Cooperative Institute for Climate and Ocean Research

CICOR

Cooperative Agreement Final Summary Report
July 1, 1998 - June 30, 2002

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CICOR 1998 – 2002 Final Summary
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TASK I — Program Development

Robert A. Weller, Principal Investigator

Progress Report: July 1998 — June 1999

The Cooperative Institute for Climate and Ocean Research (CICOR) was officially established by funding of the cooperative agreement on July 1, 1998. During our first year, we have focused mainly on establishing policies and procedures and becoming familiar with the role and expectations for NOAA Joint Institutes. Several science and research projects have been funded through CICOR as well.

The Task I funds have been used for the following activities of CICOR:

- Development of internal procedures for preparation of proposals to NOAA, including establishing a policy regarding Program Development funds.
- The Director of CICOR, Dr. Robert Weller, and the Joint Institute Administrator, Claire Reid, attended the CIASTA Review in Reno, Nevada in November.
- Dr. Weller attended the Joint Institute Directors meeting at AMS in January.
- CICOR assisted the Woods Hole Oceanographic Institution and the New England Aquarium with the Boston regional Ocean Sciences Bowl.
- Dr. Weller attended the EUROGOOS meeting in Rome in March.
- Dr. Weller and the rest of the CICOR staff attended the Joint Institute Directors and Administrators meeting at ERL in Silver Springs, MD in April.
- A CICOR Postdoctoral Scholar was selected as part of the Woods Hole Oceanographic Institution s Postdoc program. WHOI will provide the funding for the first year. Dr. Fiammetta Straneo will arrive soon from the University of Washington. She will work with Dr. Robert Pickart and others on the CICOR theme of the ocean s role in climate and climate variability.
- Dr. Weller met with the directors of CIMAS and JIMO to establish a regional GOOS effort.
- CICOR held its first Executive Board Meeting in Woods Hole in May. Since then we have been working to appoint CICOR Fellows.

TASK I – Program Development

Robert A. Weller, Principal Investigator

Progress Report: July 1999 – June 2000

The Cooperative Institute for Climate and Ocean Research (CICOR) was officially established by funding of the cooperative agreement on July 1, 1998. During our second year, we have focused mainly on establishing the Council of Fellows and establishing our Postdoctoral and Visitor programs

The Task I funds have been used for the following activities of CICOR:

- The first meeting of the CICOR Fellows was held in February in Woods Hole. Twenty-two of the thirty-two Fellows were able to attend. The CICOR themes were reviewed and discussed as well as the educational programs and visitor programs. Each Fellow had the opportunity to make a brief presentation about his/her research. The Council of Fellows was selected. In addition the Council of Fellows has elected Dr. Lloyd Keigwin, Senior Scientist at WHOI, as the Chair of the Council.

- The first CICOR Postdoctoral Scholar, Dr. Fiammetta Straneo, arrived from the University of Washington. She is working with Dr. Robert Pickart and others on the CICOR theme of the ocean's role in climate and climate variability.

- The second CICOR Postdoctoral Scholar, Dr. Jim Lerczak from Scripps Institute of Oceanography, was selected through the WHOI Postdoc selection process. He will arrive in September, 2000 to work with Dr. Dave Chapman of the Physical Oceanography department and Dr. Carin Ashjian of the Biology department in a study of coastal and shelf circulation.

- The first CICOR Visiting Scientist Dr. Fei-Fei Jin from the University of Hawaii arrived in December 1999. Dr. Jin is a leading expert on atmosphere-ocean coupling mechanisms, especially ENSO. He presented a seminar on large-scale air-sea coupling and collaborated with a number of scientists associated with CICOR.

- Dr. Mark Cane, Lamont Doherty Earth Observing center at Columbia, was our second Visiting Scientist in May, 2000.

- CICOR produced and distributed two issues of the Newsletter entitled The Bridge. This newsletter is available in PDF format on the CICOR web page.

- Dr. Weller attended the Joint Institute Directors meeting at AMS in Texas in January

- The Joint Institute Administrator, Claire Reid, and the Financial Administrator, Maurice Tavares, attend the JI Administrators meeting in Long Beach, CA.

- CICOR assisted the Woods Hole Oceanographic Institution and the New England Aquarium with the Boston regional Ocean Sciences Bowl.

- Dr. Weller attended the NEOOS (North East Ocean Observing Systems) organizational meeting at Rutgers.

TASK I – Program Development

Robert A. Weller, Principal Investigator

Progress Report: July 1, 2000 – June 30, 2001

The Cooperative Institute for Climate and Ocean Research (CICOR) was officially established by funding of the cooperative agreement on July 1, 1998. During our third year, we had an Informal Review, held on September 14, 2000. Members of our Executive Board, including Dr. Steve Brandt (GLERL), Dr. Judy Grey (AOML), and Dr. Wendy Gabriel (NMFS), heard reports on some of the science projects funded through CICOR. In addition, a financial report and a report from the Director, Dr. Robert Weller, about some of the CICOR activities were presented. Executive Board Members present discussed the Research Themes for the next cooperative agreement that will cover the period July 1, 2001 – June 30, 2006. At the conclusion of the meeting there was a reception with poster presentations of 7 other projects funded through CICOR.

Other activities of CICOR have been supported by Task I funds including:

- The first CICOR Postdoctoral Scholar, Dr. Fiammetta Straneo, from the University of Washington, continued her collaboration with Dr. Robert Pickart and others on the CICOR theme of the ocean's role in climate and climate variability.

- The second CICOR Postdoctoral Scholar, Dr. Jim Lerczak, arrived from Scripps Institute of Oceanography. He has been working with Dr. Dave Chapman of the Physical Oceanography department and Dr. Carin Ashjian of the Biology department in a study of coastal and shelf circulation.

- CICOR was able for the first time to support two graduate research assistants. J. Steven Fries is in the Applied Ocean Physics and Engineering joint program of WHOI and MIT, advised by Dr. John Trowbridge. The focus of his doctoral thesis is the observation of enhanced fine particle deposition to flat sand beds. Rob Jennings is a Ph.D. pre-candidate in the MIT/WHOI Joint Program in Biological Oceanography, advised by Dr. Ken Halanych.

- Funds were provided so that Drs. Eric Hintsa (Marine Chemistry and Geochemistry Department) and Wade McGillis (Applied Ocean Physics and Engineering Department) could attend the NOAA Air Resources Laboratory Meeting in North Carolina held in April 2001.

- The CICOR web page was redesigned and expanded. It can be accessed at:
  http:/www.whoi.edu/science/cicor

- CICOR produced and distributed the third issue of the newsletter entitled *The Bridge*. This newsletter is available in PDF format on the CICOR web page.

- Dr. Weller attended the Joint Institute Directors meeting at the AMS meeting in Albuquerque, NM in January, 2001.

- CICOR assisted the Woods Hole Oceanographic Institution and the New England Aquarium with the 4th Boston regional National Ocean Sciences Bowl.

Task I - Program Development

Robert A. Weller, Principal Investigator

Progress Report: July 1, 2001 – June 30, 2002

The Cooperative Institute for Climate and Ocean Research (CICOR) began the second Cooperative Agreement on July 1, 2002. (The first agreement covered three years (1998-2001) with a one year extension.) This second Cooperative Agreement will cover five (5) years and match the time period of the other ten NOAA Joint Institutes.

Activities of CICOR have been supported by Task I funds including:

Dr. Weller, CICOR Director Testified before Congress
"Development and Implementation of Ocean Observing Systems"

Dr. Weller attended the Joint Institute Directors meeting that was held at the Fall AGU Meeting in San Francisco, CA.

CICOR produced and distributed the fourth issue of the newsletter entitled *The Bridge*. All copies are available in PDF format on the CICOR web page. (www.whoi.edu/science/cicor).

CICOR's first Postdoctoral Scholar, Dr. Fiamma Straneo accepted a Assistant Scientist position in the Physical Oceanography Department, after finishing her CICOR Postdoctoral 2 year term, in late 2001.

CICOR's second Postdoctoral Scholar, Dr. James Lerczak finished his 18 month term (November 2000 - May 2002) and has remained here at WHOI as a Visiting Investigator.

The third CICOR Postdoctoral Scholar, Dr. Liviu Giosan, arrived from SUNY, Stony Brook in September 2001. He has been working with Dr. Lloyd Keigwin and Bill Curry of the Geology and Geophysics Department.

CICOR sponsored the NOAA Joint Institute Administrator and Finance Manager Meeting at Woods Hole Oceanographic Institution (WHOI) in Woods Hole, Massachusetts on May 21-22, 2002.
All 11 Joint Institutes were represented (a total of 25 people) and ten NOAA representatives attended. The two day meeting format allowed for NOAA and JI groups to meet in separate working groups, before their combined meetings.

CICOR's Graduate Research Assistant's Steve Fries, AOP&E Department successfully defended his thesis titled "Enhancement of Fine Particle Deposition To Permeable Sediment". in September 2001.

CICOR's present GRA, Rob Jennings, Biology Department, is continuing his work on his thesis.

CICOR assisted the Woods Hole Oceanographic Institution and the New England Aquarium with the 5th Boston regional National Ocean Sciences Bowl, on February 23, 2002.

CICOR sponsored a certificate and monetary award at the Falmouth Community Science and Technology Fair March 9, 2002 for the Outstanding Project in Marine Sciences. CICOR winners, Saoud Rana and Dan Schmitt, went on to win First Place at the Massachusetts State Science Fair.

Fiamma Straneo, CICOR Postdoctoral Scholar

As a CICOR post-doctoral scholar at the Woods Hole Oceanographic Institution, working under the supervision of Robert Pickart, Fiamma Straneo has investigated the interannual variability of deep convection in the Labrador Sea. Deep convection is a mechanism for the removal of heat from the mid to deep ocean and its release to the atmosphere. In the Labrador Sea, it results in the formation of Labrador Sea Water, a water mass found throughout the entire North Atlantic and a component of the meridional overturning circulation. Observations reveal that deep convection in the Labrador Sea is a highly time-dependent process, and modeling studies show that such variability has a potentially large impact on the North Atlantic's thermohaline circulation, and thus on our climate system. Hence investigating the causes and the mechanisms behind this variability is an important step towards our understanding of climate fluctuations.

Until recently, it had been hypothesized that variability of convection in the Labrador Sea passively mimicked the variability of the atmosphere and of the North Atlantic Oscillation (the dominant wintertime atmospheric mode of variability in the region), in particular. Through the coupling of a model for the spreading of Labrador Sea Water (based on Lagrangian data, Figure 1) and of an idealized convective model, Straneo was able to show that this is not necessarily the case. First, because the remnant of convected waters from one year affects the amount of dense water formed the following year. Second, because convection can be thought of as a non-linear transmission process between the deep ocean and the atmosphere, in which signals are transmitted only when convection actually occurs. Her results show that the ocean has the ability of modifying the atmospheric signal on timescales that are comparable to the basin's memory. By using realistic atmospheric fluxes from 1950 to the present, Straneo used the model to derive a timeseries for the amplitude of convection in the Labrador Sea. Comparison to a timeseries of Labrador Sea Water properties in the Labrador basin, shows how the model constitutes a substantial improvement in the prediction of the observed LSW variability (Figure 2).

References:

Straneo, F. and R.S. Pickart, 2001: 'Interannual Variability in Labrador Sea Water Formation and Export: Response to a Variable Atmosphere Extended Abstract, US CLIVAR Meeting on the North Atlantic, Boulder, June 2001.

Straneo, F., R.S. Pickart and K. Lavender, 2001b: 'Spreading of Labrador Sea Water: an Advective-Diffusive Study Based on Lagrangian Data'. Deep-Sea Research, submitted.

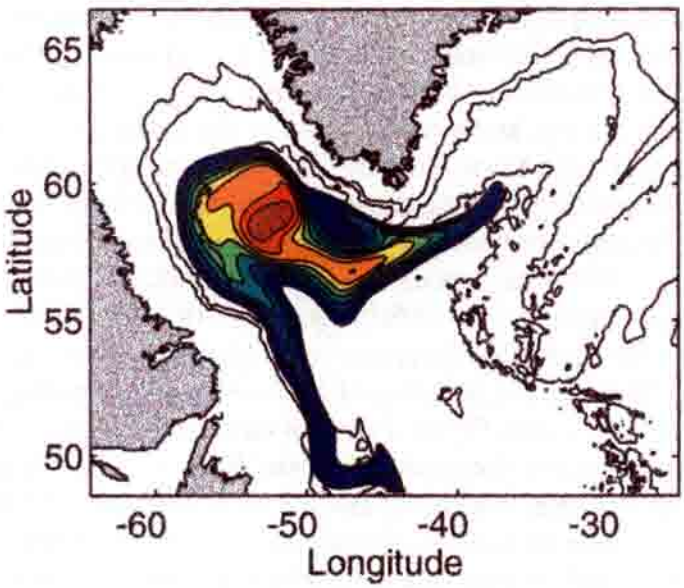

Figure 1: Spreading of Labrador Sea Water 500 days after formation by deep convection in the Labrador Sea from the modeling study of Straneo et al. (2001b)

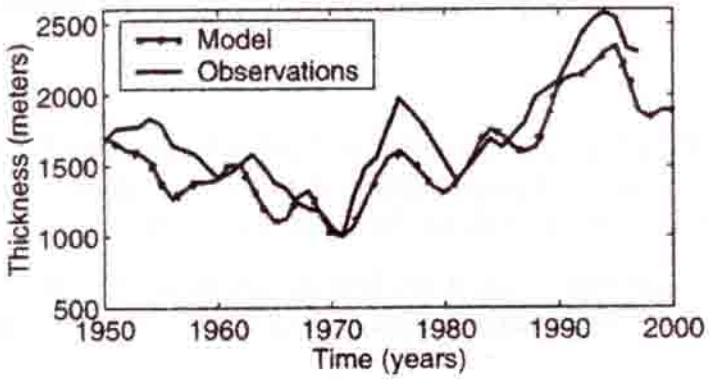

Figure 2. Ability of the convective model formulated by Straneo et al. (2001) to reproduce the observed timeseries of Labrador Sea Water formation in the Labrador Sea.

Jim Lerczak, CICOR Postdoctoral Scholar

Under the theme of coastal ocean and nearshore processes, Jim Lerczak, CICOR Postdoctoral Scholar, has been working with Rocky Geyer of the Applied Ocean Physics and Engineering Department to study cross-channel flows in estuaries. While currents mainly flow along estuary channels, the comparatively weak cross-channel flows influence how salty water from the ocean mixes with fresh water from rivers and are important to the dispersion oftracers, such as pollutants, within estuaries. These cross-channel flows are driven by cross-channel density differences, by the influence of the Earth's rotation, and by meanders in the estuary channel. Lerczak and Geyer used both field observations in the Hudson River and numerical modeling to study the dynamics of cross-channel flows. In May 2001, with Bob Chant of Rutgers University and Bob Houghton of the Lamont Doherty Earth Observatory, they injected a fluorescein dye patch into the Hudson River Estuary to directly measure the influence of cross-channel flows on the mixing and dispersion of the dye. They also collected current and density profiles to measure the mechanisms which drive the cross-channel flows over a tidal cycle. Lerczak and Geyer have also been conducting numerical simulations to study how cross-channel flows are driven in idealized estuaries under different tidal conditions, varying river flows and channel meandering.

Remaining close to shore, Lerczak has also been working with Cabell Davis and Carin Ashjian of the Biology Department and Bob Beardsley of the Physical Oceanography Department to analyze data collected in Cape Cod Bay in 1999 and 2000 to study how copepods use convergences in tidal currents to help them aggregate. Copepods need to form dense aggregations in order to enhance reproduction. These dense patches of copepods in Cape Cod Bay are a critical food source of the North Atlantic Right Whales. Detailed measurements of copepod behavior and density, as well as currents and water properties were collected to determine the dynamics of the tidal convergences and how the copepods responded to the currents.

Papers submitted for publication as of June 2001

Lerczak, J. A., M. C. Hendershott, and C. D. Winant. 2001.
Observations and modeling of coastal internal waves driven by a diurnal seabreeze. J. Geophys. Res., accepted.

Lerczak, J. A., M. C. Hendershott, and C. D. Winant. 2001.
Coherence between the semidiurnal barotropic tide and internal tidal currents on the southern California shelf. J. Phys. Oceanogr., submitted.

Lerczak, J. A., C. D. Winant, and M. C. Hendershott. 2001.
Observations of the semidiurnal internal tide on the southern California slope and shelf. J. Geophys. Res., submitted.

J. Stephen Fries, CICOR Graduate Research Assistant

Abstract from PhD Thesis

Predictions of deposition rate are integral to the transport of many constituents including contaminants, organic matter, and larvae. Review of the literature demonstrates a general appreciation for the potential control of deposition by bed roughness, but no direct tests involving flat sediment beds. Understanding the mechanisms at work for flat sediment beds would provide the basis for exploring more complicated bed conditions and the incorporation of other transport processes, such as bioturbation and bedload transport.

Generally, fine particle deposition rates are assumed to be equivalent to the suspension settling velocity, therefore, deposition rates in excess of settling are considered enhanced. Flume observations of deposition were made using treatments that covered a wide range of flow, particle, and bed conditions. Specific treatments demonstrated large enhancements (up to eight times settling). Delivery of particles to the interface is important, but models based on delivery alone failed to predict the observed enhancement.

This necessitated the development of a new model based on a balance between delivery and filtration in the bed. Interfacial diffusion was chosen as a model for particle delivery. Filtration of particles by the bed is a useful framework for retention, but the shear in the interstitial flow may introduce additional factors not included in traditional filtration experiments.

The model performed well in prediction of flow conditions, but there remained a discrepancy between predictions and observed deposition rate, especially for treatments with significant enhancement. Fluid flow predictions by the model, such as slip at the sediment water interface and fluid penetration into the sediment, appeared to be supported by flume experiments. Therefore, failure to predict the magnitude of enhancement was attributed to the filtration efficiency. A weakness of this deposition model is the lack of an observable mechanism to drive diffusion and filtration. Emerging techniques to directly measure fluid and particle motion at the interface could reveal these mechanisms. The observation of enhanced deposition to flat sediment beds reinforces the importance of permeable sediments to the mediation of transport from the water column to the sediment bed.

Stephen successfully defended his thesis September 14, 2001.

Rob Jennings, CICOR Graduate Research Assistant

From July 2001-2002, I have been working in three main areas: finishing the classes required for the Joint Program, wrapping up projects associated with the hydrothermal vent cruise I went on in May 2000, and writing and defending my thesis proposal.

I took no classes in the fall of 2001; instead I focused on research and organizing my proposal. In spring of 2002 I took two more seminars: Coral Reef Fishes and Larval Biology. At the end of the spring semester, I had the opportunity to travel to Friday Harbor Marine Labs (associated with the University of Washington) to take a five-week intensive course on Marine Invertebrate Zoology. The class was an exciting and invaluable chance for me to increase my knowledge of invertebrate biology and physiology in an incredibly diverse ecological setting. The combination of field collection, dissections, and diversity labs offered an incomparable hands-on experience, and the focus on ecology and physiology was a great compliment to my genetic and evolutionary background. I now have only one more course to take to complete my requirements.

In late summer 2001, I finished conducting molecular identifications on tubeworms that had colonized settlement blocks deployed at the hydrothermal vents at 9°N. These blocks had been set down to investigate the successional dynamics shown by the three species of tubeworms present at the vents (*Riftia pachyptila, Tevnia jerichonana*, and *Oasisia alvinae*) where*Tevnia* appears first, followed by *Riftia* and finally *Oasisia.* Pieces of tubes of different species, as well as artificial tubing and bare control patches, were used to test the idea that the successional patterns are the result of chemical cues present in the tubes. The experiments also tested whether the successional pattern might be due to *Oasisia* having a preference for the mussel-covered patches that tend to dominate as vents age. In October 2001 I presented the results of this work in a poster (Jennings, R.M., Metaxas, A., Hunt, H., Halanych, K.M., and Mullineaux, L.M. Settlement and Recruitment Patterns of Vestimentiferan Tubeworms Using Genetic RFLP Identification) at the 2nd International Conference on Deep-Sea Hydrothermal Vent Biology in Brest, France. Briefly, it appears that, although *Tevnia* may serve as a cue for initial *Riftia* settlement, the presence of adult *Riftia* can also serve as a cue for further *Riftia* settlement. Also it appears that *Oasisia* is capable of colonizing non-mussel-covered substrate in high numbers, implying that a post-settlement mechanism results in their abundance near mussels. The data are now being analyzed by the two main investigators (Drs. Hunt and Metaxas) and will be submitted for publication soon.

I also continued sequencing the mitochondrial genomes of *Riftia pachyptila* and *Ophyrotrocha diadema.* About 80% of the *Riftia* mt genome is complete, and I hope to finish this work and submit it for publication before the end of 2002. Preliminary analyses have identified several markers that might be better-suited to phylogenetic studies than those currently used. The gene order of *Riftia*, thus far, is very similar to other annelid groups, strengthening their close relationship.

Finally, in the winter and spring of 2002, I wrote my dissertation proposal and assembled my thesis committee. I defended the proposal on June 4th, 2002, and passed, giving me Ph.D. Candidate status. My thesis will focus on the link between larval dispersal and gene flow. The majority of previous work on this topic has resulted in a rich body of theory that states that organisms with a high degree of dispersal (that is, those that produce larvae which travel long distances in oceanic currents) should show less genetic differentiation between geographically separated populations. Although this theory is often well-supported, numerous studies have

described apparent contradictions (for instance, high genetic differentiation among populations even with highly-dispersive larvae). A growing body of evidence points to short timescale ecological factors as the cause: population instability, the high mortality of the larval stage, and recruitment variability from year to year. I proposed to investigate the effect these forces have on genetic structure by employing better-suited molecular markers and looking at multiple life-history stages (adults and newly-settled recruits). I have chosen to study two polychaete worms, *Clymenella torquata* and *Marenzelleria viridis,* from sites on and around Cape Cod, where surprisingly little genetic work has been done. In addition, I proposed to collect multiple years of gene flow data to investigate temporal variability in dispersal and gene flow, and to interpret my results using several new approaches that do not assume genetic equilibrium and stability. These approaches will allow me to investigate temporal variability in gene flow and its effect on demographics. A modeling component will allow me to add a genetic component to existing metapopulation models, and will provide a bridge between the theoretical and empirical underpinnings of my research plan. These goals should enable me to better understand the reasons why the gene flow/larval dispersal connection is not always accurate, as well as providing information on natural selection and post-settlement mortality.

Dr. Fei-Fei Jin, CICOR Visiting Scientist

The first CICOR visitor, Dr. Fei-Fei Jin of the University of Hawaii, arrived in December 1999. Dr. Jin's primary scientific collaboration was with Dr. Rui Xin Huang, Senior Scientist in the Physical Oceanography Department. Their joint interest was the equatorial thermocline, the equatorial undercurrent, and cross-equatorial flow. Dr. extended his visit for one month with additional support from Xin Huang and Jiayan Yang to work on a project studying SST variability in the equatorial Indian Ocean in collaboration with Lisan Yu. Another connection that was made during his visit was with Steve Anderson, who made available surface heat flux data recorded with WHOI surface moorings during the recent strong 1997/98 El Nino. Current coupled global circulation models have large errors in simulating surface heat fluxes in the eastern tropical Pacific, and Jin and Anderson plan to compare the mooring observations with model-produced heat fluxes during the El-Nino. During his stay here,Dr. Jin gave a talk titled "Decadal to Interdecadal Ocean-Atmosphere Interaction in the Pacific Basin" and led a journal club discussion on the Pacific Decadal Oscillation.

Dr. Mark Cane, CICOR Visiting Scientist

CICOR's second visiting scientitst was Mark Cane from Lamont-Doherty Earth Observatory. He gave two talks during his visit titled"On the Indonesian Throughflow" and "ENSO in the Holocene" The first was a physical oceanography talk on a subject of great relevance for studies of the ocean's role in climate. The second is a climate dynamics talk, about the influence of ocean - atmosphere interactions in the Pacific on climate variations in the past 12,000 years.

Xin Huang brought my interest to the equatorial thermocline and undercurrent theory. Our discussions have led to a collaboration in studying the hemispheric asymmetry of the equatorial undercurrent and cross-equatorial flow.

Fascinated by the ideal environment for scientific interactions and encouraged by new collaborations developed here at WHOI, I extended my visit for another month following suggestions from Xin and Jiayan who also generously offered financial support for this extension. This extension allowed me to make a good progress on a project studying SST dipole-mode discovered recently in the equatorial Indian Ocean in collaboration with Lisan. Lisan and I managed to submit an abstract to the Indo-Pacific Climate symposium held on March 6-7 at Tokyo and I will present our results at this meeting.

Through discussions with Steve, I got very interested in his mooring data, particularly the rare surface heat flux data for the entire event of 1997/98 El Ni–o. It is well-known that current coupled GCMs are of large errors in simulating the surface heat fluxes. A student of mine has started to analyze this data carefully. In collaboration with Steve, we will compare this observation with NECP reanalysis and some coupled GCM simulations to exam the contributions from the heat flux changes during the El-Ni–o.

Suggested by Xin, I led a journal club discussion on the Pacific Decadal Oscillation on Feb. 23. Xin and I are interested to work together on this issue in our future collaborations.

CICOR Visiting Student

Andrea Tascetta, visiting student from San Paulo, Brazil visited WHOI for six weeks to work with Al Plueddemann, PO Department to work on NTAS. The summary of her work follows.

Ms. Andrea Taschetto was appointed as a WHOI Guest Investigator from 9 January 2001 to 16 February 2002, and received CICOR support during her stay. Andrea had just finished her Masters work with Dr. Ilana Wainer at the University of San Paulo, Brazil. Her work at WHOI was related to the NOAA/CICOR funded Northwest Tropical Atlantic Station (NTAS) project.

Andrea evaluated the first 10 months of meteorological data from the NTAS-1 mooring deployed at 15N, 51W in the tropical Atlantic. Hourly data obtained by Argos telemetry from the buoy were used in the study. The performance of sensors on the buoy was evaluated relative to their expected accuracy. Basic meteorological variables from the buoy sensors were then compared with surface meteorology from NCEP and ECMWF models. Standard time-series analyses were performed for time scales between 6 hr (the temporal resolution of the models) and several days.

It was determined that the buoy sensors performed well and were appropriate for use as an in-situ reference for the numerical weather prediction (NWP) models. Correlation between buoy and NWP variables increased with increasing averaging time. In the mean, only the NCEP barometric pressure and the ECMWF shortwave radiation showed notable discrepancies (differences much larger than the expected buoy error). However, most NWP variables did show discrepancies on the 6 hr time scale, and for several variables (air temperature, specific humidity, longwave radiation) these discrepancies remained after averaging to 4 days.

This preliminary work provides a useful guide to the more detailed analyses to follow using the one year record of high-resolution (1 min) meteorological data obtained from the buoy after recovery.

CICOR Educational and Outreach Projects

CICOR winners of the local High School Science Fair, Saoud Rana and Dan Schmitt, went on to win First Place at the Massachusetts State Science Fair.

The Wiggle: Reducing the Oscillation of Oil Risers
Saoud Rana, Dan Schmitt
Falmouth High School, Falmouth, MA
Teacher: Dr. Johnson, Dr. Hinkle

When the oil drillers drill underwater, the drill bits stretch hundreds of feet under the water. Down there, they are subjected to currents which cause the drill bit to oscillate.

This will be tested by building a tank which has water circulating within the tank; in this tank different shaped pendulums will be tested to represent oil drills. Three different shaped pendulums were used in the experiment. One pendulum was the control and had no fins attached to it, another pendulum had a fin equal to the diameter of the pendulum, and the third pendulum had a fin twice the diameter of the pendulum attached to it.

The purpose of this project is to reduce oscillation caused by water currents.
In conclusion, it was determined that: a cylinder without stabilizer fins will have the least oscillation, the smaller fin - of equal diameter to that of the PVC - had the highest oscillary range and the larger fin had a range in between the control and the small fin. The fin was intended to break up the eddies formed by flow, but instead, it seemed to enhance them. A tail fin is not the solution to vortex-induced vibrations. There are a few possible sources of error. The flow within the tank may have varied toward the outer wall and at different depths. This would have a similar effect on all of the inverted pendulums, so the overall results would not be greatly affected. Oil companies are still working on this, they have been unable to successfully solve this problem.

Secular Variability of Warm Water Transformation in the North Atlantic

Michael McCartney and Ruth Curry, Principal Investigators

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Analyses were undertaken of low frequency ocean signals that are coordinated with North Atlantic Oscillation (NAO) atmospheric patterns. These investigations have explored aspects of the ocean's natural variability (e.g. water mass properties, strength of gyre and overturning circulations) in the context of NAO timescales.

NAO-correlated variability of subpolar deep water (LSW) has a time-delayed impact on the subtropical circulation and mid-depth water properties. Analyses of the Labrador Basin, Bermuda, and Abaco time series, indicate a 5-6 year lag for the subpolar signal to influence the interior subtropical gyre (Bermuda); and 8-10 years to propagate via the DWBC to the latitude of Abaco (26° N). The subpolar variability is manifested as shifts in T-S properties and alteration of the vertical density structure and potential vorticity characteristics of the mid-depth subtropical waters.

The North Atlantic subpolar and subtropical gyre circulations have exhibited fluctuations in baroclinic transport strength over the observational record (~50 years) that are organized around the NAO time structures. An index of the gyre strength was constructed from time series of potential energy anomaly (PEA) at the gyre centers -- an oceanic analogue to the SLP-based atmospheric NAO index. The analysis explored the mechanics of the individual gyre PEA histories, and demonstrated that they are representative of basin-scale shifts in PEA distributions. The transport fluctuation that results from these shifts reflects not only wind- and buoyancy-driven thermocline variability, but also changes in deeper layers related to deep convection, advective-diffusive movement of ocean waters, the growth and decay of mid-depth geostrophic shear, and dynamics of the deep inertial gyre system. The time-scales and coordination of these baroclinic adjustments sometimes lead to the development of large ocean signals: the eastward baroclinic transport in the upper 2000 db of the Gulf Stream/North Atlantic Current system varied by ~30% from a minimum of 48 megatons/sec circa 1970 (following a persistent low NAO phase) to a maximum of ~68 megatons/sec circa 1995 (at the culmination of a persistently high NAO phase). To first order, the ocean PEA signals reflect an integration of the atmospheric forcing history. The resulting fluctuation of gyre transport strength is synchronous with the warm/cold propagating SST anomalies, which are surface manifestations of deeper-reaching upper ocean temperature content anomalies. The enhanced or diminished gyre circulation appears to contribute to decadal alterations in the distribution of upper ocean heat and salt -- with the potential to influence the overlying atmosphere and the strength of the overturning circulation.

Warm and saline waters entering the Nordic Seas from the south are primarily supplied by upper ocean subtropical waters carried to the eastern North Atlantic by the North Atlantic Current. The progressive cooling and freshening by winter convection along this advection pathway sets the inflow characteristics. The Mediterranean Outflow Waters, which were previously hypothesized

to directly influence the Nordic Seas Inflow, plays a diminutive role through its contribution to defining the T-S relationship of the interior subtropical gyre -- from which the North Atlantic Current draws its waters. Rather than directly feeding the Nordic Seas inflow, the eastern boundary undercurrent wholly expels its transport of MOW into the eastern edge of the subtropical gyre, resulting in the plume of high salinity subtropical waters.

The following people collaborated with the Principal Investigators on this research:

C. Mauritzen (WHOI)
R. Molinari (AOML)
J. Paillet (Ifremer)
M. Arhan (Ifremer)
J. Hurrell (NCAR)
H. Bezdek (AOML)

Major journal publications

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Coral-Based Seasonally Resolved Records of Oceanic Surface Conditions at Bermuda

A.L. Cohen and M.S. McCartney, Principal Investigators

Final Summary Report CICOR Cooperative Agreement 1998-2002

The aim of this project is to develop a proxy for the North Atlantic Oscillation (or NAO) in the skeletons of massive, long-lived reef corals. In the past two years we have sought to calibrate skeletal chemistry and structural variations in 3 small braincorals from Bermuda against the instrumental records of NAO and SST. We chose this site because it is well-situated in an area identified by Sutton and Allen (1997) for the growth of SST anomalies which subsequently propogate from the western sub-tropics to the eastern sub-polar region. The case for our initial Bermuda focus has since been strengthened by the recent successes in AGCM simulations which hindcast the observed NAO history when the observed SST is applied as a boundary condition (three independent model studies: Rodwell et al. 1999, Hurrell, pers. comm. And Mehta, pers. comm). We chose to work on the braincoral *Diploria labyrinthiformis* despite the difficulties presented by its complex skeletal architecture and slow growth rate for reasons of abundance, longevity and strong annual growth banding[1].

Three small *D.labyrinthiformis* colonies were collected live in April 1999 at 50ft at the edge of the south-eastern Bermuda platform. We chose this specific part of the reef because of its exposure to the open ocean and least influence by local lagoonal processes. Well-defined high (HDB) and low density bands (LDB) are revealed in x-ray, the number and spacing of which indicates an average age of 40 years and an average growth rate of 3 mm/year. LDBs are approximately 3 times wider than HDBs. Two $\delta^{18}O$ profiles were constructed by analysing samples drilled at 0.2 mm intervals along a single septatheca in the coral calyx, a sampling strategy developed in the first year of the project. Both profiles show strong annual $\delta^{18}O$ cycles with average amplitude of 1.5 per mil, equivalent to 7.5 °C which agrees well with temperatures recorded *in situ* at our Bermuda sampling site. To determine the seasonality of density band formation, we used NIH image (a software program developed for use on CAT scans) to map high-frequency (seasonal) density changes against the $\delta^{18}O$ profiles. HDBs coincide with high temperatures (depleted $\delta^{18}O$) indicating that the densest skeleton (usually signifying least calcification) is accreted during the summer months and the least dense skeleton (signifying most calcification) is accreted during cooler months. Our observation agrees with the findings of Logan and Tomascik (1991) for this species on Bermuda even though it is unusual for corals, in general, to increase calcification in cooler water.

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[1] Abundance. Our long-range (10-year) plan is to explore past Atlantic climate variability at multiple sites chosen for their importance as SST and ocean-interaction centers. *D. labyrinthiformis* occurs throughout the tropical and sub-tropical western Atlantic. The same techniques we develop for extracting accurate climate data from Bermuda colonies can be applied to samples from other sites.

Longevity. We recently sampled a *D. labyrinthiformis* colony at Bermuda that stands more than one meter high. With a growth rate of 2 mm/year, we estimate this colony to be about 500 years old. Similar sized colonies occur throughout the Caribbean which increases our confidence that similarly long climate records can be constructed both in the sub-tropical and tropical Atlantic.

Growth banding. Of the three species of Atlantic braincoral, x-rays of *D. labyrinthiformis* reveal the strongest annual growth banding. Since annual bands are the primary method by which corals are aged and specific years identified, this feature is important when deciding on a species.

The consistent correlation between skeletal density and $\delta^{18}O$ indicated that skeletal density itself may be a proxy for SST. We smoothed the density profile using a 5-point running average which essentially decreases the "sampling" resolution from tri-monthly to annual and compared the result against actual climate data. Skeletal density, sampled at annual resolution, is significantly, positively correlated with the wintertime (J,F,M) NAO Index over the past 40 years. It is better correlated with the NAO Index than it is with wintertime SSTs for Sutton and Allen's (1997) region 3. The coral accretes a more dense skeleton when the NAO Index is positive although the reason for this is as yet unclear and requires further investigation. In the meantime results of this study indicate that low-frequency skeletal density changes in Bermuda *D.labyrinthiformis* are a good 1st-order proxy for NAO.

Wintertime $\delta^{18}O$ anomalies between 1955 and 1998 were calculated using the heaviest $\delta^{18}O$ value in each annual $\delta^{18}O$ cycle. $\delta^{18}O$ anomalies are also well-correlated with NAO but consistently precede NAO anomalies by approximately 3 years. Examination of the skeletal structure of the septothecae in petrographic thin-section shows that pore spaces evident when the skeleton is first accreted are subsequently filled-in over a period of several years. The effect of infilling on the climate signal would be to dampen the annual cycles and create a consistent phase-offset between the actual climate forcing and the measured geochemical response in the direction that we observe.

In summary, our investigation of the North Atlantic climate signal in Bermuda braincorals indicates that Best regards,the coral skeleton records the history of NAO in two independent ways, by changes in skeletal density and in skeletal chemistry. Accurate interpretation of both datasets requires that we understand how and when the corals accrete skeleton. We propose to utilize both tools to extract a multi-century long history of NAO activity from a 500-year old *D. labyrinthiformis* that we recently sampled at Bermuda.

A Numerical Study of Linkage Between the North Atlantic Oscillation (NAO) and Climate Changes in the Tropical and Subtropical Atlantic Ocean

Jiayan Yang, Principal Investigator

Final Summary Report CICOR Cooperative Agreement 1998-2002

In the past year (1999-2000) the PI has worked closely with Dr. T. Joyce on a project to examine heat content variability in the tropical and subtropical Atlantic Ocean by using both models and observed data. We have investigated several mechanisms that may contribute to the variability in the tropics. Heat content in the upper layer (0-200m) in the equatorial Atlantic Ocean has considerable variations on interannual to decadal time scales (using two sets of gridded temperature data; one from T. Joyce [WHOI] and the other from W. White [Scripps]). We studied its forcing mechanisms by examining the atmospheric variability, using both NCEP and COADS data, and responses from a model to atmospheric forcing. It was found that the change of the trade wind along the equator is a main factor that gives rise to heat content variations.

We have also investigated the role of Rossby and Kelvin waves in linking variability in the tropics and extratropics. The center of the action associated with NAO is outside the tropics. To understand how the NAO affects the tropics, one must examine how the extratropical and tropical oceans interact and communicate with each other. One of the most efficient ways is through Kelvin wave propagation along side boundaries. Rossby waves can be generated in response to NAO-induced changes in wind-stress curl. When a Rossby wave propagates westward and reflects at the western boundary, part of its energy will be reflected back to the ocean interior via short Rossby waves, but the remaining part will go to coastal Kelvin waves which propagate along the western boundary to the tropics and may affect the thermocline depth and heat content variability there.

We have examined this problem in three steps. First, we solved the Rossby-wave reflection problem analytically, and found that the magnitude of Kelvin-wave response depends a number of factors, such as the amplitude and wavelength of incoming Rossby waves, the latitude at which the reflection occurs. In high latitude, such as in Labrador Sea, the Kelvin wave response from a Rosdby-wave reflection is small. However, if Kelvin waves are directly forced by either convection or atmosphere forcing along the western boundary, their amplitude waves are much greater and the response in the tropics is significant. Second, we have used a numerical model to conduct several sensitivity tests to examine a few types of forcing associated with NAO, e.g., boundary versus interior, subtropics versus subpolar, etc., and found that model results are highly consistent with the analytical solution. Third, we have analyzed sea-level data from many tidal stations along both eastern and western boundaries to examine the Kelvin-wave connection in the Atlantic Ocean. It was found that sea-level variations along both boundaries and in almost all latitudes in the northern hemisphere are highly correlated with the NAO index. The phases of sea-level variations in these stations suggest that boundary Kelvin waves forced by surface wind stress associated with NAO play a major role.

Publications:

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

Yang, J. and T. Joyce: Kelvin and Rossby waves and a connection between the tropics and extratropics (tentative title), in preparation.

Coordinated Program in Processes and Ocean Research:GLOBEC Field Programs
Woods Hole Oceanographic Institution Marine Operations

Final Summary Report CICOR Cooperative Agreement 1998-2002

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Program Manager: Julia Neander, Coastal Ocean Program

During the period July 1, 1998 - June 30, 1999, the US GLOBEC Georges Bank program undertook three (3) cruises on R/V Oceanus with funding received through this program. The ship and technician effort was funded jointly between the National Science Foundation and this CICOR Program. The participants in these GLOBEC efforts were under the leadership of Dr. Charles Greene, Cornell University, Dr. Peter Wiebe, WHOI, Dr. Robert Beardsely and Richard Limeburner, WHOI.

Cruises aboard R/V Oceanus took place as follows:

October 19 - 28, 1998	5 NOAA/CICOR days
November 15 - 21, 1998	3 NOAA/CICOR days
December 3 - 13, 1998	7 NOAA/CICOR days

Efforts of ship's crew and the shipboard scientific services technician contributed to the scientific effort in these field studies. The scientific services technician provided shore based and sea-going expertise in shipboard data acquisition logging and scientific equipment interfacing to shipboard systems. Ship's crew worked with the scientific party to recover moorings and instrumentation placed on Georges Bank during previous cruises. Ship's crew also worked with members of the science party to modify equipment and develop techniques for recovering acoustic and video remote-sensing instrumentation in a safer and more efficient manner in order to preserve the data and the instrumentation.

Results from these field studies will be used as input to coupled physical-biological models to examine how physical transport processes in the Gulf of Maine interact with the seasonal and diel vertical migration behaviors of the populations of the zooplankton *Calanus*.

Altantic Oceanographic and Meterological Laboratory (AOML) Field Programs

Program Manager: Frederick Rossman, OAR

The Ecology and Oceanography of Toxic Alexandrium Blooms in the Gulf of Maine (ECOHAB-GOM)

Program Manager: Marilyn Moll, NOAA/OAR Joint Institutes Program.

During the period July 1, 2000 — June 30, 2001, between the AOML Field Programs and ECOHAB-GOM, a total of five (5) cruises on *R/V Oceanus* were funded. The participants in these efforts were under the leadership of Dr. Donald Anderson/WHOI, Dr. Robert Molinari/University of Miami, Dr. Albert Plueddemann/WHOI, Dr. William Douglas Wilson/ University of Miami, and Dr. Martha O Neil Baringer/ University of Miami.

Cruises aboard *R/V Oceanus* were in support of various scientific endeavors and took place as follows:

March 4 - 26, 2001	23 NOAA/CICOR days
March 27 — April 9, 2001	5 NOAA/CICOR days
April 10 — 24, 2001	15 NOAA/CICOR days
April 25 — May 8, 2001	14 NOAA/CICOR days
June 5 — 14, 2001	10 NOAA/CICOR days

Project Summaries:

Subtropical Cell Studies
(March 4, 2001 — March 26, 2001) - Molinari
Shallow tropical-subtropical cells have been identified in the South Atlantic and North and South Pacific. The cells carry water from the subtropics to the tropics at subsurface depths. At the equator, the water is upwelled to the surface and then returns to the sinking area in the subtropics. It has been hypothesized that these cells in the Pacific have an impact on decadal climate variability. The primary objective of this cruise was to determine if a similar cell is present in the North Atlantic. Data from this cruise will supplement other data collected in the region to characterize interaction between the subtropical and tropical Atlantic.

Northwest Tropical Atlantic Station for flux Measurement
(March 27, 2001 — April 9, 2001) — Plueddemann
The intent of this project was to address the need for surface flux and upper ocean measurements in the northwest tropical Atlantic and to use these observations to investigate air-sea interactions related to climate variability. The monitoring site will provide the observational data base necessary to evaluate the intrinsic modes of tropical Atlantic variability and will contribute to the investigation of other Atlantic climate research questions as outlined Climate Variability and Predictability (CLIVAR) Program planning documents.

Caribbean Transport Variability Field Program (April 9, 2001 — April 24, 2001) - Wilson
This cruise was the 18th in a series of hydrographic cruises in the passages between the Caribbean Sea and the Atlantic Ocean, dating to 1991. The primary purpose was to measure transports and water mass properties of the upper ocean flow between the Atlantic Ocean and the Caribbean Sea. This warm water inflow, in conjunction with an export of cold deep water, is the mechanism by which heat is transferred northward in the North Atlantic Ocean. Variations in this heat transport should result in variations in North Atlantic climate. Through these measurements and other associated programs, we hope to better understand the mean flow condition and its variability.

Abaco Time Series Field Program
(April 25, 2001 — May 8, 2001) - Baringer

The Abaco time series began in earnest in August 1984 when the NOAA STACS program extended its Straits of Florida program to include measurements of western boundary current transports and watermass properties east of Abaco, the Bahamas. Since 1986, over 20 hydrographic sections have been completed east of Abaco, most including direct velocity observations by Pegasus and/or LADCP. Transient tracer (CFC) measurements have been made on 7 of these sections, at roughly 2-year intervals. Current meter arrays have been maintained nearly continuously for an 11-year period from April 1986 through May 1997.

The repeated hydrographic and tracer sampling at Abaco has established a high-resolution record of watermass properties in the DWBC at 26N, which for temperature and salinity can be reasonably constructed back to about 1955 (Vaughan and Molinari, 1997; Molinari et al., 1998). Events such as the intense convection period in the Labrador Sea and renewal of classical Labrador Sea Water in the 1980's are clearly reflected in the cooling and freshening of the DWBC waters off Abaco, and the arrival of a strong CFC pulse, approximately 10 years later. This array is unique in that it is not just a single time series site but a transport section, of which very few are available in the ocean that approach a decade in length.

ECOHAB — Gulf of Maine Study
(June 5, 2001 — June 14, 2001) - Anderson

ECOHAB-GOM is a project that addresses several fundamental issues regarding Alexandrium blooms in the Gulf of Maine: 1) the source of the Alexandrium cells that appear in the fresh water plumes in the western Maine coastal current (WMCC); 2) Alexandrium cell distribution and dynamics in the eastern Maine coastal current (EMCC); and 3) linkages among blooms in the WMCC, the EMCC and on Georges Bank. Utilizing a combination of numerical modeling, hydrographic, chemical, and biological measurements, moored and drifting current measurements, and satellite imagery, we are working to characterize the structure, variability and autecology of the major Alexandrium habitats in the Gulf of Maine.

WOCE-CLIVAR Subsurface Float Data Assembly Center

Final Summary Report CICOR Cooperative Agreement 1998-2002

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The Sub-Surface Float DAC's contribution to the final DVD of WOCE data (WOCE, 2002) consists of over 2500 floats in 80 experiments. For each experiment, there is background information, a plot, a list of references, a float-by-float description (parameters, geographic and time limits, etc.), and zipped files of all the floats in ASCII and in the standardized WOCE NetCDF format. There is also a searchable inventory. The inventory and the final versions of the NetCDF files were produced by L. Charles Sun, Chief Scientist and Deputy Chief at the NODC Coastal Ocean Laboratory.

The final influx of data (thanks to the efforts of WOCE participants on several continents) resulted in Version 3.0 including at least 30 more experiments than Version 2.0.

The webpage (http://wfdac.whoi.edu) will be updated after the final WOCE conference (November 18-22, 2002), when the data is no longer proprietary.

Meetings attended:

WOCE Data Products Committee: Jan 21-25, 1997 at Scripps Institution of Oceanography, La Jolla, CA.

WOCE Data Products Committee: Jan 4-9, 1998 at University of Hawaii at Manoa, HI.

WOCE Conference: May 24-29, Halifax, N.S.
Presented a poster on WOCE Subsurface Float Archive

WOCE Data Products Committee: April 12-16, 1999 at Bidston Observatory in Birkenhead, England

WOCE Data Products Committee: April 5-7, 2000 at Texas A&M University in College Station, TX.

References:

National Oceanographic Data Center, 1995. Ocean Current Drifter Data (Sub-surface Float Data). CD-ROM NODC-53.

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

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

WOCE Data Products Committee, 2002. WOCE Global Data, Version 3.0. DVD. WOCE International Project Office, WOCE Report No.180/02, Southampton, U.K. (in preparation)

NorthEast Observatory System (NEOS)

Robert A. Weller, Principal Investigator

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The focus of the NorthEast Ocean Observing Systems (NEOS) was to develop an integrated observing system for the waters off the coast of North America. The first meeting of all interested scientists and state officials was held at Rutgers University, New Brunswick, New Jersey on November 16, 1999. A second meeting was held on January 25, 2000 during the Ocean Sciences Meeting/AGU in San Antonio, Texas. Other universities and institutes that were represented at the Texas meeting and the Coastal Ocean Observation Network sites (CoCO) are also coming onboard under the NEOS umbrella. A Memorandum of Agreement, which was finalized in early 2000 covering the sharing of data, is being signed by all participants.

NEOS is presently linked from the WHOI/CICOR homepage. It contains the NEOS goals and strategy statements, general information on the initial organizational meetings, a copy of the Memorandum of Agreement, a brief explanation of the Coastal Ocean Observatories and their role in NEOS, a list of participants with email addresses and a map with links to each of the existing data websites. The web address is www.whoi.edu/cicor/science/research.

In 2001, Eastern Consortium of Coastal Ocean Observatories (ECCOO) joined the NEOS project. ECCOO is now supporting out the web. The direction of NEOS/ECCOO is to improve our understanding of complex coastal ocean processes, long-term, region-scale measurements are required. Several oceanographic research institutions located on the U.S. East Coast have recently created coastal ocean observing systems to acquire such measurements. In order to facilitate good communication, WHOI CICOR and WHOI COI have begun to develop a central web entry point for participating coastal observatory websites. Participating observatories are presented with direct access to individual sites. As this website develops, we expect that it will become a resource for inter-observatory communication, data-sharing and outreach to the non-scientific community.

The ECCOO Web entry point includes both "estuary/embayment-coastal" and "nearshore-coastal" observatories. For our purposes, "coastal" is defined as the broad interface between continent and ocean where production, consumption and exchange processes occur at high rates. Geographically it extends from the upland penetration of the riverine salt wedge through the estuary to the edge of the continental shelf. The geographic extent of the coastal zone will expand or contract depending on the particular process under investigation.

Enhancements to Ongoing Studies of Target Strength Measurements of Gas-Bearing Marine Life

Final Summary Report CICOR Cooperative Agreement 1998-2002

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Improved estimates of fish abundance and biomass derived from fisheries acoustics surveys require fundamental understanding of sound scattering by the organisms. Acoustic scattering by fish, zooplankton, and other marine organisms is a complex function of the size, shape, morphometry, and behavior of the targets. Anatomical attributes combined with behavior of the organisms influence the estimates of organism size and number as derived from acoustic scattering survey data. Modeling of the scattering is sufficiently challenging that controlled measurements of the scattering are required. These measurements can be obtained through both in situ and laboratory experiments. This research involves laboratory measurements as a collaborative effort between WHOI and NOAA/NEFSC. The work represents an enhancement to ongoing work being funded through other sources.

In the spring of 2000, an extensive series of measurements of target strength of live individual alewife fish was successfully completed. Using a pair of broadband transducers and computer-controlled rotator, acoustic backscattering was measured over the frequency range 40-95 kHz and over all angles of orientation in two planes of rotation in one-degree increments. The morphology of the animals was studied through a combination of dissection, physical measurements, traditional x-rays (again, in two planes), medical CT scans, and phase-contrast x-rays. These data, involving twenty fish, are of very high quality.

The analysis is complete. The data have been processed in terms of their characteristics in both the time (pulse compression processing) and spectral domains. In addition, the processed data have been compared with two scattering theories-- the Kirchhoff-Ray-Mode and Fourier Matching Method formulations. Through this analysis, dominant scattering mechanisms have been identified. Specifically, it was demonstrated that, in addition to the swimbladder contributing significantly to the scattering, the head and other organs also contribute significantly for angles well off normal incidence. Also, it was demonstrated that the angle of orientation of the fish could be estimated remotely from the duration of the compressed pulse provided that the length of the fish is known. Our study concludes that the Kirchhoff-Ray-Mode theory works reasonably well for angles near normal incidence (dorsal). Well away from these angles, a more sophisticated model, such as the Fourier Matching Method, needs to be used, but with the addition of taking into account the other organs.

Preliminary results were reported in a special session on "Fish and Zooplankton Acoustics" at the Dec. 2000 scientific meeting of the Acoustical Society of America in Newport Beach, CA. Final results were reported in the June 2002 ICES symposium on "Acoustics in Fisheries and Aquatic Ecology" in Montpellier, France.

The following manuscripts have been submitted for consideration of publication in peer-reviewed scientific journals:

1. Reeder, D.B. and T.K. Stanton, "Acoustic scattering by axisymmetric finite-length bodies: An extension of a 2-dimensional conformal mapping method," submitted to J. Acoust. Soc. Am.

2. Reeder, D.B., J.M. Jech, and T.K. Stanton, "Broadband acoustic backscatter and high-resolution morphology of fish: Measurement and modeling," submitted to J. Acoust. Soc. Am.

3. Stanton, T.K., D.B. Reeder, and J.M. Jech, "Inference of fish orientation from broadband acoustic echoes," submitted to ICES J. Mar. Sci.

Finally, the results in papers #1 and #2 make up much of Ben Reeder's doctoral thesis which he successfully defended in May, 2002.

Studies in Chemistry of the Marine Atmosphere

Ronald G. Prinn and Alexander A.P. Pszenny, Co-Principal Investigators
Massachusetts Institute of Technology

Final Summary Report CICOR Cooperative Agreement 1998-2002

Work during the past year has been divided among four tasks: 1) interpretation and write-up of data from a May 1997 aerosol particle sampling effort at Bermuda, 2) interpretation of data from a September 1999 particle and halogen gas sampling effort at Oahu, Hawaii, 3) developing a global database of size-segregated aerosol bromine/bromide data, and 4) developing in concert with NOAA/AOML personnel a proposal for a study of ship plume contributions to North American air pollution. A fifth task, to establish an ion chromatography analysis capability at MIT, has not progressed significantly.

Bermuda field work.

The objective of the Bermuda field work was to estimate the pH of marine aerosols based on actual measurements of hydrogen ion activity in minimally-diluted aerosol extract solutions. A summary of the results is shown in Figure 1. They suggest that super-µm particles, which are primarily sea salt, are quite acid (pH 4 to 5). This is contrary to earlier estimates based on extract pH and conductivity measurements that suggested sea salt aerosol pH values are typically about 6 (Winkler, 1980). However, our results are consistent with more recent sea salt aerosol pH estimates based on HCl gas-aerosol equilibrium calculations (see next paragraph) and more detailed modeling of sea salt aerosol chemistry (Keene et al., 1998). Dr. Pszenny visited the University of Virginia (UVA) in early April 2001 and worked with W. Keene on a manuscript describing this work. It is now in an advanced draft stage and should be submitted to a journal sometime this summer.

Hawaii field work.

The objective of the Hawaii field work was to sample and analyze gases and aerosols hypothesized to be involved in "halogen activation" processes in the marine boundary layer. For scientific background see Pszenny et al. (1993), Sander and Crutzen (1996) and Keene et al., 1998. Tandem mist chamber (Keene et al., 1993) results confirmed that HCl vapor was present in the Hawaiian marine boundary layer (MBL) at mixing ratios of order 100 pptv (see Figure 2). Keene and Savoie (1998, 1999) argued based on observations of measured HCl mixing ratios and aerosol chemistry at Bermuda in April 1996 that the super-µm marine aerosol, which is mostly seasalt, equilibrates rapdily with this HCl and should therefore be acidic (pH ~4) rather than alkaline, like the parent seawater (pH ~8), as is generally assumed. Our results suggest that this may be true not just in the polluted western subtropical North Atlantic MBL but also in the more remote and relatively clean MBL of the tropical North Pacific. Keene et al. (1998) discuss some possible implications of the seasalt aerosol being acidic.

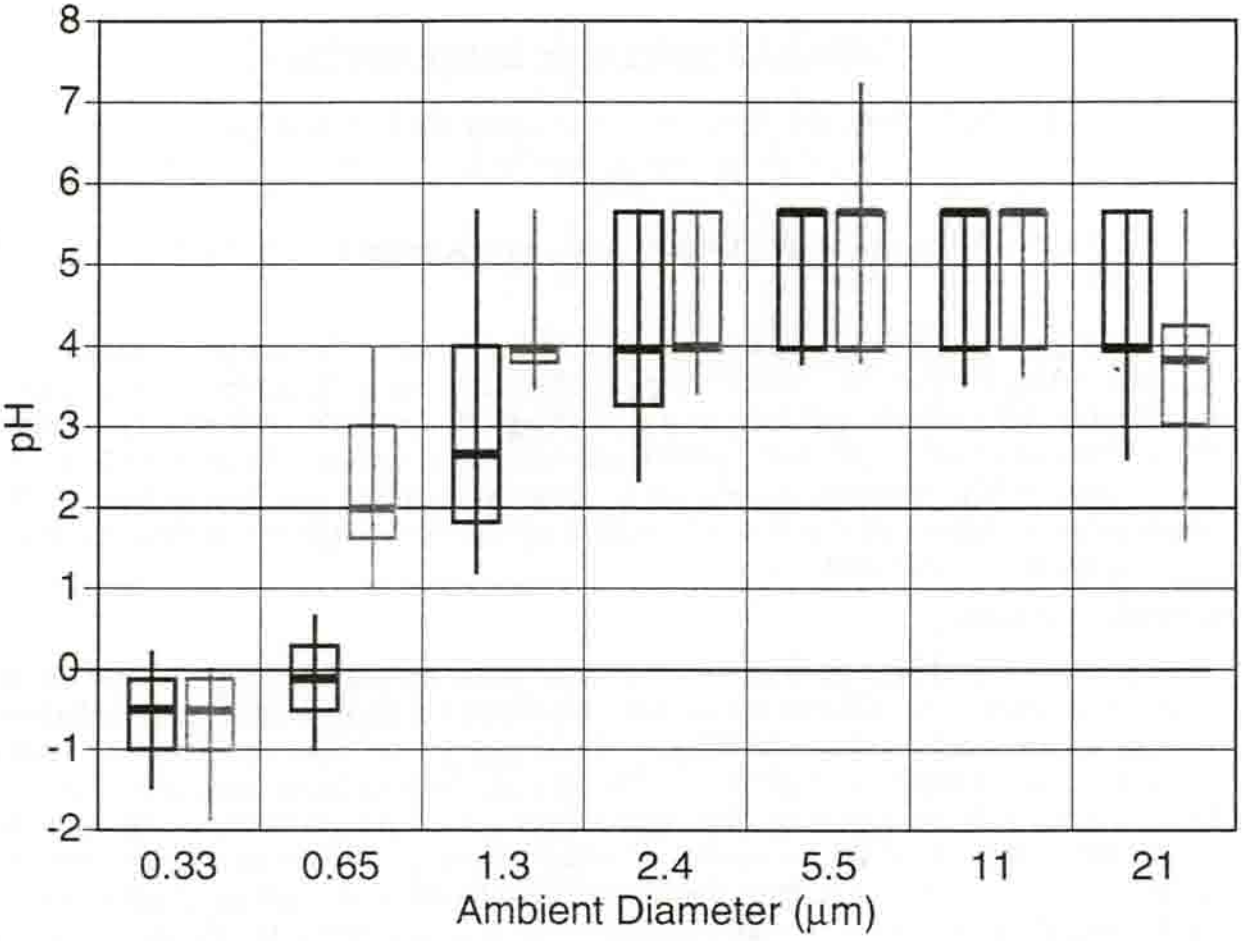

Figure 1. Box-whisker plot of estimated pH of Bermuda aerosol particles as a function of particle size based on data from 38 cascade impactor samples collected in May 1997. Blue boxes represent "raw" data. Red boxes represent values corrected for bisulfate dissociation upon dilution. Heavy horizontal bars are medians, lighter horizontal bars are deciles and ends of whiskers are extrema.

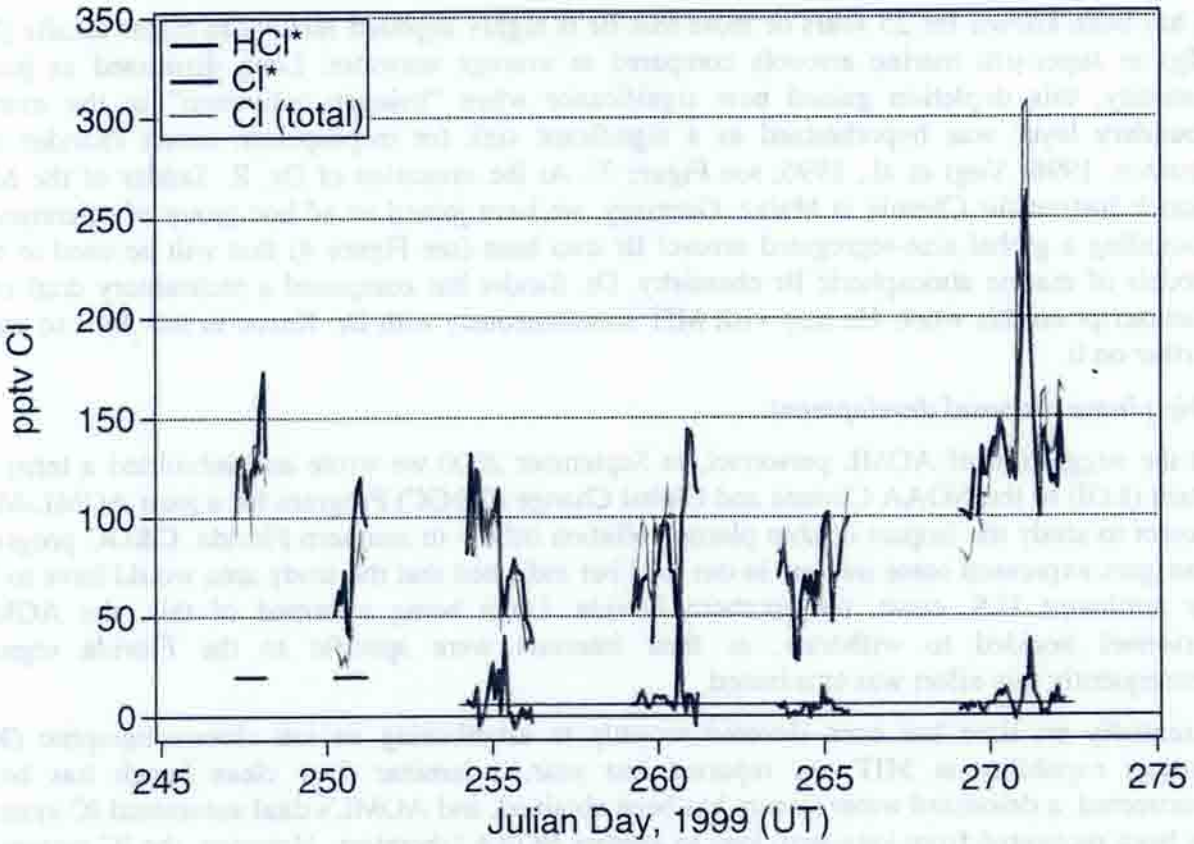

Figure 2. Time series plot of inorganic Cl gas data obtained at the University of Hawaii's atmospheric sampling site on Bellows Air Force Station, Oahu, Hawaii in September 1999. Data were obtained during two 24-hour, three 48-hour and one 72-hour "intensives" with two tandem mist-chamber samplers (Keene et al., 1993). High blanks voided Cl* data during the first two intensives. The thin green horizontal line indicates the detection limit for Cl* during the later intensives.

We also observed small but definite mixing ratios of inorganic chlorine gases other than HCl. This "Cl*" is thought to be comprised of readily photolyzable chlorine species such as Cl_2, HOCl and perhaps $ClNO_3$ and others. Photolysis of these "active" chlorine gases yields the extremely powerful oxidant atomic chlorine (Cl•), which reacts with methane and higher hydrocarbons ten to several hundred times faster than does hydroxyl radical, the dominant oxidant in the troposphere. Cl• also reacts rapidly with dimethylsulfide. The effect on CH_4 lifetime is probably small (<5%). The impact on ozone production (via hydrocarbon oxidation enhancement) and destruction (via interactions with bromine compounds) and DMS oxidation is uncertain but may be significant. Dr. Keene from UVA is tentatively planning a visit to MIT in late June 2001 during which we hope to complete the interpretation of these data and begin drafting a manuscript for journal submission.

Marine aerosol Br data review.

It has been known for 25 years or more that Br is highly depleted relative to major alkalis (Na, Mg) in super-μm marine aerosols compared to average seawater. Long dismissed as just a curiosity, this depletion gained new significance when "halogen activation" in the marine boundary layer was hypothesized as a significant sink for tropospheric ozone (Sander and Crutzen, 1996; Vogt et al., 1996; see Figure 3). At the invitation of Dr. R. Sander of the Max Planck Institut für Chemie in Mainz, Germany, we have joined an ad hoc group of scientists in compiling a global size-segregated aerosol Br data base (see Figure 4) that will be used to test models of marine atmospheric Br chemistry. Dr. Sander has composed a preliminary draft of a manuscript on this work. He may visit MIT simultaneously with Dr. Keene in late June to work further on it.

Ship plume proposal development.

At the suggestion of AOML personnel, in September 2000 we wrote and submitted a letter of intent (LOI) to the NOAA Climate and Global Change (C&GC) Program for a joint AOML-MIT project to study the impact of ship plume pollution inflow to southern Florida. C&GC program managers expressed some interest in our LOI but indicated that the study area would have to be the northwest U.S. coast, not southern Florida. Upon being informed of this, the AOML personnel decided to withdraw, as their interests were specific to the Florida region. Consequently this effort was terminated.

Essentially no time has been devoted recently to establishing an ion chromatographic (IC) analysis capability at MIT. As reported last year, a laminar flow clean bench has been constructed, a deionized water system has been obtained, and AOML's dual automated IC system has been recovered from long-term loan to another NOAA laboratory. However, the IC system is approximately a decade old and, to our dismay, was obviously used (abused?) heavily while on loan. As anticipated in our work statement for this contract, the IC system will require significant rehabilitation and upgrading before its operability can be assessed. Success of this task is questionable now because IC technology has advanced so much that the manufacturer, Dionex Corporation, no longer makes parts for or supports instruments of this vintage.

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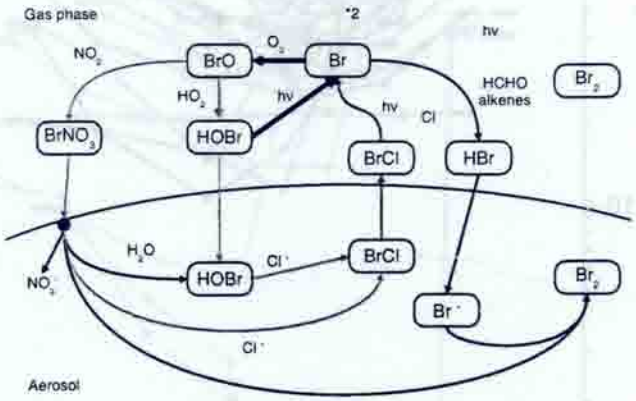

Figure 3. Hypothesized multiphase Br chemical cycle in the marine boundary layer (R. Sander, personal communication, 2001).

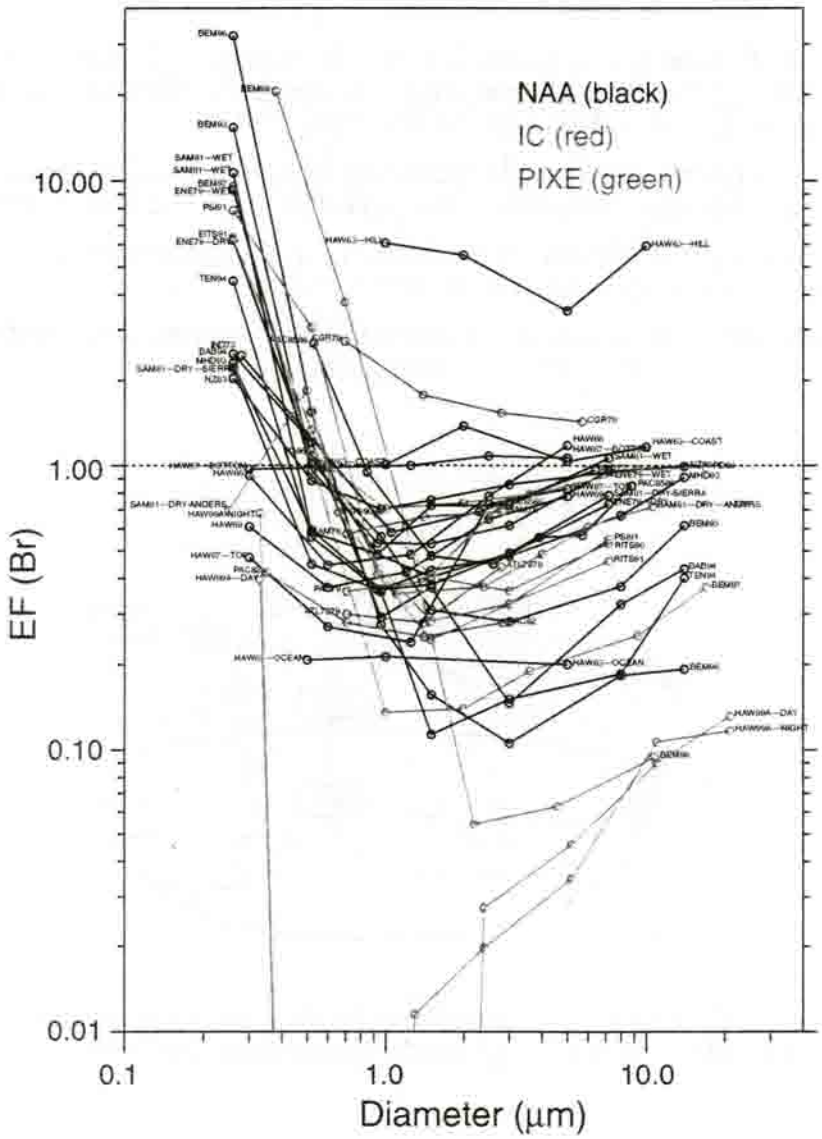

Figure 4. Summary of available data on marine aerosol particle Br enrichment factor (EF) relative to seawater as a function of particle size. Different colors represent data based on different chemical analysis methods. NAA (neutron activation analysis) and PIXE (proton-induced X-ray emission) yield total concentration data while IC (ion chromatography) yields water-soluble concentrations.

Tagging Deep Diving Odontocetes with a Digital Acoustic Recording Tag

Mark Johnson and Peter Tyack, Co-Principal Investigators

Final Summary Report CICOR Cooperative Agreement 1998-2002

The aim of this project was to demonstrate the use of a new non-invasive acoustic recording tag on sperm whales (*Physeter catodon*) in the Gulf of Mexico. Marine mammals in this area are frequently subjected to noise from seismic exploration and other activities related to the oil industry. While there are scattered anecdotes on responses of deep diving odontocetes, such as the sperm whale, to noise, there are few data on how deep divers respond to controlled exposures of noise in which any responses can be linked directly to a specified received level of sound. This makes it impossible to predict what levels of exposure are safe, and what may lead to significant disruption of critical behaviors. A major obstacle to these studies has been our inability to monitor responses when whales are at depth.

The DTAG, developed in 1999 by Mark Johnson and Peter Tyack at Woods Hole Oceanographic Institution, substantially overcomes this difficulty. The DTAG is a small electronic tag capable of recording sound and orientation (i.e., depth, pitch, roll, and heading) simultaneously. The tag uses a large array of solid-state memory to store high resolution digital data and can record continuously for 4.5 hours. The DTAG was first used, with great success, on northern right whales in 1999. The scope of the current work was to adapt the DTAG for use on deep-diving whales and then participate in a National Marine Fisheries Service (NMFS) census cruise in the Gulf of Mexico, attempting to attach the DTAG to sperm whales.

In order to be suitable for use on sperm whales, the DTAG was modified to be pressure tolerant and tested in a pressure-test facility at Woods Hole Oceanographic. The modified tag was housed in a polyethylene fairing with syntactic foam for floatation and a VHF beacon for radio tracking. A set of three suction cups in a triangular arrangement connected the tag to the whale. The tag was delivered by means of a 40' long carbon fiber pole cantilever-mounted in the bow of a customized workboat. The combination of non-invasive (suction cup) attachment and a cantilevered-pole delivery was designed to minimize the impact of tagging on the host animal and is appropriate for the relatively short recording duration of the DTAG.

The 12-day NMFS cruise took place at the end of June, 2000, on board the Research Vessel Gordon Gunter. WHOI participants were Tyack, Johnson, and mechanical engineering student Alex Shorter, a summer intern. We successfully delivered the tag to three sperm whales with a longest attachment duration of 9 hours. The recovered data included many shallow dives and high quality recordings of coda exchanges, the sequences of click sounds made by sperm whales presumably for communication. The lack of deep dives was consistent with the persistent social behavior of the study animals

during the cruise. However, the tag withstood the rubbing and jostling events that are characteristic of whale socializing.

The pilot study demonstrated the potential for controlled exposure experiments on sperm whales using a short-term non-invasive tag. We have received funding through CICOR for a follow-on project with the aims of enhancing the attachment reliability of the tag and of acquiring baseline behavioral data from Gulf of Mexico sperm whales.

PUBLICATIONS

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Assessing Risk Factors in Right Whale Vessel Collision using an Acoustic Recording Tag and Controlled Sound Exposure

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Final Summary Report CICOR Cooperative Agreement 1998-2002

WORK COMPLETED

The goal of this work is to establish factors relating to acoustic environment and behavior that increase the risk of ship collision with right whales. The experiment combined a new non-invasive acoustic recording tag with controlled sound playbacks to establish the response of right whales to the sound of approaching vessels as a function of behavioral context. We have completed 1 year of a projected 3-year project with funding from CICOR / U.S. National Marine Fisheries Service. In year 1 we built, and calibrated 4 digital acoustic recording tags (DTAGs); and conducted a 4-week field experiment with the tags. We are currently analyzing the resulting data. The tags built and fielded performed according to specifications, and we successfully completed year 1 of our field effort in the Bay of Fundy (BF). The *Hannah T* successfully attached the tags (Figure 1), and our suction cup attachment (Figure 1) attained acceptable attachment durations for our work (Table 1). We are currently analyzing data collected by the DTAG and the concurrent behavioral observations conducted from the observation vessel (OV). We were in the field in the BF from 22 July 2000 -20 August 2000, conducted field operations during 12 of those days, attached 5 tags of $\geq$ 1 hour longevity, and conducted four playbacks to three different tagged whales. More tags than expected were knocked off during social activity. We feel strongly that it is acceptable to have tags knocked off by normal inter-whale activity, and tags more firmly or invasively attached could have caused injury in the same situation. We remain committed to our non-invasive tagging approach, although due to the knock-off rate we may need to attach more tags than initially anticipated to obtain the necessary sample size. With the DTAG we successfully documented subtle sub-surface responses to our playbacks of naturally occurring sounds, data previously unobtainable for free-ranging cetaceans. Other studies have recorded acoustic reactions to playbacks (1), but the DTAG recorded behavioral changes (e.g. heading) specifically in response to our playback of whale sounds as well to sounds produced by other whales in the area. While we have not yet found any response to vessel playbacks or approaches, establishing that our tag can document subtle responses to experimental conditions is a very significant result. The basic goal of the entire project is to determine the conditions under which whales do not produce an effective avoidance response to oncoming vessels, so the lack of responses to vessel approaches is consistent with the problem we are investigating.

Work we have completed using the results from tagging efforts in the BF include: i) analyses of the swimming and diving behavior of foraging right whales; ii) auditing and analyses of acoustic data recorded by the DTAGs; iii) assembling identification photos

for the members of the New England Aquarium Right Whale Research Program, who are in the process of identifying the whales we tagged in 2000; iv) comparison of locomotor behavioral data recorded by the tag with that documented by observers on the OV; and v) analyses of vocalization patterns of focal (i.e., tagged) vs. non-focal whales in collaboration with the International Fund for Animal Welfare (IFAW) to assess the feasibility of an acoustic detection and localization system to passively track movements of right whales in high risk areas.

SUMMARY OF RESULTS

Summary of tagging

A total of 15 right whales were approached for suction-cup tagging, and tags were attached to 9 (60%) of those animals (Table 1). All tags deployed functioned without fail, and all were successfully recovered. Tagged whales were tracked on the eastern side of and east of the 'whale sanctuary' that lies to the southeast of Grand Manan, New Brunswick. Some areas the whales used overlapped with the outbound shipping lane from St. John, NS, part of which is contained in the 'whale sanctuary'. Tracks of tagged whales can be easily accessed through our website: http://dtag.whoi.edu. Tags were deployed by the *Hannah T* with assistance from Michael Moore's blubber thickness measurement team, which reduced the number of boats operating around the whales. Unfortunately, neither Moore's team nor we feel that this mode of operation is tenable in future years due to the amount of time required to attach tags. In past years each tag deployment required <30 minutes, but due to a different pattern of whale behavior this task required up to 4x as long in 2000. This increase in time required for tagging and blubber thickness measurements necessitates that we have our own boat devoted to tagging. This boat will be active only to attach tags, and after tagging will be brought on board a larger ship or towed.

Table 1. Summary of whales tagged and group sizes during the 2000 Bay of Fundy field season. *Whale identifications as confirmed by the New England Aquarium. The whale denoted by 'Eg00_XXX' has not yet been matched, and the numbers 'XXX' indicate the Julian day on which the animal was tagged. '9999' indicates a whale for which matching has been attempted but not yet confirmed, and no entry indicates whales for which matching is still in progress. [δ]Animals 'taken' as part of a group of a tagged animal. [‡]Playbacks conducted were 'W=whale sounds', 'V=vessel approach' and 'VA=opportunistic vessel approach'. [§]Surface active groups (SAG) are social aggregations of whales as defined by Kraus and Hatch (3). Clear responses were elicited by whale sound playbacks and also by naturally occurring whale sounds. No responses to vessel playback or opportunistic vessel approaches have been found to date.

Whale ID*	Date Tagged	Tagging Approaches/ Deployments/ Group size	Location of Tagging/ Approach	Tag Longevity (hr:min)	Play-backs‡	Response to Playback/Other
2642	25-Jul	3 / 1 / 1	44.358N 66.299W	0:41		
1307	1-Aug	1 / 1 / 1	44.526N 66.262W	20:12	W	Brief cessation of swimming
9999	5-Aug	1 / 1 / 1	44.366N 66.301W	3:40	W/V	Roll & temporary heading change in response to W
2740	6-Aug	1 / 1 / 1	44.363N 66.28W	0:01		
2792	6-Aug	1 / 1 / 1	44.375N 66.265W	0:06		
2760	9-Aug	1 / 1 / 2	44.437N 66.344W	1:38		
1507	9-Aug	1 / 0 / 1	44.407N 66.35W			
1603	9-Aug	1 / 1 / 1	44.409N 66.349W	0:01		
	9-Aug	1 / 0 / 1	44.413N 66.348W			
Eg00_222b	9-Aug	1 / 1 / 1	44.413N 66.348W	1:02		
1608	11-Aug	1 / 0 / 1	44.326N 66.349W			
1121	11-Aug	1 / 0 / 2	44.337N 66.338W			
1238	11-Aug	1 / 1 / 2	44.335N 66.335W	1:55	VA	Tag knocked off in SAG§ during VA
Totals	Takes= 15 (3δ)	Taggings = 9		'Tag on' time=29:16	Play-Backs=4	

Swimming and Diving Behavior of Focal Whales

The high-speed orientation sensors on the DTAG provide a detailed view of sub-surface behavior previously unavailable. The 3-axis accelerometers in the DTAG, for example, record the pitch, roll, and yaw of the focal whale. In addition, at the position of tag attachment to the whale, dorsal and approximately midway between the blowholes and caudal peduncle, the pitch angle of the animal contains a significant signal due to undulations of the body during swimming and so can provide an indication of when the animal is stroking as well as the stroke rate (Fig. 2) (5). Consequently, while a DTAG is attached to a focal whale it is simultaneously recording the animal's acoustic environment, its pitch, roll, yaw, heading, and fluke stroke rate as well as the depth and temperature of water in which the whale is swimming. Moreover, the sensor sampling rate (> 20 Hz) and resolution are sufficient to record fast or subtle movements of the whale, e.g. transient direction changes or cessation of swimming. In Figure 2, a typical dive from a whale in the BF data set illustrates how fluke stroke rate and gliding can be determined from the pitch record. Other swimming behavior of interest to our project is a whale's heading, and we have been able to successfully ground-truth the magnetometer readings from the tag with sightings from the OV (Figure 3).

Responses to playbacks and other sounds

Social activity of North Atlantic Right Whales in the BF has been documented (3), and southern right whales have been observed to respond to playbacks of sounds made by conspecifics (6, 7). We decided to use social sounds as a positive control for our playback experiments, i.e. we expected the whales to show some acoustic or motor response to these sounds. We did, in fact, record a motor response from focal whales to our playbacks (Fig. 3), and moreover we recorded a similar motor response from focal whales when the sounds of nearby whales (i.e., not our playback) occurred as recorded by the DTAG. This result demonstrates our ability to measure a response by a focal whale to a sound exposure, and confirms our choice of natural sounds as a positive control. Having a functioning positive control provides a context within which responses, or lack thereof, to experimental stimuli can be interpreted. In addition, this result constitutes the first documented, sub-surface swimming (i.e. motor behavior) response to controlled sound exposure in a free-ranging cetacean.

Sounds recorded by DTAGs attached to whales

The DTAG acoustic records from the BF contain a broad range of identifiable sounds including those produced by the focal whale and other nearby animals. The tag also recorded the sounds of many vessels. Samples of sounds recorded by the tag can be accessed on our world wide website, http://dtag.whoi.edu. Sounds from the focal whale can be distinguished from non-focal sounds by a combination of three indicators: received level, the absence of reverberation, and the presence of significant high frequency harmonic components. Knowing with confidence that the focal whale produced a particular sound is important for at least two reasons. The first motive is to chart any acoustic response by the focal to our playbacks or other sounds in the

environment. Secondly, we and other researchers would like to know whether the vocal activity of right whales is conducive to passive acoustic detection and localization schemes. If feasible, such systems could provide information as to the presence and hopefully location of right whales in areas of high risk for vessel collision. Our results are very important in this pursuit as the DTAG documents three essential types of information that have direct bearing on the appropriateness of a sound for passive detection and localization: i) the type of sound produced, i.e. some types of sound are easier to detect and localize; ii) the depth at which a whale is swimming when it produces a sound, which has implications as to how accurately a sound can be detected/localized; and iii) the duty cycle of sound production, i.e. a regular, high duty cycle is much more conducive to accurate detections. Figure 4 shows the pattern of sound production recorded from a whale tagged on 5 August, 2000.

SUMMARY OF PRODUCTS AND DISSEMINATION OF RESULTS

Results from Year 1 have contributed to 7 conference presentations: 4 at the Right Whale Consortium Meeting in October in Boston, 1 at the meeting of the Acoustical Society of America in December in Long Beach, CA, and 2 at the meeting of the European Cetacean Society to be held in May 2001. In addition, our results are included in 4 manuscripts: one in preparation comparing behavior recorded by the DTAG with that visible from surface observations; one documenting the positive buoyancy of right whales as evinced in their swimming/diving behavior in press in *The Proceedings of the Royal Society B: Biological Sciences*; one describing the DTAG architecture, technology, and products submitted to the *Journal of Ocean Engineering*; and finally a contribution to a paper documenting the vocalization patterns of right whales that is being submitted by IFAW to the *Journal of Cetacean Research and Management*. Our results are also included in an article published in the *Gulf of Maine News* in an issue focused on right whale research. In addition to these formal channels of dissemination, we have made and continue to make our data available to the right whale research community including, but not limited to, posting the data to our world wide website: http://dtag.whoi.edu.

FUTURE RESEARCH PLANS

We have applied for funding to continue this project. In the summers of 2001 & 2002 we hope to tag approximately twice as many whales per year and conduct further playback experiments. Due to the number of tags knocked-off by whale-whale contact, again a loss we are comfortable to assume, we might need to attach more tags than previously planned. As explained above, we will unfortunately be unable to collaborate with the *Hannah T* again in future years due to the significantly reduced data rate suffered by both projects. We will, however, minimize the number of boats operating around the whales by having the tagging boat operate only when actively attaching tags. In addition, we will use this same boat for the playback experiments, further reducing the total number of boats operating and transiting near the whales.

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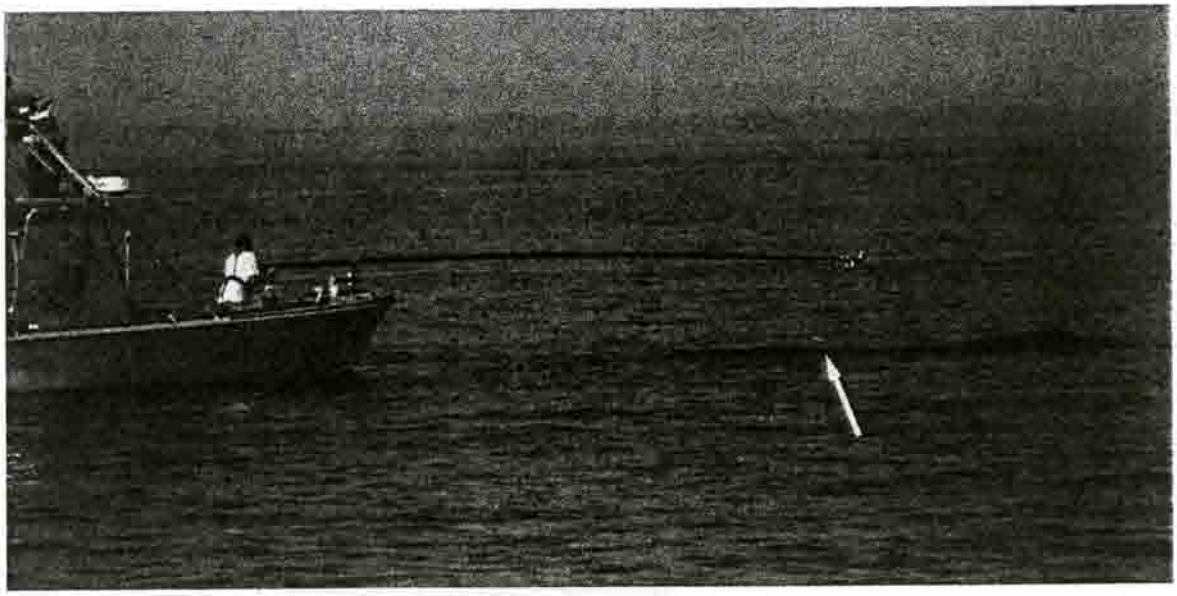

Figure 1. *Hannah T* with cantilevered attachment/blubber thickness pole extended. A DTAG (arrow) has just been attached to the whale in the figure. The pole extends at an angle off the bow so that whales can be approached from the side, negating the need to be positioned within the whale's 'footprint'.

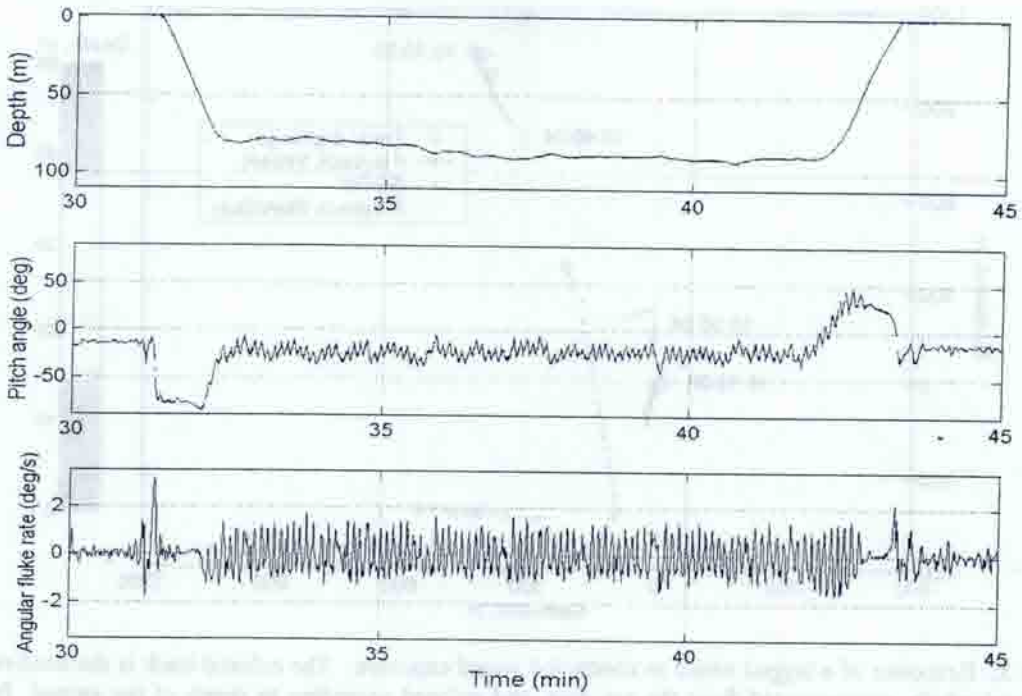

Figure 2. A typical dive of a right whale as recorded by sensors on the DTAG. The panels show (top) the time-depth record of the whale's dive; (middle) the whale's pitch angle including fluke strokes, which are small oscillations in the pitch record; and (bottom) the angular fluke rate, which is an instantaneous indicator of fluke stroke activity. Periods during which the whale is not actively swimming can be seen in both the pitch angle record and the angular fluke rate. This example of the types and detail of data recorded by the DTAG demonstrate our ability to document even subtle sub-surface changes in motor behavior, e.g. cessation of swimming.

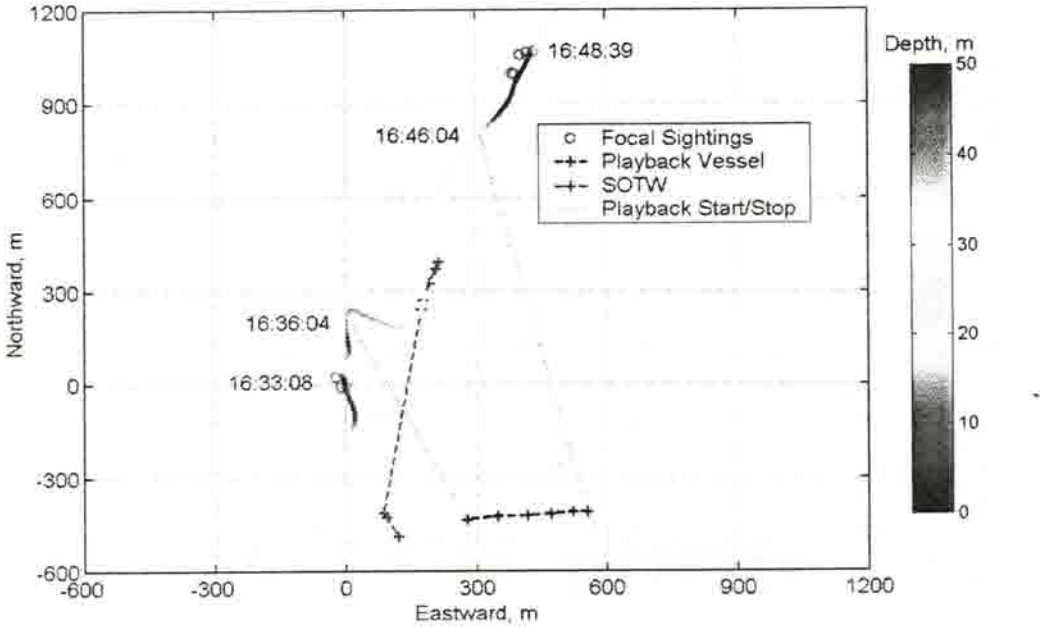

Figure 3. Response of a tagged whale to controlled sound exposure. The colored track is the dead-reckoned course of the tagged whale, reconstructed from the tag data, and colored according to depth of the animal. Pre-recorded social sounds from other right whales were played to the whale through an underwater speaker. Upon commencement of the playback, the whale, which had been traveling almost due north at depth, turned in the direction of the playback speaker. SOTW is the *Song of the Whale*, the observation vessel.

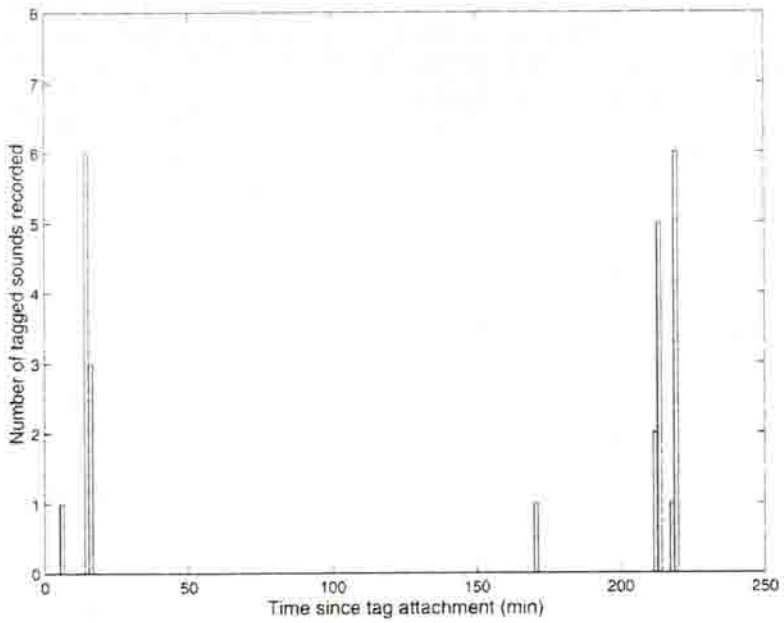

Figure 4. Pattern of sound production by right whale Eg00_218 while a DTAG was attached to it in the Bay of Fundy, Canada in August, 2000. Despite having the highest overall rate of sound production of any whale in our sample, the irregular and clustered production of the sounds by this whale present a problem for passive detection because of the prolonged periods of silence.

Real-Time Data Assimilation on Georges Bank

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As part of the third phase of the U.S. Globec Georges Bank Program, a group of investigators from six institutions (Dartmouth College, WHOI, NMFS, UNC-CH, BNL and BIO) undertook a predictive modeling effort in conjunction with field activities during several cruises from April to June 1999. Results from process studies of cross-frontal exchange on R/V Endeavor cruises EN323, EN324 and EL9905 are reported in Lynch et al. (2001).

The principal objective was simultaneous assessment of the transport of water and plankton in the vicinity of the tidal mixing front. The approach was to inject Rhodamine dye into specific density strata and then measure the movement of the dye patch and the associated planktonic community with respect to the neighboring front. This was accomplished through incorporation of the fluorometric dye detector into the Video Plankton Recorder system, facilitating real-time assessment of both tracer and plankton distributions (down to the species level). The adjacent waters were also seeded with radio- and satellite-tracked drifters. Real-time data assimilative modeling of the flow field (and associated transports of tracer and plankton) was carried out in concert with the observational activities, in order to (1) provide an additional interpretive framework for the measurements, and (2) provide nowcast/forecast products which could be used in planning sampling strategy.

Skill of the model predictions was evaluated against observed drifter trajectories. In aggregate, the error growth characteristics of the ensemble of "best" model forecasts were surprisingly uniform. For the four-day time horizon over which forecast skill was evaluated in the various experiments, forecast error was a linear function of the duration of the prediction. On average, separation between simulated and observed trajectories of drifters and dye grew at a rate of 3 km/day. This error growth rate is small given the physical context of order 100 cm/sec tides and 10-30 cm/sec residual flows in this region.

While at sea, model solutions were used as a basis for data-assimilative coupled physical/biological simulations. Observed distributions of *Calanus finmarchicus* and hydroid predators were assimilated into the modeled flow fields in order to assess their relative transports and interactions (Figure 1; also see animation at http://science.whoi.edu/users/mcgillic/globec/EN323-4/html/hydr_cal.fli.

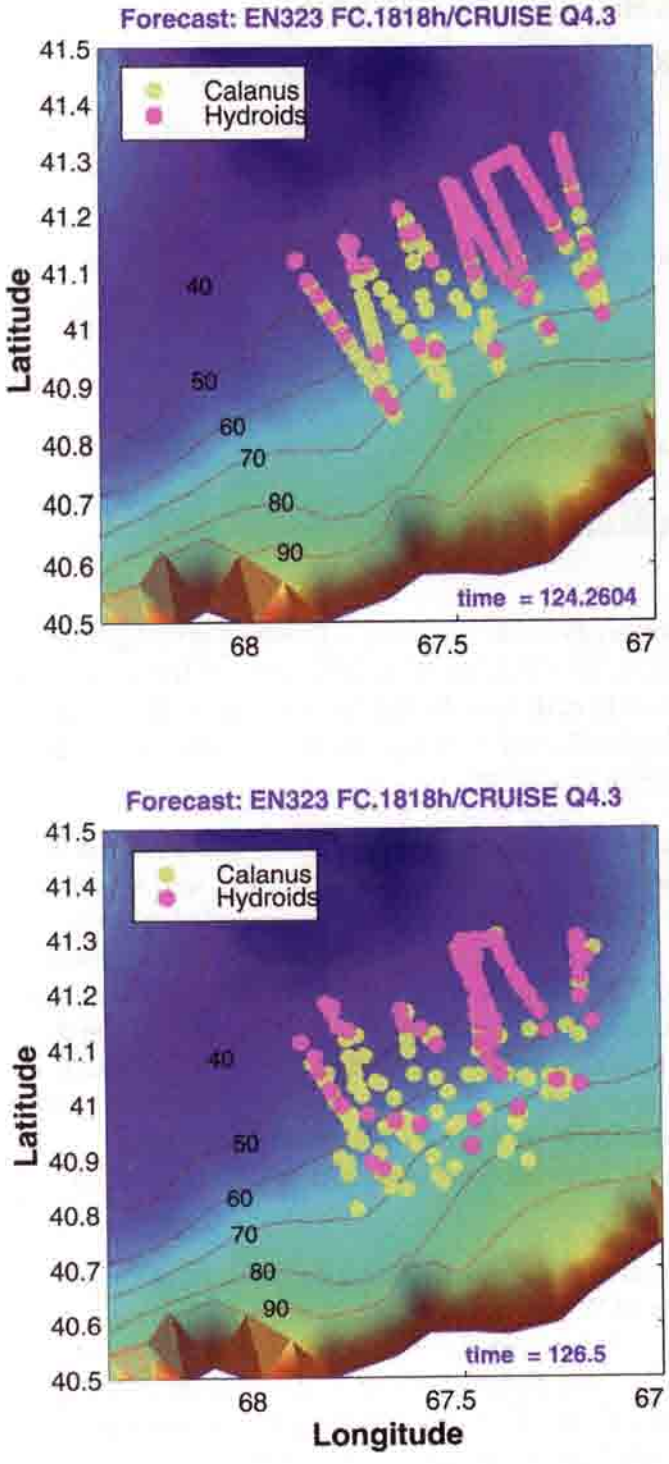

Figure 1: Individual observations of Calanus and Hydroids identified in real time using the Video Plankton Recorder. The top frame shows the geographic locations of actual observations (decimated to preserve patch structure). The bottom frame shows the same observations in a synoptic configuration assuming passive 3-D advection with the forecast flow field. The Calanus distribution was centered further off-bank and therefore advected southwest faster than the hydroids.

Coupled simulations revealed portions of overlap in the sampling coverage due to the configuration of the survey track and phasing with the tide. Relative motion between predator and prey was apparent due to the vertical separation of the two populations in the presence of shear.

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Coupled physical-biological modeling in the coastal ocean: from climatology to forecasting. University of Connecticut, Department of Marine Sciences Seminar Series (Invited), February 2000.

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A Northwest Tropical Atlantic Station for Flux Measurement (NTAS)

Final Summary Report CICOR Cooperative Agreement 1998-2002

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Background

The Northwest Tropical Atlantic Station (NTAS) project for air-sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong SST anomalies and the likelihood of significant local air-seainteraction 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 on a surface buoy measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

Objectives

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

Accomplishments

The principal accomplishment is the establishment of a site near 15 N, 51 W as a moored meteorological measurement station. The first mooring (NTAS-1) was deployed at 14 50.0' N, 51 00.0' W on 30 March 2001 during Cruise 365 of the R/V Oceanus. The second mooring (NTAS-2) was deployed at 14 44.5' N, 50 57.0' W on 04 March 2002 during cruise RB-02-02 of the NOAA ship Ronald H. Brown. The NTAS-1 mooring was recovered on the same cruise, approximately 24 hours after deployment of NTAS-2. The period between NTAS-2 deployment and NTAS-1 recovery was dedicated to an comparison and cross-calibration of sensors on the two buoys.

In support of the mooring deployments, five Air-Sea Interaction Meteorology (ASIMET) systems have been assembled, tested and calibrated. Two were deployed on the NTAS-1 mooring, two were deployed on the NTAS-2 mooring, and one was retained as a spare. Each system includes six meteorological modules that are mounted on the tower of a three-meter discus buoy. Sea surface temperature and salinity are measured by a module

attached to the buoy bridle legs. The seven-module set measures the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas. All seven modules record data internally at one minute intervals. A central logger records one minute data from all the modules on a common timebase, and also creates hourly averaged data that are transmitted via Argos satellite telemetry.

Preliminary processing of the NTAS-1 meteorological data has been completed. The use of redundant systems ensured a complete record for all variables despite the premature failure of two sensors. After post-calibration of the sensors, the corrected, 1-min data will be used for further analyses. The uncorrected, hourly Argos data are available on-line from the Upper Ocean Processes (UOP) group web site (http://uop.whoi.edu/ntas). To date, four months of hourly meteorological data from NTAS-2 are also available for examination on the UOP web site. Preliminary evaluation indicates that all NTAS-2 sensors are performing as expected.

Although subsurface measurements were not explicitly supported, efforts were made to obtain a basic level of oceanographic data from the mooring.
For NTAS-1, a 300 kHz ADCP and an acoustic current meter were borrwoed, and twelve low-precision (0.1 C) temperature sensors were purchased. This instrumentation provided velocity and temperature with 5-10 m vertical resolution within the upper 100 m. With supplemental funding from the WHOI Ocean and Climate Change Institute, it was also possible to outfit the NTAS-2 mooring with velocity and temperature sensors. For NTAS-2, higher resolution (0.005 C) temperature sensors were used in the upper 80 m.

References

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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 deployment cruise report, Woods Hole Oceanog. Inst. Tech. Rep. WHOI-2001-07, 55 pp.

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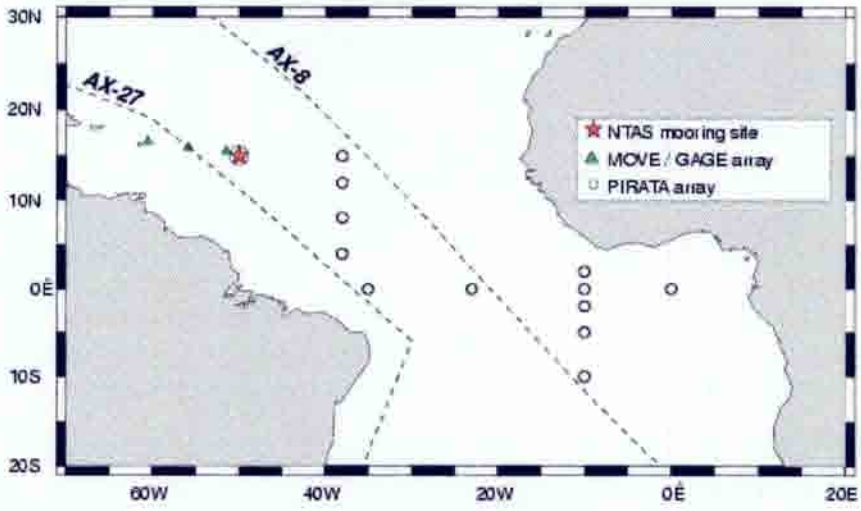
NTAS
A Northwest Tropical Atlantic Station for air-sea flux measurement

Background

The Northwest Tropical Atlantic Station (NTAS) project for air-sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong SST anomalies and the likelihood of significant local air-sea interaction. The primary science objectives of the NTAS project are to to determine the in-situ fluxes of heat, moisture and momentum, and then to use these in-situ fluxes to make a regional assessment of flux components from numerical weather prediction models and satellites, and to determine the degree to which the oceanic budgets of heat and momentum are locally balanced.

The scientific objectives will be addressed through analysis of observations from a surface mooring deployed near 15° N, 51°W. The NTAS site is at the eastern edge of the Guiana Abyssal Gyre/Meridional Overturning Variability (GAGE/MOVE) Experiment mooring array and can be considered a westward extension of the Pilot Research Moored Array in the Tropical Atlantic (PIRATA).



The NTAS project is funded through the Cooperative Institute for Climate and Ocean Research (CICOR), a partnership between the Woods Hole Oceanographic Institution (WHOI) and the National Oceanic and Atmospheric Administration (NOAA).

The NTAS Surface Mooring

A surface mooring with sensors suitable for the determination of air-sea fluxes and upper ocean properties was deployed by the Upper Ocean Processes Group at 14 50' N, 51 00' W on 30 March 2001. The three-meter discus buoy was outfitted with two complete sets of Air-Sea Interaction Meteorology (ASIMET) systems. Each system measures, records, and transmits via Argos satellite the surface meteorological variables necessary to compute air-sea fluxes of heat, moisture and momentum.

The upper 120 m of the mooring line was outfitted with oceanographic sensors for the measurement of temperature and velocity. This was the initial deployment of a multi-year occupation of the site. Plans call for the mooring to be refurbished at annual intervals.

Near-real-time Data

Hourly meteorological data are displayed as time series and available for download as ascii files. Click here to go to the data page, which is updated daily.

U.S. GLOBEC: Processes Controlling the Recruitment of *Calanus Finmarchicus* Populations from the Gulf of Maine to Georges Bank

Peter Wiebe, Principal Investigator
Charles Greene (Cornell University), Mark Benfield (Louisiana State University), Co PIs

Final Summary Report CICOR Cooperative Agreement 1998-2002

This project has focused on establishing how physical and biological processes in the Gulf of Maine (GOM) interact to regulate the recruitment of *Calanus finmarchicus* to Georges Bank each year. To address this question, a series of five survey cruises were conducted in the GOM during the autumns of 1997 through 1999. Each cruise included survey transect lines in Wilkinson, Jordan, and Georges Basins, along which multi-frequency acoustic, video, hydrographic, and bio-optical data were collected. The surveys were conducted using a high-speed, deep-towed vehicle referred to as the BIOMAPER II. This vehicle is configured with a five-frequency sonar system, a video plankton recorder (VPR), and a set of hydrographic as well as bio-optical sensors. MOCNESS (Multiple Opening/Closing Net and Environmental Sensing System) tows also were conducted in each of the deep basins. The MOCNESS samples were collected for ground-truthing and inter-comparisons with the acoustic and VPR data as well as to provide information on the abundance, distribution, and size of Calanus adult and copepodite stages.

Evaluation of the abundance and size distribution of *Calanus* continued during the year with the completion of ten more sets of net samples (8 depth strata per tow). A total of 20 sets of nets have been analyzed to date. Night tows from each of five cruises and three basins have been completed and a total of five day tows from Wilkinson and Jordan Basins are done. Day tows from Georges Basin are yet to be examined. Larger *Calanus* stage V copepodites were isolated for genetic analysis by Ann Bucklin to determine the presence of *Calanus glacialis*.

Silhouette analysis of the entire community population in one tow has been completed. This involved identifying the organisms to taxonomic group and measuring each animal for length and then obtaining a wet weight estimate using both experimentally and empirically derived formulae (Davis & Wiebe , 1985). These data were used to compare with BIOMAPER-II acoustic and VPR optical data.

The most significant result from this field study so far has been linking the order of magnitude reduction in *C. finmarchicus* abundance observed in the GOM during autumn 1998 (relative to the autumns of 1997 and 1999) to an NAO-driven modal shift in the NW Atlantic's coupled slope water system. Retrospective analyses of continuous plankton recorder and hydrographic time-series data have enabled us to place this result in the context of climate-driven changes in ocean circulation observed over the past half century (Greene and Pershing, 2000; MERCINA submitted).

Publications

Benfield, M.C., P.H. Wiebe, T.K. Stanton, C.S. Davis, S.M. Gallager, and C.H. Greene. 1998. Estimating the spatial distribution of zooplankton biomass by combining Video Plankton Recorder and single-frequency acoustic data. Deep-Sea Research II. 45(7):1175-1199.

Greene, C.H., P.H. Wiebe, C. Pelkie, M.C. Benfield, and J.M. Popp. 1998. Three-dimensional acoustic visualization of zooplankton patchiness. Deep-Sea Research II. 45(7): 1201-1217.

Greene, C.H., P.H. Wiebe, A. J. Pershing, G. Gal, J.M. Popp, N. J. Copley, T. C. Austin, A. M. Bradley, R. G. Goldsborough, J. Dawson, R. Hendershott, and S. Kaartvedt. 1998. Assessing the distribution and abundance of zooplankton: a comparison of acoustic and net-sampling methods with D-BAD MOCNESS. Deep-Sea Research II. 45(7): 1219-1237.

Greene, C.H., and A.J. Pershing. 2000. The response of Calanus finmarchicus populations to climate variability in the Northwest Atlantic: Basin-scale forcing associated with the North Atlantic Oscillation. ICES J. Mar. Sci. 57: 1536-1544.

MERCINA. 2001. Oceanographic responses to climate in the Northwest Atlantic. Oceanography 14: 77-83.

Wiebe, P.H., T.K. Stanton, C.H. Greene, M.C. Benfield, H.M. Sosik, T. Austin, J.D. Warren, and T. Hammar. In Press. BIOMAPER II: an integrated instrument platform for coupled biological and physical measurements in coastal and oceanic regimes. IEEE J. Ocean. Eng.

This grant also has supported our participation in trans-Atlantic efforts to study the responses of North Atlantic shelf ecosystems to climate variability and change. In addition to six presentations on this topic at various national meetings, the following presentations have been made internationally:

International Presentations

Greene, C.H., and A.J. Pershing. The response of Calanus finmarchicus populations to climate variability in the Northwest Atlantic: basin-scale forcing associated with the North Atlantic Oscillation. ICES Symposium: Population Dynamics of Calanus in the North Atlantic, Tromso, Norway; August 1999.

Greene, C.H. The response of Northeast and Northwest Atlantic shelf ecosystems to climate variability and change (Invited Symposium Speaker). ASLO Summer Meeting, Copenhagen, Denmark; June 2000.

Greene, C.H., and A.J. Pershing. Trans-Atlantic responses of Calanus finmarchicus to basin-scale forcing associated with the North Atlantic Oscillation (Invited Symposium Speaker). American Geophysical Union Chapman Conference on the North Atlantic Oscillation, Ourense, Spain; November 2000.

Greene, C.H., and A.J. Pershing. Trans-Atlantic responses of Calanus finmarchicus to basin-scale forcing associated with the North Atlantic Oscillation (Invited Symposium Speaker). 70th Anniversary of the Continuous Plankton Recorder Surveys of North Atlantic Symposium, Edinburgh, Scotland; August 2001.

The presentation at the ASLO Summer Meeting during June 2000 was part of a special symposium and workshop on this topic organized by C. Greene and Dr. Benjamin Planque (IFREMER). This workshop led to the formation of a new working group dedicated to investigating Marine Ecosystem Responses to Climate In the North Atlantic (MERCINA -http://www.geo.cornell.edu/mercina/). The primary goal of the group is to provide a climatological context for interpreting the findings from large, multi-national field programs conducted on the continental shelves of the North Atlantic. A second meeting of this working group will be held at the AGU/ASLO Ocean Sciences Meeting in Hawaii during February 2002. This working group meeting is being organized by C. Greene and Dr. Michael Fogarty (US GLOBEC Steering Committee Chairman).

Morphological and Molecular Aspects of Reproductive Failure in Northern Right Whales

Final Summary Report CICOR Cooperative Agreement 1998-2002

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Background

The northwest Atlantic right whale population is highly endangered, comprising less than three hundred individuals. Models of population survival and reproductive rates indicate an appreciable decline in recent years (IWC, 2001). The population has a markedly low rate of increase, 1% (Caswell et al., 1999), in contrast to the 7-8% increase of the southern hemisphere right whale populations (Best et al., 2001 Payne et al., 1990). High mortality from ship strikes and fishing gear entanglements affect the low rate of increase in the northwest Atlantic population (Knowlton and Kraus, 2001). However, these two sources of mortality only account for one half of the recruitment shortfall. Evidence suggests that the shortfall may also be affected by decreased fecundity. The reproductive rate is about half that of the southern populations (Kraus et al., 2001) and the calving interval is greater in the northwest Atlantic (>5years; Kraus et al., 2001) than in the southeast Atlantic (3 years; Best et al., 2001). In addition, a 1.4-fold increase in the calving interval over a period of twenty years has been observed by two different studies (Cooke and Glinka, 1999; Kraus et al., 2001). Finally, stage structured demographic analysis indicates that the declining survival and population growth trends are primarily due to the declining survival rate of calving females (Fujiwara and Caswell 2001).

Inbreeding, disease, toxic chemical exposure and body condition associated with inadequate nutrition may influence reduced fecundity. In terrestrial mammals fertility is impacted by an insufficiency of body fat (Frisch, 1984; Marshall and Hammond, 1926; Thomas, 1990). Likewise, in the Northeast Atlantic fin whale, *Balaenoptera physalus*, improved body fat condition due to increased food supply appeared to be associated with increased fecundity (Lockyer, 1986). Therefore, it is important to determine if body condition is an important factor in the reproductive failure of the North Atlantic right whale.

It is unknown whether the measurement of blubber thickness is an adequate assessment of right whale body condition. Tormosov et al., 1998 found no seasonal differences in

blubber thickness in southern right whales. It is possible that the lipid content of blubber changes before any changes in blubber thickness can be detected. In addition, Lockyer et al., 1985 discovered that an increase in blubber thickness in fin whales was not sufficient to account for the tremendous increase in body girth and thus proposed that increases in body fat in muscle and around visceral organs most likely cause increases in body girth. Therefore, we must establish an acoustic assessment of blubber lipid content and establish a more complete body condition index that includes girth, length and lipid content and thickness of blubber.

The highly successful 2000/2001 reproductive season (December 00 — March 01), with 31 calves born (Conger *et al.* 2001), vs. a mean of 11.32 for the years 1980 through 1998 (Kraus *et al.* 2001), may have been the result of the improvement in body condition described below. This would further implicate the importance of a nutritional factor in determining reproductive success.

Results

During this project we assessed right whale body condition acoustically by measuring blubber thickness with amplitude-mode ultrasound (Moore et al., 2001). A 0.5 MHz transducer on a cantilevered 12m carbon fiber pole is deployed to briefly touch the dorsal aspect of surfacing right whales. The ultrasound receives an acoustic echo from the sub-dermal connective tissue sheath at the blubber-muscle interface and graphically displays blubber thickness (Moore et al., 2001). The figures below illustrate our progress in this ongoing project, currently funded by the Northeast Consortium.

Concurrent photo-identification of individual animals allows correlation of blubber thickness with catalogued biological data, such as gender, age and reproductive history. At the same time, overhead stereo video footage allows measurements of length and girth.

Analysis of these blubber thickness records has shown evidence of the declining northern right whales having significantly less blubber than the more successful southern right whales. Continuation of our fieldwork, along with data generation on length and girth of the same animals will allow an in depth test of the hypothesis that these parameters are related to reproductive success in right whales. Before we can adequately test our hypothesis we need a longer series of data from northern right whales.

Ultrasound probe landing on right whale

25 boat for deployment of ultrasound and overhead video

Overhead video image — one of a stereo pair. White bars = 50cm.

Acoustic blubber thickness measurement of an *E. glacialis* adult female. The measurement was taken on 11 Aug 99 at 14:37 hours in the Bay of Fundy. Left-hand arrow shows where the ultrasound transducer makes contact with the skin. Right-hand arrow indicates sound echo from the subdermal connective tissue sheath at the blubber-muscle interface. Range on this echogram is 31cm. Blubber thickness is 21.7 cm.

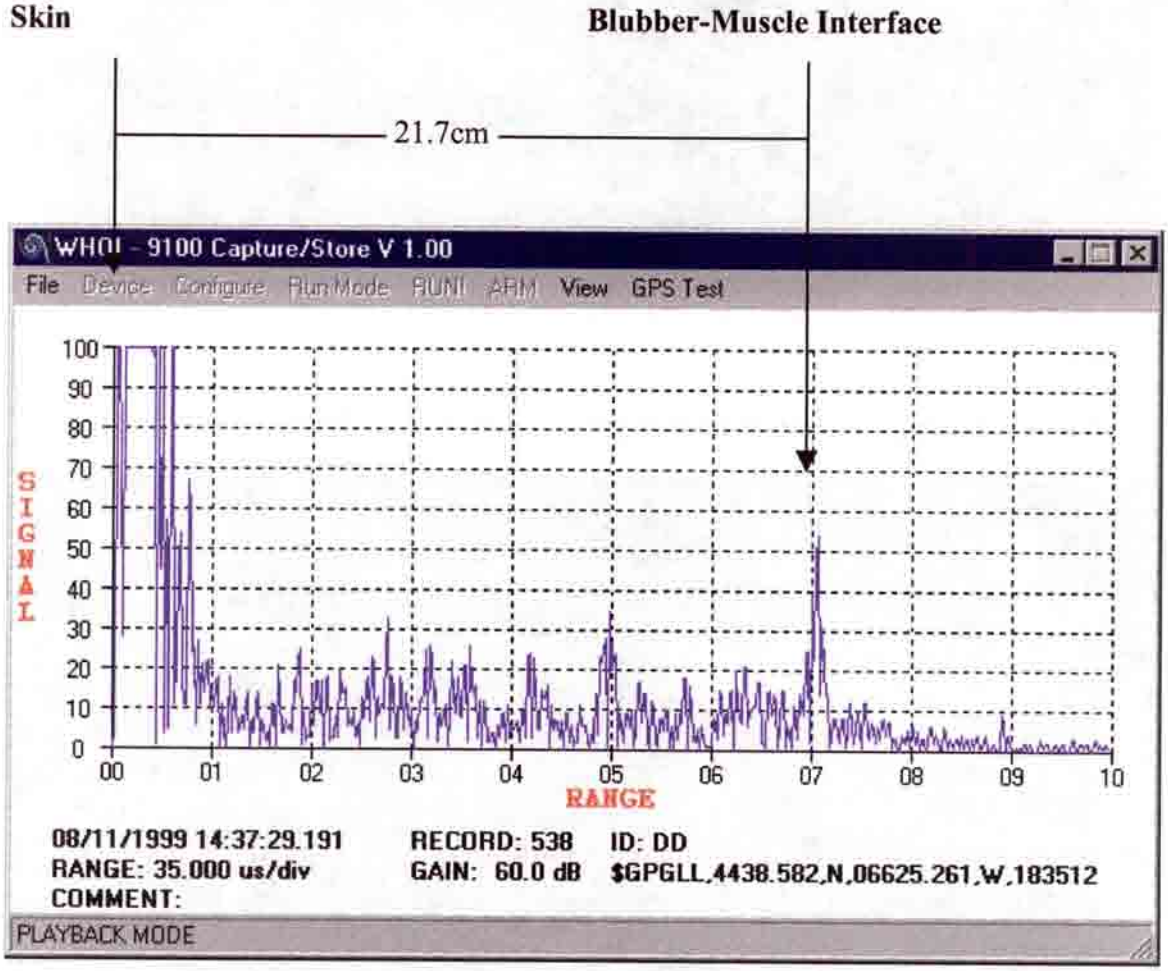


Table 1. Summary of the demographics of the *E. glacialis* from which acoustic blubber thickness measurements were collected during 1998, 1999, 2000 and 2001.

Sex	Age Class	1998	1999	2000	2001
Male	Adult (known age)	7	6	1	1
	Adult (unknown age)	8	3	1	0
	Juvenile (known age)	11	8	2	3
	Unknown	0	0	1	1
Female	Adult (known age)	6 (3/3)*	6 (3/3)*	0	6 (6/0)*
	Adult (unknown age)	0	3 (1/2)*	3 (2/1)*	10 (9/1)*
	Juvenile (known age)	9	5	3	1
	Unknown	0	1	0	2
Unknown	Adult	0	1	0	0
	Juvenile	3	2	0	0
	Unknown	0	0	0	0
	Calves	0	0	0	8
Unmatched Animals		51	0	14	6
	Total	95	35	25	39

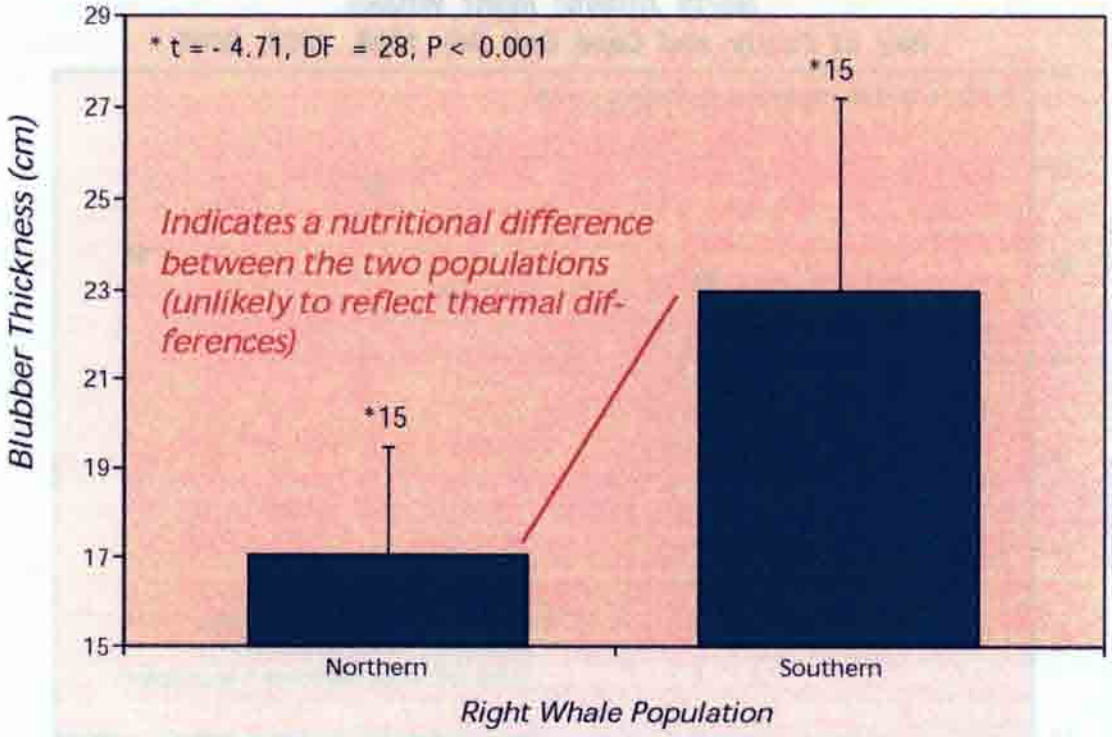
*(# of known calving females / non-calving females)

Fieldwork in South Africa was completed as proposed, top portion of table 2. The dates of the field period differ from those originally proposed because we wanted to obtain measurements from cows during the latter part of the early lactation season. The bottom portion of table 2 summarizes the field events of the 1999 season in South Africa, prior to year one of the NMFS/CICOR project.

Table 2. Summary of field events during approaches of *E. australis* for acoustic blubber thickness measurements, St. Sebastian Bay and Walker Bay, South Africa 1999/2000.

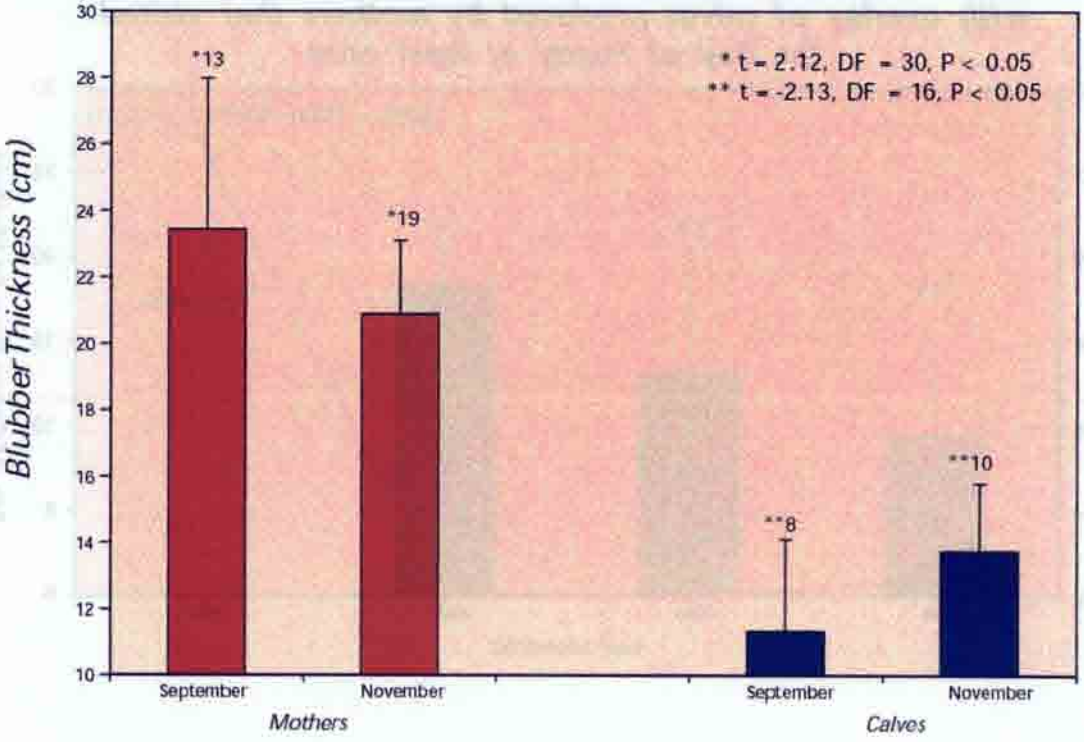
Day	Date	# of Whales Photo'd	# of Approaches for Acoustic Blubber Measurements	# of Acoustic Blubber Measurements	# of Individuals Measured	# of Cows Measured	# of Calves Measured
1	28-Oct-00	4	4	4	0	2	2
2	4-Nov-00	8	6	5	2	2	1
3	5-Nov-00	20	16	15	7	5	3
4	6-Nov-00	14	12	10	4	5	1
5	7-Nov-00	5	4	4	3	1	0
6	10-Nov-00	10	10	9	6	2	1
7	11-Nov-00	17	17	16	6	6	4
	Total	78	69	63	28	23	12
1	31-Aug-99	14	14	10	9	0	1
2	3-Sep-99	14	14	12	7	5	0
3	4-Sep-99	14	14	12	2	6	4
4	6-Sep-99	19	19	18	4	7	7
5	13-Sep-99	4	4	4	4	0	0
6	14-Sep-99	9	8	5	5	0	0
7	15-Sep-99	20	19	17	17	0	0
8	21-Sep-99	6	3	3	3	0	0
	Total	100	95	81	51	18	12

Adult Right Whale Blubber Thickness
Northwest Atlantic vs. South Africa

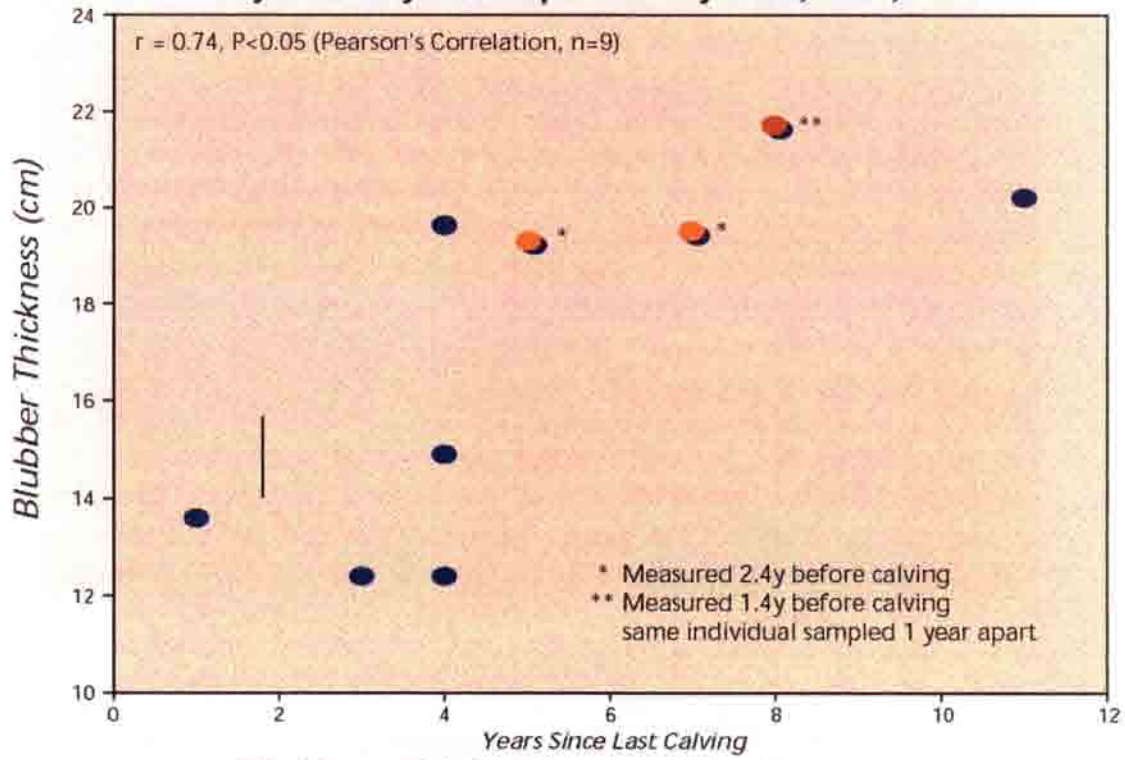


Early Lactation Season:
September 1999 vs. November 2000

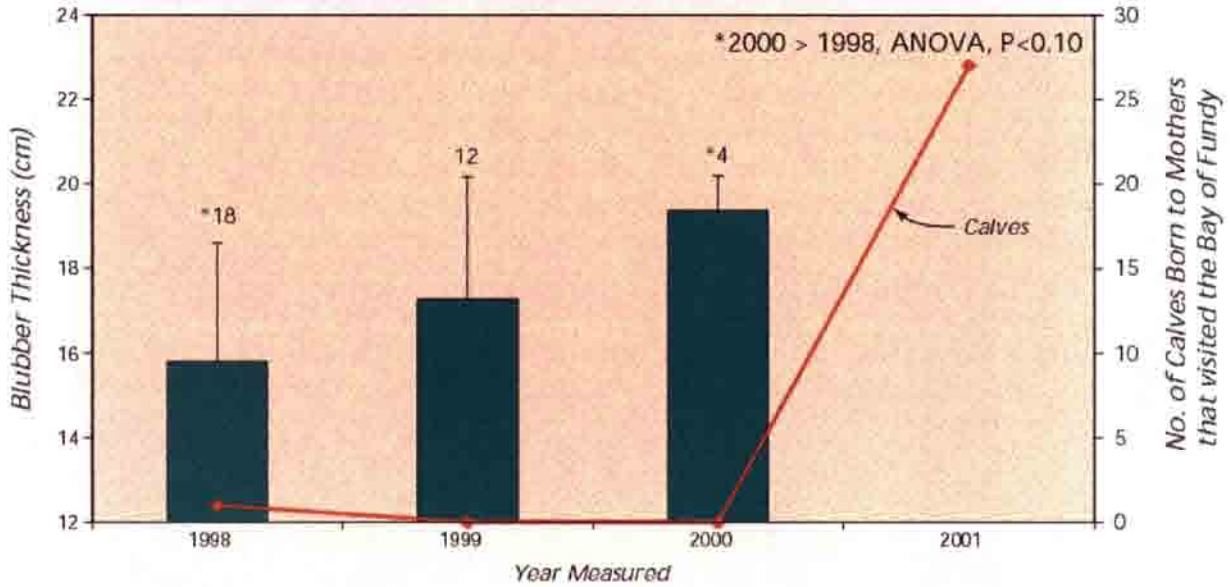
Southern Right Whale Mother and Calf Blubber Thickness - South Africa



Blubber Thickness vs. Time Since Last Calving
North Atlantic Right Whales
Bay of Fundy and Cape Cod Bay 1998, 1999, 2000



Blubber Thickness vs. Year Measured
Adult N. Atlantic Right Whales; Bay of Fundy, 1998, 1999, 2000
with overlay of calves produced by mothers that visited
the Bay of Fundy at least once



Body length measurements

A 2-D computer-based photogrammetric analysis is being carried out on video footage of North Atlantic right whales, obtained from fieldwork conducted in 1999 and 2001. This process consists of four main parts namely, digitising and frame grabbing; lens unbarrelling; image transformation; and the acquisition of measurement data.

Digital, time-coded video footage is reviewed and assessed for usability. Acceptable segments of the video footage are edited and saved as shorter clips using Media 100i version 3.0, MacIntosh compatible, software. Consecutive frames of individual whales, in which the whales head and base of fluke notch are both visible, are selected/grabbed and saved in Quicktime format, using Media 100i. In order to increase the quality and definition of the images, the frames are opened using IP LabSpectrum (MacIntosh version) and colour filtered using a linear filter.

The Andromeda software lens filter called LensDoc is accessible as an Adobe Photoshop (version 5.02) plug-in. LensDoc enables the user to cancel out the barrelling applied to images by various camera lenses. Calibration grids are used to help with the selection of points required when making use of the LensDoc software. LensDoc settings are applied to calibration images (containing known-size objects) which then undergo various sets of user-defined transformations, using the transformation tool found in Adobe Photoshop. Once the correct set of transformations has been determined, the whale images are run through the LensDoc unbarrelling process, followed by the determined Adobe Photoshop image transformations. After being transformed, the images are saved in .tiff format and are ready for measuring. Whale lengths (tip of bonnet callosity to base of fluke notch) are measured using IP LabSpectrum software on a 1:1 pixel basis.

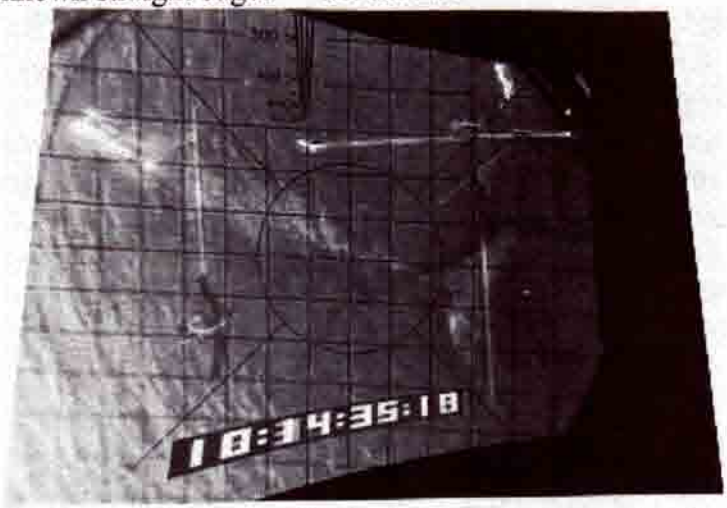
Progress to date:

Approximately 36 hours of digital video footage has been reviewed and assessed for usability. An estimated 850 individual frames have been grabbed and filtered. LensDoc settings for the 1999 calibration grid has been determined, while the 2001 settings are currently being determined. Multiple transformations (using the Adobe photoshop transformation tools) for the 1999/2001 data are presently being tested. The reproducibility of point selection, by making use of x-y co-ordinates, using IP LabSpectrum is also currently being assessed.

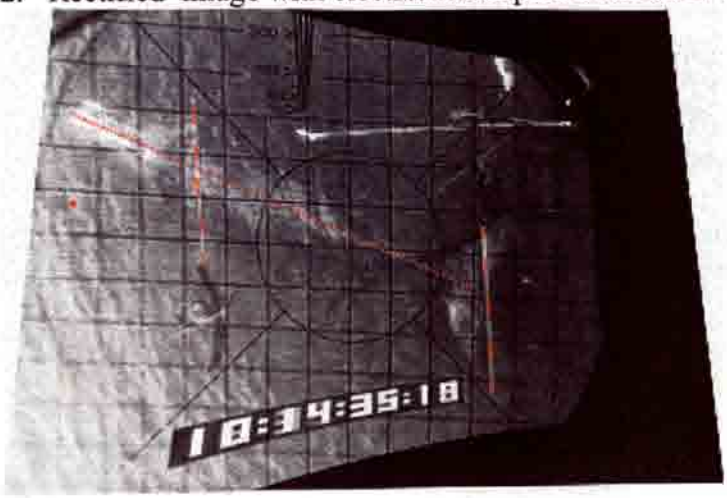
Jonathan Howland (WHOI) has written a 3-D photogrammetric programme using Matlab software. His programme makes use of filtered frames described above and is currently being tested.

Raw, oblique image with scaling objects (A kayak and 2x4 of known lengths) superimposed

1. Image transformed to rectify the image to known straight edges — i.e. the 2x4



2. Rectified image with electronic calipers overlaid in red.



Conclusions

This project is evolving in to a long term monitor of right whale body condition. We have learnt that northern right whales are significantly thinner than southern right whales, that right whale cows loose blubber thickness during suckling, and that they need to restore that lost blubber prior to calving anew. Thus we have developed a very important tool to assess the role of body condition, which probably serves as a proxy for recent habitat quality. The practicalities of gathering these data in the field and reducing them in the laboratory have proved to be extremely labor intensive. Thus our data analyses are ongoing with current funding. Our original proposal included the aim of studying molecular aspects of right whale reproduction by evaluating the expression of the leptin protein. To date our efforts in this regard have not borne fruit. In spite of this we are pleased with our progress and anticipate a major series of publications based on the above data, along with other data currently under process.

References: (including talks and papers)

1) Published Paper (attached as file P301-309)

Ultrasonic measurement of blubber thickness in right whales
M.J. Moore, C.A. Miller, M.S. Morss, R. Arthur, W.A. Lange, K.G. Prada, M.K. Marx and E.A. Frey *J. CETACEAN RES. MANAGE. (SPECIAL ISSUE) 2,* 301—309, 2001

2) Platform Presentation

Acoustic measurements of Blubber thickness vs. age, sex and reproductive history in free-ranging northern right whales
C.A.Miller, M.S.Morss, M. Marx, and M. Moore
13th Biennial Conference on the Biology of Marine Mammals — Wailea, Maui, HI USA Nov 28 — Dec 3 1999

3) Blubber thickness and Reproductive Success in Right Whales

Miller CA, Reeb, D, Best, PB, and Moore MJ
14th Biennial Conference on the Biology Of marine Mammals, Vancouver, Canada Nov 28 to Dec 3 2001

Second Prize to first author for Student poster presentation.

4) Presentations also made each year at the Fall Right Whale Consortium Meeting at the New England Aquarium in Boston.

Air-Sea Carbon Dioxide Fluxes and Surface Physical Processes

Final Summary Report CICOR Cooperative Agreement 1998-2002

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Program Manager: James Todd, Office of Global Programs

1.0 INTRODUCTION

CO_2 exchange across the air-sea interface is an important mechanism in modulating global climate and the absorption of anthropogenically produced CO_2 (Siegenthaler and Sarmiento, 1993). Depending on the time of year, different regions of the ocean can be sources or sinks for atmospheric CO_2. Currently, it is estimated that the ocean as a whole acts as a sink for CO_2, taking up about 2 gigatons per year of the approximately 5.5 gigatons of carbon dioxide produced by industrial and agricultural activity. However, there is significant uncertainty in this estimate, partly because the kinetics of ocean-air CO_2 transfer are not well understood.

The GasEx-2001 study took place aboard the *NOAA Ship RONALD H. BROWN (RHB)* in the Eastern Equatorial Pacific along 3¡S between 125¡W-130¡W. The primary.objective was to use direct gas flux measurements to improve our understanding of the forcing functions on the kinetics of air-sea gas exchange. A second focus was to determine the physical, chemical, and biological factors controlling pCO_2 in the surface water (Figure 1). The region is a CO_2 source with relatively low wind speeds offering a strong contrast with the first 1998 Gas-Ex study conducted in the North Atlantic in an area of high winds and large CO_2 sink.

The Equatorial Pacific has been a focal point for chemical and physical studies such as JGOFS and TOGA because it has a major influence on climate variability through the ENSO cycle. The questions about mesoscale CO_2 dynamics in this region relate to biological versus physical control, and remote versus local influences. Near the upwelling center it seems that the patterns in pCO_2 are dominated by physics while further off-axis biological control becomes more important. The pCO_2 in the surface water relates directly to upwelling strength, but regional fluxes are strongly influenced by remote factors such as the capping off of the upwelling system by the low salinity water advecting from the West. Diurnal heating, tropical instability waves, variations in biological productivity, and trace metal limitations on productivity are also important.

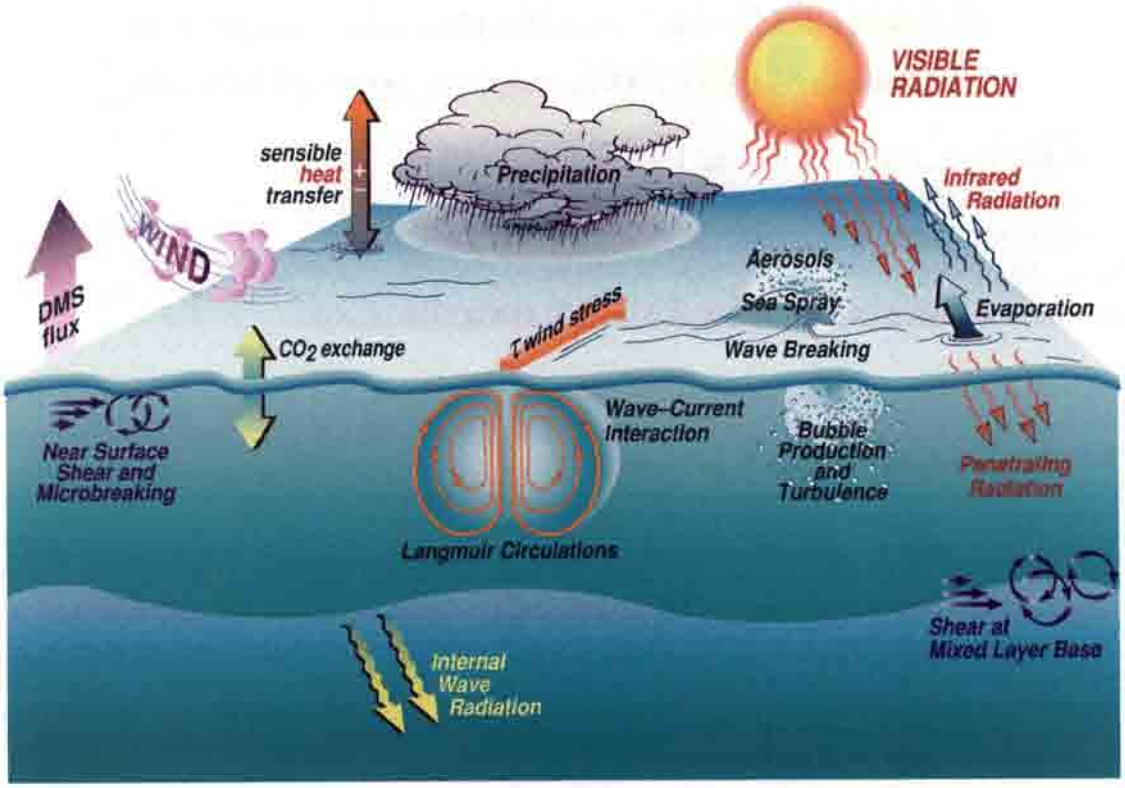

Figure 1: Physical processes controlling air-water CO_2 exchange.

2.0 PROJECT GOALS

The main objective of the February/March GasEx 2001 process study was to determine the magnitude and controls on the CO_2 gas transfer velocity in the Equatorial Pacific. This region is the largest oceanic source of CO_2 and shows large interannual variability caused by the ENSO cycle. The area experiences low wind speeds relative to most other ocean regions. Since the area is of such importance to the global carbon cycle, and because of its unique conditions, the region warrants direct determination of fluxes and gas transfer velocities, rather than using parameterizations developed for other environments. The study was performed in a similar fashion as the study in the North Atlantic, GasEx-98, where direct flux measurements (eddy co-covariance and gradient measurements) could be reconciled with fluxes inferred from mass balances of CO_2 with the addition of surface forcing characteristics. The GasEx-98 study was done in a Lagrangian frame of a warm core eddy with a relatively homogeneous water mass such that the air-water difference in partial pressure of CO_2 (ΔpCO_2), was large and remained relatively uniform.

Goals during the GasEx-2001 air-sea gas transfer study were to:

- Use the Air-Sea Interaction Spar buoy (ASIS), to explore the role of physics and biogeochemistry in the lower atmosphere and surface ocean.
- Perform continuous measurements of the air-sea fluxes of momentum, heat, water vapor, and CO_2, surface wave characteristics, profiles of currents, TKE dissipation rate, temperature, salinity, O_2 and CO_2 in the oceanic boundary layer, and mean atmospheric properties and boundary layer stability.
- Contribute to better parameterization of gas exchange velocities in the study region.

3.0 METHODOLOGY

GasEx-2001 consisted of cruise legs 1A, 1B, and 1C. Leg 1A was a 1-1/2 day transit between Charleston and Miami, and was used as training for both ETL and UW personnel. Most Leg1A scientists disembarked in Miami. Leg 1B began in Miami and ended in Panama. Most scientists participating in the GasEx-2001 cruise embarked in Miami for the duration of the cruise to Honolulu; however, several scientists were aboard for testing and training purposes and disembarked in Panama.

Leg 1C was the primary leg of GasEx-2001. The operations during the GasEx-2001 cruise was multi-faceted with high demands on ship s operations. A wide range of intensive over-the-side measurements were performed including: the LADAS catamaran, the ASIS platform, CARIOCA/SAMI buoy, and FSTP buoys, zodiac SMS and SPIP operations, CTD/Niskin sampling, underway seawater surface measurements and SPMR biological profiler measurements. In addition, atmospheric measurements were made using equipment mounted on the *RHB* bow tower, which is aft of the jackstaff; additional atmospheric measurements were made from a bow boom.

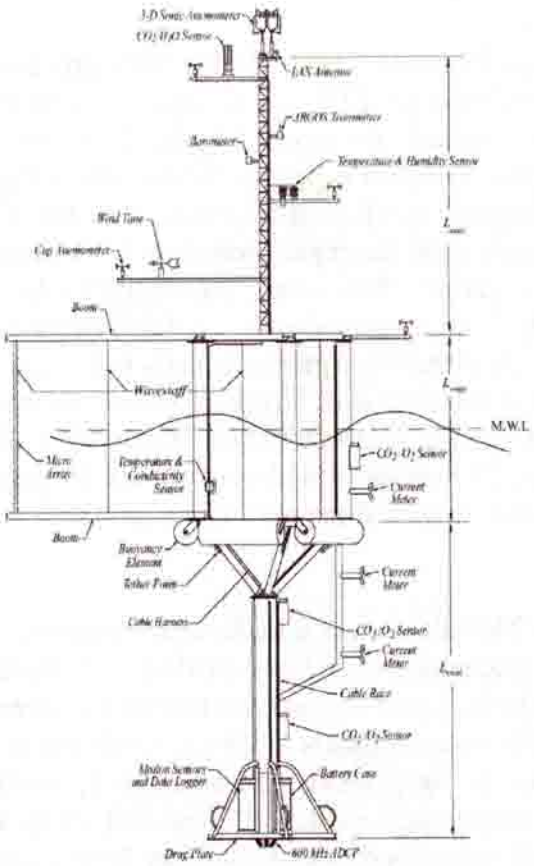

Figure 2: ASIS instrumented for GasEx 2001.

The Air-Sea Interactions Spar buoy, shown in Figure 2, was instrumented by RSMAS (PIs: Donelan and Drennan) and WHOI (PIs: McGillis, Edson, and Terray). This work was also conducted by Mike Rebozo (RSMAS), Joe Gabriele (CCIW), Sean McKenna (WHOI), Neil McPhee (WHOI), Tito Collasius (WHOI), and Ed Hobart (WHOI). The Air-Sea Interaction Spar (ASIS) is a hybrid spar buoy designed to provide a stable platform for near-surface measurements of air- and water-side fluxes. During GasEx-2001 it was deployed on four separate occasions — the table below lists the deployment times and locations. The top of the meteorological tower on the spar is roughly 5.5 meters above the mean water level (MWL), while the base of the spar is approximately 6.5 m below MWL. The buoy was equipped along its length with a variety of meteorological and oceanographic sensors, including sonic anemometers, CO2 and water vapor sensors, and sensors to measure air temperature, relative humidity, barometric pressure, short- and long-wave radiation, surface waves (having wavelengths greater than 2 m), and near-surface profiles of temperature and current along the spar. In addition, we deployed a downward-looking ADCP at the base of the spar. This instrument measured current profiles to a depth of approximately 40 m. An inventory of the data collected is given in summary form in the second table below.

Figure 3: ASIS buoy and RHB during GasEx-2001.

During the experiment, a surface platform train consisting of the ASIS spar buoy (Figure 3), CARIOCA pCO_2 buoy, and SAMI/YSI chain was constructed and deployed. The platform assembly stayed on the desired track line. Daily Argos transmissions showed that ASIS was taking continuous, good quality measurements. CARIOCA drifted down current of ASIS, then the drogue. CARIOCA contained a single SAMI and a YSI at about 1.5 m. ASIS had 2 SAMIs and 1 YSI at about 1.5m, and a SAMI at about 5 m. The drogue had 2 SAMIs with YSIs (at 4 and 30 m) and 2 Langdon probes (at 10 and 15 m). Two GPS/Argos trackers were mounted on CARIOCA, one on ASIS, and one on the GPS buoy on the drogue.

The Surface Processes Instrument Platform — SPIP (Figure 4) is a 15-foot remotely-operated Hobie Wave catamaran and was used to measure the atmospheric gradients of CO_2, temperature, water vapor, and momentum very close to the air-water interface. During this study, SPIP was deployed as a self-contained unit to determine the processes that effect these air-sea exchanges and has supporting measurements of the water-side forcing. SPIP has the advantage of measuring gradients right at the surface that the Brown mast may miss and with potentially less flow distortion than the Brown mast and ASIS. Operationally, SPIP has a mast with fixed and traveling atmospheric sensors. The fixed atmospheric sensors are located at the top of the mast while a second set of identical sensors are mounted to a motorized traveler with 3 meters of range on the mast track

from the top of the mast to 30 cm above the water surface. From the measured gradients, we calculate the CO_2, latent, sensible, and momentum fluxes as well as the appropriate transfer coefficients for comparison to the direct covariance measurements and bulk formulae.

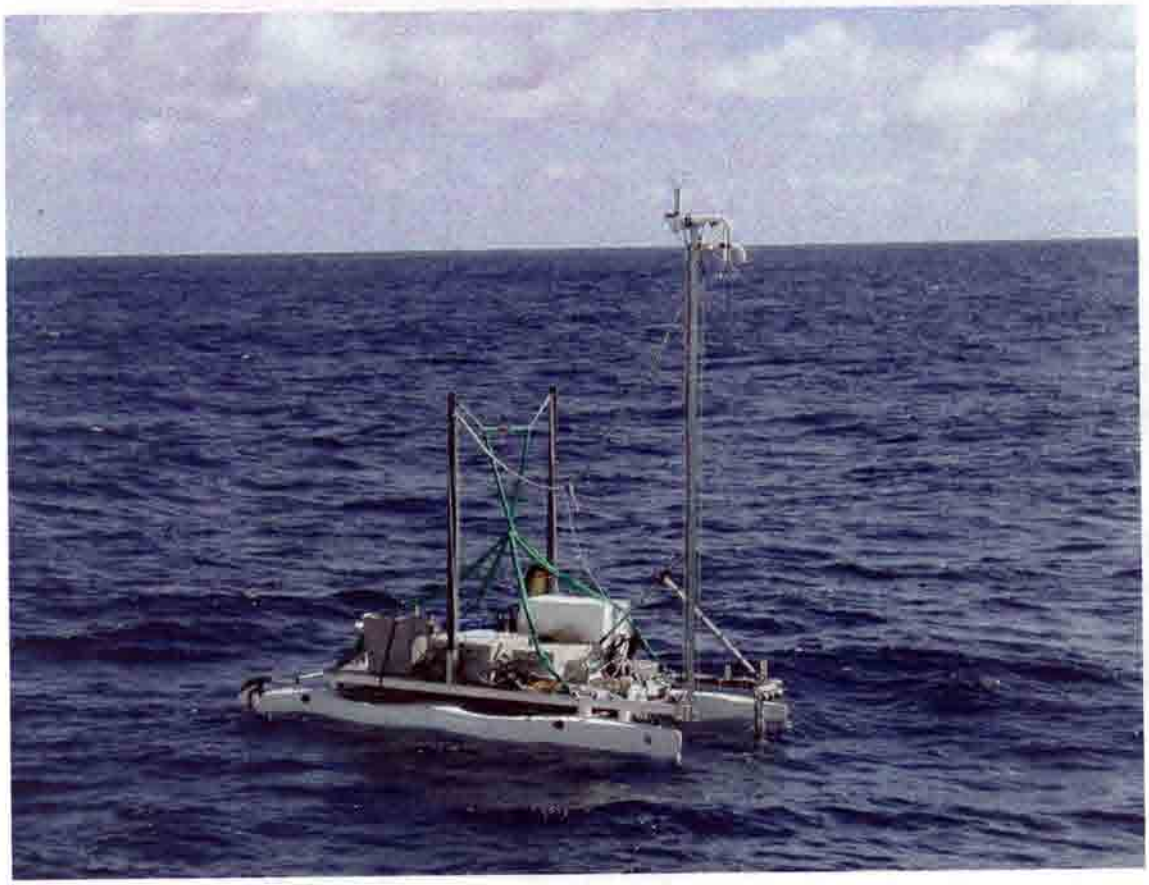

Figure 4: The surface processes instrument platform deployed during GasEx-2001 to measure very near surface processes.

4.0 WORK COMPLETED

The ASIS/CARIOCA/SAMI buoy train continuously measured surface forcing (Figures 5 and 6), air-sea fluxes, and vertical profiles of currents, temperature, pCO_2, and salinity. An intercomparison of the meteorological measurements made from the ship systems and ASIS MET systems is shown in Figure 7. The agreement between the systems is good. The steady winds found in the equatorial Pacific provide the capability to understand the role that surface diurnal heating, instabilities in the lower marine boundary layer, and stability in the upper surface ocean have on air-sea fluxes. Under these conditions, we will reduce our measurement uncertainty and provide an accurate understanding of the air-sea CO_2 flux in this region.

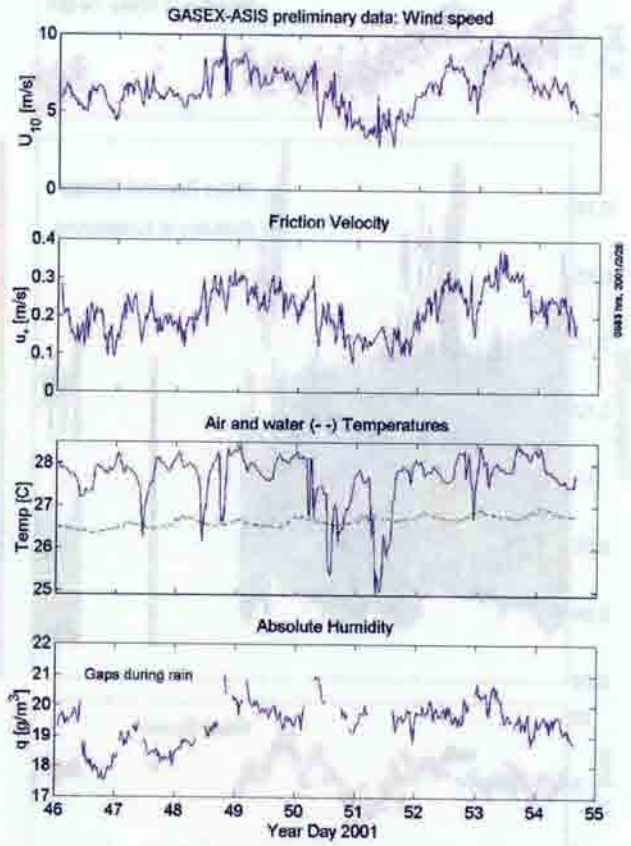

Figure 5: ASIS meteorological measurements.

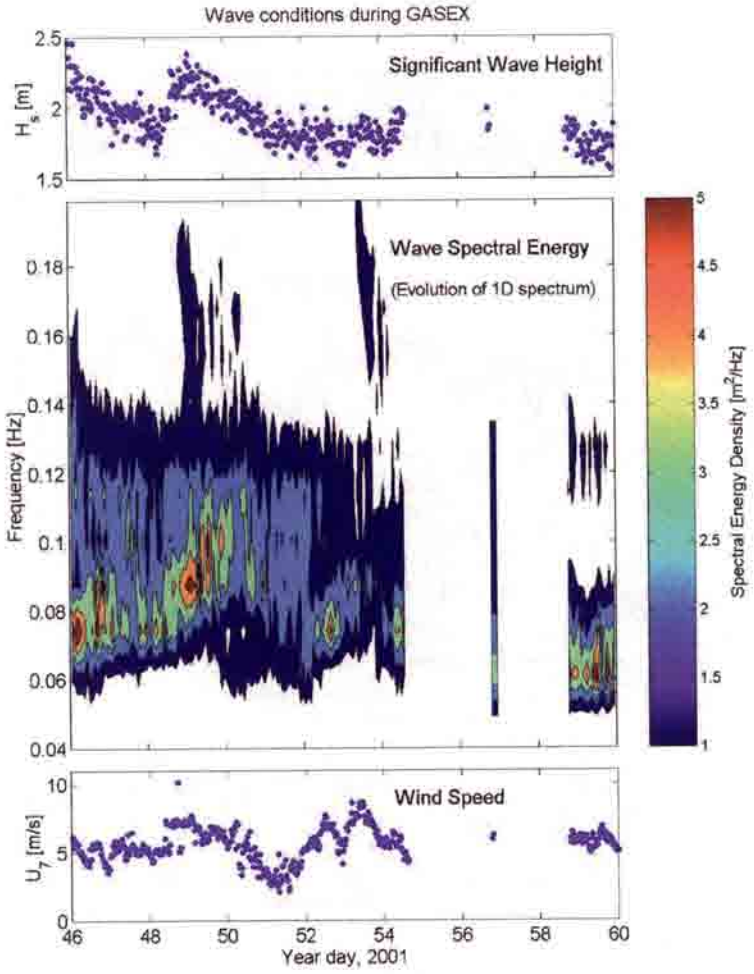

Figure 6: ASIS surface wave measurements.

During GasEx-2001, the ASIS, CARIOCA, and drifter buoy train were a central focus of surface process measurements. The measurements from this system are being used for collaborations with many interdisciplinary studies performed during GasEx-2001. Progress will continue on ASIS/SPIP data synthesis and analysis. The data has been analyzed for quality assurance and instrument calibrations.

The mean oceanic and atmospheric measurements (U, T_a, SST, q, CO_2), along with momentum and latent heat fluxes have been calculated. Inter-comparisons with other underway systems measurements have been performed. Corrections for surface drift have been applied to wind speed and momentum calculations. All1-D and partial 2-D wave parameters (H_s, f_p) and spectra have been calculated for the full ASIS deployment period (shown in Measurement Tables).

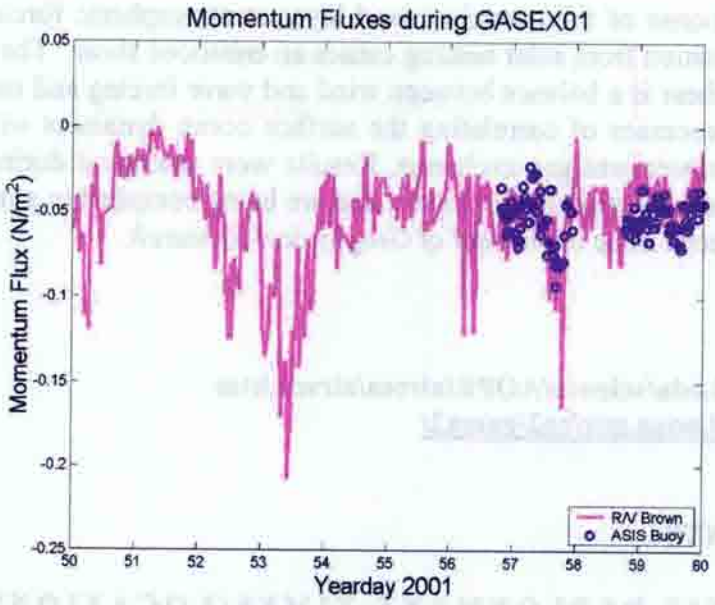

Figure 7: Comparison between the momentum fluxes measured directly from the NOAA Research Vessel Ronald H. Brown (line) and the ASIS buoy (circles).

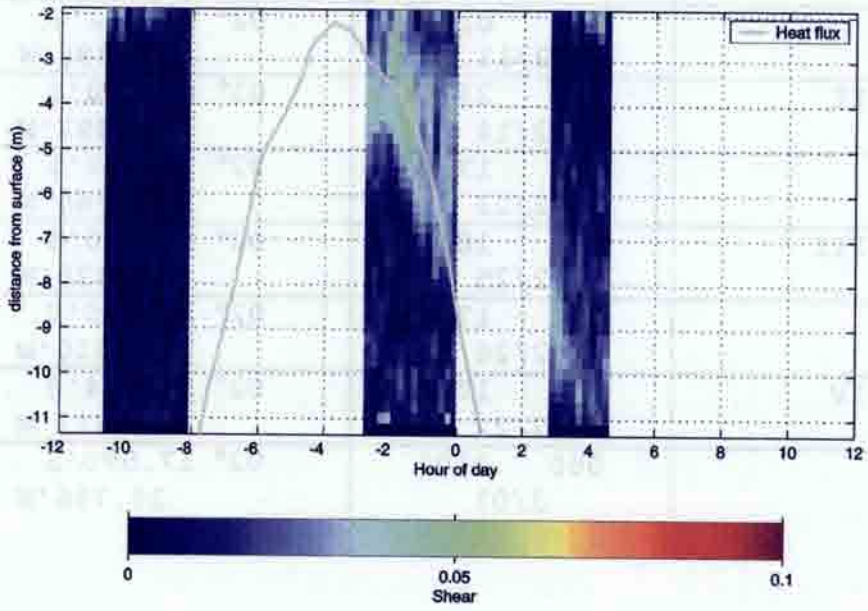

Figure 8: Diurnal surface shear and net air-sea heat flux measurements. Shear measurements from SPIP and heat flux measurements from RHB. The diurnal heating provides a surface stratification resulting in an enhanced shear. The shear is greatest between 3 and 6 meters between —2 and 0 hours of day. Stratification and shear is deepened as surface heat flux is decreased and surface mixed layer is increased.

The physical response of the oceanic mixed layer to atmospheric forcing is shown in Figure 8. Stratification from solar heating causes an enhanced shear. The magnitude and dynamics of the shear is a balance between wind and wave forcing and stratification. We are now in the processes of correlating the surface ocean dynamics with atmospheric forcing and the subsequent gas exchange. Results were presented during the February 2002 AGU National Meeting in Honlolulu, and are being compiled in a manuscript to be submitted to a special issue of *Journal of Geophysical Research*.

LINKS

http://www.whoi.edu/science/AOPE/airsea/airsea.htm
http://www.pmel.noaa.gov/co2/gasex2/

MEASUREMENTS

ASIS DEPLOYMENT TIMES/LOCATIONS

Deployment	Yday UTC Date	Latitude	Longitude
Start I	041 1710 2/10	02° 40.160'S	110° 00.360'W
End	042 0100 2/11	02° 46.802'S	110° 00.388'W
Start II	045 2335 2/14	03° 00.020'S	125° 59.997'W
End	054 1750 2/23	02° 27.938'S	128° 40.765'W
Start III	056 1810 2/25	02° 25.510'S	129° 41.320'W
End	057 1750 2/26	02° 27.720'S	130° 09.210'W
Start IV	058 1708 2/27	02° 21.414'S	130° 42.311'W
End	060 0100 3/01	02° 17.590'S	131° 28.796'W

ASIS DATA INVENTORY

Measurements	Deployments			
Meteorological	I	II	III	IV
Wind u, v, w, c	X	X	X	X
Air Temperature	X	X	X	X
Humidity	X	X	X	X
Barometric Pressure		X	X	X
$_{p}CO2$	X	X	X	X
Radiation (Solar + IR)	X	1st day only	X	X
Oceanographic				
Surface Waves	X	X		X
Current Profiles	1-4 m	6-40 m	1-40 m	1-40 m
Temperature Profiles*	1 m	2-6 m	1-6 m	1-6 m
Salinity*, O2*, pCO2*	X	X	X	X

Measurements from the Surface Processes Instrument Platform

Instrument	Data Products	Data Return
2 Gill 2-D sonic anemometers	Wind Speed; Wind Speed Profiles; friction velocity; momentum flux	All for Deployments 1-4; Wind Speed only for 5-10
2 Licor closed path sensors	Absolute, profiles of, fluxes of, and transfer coefficients of CO_2 and water vapor	Deployments 1-7, 9, 10
2 Vaisala RH/T microprocessors	Absolute, profiles of, fluxes of, and transfer coefficients of water vapor and temperature	Deployments 1-7, 9, 10
2 Aspirated Thermocouples	Absolute, profiles of, fluxes of, and transfer coefficients of temperature profiles	Deployments 1-7, 9, 10
YSI probe	Water Temperature, Salinity at 30 cm depth	Deployments 1-7, 9, 10
3rd Licor closed path Aqueous system	Aqueous pCO_2 at 30 cm depth	Deployments 1-7, 9, 10
Sontek Pulse-Coherent ADP	Near-surface water velocities (top 30 cm); shear profiles	Deployments 1-7, 9, 10
2 Sontek ADV	High frequency (25-Hz), point-source 3-D water velocities at 30 cm depth; near-surface turbulence	Deployments 2-7, 9, 10
RDI ADCP	Current/shear profiles from 30 cm down to 10 m	Deployments 1-7, 9, 10

Tracing a Thermohaline Anomaly in the Tropical Circulation

Ruth Curry, Principal Investigator

Final Summary Report CICOR Cooperative Agreement 1998-2002

In the late 1980's and 1990's, a major shift of deep water production from the Nordic Seas to the Labrador Basin precipitated significant changes in the character of water masses feeding the deep western boundary current (DWBC) of the North Atlantic. In particular, the subpolar Labrador Sea Water (LSW) properties became colder, fresher, and denser than at any time in the previous fifty years. Also distinctive were the depth of convective penetration, its vertical homogenity, and degree of ventilation with oxygen and other atmospheric tracers. Through its signature shift in temperature - salinity (θ-S) and elevated CFC concentrations, the LSW anomaly was first observed to enter the tropical DWBC in 1996 in a decade-long time series of measurements at Abaco (near 26°). In February 2000, observations revealed a surprisingly strong presence of the LSW anomaly all along the deep western boundary current (DWBC) between 18°N and 13°N. This project was undertaken as a rapid response to those measurements – its purpose was to assess the strength and equatorward progress of this anomaly. Taking advantage of a fortuitous transit of *R/V Knorr* (from Recife, Brazil to Norfolk, VA in May - June 2000) the leading edge of the water mass was located at 10°N in the DWBC. These measurements provided a rare opportunity to directly determine the speed with which a high latitude climate signal moves through the deep ocean and the degree to which that signal is adulterated in its passage. Such information is key for understanding how Earth's climate system responds to decadal fluctuations such as the North Atlantic Oscillation. The phenomena involved are poorly represented in present climate models, yet are likely to be an important factor determining the predictive skill of such models.

The total costs of the observations were split between NSF and NOAA – NSF supplying two extra days of ship time, and NOAA and NSF each providing half of the funds to acquire the measurements. A four-person team accomplished the field work: five short CTD sections (5 stations each) across the DWBC were acquired at the Equator, 6°N, 8°N, 11°N, and at Puerto Rico (66°W). Water samples were drawn and analyzed for calibration of the salinity and oxygen sensors. Additional samples were frozen at sea, and subsequently analyzed for silicate content by Joe Jennings at Oregon State University. Preliminary reports were submitted to the State Department and all countries granting political clearances for this work.

Comparison of the measurements acquired in 2000 with those from the 1980s and early 1990s has revealed the spatial and temporal development of the tropical LSW signal. A prominent shift in θ-S properties at Abaco (26°N) is characterized with values fresher by

>0.02 in the DWBC profiles of 1998 compared to the previous two decades. The bend in θ-S curves occurs in the 3.2 - 4.0°C potential temperature range, corresponding to the depth range 1600 - 2300 m. The equatorward progression of that θ-S signature – with similar unmistakable shifts in the 2000 DWBC measurements – was documented at multiple sites along the boundary: at Puerto Rico (18.5°N, 66°W), Barbuda (18°N, 61°W), Guadaloupe (15°N), Barbados (13°N), and Trinidad (11°N). The freshening is more pronounced in the upstream direction and slightly weaker downstream towards Trinidad. The signal has not arrived in any appreciable strength equatorward of 10°N: for example in measurements taken at 8°N, 6°N, and in the equatorial channel near 36°W. The horizontal distribution of the θ-S signal is similar in all the post-1997 measurements upstream of 10°N: it is ubiquitous in the DWBC with an abrupt transition to more saline θ-S seaward of the high shear regime. The recent θ-S values offshore from the DWBC revert to a curve nearly identical to the 1980's and early 1990's observations.

The interpretation is quite clear. We are witnessing the incursion of the LSW transient into the tropical deep circulation and it is transiting appreciable distances in the DWBC without being mixed away by eddies or diffusion into the adjacent interior. An estimate of the effective spreading rate from Abaco to 11°N, a distance of about 2850 km along the boundary in 4 years, is approximately 2.3 cms^{-1} faster by a factor of two compared to the effective spreading rates estimated by tracer studies for the upper deep water circulation of the previous two decades. Moreover, the tropical expression of this thermohaline anomaly involves more than a simple shift in water mass characteristics. There have been simultaneous alterations of the DWBC vertical density structure, potential vorticity, and baroclinic velocity distributions that suggest dynamical implications for the deep circulation.

Funding for a more complete analysis of these data was awarded to the PI this year by NSF. Geostrophic calculations of velocity and transport will be compared with previous measurements acquired during STACS and WOCE programs. The interpretation of these data may suggest a field measurement program to acquire longer term averages of the velocity field associated with the LSW transient, and/or modeling studies to explore its dynamical consequences. At its present rate of advance, the LSW transient will arrive at the equator circa 2003. Its time history, recorded in repeated hydrography sections upstream near Abaco and Puerto Rico, suggests that isopycnal layer thickening and intensification of its velocity core will develop within three years of its initial incursion. An equatorial potential vorticity anomaly is an interesting prospect because of the potential to incite planetary waves that could perturb the upper ocean dynamics. This would represent an oceanic teleconnection for high-latitude changes to affect the MOC's warm limb. Monitoring this event will provide an opportunity to assess potential linkages between high latitudes and the tropics in the context of climatically relevant (i.e. MOC and NAO) phenomena.

Progress Report: Air-Sea Interaction in the Eastern Tropical Pacific ITCZ/Cold Tongue Complex

Final Summary Report CICOR Cooperative Agreement 1998-2002

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Program Manager: Mike Patterson, OGP

A pilot field study in the eastern tropical Pacific was conducted as part of a larger, cooperative effort to investigate air-sea coupling in the tropical regions of the Americas and its links to climate variability in the Americas. The observational program began in April 1997 when two surface moorings were deployed at the 3° S (cold tongue) and 10° N (ITCZ) on 125° W. The goal of this project is the scientific analysis and publication of results from this field study. The foci of our analysis are the sea surface temperature, air-sea fluxes, air-sea coupling and the upper ocean variability in the PACS study region.

The processed meteorological and air-sea flux data have been placed onto a CD-ROM and distributed, with the Technical Report, to PACS PI's and other interested scientists. The data and report has also been submitted to the PACS Data Center. The data have also been contributed to the SEAFLUX database. The data and report have been well received and many are now actively using the data in analysis. We presented preliminary evaluations of NCEP and ECMWF surface flux products at the 2000 CLIVAR Pan Am PI Meeting. Preliminary results on the heat budget were also presented at the PI Meeting. This will allow us to determine the major processes that determined the temporal evolution of SST during the ENSO event. We also presented results at the Universidad de Concepci n, Chile, during a planning trip for further PACS work. Results from the boundary layer profiles collected during the final mooring recover cruise were published in the Journal of Climate (Anderson, 2001). The profiles show the rapid transformation of a stable boundary layer over the cold tongue to an unstable boundary layer on the north side of the front. Collocated with this transition was the rapid acceleration of surface winds. These observations are consistent with the hypothesis that the surface wind field over the cold tongue is modulated by boundary layer stability.

Late in 2000 on the the PI's left WHOI to work at Horizon Marine. Because Anderson was taking the lead on this project up to that time, a change in work plan was needed. Weller took over directing the effort, and graduate student Tom Farrar began work on the PACS analysis as part of his thesis research. Weller and Farrar have mapped out here publications: 1) Air-sea coupling across the cold tongue/ITCZ, with an emphasis on accurate in-situ fluxes, the time scales that contribute to air-sea coupling, and specification of the in-situ fluxes during the 1997-1998 ENSO event, 2) the ocean response, described in detail, during the 1997-1998 ENSO at our two sites (3°S, 125°W and 10°N, 125°W), and 3) modeling of the tropical eastern Pacific during 1997-1998, looking at the relative contributions of local air-sea coupling and remotely forced waves to the evolution. The first paper is in draft and the analysis and modeling work for the next two is underway.

There was a delay before momentum on the work effort built, so it was agreed with the program manager that the third year of funds originally requested would be delayed until the work was underway again and a new third year budget could be submitted. This was done in June 2002.

Publications and Presentations:

Anderson, S. P., K. Huang, N. Brink, M. Baumgartner and R. Weller, 2000: Pan American Climate Studies (PACS) Data Report. WHOI Technical Report WHOI-2000-03, March 2000, pp. 145.

Anderson, S. P. and R. A. Weller, 2000: Moored Observations of Air-Sea Interaction in the Eastern Tropical Pacific During the 1997-1998 ENSO. University of Concepcion, June, 2000, Chile.

Anderson, S. P., K. Huang, and R. Weller, 2000: Upper Ocean Variability and Heat Budget Estimates From the PACS Pilot Study Surface Moorings. Presented at CLIVAR PACS PI meeting, September, 2000, Maryland.

Anderson, S. P., K. Huang, and R. Weller, 2000: Air-Sea fluxes from the PACS Pilot Study Surface Moorings. Presented at CLIVAR PACS PI meeting, September, 2000, Maryland.

Anderson, S. P., 2001: On the Atmospheric Boundary Layer over the Equatorial Front. Journal of Climate, 14, 1688-1695.

Final Report: Long-Term Evolution and Coupling of the Boundary Layers in the Stratus Deck Regions of the Eastern Pacific

Final Summary Report CICOR Cooperative Agreement 1998-2002

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The project consisted of two Tasks. Task 1 is the fieldwork to be conducted by Weller under the stratus cloud deck region west of Chile and the related science and analyses. This work continues, funded under the second cooperative agreement with CICOR. This report summarizes the work on Task 1 done under the grant awarded through the first cooperative agreement. Task 2 is the analysis and publication of results from the intercomparison of WHOI, PMEL, and JAMSTEC buoy meteorological systems, based a field trial conducted at WHOI in the spring-summer of 2000.

Task I

The remarkably persistent stratus decks to the west of Peru and Chile exert a strong cooling influence on the local and global heat balance, as verified in recent experiments with ocean and coupled models. However, there have been few measurements of tropical and Peruvian stratus decks. The weak observational foundation is currently limiting our ability to better understand and model this region. Thus, an observational focus on eastern Pacific stratus has been recommended for the EPIC (Eastern Pacific Investigation of Climate) program and plans for two phases of investigation have been outlined. Phase 1 will provide an assessment of the present understanding of the stratus decks, including select observations to improve understanding of the air-sea coupling and investigations of the performance of existing models in replicating these observations. Phase 2 would be an intensive observational phase to follow later, pending the results of Phase 1.

Our work is a central element of Phase 1 and revolves around the deployment of a well-instrumented air-sea interaction surface mooring under the stratus clouds off northern Chile. The immediate goals of the deployment are to obtain time series of:

- accurate air-sea fluxes and surface meteorology
- the temporal evolution of the vertical structure of the upper ocean temperature, salinity, and horizontal velocity fields

The goals of the analyses of this data will be to:

- examine the temporal evolution of the upper ocean heat content,
- quantify the roles, at time scales from minutes to seasonal, of atmospheric forcing, and local, 1-D process in that evolution,
- investigate how the atmosphere drives the ocean under the stratus deck,
- examine the relative importance of shortwave, longwave, and latent heat flux variability related to the cloud cover, and
- explore the possible feedback mechanisms that would link the evolution of the atmospheric and oceanic boundary layers.

In addition, after calibration, the data will be made available and used in ground-truthing remote sensing, as benchmark time series for atmospheric, oceanic, and coupled models, and to develop improved air-sea flux fields in that region.

We designed and constructed the mooring, tested the instrumentation, and deployed during a cruise on October 2-14, 2000. The instrument payload was designed to acquire the surface forcing data and oceanographic time series required to meet the science goals given above. The surface buoy has 2 IMET systems measuring air and sea surface temperatures, humidity, barometric pressure, wind speed and direction, incoming shortwave and longwave radiation, and precipitation. The ocean measurements include a floating SST sensor (5 cm depth), 16 temperature and 10 conductivity/temperature loggers in the upper 200 m, 2 Vector Measuring Current Meters, and 1 300 kHz ADCP to measure velocity in the upper 150 m. Subsurface acoustic rain gauges on the mooring will be deployed by Jeff Nyusten (UW APL). The mooring design was developed based on the payload and the currents, surface waves, and winds anticipated at the site. Since the start of the project, materials and instruments have been acquired and the mooring fabricated. The instrumentation has been tested in the laboratory and, in the case of the

IMET packages, on the beach in Woods Hole (see Task 2 below). The IMET packages were mounted in the buoys and tested as they will be deployed. This pre-deployment testing finished in July. In planning the first cruise, we worked to develop collaborations with colleagues in Chile. The location for the well-instrumented air-sea interaction buoy to be placed under the persistent stratus cloud deck for three years was chosen to be 85°W, 20°S, in part because of the great interest in Chilean oceanographers in that site.

The mooring cruise was conducted using *R/V Melville*, sailing out of and back into Arica, Chile. The cruise track was of great interest to us because it transited the stratus cloud region from the Chilean coast to the mooring site, so we carried out underway meteorological and air-sea flux measurements on the way out as well as a closely spaced XBT section. It was also of great interest to Chilean colleagues as it transited the Chile and Peru basins along a track parallel to CTD transects Chile was occupying further south. Thus, on the return to Arica after the mooring deployment, the Chileans collected water samples while we occupied a CTD section. These samples were analyzed to look at the chemical (oxygen minimum, in particular) and biological structure of these basins. An observer from the Chilean Naval Hydrographic and Oceanographic Office was also onboard.

To fulfill our requirements to the U.S. Department of State and to Chile for granting permission to sample within up to 12 miles from the coast, we submitted in June, 2001 a detailed cruise report and a CD-ROM of all the data collected during the cruise and of the software needed to read that data. A copy of the cruise report accompanies this report, as does a draft video of the first deployment under the stratus cloud deck.

Following up on the cruise, the work shifted to preparing a cruise report, due as required by the State Department to both the State Department and to Chile, to quality controlling telemetered meteorological data and exchanging it with numerical weather prediction centers, and to preparing for the cruise scheduled for October 2001. The end date for this funding was nominally 6/30/2001, the end date of the first CICOR cooperative agreement. At this time funds remained, and permission was requested for a one-year no cost extension. The remaining funds were used toward these three activities and toward participation in the cruise on October 2001.

Task II

In late April 2000, crews from the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory (PMEL) and the Japan Marine Science and Technology Center (JAMSTEC) had mounted buoy meteorological systems side-by-side with a 3 m discus buoy from the Woods Hole Oceanographic Institution Upper Ocean Processes (UOP) group at a site 30 m from the water's edge on Nantucket Sound, in Falmouth, Massachusetts. PMEL installed two of their Atlas buoy tower tops, each with wind, relative humidity, air temperature, barometric pressure, precipitation, short wave radiation and long wave radiation sensors. JAMSTEC installed one of their Triton buoy systems with ASIMET wind, relative humidity/air temperature, and short wave radiation modules, and a precipitation and barometric pressure sensor. The UOP buoy had two complete IMET systems including wind, relative humidity/air temperature, precipitation, barometric pressure, short wave radiation and long wave radiation modules. All systems transmitted a subset of their data to their home laboratories by Argos satellite. The data comparison period is from 4 May, when all systems were operational, to 27 June, when the JAMSTEC system was removed for shipment back to Japan.

Preliminary analysis of the data has been completed. With this a draft technical report was written and circulated to PMEL and to JAMSTEC. Comments were exchanged and preparation of the final report begun.

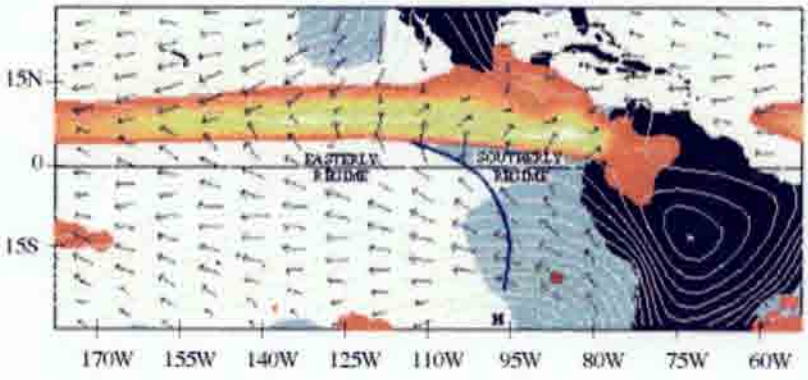
Home	Overview	Sponsors	Stratus 1	Stratus 2	Stratus 3	Documents

As part of the Eastern Pacific Investigation of Climate (EPIC) program, the UOP group has undertaken a study of Long-Term Evolution and Coupling of the Boundary layers in the Stratus Deck regions of the eastern tropical Pacific. The goal of the STRATUS project is to observe and understand air-sea interactions and the surface forcing in the cold tongue/intertropical convergence zone (ITCZ) and in the region.

We are currently maintaining a well-instrumented surface mooring for several years under the stratus deck, to collect accurate time series of surface meteorology and upper ocean temperatures, velocities and salinities.

STRATUS is funded by the National Oceanic and Atmospheric Administration (NOAA).

A surface mooring with sensors suitable for the determination of air-sea fluxes and upper ocean properties was deployed by the Upper Ocean Processes Group at 20' S, 85'W on 19 October 2001.



The Eastern tropical Pacific, showing climatological stratus clouds (gray), rain (orange), and surface winds for September-October. The position of the buoy at 20'S, 85'W is marked by a red square.

Contact: Robert Weller

IMET flux Instrument Suite Upgrade Requested Funding Under Task III

Final Summary Report CICOR Cooperative Agreement 1998-2002

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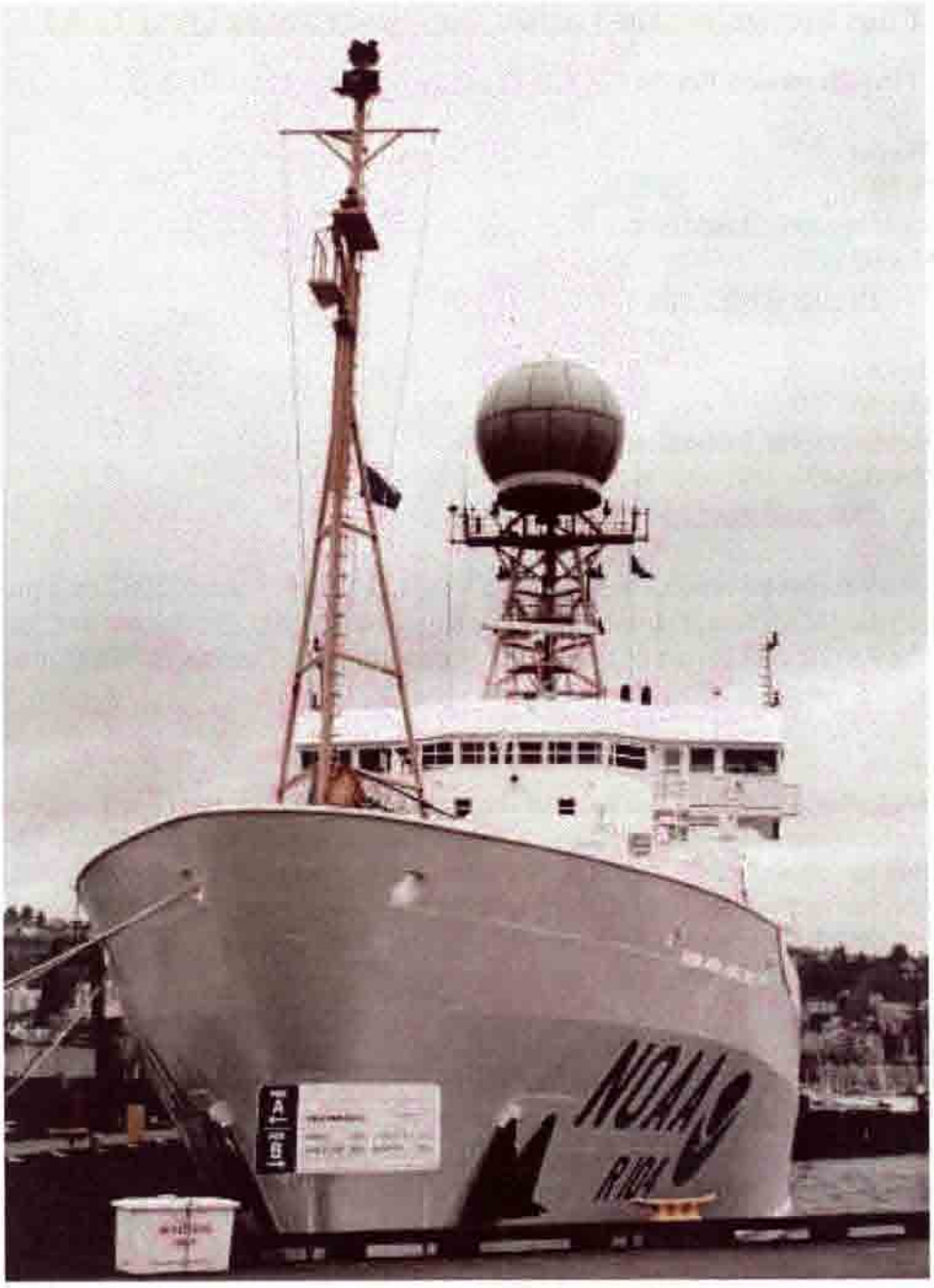
This is the summary technical report for the period May 1, 2000 to 30 June, 2002 on a program to make upgrades to the IMET flux instrument suites on the NOAA ship *RonBrown*, and for the second ship in the Pacific that is part of the CORC (Consortium on Ocean's role in Climate) Program.

1. Project Goals.

The NOAA ship *RonBrown* has most of the instrumentation required for measurement of flux but lacks the longwave radiation module. This proposal will purchase two IMET LWR modules (one plus spare) and deliver them to NOAA. The second ship in the Pacific that is part of the CORC program has all but one relative humidity / air temperature module. This proposal will purchase one IMET HRH module for use on that ship. This will increase the number of "Flux Ships" available to the climate research program.

2. Description of Work.

The two IMET LWR modules were fabricated and have been shipped to the NOAA ship *RonBrown*. The IMET HRH module has been completed, calibrated, and was installed on the *ColombusFlorida* in Long Beach CA in August 2001. This is part of a new complete installation of the complete suite of flux modules on this second ship in the Pacific. The first ship is the *CSXEnterprise* that has had the flux suite installed and serviced for the past several years. Three sets of IMET modules are needed to service these two ships. The set of modules last removed from a ship is repaired, calibrated and ready to be installed on the next ship. In this way the IMET modules on a ship are calibrated and the one minute data retrieved for post-processing of the climate quality data every six months. Future programs will add the capability for near real-time satellite transmission of forecast quality data using the NOAA SEAS (Shipboard Environmental (Data) Acquisition System) and Inmarsat C. The following picture is of the NOAA ship *RonBrown* showing the bow mast where IMET modules are installed.



R.V Ron Brown with bow mast configuration.

An Integrated System for Real-time CTD Profiling Float Data on Basin Scales (NOPP)

Final Summary Report CICOR Cooperative Agreement 1998-2002

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Program Manager: Steve Piotrowicz, NOAA/OAR

Background

As one of the first components of the long-term ocean observing system, the Argo float program has been initiated to provide 2000 profiling floats that will deliver temperature and salinity profiles to depths of up to 2000 m every 10 days. This array of floats will be global in extent and provide the data in real-time so that it can be used for operational oceanographic forecasting for both mesoscale and seasonal to interannual variability. This data set will also become one of the significant global data sets that will be used by such research programs as CLIVAR to investigate climate variability.

Objectives

This grant covers WHOI's contribution to the initial implementation of this program. It includes both development and improvements of the float technology to meet the objectives of the Argo float program, manufacturing of floats for the Argo array, quality-control of the data, and contributions scientific management of both the Argo Float program and Global Ocean Data Assimilation Experiment (GODAE).

Accomplishments

An electronic package, based on a board set that we have been using for RAFOS floats was modified to include interfaces to the Falmouth Scientific Instrument or Seabird CTD systems and with either an Argos PTT or ORBCOMM transmitter as communications links for data transmission and location determination. Software was developed to control the various functions required to carry out the float mission. Several floats are now in the water using this controller with an FSI CTD and taking advantage of the ORBCOMM communications system. As an example, a float, serial number 421, was deployed near Bermuda on 9 November, 2001. It profiles to roughly 1200 m with a resolution of 2 m to 500 m and 5 m below that depth. This float was programmed for a 5 day repeat cycle, twice as often as the normal Argo float, to accelerate the number of cycles to verify the new float design. The float spends typically 30 minutes on the

surface obtaining a GPS fix and sending the data back. The vertical resolution and precision of the data are both over an order of magnitude than is possible using Service Argos. The position of the float and the raw temperature and salinity profiles transmitted from the float are shown in figures 1-3.

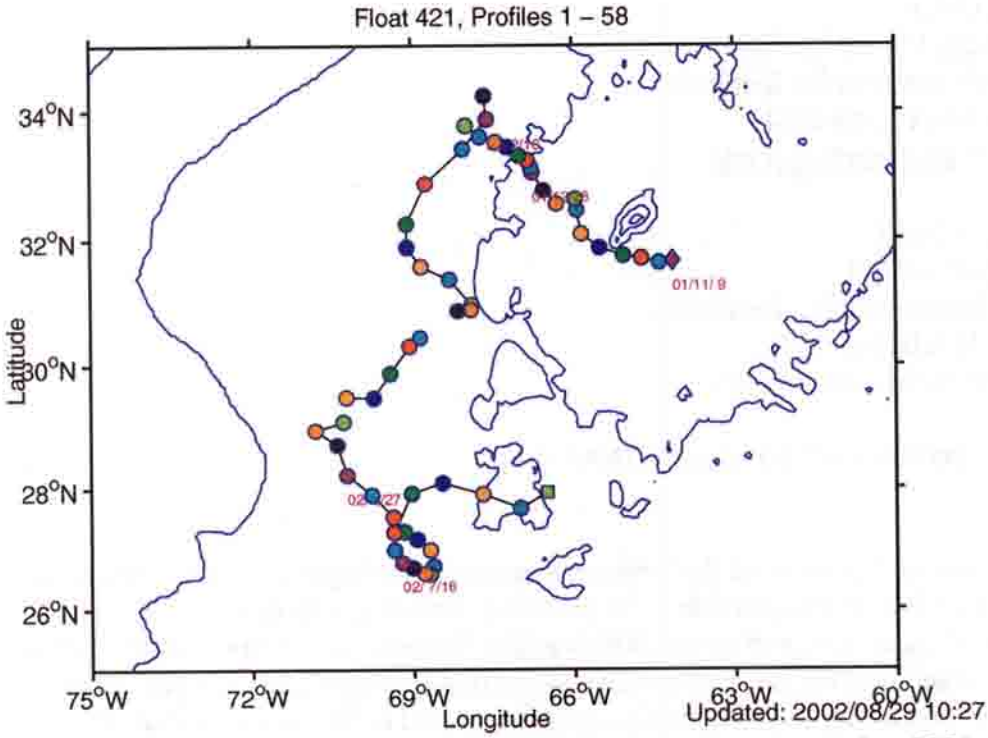

Figure 1. Positions of Float 421 launched in November 2001.

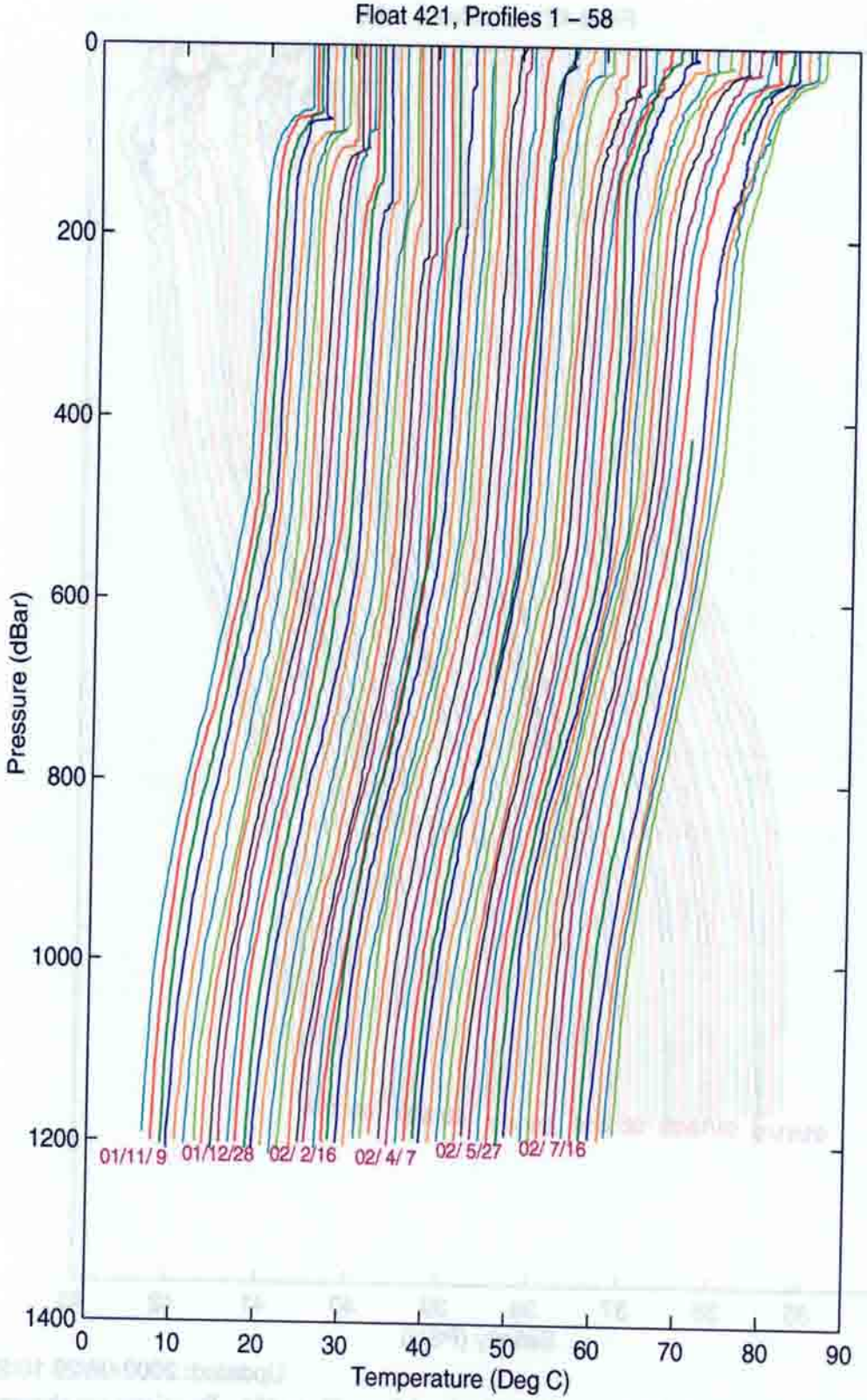

Figure 2. Cascade plot of temperature profiles obtained from Float 421. Positions are shown in Figure 1.

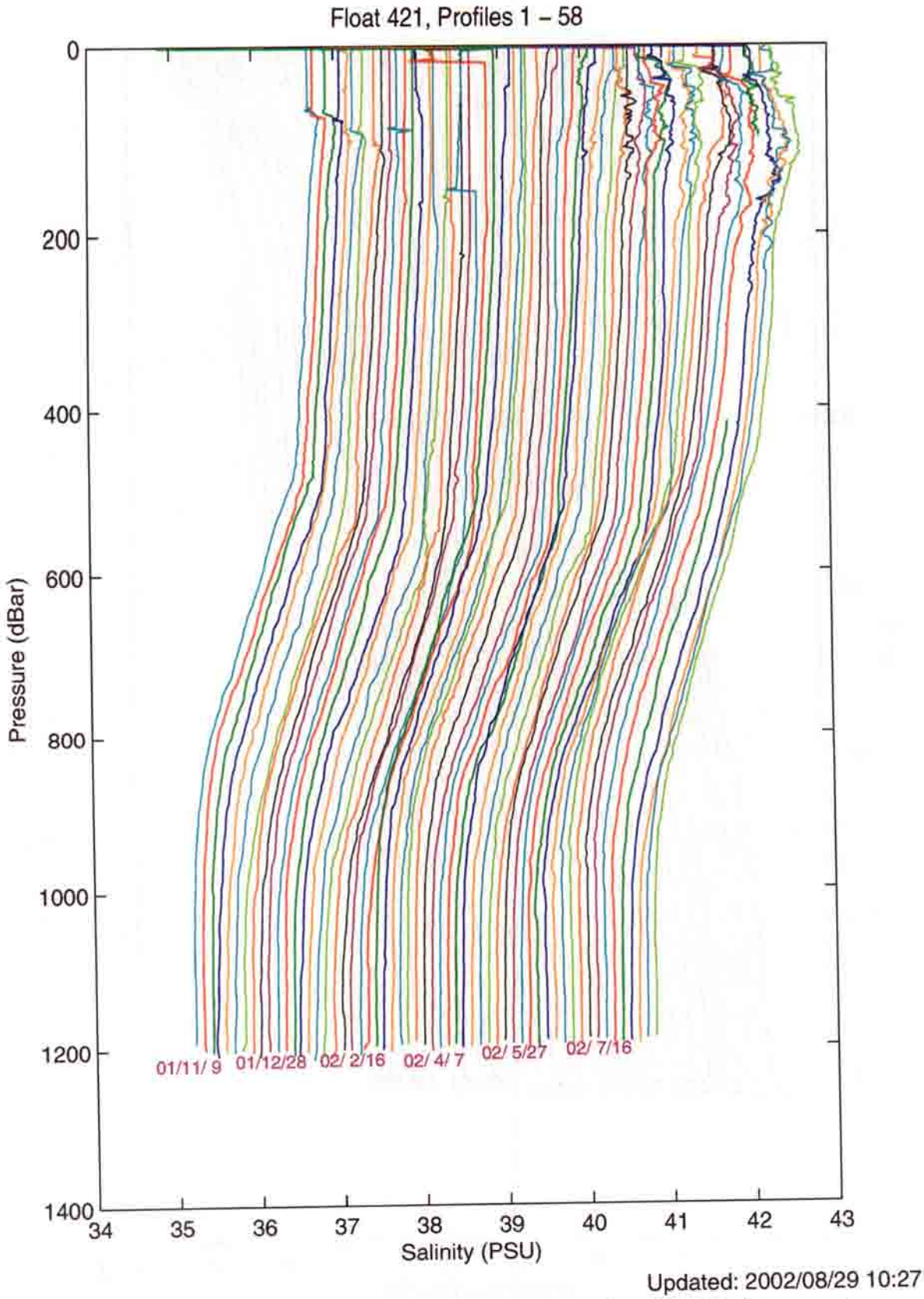

Figure 3. Cascade plot of salinity profiles obtained from Float 421. Positions are shown in Figure 1.

In addition to this float design, a number of floats using the older controller developed for the WOCE Palace floats were also manufactured. These floats use the Seabird CTD package. The floats that were manufactured for the Argo array are a combination of the two float designs. A total of 64 floats were manufactured for the array. A small fraction of these floats remain in the lab waiting for some replacement parts that we believe will significantly improve the reliability. These parts have just been delivered and we expect all these floats to be in the water by the end of September.

As part of the quality control effort, Owens collaborated with G. Johnson and A. Wong from PMEL to develop a methodology to provide a delayed estimate of the drift of the conductivity sensors on the floats. This procedure involves copmparing the float observations to estimates based on spatial and temporal interpolations/extrapolation of data from a quality controlled climatology. The temporal extrapolation uses times scales estimated from transient tracers (CFC's) which effectively gives higher weights to more recent observations. This work was presented at the January, 2000 AMS meeting. A manuscript (Wong, Johnson, and Owens, 2002) has been accepted for publication in the Journal of Atmospheric and Oceanic Technology.

Owens has served on various Argo and GODAE scientific steering groups. This work has been necessary to push through the implementation of both programs. This includes membership in the Argo International Working Group, and co-chairmanship of the US scientific steering committees for both Argo and GODAE. Owens has also collaborated with Roemmich (Roemmich and Owens, 2000) on a article published in Oceanography magazine describing the Argo float program.

References

Roemmich, D., and W. B. Owens, 2000. The Argo Project: Global ocean observations for understanding and precdiction of climate variability. *Oceanography*, 13, 45-50.

Wong, A. P. S., G. C. Johnson, and W. B. Owens, 2002. Delayed-mode calibration of autonomous CTD profiling float salinity data by ϑ-S climatology. *Journal of Atmospheric and Oceanic Technology*, accepted.

In Situ Measurement of DMS Fluxes and Gas Transfer Velocity during GasEx-2001

Final Summary Report CICOR Cooperative Agreement 1998-2002

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INTRODUCTION

One of the biogenic gases present in the atmosphere, dimethylsulfide (DMS), is a major contributor to the sulfur cycle on earth. DMS is also considered to play an important role in climate regulation because its oxidation products may become cloud condensation nuclei that affect the earth s radiative balance. The major source of DMS is the ocean s plankton. There is a large DMS concentration difference between the ocean and the atmosphere, with concentrations in the ocean typically orders of magnitude higher than in the air where it is oxidized by OH-radicals. The high concentration gradient of DMS makes it an ideal tool for the determination of gas transfer velocities: knowing the flux of DMS and knowing the concentration in surface seawater allows calculation of the gas transfer rate.

PROJECT GOALS

GasEx 2001 was a multi-disciplinary study focusing on the flux of CO_2 across the air-sea interface. The primary goal was to measure air-sea CO_2 fluxes and the surface physical and biogeochemical processes which control CO_2 fluxes over short (<hour) time scales.

This sub-project was directed at measuring the flux of DMS from the ocean to the atmosphere. Unlike CO_2, which may move in either direction across the ocean surface depending on biological and physical circumstances, DMS always fluxes to the atmosphere because of its biological source in the surface ocean. The rates we measured can be used to corroborate CO_2 fluxes since they help characterize the gas transfer rates of the surface layer. Accurate estimates of DMS flux are also important for understanding sulfur chemistry, improving models of atmospheric sulfur, and quantifying the role of DMS in aerosol dynamics.

METHODOLOGY

Sea-to-air DMS fluxes were measured during the GasEx-2001 cruise using the atmospheric Gradient Flux (GF) technique. The approach is designed to make measurements on the temporal and spatial scales which are appropriate for investigating the factors that control fluxes across the ocean surface. By combining these measurements with measurements of the concentration of DMS in the surface water, gas transfer velocities (k_{gas}) across the air-sea interface can be estimated.

Figure 1: Images of the NOAA research vessel Ronald H. Brown with the bow boom/mast system used in GasEx-2001.

WORK COMPLETED

During GasEx-2001 DMS fluxes were measured with the GF technique from the NOAA research Vessel Ronald H. Brown bow boom/mast system (Figure 1). Air was sampled at three different elevations for 30-minute intervals at a flow rate of 300 ml min^{-1}. The sampled air was stored in Tedlar bags, and analyzed for DMS using a GC equipped with a Sievers sulfur chemiluminescence detector. These measurements are used to estimate the transfer velocity and will be compared with flux measurements of CO_2 and wind speed parameterizations. The data products from this effort includes the DMS sea-air flux and gas transfer velocity. Measurements of aqueous DMS were also made regularly during the cruise.

The environmental conditions were fairly constant over the time span of the experiment (February 2001) near 125W 3S. Average U_{10} wind speeds varied around 5 m sec^{-1}, mean water temperature was 26…C and mean air temperature was 25…C. Unstable atmospheric conditions prevailed during the experiment. DMS concentrations in the water surrounding the sampling systems varied around 2.6 nM. The profiles measured from the bow of the NOAA research vessel Ronald H. Brown show that the atmospheric profiles of DMS concentration were semi-logarithmic with increasing height. DMS fluxes derived from the profiles ranged up to almost 40 mol m^{-2} d^{-1} with the highest rates coinciding with higher wind speeds (Figure 2).

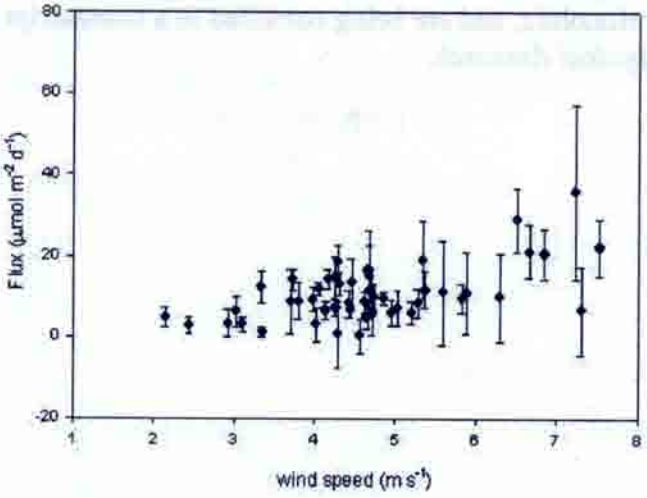

Figure 2: Plot of DMS Fluxes (mol m^{-2} d^{-1}), derived from GF measurements during the GasEx cruise. Error bars represent the 95% confidence interval.

Data collected during the GasEx2001 project yield higher transfer velocities at low wind speeds than predicted by the Wanninkhof relationship (Figure 3).

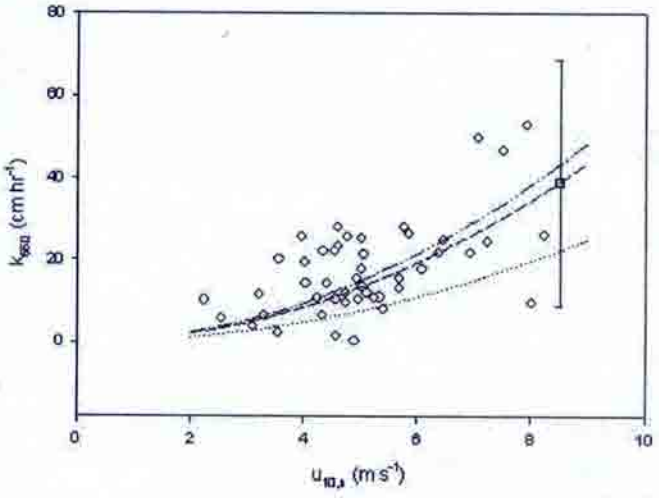

Figure 3: Open circles represent gas transfer velocities versus wind speed derived from gradient measurements of DMS fluxes during the GasEx2001 cruise. The square is the average of gas transfer velocities derived from DMS gradient measurements during Gasex-98 cruise (n = 3). Transfer velocities are normalized to the transfer velocity of CO_2 in water of 20ßC and a salinity of 33 . The dashed line is the equation that is based on eddy correlation measurements of the CO_2 flux: 0.54 u^2_{10n} (Jacobs et al., 1999). The dotted line is the Wanninkhof (1992) fit: k_{660} = 0.31 $u^2_{10.}$. The dashed-dotted line is the quadratic fit through the GasEx 2001 results: k_{660} = 0.60 (+/-0.04) $u^2_{10.}$

These measurements of DMS flux contribute to the development of more accurate estimates of the gas transfer velocity and an improved understanding of the processes controlling air-sea CO_2 fluxes.

These results were presented in the National Meeting of the AGU during the February 2002 meeting in Honolulu, and are being compiled in a manuscript to be submitted to the *Journal of Geophysical Research*.