly lift off the bottom. This has the character of a hydraulic jump. Furthermore, some of the properties of the layer (e.g. turbidity, fluorescence, buoyancy frequency) show a tongue emanating from offshore in this region (near 60m at station 74 in Figure 4b) which is another characteristic of a hydraulic jump.

Roughly a month after the RUSALCA survey, a hydrographic section was occupied across the Chukchi shelfbreak at 166oW (approximately 350 km to the east of Herald Canyon, Figure 1) as part of the Western Arctic Shelf-Basin Interactions Program (SBI). If one assumes an advective speed of 10-15 cm/s for the water exiting Herald Canyon (a plausible speed based on previous SBI measurements), it means that the 166oW section likely sampled the same water measured during the RUSALCA survey. This gives us the opportunity to investigate the far-field product. An analysis in T-S space (not shown) reveals that the water became warmer, fresher, and less dense, along the same mixing line that was observed in the canyon. Overall, however, relatively little mixing occurred over this large distance, indicating that the evolution of the dense water within Herald Canyon sets, to first order, the properties of the water that eventually ventilates the upper halocline. This demonstrates the importance of canyon dynamics in influencing both the water mass product, and where the water ultimately ends up in the Arctic basin.

## FIGURES AND IMAGES

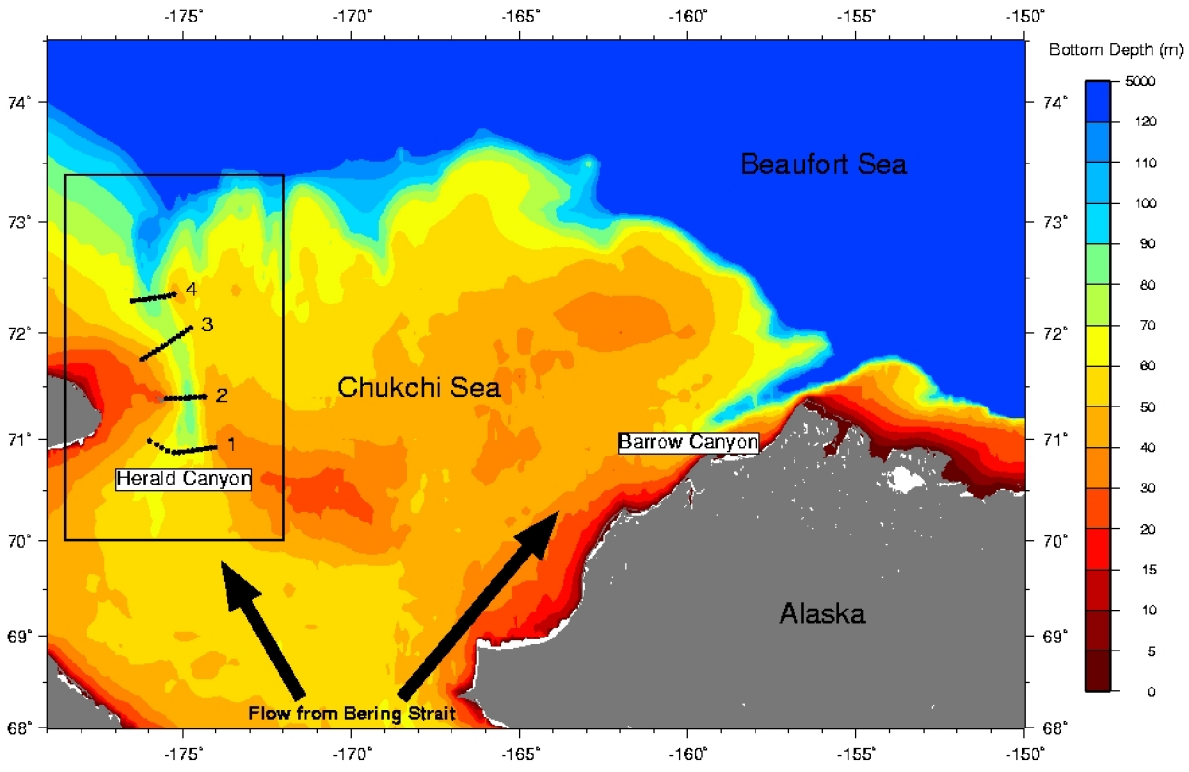


Figure 1: Topography of the Chukchi Sea (color), showing the two canyons that emanate from the shelfbreak. The four high-resolution CTD/velocity transects across Herald Canyon from the 2004 RUSALCA expedition are shown.

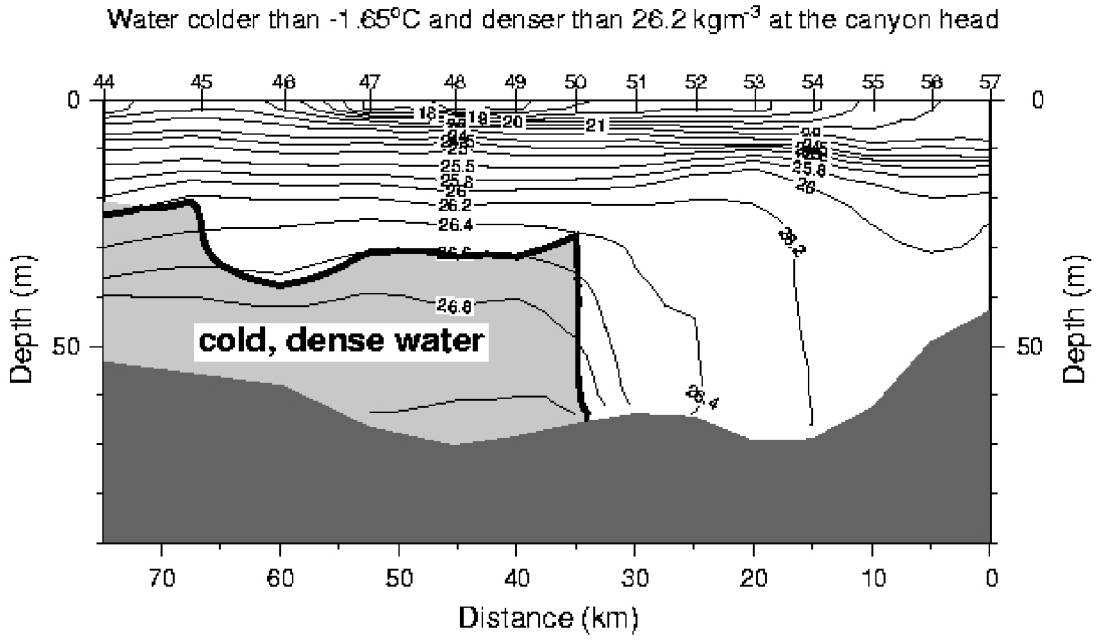


Figure 2
looking northward. The dense layer is defined by water that is colder than -1.65oC (shaded) and denser than 26.2 kgm-3. Station numbers are indicated along the top axis.

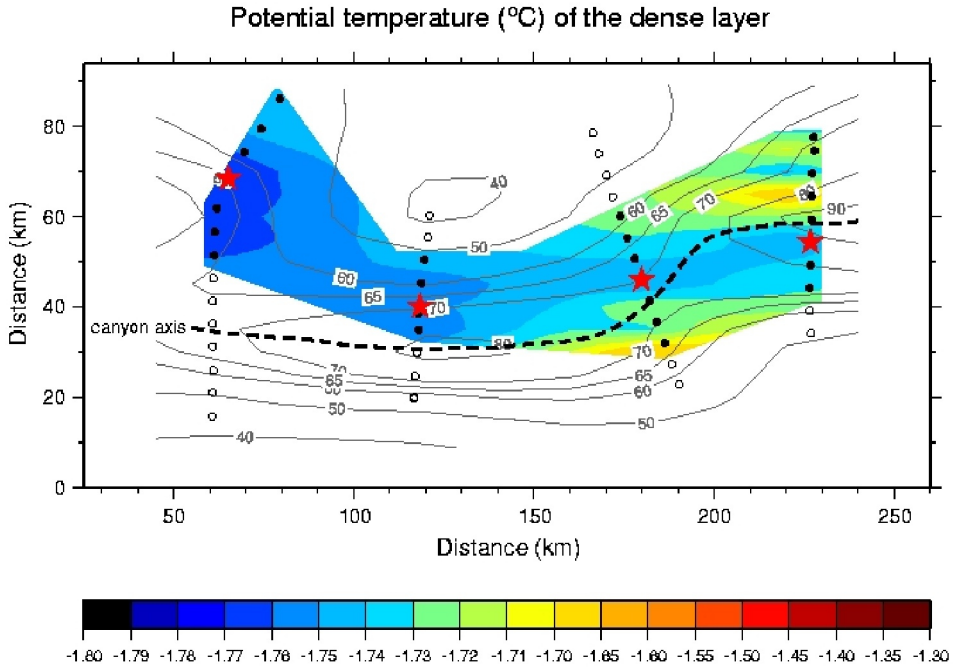


Figure 3: Average potential temperature of the dense layer flowing through Herald Canyon, revealing how the flow switches sides of the canyon. The figure is oriented such that north is to the right. The bathymetry (contours in meters) is from the shipboard altimetry data. The circles indicate the station positions (open circles mean that the dense layer was not present at those stations). The thick dashed line denotes the canyon axis, and the red stars indicate the center stations of the layer used in constructing Figure 4.

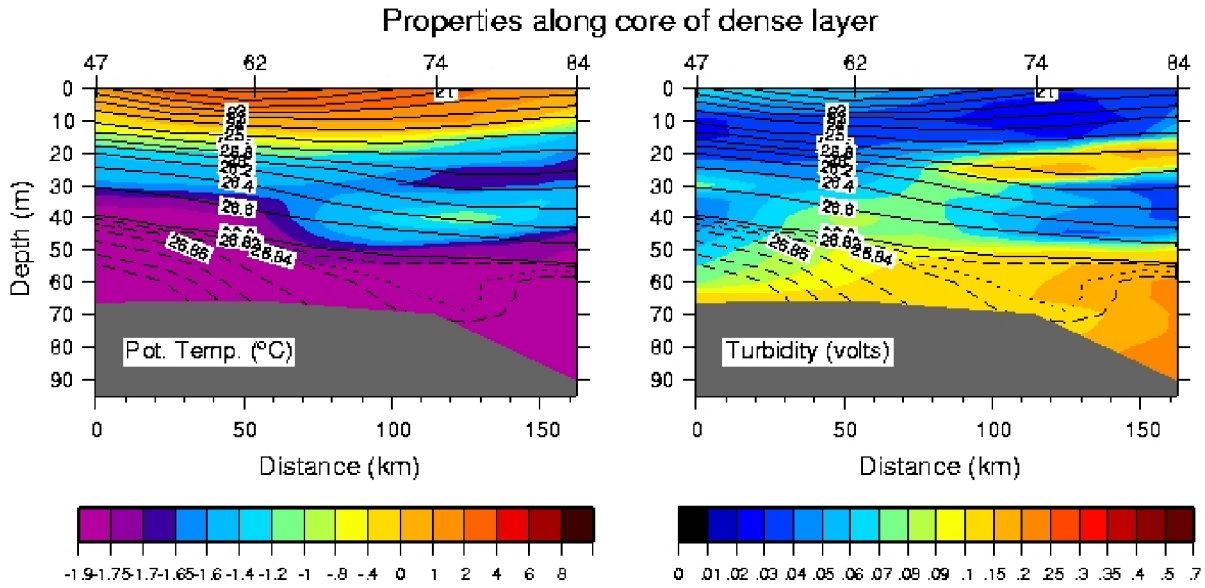


Figure 4: Section along the core of the dense layer in Herald Canyon. The stations used for the section are marked in Figure 3 (the mouth of the canyon is to the right). (a) The left-hand panel is potential temperature (color, oC) overlaid on potential density (contours, kgm-3). (b) The right-hand panel is turbidity (color, volts) overlaid on potential density.

## PUBLICATIONS

Pickart, R.S., Pratt, L., and Whitledge, T. "Dynamics of the flow of Pacific water through Herald Canyon: Implications for ventilation of the western Arctic halocline". Manuscript in preparation.

## SUMMARY OF INTERACTION WITH NOAA

Subsequent to the RUSALCA field program the PI participated in a synthesis workshop and presented preliminary results from the study. A report describing the processing of the hydrographic data was distributed to the PIs in the project, and vertical sections were constructed and made available to the program manager and PIs via a website.

# AUVSA - Autonomous Underwater Vehicles (AUVs) for Scientific Applications: A Conference to Promote Dialog Between AUV Developers, Engineers and Science Users

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 393
January 1, 2006 through December 31, 2006

**Dr. Hanumant Singh**
Woods Hole Oceanographic Institution, Woods Hole, MA 02543
Tel: (508) 289-3270 E-mail: hsingh@whoi.edu

Program Manager: Mr. Justin Manley NOAA/OAR/Battelle

Related NOAA Strategic Plan Goal:
Goal 1. Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.
Goal 3. Serve society's needs for weather and water information.

## PROJECT OVERVIEW

A conference to facilitate dialog between Autonomous Underwater Vehicle (AUV) developers, engineers and science users was held at the Woods Hole Oceanographic Institution, June 6-7, 2006. Funding for conference costs were provided NOAA's Ocean Exploration program, NSF (Engineering Directorate through the Censsis Engineering Research Center), NSF (OCE), and Woods Hole Oceanographic Institution's Deep Ocean Exploration Institute.

## ACCOMPLISHMENTS/PROGRESS/STATUS

Autonomous Underwater Vehicles (AUVs) have, in the past decade, reached a high level of maturity in their application to marine geological, biological, chemical, and physical oceanographic problems. A variety of scientific and commercial AUVs have been designed, built and deployed for scientific applications from shallow water to 11,000 m depths. However, the broad scientific community has not been exposed to an up-to-date review of the relative merits of using different kinds of AUVs for different applications.

In order to best plan and propose a wide range of field research employing AUV technology, - not least in support of forthcoming Ocean Observatories Initiative (OOI) activities - the range of subjects covered by this workshop included:
- depth ratings, operational capabilities and costs of AUVs available to science;
- pros and cons of various hull designs (e.g., torpedo shaped vs. multi-hulled);
- available sensor packages (resolution, power requirements, operational guidelines);
- science requirements versus operational requirements in AUV missions;
- optimization of AUV characteristics for different types of operation/investigation (e.g., near-bottom bathymetry/geophysics, mid-water water column sensing, near-bottom photography);
- vertical integration of sensors, platforms and algorithms into finished science products.

In order to address the topics presented above and provide a forum for discussion between AUV researchers and scientists, a 2-day workshop was held at Woods Hole Oceanographic Institution on June 6-7, 2006 with the primary purpose of bringing together leading developers of scientific AUVs with leading scientific users. There were 105

registrants for the workshop, which included six sessions over the course of two days with 2 co-chairs for each session, 21 speakers during the six sessions, and a panel discussion to conclude the workshop, in addition to the dialog that continued outside the workshop agenda. The AUVSA Workshop spawned several special sessions at the annual American Geophysical Union meeting in San Francisco in December 2006. The dialog established at the workshop and during the AGU meeting continues well beyond these venues.

## SUMMARY OF INTERACTION WITH NOAA

In addition to the funding for the workshop provided by NOAA, representatives from NOAA were registrants, speakers, and panelists at the 2-day workshop. NOAA has been one of the core agencies in employing AUV technologies and applying them to oceanographic problems.

## SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

We expected between 50 and 75 attendees to the conference with an even split between the engineering and science disciplines. Instead we had over 100 registrants with more than a dozen students and representation from industry in addition to the developers, engineers and scientists.

The workshop was comprised of six sessions over the course of two days with 2 co-chairs for each session, 21 speakers during the six sessions, and a panel discussion to conclude the workshop. The AUVSA Workshop spawned several special sessions at the annual American Geophysical Union meeting in San Francisco in December 2006.

**AUVSA: - Autonomous Underwater Vehicles (AUVs) for Scientific Applications:**
**A conference to Promote Dialog Between AUV Developers, Engineers and Science Users**
Co-Convenors:
H. Singh, C. German, M .Tivey, T. Shank (WHOI) L. Mayer (UNH), L. Whitcomb (JHU),

Woods Hole Oceanographic Institution ~ Quissett and Village Campuses
Woods Hole, Massachusetts
June 6 - 7, 2006

**Day 1: Tuesday, June 6, 2006 Clark 507 Quissett Campus**
8:30 a.m. Welcome, Hanumant Singh ,WHOI
8:35 a.m. Opening Remarks, Robert Detrick WHOI

***Session I***
***Session Co- Chairs***
*Ralf Bachmayer, National Research Council Canada*
*Ryan Eustice, John Hopkins University*

8:50 – 9:20 Dana Yoerger WHOI , The ABE and Sentry AUVs
9:20 – 9:50 Maurice Tivey WHOI , Magnetic Mapping with ABE
9:50 - 10:20 Jeff Karson Duke University , ABE User Talk II
10:20- 10:30 Break ~ Coffee / Tea / Juice / Water and Pastries available in the Lobby

***Session II***
***Session Co- Chairs***
*Kevin McCarthy, Hydroid LLC*
*Mark Patterson, VIMS William & Mary*

10:30- 10:50 Scott Willcox, Joe Bondaryk, Bluefin Technologies
11:00-11:30 Art Kleiner, C & C Technologies
11:30-12:00 Jim McFarlane, ISE Technologies
12:00- 1:00 Buffet Lunch available in the Clark Lobby

***Session III***
***Session Co- Chairs***
*Rich Camilli, WHOI*
*Brian Bingham, Olin College*

1:00 – 1:30 Tom Austin WHOI , The REMUS AUVs
1:30 – 2:00 Glenn Gawarkiewicz WHOI , REMUS User Talk I
2:00 - 2:30 Mark Moline, California Polytechnic State University, REMUS User Talk II
2:30 – 3:00 Louis Whitcomb, Johns Hopkins University, The 11,000 HROV
3:00-3:10 Break ~ Soda / Juice / Water and Cookies available in the lobby .
***AUVSA:*** - Autonomous Underwater Vehicles (AUVs) for Scientific Applications
Woods Hole Oceanographic Institution ~ Quissett and Village Campuses
June 6 - 7, 2006

***Session IV***
***Session Co- Chairs***
*Larry Mayer, CCOM- University of New Hampshire*
*Jennifer Reynolds, West Coast & Polar Regions Undersea Research Center (NURP)*

3:10 – 3:40 Jim Bellingham, MBARI, MBARI AUV Operations for Science
3:40 - 4:10 Colin Ware/Roland Arsenault, UNH, Visualization of AUV data
4:10 - 4:40 Timothy Shank WHOI , Biological Mapping and Sampling with AUVs
4:40 – 5:20 John Ryan MBARI, AUVs as Elements of Ocean Observing Systems
6:30 – 8:00 Buffet Dinner (Location: WHOI Quissett Campus Clark 507 )

**Day 2: Wednesday, June 7, 2006 Redfield Auditorium – Village Campus**

***Session V***
***Session Co- Chairs***
*Milene Cormier, Lamont-Doherty Earth Observatory*
*Rob Reves-Sohn, WHOI*
8:30 – 9:00 Steve McPhail, SOC, The Autosub AUV
9:00 – 9:30 Chris German WHOI , Chemical Sensing on the Autosub AUV
9:30 – 10:00 Henrik Schmidt, MIT, Acoustics Applications of AUVs
10:00-10:15 Break ~ Coffee / Tea / Juice / Water and Pastries available in Lobby

***Session VI***
***Session Co- Chairs***
*Breea Govenar, WHOI*
*Jeff Williams, USM*

10:15 – 10:45 Hanumant Singh WHOI , The Seabed, Jaguar and Puma AUVs
10:45 – 11:15 Elizabeth Clarke, NWFSC, "West Coast Groundfish Monitoring in Trawlable Areas"
11:15 – 11:45 Neal Driscoll, SIO, Mapping the Gas Blowout Site
11:45 – 12:15 Justin Manley, Battelle, AUVs at NOAA, From Research to Operations
12:15 - 1:15 Lunch (One Slide, five minute, presentations) Box Lunch available in Lobby .
1:15 – 2:30 Panel Discussion on AUVs for OOI
**Panel:**
*James Bellingham, MBARI*
*Dan Frye, WHOI*
*Rocky Geyer, WHOI*
*Susan Humphris, WHOI*
*Dana Yoerger, WHOI*

# Broadband Discrimination Between Anatomical Groups of Fish and Zooplankton--Demersal and Pelagic Regions

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 397
January 1, 2006 through December 31, 2006

**Dr. Timothy Stanton**
Woods Hole Oceanographic Institution, Woods Hole, MA 02543
Tel: (508) 289-2757 E-mail: tstanton@whoi.edu

Program Manager: Michael Jech NOAA/NMFS

Related NOAA Strategic Plan Goal:
Goal 1. Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.

## PROJECT OVERVIEW

The purpose of the research is to address the limitations of traditional high frequency acoustic systems by using a novel broadband acoustic system spanning most of the frequency range, 1-100 kHz. The lower portion of this frequency range fills in the crucial "gap" missed by high frequency systems so that the difference in scattering characteristics between fish with swimbladders, fish without swimbladders, and large zooplankton can be determined unambiguously. In this one-year study, data recently collected in the Georges Bank and Gulf of Maine regions with the FR/V Delaware II are analyzed. The analysis is focussed on studying the frequency dependence of the acoustic scattering by organisms of different anatomical groups.

## ACCOMPLISHMENTS

Two major anatomical groups were observed-- Atlantic Herring (swimbladder-bearing) and various macrozooplankton (no gas inclusion). The difference in scattering characteristics is striking (Figs. 1, 2). In the case of the swimbladder-bearing fish, there was a strong resonance at approximately 3.7 kHz, above which the scattering level drops. In the case of the zooplankton, the scattering was of negligible strength at that frequency and increased rapidly with frequency until leveling off at frequencies above about 80 kHz. The acoustic signatures of these two different types of organisms are irrefutably different. These data provide a basis for discriminating organisms belonging to different anatomical groups with significantly reduced ambiguity over existing high frequency acoustics methods.

One conference proceedings describing the above is in print and a journal article is in preparation.

## PUBLICATIONS

Stanton, T.K, Chu, D., Jech, J.M., and Irish, J.D. (2007), "A broadband echosounder for resonance classification of swimbladder-bearing fish," Proceedings of the 2007 IEEE Oceans Conference in Aberdeen, Scotland.

## SUMMARY OF INTERACTION WITH NOAA

These data were collected on the FR/V Delaware II on leg 1 of the 2005 herring cruise, sponsored by NOAA. The research was in collaboration with Dr. Mike Jech of NOAA.

## FIGURES AND IMAGES

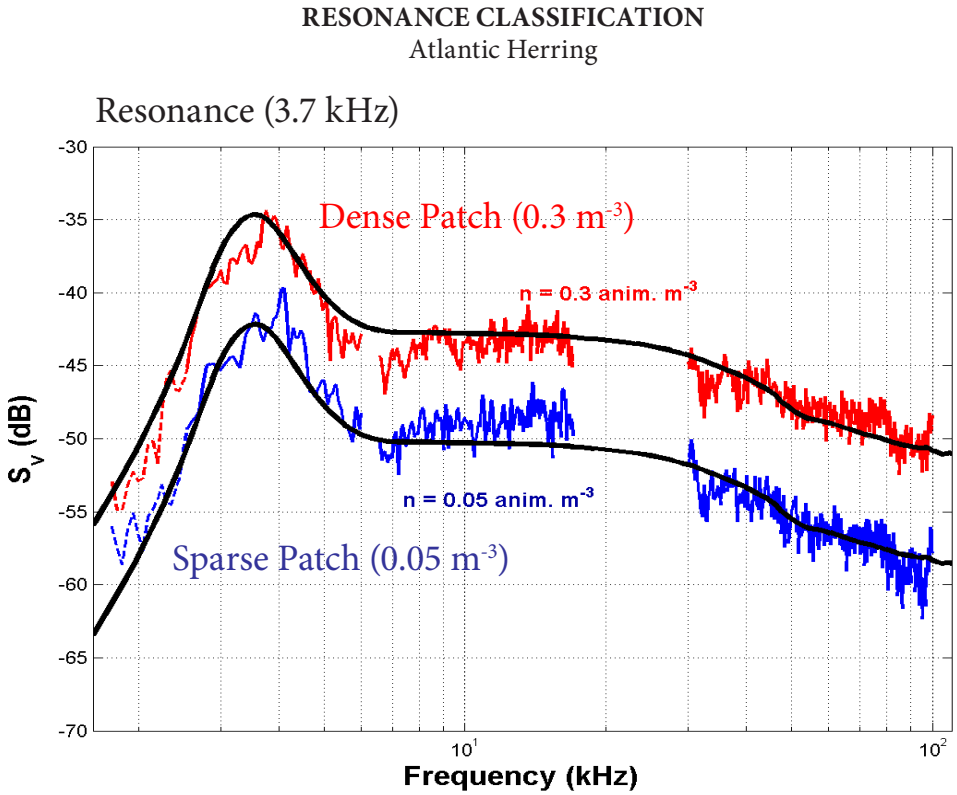


Figure 1. Acoustic scattering versus frequency by Atlantic Herring, 23 cm in length. The scattering is shown to have a resonance at about 3.7 kHz which is characteristic of the fact that this type of fish contains a gas-filled swimbladder.

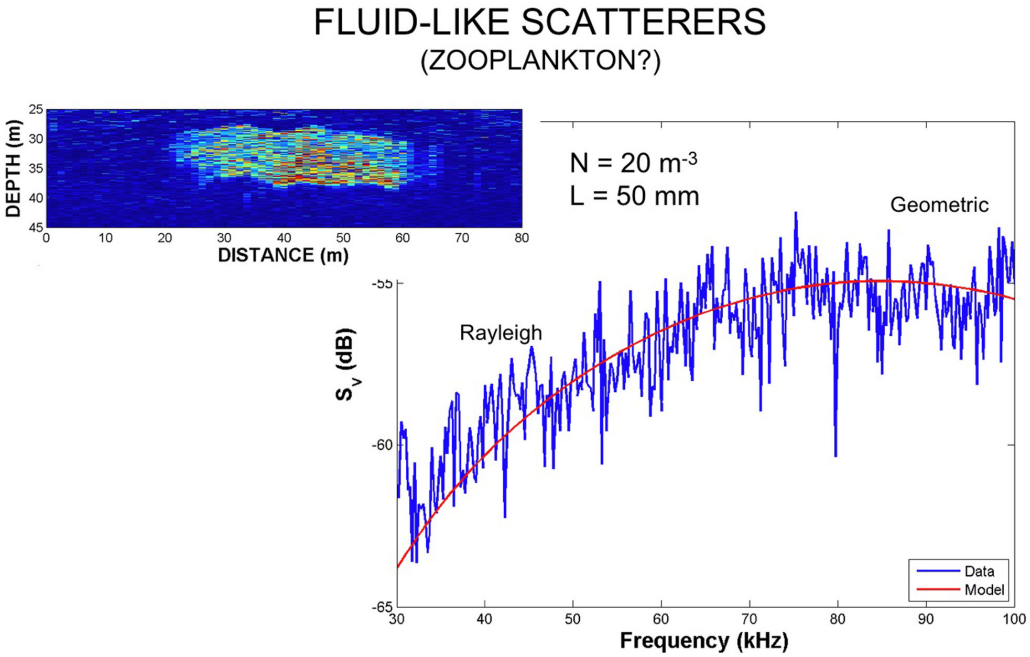


Figure 2. Acoustic scattering versus frequency by what is believed to be 5-cm-long zooplankton. The scattering rises rapidly with frequency until it levels off above about 80 kHz. This scattering behavior is characteristic of an organism that is composed principally of tissue (i.e., no gas).

# A Fifty-year Analysis of Global Ocean Surface Heat Flux

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 351
July 1, 2006 through June 30, 2007

**Drs. Lisan Yu and Bob Weller**
Woods Hole Oceanographic Institution, Woods Hole, MA 02543
(508) 289-2504, lyu@whoi.edu

Program Manager: Dr. Mike Johnson, NOAA/OCO
Dr. Miller, NOAA/CCDD

Related NOAA Strategic Plan Goal:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

## PROJECT SUMMARY

The ocean and the atmosphere exchange heat at their interface via a number of processes: solar radiation, longwave radiation, sensible heat transfer by conduction and convection, and latent heat transfer by evaporation of sea surface water. The amount of heat being exchanged is called heat flux. The distribution of heat flux over the global oceans is a key element for climate studies, as it is required to establish air-sea feedback mechanisms, to provide guidance and motivation for modeling studies, to verify individual or coupled atmosphere-ocean general circulation model simulations, and to serve as forcing functions for ocean model exercises. However, direct flux measurements are sparse. Our present knowledge of the global air-sea heat flux distribution stems primarily from the bulk parameterizations of air-sea fluxes as functions of surface meteorological variables (e.g., wind speed, temperature, humidity, cloud cover, etc). The source of observations for those flux-related variables includes marine surface weather reports from Voluntary Observing Ships (VOS) collected by Comprehensive Ocean-Atmosphere Data Set (COADS) and satellite remote sensing from various platforms. Atmospheric reanalyses from numerical weather prediction (NWP) centers such as National Centers for Environmental Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasts (ECMWF) provide additional model-based database. Nonetheless, none of the three data sources are perfect as each suffers from at least one of the four deficiencies: (1) incomplete global coverage, (2) relatively short time series, (3) systematic bias, and (4) random error.

While improving the quality of each data source is a necessary step toward improving the estimates of surface heat fluxes, this project takes an alternative approach, i.e., to improve the quality of the flux estimates through objectively synthesizing the advantages of the three data sources. Synthesis denotes the process of using an advanced objective analysis approach to combine several kinds of individual data sources with different characteristics. Such a process reduces the errors in data and produces an estimate that has the minimum error variance at the solution. This type of approach has been applied successfully to generate gridded products surface vector wind, SST, and precipitation. This project, which is termed "Objectively Analyzed air-sea heat Fluxes (OAFlux)", is to develop an equivalent global synthesis product for surface heat fluxes by utilizing the methodology developed and experience learnt from a previous pilot study for the Atlantic Ocean.

The project has two main objectives. The first objective is to produce a 50-year (from the mid 1950s onward) analysis of surface latent, sensible, net shortwave and net longwave radiation fluxes over the global oceans with improved accuracy. This is to be achieved by an appropriate combination of COADS data, NWP reanalysis outputs, and satellite retrievals using advanced objective analysis. The target resolution is 1° longitude by 1° latitude and monthly. Daily flux fields will be produced when satellite data are available. The second objective is to use the data

to study the heat flux variability on seasonal, annual, interannual, decadal and longer timescales and their relation to global climate change. The scientific investigation helps to assess the quality and reliability of the dataset in depicting the multi-decade climate record since 1950s and to provide physical insights into the dataset.

The end product, multi-decade, gridded global fields of surface latent, sensible, fluxes with monthly and/or daily resolutions is freely available to the community via the project website (http://oaflux.whoi.edu). The proposed study contributes to CLIVAR programs including CLIVAR Atlantic, Pacific and PACS, and benefits the CLIVAR and other research communities on studies of climate variability and predictability.

## ACCOMPLISHMENTS

Two major tasks, with one on the product development and the other on the analysis study of climate variability of global heat fluxes, have been undertaken in response to the two main objectives stated in the project summary.

*(i) Task 1: Product development*
The data development efforts in FY2006 have been placed on the production of the 50-year time series of global latent and sensible heat fluxes from the mid 1950s to present. This is achieved by applying a synthesis approach to each of the flux-related variables (i.e., wind speed, air and sea surface temperatures, and specific air humidity) and then computing the estimates of latent and sensible heat fluxes using the state-of-the-art bulk flux algorithm version 3.0, which was developed from the Coupled Ocean Atmosphere Response Experiment (COARE) (Fairall et al. 2003). The input data for the synthesis include satellite observations and NCEP and ECMWF model reanalyses and operational analyses. However, no satellite observations were available before 1981. A two-phase development process is, therefore, carried out and discussed below.

The first development phase is for the satellite era from 1981 onward. For this period, most flux-related variables (e.g., wind speed, sea surface temperature (SST), humidity) can be derived from passive and active satellite sensors such as the Advanced Very High Resolution Radiometer (AVHRR), Advanced Microwave Scanning Radiometer (AMSR), NSCAT and Quikscat scatterometers, TRMM Microwave Imager (TMI), and the Special Sensor Miscrowave Imager (SSM/I). Nevertheless, not all flux-related variables are satellite retrievable. To fill the data gap, the surface meteorology outputs from ECMWF operational forecast, ECMWF ReAnalysis-40 (ERA40), and NCEP-1 and NCEP-2 reanalyses are incorporated. COADS ship observations are not a direct input data source; but they, together with in situ buoy measurements, serve as the base data to provide the estimates for error properties of each input dataset and to validate flux estimates at the buoy sites. The analysis of daily global latent and sensible heat flux fields on a 1-degree grid from 1981 to 2002 has been made online since December 2005 via the project website http://oaflux.whoi.edu/.

The second phase is for the pre-satellite era from the mid 1950s to 1980, the period that there are only limited ship reports of surface meteorology. In absence of sufficient observations, NWP reanalyses play a major role in the development. Extensive efforts are made to compare NWP surface meteorology against available COAD in situ observations, from which error statistics are computed and included as weighting information during synthesis to control the actual contribution of each dataset. That is, data with poor quality are given a small weight so that their impact on the solution is minimized. To date, we have completed the analysis and validation of the dataset, and are in preparation for the release of the entire dataset in the coming months. Only monthly-mean data fields are to be distributed for this period, as the dataset may not be sufficient to resolve the spatial and temporal evolution of synoptic variability due to the lack of observations.

*(ii) Task II: Analysis study*
A series of the analysis study has been conducted to utilize the newly developed flux dataset to investigate climate variations of global heat flux fields, their relation to SST, and their implications for regional and global climate change. As a result, six papers have been submitted/accepted/published in peer-review journals during FY2006. The major findings are highlighted and discussed below.

(1) The manuscript on "Objectively Analyzed air-sea heat Fluxes (OAFlux) for the global ice-free oceans" (Yu and Weller, 2007) introduced the newly developed 25-year (1981-2005) time series of daily latent and sensible heat fluxes and also presented variability of the global ocean heat flux fields on seasonal, interannual, decadal and longer

timescales suggested by the new dataset. The paper showed that among all the climate signals in study the most striking is a long-term increase in latent heat flux that dominates the 25-year data record. Positive linear trends occur on a global scale, being most significant over the tropical Indian and western Pacific warm pool and the boundary current regions. The increase in latent heat flux is found to be in concert with the rise of sea surface

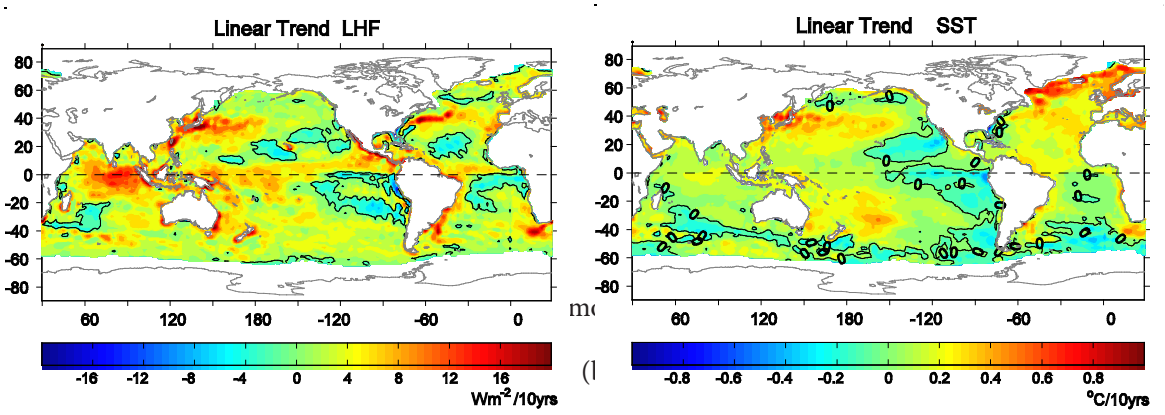


Figure1 Linear trends in yearly-mean (a) latent heat flux (LHF) and (b) SST derived from the period from 1981 to 2005. Zero contours are highlighted.

(2) The ocean, being the source of 86% of the global evaporation and the receiver of 78% of global precipitation, is a key component of the global water cycle. A good understanding of the change of oceanic evaporation can lead to improved understanding of the climate behavior of the water cycle in the context of global climate change. Evaporation (*Evp*) is related to latent heat flux (LHF) by $Evp = LHF/\rho_w L_e$. Hence, time series of global evaporation fields is derived as a by-product of the OAFlux project (Figure 2a). The manuscript on "Global variations in oceanic evaporation (1958-2005)" (Yu, 2007) showed that the decadal change of the global oceanic evaporation (*Evp*) is marked by a distinct transition from a downward trend to an upward trend around 1977-78. Since the transition the global oceanic *Evp* has been up about 12 cm $yr^{-1}$ (~11%), from a low at 115 cm $yr^{-1}$ in 1977 to a peak at 127 cm $yr^{-1}$ in 2002 (Figure 2b). The increase in *Evp* is most significant during the decade of the 1990s. The analysis of the cause of the *Evp* change suggested a dominant role of the wind forcing. It is hypothesized that wind impacts *Evp* by two ways. The first way is direct: the greater wind speed induces more evaporation by carrying water vapor away from the evaporating surface to allow the sea-air humidity gradients to be reestablished at a faster pace. The second way is indirect: the enhanced surface wind strengthens the wind-driven subtropical gyre, which in turn drives a greater heat transport by the western boundary currents, warms up SST along the paths of the currents and extensions, and causes more evaporation by enlarging the sea-air humidity gradients. Although the trend in *Evp* can be traced directly to changes in surface wind forcing and its effects on sea-air humidities, the long-term trend in SST is, nevertheless, the ultimate cause of the change.

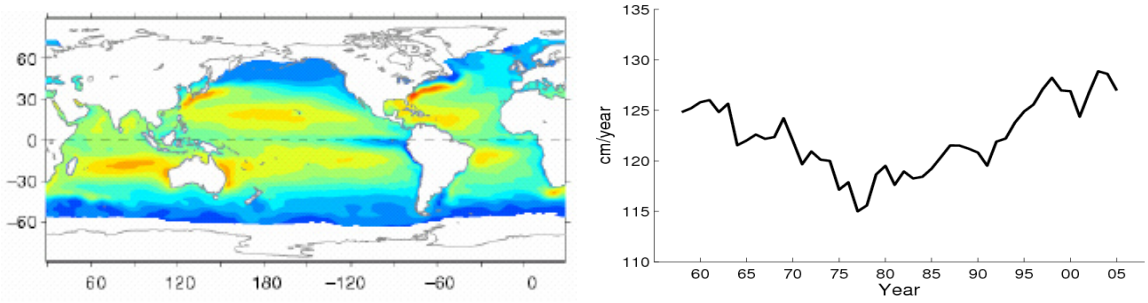


Figure 2 (a) Mean global evaporation pattern averaged over the 1958-2005 period. (b) Time series of the yearly-mean evaporation averaged over the global ice-free regions.

(3 In situ flux measurements made by buoys and ships provide benchmark time series for evaluation the accuracy of various heat flux products. The manuscript on "Annual, Seasonal, and interannual variability of air-sea heat fluxes in the Indian Ocean" (Yu et al. 2007) presented an evaluation study for six net heat flux products, including the latent and sensible fluxes from OAFlux plus net shortwave and longwave radiation from the International Satellite Cloud Climatology Project (ISCCP), the heat flux analysis from Southampton Oceanography Centre (SOC), NCEP1, and NCEP2, ECMWF operational (ECMWF-OP) and ERA40. The study showed that the net heat flux into the northern Indian Ocean is considerably underestimated by the four NWP model flux products; sometimes, even the sign is wrong. At the two in situ measurements sites, NCEP1 net heat flux is 52 – 69 Wm-2 lower, and ERA40 is about 26 Wm-2 lower – the magnitude of the bias is larger than the mean itself. On the other hand, the OAFlux+ISCCP has the best comparison at both measurement sites, differing from buoy/ship flux measurements by about 5% on average.

(4) The manuscript on "Role of net surface heat flux in the seasonal evolution of sea surface temperature in the Atlantic Ocean" provided an example that the better fluxes can lead to a better understanding of SST variability (Yu et al. 2006). Ocean observations indicate that the seasonal SST increase in the tropical Atlantic Ocean is associated with a shallow thermocline, suggesting that the major contributor to the surface mixed layer heat budget is the net surface heat flux through the air-sea interface. By combining the OA latent and sensible heat fluxes with ISCCP surface radiation, the role of surface heat fluxes was clearly depicted. In consistent with ocean subsurface observations, surface heat fluxes are the forcing for the seasonal SST cycle over most of the tropical Atlantic basin except for the equatorial cold tongue and the region under the Intertropical Convergence Zone (ITCZ) (Figure 3a). Such depiction cannot be established using NWP flux products from NCEP and ERA40. The seasonal evolution of dSST can be well simulated by the OAFlux+ISCCP heat fluxes outside of the two zonal belts

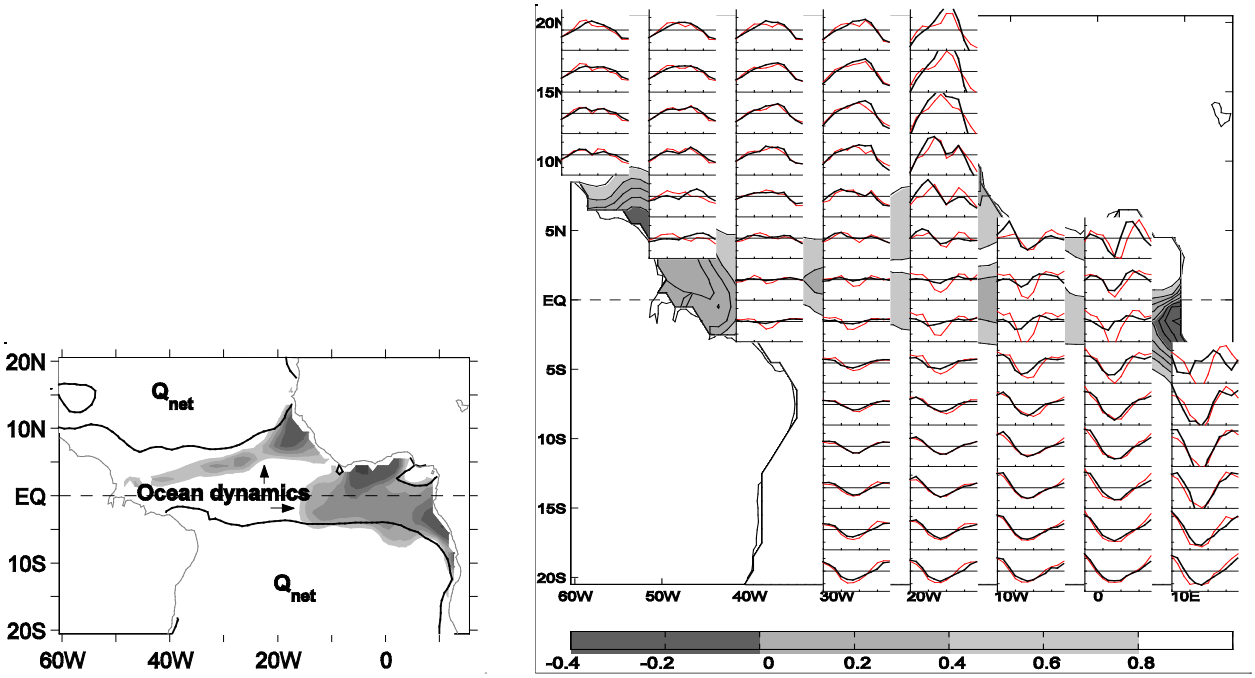


Figure 3 (a) Schematic diagram of the dominant influence of net heat flux ($Q_{net}$) and ocean dynamic processes in seasonal variations of SST of the tropical Atlantic Ocean. The pattern is based on the 0.9 correlation coefficient of <$Q_{net}$, *dSST*> derived from the OAFlux product. *dSST* denotes the monthly increment in SST. The role of oceanic process is deemed important in the two zonal belts (gray color shaded). (b) Model predicted (black) versus observed (red) *dSST*. The individual plots are drawn at every 10° in longitude and every 3° in latitude starting from the grid location (60.5°W, 18.5°S). The x-axis is Month and the y-axis ranges between -1.6 to 1.6°C.

## 3. PUBLICATIONS AND REPORTS

Yu, L., R. A. Weller, 2007: Objectively Analyzed air-sea heat Fluxes (OAFlux) for the global ice-free oceans. *Bull. Amer. Meteor. Soc*. 88, 527-539.
Yu, L., X. Jin, and R. A. Weller, 2007: Annual, Seasonal, and interannual variability of air-sea heat fluxes in the Indian Ocean. *J. Climate*. **20**, 3190–3209.
Yu, L., 2007: Global variations in oceanic evaporation (1958-2005). *J. Climate*. In press.
Yu, L., X. Jin, and R. A. Weller, 2006: Role of net surface heat flux in the seasonal evolution of sea surface temperature in the Atlantic Ocean. *J. Climate*, **19**, 6153–6169.
Arguez, A., et al., 2007: State of the Climate in 2006. *Bull. Ameri. Meteor. Soc*., 88, s1-s135
Yu, L., 2006: Objectively analyzed air-sea fluxes (OAFlux) for the global oceans. Proceeding of the 86th American Meteorological Society Annual Meeting. Atlanta, Georgia. January, 2006.
Helber, B., F. Bonjean, R. H. Weisberg, E. S. Johnson, and L. Yu, 2006: Heat transport analyses of the tropical Atlantic Ocean mixed layer. Proceeding of the 86th American Meteorological Society Annual Meeting. Atlanta, Georgia. January, 2006.
Yu, L., Xiangze Jin, and R. A. Weller, 2006: Objectively analyzed air-sea fluxes (OAFlux) for the Indian Ocean climate studies. Proceeding of the 13th AGU Ocean Sciences meeting. Honolulu, Hawaii.
Jin, X., L. Yu, and R. A. Weller, 2006: Global daily air-sea heat fluxes from the WHOI OAFlux Project. Proceeding of the 13th AGU Ocean Sciences meeting. Honolulu, Hawaii.
Helber, B., F. Bonjean, R. H. Weisberg, E. S. Johnson, and L. Yu, 2006: Heat transport analyses of the tropical Atlantic Ocean mixed layer. Proceeding of the 13th AGU Ocean Sciences meeting. Honolulu, Hawaii.

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

NOAA Cooperative Agreement No. NA17RJ1223, sub-point 325 (continuation from NA87RJ0445)
July 1, 2006 - June 30, 2007

**Dr. Robert A. Weller**
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Woods Hole, MA 02543
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Program Manager: Dr. Jin Huang, NOAA Climate Prediction Program for the Americas

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

## PROJECT OVERVIEW

As part of the NOAA funded Pan American Climate Study (PACS), two surface moorings were deployed on 125° 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 and 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. Tom Farrar completed his Ph.D. thesis during the past year under Weller's supervision and manuscripts are being prepared for publication. That effort used the PACS mooring data and satellite observations to study air-sea interaction and the processes that set SST in these two contrasting regions. Analysis of this data has had two principle foci: (1) Understanding of the balance of processes that set SST, and (2) Characterization of air-sea fluxes of heat, momentum, and freshwater in these two climactically and meteorologically important regions.

Accomplishments
*1. Processes affecting SST at two contrasting sites in the eastern tropical Pacific*
The well-resolved time series of upper-ocean temperature and velocity, together with the accurate estimates of air-sea heat fluxes and satellite observations of SST, allow examination of the relative importance of surface heat fluxes and horizontal advection in setting the local SST. The residual of the temperature balance equation can be used to assess the role of vertical mixing and other unresolved processes. Analysis of the surface layer temperature balance (e.g., Cronin and McPhaden, 1997) has been carried out at both mooring sites, and results are being prepared for publication.

At the southern site, horizontal advection was important throughout most of the mooring deployment. In particular, southward advection from the equatorial cold tongue by wind-driven Ekman transport was important in bringing about the local establishment of the equatorial cold tongue during the transition from El Niño to La Niña states. At the northern site, the surface temperature balance was primarily between surface heating and

vertical mixing during the 1997 ITCZ season (July-December), but the balance shifted to one of surface heating and horizontal advection during the trade-wind season (January-May; Figure 2).

*2. Mesoscale variability in SST, velocity, and sea surface height in the east Pacific warm pool*
Prominent meridional current fluctuations with a period of about 2 months (Figure 2) were observed in the mooring data at the northern site, and these current fluctuations exerted a strong influence on the local SST through horizontal advection (Figure 1), causing SST to fluctuate with about a 2 month period from January-June of 1998. The SST fluctuations associated with this signal were substantial, with peak-to-peak amplitudes ranging from 0.5-0.8°C. The two month signal in meridional currents was linked to a previously recognized sea surface height signal that is strongest in the latitude band 9-13°N east of 120°W (Miller et al., 1985; Perigaud, 1990; Giese et al., 1994). To resolve discrepancies in prior studies of the signal (Perigaud, 1990; Giese et al., 1994), an effort was undertaken to characterize the signal observed at the mooring within its larger spatial and temporal context using satellite SST and sea surface height measurements (Figure 3). The signal was found to be associated with relatively short (5-15° wavelength) baroclinic Rossby waves. There is evidence that the intraseasonal velocity variability and its annual cycle are associated with instability of the westward flowing North Equatorial Current as it intensifies in the spring of each year. The mooring observations were instrumental in this study, because they allowed establishment and understanding of the link between the intraseasonal SSH and SST fluctuations. These findings were published in the *Journal of Geophysical Research* (Farrar and Weller, 2006).

*3. Impact of mesoscale SST variability on atmospheric convection and clouds at intraseasonal timescales*
The PACS buoy observations from the 10°N site further indicate that there is variability in surface solar radiation coupled to the sea surface temperature (SST) signal of the Rossby wave, which suggests that oceanic Rossby waves may affect atmospheric convection by modulating SST. This hypothesis was investigated using satellite measurements of SST, columnar cloud liquid water (CLW), cloud reflectivity, and surface solar radiation. A statistically significant relationship between SST and these cloud properties was identified within the wavenumber-frequency band of oceanic Rossby waves (e.g., Figure 4a). For example, analysis of seven years of data indicates that 10-20% of the variance in the logarithm of CLW at intraseasonal periods and zonal scales on the order of 10° longitude can be ascribed to SST signals driven by oceanic Rossby waves (Figure 4b). The robust relationship identified in multiple data sets suggests that the oceanic mesoscale SST variability in the region modulates the likelihood and/or intensity of atmospheric convection.

**FIGURES**

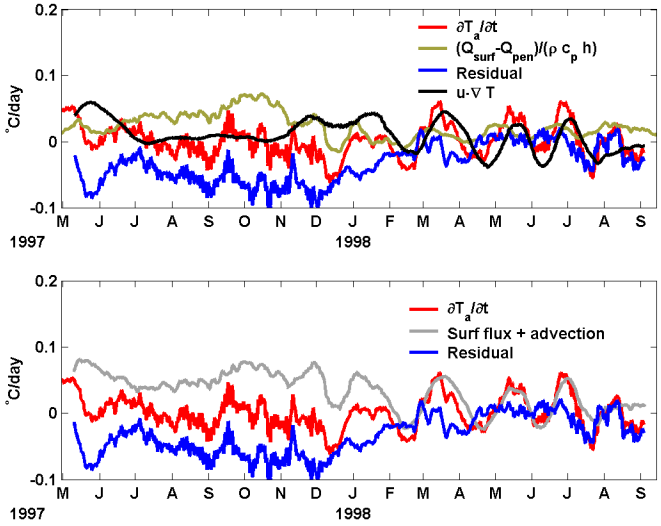



**Figure 1**. Terms in surface layer temperature balance at the 10°N, 125°W site. The terms estimated are: rate of change of layer-averaged temperature ($\partial T_a/\partial t$), heating of the layer associated with surface heat flux ($(Q_{surf}-Q_{pen})/(\rho c_p h)$), and horizontal advection ($-u \cdot \nabla T$). In the lower panel, the surface heating term and horizontal advection term have been combined to more clearly show their contribution to rate of change of temperature.

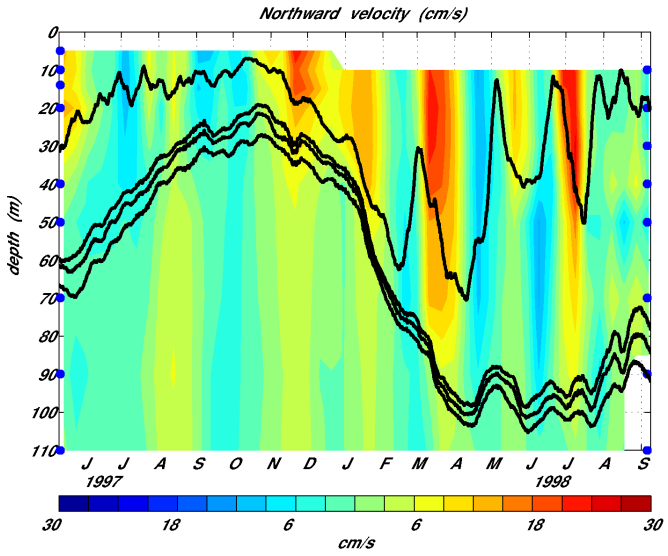



**Figure 2**. Northward velocity observed at 10°N, 125°W (10 day averages). The upper black line marks the mixed layer depth, and the lower three black lines mark isotherms in the thermocline (19, 22, and 24° C). The blue circles on the left and right edges of the figure indicate current meter depths.

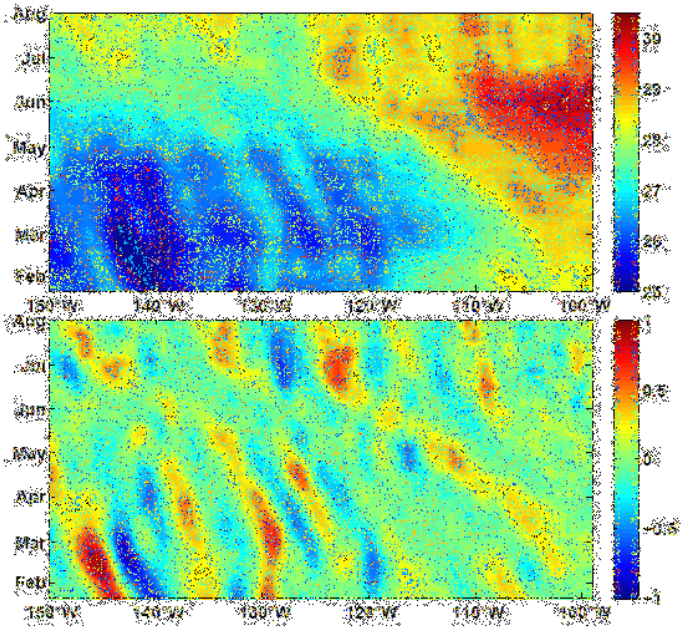
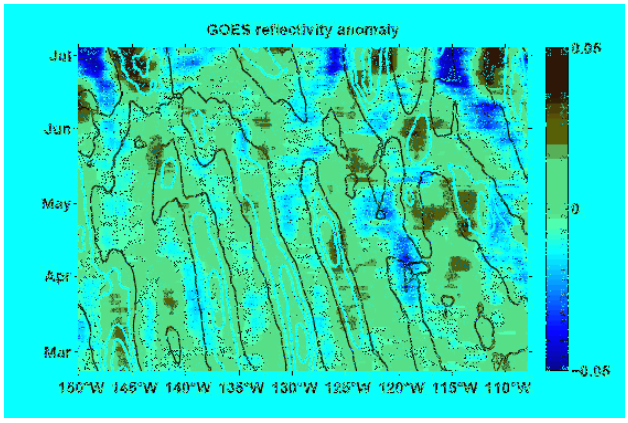



**Figure 3**. Upper panel: Longitude-time plot of SST (°C) along 10°N during 1998 from the TMI instrument aboard the TRMM satellite. Lower panel: The same, except a 10° longitudinal running average has been removed to emphasize the mesoscale variability. The westward propagation of the SST signals is caused by advection associated with Rossby waves.



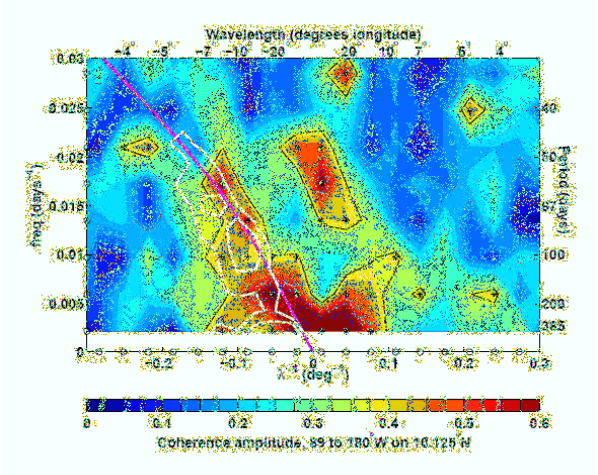




**Figure 4**. Left panel: Longitude-time plot of visible (cloud) reflectivity along 10°N during 1998 from the GOES-9 satellite (colored, in %), filtered as in Figure 3b. Mesoscale SST anomalies (Figure 3b) are contoured in white at 0.1°C intervals, and the zero contour is black. Right panel: Coherence amplitude of SST and the base-ten logarithm of cloud liquid water. Points where the coherence is significant at 99% confidence are marked by asterisks and surrounded by a black contour. The white contours show the peak power spectral density in north-south velocity (measured by the zonal slope of sea surface height), and the pink line is a theoretical estimate of the Rossby wave dispersion relation that accounts for Doppler shifting by the westward-flowing North Equatorial Current.

## PUBLICATIONS

Farrar, J.T. and Weller, R.A. 2006. Intraseasonal variability near 10°N in the eastern tropical Pacific Ocean. *J. Geophys. Res., 111,* C05015, doi:10.1029/2005JC002989.

Plueddemann, A.J. and Farrar, J.T. 2006. Observations and models of the energy flux from the wind to mixed layer inertial currents. *Deep Sea Research II*, 53, 5-30, doi:10.1016/j.dsr2.2005.10.017.

Farrar, J.T. 2007. Air-sea interaction at contrasting sites in the eastern tropical Pacific: Oceanic mesoscale variability and atmospheric convection at 10°N. Massachusetts Institute of Technology- Woods Hole Oceanographic Institution, Ph.D. thesis.

PRESENTATIONS/CONFERENCE ABSTRACTS

Farrar, J.T. and Weller, R.A. Oceanic mesoscale variability and atmospheric convection on 10°N in the eastern Pacific. NOAA Climate Prediction Program for the Americas PI Meeting, August 2006, Tucson, AZ.

Farrar, J.T. Oceanic mesoscale variability and atmospheric convection on 10°N in the eastern Pacific. Oceanography and Climate Sack Lunch Seminar, Massachusetts Institute of Technology, September 2006.

Farrar, J.T. and Weller, R.A. The relationship between oceanic mesoscale motions and atmospheric convection on 10°N in the eastern tropical Pacific Ocean. *EOS Trans. AGU, 87*(52), Fall Meet. Suppl., Abstract OS51E-06. 2006.

Farrar, J.T. Oceanic mesoscale variability and atmospheric convection on 10°N in the eastern Pacific. Ocean and Climate Physics Seminar, Lamont-Doherty Earth Observatory, April 2007.

Summary of Education and Outreach Activity

Under Weller's supervision, graduate student Tom Farrar completed his Ph. D. thesis work in February 2007 using the high quality PACS observations to study the role of air-sea exchange and upper-ocean processes in setting SST in these two contrasting regions. Farrar continues to work under Weller's supervision as a post-doc, and manuscripts are being prepared for publication.

**Works cited:**

Cronin, M.F. and McPhaden, M.J. 1997. The upper ocean heat balance in the western equatorial Pacific warm pool

during September-December 1992. *J. Geophys. Res.*, 102:8533-8553.
Fairall, C.W., Bradley, C.W., Rogers, D.P., Edson, J.B. and Young, G.S. 1996. Bulk parameterization of air-sea fluxes during TOGA COARE. J. Geophys. Res., 101:3747-3764.
Giese, B.S., Carton, J.A., and Holl, L.J. 1994. Sea level variability in the eastern tropical Pacific as observed by TOPEX and the Tropical Ocean-Global Atmosphere Tropical Atmosphere-Ocean Experiment. *J. Geophys. Res.*, 99:24,739-24,748.
Miller, L., Watts, D.R., and Wimbush, M. 1985. Oscillations in dynamic topography in the eastern Pacific. *J. Phys. Oceanogr.*, 15:1759-1770.
Perigaud, C. 1990. Sea level oscillations observed with Geosat along the two shear fronts of the North Equatorial Counter Current. *J. Geophys. Res.*, 95:7239-7248.

# Long-Term Evolution and Coupling of the Boundary Layers in the STRATUS Deck Regions of the Eastern Pacific

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 308
July 1, 2006 through June 30, 2007

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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.

## PROJECT SUMMARY

The stratus project has been successful in elucidating the physical processes that maintain the observed cool surface waters of the Peru-Chile stratus region. Colbo and Weller (2005a) synthesized the mooring data with historical hydrographic and satellite data to show that the upper ocean heat and salt budgets had a large component that was contributed by the divergence of the "eddy" flux. This large transport of cool, fresh water from the coastal upwelling region to the deep ocean through the eddy field has not been noted before. It also helps explain the deficiencies observed in many global models of the region, which are not eddy resolving, and hence cannot adequately capture this important oceanic transport.

In using the ocean reference station data for this project, as well as others, it was necessary to understand the accuracy of the basic surface meteorology and the derived flux products. To this end a series of meetings was organized for the scientific and engineering staff at WHOI with direct experience of the IMET package. (The IMET package is the standard meteorological sensor suite used on all the Ocean Reference Stations, as well as most US Volunteer Observing Ships and Research Vessels.) These meetings have been synthesized into a single document which has now been transformed into a journal article (Colbo and Weller 2005b). It lays out the expected accuracy of all the individual meteorological sensors in detail, and shows how those errors propagate into the heat, freshwater and momentum fluxes. This is a crucial step in validating the observations and is necessary for any future climate studies involving the Ocean Reference Station data.

The first four years of surface meteorological and air-sea flux data is being used to describe and characterize the surface forcing and atmosphere-ocean coupling observed under the stratus cloud deck at a site close to the region of climatological maximum low cloud cover (Weller and Colbo 2005). This site is data sparse, and these buoy data provide the first accurate long time series that can be used to characterize the site. Both model and climatological values are found to differ significantly from the observations. Though the regime is basically a trade wind regime, with very stable wind direction, wind speed at times drops to low enough values to allow strong diurnal warming in sea surface temperature. Strong diurnal variability is also found in other variables, including the incoming longwave radiation. Links between local variability at diurnal and synoptic time scales to regional synoptic variability are being explored. At the same time significant interannual variability and work is underway to examine whether or not this is tied change in the South Pacific subtropical circulation in the atmosphere and to other causes.

**BIBLIOGRAPHY**

Colbo, K and R. A. Weller, 2007a: The variability and heat budget of the upper ocean under the Chile-Peru stratus. *J. Mar. Res*., in press.
Colbo, K. and R. A. Weller, 2007b: The accuracy of the IMET sensor package. *J. Atmos. Oceanic Technol.*, in review.
Weller, R. A. and K. Colbo 2005: Surface Meteorology and Air-Sea Fluxes Under the Stratus Clouds off Northern Chile. In preparation.

Conference Seminars and Presentations (K. Colbo):
"What Maintains the Cold Ocean off of Peru": VOCALS Science and Implementation Workshop, Corvallis, 2004 (talk)
"Climate Observations from the Peru-Chile Stratus Deck": International CLIVAR Science Conference, Baltimore, 2004 (poster)
"How Accurate are Surface Meteorology Measurements from a Buoy?": International CLIVAR Science Conference, Baltimore, 2004 (poster)
"Observations from the subtropical Pacific Ocean: What sets SST under the clouds?": AGU Ocean Sciences, Portland, 2004 (poster)
"Moored Observations from Under the Stratus Deck": EPIC-PACS meeting, Boulder, 2003 (poster)

Recent Individual Seminars (K. Colbo)
"Upper Ocean variability in the Chile-Peru Stratus"
University of New South Wales @ Australian Defense Force Academy --- March 2005
Woods Hole Oceanographic Institution --- April 2005
"What maintains the cool SST under the Chile-Peru Stratus Deck"
Oregon State University,
University of Washington,
University of British Columbia,
University of Victoria,
Institute of Ocean Sciences --- October 2004

Interactions with NOAA

Attend and present at the NOAA sponsored EPIC/PACS meeting, Boulder 2003
Attend and present at the NOAA sponsored VOCALS Planning Meeting, Corvallis, 2004
Discussions with NOAA scientists outside of NOAA sponsored meetings, including: Meghan Cronin, Mike McPhaden, Gregory Johnson, and Chris Fairall.

# Ships of Opportunity Program

NOAA Cooperative Agreement No. NA17RJ1223 sub-points 400-402
July 1, 2006 through June 30, 2007

Co- Principal Investigators
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**Mr. David S. Hosom, E-mail: (dhosom@whoi.edu)**

Field Operations: Mr. Frank Bahr (fbahr@whoi.edu)
Engineering Support: Mr. Geoff Allsup (gallsup@whoi.edu)
Physical Oceanography Department, Woods Hole Oceanographic Institution

Program Manager: Dr. Michael Johnson NOAA/OGP

Related NOAA Strategic Plan Goal:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

## PROJECT OVERVIEW

Central to present efforts to improve the predictability of climate is the need to understand the physics of how the atmosphere and ocean exchange heat, freshwater, and momentum and, in turn, to accurately represent that understanding in the models to be used to make predictions. At present, over much of the globe, our quantitative maps of these air-sea exchanges, derived either from ship reports, numerical model analyses or satellites, have errors that are large compared to the size of climatically significant signals. Observations made using the IMET technology on the Volunteer Observing Ships on long routes that span the ocean basins are essential to providing the accurate, in-situ observations needed to:

1) identify errors in existing climatological, model-based, and remotely-sensed surface meteorological and air-sea flux fields,
2) to provide the motivation for improvements to existing parameterizations and algorithms,
3) to provide the data needed to correct existing climatologies,
4) to validate new model codes and remote sensing methods.

This project is managed in accordance with the Ten Climate Monitoring Principles.

The workstatement for the Ships of Opportunity Program is outlined in the following three tasks: A) VOS Field Operations, B) Instrumentation Development and Upgrades, and C) Data Processing. Previous VOS project budgets have included these three components but now it is more logical to provide details under these headings. We have reviewed our Ocean Reference Stations and Ships of Opportunity programs and consider the sum of those two projects. The VOS Field Operations will be reduced which permits us to concentrate on processing the data from the VOS for improved science and to address present meteorological sensor and electronics problems (to keep our quality and data return rate high) and to build toward the future where the Ocean Reference Stations provide upper ocean heat content in real time in addition to the surface meteorology and air-sea fluxes.

AutoIMET was developed by the Woods Hole Oceanographic Institution to meet the need for improved marine weather and climate forecasting. It is a wireless, climate quality, high time resolution system for making systematic upper ocean and atmospheric measurements. This interfaces to the NOAA SEAS 2000 (Shipboard Environmental

(Data) Acquisition System) that automatically receives meteorological data (from the AutoIMET) and sends in automated one hour satellite reports via Inmarsat C. This system will document heat uptake, transport, and release by the ocean as well as the air-sea exchange of water and the ocean's overturning circulation.

**ACCOMPLISHMENTS**

**A) VOS Field Operations.**

Ship selection and interface to the NOAA SEAS system was via AOML and SIO. We will focus our Ship program on two ships. The first is our longest running vessel, doing the Oakland -Hawaii-Guam-Taiwan-Tacoma run. The second is an Atlantic ship to complement the Barbados Ocean Reference Station. We understand the perspective of COSC on the return to this program per dollar invested in this effort and are reducing the field effort to provide improved analyses and science payback. At the same time, keeping two ships going keeps our involvement active and allows us, if we can prove value and if the budgets are sustained or increased, to ramp back up. The list of activities include:

- May '06, Tacoma, WA: Craig Marquette and Frank Bahr met the Horizon Enterprise in Tacoma for a AutoIMET calibration turn-around. On the previous trip, SST had failed when the ship, in an emergency medical run, moved rarely-used equipment that entangled and parted our SST-> logger cable. Carrie Wolfe (SCMI) had repaired the cable during her XBT voyage, but SST failed again later, presumably due to then exhausted batteries from continued tries to connect.
- November '06; Tacoma, WA: On November 18, Carrie Wolfe from SCMI and Frank Bahr from WHOI visited the container ship Horizon Enterprise in Tacoma, WA, a standard bi-annual AutoIMET sensor suite calibration turn-around. Unfortunately, once on the bowmast platform, we found that the longwave sensor had been destroyed. It had obviously been hit very hard: not only was the longwave glass dome missing, but the mounting pins for the whole LHPS unit that longwave was part of had been bent.
- April '07; Oakland, CA On April 11, Ben Hodges and Frank Bahr from WHOI visited the Horizon Enterprise for a standard AutoIMET sensor turn-around. The ship's officers had noticed that the wind readings appeared high. We found that the wind sensor was significantly misaligned. Its forward axis was rotated away from the ship's forward direction by perhaps 30 degrees. It was also tilted away from its usual straight upward direction. This misorientation prevented the correct subtraction of ship speed from the relative wind measurement, leading to the observed high absolute winds. The sensor alignment has now been corrected.

- June '07; Honolulu, HI: Craig Marquette and Frank Bahr installed an AutoIMET system on the University of Hawaii ship R/V Kilo Moana for the duration of the WHOTS buoy turn-around cruise by Al Plueddemann (WHOI). The system remained onboard until July 1st, and was then taken down and shipped back to WHOI by Sean Whelan and Jeff Lord.

- June '07; Honolulu, HI: On June 18, Frank Bahr met the Horizon Enterprise in Honolulu, HI, to address a problem with the air temperature (AT) and humidity (HRH) readings. These channels had repeatedly dropped out when the ship approached Hawaii (and warmer temperatures), but had come back on line within a day or so of leaving Hawaii (when temperatures had dropped again). Swapping the AT/HRH sensors did not bring these readings back. Eventually, the problem was traced to a barely connecting fuse, which metal holder apparently slightly opened and closed under ambient temperature changes.

In addition to the AT/HRH prooblem, the whole AutoIMET data feed to the SEAS2000 system on the bridge had stopped shortly before Frank met the ship. It appeared that during repairs to ship's gear in the focslehead, our power cord had been unplugged and replaced with a work light (both our plug and that of the work light were on deck close to the outlet). I hooked our system back up, and labeled the power cord. The Chief Mate had been following my progress with interest, and we went to the focslehead together where I showed him our setup.

Back on the bridge, AutoIMET data were now coming in to SEAS2000 "loud and clear". The next day, I head from Steve Noah (NOAA, Seattle) that a problem with SEAS2000 XBT system had also cleared at the same time. I do not know how the two issues (AutoIMET and XBT) could be related, but the coincidence is curious.
- July '07; Oakland, CA: On July 16 and 17, Frank Bahr met the container ship Horizon Hawk in Oakland to inspect

the vessel for a new AutoIMET installation. The bowmast platform is very well suited for such an installation. The Scripps group has already installed a SEAS2000 system for XBT surveys, so a computer is in place to receive our AutoIMET string for broadcasts back to NOAA. A group from WHOI will visit the Hawk on September 21 for the new installation.

**B) Instrumentation Development and Upgrades**

This task will be used to address shortcomings in sensors and electronics. Design revision will cope with obsolete parts and cold sensitivities. These developments will provide improved operation of the Ocean Reference Stations as well as the VOS. A related development task is to start work on the technology needed to bring more subsurface data to the surface, telemeter it, and be able to show on our website the temporal evolution and anomalies of the upper ocean heat content as well as the variability in surface meteorology and air-sea fluxes. The list of activities include:

- Design, layout, and fabrication of prototype DS89C450-based ASIMET module main board with native Compact FLASH storage and wide temperature range operation. The fabrication of ASIMET modules has been transferred to Star Engineering of Foxboro MA; ongoing engineering/embedded systems support for Star by WHOI.

- Embedded hardware and software support for AUTOIMET ship system logger;
Major revision of ASIMET logger software to add Compact FLASH storage on existing DS87C530-based logger hardware in place of original custom PCMCIA FLASH storage; current revision is NEWLGR53-CF v4.10cf

- Major revision of all ASIMET module software to add Compact FLASH storage on existing DS87C530-based main board in place of original custom PCMCIA FLASH storage; current revisions are:

VOSHRH53-CF v4.28cf
VOSLWR53-CF v4.01cf
VOSSWR53-CF v4.00cf
VOSPRC53-CF v4.02cf
VOSWND53-CF v4.00cf
VOSBPR53-CF v4.02cf
SONICWND53-CF v4.03cf
SPN1SWR53-CF v4.10cf

- Ongoing revision and additions to instrumentation documents on the DGE website at frodo.whoi.edu; additional CDROM documentation for shipment with VOS instruments produced by Star Engineering.

- Software FETSWBD45 v1.01 for new Iridium Power Control board based on Dallas DS89C450 processor; used to cycle power to the IRIDIUM comms controller system, and condition power for the NAL Iridium modem

- Design, layout, fabrication and test of DS89C450-based power control and conditioning board for 2nd generation Iridium communications controller. Software updates for 4th (prototype) IRIDIUM Communications Controller – periodically collects data from SIM53 (ASIMET) Seabird inductive modem interface, processes it (averaging), formats and sends to IRIDIUM Modem as SBD message.

- Hardware fabrication and test of ASIMET-compatible interface between Seabird inductive modem communicating with underwater instrument string, and Iridium communications controller. Updates & cleanup to SIM53 v1.10 software for Seabird inductive modem interface module.

- Fabrication and test of 3 additional ASIMET sonic wind modules based on GILL sensor. Also uses updated SONICWND53-CF v4.03cf software for Compact FLASH storage.
Updated sonic wind module interface software GILWND45 Ver 1.41 for GILL sensor front end board.

- Update to sonic wind module main controller software SONICWND Ver 3.11 for the GILL sensor-based ASIMET acoustic wind module; for initial standalone test deployment on Climode buoy.

- Preliminary software design, VOSHRH45-CF v5.00 (for high-latitude versions of ASIMET board sets based on

Dallas DS89C450 processor with internal FLASH program memory, and Compact FLASH data storage capability)
- Final calibration and prep for tension measurement module on 2nd CLIMODE deployment. Revisions & updates to TCELL53 v1.10 and TCELLIF v1.30 software for Climode tension cell module (for Climode 2nd deployment)

- Modification to software NEWLGR53 Ver 3.21 to for use on WHOTS project – cycle power once a day to standalone GPS logging module.

- Design, fabrication, and test of prototype SWR module based on Delta-T Devices SPN1 Pyranometer. Preliminary software VOSSPN53 v4.10cf for prototype ASIMET SWR module based on Delta-T Devices SPN1 Pyranometer.

- New or updated LinuxPC software to perform initial processing of binary files from various ASIMET instruments, data loggers, system controllers; also ongoing update of FLASH card reading procedures via Linux Laptop PC.

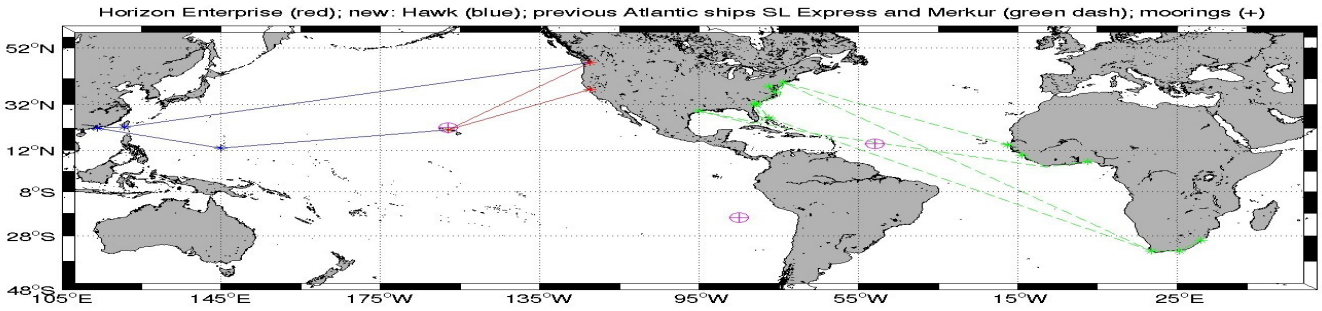
**C) Data Processing**

This task is to increase the effort on the analysis of the long-running Pacific VOS data set and the current Atlantic set. Effort will also be put into the analysis and public presentation of the Ocean Reference Site buoy data. This would involve computing air-sea fluxes on the fly in near real time, comparing buoy fluxes/met with ECMWF, NCEP, Lisan Yu's product. This would also show departures of buoy flux/met from climatologies, and use anomalies from climatology as well as present absolute values to better project the climate variability record at each site. We have a vision of expanding this presentation in the future to show regional flux patterns from Lisan and regional ocean heat content from the Argo float data.

Note that descriptions, technical information and data from the several VOS being serviced is posted on the site: http://uop.whoi.edu/vos/ Figures are available for datasets from all ships. All AutoIMET datasets from the Enterprise (Dec 2003 to the present) can be downloaded directly from the web site as well. For the datasets from other ships please contact Frank Bahr at: fbahr@whoi.edu

There is a link to the site: http://frodo.whoi.edu where there is detailed information on the AutoIMET and ASIMET modules. Instrument design questions can be addressed to Dave Hosom at: dhosom@whoi.edu

**FIGURES AND IMAGES**




This map shows current and past ship tracks as well as the Ocean Reference Stations (circle with cross) at Barbados, Galapagos, and Hawaii. The blue track is the old Enterprise track and now the new Hawk track. The new Enterprise track is shown in red. The previous Atlantic tracks are shown in dashed lines.


Horizon Hawk, the new trans-Pacific ship.

## SUMMARY OF INTERACTION WITH NOAA

The Climate Observation Program Workshop in Silver spring, MD was attended by Dr. Robert Weller, Dr Albert Plueddemann, and Mr. David Hosom. A poster entitled "Spatial Variability in Surface Meteorology from a VOS and the ECMWF Model" by Al Plueddemann, Frank Bahr, Dave Hosom and Bob Weller was presented.

There was ongoing cooperation with Scripps via the CORCIII program as well as Southampton Oceanography Centre (SOC) of Southampton UK on Computer Flow Dynamics (CFD) for evaluation of the flow turbulence around the ship and its effect on the sensor placement. Some logistic support was provided by the Southern California Marine Institute (SCMI) on ship turnarounds. There is ongoing cooperation with the Atlantic Marine Ocean and Atmosphere Laboratory (AOML) in Miami on the Atlantic VOS program. There is also ongoing cooperation with many sensor manufacturers.

# Ocean Reference Stations

NOAA Cooperative Agreement No. NA17RJ1223 Sub-points 403-407
July 1, 2006 through June 30, 2007

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Program Managers: Mike Johnson, Joel Levy, Climate Observation Program

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 these related observational projects is to maintain long-term surface moorings, known as Ocean Reference Stations, as part of the integrated ocean observing system. These Ocean Reference Stations collect long time series of accurate observations of surface meteorology and upper ocean variability in regions of key interest to climate studies. The resulting meteorological and oceanographic observations provide a set of high quality air-sea fluxes of heat, freshwater and momentum. The scientific rationale for the collection of these flux products is manifold: 1) to describe the upper ocean variability and the local response to atmospheric forcing; 2) to motivate and guide improvement to atmospheric, oceanic, and coupled models; 3) to calibrate and guide improvement to remote sensing products and capabilities; and 4) to provide anchor points 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 are being 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 known as the WHOI Hawaii Ocean Time-series Station or WHOTS at 22.75°N, 158°W. Moorings at the Stratus and NTAS sites were initially deployed and serviced annually under NOAA OGP support; these sites have now transitioned to long-term Ocean Reference Stations. WHOTS was established in 2004, 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**). Second, the maintenance of the Stratus site (**Task II**), for which the sixth year of operation was successfully completed. Third, maintenance of the NTAS site (**Task III**) for which the sixth year of operation was completed. Fourth, maintenance of the WHOTS site, (**Task IV**), for which the third year of operation was completed. Progress on each of the Tasks is reported in more detail below.

## PROGRESS

**Task I: Engineering, oversight and data:**
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. Hourly meteorological data are transmitted via Argos telemetry and made available via an FTP server and a website with download capability. Subsurface data acquired via Iridium from the NTAS site is also collected and made available. We maintain a public access archive of Upper Ocean Processes (UOP) Group data from mooring deployments.

As we look ahead to adding new sensors to the meteorological suite and/or telemetering subsurface data, using Argos becomes increasingly untenable due to data rate limitations. More importantly, we have found that the Argos transmissions introduce noise in some sensors and can degrade data quality. The trials with an Iridium modem on the WHOTS and NTAS buoys indicate that meteorological data can be successfully packaged by the controller, sent via Iridium short-burst messaging and received on shore as an email attachment. We have completed and implemented for the Iridium telemetry an automated, shore-based decoding and processing system. At present we bear the costs of the Iridium data telemetry, and cost constraints prevent us from implementing Iridium on Stratus and NTAS. Should NOAA arrange for a tariff agreement for Iridium as for Argos, we would be able to shift over to Iridium.

We continue to partner with Dr. Chris Sabine (NOAA PMEL) to incorporate his $pCO_2$ instrumentation on board our buoys. In prior years pCO2 measurement was limited to the Stratus buoy, but this year we arranged with Sabine to transfer a system from the MOSEAN buoy to the WHOTS buoy deployed in June 2007. Thus, pCO2 is being now being measured at two ORS sites. The Stratus buoy is also being used as the site where we are testing the addition of sensors to measure surface waves. This is being done in collaboration with the National Data Buoy Center (NDBC), with NDBC providing hardware and guidance on how to implement wave measurements on the ORS buoys.

The major engineering initiative this year has been the implementation at the NTAS site of the capability to collect and telemeter data in near-real time from subsurface instruments on the mooring line. An electro-mechanical (EM) interface was developed for subsurface data telemetry on ORS moorings. Previous hardware designs developed separately for inductive and acoustic telemetry by the WHOI Applied Ocean Physics and Engineering Department were adapted to create a robust, reusable EM interface supporting both inductive and acoustic telemetry. The mechanical components of this interface (Fig. I-1) include a specially designed universal joint, an upper flanged spacer, a six-meter electro-mechanical "compliant section", a lower flanged spacer, and a wire coupling assembly that includes a bell mouth and socket to accept a specially terminated shot of 7/16" jacketed mooring wire and space for an acoustic modem to be mounted alongside (acoustic telemetry was not used for this deployment).

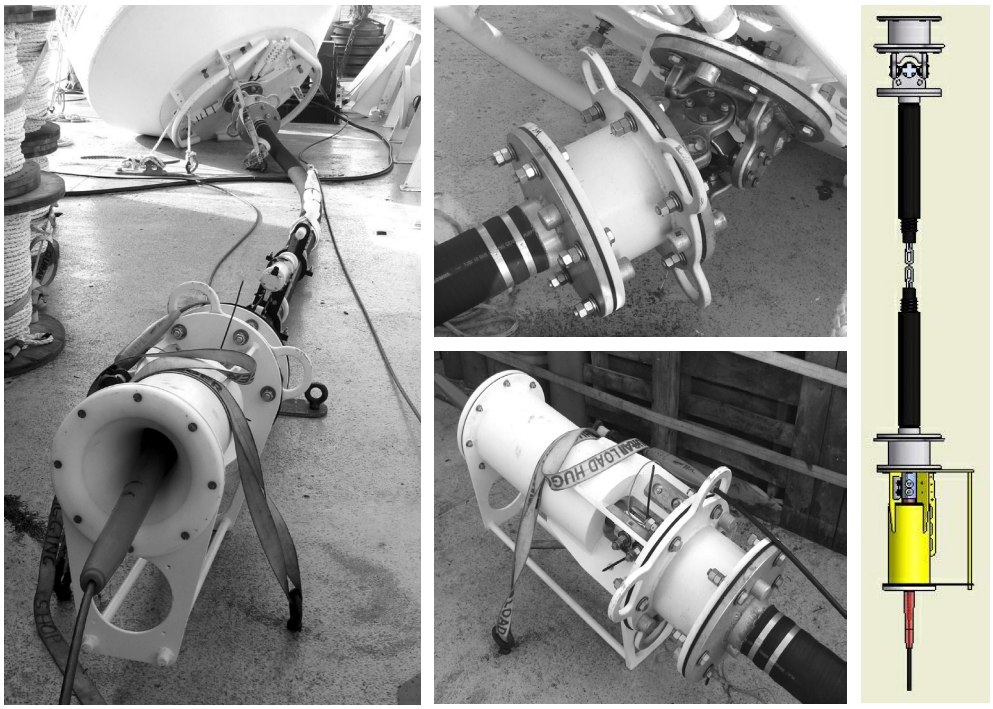

Figure I-1. Hardware components of the telemetry system implemented for NTAS-7.

The UOP Group implemented a communications system to support inductive telemetry. The system was built around an Air-Sea Interaction Meteorology (ASIMET) controller board, and included a Seabird Inductive Modem (IM) and an Iridium Communication Module (ICM). The controller uses only a few milliwatts, and runs continuously, while the IM and ICM, which use considerably more power, are turned on intermittently. The controller powers up the IM every 5 minutes and the IM awakens the modems of all attached instruments. The controller then polls fixed addresses on the IM loop and places up to 4 hours of sensor data, obtained at 5 minute intervals, in a circular buffer. After 4 hours the ICM turns on, requests the most recent buffered data, creates and logs 4 one-hour averages, formats the averages as a Short Burst Data (SBD) message, and sends the SBD message via Iridium.

SBD messages are received and processed on a workstation at WHOI by an automated shell script which invokes a series of processing programs when new data arrives. The software suite extracts the data payloads from email attachments sent to WHOI by the Iridium SBD system, decodes the binary data, and produces data listings and plots on the UOP web site within minutes of data being transmitted from the buoy (see Data Links: Iridium at http://uop.whoi.edu/projects/NTAS/ntasdata.htm).

**Task II: Stratus Site:**
The stratus surface mooring was originally deployed under a previous grant (from the Pan American Climate Studies) in October 2000. It has been annually redeployed and recovered since that time. 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, 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 (Bigorre et al., 2007). Telemetry from the buoy presently deployed indicates that it is on station and both meteorological systems are functioning well.

Work this year included deploying the new and recovering the old mooring, doing calibrations (both pre and post-deployment), data processing, writing cruise reports, preparing mooring hardware and instrumentation for the new deployment and cleaning and assessing the recovered equipment. The FY2007 deployment was carried out aboard the *R/V Ronald H. Brown* which sailed from Rodman, Panama on October 9, 2006 and arrived into Valparaiso, Chile on October 27, 2006.

The planning and observational preparation for the cruise begins many months before the deployment. During the summer of 2006 instruments were gathered and placed on the new mooring buoy 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 2006, members of the UOP group loaded the *R/V Ron Brown* in Charleston.

The Stratus 7 buoy was deployed first due to the lack of space on deck to have both the recovered Stratus 6 buoy and the Stratus 7 buoy aboard at the same time. The Stratus 7 buoy was deployed October 16, 2006. The Stratus 6 mooring was recovered on October 18th with no undue problems. As in some previous years, several upper ocean instruments were fouled by fishing line. In response to this, we have shifted our mechanical current meters to deeper sites and added acoustic current meters to the shallow locations on the mooring; these acoustic current meters suffer much less data loss associated with fising line.

After the work at the Stratus buoy, the *Brown* sailed east to the site of the Chilean tsunami buoy. The existing DART surface buoy and bottom package were recovered on October 22, 2006. A new bottom package and surface buoy were deployed on October 23.

On the Stratus 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 and measures temperature, salinity, and velocity. During the deployment, high data rate (up to 1 sample per minute) data are stored in each instrument. 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.

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 assess 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 VOCALS and other investigator communities (including Sandra Yuter, Chris Bretherton, Meghan Cronin) after recovery. 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 to investigate air-sea coupling and upper ocean variability under the stratus deck (Colbo and Weller 2007a). The initial archive is maintained by the Upper Ocean Processes Group at WHOI, which runs a public access server for their mooring data. We are providing the data to Ocean SITES (http://www.oceansites.org/). This year an effort was made to quality control and share the first 6 years of data. This was done in part to facilitate planning of the VOCALS (VAMOS Ocean Cloud Atmosphere Land Study) to be conducted in conjunction with the October 2008 Stratus cruise. Data files and plots were shared in support of proposal writing and pilot studies in advance of VOCALS.

Both before the recovery of the old buoy and after the deployment of the new buoy, *in situ* comparisons of the ship's and buoys' twin meteorological sensors were carried out. These comparisons have been a crucial component of the post-recovery data processing, particularly for sensitive instruments that may suffer damage during the return shipment to WHOI. Extensive shipboard meteorological and air-sea flux instrumentation was installed on the *Ron Brown* and operated by Chris Fairall from the NOAA Earth System Research Laboratory (ESRL) in Boulder, CO. 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. Colbo and Weller (2007b) summarized what has been learned from this work about the accuracy of the moored meteorological sensors and the resultant air-sea flux estimates.

ESRL 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. ESRL 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) is 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.

The Stratus cruises serve the wider scientific community by providing a platform on which to study the regional ocean. Additional researchers who participated in collaborative research or benefited from shared ship time in FY2007 have come from many institutions: NOAA Earth System Research Laboratory (ESRL), NOAA Pacific Marine Environmental Laboratory (PMEL), Servicio Hydrografico y Oceanografico de la Armada (Chile), University of Concepcion (Chile), University of Colorado, University of Miami, and University of Buenos Aires.

These collaborations have included: enhanced regional surface flux and lower atmosphere surveys, both offshore and within Chilean coastal waters (NOAA ESRL, U. Miami, U. Colorado), extensive hydrographic surveys with CTDs and XBTs (multi-user), and the support of maintaining a tsunami warming buoy (Chilean Navy).

The 2006 stratus cruise also hosted a teacher from NOAA's Teachers-at-Sea program (Brett Hoyt). During the cruise, the teacher assisted with science operations including mooring deployments and recoveries. He also wrote logs, took photos, and interviewed science members and crew. This information was used to communicate the experience.

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

**PUBLICATIONS (CUMULATIVE):**


Colbo, K and R. A. Weller, 2007a: The variability and heat budget of the upper ocean under the Chile-Peru stratus. *J. Mar. Res*., in press.

Colbo, K. and R. A. Weller, 2007b: The accuracy of the IMET sensor package. *J. Atmos. Oceanic Technol*., in review.

Bigorre, S. R. Weller, J. Lord, S. Whelan, N. Galbraith, D. Wolfe, L. Bariteau, V. Ghate, U. Zajaczkovski, A. Vera, S. Maenner, and B. Hoyt, 2007. Stratus Ocean Reference Station (20°S, 85°W), Mooring Recovery amd Deployment Cruise, R/V *Romald H. Brown*, Cruise 06-07, October 9 – October 27, 2006. Woods Hole Oceanogr. Inst. Tech. Rept. WHOI-2007-01, 154 pages.

Cronin, M. F., N. A. Bond, C. Fairall, and R. A. Weller, 2006. Surface cloud forcing in the east Pacific stratus deck/cold tongue/ITCZ complex. *J. Climate*, **19(23),** 392-409.

Hutto, L., R. Weller, J. Lord, J. Smith, P. Bouchard, C. Fairall, S. Pezoa, L. Bariteau, J. Lundquist, V. Ghate, R. cstro, and C. Cisternas, 2006: Stratus Ocean Reference Station (20° S, 85° W), Mooring Recovery and Deployment Cruise: R/V *Ronald H. Brown* Cruise 05-05, September 26 – October 21, 2005. Woods Hole Oceanogr. Inst. Tech. Rept., WHOI-2006-06.

Cronin, M. F., N. A. Bond, C. W. Fairall, and R. A. Weller, 2006: Surface Cloud Forcing in the East Pacific Stratus Deck/Cold Tongue/ITCZ Complex. *J. Climate*, **19**, 392-409, doi: 10.1175/JCLI3620.1.

Colbo, K., R. Weller, J. Lord, J. Smith, P. Bouchard, C. Fairall, D. Wolfe, E. Serpetzoglou, A. G. V. Tisandie, J. F. S. Bustos, F. Bradley, and J. Tomlinson 2005: Stratus Ocean Reference Station (20° S, 85° W), Mooring Recovery and Deployment Cruise: R/V *Ronald H. Brown* Cruise 12-04, December 5 – December 23, 2004. Woods Hole Oceanogr. Inst. Tech. Rept., WHOI-2005-06.

Cronin, M. F., N. Bond, C. Fairall, J. Hare, M. J. McPhaden, R. A. Weller. Enhanced oceanic and atmospheric monitoring underway in Eastern Pacific. EOS, Transactions, AGU, 83(19), pages 205, 210-211, 7 May 2002.

Hutto, Lara, Robert A. Weller, Jeff Lord, Jason Smith, Jim Ryder, Nan Galbraith, Chris Fairall, Scott Stalin, Juan Carlos Andueza and Jason Tomlinson, 2003. Stratus Ocean Reference Station (20° S, 85° W), Mooring Recovery and Deployment Cruise: *R/V Revelle* Cruise Dana 03, November 10 – November 26, 2003. Woods Hole Oceanogr. Inst. Tech. Rept., WHOI-2004-04.

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.


**SEMINARS AND PRESENTATIONS:**

"VOCALS Ocean Science and Implementation" VOCALS Planning Workshop, Snatiago, Chile, April 2006
"Ocean surface heat fluxes," presentation at Office of Climate Observations annual Workshop, May 2006
"Climate observations for research", presentation at Office of Climate Observations annual Workshop, May 2006
"Climate quality buoy and ship observations", High Resolution Marine Meteorology Workshop, Tallahassee, March 2003
"The variability under the stratus deck - surface mooring results", VAMOS Panel Meeting 7, Guayaquil, Ecuador, Feb 2004
Ocean Observations Panel for Climate (OOPC), SOC, UK Report on the Status of Air-Sea Fluxes and the WCRP Working Group, June 2004

"How Accurate are Surface Meteorology Measurements from a Buoy?", *First International CLIVAR Science Conf.*, 21-25 June 2004, Baltimore, MD (poster).

**Task III: NTAS Site:**
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 local 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.

NTAS has two primary science objectives: 1) 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. 2) 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.

A mooring turn-around cruise was conducted on the NOAA ship *Ronald H. Brown* in order to retrieve the existing mooring (NTAS-6, deployed 25 February 2006) and replace it with a new mooring (NTAS-7). In preparation for this cruise, three Air-Sea Interaction Meteorology (ASIMET) systems were assembled and tested. Two systems, comprised of the best performing sensors, were mounted on the newly developed 2.7 m modular ORS buoy in preparation for deployment. The NTAS-7 mooring was deployed on 19 April 2007 and the NTAS-6 mooring was recovered on 24 April. The period between deployment and recovery was dedicated to a comparison of the two buoy systems, with the shipboard system as an independent benchmark. To ensure high-quality meteorological data, all NTAS-7 sensors were calibrated prior to deployment, and NTAS-6 sensors will be post-calibrated. A cruise report is in preparation.

In addition to the NTAS mooring turnaround, the 2007 NTAS cruise accommodated mooring service work for NDBC, site servicing for the Meridional Overturning Variability Experiment (MOVE), Argo drifter deployments, and testing of a novel air-sea heat flux drifter developed by Jim Boyle of W. Connecticut State University.

As a part of outreach and education for the ORS project this year, two interns from the Joint Oceanographic Institutions (JOI) were hosted on the NTAS-7 cruise. The interns conceived, prepared and implemented a live "expedition" web site documenting NTAS science, technology, and cruise operations (http://joiserver.joiscience.org/mission1551). This effort was successful, with an estimated 2,300 first-time visitors to the site during the cruise, along with 4 press releases, 4 newspaper articles, 15 web links from other sites, and an Oceanus article.

Preliminary processing of the NTAS-5 meteorological data has been completed. Data return was very good, with all sensors except one wind module operating for the complete deployment period. The comparison period showed very encouraging results, indicating little degradation of NTAS-5 sensor performance after one year at sea. After post-calibration of the sensors, the corrected, 1-min data will be used for further analyses. The uncorrected, hourly Argos data from NTAS-4, 5 and 6 are available on-line from the Upper Ocean Processes (UOP) group web site (http://uop.whoi.edu/projects/NTAS/ntas.htm). At present, about 5 months of hourly meteorological data from NTAS-7 are also available for examination on the UOP web site. Preliminary evaluation indicates that all NTAS-7 sensors are performing as expected. Meteorological sensors from NTAS-1 through 5 have been post-calibrated, and NTAS-1 and 2 data have been post-processed. Hourly averaged files from the post-processed data sets are available on the UOP web page. The 1 min data are being used as the basis for air-sea flux computations using bulk formulas.

For the telemetry trial on NTAS-7, the inductively coupled mooring line was outfitted with instruments from the UOP Group inventory which contained inductive modems. Three Seabird SBE-37s were deployed at 25, 45 and 65 m and a Sontek Argonaut current meter was deployed at 14 m. Hourly averages of subsurface data were obtained at 4 hour intervals via Iridium. The telemetered message is a subset of the data returned from inductive polling. For example, only temperature and conductivity (later converted to salinity) are transmitted from the SBE-37s, and the Argonaut data record is reduced to just 8 variables. The inductive coupler on the current meter failed soon after deployment, but temperature and salinity data are being obtained routinely and are available from the UOP web site.

**PUBLICATIONS AND PRESENTATIONS (CUMULATIVE):**


Goldsmith, R.A. and A.J. Plueddemann, 2002. Moored buoy site evaluations, *Marine Geography*, J. Breman, Ed., ESRI Press, pp 73-77.
Halpern, D., R. Weller and A. Plueddemann, 2006, *Ocean Atmosphere Interfaces in Climate*, Solar Radiation and Climate Experiment (SORCE) Science Meeting, San Juan Island, WA.
Plueddemann, A., 2003, In-situ meteorology from the Northwest Tropical Atlantic Station, *Proc. U.S. CLIVAR Atlantic Conf.*, Wash, DC, pp 9-13.
Plueddemann, A.J., 2003. In-situ meteorology and air-sea fluxes in the Northwest Tropical Atlantic, *NOAA Climate Observation Program Workshop*, Silver Spring, MD (poster).
Plueddemann, A.J., 2003. In-situ meteorology and air-sea fluxes in the Northwest Tropical Atlantic, *NOAA Climate Observation Program Workshop Report*, 13-15 May 2003, Silver Spring, MD.
Plueddemann, A., 2004, Multi-year, in-situ surface fluxes in the northwest tropical Atlantic, *First International CLIVAR Science Conf.*, 21-25 June 2004, Baltimore, MD (poster).
Plueddemann, A.J., 2007. Ocean Reference Stations: An Air-Sea Flux Reference Network, *MTS/IEEE Oceans '06*, Boston, MA, (talk).
Plueddemann, A., F. Bahr, D. Hosom and R. Weller, 2006. Surface meteorology from volunteer observing ships, *First Joint GOSUD/SAMOS Workshop*, 2-4 May, Boulder, CO (poster).
Plueddemann, A., F. Bahr, D. Hosom and R. Weller, 2006. Surface meteorology from volunteer observing ships, *NOAA Office of Climate Observation Annual System Review*, Silver Spring, MD (poster).
Plueddemann, A., F. Bahr, D. Hosom and R. Weller, 2007, Spatial Variability in Surface Meteorology from a VOS and the ECMWF model, *NOAA Office of Climate Observation Annual System Review*, Silver Spring, MD, (poster).
Plueddemann, A.J., N.R. Galbraith, W.M. Ostrom, G.H. Tupper, R.E Handy, and J.M. Dunn, 2001. The Northwest Tropical Atlantic Station (NTAS): NTAS-1 Mooring Turnaround Cruise Report. *WHOI Tech. Rept. WHOI-2001-07,* 55 pp.
Plueddemann, A.J., W.M. Ostrom, N.R. Galbraith, P.R. Bouchard, G.H. Tupper, J.M. Dunn and M.A. Walsh, 2002. The Northwest Tropical Atlantic Station (NTAS): NTAS-2 Mooring Turnaround Cruise Report, *WHOI Tech. Rept. WHOI-2002-07,* 68pp.
Plueddemann, A.J., W.M. Ostrom, N.R. Galbraith, J.C. Smith, J.R. Ryder, J.J. Holley and M.A. Walsh, 2003. The Northwest Tropical Atlantic Station (NTAS): NTAS-3 Mooring Turnaround Cruise Report, *WHOI Tech. Rept. WHOI-2003-04,* 69 pp.
Plueddemann, A. J., W. M. Ostrom, N. R. Galbraith, P. R. Bouchard, B.P. Hogue, B. R. Wasnewski and M. A. Walsh, 2006. The Northwest Tropical Atlantic Station (NTAS): NTAS-4 mooring turnaround cruise report. *WHOI Tech. Rept. WHOI-2006-09*, 65 pp.
Plueddemann, A.J. and R.A. Weller, 2004. Meteorology and air-sea fluxes from ocean reference stations, *NOAA Office of Climate Observation Workshop*, 12-14 April 2004, Silver Spring, MD (poster).
Plueddemann, A.J. and R.A. Weller, 2005. Meteorology and air-sea fluxes from ocean reference stations, *NOAA Office of Climate Observation Workshop*, 25-27 April 2005, Silver Spring, MD (talk).
Plueddemann, A. J., R. A. Weller, R. Lukas, J. Lord, P. R. Bouchard and M. A. Walsh, 2006. WHOI Hawaii Ocean Timeseries Station (WHOTS): WHOTS-2 Mooring turnaround cruise report, *WHOI Tech. Rept. WHOI-2006-08*, 68 pp.
Plueddemann, A., R. Weller, J. Lord, N. Galbraith, P. Bouchard and S. Whelan, 2007, Inductive Telemetry for UOP Ocean Reference Stations, *NOAA Office of Climate Observation Annual System Review*, Silver Spring, MD, (poster).
Upper Ocean Processes Group, 2007. Inductive telemetry for UOP Ocean Reference Station moorings, *UOP Technical Note,* August 2007, http://uop.whoi.edu/techdocs/TN-telemetry-NTAS-Aug07.pdf
Weller, R, A. Plueddemann, D. Hosom, R. Payne, J. Smith F. Bahr and F. Bradley, 2003. The quality of surface meteorology from unattended buoys and volunteer observing ships, *CLIMAR-II Workshop on Advances in Marine Meteorology,* Brussels, Belgium, 17-22 November 2003 (poster).
Weller, R, L. Yu, A. Plueddemann, D. Hosom, and S. Sathiyamoorthy, 2003. Synthesis of basin-scale air-sea flux fields, *CLIMAR-II Workshop on Advances in Marine Meteorology,* Brussels, Belgium, 17-22 November 2003 (poster).


**Task IV: Hawaii Site:**

The Hawaii Ocean Time-series (HOT) site, 100 km north of Oahu, Hawaii, has been occupied since 1988 as a part of the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS). Among the HOT science goals are to document and understand seasonal and interannual variability of water masses, relate

water mass variations to gyre fluctuations, and develop a climatology of high-frequency physical variability in the context of interdisciplinary time series studies. The primary intent of the WHOI Hawaii Ocean Timeseries Station (WHOTS) mooring is to provide long-term, high-quality air-sea fluxes as a coordinated part of the HOT program and contribute to the goals of observing heat, fresh water and chemical fluxes at a site representative of the oligotrophic North Pacific Ocean. It is expected that establishment of the WHOTS mooring will accelerate progress toward understanding multidisciplinary science at the site, provide an 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.

The first ORS mooring was deployed at the HOT site in August 2004, representing a two year advancement of the timetable originally proposed (financial support for this acceleration was provided by the NOAA Office of Climate Observations as an Add Task). The observational strategy is to maintain a surface mooring at approximately 22.75° N, 158° W, instrumented to obtain meteorological and upper ocean measurements, through successive (annual) turnarounds done in cooperation with HOT investigators. Redundant meteorological systems on the surface buoy measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas. Subsurface oceanographic sensors on the mooring are being provided through cooperation with Roger Lukas (U. Hawaii; funded by the National Science Foundation). The WHOTS mooring is nearby the Multi-disciplinary Ocean Sensors for Environmental Analyses and Networks (MOSEAN) mooring of Tommy Dickey (U.C. Santa Barbara; funded by the National Oceanographic Partnership Program). We have established links with U. Hawaii and the MOSEAN group to improve the efficiency of field logistics. This year we also worked with Chris Sabine to implement pCO2 measurements on the WHOTS buoy given uncertainty about whether the MOSEAN mooring would be redeployed.

A mooring turn-around cruise was conducted during June and July 2007 in order to retrieve the existing mooring (WHOTS-3, deployed June 2006) and replace it with the new mooring (WHOTS-4). This year, we operated for the first time from the U. Hawaii ship *Kilo Moana*. In preparation for this cruise, three ASIMET systems were assembled and tested. Two systems, comprised of the best performing sensors, were mounted on a 2.7 m modular ORS buoy in preparation for deployment. The WHOTS-4 mooring was deployed on 25 June 2007, and the WHOTS-3 mooring was recovered on 28 June. The period between deployment and recovery was dedicated to an intercomparison of the buoy and shipboard meteorological systems. The WHOTS-3 mooring included Iridium meteorological data telemetry systems, developed under the ORS Engineering, Oversight and Data project. These systems were not deployed in WHOTS-4. However, the Iridium subsurface telemetry system used on NTAS was based on the successful WHOTS 2 and 3 deployments. To ensure high-quality meteorological data, all WHOTS-4 sensors were calibrated prior to deployment, and WHOTS-3 sensors will be post-calibrated. A cruise report is in preparation.

Preliminary processing of the WHOTS-1 and 2 meteorological data is in progress. Data return was good. The WHOTS-3/4 intercomparison period showed encouraging results. Extended mounts for air temperature/relative humidity sensors were used on both buoys, and no evidence of diurnal heating was seen. Commercial bird-deterrent spikes deployed on the WHOTS-3 buoy significantly reduced contamination and shadowing from birds landing on the buoy, and a similar installation was used for WHOTS-4. The hourly Argos meteorological from WHOTS 1-4 data are available on-line from the UOP group web site (http://uop.whoi.edu/projects/WHOTS/whotsdata.htm).

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

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 324
July 1, 2006 through June 30, 2007

**PROJECT PARTICIPANTS:**

PIs:
*CICOR/NOAA*: **P.H. Wiebe, C. Ashjian, and D. McGillicuddy (WHOI)**

*NSF*: **L. Madin (WHOI); S. Bollens (SFSU); D. Townsend (UM); A. Bucklin and Runge (UNH); E. Durbin, R. Campbell, & B. Sullivan-Watts (URI)**

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

**PROGRAM MANAGERS**

NOAA Program Manager: Dr. Elizabeth Turner
NOAA Coastal Ocean Program, 146 Environmental Technologies Building (ETB), 35 Colovos Road, University of New Hampshire, Durham, NH 03824-3534

NSF Program Manager: Dr. Phil Taylor,
Biological Oceanography Program Director, National Science Foundation, 4201 Wilson Boulevard, Arlington, Virginia 22230, USA

**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 involves 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. 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?

While most of the work has been completed (see summary in last progress report), there are two components with remaining funds that are currently being completed.

*Reproduction of Calanus finmarchicus and Pseudocalanus spp.*: 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 *C. finmarchicus* for each broad-scale cruise and plotted using OAX objective analysis as well as the standard broadscale survey grid. The broad-scale egg production data are used in the calculation of *C. finmarchicus* Georges Bank egg-N2 mortality rates published or in preparation 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. The estimation of *Pseudocalanus* egg production from broad-scale samples proved to be 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 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 (Runge et al. 2005). He also received partial support from this award for his contribution to a research article that presents the hypothesis that variability in the magnitude of the fall phytoplankton bloom results in bottom-up influences on copepod and herring abundance in the Gulf of Maine (Pershing et al. submitted).

Additional effort is being expended to complete the papers in preparation by Ohman et al. (in prep.) and Runge et al (in prep. a, b). Ohman et al. (in prep.) 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*. Runge et al., (in prep. a) 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. (2005, 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. was accepted. Runge et al. (in prep. b) describes a method for estimated population egg production rate of copepod species and shows as an example the horizontal/seasonal distribution of egg production rates of five dominant copepod species on Georges Bank using data from the broad-

scale survey collections.
*Predators of target species.* Larry Madin and Steve Bollens have been heading up the work on the invertebrate predators on the GLOBEC Georges Bank target species (cod, haddock, *Calanus finmarchicus* and *Pseudocalanus* spp.). There are funds remaining a WHOI to complete the work on assembling the algorithms to specify feeding rates of the predator groups in order to estimate their feeding impact on prey both on Georges Bank and in the Gulf of Maine. Steve Bollens recently changed institutions (from San Francisco State University to Washington State University), and this has resulted in some unavoidable delays to his research program, e.g., setting up three new laboratories, hiring new technical staff, recruiting new graduate students, and most recently, getting zooplankton samples shipped from San Francisco, California to Vancouver , Washington. Overall though, the research facilities and capabilities of his new institution far surpass that of his previous institution. Moreover, his progress on this particular award continues to be solid (e.g., one publication in 2005, with two new ones "in progress"). However, considerable work remains to be done to complete this project, primarily in the areas of i) data analysis, and ii) manuscript preparation. Additional time will be used to subject the data (i.e., MOC-10 marcozooplankton/ micronekton and hydrographic data) to rigorous multi-variate statistical analyses, and the results interpreted and synthesized into peer-reviewed publications.

**RECENT RESEARCH PAPERS OR PAPERS IN PROGRESS RECEIVING SUPPORT FROM THIS AWARD:**

Bollens, S., D. Gewant, H. Brown, L. Madin and E. Horgan. In Preparation. Regional Variation in the Community Structure of Macrozooplankton and Micronekton on Georges Bank/Northwest Atlantic in Relation to Environmental Conditions, 1995-1999.

Madin, L., E. Horgan, S. Bollens and B. Sullivan. In Preparation. Predation rates of invertebrate and fish predators on target species of copepods and larval fishes on Georges Bank.

Ohman, M. D., K., Eiane, E.G. Durbin, J.A. Runge and H.-J. Hirche. 2004. A comparative study of *Calanus finmarchicus* mortality patterns in five localities in the North Atlantic. ICES J. Mar. Sci. 61: 687-697.

Ohman, M. D., B. Sullivan, E.G. Durbin, and J.A. Runge. In prep. Relationship of predation potential to mortality for *Calanus finmarchicus* on Georges Bank, N.W. Atlantic Ocean.

Pershing, A., C. Greene, E. Durbin, E. Head, S. Hakkinen, D. Mountain, J. Jossi, J. Runge, et al. submitted. Remote forcing of marine ecosystem dynamics in the Northwest Atlantic. Limnol. Oceanogr.

Runge, J.A., F.E. Werner, E. G. Durbin, J.A. Quinlan, R.G. Lough, L. J. Buckley, K. Pehrson Edwards, S. Plourde and M. D. Ohman. In prep. The effect of spatial and temporal variation in zooplankton concentrations on larval cod growth on Georges Bank: a comparison of two years based on modelling and observations.

Runge, J.A., E. Durbin, M. Casas and S. Plourde. In prep. Estimates of copepod egg production rates on Georges Bank.

Runge, J.A., P.J.S. Franks, W.C. Gentleman, B.A. Megrey, K. A. Rose, F.E.Werner and B. Zakardjian. 2005. Diagnosis and prediction of variability in secondary production and fish recruitment processes: developments in physical-biological modelling. Pp. 413-473 in The Sea. Vol. 13: The Global Coastal Ocean: Multi-Scale Interdisciplinary Processes. A.R. Robinson and K. Brink, eds.

# GLOBEC-01: Phase IV Support for the Scientific Investigators' Data Synthesis Symposia

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 323
July 1, 2006 through June 30, 2007

**Dr. Peter H. Wiebe [Co-PI: Robert C. Groman]**
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Program Manager: Dr. Elizabeth Turner NOAA/NOS/CSCOR.

Related NOAA Strategic Plan Goal:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

## PROJECT OVERVIEW

This project has been supporting the US GLOBEC Georges Bank Phase IVa and b yearly workshops and other meetings. These funds have been used to defray the costs of the meeting facilities and pay partial or full travel support for that investigator whose presence at one or more of these meetings was deemed important by the US GLOBEC Georges Bank Executive Committee and yet may not have had sufficient funds to attend the meetings on his/her own. The funds were also used to assist in the documentation of the meetings through the preparation of reports, which will be published both in hard copy and on the Program's web site (http://globec.whoi.edu/), as has been done in the past. It is anticipated that some funds will be used to assist in the planning and development of the book showing the results of the analysis and synthesis of the GLOBEC George Bank program data sets and modeling efforts during the Phase IVb funding period.

There were five US GLOBEC Georges Bank science projects in Phase IVa of the program. These are as follows:
**1) The Physical Oceanography of Georges Bank and Its Impact on Biology.** Robert Beardsley (WHOI), Ken Brink (WHOI), Dick Limeburner (WHOI), Jim Churchill (WHOI), Jim Ledwell (WHOI), Changsheng Chen (UMassD), James J. Bisagni (UMassD), Charles Flagg (BNL), Peter Smith (BIO), Ron Schlitz (NEFSC), Jim Lerczak (WHOI)
**2) Zooplankton Population Dynamics on Georges Bank: Model and Data Synthesis.** Peter Franks (SIO), James Pringle (UNH), Changsheng Chen (UMassD), Ted Durbin (URI), Wendy Gentleman (UW)
**3) Patterns of Energy Flow and Utilization on Georges Bank**. Dian Gifford (URI), James J. Bisagni (UMassD), J.S. Collie (URI), E.G. Durbin (URI), Michael Fogarty (NEFSC), Jason Link (NMFS), Larry Madin (WHOI), David Mountain (NMFS), Debbie Palka (NMFS), Michael E. Sieracki (BLOS), John Steele (WHOI), B.K. Sullivan (URI)
**4) Tidal Front Mixing and Exchange on Georges Bank: Controls on the Production of Phytoplankton, Zooplankton and Larval Fishe**s. Robert W. Houghton (LDEO), Dave Townsend (UME), Changsheng Chen (UMassD), R. Gregory Lough (NEFSC), Lew Incze (BLOS), Jeff Runge (UNH)
**5) Integration and Synthesis of Georges Bank Broad-Scale Survey Results.** Peter Wiebe (WHOI), Carin Ashjian (WHOI), Larry Madin (WHOI), Dennis McGillicuddy (WHOI), Dave Mountain (NMFS), J.R. Green (NMFS), Peter Berrien (NMFS), S.M. Bollens (SFSU), Dave Townsend (UMaine), Ted Durbin (URI), Bob Campbell (URI), Barbara Sullivan (URI), Ann Bucklin (UNH), Jeff Runge (UNH).

Most of these projects were funded for a 3 or 4 year period and one (#5) was funded for two years.

There were five additional projects funded in Phase IVb of the program, which started in 2006. These are as follows:
**1) Marine Ecosystem Responses to Climate-Associated Remote Forcing from the Labrador Sea.** C. Greene (Cornell), Pershing (Cornell), Monger (Cornell), D. Mountain (NEFSC), S. Hakkinen (Goddard Space Flight Center).
**2) Factors determining early-life-stage survival and recruitment variability in N. Atlantic cod: a comparison bewteen NW Atlantic and Norwegian Sea Systems.** F. Werner (UNC), R. G. Lough (NEFSC), T. Durbin (URI), D. Mountain (NEFSC), M. Fogarty (NEFSC), L. Buckley (NEFSC)
**3) Effects of climate variability on *Calanus* dormancy patterns and population dynamics in the Northwest Atlantic.** J. Runge (UNH), A. Leising (NMFS)
**4) Impacts of Climate and Basin-Scale Variability on Seeding and Production of *Calanus finmarchicus* in the Gulf of Maine/Georges Bank Region.** A. Gangopadhyay (UMassD), H. Batchelder (OSU), D. Gifford (URI), J. Bisagni (UMassD)
**5) Processes Controlling Abundance of Dominant Copepod Species on Georges Bank: Local Dynamics and Large-Scale Forcing.** C. Davis (WHOI), R. Beardsley (WHOI), C. Chen (UMassD), R. Ji (WHOI), T. Durbin (URI), D. Townsend (UMaine), J. Runge (UNH), C. Flagg (SUNY-SB)

## ACCOMPLISHMENTS

Two scientific investigator workshops for GLOBEC Phase IVb scientists were held with support from this grant. The first workshop was held on 2 - 3 October 2006 and the second on 23 - 24 April 2007. Both workshops were held at WHOI in the Clark Laboratory (Conference Room 507). The workshops included 22 and 30 participants, respectively.

The purpose of both workshops was to update program PIs on the ongoing research results by the various projects. Funds for the workshops were used for catering and group dinners. PIs paid their own travel. Both workshops achieved their goals and the GLOBEC Phase 4B Synthesis projects are proceeding as planned.

The reports/talks are available on-line at:
http://globec.whoi.edu/globec-dir/phase4doc/simeeting2006/attendees.shtml
and
http://globec.whoi.edu/globec-dir/phase4doc/simeeting2007/report.shtml

Three investigators were also supported to attend the U.S. GLOBEC pan-synthesis meeting held at the National Center for Atmospheric Research in Boulder, Colorado from 27 to 30 November 2006. A report of the meeting entitled "First U.S. GLOBEC Pan-Regional Synthesis Workshop" has been circulated to the participants for final comment before official publication.

## PUBLICATIONS

Groman, R.C., M.D. Allison, and P.H. Wiebe. 2007. New MapServer interface to US GLOBEC data sets. GLOBEC International Newsletter, April 2007. Pages 92-94.

## SUMMARY OF INTERACTION WITH NOAA

This synthesis project was a collaborative integrative effort that involved scientists from academic institutions and the NOAA/NEFSC working together in the analysis, synthesis, and publication of data collected during the U.S. GLOBEC Northwest Atlantic Georges Bank field years (1994-1999). It has been a very productive and successful partnership.

## SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

The U.S. GLOBEC data and information web site (See http://globec.whoi.edu/ ) provides open access to the data collected by all of the U.S. GLOBEC modules and information about the Georges Bank program. It is frequently accessed not only by scientists, but also by educators, students, and managers.

Appendix I: Publication Statistics

| | JI Lead Author | | | | | | Other Lead Author | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FY01 | FY02 | FY03 | FY04 | FY05 | FY06 | FY01 | FY02 | FY03 | FY04 | FY05 | FY06 |
| Peer-Reviewed | 26 | 40 | 37 | 13 | 23 | 20 | 0 | 0 | 0 | 5 | 2 | 5 |
| Non-Peer-Reviewed | 0 | 23 | 15 | 12 | 6 | 14 | 0 | 0 | 0 | 0 | 0 | 15 |