

C I C O R

Cooperative Institute for Climate and Ocean Research

of the Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Annual Progress Report

July 1, 2005 - June 30, 2006

Dr. Robert A. Weller, Director



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CICOR 2005 – 2006 Annual Progress Report

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CICOR
Cooperative Institute for Climate and Ocean Research
Annual Report 2004-05

Executive Summary
Robert A. Weller, CICOR Director

CICOR is a Cooperative Institute between the National Oceanic and Atmospheric Administration (NOAA) and the Woods Hole Oceanographic Institution (WHOI). CICOR's specific research themes are the coastal ocean and near-shore processes, the ocean's participation in climate and climate variability, and marine ecosystem processes analysis. CICOR brings to NOAA research excellence in oceanographic research and marine policy and access to research ships and submersibles, remotely operated and autonomous vehicles, and state of the art ocean observing systems.

Education and Outreach activities are key priorities for CICOR. This year CICOR has continued its support of graduate students and Postdoctoral Scholars as well as its participation in a local science fair. It has also sponsored 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 two CICOR research cruises hosted teachers. Eric Heltzel, a high school teacher from Wyoming, was on board NOAA Ship RONALD H. BROWN for 28 days in September and October, while scientists conducted atmospheric research on the stratus cloud deck. They traveled from Miami, through the Panama Canal, and all the way to Chile. Diana Griffiths, a high school chemistry teacher from Pennsylvania, was aboard UNOLS Ship Roger Revelle for eight days in June while scientists conducted oceanographic research in Hawaiian waters. More details on their experience can be found in the K-12 section of this report.

CICOR continues to stimulate interaction with the external community by supporting visitors to WHOI and interaction with NOAA laboratories by offering travel support for WHOI investigators who wish to visit those labs to explore possible collaborative research. For example, CICOR co-sponsored a summer Indian Ocean Seminar Series with WHOI's Ocean and Climate Change Institute. The two-week-long seminar series included lectures and informal discussions with Indian Ocean specialists from China, Australia, the U.S. and WHOI. CICOR hosted the QARTOD IV workshop (Quality Assurance in Real Time Oceanographic Data) which was facilitated by a capable group of data professionals from NOAA, WHOI and other institutions around the country. CICOR also contributed significantly to the OceanSITES Data and Steering Committee Meeting which took place in February of 2006. To support this time series group interested in building sustained support for long-term ocean observing stations, CICOR produced a 12 page color brochure and redesigned the group's website.

The CI Directors meeting in the winter of 2006 led to discussion of how best to affect greater involvement of the Cooperative Institutes in the planning process at NOAA. Part of this plan continues the initiative that the Cooperative Institutes were to host workshops to plan future research activities in areas of key interest to OAR and to populate these workshops with both

NOAA and external researchers in order to stimulate interaction between the external community and NOAA OAR during the planning process. In addition, NOAA indicated the intent to work towards greater involvement of the CI directors in the annual NOAA planning process as well as in longer term strategic planning.

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 following events: a domoic acid event in Oregon, a fish-killing *Karenia brevis* bloom in Texas, and one in Florida.
- Cabell Davis and Qiao Hu are developing 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. This year they have developed two methods to extract objects based on color and conducted method testing to characterize texture features.
- Rui Xin Huang and company have made substantial progress during the past 24 months. The most important discovery is that wind energy input to the oceans has increased greatly over the past 50 years. Wind energy input to the oceans is the most important source of mechanical energy sustaining and regulating the oceanic general circulation. Numerical experiments designed for testing the decadal variability of the equatorial circulation related to ENSO have been carried out and indicate that variability in diapycnal mixing, which is induced by wind stress energy input, can induce large amplitude of SST anomaly in the equatorial Pacific; thus, this may be one of the most important ingredients sustaining the decadal variability in ENSO dynamics. Their study has been written up in a manuscript, which has been through second reviews and it is expected that it will soon be accepted for publication.
- 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 147 floats, primarily in the Atlantic Ocean. The group has now developed a SOLO float that uses the Iridium Short Burst Data communications system. During the present year, Xingwen Li and Owens have carried out an analysis of the seasonal variation in heat (SH) and (salt content in the upper one kilometer of the ocean.
- 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. This year, they have found that combining the transport estimates with the air-sea flux estimates (Figure 6) provides more a complete picture of the meridional circulation of TIC. Most notably, there is a strong southward transport of TIC from the northern hemisphere across the equator supplied in part by a substantial uptake of carbon from the atmosphere between 47°N and 24°N.

- Andrey Proshutinsky guided the production of an annual report fully assessing the state of the Arctic Ocean. The report was developed via a workshop with leaders in the field. The 2006 NOAA global climate report includes a section with a review of recent Arctic data by an international group of scientists who developed a consensus on the arctic environment information content and reliability. The report highlights data primarily from 2000 to 2005 with a first look at winter 2006, providing an update to some of the data records of physical processes discussed in the Arctic Climate Impact Assessment (ACIA 2004, 2005).
- John Steele's analysis of an end-to-end food budget for Georges Bank showed that because some predators can switch to different prey that it was essential to management of fisheries resources there to develop a comprehensive food budget including all trophic levels. This year he and his group constructed an end-to-end budget of Georges Bank ecosystem by balancing the output of the lower food web with fish consumption.
- Dennis McGuillicuddy lead the first 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, July 11-13, 2006.
- 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.
- Terry Joyce and Jiang Yang have found that atmospheric wind stress forcing along the equator is the leading driver for the seasonal cycle of the NECC transport. This hypothesis was tested by several sensitivity experiments. Their research supports their hypothesis and was published: Yang, J. and T. Joyce, 2006: Local and equatorial forcing of seasonal variations of the North Equatorial Countercurrent in the Atlantic Ocean. *Journal of Physical Oceanography*, Vol. 36, 238–254.
- Postdoctoral Investigator Brian Ward made further contributions to the team effort of developing an improved model of the diurnal warming of sea surface temperature by addressing the fact that many of the available SST measurement techniques do not sample above the upper 1 m (e.g. ship-mounted CTD), nor continuously through the water column (e.g. fixed sensors attached to buoys) by incorporating the unique measurements provided by the Skin Depth Experimental Profiler (SkinDeEP) which enables an unprecedented opportunity to validate simulations of the structure and evolution of near-surface diurnal warming. This work is being carried out in collaboration with Dr. Gary Wick at NOAA in Boulder.
- 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.
- Dave Hosom and Robert Weller's collection of high quality surface meteorological 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. This year their group successfully changed one of the three systems (Hawaii) over to an Iridium satellite communications system. Also, to further support ground-truthing of satellite data and increased understanding of the ocean in the eastern South Pacific, 16 drogued surface drifters and 8 profiling ARGO floats were deployed in the South Pacific along Stratus (Chilean) the cruise track.
- Graduate student Tom Farrar's analyses of air-sea interaction and upper ocean variability at two sites spanning the eastern Pacific cold tongue during the 1997-1998 ENSO event have uncovered compelling evidence of the link between the intraseasonal SSH and SST fluctuations there. These findings were published in the Journal of Geophysical Research (Farrar and Weller, 2006).

CICOR Annual Highlights/Accomplishments 2004-2005

- | | |
|-------------|---|
| August 2005 | Co-hosted Indian Ocean Seminar Series with the Ocean and Climate Change Institute |
| Nov. 2005 | Teacher At Sea Program Stratus Cruise NOAA ship, the Ronald H. Brown |
| Dec. 2006 | Took over the OceanInstruments website from WHOI Academic Programs Office adding quality writing and graphics for over ten new instruments. |
| Feb. 2006 | Sponsored travel for OceanSITES meeting in Honolulu, HI and presented the Science Team with a first draft of the OceanSITES brochure and website. |
| April 2006 | JI Directors and Administrators Meeting Silver Spring, MD. |
| June 2006 | Publication of 5,000 copies of the 12 page OceanSITES brochure: OceanSITES, Taking the Pulse of the Global Ocean. |
| June 2006 | Teacher At Sea Program on the WHOTS cruise aboard the R/V Revelle. |

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. The Great Lakes Environmental Research Laboratory (GLERL) is CICOR’s formal partner within the NOAA OAR structure. 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.

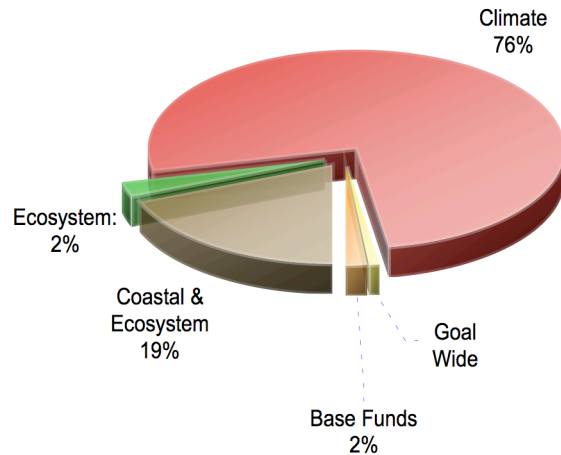
CICOR completed its first cooperative agreement with NOAA OAR, which lasted 3 years, in the summer of 2001. A new 5-year cooperative agreement was signed July 2001. Under the cooperative agreement CICOR research is organized around three **science themes**. At the same time, for administrative purposes budgets are organized around four **tasks**.

CICOR’s three research themes are:

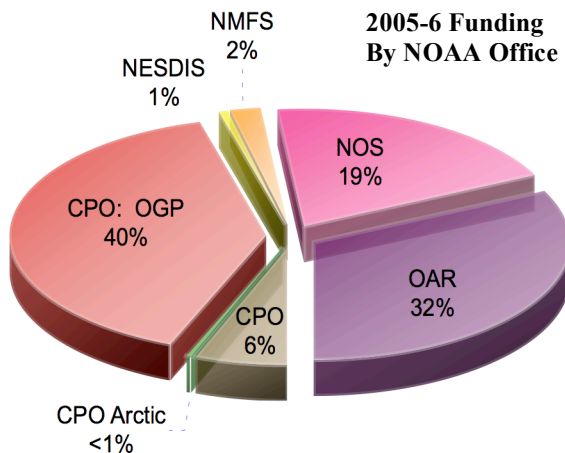
- The coastal ocean and near shore processes,
- The ocean's participation in climate and climate variability and
- Marine ecosystem processes analysis.

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 Funding by Theme



2005-6 Funding By NOAA Office



CICOR has been in existence for eight 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 5-year Cooperative Agreement through June '06 is \$27,337,680. This year, the total amount awarded for projects with start dates of June '06 or earlier is \$6,755,848.

Although NOAA is the primary funder of 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 the same as the overhead rates negotiated with our cognizant agency (ONR), with the exception that the rate would remain fixed 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. 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. This contribution was \$162,850 in 2005. CICOR's current cooperative agreement has been extended two years from June 30, 2006 to June 30, 2008 with no increase or change to the overhead structure. To-date, the WHOI's contribution on overhead for the current cooperative agreement totals over \$692,000.

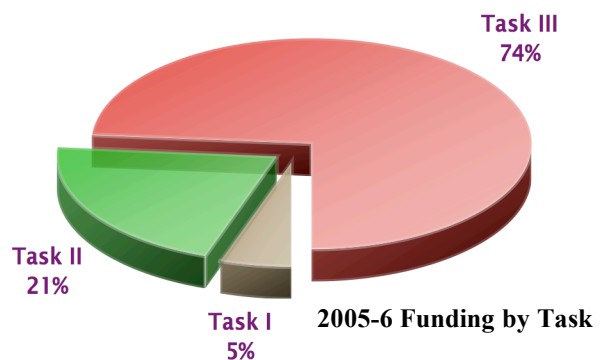
CICOR program development fees during this reporting year covered two post-docs, graduate student, three summer student fellows, educational outreach, travel support for CICOR PIs and post-docs to attend meetings with NOAA personnel as well as support for short term visitors for seminars and workshops. For more information see the CICOR website:

<http://www.whoi.edu/science/cicor>

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.

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

- Task I (\$348,365 of the total in 2005-6) supported administration, education, and support for visitors to and from CICOR as well as outreach activities;
- Task II is research funding with explicit participation by a NOAA investigator (\$1,436,597, 21% - a 50% increase from the previous year);
- 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 (\$4,970,886, 74%), 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.)

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.

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 CICOR is in the process of appointing two Associate Directors, one to spearhead coastal initiatives, the other for ecosystems research. The Associate Directors will work 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. Advancement of these is currently will be decided upon by the Executive Committee in the fall of 2006.

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)
Nancy Grumet Prouty	Ecosystem Processes	2004-2006	Konrad Hughen
Jeremiah Hackett	Coastal & Ecosystems	2005-2006	Don Anderson
Graduate Students	CICOR Theme	Appt. Dates	Advisor
Carlos Moffat	Climate	2005-2007	Robert Beardsley & Breck Owens
Summer Student Fellows	CICOR Theme		Advisor
Cara Hotchkin	Ecosystems/Coastal		Peter Tyack (BIO)
Peggy Lynch	Ecosystems		Hauke Kite-Powell, & Hoagland (MPC)
Ryo Saotome	Climate		Lisan Yu (PO)
Hollings Fellows	CICOR Theme		Advisor
Deborah Osborne	Ecosystems/Coastal		Don Anderson
Theresa Smith	Climate		Robert Weller
Charles White	Ecosystems		Peter Tyack Mark Johnson Sophie Parijs (NMFS)

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			

Post Doctoral Scholar Summary Reports

Activity Summary for Nancy Grumet (Prouty) CICOR Post-Doc 2005-2006

As a second year CICOR Postdoctoral Scholar I have continued my research involving the investigation of trace metal incorporation into coral skeletal aragonite. My primary research focuses on the historical analysis of land based sources of marine pollution on the inshore reefs of Bermuda. Previous studies have found elevated concentrations of trace metal contaminants Cu, Fe and Pb in Castle Harbour water and surface sediments, but provide only snapshots. I have worked extensively to develop a methodology for extending these observations back through time using slow-growing *Diploria* corals for trace metal analysis on the WHOI Plasma Mass Spectrometry Facility using the inductively coupled plasma mass spectrometer (ICP-MS). This year's progress includes the following achievements:

Highlights/New Activities:

- Established proper cleaning techniques for minimizing blank level concentrations for ultra-trace metal ICP-MS solution analysis
- Measured trace metals (i.e., Ba, Cd, Cu, Fe, Mg, Mn, Pb, Sr, and Zn) at extremely low (ppb) concentrations using protocol I developed on an ICP-MS for samples less than 2 mg
- Determined present day pollutant signal in Castle Harbour coral samples from elevated Pb, Cu, Mn and Zn concentrations
- Constructed biennial history (1994-1776) of trace element concentrations from John Smith's Bay, Bermuda (~145 samples)

Results from these activities were presented as a poster at the 2006 AGU Ocean Sciences Meeting in collaboration with my WHOI mentor, Associate Scientist Konrad Hughen and BBSR Associate Research Scientist Ross Jones. I am currently in the process of writing a manuscript which will compare trace metal records of corals from Castle Harbor and the open-water control site in John Smith's Bay to establish where and how the pollutant signal is dispersed and quantify the impact above natural baseline.

Most recently I have expanded my research to several sites corals in the Mesoamerican Reef Ecosystem (MRE). In collaboration with Dr. Hughen and Dr. Eglinton, we are investigating and quantifying the relationships between coral health and environmental stressors (in combination and in isolation), using advanced geochemical techniques. As a co-PI on a proposal submitted to the Summit Foundation, we successfully secured funding to pursue our research as part of the international, multi-institutional Healthy Mesoamerican Reef Initiative.

Our approach will include multiple geochemical analyses on samples taken from the surface of coral skeletons (i.e., "surface samples") to assess a range of threats to coral reef health – including climate change, agricultural runoff and pesticides, and coastal development and tourism. Samples will be taken from healthy, bleached, diseased and dead corals of multiple species. Multiple proxies measured on each surface sample will be used to develop quantitative "yardsticks" for reef environmental threats (e.g., SST, salinity, silt and turbidity, nutrients and pollutants), as well as coral and symbiont health and productivity. Correlations between environmental stress and coral health within a comprehensive surface sample network will enable us to map the spatial patterns of environmental stress and their impacts on coral species.

Ultimately, we anticipate that this type of information will allow us to identify regional threshold values for environmental stress and combinations of stressors by which corals become susceptible to disease, bleaching and death.

Specifically, my efforts will focus on understanding agricultural land-use and the impact on coral reef health. Dangerously high levels of nutrients can facilitate the complete replacement of corals with weedy algae and, hence, starve the coral reefs. To clarify the link between nutrient loading and fertilizer use, I will analyze bulk organic carbon and nitrogen isotopes ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) in coral skeletons, in order to identify nitrogen sources. This approach is powerful, since nutrient sources have very distinct nitrogen chemical signatures. For example, we can identify nutrient loading from synthetic versus manure fertilizers due to the difference in their nitrogen isotope signature preserved in the coral skeleton. To further elucidate the role of agricultural land-use on coral reef cover, I will build upon my background and expertise with trace metals and analyze a suite of trace elements known to be tracers of crop soil treatments, such as manganese, molybdenum and copper (Mn, Mo and Cu).

During my postdoctoral scholarship I have remained an active member and representative of the WHOI Post Doctoral Association (PDA) and WHOI Gender Equity Program Advisory Committee (GEPAC). I have also served as an external reviewer for the following journals: *Coral Reefs*, *Climatic Change*, *Global Planetary Change*, and *Internal Coral Reef Symposium Proceedings*

Summary of Accomplishment

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, is 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 is 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 is then measuring the expression of these genes in cultures of *Alexandrium* grown under nutrient stress. This work will identify 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 is 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 are currently being tested on these field samples. The QPCR method needs to be optimized before it will be clear if these genes will be good candidates to monitor the nutrient status of natural algal blooms.

Dr. Hackett is also attempting 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 *Teleanlax*. In an attempt to culture *Dinophysis*, Dr. Hackett isolated single cells of *Teleanlax* 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.

CICOR sponsored Dr. Hackett's travel to two international conferences in 2006. The first was the American Society of Limnology and Oceanography conference in Victoria, BC in June. Coming from a genomics and evolution background, this conference was an important opportunity for Dr. Hackett to learn about the latest research in the broad field of oceanography and network with the leaders in this field. Dr. Hackett was chosen to give an oral presentation at the meeting.

The second conference was the International Society for the Study of Harmful Algae conference in Copenhagen, Denmark. This meeting gave Dr. Hackett the opportunity to see the latest research in the harmful algae community and meet directly with several researchers involved in related work. Dr. Hackett also learned about two discoveries directly related to his projects, including the discovery of saxitoxin genes in cyanobacteria and attempts to culture *Dinophysis* using a ciliate prey. Both of these results will greatly accelerate Dr. Hackett's current work. Dr. Hackett was selected to give an oral presentation at this meeting as well.

Dr. Hackett was a Co-PI on a proposal submitted to the National Science Foundation to sequence the genome of a saxitoxin producing cyanobacterium and use bioinformatic methods to discover the related genes in *Alexandrium*. A panel will decide on this proposal in October 2006.

In 2006, Dr. Hackett was offered, and has accepted, a faculty position as an assistant professor at the University of Arizona, Department of Ecology and Evolutionary Biology, in Tucson, AZ. He will begin 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 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 2005-2006 reporting year.

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

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 past year, I have been examining 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 the APCC provides a favorable environment for biological production.

An initial version of these results were presented in February of this year 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.

CICOR Summer Student Fellows

In the summer of 2006, CICOR supported three Summer Student Fellows, one in each of CICOR's three themes. The Summer Student Fellow Program, coordinated by WHOI's Academic Programs Office, is a highly competitive opportunity for undergraduate students completing their junior or senior year at colleges or universities. Applicants can be studying in any of the fields of science or engineering and have at least a tentative interest in the ocean sciences, oceanographic engineering, mathematics, or marine policy. Fellowships are awarded to pursue an independent research project under the guidance of a member of the Scientific or Senior Technical Staff. These projects typically are suggested by the advisor, and are agreed upon jointly by fellow and advisor. Through this program of Summer Fellowship grants, Woods Hole Oceanographic Institution's (WHOI) aim is to give a promising group of science and engineering students experience, which will assist them in determining whether they wish to devote careers to the study of the oceans. These competitive awards are for a ten to twelve-week period in the summer, with a stipend of \$396 per week and housing provided.

The 2006 CICOR Summer Student Fellows included: (Detailed individual reports follow.)

Cara Hotchkin

University of Rhode Island

WHOI Advisor: Peter Tyack, Biology Department

Project: Possible Heading Changes in North Atlantic Right Whales (*Eubalena glacialis*) When Approached by Small Boats.

Peggy Lynch

B.S. Biological Sciences, Stanford University, 2006

WHOI Advisors: Hauke Kite-Powell, Porter Hoagland, Marine Policy Center, WHOI

Project: Appropriate spatial scales for ocean management

Ryo Saotome

Minority Summer Student Fellow

Trinity College, Physics and Mathematics, 2008

Advisor: Lisan Yu, Department: Physical Oceanography

Project: Role of Sea Surface Temperatures on Hurricane Formation

Cara Hotchkin

Summer Student Fellow

University of Rhode Island

B.S. Marine Biology and Biological Oceanography (2007)

B.S. Coastal and Marine Policy and Management (2007)

Biology Department

Advisor: Peter Tyack

Project: Possible Heading Changes in North Atlantic Right Whales (*Eubalena glacialis*) When Approached by Small Boats.

Related NOAA Strategic Plan Goal:

Goal 1. Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.

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



Activity Report

My project for the summer is to determine whether North Atlantic Right Whales respond to small vessel approaches by changing direction or turning. To do this, I am analyzing data gathered by Dr. Douglas Nowacek in the Bay of Fundy in Canada during the 2005 field season.

The data was gathered using Digital Acoustic Recording Tags (DTAGs), developed by Mark Johnson and Peter Tyack. The DTAG records the animal's depth, orientation (pitch, roll, and compass heading), and any sounds in the water around the whale on the same time scales, allowing for accurate analysis of the animal's behavioral reactions to experimental noises.

I have been plotting the tracks of the approaching vessel and the whales, to see if the animal changes orientation when the boat is nearby, and, if it does, whether the animal orients towards or away from the vessel. I also intend to plot the level of sound received by the animal against the animal's angular range (compass heading), to determine if sound level is a factor in whether there is a response by the animal.

I have also been familiarizing myself with cetacean biology and anatomy by attending necropsies when possible. This will enable me to gain a better understanding of what may or may not affect the animals in their natural environment.

Peggy Lynch

Summer Student Fellow

Project: Appropriate spatial scales for ocean management

Department: Marine Policy Center, WHOI

Advisors: Hauke Kite-Powell, Porter Hoagland

Education:

B.S. Biological Sciences, Stanford University, 2006



Related NOAA Strategic Plan Goal:

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

Research Overview:

This summer I'm investigating the role of spatial scale in designing intelligent ocean management schemes. For ecological, economic, and sociopolitical reasons, the scale at which natural resources are managed can make a tremendous difference in the success of a management scheme, ecosystem health, and resource sustainability. The choice of appropriate management scale is particularly challenging and relevant in the marine environment, where ecological, physical, and political boundaries are often not easily apparent. I'm focusing specifically on the design of marine reserves and marine protected areas, their role in ecosystem-based management, and how to best integrate the optimal scales of reserve networks, as determined by physical and biological factors such as current patterns and life-history characteristics, with social and economic concerns and existing management frameworks.

I'm also contributing, along with Merrielle Macleod, a graduate student at Brown, to the research and writing of an article Dr. Hoagland is preparing on ocean zoning for the upcoming edition of the Encyclopedia of Ocean Sciences. Ocean zoning is a relatively new approach to ocean management, based on the established practice of land zoning, involving the designation of particular areas of the ocean for particular uses. We plan to incorporate the ongoing discussions on comprehensive ocean management in Massachusetts (related to SB 529: An Act Relative to Oceans, currently pending approval in the Senate) as a case study in the piece, so I've had the opportunity to interview representatives of various state agencies, businesses, and non-profit organizations with have interests in the outcome of this process, such as the Department of Marine Fisheries, Office of Coastal Zone Management, and the Conservation Law Foundation.

I've truly enjoyed my research this summer, especially the opportunity to work so closely with my advisors, and I know the knowledge I've gained of the policy realm will serve me well in my future studies of marine systems.

Ryo Saotome

Minority Summer Student Fellow

Trinity College, Physics and Mathematics, 2008

Advisor: Lisan Yu

Department: Physical Oceanography

Project: Role of Sea Surface Temperatures on Hurricane Formation



Related NOAA Strategic Plan Goal:

Goal 1. Understand climate variability and change to enhance society's ability to plan and respond.

Goal 2. Serve society's needs for weather and water information.

Activity Report

My project this summer is concerned with the role of sea surface temperatures in the formation of hurricanes. Better understanding of the conditions under which hurricanes form should allow for better predictions and response times. I spent the first couple of weeks of this summer familiarizing myself with MATLAB and learning more background information on hurricanes. The rest of my summer was spent analyzing various satellite data on ocean conditions and plotting them against known information on hurricanes using MATLAB to try to find a connection. Currently I am analyzing data on hurricanes and sea surface temperatures using a technique known as singular value decomposition, the results of which are not yet known.

As a part of the SSF/MF program this summer I was able to attend a variety of interesting lectures through the Summer Lecture Series and also attend a very useful Ethics in Science Workshop. I was also able to take a day cruise on the Tioga and have a hands-on learning experience on the various methods of data collection on research vessels.

CICOR Hollings Fellows Summer Internships

The summer of 2006 marked the first year of the Hollings Scholars summer internships and CICOR was proud to fully participate in this ambitious NOAA initiative. The program is designed (1) to increase undergraduate training in oceanic and atmospheric science, research, technology, and education and foster multidisciplinary training opportunities; (2) to increase public understanding and support for stewardship of the ocean and atmosphere and improve environmental literacy; (3) to recruit and prepare students for public service careers with NOAA and other natural resource and science agencies at the Federal, state and local levels of government; and (4) to recruit and prepare students for careers as teachers and educators in oceanic and atmospheric science and to improve scientific and environmental education in the United States.

Charles E. White, II Hollings Scholar

Undergraduate
University of North Carolina Wilmington
Computer Science and Mathematics

WHOI advisors:
Mark Johnson and Peter Tyack

Project/Focus Title:
Analysis of DTAG data from simultaneously tagged long-finned
pilot whales (*Globicephala melas*)

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



Summary of Accomplishments:

During the summer of 2006 White analyzed data from simultaneously tagged long-finned pilot whales to quantify how these animals use the sonic environment to coordinate group behaviors. A group of three synchronously diving, cross-audible pilot whales was identified from a 2004 DTAG data set. A generalized time difference of arrival (TDOA) acoustic transponder approach was used to calculate estimates for the distance between each pair of animals during the synchronized dive cycle. From these distance estimates, a dynamic baseline was established to later track untagged whales in the synchronized group.

White also participated in the Stellwagen Bank National Marine Sanctuary 2006 Humpback DTAG tagging cruise (P.I. David Wiley). On this cruise his responsibilities included field support in the tagging and tracking of humpbacks in the sanctuary and analysis of data upon the retrieval of tags.

Deborah Osborn
Hollings Scholar

Bucknell University, Chemical Engineering, 2007
Linda McCauley/Anderson Lab
Pseudo-nitzschia: Emerging HAB threat in the Gulf of Maine

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.



Strapping down the CTD on the Oceanus in the Gulf of Maine

Summary of Accomplishments

Pseudo-nitzschia is a marine diatom found in the Gulf of Maine (GOM). Some species are capable of producing domoic acid, which causes amnesic shellfish poisoning and is believed to have killed over twenty whales and forty seals in the GOM in 2003 alone. The species distribution and which species are toxic in the GOM is not well known, so the Anderson lab was awarded a NOAA grant to investigate in the interest of being able to inform the public of any danger arising from the domoic acid toxicity and developing the background information necessary to be able to respond to blooms.

My summer work consisted of using molecular techniques to identify the species of *Pseudo-nitzschia* in the GOM and determine whether molecular probes developed on the West Coast could be used here. I sampled nearshore and offshore waters in the GOM while participating on the Oceanus cruise OC425, established clonal cultures, identified the strains to the species level using molecular techniques, and compared the sequences I found to the molecular probes.

The analysis revealed four unique sequences resembling different species or strains of *Pseudo-nitzschia*. Comparing the molecular probes developed on the West Coast to these four sequences revealed that the probes will not work and must be redesigned. The sequence information and clonal cultures I established are a strong starting point for the continued work on *Pseudo-nitzschia* in the Gulf of Maine.

Presenting my work during the Hollings Conference at NOAA headquarters in Silver Springs, MD went very well and sparked numerous comments and questions on this project over my time there. I really enjoyed working in the Anderson Lab this summer thanks to the amazing people there and knowing the importance of the project I was contributing to.

Theresa L. Smith
Hollings Scholar
University of Rhode Island

Advisor: Robert Weller, Upper Ocean Processes Group

NOAA Hollings Scholar Summer Internship

Related NOAA Strategic Plan Goal:

- Understand climate variability and change to enhance society's ability to plan and respond.
- Serve society's needs for weather and water information.



Theresa Smith during the
WHOTS 2006 cruise

Summary of Accomplishments

I had three major projects during my internship: 1.) Mooring Instrumentation Documentation, 2.) WHOI Hawaii Ocean Time Series (WHOTS) buoy recovery and deployment, and 3.) Web writer and editor for CICOR/WHOI Ocean Instruments Website. A side project was to learn data processing using Matlab for UOP telemetry team.

- Developed valuable skills in buoy recovery and deployment during the WHOTS 2006 aboard R/V Roger Revelle research cruise in the Pacific Ocean near the Hawaiian Islands.
- Helped write script using Matlab for an intercomparison exercise during the cruise which enabled scientists to plot real-time meteorological data from the buoy and the ship.
- Updated the mooring instrumentation database by weighing and measuring instruments and mooring assemblages, photographing them and collecting various specifications needed to construct deep ocean buoys for the UOP group. In addition, I designed a template which will be used to add more instruments to the database. This template was used to create a manual that could be published on the web in order to make WHOI mooring instrumentation information available to other scientists and engineers.
- Researched and wrote about each of the sensors which are a part of UOP group's Air Sea Interaction Meteorology ASIMET. Using a web development program and template provided by WHOI, I constructed "ASIMET Sensors" web page (see <http://www.whoi.edu/instruments/viewInstrument.do?id=14686#15226> and <http://www.whoi.edu/instruments/viewInstrument.do?id=12827>)
- Presented these achievements at the NOAA headquarters in Silver Spring
- Attended weekly UOP group meetings
- Attended WHOI Student Fellowship summer seminars
- Future presentation of this internship experience at a brown bag event where I am currently employed (Provincetown Center for Coastal Studies)

CICOR K-12 Outreach

CICOR has continued its commitment to K-12 educational outreach. The primary K-12 initiatives over the past year include: CICOR's support of a Harmful Algal Bloom multi-media display that has been built in the WHOI Exhibit Center which along with the WHOI Information Office serves more than 30,000 visitors each year. CICOR again sponsored an award for the Falmouth High School Science Fair held at Falmouth High School, Falmouth, MA in March 2006. The "CICOR Outstanding Project in the Marine Sciences" is awarded every year to a local high school student. In 2006, along with a certificate a cash award were presented to the winner to encourage the student to maintain their interest in marine science during their school years. CICOR is proud to have the opportunity to recognize the scientific potential of the youth of the local community. This year's recipient was Zacary Carman with a project on the marine nuisance species: genus didemnum, also known as colonial tunicate, ascidian, and sea squirts. The CICOR office continues to distribute the Teacher At Sea books, which were published in 2005 as well as host Teacher at Sea Program participants on CICOR-funded cruises. Later in this report more details are presented on this involvement and on CICOR-hosted visits from K-12 educators involved with the New Bedford Oceanarium.

In addition to the programming initiated by CICOR, many CICOR PIs initiate their own outreach efforts. We include here a sampling of these initiatives.

Rick Rupan who works with Breck Owens in the Argo Float Program took time off this summer to teach summer program students of the Center for Talented Youth (CTY) administered by Johns Hopkins University. He was the Instructor for the Flight Science class at the Washington College site in Chestertown, MA. At CTY he was able to connect his background as an aerospace engineering student and his work experiences with ocean sciences to provide students with broad range of topics from Newton's Laws and lift to buoyancy and boundary layer effect. He also spent time this summer teaching the Marine Electronics and Engineering class for the Children's School of Science in Woods Hole, MA. By the end of the class the students built and operated seven working remotely operated vehicles (ROVs) that can be used to do actual research.



A number of CICOR PIs are members of NE-COSEE. The New England COSEE seeks to strengthen the New England region's capacity to develop and provide high-quality ocean science

education in both formal and informal settings, by understanding the needs of, working with, and facilitating interactions among educators, researchers, and the public. For example, Al Plueddemann is a member of the NE-COSEE Science Advisory Group and has participated in several workshops geared towards K-12 Outreach.

Another example of NE-COSEE involvement is the active role that Alison MacDonald has taken in Ocean Science Education Institute (OSEI-II). She has been working with education professionals and, specifically teachers in Massachusetts New Bedford Global Learning Charter School. Here, she has been bringing physical oceanography concepts and the results of her own research (such as that described in the highlights for NOAA/CICOR grants 37122326 and 31722350) to middle school students, and participating in the larger effort to bring oceanography into Massachusetts' middle school curricula.

U.S. Research Vessel Surface Meteorology Data Assembly Center at Florida State University, Tallahassee, FL annually participates in the FSU Young Scholars Program, by sponsoring the research activities of 2 high school students. The YSP students spend six weeks on the FSU campus taking classes and conducting directed research. They have been involved in the YSP program since 1998.

New Bedford Oceanarium

In 2005-6 CICOR strengthened contacts with the New Bedford Oceanarium WOW Mobile (*WithOut Walls*) and its mission "To create an Oceanarium in New Bedford that will educate as it entertains, foster scientific research and awareness of our oceans, and generate jobs and economic development for Southeastern Massachusetts." The lead teacher of the program visited WHOI and was given a host of instruments and resources to include in the summer curriculum. Also, a group of 8 high school WOW Mobile staff visited CICOR and WHOI prior to beginning their summer hands-on responsibilities and were not only exposed to cutting edge research facilities, but also had time scheduled with WHOI/CICOR scientists.

Background:

The WOW MOBILE is a movable classroom operated by the New Bedford Oceanarium since Spring 2005. The truck has bright, colorful murals created by two exceptional New Bedford-area high school art students, Marcel Plante and Sarah Vieira. The foundation of WOW Mobile activities is to inspire a sense of *wonder, discovery, beauty, and adventure* and to encourage the idea that *science can be interesting, creative, tangible, and fun*.



In 2005, the WOW Mobile programs focused on marine biology and met many of the Massachusetts Curriculum Standards, not just the Science and Technology Standards. The 2005 summer program ran for eight weeks, with approximately 2500 participants at 64 venues. These included Summerfest, summer camps, the Boys & Girls Club of Greater New Bedford, and CS2 (Communities & Schools for Career Success) at New Bedford High School.



Since April 2006, the WOW Mobile staff has developed and delivered several hands-on marine science activities that are directly linked to the Massachusetts Science Curriculum Frameworks. Near the end of the 2005/2006 academic year, the WOW Mobile made initial visits to several New Bedford Public elementary schools and began pilot work with the New Bedford Public School's Sea Lab Program.

During the summer of 2006, the WOW Mobile ran weekly programs at the New Bedford YMCA, the Boys & Girls Club of Greater New Bedford, Wareham Recreation Department, and for the Mass. Migrant Program in Fall River, MA. It also spent Wednesdays at the Buttonwood Park Zoo and Saturdays at Clasky Park Farmers Market.

Over 3500 visitors were exposed to the WOW Mobile and marine science this summer.

In Fall 2006, the WOW Mobile staff will deliver five different Science and Technology standards-based single lesson programs from the grades 3-5 Massachusetts curriculum frameworks over a five-week cycle to participating classrooms. Classroom teachers will also be supplied with activities to further enhance and reinforce the lessons delivered by the WOW Mobile staff. The five programs developed will focus on: (1) Using maps and mapping to study nature and geology, (2) The Water Cycle and the SouthCoast, (3) Food Chains and Food Webs, (4) Variations in Nature: Adaptations and Survival and (5) Change and Invasive Species. The WOW Mobile Programs will provide creative ways to introduce these critical science concepts to students in lower grades.

The educational capabilities of the WOW Mobile are endless. With the ability to bring hands-on programs to a classroom, the WOW Mobile can address areas of high need such as Life Science and Earth Science. The goal of the WOW Mobile staff is to continue developing and delivering valuable marine science curriculum in classrooms throughout Greater New Bedford while providing informal science education during the summer and through after school programs.

Teacher At Sea Program Involvement

Two Teachers at Sea participated on CICOR – funded cruises during the 2005-06 funding period. Eric Heltzel who teaches oceanography and meteorology in Wyoming joined the Stratus cruise which went through the Panama Canal and traveled to the coast of Chile where the Stratus buoy was recovered and a new one deployed.

The teachers in this program are responsible for providing daily logs which get posted to a NOAA Teacher at Sea website. Eric's final log included the following:

Log 17

NOAA Teacher at Sea: Eric Heltzel

NOAA Ship RONALD H. BROWN

Mission: Stratus 6

Wednesday, October 19, 2005

Personal Log

Sailing on the RONALD H. BROWN as a NOAA Teacher at Sea has been an opportunity to experience scientific research first hand. I have been impressed by the commitment to excellence exhibited by all members of the scientific teams. They have undertaken the design and logistical challenges of the Stratus 6 cruise with great attention to detail, absolute commitment to execution of the plan, and countless hours of effort. Tasks were carried out with a high degree of professionalism and in good humor. The officers and crew of the BROWN were not only generous and considerate, but they were also very competent. People knew their jobs and did them without complaint. There seems to be an enthusiasm for the research that the ship facilitates. Throughout the cruise I felt confident that the ship was in good hands. Going to sea for the first time has been a challenge for me. As with many things that push us outside our comfort zone and away from the familiar, learning is fast paced and intense. This will be my last log from the RONALD H. BROWN. I wish to thank the Teacher at Sea program of NOAA for making this experience possible. Thanks to Captain Tim Wright and the officers and crew of the BROWN for helping this previously land-locked teacher from Wyoming have a great experience. Special thanks to Dr. Bob Weller and the team from Woods Hole Oceanographic Institution for taking me under their wings and answering my numerous questions. Thanks to Peggy Decaria for substituting for me in my classes at Evanston High School. I never would have been able to have this experience if not for the support of Superintendent Dennis Wilson and all of Uinta County School District #1. I'm going back to school with a rich experience to share, new resources to facilitate my teaching, and many new ideas. Thanks to you all.



In a recent e-mail Eric reflected on his experience:

The fall of 2005 found me aboard the RONALD H. BROWN, a NOAA research vessel. I had been invited as a Teacher At Sea to join the Stratus VI cruise, a venture headed by Bob Weller of Woods Hole Oceanographic Institution. I joined the cruise in Miami Beach, sailed across the Caribbean, through the Panama Canal and on to the research site at 20 degrees south, 85 west. Here we replaced the buoy and instrument packages. I teach Oceanography and Meteorology in

Wyoming, rather far from the ocean. This first hand experience has helped me bring relevance and credibility to my classroom. Weller's Wood's Hole team was awesome and the NOAA crew terrific as was my experience aboard ship.

Diana Griffiths , a classroom teacher in Pennsylvania participated on the two week Hawaii Ocean Time Series cruise, HOTS with the WHOI Upper Ocean Processes group, lead by Weller along with scientists from other institutions. In day three of her personal log Ms. Griffiths wrote:

NOAA Teacher at Sea: Diana L. Griffiths

UNOLS Ship ROGER REVELLE

Mission: Recovery of WHOTS-2 mooring and deployment of WHOTS-3 mooring

Day 3: Friday, June 24, 2006

Time: 1800

Weather Data from Bridge

Visibility: 10 miles to less than 25 miles

Wind direction: 065°

Wind speed: 06 knots

Sea wave height: small

Swell wave height: 4-6 feet

Sea level pressure: 1014.5 millibars

Cloud cover: 3, type: stratocumulus and cumulus



Recovery of WHOTS 2 buoy aboard R/V Revelle

Personal Log

The theme that keeps going through my mind during this trip and today especially, is how much of a cooperative effort this research requires. It begins with the coordination between Dr. Weller and Dr. Lukas to simultaneously collect atmospheric data using the buoy and subsurface data with the mooring instruments. In addition, Dr. Frank Bradley, an Honorary Fellow at the CSIRO Land and Water in Australia, is on the cruise working to create a manual set of data points for relative humidity using an Assman psychrometer to further check the relative humidity data produced on the buoy. Within the science teams, coordination has to occur at all stages, from the collection of data to its analysis. This was very evident in physical form today with numerous people on deck throughout the day working to retrieve the mooring, fix machinery as it broke down (the winch stopped twice), and clean the instruments. In the labs, others were working to upload data and configure computer programs to coordinate all of the data. In addition to all of this is the quiet presence of the ship's crew who are going about their duties to be sure that the ship is running smoothly.

CICOR Workshops and Meeting Support

During the last year CICOR was involved with three multi-day meetings. Below a synopsis of the meetings and related outreach activities is described:

The Role of the Role of The Indian Ocean On Climate: A Seminar Series

CICOR co-sponsored the series with WHOI's Climate Change Institute August 8 – 19, 2005. The rationale that led to the development of the workshop was that recent research indicates that the Indian Ocean impacts climate around the globe, including the widespread drought from 1998-2002 in the US, southern Europe, and parts of Asia. This realization of the importance of the Indian Ocean to remote climate variability has coincided with a renewed interest in pushing ahead with multinational observing and research efforts in the Indian Ocean. It is timely to catalyze at WHOI and in the United States a dialog about the research and observing systems that would be most effective for developing a better understanding and predictive capability of the coupled ocean-atmosphere variability in the Indian Ocean. This seminar series brought to WHOI world-renowned experts on Indian Ocean oceanography, meteorology, paleo-oceanography, the societal impacts of Indian Ocean variability, and the value to society of improved understanding of the role of the Indian Ocean in climate. Seminar participants were at WHOI during the dates outlined below. Each guest presented at least one seminar, lead one coffee hour and was available to meet with interested staff. Guest speakers included:

- Prof. Toshio Yamagata, Aug. 5 – 12, JAMSTEC & Professor, University of Tokyo
- Prof. Roger Lukas, Aug. 5 – 13, Department of Oceanography, University of Hawaii
- Dr. Stuart Godfrey, Aug. 5- 23, CSIRO Marine Research, Hobart, Australia
- Dr. Chris Charles, Aug. 13 – 19, Assoc. Professor, Geosciences Res. Division, Scripps
- Dr. Markus Jochum, Aug. 15 – 19, National Center for Atmospheric Research
- Dr. Lisan Yu, PO Department, WHOI

Quality Assurance and Real Time Oceanographic Data (QARTOD) IV

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. QARTOD IV was held at the Woods Hole Oceanographic Institution, June 21 - 23, 2006. Related materials are posted on the QARTOD website: <http://qartod.org>.

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. The CICOR office was instrumental in coordinating the facilities and arrangements for the workshop as well as providing some salary support for group facilitators.

OceanSITES Data and Science Team Meeting

Honolulu, HI

16-19 February, 2006

The NOAA Office of Global Programs provided support through CICOR for the OceanSITES Data and Science Steering Teams meeting in Hawaii in February, 2006. The OceanSITES effort is an international collaboration to plan and coordinate the establishment of a global array of open ocean time series sites. The Data Team is working to establish a common data format and an open archive of all OceanSITES time series. The Science Steering Team is working to identify key locations for time series stations, document the goals and value of long term occupation of these sites, and follow through on seeing the utilization of the resulting data for diverse uses. Members of these teams find support for their time, but are greatly aided by having travel support. This NOAA funding provided travel support for some members of the teams who would have otherwise been unable to attend.

In addition to the travel support, the CICOR office contributed significant support to the publication of a brochure highlighting the OceanSITES Initiative as well as in the redesign and publication of an updated OceanSITES website: oceansites.org. A clip of the home page of the site is provided below. Over 1500 copies of the brochure have been shipped to key people in this country and abroad.



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Putting eyes and ears in the deep ocean

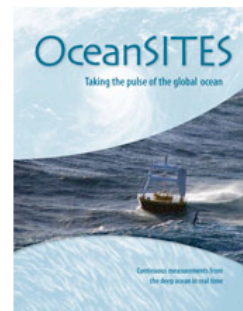
OceanSITES is a worldwide system of long-term, deepwater reference stations measuring dozens of variables and monitoring the full depth of the ocean from air-sea interactions down to 5,000 meters.

Since 1999, the international OceanSITES science team has shared both data and costs in order to capitalize on the enormous potential of these moorings. The growing network now consists of about 30 surface and 30 subsurface arrays. Satellite telemetry enables near real-time access to OceanSITES data by scientists and the public.

OceanSITES moorings are an integral part of the Global Ocean Observing System. They complement satellite imagery and ARGO float data by adding the dimensions of time and depth.

For more information or to coordinate your research with the OceanSITES program, please contact the NOAA Cooperative Institute for Climate and Oceans Research at the Woods Hole Oceanographic Institution:
cicor@whoi.edu

News:



OceanSITES Brochure

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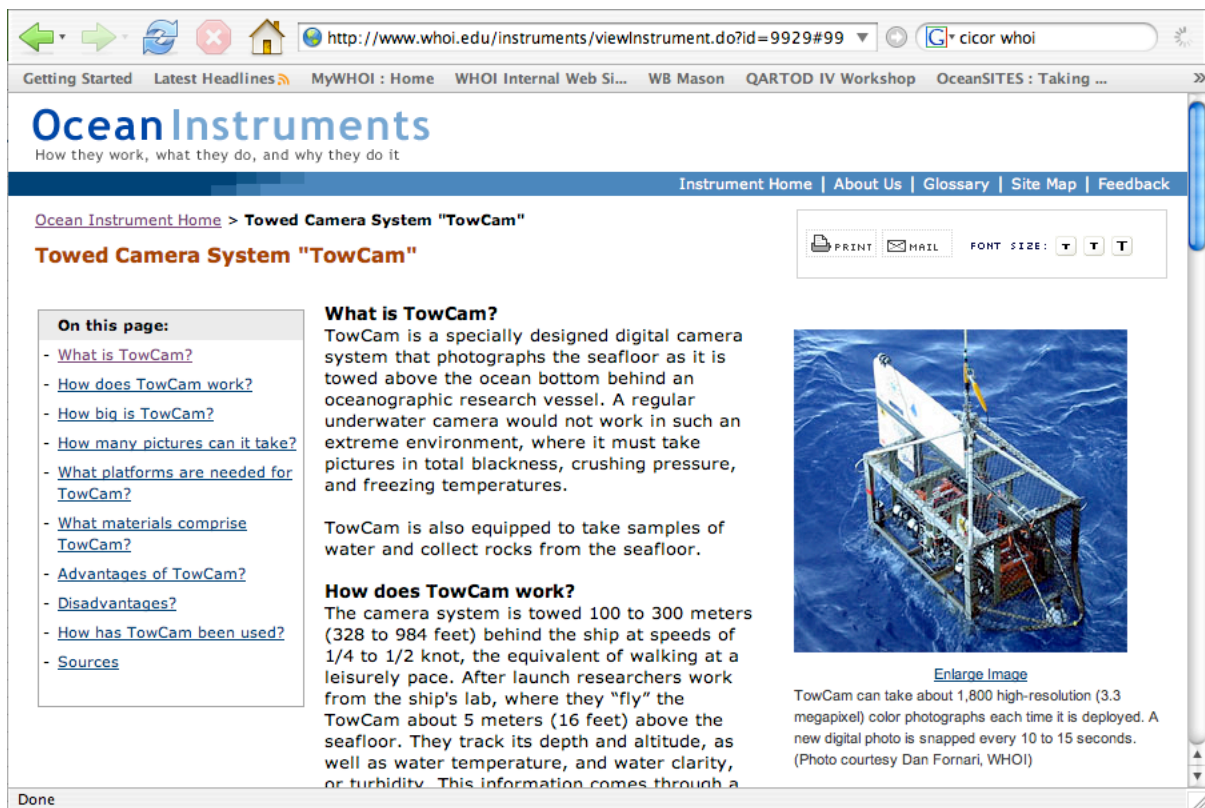
**Quality Assurance of
Real-Time**

Oceanographic Data

Ocean Instruments Web Site

In collaboration with WHOI's Center for Ocean, Seafloor and Marine Observing Systems (COSMOS), CICOR is now the home of the Ocean Instruments web site developed with funding from the Arthur Vining Davis Foundations. The web site is an informative educational and outreach tool that highlights the instrument and platform technologies currently used in oceanography.

The site, developed by WHOI to enhance undergraduate education efforts in the ocean sciences, features text, images, diagrams and background information about ocean sampling, instrumentation and platforms. After advisory meetings with undergraduate professors the site was formed with the input from scientists and engineers, and tested with students, potential users and potential contributors. Although it was designed with undergraduates in mind, it can be and is used by the general public, policy makers and journalists. The site provides links to glossaries and multimedia technologies including video streaming, audio packages, and searchable databases. Even without wide publicity the traffic at the site has been significant, (as high as over three thousand hits a month). The internal community has begun to use the site as a depository for technical notes on specific instrumentation. The current location is: <http://www.whoi.edu/science/instruments/>



The screenshot shows a web browser window displaying the Ocean Instruments website. The browser's address bar shows the URL <http://www.whoi.edu/instruments/viewInstrument.do?id=9929#99>. The website header includes the title "Ocean Instruments" and the tagline "How they work, what they do, and why they do it". A navigation menu contains links for "Instrument Home", "About Us", "Glossary", "Site Map", and "Feedback". The main content area is titled "Towed Camera System 'TowCam'" and includes a "PRINT" button, a "MAIL" button, and a "FONT SIZE" selector. On the left, a "On this page:" section lists several links: "What is TowCam?", "How does TowCam work?", "How big is TowCam?", "How many pictures can it take?", "What platforms are needed for TowCam?", "What materials comprise TowCam?", "Advantages of TowCam?", "Disadvantages?", "How has TowCam been used?", and "Sources". The main text area contains three sections: "What is TowCam?" which describes the system as a specially designed digital camera system towed behind a research vessel; "How does TowCam work?" which details the towing process and data collection; and a partially visible section. To the right, there is a photograph of the TowCam system being towed by a ship, with a caption that reads: "TowCam can take about 1,800 high-resolution (3.3 megapixel) color photographs each time it is deployed. A new digital photo is snapped every 10 to 15 seconds. (Photo courtesy Dan Fornari, WHOI)".

Annual Research Summaries

The following pages represent summaries of the science research projects that were undertaken through CICOR from July 1, 2005 through June 30, 2006. Some of these projects were continued from the previous year, others were new. Two projects, though funded for this year, will be reported on in September 2007.

Specifically, these are:

1. Robert Pickart's project "Dynamics of the Flow of Pacific Water Through the Western Chukchi: Analysis of the 2004 RUSALCA Herald Canyon Hydrographic Data" funded by NOAA's Arctic Research Office, (Dr. John Calder, Program Manager). Dr. Pickart was away on sabbatical during the 05-06 academic year and anticipates completing this work in the Fall of 2006. The funding for this project has been incorporated into the totals for this year.
2. Drs. Timothy Stanton and Dezhang Chu's project entitled "Broadband Discrimination" funded by NMFS, (Dr. J. Michael Jech, Program Manager). Although CICOR set up an account for pre-spending in June, the funding from NOAA did not arrive until July. Therefore, the project will be incorporated in the September 2007 financial and scientific reporting.

A note on the reporting conventions: Each project is given an account number within the CICOR grant at WHOI. Because this number is of use to WHOI we have included a reference to it in the following reports. Until this year, it was sufficient to include only the last two digits, because all CICOR reports have here-to-fore begun with: 371223XX. Recently, however, CICOR accounts have extended past one hundred. Therefore, we have begun to refer to the accounts by the last three digits. Whether 2 or 3 digits, all reports included here are among the first 100 CICOR projects. (We do not want to leave readers with the impression that there are over three hundred projects.)

The following reports represent the work of over 100 scientists and their research and support staff and span CICOR's three themes. Although there is a heavy concentration in climate research, the ecosystems and coastal research is playing a growing role in CICOR's portfolio of research that is designed to address NOAA's goals and missions.

U.S. PROGRAM IN MARINE BIOTOXINS AND HARMFUL ALGAE

NOAA Cooperative Agreement No. NA17RJ1223 sub-points 09, 10, 11, 36 and 88
July 1, 2005 through June 30, 2006

Dr. Donald Anderson

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

Program Manager: Dr. Quay Dortch, Ms. Susan Banahan, 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. This office is a critical coordination component of the national program for marine biotoxins and harmful algal blooms (HABs), an expanding program that encompasses initiatives ranging from the Ecology and Oceanography of HABs (ECOHAB), Monitoring and Event Response for HABs (MERHAB), two programs on Oceans and Human Health (OHH) involving HABs, and several other ongoing or planned initiatives. The primary objectives for the National Office are to provide organizational and informational support to the academic HAB community and to provide technical support to the HAB management community.

ACCOMPLISHMENTS

- The Marine Biotoxins and Harmful Algal Blooms webpage (<http://www.whoi.edu/redtide>) is a critical resource for the U.S. HAB community. The National Office continued to expand the contents and update information to reach an ever-widening audience of HAB researchers and students. The website includes reports of marine HAB outbreaks, recent publications, new research methodologies and developments, funding opportunities, links to related HAB sites etc.
- Another activity in this regard is the creation and 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. We also continue to update and maintain a listserver for the International Society of the Study of Harmful Algae (ISSHA).
- The National Office provided significant assistance with the organization of the 3rd U.S. HAB Symposium, held October 2-7, 2005 in Monterey, California. Efforts included assistance with fundraising, compiling abstracts for oral presentations and posters; program development, obtaining funding for travel awards for students and Postdocs, reviewing applications, and making and processing subsequent awards. We also maintained the

website for the symposium and disseminated information to the US HAB community and other interested groups. Planning is underway for the 4th US HAB Symposium which will be held in Woods Hole in late 2007. The National Office will, once again, coordinate this effort.

- 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 2006 ICES Working Group on Harmful Algal Bloom Dynamics, held in Gydnia, Poland. 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 domoic acid event in Oregon, a fish-killing *Karenia brevis* bloom in Texas, and one in Florida.
- The National Office is supporting the newly formed National HAB Committee (NHC) which will oversee coordination and implementation of the new US National Plan for HABs. The goals and responsibilities of the NHC are to: raise the visibility and understanding of HAB issues nationally; garner support for the new national HAB plan among users, researchers, and agencies; and interface with related national and international initiatives, form *ad hoc* technical advisory committees, as needed, to address issues or requests. The initial tasks of the committee will be to procure funding for future meetings of the NHC, to organize and convene an Implementation Plan workshop, and to establish and maintain a web presence.
- 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 12th International Conference on Harmful Algal Blooms (Steering Committee member; Copenhagen, September 2006); 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, and a on “*Intercalibration Workshop on New and Classic Techniques for the Determination of Numerical Abundance and Biovolume of HAB-species*”.
- 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, an Estuarine Research Foundation workshop, the IOC Phytoplankton course, the 3rd US HAB symposium, and the 12th International HAB Conference on Harmful Algal Blooms.

PUBLICATIONS

Anderson, D.M. 2006. The ecology and oceanography of harmful algal blooms: multidisciplinary approaches to research and management. Anton Bruun Memorial Lecture, Intergovernmental Oceanographic Commission, UNESCO, Paris. (in press.)

Anderson, D.M and J.L. Kleindinst. 2006. Development of a new HAB National Plan for the United States: Rationale, process, and product. pp. 6-11, in: *Key Research Findings to Harmful Algal Blooms in the South China Sea. Proceedings of the (3rd) International Conference on the Prevention and Management of Harmful Algal Blooms in the South China Sea*, Ho, K.-C., .S.-H. Lu, Y. Wang, and J.-F. Chen (eds.), The Association on Harmful Algal Blooms in the South China Sea.

Anderson, D.M. and J.S. Ramsdell. 2005. HARRNESS – a framework for HAB research and monitoring in the United States for the next decade. *Oceanography* 18(2): 238-246.

Ramsdell, J.S., D.M. Anderson, and P.M. Glibert (Eds). HARRNESS. 2005. Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015. Ecological Society of America, Washington, DC, 96 pp.

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, and so forth. We also work with this program in administering rapid response funds for HAB events throughout the country.

The National Office worked closely with the Center for Coastal Environmental Health and Biomolecular Research (CCEHBR), Charleston Laboratory, on a revision of the National Plan, “HARRNESS. *Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015*”.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

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.

We also distribute many reports and publications, including Proceedings from the various international HAB conferences, *Monitoring and Management Strategies for Harmful Algal Blooms in Coastal Waters* (published by APEC and IOC), *The Ecology and Oceanography Of Harmful Algal Blooms: A National Research Agenda*, *Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States*, and other reports.

RESPONSE TO THE NEW ENGLAND RED TIDE OF 2005

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 69
July 1, 2005 through June 30, 2006

Dr. Donald Anderson

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

Program Manager: Dr Quay Dortch, Ms. Susan Banahan, 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

In May and June 2005, a massive “red tide” of the toxic dinoflagellate, *Alexandrium fundyense*, occurred in New England. This bloom, the worst since 1972, caused extensive shellfish closures in state waters of Maine, New Hampshire and Massachusetts and offshore federal waters and garnered nationwide media attention.

Timely cell count information proved to be extremely useful to state managers in their efforts to monitor the 2005 New England red tide and to protect public health through shellfish closures. A primary goal of this project is to determine the number of cells that are transported into southern New England waters from the Gulf of Maine (GOM), potentially affecting Massachusetts Bay as well as the offshore (federal) shellfish resources. The latter are now closed over a 15,000 square mile area, and can only be reopened if data indicate that the resource will be safe. By occupying transects that we have been sampling throughout this event in the northern portions of Massachusetts Bay, we will be able to provide information of value not only to the state, but to the federal government (FDA, NMFS) as well. Samples will be processed and cells enumerated using newly developed, highly specific molecular methods. The results will be communicated rapidly to all relevant state and federal officials.

Throughout this bloom, tremendous numbers of samples (both for cell counts and nutrients) have been collected. Likewise, ADCP data and CTD data have been collected on every cruise. These data will be compiled, quality controlled, and plotted to reveal the patterns underlying this bloom, for example to determine the role of weather, freshwater and nutrient input in causing the bloom. Additionally, data reduction and analysis are intended to bring the information to the level where it can ultimately be incorporated into the predictive models that have been developed for *Alexandrium* blooms in the region.

The production of cysts are one important aspect of the life cycle of *A. fundyense* that has important implications with respect to future bloom events, and management strategies to deal with those blooms. The cyst stage allows the species to remain dormant in bottom sediments through adverse conditions. Cysts are important in bloom initiation, regulating both the size of the initial cell inoculum in surface waters and the location of those blooms, but it also allows the species to disperse and colonize new areas. Given the extremely high cell concentrations

observed during the 2005 bloom, there is now a concern that many cysts will have been dropped to bottom sediments to colonize southern New England waters that have historically been virtually free of cysts of these species. We hypothesize that these newly deposited cysts will change bloom dynamics in future years, serving as a major seedbed for blooms and increasing the likelihood of subsequent paralytic shellfish poisoning (PSP) outbreaks within Massachusetts, Cape Cod and Buzzards Bays, as well as in waters west and south of Cape Cod. In effect, the 2005 bloom may have been the “next” step in the southward expansion of the New England PSP problem, which began when a massive 1972 bloom introduced the organism into western GOM waters, leading to recurrent outbreaks over the ensuing decades.

The second major objective of the project is to document the cyst “footprint” of the 2005 New England red tide and to investigate the role that new cyst deposits play in the initiation of toxic blooms in southern waters. Specific project tasks are to: 1) Map *A. fundyense* cysts in bottom sediments of a broad region from the waters south of Nantucket Island to the Bay of Fundy, 2) Compare this cyst distribution with that mapped in 2004 to ascertain the changes that have occurred regionally following the 2005 bloom season; 3) Examine the time course of cysts deposited in sediment traps deployed by the USGS in Massachusetts Bay during 2005; 4) Working closely with state managers, investigate the extent to which newly germinated cysts contribute to blooms within Massachusetts, Cape Cod, and Buzzards Bays, and potentially to toxicity in deeper waters far to the south of Nantucket and Martha’s Vineyard; and 5) Assess the overall likelihood of recurrent, self-seeding blooms in Massachusetts, Cape Cod, and Buzzards Bays.

ACCOMPLISHMENTS

1. *Response to the 2005 Alexandrium fundyense Bloom*

Multiple cruises were completed on the R/V *Tioga* and R/V *Gulf Challenger* during late May-July 2005 in response to the *Alexandrium fundyense* bloom that was initially discovered during a 11-day cruise on the R/V *Oceanus* in early May (Figure 1). Over 1200 samples were collected and analyzed using a whole cell (WC) molecular probing technology (i.e., cells hybridized and microscopically visualized with a fluorescently-labeled oligonucleotide probe). The 2005 cell and hydrographic data are being distributed to collaborators in both research and management for interpretation. To facilitate that task, a website is now in place and it is constantly updated with new data that illustrates the cell and hydrographic contours for each cruise (data from late June/July cruises will be posted soon). See http://science.whoi.edu/users/olga/alex_surveys_2005/WHOI_Alexandrium_Surveys_2005.html.

Preliminary results from the 2005 bloom have been published (Anderson et al., 2005). As more preserved WC count data became available, the results generally confirmed the earlier live count observations from the surface (up to about 40,000 cells/L) and also revealed that the *A. fundyense* population extended to at least 20m in the water column, mostly confined to the less-saline waters (<32 PSU) of the Gulf of Maine. At one station east of Cape Cod at 10m, >140,000 cells/L were recorded at the peak of the bloom when toxicity expanded into southern New England south of Martha’s Vineyard (MV). This extremely high abundance may be due to the local dynamics near the Nauset Inlet on Cape Cod, an area of relatively high and frequent shellfish toxicity combined with the large-scale GOM distribution. Later in the bloom season (late June), high abundances (10,000 cells/L) were sometimes observed

much deeper in the water column than earlier in the bloom, while the surface waters were relatively low. This dynamic occurred both offshore of Massachusetts Bay and south of MV. Thus, the recent results suggest a general progression of the peak abundance down into the water column with the duration of the bloom. That dynamic is currently a topic for further investigation. The high abundances observed in the bloom of 2005 were a combination of several factors: high cyst abundance (see below), strong downwelling-favorable winds, and relatively high freshwater runoff that stratify the water column and deliver nutrients for growth. While only the macro-nutrients were measured during the surveys, high runoff can also add micro-nutrients and organics to the system. The relative contribution of these factors is currently being examined using coupled biological-physical models in collaboration with the laboratories of Dennis McGillicuddy and Ruoying He. Preliminary model results indicate that the high abundance of benthic cysts that supply the initial inoculum to the water column and the winds are the two most important factors that led to the 2005 bloom.

2. *Map the distribution of cysts following the bloom and compare to earlier cyst surveys*

As noted above, the cyst stage has important implications for bloom initiation, termination, and species dispersal. To fulfill the second objective of the project, two benthic cyst surveys (one in the Gulf of Maine on R/V *Oceanus* and one south of MV and east of Nantucket) were completed in the fall of 2005 to determine the “footprint” of the 2005 spring/summer bloom due to the deposition of new cysts. Currently, surface sediment samples from the top 1cm have been completed and additional samples from just below the 1cm superficial layer are now being counted as well. The results are being compared to earlier large-scale cyst surveys in the Gulf of Maine (from the Fall of 1997 and 2004), each covering hundreds of km in the alongshore direction and reaching 50 – 100 km offshore.

The first survey (in 1997) revealed a widespread cyst distribution, with two centers of abundance, one in the Bay of Fundy, and a second offshore of Casco and Penobscot Bays in western Maine. The second survey (2004) shows a much larger cyst population, with approximately 10x as many cysts in the western Maine seedbed area, and no significant change in Bay of Fundy cyst abundance. This was the cyst distribution that preceded, and undoubtedly contributed to, the massive 2005 *A. fundyense* bloom in southern New England. The third cyst survey was conducted after the 2005 bloom, and revealed no change in cyst abundance in the Bay of Fundy once again, and levels of cysts in western Maine that were 5X the 1997 levels, and 50% lower than the 2004 levels. No significant geographic expansion of cysts into southern waters was observed, as had been feared based on the high cell concentrations that occurred in those waters during the 2005 bloom. Computer simulations revealed the relative importance of the Bay of Fundy vs. Casco/Penobscot Bay seedbeds, highlight the importance of the size of the overall cyst seedbed in the magnitude of subsequent blooms, and suggest mechanisms for formation of the seedbeds. Based on these observations, we hypothesize that southern New England may have entered a “new regime” in which PSP toxicity will be high and frequent in the coming years. The cyst maps were released to the press and collaborators as soon as the top 1cm contours became available. See figure 2 below and the press release at: <http://www.whoi.edu/mr/pr.do?id=11987>

3. *Response to the 2006 Alexandrium fundyense Bloom*

In anticipation of another potential outbreak in 2006, seven cruises were scheduled on the R/V *Tioga* sampling the Massachusetts Bay region with assistance for additional sample

collection provided by the Center for Coastal Studies at Provincetown, MA and the University of New Hampshire to extend the coverage to the north and southeast of the study domain. As the bloom progressed, an 11-day, large-scale cruise on the R/V *Oceanus* was added in June, expanding the measurements into the Gulf of Maine and providing broader geographical comparisons with model simulations.

Based on the available live count data from onboard measurements, the 2006 bloom in southern New England was generally not as intense as in 2005 (2000-3000 cells/L in 2006 vs >10,000 cells/L in 2005), but relatively high cell abundances and associated shellfish toxicity were detected in Massachusetts Bay for the second year in a row (Figure 3). That scenario has not happened since 1989-1990, supporting the accumulating evidence for a “new regime” and substantiating the link with relatively high cyst abundances still remaining in the Gulf of Maine. Furthermore, the bloom was transported into the nearshore waters of Massachusetts Bay in two pulses (one in early May detected by the *Tioga* cruises and one in early June detected during the *Oceanus* cruise) following downwelling-favorable wind events, a critical factor identified for the 2005 bloom. The highest abundances in 2006 were measured on the *Oceanus* cruise with abundances in the thousands/L in the western Gulf and nearing 10,000 cells/L on the northwestern flank of Georges Bank suggesting that continued offshore shellfish closures were justified. Indeed, yet another cruise on EPA’s vessel (OSV *Bold*) in July 2006 detected *Alexandrium fundyense* populations >1000 cells/L and shellfish toxicity off of Nantucket Shoals. During the course of the bloom, timely cruise results were provided to resource and water quality managers via a Listserver that was established specifically to enhance communication during bloom events. Preserved WC samples from this effort are now being counted with the cell and hydrographic data posted as it becomes available to the following Website address:

http://science.whoi.edu/users/olga/alex_surveys_2006/WHOI_Alexandrium_Surveys_2006.html

In collaboration with Ruoying He and Dennis McGillicuddy, the cyst distribution data (with the lab-derived germination rates) from 2005 have now been used as initial input into coupled biological-physical models to simulate the 2006 bloom dynamics in near real time. The 2006 cell and hydrographic observations will be used to verify the results of those simulations. The preliminary model/data comparisons are available at: http://science.whoi.edu/users/ruoying/Redtide_06/

FIGURES AND IMAGES

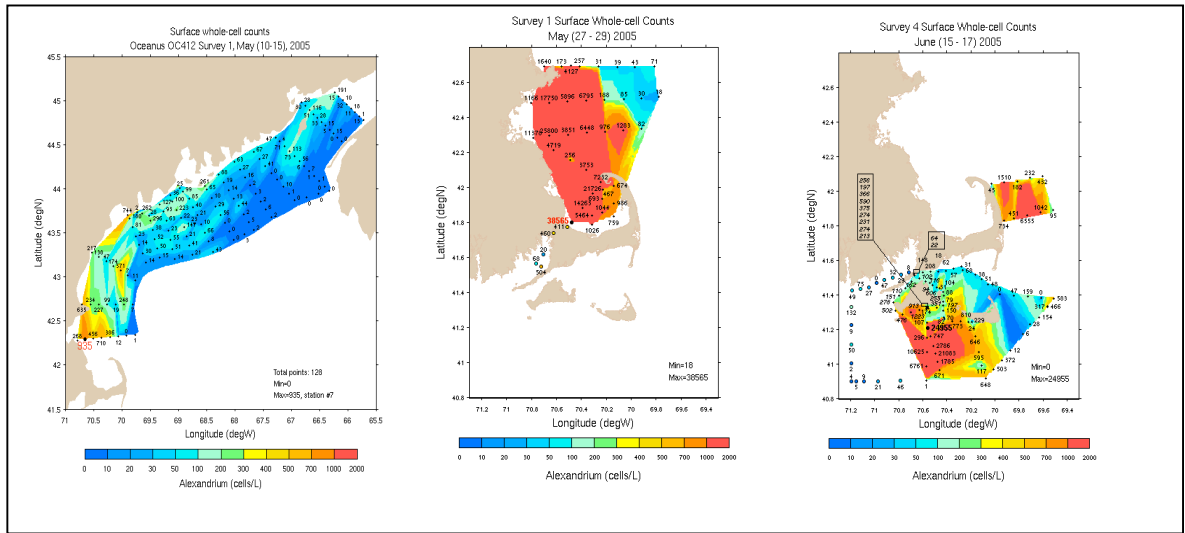


Figure 1. Progression of the 2005 *Alexandrium fundyense* bloom in southern New England. Left panel shows early detection of high *Alexandrium fundyense* populations (1000 cells/L) in Massachusetts Bay in early May prior to shellfish toxicity detection in the southern region. Mid-panel shows the highest concentrations (>10,000 cells/L) that developed within Mass Bay during the outbreak of shellfish toxicity at the end of May. Right panel shows the bloom progression (10,000 cells/L) south of Cape Cod during June that presumably developed due to transport from populations north of Cape Cod.

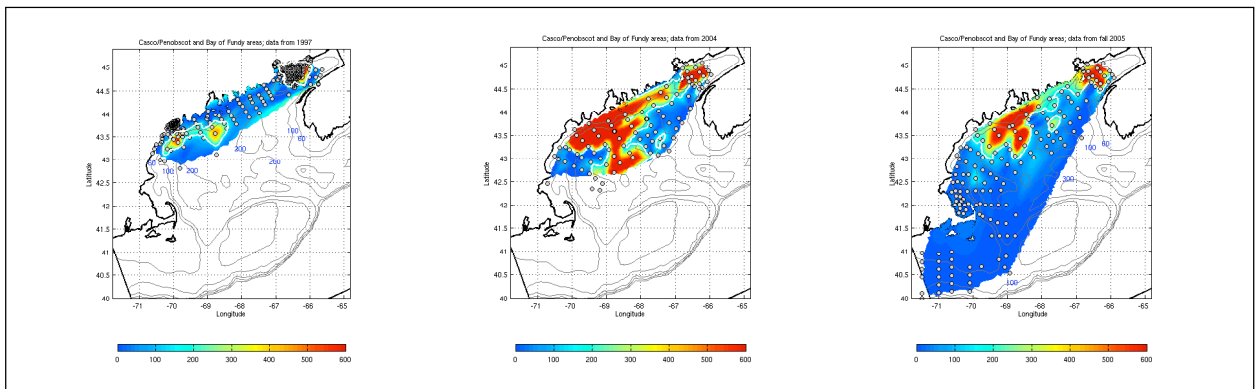


Figure 2. Maps of *Alexandrium fundyense* cyst abundance in surface sediments of the Gulf of Maine. The warmest colors (reds and yellows) denote the highest concentrations. Note the changes in cyst abundance in the region during the last decade. In 1997, cyst abundance was very low compared to the levels measured in the fall of 2004, preceding the spring/summer bloom of 2005. Following that bloom, cyst numbers in the Fall of 2005 were still very high compared to 1997 levels, but are approximately 1/2 those in 2004. Note that the 2005 map extends into the waters south and east of Cape Cod, areas underlying the southern extent of the bloom. That area was not covered in the earlier surveys and did not contain high cyst abundances.

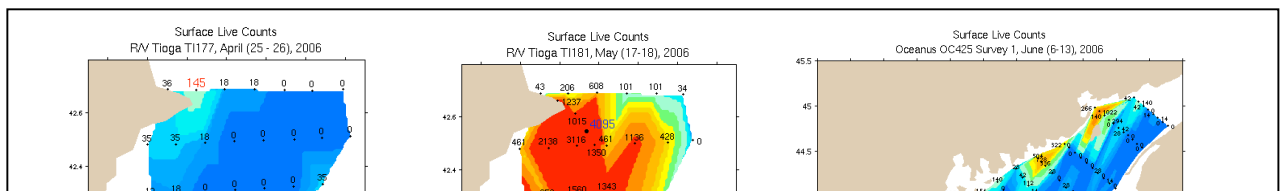


Figure 3. Progression of the 2006 *Alexandrium fundyense* bloom in southern New England. Based on preliminary onboard live count data, the first pulse of toxic cells into Massachusetts Bay during the 2006 bloom occurred in late April (left panel) and developed into a significant population (2000-3000 cells/L) by mid-May (middle panel). The large-scale distribution of the *A. fundyense* population sampled later in June indicated that the population was widespread in the Gulf of Maine and Bay of Fundy, but mainly concentrated in the western Gulf of Maine (2000-5000 cells/L) with the leading edge entering Massachusetts Bay in a second pulse. High concentrations (10,000 cells/L) were also observed offshore on Georges Bank (to the southeast of the region shown here).

PUBLICATIONS

Anderson, D.M., B.A. Keafer, D.J. McGillicuddy, M.J. Mickelson, K.E. Keay, P.S. Libby, J.P. Manning, C.A. Mayo, D.K. Whittaker, J.M. Hickey, R. He, D.R. Lynch, and K.W. Smith. Initial observations of the 2005 *Alexandrium fundyense* bloom in southern New England: General patterns and mechanisms. *Deep-Sea Res. II* 52(19-21): 2856-2876.

SUMMARY OF INTERACTION WITH NOAA

Attendance at one day workshop on the New England Red Tide Bloom at NOAA/NEFSC Woods Hole, Sept. 2005 hosted by Kevin Chu (NOAA).

Participated in a Joint NOAA/EPA cruise with Kevin Chu, chief scientist on the EPA vessel OSV *Bold*. The objectives were to determine shellfish toxicity levels in the offshore resources of the state and federally managed areas shut down during the 2005 bloom. The WHOI group provided onboard support for toxic phytoplankton/cyst collection and enumeration.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

We have sponsored five Northeastern undergraduate students as interns in our laboratory during this period – they have all contributed to this project by participating in field work, processing

and analyzing samples, and helping to work up the data. In addition, several undergraduate and graduate students (Northeastern, MIT/WHOI) have participated in the R/V *Oceanus* and *Tioga* cruises.

We have created a website for New England PSP information where we post cruise observations, cell count maps, drifter tracks, etc.-

<http://www.whoi.edu/sbl/liteSite.do?litesiteid=3230>

Presentations/Professional talks by D.M. Anderson:

- 08/05 The 2005 New England red tide: Future prospects. Massachusetts Bay Outfall Monitoring
Scientific Advisory Panel (OMSAP) briefing. Duxbury, MA.
- 11/05 The 2005 New England red tide. Pleasant Bay Alliance, Chatham, MA.
- 02/06 Paralytic shellfish poisoning and “red tides” in the Gulf of Maine: present status and future prospects. Seminar, UMASS, Dartmouth.
- 02/06 The 2005 New England red tide. North and South Rivers Watershed Association, Norwell, MA.
- 03/06 Paralytic shellfish poisoning and “red tides” in the Gulf of Maine: present status and future prospects. Maine Fisherman’s Forum, Rockport, ME.
- 04/06 Overview of the 2005 *Alexandrium* bloom: A regional perspective. MIT Sea Grant, Cambridge, MA.
- 05/06 The 2005 New England red tide: mechanisms and implications for the future. New England Shellfish Sanitation Association annual meeting, Port Jefferson, NY.

Presentations/Professional Talks by B.A. Keafer

- 04/06 Initial Observations of the 2005 *Alexandrium fundyense* Bloom in southern New England: General Patterns and Mechanisms. Symposium on Boston Harbor and adjacent coastal waters. New England Estuarine Research Society. Nantasket, MA

Climatic Dynamics of Rainfall, Snow and Vegetation over Complex River Basins – Fully Distributed Hydrological Modeling Approach

NOAA Cooperative Agreement No. NA17RJ1223

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Program Manager: Dr. Jin Huang, Climate Prediction program for the Americas, NOAA

Related NOAA Strategic Plan Goal:

- Goal 1. Understand climate variability and change to enhance society's ability to plan and respond.
- Goal 2. Serve society's needs for weather and water information.

PROJECT OVERVIEW

The focus of this research is to enhance our understanding of the spatial effects of rainfall and dynamic vegetation on basin hydrologic response at multiple, nested gauging stations. These spatial processes are critical to understanding catchment hydrology, with the hydrometeorology driving rapid runoff response and the vegetation modulating interstorm moisture redistribution. Current forecasting tools represent each of these spatial effects inadequately by using spatially-lumped approaches. They should be studied within the context of fully-distributed modeling on complex terrain. We seek to answer the following questions: a) what is the role that rainfall and basin feature variability have on hydrologic response; b) what are the bidirectional interactions between vegetation dynamics (transpiration, water stress) and hydrological mechanisms occurring over complex terrain? c) what are the impacts that dynamic vegetation exerts on moisture cycling in a catchment and the effects of these impacts on extreme flood events? In order to answer these questions effectively, the research couples a vegetation model that explicitly considers plant dynamics to the existing distributed hydrological model accounting for the spatial variability of water and energy fluxes. This approach overcomes two major limitations in current modeling approaches: the static nature of vegetation in most hydrology models and the lumped or point representation in most vegetation-hydrology models.

ACCOMPLISHMENTS

This work was a one-year proof-of-concept effort, leading to a full scale proposal. Indeed that proposal was written and accepted by NOAA and should be starting soon. All the limited objectives of the on-year effort were accomplished. A weather generator was added to the *TIN-based Real-time Integrated Basin Simulator* (tRIBS), a fully-distributed physically-based hydrological model used in this project and developed by the proponents. The stochastic climate simulator of *Curtis and Eagleson* [1982] was used as the foundation of this work. The weather generator allows synthetic simulation of several hydrometeorological variables representative of a given geographic location: precipitation, total cloud cover, incoming shortwave radiation, air temperature, humidity, and wind speed. The approach captures the essential relationships among the quantities of interest, while modeling the diurnal variation of weather conditions at the hourly scale. Precipitation is considered to be the key driver of simulated hydrometeorological conditions, which leads to a consistent co-variation of the weather variables. The generator was calibrated and validated with data from three meteorological stations located in New Mexico,

Arizona, and Oklahoma. The model is suitable for creating scenarios of climate regimes (e.g., dry vs. wet climates), which are a part of the implementation plan of this project. An example of simulation realization of the weather generator is shown in Figure 1.

Dynamic vegetation has also been added to tRIBS, which represents one of the essential aspects for achieving the objectives of this project. The functions of dynamic vegetation in tRIBS are built on existing schemes such as LPJ of *Sitch et al.* [2003], *Levis et al.* [2004], CTEM of *Arora and Boer* [2005], Hybrid v3.0 of *Friend et al.* [1997], DGVM of *Foley et al.* [1996], BIOME3 of *Haxeltine and Prentice* [1996], and other ecologic models to capture the essential characteristics of vegetation including albedo, leaf-area index (LAI), stomatal resistance, rooting depth, and surface roughness that are important in determining water and energy balance. A number of plant functional types (PFT), e.g. deciduous/coniferous trees, C3/C4 grasses, and shrubs, are represented simultaneously via fractional weighting of the individual plant types. Each PFT is quasi-uniformly distributed in a model element where all vegetation types are under identical climate forcing and soil conditions, but respond differently as their water use strategy and tolerance to soil moisture deficit vary. Carbon pools of leaves, stems and roots are simulated for each vegetation type within a model element. Canopy of represented vegetation types is treated as two “big-leaves” (sunlit and shaded). The modeled plant physiology include:

- *Photosynthesis and stomatal resistance*: The Gross Primary Productivity (GPP) is computed using the biochemical model of leaf photosynthesis developed by *Farquhar et al.* (1980), extended to C3 and C4 plants by *Collatz et al.* [1991, 1992]. The process of up-scaling from leaf to canopy follows the work of *Wang and Leuning* [1998]. *Ball et al.* [1987] stomatal resistance model is directly related to the root soil moisture as in *Bonan* [1996]. The Net Primary Productivity (NPP) is therefore explicitly affected by the hydrometeorological conditions through the soil water and radiation dynamics.
- *Plant Respiration*: Plant respiration rates are calculated based on a common approach used in many ecological models. The growth respiration is expressed as a constant fraction of NPP and maintenance respiration is estimated separately for different plant compartments based on their carbon pool size and climatic variables.
- *Tissue turnover and stress-induced foliage loss*: tissue turnover is estimated based on first-order kinetics reaction with a heuristic function accounting for a rapid foliage loss during water stress.
- *Carbon Allocation*: The net assimilated carbon is partitioned into carbon pools of leaf, stem and root. We use the allocation scheme proposed by *Friedlingstein et al.* [1999] and *Arora and Boer* [2005] that allocates carbon to different plant components based on resource availability (water and light).
- *Phenology*: Cycles of onset and offset of leaves are accounted for to define the time period during which plants influence the energy and water fluxes. The “carbon gain” parameterization proposed by *Ludeke et al.* [1994] and refined by *Arora and Boer* [2005] is adopted. Phenology is linked to hydrometeorological conditions through air and soil temperature and soil moisture availability.

A diagram of carbon fluxes simulated for a vegetated land unit is shown in Figure 2. A short-term simulation showing the response of a generic C4 grass to hydrometeorological conditions of semi-arid climate of New Mexico is illustrated in Figure 3.

An initial testing of the vegetation-topography interaction using synthetic catchments generated by CHILD (Tucker et al. 2001) was also carried out. The two domains represent diffusive and fluvially dominated landscapes. Figure 4 illustrates the spatial distribution of the mean annual Above-ground Net Primary Productivity obtained for a generic C4 grass on loamy soil over the 50-year simulation period.

Diffusion erosion dominated landscape is shown. The semi-arid climate of New Mexico was assumed and the simulations were driven using the series generated by the developed weather generator. The two cases shown correspond to the “base” case (panel (a)) with essentially negligible lateral transfer of water in the domain, and the “runon” case (panel (b)), where runoff produced due partially impermeable soil was allowed to re-infiltrate at downstream locations. As seen, the obtained spatial distributions of the mean annual ANPP corroborate those observed in the field spatial distribution of grass, *e.g.*, association of higher amounts of biomass with North-facing slopes. Additional association of more favorable sites with convergent topographic locations, particularly often observed in the field, can also be clearly seen in the modeling results for the case with significant lateral transfer (panel (b)).

FIGURES AND IMAGES

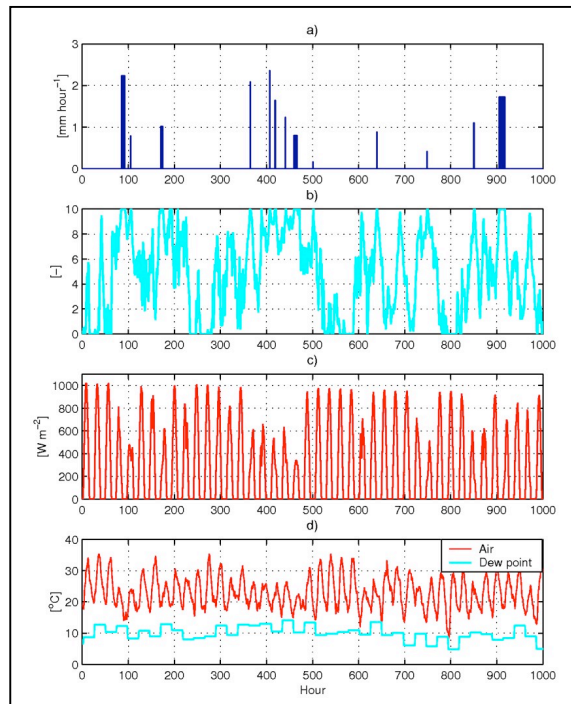


Figure 1. Simulated hourly hydrometeorological variables based on parameters derived for the location of Albuquerque (NM) (August): a.) rainfall; b.) cloud cover; c.) incoming shortwave radiation; and d.) air and dew point temperature.

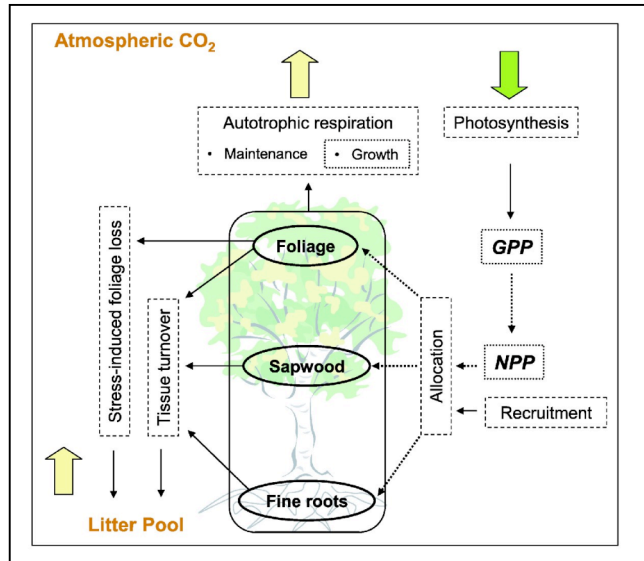


Figure 2. A conceptual diagram of carbon fluxes simulated by the model and an outline of the processes involved. The three major carbon pools are leaves, fine roots, and sapwood (woody species). Boxes outlined with dashed lines illustrate processes that affect the carbon balance. The dotted-line boxes represent intermediate quantities, whose magnitude impacts the occurrence of processes that are assumed to follow. The solid-line arrows show carbon fluxes, while dotted-line arrows depict an intermediate partition of carbon fluxes, which depends on the outcome of carbon balance at the preceding stage. The filled downward arrow depicts carbon uptake from CO₂, while the filled upward arrows show carbon loss by vegetation.

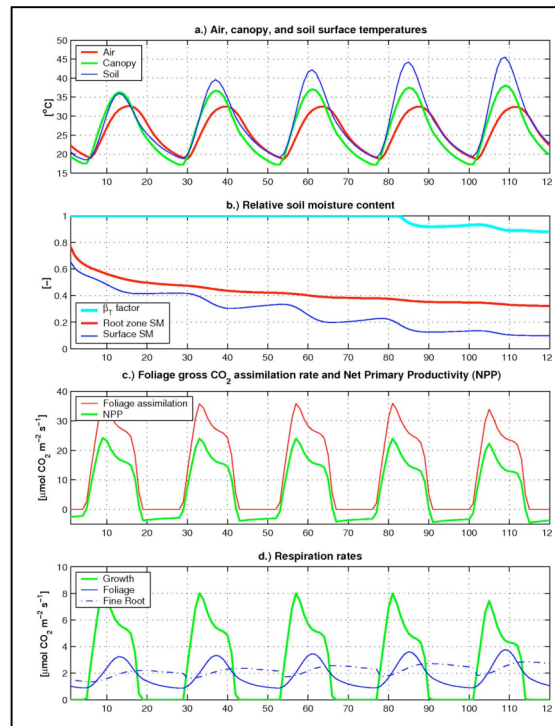


Figure 3. The time-series of environmental characteristics and grass biochemical CO₂ fluxes for it initially wet soil: a.) air, canopy, and soil surface temperatures; b.) relative soil moisture contents and transpiration factor; c.) foliage gross CO₂ assimilation rate and Net Primary Productivity (NPP); d.) growth, foliage, and root respiration flux rates. The rates are provided for a unit area of vegetated fraction of the computational element.

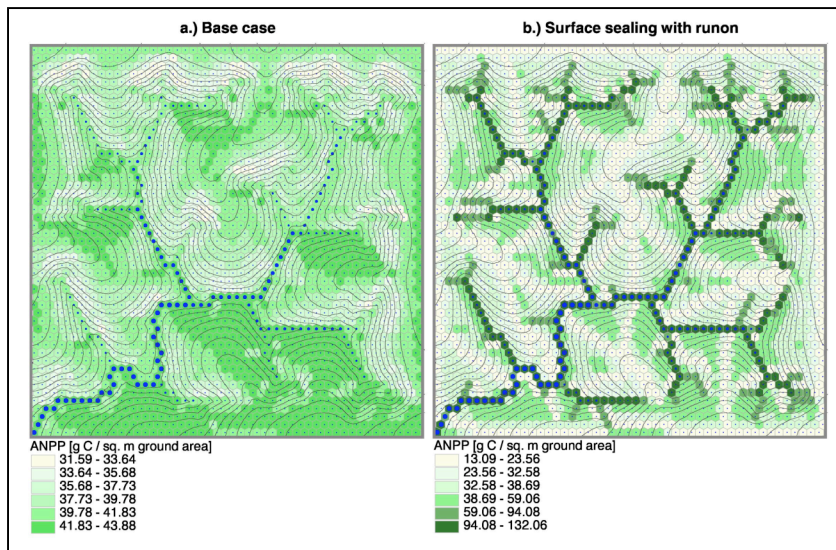


Figure 4. Spatial distribution of mean annual ANPP simulated for C4 grass on loamy soil in a synthetic domain (diffusion erosion dominated landscape): a) “base” case scenario (negligible lateral water transfer); b) “runon” case (significant water redistribution in the domain due to the runon process). The climate of New Mexico was used to force the modeled vegetation-hydrology dynamics. The blue circles show the relative magnitude of the contributing area.

PUBLICATIONS

Ivanov, V.Y., Bras, R.L., Curtis D.C. A Weather Generator for Hydrological, Ecological, and Agricultural Applications, *submitted to Water Resources Research*, July 2006.

Ivanov, V.Y., Bras, R.L., Vivoni, E.R. Vegetation-Hydrology Dynamics in Complex Terrain of Semi-Arid Areas: I. A mechanistic Approach to Modeling Dynamic Feedbacks, *in preparation*.

SUMMARY OF INTERACTION WITH NOAA

A new proposal to continue the work was submitted and accepted by NOAA.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

None.

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- Levis, S., G. B. Bonan, M. Vertenstein, K. W. Oleson, TN-459+IA The Community Land Model's Dynamic Global Vegetation Model (CLM-DGVM): Technical Description and User's Guide, CGD, 60 pp. May 2004.
- Ludeke, M. K. B., et al., The Frankfurt Biosphere Model: A global process oriented model of seasonal and long-term CO₂ exchnage between terrestrial ecosystems and the atmosphere, I, Model description and illustrative results for cold deciduous and boreal forests, *Clim. Res.*, 4, 143-166, 1994.
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- Wang, Y. P., and R. Leuning, A two-leaf model for canopy conductance, photosynthesis and partitioning of available energy I. Model description and comparison with a multi-layered model, *Agric. For. Meteorol.*, 91, 89-111, 1998.

Multi-Sensor Improved SST (MISST) for GODAE

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 357
July 1, 2004 through June 30, 2005

Dr. Sandra Castro

Colorado Center for Astrodynamics Research, University of Colorado, Boulder, CO 80302
(303) 492-1241, sandrac@colorado.edu

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. 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.

ACCOMPLISHMENTS

1. *First Accomplishment:*
Completed derivation of error statistics for AVHRR, AMSR-E, and TMI as a function of satellite derived sensor and environmental parameters.
2. *Second Accomplishment:*
Completed study of optimal error characterization approach for combination of infrared and microwave SST products.
3. *Third Accomplishment*

Submission of paper to Journal of Geophysical Research describing these results (see attachment).

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. Maps of the monthly mean AMSR-E – AVHRR SST differences for June 2004 before and after the leading combination of corrections are shown in Figure 1. The relative magnitude and spatial distribution of individual components of the corresponding biases are displayed in Figure 2. 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. Additional results described in attached manuscript.

FIGURES AND IMAGES

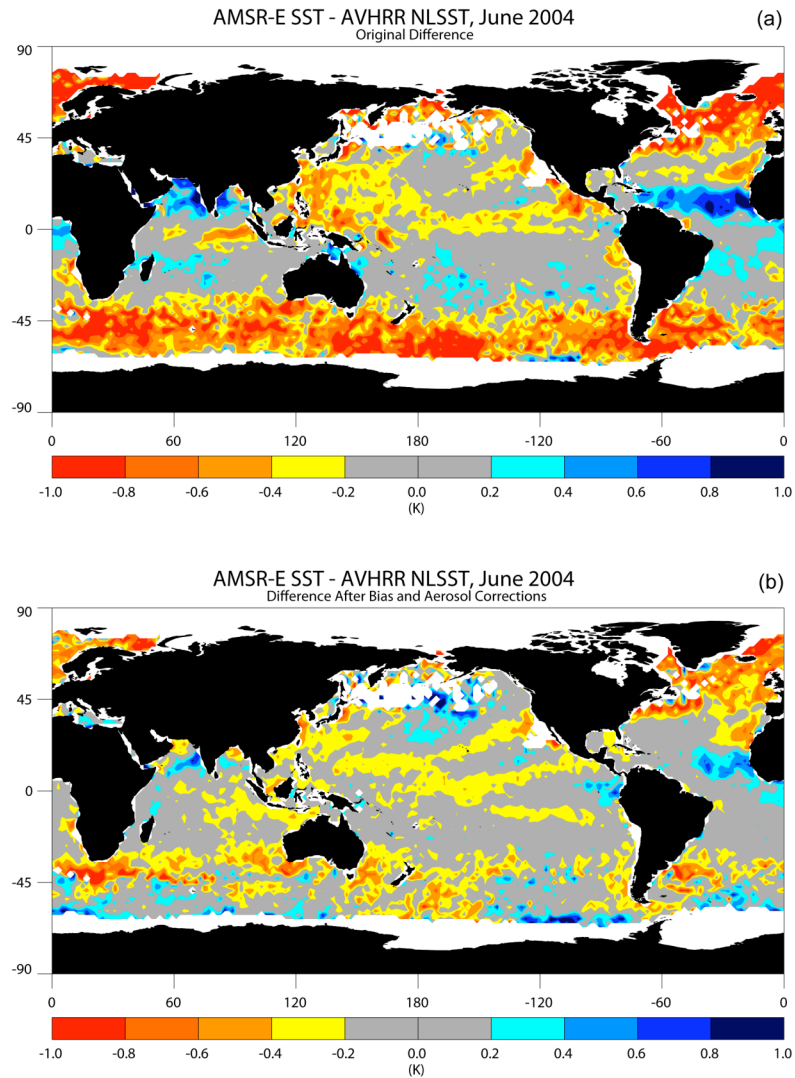


Figure 1. Monthly averaged gridded nighttime differences between the AMSR-E SST and AVHRR NLSST for June 2004 (a) before, and (b) after bias adjustments.

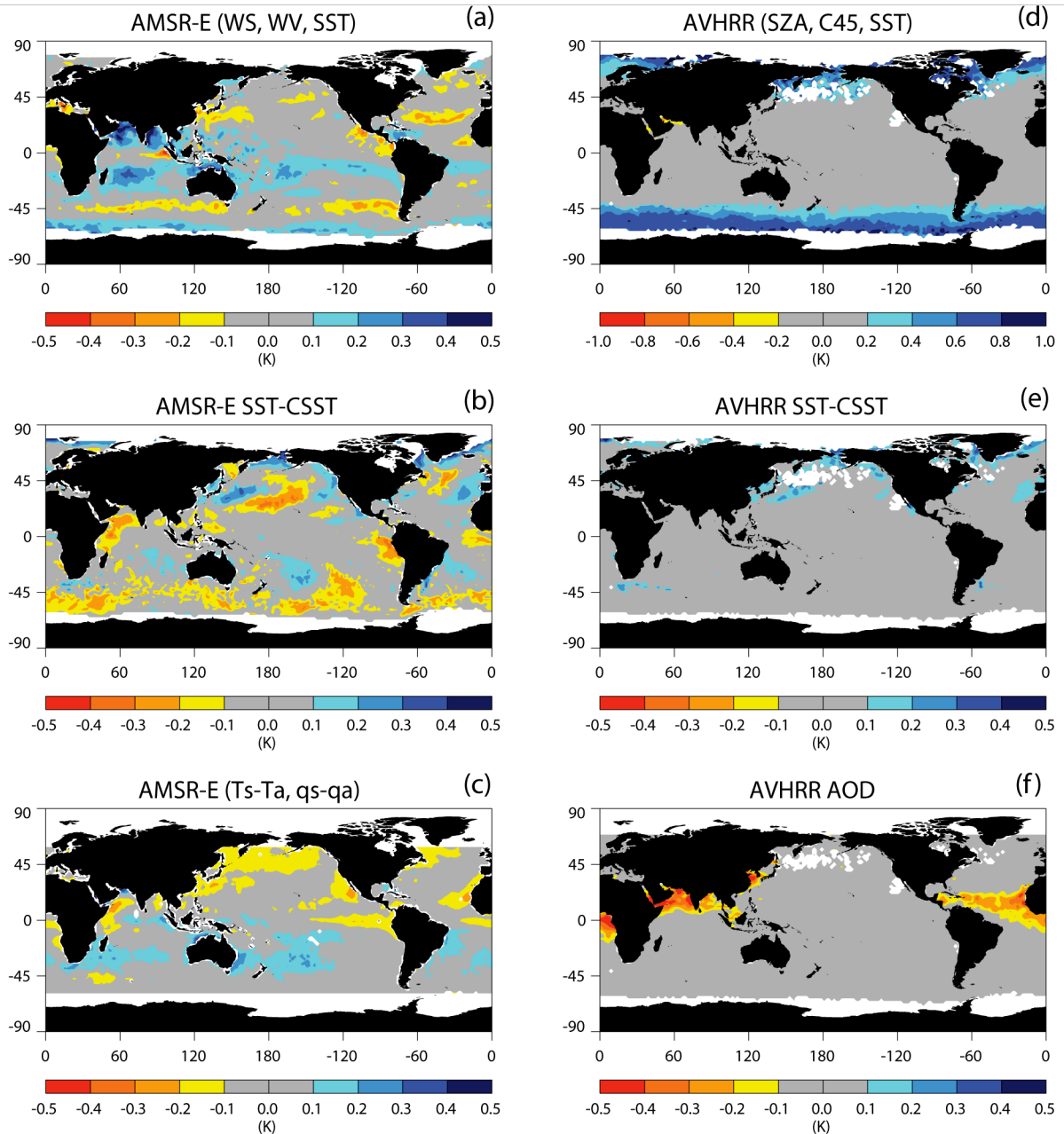


Figure 2. Monthly averaged maps of the individual components of the derived biases for June 2004. The left panels show the microwave corrections and the right panels are for the infrared. The source of each correction is shown above each panel with the terms as defined in the text. These are computed biases that are then subtracted from the corresponding SST product. Note the change in scale in panel (d).

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.*, 2006.

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 planned impact studies incorporating our results will be conducted by NOAA/EMC within NESDIS.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

Results were presented in student seminars at the University of Colorado, and during visits of Dr. William Emery to universities in Spain and Germany.

Application of the leaf wax-aerosol method to assess spatial and temporal patterns of carbon isotopic fractionation of atmospheric CO₂ by terrestrial photosynthesis

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 354
July 1, 2006 through June 30, 2008

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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 CO₂ (D), yet no satisfactory method exists to measure this on large spatial scales. Terrestrial biospheric discrimination of CO₂ (D) reflects the integrated consequences of environmental and physiological factors on photosynthetic processes, and the extent to which D 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 D and its temporal variation on large spatial scales. The operational plan entails continuous bulk aerosol sampling at four strategically located sites (Bermuda, Barbados, Amazonia, Ascension) 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 CO₂. 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 established ongoing aerosol sampling programs on Bermuda in July 04 and Barbados in Apr 05. Collections on Bermuda are 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. Sampling is scheduled to continue until this fall. Collections on Barbados are made at the Univ. Miami Ragged Point tower on the eastern end of Barbados. Trades in Barbados bring African air year-round.

In October, I will travel to French Guyana to set up a 1-yr aerosol sampling at the Nouragues experimental site. This CNRS field site is located in the pristine Amazon rainforest and provides excellent sampling support. This site was selected for the sampling rather than the Brazilian site I proposed originally because current logistical considerations make continuous collections at the Brazil site problematic.

1. First Accomplishment

Generated a 2-yr continuous record of bulk carbon and wax aerosol molecular and isotopic composition at Bermuda. One year of sample analyses for waxes completed. Variations in isotopic composition reflect changes in source vegetation (C3 vs C4 species, seasonal variations in photosynthetic discrimination of CO₂) in the sample's footprint, which primarily reflects North American sources. The new wax aerosol data agree well with wax aerosol data previously collected in 1995-1998 (Fig. 2). Photosynthetic discrimination (D) in 2005, estimated using the wax aerosol isotopic composition, ranges from 16-19 per mil for wax n-alcohols and 14-18 per mil for wax n-acids (Fig. 3).

2. Second Accomplishment

Generated an 16-month record of bulk carbon and wax aerosol molecular and isotopic composition at Barbados. Six months of sample analyses for waxes completed. The Barbados aerosols fall off the trend line observed for the North American samples (Fig. 2). The n-acids are isotopically enriched relative to those at Bermuda, as expected given the higher contribution of C4 vegetation in aerosol source regions. Unexpectedly, the n-alcohols are significantly depleted in ¹³C. This may indicate a larger C4 contribution to the wax n-acids at Barbados. The Barbados record to date indicates only weak seasonality in photosynthetic discrimination (D) (Fig.3). While the n-alcohol estimates of D are similar to those for Bermuda (16-18 per mil) the n-acid estimates are 1-4 per mil lower (13-14 per mil).

FIGURES AND IMAGES

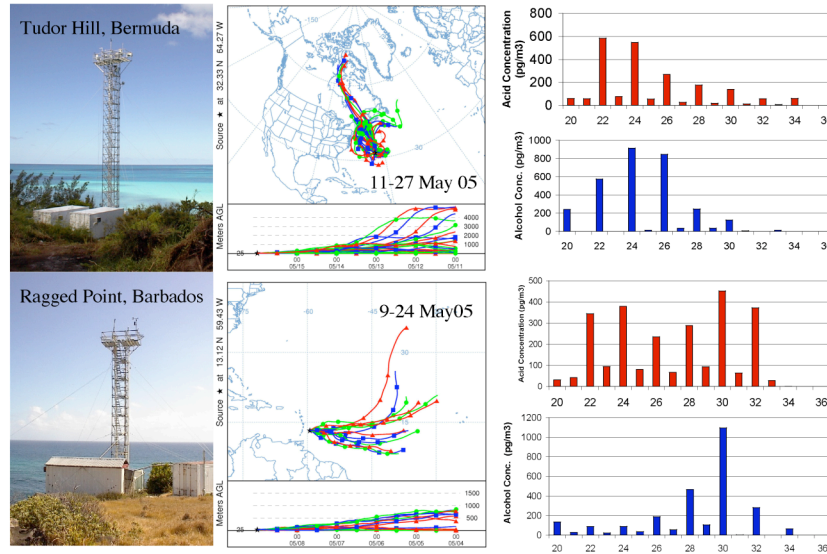


Figure 1. Left panel: Atmospheric sampling tower at Bermuda and Barbados. Center panel: Five-day back air mass trajectories for representative spring samples. Right panel: Concentrations of the individual *n*-acids and *n*-alcohols in the wax aerosols. The distributions show the expected even/odd carbon preference for plant wax sourced material and also source vegetation differences in molecular distributions for the plant wax *n*-acids (red) and *n*-alcohols (blue) in the aerosol footprints in these samples.

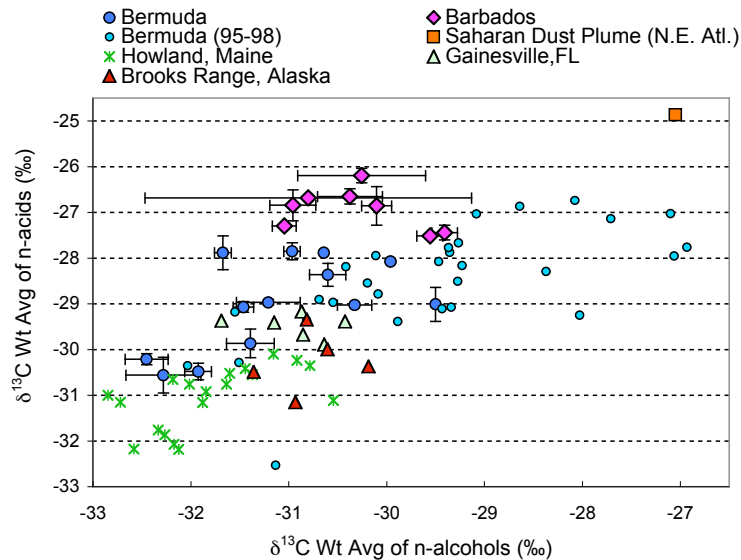
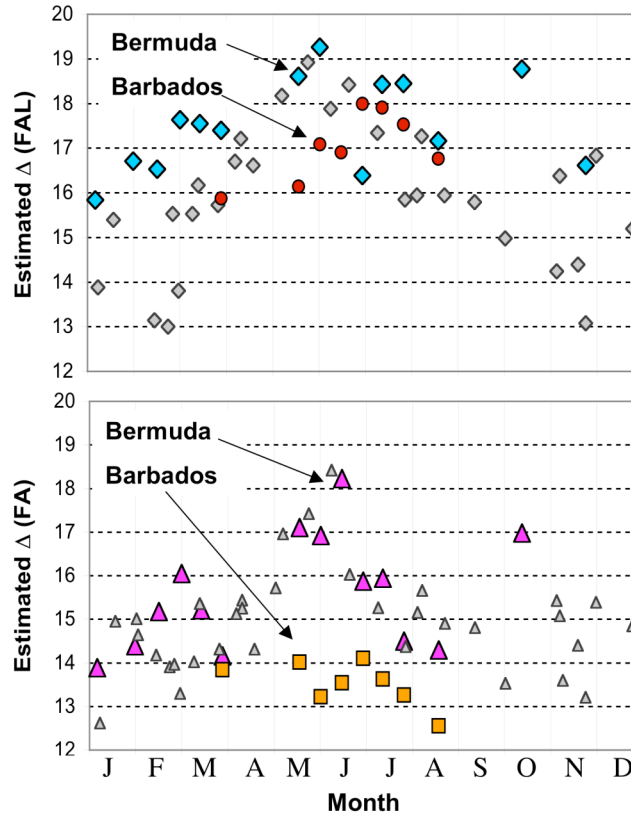


Figure 2. Carbon isotopic composition ($\delta^{13}\text{C}$) of the concentration-weighted average of the wax aerosol C_{22-34} *n*-acids and C_{22-34} *n*-alcohols at Bermuda and Barbados. Shown for comparison are Bermuda aerosols collected in 1995-1998, and wax aerosols collected in Maine, Florida, northern Alaska and in a boundary layer Saharan dust plume collected off Cape Verde. The Bermuda data are quite consistent with the North American source data. In contrast, Barbados receives copious quantities of Saharan dust, but the wax aerosol *n*-acids and *n*-alcohols are isotopically

depleted relative to a boundary layer Saharan dust plume sampled off Cape Verde. This indicates that air masses transported to the western subtropical Atlantic from northern Africa contain a significant overprint of waxes from C3 vegetation sources that is admixed with waxes from C4 plant sources typical of the arid subSaharan regions.



• Figure 3. Wax aerosol-derived estimates of the terrestrial photosynthetic discrimination (D) of source vegetation in continental footprints of Bermuda and Barbados aerosols collected in 2005. The Bermuda data from 1995-1998 is shown for comparison (grey symbols). The difference in the wax alcohol (FAL) and acid (FA) estimates may reflect either differences in source strengths of vegetation types having different discrimination and/or differences in the wax biosynthetic isotopic offset relative to fixed CO_2 . Estimated seasonality at Bermuda is 3-4 per mil, slightly lower than for the 1996-97 period. Only weak seasonality is indicated by the Barbados record analyzed to date.

PUBLICATIONS

In progress, nothing yet to report.

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/UMiami 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.

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 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.



ABOVE: QARTOD IV Participants.
BELOW: QARTOD IV Organizing Committee and WHOI Support.



LEFT: Christoph Waldman (Bremen, Germany) briefs the QARTOD IV participants on European efforts.

Carbon Dynamics of North American Boreal Forest Regrowth

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 334
04/01/2003-03/31/2006

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Program Manager: Kathy Tedesco NOAA/OGP Global Carbon Cycle Program

Related NOAA Strategic Plan Goal:

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

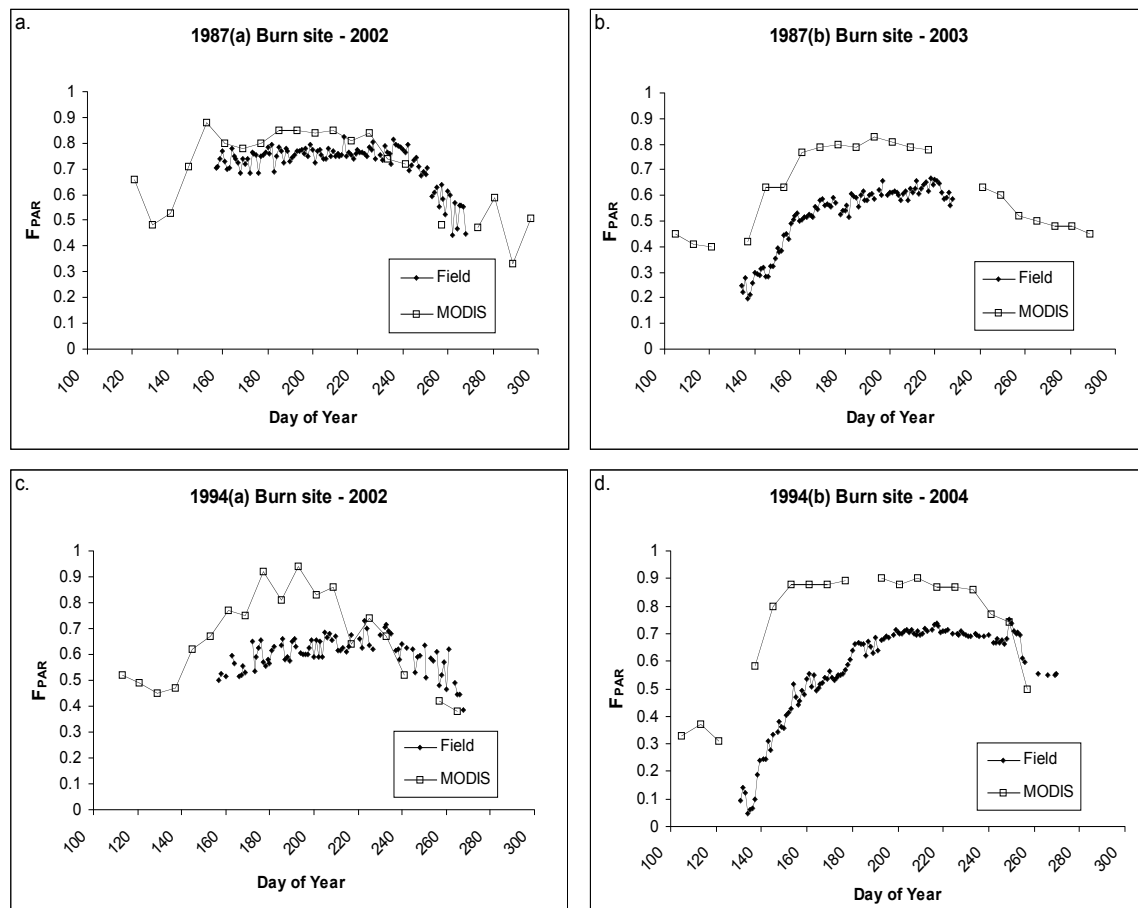
Project Background:

This project was focused on the analysis of North American boreal forest carbon dynamics. There were several aspects to the project, including: (i) time series analysis of NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery on 10-15 day intervals over the past two decades, (ii) estimation of biophysical attributes of the vegetation, including canopy light harvesting as it relates to photosynthesis over large areas, (iii) use of the image data, along with ancillary data sets, to track seasonal and interannual variability in burned, unburned and regenerating areas, (iv) collection and analysis of field data sets to calibrate and validate the results. The data sets that we produced and the analyses that we conducted have direct relevance to the research objectives of NOAA's Climate and Global Change Program, and the USGCRP North American Carbon Program.

Results:

The results of much of this work summarized here are also provided on the internet at www.whrc.org/borealamerica. Our estimates of vegetation processes from satellite observation were based on field measurement activities in interior Alaska. We describe the indirect estimation of leaf area index (LAI) from handheld instruments at 34 sites in the study area, including factors which influence the uncertainty of estimates (Hyer and Goetz 2004, listed under publications). Our related continuous field measurements of canopy light interception (F_{par}) were processed for the period 2001 through 2004, with careful sensor cross-calibration. We used these data to analyze temporal variation in light harvesting, for validation of estimates from satellite observations (Figure 1), and for scaling the observations to other satellite data sets of different spatial resolution. We published on this component of the project in a special issue on MODIS validation (Steinberg et al. 2006, see publications).

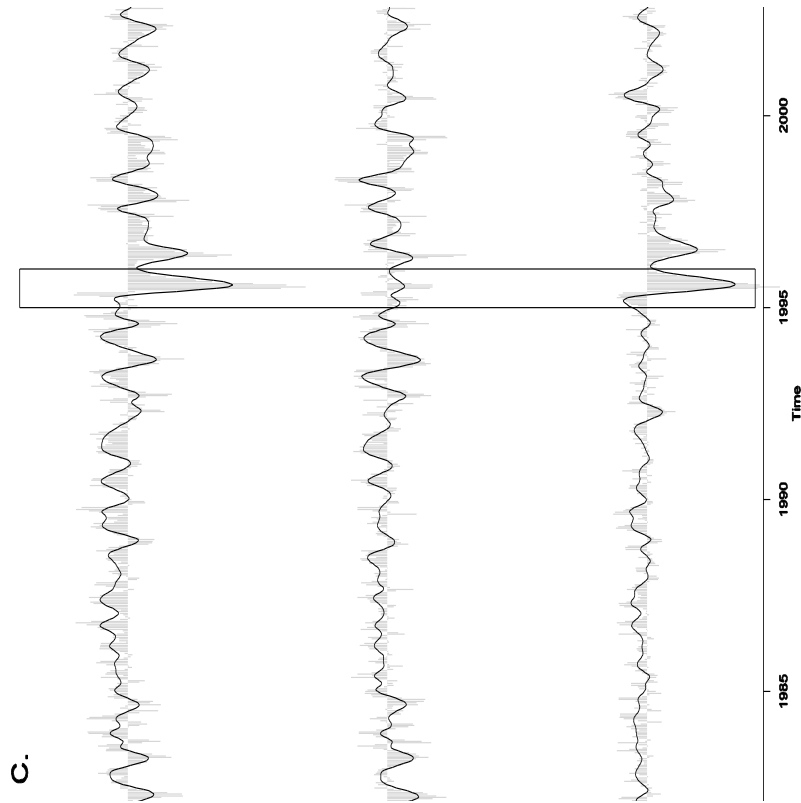
Figure 1. Example comparisons of canopy light harvesting (F_{PAR}) across sites measured using field PAR cell arrays versus those estimated from satellite (MODIS). From Steinberg et al. (2006).



The time series analysis of AVHRR satellite data sets (64 km^2) was conducted across boreal North America following processing of the data sets (described in the Year 1 report). The normalized difference reflectance index (NDVI) data set was converted to estimates of the fraction of incident photosynthetically active radiation (PAR) intercepted by vegetation (i.e., F_{par}), and these data were then analyzed across a wide range of burned areas across boreal North America.

Regeneration from fires that burned in three episodic fire years (1981, 1989, and 1995) was characterized, including the gradual increase in canopy light harvesting (F_{par}) as vegetation density and stature increased through time after fire (Figure 2). The rate of recovery varied in different fire years, even for the three episodic fire years on which we focused our analysis. Variability in the time series remaining after accounting for environmental factors, represented by the difference of burned and unburned area anomalies, increased beyond the observed post-fire recovery period which may indicate residual effects of fire disturbance over the regrowth period. As part of this analysis we also conducted a comparison of different AVHRR data sets. The results of this component of the project were also published (Goetz et al. 2006, see publications).

Figure 2. Time series of AVHRR Fpar anomalies between 1981 – 2000, for all fires that occurred in 1995. The top graph shows the time series anomalies across burned areas, the center graph the same for unburned areas, and the bottom graph the residual difference. The graphs show both seasonal variation in Fpar as well as a gradual trend towards increased light interception through time as the vegetation recovers over the 20 year period (i.e., 20 years * 36 intervals per year = 720 values). From Goetz et al. (2006).



The same AVHRR data sets were used to conduct a rigorous time series and trend analysis of photosynthetic activity (Pg) over the 22 year period across boreal North America, where Pg was estimated from Fpar (above). The trend analysis, which focused on unburned areas in order to characterize ecosystems responses other than disturbance, revealed that tundra vegetation experienced an increase in both peak photosynthesis and growing season length, whereas many forested areas actually experienced a decline in photosynthetic activity between 1981 and 2003 (Figure 3). Climatic warming occurred across the entire region (Figure 4), but the change in the forest response indicates that long-term changes may not be predictable from initial, short-term observations. Fire disturbance also increased with the warming (see inset of Figure 3) but did not explain the decline in forest photosynthetic activity.

Figure 3. Spatial distribution and magnitude of trends in photosynthetic activity across Canada and Alaska from 1982 through 2003. Colors on the inset figures correspond to those in the map. The total area burned annually across Canada and Alaska from 1980 to 2005 is shown in the bottom left. From Goetz et al. (2005).

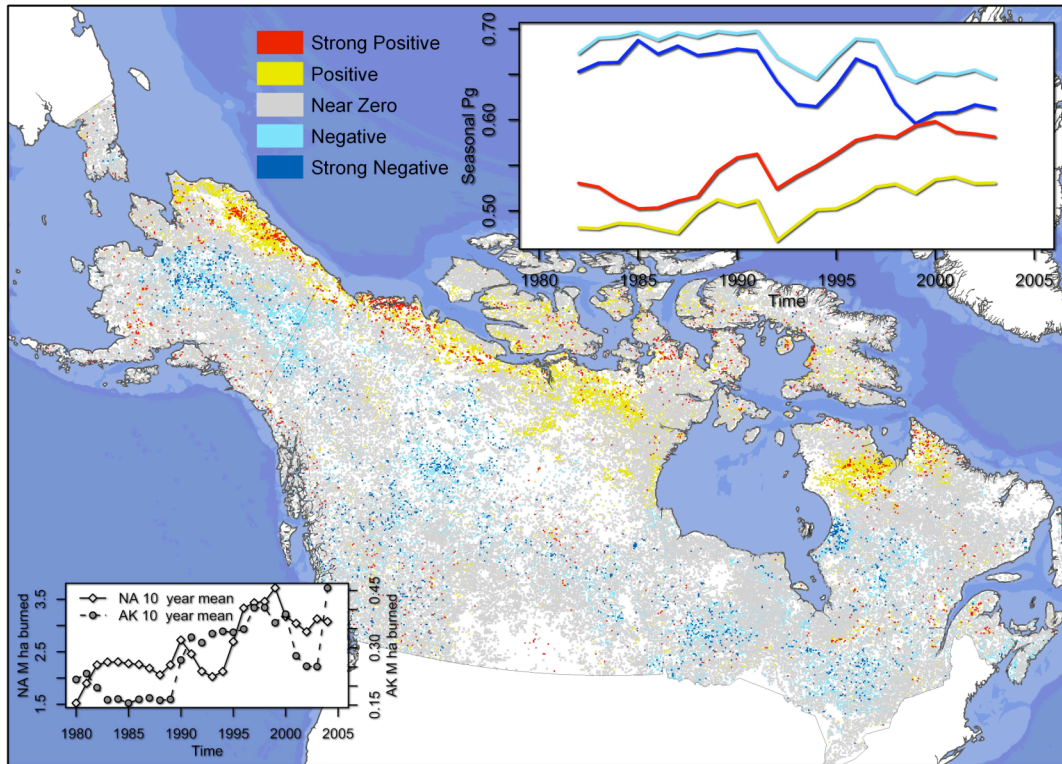
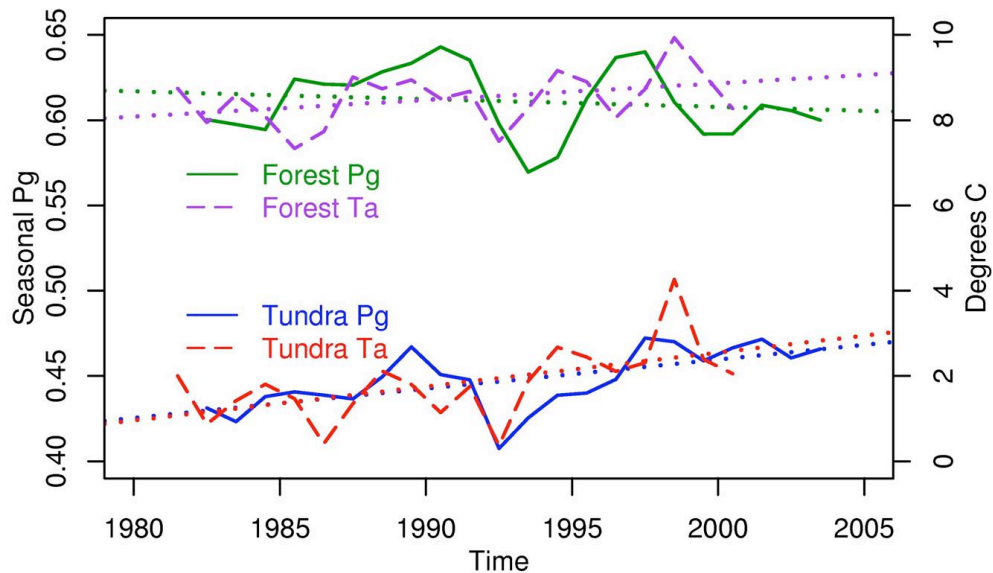


Figure 4. Growing season (June, July and August) photosynthetic activity from tundra and forest areas compared to temperature observations. The satellite data extend from 1982 to 2003 and the temperature data from 1982 through 2000. The dotted lines are statistical fits to the data. Note the close correspondence of increasing temperature and photosynthetic activity in tundra areas, and how they diverge in forest areas. From Goetz et al. (2005).

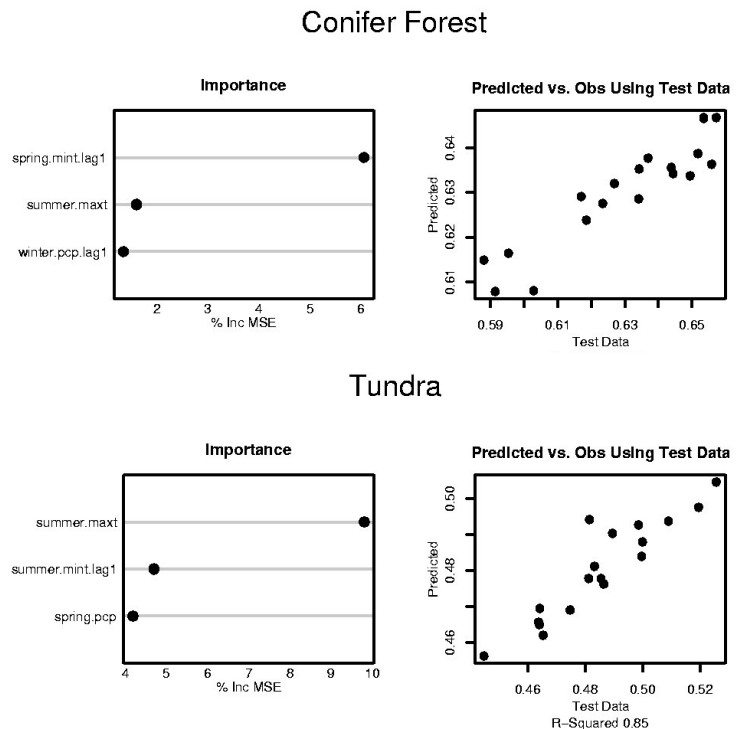


This work represents a potentially important advance at broad spatial scales by making use of the full extent of the satellite observational record to document unique vegetation responses to climatic warming. The results are striking, unexpected, and at odds with some earlier work that indicated ubiquitous greening. Our results were published in the Proceedings of the National Academy of Sciences (Goetz et al. 2005, see publications), and were picked up by a number of public media outlets. NASA’s “Earth Observatory” and other organization published features on the work (summarized below). These results provided some of the first evidence that high latitude forests may be in decline following an initial greening trend associated with CO₂ and warming. These trends have important implications for the direction of feedbacks to the climate system through changes in surface albedo and, when considered with our related work, fire disturbance regimes. This is particularly important since climate models predict continued warming and interior drying across the region.

We considered a number of possible causes for these observations, and extended the analysis in three ways: (i) by analyzing results specific to cover type, canopy density, and timing (seasonality) of the observed trend, (ii) by analyzing the primary climate variables associated with observed photosynthetic responses, including temporal lags in responses, (iii) by analyzing the AVHRR data sets across the entire circumpolar high latitude region. The results of these analyses, which were summarized in Bunn et al. (2005) and Bunn and Goetz (2006) (see publications), improved our understanding of the processes involved. Specifically, we found that (i) trends were strongest in late summer, indicating that drought stress (warmer and dryer air masses) was an important factor, (ii) areas of greater tree canopy density were more negatively impacted than sparse tree cover and/or more herbaceous areas, (iii) vegetation cover types keyed on different climate variables and had associated differences in their lagged responses to climate (figure 5), (iv) the observed trends held for high latitude forests of northern Eurasia as well as North America.

We have proposed to examine these factors in greater detail as part of follow-on work (proposal pending under FY07 NOAA OGP announcement of opportunity).

Figure 5. The importance of the top three variables in a statistical machine learning model of summer productivity for two cover types (left). Higher values indicate great importance, e.g., spring minimum T_a of the previous year for boreal conifers (top left) versus summer maximum T_a of the current year for tundra (lower left). The plots on the right show the fit between the predicted and the test data.



Publications Resulting from this Project:

- Bunn A. G., Goetz S. J. & Fiske G. J. (2005). Observed and predicted responses of plant growth to climate across Canada. *Geophysical Research Letters*. 32: doi:10.1029/2005GL023646
- Bunn, A. G., and S. J. Goetz. (2006) Trends in circumpolar satellite observed gross photosynthesis from 1982-2003: The role of cover type and vegetation density. *Earth Interactions* 10(12):1-19.
- Goetz S. J. Fiske G. & Bunn A. (2006). Using satellite time series data sets to analyze fire disturbance and recovery in the Canadian boreal forest. *Remote Sensing of Environment* 101 (3): 352-365.
- Goetz S. J., Steinberg D., Fiske G. & Houghton R. A. (2005) Satellite observed photosynthetic trends across boreal North America associated with climate and fire disturbance. *Proceedings of the National Academy of Sciences* 102(38): 13521-13525.
- Hyer, E., and S. J. Goetz (2004). Comparison and sensitivity analysis of instruments and radiometric methods for LAI estimation: assessments from a boreal forest site. *Agricultural and Forest Meteorology* 122 (3/4):157-174.
- Kasischke, E. S., S. J. Goetz, M. Hansen, M. Ozdogan, J. Rogan, S. L. Ustin, and C. E. Woodcock. (2004). *Temperate and Boreal Forests*. Pages 147-238 in S. L. Ustin, editor. Remote Sensing for Natural Resource Management and Environmental Monitoring. co-published by John Wiley & Sons and American Society of Photogrammetry and Remote Sensing, Hoboken, NJ.
- Steinberg D. C., Goetz S. J. & Hyer E. (2006) Validation of MODIS Fpar products in boreal forests of Alaska. *IEEE Transactions on Geoscience and Remote Sensing* 44(7):1818-1828.

Outreach Activities:

Presentations

- Ecosystem responses to high latitude warming*, Public Symposium at Cape Cod Community College (March 2006), Barnstable MA
- Trends in Circumpolar Photosynthetic Activity from 1982-2003*, Arctic Research Consortium of the United States (May 2006) and American Institute of Biological Sciences (May 2006), Washington DC
- Photosynthetic trends in the high latitudes: Is the boreal forest greening or browning?* AGU Fall Conference (Dec 2005), San Francisco
- Mapping and Monitoring Boreal Forest Regrowth Dynamics using Satellite Data Products*, AGU Fall Conference (Dec 2004), San Francisco.
- Remote Sensing and Modeling of Boreal Forest Regrowth Dynamics*, International Boreal Forest Research Association (IBFRA) Conference, Climate-Disturbance Interactions in Boreal Forest Ecosystems (May 2004), Fairbanks, Alaska.

Other venues (selected)

- American Museum of Natural History, *Browning boreal forests*,
<http://sciencebulletins.amnh.org/bio/s/boreal.20060508/index.php>
- Anchorage Daily News (front page feature), 15 Sept 2005, *Arctic tundra growing greener as northern forests dry out*, <http://www.adn.com/front/story/6970702p-6870818c.html>
- Dozens of other periodicals picked up portions of releases by the Associated Press and United Press International, including *Climate change in high latitudes studied*,
<http://www.upi.com/NewsTrack/view.php?StoryID=20060517-020550-9085r>

NASA Earth Observatory, *Forest on the Threshold*,
<http://earthobservatory.nasa.gov/Study/BorealThreshold/>

NPR Earth and Sky, Don't count on forests to keep us cool,
<http://www.earthsky.org/shows/show.php?date=20060624>.

An Intercalibration and Quality Assurance Program using a Stand-Alone Wireless IMET System

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 368 & 382
July 1, 2004 through June 30, 2005

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Program Manager: Dr. Sidney W. Thurston, NOAA/CPO/OCO

Related NOAA Strategic Plan Goal:

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

PROJECT BACKGROUND

The Nation is entering a new era of climate research and prediction requiring a major expansion of capabilities for climate observations over the oceans. Improved observations are needed for operational forecast centers, international research programs, and major scientific climate assessments. Air-sea interaction plays a significant role in this problem and, as time scales increase from weeks, to intra-seasonal, to seasonal, the importance of air-sea interaction increases.

This project is directed at the development of a system to ensure that shipboard observations of the air-sea fluxes are of the highest quality, as needed by research programs such as CLIVAR and SOLAS, and as needed so that the shipboard systems can provide in-situ calibrations of the ocean observatories under development by NSF. The goal of the project is to improve the quality and quantify the accuracy of shipboard meteorological and air-sea flux observations to the point that the data will meet the requirements of the science programs and provide the means to do in situ calibrations of the time series stations that will be maintained by some of these same ships. Future proposals will address the fabrication and engineering test of the system.

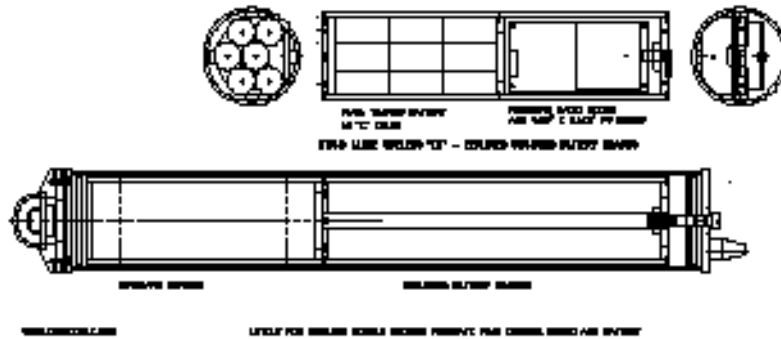
OBJECTIVES

It is a challenging task to instrument a ship to do high quality meteorological and air-sea flux observations. Placement of the sensors is critical. Distortion of the flow, shadows, heat, soot, radio frequency emissions, and spray effects must be minimized, but at the same time the sensors must be accessible. For each sensor, the issues are different; and while computation of the flow around the ship helps locate optimum locations, to date an empirical approach has proven to be most useful. Further, there needs to be a standard or reference set of observations to be used to judge the success of the trials to identify best locations. A recent workshop on high-resolution marine meteorological measurements (Smith, et al. 2003) discussed the problem and identified three important issues: (1) the need to have a data quality assurance program to firmly establish that meet the observations accuracy requirements, (2) a need for observations at high time resolution (about 1 minute), and (3) a need to more efficiently utilize research vessels

including realizing their potential for the highest quality data and their potential to provide more direct and more comprehensive observations.

At present, observations from scientific research vessels have well-documented problems and may not be routinely recorded when the vessel is at sea; and because of accuracy limitations, many VOS data require cumbersome correction procedures and are still not useful in some applications. To address these problems, it is proposed to construct a transportable instrument suite to provide a standard for evaluating and improving ship-based observations of variables used in near-surface bulk meteorology and fluxes. The “roving standard” would be installed on the NOAA ship Ron Brown as an engineering test. After successful test and evaluation, and using NOAA-OGP funding for operational use, this ‘roving standard’ will be deployed on UNOLS (NSF and Navy) and NOAA research vessels in a sequence of studies of each vessel.

- The sampling concept for the HRSAW is for the Central Controller to collect one minute data from all modules each one (or more) hours and relay that data to the bridge or science lab on the ship for processing, merging with data from the ship’s standard sensors for comparison purposes. Obtaining 60 (or more) one-minute values as a block permits the radio modem to duty cycle for reduced power. The bridge would use a radio modem and Bridge Computer (PC) operating on ship power. The Central Controller and all of the HRSAW modules would be battery powered for up to a month at a time. The inside-hull-mounted SST (sea surface temperature) system would use the HullCom acoustic modem from the AutoIMET system used on VOS so that cabling is not required. The SST would record one minute data internally but only send averaged data to the deck every 15 minutes or so. The following figure shows the module configuration.



Module Cross Section, Standard and with “kit”.

STATUS

The following Task List has the status comments in bold print.

1. Develop the HRS AW “kit” including the mechanical configuration and PC board layout and firmware. Purchase a custom battery for the unit. Prototype a unit for test and evaluation. **The mechanical configuration is complete. The PC boards are in work.**
2. Modify existing ASIMET firmware to store several hours of one minute data and create a new command for access to this data. Evaluate the existing memory board for improved operation including data extraction. **The PCMCIA memory card can now be replaced by a standard Compact Flash Card for lower cost and greatly increased storage capability. The new module controller PC card is in work that will use the CF and will have improved low temperature operation. The firmware for this card is in work and will address the HRS AW requirement for data retrieval via wireless connection to the bridge.**
3. Design and prototype a mounting-bracket system that is easy to install and use. **This mounting system is in work and is similar to the VOS brackets now in use.**
4. Design the Central Controller including packaging, PC board layout and firmware. Prototype a unit for test and evaluation. **Work on this task is not started.**
5. Purchase and design the Bridge Computer System for test and evaluation. **The bridge computer is being purchased in preparation for system design.**

These tasks complete the design phase of the program. The following tasks will be proposed for future funding from multiple agencies. This will result in a research ship and VOS, portable calibration system for the climate community.

1. Purchase commercial ASIMET modules and parts for HRS AW “kits”.
2. Plan the CFD modeling for the Oceanus and Ron Brown in cooperation with SOC.
3. Complete fabrication and testing of system components.
4. Initial calibration for all modules.
5. System integration and burn-in at WHOI.
6. Installation and test of key system components on the R/V Ron Brown for coordinated engineering evaluation of components and system and will be performed dockside.
7. Upgrade and modify as required based on engineering evaluation.
8. SOC will complete the CFD for the Oceanus testing.
9. Install on WHOI ship for short test cruise. (Probably the R/V Oceanus)
10. Upgrade and modify system as required based on test cruise.

Thermohaline Circulation in the Atlantic and its Variability under the Energy Constraint

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 49
July 1, 2004 through June 30, 2006

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Program Manager: Dr. James F. Todd, NOAA

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 this project is to study the decadal variability of the oceanic circulation, and oceanic circulation model's sensitivity under the energy constraint and the traditional buoyancy constraint.

Fiscal Year 2004-2006 Progress:

Substantial progress has been made during the past 24 months. The most important discovery is that wind energy input to the oceans has increased greatly over the past 50 years. Wind energy input to the oceans is the most important source of mechanical energy sustaining and regulating the oceanic general circulation. Over the past 50 years, wind energy input into the oceans increased 20%, with a large increase in the Southern Ocean and a slight decline in the equatorial band. The impact to the wind-driven and thermohaline circulation of such a large variability in wind energy input can be substantial. The focus of this project is to continue to explore the dynamic impact of changes in mechanical energy input to the ocean, using both simple theoretical models and realistic oceanic general circulation models.

Numerical experiments designed for testing the decadal variability of the equatorial circulation related to ENSO have been carried out, in which dynamical impact due to decadal variability in diapycnal mixing coefficient has been tested in a layer model for the equatorial Pacific. Our numerical experiments indicated that variability in diapycnal mixing, which is induced by wind stress energy input, can induce large amplitude of SST anomaly in the equatorial Pacific, on the order of 0.3-0.4°C; thus, this may be one of the most important ingredients sustaining the decadal variability in ENSO dynamics. Our study has been written up in a manuscript which has been through second reviews and we hope it will soon be accepted for publication.

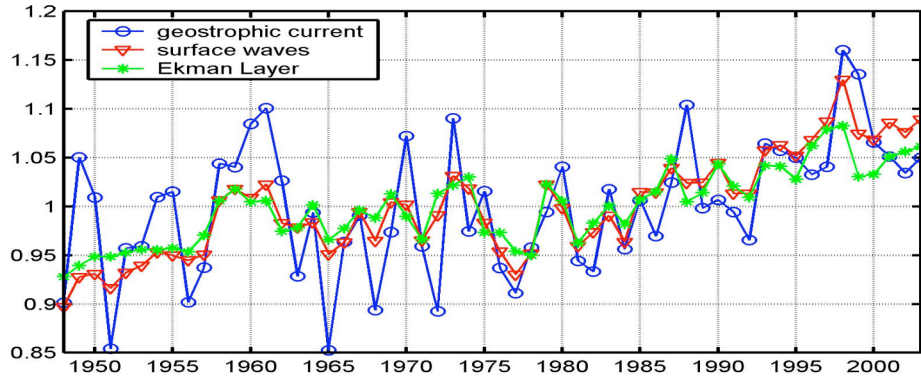


Figure 1. The time evolution of the normalized wind energy input through geostrophic current (circle), surface waves (triangle), and Ekman layer (star). (Huang et al., 2006)

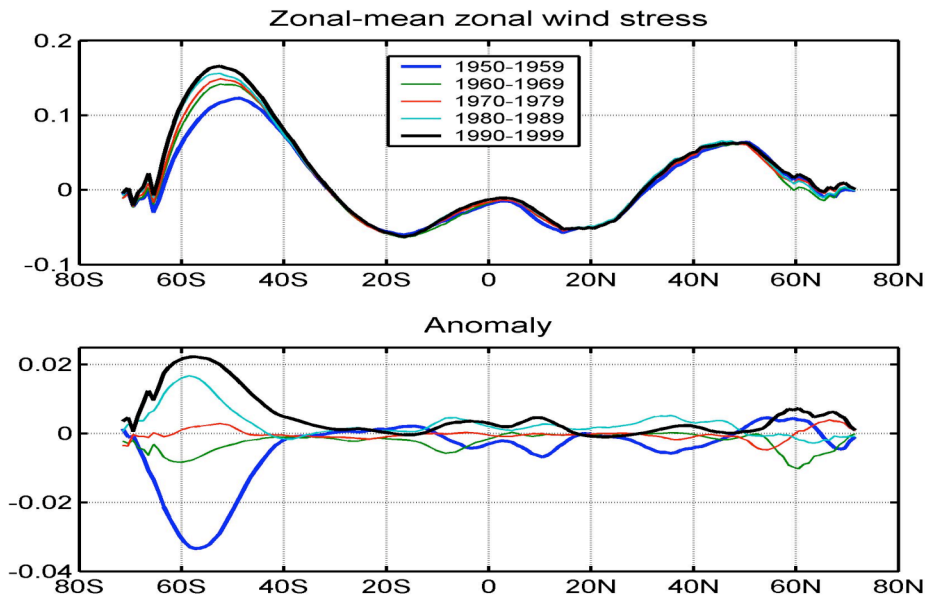


Fig. 2. Decadal-mean zonal wind stress in the world's oceans, and the deviation from the 50-year mean (in Pa), based on NCEP wind stress. (Huang et al., 2006)

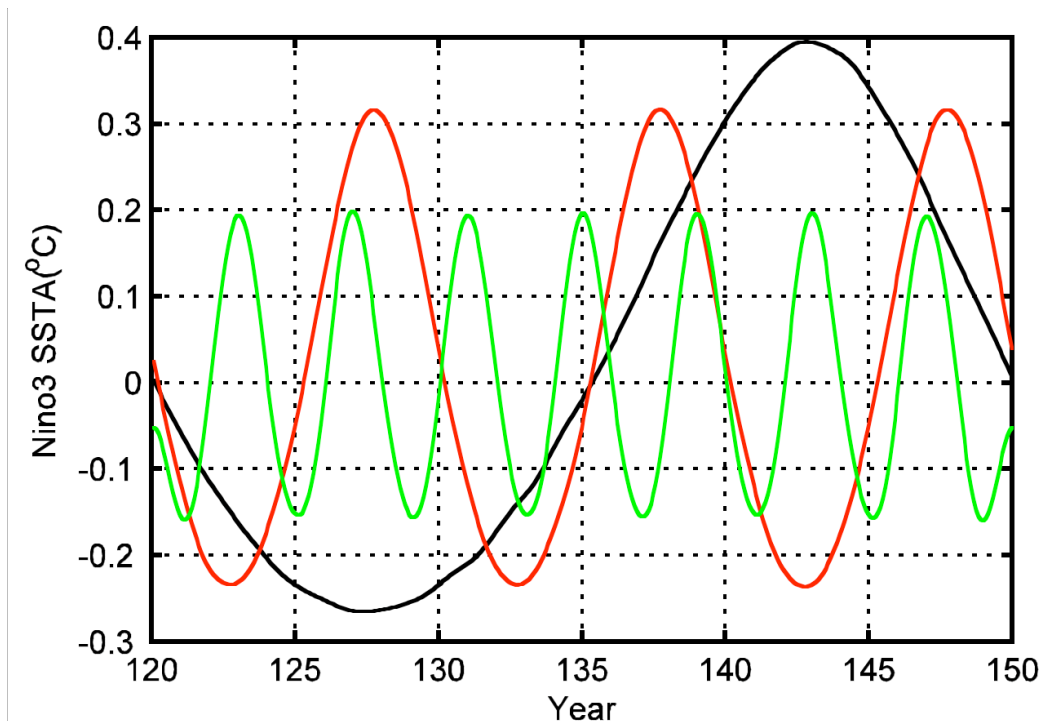


Fig. 3. Time evolution of SSTA at Nino3 obtained from a model for the Equatorial Pacific forced with climatologically monthly mean wind stress and relaxed towards the monthly mean surface temperature and salinity. The diapycnal mixing coefficient has a background value of $\kappa_d^0 = 0.15 \times 10^{-4} \text{ m}^2 \text{ s}^{-1}$, plus a decadal variability of $0.12 \times 10^{-4} \sin(2\pi t/T) \text{ m}^2 \text{ s}^{-1}$, where T is the period, and it is 5 yr for Exp. B (green), 10 yr for C (red), and 30 yr for D (black). (Huang, Wang, and Huang, 2006, manuscript)

Publications:

Wang, Q. and R. X. Huang, 2005: Decadal variability of pycnocline flows from the subtropical to the equatorial Pacific. *J. Phys. Oceanogr.*, **35**, 1861-1875.

R. X. Huang, W. Wang, and L. L. Liu, 2006. Decadal variability of wind energy input to the world ocean, manuscript, submitted to *Deep Sea Research II*, **53**, 31-41.

Huang, C. J, W. Wang, and R. X. Huang, Climate variability in the Equatorial Pacific Ocean induced by decadal variability of mixing coefficient, submitted to *J. Phys. Oceanogr.*, (in the process of review).

Outreach Activities:

I have taught an advanced course, theory of the oceanic general circulation, for graduate students in the MIT/WHOI Joint Program. The course is offered every two years. The course was offered in spring 2006, and the class lecture notes have been put on the website available for public approach.

I also worked as thesis committee member for two graduate students in the MIT/WHOI Joint Program students.

Assessment of Air-Sea CO₂ Exchange Rates in the World's Oceans Using Bomb ¹⁴C 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 CO₂ 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 CO₂ exchange rates is critical to these goals because this exchange is the primary mechanism for CO₂ transfer between the atmospheric and oceanic carbon reservoirs. The ocean inventory of bomb-produced radiocarbon (¹⁴C) is directly related to air-sea CO₂ 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 CO₂ exchange rates.

Project Goals:

This project has three main objectives:

- (1) To determine air-sea CO₂ 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 CO₂ exchange rates based upon the bomb ¹⁴C inventory estimated from the 1970s- GEOSECS data using an improved method of separating natural ¹⁴C from the observed ¹⁴C, and
- (3) To use inverse methods to derive the air-sea CO₂ exchange rates from the WOCE era oceanic bomb ¹⁴C 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

3. *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).

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

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 14C 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 14C 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 CO₂. 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 simple 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.

4. *Lateral Transport Model*

Broecker et al., (1985) developed lateral transport models for the three major ocean basins to simulate the GEOSECS bomb ¹⁴C 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 CO₂ exchange rates on the distribution of bomb ¹⁴C 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 ¹⁴C inventories based on separation of the natural and bomb ¹⁴C components according to PALK method (Rubin and Key, 2002). The CO₂ exchange rates given in Broecker et al (1985) were based on bomb ¹⁴C inventories estimated from Tritium penetration depth and smooth natural ¹⁴C 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 $4^\circ \times 5^\circ$ 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 ($\text{mol m}^{-2}\text{yr}^{-1}$)
	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 $\text{mol m}^{-2}\text{yr}^{-1}$ 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 $22.3 \text{ mol m}^{-2} \text{ yr}^{-1}$ 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.

5. *Inverse Modeling*

The final focus within this project is 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 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 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, a more useful direction, given the results of the lateral transport model, is to use the circulation defined by the inverse box model in place of the lateral transport model. The results will be compared to the Pacific 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 year.

Figures and Images

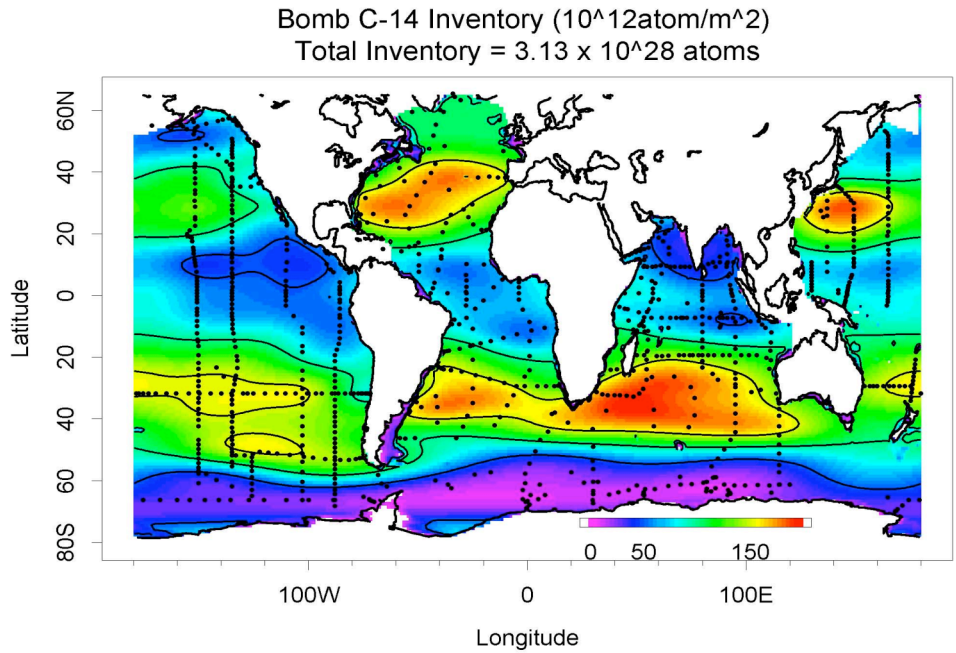


Fig. 1. Distribution of bomb ^{14}C inventory (10^{12} atom/m²) in the global oceans.

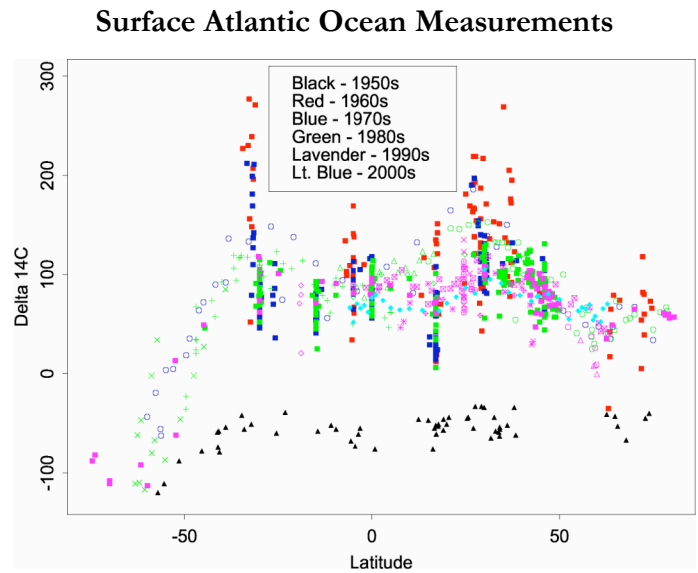


Fig. 2. Collected surface $\Delta^{14}\text{C}$ measurements (‰) in the Atlantic. Colors indicate the measurement decade and symbols indicate different expeditions within each decade.

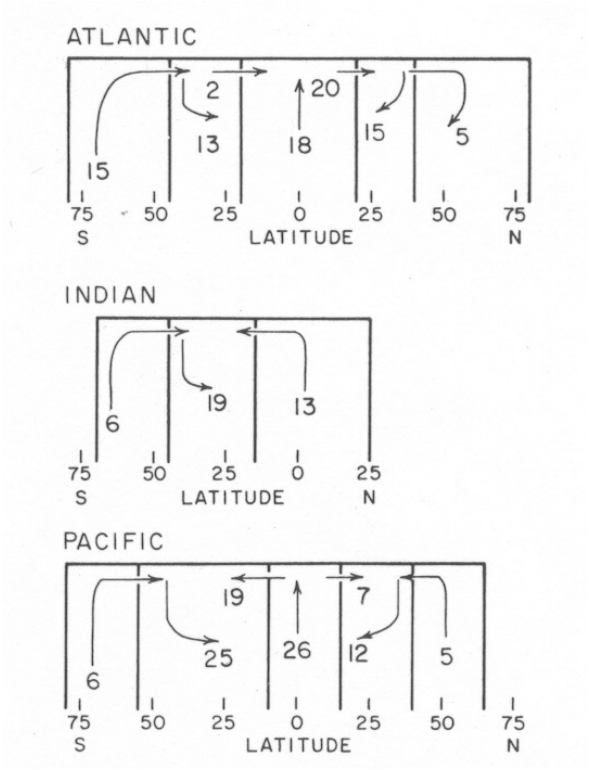


Figure 3. Transport model used to estimate the distribution of bomb ^{14}C in the World Ocean.

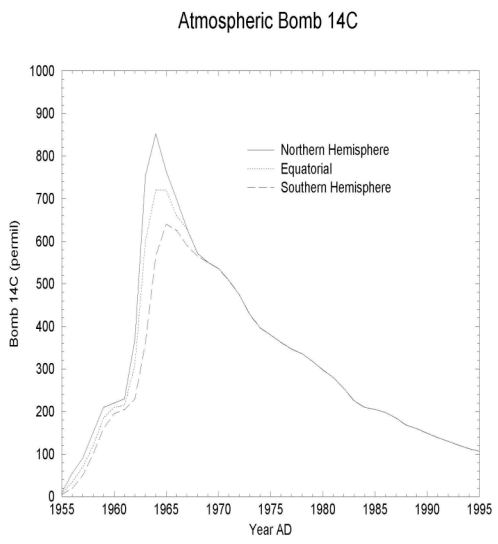


Figure 4. Atmospheric bomb ^{14}C input function.

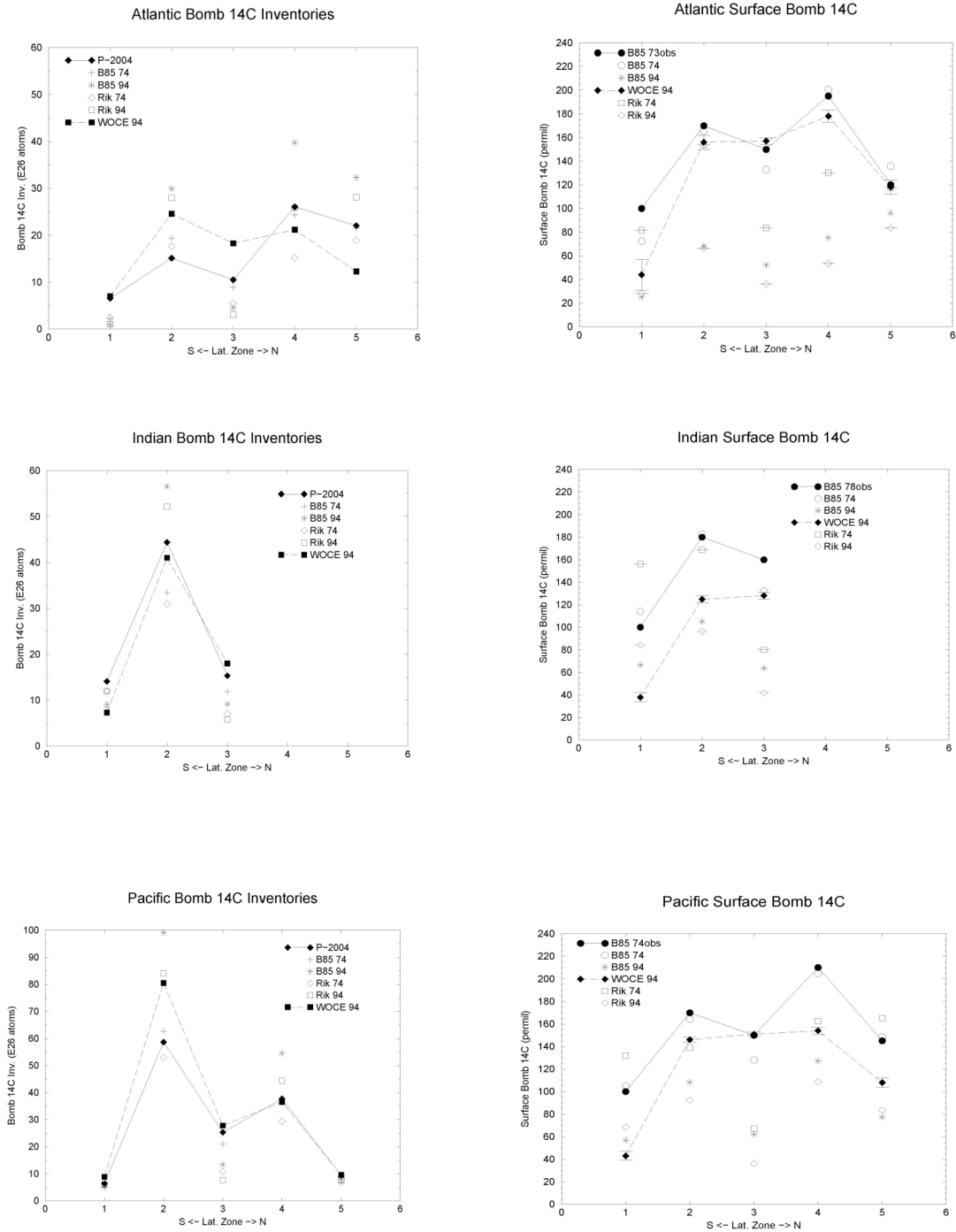


Figure 5. Model results for year 1974 (GEOSECS) and 1994 (WOCE) using re-calculated invasion rates (Rik 74 and 94) compare to those using Broecker et al.1985 (B85 74 and 94) constant ocean basin wide invasion rates. The solid symbols are observed values. Zone 1 = Antarctic, 2 = S. Temperate, 3 = Equatorial,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

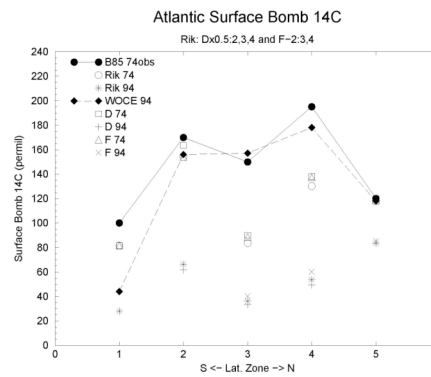
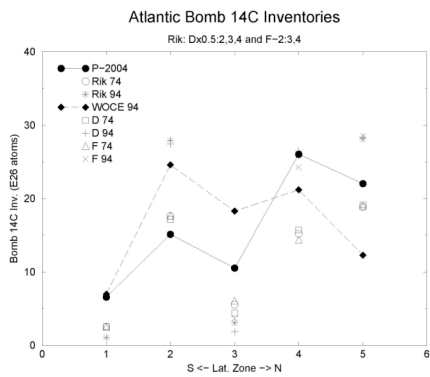
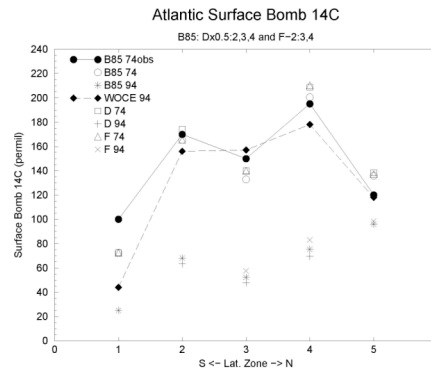
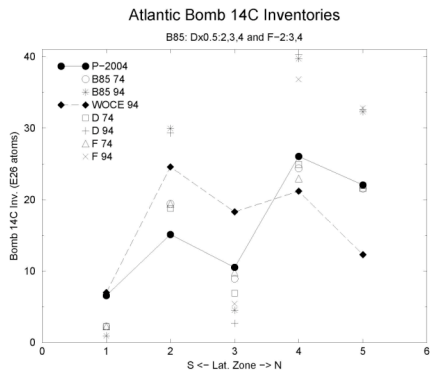


Figure 6. Model sensitivity tests for adjusting vertical diffusivity by 50% in zones 2, 3, and 4 in the Atlantic Ocean, and for adjusting fluxes in zones 3 and 4 by 2 Sv also in the Atlantic Ocean.

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

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- **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 responsible for the lateral transport model results. I have worked with them in designing the circulation used in the lateral transport model and have converted their model code to Matlab.

Summary of Education and Outreach Activity

Over the past year I was in contact with teachers from three different Massachusetts middle schools, but was unable to make dates to actually visit the classrooms. Nevertheless, I have stayed involved with COSEE New England. I have attended two Telling Your Story (TYS) workshops (one at the Univ. of CT, the other at Univ. of Mass. Boston). At the former I participated as a panel member and at the latter I also gave an example TYS presentation to a group of Boston middle school students. I have also agreed to join the COSEE New England team.

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

NOAA Cooperative Agreement No. NA17RJ1223 Subpoint 26
1 March 2004 – 31 August 2006

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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:

Ocean circulation redistributes carbon zonally, meridionally and vertically, moving waters through, i.e. towards and away from, formation sites, bringing under-saturated waters to the surface and bearing natural and anthropogenic carbon to depth. It effects the location and magnitude of storage and can provide feedbacks on the atmospheric CO₂ gradient. The Atlantic's central role in the global thermohaline circulation suggests that this basin should be an important laboratory for understanding the ocean carbon cycle and possible temporal variations in that cycle. Much of what is known about the oceanic carbon cycle has been sought through numerical models and indirectly through atmospheric measurements. With the now relative abundance of CO₂ data provided by the World Ocean Circulation Experiment (WOCE), the Joint Global Ocean Flux Study (JGOFS), the National Oceanographic and Atmospheric Administration's Ocean Atmosphere Exchange Study (OACES) and other programs, direct estimates of oceanic CO₂ flux and storage can be made. The project is designed to create a detailed Atlantic, WOCE-era data synthesis focusing on the circulation and associated oceanic transport and divergence of total inorganic carbon (TIC) and anthropogenic carbon (C_{ant}) derived from a box inverse model, and considering temporal differences in carbon & related property concentrations where repeat transects are available.

Project Goals:

The project objectives:

- (1) focusing on the Atlantic, where many of the newly available one-time and repeat WOCE/OACES/JGOFS hydrographic transects which included carbon measurements were performed (Figure 1), to synthesize these high-resolution, zonal and meridional data into an inverse model capable of providing an estimate of the three dimensional circulation of the full Atlantic Ocean which could then be used to investigate the uptake, transport and storage of total inorganic carbon (TIC), anthropogenic carbon (C_{ant}) and pre-industrial or natural (C_{pre}),

(2) to further our understanding of possible temporal changes in the sources and sinks of carbon throughout as much of the Atlantic as had been covered by repeat transects which included carbon parameters.

(3)

Method:

Using the available hydrographic data set, we are working on the development of two different inverse box models. The first is a simple 2 box version of the North Atlantic; the second is the full Atlantic model. The following basic description is valid for all the models we are formulating. Each model is defined by a set of simultaneous linear equations which are solved using a Gauss-Markov type tapered weighted least squares (Wunsch, 1996; Ganachaud, 1999; Macdonald *et al.*, 1998). Keeping in mind that not all equations include all terms, the general equation which is formed from observed variables describes conservation of a property within a density layer or set of layers and has the form:

$$\begin{aligned}
 & \sum_s \sum_{i,j=U}^L \rho_{sij} \mathbf{a}_{sij} C_{sij} \mathbf{v}_{si_R} - \sum_m \mathbf{E}_s \sum_i \sum_{k=U_E}^{L_E} \rho_{sik} \mathbf{a}_{sik} C_{sik} \mathbf{v}_{sik_E} - \mathbf{w}_U A_U C_U + \mathbf{w}_L A_L C_L \\
 & + \mathbf{k}_{zU} A_U (\partial C_U / \partial z) - \mathbf{k}_{zL} A_L (\partial C_L / \partial z) + \mathbf{VJ} \qquad \qquad \qquad \text{Equation 1} \\
 & \approx - \sum_s \sum_i \sum_k \rho_{sij} \mathbf{a}_{sik} C_{sij} \mathbf{v}_{sij_G} - \sum_s \sum_i \sum_k \rho_{sik} \mathbf{a}_{sik} C_{sik} \mathbf{v}_{sik_E}
 \end{aligned}$$

where in this equation, for clarity, the unknown values are in boldface type; i, j and k are indices to the station pairs, CTD pressure surfaces in the layer(s) and in the associated Ekman layer, respectively; s represents the indices to each segment (i.e. box side or portion of a box side); ρ is *in situ* density; \mathbf{v}_R , \mathbf{v}_E , and \mathbf{v}_G are the unknown reference, known geostrophic and initial Ekman velocities, respectively; $C_{i,j,k}$ and $C_{U/L}$ are the average property concentration or concentration anomaly at pressure surface for a pair and on a density interface, respectively; A & a are the horizontal and vertical layer areas; \mathbf{E} are Ekman correction factors defined for each segment; \mathbf{w} , \mathbf{k}_z are diapycnal velocity and diffusivity terms; U, L indicate upper and lower bounding density interfaces; \mathbf{J} are layer source/sink terms and V is the volume of the layer.

Most of the available measured properties (Table 1) from each hydrographic line (obtained from WHPO, now CCHDO, <http://whpo.ucsd.edu/whpoatlantic.htm> or from CDIAC/GLODAP (Carbon Dioxide Information Analysis Center/Global Ocean Data Analysis Project (Key *et al.*, 2004, Lee *et al.*, 2003) have been included in the quality control procedures and retained for use within the inversion or for analysis of absolute property transport. In general, the constraints which are applied to the data include conservation of top to bottom mass and silica, layer volume, layer salt and heat anomaly (Wijffels 1993; Ganachaud 1999, 2000) and some form of conservation of oxygen/phosphate. Currently, the latter is applied as a Redfield coupling, *i.e.*, \mathbf{J}_{ox} is substituted by \mathbf{J}_{ph} assuming Redfield ratios (Redfield, 1963) with P:O₂ = 1:170 (Anderson and Sarmiento, 1994). To complete the model we supply along with the initial estimates of the unknowns, initial estimates of the (co)variance in the solution and the constraints.

ACCOMPLISHMENTS

6. *The North Atlantic Model*

Our initial model was simple, *i.e.*, it contained no meridional lines, and therefore, was not subject to crossover issues. Focused on the North Atlantic, its two boxes are defined by data sets taken over a time period spanning less than one year between 1997 and 1998 across 24°N, 47°N, and nominally 57°N, between Newfoundland and Greenland and between the Hebrides and Greenland. Each of these lines is a repeat of a previous section occupied in the early 1990s. A comparison (as done for 24°N) of the early 1990's to late 1990's fields of TIC, Cant and other carbon related parameters is being done as part of this project. We use this model testing purposes. Its results helping us understand the effect of the meridional data used in the full model.

For the North Atlantic model using a basic set of conservation constraints (as described above), and initial reference surfaces as defined by Macdonald *et al.* (2003) at 24°N and from averaged float velocities across most of the two northern latitudes, a TIC flux across 24°N is suggested which is not significantly different from the previous estimate using the 1998 24°N data alone (Figure 2). As expected and more importantly, however, the uncertainties have been reduced by half from those found using a single line model at 24°N (Macdonald *et al.*, 2003). At 57°N, our estimate of net TIC transport and uncertainty is surprisingly similar to previous findings given that different data sets and different analysis techniques were employed. At 47°N, the model produced the interesting result of a very strong southward transport of TIC ($2.1 \pm 0.7 \text{ PgCyr}^{-1}$) implying that strong uptake of carbon is occurring further north than originally expected, and that the outgassing within the subtropics which may be (depending on which 24°N value you choose to believe) nearly as strong. This model also suggests a relatively weak northward transport of Cant across 47°N.

These results are affected by the strong variability at the western end of the 47°N transect. We are currently working on basing our reference levels and transport field for this region on the mooring data results of Schott *et al.* (2004) and the repeat transect work of Lumpkin and Speer (2003) and Lumpkin *et al.*, 2006, however, none of the different referencing schemes we have attempted thus far have had a significant effect the results large southward transport of TIC across 47°N. What we have found is that the inclusion of constraints based on the conservation of phosphate and oxygen (1:170, Anderson and Sarmiento, 1994), significantly reduces the 47°N TIC transport value. This result is shown in the next section.

7. *The Full Atlantic Model*

When combined, the variety of TIC transport estimates in Figure 2 suggest there may be substantial uptake of CO₂ to the north of 24°N and outgassing to the south (Roson *et al.*, 2002; Alvarez *et al.*, 2003). However, except for the Holfort's (1998) values in the South Atlantic and the values provided by the North Atlantic model described above, all the estimates come from independent studies and include no guarantee of consistent physics and assumptions. To provide a physical consistent vision of the Atlantic circulation using the available data we have created a full Atlantic model (Figure 1).

The one time coverage is decent (Table 1), however, not all the stations include TIC or Cant estimates. Since in the initial runs we are not including direct constraints on these properties, it is not necessary that they exist everywhere. We chose only to examine results where data is

available rather than mapping data to cover gaps. Our reasoning is that as we are looking for sources and sinks, and we need to be careful not to create or remove what we are looking for through mapping errors.

The meridional lines running across the equator will not be used. In the equatorial regions, estimation of synoptic geostrophic velocities is problematic. We initially looked to handle this issue in the same manner as was done for the large Pacific inversion of Toole and Robbins through the use of direct velocity of measurements within the 2°S–2°N latitude band. In the Pacific inversion these are time averaged underway ADCP absolute velocity profiles which are mapped to the mid-point positions between station pairs and used as the initial guess in place of the geostrophic estimates. However, in the Atlantic, coverage will not allow for the same technique to be used (G. Johnson pers. comm.).

The full Atlantic model is currently made up of about “small” 40 boxes (Figure 1), 10 large boxes (defined by the zonal transects, Figure 3) and a super box which constrains the entire basin. We will choose to combine some of the smaller boxes if it is found that aliasing of spatial and temporal variations causes the model to produce unrealistic flow patterns. Within this system the “large” boxes (Figure 3) used in conjunction with the “small” boxes (Figure 1) act to hold the constraints together and keep the noise in the small boxes from overwhelming the full solution. Comparing the carbon data along the zonal lines (Figure 4), one can see the high TIC values in the upper waters of the tropics where upwelling of deep older waters occurs, low TIC values in the deep north due to the water formation and higher values as depth to south where abyssal waters are older. In the anthropogenic carbon (Cant) profiles one can again see the effect of ventilation in the high deep values in the north and the high to low intermediate water values in both hemispheres as one moves from the poles to the equator.

The full Atlantic model combines the WOCE-era data in a physically consistent fashion and presents a rather different picture (Figure 5) of present day TIC oceanic transport and divergence. In particular, because it includes conservation P:O₂, the transport of TIC across the 24°N transect is vastly reduced, removing completely the sense that there is strong uptake in the subpolar North Atlantic. The model also includes constraints requiring conservation of TIC made possible because the model includes air-sea flux terms. Combining the transport estimates with the air-sea flux estimates (Figure 6) provides more a complete picture of the meridional circulation of TIC. Most notably, there is a strong southward transport of TIC from the northern hemisphere across the equator supplied in part by a substantial uptake of carbon from the atmosphere between 47°N and 24°N. There is also strong uptake in the southern ocean south of 30°S. As might be expected, outgassing occurs in the boxes surrounding the equator. The interior source/sink terms are small compared to the air-sea exchange terms and some effort still needs to be made to understand their magnitude and to investigate possible vertical structure in their patterns.

Anthropogenic carbon (Cant) is not available along all the lines and so presents a less complete picture. However, what is abundantly clear in Figure 7 is 1) the pattern of a general northward flow of Cant throughout the Atlantic Basin, 2) some disagreement as to the magnitude of the Cant transport, particularly in the Northern Basin, but 3) the sense that the Cant transport estimates are still small compared to the TIC estimates indicating that without temporal changes in circulation (which are possible) Cant is not yet going to reverse the sense of the Atlantic carbon transport compared to its pre-industrial state.

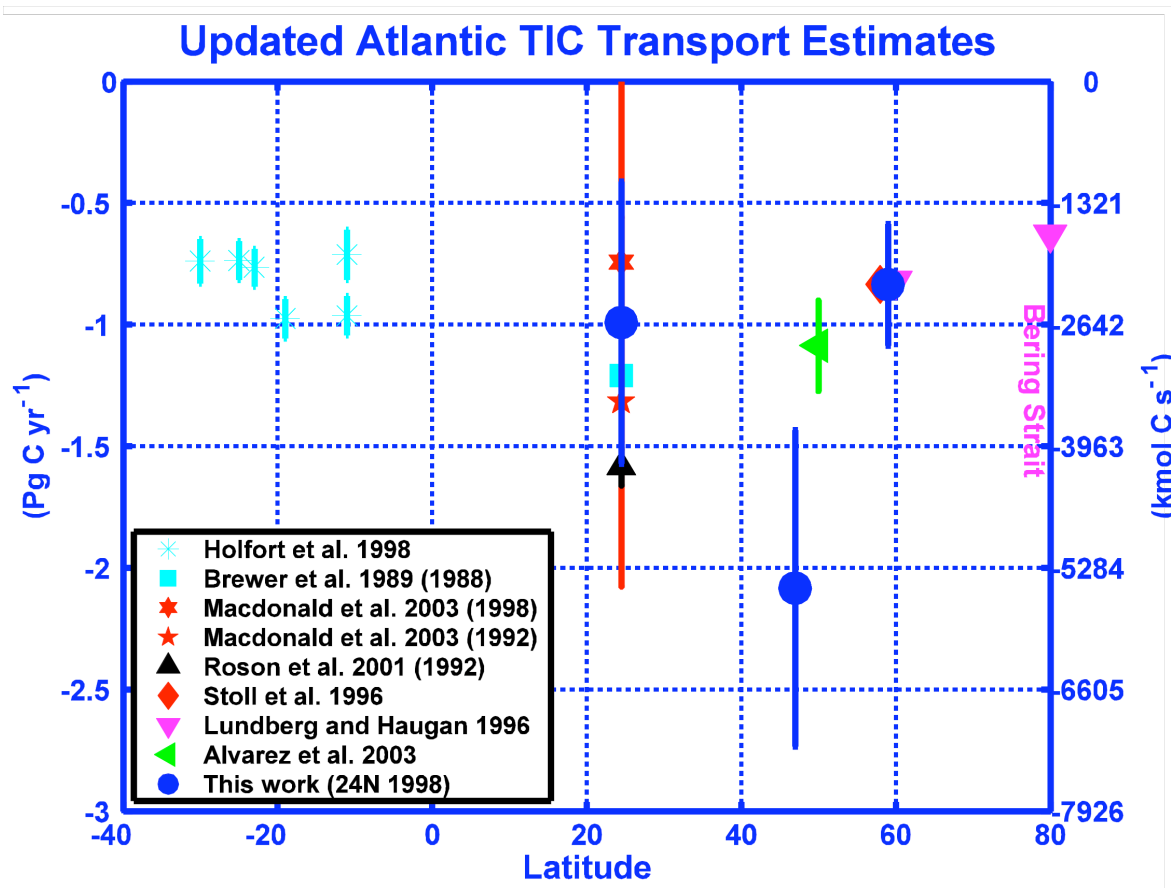


Figure 2. TIC transport from various independent studies as a function of latitude in the Atlantic. The net flux through Bering Strait and the Arctic is included in all the estimates. The legend dates in parenthesis indicate the transect year of occupation for the 24°N data used in the particular studies.

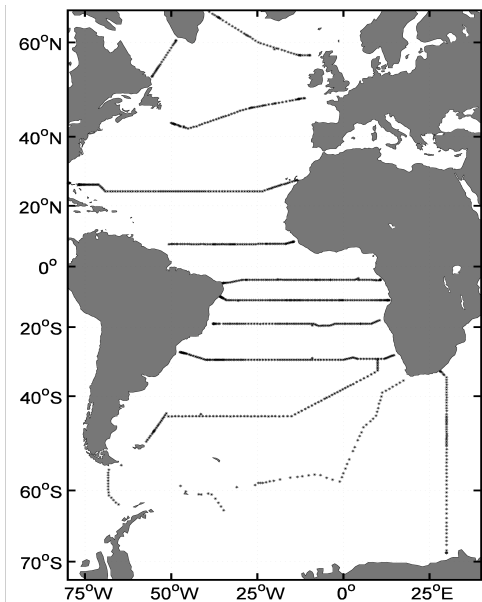


Figure 3. The 10 large boxes defined by the zonal transects along with the meridional lines between Antarctica and South Africa, and Antarctica and South America.

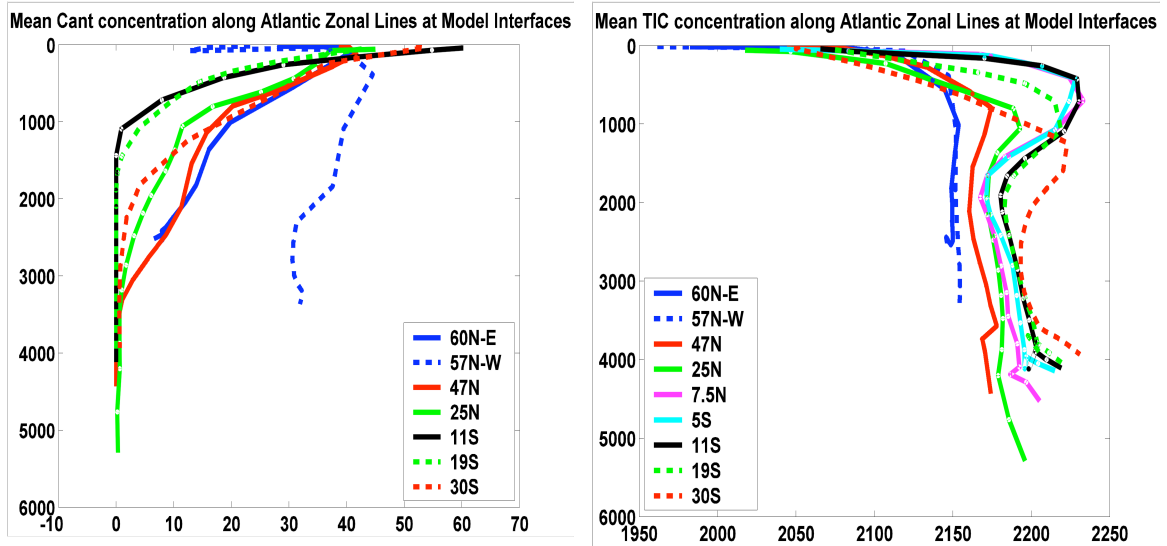


Figure 4. Zonally averaged anthropogenic (left panel) and total inorganic carbon (right panel) Units $\mu\text{moles/kg}$.

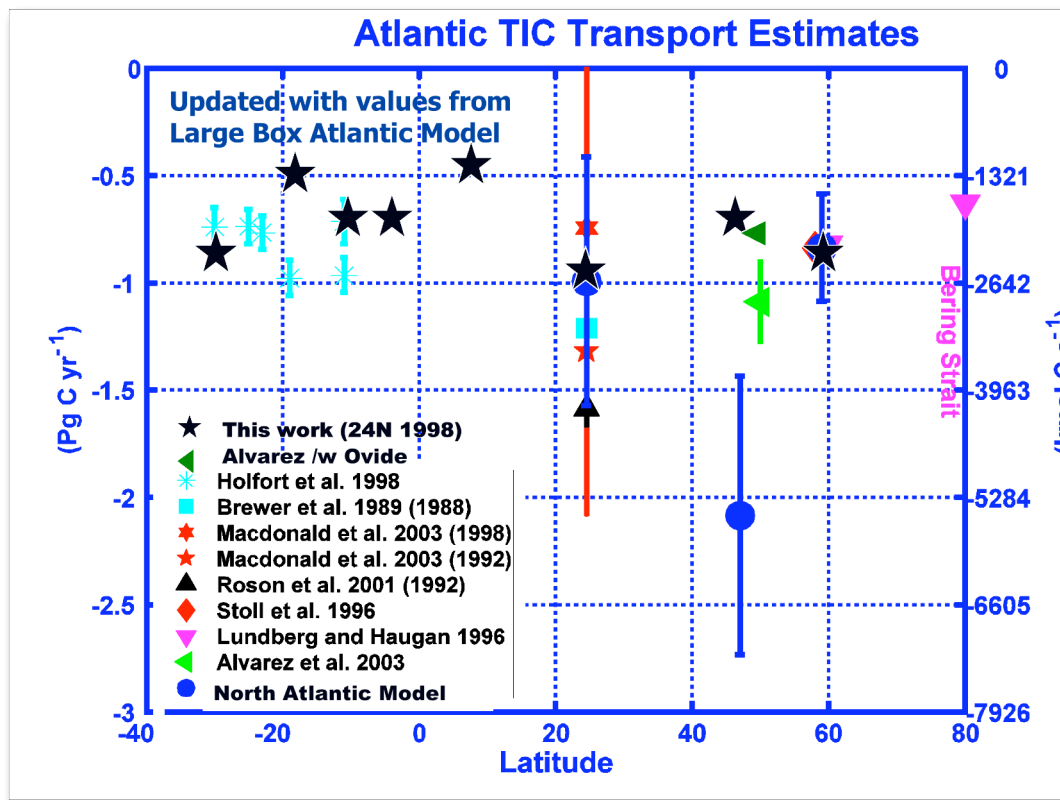


Figure 5. Same as Figure 2, but including estimates of meridional TIC transport from the full Atlantic model (black stars).

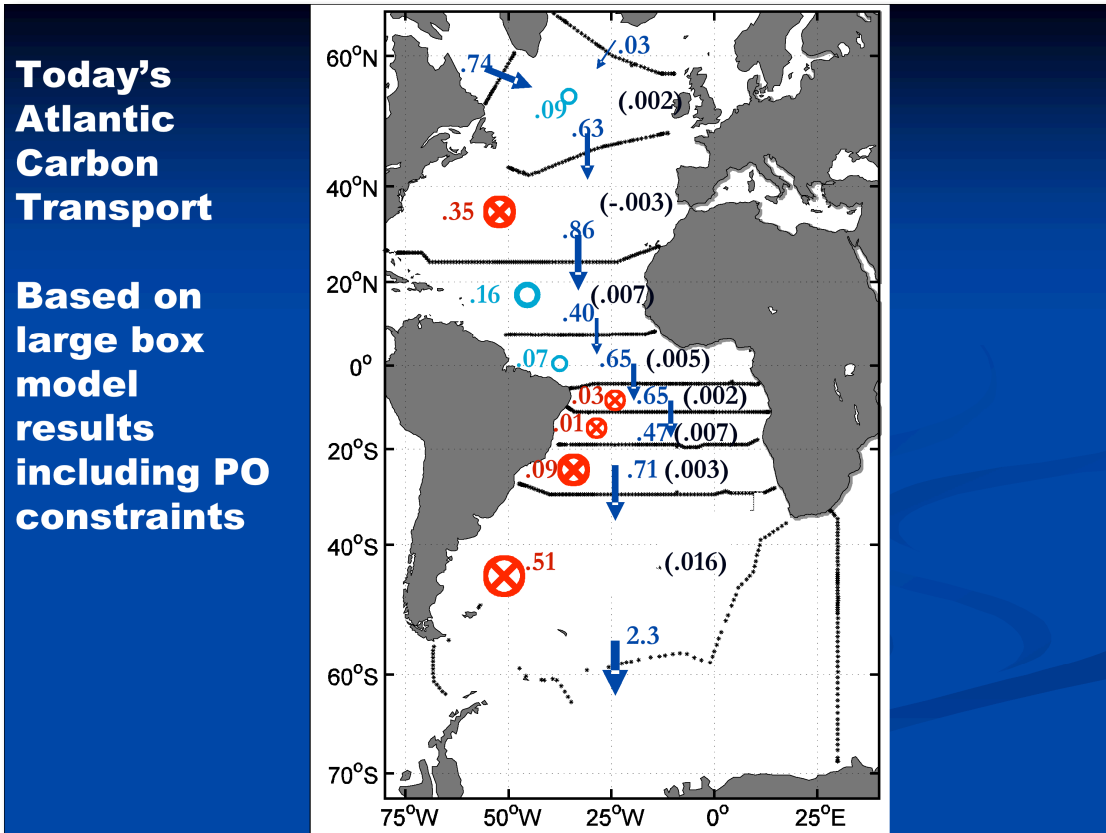
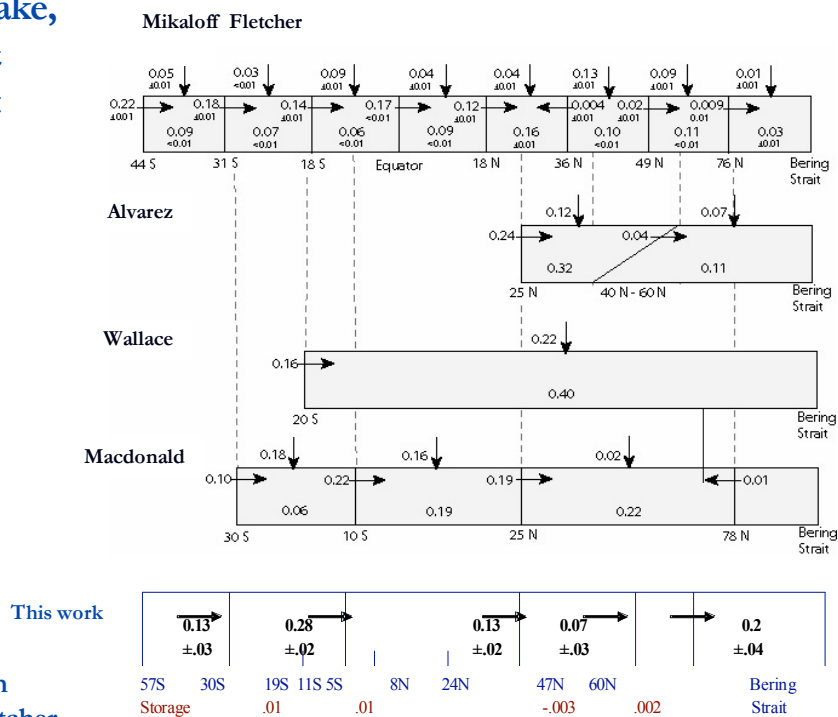


Figure 6. The TIC balance in the large boxes accomplished through meridional advection (blue arrows and numbers), air-sea exchange (outgassing light blue circles and numbers, uptake red arrow tails and numbers) and other processes (e.g. respiration and remineralization) represented in the model as interior source sink terms (black values in parentheses).

Cant Uptake, Storage & Transport



Adapted from
Mikaloff Fletcher
et al. (2006)

Figure 7. Estimates of uptake, storage and transport of Cant within the Atlantic (PgCyr^{-1}) from the present study, Mikaloff-Fletcher et al. (2006), Alvarez et al. (2003) using 24°N values from Roson et al. (2003), Wallace (2001) using Holfort et al. (1998) values, Macdonald (2003) which includes both the Holfort et al. (1998) values and those of Lundberg and Haugan (1996). The figure is adapted with permission from Mikaloff-Fletcher et al. (2006).

PUBLICATIONS

Publications and presentations to date derived partially, if not wholly from NOAA grant 37122326 include:

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

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

Macdonald, A. M., North Atlantic CO_2 transport and divergence, Invited talk, EGU Meeting, Nice, France, 2004.

Also presented at the Cooperative Institute for Climate and Ocean Research (CICOR) Executive Board Meeting, WHOI, May, 2004.

Extended version given at the Wednesday PO lunch seminar in October 2004.

- Macdonald, A. M., Oceanic CO₂ Transport, Divergence and Air/Sea Exchange in the North Atlantic, 2nd Annual CARINA general meeting and open science conference, 2003. Also presented at the NSF NACP PI Meeting, May 2003.
- Macdonald, A. M., M. O'Neil Baringer, D. W. R. Wallace and R. Wanninkhof, Carbon Transport at 24.5°N in the Atlantic, Presented by R. Wanninkhof at the CIMAS external review, 2003.
- Macdonald, A. M., CO₂ Transport and Divergence in the North Atlantic, Seminar at AOML in Miami, March 2005.
- Macdonald, A. M., Ocean Carbon Transport, talk presented at the CARBOOCEAN data synthesis workshop in Laugarvatn, Iceland June 2006

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SUMMARY OF INTERACTION WITH NOAA

I have had little specific recent interaction with NOAA on this project although I do stay in contact with R. Wanninkhof and M. Baringer at AOML. I also recently discussed these results with R. Feely at (PMEL)

Summary of Education and Outreach Activity

Over the past year I was in contact with teachers from three different Massachusetts middle schools over the past year, but was unable to make dates to actually visit the classrooms. Nevertheless, I have stayed involved with COSEE New England. I have attended two Telling Your Story (TYS) workshops (one at the Univ. of CT, the other at Univ. of Mass. Boston). At the former I participated as a panel member and at the latter I also gave an example TYS presentation to a group of Boston middle school students. I have also agreed to join the COSEE New England team.

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, 2005

Dr. Dennis J. McGillicuddy, Jr.

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Program Manager: Dr. Elizabeth Turner, NOAA

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 will conduct an initial workshop 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 will define a set of papers to be composed for a refereed journal. A subset of participants will begin planning a specific Model Intercomparison and Evaluation Project (MIEP). A second workshop will reconvene the participants to present the papers and synthesize the results. The MIEP working group will prepare an implementation plan, and contribute an accompanying paper.

ACCOMPLISHMENTS

The first workshop for Skill Assessment for Coupled Biological/Physical Models of Marine Systems was held at the Friday Center in Chapel Hill NC, July 11-13, 2006. The attendance list is posted on the project website¹. The first 1.5 days were spent in plenary. The .ppts used and the 1-page summaries of each are posted in a password-protected area of the project website. In the evening of Day 1 an informal discussion was held concerning prospects for a Model Intercomparison and Evaluation Project [MIEP]. That discussion continued throughout the workshop. In the second day the group broke into pre-determined discussion groups:

- HABs
- Ecosystems and Fisheries
- Carbon Cycling
- Water Quality

Reports from these 4 groups are posted on the project website.

¹ http://www-nml.dartmouth.edu/Publications/internal_reports/NML-06-Skill

On the third morning the group assembled to consider ‘cross-cutting issues’ selected in plenary:

- Skill Metrics
- Data Assimilation
- Error Models
- Intercomparison Exercises

Reports from the 4 groups are on the website. The continuing coordinated activities are:

- a) Skill Metrics: There was wide concurrence on the need for unifying group products, with Matlab and Fortran toolkits, bibliography, etc. Dennis McGillicuddy will focus this continued development.
- b) Data Assimilation: There was consensus on the need for a unifying group exposition of key concepts; yet details on how this would be carried forward remain to be resolved. Recent reviews by Robinson and Lermusiaux and by Hoffman and Friedrichs (The Sea, 2002) may have already achieved what is needed here; others are sought. Watson Gregg volunteered to initiate a draft for early distribution to the entire group with help from Alan Robinson, Marjy Friedrichs, Keith Thompson, Charlie Stock, and others.
- c) Error Models: Consensus emerged that this item needed group clarification; that it overlaps with Data Assimilation needs; and that a single composite group (DA + Error Models) should carry this forward to the next workshop in the form of a single workshop document. The charge to Watson’s group (above) is expanded accordingly.
- d) Intercomparison Exercises: The report from this group is on the website. Additional activities would have to be explored before an exercise can be properly defined. The working group reports on this topic to discuss issues and desirable attributes of such exercises; they may be shared in wider, project – oriented circles for implementation. Enrique Curchister will circulate some ideas in the USGLOBEC community and keep the present ‘Skill’ community informed.

Project timeline

A key concern is the coordination exhibited between individual papers and the front-matter synthesis of terminology. The timeline below includes the following elements: (1) accelerated progress on cross-cutting topics (including terminology) so draft materials will be available to authors as they compose their individual manuscripts; (2) authors are expected to circulate (subject to editorial discretion) completed drafts of their individual manuscripts prior to the second workshop; (3) the primary goal of the second workshop is to synthesize and coordinate all of these contributions. The following schedule is recommended:

Cross-cut work products (DA, Skill Metrics) to be reported to editors and circulated to all; editors to begin synthesis of same. **1 November 2006**

Editors complete 1st draft of front-matter synthesis and distribute same to workshop participants.

1 February 2007

Authors complete 1st draft of individual papers; editors to post these to website (password-protected) unless authors request otherwise. **15 February 2007**

Authors' Workshop 2: **March 2007**

Final papers complete and submitted to editors for review **1 April 2007**

External Peer Review of papers begins **1 April 2007**

Publication **late 2007 / early 2008**

SUMMARY OF INTERACTION WITH NOAA

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

U.S. Research Vessel Surface Meteorology Data Assembly Center

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 356
July 1, 2004 through June 30, 2005

Dr. James J. O'Brien, Shawn R. Smith, Mark A. Bourassa

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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 implemented an automated method of transferring observations from vessels at sea to the DAC for quality evaluation and distribution. In addition, the DAC continues delayed mode quality evaluation of observations from the *Ronald Brown* and *Ka'Iimimoana*. 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. SAMOS are 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 are 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 will result in a "research" quality SAMOS product. Plans are

being developed to provide distribution services for the quality controlled data in formats that meet user needs and to ensure that the original and quality controlled data are submitted to several world data center archives.

ACCOMPLISHMENTS

Over the past year our efforts have focused on the continued development of the SAMOS Initiative. We wrapped up a successful data exchange pilot project with WHOI and now are receiving routine data transmissions from the *Knorr* and *Atlantis* while they are at sea. We continued to expand our SAMOS data quality evaluation system and have improved access to both preliminary data files and metadata on our web pages. Throughout the year DAC personnel have been actively promoting the SAMOS Initiative through meetings and working groups, and in May 2006 the DAC coordinated the 1st Joint SAMOS/GOSUD Workshop in Boulder, Colorado (with supplemental funding from NOAA/OCO). Finally, we continue our delayed mode data processing for NOAA vessels and are actively recruiting additional vessels to participate in SAMOS.

1. *Daily processing of Knorr and Atlantis data*

The DAC completed development of the preliminary processing of SAMOS observations received via daily email messages from participating research vessels. Currently two vessels, the *Knorr* and *Atlantis*, have automated their transmission of daily data messages (which include all one minute average observations for the day) to the DAC. The data messages are generated on each vessel by scripts developed by the vessel operators. Once the data file arrives at the DAC (as an attachment to an email), the data are unpacked, verified that they conform to the format and parameters expected for the individual vessel, and finally 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 to the file being posted for users on the web and ftp. 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).

The spatial distribution of data received, processed, and on-line from the *Knorr* and *Atlantis* is shown in Figure 1. Each individual data file has been augmented with extensive metadata that is stored in a ship profile database. In addition, each file is tracked throughout the process and individual data quality statistics are stored in a file tracking database. Strict version control is used to track individual data files received from their original email attachment to the preliminary netCDF files posted for users.

2. *Delayed-mode SAMOS processing*

The initial processing of SAMOS observations is completed in near-real time (see 1 above). Due to data logging problems on the ship or communication drop-outs, 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 can be fragmented and may arrive as multiple files attached to an 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.

Over the past six months, the code to merge multiple files has been developed, tested, and is 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 data base. 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. In the near future, we will begin visual data quality inspection of the merged files for all available data (Figure 1). Once visual inspection is completed, the delayed mode, research quality files will be distributed and archived.

3. *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*. Over the past year the DAC has received and processed *Ronald Brown* observations for the periods May 2004 – March 2005 (Rolph and Smith 2005) and July 2005 – November 2005 (Rolph and Smith 2006). We continue to see improvements in the quality of the meteorological observations from the *Ronald Brown* and these data make up an extensive (1999-2005) data set for a wide array of satellite and model validation studies. To date we have not received any data for cruises in 2006. The data for the *Ka’Imimoana*

tend to arrive in multiple data formats which complicates their conversion for quality processing. We recently converted observations for September 2004 - December 2005 which will undergo visual quality inspection shortly. Additional data for the *Ka'imimoana* arrive on a regular basis.

4. *Public access to observations and metadata*

A web presence for SAMOS has been completed and 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 the *Knorr* and *Atlantis*. 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. Tools are being tested to allow users to construct quick time lines of available data for each vessel. In addition, both graphical and tabular displays of data quality evaluation statistics are being developed. These new tools will be added to the web site for users when testing is complete.

5. *Vessel recruitment*

Recruitment of additional vessels to participate in the SAMOS Initiative has been an ongoing, albeit slow, process. Co-PI Smith attended the annual UNOLS RVTEC meeting in Oregon last fall and had good conversations with several vessel operators. Most expressed interest in participating, but initiating new data transfers is still difficult in these times of tight operational budgets for research vessels. This past spring a plan was established with NOAA OMAO to use a new fisheries vessel, the *Bigelow*, as a pilot vessel to establish SAMOS data transfers from NOAA vessels. Most NOAA vessels are equipped with the scientific computing system (SCS) software and the latest version of SCS will be installed on the *Bigelow*. The new SCS will facilitate SAMOS data transfers and once tested can then be spread to other vessels in the NOAA fleet. We anticipate that our collaboration with OMAO will bring several NOAA vessels into the SAMOS Initiative over the next year. In addition to the NOAA vessels, a dialog is underway with several other UNOLS operators and the International SeaKeepers program to bring additional vessels into the SAMOS Initiative.

6. *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 among these activities was the coordination of the 1st Joint 1st Joint Global Ocean Surface Underway Data (GOSUD)/Shipboard Automated Meteorological and Oceanographic System (SAMOS) Workshop held in Boulder, CO on 2-4 May 2006. Although separate NOAA funds supported the travel, logistics, and venue for the workshop, all planning of the scientific

program, pre- and post-meeting documentation, and the workshop web page (http://www.coaps.fsu.edu/RVSMDC/marine_workshop3/) were supported by the DAC. The workshop focused on establishing collaboration between GOSUD and SAMOS and addressing the need of the research and operational community for high-quality underway oceanographic and meteorological observations from ships. The SAMOS initiative is working to improve access to calibrated, quality-controlled, surface marine meteorological data collected in-situ by automated instrumentation on research vessels (primarily) and merchant ships. GOSUD focuses on the collection, quality evaluation, and distribution of near surface ocean parameters (salinity and sea temperature) from vessels.

The workshop organizing committee (Shawn Smith, Robert Keeley, Thierry Delcroix, Mark Bourassa, and Christopher Fairall) brought together representatives from the scientific and operational marine observational communities. Participants from the U.S. government represented NOAA (ESRL, AOML, NDBC, NODC, OMAO), the Army Cold Regions Laboratory, and the U.S. Coast Guard. The U. S. university community was represented by the Woods Hole Oceanographic Institution, the Scripps Institution of Oceanography, the University of Miami, University of Alaska, Oregon State University, the National Center for Atmospheric Research, and the Florida State University. A significant international presence included representatives from the CSIRO (Australia); CNRS, IRD, IFREMER, and Mercator Ocean (France and New Caledonia); Environment Canada and MEDS (Canada); Tokai University and JAMSTEC (Japan); and the NOC (UK). Finally, the private sector was represented by Raytheon Polar Services, ADA Technologies, Earth and Space Research, and the International Sea Keepers Society.

The workshop was organized in three sessions: (1) parallel SAMOS and GOSUD technical working group meetings, (2) invited talks and posters focusing on applications of SAMOS and GOSUD observations and potential collaborations between marine observing programs, and (3) a plenary discussion encompassing sessions (1) and (2). A primary discussion topic was the scientific user needs for high-quality, automated, near-surface ocean and atmosphere measurements to achieve objectives ranging from satellite calibration and validation, ocean data assimilation, polar studies, air-sea flux estimation, and improving analyses of waves, precipitation, and radiation. The quantification and reduction of measurement bias and uncertainty was also addressed. The SAMOS and GOSUD working groups addressed both issues internal to each program as well as future interaction between SAMOS, GOSUD, and other international marine observing programs. The result of the workshop was a series of action items, recommendations, and reports (Smith 2006).

Additional collaborative activities are promoted by the SAMOS DAC. Colleagues at NOAA/ESRL/PSD and WHOI are working to develop a portable seagoing air-sea flux standard instrument suite. This system will be deployed on UNOLS and other research vessels to assess the accuracy of the SAMOS installations on those vessels. Once deployed recommendations for improving SAMOS on individual vessels can be made. The SAMOS DAC continues to promote the development of training materials for marine technicians and scientists planning to make meteorological measurements at sea. The first achievement of the training effort will be the publication of a "Guide to making climate quality meteorological and flux measurements at sea". Lead authors of the guide are Frank Bradley (CSIRO, Australia) and Chris Fairall (NOAA/ESRL/PSD) and the guide has been a collaborative effort of the SAMOS initiative and the WCRP Working Group on Surface Fluxes. A new collaboration with the National Oceanography Centre (UK) and NOAA/ESRL will allow the SAMOS Initiative to

undertake a program of computational fluid dynamics (CFD) modeling of research vessels. The primary focus of the CFD modeling is to identify the accelerations/decelerations of the wind flow over the vessel structure, allowing sensors to be moved to the “best” possible exposure on the vessel. The program will evaluate existing techniques and new methods to model the maximum number of vessels for the lowest cost.

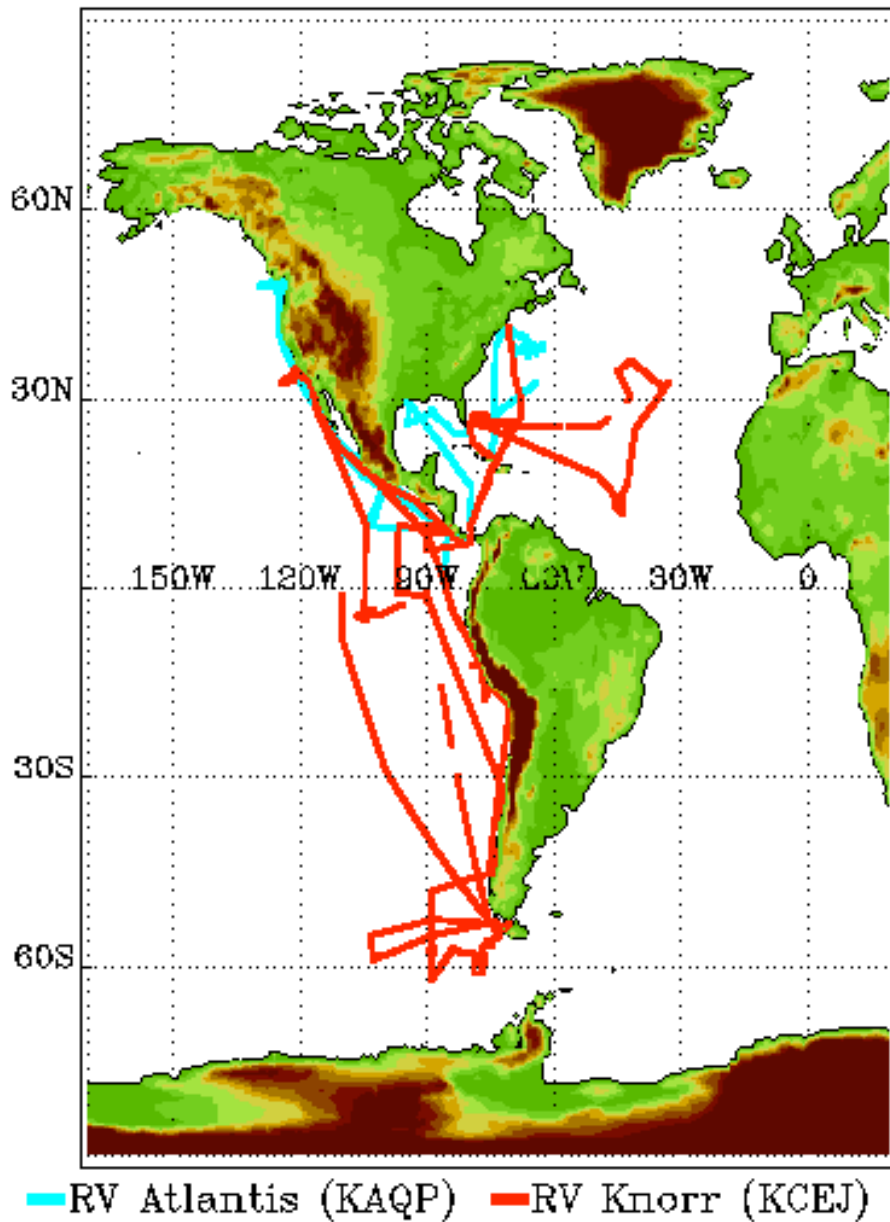
7. *SAMOS vs. bridge data comparisons*

A preliminary comparison was completed between marine meteorological observations that currently are available in the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) and those collected by automated science instrument systems on a dozen research vessels (R/Vs). Research vessels are typically equipped with both an automated science instrument system and a set of independent sensors used by the bridge crew for routine weather reports. The routine bridge reports are the typical source of observations in ICOADS and tend to be reported at one, three, or six hourly intervals. Hourly observations, derived from one-minute interval science system data, are used to evaluate the ICOADS reports from each R/V.

For this experiment, comparison data come from a dozen R/Vs that participated in the World Ocean Circulation Experiment. The comparison reveals large differences in temporal coverage provided by the bridge and science reporting systems on R/Vs. For the vessels examined, a large fraction of the bridge observations do not routinely appear in ICOADS (Figure 2). Using standard statistical techniques, differences in atmospheric pressure, sea and air temperature, humidity, and true wind direction and speed are examined. In some cases, large differences exist between bridge and science observations on individual vessels (Figure 3). Using available metadata (e.g., instrument heights, varying data sources in ICOADS, etc.) we will next consider possible causes for observed differences between the bridge and science observations and their impact on turbulent air-sea fluxes.

FIGURES AND IMAGES

SAMOS data received daily
2005 – 2006



plot created Thu Aug 3 13:22:58 2008

Figure 1. Cruise tracks for the Knorr and Atlantis for which SAMOS data were received, processed, and distributed by the DAC. The period of record is May 2005 through July 2006. A total of 760,948 individual one-minute marine reports are available.

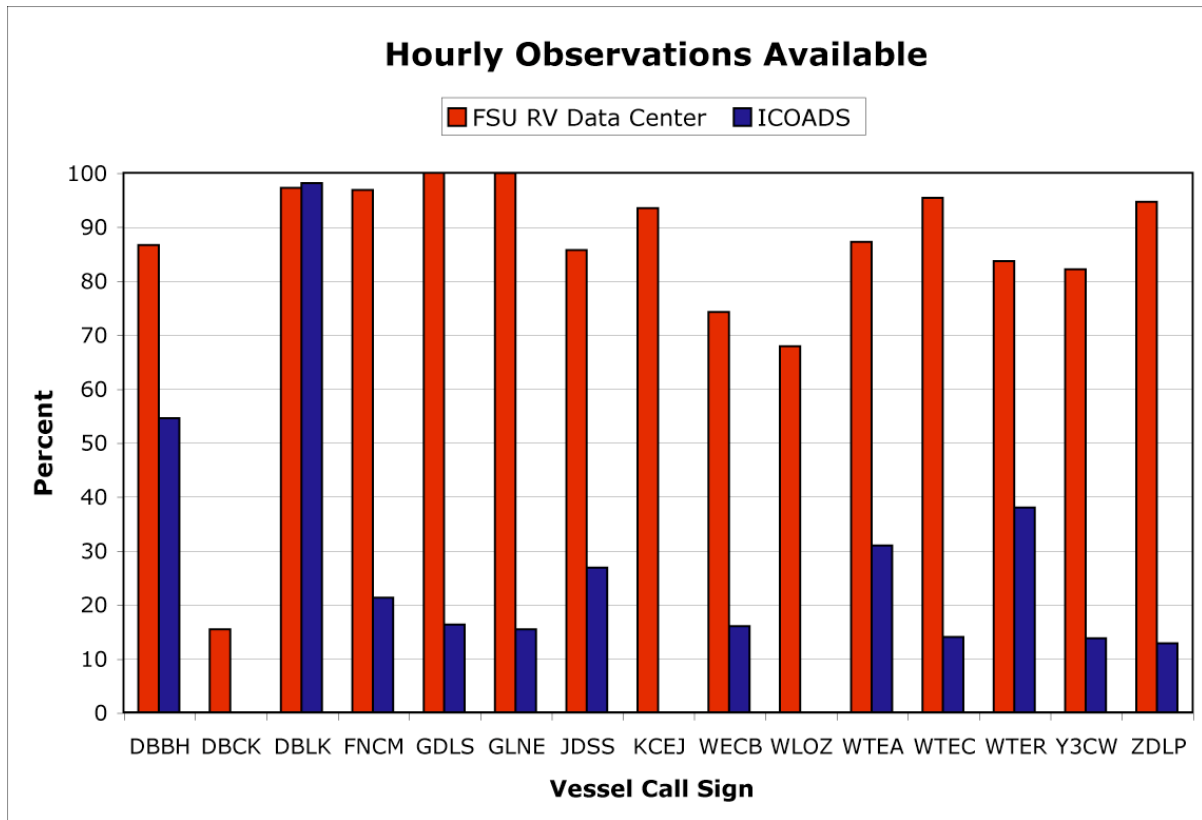
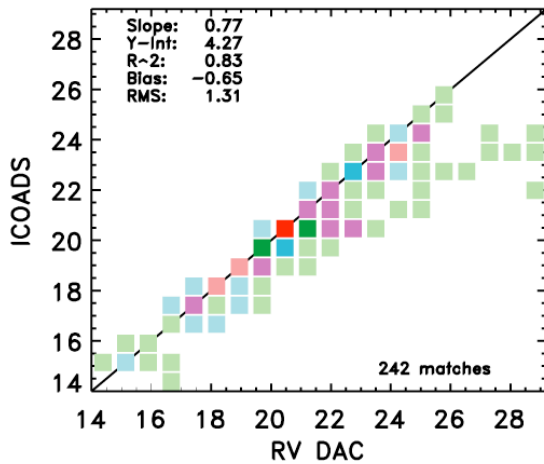
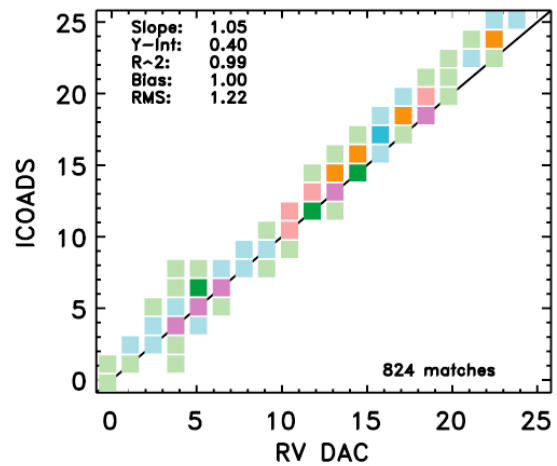


Figure 2: Percentage of hourly marine reports available during 90 WOCE cruises from the ICOADS (bridge) and FSU R/V data center. Vessels evaluated include the *Meteor* (DBBH), *Heincke* (DBCK), *Polarstern* (DBLK), *L'Atalante* (FNCM), *Charles Darwin* (GDLS), *Discovery* (GLNE), *Hakuho Maru* (JDSS), *Knorr* (KCEJ), *Melville* (WECB), *Maurice Ewing* (WLOZ), *Discoverer* (WTEA), *Ronald Brown* (WTEC), *Malcolm Baldrige* (WTER), *A. von Humboldt* (Y3CW); and the *James C. Ross* (ZDLP).

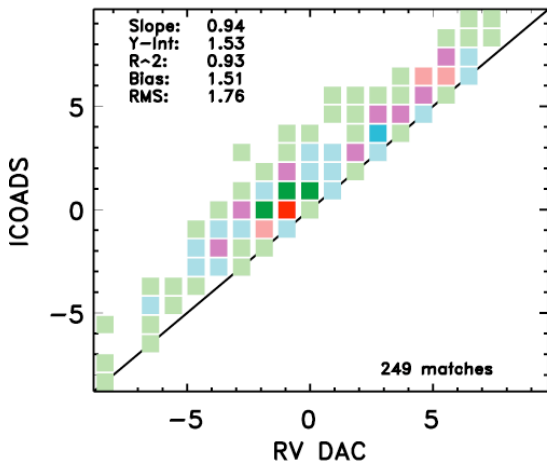
Air Temperature *A. von Humboldt*



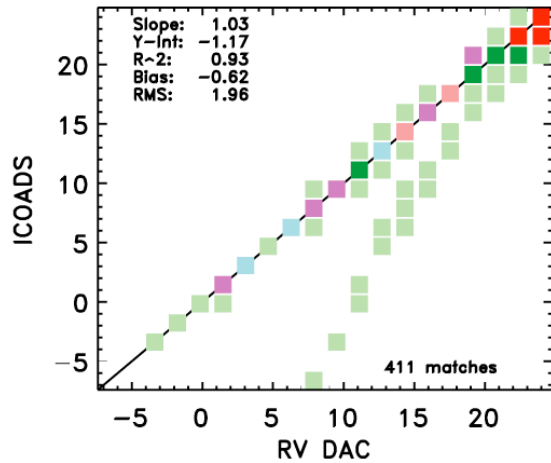
Dewpoint Temperature *Heincke*



J. C. Ross



Hakuho Maru



0 1 2 3 4 5 6 7 >8 %

Figure 3: Comparison histograms for unadjusted air (left) and dewpoint (right) temperature ($^{\circ}\text{C}$). Histograms represent the percentage of one-to-one matches that fall within each bin on the graph (similar to a scatter plot). Each graph is divided into 20 equal bins on the x and y axis. Percentages are calculated relative to the number of matches for each variable (lower right on each plot). Plots are labeled with the vessel that provided the observations.

PUBLICATIONS

Refereed

- Smith, S. R., 2006: A Partnership between Shipboard Oceanic and Atmospheric Data Programs. *EOS, Trans Amer. Geophys. Union*, submitted.
- Gould, W. J and S. R. Smith, 2006: Research vessels: Underutilized assets for climate observations. *EOS, Trans Amer. Geophys. Union*, **87**, 214-215.

Technical reports

- Rolph, J. J., and S. R. Smith, 2005: *Ron Brown IMET data quality control report: May 2004 – March 2005*. RVSMDC report 05-04, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 14 pp.
- Rolph, J. J., and S. R. Smith, 2006: *Ron Brown IMET data quality control report: July 2005 – November 2005*. RVSMDC report 06-02, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 15 pp.

Conference proceedings/presentations

- Bourassa, M. A., 2006: Uncertainty in monthly surface wind fields from in situ observations. *1st Joint GOSUD/SAMOS Workshop*, May, Boulder, CO.
- Bourassa, M. A., and P. J. Hughes, 2006: Hybrid surface turbulent fluxes model. *3rd SEAFLEX Workshop*, March, Tallahassee, FL.
- Bourassa, M. A., 2005: New insights into how wind influences stress, and resulting implications to equivalent neutral winds and wind retrieval, *Ocean Vector Wind Science Team Meeting*, March, Seattle, WA.
- Bourassa, M. A., 2005: On the important differences between earth-relative winds and equivalent neutral winds. *Scatterometer High Wind Model Function Meeting*, July, Pasadena, CA.
- Bourassa, M. A., 2005: Wave Influences on Surface Turbulent Fluxes. *2nd International Workshop on Advances in the Use of Historical Marine Climate Data (MARCDAT-II)*, October, Exeter, U.K.
- Smith, S. R., 2006: Progress of the Shipboard Automated Meteorological and Oceanographic System (SAMOS) initiative. *Short Abstract, Climate Observation Program 4th Annual System Review*, Silver Spring, MD, USA, NOAA (in press).
- Smith, S. R., 2006: A Comparison of SAMOS and Bridge Observations on Research Vessels, *1st Joint GOSUD/SAMOS Workshop*, Boulder, CO, NOAA Office of Climate Observation, in press.
- Smith, S. R., S. D. Woodruff, and S. Worley, 2005: Marine climatology from research vessels. Abstracts from *2nd International Workshop on Advances in the Use of Historical Marine Climate Data (MARCDAT-II)*, Exeter, UK, in press.
- Smith, S. R., 2005: Progress of the shipboard automated meteorological and oceanographic system (SAMOS) initiative. Abstracts from *2nd International Workshop on Advances in the Use of Historical Marine Climate Data (MARCDAT-II)*, Exeter, UK, in press.

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 Office of Climate Observation. The network of oceanographic research vessels provides an important, though underutilized (Gould and Smith 2006), component of the ocean observing system. Through OCO 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 "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 which are now available as a supplement to the International Comprehensive Ocean Atmosphere Data Set (ICOADS).

During the past year, we have expanded our interactions with the Office of Marine and Aviation Operations (OMAO). Through recent collaborations with Doug Perry, we plan to implement SAMOS data transfers from the new NOAA fisheries vessel *Bigelow* in late 2006. This activity will be a pilot for routine SAMOS data transfers from additional NOAA vessels. In time we hope to implement automated data transfers from the *Ronald Brown* and *Ka'imimoana* to replace the current delayed mode data acquisition.

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 and we continue to work with the ICOADS project in collaboration with NCDC.

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 one high school student. 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 "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. A hardcopy version of the guide will be printed in late summer 2006 for distribution at several fall workshops (including INMARTECH 2006). A dynamic, on-line version of the handbook will be prepared later this year. The structure proposed will have "drill down" capacity, keeping the top level of the handbook fairly simple and allowing users to search for additional technical detail if desired. In the future, users will be able to download relevant computer code, specifications, and technical information whether on land or at sea (as broadband ship-to-shore communication technology develops). Future plans also include holding training workshops for marine technicians. The lead authors of the guide are Frank Bradley (CSIRO, Australia) and Chris Fairall

(NOAA/ESRL/PSD) and is a collaborative effort of the SAMOS initiative and the WCRP Working Group on Surface Fluxes.

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. 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 for phase II through CICOR represents approximately 15% of the array. The duration of phase II is 5 years, starting in July 2001.

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

During the last year of this grant, we have effectively gotten on schedule for manufacturing floats. We presently have an inventory of over 30 floats in the lab waiting for deployment opportunities in the Atlantic Ocean. We are coordinating with AOML to find additional deployment opportunities. We further streamlined the manufacturing of SOLO floats at WHOI, including a reorganization of the duties within the operations group and assigned the

procurement and inventory control to a administrative professional, Mary Ann Lucas. This has further improved the collaboration and coordination with the Instrument Development Group at Scripps. The redesigned SOLO float has a failure rate that is less than 2% at 1 year which means that we should be able to meet the design specifications for the Argo float array. The floats are now routinely initiated once they have been delivered to the ship, which guarantees that they are turned on before they are deployed. When the float encounters 50 dbar pressure, it begins its mission.

Over the past 12 months a total of 147 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 floats 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 now developed a SOLO float that uses the Iridium Short Burst Data communications system for data communications and GPS for positioning. Three floats were deployed in the Arctic Ocean under separate funding. A second-generation version will be deployed in October. 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 should be able to incorporate a continuous profile of dissolved oxygen with the same battery pack presently used for floats equipped with an Argos transmitter. During the next year we expect to test such a float.

During the present year, Xingwen Li and Owens have carried out an analysis of the seasonal variation in heat (SH) and (salt content in the upper one kilometer of the ocean. This work has been difficult because of significant drift in the conductivity measurements due to a bio-fouling agent that was used in the early floats that ablated over time at a non-uniform rate. Spatial maps, seasonal and interannual variability of heat and salt content in the upper one kilometer and dynamic height over the same interval have been estimated and compared with sea level height. Heat content and sea level height are correlated, suggesting that there is a significant steric contribution to sea level changes. However, heat and salt content are also correlated, suggesting that there is partial compensation so that the dynamic height changes are smaller than changes in heat or salt content.

Owens has worked 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 procedure is in final evaluation and is likely to be the approved method for calibrating Argo float conductivities.

Owens has continued to spend some time involved with the International Argo Steering Team and the Argo Advisory panel. He attended the second Argo science workshop, held in March, 2006 in Venice and presented a talk on mapping of the velocity field from float data.

In summary, the WHOI contribution to the Argo Float Program has significantly accelerated and improved the performance of the floats. Improvements in both the communications system and the calibration procedures have also been implemented.

State of the Arctic Report

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 378
July 1, 2005 through June 30, 2006

Dr. Andrey Proshutinsky

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Program Manager: Dr John A. Calder, NOAA Arctic Research

Related NOAA Strategic Plan Goal:

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

PROJECT OVERVIEW

The overall goal of the proposed task is to produce an annual report fully assessing the state of the Arctic Ocean. Specific objectives include:

1. Hosting a workshop on the state of the Arctic.
2. Preparing a baseline report on the state of the Arctic.
3. Developing a methodology for an annual reassessment
4. Widely disseminating the report.

The annual assessment was based on data obtained from U.S. and international sources and covers:

1. Atmospheric circulation
2. Surface air temperature and barometric pressure
3. Sea ice concentration, thickness, concentration, and mass balance.
4. Sea ice drift
5. Arctic Ocean circulation, thermohaline structure, and heat content
6. Ocean transport of freshwater, heat and nutrients through major Arctic gateways
7. Sea level
8. Biological activity from primarily productivity to fish to marine mammals.

The report was produced by a team of experts lead by Jacqueline Richter-Menge (sea ice), James Overland (atmosphere), and Andrey Proshutinsky (ocean). The science advisory team consisted of national and international Arctic experts from universities and government laboratories. To assist in formulating the report we hosted a workshop on the state of the Arctic (This workshop included invited presentations by the team members on the state of key atmosphere, ice, and ocean parameters, as well as small discussion sessions).

The information in this report was disseminated in several ways. It was presented as a peer-reviewed article as part of the American Meteorological Society annual climate summary. We also developed a Web site with an electronic version of the report plus an easily accessible, complete representation of all of the reporting activities. Highlights from the annual assessment were and will also be presented at major conferences.

ACCOMPLISHMENTS

The major project accomplishment is the report describing the Arctic climate. The 2006 NOAA global climate report includes a section with a review of recent Arctic data by an international group of scientists who developed a consensus on the arctic environment information content and reliability. The report highlights data primarily from 2000 to 2005 with a first look at winter 2006, providing an update to some of the data records of physical processes discussed in the Arctic Climate Impact Assessment (ACIA 2004, 2005). Of particular note:

- Atmospheric climate patterns are shifting. The late winter/spring pattern for 2000–2005 had new hot spots in northeast Canada and the East Siberian Sea relative to 1980–1999. Late winter 2006, however, shows a return to earlier climate patterns, with warm temperatures in the extended region near Svalbard.
- Ocean salinity and temperature profiles at the North Pole and in the Beaufort Sea, which changed abruptly in the 1990s, show that conditions since 2000 have relaxed toward the pre-1990 climatology, although 2001–2004 has seen an increase in northward ocean heat transport through Bering Strait, which is thought to impact sea ice loss.
- Sea ice extent continues to decrease. The sea ice extent in September 2005 was the minimum observed in summer during the satellite era (beginning in 1979), marking an unprecedented series of extreme ice extent minima beginning in 2002. The sea ice extent in March 2006 was also the minimum observed in winter during the satellite era.
- Tundra vegetation greenness increased, primarily due to an increase in the abundance of shrubs. Boreal forest vegetation greenness decreased, possibly due to drought conditions.
- There is increasing interest in the stability of the Greenland ice sheet. The velocity of outlet glaciers increased in 2005 relative to 2000 and 1995, but uncertainty remains with regard to the total mass balance.
- Permafrost temperatures continue to increase. However, data on changes in the active layer thickness (the relatively thin layer of ground between the surface and permafrost that undergoes seasonal freezing and thawing) are less conclusive. While some of the sites show a barely noticeable increasing trend in the thickness of the active layer, most of them do not.
- Globally, 2005 was the warmest year in the instrumental record (beginning in 1880), with the Arctic providing a large contribution toward this increase.

Many of the trends documented in the ACIA are continuing, but some are not. Taken collectively, the observations presented in this report indicate that during 2000–2005 the Arctic system showed signs of continued warming. However, there are a few indications that certain elements may be recovering and returning to recent climatological norms (for example the central Arctic Ocean and some wind patterns). These mixed tendencies further illustrate the sensitivity and complexity of the Arctic physical system. They underline the importance of maintaining and expanding efforts to observe and better understand this important component of the climate system to provide accurate predictions of its future state.

FIGURES AND IMAGES

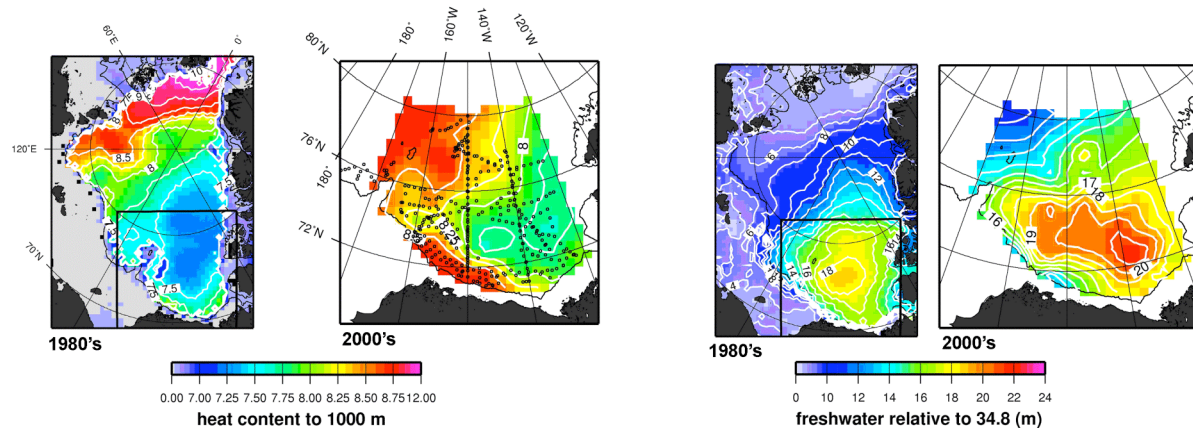


Figure 1 Summer heat (10^9 J/m^2 , left) and freshwater (m, right) content. Panels 1 and 3 show the heat and freshwater content in the Arctic Ocean based on 1980s climatology (EWG, 1997, 1998). Panels 2 and 4 show the heat and freshwater content in the Beaufort Gyre in 2000–2005 based on hydrographic surveys (the black dots indicate locations of hydrographic stations). For reference, this region is outlined in black in panels 1 and 3. The heat content is calculated relative to the water temperature freezing point in the upper 1000-m ocean layer. The freshwater content is calculated relative to a reference salinity of 34.8.

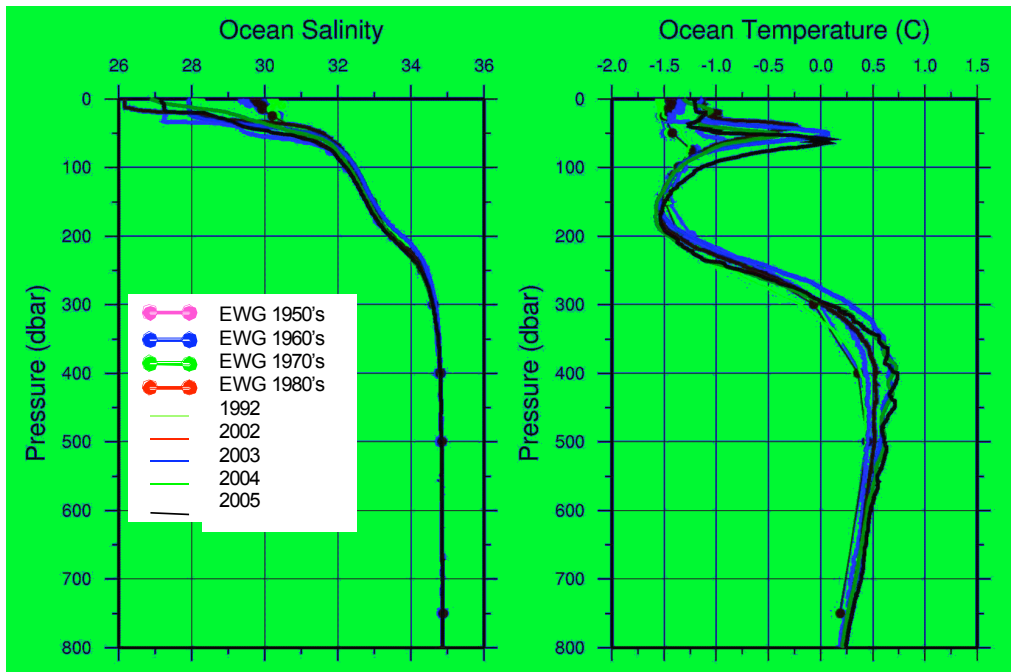


Figure 2 Beaufort Gyre hydrography for 1991–2005 (lines) compared with EWG climatology (lines with circles) for the vicinity of 75°N and 150°W ; left: salinity, right: temperature.

PUBLICATIONS

J. Richter-Menge, J. Overland, A. Proshutinsky, V. Romanovsky, J. C. Gascard, M. Karcher, J. Maslanik, D. Perovich, A. Shiklomanov, and D. Walker (2006), Arctic, In: State of the climate report in 2005, Ed. K. A. Shein, Special supplement to the Bulletin of the American Meteorological Society, vol. 87, No 6, June 2006.

J. Richter-Menge, J. Overland, A. Proshutinsky, V. Romanovsky, L. Bengtsson, L. Brigham, M. Dyurgerov, J.C. Gascard, S. Gerland, R. Graverson, C. Haas, M. Karcher, P. Kuhry, J. Maslanik, H. Melling, W. Maslowski, J. Morison, D. Perovich, R. Przybylak, V. Rachold, I. Rigor, A. Shiklomanov, J. Stroeve, R. Volker, D. Walker and J. Walsh (2006), State of the Arctic Report, NOAA web site (submitted)

SUMMARY OF INTERACTION WITH NOAA

The report was produced under supervision of J. Calder and we have successfully and efficiently interacted in order to complete this work in time and successfully.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

The major project results were prepared by a group of experts from USA, Germany, France, Russia, Poland, Canada, and Sweden and the project results were respectively disseminated in these countries. The major project results will be also presented at the AGU 2006 Fall meeting, and AAAS meeting at University of Alaska Fairbanks.

GLOBEC-01: Patterns of Energy Flow and Utilization on Georges Bank

NOAA Cooperative Agreement No. NA17RJ1223 sub-points 22 and 55
July 1, 2005 through June 30, 2006

Dr. John Steele

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Program Manager: Dr. Elizabeth Turner, NOAA/COP

Related NOAA Strategic Plan Goal:

Goal 1. Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.

PROJECT OVERVIEW

Oceanographic regimes on the continental shelf display a great range in the time scales of physical exchange, biochemical processes and trophic transfers. The close surface-to-seabed physical coupling at intermediate scales –weeks to months – means that the open ocean paradigm of a relatively autonomous microbial loop is inadequate. But purely top-down trophic depictions are insufficient to constrain a system subject to physical forcing as well as fishing. These processes are found on most continental shelves but are particularly important on Georges Bank in the northwest Atlantic where the weeks-to-months regime is dominant in relative area and in productivity.

We have generated budgets for the microbial food web for three physical regimes (well mixed, sporadically mixed and stratified) and for three seasons (spring, summer and fall/winter). The calculations show that vertical mixing and lateral exchange between the three regimes are important for zooplankton production as well as for nutrient input. Benthic suspension feeders (anchored plankton) are an additional critical pathway for transfers to higher trophic levels. Estimates of production by mesozooplankton, benthic suspension feeders and deposit feeders provide input to an upper trophic food web. Diets of commercial fish populations are used to calculate food requirements in three categories, planktivores, benthivores and piscivores, for four decades or stanzas, between which there were major changes in the fish communities.

Comparisons of fish energetic requirements for plankton and benthos, in conjunction with inputs from the microbial web, indicate that we obtained reasonable agreement for the last three decades: 1973 to 2002. But for the first decade the fish food estimates were significantly less than the inputs based on the GLOBEC years 1995-1999. This decade 1963-1972 corresponds to a period characterized by a strong Labrador Current and lower nitrate levels at the shelf edge, demonstrating how strong bottom-up physical forcing may determine overall fish yields.

ACCOMPLISHMENTS

8. *First Accomplishment*

We constructed an end-to-end budget of the Georges Bank ecosystem by balancing the output of the lower food web with fish consumption. Mass balance was achieved by accounting specifically for the ratio of new production to production recycled through the microbial loop and for advective loss off Georges Bank.

9. *Second Accomplishment*

Compared with previous food webs, we estimate less consumption by juvenile fish and more by carnivorous invertebrates. Surprisingly, there is no evidence for the depletion of predatory fish during the intense exploitation in the 1980s. While the cod stock was depleted, the biomass of other piscivores peaked in the 1980s. Time series are lacking for the lower trophic levels, but there is no signal of altered piscivory to trigger a trophic cascade. Instead, there is evidence of bottom-up control through reduced nutrient input in the 1960s.

10. *Third Accomplishment*

Reduction of the commercially important fish stocks was accompanied by replacement with non-commercial species, maintaining the functional diversity of the ecosystem. Bottom-up control of the food web implies that recovery of the commercially important fish stocks will be accompanied by a reversal of these species shifts, as may be occurring in the most recent decade.

PUBLICATIONS

Steele, J. H. & Collie, J. S. (2005). Functional diversity and stability of coastal ecosystems. In: A.R. Robinson and K. Brink, *The Sea*, Vol. 13 (pp. 783-817), Harvard University Press, Cambridge

J. Steele, J. Collie, J. Bisagni, M. Fogarty, D. Gifford, J. Link, M. Sieracki, B. Sullivan, A. Beet, D. Mountain, E.G. Durbin, D. Palka and W. Stockhausen (submitted). Balancing end-to-end budgets for the Georges Bank ecosystem. Progress in Oceanography

SUMMARY OF INTERACTION WITH NOAA

Discussions with Drs Turner, Fogarty, Sissenwine, Murawski.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

Papers presented at various scientific meetings

Multi-sensor Improved Sea-Surface Temperature (MISST) for GODAE

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 358

July 1, 2004 through June 30, 2005

Dr. Brian Ward

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Program Manager: Dr. Eric Bayler, NOAA/OAR

Related NOAA Strategic Plan Goal:

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

PROJECT OVERVIEW

The Multi-sensor Improved Sea Surface Temperatures (MISST) for the Global Ocean Data Assimilation Experiment (GODAE) project intends to produce an improved, high-resolution, global, nearreal-time (NRT), sea surface temperature analysis through the combination of satellite observations from complementary infrared (IR) and microwave (MW) sensors.

The PI's (Ward) role in this project is to:

- Provide near surface (5 m) ocean temperature datasets from the SkinDeEP profiler, as well as corresponding datasets of the model forcing parameters (wind speed, heat flux)
- Analyse model output data against the in-situ profile data
- Quantify the errors in the model and determine mechanisms by which the models can be improved.

ACCOMPLISHMENTS

Diurnal warming at the ocean surface results in significant temperature gradients over the upper few meters of the ocean (Ward, 2006). In the absence of radiometric measurements, this warm layer needs to be accounted for in ocean models when calculating air-sea fluxes, as well as for the validation of satellite sea surface temperature (SST).

Many of the available SST measurement techniques do not sample above the upper 1 m (e.g. ship-mounted CTD), nor continuously through the water column (e.g. fixed sensors attached to buoys). However, the unique measurements provided by the Skin Depth Experimental Profiler (SkinDeEP) enable an unprecedented opportunity to validate simulations of the structure and evolution of near-surface diurnal warming. This work is being carried out in collaboration with Dr. Gary Wick at NOAA in Boulder.

SkinDeEP is an autonomous profiler capable of measuring temperature with sub-centimeter resolution in the upper 10 m of the ocean. The instrument obtains repeated profiles by changing its density through inflating and deflating an external neoprene sleeve. Measurements are made only during ascent in order to minimize disruption by the instrument.

Profiles from SkinDeEP deployments in the waters around Baja California in 1999 and in the Mediterranean Sea in 2003 were used to validate simulated near-surface temperature profiles from a modified version of the Kantha and Clayson (1994) 1D mixed layer model (Figure 1). Coincident wind and heat flux observations were used to force versions of the model with and without a new parameterization of turbulence generated by wave breaking. Profiles were computed at 60-s temporal and 2-cm vertical resolution for several days with significant diurnal warming (Figure 2). Comparisons of simulations from full diurnal warming models with detailed temperature profile measurements from the SkinDeEP instrument identified the best combination of model physics for use in evaluation of simplified parameterizations and quantified expected errors in estimates of diurnal warming.

FIGURES AND IMAGES

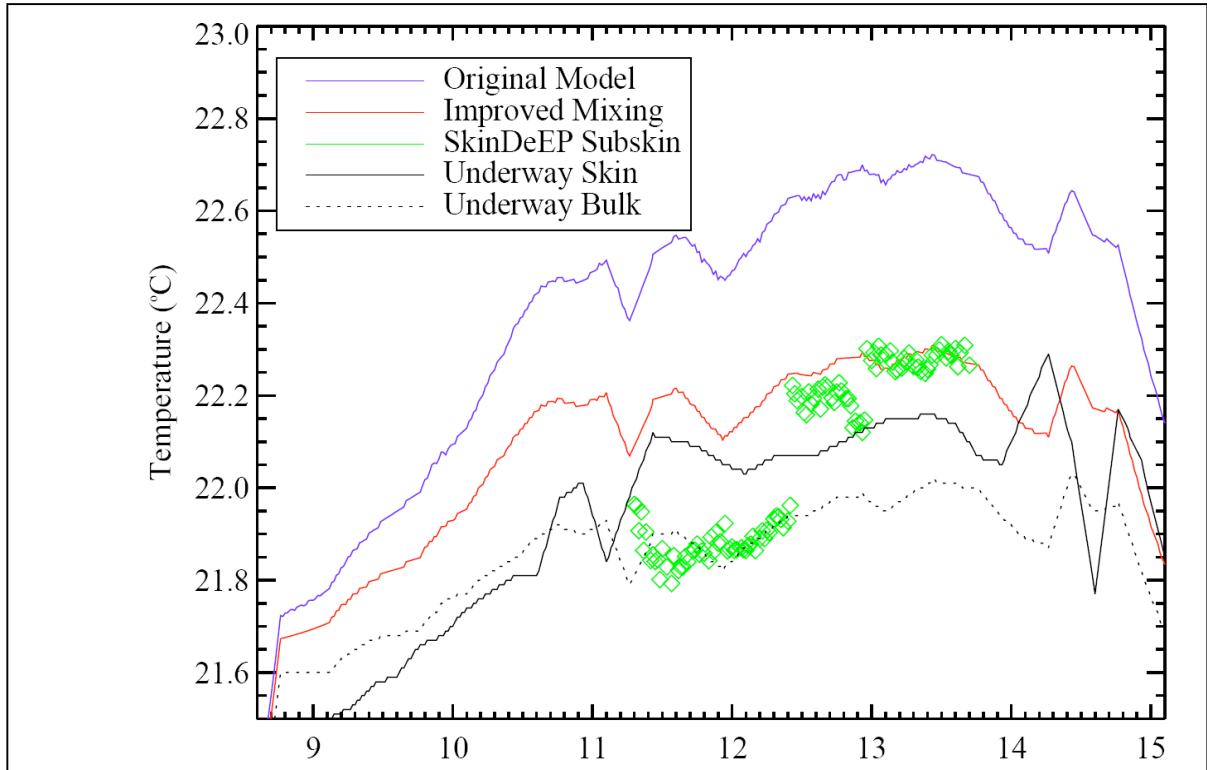


Figure 1. Measurements from the MOCE-5 cruise in the Gulf of California (See Ward 2006) as well as corresponding model results.

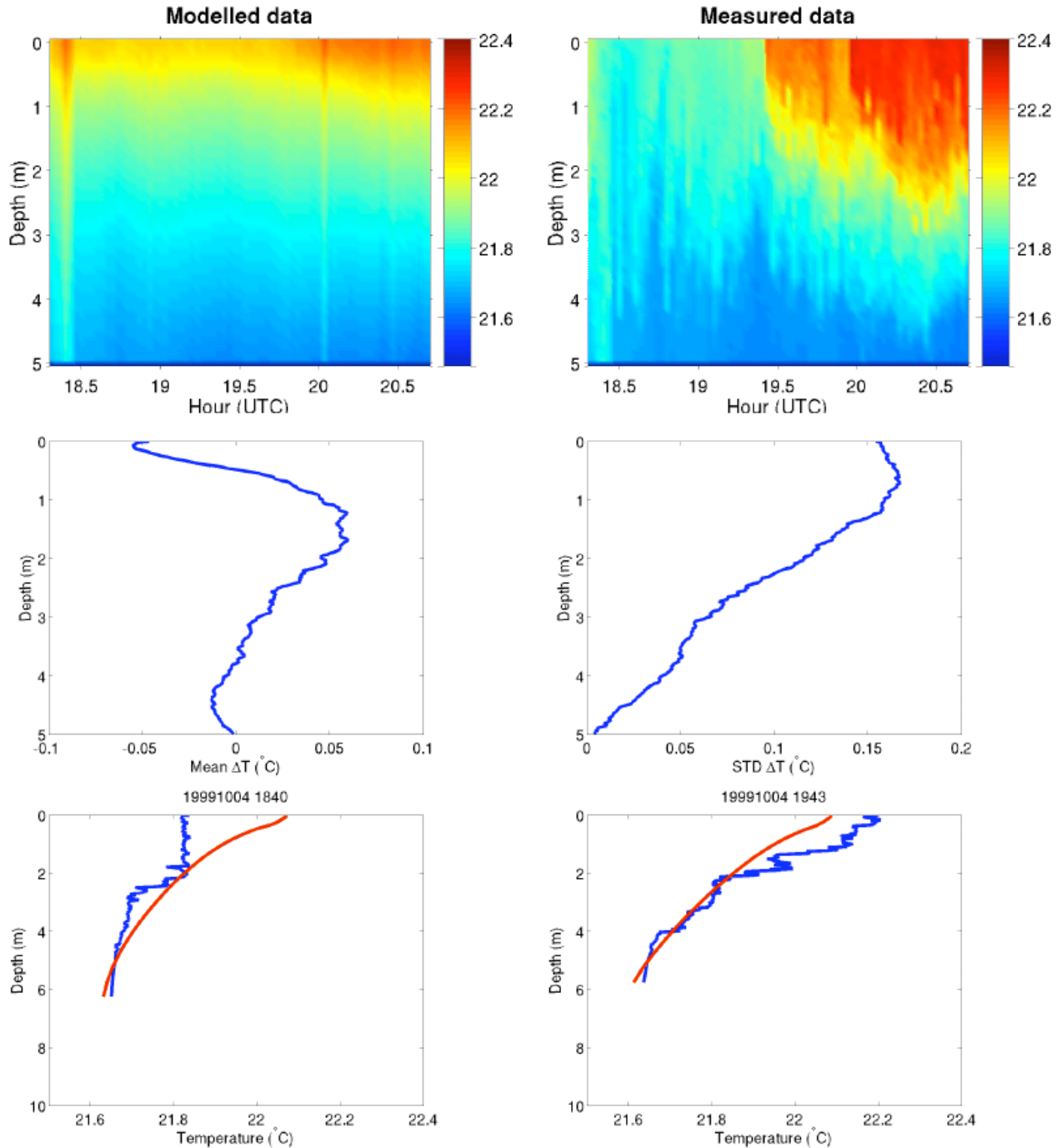


Figure 2. The figures show comparisons between the time and depth evolution of the measured and modeled temperatures (top), errors in the modeled temperatures averaged over the SkinDeEP deployment (middle), and sample instantaneous profile comparisons (bottom).

Some of the conclusions that can be drawn from this study are:

- High-resolution profile measurements enable unique detailed validation of simulations of the near-surface temperature profile.
- While the model shows skill in reproducing the general shape of the temperature profile at times, many details are not captured with existing mixing schemes.

- Incorporating enhanced mixing near the surface due to wave breaking results in more realistic surface temperatures at most times.
- Significant challenges remain in accurately simulating the detailed temperature profile near the ocean surface.

PUBLICATIONS

Ward, B., 2006, Near-surface ocean temperature, J. Geophys. Res, 111 , C02004, doi: 10.1029/2004JC002689 (funding acknowledged as National Oceanographic Partnership Program Award No. NNG04GM56G.)

SUMMARY OF INTERACTION WITH NOAA

This work was carried out in collaboration with Gary Wick from the NOAA Lab in Boulder, CO.

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

NOAA Cooperative Agreement No. NA17RJ1223
July 1, 2004 through June 30, 2005

Dr. Robert A. Weller

Principal Investigator, E-mail: (rweller@whoi.edu)
Field Operations: Mr. Frank Bahr (fbahr@whoi.edu)
Engineering Support: Mr. David S. Hosom (dhosom@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) and to validate new model codes and remote sensing methods.

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

Ship selection and interface to the NOAA SEAS system is via AOML. There is 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 is provided by the Southern California Marine Institute 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 and the VOS people at the German Weather Service (Deutscher Wetter Dienst) in Hamburg Germany.

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

Note that descriptions, technical information and data from the several VOS being serviced is posted on the site: <http://uop.whoi.edu/vos/> Data (plots) are available for all ship sets.

Data (numbers) are available via anonymous ftp for the last data set only: <ftp.whoi.edu/pub/users/fbahr/VOS>. If data from previous times are desired 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

ACCOMPLISHMENTS:

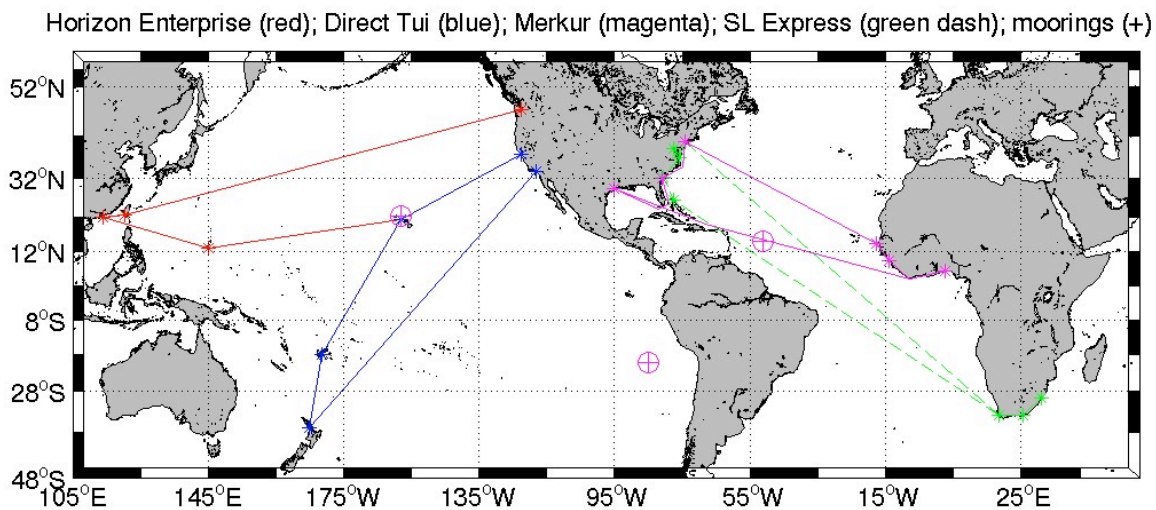
The following list starts in March of 2005 rather than in July to include events that were not listed in last year's report due to the early submission of that report.

- February '05; Newark, NJ: meet the *SeaLand Express* to remove the AutoIMET installation, after we had learned, on short notice, that the ship had been sold and was going to changed routes.
- April '05: present a poster on the annual NOAA meeting in Silver Springs that included data products from the *SeaLand Express*.
- April '05: meet Steve Cook in Newark, NJ, to visit a new VOS candidate *M/V Merkur*. However, problems related to a crew change prevented us from boarding the vessel.
- May '05; Houston, TX: together with Steve Cook, visit *M/V Merkur* in preparation for a new AutoIMET installation. Meet with the ship's captain and electrician to identify cable penetrations on the bridge and to the ship's bow thruster chamber.
- July '05; Newark, NJ: visit *M/V Merkur* to install a new system. Carrie Wolfe had met the ship just a few days prior in Houston to installing the SEAS2000 computer on the bridge. She also started "our" portion of the installation by mounting the radio link antenna onto the wheel house and running the cable to the SEAS2000 computer. Unfortunately, because the ship was a week behind schedule, the Newark port stop was shortened to just one night, and we did not finish.
- September '05: Houston, TX: meet the *M/V Merkur* to complete the installation. However, two of the sensors (wind and sea surface temperature) did not start. I followed the ship to the next port stop in Savannah, GA, to fix the two sensors. The

repairs were successful for the wind sensor, but not for SST. Will meet the ship again on its next cycle with additional trouble-shooting tools.

- October '05: Savannah, GA: meet *MV Merkur* to repair SST. I had to swap both the power supply box and the logger before getting SST transmitted to the bridge and out via SEAS2000. I suspect that an electrical (wiring?) problem in the power box caused damage to the SST circuitry in the logger. All systems are running now.
- February '06, Houston, TX: Meet the M/V *Merkur* in Houston to take down the AutoIMET system. This was planned as a normal sensor calibration exchange visit, but we had received notice just a few days prior to the trip that the ship had been sold and was not going to return to U.S. ports in the future.
- May '06: present a poster at the GOSUD/SAMOS meeting in Boulder, and at the annual NOAA meeting in Silver Springs, describing initial results from a comparison of VOS data from the *SeaLand Express* and the *Merkur* to the Ocean Monitoring Station in the equatorial North Atlantic ("NTAS buoy").

FIGURES AND IMAGES



Route Map

Note the Ocean Monitoring Stations (circle with cross) being operated by WHOI. The Horizon Enterprise is shown in red. The Direct Tui (replaced the Columbus Florida) is shown in blue. The M/V Merkur is shown in magenta. The Sealand Express route is open and waiting on a new ship assignment.



M/V Merkur

SUMMARY OF INTERACTION WITH NOAA

The Climate Observation Program Workshop in Silver spring, MD was attended by Dr. Robert Weller. The GOSUD/SAMOS meeting in Boulder CO was attended by Mr. Frank Bahr. A poster presentation on VOS was made at both meetings.

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

NOAA Cooperative Agreement No. NA17RJ1223, sub-point 25 (continues NA87RJ0445) July 1, 2005 - June 30, 2006

Dr. Robert A. Weller

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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. Ph.D. student Tom Farrar, working with Weller, is using the PACS mooring data 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

11. 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).

12. *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).

13. *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 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

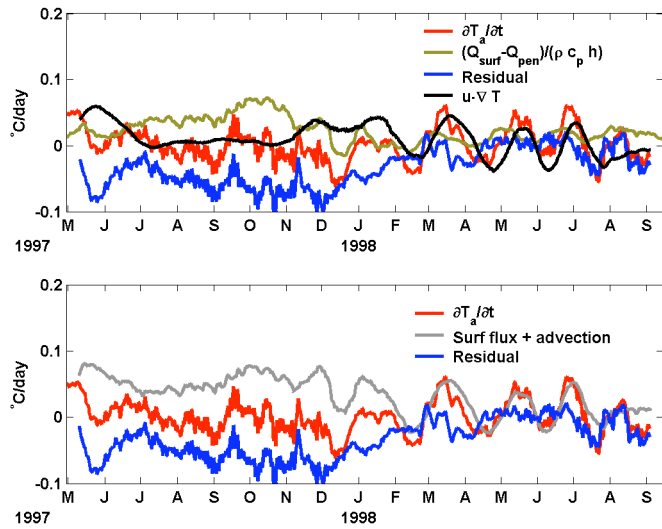


Figure 1. Terms in surface layer temperature balance at the 10°N, 125°W site. The terms estimated are: rate of change of layer-averaged temperature ($\partial T_a / \partial t$), heating of the layer associated with surface heat flux ($(Q_{\text{surf}} - Q_{\text{pen}}) / (\rho c_p h)$), and horizontal 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.

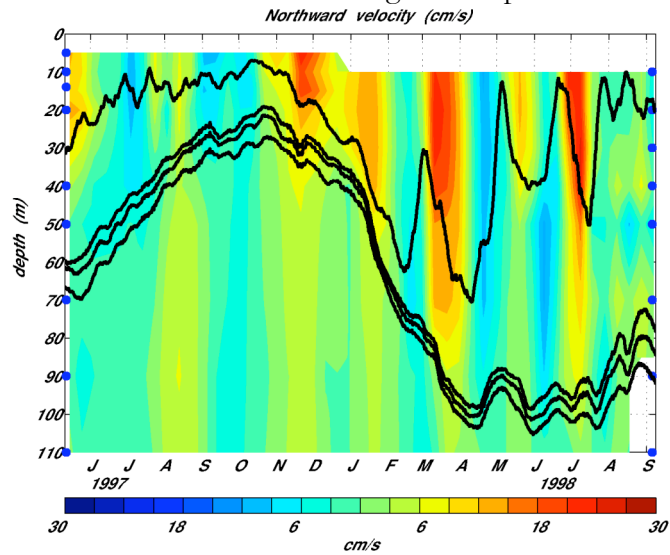


Figure 2. Northward velocity observed at 10°N, 125°W (10 day averages). The upper black line marks the mixed layer depth, and the lower three black lines mark isotherms in the thermocline (19, 22, and 24° C). The blue circles on the left and right edges of the figure indicate current meter depths.

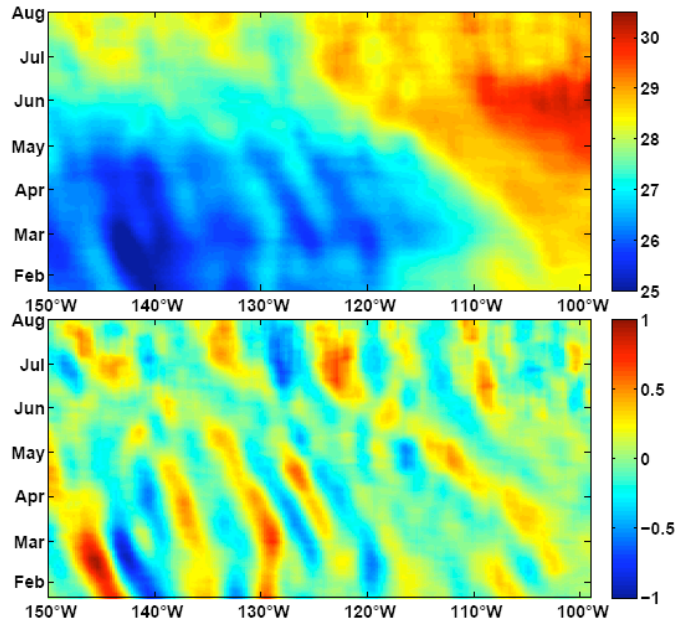


Figure 3. Upper panel: Longitude-time plot of SST ($^{\circ}\text{C}$) along 10°N during 1998 from the TMI instrument aboard the TRMM satellite. Lower panel: The same, except a 10° longitudinal running average has been removed to emphasize the mesoscale variability. The westward propagation of the SST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

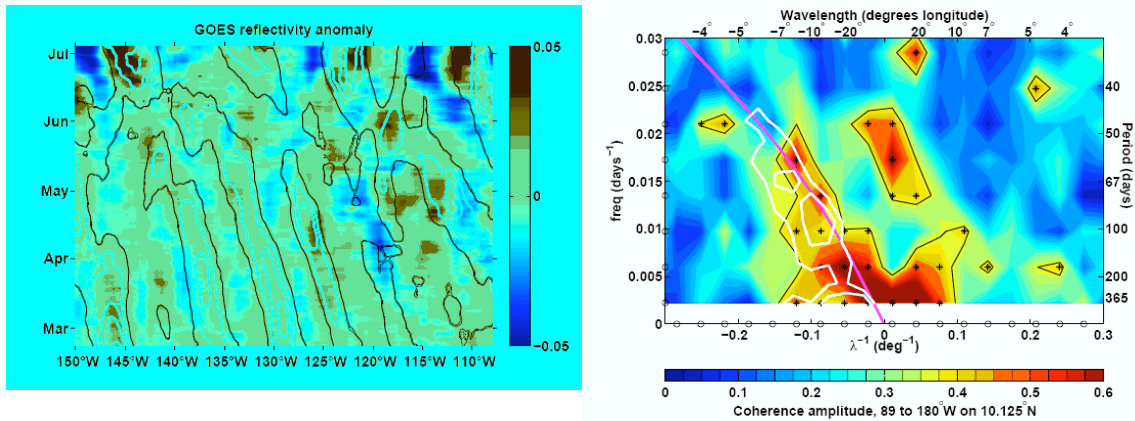


Figure 4. Left panel: Longitude-time plot of visible (cloud) reflectivity along 10°N during 1998 from the GOES-9 satellite (colored, in %), filtered as in Figure 3b. Mesoscale SST anomalies (Figure 3b) are contoured in white at 0.1°C intervals, and the zero contour is black. Right panel: Coherence amplitude 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.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

Graduate student Tom Farrar, who started his Ph. D. thesis work in October 2004 under the supervision of Weller, is 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. Completion of the thesis is anticipated September 2006, 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.

Ocean Reference Stations

NOAA Cooperative Agreement No. NA17RJ1223 (subpoints 27, 28, 29, 59 and 83)
July 1, 2005 through June 30, 2006

Dr. Robert A. Weller and Dr. Albert J. Plueddemann, Co-PIs.

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Program Manager: Mike Johnson, 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 will be maintained: a 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 Woods Hole HOT Site or WHOTS. The Stratus and NTAS surface moorings were deployed and serviced annually under NOAA OGP support; these sites have now transitioned to long-term Ocean Reference Stations. The Hawaii Ocean Reference Station was initiated 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**); work in this area is underway and progress reported below. Second, the maintenance of the Stratus site (**Task II**), also with work underway and progress reported below. Third, the maintenance of the NTAS site (**Task III**) which in FY2005 shifted to support as one of the operational Ocean Reference Stations. Fourth, the maintenance of the Ocean Reference Station at Hawaii, (**Task IV**), whose second year of operation was successfully completed. Progress on each of the Tasks is reported in more detail below.

ACCOMPLISHMENTS

Task I: Engineering, oversight and data:

- All three sites are now occupied by the modern design (Fig. I-1). These new buoys replaced the 15 to 20 year old hulls previously used, which were degrading (corrosion of the welded aluminum) and were expensive to ship as they do not fit inside a sea container like the new hulls. Testing of Iridium data telemetry hardware was begun at the WHOTS and worked successfully.

- Data processing continues on schedule. New routines have been developed to provide consistent processing over the multi-year deployment. The “best” quality meteorological and flux data is being made accessible through the web, within a year of recovery. The post-doctoral investigator (Keir Colbo: supported under sub-point 08) working on the Stratus data set has also submitted a paper outlining the expected accuracy of the meteorological and flux data products.

- 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. We maintain a public access archive of Upper Ocean Processes 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 Hawaii buoy 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. With Add-Task funding for FY 2005 we have completed development of an Iridium telemetry subsystem and implementation of an automated, shore-based decoding and processing system for the telemetered data. Another area in which we have moved forward is to partner with Dr. Chris Sabine (NOAA PMEL) to in the future incorporate his CO₂ on board our buoys. The first deployment will be on the Stratus buoy in October 2006.

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



Figure I-1: The old rigid hull (left) and the new modular buoy (right). Photo taken during the December 2004 Stratus deployment and recovery cruise.

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.who.edu/projects/Stratus/stratus.htm>). 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 (Hutto et al., 2006). 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 FY2006 deployment was carried out aboard the *R/V Ronald H. Brown* which sailed from Rodman, Panama on September 26, 2005 and arrived into Arica, Chile on October 21, 2005. The preparation for the cruise begins many months before the deployment. During the summer of 2005 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 early September of 2005, members of the UOP group loaded the *R/V Ron Brown* in Woods Hole.

The Stratus 5 mooring was recovered on October 12th with no undue problems. The old mooring is traditionally recovered first so as to assess any problems that may have arisen, and to hence make last minute changes on the new mooring. As in some previous years, several upper ocean instruments were fouled by fishing line. In response to this, a new site was selected and surveyed for the new buoy. The Stratus 6 mooring was deployed on October 14th.

On the buoy we measure air temperature, sea surface temperature, relative humidity, incoming shortwave and longwave radiation, wind speed and direction, rain rate, and barometric pressure. On the mooring line the instrumentation is concentrated in the upper 300m 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 SEAFLEX project). The oceanographic data are being used by Weller and a Postdoctoral Investigator (Keir Colbo) at WHOI to investigate air-sea coupling and upper ocean variability under the stratus deck. 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>).

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.

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 FY2006 have come from many institutions: NOAA Environmental Technology Laboratory, Servicio Hidrografico y Oceanografico de la Armada (Chile), University of Concepcion (Chile), University of Chile, CSIRO (Australia), and University of Miami. These collaborations have included: enhanced regional surface flux and lower atmosphere surveys, both offshore and within Chilean coastal waters (NOAA ETL, CSIRO, U. Miami, U. Chile), extensive hydrographic surveys with CTDs and XBTs (multi-user), water sampling in support of biological monitoring (U. Concepcion), and the support of maintaining a tsunami warning buoy (Chilean Navy).

During transit legs, water samples were collected by investigators from the University of Concepcion in order to perform biomarker and molecular biological sampling for nitrogen fixers.

To further support ground-truthing of satellite data and increased understanding of the ocean in the eastern South Pacific, 16 drogued surface drifters and 8 profiling ARGO floats were deployed in the South Pacific along the cruise track.

The 2005 stratus cruise also hosted a teacher from NOAA's Teachers-at-Sea program (Eric Haltzel). 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. All of the logs are available at <http://teacheratsea.noaa.gov/2005/heltzel/index.html>.

Following the cruise an effort was initiated to get all the surface meteorological and air-sea flux time series quality controlled and out for public access. This is being followed by an effort on quality controlling the ocean time series. In addition, on the hardware side, collaboration with Dr. Chris Sabine's group at NOAA PMEL has led to the installation on the buoy being prepared for deployment in September 2006 of his CO₂ instrument.

PUBLICATIONS (CUMULATIVE):

- Colbo, K and R. A. Weller, 2006: The variability and heat budget of the upper ocean under the Chile-Peru stratus. *J. Mar. Res.*, in review.
- Colbo, K. and R. A. Weller, 2006: The accuracy of the IMET sensor package. *J. Atmos. Oceanic Technol.*, in review.
- Hutto, L., R. Weller, J. Lord, J. Smith, P. Bouchard, C. Fairall, S. Pezoa, L. Bariteau, J. Lundquist, V. Ghate, R. Castro, 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.
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- Hutto, Lara, Robert A. Weller, Jeff Lord, James Ryder, Alice Stuart-Menteth, Nancy Galbraith, Paul Bouchard, Jenny Maturana, Oscar Pizarro, and Jaime Letelier, 2003. Long-Term Evolution of the Coupled Boundary Layers (Stratus) Mooring Recovery and Deployment Cruise Report R/V *Melville*. Technical Report, WHOI-2003-02, UOP-2003-01.
- Lucas, Lisan E., Bryan S. Way, Robert A. Weller, Paul R. Bouchard, William M. Ostrom, Albert S. Fischer, Carlos F. Moffat, Wolfgang Schneider, Melanie R. Fewings, 2001. Long-Term

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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:

“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-5, deployed 11 March 2005) and replace it with a new

mooring (NTAS-6). 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 a 2.7 m modular ORS buoy in preparation for deployment. The NTAS-6 mooring was deployed on 25 February 2005 and the NTAS-5 mooring was recovered on 28 February. 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-6 sensors were calibrated prior to deployment, and NTAS-5 sensors will be post-calibrated. A cruise report is in preparation.

The 2006 NTAS cruise represented the start of a collaboration with the National Data Buoy Center (NDBC) wherein the newly established NDBC west and middle Atlantic sites (41040 and 41041) were serviced. The 2006 cruise also included the deployment of 7 ARGO floats at the request of NOAA AOML, and a bathymetric survey offshore of Barbados at the request of the US Embassy in Barbados and in support of work being done by the Barbados Coastal Zone Management Unit.

Preliminary processing of the NTAS-5 meteorological data has been completed. Data return was good, with most sensors operating for the complete deployment period. Exceptions were one longwave radiation sensor and one wind sensor. The former failed on 10 February 2006 and the latter on 3 September 2005. The comparison period indicated only minor 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-5 are available on-line from the Upper Ocean Processes (UOP) group web site (<http://uop.whoi.edu/projects/NTAS>). At present, about 6 months of hourly meteorological data from NTAS-6 are also available for examination on the UOP web site. Preliminary evaluation indicates that all NTAS-6 sensors are performing as expected.

Meteorological sensors from NTAS-1 through 4 have been post-calibrated, and NTAS-1 and 2 data have been post-processed. Hourly averaged files from the resulting data sets have been posted on the UOP web page. The 1 min data are being used as the basis for air-sea flux computations using bulk formulas. Evaluation of NTAS surface meteorology in conjunction with volunteer observing ship data from the Atlantic has been initiated. Auto-correlation times for both buoy and ship meteorological variables are from 3-6 h. The semidiurnal atmospheric tide, and the solar cycle, result in significant correlation between buoy and ship records for barometric pressure and shortwave radiation, respectively. Other variables show weak or no correlation for records of ~20h at distances of 300-500 km.

PUBLICATIONS AND PRESENTATIONS (CUMULATIVE):

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- Goldsmith, R.A. and A.J. Plueddemann, 2002. Moored buoy site evaluations, *Marine Geography*, J. Breman, Ed., ESRI Press, pp 73-77.
- 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. F. Bahr, R.A. Weller and D. Hosom, 2006. Surface Meteorology from volunteer observing ships, *NOAA Office of Climate Observation Workshop*, 10-12 May 2006, 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. 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., 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., 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., 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.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., 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.
- Weller, R, A. Plueddemann, L. Yu and D. Hosom, 2003. Ocean Reference Stations, *ORION Workshop*, 4-8 January 2004, San Juan Puerto Rico (poster).
- 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.

A mooring turn-around cruise was conducted in 2005 on the Scripps ship *Melville* in order to retrieve the existing mooring (WHOTS-1, deployed August 2004) and replace it with the new mooring (WHOTS-2). This year, the mooring turn around was in June and on the Scripps ship *Revelle*. 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 a 2.7 m modular ORS buoy in preparation for deployment. The WHOTS-2 mooring was recovered on 24 June 2006 and the WHOTS-3 mooring was deployed on 26 June. Periods of about 24 hours prior to the WHOTS-2 recovery and after the WHOTS-3 deployment were dedicated to an intercomparison of the buoy and shipboard meteorological systems. The WHOTS-2 mooring was used as a test-bed for implementation of an Iridium data telemetry system, developed under the ORS Engineering, Oversight and Data project. Initial results indicate that the system worked well, and the WHOTS-3 buoy was deployed with two such Iridium systems as a further test. To ensure high-quality meteorological data, all WHOTS-3 sensors were calibrated prior to deployment, and WHOTS-2 sensors will be post-calibrated. A cruise report is in preparation.

Preliminary processing of the WHOTS-1 meteorological data has been completed and that of WHOTS-2 has begun. Data return was good. The intercomparison period showed encouraging results. The intercomparison last year showed some evidence of diurnal heating effects suggesting that some sensor positions on the 2.7 m buoy tower was suboptimal. Mounts for air temperature/relative humidity sensors were extended and no evidence of this heating was seen this year. In addition, on the WHOTS3 buoy we installed commercial bird-prevention spikes to reduced contamination and shadowing from birds landing on the buoy. The raw, hourly Argos and Iridium, are available on-line from the Upper Ocean Processes (UOP) group web site (<http://uop.whoi.edu/projects/WHOTS/whots.htm>).

PUBLICATIONS AND PRESENTATIONS (CUMULATIVE):

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*, 67 pp.

The Oceanic Role in Tropical Atlantic Climate Variability on Interannual to Decadal Time Scales

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 348
July 1, 2005 through June 30, 2006

Drs. Jiayan Yang and Terrence M. Joyce

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Program Manager: Dr. Jim Todd, NOAA Office of Climate, CLIVAR-Atlantic Program

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 project is to investigate the role of oceanic dynamics in the seasonal to interannual climate variability in the tropical Atlantic Ocean. In the first year of the project, we have analyzed the SST dipole mode and identified that the cross-equatorial transport, forced by the wind-stress curl, and the North Equatorial Countercurrent (NECC) play important role in the development of the SST dipole mode. So we have emphasized studying these two processes in the last one year. It was found that the NECC transport is forced both remotely by equatorial wind and locally by local wind stress. The contribution from the equatorial forcing is much greater for the seasonal time scales. The finding leads to a paper published in *Journal of Physical Oceanography* in 2006. Currently, we are investigating both local and remote forcing mechanisms for the interannual and decadal time scales. We have also studied the South Equatorial Countercurrent (SECC) variability.

ACCOMPLISHMENTS

Yang, J. and T. Joyce, 2006: Local and equatorial forcing of seasonal variations of the North Equatorial Countercurrent in the Atlantic Ocean. *Journal of Physical Oceanography*, Vol. 36, 238–254.

Abstract: The seasonal variation of the North Equatorial Countercurrent (NECC) in the tropical Atlantic Ocean is investigated by using a linear, one-layer reduced gravity ocean model and by analyzing sea level height (SSH) data from TOPEX/POSEIDON (T/P) altimeters. The T/P data indicate that the seasonal variability of the NECC geostrophic transport, between 3°N and 10°N, is dominated by SSH changes in the southern flank of the current. Since the southern boundary of the NECC is located partially within the equatorial waveguide, the SSH variation there can be influenced considerably by the equatorial dynamics. We hypothesize therefore that the wind stress forcing along the equator is the leading driver for the seasonal cycle of the NECC transport. The wind stress curl in the NECC region is an important but smaller

contributor. This hypothesis is tested by several sensitivity experiments that are designed to separate the two forcing mechanisms. In the first sensitivity run, a wind stress field that has a zero curl is used to force the ocean model. The result shows that the NECC geostrophic transport retains most of its seasonal variability. The same happens to another experiment in which the seasonal wind stress is applied only within a narrow band along the equator outside the NECC range. To further demonstrate the role of equatorial waves, we ran another experiment in which the wind stress in the southern hemisphere is altered so that the model excludes hemispherically symmetrical waves (Kelvin waves and odd-numbered meridional modes of equatorial Rossby waves), and instead, excites only the anti-symmetrical equatorial Rossby modes. The circulation in the northern tropical ocean, including the NECC, is affected considerably even though the local wind stress there remains unchanged. All these appear to support our hypothesis.

PUBLICATIONS

Yang, J. and T. Joyce, 2006: Local and equatorial forcing of seasonal variations of the North Equatorial Countercurrent in the Atlantic Ocean. *Journal of Physical Oceanography*, Vol. 36, 238–254.

SUMMARY OF INTERACTION WITH NOAA

Our interactions with the NOAA have been in the form of informal science discussions with AOML and PMEL scientists.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

Jiayan Yang has supervised a MIT-WHOI Joint Program student, Mr. Shin Kida, who defended his Ph.D dissertation successfully in July, 2006. Yang has also served as a committee member in the WHOI Summer and Minority Student Committee in the last three years. Through this role he has interacted with some undergraduate students who have been interested in marine research.

FIGURES AND IMAGES

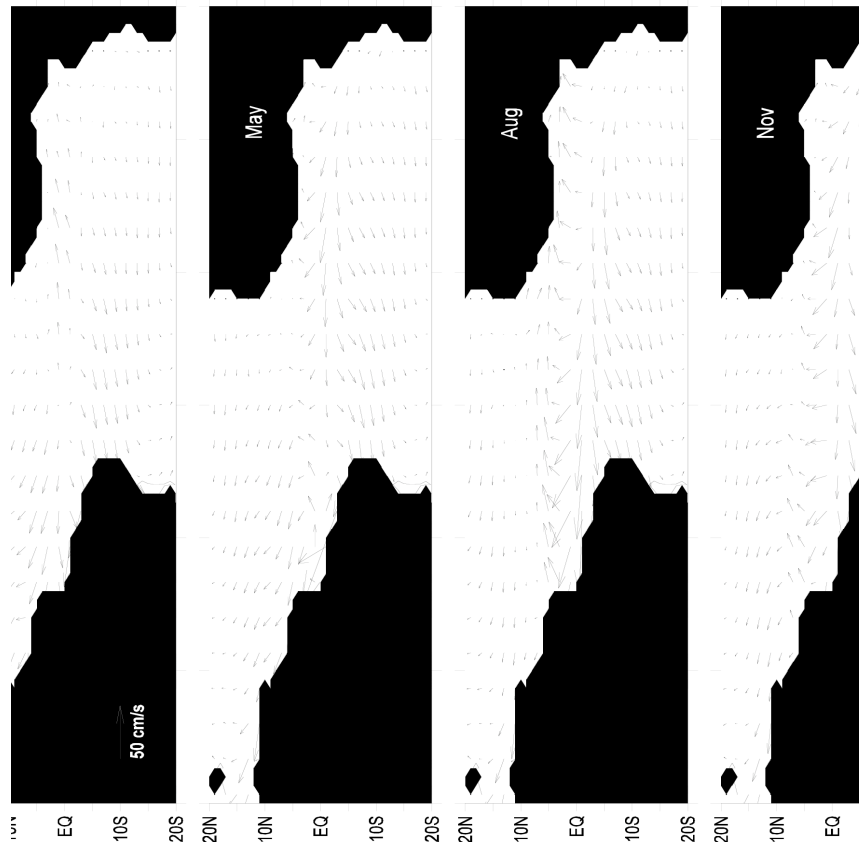


Figure 1: The oceanic current in the surface mixed layer (both Ekman and geostrophic components) in February, May, August and November. The seasonal variation of the NECC is similar to the velocity field derived from ship drift data except that westward flow along the equator and western boundary current are too weak in the model. This is likely due to the absence of the model representation of thermohaline circulation which a main component of the cross equatorial flow in the Atlantic Ocean. The annual mean is included in this plot.

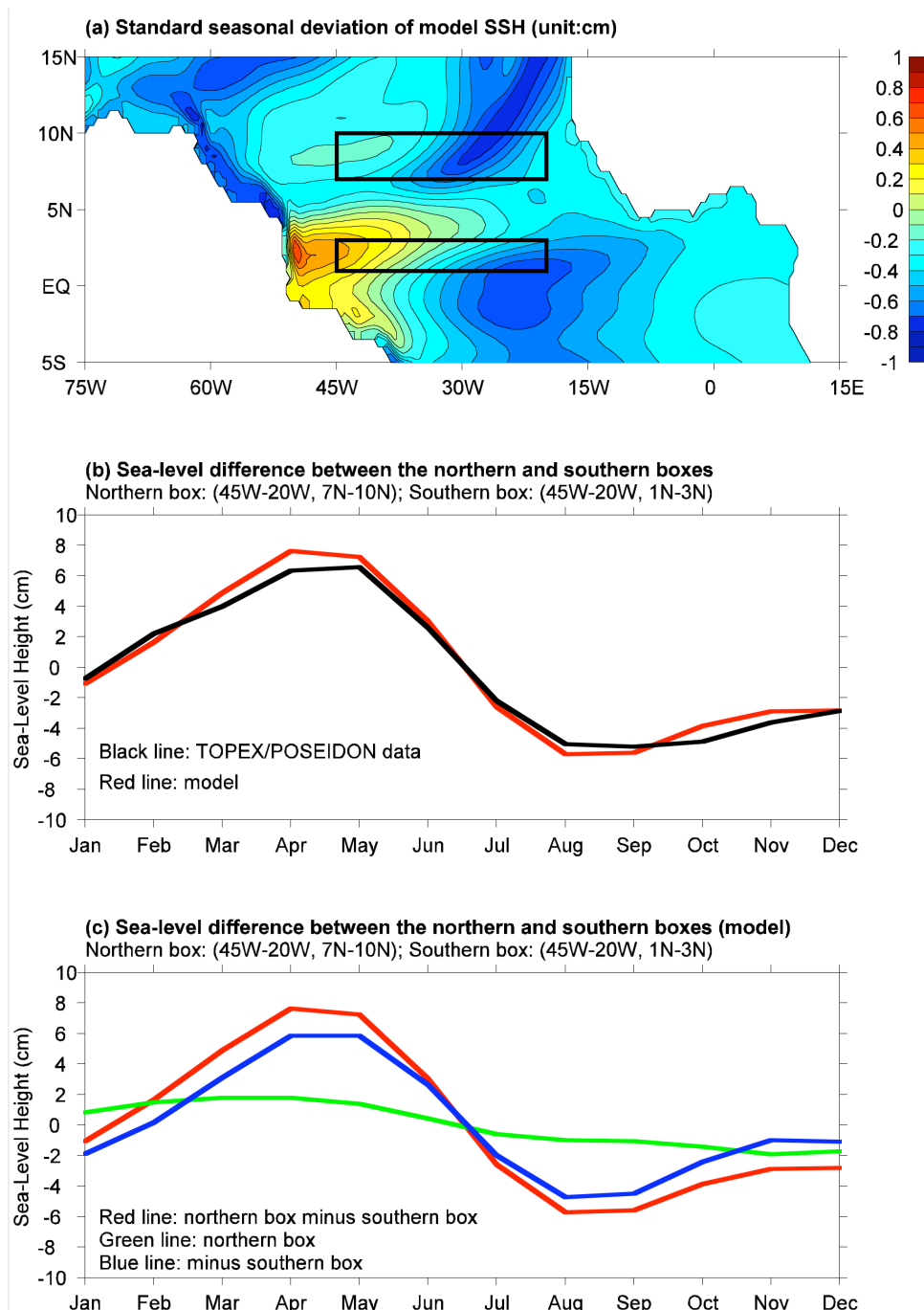


Figure 2: (a) The standard seasonal deviation of model SSH deviation (unit: cm). This compares well with that computed from TOPEX/Poseidon altimetry data. (b) The difference of the SSH between two boxes, one to the north of NECC (45W-20W, 7N-10N) and the other to the south (45W-20W, 1N-3N). The black line from T/P data and the red line is from the model result. These two lines compare very well for both amplitude and phase evolution. (c) The blue line is for the SSH variation in the southern box (multiplied by -1) and the green line is for the northern box. The SSH difference between these two boxes (red line) is clearly dominated by changes in the southern box.

A FIFTY-YEAR ANALYSIS OF GLOBAL OCEAN SURFACE HEAT FLUX

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 351
July 1, 2005 through June 30, 2006

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Program Manager: Dr./Mr 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 OVERVIEW

This project, which is named "Objectively Analyzed air-sea Fluxes" (OAFlux), has the objective to produce estimates for surface latent heat, sensible heat, shortwave, and longwave radiative flux fields over the global ice-free oceans for the past 50-years.

ACCOMPLISHMENTS

1. Time series of the global ocean surface latent and sensible heat flux fields (1958-2005)

New latent and sensible heat flux estimates over the global ice-free oceans from 1958 to 2005 have been produced over with daily and $1^\circ \times 1^\circ$ resolution. The development is based on a weighted objective analysis that combines satellite retrievals, outputs of numerical weather prediction models, and ship reports from COADS. The OAFlux dataset for the period from 1981 to 2002 along with net surface short- and long-wave radiations obtained from the International Satellite Cloud Climatology Project (ISCCP) are free for public access from the project website at: <http://oaflux.whoi.edu/>. Figure 1 shows the annual-mean latent and sensible heat fluxes in 2005 estimated by OAFlux.

2. Enhanced latent heat loss over the global oceans under global warming

The newly developed heat flux time series show that over the analysis period from 1981 to 2005 there is a long-term upward trend in global latent heat flux. During this period the increment of the latent heat flux is roughly 10 Wm^{-2} , which amounts to nearly 11% increase of the mean value. Positive linear trend appears on a global scale, being most significant over the tropical Indian and western Pacific warm pool and the boundary current regions. The analysis shows that the increase in latent heat flux is in concert with the rise of sea surface temperature, which suggests an atmospheric response to oceanic forcing (Fig2).

3. In situ validation analysis of the surface heat flux products from OAFlux, ISCCP, and atmospheric reanalyses

In situ flux observations were used to evaluate the mean state and the variability of the newly developed OAFlux product, as well as the shortwave and longwave radiation from the International Satellite Cloud Climatology Project (ISCCP) -FD dataset, and the atmospheric reanalyses flux products. The results (Figure 3) show that the OAFlux flux products have good

comparison with in situ flux measurements. The difference between OAFlux and buoys are within $3\text{-}8\text{ Wm}^{-2}$ over most buoy sites, except for some buoys that are under the Intertropical Convergence Zone (ITCZ) in the tropical oceans and under the influence of synoptic storms off the coast of North America. At these locations OAFlux underestimates the turbulent latent and sensible heat loss by as much as $10\text{-}20\text{ W m}^{-2}$. The ISCCP net downward radiations are found to be overestimated at almost all the buoy locations, suggesting a persistent overestimation bias. The reanalyses flux products do not have good comparisons, as they all underestimate the oceanic heat gain. The model fluxes, including ERA40, NCEP/NCAR and NCEP/DOE, have the same tendency to overestimate latent heat loss (by the amount of $10\text{-}40\text{ W m}^{-2}$) and underestimate incoming shortwave ($10\text{-}40\text{ W/m}^2$).

FIGURES AND IMAGES

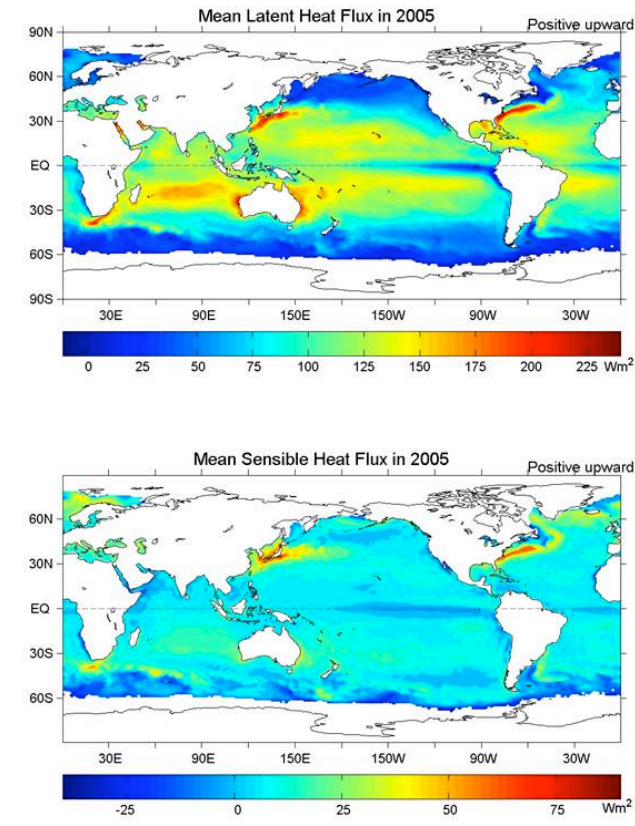


Figure 1. Mean global ocean surface latent and sensible heat fluxes in 2005 from OAFlux.

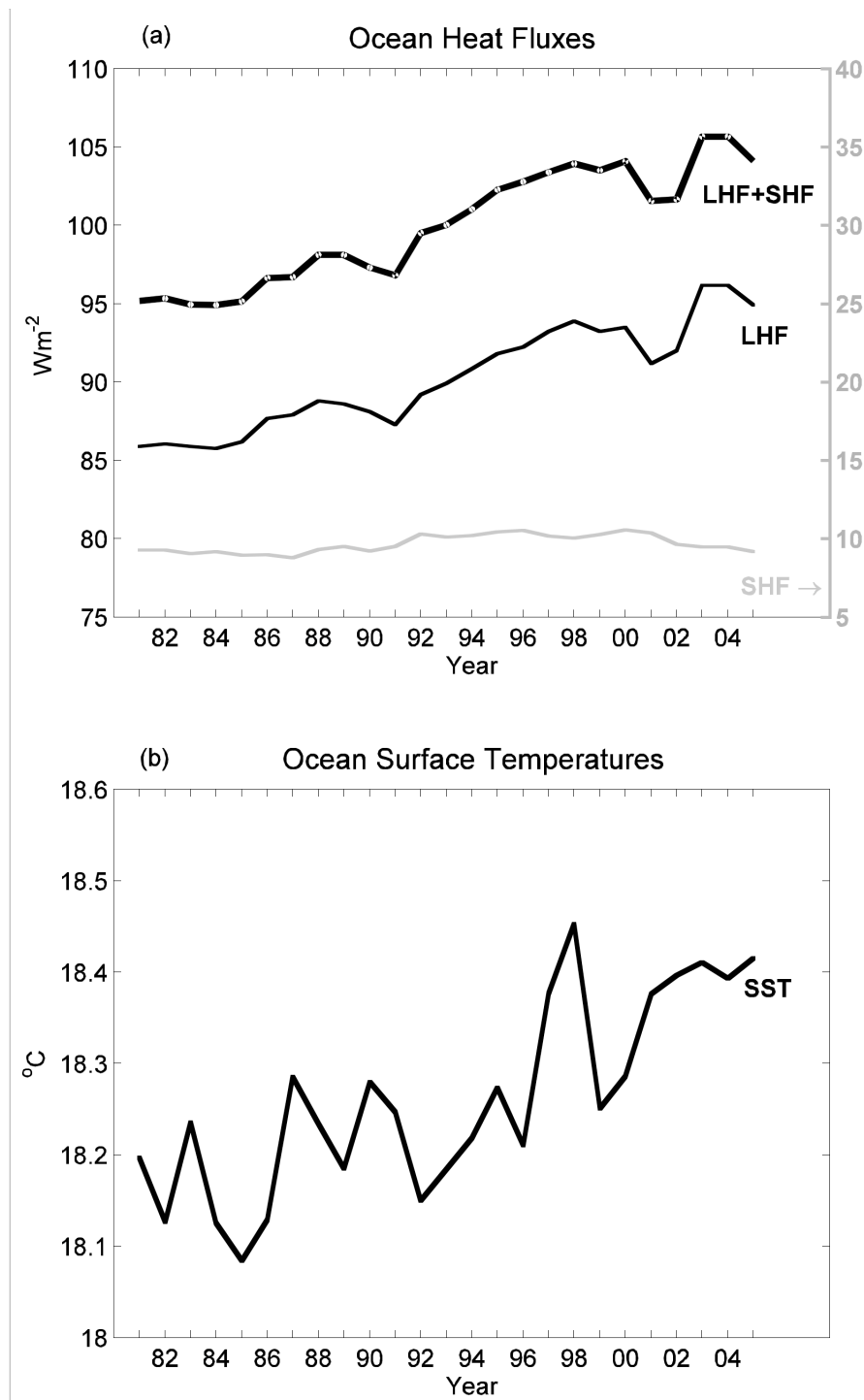
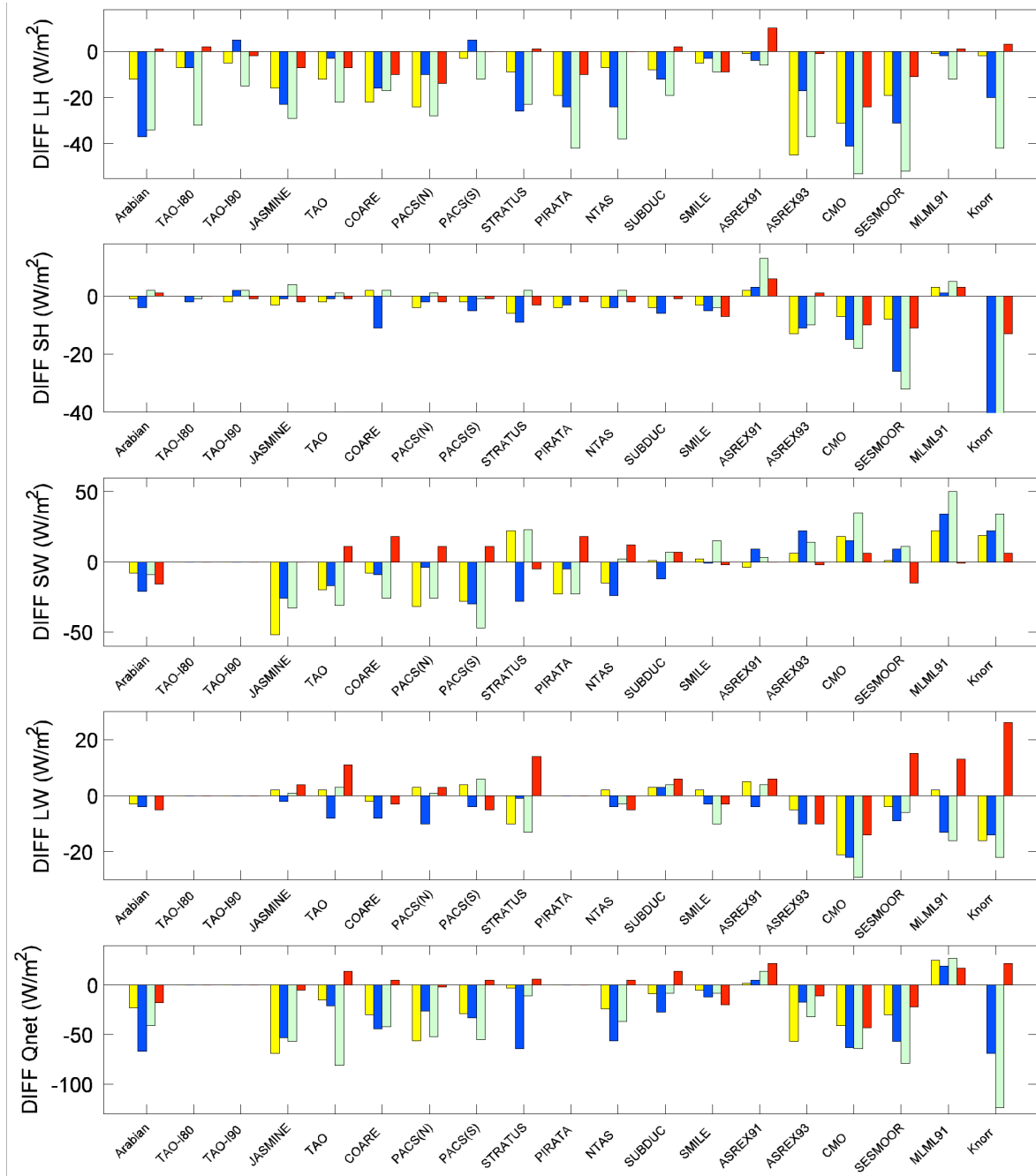


Figure 2 Year-to-year variations of yearly-mean (a) latent heat flux, sensible heat flux, and latent and sensible heat fluxes, and (b) SST averaged over the global ice-free oceans.



■ ERA40 ■ NCEP1 ■ NCEP2 ■ OAFlex+ISCCP

Figure 3. (From top to bottom) Differences between flux products and in situ flux measurements for latent (LH), sensible (SH), shortwave (SW), longwave(LW), and net heat fluxes (Qnet).

PUBLICATIONS

- Yu, L., R. A. Weller, 2006: Objectively Analyzed air-sea heat Fluxes (OAFlux) for the global ice-free oceans. Bull. Amer. Meteor. Soc. Revised.
- Yu, L., X. Jin, and R. A. Weller, 2006a: Annual, Seasonal, and interannual variability of air-sea heat fluxes in the Indian Ocean. *Journal of Climate*. In press.
- Yu, L., X. Jin, and R. A. Weller, 2006b: Role of net surface heat flux in the seasonal evolution of sea surface temperature in the Atlantic Ocean. *Journal of Climate*. In press.
- Yu, L., R. A. Weller, 2006: Oceanic heat fluxes in 2005. *State of the Climate in 2005*. K. A. Shein Ed. *Bulletin of the American Meteorological Society*, 87(6), s24-25.

SUMMARY OF INTERACTION WITH NOAA

The project provides the best possible estimates of air-sea heat fluxes over the global oceans that can be used to study climate variability and changes on synoptic, seasonal, interannual, and decadal timescales. The research contributes to NOAA research emphasis on detecting, identifying, and understanding the climate change and to NOAA research need on model validation and initialization.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

Lisan Yu worked with a WHOI 2006 summer student minority fellow sponsored by the CICOR office in the summer of 2006. They together studied the relationship between the Atlantic hurricane activities and the basin-scale SST variability using historic data records. The investigation yielded an interesting pattern and correlation between the location of hurricane formation and the SST change of the basin-scale. An increased hurricane activity associated with a changing SST pattern after the mid 1990s is particularly noted.

Appendix I: Publication Statistics

	<u>JI Lead Author</u>					<u>Other Lead Author</u>				
	FY01	FY02	FY03	FY04	FY05	FY01	FY02	FY03	FY04	FY05
Peer-Reviewed	26	40	37	13	23	0	0	0	5	2
Non-Peer-Reviewed	0	23	15	12	6	0	0	0	0	0