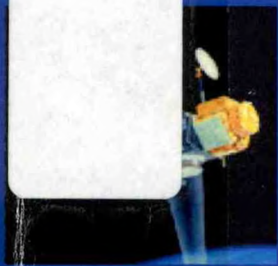
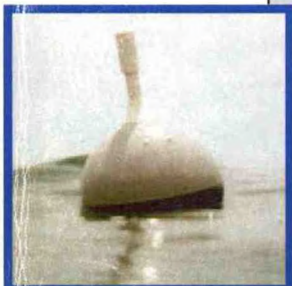
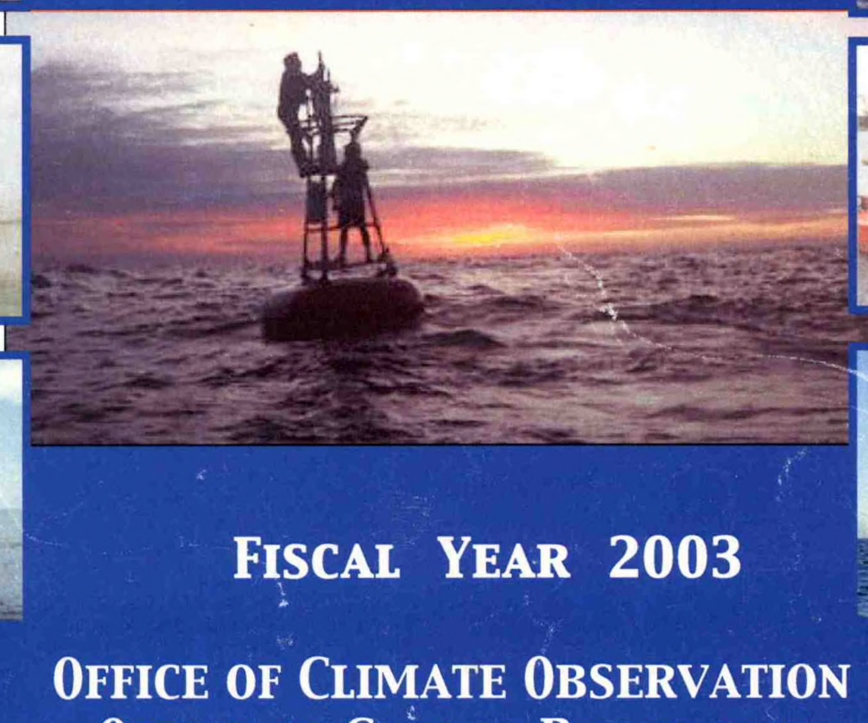
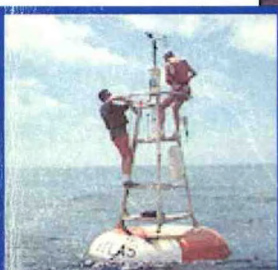


ANNUAL REPORT

THE STATE OF THE OCEAN AND THE OCEAN OBSERVING SYSTEM FOR CLIMATE







FISCAL YEAR 2003

OFFICE OF CLIMATE OBSERVATION
OFFICE OF GLOBAL PROGRAMS
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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ANNUAL REPORT ON THE STATE OF THE OCEAN AND THE OCEAN OBSERVING SYSTEM FOR CLIMATE

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Executive Summary

Diane Stanitski, Ph.D.
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This Annual Report is a compilation of articles, progress reports, and references focused on the current state of the ocean and the status of the ocean observing system for climate in fiscal year (FY) 2003. The report synthesizes *in situ* observations integrated with models and scientific expertise to provide products to decision makers, the science community, and the public. This reporting framework establishes a formal mechanism for implementing a "user-driven" observing system and for reporting on the system's performance in meeting the requirements of operational forecast centers (e.g., National Centers for Environmental Prediction (NCEP)), international research programs (e.g., International Climate Variability and Predictability (CLIVAR) program), and major scientific assessments (e.g., Intergovernmental Panel for Climate Change (IPCC) report). Stakeholders are invited and encouraged to provide formal recommendations for system improvement and evolution as part of the annual report process.

Chapter 1 provides an introductory overview of the ocean and its role in climate with an explanation of the ocean's physical parameters that contribute to the hydrological cycle. Ocean-atmosphere interactions are addressed along with the impacts of climate change on sea ice extent and resultant sea level. Connections are made between ocean observations and economic and societal impacts.

Chapter 2 includes a series of summaries focused on ocean climate (anomalies) from FY 2003 placed in historical context, reasons why it is increasingly important to monitor climate variables, accompanying climate applications, and how the observing system needs to be enhanced to improve ocean analysis and product development. Chapter 2 focuses on the products linked with the observing system, specifically sea level, ocean carbon, sea surface temperature, surface currents, sea surface pressure, air-sea exchanges of heat, momentum, and freshwater, and heat content variations.

Chapter 3 focuses on the observing system and provides a compilation of all FY 2003 progress reports written by the OCO-funded project managers. These projects are focused on the mission of the Office of Climate Observation, namely, documenting long-term trends in sea level change, ocean carbon sources and sinks, ocean's storage and global transport of heat and fresh water, and the ocean-atmosphere exchange of heat and fresh water, along with accompanying parameters.

Chapter 4 contains selected abstracts from refereed publications, and a bibliography of science articles and publications published by the scientific community during FY 2003 treating the global observation of ocean heat, carbon, fresh water, and sea level change.

The driving force for this report is the Climate Change Science Program (CCSP) overarching question for guiding climate observations and monitoring - "What is the current state of the climate, how does it compare with the past, and how can observations be improved to better initialize and validate models for prediction or long term projections?"

Present ocean observations are not adequate to deliver the products described in Chapter 2 with confidence. The fundamental deficiency is lack of global coverage by the *in situ* networks. Present international efforts comprise approximately 45% of what is needed in the ice-free oceans and 11% in the Arctic. The *Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCCC* concludes that "the ocean networks lack global coverage and commitment to sustained operations....Without urgent action to address these findings, the Parties will lack the information necessary to effectively plan for and manage their response to climate change." The *Strategic Plan for the U.S. Climate Change Science Program* calls for "complete global coverage of the oceans with moored, drifting, and ship-based networks" (Johnson, Chapter 3 of this report).

The critical nature of our understanding of the ocean's role in climate variability and change provides immediate justification for the presence of a global observing system, however, many other applications, including societal and environmental, validate the presence of an ocean observing system for climate.

Incremental advancements across all observing system networks occurred in FY 2003, enabling expansion from 40% completion in FY 2002 to 45% in FY 2003. In addition to the scientific activities completed by the principal investigators in FY 2003 (as outlined in Chapter 3), their accomplishments in the service arena are equally astounding. Principal investigators and project leaders served the scientific community through more than 70 appointments to science and implementation panels, science teams, advisory boards, as committee members, officers, and steering committee members. PIs presented at or attended 140 conferences and workshops. On more than a dozen occasions scientists contributed their time and talent through outreach during press/media interviews, public lectures, and school visits.

An Observing System Monitoring Center (OSMC) is in progress as a joint effort between the Pacific Marine Environmental Laboratory (PMEL), the National Data Buoy Center (NDBC), and NOAA's Office of Climate Observation (OCO). The OSMC system is an information gathering, decision support, and reporting system for the OCO to display the current and historical status of globally distributed data collection systems. The OSMC will eventually provide the data visualization tools necessary to identify the coverage of any collection of ocean platforms and parameters accessed with the use of any conventional web browser on the Internet and through a monitoring center and briefing area at the new OCO office in Silver Spring, Maryland.

International and interagency partnerships are central to the Climate Observation Program implementation strategy. All of the Program's contributions to global observation are managed in cooperation internationally with the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), and nationally with the U.S. Integrated Ocean Observing System (IOOS). NSF has initiated their Ocean Observatories Initiative (OOI), which will potentially provide significant infrastructure in support of ocean climate observation, beginning in FY 2006. Commencement of an ongoing NSF-NOAA cooperative project for CLIVAR-carbon ocean surveys has proved to be an interagency-international-interdisciplinary success. ONR maintains a GODAE data server at Monterey that needs to be sustained after the experiment period (2003-2005) as permanent international infrastructure. NOAA ships and the UNOLS fleet provide ship support for ocean operations and NASA's development of remote sensing techniques is vital (Johnson, Chapter 3 of this report). The OAR laboratories, joint institutes and university partners are presently implementing most NOAA contributions to the global system.

With new and continuing partnerships the complete global ocean observing system for climate will become a reality.

CHAPTER 1

THE ROLE OF THE OCEAN IN CLIMATE

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a. The Role of the Ocean

The oceans cover about 71% of the Earth's surface and contain 97% of the Earth's water. Through their fluid motions, their high heat capacity, and their ecosystems, the oceans play a central role in shaping the Earth's climate and its variability. Changes in sea level have major impacts on coastal regions. Accordingly, it is vital to monitor and understand changes in the oceans and their effects on climate, and improve the quality of model ocean simulations. Much of the following is adapted from Trenberth (2001).

The most important characteristic of the oceans is that they are wet and, while obvious, this is sometimes overlooked. Water vapor, evaporated from the ocean surface, provides latent heat energy to the atmosphere during the precipitation process. In units of 1,000 km^3 per year, evaporation E over the oceans (436) exceeds precipitation P (399), leaving a net of 37 units of moisture transported onto land as water vapor. On average, this flow must be balanced by a return flow over and beneath the ground through river and stream flows, and subsurface ground water flow. The average precipitation rate over the oceans exceeds that over land by 72% (allowing for the differences in areas), and precipitation exceeds evapotranspiration over land by this same amount (37) (Dai and Trenberth 2002). This flow into the oceans occurs mainly in river mouths and is a substantial factor in the salinity of the oceans, thus affecting ocean density and currents. A simple calculation of the volume of the oceans of about 1330×10^6 km^3 and the through-flow fluxes of E and P implies an average residence time of water in the ocean of over 3,000 years.

Changes in phase of water, from ice to liquid to water vapor, affect the storage of heat. However, even ignoring these complexities, many facets of the climate can be deduced simply by considering the heat capacity of the different components of the climate system. The total heat capacity depends on the mass of the substance involved as well as its capacity for holding heat, as measured by the specific heat (the amount of heat needed to raise the temperature of one gram of a substance by 1 C), of each substance.

The atmosphere does not have much capability to store heat. The heat capacity of the global atmosphere corresponds to that of only a 3.2 m layer of the ocean. However, the depth of ocean actively involved in climate is much greater than that. The specific heat of dry land is roughly a factor of 4.5 less than that of seawater (for moist land the factor is probably closer to 2). Moreover, heat penetration into land is limited by the low thermal conductivity (the degree to which a substance transmits heat), of the land surface; as a result only the top two meters or so of the land typically play an active role in heat storage and release (e.g., as the depth for most of the variations over annual time scales). Accordingly, land plays a much smaller role than the ocean in the storage of heat and in providing a memory for the climate system. Major ice sheets, like those over Antarctica and Greenland, have a large mass but, like land, the penetration of heat occurs primarily through conduction (molecular transfer of energy due to a temperature gradient), so that the mass experiencing temperature changes from year to year is small. Hence, ice sheets and glaciers do not play a strong role in heat capacity, while sea ice is important where it forms.

The seasonal variations in heating penetrate into the ocean through a combination of radiation, convective overturning (in which cooled surface waters sink while warmer more buoyant waters below rise) and mechanical stirring by winds. These processes mix heat through the mixed layer, which, on average, involves about the upper 90 m of ocean. The thermal inertia of a 90 m layer can add a delay of about 6 years to the temperature response to an instantaneous change (this time corresponds to an exponential time constant in which there is a 63% response toward a new equilibrium value following an abrupt change). As a result, actual changes in climate tend to be gradual. With its mean depth of about 3800 m, the total ocean would add a delay of 230 years to the response if rapidly mixed. However, mixing is not a rapid process for most of the ocean so that in reality the response depends on the rate of ventilation of water between the well-mixed upper layers of the ocean and the deeper, more isolated layers that are separated by the thermocline (the ocean layer exhibiting a strong vertical temperature gradient). The rate of such mixing is not well established and varies greatly geographically. An overall estimate of the delay in surface temperature response caused by the oceans is 10–100 years. The slowest response should be in high latitudes where deep mixing and convection occur, and the fastest response is expected in the tropics. Consequently, the oceans are a great moderating effect on climate changes.

Wind blowing on the sea surface drives the large-scale ocean circulation in its upper layers. The oceans can move heat around through convection and advection (in which the heat is carried by the currents, whether small-scale short-lived eddies or large-scale currents). Hence, ocean currents carry heat and salt along with the fresh water around the globe. The oceans therefore store heat, absorbed at the surface, for varying durations and release it in different places; thereby ameliorating temperature changes over nearby land and contributing substantially to variability of climate on many time scales.

The ocean thermohaline circulation (THC), which is the circulation driven by changes in sea water density arising from temperature (thermal) or salt (haline) effects, allows water from the surface to be carried into the deep ocean, where it is isolated from atmospheric influence and hence it may sequester heat for periods of a thousand years or more. The oceans also absorb carbon dioxide and other gases and exchange them with the atmosphere in ways that change with ocean circulation and climate change. In addition, it is likely that marine biotic responses to climate change will result in subsequent changes that may have further ramifications.

b. An example: The annual cycle

In the subtropics, the oceans typically take up in excess of 100 W m^{-2} in the winter months and give it to the atmosphere in summer mostly in the form of evaporation of moisture. This cools the ocean while eventually warming the atmosphere when released as latent heat in precipitation (Trenberth and Stepaniak 2003). In mid-latitudes, air coming off the ocean is warmer than the land in winter and cooler in summer, giving rise to refreshing sea breezes and moderating temperatures. Regions influenced by the ocean in this way are referred to as having maritime climates.

An example of the role of the oceans in moderating temperature variations is the contrast in the mean annual cycle of surface temperature between the northern hemisphere (NH) (60.7% water) and southern hemisphere (SH) (80.9% water). The amplitude of the 12-month cycle between 40 and 60 latitude ranges from <3 C in the SH to about 12 C in the NH. Similarly, in mid-latitudes from 22.5 – 67.5 latitude, the average lag in temperature response relative to peak solar radiation is 32.9 days in the NH versus 43.5 days in the SH (Trenberth 1983), reflecting the differences in thermal inertia.

c. The oceans and sea ice

Sea ice is an active component of the climate system and varies greatly in areal extent with the seasons, but only at higher latitudes. In the Arctic where sea ice is confined by the surrounding continents, mean sea ice thickness is 3–4 m thick and multi-year ice can be present. Around Antarctica the sea ice is unimpeded and spreads out extensively, but as a result the mean thickness is typically 1–2 m. Sea ice caps the ocean and interferes with ocean-atmosphere exchanges of heat, moisture, and other gases. Melting sea ice freshens the ocean and diminishes the density. However, its greatest impact is through changes in albedo of the surface, the much darker ocean surface absorbs more solar radiation, further warming the ocean and leads to the ice-albedo positive feedback that amplifies initial perturbations. Diminished sea ice also increases moisture fluxes into the atmosphere, which may increase fog and low cloud, adding further complexity to the net albedo change. Ocean currents transport sea ice, which is also subject to stresses from surface wind.

d. Coupled ocean-atmosphere interactions

Understanding the climate system becomes more complex as the components interact. El Niño events are a striking example of a phenomenon that would not occur without interactions between the atmosphere and ocean. El Niño events involve a warming of the surface waters of the tropical Pacific. Ocean warming takes place from the International Dateline to the west coast of South America and results in changes in the local and regional ecology. Historically, El Niño events have occurred about every 3–7 years and alternated with the opposite phases of below average temperatures in the tropical Pacific, dubbed La Niña. In the atmosphere, a pattern of change called the Southern Oscillation is closely linked with these ocean changes, so that scientists refer to the total phenomenon as ENSO. Then El Niño is the warm phase of ENSO and La Niña is the cold phase.

The strong sea surface temperature (SST) gradient from the warm pool in the western tropical Pacific to the cold tongue in the eastern equatorial Pacific is maintained by the westward-flowing trade winds, which drive the surface ocean currents and determine the pattern of upwelling of cold nutrient-rich waters in the east. Because of the Earth's rotation, easterly winds along the equator deflect currents to the right in the NH and to the left in the SH and thus away from the equator, creating upwelling along the equator. Low sea level pressures are set up over the warmer waters while higher pressures occur over the cooler regions in the tropics and subtropics. The moisture-laden winds tend to blow toward low pressure so that the air converges, resulting in organized patterns of heavy rainfall and a large-scale overturning along the equator called the Walker Circulation. Because convection and thunderstorms preferentially occur over warmer waters, the pattern of SSTs determines the distribution of rainfall in the tropics, and this in turn determines the atmospheric heating patterns through the release of latent heat. The heating drives the large-scale overturning circulations in the tropics, and consequently determines the winds. If the Pacific trade winds relax, the ocean currents and upwelling change, causing temperatures to increase in the east, which decreases the surface pressure and temperature gradients along the equator, and so reduces the winds further. This positive feedback leads to the El Niño warming persisting for a year or so, but the ocean changes also sow the seeds of the event's demise. The changes in the ocean currents and internal waves in the ocean lead to a progression of colder waters from the west that may terminate the El Niño and lead to the cold phase, La Niña, in the tropical Pacific. The El Niño develops as a coupled ocean–atmosphere phenomenon and, because the amount of warm water in the tropics is redistributed, depleted and restored during an ENSO cycle, a major part of the onset and evolution of the events is determined by the history of what has occurred one to two years previously. This means that the future evolution is potentially predictable for several seasons in advance.

e. Sea level

Another major role of oceans in climate that has major impacts on multi-decadal time-scales is sea level rise. Climate models estimate that there is a current radiative imbalance at the top-of-the-atmosphere of about 7 W m^{-2} owing to increases of greenhouse gases, notably carbon dioxide, in the atmosphere. This has increased from a very small imbalance only 40 years ago. Where is this heat going? Some heat melts glaciers and ice, contributing to sea level rise. However, the main candidate for a heat sink is the oceans, leading to thermal expansion and further sea level rise. Levitus et al. (2000) have estimated that the heat content of the oceans has increased on average at a rate of about 3 W m^{-2} over the past few decades.

Sea level has risen throughout the twentieth century by 1.5±0.5 mm/year (IPCC 2001) but the rate appears to have accelerated in the 1990s when accurate global measurements of sea level from TOPEX/POSEIDEN altimetry became available. Recent estimates of sea level rise are 3.0 mm/year for 1993-2002 (Cazenave 2003, personal communication; and see Cabanes et al. 2001). To quote a recent assessment by Anny Cazenave (personal communication 2003) "During the 1990s, observed sea level rise is totally explained by thermal expansion. However, there is strong observational evidence for a significant eustatic contribution" of order 1 mm/yr. That is to say that melting of glaciers and ice sheets have added mass to the oceans at this rate (see e.g., Meier and Dyurgerov 2002). Estimates of other contributions (e.g., Cazenave et al. 2000) find that increased storage of water on land in reservoirs and dams accounts for –1.0±0.2 mm/yr; irrigation accounts for another –0.56±0.06 mm/yr but these are compensated for by ground water mining, urbanization, and deforestation effects so that the net sum of land effects is –0.9±0.5 mm/yr. Other small contributions also exist but there has been a reasonable accounting for the observed changes. Nevertheless, controversy remains about longer-term sea level rise (Munk 2003) and there is evidence of bias in the historical sea level station network (Cabanes et al. 2001). The so-called steric contribution from thermal expansion is based mostly on the analysis of the historical record of Levitus et al. (2001). Yet that record is based on sub-surface ocean measurements which are inadequate in many areas, for instance little or no sampling over many parts of the southern oceans to even determine the mean, let alone the variations with time. Future sea level rise, and whether or not the rate is increasing are vital issues for climate change and impacts on small island states and coastal regions.

f. Why are we observing the ocean?

The above describes the critical role of the oceans in climate. Oceans take up heat in the summer half year and release it in winter, playing a major role in moderating climate. The oceans play a crucial role in ENSO. However, the enormous heat capacity of the oceans means that the oceans also play a key role on decadal and longer timescales. The exact role of the oceans in the North Atlantic Oscillation (the predominant mode of atmospheric variability in the Northern Hemisphere in winter that relates to the strength of the hemispheric-scale westerly flow) is being explored. Variations in the ocean affect ecosystems, including fisheries, which are of direct importance for food and the economy. It is therefore important to track the changes in ocean heat storage, as well as the uptake and release of heat in the oceans through the surface fluxes.

Salinity effects on ocean density are also important but are poorly measured at present. It is essential to be able to attribute changes in ocean heat content and the mass of the ocean to causes (such as changing atmospheric composition), perhaps using models. Climate models suggest that the THC could slow down as global warming progresses, resulting in counter-intuitive relative regional cooling or, more likely, reduced warming on multi-decadal time-scales.

It is vital to establish a baseline of the current state of the ocean as a reference for future assessments. Monitoring of the top 500 m of the near-equatorial Pacific Ocean has been established because of ENSO. It is an excellent start. The Tropical Oceans Global Atmosphere (TOGA) program and World Ocean Circulation Experiment (WOCE) have paved the way. Increasing attention will be devoted to measurements of the biogeochemistry of the oceans and especially the carbon cycle, and possible feedbacks on carbon dioxide levels in the atmosphere. Relationships of physical ocean changes to ecosystems and fish stocks will enable improved fishery management. Observing technologies are evolving, and plans are already underway for an initial ocean observing system, but it has yet to be fully implemented. The observing system must evolve in ways that protects the integrity and continuity of the climate record. Such a system must be linked to comprehensive analysis capabilities of not only the ocean, but also the atmosphere, sea ice, radiation, precipitation, and other ingredients in the climate system. From time to time it is expected that reanalyses of the past ocean and climate record will be desirable as improvements are made in models and data assimilation systems. Tracking the performance of the observing system to ensure that it is meeting needs is another necessary component (Trenberth et al. 2002). With such information, and good models, we will be enabled to make skilful predictions of climate on timescales ranging from weeks, to interannual (ENSO), to decades. However, good ocean observations are also essential for developing better models.

Ongoing assessments are therefore required of the continually changing state of the ocean, as well as our ability to observe it and assess what is going on. It is therefore appropriate for NOAA to carry out an annual assessment of both the state of the ocean and the state of the observing system, examine how well needs are being met, and find timely remedies for inadequacies.

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CHAPTER 2

THE STATE OF THE OCEAN

This chapter includes an overview of the current state of knowledge about ocean climate, including anomalies, placed in historical context. Expert scientists who monitor, observe, and analyze the ocean products described in this chapter (e.g., sea level, ocean carbon, SST) have produced concise summaries describing why it is important to monitor these variables. Climate applications are presented along with an explanation of how the observing system needs to be enhanced to improve ocean analysis and reduce present uncertainties. This chapter focuses primarily on decision makers and non-scientists interested in, and concerned about, ocean research.

A performance measure is a structured statement describing how progress will be evaluated. Performance measures consist of four parts: indicator, unit of measure, baseline and target. An indicator defines the attribute or characteristic to be measured. The unit of measure describes what is to be measured. A baseline establishes the basis for comparison through an initial collection and analysis of data. A baseline should include both a starting date and level. A target establishes the desired level to be reached in a defined period, usually stated as an improvement over the baseline. Targets are based on research and a thorough understanding of the goal/program and are challenging, worthwhile and achievable (NOAA definition). A metric is any type of measurement used to gauge some quantifiable component of an agency's performance. Currently, the following performance measures exist for the ocean observation program.

<u>Present Performance Measure</u>:

1. Reduce the uncertainty in projections of *sea level rise* during the 21^{st} century. Metric – the range between credible estimates of sea level rise (centimeters):

2002	2003	2004	2005	2006	2007	2008	2009	2010
80 cm	80 cm	70 cm	60 cm	50 cm	40 cm	30 cm	25 cm	25 cm

2. Reduce the uncertainty in estimates of the increase in *carbon inventory* in the global ocean. Metric – uncertainty in estimates of anthropogenic change per decade (Gigatons):

2002	2003	2004	2005	2006	2007	2008	2009	2010
10 Gt	10 Gt	10 Gt	8 Gt	8 Gt	7 Gt	6 Gt	4 Gt	4 Gt

3. Reduce the error in global measurement of *sea surface temperature*. Metric – estimated maximum monthly mean error in 5° regions (degrees Celsius).

2002	2003	2004	2005	2006	2007	2008	2009	2010
1.3 C	1.3 C	1.0 C	0.8 C	0.6 C	0.5 C	0.4 C	0.3 C	0.3 C

The short articles presented in this chapter describe the products listed in Table 2.1 and are the result of ocean projects funded, in whole or in part, by NOAA's Office of Climate Observation.

Table 2.1. Products

2.1 Sea level to identify changes resulting from climate variability – *Laury Miller, Bruce Douglas, Robert Cheney*

2.2 Ocean carbon content every ten years and the air-sea exchange seasonally – *Rik Wanninkhof, Richard Feely*

2.3 Sea surface temperature to identify significant patterns of climate variability – *Richard Reynolds*

2.4 Surface currents to identify significant patterns of climate variability – *Peter Niiler, Nikolai Maximenko*

2.5 Sea surface pressure to identify changes in forcing functions driving ocean conditions and atmospheric conditions – *Ed Harrison*

2.6 Air-sea exchange of heat, fresh water, momentum to identify changes in forcing functions driving ocean conditions and atmospheric conditions – *Bob Weller*

2.7 El Niño and heat content variations – *Michael McPhaden*

2.1 GLOBAL SEA LEVEL RISE: THE PAST DECADE VS. THE PAST 100 YEARS

by Laury Miller[1], Bruce C. Douglas[2], Robert Cheney[1]

[1]Laboratory for Satellite Altimetry, NOAA/NESDIS, Silver Spring, MD
[2]Florida International University, Miami, FL

While "Climate Change" may seem a vague concept to some individuals, to the 100 million people who live within 1 meter of present day sea level, global sea level rise is anything but an abstraction, especially considering that sea level rose about 20 centimeters over the past century. How and why this change occurred, and whether the rate of global sea level rise (GSLR) is accelerating are questions of great interest to those directly threatened, to the governments and international bodies which ultimately will be called upon to deal with this issue, and to the public at large. And yet, it is important to note that the rate and causes of sea level rise are currently the subjects of intense scientific controversy.

The main elements of this controversy are documented in the climate assessment reports published periodically by the Intergovernmental Panel on Climate Change (IPCC). At the time of the second IPCC report in 1995, there seemed to be little dispute regarding GSLR. Most tide gauge estimates ranged between 1.5 to 2.0 mm/year. Most of this rise was thought to be due to ocean warming causing the volume of the oceans to increase, with the rest due to the melting of continental ice, primarily in Greenland and Antarctica, causing the mass of the oceans to increase. However, by the time of the 2001 IPCC assessment, this consensus view had collapsed. New and better estimates of ocean warming had reduced the volume component of GSLR to about 0.5 mm/year and the mass component was thought to be even smaller. This left a large unexplained gap between direct and indirect estimates of GSLR that has come to be known as the "attribution problem". Either the gauge estimates are too high, or one (or both) of the mass and volume change estimates is too low.

Two recent studies offer opposing solutions to this dilemma. Cabanes et al. (2001) argue that tide gauge measured rates of GSLR are 2 to 3 times too high because the gauges happen to be located in areas of abnormally high ocean warming. They arrive at this result by comparing gauge measured sea level trends with those obtained from objectively interpolated temperature and salinity measurements. They conclude that the true rate of GSLR is actually 0.5 to 1.0 mm/year, due mostly to ocean warming. This solution provides a way out of the attribution problem, but implies a huge acceleration of GSLR in the 1990's if recent satellite altimetric estimates of ~2.5 mm/year are to be believed.

Alternately, Antonov et al. (2002) suggest that the problem may be solved by revising upward the mass component estimate. They show that the oceans are freshening at a rate equivalent to the addition of 1.4 mm/year of fresh water, approximately the amount needed to bring the mass plus volume rate close to the tide gauge measured rate. However, this solution assumes a continental ice source rather than floating ice, a key point that they are unable to demonstrate.

In the latest chapter of this debate, Miller and Douglas (2004) have re-examined the tide gauge bias issue on a regional as well as local scale. They identify large ocean areas that are either bounded by or adjacent to several gauge sites exhibiting similar trends and variability. For those areas they compare average gauge measured sea level trends with the trends computed from actual rather than interpolated measurements of temperature and salinity.

Figure 1 presents an example of their analysis for a region in the Eastern Pacific bounded by the gauges at Honolulu, San Francisco, San Diego, and Balboa, Panama. All four gauge records

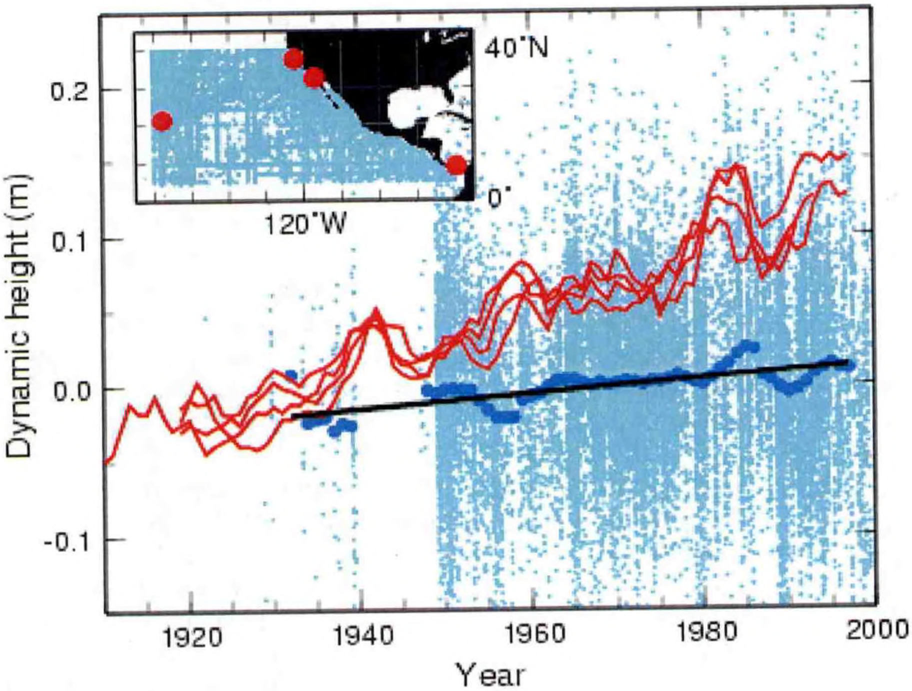

Figure 1. Eastern Pacific hydrographic observations of temperature and salinity converted into 1000 m dynamic height anomalies (light blue), their 5 year running means (dark blue) and linear regression (black) compared with 5 year running mean relative sea levels from tide gauge observations at San Francisco, San Diego, Honolulu, and Balboa (red). Tide gauge series have been vertically offset to coincide with earliest dynamic heights. Map inset shows tide gauge locations in red and observed dynamic height locations in light blue (Miller and Douglas, 2004).

show sea-level trends of about 2 mm/year during the 20th century, despite the fact that the gauge sites are widely separated and, thus, subject to different vertical land motions and local hydrographic conditions. However, the ~19,000 hydrographic stations from the ocean interior show that only about 0.5 mm/year of sea-level rise can be accounted for by temperature and salinity changes.

Limiting this analysis to small areas immediately adjacent to the gauge sites gives essentially the same results. Locally, only a fraction of the gauge-measured sea level rise is the result of hydrographic (volume) changes. One conclusion of this study is that the gauges are not situated in regions of abnormally high warming. Thus, gauge estimates of 1.5 to 2.0 mm/year for 20th century GSLR are probably correct. Another, perhaps more surprising conclusion is that the melting of continental ice sheets and glaciers plays a more important role in GSLR than ocean warming.

While the debate over 20th century GSLR will no doubt continue, the question of whether the present rate of GSLR differs from the 20th century rate is beginning to attract attention because of the recent availability of satellite altimeter observations of sea level rise. Unlike tide gauge data, which are geographically sparse and require a long (50 to 75 year) averaging interval to filter out interdecadal variability, satellite altimeter data have the advantage of dense, global coverage and are beginning to offer, in a relatively short time, new insights into the GSLR problem.

For example, Figure 2 presents global sea level time series from the six satellite altimeters that operated from 1992 onward. Each record trends upward, with a group average rate of about 2.4 mm/year. The TOPEX/Jason series, considered the most accurate of the group, give a rate of about 2.8 mm/year. Whether either of these values reflects a true acceleration with respect to the 20th century tide gauge-derived rate or is simply evidence of decadal variability is unclear at this time. The 1990's were a period of exceptional warming events in the ocean. In addition to intense ENSO variability in the tropics, there is evidence from both altimeter and *in situ* hydrographic measurements of strong regional warming at mid-latitudes in the southern hemisphere which may account for as much as 1.8 mm/year of global rise between 1993 and 2002 (Willis et al., 2004). It is thought that 15 to 20 years of continuous altimeter measurements may be needed to obtain a stable value for the current rate of GSLR. They also highlight the importance of in-situ observing systems, like the NOAA-supported tide gauge network and ARGO profiling array, to validate the altimeter results and provide information on the internal structure of the oceans essential to understanding the processes governing GSLR.

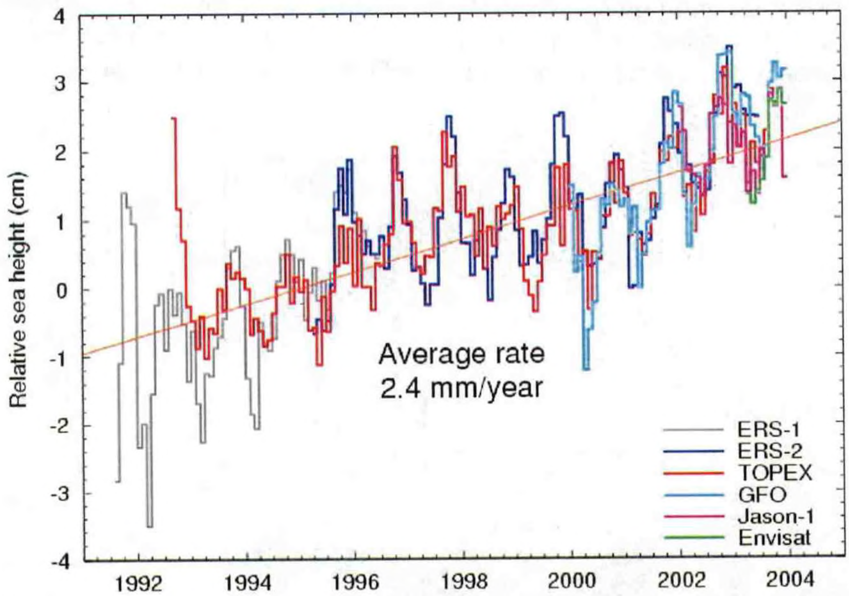

Figure 2. Global sea level rise determined over the past decade by TOPEX/Poseidon, Jason, Geosat Follow-on, ERS-1 and 2 satellite altimeters. After removing respective biases, the general trend is approximately 2.4 mm/year.

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2.2 OBSERVING THE GLOBAL OCEANIC CARBON CYCLE

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The Global Carbon Cycle: Inventories, Sources and Sinks

Carbon dioxide is one of the major greenhouse gases, contributing about 60% of the total change in radiative forcing due to human perturbations (Houghton et al. IPCC, 2001). The total emission due to fossil fuel use and cement production averaged about 6.3 ± 0.4 Pg C per year in the 1990s (1 Pg C = 1 peta gram carbon = 10^{15} gram = 1 gigaton). Although this annual CO_2 release has an appreciable effect on the earth radiation balance, it is a small fraction of the reservoir sizes comprising less than 1% of the CO_2 in the atmosphere, 0.3% of the labile terrestrial carbon pool; and 0.02% of the total carbon content of the ocean. The annual addition is also much smaller than the natural exchanges between the reservoirs comprising less than 10% of the natural annual exchanges between ocean and atmosphere, and between the terrestrial biosphere and atmosphere. The reservoir sizes and exchanges between reservoirs on an annual basis are shown in Figure 1.

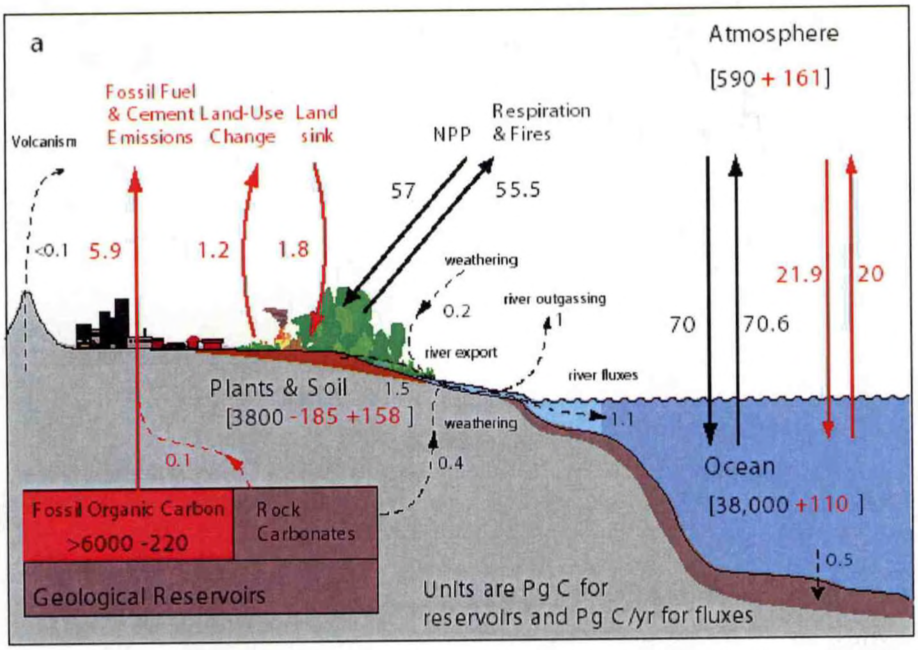

Figure 1. Cartoon of fluxes (arrows) and inventories (number in boxes) of the labile components of the global carbon system for the 1980s. The red arrows are the perturbation fluxes resulting from emissions of anthropogenic CO_2. From Sabine et al. (2003).

Although the anthropogenic perturbation seems small compared to the natural cycling of carbon between ocean, atmosphere and terrestrial systems, models and observations suggest that the increasing CO_2 levels in the atmosphere are causing an increase in global temperature (Fig. 2). While the evidence is rapidly growing for a causal relationship, it has not been unambiguously established yet. The perturbation is also showing effects on terrestrial and oceanic ecosystems.

Based on carbon and carbon isotopic records in ice cores and tree rings we know that the atmospheric CO_2 levels remained very constant at 280 ± 5 parts per million (ppm) for the millennium prior to the industrial revolution. The remarkable constancy of atmospheric CO_2

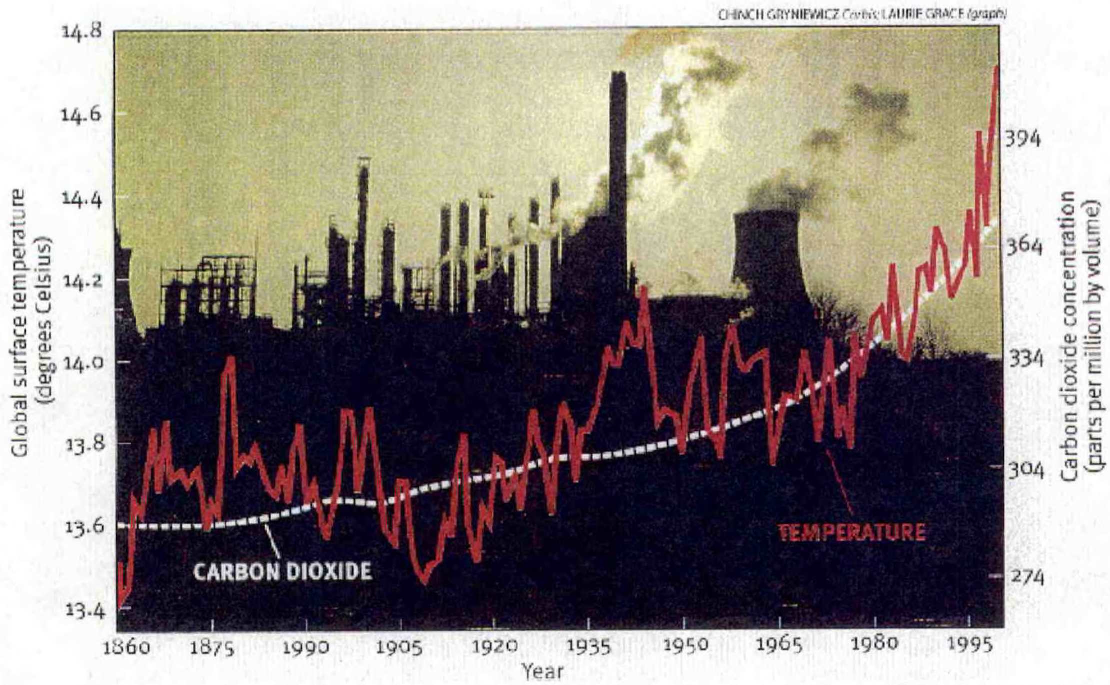

Figure 2. Trends of atmospheric carbon dioxide levels (white dashed line, right axis) and global surface temperature (red dashed line).

despite large exchanges between the major reservoirs suggests a well-balanced global carbon cycle prior to the Industrial Revolution. However, we also know from the paleo-records that atmospheric CO_2 levels varied in proportion to global temperatures between ice ages and warmer periods. Therefore, it seems quite possible that the current dramatic atmospheric CO_2 level rise will have a significant effect on climate and ecosystems. Moreover, although we have good paleo-records of climate in low CO_2 environments we have very limited information of how the earth responds to the current unprecedented high CO_2 levels and anticipated increases in the next century.

Our current knowledge of the fate of the anthropogenic CO_2 released to the atmosphere is based on models; atmospheric observations of CO_2, carbon isotopes and small decreases in oxygen levels; terrestrial measurement of biomass inventories and primary productivity; and oceanic measurements of CO_2 inventories and fluxes between air and ocean. Less than a decade ago there were significant discrepancies between estimates leading to the popular notion of the "missing carbon sink". There now is broad agreement that the "missing sink" is uptake by the terrestrial ecosystems based on disparate methods as summarized in Table 1.

As the table indicates, our level of confidence in different observations ranges from a general good knowledge of the annual changes in some reservoirs, to highly uncertain estimates in others. Annual releases due to fossil fuel burning and cement production, and annual atmospheric CO_2 increases are the most constrained. Decadal changes in the ocean carbon inventory have recently been established with reasonable confidence. Changes in the terrestrial biosphere have been more difficult to pinpoint. From a variety of observations we now have a reasonable estimate of the partitioning of the fossil fuel carbon between reservoirs over the last two centuries with roughly 50% ending up in the ocean. The terrestrial systems released CO_2 over this same period. Over the last two decades, however, the terrestrial systems appear to have taken up CO_2 but the

Table 1. Global inventory of anthropogenic CO_2 for the past 200 and 20 years

CO_2 Sources	1800-1994 [Pg C][a]		1980-1999 [Pg C][g]
Constrained sources and sinks			
(1) Emissions from fossil fuel and cement production	244 [(b)]	± 20	117±5
(2) Storage in the atmosphere	-165 [(c)]	± 4	-65±1
(3) Uptake and storage in the ocean	-118 [(d)]	± 19	-37±8
Inferred net terrestrial balance			
(4) Net terrestrial balance = [-(1)-(2)-(3)]	39	± 28	-15±9
Terrestrial balance			
(5) Emissions from land use change	100 to 180[(e)]		24±12
(6) Terrestrial biosphere sink = [-(1)-(2)-(3)]-(5)	-61 to -141		-39±18

From Sabine et al., 2004

magnitude, cause, and particularly the longevity of this sink remains in great doubt. Significant efforts, such as those proposed in the North American Carbon Plan (NACP), are underway to directly determine CO_2 sources and sinks in the terrestrial system. However, in the foreseeable future the best approach for constraining the net terrestrial flux will be from the difference between atmospheric and oceanic observations and model calculations.

The need for an integrated investigation of the carbon cycle has been well articulated in the US Carbon Cycle Science Plan (Sarmiento and Wofsy, 1999). Through efforts of the Interagency Carbon Working Group and the Scientific Advisory Committee, science and implementation plans have been developed for subcomponents of the program including the NACP Science Plan, the NACP Implementation Strategy, the Ocean Carbon and Climate Change Implementation Strategy, and the Large Scale Carbon Observing Plan (LSCOP) (Bender et al., 2001). The LSCOP plan in particular focuses on the implementation and justification for sustained ocean observations. All of the plans address the central tenets of the Carbon Cycle Science Plan, which focuses on the "excess carbon", that is the carbon produced by fossil fuel burning and other activities of mankind releasing CO_2 such as land use change:

- Where has the excess carbon gone to over the last two centuries?

- Where will the excess carbon go to in the future?
- What processes are involved in sequestration of the excess carbon?
- Can the future sinks be managed and increased?

Because of the sensitivity of the global economy to terrestrial and oceanic ecosystems, and regional climate, the issue of carbon accounting transgresses the usual stakeholders of scientific information. Like emissions of pollutants, carbon emissions now have an economic value. The number \$40 per metric ton carbon sequestered is often used in estimates. Improved constraints on the carbon sources and sinks can now be directly translated into a currency equivalent. For instance, the global uptake of carbon by the ocean of about 1.6 Pg C yr^{-1} (Table 2) translates into a \$64 billion service to the global economy. As shown in Table 2, the uncertainty in the ocean sink is significant translating into an uncertainty in the value of this commodity. Knowledge of the future sink strength of the ocean is thus critical from scientific and economic perspective.

Table 2. Summary of estimated global CO_2 fluxes using different gas transfer velocities but the same $\leq pCO_2$ climatology.

Parameterization	Uptake (Pg C/yr)
Wanninkhof, 1992	-1.6
Wanninkhof and McGillis, 1999	-1.9
Nightingale, 2000	-1.2
Liss and Merlivat, 1983	-1.0

All these values were obtained using the $\leq pCO_2$ climatology of Takahashi et al. (2002) and 41-year climatological 6-hour winds from the NCAR/NCEP reanalysis project. The divergence of values illustrates that besides determining seasonal $\leq pCO_2$ fields the gas transfer velocity needs to be better constrained.

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The Sustained Ocean Component of the Carbon Cycle Science Plan

The oceanic carbon-observing program addresses two important subcomponents of the determination of the fate of the excess CO_2 in the ocean:

- Determining oceanic carbon inventories and attributing the cause of the variations in inventories over time
- Quantifying the air-sea CO_2 fluxes and creating of seasonal flux maps

Ocean inventories

As a result of the measurements during the global CO_2 survey in the 1990s and improved methods of quantifying the anthropogenic CO_2 signal above the large natural background, we now have the first measurement based inventory of anthropogenic CO_2 in the ocean. The excess CO_2 has been gridded at 1 degree spacing and 33 levels so it can be compared directly with model outputs. The observations show that surface waters are in near equilibrium with the atmospheric rise with a perturbation of the total carbon content of about 3% (60 ≤mol kg^{-1} out of a natural background of 2000 ≤mol kg^{-1}). The anthropogenic inventory decreases rapidly with depth for most parts of the ocean. Characteristic cross sections for the Atlantic, Indian and Pacific basins are shown in Figure 3. The distribution closely follows the known ventilation pathways of the ocean with deep penetration in the North Atlantic and storage of much of the carbon in the mid-latitude convergence zones. The total uptake over the past 200 years shown in Table 1 validates the model estimates. The total inventory is similar to models but the regional inventory is quite different suggesting that most of the models do not adequately capture the processes responsible for uptake at regional scales.

Decadal inventory changes

The measurement based total inventory of anthropogenic carbon in the ocean is a critical constraint for models and for our understanding of the role of the ocean in the sequestration of excess carbon. However, information on shorter timescales is essential to determine any feedbacks of oceanic carbon sequestration due to climate change, and to determine the role of natural variability on the oceanic carbon system. Therefore the COSP has started, in collaboration with NSF and NASA, a repeat hydrography program. The main objective of the repeat hydrography component of the sustained ocean observing system for climate is to document long-term trends in carbon storage and transport in the global oceans. This program will provide composite global ocean observing system large-scale observations that include: 1) detailed basin-wide observations of CO_2, hydrography, and tracer measurements; and 2) data delivery and management. This repeat hydrography program will provide the critical and timely information needed for climate research and assessments, as well as long-term, climate quality, global data sets.

The first three cruises of the repeat hydrography program were completed in 2003 focusing on the North Atlantic to provide a constraint for the NACP program. The initial highlights are that the ventilation pattern/circulation in the North Atlantic thermocline has changed based on a significant change in oxygen content (Fig. 4). Also, we have been able to unambiguously determine an increase in total carbon content in the upper ocean over 6 to 10 years suggesting that uptake of anthropogenic CO_2 continues unabated and that we can detect anthropogenic carbon increase in the ocean on decadal timescales. (Fig. 5)

Atmosphere-Ocean CO_2 Fluxes

Background

Changes in carbon inventory are the most robust means of assessing sources and sinks but for the oceans these methods are limited to changes over decadal timescales. On average the total dissolved inorganic carbon content (DIC) of the surface ocean increases by about 1 ≤mol kg^{-1} per year or about 0.05% over the background. While the accuracy of DIC measurements is about 2 ≤mol kg^{-1} making detection of the anthropogenic signal in principle possible on shorter time

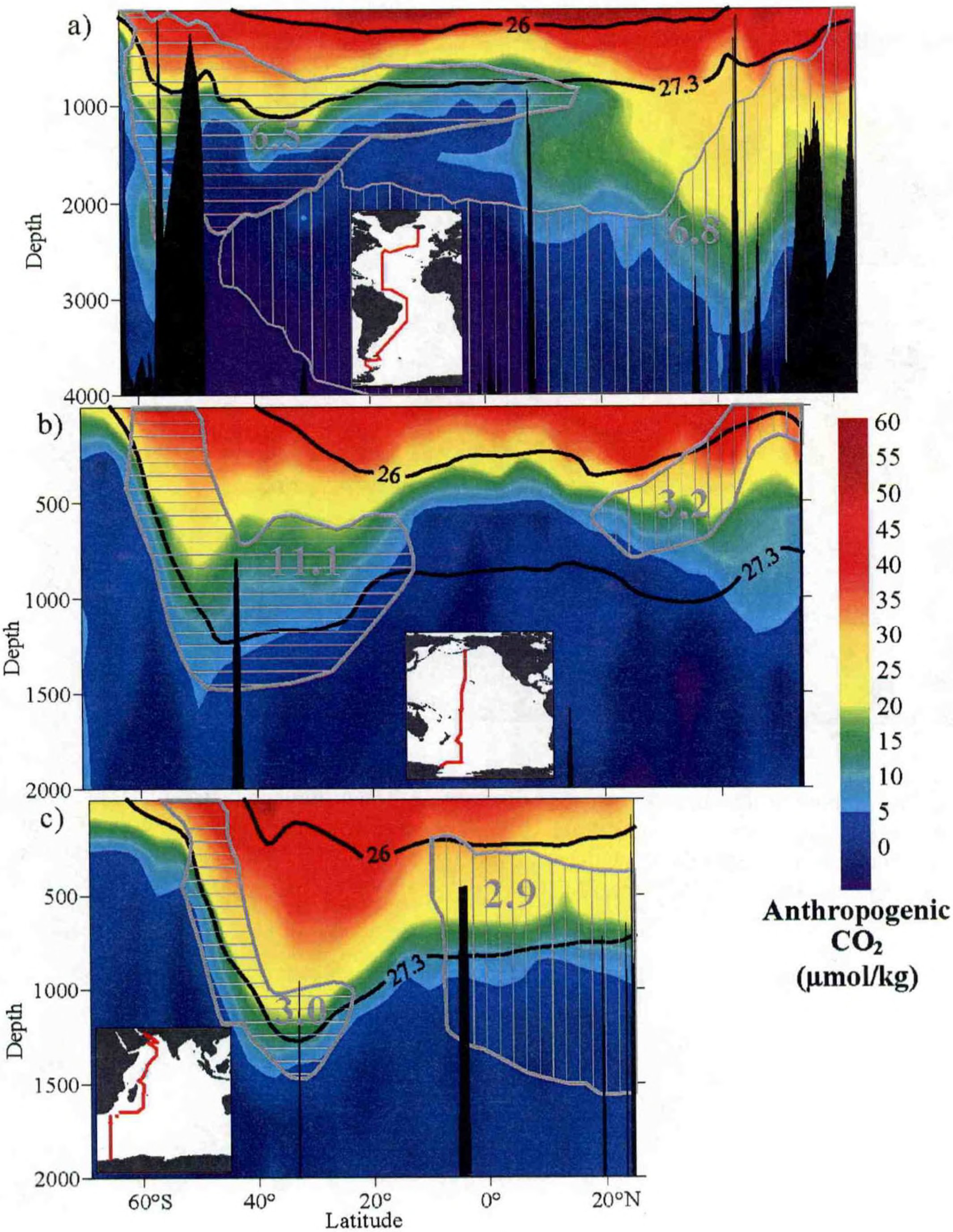

Figure 3. Representative sections of anthropogenic CO_2 ($\leq$mol kg^{-1}) from the Atlantic (a), Pacific (b) and Indian (c) Oceans. Grey hatched regions and numbers indicate amount of anthropogenic carbon stored (Pg C) in the intermediate water masses. The two heavy lines on each section give the characteristic potential density contours for the near surface water and intermediate water. Much of the penetration of anthropogenic carbon into the ocean follow isopycnal surfaces. From Sabine et al. (2004).

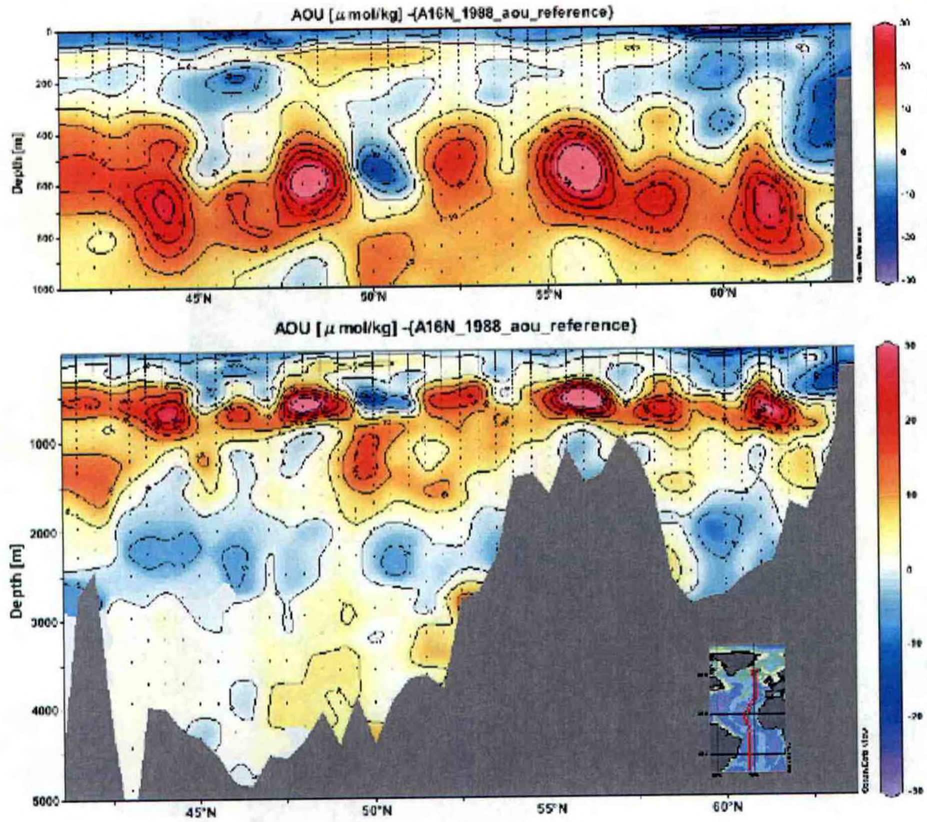

Figure 4. Distribution of the apparent oxygen utilization (AOU) difference between 2003 – 1988 (≤mol kg^{-1}) in the North Atlantic Ocean along 20°W. The large differences between 400 – 800 m in the water column corresponds to changes in oxygen content of over 20% at these depths (preliminary data provided by J. Bullister, PMEL).

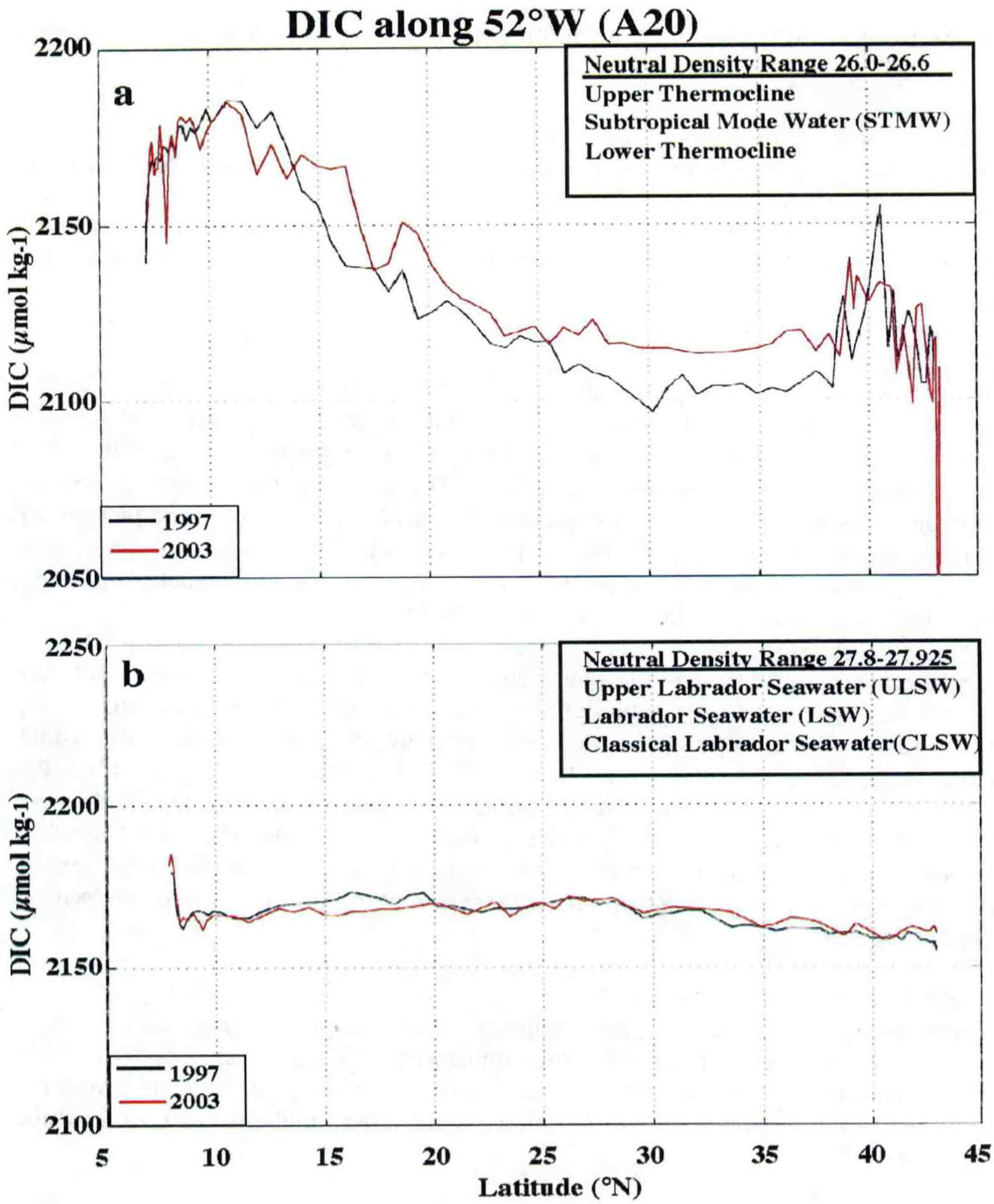

Figure 5. Comparison of the total dissolved inorganic carbon concentrations, DIC concentrations a) near the surface (in the density range of 26.0 – 26.6); and b) for the 27.80 – 27.93 isopycnals for 1997 and 2003 in the western North Atlantic. (based on preliminary data from M. Roberts-Lamb, PMEL)

scales, the surface ocean DIC changes by 20 to 50 ≤mol kg^{-1} seasonally masking changes less than 5 to 10 ≤mol kg^{-1}.

To assess changes in exchanges between reservoirs on sub-decadal timescale we have to determine the fluxes. The fluxes can be determined from measuring the partial pressure differences of CO_2 between surface ocean and lower atmosphere, ≤pCO_2, and a quantity referred to as the gas transfer velocity that is related to physical forcing and often parameterized with wind speed. Thus, if ≤pCO_2 fields can be determined and used in combination with wind fields, regional fluxes can be obtained.

Creation of flux maps

This approach has been applied successfully using a global climatology of ≤pCO_2 painstakingly developed based on 40-years of ≤pCO_2 data from many investigators (Takahashi et al., 2002). Uptakes based on this climatology range from 1 to 1.9 Pg C yr^{-1} depending on the relationship between gas exchange velocity and wind speed (Table 2). This approach will be used to quantify regional fluxes on a seasonal timescale. The implementation will require a significant increase in ≤pCO_2 observations, development of methods to interpolate ≤pCO_2 in time and space, and improvement of algorithms to quantify the gas transfer from wind or other relevant parameters, such as surface roughness, that can be directly observed from remote sensing.

Following a recommendation in the LSCOP plan a surface ocean flux observing system is being put in place with autonomous instrumentation on volunteer observing ships VOS, research ships, and buoys. The LSCOP plan lays out an observing strategy based on scaling analysis that involves sampling of the ocean roughly at 10 degree spacing and monthly intervals. By coordinating efforts with international and national partners this goal will be attainable in the next decade for the North Atlantic, North Pacific and Equatorial Pacific, particularly if we develop methods to increase time and space scales of observation through use of remotely sensed observations. The scheme of implementing such a system utilizing *in situ* and remotely sensed data is outlined in Figure 6.

Determining and attributing changes in ΔpCO_2

The approach of utilizing remote sensing, algorithms of ≤pCO_2 and gas exchange with remotely sensed products has been utilized in test beds in the Equatorial Pacific and Caribbean Sea. Flux map products for these regions are shown in Figures 7 and 8. For the Equatorial Pacific work the algorithms are used in a retrospective fashion to determine the large variations in air-sea flux due to the ENSO Cycle.

Limited time series records of surface water pCO_2 levels have shown that for much of the ocean the surface water pCO_2 rises roughly at the same rate as the atmospheric increase implying that the global air-sea flux remains the same. However, changes in the rate of increase are a sensitive indicator of changes in the uptake of the ocean and perturbations in the biogeochemical cycles. Using a historical database of ≤pCO_2 for the Equatorial Pacific Takahashi et al. (2003) determined significantly slower increases in the 80s than in the 90s that were attributed to a climatic re-organization in the North and Equatorial Pacific referred to as the Pacific Decadal Oscillation (PDO).

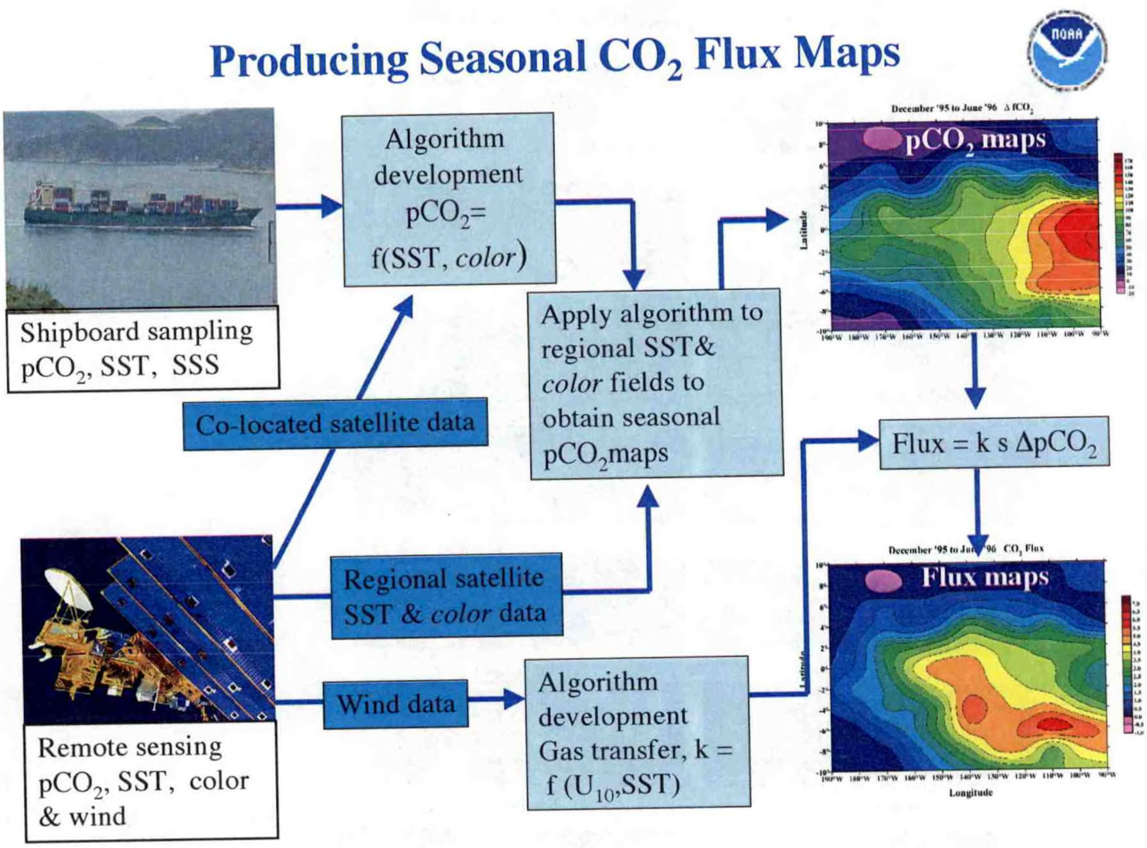

Figure 6. Flow diagram of data and procedures to produce pCO_2 flux maps.

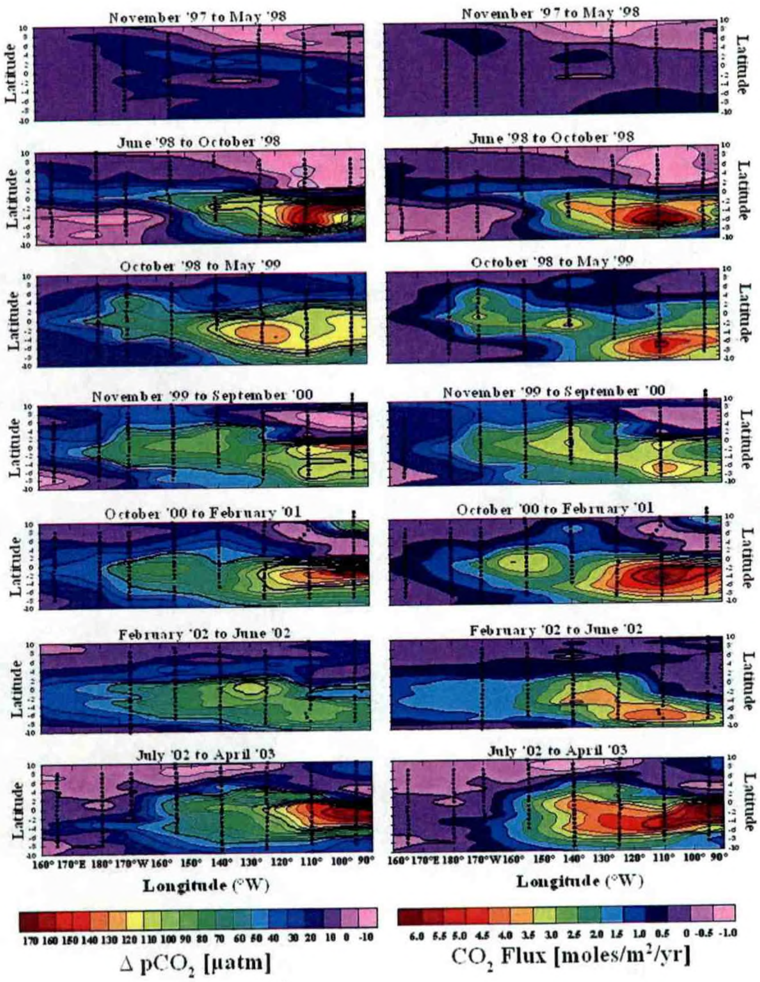

Figure 7. Maps of ≤pCO_2 (left) and CO_2 fluxes in moles m^{-2} yr^{-1} in the equatorial Pacific from November 1997 thru April 2003 based on *in situ* observations and remotely sensed winds and sea surface temperature. The higher pCO_2 values and normal winds in the eastern Pacific during the 2002-03 El Niño event led to unusually high sea-to-air CO_2 fluxes for an ENSO event. After Feely et al. (2002).

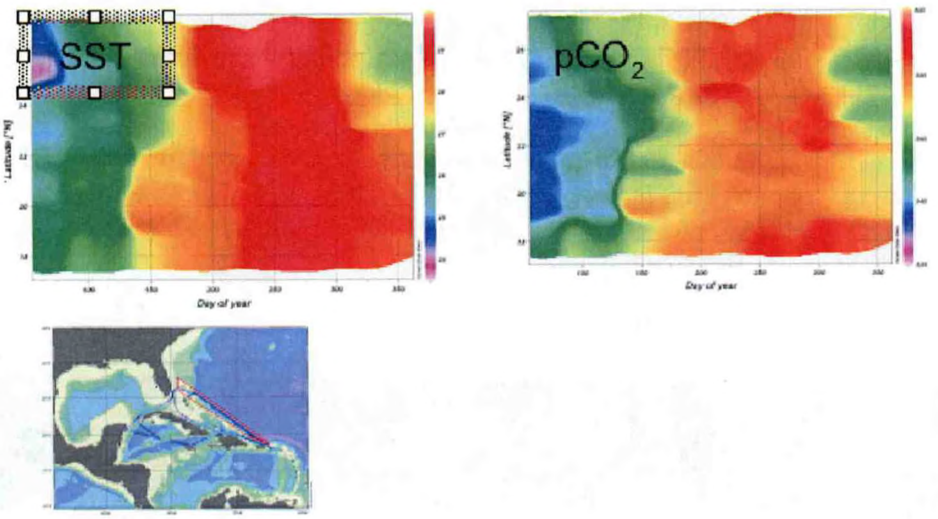

Figure 8. Production of pCO_2 maps in the Caribbean. Empirical algorithms are being developed with parameters that are measured at higher density/frequency (e.g., through remote sensing). The close correspondence of temperature (left panel) trends and pCO_2 (right panel) along the cruise track (bottom) facilitates robust algorithms to extrapolate the pCO_2 to regional scales. From Olsen et al. (2004).

Future plans and milestones

The observational efforts to detect changes in water column inventories and to attribute the causes, and the development of regional CO_2 flux maps are part of well documented and justified integrated carbon plans. The CO_2/CLIVAR Repeat Hydrography Program has a series of cruises planned for the next decade that will yield sequential basin wide inventory changes for the Atlantic, Pacific, Southern and Indian oceans. The cruise sequence is listed in Table 3. NOAA/COSP has the lead on the cruises for A16S, A16N, P16N, P18 and I8. NOAA participants will perform DIC and pCO_2 measurements on all cruises. Operational Milestones are provided in Table 4.

Table 3. Schedule of the repeat hydrography transects

Schedule of US CO2/CLIVAR Hydrography Lines (as of 4/25/03)

Dates	Cruise	Days	Ports	Year	Contact/Chief Scientist
					overall coordinator: Jim Swift, SIO
6/19/03-7/10/03	A16N, leg 1	22	Reykjavik-Madeira	1	Bullister, PMEL
7/15/03-8/11/03	A16N, leg 2	28	Madeira - Natal, Brazil	1	Bullister, PMEL
9/15/03-10/13/03	A20	29	WHOI - Port Of Spain	1	Toole, WHOI
10/16/03-11/07/03	A22	21	Port Of Spain - WHOI	1	Joyce, WHOI
summer 2004	P2 (two legs)	66	San Diego-Honolulu-Yokohama	2	Swift/Robbins, SIO
austral summer 05	A16S	44	Montevideo-Fortaleza Brazil	3	
austral summer 05	P16S	40	Wellington-Tahiti	3	
2006	P16N	57	Tahiti-Alaska	4	
austral summer 07	S4P/P16S	25.5	Wellington-Perth	5	
austral summer 07		25.5	Wellington-Perth	5	
2008	P18	32	Punta Arenas-Easter Island	6	
2008		35	Easter Island- San Diego	6	
2008	I6S	42	Cape Town	6	
2009	I7N	47	Port Louis/Muscat	7	future planning
2009	I8S	38	Perth- Perth	7	future planning
2009	I9N	34	Perth- Calcutta	7	future planning
2010	I5	43	Perth - Durban	8	future planning
2010	A13.5	62	Abidjan-Cape Town	8	future planning
2011	A5	30	Tenerife-Miami	9	future planning
2011	A21/S04A	42	Punta Arenas-Cape Town	9	future planning
2012	A10	29	Rio de Janeiro-Cape Town	10	future planning
2012	A20/A22	29	Woods Hole-Port of Spain-Woods Hole	10	future planning

Years 1-6 are funded.

Table 4. Operational milestones of the CO_2/CLIVAR Repeat Hydrography Program

Summer 2003	Organize and complete the A16N cruise in the North Atlantic and provide leadership (chief scientist), CTD, oxygen, nutrient, total carbon and pCO_2 analysis
Winter 2003/2004	Provide final CO_2, oxygen, CTD data to the repeat hydrography data center at Scripps
Summer 2004	Analyze total inorganic carbon on the P2 cruise
Winter 2004/2005	Provide final total CO_2 data to the repeat hydrography data center at Scripps
Winter 2004/2005	Organize and complete the A16N cruise in the North Atlantic and provide leadership (chief scientist), CTD, oxygen, nutrient, total carbon and pCO_2 analysis
Winter 2004/2005	Analyze total inorganic carbon on the P16S cruise
Spring 2006	Organize and complete the P16N cruise in the Pacific and provide leadership (chief scientist), CTD, oxygen, nutrient, total carbon and pCO_2 analysis

The COSP CO_2 flux map effort focuses on the $\leq pCO_2$ observations needed to create the seasonal maps. The initial lines in the North Atlantic are shown in Figure 9. The implementation schedule is presented in Table 5 with the italicized text that will be proposed in FY 05. The effort is starting to incorporate time series on moorings that are critical to determine the higher frequency (< 1 month) temporal variability. Particularly in the coastal oceans and Equatorial Pacific large changes can occur on weekly timescales. The exact balance and number of fixed pCO_2 observing sites vs. ship-based (moving) observing platform has not been firmly established. Analysis of the results of the initial surface pCO_2 observing system will be used to optimize spacing, frequency, and mix of observing methods. Optimizing the observing system requires inclusion of measurements of biogeochemical and physical parameters that influence pCO_2 as well in order to investigate extrapolation routines. The added benefit will be that these parameters yield mechanistic information that can be used in prognostic models and interpolation schemes utilizing satellite data. An end-to-end iterative effort starting from observations to interpretation and analysis feeding into improved observing system design and assessing the state of the ocean carbon cycle is critical at this point and attainable within national and international frameworks.

National and International Linkages

The COSP carbon program is an integral part of national and international programs in carbon cycle research. NOAA's contribution is unique as it is the only program that has the sustained observational effort necessary to constrain sources and sinks and provide input for prognostic models to predict future trends. The international connection for the repeat hydrography effort is through WCRP/CLIVAR and the IGBP/IMBER programs. The former is focused on the physical aspects of climate variability while the latter is geared to the ecological and biogeochemical components. The flux map effort is connected to the SOLAS effort theme 3: Air-Sea Flux of CO_2 and Other Long-Lived Radiatively-Active Gases. International coordination for both aspects of CO_2 COSP will occur through the International Ocean Carbon Co-ordination Project (IOCCP). International ties between the ocean carbon programs and the atmospheric, terrestrial, and human dimension carbon cycle research are provided through the IGBP/WCRP/IHDP Global Carbon Project (GCP).

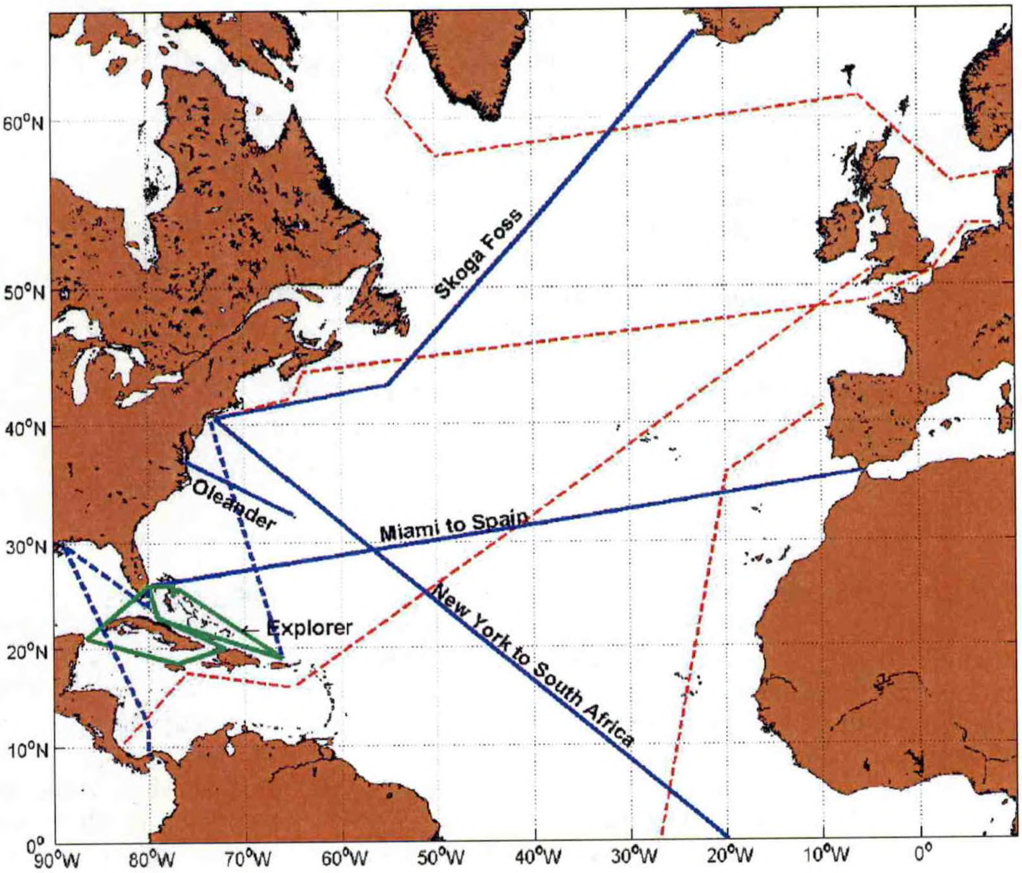

Figure 9. VOS pCO_2 lines in the North Atlantic. The blue and green lines are those funded by COSP and are part of the GOOS XBT observing network. The dashed lines are the routes outfitted by our European partners as part of the proposed European Carbo-Oceans project.

Table 5. Operational milestones pCO_2 project

Fall 2003	Complete installation of pCO_2 system on Skogafoss (Iceland-Norfolk) line AX2
Spring 2004	Complete installation of pCO_2 system and TSG system on Columbus Waikato (Long Beach - New Zealand) line PX13
Summer 2004	Complete installation of pCO_2 system on Oleander (Bermuda-Norfolk)
Winter 2004/2005	Complete standardized data reduction and quality control scheme for all ships Start submitted data to LDEO on routine basis for contextual QC
Spring 2005	Complete installation of pCO_2 system on Sealand Express (Iceland-Norfolk)
Fall 2005	Complete installation of pCO_2 system on 24°N line (Miami-Gibraltar)
Winter 2005/2006	Install system on VOS ship in North Pacific
Spring 2006	Install system on NOAA survey ships in Gulf of Mexico (Gunther) and Bering Sea (Rainer)

Data for all projects will be distributed to the community at large through a Live Access Server within two years after collecting the data.

At a national level the CO_2 COSP effort is part of the US Carbon Cycle Science Plan. Its critical role in the overall US ocean science effort is outlined in the multi-agency implementation plan, the Ocean Carbon and Climate Change plan (Doney, 2004). Information about the programs linked to, or which are a part of, COSP-CO_2 can be found in Table 6.

Table 6. Web sites of the CO_2/COSP program and program partners

Data sites for pCO_2 data from ships:	
AOML	http://www.aoml.noaa.gov/ocd/gcc
PMEL	http://www.pmel.noaa.gov/uwpco2/
LDEO	http://www.ldeo.columbia.edu/res/pi/CO2/
Program sites:	
CLIVAR	Climate Variability and Predictability: www.clivar.org
SOLAS	Surface-Ocean Lower Atmosphere Study: www.uea.ac.uk/env/solas/
IOCCP	International Ocean Carbon Coordination Project: www.ioc.unesco.org/ioccp
IGBP	International Geosphere-Biosphere Project: www.igbp.kva.se/cgi-bin/php/frameset.php
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research: http://www.igbp.kva.se/cgibin/php/
WCRP	World Climate Research Program: www.wmo.ch/web/wcrp/wcrp-home.html
GCP	Global Carbon Project: http://www.globalcarbonproject.org/

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2.3 IN SITU DATA REQUIREMENTS FOR RECENT SITU SEA SURFACE TEMPERATURE ANALYSES

by Richard W. Reynolds, National Climatic Data Center, Asheville, North Carolina

Sea surface temperatures (SST) are an important indicator of the state of the earth's climate system as well as a key variable in the coupling between the atmosphere and the ocean. Accurate knowledge of SST is essential for climate monitoring, prediction and research. It is also a key surface boundary condition for numerical weather prediction and for other atmospheric simulations using atmospheric general circulation models. SST is also important in gas exchange between the ocean and atmosphere, including the air-sea fluxes of carbon.

The longest data set of SST observations is based on observations made from ships. These observations include measurements of SST alone as well as temperature profiles with depth. However, the observations of SST alone dominate the data sets and account for more than 90% of the observations. These observations are typically made by measuring the temperature in buckets of seawater collected from the ship or by the ship engine intake temperature gauge. Typical RMS errors from ships are larger than 1°C and may have daytime biases of a few tenths of a degree C (Kent et al., 1999). Although the earliest observations were taken in the first half of the 19th century, sufficient observations to produce a global SST analysis were not available until about 1870.

SST observations from drifting and moored buoys began to be plentiful in the late 1970s. These observations are typically made by thermistor or hull contact sensor and usually relayed in real-time by satellites. Biases in the SSTs from buoys can occur in some designs. For example, significant diurnal heating of the hull may occur under low wind conditions with some hull configurations. Although the accuracy of the buoy SSTs varies, it is usually better than 0.5°C, which is better than ship SSTs. In addition, typical depths of the observations are roughly 0.5 m rather than the 1 m and deeper depths from ships.

In late 1981, accurate SST retrievals became available from the Advanced Very High Resolution Radiometer (AVHRR) instrument, which has been carried on many NOAA polar orbiting satellites. These retrievals improved the data coverage over that from *in situ* observations alone. The satellite retrievals allowed better resolution of small-scale features such as Gulf Stream eddies. In addition, especially in the Southern Hemisphere, SSTs could now be observed on a regular basis in many locations. Because the AVHRR cannot retrieve SSTs in cloud-covered regions, the most important problem in retrieving SST is to eliminate clouds. The cloud clearing algorithms are different during the day and the night because the AVHRR visible channels can only be used during the day. After clouds have been eliminated, the SST algorithm is derived to minimize the effects of atmospheric water vapor. The satellite SST retrieval algorithms are "tuned" by regression against quality-controlled buoy data (McClain et al., 1985). This procedure converts the satellite measurement of the "skin" SST (roughly a micron in depth) to a buoy "bulk" SST (roughly 0.5 m).

Future improvements in the SST observing system will primarily be due to new satellite data. In roughly the last decade, new infrared sensors, such as the Moderate Resolution Imaging Spectroradiometer (MODIS), have become available on other satellites. Beginning in December 1997, SSTs began to be available on the Tropical Rainfall Measuring Mission (TRMM) satellite. Additional microwave instruments have become available in late 2002 and more are planned. SSTs from microwave instruments have lower spatial resolution than from IR instruments.

However, microwave instruments are able to retrieve SSTs in cloud-covered regions where IR instruments cannot.

The purpose of this discussion is to examine the accuracy of climate scale SST analyses, which are defined at spatial scales of 1° and larger and temporal scales of one week and longer. It is necessary to briefly review the types of errors that can be expected. With any measurements, the first type of error is random error, which is the observational error caused by the instrument and/or the observer. Most analyses attempt to account for the random errors. For analyses with non-uniform data distribution, the second type of error is sampling error. The sampling error usually becomes important in an analysis and may become more important than the random error. Analyses such as the optimal interpolation (OI) compute the combined random and sampling analysis error. However, these combined analysis errors are only estimates because they depend on estimates of the data and analysis error covariances in space and time. The remaining source of error is bias error, which is due to a systematic difference between one instrument or a set of instruments and another.

For the examination of errors, the OI analysis (Reynolds and Smith, 1994 and Reynolds et al., 2002) was used. At each analysis grid point, the OI objectively determines a series of weights for each observation. The OI method assumes that the data do not contain long-term biases. Because satellite biases occur, an optional step using a Poisson's Equation can be carried out to remove satellite biases relative to *in situ* data prior to the OI analysis. This method adjusts any large-scale satellite biases and gradients relative to the *in situ* data. In the OI procedure, various error statistics are assigned that are functions of latitude and longitude. The OI has been computed since November 1981 and uses *in situ* and AVHRR satellite data.

It is useful to examine the input data for one week. Figure 1 shows the input data from the AVHRR and the *in situ* data along with the completed OI analysis. The result clearly shows that the satellite coverage is far superior to the *in situ* coverage. The missing satellite data here is due to cloud cover, which restricts the retrievals. Microwave data would have better coverage since microwave retrievals can be in cloudy regions unless it is raining. Because of the high density of satellite observations, the sampling and random errors are relatively small and are usually below 0.3°C on monthly scales on a 5° grid. However, satellite bias errors can be large even on monthly scales. Reynolds (1993) found that the absolute satellite biases from the AVHRR instrument exceeded 2°C during the eruptions of Mt. Pinatubo. Biases on these scales lasted several months, and biases greater than 0.5°C persisted for almost a year. In addition, biases may occur at the end of a satellite instrument's useful lifetime and can also reach levels of 2°C. Reynolds et al. (2004) showed an example for the AVHRR instrument on the NOAA-14 satellite. The aerosol biases are often confined to the tropics. However, biases due to instrumental problems can occur at higher latitudes. As it is not known when biases of this magnitude will occur, the *in situ* network must be designed to correct the potential bias to the required accuracy.

Before examining the *in situ* network, it is necessary to define an acceptable bias error. A maximum allowed bias error was specified by Needler et al. (1999) for a 500 km by 500 km box on a weekly time scale as 0.2-0.5°C. Because satellite biases do not change greatly from weekly to monthly periods and because a 5° latitude-longitude box is close to a 500 km box (only 10% larger at the equator), the minimal bias accuracy considered here will be less that 0.5°C on a monthly 5° grid. This modification was made for computational convenience and to simplify buoy deployment plans.

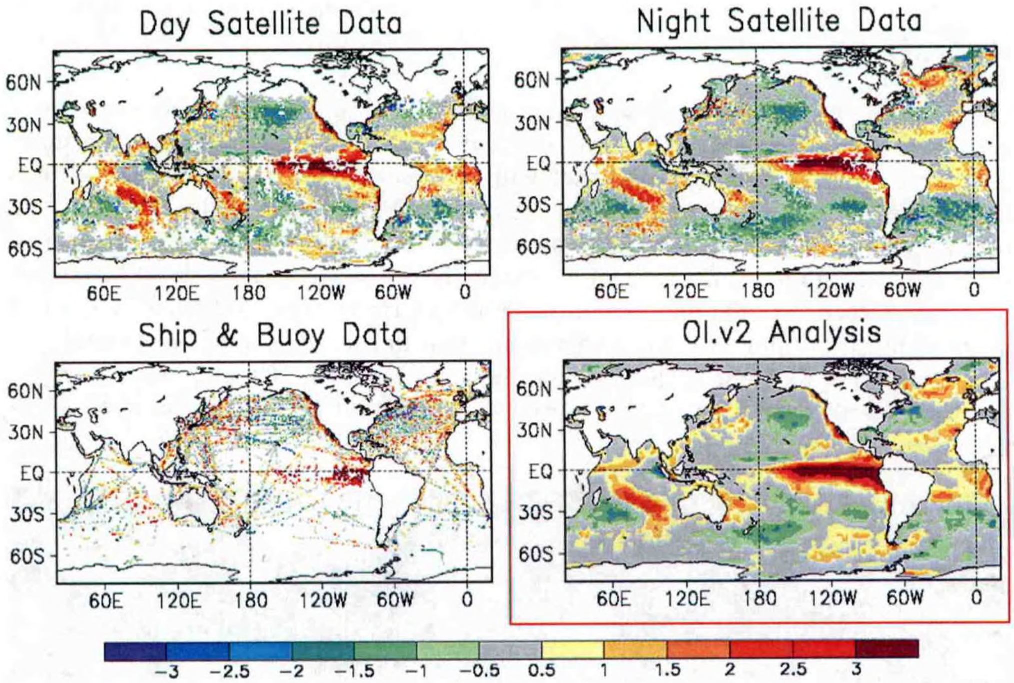

Figure 1. Weekly SST input data for the optimum interpolation (OI) SST analysis for December 14-20, 1997. The top two panels show the daytime and nighttime AVHRR satellite SST data. The bottom left panel shows the *in situ* (ship and buoy) SST data. The analysis (bottom right panel) combines the satellite and *in situ* data into a smoothed product. The data and analyses are shown as anomalies (departures from normal) in °C. White regions indicate missing data. Please note the superior coverage of the satellite data compared to the *in situ* data.

To better design an *in situ* network to correct satellite SST biases, it was necessary to examine the scales of the bias. Zhang et al. (2004a) examined the biases and extracted the six most important bias fields. The next step is to compute the buoy density needed to reduce any potential satellite bias errors below 0.5°C over the global ocean. Because there is no systematic way to define the bias errors, the OI analysis was used with simulated satellite and *in situ* data. Satellite data were simulated by each of the six spatial bias patterns at the locations of the actual satellite data. Buoy data were simulated without bias error on regular grids at various grid resolutions. By design, the simulated satellite biases will be reduced by the simulated buoy data. The purpose is to determine the buoy grid density at which the satellite SST biases can be reduced to within the required accuracy (i.e., below 0.5°C) over the global ocean. The spatial satellite biases are scaled to give a potential satellite bias error of 2°C if there were no buoy data. The word 'potential' is used in the definition as a reminder that the satellite bias was scaled.

The results of the simulations are described in detail in Zhang et al. (2004b). The simulations show that at least 2 buoys are needed on a 10° grid to reduce the potential satellite bias below 0.5°C. To use this requirement in actual distributions, it is necessary to determine how to combine ship and buoy data in the results. Because ship observations are noisier (random error of 1.3°C, Reynolds and Smith 1994) than buoy observations (random error of 0.5°C), roughly 7 ship observations are required to have the same accuracy of one buoy observation. Therefore, an equivalent-buoy-density (*EBD*) is defined as: $\boldsymbol{EBD = n_b + n_s/7}$. Here $\boldsymbol{n_b}$ and $\boldsymbol{n_s}$ are the number of buoys and number of ships in a 10° box, respectively.

The *EBD* was defined for each month, and then averaged seasonally for operational buoy deployment. An example is shown in Figure 2 for October – December 2003. Boxes poleward of 60°N and 60°S were not shown along with boxes with less than 50% ocean by area as well as boxes in Hudson Bay and the Mediterranean Sea. Color shading is used in the figure to help indicate where additional buoys are needed, as indicated in the figure caption. The number of additionally needed buoys to reach *EBD*=2 for all shaded boxes in Figure 2 has been computed. The number of buoys needed in the middle latitude Southern Hemisphere (60°S-20°S) shows a rapid drop with time in the mid 1990s due to the increase in the number of buoys deployed (Reynolds et al. 2002). For the three-month average shown in Figure 2, 189 additional buoys are needed between 60°N-60°S, of which 102 are needed between 60°S-20°S, 65 between 20°S-20°N, and 22 between 20°N-60°N.

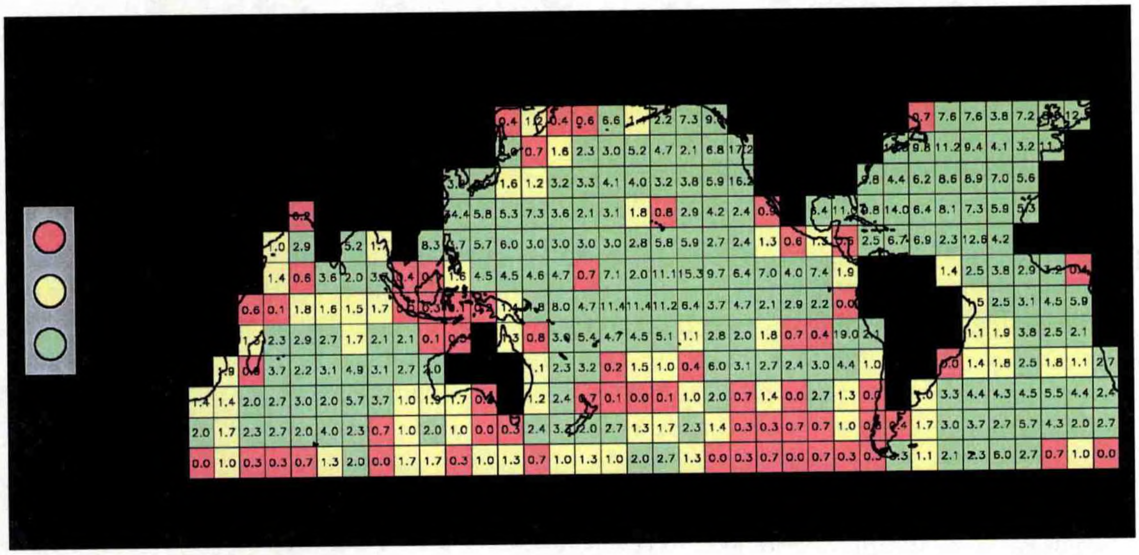

Figure 2. Equivalent buoy density (*EBD*) with respect to a 10° grid for the season of October – December 2003. Green shading is used where *EBD*≤2 and indicates regions where no more buoys are needed. Red shading is used where *EBD*<1 and indicates regions which have a high priority to be filled with more buoys. Yellow shading indicates where1≤*EBD*<2 and indicates regions where more buoys are needed but at a lower priority than the red shading.

The current *in situ* observation network was designed for other purposes and is thus not necessarily the most efficient network for climate SST. For example, the *EBD* exceeds 5 in most of the North Atlantic Ocean (see Figure 2), while the *EBD* is less than 2 in a large number of boxes in the Southern Oceans. For climate purposes alone, the current buoy distribution could be relocated in some regions, especially in the North Atlantic and North Pacific. These results have already had an influence on future buoy deployments. The NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) is now using figures like Figure 2 to guide surface drifting buoy deployments. It is hoped that this study will be useful in helping to objectively define requirements for an integrated ocean observing system.

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2.4 Surface Currents to Identify Significant Patterns of Climate Variability

by Peter Niiler[1] and Nikolai Maximenko[2]

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The oceans affect the changes of the habitability of the globe because they are the earth's principal time-varying reservoirs of thermal energy and moisture. If the temperature of the air over the oceans departs from SST, there is an exchange of heat and moisture, and the temperature of the air, because of its low heat capacity, adjusts to SST. The thermal energy reservoirs of the ocean depend crucially upon the ocean circulation patterns. The climate change of the atmosphere is best understood and modeled if the general circulation of the oceans and its changes are well known.

Climate scientists use global ocean circulation models to study and predict the processes that cause climate change. If models replicate the recent, short-term climate changes it is thought that they can also be used to predict longer time scale changes into the future. The accuracy of global climate change models can only be determined with spatially and temporally extensive data sets on the currently evolving state of the circulation and property distributions of the global oceans. Global surface velocity data is important for the description and modeling of the modes of climate change because surface currents are one of the principal physical causes for the changes of SST.

The global ocean surface currents and SST are measured with satellite located drifting buoys in an international program called the "Global Drifter Program". This program began in 1988 and since 1992 there have been about 625 drifters in the ocean. In late 2003, the number of drifters has increased to about 950 and in 2004 a full deployment of 1250 drifters will be implemented. These data have been combined with satellite altimeter data to make the 1992-2004 time mean atlas of ocean currents at 15m-depth over the entire globe. Both the geostrophic and wind driven currents have been computed. Before climate related changes of the surface circulation are computed, a time mean must be defined, which has been the first task in the 2003-04 period.

Figure 1 displays the absolute sea level computed from drifter and satellite altimeter data (Niiler *et al.*, 2003); the geostrophic component of the near surface current is computed from the gradient of this sea level distribution just like air currents are computed from sea level pressure maps. The wind driven, or Ekman, current is shown in Figure 2. Ekman currents are calculated using Ralph and Niiler (1999) parameterization with coefficients optimized to recent data of the pair of satellites called GRACE (Gravity Recovery And Climate Experiment), and are to the right of the wind in the northern hemisphere and to the left of the wind in the southern hemisphere. These digital ocean surface current data are available on request from: pniiler@ucsd.edu. The raw data and the research publications that have used these data to understand ocean circulation are available from: http://www.aoml.noaa.gov/phod/dac/dacdata.html/.

To observe the climate variability of ocean currents, the short-term variability has to be 'averaged' out. Statistical measures can be established to show how well any map of surface current represents a phenomenon described on specified space and time scales. Drifters sample the ocean currents accurately, but not very often. Satellite altimeter data can be used to compute geostrophic ocean currents on a regular time interval, but since ocean currents contain significant

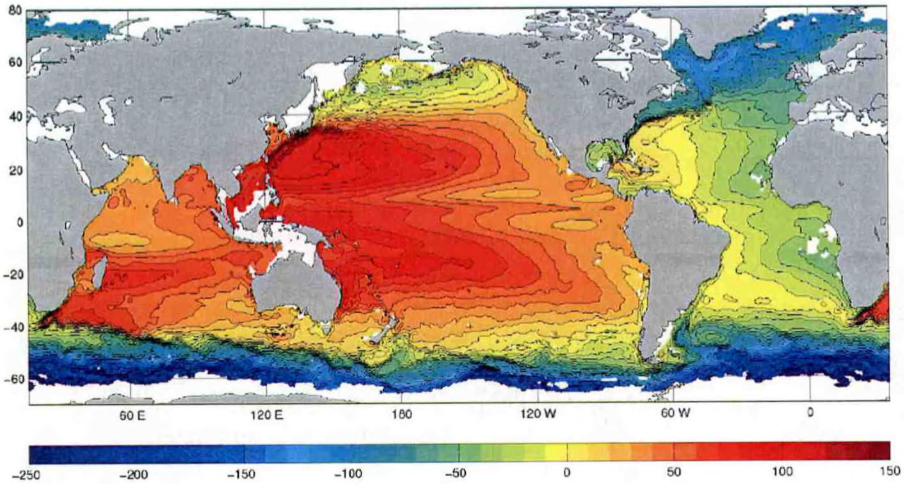

Figure 1. 1992-2002 absolute mean sea level computed as described by Niiler et al., 2003 but with Ekman parameterization optimized to the GRACE data. Contour interval is 10 cm.

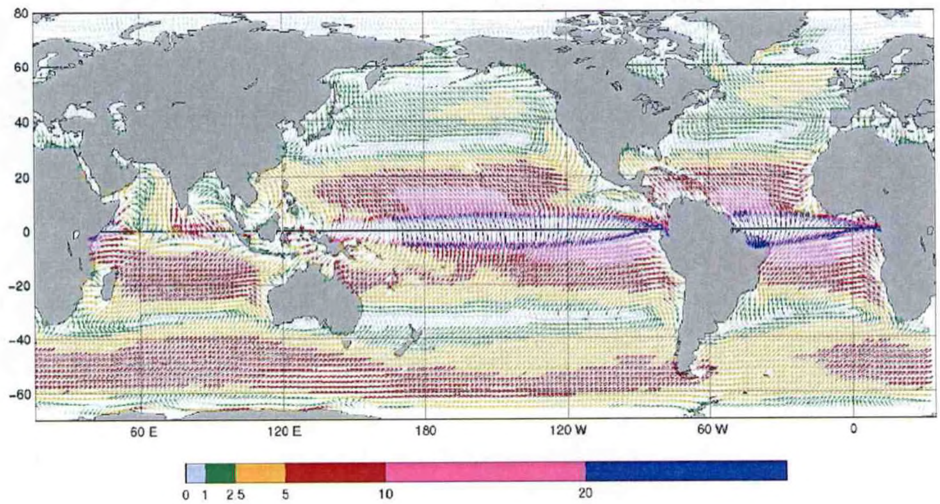

Figure 2. 1992-2002 mean Ekman currents at 15 m depth as calculated using NCAR/NCEP re-analysis winds and Ralph and Niiler (1999) parameterization optimized to the GRACE data. Colors of velocity vectors correspond to their magnitudes (colorbar is in cm/s).

Ekman components and are not in geostrophic balance near the equator, their derivations from altimeters also use drifter observations. A combined field of circulation derived from drifters and altimeters (and wind) will have less sampling bias and is more accurate than the fields derived separately. The following performance measures are established for obtaining confidence intervals for surface circulation:

Table 1. "Surface Velocity Program (SVP)" Statistical confidence measures

FISCAL YEAR	2002	2003	2004	2005	2006	2007	2008
1) Observe the mean circulation confidence on a 0.5°x0.5° spatial scale	30%	35%	50%	55%	65%	75%	85%
2) Observe the 50 km spatial scale mesoscale eddy energy* confidence	60%	65%	70%	75%	80%	85%	operational
3) Compute maps of seasonally varying tropical current systems with confidence	50%	60%	70%	70%	75%	75%	operational
4) Interannual, large spatial scale (2° Lat. x 5° Long.) current systems with confidence	30%	35%	40%	45%	50%	50%	

* Eddy energy can also have seasonal and interannual variability.

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2.5. SEA SURFACE PRESSURE

Excerpt from The Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC, April 2003, with contributions by
Ed Harrison, Pacific Marine Environmental Laboratory, Seattle, Washington

Parameter: Surface air pressure

Main climate application

Surface air pressure data provide vital information about atmospheric circulation patterns in the climate system. Long-term air pressure data compilations can be used to assess changes, fluctuations and extremes in climatic circulation regimes. Such analyses aid ongoing efforts to assess the relative importance of anthropogenic and natural influences, and to estimate possible future impacts of atmospheric circulation changes on human activities.

Contributing baseline GCOS observations

The GCOS surface network (GSN), is a subset of approximately 1000 stations that supports the global network of locations that provide local and regional-scale observations. The GSN promotes best practice and is a baseline against which to assess the long-term homogeneity of the rest of the surface network. The GSN must be augmented with additional surface air pressure data, especially over the oceans, in order to provide more detailed patterns of spatial changes, fluctuations and extremes in atmospheric circulation.

Other contributing observations

There is a Surface Synoptic (SYNOP) pressure network of 7000 surface recording stations as well as additional national and research observing networks. Voluntary Observing Ships, fixed platforms, moored and drifting buoys often report air pressure over the ocean.

Significant data management issues

GSN data management is achieved by a combination of national data management organizations, GCOS GSN monitoring and analysis centers, and CBS GCOS lead centers.

Analysis products

Time series are created for individual stations, station differences, regional averages, hemispheric averages, and global averages. Gridded fields are created via objective analysis and data synthesis (e.g., reanalysis, HadSLP). Indices of climatic phenomena (e.g., Southern Oscillation, North Atlantic Oscillation), means, seasonal cycles, and extreme events can all be derived from surface air pressure observations.

Current capability

Gridded global monthly, seasonal and annual surface air pressure compilations are capable of resolving important information about circulation changes and fluctuations over the last 120-150 years. Examinations of circulation extremes and storminess require daily surface air pressure data. To date, this has mainly been temporally limited to the last half-century or less and also spatially limited to parts of the Northern Hemisphere, especially in the US-European sector.

Issues and priorities

The following issues and priorities exist:

- Data archaeology, digitization of longest available data records
- Access to daily data
- Homogenization of daily data as much as possible

- International surface air pressure database
- Testing climate model data sets against observational data products
- Checking on reduction to standard gravity

Conclusions (contributed by Ed Harrison)

Surface pressure variability drives a direct oceanic response that can be a significant source of sampling troubles in some situations, or the sea level/surface pressure link. Surface pressure is highly important as an indicator of the strength of the atmospheric circulation, and is important to know over the ocean even without wind stress.

Because 1 mb of sea level pressure (SLP) uncertainty translates directly into 1 cm uncertainty in sea level height (assuming an inverse-barometer relationship), we would like to have the local point instantaneous error in SLP analysis from the operational meteorological centers be 0.5 mb or less. This is a challenging standard. At the moment, in places where there is little *in situ* error, we have root mean square (RMS) differences (between the European Centre for Medium-Range Weather Forecasts (ECMWF) and the National Center for Environmental Prediction (NCEP)) of as much as 2-3 mb or point errors up to about three times this value. Typical maximum point errors presently over the better-sampled parts of the globe *may* be in the 2-3 mb range. If we enhance the global drifter array by attaching sensors to measure SLP, it is believed to be possible to decrease the maximum point uncertainty to 1 mb or better. This is the present goal. To further improve, better SLP sensors will also be needed on ships.

2.6 AIR-SEA EXCHANGE OF HEAT, FRESH WATER, MOMENTUM

by Robert C. Weller, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

Goal: to identify changes in forcing functions driving ocean conditions and atmospheric conditions

The ocean has a distinct role in governing the variability of the earth's atmosphere, land, and ocean. It carries heat poleward from the equatorial regions where the sun shines most strongly. It releases heat and moisture into the lower atmosphere to drive weather patterns, storms and hurricanes, and longer period climate variability that includes the El Niño-Southern Oscillation. The ocean, which covers 70% of the earth, can store 1100 times more heat than the atmosphere due to the larger heat capacity and density of water. The upper 2.5 m of the ocean, when warmed 1°C, thus stores an amount of heat that would raise the entire column of air above it 1°C as well. As a consequence, an anomalously warm region of the ocean has the potential of releasing considerable energy to the atmosphere above and thus driving the weather on short time scales and, if the release of heat persists, can alter climate. Energy to drive the atmosphere is also transferred from the ocean by evaporation, and the ocean's role as a source of moisture is also critical to understanding weather and climate as well as the global cycle of freshwater. The ocean also stores 97% of the earth's water and plays a major role in the global cycle of freshwater that heavily impacts agriculture and human activities; 86% of the evaporation and 78% of the precipitation occur over the ocean. The third exchange of interest is that of momentum, in other words, determining how the surface winds drive the ocean currents and how the ocean surface provides drag to the atmosphere. The shallow, wind-driven ocean currents are of particular interest because of their role in transporting the surface waters that are warmed and cooled by exchanges with the atmosphere.

One goal of the NOAA Climate Observation Program is to collect long, accurate time series of the air-sea exchanges of heat, freshwater, and momentum at key locations around the world's ocean, aiming toward 16 such sites by 2006 and building to 51 of these sites, known as ocean reference stations. A second goal is to use these accurate observations together with surface meteorological and air-sea flux observations from Volunteer Observing Ships (VOS) to produce daily maps of the air-sea fluxes over the global ocean.

What are the reasons for these goals? First, these maps will show where and how much heat and freshwater are exchanged between the ocean and atmosphere, show how the winds drive the surface currents, and thus quantify the exchanges between the ocean and atmosphere that play important roles in weather, climate, and the global water cycle. Thus, we would be able to document, for example, the impact on climate of years of anomalous heat and freshwater loss to the atmosphere by a region of the ocean and to search for connections across the globe between rainfall anomalies on land and where and how much freshwater was released from the ocean. At present, due to sparse observations and large uncertainties in the present estimates of the air-sea exchanges, we cannot (across time scales that range from hurricanes to decadal) determine across the globe whether or not anomalous ocean conditions cause or result from anomalous atmospheric conditions. We look to new, accurate flux maps with good temporal and spatial resolution to show where and when change in the ocean leads or lags change in the atmosphere.

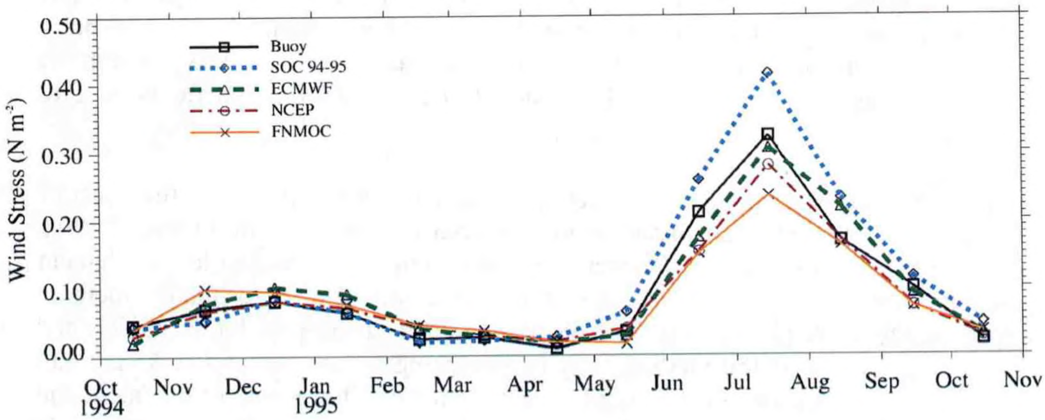
Second, the flux maps will provide the surface forcing for numerical ocean models now used to investigate oceanic variability and the ocean's role in climate; such models are now forced using climatological surface fluxes or other fields of fluxes that have large uncertainties, which in turn add uncertainty to the results of the ocean modeling. The ocean, as pointed out above, has a large ability to store heat. It also has a three-dimensional circulation that is much slower than that of the atmosphere, with the deep waters being exposed to the atmosphere only every 100 years or so. Accurate surface forcing is needed as we look to improve the ability of these ocean models to properly simulate the mixing, overturning, and decadal and longer term transport, storage, and release back to the atmosphere of heat and freshwater.

Third, atmospheric models are now forced at the sea surface with sea surface temperature fields and use their own parameterizations to develop surface fluxes of heat, fresh water, and momentum. By comparison with data from the ocean reference stations that are being deployed by the NOAA Climate Observation Program, the air-sea fluxes in these atmospheric models are found often to have large differences from the actual fluxes. This needs to be addressed because many ocean modelers use the atmospheric model flux fields as their surface forcing and also because the role of the ocean in weather and climate variability in these atmospheric models and in climate models that use the same or similar code may not be well represented. Moreover, accurate fields of the surface exchanges are required for evaluation of the ability of coupled ocean-atmosphere climate models, such as those used in IPCC (Intergovernmental Panel on Climate Change) predictions of future climate change, to simulate present day climate. Such evaluations are necessary if we are to have confidence in the future climate change scenarios predicted by these models.

Fourth, surface flux fields are widely used in observational studies by the oceanographic research community studying large scale ocean circulation and its impact on climate, in synthesis with sub-surface measurements, to determine the transports of water and heat across basin scale ocean sections. In particular, the fields of momentum flux are required to determine the wind-driven or Ekman component of the ocean transport, and the fields of heat, fresh water, and momentum flux are needed to provide surface forcing conditions for analyses of hydrographic (ocean temperature and salinity) data which use inverse techniques to estimate the transports of water with different, characteristic temperatures and salinities.

Finally, the accurate time series from the ocean reference stations serve several key functions: 1) provide accurate long time series of known accuracy at key locations which are of high value as records of variability and change in the coupling of the ocean and atmosphere, 2) help to calibrate and validate remote sensing, 3) provide the ability to examine the realism of the air-sea fluxes in numerical weather and climate models, 4) provide accurate records of the surface forcing to be used in studies of oceanic response to and interaction with the atmosphere, and 5) provide critical points across the ocean basins to use as standards and anchor sites to develop the global air-sea flux fields through the synthesis of data from the diverse sources needed to achieve daily, global fields.

The context for this element of the Climate Observation Program can be illustrated by Figure 1, which compares time series of air-sea fluxes from a surface mooring of the type being deployed at the Ocean Reference Stations. Monthly means of wind stress (momentum flux) and net heat flux from two state of the art numerical weather models, one from the National Center for Environmental Prediction (NCEP) and one from the European Centre for Medium Range Weather Forecasts (ECMWF) are plotted against the monthly means from the buoy and monthly means from flux fields developed at Southampton Oceanography Centre (SOC) from VOS observations. Note not only how large the differences in net heat flux are between the NCEP and ECMWF monthly means and those of the buoy but also that the NCEP heat fluxes have the wrong sign during June and July. Indeed the ECMWF model indicates through the year about 50 W m^{-2} less heat into the ocean than observed, and the NCEP has a negative bias of about 100 W m^{-2}. Errors of this size have been seen at other sites. Yet, recent ongoing efforts to understand the dynamics of the upper ocean and the ocean's role in climate, such as the World Ocean



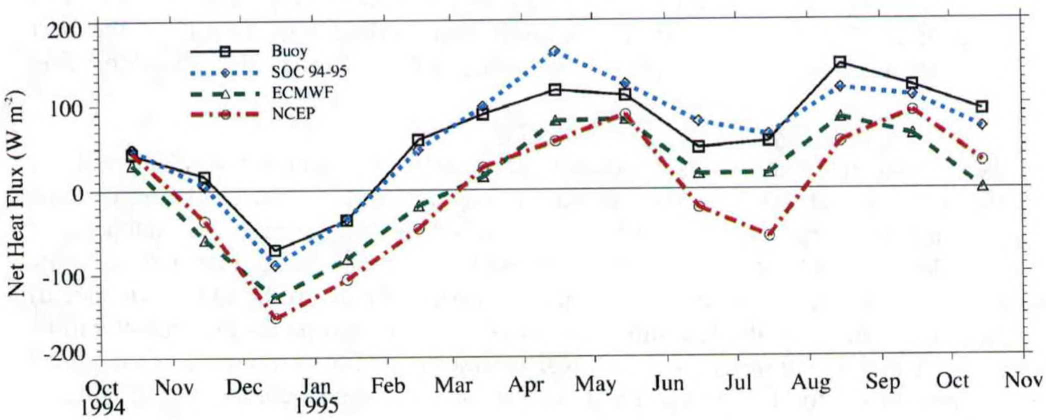


Figure 1. Monthly mean wind stress (momentum exchange) (upper) and net heat flux (positive into the ocean) at a mooring deployed in the northern Arabian Sea for one year.

Circulation Experiment (WOCE), the Tropical Ocean-Global Atmosphere Program (TOGA), and the Climate Variability (CLIVAR) Program have identified the need for monthly mean net heat flux estimates to be available with accuracy of better than 10 W m^{-2}. Consistent accuracy targets for precipitation and wind stress are 0.01 mm hr^{-1} and .01 N m^{-2}, respectively. These lead to target accuracies for sea and air temperature of 0.1°C, for wind speed of better than 5%, for relative humidity of better than 3%, for incoming shortwave of better than 10 W m^{-2}, and for incoming longwave of better than 5 W m^{-2}. Some of the errors cancel, and these target accuracies typically allow the 10 W m^{-2} goal in the net heat flux to be met at present. A more challenging objective for the future of this effort motivated by the desire to better understand long term climate change would be to resolve mean values of the net heat flux well enough to be able to sense shifts in the surface radiation budget associated with changes in greenhouse gases and aerosols, thus requiring the reduction of errors in the net heat flux to approximately 4 W m^{-2}.

This element of the Climate Observation Program is in its initial phase. The goals are to deploy and maintain the Ocean Reference Stations and, using these time series as the critical accurate reference observations, to produce global maps of the air-sea fluxes of heat, freshwater, and momentum. The challenge is a significant one, requiring cruises to deploy and maintain each Ocean Reference Station once per year, requiring dedicated on the land and at sea calibration efforts to obtain the sought after accuracies in these unattended surface moorings, and also requiring well-instrumented VOS that cross the ocean basins to obtain essential complementary information about the spatial variability in the surface meteorological and air-sea fluxes and in the differences between these observed fields and the model and remotely-sensed fields used to synthesize global maps.

At present, one Ocean Reference Station is operating under the stratus clouds off the coast of northern Chile (20°S, 85°W) and one in the tropical western North Atlantic (15°N, 51°W). Immediate plans are to add a third Ocean Reference Station north of Hawaii and to complement the sensors on four existing TAO-TRITON sites in the equatorial Pacific to qualify them as Ocean Reference Stations. A pilot project has been conducted, using past buoy, model, and satellite data, to test and develop the methodology of producing air-sea fluxes fields on basin scales. Figure 2 shows a comparison of the long-term (1988 to 1997) mean sum of the latent and sensible heat flux components from a new flux product developed by L. Yu at Woods Hole Oceanographic Institution (WHOI) with the SOC climatology and mean fields from ECMWF and NCEP. The WHOI product produced by data assimilation methodology compared the best against the buoy data available from this period; this pilot project affirmed the approach being taken.

As yet, the observations made under this component are sparse. The data are withheld and not used in preparation of model fields by the operational weather and climate modeling centers. This is done so that the Ocean Reference Station time series can serve as an independent assessment of model performance and thus to stimulate the ongoing dialog that will motivate improvements to these models. The sparse Ocean Reference Stations are building evidence of biases and errors in the models at the few sites now occupied. A milestone for the project will be when the deployed buoys cover many of the critical weather and climate regimes of the global ocean and thus can be used to identify and fix problems in these models common to all sites as well as to identify issues unique to specific regimes.

With sufficient funding and with new observatory technology to be developed under the Ocean Observatory Initiative of the National Science Foundation, the deployment of the planned numbers of Ocean Reference Stations is entirely feasible. Each site will require a regular, once per year commitment of ship time and of on land and at sea calibration. Significant milestones will be achieved when the Ocean Reference Stations in each basin provide time series from the meteorological and air-sea regimes characteristic of those basins. When that is accomplished, the time series from these moorings will provide compelling evidence to drive the process of partnering with the atmospheric modeling community to improve the realism of those models and to produce basin scale flux fields of the desired accuracy. These time series sites should be accompanied by accurate measurements from the ship that deploy and recover the mooring to provide in-the-field calibration of the moored time series. They should also be accompanied by improved measurements from selected VOS to obtain direct observations of the spatial variability of the surface meteorological and air-sea flux fields. Practical considerations require the implementation of a hierarchy of VOS observations systems. The state of the art instrumentation of two to three long cross-basin ship lines (with preference for the high resolution XBTs lines) in each ocean basin will provide estimates of high absolute accuracy. A few hundred ships recruited under the VOSClim program will have improved instrumentation and sufficient documentation to allow any measurement biases to be quantified and corrected through comparison with the Ocean Reference Stations. The majority of the international VOS fleet (some six thousand ships) will continue to provide basic observations over large areas of the world oceans which must be verified against the higher quality observations from the specially chosen ships and buoys. These observing efforts should be accompanied by quality control efforts, by close interaction with the

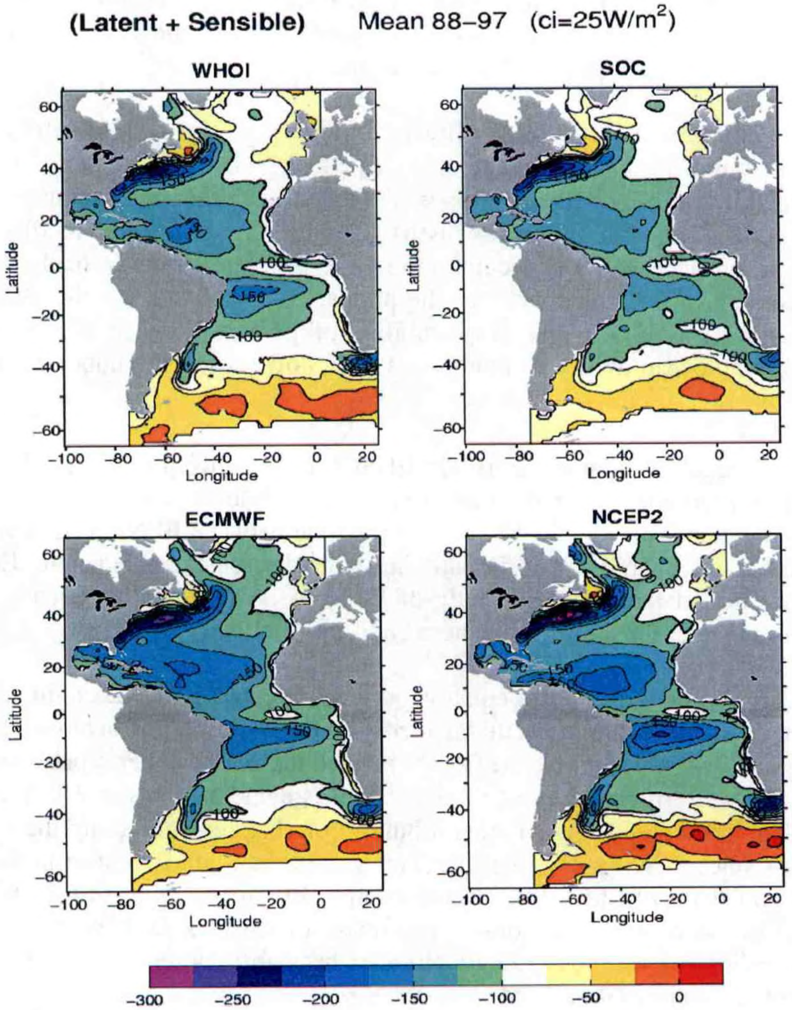


Figure 2. Four maps of the long-term (1988-1997) sum of latent and sensible heat flux components in the Atlantic basin. WHOI was produced by L. Yu at WHOI and validated against buoy data. SOC is a climatological product based on VOS data; ECMWF and NCEP2 are analyses based on those numerical weather prediction models.

atmospheric modeling centers and those working up remotely-sensed fields at the ocean surface, and by production of global fields of the air-sea exchanges of heat, freshwater, and momentum that are made available to the research and operational communities.

Acknowledgement:
This section on air-sea exchange of heat, fresh water and momentum was written with input from Drs. Peter Taylor and Simon Josey of the Southampton Oceanography Centre, UK, Dr. Chris Fairall of the NOAA Environmental Technology Laboratory, Boulder, Colorado, and Dr. Frank Bradley of the Commonwealth Scientific and Industrial Research Organization (CSIRO), Canberra, Australia.

2.7 EL NINO AND HEAT CONTENT VARIATIONS

by Michael J. McPhaden, Pacific Marine Environmental Laboratory, Seattle, Washington
(Adapted from McPhaden, M. J., Evolution of the 2002-2003 El Niño, *Bulletin of the American Meteorological Society*, in press, 2003.)

El Niño Southern Oscillation (ENSO) variability is intimately linked to alternating stages of oceanic heat content build-up and discharge from equatorial latitudes. These heat content variations are mediated by wind-forced equatorial waves and affect sea surface temperature (SST) through equatorial upwelling and other processes. Changes in SST then feedback to the atmosphere to modify surface wind and precipitation patterns. The slow seasonal evolution of upper ocean heat content and its feedbacks to the atmosphere accounts for the characteristic interannual time scale of ENSO. The predictability of ENSO likewise derives from the deterministic wind-driven ocean dynamics that govern this slowly evolving upper ocean thermal field.

According to the "recharge" oscillator theory for ENSO: 1) a build-up of excess heat content along the equator is a prerequisite for the occurrence of El Niño; 2) the equatorial Pacific is purged of excess heat content during El Niño; and 3) the time between El Niños is determined in part by the time it takes to recharge equatorial latitudes with excess heat once again. Empirically it has also been determined that the magnitude of El Niño SST anomalies usually scales in proportion to the magnitude of the prior heat content build-up.

Zonally integrated heat content along the equator provides a convenient index for interpreting ENSO variability in terms of recharge oscillator theory. One definition of heat content for this purpose is the integrated warm water volume (WWV) above the 20°C isotherm between 5°N–5°S from the eastern to the western boundary of the Pacific. It is evident from the WWV time series and the NINO3.4 SST index (see Figure 1) that a build-up in heat content along the equator has preceded all El Niños since 1980 by 2–3 seasons. The heat content build-up prior to the 2002–03 El Niño was about half that prior to 1997–98, and comparable to that prior to the 1986–87 and 1991–92 El Niños. Based on this heat content precursor, one would have expected maximum NINO3.4 SST anomalies for the 2002–03 El Niño to be significantly smaller than those in 1997–98 and similar to those in 1986–87 and 1991–92.

WWV along the equator peaked in September 2002 after which it began to rapidly decrease, in accordance with the idea that El Niño should purge excess heat from the equatorial band. WWV became weakly negative in February–April 2003, consistent with the existence of a shallower than normal thermocline along the equator at that time. The steep plunge in WWV from September 2002 to February 2003 was a harbinger of the 2002-2003 El Niño's demise, though WWV subsequently rebounded to positive values in mid-2003 in response to renewed episodic westerly wind forcing (Figure 2). The persistence of this elevated WWV during the second half of 2003 is linked to slightly elevated El Niño-like SSTs in the equatorial Pacific that some forecast models indicate will persist into the Northern Hemisphere spring.

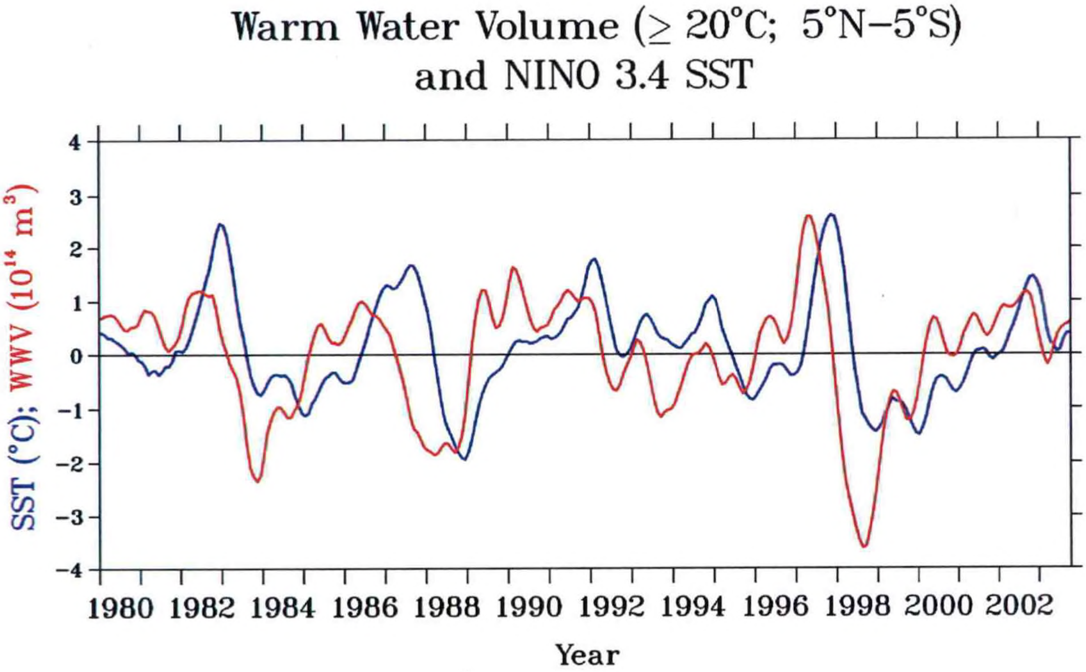


Figure 1. Monthly anomalies of warm water volume (5°N–5°S, 80°W–120°E above the 20°C isotherm) and NINO3.4 SST (5°N–5°S, 120°W–170°W) from January 1980 to December 2003. Warm water volume is based on a blended analysis of TAO/TRITON moored time series data and ship-of-opportunity expendable bathythermograph (XBT) data. Time series have been smoothed with a 5-month running mean filter for display.

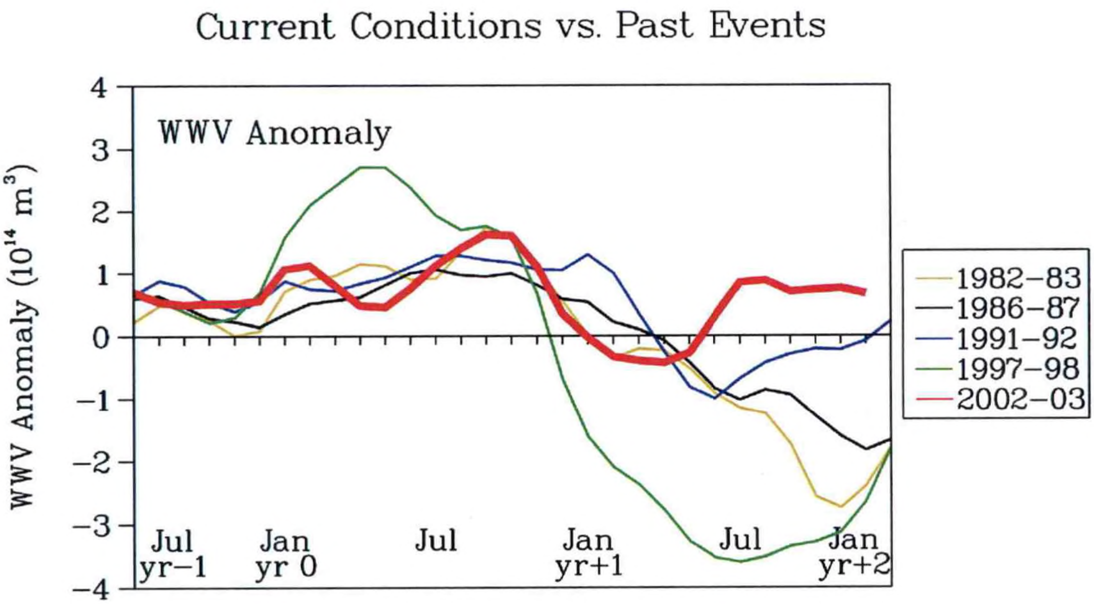


Figure 2. Monthly warm water volume (WWV) variations in the Pacific during El Niños since 1980, starting in July the year before each El Niño and ending in January the year after.

CHAPTER 3

THE STATE OF THE OBSERVING SYSTEM

Project Summaries, FY 2003 Progress, FY 2004 Plans

This chapter is comprised of FY 2003 progress reports followed by FY 2004 plans submitted by scientists funded by NOAA's Climate Observation Program. A request for annual progress reports using a new structured report format was issued in late August 2003 (see Appendix D). Excerpts from the submitted reports are presented here summarizing efforts focused on enhancement of the global ocean observing system for climate.

The chapter begins with a report describing the Office of Climate Observation's Climate Observation Program, the primary sponsor of the documented projects, followed first by a table of OCO-funded projects and their accompanying web sites, and then by an overview of the Observing System Monitoring Center (OSMC), including a description of partners involved. The reports that follow are in alphabetical order based on the Principal Investigator's last name.

PROGRAM OVERVIEW
FY 2003 PROGRESS

Office of Climate Observation, Climate Observation Program, The Ocean Component

by Mike Johnson, Office of Climate Observation, Silver Spring, MD

Introduction

This report provides an annual progress report and work plan for NOAA's Climate Observation Program. The program was initiated by the Office of Global Programs (OGP) with Climate and Global Change (C&GC) funding in 1998. Since then the program has grown to include funding accounted for within seven separate OAR budget lines. This report presents the composite Program as administered through the Office of Climate Observation (OCO).

Program Description

Goal and Objectives:
The goal of the program is to build and sustain the ocean component of a global climate observing system that will respond to the long term observational requirements of the operational forecast centers, international research programs, and major scientific assessments. The program objectives are to:

- document long term trends in sea level change;
- document ocean carbon sources and sinks;
- document the ocean's storage and global transport of heat and fresh water;
- document ocean-atmosphere exchange of heat and fresh water.

Specific issues, requirements, and customer need motivating the program:
The ocean is the memory of the climate system and is second only to the sun in effecting variability in the seasons and long-term climate change. In order for NOAA to fulfill its climate mission, the global ocean

must be observed. At present, the Climate Observation Program is arguably the world leader in supporting implementation of the *in situ* elements of the global ocean climate observing system.

The observing system needs to have the capability to deliver continuous instrumental records and analyses accurately documenting:

- Sea level to identify changes resulting from climate variability.
- Ocean carbon content every ten years and the air-sea exchange seasonally.
- Sea surface temperature and surface currents to identify significant patterns of climate variability.
- Sea surface pressure and air-sea exchanges of heat, momentum, and fresh water to identity changes in forcing function driving ocean conditions and atmospheric conditions.
- Ocean heat and fresh water content and transports to identify where anomalies enter the ocean, how they move and are transformed, and where they re-emerge to interact with the atmosphere.
- The essential aspects of thermohaline circulation and the subsurface expressions of the patterns of climate variability.
- Sea ice thickness and concentrations.

Present ocean observations are not adequate to deliver these products with confidence. The fundamental deficiency is lack of global coverage by the *in situ* networks. Present international efforts constitute only about 45% of what is needed in the ice-free oceans and 11% in the Arctic. The *Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCCC* concludes that "the ocean networks lack global coverage and commitment to sustained operations…Without urgent action to address these findings, the Parties will lack the information necessary to effectively plan for and manage their response to climate change." The *Strategic Plan for the U.S. Climate Change Science Program* calls for "complete global coverage of the oceans with moored, drifting, and ship-based networks." The draft Ocean.US interagency plan for *Implementation of the Initial U.S. IOOS* specifies that "the highest priority for the global component of the IOOS is sustained, global coverage."

The recent Earth Observation Summit raised to the highest levels of governments the awareness of the need for a global observation system. The climate question is high on the political agendas of many nations and can be answered authoritatively only by sustained earth observation. The Earth Observation Summit reaffirmed NOAA's leadership and commitment to fulfilling the need for global coverage and the Climate Observation Program is NOAA's management tool for implementing the ocean component.

Partnerships:
The Climate Observation Program is managed as an inter-LO, interagency, and international effort. Presently most NOAA contributions to the global system are being implemented by the OAR laboratories, joint institutes and university partners. NOS, NMFS, and NWS maintain observational infrastructure for ecosystems, transportation, marine services and coastal forecasting that do or have potential to contribute to climate observation. NOS sea level measurements in particular provide one of the best and longest climate records existent. NESDIS data centers are essential. NMAO ship operations are necessary for supporting ocean work. NESDIS and NPOESS continuous satellite missions are needed to provide the remote sensing that complements the *in situ* measurements.

International and interagency partnerships are central to the Climate Observation Program implementation strategy. All of the Program's contributions to global observation are managed in cooperation internationally with the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), and nationally with the U.S. Integrated Ocean Observing System (IOOS). NSF has initiated their Ocean Observatories Initiative (OOI) which will potentially provide significant infrastructure in support of ocean climate observation, beginning in FY 2006. The ongoing NSF-NOAA cooperative project for CLIVAR-carbon ocean surveys has proved to be an interagency-international-interdisciplinary success. ONR maintains a GODAE data server at Monterey that needs to be sustained after the experiment period (2003-2005) as permanent international infrastructure. The UNOLS fleet provides ship support for ocean operations. NASA's development of remote sensing techniques is key.

Focus of the Program:

- Extending the *in situ* networks to achieve global coverage – moored and drifting buoys, profiling floats, tide gauges stations, and repeated ship lines. The networks are illustrated in Figure 1.
- Building associated data and assimilation subsystems.
- Building observing system management and product delivery infrastructure.

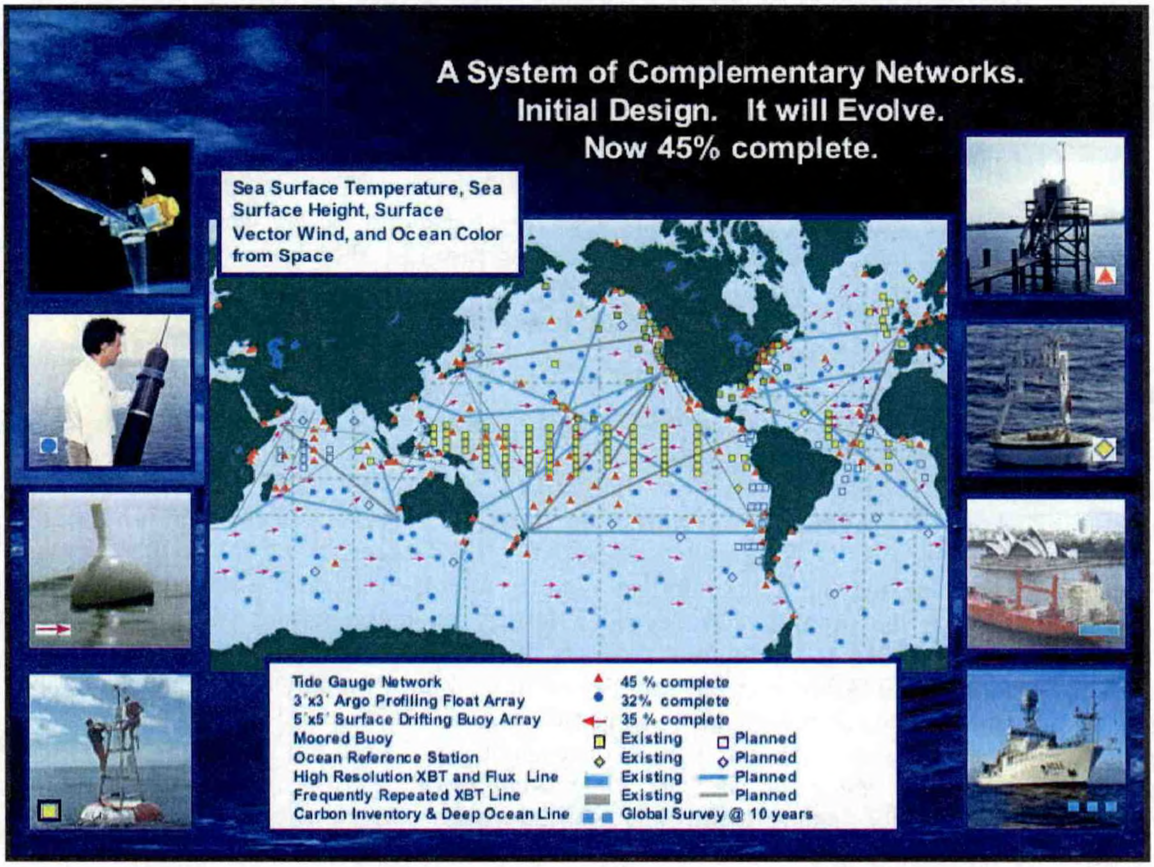


Figure 1

Linkage to NOAA strategic goals:

- NOAA's Mission Goal 2 – "Understand climate variability and change to enhance society's ability to plan and respond."
- NOAA Strategy – Monitor and Observe: "We will invest in high-quality, long-term climate observations and will encourage other national and international investments to provide a comprehensive observing system in support of climate assessments and forecasts."

Intended program outcomes and performance measures:

- Outcome -- A sustained global system of complementary *in situ*, satellite, data, and modeling subsystems adequate to accurately document the state of the ocean and force climate models.

- Performance Measures:
  NOAA Performance Measures (from the Strategic Plan):
    - Increased number of long-term observations collected, archived, available, and accessible where random errors and time-dependent biases have been minimized and assessed.
    - Increased number, accuracy, and regional specificity of U.S. climate, water, and coastal resource products.
    - Increased volume of NOAA climate data and information used by NOAA customers.
    - Decreased uncertainty in observational measures and elimination of observation gaps, redundancies, and losses to achieve better coverage, timeliness, reliability, and maintainability of observations for users.
    - Increased use of other nations' observation platforms, resources, and assets to meet user observation and data management requirements.
    - Increased number of partnerships that promote international cooperation in global observations and data management programs.
    - New climate observations introduced.
    - Number of new monitoring or forecast products that become operation/year.

  Program Specific Performance Measures:
    - Reduced uncertainty in projections of sea level rise during the 21st century.
    - Reduced uncertainty in estimates of the increase in carbon inventory in the global ocean.
    - Reduced error in global measurement of sea surface temperature.

Schedule and milestones:

Year	2002	2003	2004	2005	2006	2007	2008	2009
System % complete:	40	45	48	53	77	88	94	99

Communications plan for providing information to decision makers (government and non-government):
The observing system delivers the "up front" information to the forecast centers, research programs, and assessments. In the past, the program has depended largely on these partner Climate Program Components to develop and deliver information products that are user-friendly for management and policy decisions. During FY 2003, however, the need was identified for the program to begin addressing the development of climate data records and analyses as first order products in addition to depending on the forecast, research, and assessment partners for climate product delivery. In 2004 and beyond the project will produce an *Annual Report on the State of the Ocean and the Observing System*. The report will include sections targeted for three audiences: 1) decision-makers and non-scientist, 2) scientists, 3) observing system managers.

How implementation is being accomplished:
The "Networks" are managed by distributed centers of expertise at the NOAA Labs, Centers, Joint Institutes and university partners. The "System" is centrally managed at the Project Office of Climate Observation (OCO), a division of OGP with dual reporting to OGP and the NOAA Climate Office.

Where it is being done (lab, university, joint institute):
AOML, PMEL, ETL, JIMAR (University of Hawaii), JIMO (Scripps Institution of Oceanography), CICOR (Woods Hole Oceanographic Institution), JISAO (University of Washington), CIMAS (University of Miami), CICAR (Columbia University), NCDC, NODC, CO-OPS, AMC, PMC, NDBC, FSU (Florida State University), and OCO.

By whom (detail on number and type of personnel involved):

- 43 Federal FTEs
- 90 non-Federal FTEs
- 2 Contract FTEs and 1 Federal seconded FTE at international coordination offices

Customers, NOAA and non-NOAA, served:

- Operational forecast centers (e.g., NCEP, ECMWF, BoM, JMA)
- International research programs (e.g., CLIVAR, GEWEX, ASOF)
- Major scientific assessments – national and international (e.g., IPCC)

Potential benefits:
The Nations of the world will have the quantitative information necessary to: 1) forecast and assess climate variability and change, and 2) effectively plan for and manage their response to climate change.

FY 2003 Accomplishments:
Incremental advances were accomplished across four of the networks. The global carbon inventory survey was initiated. Eighty additional drifters were ordered but not deployed by the end of the fiscal year – they were deployed by the end of the calendar year. The Florida Current time series was shifted to sustained operations. Although not managed as part of this program, the Argo array is a central element of the system; Argo advanced by 379 floats deployed. The ocean system overall advanced from 40% complete in FY 2002 to 45% complete in FY 2003 which is 1% greater than the milestone target of 44%.

The new Office of Climate Observation (OCO) was established in accordance with the Annual Operating Plan as "a center to manage the climate observing system under the auspices of the NOAA Climate Program Office" (Q3 milestone). The OCO terms of reference provide for development of value added services to:

- Monitor the status of the globally distributed networks; report system statistics and metrics routinely and on demand.
- Evaluate the effectiveness of the system; recommend improvements.
- Advance the multi-year Program Plan; evolve the *in situ* networks.
- Focus intra-agency, interagency, and international coordination.
- Organize external review and user feedback.
- Produce annual reports on the state of the ocean and the adequacy of the observing system for climate.

The first Annual System Review was conducted May 13-15 in Silver Spring. This meeting brought together all of the project managers to discuss system-wide issues and engage in program strategic planning. It also initiated an annually scheduled forum for observing system users to provide feedback and discuss their requirements and recommendations for system evolution with the project managers. The most significant issue identified by the review was the gap in delivery of ocean analyses as an end product of ocean observations. The Climate Observation Program needs to either begin funding ocean analysis or work with other programs to ensure that this gets done.

A format was established for OCO to begin issuing a routine *Annual Report on the State of the Ocean and the Observing System.* The first report, for FY 2003, will be issued in March 2004. The report will:

- Explain the ocean's role in climate, in layman's terms.
- Provide information on the observed state of the ocean during the year.
- Document observing system activities during the year, based on the project manager annual reports.
- Summarize important advancements in ocean climate science during the year based on published scientific papers.

A framework was designed for establishment of Expert Teams to continually evaluate the effectiveness of the observing system and recommend system improvements. The framework calls for seven teams:

- Four "goal teams" will focus on evolving the observing system to ensure adequate and accurate measurement of ocean state and forcing variables:
    1) Sea level variability and change
    1) Ocean carbon sources and sinks
    1) Ocean storage and transport of heat and fresh water
    1) Air-sea exchange of heat and fresh water

- Three "mission teams" will cross-cut all goals to ensure that the observing system evolves in response to NOAA's forecast and assessment missions:
    1) Seasonal Forecasting
    1) Decadal Forecasting
    1) Climate Change

The Seasonal Forecasting expert team was initiated through collaboration with the CDEP Program. The CDEP ODASI Consortium served as the core for this team. ODASI conducted an initial experiment to evaluate the TAO array's impact on seasonal forecasting – initial results were presented at the Climate Diagnostics Workshop.

OCO began issuing routine quarterly reports on Observing System Status for the system's adequacy in measurement of sea surface temperature (see below). Status reports will be created in the future for all ocean state variables.

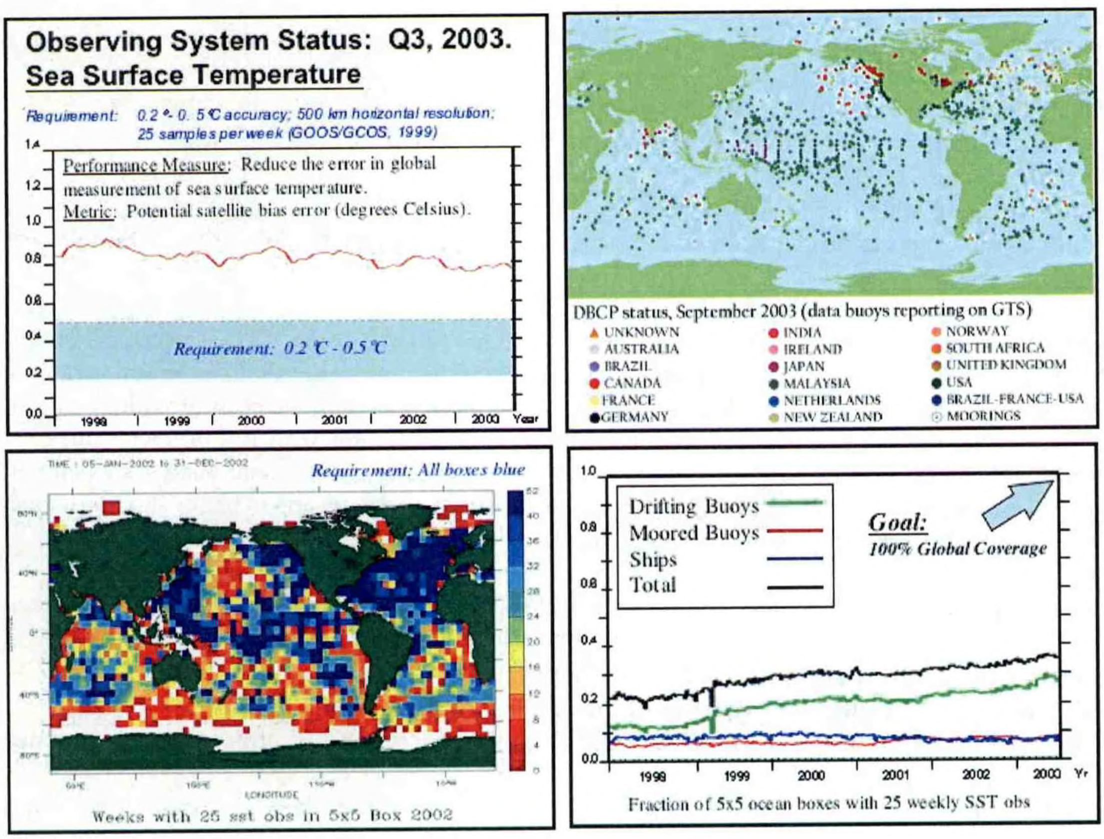


Table 3.1. Names of PIs (in alphabetical order by primary PI), the title of their funded projects, and project websites.

Office of Climate Observation Funded Projects and Websites		
Principal Investigator/ Co-Principal Investigator(s)	**Title of Project**	**Project Website**
Baringer, Molly Johns, Elizabeth Meinen, Christopher Garzoli, Silvia Flosadottir, Agusta	Western Boundary Time Series in the Atlantic Ocean	http://www.aoml.noaa.gov/phod/GOOS/work/trinanes/BAHAMAS/
Cook, Steven Molinari, Robert	ENSO Observing System	Drifters: http://www.aoml.noaa.gov/phod/dac/dacdata.html XBT: http://seas.amverseas.noaa.gov/seas/goosplots.html Associated projects: http://ww.jcommops.org http://seas.amverseas.noaa.gov/seas http://www-hrx.ucsd.edu http://www.cmdl.noaa.gov http://www://sahfos.org http://www.aoml.noaa.gov/phod/benchmarks/index.html http://www.aoml.noaa.gov/phod/enso/index.html http://www.aoml.noaa.gov/phod/taos/index.html
Consortium on the Ocean's Role in Climate (CORC)		
Davis, Russ	1. CORC: Project Infrastructure	
Roemmich, Dean	2. CORC: High Resolution XBT/XCTD (HRX) Transects	http://www-hrx.ucsd.edu
Weller, Robert Hosom, David	3. CORC: Observations of Air-Sea Fluxes and the Surface of the Ocean	http://science.whoi.edu/users/seasoar/vos/index.html
Niiler, Peter	4. CORC: Drifter Observations	
Davis, Russ	5. CORC: Underwater Gliders for Monitoring Ocean Climate	
Schmitt, Ray	6. CORC: Lagrangian Salinity Profiling: Evaluation of Sensor Performance	
Rudnick, Daniel	7. CORC: Development of an Underway CTD	
Cayan, Daniel	8. CORC: Northeast Pacific Air/Sea Flux Variability from Surface Marine Observations	
Cornuelle, Bruce; Stammer, Detlef; Miller, Art	9. CORC: Data Assimilation	
Fairall, Chris	High Resolution Climate Data from Research and Volunteer Observing Ships	http://www.etl.noaa.gov/et6/air-sea/

Feely, Richard; Wanninkhof, Rik; Sabine, Christopher; Johnson, Gregory; Baringer, Molly; Bullister, John; Mordy, Calvin; Zhang, Jia-Zhong	Global Repeat Hydrographic/CO_2/Tracer Surveys in Support of CLIVAR and Global Carbon Cycle Objectives	http://whpo.ucsd.edu/data/co2climvar/atlantic/a16/a16n_2003/index.htm
Feely, Richard; Wanninkhof, Rik Bates, Nicolas; Millero, Frank; Takahashi, Taro; Cook, Steven	Document Ocean Carbon Sources and Sinks: Initial Steps Towards a Global Surface Water pCO_2 Observing System Underway CO_2 Measurements on the NOAA ships Ka'imimoana and Ron Brown and RVIB Palmer and Explorer of the Seas	Central site at: http://www.aoml.noaa.gov/ocd/pco2/ Sites that have been centralized: http://www.aoml.noaa.gov/ocd/gcc http://www.pmel.noaa.gov/uwpco2/ http://www.ldeo.columbia.edu/res/pi/CO2/
Garzoli, Silvia	Tropical and Sub-tropical Atlantic Surface Drifters Array	www.aoml.noaa.gov/phod/dac/
Garzoli, Silvia Goni, Gustavo Baringer, Molly Molinari, Robert	Implementation of High Density XBT Lines in the Atlantic Ocean	http://www.aoml.noaa.gov/phod/hdenxbt/
McPhaden, Michael	TAO Array and PIRATA	http://www.pmel.noaa.gov/tao/
Merrifield, Mark	Global Sea Level Center: In-Situ Sea Level; The University of Hawaii Sea Level Center	http://uhslc.soest.hawaii.edu
Morrissey, Mark Postawko, Susan Greene, Scott	Program Support through the Assimilation, Analysis and Dissemination of Global Raingauge Data	http://www.evac.ou.edu/srdc http://srdc.evac.ou.edu
Niiler, Peter	The "Global Drifter Program"	http://www.aoml.noaa.gov/phod/dac/drifter_bibliography.html
O'Brien, James; Bourassa, Mark; Smith, Shawn	Climate Variability in Ocean Surface Turbulent Fluxes	http://www.coaps.fsu.edu/RVSMDC/SAC http://www.coaps.fsu.edu/RVSMDC/html/winds.shtml
O'Brien, James; Bourassa, Mark; Smith, Shawn	Quality-Evaluated Meteorological Data from Research Vessels	http://www.coaps.fsu.edu/RVSMDC/
Reynolds, Richard	*In situ* and Satellite Sea Surface Temperature (SST) Analyses	http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/
Weller, Robert Plueddemann, Albert	Ocean Reference Stations and Northwest Tropical Atlantic Station for Flux Measurement (NTAS)	WHOI: https://www.whoi.edu UOP Group: http://uop.whoi.edu Stratus Project: http://uop.whoi.edu/stratus NTAS Project: http://uop.whoi.edu/ntas
Weller, Robert Hosom, David	Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic (Atlantic VOS)	http://frodo.whoi.edu

FY 2003 Accomplishments

NOAA Observing System Monitoring Center

by Landry Bernard, Steve Hankin, James Hall, Kevin O'Brien, Cheryl Demers

The items below detail the activities that NDBC and PMEL has performed in support of the Observing System Monitoring Center (OSMC) project for the period June-December, 2003.

Project Startup Activities:

Drafted the Conceptual Project Plan for the NOAA Observing System Monitoring Center as a joint project between NDBC and PMEL. This plan included a Plan of Actions & Milestones (POA&M) and cost estimates. This occurred during the June-July 2003 timeframe and initiated the project.

Developed a Statement of Work (SOW) for SAIC to cover the two positions required to support the OSMC project as detailed below:

- Observing systems Monitoring Center NDBC IT Support
- Observing Systems Monitoring Center OGP IT Support

Developed the NDBC Technical Directive (TD) and the Internal Work Request to cover the two statements of work.

Worked with SAIC to negotiate an acceptable labor rate and skill set to cover the two positions.

July 2003, the NDBC IT position is filled with an SAIC Hampton resource.

In August after an extensive interview process the OGP IT (Ops Officer) position is filled. After one week on the job the individual submits his resignation.

After the resignation of the first Ops Officer, the next two highest applicants were contacted to see if they were still interested in the job. OGP was involved in a re-interview process, which led them to determine that they may want to change the job requirements since the existing requirement appeared hard to fill. In the October 2003 timeframe OGP decided to cancel the requirement and fill the position with an in-house contractor.

Project Management Activities:

Developed a Gantt chart in Microsoft Project to track OSMC related project taskings and deliverables.

Started a weekly OSMC Teleconference to coordinate activities between NDBC and PMEL. The teleconference is currently held on Monday mornings and include personnel from PMEL, NDBC, SAIC at NDBC, and SAIC in Hampton. The OGP Ops officer is also invited to participate.

Provide monthly project status reports to OGP that include the following information: Contract Summary, Cost Summary, Accomplishments, Plans and Concerns/Recommendations. The status report includes an updated project plan as an attachment.

Technical Project Support Activities:

Since the OGP Ops position was not filled in a timely manner and to support the customer requirement, NDBC provided one of our SAIC contractors to support OSMC work. During the months of August and September, that individual spent the majority of his time in Silver Spring handling issues related to the OSMC briefing center. As a part of this task, he researched and tested various monitor/display configurations and provided a final brief and recommended solution to OGP. Once, the final decision was made by OGP, the SAIC resource assisted in putting the procurement actions together.

Prepared a brief on the OSMC effort for OGP to present to the US-Japan UJNR "Pacific Ocean Observations and Research Initiative" (TYKKI) Panel science meeting held in Tokyo Japan.

The majority of the NDBC IT resource time was spent researching the platform and parameters identified in the "Bubble Chart" in an effort to develop a Draft Data Management and I/O Requirements document. The Data Management and I/O Requirements document is being developed incrementally with a draft having been provided to NDBC in September and December 2003. The final document is scheduled for delivery to NDBC in March 2004.

The NDBC IT resource also spent a great deal of time developing the Draft OSMC Architecture document. In order to assist in this effort a database was setup in Microsoft Access and a limited amount of data was ingested to help in identifying sizing requirements and potential performance issues. The Architecture document is being developed incrementally with a draft having been provided to NDBC in December 2003 and the final document scheduled for delivery to NDBC in March 2004. The final Architecture document will consist of the recommended hardware, software and telecommunications.

Researched cross-platform (MAC/PC) Video Conferencing capabilities. The iVisit software/site appears most promising. The free version of this program (with limited capabilities) was installed on 3 machines and tested across the firewall with good success. We recommend that OGP download the Mac version and arrange an OGP/NDBC test. Other cross-platform possibilities exist if this path is not successful.

The server software to support a local Live Access Server was installed on a test system at NDBC. The configuration of the system will take additional work next year that will require support from the PMEL subject matter experts.

PMEL Activities:

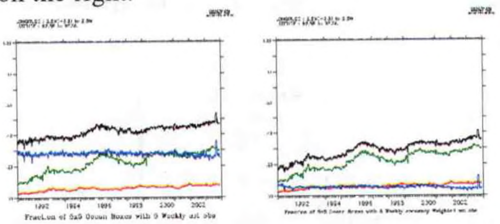
Creation of monthly statistical observation database using data from NCEP and US GODAE

Implemented prototype to meet anticipated September inauguration of OGP "War Room"

- Creation of OSMC streamlined "Executive" user interface provides graphics for the evaluation of:
  - Spatial density of observations
  - Depth of salinity and temperature observations
  - Sea surface temperature (SST) observations
- Creation of custom animations for selected variables (using Mac-compatible "Flash" software)
- Make user interface, graphics and animation modifications to address comments received from OGP

Enhancements to initial prototype

- For "Executive" user interface
    - Created "ship-weighted SST" as an output product for the spatial density of observations page. An example of the difference is below: In each figure, the blue line is ship observations and the black line is total observations. The figure using ship-weighted observations is on the right:



- Creation of Live Access Server user interface for in-depth data exploration
    - Advanced the LAS interface on the OSMC to IOC (Initial Operational Capability) status
    - Add user-settable thresholds to specify the minimum percent of time a 5x5 degree box had observations in a given week
    - Backend database and figure scripts updated to enhance speed of LAS

Interface and Data Management/IO Documents

- Guide SAIC in transfer of OSMC to NDBC
- Created document describing basic harvest methods of in-situ data and structure of database
- Created technical document describing data harvesting
    - Where to obtain *in situ* data
    - How to ingest the data into our developed databases
    - Including code examples as well as statistical methods incorporated in the database construction.
- Created draft documentation of the interface requirements for the OSMC raw observational database

Ongoing tasks

- Monthly updating of statistical observation database using latest data from NCEP and US GODAE
- Monthly updating of high performance (pre-generated) images needed for the "Executive" User Interface

THE OBSERVING SYSTEM MONITORING CENTER:

A TOOL FOR THE EVALUATION OF THE GLOBAL OCEAN OBSERVING SYSTEM

Kevin O'Brien[1], Kevin McHugh[1], Gabriel Vecchi[1], Ed Harrison[2], Steve Hankin[2], Ansley Manke[2]

[1]JISAO/University of Washington

[2]NOAA/Pacific Marine Environmental Lab

OSMC Background

Executive Summary

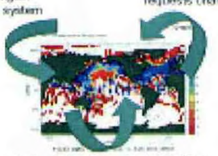
- There is a clear need for a system that provides a full view of the global ocean climate observing system.
- OMSC is to be a decision support tool that shows the gaps and overlaps in the observing system.

- **Primary focus is decision support for NOAA**
  - Accessed via Internet during decision making process
  - Displayed by large-panel displays in OSMC briefing room
- **Expected to be very useful for the community at large**
  - Managers of each platform family
  - Researchers evaluating model performance
- **OSMC servers hosted by National Data Buoy Center (NDBC) at Stennis Space Center in Mississippi**
  - Experienced with maintaining production NOAA info systems
  - Leveraging existing NDBC server systems

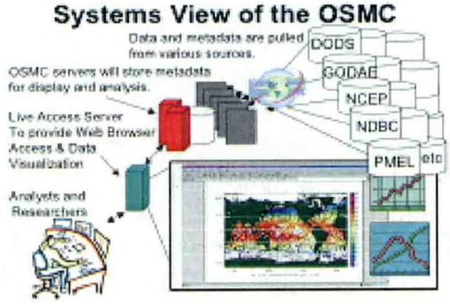
Timeline

- Incremental, Quarterly enhancements 2003-2004
- PMEL already has a working prototype
- NDBC to host prototype system in early 2004
- Initial Operational Capability in late 2004
- Full Operations Capability in late 2005

Software Development Approach



Systems View of the OSMC

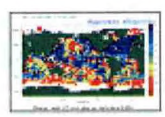


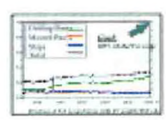
OSMC at NOAA's Pacific Marine Environmental Lab

Initial prototype at **http://www.ferret.noaa.gov/OSMC**

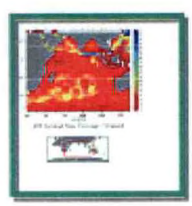
OSMC will remain web accessible

"Executive" User Interface
(for standard analysis)





Live Access Server
(a probe to look deeper)



Western Boundary Time Series in the Atlantic Ocean

by Molly Baringer, Elizabeth Johns, Christopher Meinen, Silvia Garzoli, and Agusta Flosadottir

PROJECT SUMMARY

Scientific Rationale and General Overview:

The Atlantic meridional overturning circulation consists primarily of two western boundary components: the northward flowing Gulf Stream and the southward flowing Deep Western Boundary Current. The Gulf Stream is the strong surface intensified flow along the east coast of the United States that brings warms waters of tropical origin along the eastern seaboard of the United States. The Gulf Stream also brings with it carbon, nutrients and tropical fish. It supplies warm waters along the coast that impact a multitude of important climate phenomena including hurricane intensification, winter storm formation and moderate European weather. The Gulf Stream represents the bulk of what we call the upper limb of the thermohaline circulation in the subtropical Atlantic, in addition to a strong wind-driven flow. As the Gulf Stream flows northward, it loses heat to the atmosphere until eventually in the subpolar North Atlantic some of it becomes cold enough to sink to the bottom of the ocean. This cold deep water then returns southward along the continental slope of the eastern United States as the Deep Western Boundary Current, completing the circuit of the overturning circulation.

Off the coast of Florida, the Gulf Stream is referred to as the Florida Current and is fortuitously confined within the limited geographic channel between Florida and the Bahamas Islands, thus making a long-term observing system cost effective and sustainable. Similarly, the Deep Western Boundary Current is located within several hundred miles to the east of the Abaco Island, Grand Bahamas. The convenient geometry of the Bahamas Island chain thus allows an effective choke point for establishing a long term monitoring program of this deep limb of the overturning circulation.

This project consists of four components to monitor the western boundary currents in the subtropical Atlantic: _Task 1:_ Florida Current transport measurements using a submarine telephone cable plus calibration cruises, _Task 2:_ Deep Western Boundary Current transport and property measurements using dedicated research ship time, _Task 3:_ Quality control of continuous Cable Transport Measurements and _Task 4:_ Moored observations of the Deep Western Boundary Current.

Project Description

Task 1: Continuous Transport of the Florida Current

The project maintains NOAA's well-established and climatically significant Florida Current volume transport time series. Over 16 years of daily mean voltage-derived transports have been obtained for the Florida Current using out-of-service and in-use cables spanning the Straits of Florida. The cable voltages can be converted to physically meaningful transport estimates i.e., intensity of the flow, using electromagnetic induction theory. These transport measurements contain decadal changes on the order of 10-25% of the long-term mean transport and these decadal changes track the North Atlantic Oscillation Index. There is a strong correlation of Florida Current transport variability with the North Atlantic Oscillation, and by extension with the large-scale sea-surface temperature patterns associated with the North Atlantic Oscillation. This suggests connections to tropical Atlantic variability on climatically significant time scales, and links with the numerous societally significant weather and climate phenomena that are thought to be related through large scale ocean-atmosphere patterns in the Atlantic, including decadal and interdecadal variations in fisheries, rainfall, and hurricane activity.

Funding provides for continuous collection of cable voltages (every minute) and automated processing of simple geomagnetic corrections. In addition to the cable measurements, quarterly calibration cruises are required for this project's success. These measurements complement a related project that measures the upper ocean thermal structure in the Atlantic through high-density VOS XBT observations. Funding provides for four two-day small charter boat calibration cruises on the R/V F. G. WALTON SMITH each year.

Task 2: Deep Western Boundary Current Time Series

The Abaco time series began in August 1984 when the NOAA Subtropical Atlantic Climate Studies Program extended its Straits of Florida program to include measurements of western boundary current transports and water mass properties east of Abaco Island, Grand Bahamas. Since 1986, over 20 hydrographic sections have been completed east of Abaco, most including direct velocity observations, and salinity and oxygen bottle samples. Many sections have also included carbon, chloroflourocarbon, and other tracers. The repeated hydrographic and tracer sampling at Abaco has established a high-resolution record of water mass properties in the Deep Western Boundary Current at 26N. Events such as the intense convection period in the Labrador Sea and the renewal of classical Labrador Sea Water in the 1980's are clearly reflected in the cooling and freshening of the Deep Western Boundary Current waters off Abaco, and the arrival of a strong chlorofluorocarbon pulse approximately 10 years later. This data set 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.

These continued time series observations at Abaco are seen as serving three main purposes for climate variability studies:

- Monitoring of the DWBC for water mass and transport signatures related to changes in the strengths and regions of high latitude water mass formation in the North Atlantic for the ultimate purpose of assessing rapid climate change.
- Serving as a western boundary endpoint of a subtropical meridional overturning circulation (MOC)/heat flux monitoring system designed to measure the interior dynamic height difference across the entire Atlantic basin and its associated baroclinic heat transport.
- Monitoring the intensity of the Antilles Current as an index (together with the Florida Current) of interannual variability in the strength of the subtropical gyre.

Task 3: Quality Control of Continuous Cable Transports

Cable voltage measurements must be analyzed with respect to the earth's changing magnetic field, and compared to ground truth observations, in order to estimate the voltage induced by the Florida Current transport. Part of this task includes:

- More refined processing, analysis and quality control of the data, including signal separation for signals of tidal and geomagnetic origin, and watching for possible symptoms of any cable faults or electrode problems, to produce the research quality data set required for modeling and statistical studies and to fully implement the 'Ten Rules for Climate' reference time series.
- Cable protection activities, including interaction with the International Cable Protection Committee. Maintaining visibility and good relations with the telecom industry's cable protection association provides an essential element of protection from damage during installation of new cable and pipeline systems.
- Contingency response and long-range planning. This includes planning for equipment failures and maintenance issues, as well as cable owner and cable station relations. Although not funded by the budget below, it is also essential for long-range reliability that we begin planning to prepare for instrumenting other cable systems across the Florida Current.

Task 4: Moored observations of the Deep Western Boundary Current

Over the past 20 years a variety of snapshot sections and time series moorings have been placed along the continental slope east of Abaco Island, Grand Bahamas, in order to monitor variability of the transport carried by the Deep Western Boundary Current. This task seeks to develop a low cost method for long-term monitoring this flow. The project will deploy four pressure gauge equipped Inverted Echo Sounders (PIES) across the shallow northward flowing Antilles Current as well as the southward flowing Deep Western Boundary Current. The PIES deployment will be part of an interagency and international partnership that is testing a variety of low cost methods for observing the Deep Western Boundary Current east of Abaco.

Funding was provided at the end of the fiscal year for the purchase of three PIES from the University of Rhode Island. The PIES will be deployed along 26.5°N east of Abaco Island in June 2004. The instruments will be recovered in spring-summer 2006.

How this project addresses NOAA's Program Plan for *Building a Sustained Ocean Observing System for Climate*:
The program plan for "Building a Sustained Ocean Observing System for Climate" includes the objectives of:

1) Documenting the heat uptake, transport, and release by the ocean; and
2) Documenting the air-sea exchange of water and the ocean's overturning circulation.

This project is one component of the "Ocean Reference Station" at approximately 26°N in the Atlantic Ocean that specifically addresses these goals by providing long term integrated measures of the global thermohaline (overturning) circulation. This project is designed to deliver yearly estimates of the state of the thermohaline circulation, i.e., its intensity, properties, and heat transport. Heat and carbon generally are released to the atmosphere in regions of the ocean far distant from where they enter. Monitoring the transport within the ocean is a central element of documenting the overturning circulation of fresh water, heat and carbon uptake and release. Long-term monitoring of key choke points, such as the boundary currents along the continents including the Gulf Stream and the Deep Western Boundary Current, will provide a measurement of the primary routes of ocean heat, carbon, and fresh water transport and hence include the bulk of the Meridional Overturning Circulation.

How this project is managed in cooperation with the international implementation panels, in particular the JCOMM (Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology) panels:
This program is managed under the AOML Global Ocean Observing System (GOOS) Center, created in cooperation with national and international steering committees to provide an administrative umbrella that coordinates several operational oceanographic data collection networks. As part of GOOS, this program falls within the Observations Program Area of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM).

Responsible institutions for all aspects of project:
NOAA/AOML is responsible for *Tasks 1, 2,* and *4* of this project.
NOAA/JISAO is responsible for *Task 3* of this project.

Project web site URL and pertinent web sites for your project and associated projects:
http://www.aoml.noaa.gov/phod/GOOS/work/trinanes/BAHAMAS/
The project web page is under development until the data is deemed research quality (see *Task 3*).

Interagency and international partnerships:
This project provides the cornerstone observations required for a national and international pilot program to develop an observing system to monitor the intensity and heat transport of the overturning circulation at 26°N in the Atlantic. Partners in this project include the National Science Foundation, University of Miami, Woods Hole Oceanographic Institution, University of Southampton (England), the United Kingdom's National Environmental Research Council (NERC) and NOAA/AOML. This NOAA project provides the essential Florida Current component of the monitoring system, plus ship time and hydrographic observations to augment the moored observations east of Abaco Island, Grand Bahamas. Programs include the NSF sponsored Meridional Overturning, Circulation and Heat transport Array (MOCHA) proposal and the NERC Rapid Climate Change program.

Statement that your project is managed in accordance with the Ten Climate Monitoring Principles (reference attached Program Plan)
This program is managed in accordance with the Ten Climate Monitoring Principles (Program Plan, Mike Johnson, 2003). This time series contains several gaps in the continuous record due to logistical requirements, funding shortfalls and, more recently, to instrument failure. To better assure an adequate climate record, parallel testing and parallel measurements would be required to assure continuity of the time series without gaps. 'Data quality and continuity', principle 4 of the ten climate monitoring principles, and 'data and meta data access', principle 10, have suffered as a direct result. We request additional funds in "Add Task" to address these deficiencies and assure a better research quality time series.

FY 2003 PROGRESS
Instrument/platform acquisitions for fiscal year and where equipment was deployed

Task 1: Continuous transport of the Florida Current
Recording instruments are located at Eight Mile Rock, Grand Bahamas Island. At Eight Mile Rock and in West Palm Beach, Florida, electrode equipment is in place, securing a stable reference voltage (i.e. grounds) at either end of the submerged telephone cable owned by AT&T. The monitored cable can be seen in Figure 1, stretching across the Florida Straits. Equipment acquisitions this year include maintenance and repair items including digital phone line filters, electrodes (to provide stable reference ground voltages), an isolation transformer and a modem. This equipment now resides in the Bahamas at the BattelCo Telephone station with our recording equipment.

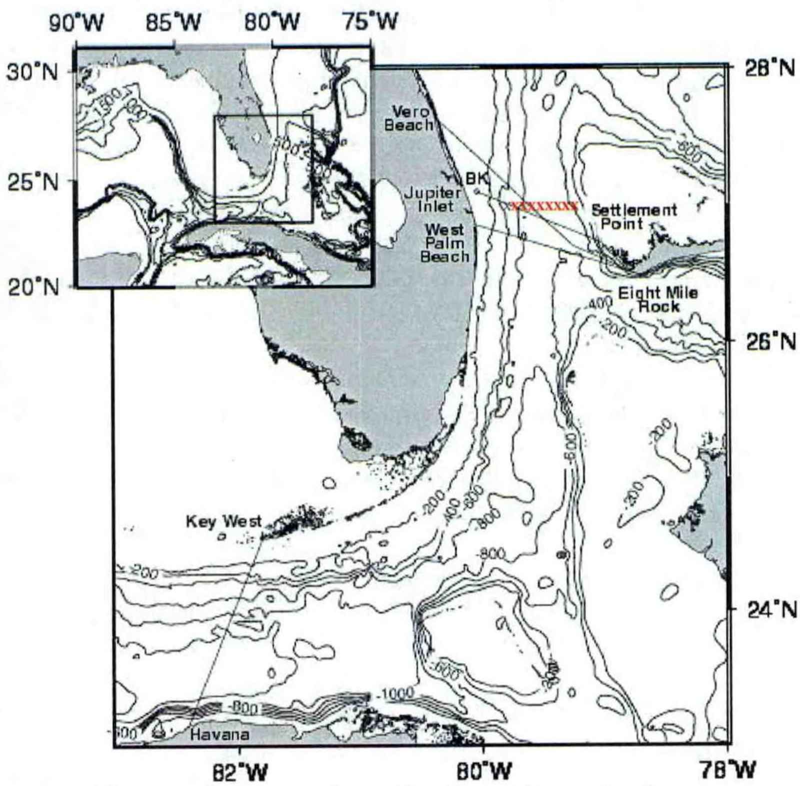


Figure 1: Location of submarine telephone cables (solid black) and nine stations (red) occupied during small boat calibration cruises.

Small charter boat calibration trips
Calibration cruises include occupation of the same 9 locations at 27°N in the Florida Straits. The locations are shown in Figure 1.
Full Water Column surveys: No new equipment acquisitions.
Net transport surveys: Purchased equipment to build a new dropsonde after the loss of the previous dropsonde on August 23, 2002. New purchases included a self-recording conductivity, temperature depth (CTD) recorder, GPS, radio transmitter, glass pressure housing, batteries and antennae.

<u>*Task 2: Deep Western Boundary Current time series*</u>
The hydrographic cruise this year took place on the RV RONALD H. BROWN during Feb 3 to 15, 2003. A total of 54 stations were occupied at the locations shown in Figure 2. No new equipment acquisitions were required. Three inverted echo sounders were recovered.

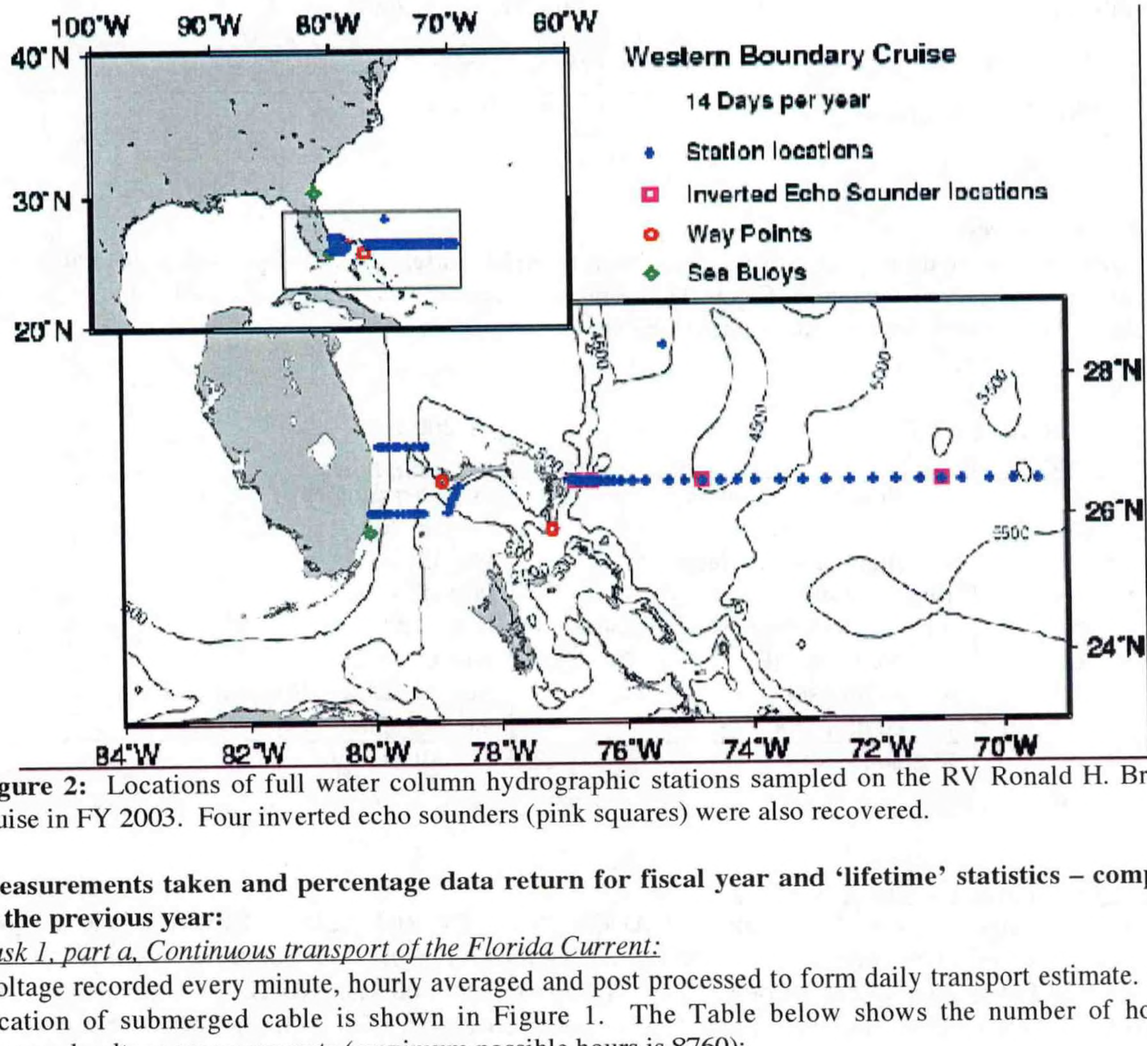


Figure 2: Locations of full water column hydrographic stations sampled on the RV Ronald H. Brown cruise in FY 2003. Four inverted echo sounders (pink squares) were also recovered.

Measurements taken and percentage data return for fiscal year and 'lifetime' statistics – compare to the previous year:
<u>*Task 1, part a, Continuous transport of the Florida Current:*</u>
Voltage recorded every minute, hourly averaged and post processed to form daily transport estimate. The location of submerged cable is shown in Figure 1. The Table below shows the number of hourly averaged voltage measurements (maximum possible hours is 8760):

FY 2003	FY 2002
7755 Hours 89% Return	6264 Hours 72% Return[1]

<u>*Task 1, part b, Calibration cruises:*</u>

[1] Note old recording system failed in FY 2002.

Full Water Column surveys:
Two day cruise on RV Walton Smith, four per year scheduled. All cruises include nine stations with full water column CTD, lowered ADCP, and continuous shipboard ADCP. The station locations are shown in Figure 1. The Table below includes number of water samples taken for oxygen concentration (O2) and salinity (S).

FY 2003		FY 2002	
Date	Water Samples	Date	Water Samples
Nov 20, 2002	43 O2, 44 S	NA	
Mar 22, 2003	59 O2, 49 S	Mar 8-9, 2002	33 O2, 24 S
July 16, 2003	56 O2, 46 S	May 31- Jun 1, 2002	37 O2
Sep/Oct 2003	Not yet available	Aug 19, 2002	49 O2
100% of Planned Cruises		75% of Planned Cruises	

Net transport surveys:
One day survey using dropsonde profiler (maximum of eight cruises scheduled per year). Measurements are taken at nine stations (shown in Figure 1) and include vertically averaged horizontal velocity, surface velocity and expendable temperature probes (XBTs):

Planned Cruise	FY 2003	FY 2002
1	- clearance problems	- weather problems
2	- clearance problems	Dec 14, 2001
3	- equipment problems	Mar 12, 2002
4	Mar 18, 2003	Mar 18, 2002
5	June 7, 2003 – dropsonde failure	June 3, 2002
6	- no dropsonde	June 6, 2002
7	- no dropsonde	Aug 23, 2002 – dropsonde failure
8	- no dropsonde	-no dropsonde
	13% successful[2]	63% successful

<u>*Task 2. Deep Western Boundary Current time series:*</u>
Full water column cruise of CTD, Lowered ADCP on the RV RONALD H. BROWN (one per year scheduled). A total of 54 stations were occupied during the cruise. At each station, a package consisting of a Seabird Electronics Model 9/11+ CTD O_2 system, an RDI 300 kHz Workhorse Lowered Acoustic Doppler Current Profiler, and 24 10-liter Niskin bottles, was lowered to the bottom. This provided profiles of velocity, pressure, salinity (conductivity), temperature, and dissolved oxygen concentration. Water samples were collected at various depths and analyzed for salinity and oxygen concentration to aid with CTD calibration. Underway Seabird Electronics SBE-21 thermosalinograph data and bathymetry data were also collected. A survey of the bathymetry in the Florida Straits near 27°N was also conducted,

[2]See section describing encountered. Four calibration points were missing due to dropsonde failure. Two calibration points missing due to failure to obtain clearance to work in Bahamian waters.

using the Seabeam 2112 (12 kHz) swath bathymetric sonar system, to aid in the analysis of ocean transport measurements made by a submarine cable in that area (Task 1).

FY	Date	Stations	Bottle Samples	Add-On
2003	Feb, 2003	54	2000	IES Mooring recovery, Short Seabeam in Florida Straits
2002	June 2002	45	2000	Extended Seabeam survey east of Abaco Island

Task 3: Quality Control of Continuous Cable Transports

This past year our major effort under Task 3 has unfortunately had to be in the category of contingency response, contributing to the diagnosis and resolution of data problems. While there was a good return of data coming in from the field, it became clear fairly early in the year that the data were having some intermittent, but persistent problems. Starting with a few highly intermittent offsets in the voltage level, over the course of the year the level of the cross-stream voltage became obviously too high to be realistic. We were initially led in conflicting directions as to possible sources of the problem. In response, we delayed posting the data for use of the general community while attempting to establish the cause of the problems and possible means of correction.

Diagnosis was made difficult by the highly intermittent nature of the initial symptoms, and complicated by some equipment damage precipitated by failure of an isolation transformer. During the year, we consulted with Jim Larsen, who built the successful record of the previous two decades of the cable time series, with Tom Sanford of the University of Washington, and with Chip Cox of SIO, all authorities on electric measurements in the ocean, and with the engineers who built the recording equipment. Field trips by AOML employees were made for repairs and troubleshooting. The antiquated recording equipment that had broken down the previous year was resurrected and patched together with new components to run in parallel with the new system, but eventually failed again.

Just before submission of this report, we believe that we have turned the corner, and are again collecting good data. AOML engineers have diagnosed a combination of a bad electrode and of ground loops, possibly caused by prior equipment damage, as the source of our problems. The failed electrode has been replaced, and they have put the system in a temporary configuration that eliminates the ground loop problems and appears to be producing good data.

Task 4, Mooring observations of the Deep Western Boundary Current:

Inverted echo sounders will be deployed in FY 2004.

Where data are stored, data distribution, availability and access to data

All data are stored at AOML and are available upon request. Cable data are collected and stored on a computer in the Bahamas and downloaded daily to AOML. Preliminary cable data are available via web interface upon request and will be more freely available once the new calibration system is operational. CTD data will be distributed to NODC and the WOCE hydrographic program office when final calibration is complete.

How data are currently being used and shared

Small boat calibration data are processed to supply a total transport of the Florida Current and are used to check the cable voltage measurements. Water bottle sample data are used to calibrate CTD data, to compute property fluxes within the Deep Western Boundary Current and Florida Current. Water properties of the Deep Western Boundary Current are used to infer time scales of deep-water renewal and monitor the intensity of the thermohaline circulation. All data are stored at AOML and are freely available upon request.

Anticipated and unanticipated project costs

Task 1, Part a (voltage recording): Unanticipated costs included extensive repair of the cable recording system in the Bahamas, equipment, travel and personnel costs. In excess of eight trips have been made this FY to diagnose equipment malfunctions.

Task 1, Part b (calibration cruises): Additional unanticipated costs included the loss of the dropsonde equipment in August 2002 and again in July 2003.

Problems encountered

Task 1, Part a, Continuous cable voltage recording: Problems included the failure of an electrode at Eight Mile Rock, Grand Bahamas (which supplies the stable voltage to compare with transport induced voltages on the submarine cable) and two recently diagnosed ground loops in the replacement recording equipment built by APL/UW (purchased in Jan 2002). The electrode failure induced abrupt but correctable offsets in the cable voltages (Larsen 1992).

Task 1, Part b, Calibration cruises: Problems included the inability to acquire clearances with the Bahamian government until mid December after the first two scheduled cruises. In July 2003, the second dropsonde in more than two decades was lost at sea. Flooding of the pressure casing was suspected.

Logical considerations (e.g., ship time utilized)

- Clearances to do technical work in the Bahamas to the recording equipment are necessary and very difficult to obtain.
- Blanket clearances are necessary to work on calibration cruises due to the short lead-time for scheduling the cruises.
- Bahamian clearances for the large ship Deep Western Boundary Current cruises are also necessary.
- This work would not be possible without the considerable help of BattelCo, the Bahamian telephone company, for the use of their facilities to store our equipment, install phone lines and to instrument their telephone submerged cable.
- Vigilance towards cable protection activities is also required to prevent the cable from being inadvertently cut.
- Ship days required:

Ship	Seadays per trip	Trips per year	Total Seadays
RV Ronald H. Brown	14	1	14
RV Walton Smith	2	4	8
Charter Fishing Boat	1	8	8

Research highlights

Task 1: Part a, Continuous transport of the Florida Current

Voltage estimates recorded from the submarine cable were corrected for geomagnetic variations due to the changing ionosphere and then adjusted using the transfer function that relates voltages to total flow through the Florida Straits (Larsen, 1992). Preliminary estimates of the flow are shown in Figure 3 and are available on the project web site. Several features of note appear to be related to the failure of the reference electrode at Eight Mile Rock, Grand Bahamas. In July 2002 and later September 2002 the voltages jumped abruptly in magnitude and then returned to more normal values. Testing revealed no problem; the old recording equipment was re-installed to act in parallel (the old equipment is referred to as the "BBIS" system and was designed by PMEL engineers in the early 1980's and later repaired by

AOML engineers). Another jump in voltages was observed in October of 2003 on both systems. The last jump occurred in May 2003, which was observed in only the new system (which is referred to as the "UW" system since it was built under subcontract by the University of Washington's Applied Physics Laboratory). Due to the intermittent nature of the problem, diagnosis was difficult. Recently, it has been determined that the "UW" system contains two undiagnosed and unexpected ground loops. The current hypothesis is that the system began to malfunction when the system was connected to the station ground in order to obtain redundant reference information (the "UW" system allows us to monitor an additional voltage source or channel). Unfortunately, once connected to this ground, several ground loops were induced, carrying large current from the station ground to our buried reference electrode. Too much current sent to the reference electrode (which was also several decades old), caused the electrode to short out, producing an open circuit. The reference electrode has been replaced and the "UW" system has been 'isolated' to prevent future ground loops. The system is now monitoring only the submerged cable and the reference electrode. The excess ground loops appear to have harmed the back up recording system as well, the "BBIS" system, which failed in August 2003.

In order to assure research quality data, these data will need to be carefully examined and corrected by judicious use of the final geomagnetic data, comparing tidal signals, and using tidally-corrected transport calibration data. Unfortunately, electrode failure is to be anticipated (and similar problems have occurred in the past, which were corrected – see Larsen, 1992). In order to assure the best climate time series several steps are recommended:

1. A backup system must be available and in good repair, in case of catastrophic failure of the primary recording system.
2. A second submarine cable should be instrumented and recorded in parallel. This would guard against failure of the submarine cable itself and provide a useful diagnostic for comparison with the primary cable.
3. Data recovery efforts should include careful analysis of tidal signals in overlapping 30 day segments of the time series to adjust for jumps in the data, and careful removal of ionospheric induced voltages.

Task 1, part b: Florida Current calibration cruises

Calibration cruises show transports of the Florida current varying from 26.9 to 30.8 Sv. Note that, the current is not always monotonically northward. A subsurface southward flow between 150 to 500 meters deep along the western side of the Strait can be seen in several of the full water column sections.

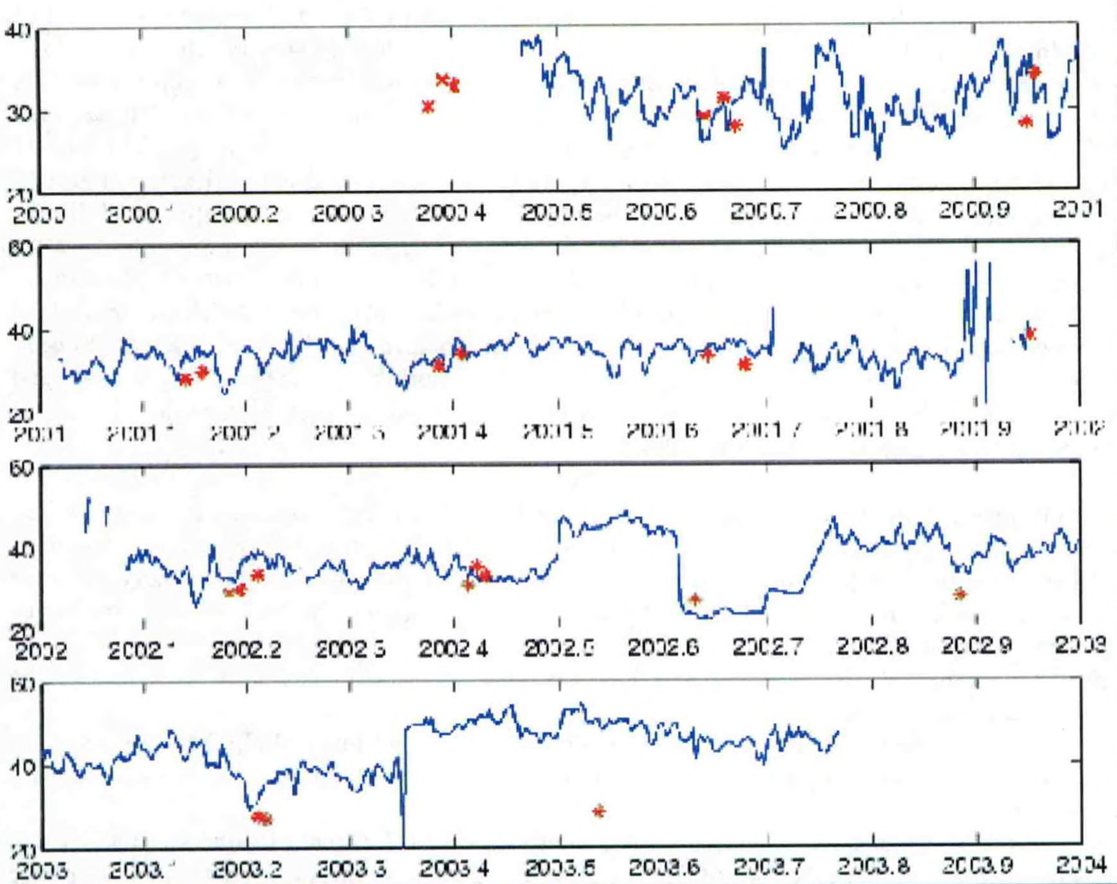


Figure 3: Daily estimates of Florida Current transport determined by voltages induced in submerged, submarine telephone cable. Transports given in Sv (1 Sv = 10^6 m^3 s^{-1}). Red symbols represent calibration cruises from small charter boats.

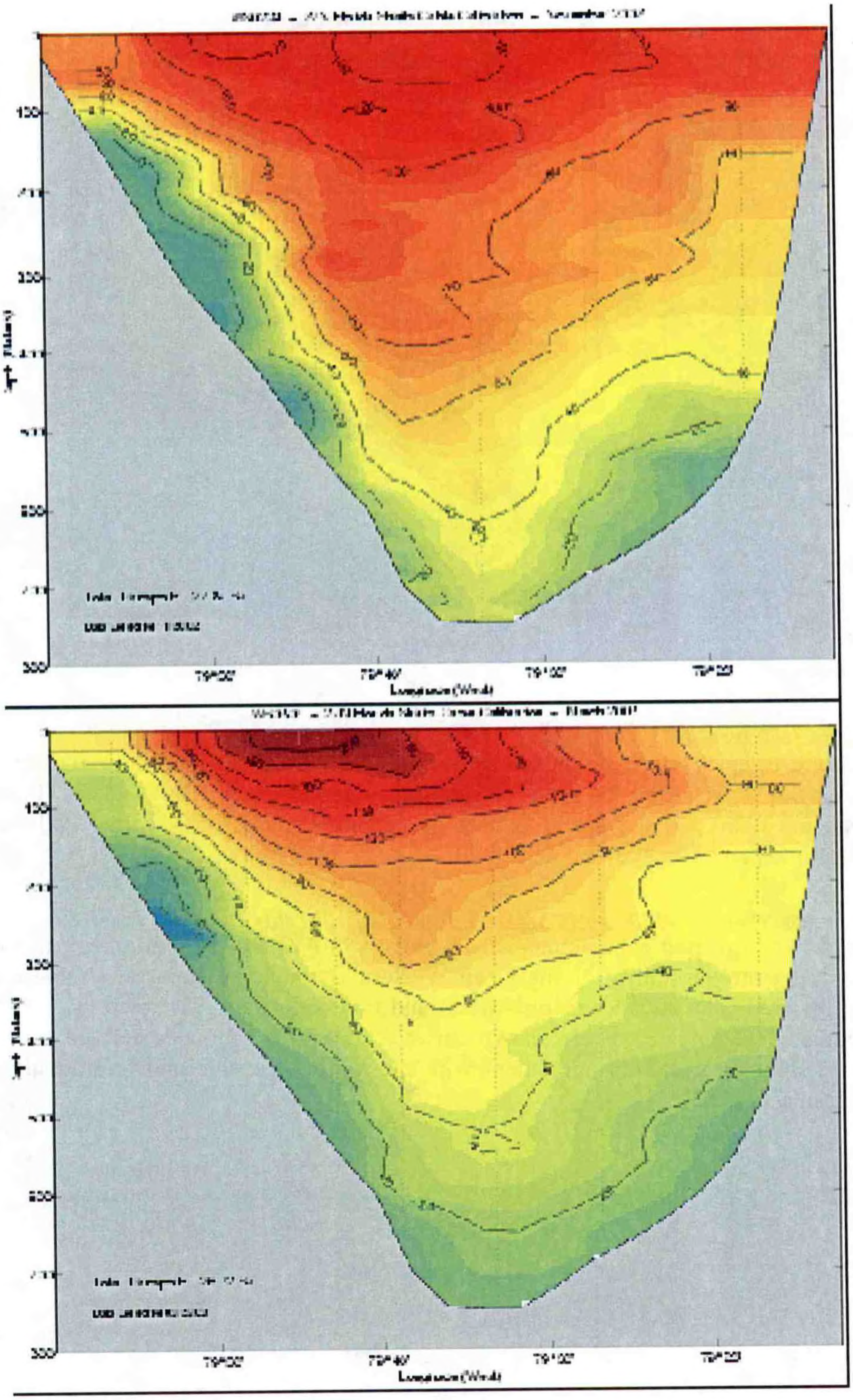


Figure 4: Small boat calibration cruises show the complex vertical structure of the Florida Current. Note that the Sep/Oct 2003 cruise is not yet available.

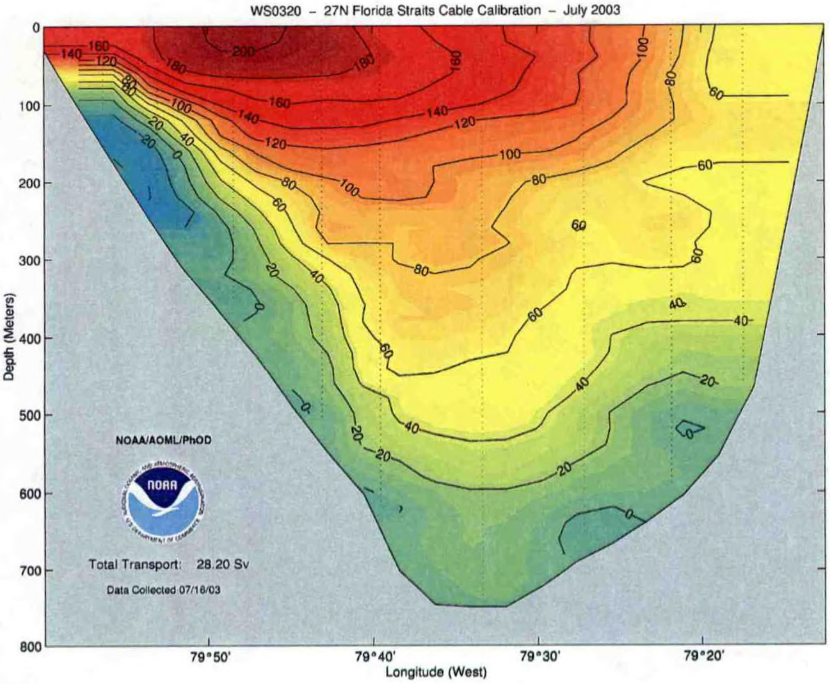


Figure 4: (continued)

Task 3: Deep Western Boundary Current Time Series

Full water column Deep Western Boundary Current CTD/LADCP sections show the arrival of newly formed Labrador Sea water in the center of the subtropical gyre beginning in late 1994 (Figure 5). Since its first arrival, the Labrador Sea Water is seen to become progressively colder and fresher and its influence is felt further and further offshore.

Task 4: Moored observations of the Deep Western Boundary Current

In preparation for the inverted echo sounder deployments in FY 2004, a preliminary test of the use of PIES for measuring the variability of the Deep Western Boundary Current and the Antilles Current utilizing three inverted echo sounder records (IES) and two bottom pressure records (BPR) from 1996-1997 was completed. Comparisons are shown between transports estimates derived from the IES and BPR (Figure 6) showing excellent agreement with the more expensive and traditional current meter moorings (Meinen *et al* 2003).

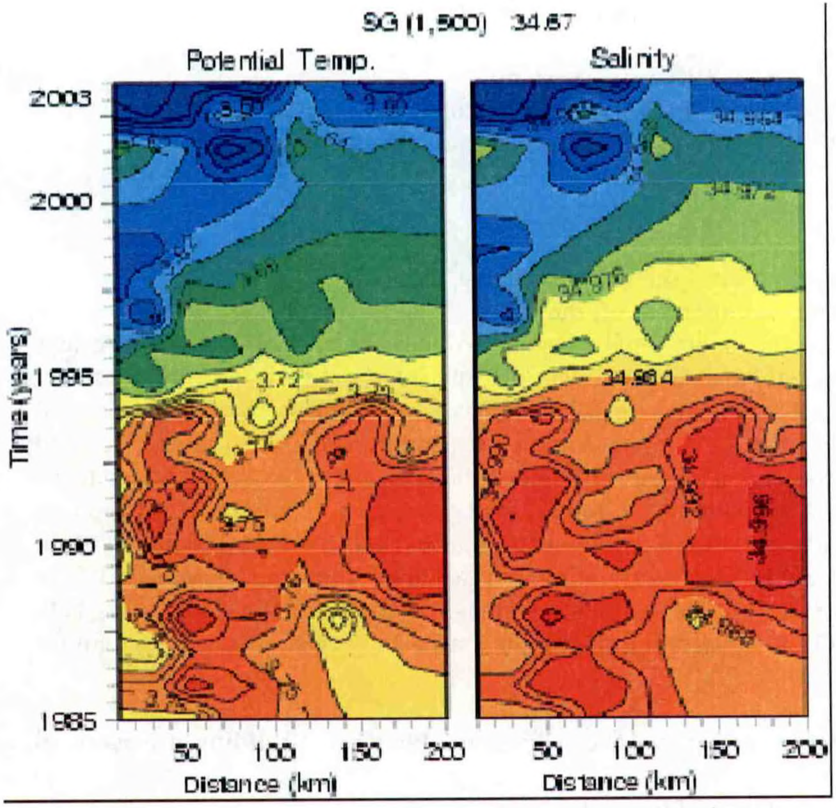


Figure 5: Potential temperature and Salinity time series within the Deep Western Boundary Current off Abaco Island, Grand Bahama on the density surface representative of the Labrador Sea Water ($\_{1.5}$ = 34.67, approximately 1700 meters). The time series shows the arrival of cold, fresh Labrador Sea Water in late 1994, which steadily extends offshore through the 2003 cruise.

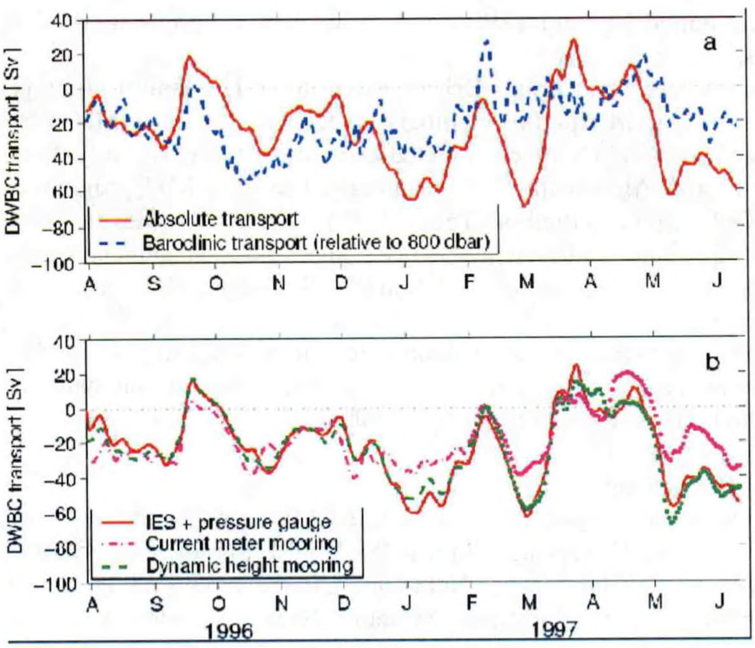


Figure 6: Transport of the Deep Western Boundary Current offshore of Abaco Island. a) Baroclinic transport, relative to an assumed level of no motion at 800 dbar, and absolute transport integrated between 800 dbar and 4800 dbar and between mooring sites B and D. b) Absolute transport from the IES combined with the bottom pressure measurements compared to absolute transport integrated from the observations of the coincident current meter line. Because the current meter data was only available at 1200 dbar and below, the transports in this panel are integrated only over 1200-4800 dbar. Also shown is the transport determined by calculation dynamic heights from the temperature sensors moored alongside the current meters, utilizing the same bottom pressure sensors for the barotropic reference as were used with the IES data. Current meter and dynamic height mooring estimates are dotted after February 1997 because the mooring at site B lost its top portion at that time. Units are in Sverdrups (1 Sv = 10^6 m^3 s^{-1}).

ENSO Observing System

by Steven K. Cook and Dr. Robert L. Molinari (PI) with Silvia Garzoli, Craig Engler, Mayra Pazos, Jim Farrington, Paul Chinn, Gary Soneira, and Janet Brocket

PROJECT SUMMARY

General overview of the project, including brief scientific rationale.
The primary objective of the AOML component of the ENSO Observing System is to provide oceanographic data need to initialize the operational seasonal-to-interannual (SI) climate forecasts prepared by NCEP. Specifically, AOML manages a global drifting buoy network that provides sea-surface temperature (SST) data needed to calibrate SST observations from satellite and a global expendable bathythermograph network that provides subsurface temperature data. Both the surface and subsurface data are used in the initialization of the SI forecast models and have been shown to be necessary requirements for successful predictions. Global coverage is now required as the forecast models now not only simulate Pacific conditions but global conditions to improve prediction skill. Secondary objectives of this project are to use the resulting data to increase our understanding of the dynamics of SI variability and to perform model validation studies. Thus, this project addresses both operational and scientific goals of NOAA's program for building a sustained ocean observing system for climate.

Statement about how your project addresses NOAA's Program Plan for "Building a Sustained Ocean Observing System for Climate".
This project provides critical data for initializing SI forecasts.

Statement about how your project is managed in cooperation with international implementation panels, in particular the JCOMM panels.
The GOOS Center and its integral components, the Global Drifter Program (GDP) and Voluntary Observing Ship (VOS) XBT Program are both participating members of JCOMM and JCOMMOPS. Both the GDP and GDP – Data Assembly Center (DAC) are represented annually at the WMO/IOC Data Buoy Cooperation Panel (DBCP) and Joint Tariff Agreement (JTA) meetings. The VOS XBT program is also represented annually at the WMO/IOC Ship Observations Team (SOT) meeting and Steven Cook presently chairs the Ship of Opportunity Implementation Panel (SOOPIP). The Data management aspect of the XBT program are coordinated by the Global Temperature and Salinity Profile Project (GTSPP).

Participation on these international panels provides an important mechanism for integrating and coordinating with other national or regional programs which, in the long run, improves our national climate mission by making more efficient and effective use of available resources.

Responsible institutions for all aspects of the project.
The GOOS Center located within the Physical Oceanography Division at AOML manages and operates the Global Drifter Program (GDP) and Voluntary Observing Ship (VOS) XBT Program. The GDP is closely aligned with SIO for the procurement of Drifting Buoys. Both the GDP and VOS XBT Programs utilize the National Weather Service Global Telecommunications System (NWSGTS) gateway for the real-time distribution of data and the National Oceanographic Data Center (NODC) and Marine Environmental Data Services (MEDS) for the archival of delayed mode data.

Project web site URL and pertinent web sites for your project and associated projects.
Drifters - http://www.aoml.noaa.gov/phod/dac/dacdata.html
XBT - http://seas.amverseas.noaa.gov/seas/goosplots.html

Associated projects –
http://www.jcommops.org
http://seas.amverseas.noaa.gov/seas
http://www-hrx.ucsd.edu
http://www.cmdl.noaa.gov
http://www://sahfos.org
http://www.aoml.noaa.gov/phod/benchmarks/index.html
http://www.aoml.noaa.gov/phod/enso/index.html
http://www.aoml.noaa.gov/phod/taos/index.html

Interagency and international partnerships.
The GOOS Center has close cooperative working arrangements across all NOAA Line Offices (NWS, NESDIS, NOS, NMFS and OMAO), the U.S. Navy and Coast Guard, several major national (SIO, WHOI, RSMAS, URI, UW and SCMI) and international (BSH, CSIRO, BOM, SABOM, JAMSTEC, IFREMER, IRD-Brest and IRD-Noumea) oceanographic and meteorological institutions as well as private contractors.

Statement that your project is managed in accordance with the Ten Climate Monitoring Principles (reference attached Program Plan)
This program is managed in accordance with the Ten Climate Monitoring Principles.

FY 2003 PROGRESS

Instrument/platform acquisitions for the fiscal year and where equipment was deployed.
Drifting Buoys – All Drifters for the Global Drifter Center are purchased by SIO. Other Drifters for the tropical Atlantic are purchased by AOML and are accounted for under another Project. Drifting Buoys are deployed globally.

XBT – Level funding at $310 K and a fixed contractual price over the past five years of $32.00 per probe annually purchases 9687 probes. XBT's are deployed along selected transects in the Pacific, Atlantic and Indian Oceans.

Number of deployments – compare to the previous year.
Drifting Buoys –
- 2002 – Deployed 346
- 2003 – Estimated 376

LD XBT –
- 2002 – 8685
- 2003 – Estimated 8888

Percentage of data return for fiscal year and "lifetime" statistics – compare to previous year.
Drifter Buoys –
On average on any given day we are receiving in real-time six (6) Sea Surface Temperature (SST) observations per Drifting Buoy deployed. As the total global array approaches 800 Drifters we are receiving about 5000 SST observations per day.

Analysis of the previous 10 years of Drifter deployments has shown the following:
- Transmitter life has improved from 296 to 453 days.
- SST sensor life has improved from 281 to 424 days.
- Drogue life has improved from 161 to 308 days.
- Drifter failure upon deployment remains about 2%.

XBT –

XBT's deployed vs. real time transmitted is essentially 100%. However, not every High Density XBT collected is transmitted in real time primarily due to time limitations while sampling. All delayed mode data not transmitted in real time are still inserted onto the GTS within 30 days of the completion of each cruise. Probe failure remains consistently between 2% and 5% with expected higher failure rates in the higher latitudes during the winters.

Measurements taken, where data are stored, data distribution, availability and access to data.
Drifters –Lagrangian position data, sea surface temperature (SST), some sea surface barometric pressure, some wind speed and direction. Data are stored at the Global Ocean Observing System Center in the Global Drifter Program's Data Assembly Center (DAC). Real time data are transmitted via Argos transmitters and distributed via the Global Telecommunications System (GTS) by Service Argos and available to everyone. The delayed mode and scientifically quality-controlled data are available via access to web, ftp or personal communication with the DAC within two months of collection. A copy of the data are archived at the Marine Environmental Data System (MEDS).

XBT data provide subsurface temperature data to a depth of approximately 800 meters along 30 selected transects in the Pacific and Atlantic Ocean. Data are stored on the computer system on the ships on which we have installed Shipboard Environmental data Acquisition (SEAS) Systems. The real-time data are transmitted via Inmarsat Std. C and are distributed on the GTS. The delayed mode or full resolution data are stored at the National Oceanographic Data Center (NODC). Additionally, all Atlantic XBT data are scientifically quality controlled as part of the GTSPP and stored at the Atlantic Data Assembly Center located at AOML.

How data are currently being used and shared.
Drifter Lagrangian data are used in circulation research by many national and international oceanographic institutions. The SST data are used by many national and international centers for environmental prediction, for ENSO monitoring and prediction, and to initialize climate models. There are no restrictions on sharing this information as it is distributed in real time on the GTS.

XBT data are used in real time for ENSO monitoring and prediction and the initialization of climate models at centers for environmental prediction and in delayed mode for research concerning seasonal to decadal climate studies of the upper ocean thermal layer. There are no restrictions on sharing this information as it is distributed in real time on the GTS.

Where the data are archived.
Drifter data are archived at the GOOS Global Drifter Program Data.
Assembly Center and at the Marine Environmental Data Service (MEDS) in Canada.

All XBT data are archived at the NODC and a subset of all Atlantic XBT data are archived at the DAC located at AOML.

Anticipated and unanticipated project costs.
Drifter costs are declining because of improved design changes but shipping costs have increased due to late funding which precipitated having to use air shipping rather than the less expensive ground shipping.

We anticipate the cost of XBT's to increase by 29% next year as well as the cost of associated XBT hardware such as Mk-21 cards and hand launchers. We will not be able to support our international colleagues and the routes they support because of this price increase.

Problems encountered.
Volatile shipping industry requires a lot of time and travel resources to continually recruit and re-outfit vessels for participation in the VOS. This volatility is particularly troublesome in the Indian Ocean, where we have not been able to maintain a portion of the low density network.

Late funding has precipitated an increase of air shipping vs. ground shipping to deliver on time both Drifters and XBT's to those participating Research and Voluntary Observing Ships that had set schedules.

Logistical considerations (e.g. ship time utilized)
We occasionally will use NOAA, as well as other Research Vessels, opportunistically, with drifters deployed on a not to interfere basis.

Research highlights.
The recognition that at a minimum, accurate characterization of the global tropics is needed to improve SI forecast skill has increased the need for data and understanding of the dynamics of the this region. Furthermore, recent research has shown that the tropical Atlantic independent of the tropical Pacific can generate climate anomalies in the United States and surrounding countries. Thus, much of AOML research activity has been directed at the tropical Atlantic. Specifically, Subtropical Cells (STC's) and Tropical Cells (TC's) have been identified as oceanographic features that have the potential for affecting tropical Atlantic SST and through feedbacks the overlying atmosphere. Research, using the drifter data in particular, has provided a summary of the present understanding of Atlantic STC's. This information is presently being used to design future process studies and improve monitoring strategies in the basin. In addition, TC's have been identified in the western tropical Atlantic from direct velocity observations. Surface characteristics of these cells have been studied using drifter data. These results will also be used to improve future monitoring activities as well as to verify the results from the forecast models. Continued interactions with international scientists have increased the data available for studying the tropical Atlantic. For example, direct velocity observations collected by French, U.S. and German investigators have been used to improve the characterization of the tropical current system in the Atlantic.

CONSORTIUM ON THE OCEAN'S ROLE IN CLIMATE (CORC)

Project Infrastructure

by Russ E. Davis

PROJECT SUMMARY

The Consortium on the Ocean's Role in Climate (CORC) addresses climate observations from a spectrum of perspectives: (a) maintaining elements of the Climate Observing System and using their data to describe climate variability, (b) using data-assimilating models to evaluate the observing system and to synthesize data from it, and (c) developing new observational techniques to improve the observing system. The consortium originally included a large number of laboratories and universities but as the focus has contracted to ocean observations of the modern climate, participation has narrowed to Woods Hole Oceanographic Institution and Scripps Institution of Oceanography.

The philosophy of CORC is that it is valuable to integrate the usually separated functions of technology development, observing, and data synthesis because technology enables observation, which makes possible synthesis. Separate progress reports for each component accompany this report to simplify description of the Climate Observation Program (COP). We wish to note here that CORC remains a coordinated program that does, in fact, benefit from the common efforts of diverse researchers.

Progress in FY 2003

As described in the component reports, FY 2003 was a productive year for CORC and each component made good progress. The data assimilation component, which intellectually brings the CORC observing components together with the other elements of the COP, is presently assimilating remotely sensed data into the CORC equatorial model and will soon assimilate the TAO array, Argo, high-resolution XBT/XCTD lines, and drifters. Logistical cooperation between XBT/XCTD and surface flux observations on the same voluntary observing ships is contributing to efficiency while the CORC drifter program provides flexibility to the international Surface Velocity Program and develops new methods for it. Improved CTDs for Argo, an Underway CTD for VOS, and underwater gliders to augment Argo sampling are all technical developments that can soon be made operational.

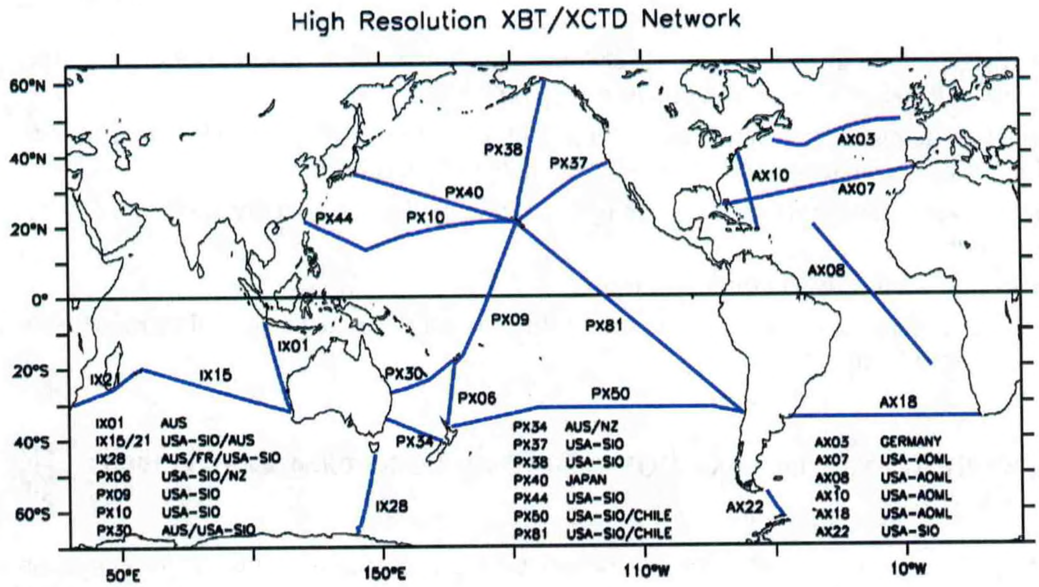
CORC has attracted graduate students into ocean climate research and during the September 2002 through June 2003 school year a first year student was fully supported. Russ Davis coordinated work in the project, assembled progress reports, present CORC for OGP review, and oversaw use of infrastructure funds to deal with funding delays to operational observing components.

High Resolution XBT/XCTD (HRX) Transects

By Dean Roemmich

PROJECT SUMMARY

The Ships of Opportunity Networks are a major activity within NOAA's Program Plan for *Building a Sustained Ocean Observing System for Climate*. Following the consensus developed at the 1999 Upper Ocean Thermal (UOT) Review and OceanObs99 Conference, these networks are undergoing a transition from broadscale sampling (replaced by Argo) to High Resolution (HRX) and Frequently Repeated (FRX) lines. Scripps (D. Roemmich, PI) manages a major portion of the HRX network (Fig 1) with funding from both NOAA and NSF (http://www-hrx.ucsd.edu). Roemmich is a member of the JCOMM Observations Coordination Group and is responsible for international linkages (Australia, New Zealand, Japan, Chile) of the HRX networks in the Pacific and Indian Oceans. He has carried out HRX sampling programs since 1986. Linkages between Scripps (Roemmich) and AOML (R. Molinari) in the national program have enabled common software development, resource sharing across HRX and FRX programs in the Indo-Pacific and alignment of the Indo-Pacific and Atlantic HRX programs.



What are high resolution lines?

High resolution XBT (HRX) lines are those whose sampling criteria require boundary-to-boundary profiling, with closely spaced XBTs to resolve the spatial structure of mesoscale eddies, fronts and boundary currents. The present set of regularly sampled HRX lines is shown in Fig 1, with probe spacing that is typically 10 km through boundary currents and 35-50 km in mid-ocean. Time-series of HRX lines are as long as 17 years in the case of PX06 (Auckland-Suva). The repetition frequency is about four times per year. In most cases, measurements are made by a technician or scientist on board the ship.

The unique niche of the HRX mode among global ocean observations is in spanning spatial scales from that of eddies and boundary currents to basin-width, and time scales from seasonal to (potentially) decadal. The closest analog to HRX sampling, but usually in regional-scale observations, is repeat hydrography. HRX sampling is substantially more labor-intensive than broad-scale or high frequency lines. It returns higher quality datasets through use of (i) a stern-mounted automatic launcher (ii) redrops of questionable profiles (iii) horizontally coherent sampling. The characteristics and objectives of HRX lines dictate careful selection of a limited set of routes for this sampling mode.

Scientific objectives of HRX sampling.

(1) Measure the seasonal and interannual fluctuations in the transport of mass, heat, and freshwater across ocean spanning transects (e.g. at tropical/ subtropical boundaries) or through the perimeter of large ocean areas (e.g. Tasman Box PX6/30/34, Western Atlantic AX7/10 etc.).

(2) Characterize the structure of baroclinic eddies and estimate their significance in the transports of heat and water masses.

(3) Determine the spatial statistics of variability of the temperature and geostrophic velocity fields.

(4) Identify persistent or permanent small-scale features.

(5) Determine the scale-dependent correlation of sub-surface temperature and dynamic height with altimetric height. What are the minimal requirements for *in situ* data?

(6) Facilitate additional measurements from a small set of highly instrumented Volunteer Observing Ship (VOS) platforms (XCTD, SSS, improved SST and meteorological observations, float deployment etc.)

(7) Determine the long-term mean, annual cycle and interannual fluctuations of temperature and large-scale geostrophic velocity and circulation in the top 800 m of the ocean.

(8) Obtain long time-series of temperature and salinity profiles at precisely repeating locations in order to unambiguously separate temporal from spatial variability of properties.

(9) Determine the representativeness of one-time hydrographic sections in a variety of different dynamical settings.

(10) Provide appropriate *in situ* data for model testing.

(11) Describe characteristic (and coherently sampled) structures of the mixed layer and thermocline in relation to surface forcing.

PROGRESS DURING FY03 ON NOAA/CORC - FUNDED LINES PX50, PX81, IX15/21

Observations -

Quarterly High Resolution XBT/XCTD transects have been collected along the basin-spanning routes New Zealand-to-Callao (PX50) and Honolulu-to-Coronel (PX81). Along PX50, transects during FY03 were in November of 2002, plus February and April of 2003. At present, there is no longer direct shipping between New Zealand and South America as this trade has been re-routed to the Panama Canal. We are planning to continue sampling the South Pacific using New Zealand to Panama service (PX08) beginning in December. That route crosses PX81 so that portions of each transect can be combined to form the zonal crossing. PX08 has been well sampled in low density mode, providing substantial historical XBT data for our changeover. Along PX81, transects were in October 2002, plus February, May, July, and October of 2003.

We are in the process of initiating a new HRX line in the Indian Ocean, from Fremantle to Durban (IX15/21), in collaboration with CSIRO Marine Research (Australia). The line is a high priority one in the global HRX network, but it has taken an extended time to identify appropriate shipping and obtain permission for a ship rider. The CSIRO principal investigator is Helen Phillips. The first cruise along this route will be carried out in December 2003, and XBT probes for the first year of sampling have been shipped to Fremantle.

During each cruise on any line, XBT temperature profiles (0-800 m) are collected at spatial intervals from 10 km near ocean boundaries and the equator, to 40 km in interior regions – resolving boundary currents and interior eddies to enable ocean-spanning integrals of geostrophic transport. Sparse XCTD profiles are obtained to observe large-scale variability of the T/S relation. In addition to the basic XBT/XCTD datasets, we provide technical support for installation and maintenance of CORC VOS IMET systems (R. Weller, PI), for deployment of Argo floats, and for testing of new instruments such as the Sippican T-12 XBT (2000 m, research quality). Major software development work is in progress to convert the XBT autolauncher system from MS-DOS/Sippican MK-12 data acquisition to Windows/Sippican MK-21. This conversion is being done collaboratively with NOAA/AOML. HRX data are displayed and made available for download (as complete transects) at http://www-hrx.ucsd.edu. HRX data are transmitted on the GTS immediately after collection for real-time applications.

Analysis-

HRX data are being incorporated in both regional and Pacific basin-wide analyses. Willis *et al* (2003a) developed a new technique for combining XBT and satellite datasets, and applied it in the Tasman Box region of the southwestern Pacific. A closed heat budget for the Tasman Box is described by Roemmich *et al* (2003). Here the HRX network is used to estimate the ocean heat flux convergence in the region with errors on interannual time-scale of less than 10 W/m^2. These regional studies have been followed by a global estimate of interannual heat storage (Willis et al, 2003b). The latter study is especially significant for the South Pacific HRX network. It shows that the global maximum in zonally-averaged ocean heat gain over the past 10 years was 4 W/m^2 at 40-S (four times the global mean of 1.0 W/m^2), and was especially pronounced in the western South Pacific. Our ongoing analyses are aimed at understanding how ocean circulation variability contributes to the evolution of this signal.

Our analysis of HRX data is evolving to include not only statistical studies, but also work that uses a regional quasi-geostrophic data assimilation model (e.g. Cornuelle *et al*, 2003) and studies that compare HRX data to the global ECCO data assimilation results (Douglass *et al*, 2003). Data assimilation models are progressing rapidly and are becoming very complementary to the statistical studies. They will allow better dynamical interpretation and can be used to address the sampling limitations of the HRX data (depth and frequency). They also allow additional datasets such as Argo floats and air-sea fluxes to be synthesized along with the HRX data.

This report covers two programs for VOS (Volunteer Observing Ships) funded by the NOAA Office of Global Programs (OGP) and therefore is an integrated report for ships using the new high accuracy, automated meteorological system called AutoIMET / NOAA SEAS. The two programs have been previously reported and are:

Observations of Air-Sea Fluxes and the Surface of the Ocean
by Robert A. Weller and David S. Hosom
(REPORT PERIOD: July 1, 2002 through June 30, 2003)

AND

Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic
by Robert A. Weller and David S. Hosom
(REPORT PERIOD: July 1, 2002 to June 30, 2003)

PROJECT SUMMARY

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

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

AutoIMET was developed by the Woods Hole Oceanographic Institution to meet the need for improved marine weather and climate forecasting. It is a wireless, climate quality, high time resolution system for making systematic upper ocean and atmospheric measurements. This interfaces to the NOAA SEAS 2000 (Shipboard Environmental (Data) Acquisition System) that automatically receives meteorological data (from the AutoIMET) and sends in automated one-hour satellite reports via Inmarsat C. This system will document heat uptake, transport, and release by the ocean as well as the air-sea exchange of water and the ocean's overturning circulation.

One minute sampled data is stored in the Auto-IMET system for retrieval at the six-month ship turnaround and used for climate studies. Data from each VOS is posted on the web site: http://uop.whoi.edu/vos/ while technical information on the Auto-IMET can be found on the web site: http://frodo.whoi.edu.

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

FY 2003 PROGRESS

The CORCIII program supports two ships in the Pacific and had the following activities:

Horizon Enterprise.

Columbus Florida

This is for the period 1 July 2002 through 30 September 2003 on a program to improve the surface meteorological and sea surface temperature observations made by U.S.VOS as described by WHOI Proposal Serial No. PO10731.01. The actual accomplishments at this point in time match the goals and objectives of the proposal. During this period we continued to build the program to attempt to improve the observations made by the U.S. Volunteer Observing Ship (VOS) fleet and to collaborate with VOS Expendable Bathythermograph (XBT) investigators on testing and evaluating data from modules developed during the program.

On 22-26 July 2002, an instrument turnaround was made on the Columbus FLORIDA in Long Beach, CA. The modules were returned to WHOI for downloading the 1-minute sampled data and calibration. Data processing for the February 2002 to July 2002 time was sent to SIO for review. Dave Hosom was able to do this turnaround with the support of Carrie Wolfe and Brian Tufts of SCMI (Southern California Marine Institute).

On 19 – 25 Oct 2002, an instrument turnaround was made on the CSX ENTERPRISE in Oakland CA by Frank Bahr and Dave Hosom. There was some delay in travel due to the dock strike. The modules were returned to WHOI for data retrieval and calibration. Data processing for the April 2002 to October 2002 time was posted on a web site for to SIO for review. Note that Frank Bahr now has the responsibility for the CORC VOS fieldwork and that he will also be doing the preliminary data processing at WHOI. The data is posted on a web site that Frank created.

Fabrication of the AutoIMET system for the third Pacific ship was started and completed in March 2003. This system will be installed on the Columbus Florida in June 2003. The ASIMET modules currently in use require extensive repair and upgrade and therefore the ASIMET stand-alone modules on the CSX Enterprise and Columbus Florida will be upgraded to the AutoIMET configuration in 2003. This system is lower cost than the ASIMET modules and provides the capability to communicate with the NOAA SEAS system for display on the bridge and for automatic insertion of meteorological data into the SEAS reports. The last of the converted systems will be available for installation on the third Pacific ship in 2004 as planned. All of the VOS systems in the Pacific and Atlantic will use the AutoIMET configuration to benefit from commonality of parts and better logistics.

On 13 – 17 Jan 2003, an instrument replacement was made on the Columbus FLORIDA in Long Beach, CA. Carrie Wolfe and Brian Tufts of SCMI had removed the modules after the FLORIDA had bow mast damage at sea in Nov and shipped them back to WHOI. The modules had the data dumped. Data processing for the July 2002 to January 2003 time was posted on a web site for SIO for review. Frank Bahr was able to do this turnaround with the support of Carrie and Brian.

On 19 – 23 June 2003, an instrument turnaround was made on the CSX ENTERPRISE in Oakland CA by Frank Bahr. The modules will be returned to WHOI for data retrieval and calibration. Data processing for the October 2002 to June 2003 time will be posted on a web site for to SIO for review. The returned modules have been upgraded to the AutoIMET configuration.

On 23 – 26 June 2003, an instrument replacement was made on the Columbus FLORIDA in Long Beach, CA. Dave Hosom from WHOI, and personnel from Harris Acoustic Products installed the AutoIMET system including the HullCom (acoustic modem) for near real time SST. Steve Cook and Janet (Brockett) Roseli of NOAA SEAS installed the new SEAS 2000 system on the ship. Carrie Wolfe and Brian Tufts from SCMI provided support. The modules were returned to WHOI for data retrieval and calibration. Data processing for the Jan 2003 to June 2003 time will be posted on a web site for to SIO for review. The returned modules have been upgraded to the AutoIMET configuration.

The CFD (Computer Flow Dynamics) work continues at Southampton Oceanography Centre on the feasibility of CFD on generic VOS.

The Atlantic VOS Program fabricated equipment, will support one ship in the Atlantic, and had the following progress:

The two systems (designated AIA1 and AIA2 for AutoImetAtlantic1 and 2) have been completed, calibrated and burned-in on the bench at WHOI. They are ready for installation on the selected VOS. Batteries have been purchased and are on hand.

Interface with the NOAA-SEAS office in Silver Spring, MD has gone well and the SEAS 2000 system with AutoIMET is working well on the bench. WHOI provided a test bow mast logger and radio modem for NOAA-SEAS (Janet Brockett) to use in her software development and test.

Ship selection has not been made. While the Lykes Winner was visited last summer and Steve Cook has obtained permission of the ship owners for the installation, it was determined by WHOI not to be suitable for a first time installation of a new system.

The plan now is to install AutoIMET on the Columbus Florida in June (part of the CORC program) with excellent ship cooperation and very excellent support from Carrie Wolfe of the Southern California Marine Institute (she is also the official VOS coordinator in Long Beach). Some of the learning curve for a new system can take place in a good environment.

An alternate ship has been found – the Sealand Express. Installation is planned for fall of 2003 in Port Elizabeth, NJ.

Sealand Express

Drifter Observations
by Pearn P. Niiler

PROJECT SUMMARY

CORC drifter observations are an enhancement of the "Global Drifter Program" (*GDP*). GDP is the principal component of the *"Global Surface Drifting Buoy Array"* of the NOAA Ocean Observing System for Climate and a scientific project of the Data Buoy Cooperation Panel (DBCP) of the World Meteorological Organization (WMO) and the International Oceanographic Commission (IOC). It is a near-operational ocean-observing network of drifters that, through ARGOS satellite system, returns data on ocean currents, SST and atmospheric pressure (and winds and salinity) and provides a data processing system for scientific utilization of that data. Within CORC, drifters are deployed as enhancements of the tropical Pacific array for the purpose of obtaining a time-space evolution of the near surface circulation because the tropical surface currents are not in geostrophic balance and satellite altimeters alone cannot be used to determine the water velocity.

The scientific objectives of CORC in *GDP* are to:

1) Observe the mixed layer velocity with 2°x 5° (and higher) resolution and produce new charts of the seasonal and interannual changing circulation of the tropical Pacific.

2) Develop and introduce into the drifter construction technological advances in sensors, electronics, power, methods of assembly and deployment packaging.

3) Provide enhanced data sets of ocean circulation that include drifter data from individual research programs. In this context, the CORC drifter observations

- Provide to the coupled ocean-atmosphere climate prediction models gridded, Pacific basin data sets for assimilation of surface velocity and for the verification of the parametrized processes, such as wind-driven currents.

- Provide the Lagrangian data sets for the computation of lateral diffusion, and descriptions of the circulation via computation of the Lagrangian space and time scales.

- Support short-term research projects that require enhanced upper ocean velocity observations in the tropical Pacific basin.

- Carry out analyses of the role of near surface circulation on the convergences of mass, thermal energy and vorticity of the tropical oceans.

PROGRESS DURING FY 2003

Observations –
CORC supported the purchase of 111 SVP –Mini drifters for deployment into the tropical Pacific. The delivery of drifters from manufacturers has now begun to AOML. Since November 2002, the tropical Pacific array within 30° of the equator was populated with more than 230 drifters each month, meeting the objectives of a "dense" velocity-sensing array. In October 2003, CORC collaborated with ONR in the deployment of a coherent array near Luzon Strait through which a significant mass of Philippine Sea water enters during October-January period of the northeast Monsoon (Figure 1).

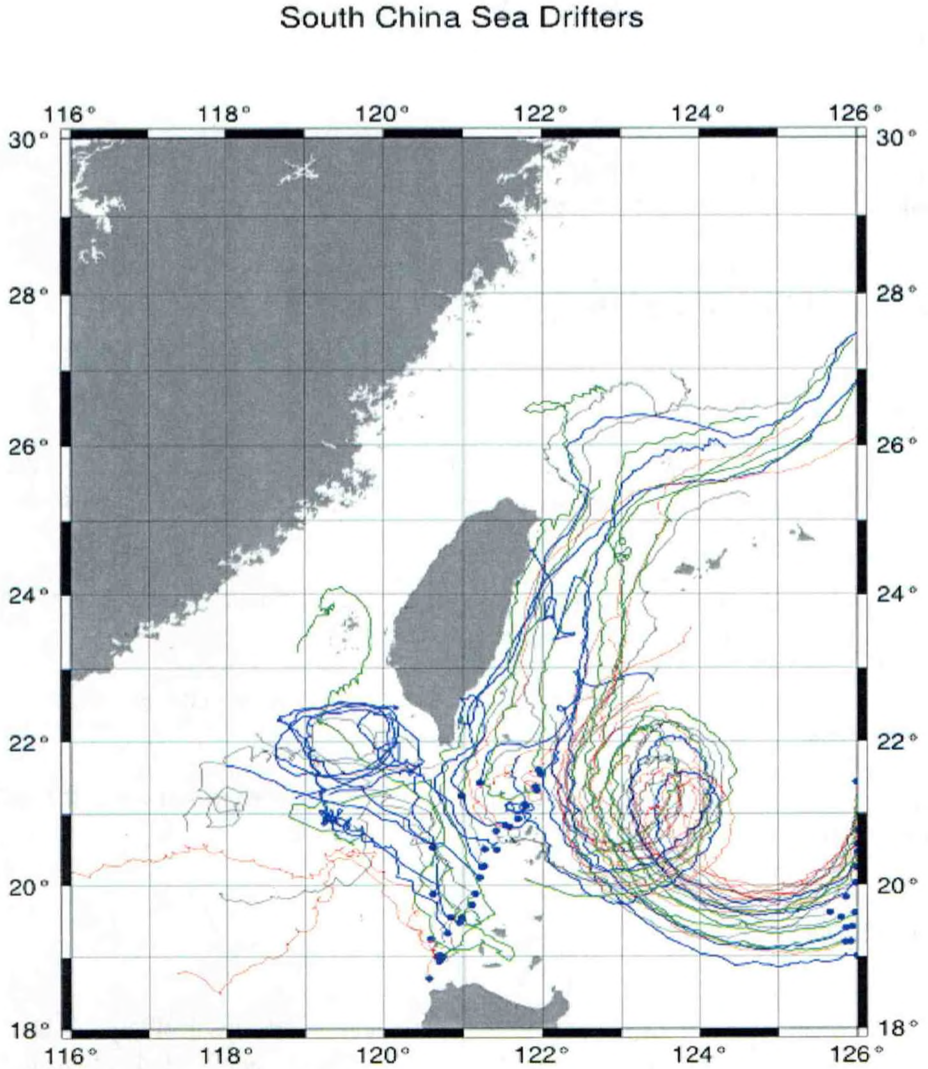


Figure 1. Track of drifters deployed in early October 2003 near the Luzon Strait in the CORC/ONR joint program for the study of the flow of Pacific surface water into the South China Sea. Blue dots mark the deployment locations and data is about 30 days with last fix on November 11, 2003.

The deployments supported by ONR (and the Pusan National University) will add 60 drifters per year to the South China Sea circulation study in 2004 and 2005, for a total of 300 drifters. During the northeast Monsoon, several drifters in the historical file have moved from the South China Sea across the Banda Shelf into the Indian Ocean and these new data will enhance our knowledge of the connections between the equatorial Pacific and the Indian Oceans.

Technology-

We have made further progress on the construction and deployment of SVP-SSS drifters.
In 2003 we built 8 drifters with SeaBird Seacats and these were deployed in August-September period in the East China Sea. Two recovered SVP-SSSs were sent back to SeaBird for post calibration and we are waiting for the results.

The second technology advancement was made in the design and construction of air-deployment containers and rugged Minimet drifters into hurricanes. Minimets, in addition to SST and velocity, measure ambient noise, wind direction and sea-level pressure. The containers successfully deployed 14 (out of 16) Minimets in front of a class 4 hurricane, *Fabian*, in early September 2003. It is quite remarkable that 8 Minimets produce 'good' data through the Fabian (Figure 2).

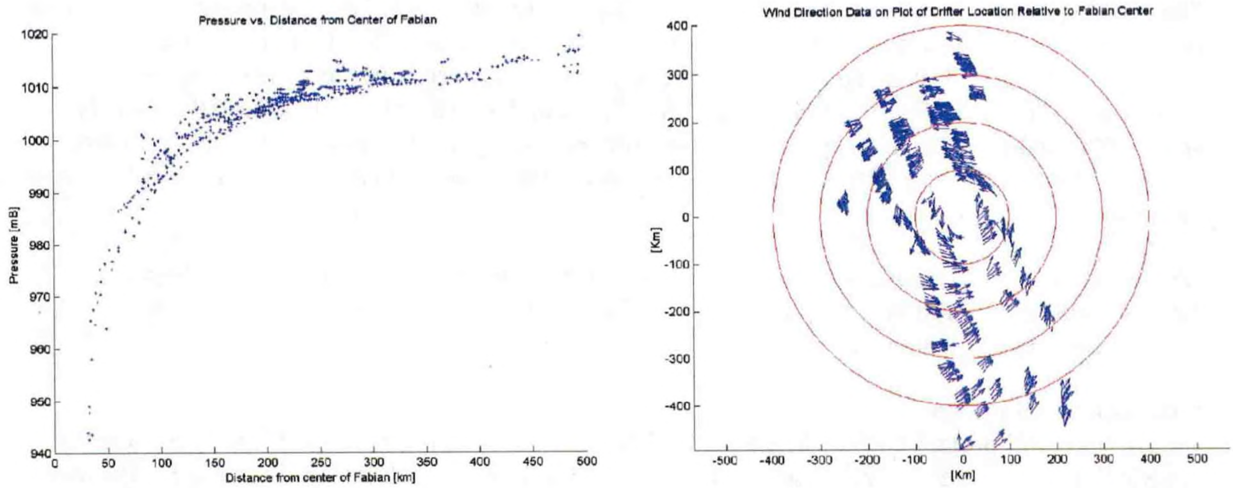


Figure 2. Atmospheric pressure (left panel) and wind direction (right panel) as a function of radius from the hurricane center measured by 8 Minimet drifters during the passage of hurricane *Fabian* September 4, 2003.

Analysis-
We have completed the analysis of the role of circulation in the ENSO time scale evolution of the tropical Pacific thermal energy convergence. The paper on this subject is still in the process of review before publication (viz. below). The enhanced data set to which CORC contributed 100 drifters and which was taken during the July 1999 cruise in the eastern Pacific North Equatorial Countercurrent is ongoing. The first paper, on the nonlinear vorticity structure of the seasonal Countercurrent is now in early manuscript stage. The analysis on the changes of the upper layer salinity in the East China Sea that are produced by the diversions of fresh water by the Yangtze River Dam, as observed by the SVP-SSS drifters, is complete and the first draft of a manuscript will be complete by end of November. In the past two years, the publications below were supported in part by CORC data sets and/or funds for computations and analysis.

Underwater Gliders for Monitoring Ocean Climate
by Russ E. Davis

PROJECT SUMMARY
Temperature, salinity and velocity are the fundamental variables for ocean climate observations. These variables are directly connected to the large-scale processes that shape climate variability and change. They directly specify the heat and freshwater budgets that define climate change and represent the dynamically important fields that must be known to forecast climate variability.

The Argo array of profiling floats is beginning to provide global coverage of temperature and salinity while a subset of the TAO Array provides observations of velocity in the tropical ocean. A gap that exists in this observing system is the difficulty of monitoring boundary currents, or other narrow flows, that transport significant quantities of heat and freshwater and are central elements in the climate system. While Argo floats sample these currents, their density is much too low (typical spacing of 300 km) to resolve them or even to determine even their overall transports. Because floats are swept along by the flow, it is not cost-effective to increase their density these limited regions of generally strong currents.

This CORC project aims to develop underwater gliders to provide cost-effective temperature, salinity and velocity measurements at specified locations and in higher local density than is feasible with floats. Gliders are buoyancy-driven vehicles, much like Argo floats, that use wings to glide forward while cycling up and down. The glider used for this effort is 'Spray' which was developed at SIO, initially under ONR funding. Our challenge is to turn an untested prototype into a reliable operational vehicle and sensor system that can be deployed in localized ocean circulation features like boundary currents or along the equator.

Within the Climate Observation Program, glider research is now best thought of as technology development for the Argo Program although the ability to measure velocity profiles will allow gliders to augment sampling by moored TAO and coastal arrays.

PROGRESS IN FY 2003

Early work in this program, which began in FY2001, showed that there were significant problems with Spray reliability. In one of our first sections off the California coast, a glider was lost after gliding about 250 km offshore. A thorough design review indicated that the systems most likely to have precipitated the failure included communication, buoyancy control, high-pressure integrity and the control mechanism for gliding. A number of modifications to these systems were designed and implemented in FY2002.

Following implementation of upgrades, a sequence of increasingly long local field tests was begun early in late FY 2002. On the third test, the vehicle was lost. This initiated a second round of design reviews that led to the decisions to switch communication to Iridium, to employ redundant communication/GPS antennas, and to install a backup Argos system. Quite fortunately, two months after the glider's disappearance, it was recovered 150 miles away by a fisherman who returned it. Examination disclosed that while at the surface the glider had been run down by a high-speed vessel. The hull, rated to 1500 m, was badly dented and the active antennas had been sheared off long before the fisherman's recovery. Encouraged that the problem was not with our technology, we went ahead with the planned communications improvements.

The ONR sponsored, August 2003, Autonomous Ocean Sampling Network II field experiment in Monterey Bay provided an attractive opportunity to prove out the various improvements introduced to Spray. Two NOAA-sponsored Sprays and three purchased with ONR funds were deployed along a 100 km stretch of coast spanning Monterey Bay and directed to run back and forth on offshore lines of approximately 80 km length. Figure 1 shows the trajectories of the vehicles during a 10-day period early in the experiment. Gliders profiled temperature and salinity, generally to 400 m but occasionally to 750 m, and measured the vertically averaged water velocity as the difference between the measured motion through the water and distance made good. All five vehicles functioned perfectly for periods of 35-42 days before normal recovery in September.

A number of things were learned about the vehicle and sensors during the Monterey operation: (1) one vehicle indicated a transient inability to pump, which indicates air bubbles in the hydraulic system caused the hydraulic pump to lose prime; (2) calibration of our Precision Measurement Engineering conductivity probe jumped frequently, apparently as the result of impact with biological particles, and salinity errors reached 0.2 psu; (3) all five chlorophyll-a fluorometers and optical backscatter sensors were bio-fouled to the point of inoperability by the end of the experiment; (4) the new Iridium system and antennas worked well; and (5) operations went smoothly and the Sprays' superior battery life made them much easier to tend than the Webb Research gliders also taking part in the experiment.

In parallel with these field trials we have completed the mechanical design for installing a Sontek 600 kHz Acoustic Doppler Current Profiler (ADCP) on Spray. The additional effort we have put into correcting problems with the vehicle itself has slowed this development from our initial schedule.

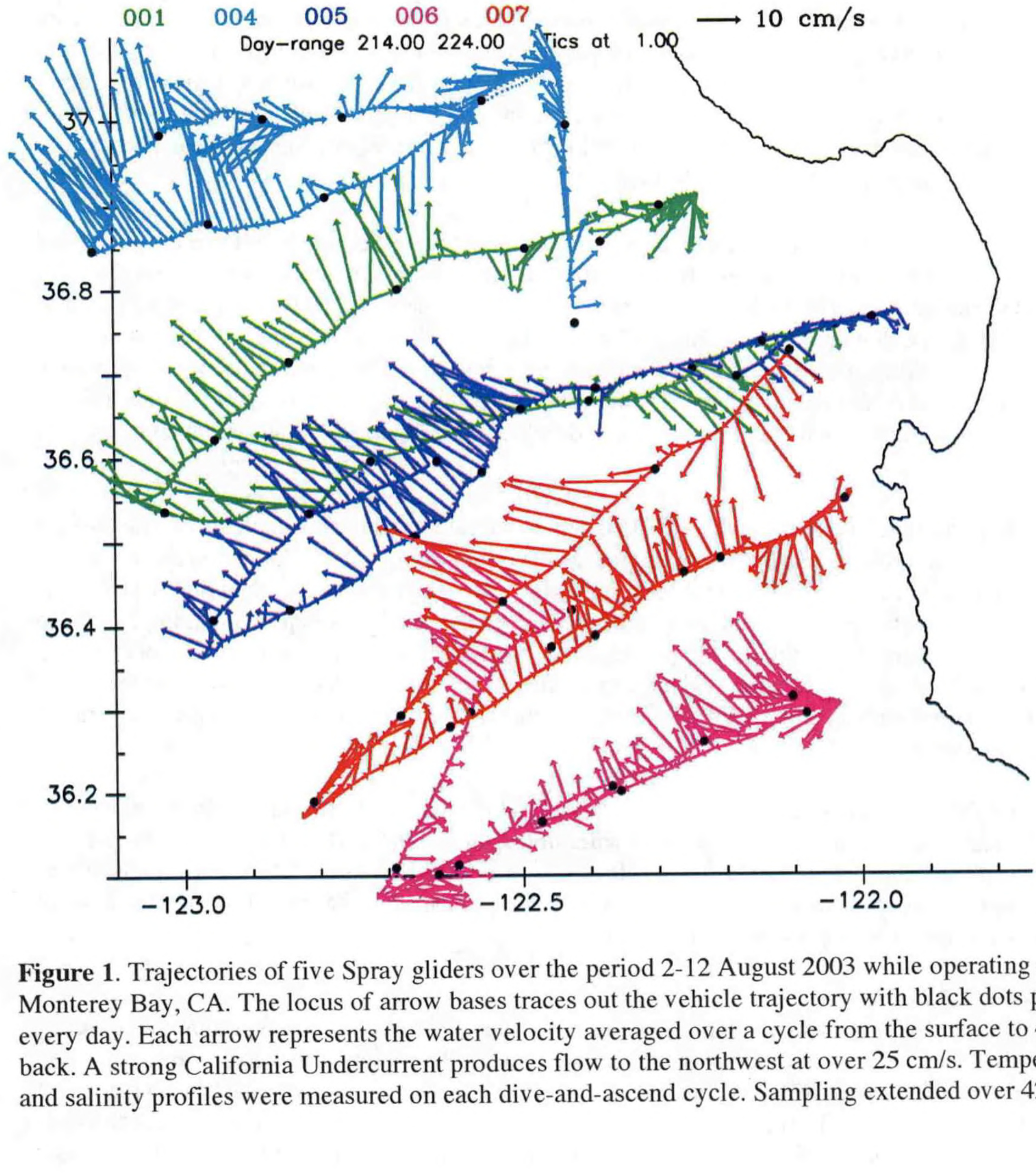


Figure 1. Trajectories of five Spray gliders over the period 2-12 August 2003 while operating off Monterey Bay, CA. The locus of arrow bases traces out the vehicle trajectory with black dots placed every day. Each arrow represents the water velocity averaged over a cycle from the surface to 400 m and back. A strong California Undercurrent produces flow to the northwest at over 25 cm/s. Temperature and salinity profiles were measured on each dive-and-ascend cycle. Sampling extended over 42 days.

Development of an Underway CTD
by Daniel L. Rudnick

PROJECT SUMMARY

The development of the Underway CTD (UCTD) is motivated by the desire for inexpensive profiles of salinity from volunteer observing ships (VOS). While XCTDs do provide the needed salinity profiles at present, their cost limits how many can economically be used. The temperature-salinity (T-S) relationship is most variable in the mixed layer and seasonal thermocline where the ocean is in direct contact with the atmosphere. Deeper, climatological T-S relationships combined with XBTs are sufficient for observing the hydrographic structure that enters into momentum, heat and salt budgets. Thus, the design goal for UCTD was to obtain profiles deeper than 100 m at 20 knots (typical of a VOS). This goal has been surpassed, as we are able to profile to over 150 m at 20 knots.

The UCTD operates under the same principle as an XBT. By spooling tether line both from the probe and a winch aboard ship, the velocity of the line through the water is zero, line drag is negligible and the probe can get arbitrarily deep. The challenge is to recover the probe, because the line velocity will then equal the ship speed, and line drag may become large. This has proven possible using a 0.06" diameter Spectra line with a breaking strength of 650 lb. Tensions have peaked at 200 lb so we are working well within the specifications of the line. We have also successfully completed tests with a 300 lb line. The advantage of the lighter line is that it allows smaller and lighter gear aboard ship, thus enhancing portability.

A number of advantages accrue because the UCTD is recovered rather than expendable. First, the cost per profile decreases as the probe is reused. We anticipate a cost of approximately $2000 per probe once development is complete, so at least five profiles reduces the cost per profile to less than that for an XCTD. Second, because the probe is recovered, sensors can be calibrated post-deployment, improving the quality of the observations. Third, the UCTD carries a pressure sensor so depth is measured more accurately than by the drop-rate equation typical for an expendable. Finally, data is obtained on the upcast; which is a significant advantage for near-surface data that are often dominated by transients in downcast-only expendable profiles.

The UCTD is useful on research vessels to improve horizontal resolution on standard hydrographic cruises. UCTD casts can be done between stations without loss in ship time. Because research vessel speeds are typically 10 knots, and line drag is one-fourth as large as on 20-knot VOS ships, depths of up to 600 m are possible. To this end we designed a probe capable of carrying 500 m of line, and have tested it to depths of over 400 m at ship speeds of 12 knots.

PROGRESS DURING FY03

As the concept of the UCTD is now proven, work during the past year has focused on improving ease of use, and verifying accuracy and long-term stability of the sensors. To achieve these goals we have undertaken three main activities. First, we have constructed a calibration facility to quantify sensor accuracy. Second, we have conducted a series of field tests on board a small boat to evaluate operational procedures, and test sensors. Third we participated on a CalCOFI cruise as a full-scale test of the complete system. These activities are discussed below.

The calibration facility consists of three separate tanks. The first tank, used for temperature calibrations, is stirred and heated. A calibration run involves taking near-freezing water and warming it in a series of steps. The second two tanks have submersible pumps for stirring, are large enough to maintain very stable temperatures and salinities, and accommodate two SeaBird SeaCat CTDs for reference. These tanks are kept at two different salinities, for conductivity calibration. The calibration facility is capable of verifying accuracies of better than 0.01 °C and 0.01 psu.

Figure 1. The UCTD being deployed from the R/V Revelle in April 2003.

Field tests have been performed on our 26 ft boat, R/V Saikhon. These field tests allow us to confirm that line tensions remain low enough to be safe. We are also able to use the sensors in the field repeatedly to assess long-term stability of the sensors. Finally, we use these cruises to test modifications of the system. Several daylong field tests were done over the year.

The main achievement of the past year was a full-scale test on the R/V Revelle in April 2003. CalCOFI cruises consist of a series of comprehensive hydrographic stations. UCTD casts as deep as 400 m were done between each pair of standard CTD stations while steaming at 12 knots, doubling the horizontal resolution at no cost in ship time. Cast time from the time the probe hit the water until recovery was 20 min. With respooling taking 5-10 min, a turnaround time of 30 min was possible. Comparisons with a SeaBird CTD on station were better than 0.01°C and 0.01 psu, thus achieving our desired accuracy.

The CalCOFI cruise revealed problems in our respooling procedure. In response we have designed a new respooling mechanism which has reduced the time required to approximately 2 minutes with little skill required of the operator.

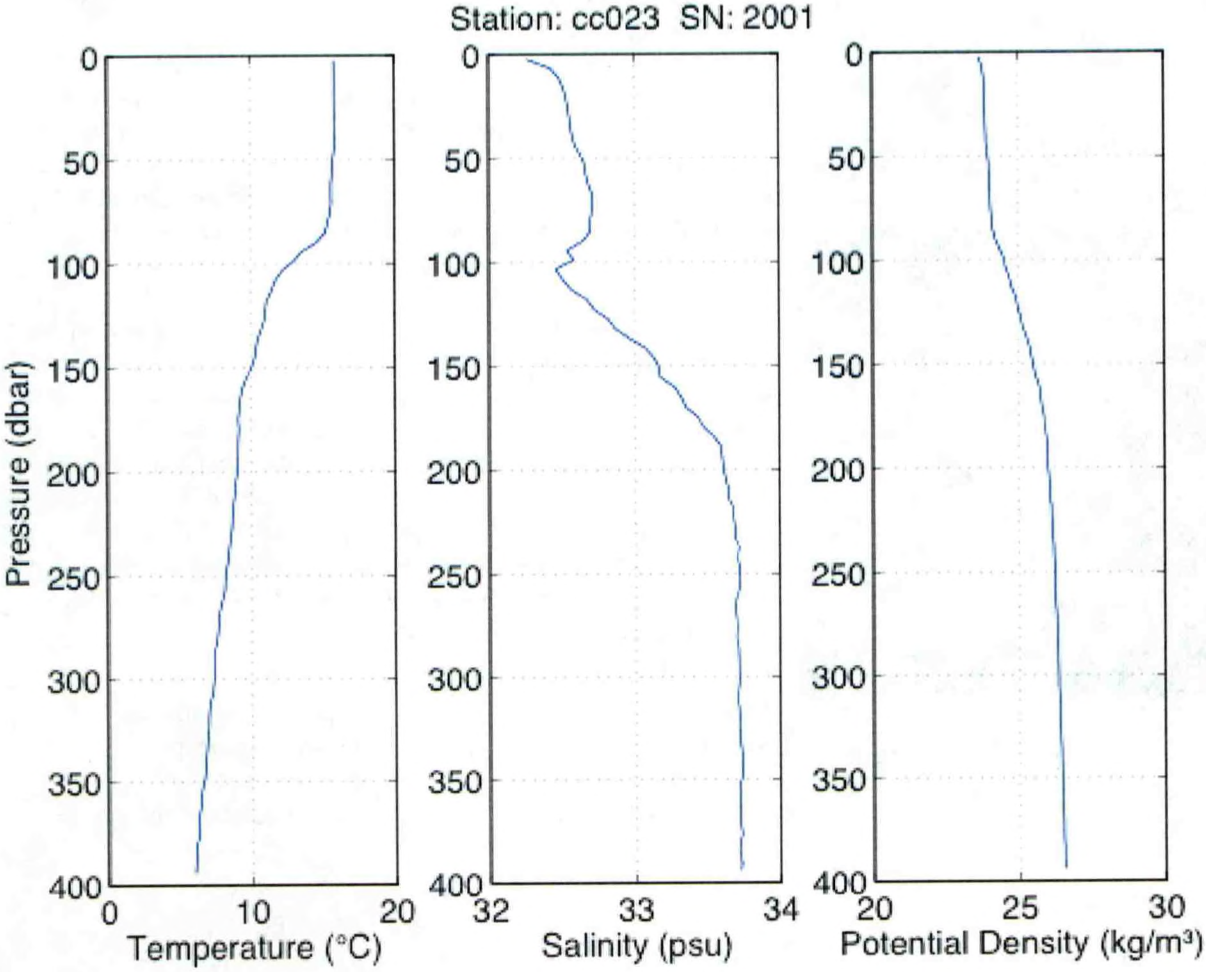


Figure 2. Profiles of temperature, salinity and potential density from the CalCOFI cruise in April 2003.

Lagrangian Salinity Profiling: Evaluation of Sensor Performance
by Ray Schmitt

PROJECT SUMMARY

Principle investigator Schmitt has long been concerned with the challenge of assessing the strength of the hydrologic cycle over the ocean (Schmitt et al, 1989; Schmitt, 1995). One important indicator is the salinity structure of the upper ocean (Schmitt and Montgomery, 2000). Under CORC sponsorship he has sought to advance automated salinity measurement technology by working with Falmouth Scientific, Inc. (FSI) to improve their conductivity cell performance and assist in development of their "Excell" Float CTD. This work helps to address problems with present instrumentation and provide diversified technology sources for salinity measurements within the ARGO float program.

Problems Addressed

Early salinity measurements on floats were made by adding a conductivity cell into existing temperature and pressure sensors. The FSI inductive cell was used in this mode and problems were found in electronic jumps and drifts due to both fouling and ablation of antifoulant coatings. The separation of conductivity and temperature sensors also led to problems with salinity spiking and inaccuracies in high gradient regions of the thermocline. These problems were addressed with a float specific CTD termed the Excell. Early versions were tested extensively for electronic performance and tuned to have proper dynamic response. Best practice for antifouling for deep-cycling floats proved to be no antifoulant in most cases, as untreated cells appear more stable than those with antifouling paint, which slowly ablates and causes a change in cell constant. The contrast between early and recent results from FSI equipped floats in the Atlantic shows the progress achieved in the past few years (Figure 1).

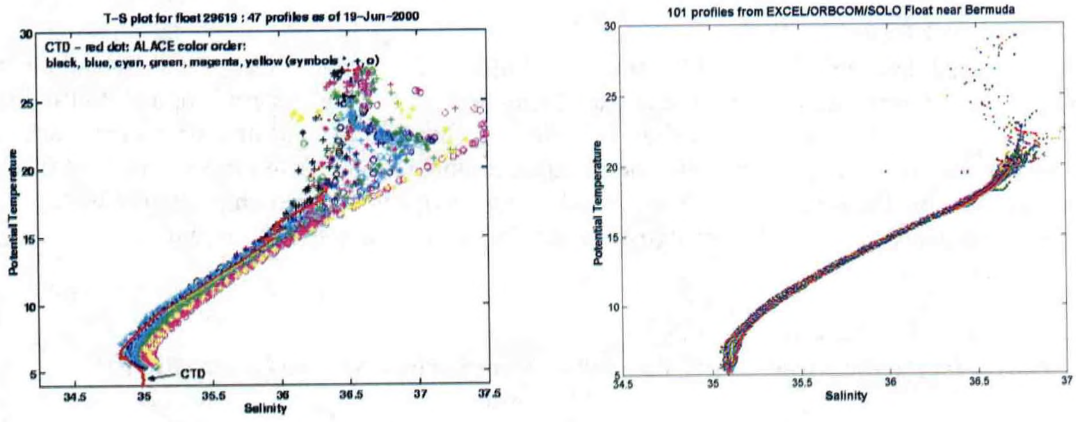
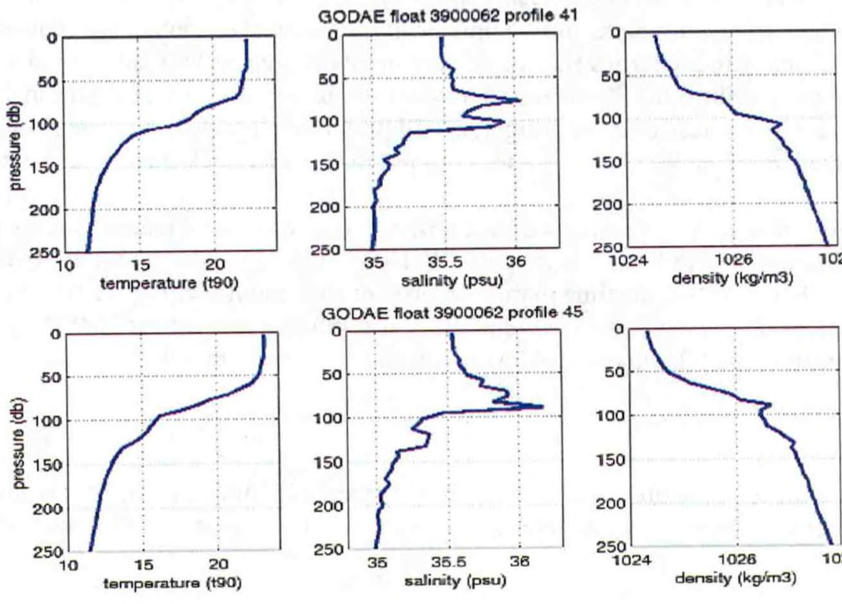


Figure 1a. (left) Temperature-Salinity diagrams from profiling floats. Early float equipped with FSI conductivity cell displayed salinity drift with slow ablation of antifoulant paint. **Figure 1b.** (right) Recent data from FSI EXCELL CTD show no sensor drift, as the small observed variability is consistent with regional water mass gradients.

Considerable effort has also gone into the dynamic response of the sensors. Dynamic response is always a concern with salinity measurements from moving sensors, as temperature and conductivity cells inevitably have different response times, with different speed dependencies. This leads to an error in the calculated salinity which can be significant in strong thermoclines, and leads to subtle errors elsewhere. Examples of salinity spiking and density inversions from SeaBird-equipped floats in the eastern tropical Pacific are shown in figure 2.

Figure 2. Salinity spiking and density inversions from SeaBird-equipped floats in the tropical Pacific.



Such large salinity spikes can be avoided if the dynamic response characteristics of temperature and conductivity cells are understood and adjusted for prior to calculation of salinity. This is an especially important issue for profiling floats as transmission of raw data is impractical and data reduction must be done on-board. In order to address this problem we have constructed a special double-diffusive interface tank capable of long-term maintenance of a very sharp temperature/salinity step. Traversing the CTD through the interface allows development of an appropriate filter to optimize the accuracy of the salinity calculations. This has been done for the Excell float CTD.

PROGRESS DURING FY03

Parts shortages delayed float construction of the final nine FSI Excell equipped CORC floats to be built at WHOI, but these have recently been completed and are being deployed in the Eastern Tropical Pacific in November 2003 on a mooring turn-around cruise of R. Weller. They will be in an area with a particularly strong shallow thermocline that has illuminated the dynamic response problems of the SeaBird float CTD (G. Johnson, pers. comm.; Figure 2 above). Thus, we expect to have a good intercomparison of both stability and dynamic response issues for the two different float CTD systems in this region.

Northeast Pacific Air/Sea Flux Variability from Surface Marine Observations

by Daniel R. Cayan

PROJECT SUMMARY

Surface marine observations provide an important source of understanding the variability of conditions at the air/sea interface. While these observations are generally much less accurate than those collected on research vessels or from moored buoys, they have much greater spatial coverage and a much longer time history than is available from other *in situ* sources. This study by Dan Cayan is extracting routine ship and buoy observations to study the spatial and temporal variability of heat and moisture fluxes and how they are linked to ocean surface temperature fluctuations.

COADS Surface Marine Observations, Day vs. Night Samples

Typically, monthly turbulent and radiative fluxes have been estimated using aggregates of bulk formulae calculations over all of the observations each month. Motives for looking at these separately are to avoid errors from ship reporters taking visual sky cover and occasional visual sea-state surface wind observations taken after dark, and (optimistically) to understand actual differences in the exchanges that are associated with properties such as the day-night differences in wind, air and sea temperature, atmospheric stability, and cloudiness. This daytime-based flux dataset begins in 1950 and is updated through 2002. Because other investigators will prefer to apply their own menu of bulk formulae, we are saving the individual weather variables required to calculate each flux component.

As an area of interest to CORC, we have processed the individual marine reports from the COADS set over the eastern North Pacific region (165W-105W, 15N-35N) during the 1950-2002 period. This region contains about 240,000 daytime marine reports for each month during the 53-year period. There are more observations during daytime than nighttime hours, ranging from about 30,000 more observations during winter months and 80,000 more observations during summer months.

Objectives

1) extract a separate set of monthly daytime and nighttime marine observations of weather and ocean temperature variables necessary to compute fluxes and diagnose SST variability

2) calculate fluxes for day and night sample subsets and assess differences between the two

3) determine variability and investigate linkages between fluxes and SST separately for night and day samples

PROGRESS DURING FY03

We have processed the individual COADS marine reports into day and night subsets and have begun to analyze differences in some of the fundamental components used in estimating bulk formulae fluxes. Processing and graphics for this effort are being carried out by Ms. Emelia Bainto, a programmer analyst working with Cayan.

There are substantial differences between daytime and nighttime properties. Daytime cloud cover reports (about 3500 to 4500 observations per month, on average) are higher than those observed after dark in most months (by about .4 oktas or about 5%), as itemized in Table 1. Daytime wind speeds are higher by about 0.4m/s or about 5%. The air near the sea surface warms and cools diurnally more than does the ocean surface, and it is seen that daytime sea surface temperature-minus-air temperature (*deltaT*) is less than that in the nighttime by 0.4C to 1.0C. In relative terms, specific humidity does not vary as much from day to night. However, in winter, daytime sea surface saturation specific humidity-minus-air specific humidity (*deltaQ*) is greater than that in the nighttime by a few tenths of g/Kg.

Table 1 *Day and Night averages 165W-105W, 15N-35N, 1950-2002 COADS data*

	cloud cover (oktas)		**wind speed** (m/s)		**deltaT** (°C)		**deltaQ** (g/Kg)		
	day	night	day	night	day	night	day	night	Delta
Jan	5.1	4.7	7.7	7.3	0.9	1.3	4.1	3.9	
Feb	5.0	4.6	7.5	7.2	0.7	1.2	3.9	3.7	
Jul	5.2	5.3	6.4	6.5	-0.0	0.9	4.1	4.3	
Aug	4.9	4.9	6.3	6.3	0.0	1.0	4.5	4.7	

Not surprisingly, northeast Pacific average air temperature (Tair) and sea surface temperature (SST) are warmer in daytime than nighttime. However, somewhat surprisingly, the amplitude of the day-night difference in SST is not much smaller than for Tair. A common measure of stability at the air/sea interface, *deltaT*, is used in bulk formulae to regulate turbulent fluxes of heat, momentum and moisture. Interestingly, nighttime *deltaT* in the NE Pacific varies relatively little between winter and summer, with average values ranging between about 1.5 in late winter to 1.0 in summer. *DeltaT* is less in daytime than in the nighttime for each month and over most of the ocean basin, as seen in a separate analysis of the global *deltaT* distribution. Also, in contrast to the nighttime case, daytime *deltaT* has more seasonal variation, from 1.0 in winter to -0.06 in early summer.

The SST-Tair analysis suggests that the seasonal cycle of turbulent fluxes is more strongly controlled by daytime than nighttime processes. Implications of the cloudiness and wind speed results suggests that using the daytime subset alone would appear to be: lower net (into ocean) shortwave fluxes, greater latent and especially sensible flux heat losses from the ocean.

Our present effort is to calculate two separate sets of monthly histories of latent, sensible and radiative fluxes using the daytime and nighttime observations. Along with this, we are producing monthly day and night sequences of sea surface temperature, so that daytime and nighttime connection of fluxes and ocean temperature can be examined separately. In addition to examining the NE Pacific in lumped (spatial aggregate) fashion, the day and night data is being processed onto 1 degree latitude/longitude for each month of the time history to provide for a view of how variability and ocean/atmosphere linkages occur across the Pacific basin.

Data Assimilation
by Bruce Cornuelle, Detlef Stammer and Art Miller

PROJECT SUMMARY

The goal of this effort is to use a model to put the CORC, TAO, satellite, and ARGO data into a common, dynamically consistent framework for understanding the variability of the tropical Pacific in greater detail than was possible before. The observational dataset is both sparse and inhomogeneous, and one of the major challenges of data management for the effort is to combine the disparate data types into a coherent and useful picture of the state of the Tropical Pacific Ocean, both physical and biological.

Model and Assimilation

We are using the MIT General Circulation Model (MITGCM), which is enabled for adjoint data assimilation, and is developed and maintained as part of the ECCO project. The MITGCM produces a time-dependent, 3-D estimate of the ocean state given initial conditions, boundary conditions, and forcing. These control parameters have already been estimated as part of the ECCO project, and the goal here is to refine them further using a higher-resolution model for the Tropical Pacific. The uncertainty of the control parameters is far less than that of the time-evolving 3-D ocean state because of the dynamical constraints (conservation of mass, momentum, heat, salt, and eventually biologic dynamics) built into the model. If the model is an accurate reproduction of the true ocean, the model state can in principle be brought into agreement with the observations by adjusting the control parameters. This means that the information in the data can compensate for the uncertainty in the forcing, boundary, and initial conditions. Conversely, a limited amount of data should be able to produce a higher quality estimate of the ocean when combined with a good model. One of the scientific goals of this approach is to assess the quality of the model and assumptions (such as mixing parameters). An important part of this work will be to estimate and to improve the quality of the modeling system by looking carefully at the differences between the model fields and the observations.

The "adjoint method", or 4DVAR, uses the adjoint of a linearization of the GCM around a guessed state (and trajectory in time) to make corrections to the control parameters of the model in order to improve the fit to the observations. This technology has been developed for the MIT model, and has been used at global resolution as part of the NOPP-funded ECCO project. One of the questions raised by that work is how the limited resolution of the global model may cause representational errors due to unresolved physics, and these errors may be aliased into unrealistic values for the control parameters. The equatorial Pacific is a candidate region for such under-resolution, and part of the goal in working in this region is to see how the optimal forcing and boundary conditions are altered by increasing the model resolution in a critical region. We are using the ECCO technology to estimate our control parameters, so the only difference between the two estimates is model resolution.

To achieve high resolution at lower cost, we have made a regional domain including only the tropical Pacific, with open boundaries at 26°N, 26°S, and in the Indonesian throughflow. The values at those boundaries are prescribed by the monthly outputs of the ECCO assimilated global model, which has

1°x1° resolution, creating a 1-way nested configuration. The outer model has assimilated global data, including most of the data of interest to us in the smaller domain. Forcing fields, boundary conditions, and model initial conditions are all taken from the assimilated ECCO global state estimates. The assimilated output is currently available from January 1992 through 2002. At the western boundary, an estimated Indonesian throughflow is imposed.

The inner model has been run in forward mode, for data comparisons and sensitivity studies in preparation for assimilation experiments. Assimilation has recently begun, and the first few steps have made improvements to the fits to observations. Many challenges still remain in applying the assimilation, due to the instabilities and nonlinearities of this region, which greatly increase the difficulty of the assimilation over the large-scale example.

Scientific Goals

- Reproduce Equatorial dynamics to diagnose and understand the differences between ENSO cycles over time, including the effects of boundary controls and forcing.
- Diagnose instability wave mechanisms and their role in mixing and the shallow overturning cell in the Tropical Pacific.
- Improve surface forcing fields by bringing them into balance with ocean dynamics and observations.
- Test the MITGCM by detailed comparisons with observations at a resolution that is expected to produce good agreement.
- Provide a dynamically consistent merging of the various datasets for use by others to do further analysis of the Tropical Pacific, including overturning, barotropic instability of the Equatorial current system, and dynamical balances of the circulation.
- Investigate predictability time-scales for the tropical ocean. For example, on what scales do nonlinearities come to dominate?
- Incorporate a biological model into the physical model and explore the effects of biology on physics in the tropical Pacific.

Progress in FY 2003

Comparison with observations

The comparisons to observations are evaluated for several different 9-year integrations to validate the model and to study its sensitivity to the forcing fields and to the horizontal resolution.

Two data sets are used to force the model. The first consists of the sea surface fields from the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) re-analysis project. This data set is available on a 1°_1° global grid and contains the main atmospheric and surface parameters requited to force the MIT model, namely, twice-daily wind stress vectors and daily net heat flux, net short-wave radiation and water flux at the sea surface. The second forcing set is obtained from the optimized ECCO forcing fields. These forcings are the NCEP forcings optimized by a global state estimation procedure on a 2°_2° grid. Comparison of the model outputs to different data sets has shown that the model behaves generally better when the ECCO forcing is used (Figure 1). There is still however a lot of room for improving the model performance using assimilation (Figure 2).

The model was also integrated on a three different 1°_1°, 1/3°_1/3° and a 1/6 ° _1/6 ° grid using the ECCO forcing fields. A reasonable conclusion to draw from current runs is that the ocean grid spacing could be set to about 1/3 ° grid spacing in the tropical Pacific to accrue the benefits of enhanced resolution without paying an excessive price in computer time (Figure 3).

Assimilation: first steps

The adjoint assimilation has now been run for several steps in the 1/3 ° model, and the machinery has been working. The cost function (Figure 4) decreases at the start, but soon becomes flat. The adjoint model shows responses growing nearly exponentially with time lag, but these large sensitivities do not occur for finite-amplitude perturbations. The assumed reason is fast-growing instabilities that cease to grow after reaching finite amplitude due to nonlinear interactions with the rest of the flow. These sensitivities can be greatly reduced by running the adjoint model at 10 times the viscosity and diffusivity of the forward model, but this is a less-than-satisfactory procedure.

Many papers have dealt with the stability of the adjoint in highly nonlinear models. All these papers agree that the adjoint becomes very unstable and its variables grow exponentially when the model is highly nonlinear. The cost function also becomes very irregular yielding to multiple minima, making the optimization process very complicated. Moreover, the number of these minima grows very fast as the integration length increases. In brief, this means that the assimilation can be only carried out within the periods in which the model is weakly nonlinear, where the adjoint is indeed stable.

We have investigated this by carrying out several forward runs of the tropical pacific model to quantify the sensitivities and nonlinearities in the familiar forward sense. In the first experiment (E1), we made 3 runs:

- R1: A forward run.
- R2: The same run as R1 but with a constant (*eps*>0) perturbation on the wind stress.
- R3: The same run but with *-eps* as constant perturbation on the wind stress.

The use of *+/-eps* as perturbations allows us to compute the second derivative of the model with respect to the initial conditions, and thus to measure the nonlinearity in the model. As is shown in Figure 5, the error grows very quickly in time. The nonlinearities appear after only a few weeks (rightmost column) and become more and more important. This is consistent with the timing of the adjoint model instabilities. The norm of the perturbation (not shown here) grows also exponentially in the first months before moderating its growth due to the nonlinearities.

A second experiment (E2) was performed identical to the first one, but perturbing the initial conditions (S and T) and very similar behavior was seen.

These experiments show that the model is significantly nonlinear if the viscosities and diffusivities are set at realistic values. This can explain the instabilities of the adjoint model, including their timing (after 1 month integration), which considerably limit the length of the assimilation period in our experiments (2-3 months). At high viscosity and diffusivity, the model becomes almost linear, at least during the first 9 months, allowing the assimilation on substantially larger periods.

Biological model

We are also developing the capability to model ecosystem response in both the tropical Pacific, where the majority of CORC modeling research is being executed, and the California current region (Figure 6), where an ecosystem model has been already running using the Regional Ocean Model System (ROMS). The biological model is a 7 component, Fasham-style ecosystem model (tracking nitrogen) with the capability of being expanded to a 10-component carbon cycling model (tracking nitrogen, oxygen, and carbon).

Our primary effort involves 1) the incorporation of biology into the MITGCM running on the SIO COMPAS cluster machine for use in any domain and 2) a comparison of output from the resulting MIT model with output from the ROMS in the California Current domain. To date, we have a functioning MITGCM model without biology and have ported a ROMS model, running on the target domain (Figure 6), to the COMPAS. We have made preliminary comparisons of the output of the physical ROMS runs with previous runs made on a different machine. We have made preliminary progress in converting the

ROMS input files to the format used by the MITGCM, testing the ROMS biology code, and importing the ROMS biology code into the MITGCM.

High Resolution Climate Data From Research and Volunteer Observing Ships
by C. W. Fairall

PROJECT SUMMARY

This project involves the measurement of direct high-resolution air-sea fluxes on two cruises per year and the development of a roving standard flux measuring system to be deployed on a series of NOAA and UNOLS research vessels to promote the improvement of climate-quality data from those platforms. An adjunct task is maintenance and operation of the C-band scanning Doppler radar and the stabilized wind profiling radar on the NOAA ship *Ronald H. Brown.* Because buoys and most ships and satellites rely on bulk methods to estimate fluxes, another aspect of this project is the use of direct measurements to improve the NOAA/COARE bulk flux algorithm. One cruise is the annual TAO buoy tending cruise to 95 and 110 W on the *Ronald Brown*, which occurs every Fall. The other cruise is the annual cruise to turn around the Climate Buoy at 20°S 85°W, also in the fall. A full suite of direct, inertial-dissipation, and bulk turbulent fluxes are measured along with IR and solar radiative fluxes, precipitation, and associated bulk meteorological properties. This effort represents a partial transition of research from the OGP CLIVAR PACS program to operations under the Climate Observations Program (COP).

The project is the result of a recent NOAA-sponsored workshop on high-resolution marine measurements (Smith et al., 2003, *Report and Recommendations from the Workshop on High-Resolution Marine Meteorology*, COAPS Report 03-01, Florida State University, pp38) which identified three important issues with the planned NOAA air-sea observation system: 1) the need to a data quality assurance program to firmly establish that the observations meet the accuracy requirements, 2) a need for observations at high time resolution (about 1 minute), 3) a need to more efficiently utilize research vessels including realizing their potential for the highest quality data and their potential to provide more direct and more comprehensive observations. For seasonal time scales the net air-sea flux (sum of 5 flux components) needs to be constrained within 10 W/m^2. Buoys and VOS systems must operate virtually unattended for months, so considerations of practical issues (e.g., power availability, ruggedness, or safe access) are balanced against inherent sensor accuracy and optimal sensor placement. As discussed above, an important function of the *in situ* measurements is to provide validation data to improve NWP and satellite flux fields. Here, high time resolution and more direct observations can be invaluable for interpreting surface flux measurements and diagnosing the source of disagreements; such information can be provided by suitably equipped RV's. Thus, the accuracy of buoy and VOS observations must be improved and supplemented with high-quality, high time resolution measurements from the US Research Vessel fleet (which is presently underutilized). The necessity for both high time resolution and high accuracy places extreme demands on measurements because some sources of error (such as the effect of ship flow distortion on wind speed) tend to average out over a large sample. To accomplish this will require a careful intercomparison program to provide traceability of buoy, VOS, and RV accuracy to a set of standards.

This project directly addresses the need for accurate measures of air-sea exchange (Sections 5.2 to 5.4, *Program Plan for Building a Sustained Ocean Observing System for Climate.* The project is a joint effort by ETL and the Dr. Robert Weller, Woods Hole Oceanographic Institution (WHOI). NOAA COP funds the ETL component and Dr. Weller is seeking NSF fund for the WHOI component. The ETL air-sea interaction group website is http://www.etl.noaa.gov/et6/air-sea/. ETL also cooperates with Dr. Andy Jessup (APL University of Washington) on radiative sea surface temperature measurements, Dr. Frank Bradley (CSIRO, Canberra Australia) on precipitation, Drs. M. Cronin and N. Bond (PMEL) on buoy-ship intercomparisons and climate variability analysis, and Dr. Mike Reynolds (DOE BNL) on radiative fluxes. A new website is under construction for this project (High Resolution Climate Observations). The website is planned to contain a handbook on best practices for flux measurements plus a database of high-resolution flux data. This work will be closely monitored by the new WCRP Working Group on Surface Fluxes (WGSF), which is chaired by C. Fairall. This will give the project high visibility in the CLIVAR, GEWEX, and SOLAS programs. This project will be managed in cooperation with JCOMM (and other) panels as per instructions of Mike Johnson.

FY2003 PROGRESS

The air-sea flux part of this project has been transitioned from the CLIVAR/PACS program to Climate Observations Program, so COP did not fund any observations in FY03. The TAO tender cruise was conducted in the fall of 2002. A complete 8-cruise PACS database is now available at ftp://ftp.etl.noaa.gov/et7/users/cfairall/EPIC/epicmonitor/combined_files. These data include air-sea fluxes, cloud properties, wind profiles, and rawinsondes. The data are publicly open to all and are shared explicitly with joint investigators (see above). The data are also used in scientific collaboration by Dr. Z. Xeng (U. Arizona), C. Bretherton (U. Washington), B. Albrecht (U. Miami), and B. Stevens (UCLA). The cruises are done in piggyback mode, so there is no impact on ship time requests. Approximately k$65 was spend ordering new sensors (aerosol spectrometer, two laser wave gauges, and a fast humidity sensor) for future field programs. Additional high quality mean humidity/temperature sensors and computers were ordered on ETL base funds. Considerable effort was devoted to planning and preparations for the two upcoming fall cruises. Installation of the equipment on the ships and execution of the cruises will occur in FY04.

For the *Ronald Brown* C-band and wind profiler radar project, training sessions for scientists and engineers were done on the ship, in Boulder, and at Sigmet, Inc. This expanded the number of people who are trained to operate this radar system. Routine maintenance was done on the radar in Charleston. This included replacing wiring, calibrations and leveling of the C-band radar. New Linux computers were configured to replace the two radar computers on the ship. The software licenses and maintenance were also continued with Sigmet, Inc.

Two research accomplishments are highlighted here. The latest version of the NOAA/COARE bulk flux algorithm was published (Fairall et al., 2003). This algorithm is the most accurate and widely used method to compute air-sea fluxes and is the basis of most air-sea fluxes computed from buoys. This algorithm was cited 281 times in the scientific literature in the calendar year 2003. It also contains the most accurate representation of CO_2 fluxes presently available, which also impacts the second objective of the COP sustained ocean observing system (Document ocean carbon sources and sinks). A second highlight is the use of the 8-cruise database to examine efficacy of the parameterization of planetary boundary layer (PBL) height in the current version of the NCAR Community Climate Model (CCSM2). The analysis showed that the present implementation in CCSM2 gave poor correlation (r^2=0.06) with measured PBL heights but that if the model vertical resolution was doubled the correlation increased significantly (r^2=0.78). This is a major demonstration of how marine observations can be used to improve climate models.

PROJECT SUMMARY AND FY 2003 PROGRESS

Document Ocean Carbon Sources and Sinks
Encompassing the proposals:

Initial Steps Towards a Global Surface Water pCO_2 Observing System.
and:
Underway CO_2 measurements on the NOAA ships *Ka'imimoana* and *Ron Brown* and RVIB *Palmer* and *Explorer of the Seas*

by Richard A. Feely and Rik Wanninkhof, with Nicolas R. Bates, Frank Millero, Taro Takahashi and Steven Cook

PROJECT SUMMARY

Understanding the global carbon cycle and the determination of the regional sources and sinks of carbon are of critical importance to international policy decision making as well as for forecasting long term climate trends. Projections of long-term global climate change are closely linked to assumptions about feedback effects between the atmosphere, the land, and the ocean. To understand how carbon is cycled through the global climate system, ocean measurements are of utmost importance. In this effort NOAA is outfitting research and commercial vessels with autonomous carbon dioxide sampling equipment to analyze the seasonal variability in carbon exchange between the ocean and atmosphere. This task is coordinated at national level with the U.S. Global Carbon Cycle Science program and its subcommittee on Ocean Carbon and Climate change (OCCC). Internationally, it is a component of the International Ocean Carbon Coordination Project (IOCCP), which is a joint endeavor of the SCOR/IOC CO_2 panel and the IGBP-IHDP-WCRP Global Carbon Project. Documenting carbon sources and sinks relies critically on other efforts undertaken by the Climate Observations and Services Program, COSP including implementation of the ship lines, and moored and drifting arrays. The surface water pCO_2 programs support climate services by providing knowledge and quantification of climate forcing of the radiatively important gas, carbon dioxide. The near term (< 5-year) focus is on completion of the Northern Hemisphere ocean carbon observing system to assist in determining carbon dioxide sources and sinks over the coterminous United States in partnership with the atmospheric CO_2 observing system. Our effort, henceforth called the underway pCO_2 observing program, is a partnership of AOML, AOML/GOOS, PMEL, LDEO of Columbia University, RSMAS of the University of Miami, and the Bermuda Biological Station for Research (BBSR).

FY 2003 progress

Acquisitions, deployments and data return:

The pCO_2 observations from research ships have been performed on a routine basis on:

- NOAA ship *Ka'imimoana*: 9 cruises servicing the TAO mooring in the Equatorial Pacific
- NOAA ship *Ron Brown*: 15 cruises in Atlantic and Eastern Equatorial Pacific
- RVIB *Palmer*: 8 cruises in the Southern Ocean and Arctic, including a trans Pacific transit
- Royal Caribbean cruise line *Explorer of the Seas*: 40 cruises in the Caribbean Seas

The cruise schedule was similar to the previous year. Some data loss occurred, most notably on the *Ka'imimoana* whose system has exceeded the operational lifetime of the instrument (5-years), and the *Explorer of the Seas* where a re-installation of the instrument and operating system upgrade caused a software problem that took several months to resolve.

A major component of the VOS pCO_2 work revolved around designing, building and testing a new pCO_2 system for ships of opportunity. Four systems were built by a contractor with extensive input from the NOAA sponsored partners. The system was compared against several other units at an intercomparison study in Japan in May 2003. The performance of the system was such that it is rapidly becoming "the gold standard" and ordered by many other groups throughout the world. In addition, the VOS group has built a gas standard referencing system and a system intercalibration laboratory such that all systems that will be deployed will have documented performance characteristics. The efforts of the NOAA VOS pCO_2 group thus have met the important monitoring principle of uniform instrumentation with a quantifiable accuracy. Since the first units were delivered in the summer of 2003, within a year of receipt of program funding, and still undergoing validation tests, no VOS ships were outfitted in the performance period.

Data management and dissemination:

An important part of the VOS effort is to disseminate quality controlled data to the community at large in an expedient fashion. The LDEO group will, in close interaction with the data acquisition groups, oversee shipboard quality control so that the quality of data will be monitored as closely as possible to real time. This close coupling of the data acquisition with data processing/evaluation and interpretation will guarantee high quality of field observation data. The LDEO group will also coordinate submission of the collated data to the underway pCO_2 data center for community access. They will participate in data interpretation with the data acquisition groups. This will prevent the data acquisition groups to be detached intellectually from data interpretation, and thus will insure that the observationalists will be engaged deeply in the interpretation processes.

Data obtained from the research ships are currently served from the institution responsible for the measurement (see web sites above). Although this component was not explicitly listed in the LDEO data management effort for the VOS proposal, the data from the research ships are currently being ingested by the LDEO group for their first annual release.

Data are archived at the responsible laboratories with concrete plans to unify quality control and distribution. Data will be released to the internationally sanctioned data centers, NODC and CDIAC. Investigators, and the oceanographic community use the data extensively. These data are used for national and international assessments such as the IPCC.

Problems:

The major problems encountered were late receipt of funds from NOAA, in particular for our academic colleagues, which slowed down the work schedule. For the research ship projects instrumentation on the Ka'imimoana and Palmer have encountered mechanical problems due to their age and continuous operation.

Project costs:

Anticipated- cost of data reduction, dissemination and archive, interpretation, cost of maintenance, and instrument design.

Unanticipated- higher than budgeted maintenance costs, higher than anticipated instrument development costs.

Logistical considerations- work on the research ships proceeded as planned with the benefit that the Palmer was transferred from the Antarctic to the Arctic thereby filling a data gap in the Eastern South Pacific. The Brown was used for the CO_2/CLIVAR repeat hydrography program in the North Atlantic such that the data UW pCO_2 from this system became a core measurement for this program, alleviating costs to COSP.

Research highlights:

1. A continued focus of the research ship effort has been the study of the interannual variability in the Equatorial Pacific caused by the ENSO cycle. In a collaborative effort with JGOFS oceanographers we have studied the physical and chemical processes that control the interannual variability of CO_2 fluxes in the equatorial Pacific. To date, we have successfully used the

underway pCO_2 systems on more than 100 cruises and 4 moorings in the Equatorial Pacific. The results from these cruises provided the first detailed observations of the regional variability of pCO_2 during the 1997-98 and 2002-03 ENSO events. The data show the large interannual effects of El-Niño on CO_2 exchange in the equatorial Pacific. A synopsis is provided in the supplementary material.

2. The pCO_2 measurements performed over the last two decades in the Equatorial Pacific, primarily by the investigators in this proposal, have shown a large shift in pCO_2 levels and CO_2 fluxes. The pCO_2 levels in the 80-ties increased much more slowly than in the 90-ties with the change in trend occurring at the beginning of the 90-ties. This timing corresponds with a change in the Pacific Decadal Oscillation (PDO). It reinforces the hypothesis that natural climate reorganizations have a major effect on air-sea fluxes. While studies by our group have clearly shown the large effect of the ENSO on the fluxes, this is the first time the effect of the longer time scale oscillations on the oceanic carbon system have been shown. The results have been published in a paper in Science by Takahashi *et al.* (2003), attached in the supplementary material.
3. Methods to interpolate CO_2 measurements in time and space. It is widely recognized that robust methods are needed to produce CO_2 flux maps from measurements along a line. Publications by Cosca *et al.* (2003) for the Equatorial Pacific and Olsen *et al.* (2003) for the Caribbean Seas show how temperature can be utilized to produce regional flux maps. The algorithms are area specific but show a robust predictive capacity and provide a means to utilize remote sensing to produce flux maps with high spatial and temporal resolution. The data used to create the algorithms were obtained on the ships funded under this effort. The papers are attached as supplementary material.

Global Repeat Hydrographic/CO_2/Tracer Surveys In Support Of CLIVAR And Global Carbon Cycle Objectives

by Richard A. Feely and Rik Wanninkhof with Christopher Sabine, Gregory Johnson, Molly Baringer, John Bullister, Calvin W. Mordy, and Jia-Zhong Zhang

PROJECT SUMMARY

General Overview

The Repeat Hydrography CO_2/tracer Program is a systematic and global re-occupation of select hydrographic sections to quantify changes in storage and transport of heat, fresh water, carbon dioxide (CO_2), chlorofluorocarbon tracers and related parameters. It builds upon earlier programs (e.g., World Ocean Circulation Experiment (WOCE)/Joint Global Ocean Flux Survey (JGOFS) during the 1990s) that have provided full depth data sets against which to measure future changes, and have shown where atmospheric constituents are getting into the oceans. The Repeat Hydrography CO_2/tracer Program will reveal much about internal pathways and changing patterns that will impact the carbon sinks on decadal time scales. It is designed to assess changes in the ocean's biogeochemical cycle in response to natural and/or man-induced activity. Global warming-induced changes in the ocean's transport of heat and freshwater, which could affect the circulation by decreasing or shutting down the thermohaline overturning, can be followed through long-term measurements. Below the 2000m depth of the Argo array, Repeat Hydrography is the only global measurements program capable of observing these long-term trends in the ocean. The program will also provide data for the Argo sensor calibration (e.g., www.argo.ucsd.edu), and support for continuing model development that will lead to improved forecasting skill for oceans and global climate.

By integrating the scientific needs of the carbon and hydrography/tracer communities, major synergies and cost savings have been achieved. The philosophy is that in addition to efficiency, a coordinated approach will produce scientific advances that exceed those of having individual carbon and hydrographic/tracer programs. These advances will contribute to the following overlapping scientific objectives: 1) data for model calibration and validation; 2) carbon inventory and transport estimates; 3) heat and freshwater storage and flux studies; 4) deep and shallow water mass and ventilation studies; and 5) calibration of autonomous sensors.

National Linkages

The Repeat Hydrography CO_2/tracer Program is being implemented to maintain decadal time-scale sampling of ocean transports and inventories of climatically significant parameters. The sequence and timing for the sections (Fig. 1) takes into consideration the program objectives, providing global coverage, and anticipated resources. Also considered is the timing of national and international programs, including the focus of CLIVAR on the Atlantic in the early years of the program; the Ocean Carbon and Climate Change Program (OCCC) that emphasizes constraining the carbon uptake in the Northern Hemisphere oceans, in part, in support of the North American Carbon Program (NACP); and the international Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) program. In addition, the proposed sections are selected so that there is roughly a decade between them and the WOCE/JGOFS occupation.

The scientific objectives are important both for the CLIVAR and the OCCC programs, and for operational activities such as Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS). In mid-2001 the US scientific steering committees of CLIVAR (www.clivar.org) and the Carbon Cycle Science Program, CCSP (www.carboncyclescience.gov) programs proposed the creation of a joint working group to make recommendations on a national program of observations to be integrated with international plans. Several community outreach programs and efforts have been implemented to provide information about the program, such as a web site with interactive forum (http://ushydro.ucsd.edu/index.html), articles in EOS (Sabine and Hood, 2002) and the JGOFS newsletter, as well as AGU and Ocean Science meeting forums. The Repeat HydrographyCO_2/tracer Program addresses the need, as discussed by the First International Conference on Global Observations for Climate (St. Raphael, France; October 1999), that one component of a global observing system for the physical climate/CO_2 system should include periodic observations of hydrographic variables, CO_2 system parameters and other tracers throughout the water column (Smith and Koblinsky, 2000; Fine et al., 2001). The large-scale observation component of the Ocean Carbon and Climate Change Program (OCCC) has also defined a need for systematic observations of the invasion of anthropogenic carbon in the ocean superimposed on a variable natural background (Doney et al., in press; Fig. 1).

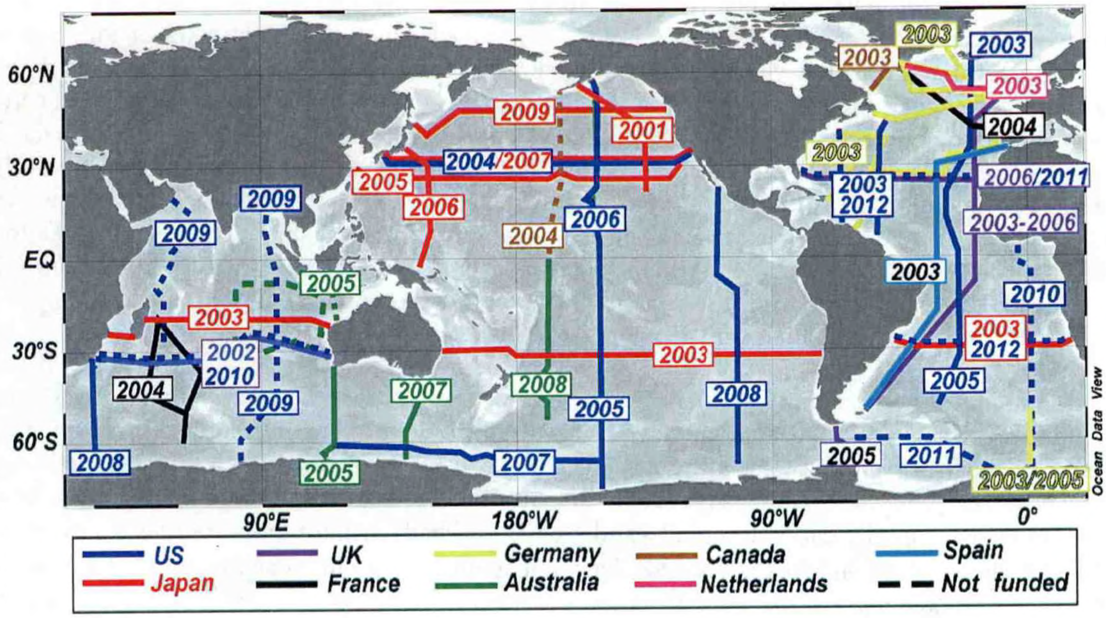


Figure 1. Global map of planned Repeat Hydrography CO_2/tracer Program hydrographic sections with carbon system measurements. Solid lines indicate funded lines. Dashed lines indicate planned lines that are not fully funded at this time. The U.S. A16N, A20 and A22 cruises in the North Atlantic are designated with solid blue lines for calendar year 2003.

The Climate Change Science Program (CCSP) has identified the critical need for the federal government to begin delivering regular reports documenting the present state of the climate system components. Through this program plan NOAA will develop the infrastructure necessary to build, with national and international partners, the ocean component of a global climate observing system and to deliver regular reports on the ocean's contribution to the state of the climate and on the state of the observing system. The goal of this plan is to build and sustain the ocean component of a global climate observing system that will respond to the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments.

Relationship to NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate

The ocean is the memory of the climate system and is second only to the sun in effecting variability in the seasons and long-term climate change. It is estimated that the ocean stores 1000 times more heat than the atmosphere, and 50 times more carbon. Additionally, the key to possible abrupt climate change may lie in deep ocean circulation. Accordingly, the main objective of the repeat hydrography component of the sustained ocean observing system for climate is to document long-term trends in carbon storage and transport in the global oceans. This program will provide a composite global ocean observing system large-scale observations that includes: 1) detailed basin-wide observations of CO_2, hydrography, and tracer measurements; and 2) data delivery and management. This end-to-end ocean system will provide the critical "up-front" information needed for climate research and assessments, as well as long-term, climate quality, global data sets. At the same time, the data management system will provide the necessary data to serve the needs of the other federal agencies in accomplishing their missions.

International Linkages

Recognizing the need to develop an international framework for carbon research, various working groups of programs like the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), the International Human Dimensions Programme (IHDP), the Intergovernmental Oceanographic Commission (IOC), and the Scientific Committee on Oceanic Research (SCOR) have worked together to develop research strategies for global carbon cycle studies. Based on the recommendations coming from these programs, NOAA and NSF have co-sponsored the Repeat Hydrography CO_2/tracers Program, with program direction coming from the Repeat Hydrography Oversight Committee (Richard Feely and Lynne Talley, co-chairs). Many other nations are also sponsoring similar carbon studies that are comparable in focus and have been designed to be complementary to our program. Consequently, there is an immediate need for global-scale coordination of these carbon observations and research efforts to achieve the goal of a global synthesis. There is also an urgent need to critically assess the overall network of planned observations to ensure that the results, when combined, will meet the requirements of the research community. Because of these issues, the IOC-SCOR Ocean CO_2 Panel and the Global Carbon Project (GCP) have initiated the International Ocean Carbon Coordination Project (IOCCP) to: (1) gather information about on-going and planned ocean carbon research and observation activities, (2) identify gaps and duplications in ocean carbon observations, (3) produce recommendations that optimize resources for international ocean carbon research and the potential scientific benefits of a coordinated observation strategy, and (4) promote the integration of ocean carbon research with appropriate atmospheric and terrestrial carbon activities. It is through the workings of the IOCCP and international CLIVAR that international coordination of data management, data synthesis and scientific interpretation of the global repeat sections results will be implemented. In addition, the Repeat Hydrography CO_2/tracer Program is being managed in accordance with the COSP Ten Climate Monitoring Principals.

FY 2003 Progress Report

A16N Cruise in the North Atlantic

In the two-month period between June and August of this year, the first survey (Repeat Hydrography Section A16N) as part of the Repeat Hydrography CO_2/tracer Program was successfully completed in the North Atlantic on NOAA Ship *Ronald H. Brown* (Fig. 1 and Table 1).

Table 1. Sequence of Repeat Hydrography CO_2/tracer cruises in the oceans for the decade staring in June of 2003. Note the A16N, A22, A20 cruises were conducted in the summer and fall of 2003.

Schedule of US CO2/CLIVAR Hydrography Lines (as of 4/25/03)

Dates	Cruise	Days	Ports	Year	Contact/Chief Scientist
					overall coordinator: Jim Swift, SIO
6/19/03-7/10/03	A16N, leg 1	22	Reykjavik-Madeira	1	Bullister, PMEL
7/15/03-8/11/03	A16N, leg 2	28	Madeira - Natal, Brazil	1	Bullister, PMEL
9/15/03-10/13/03	A20	29	WHOI - Port Of Spain	1	Toole, WHOI
10/16/03-11/07/03	A22	21	Port Of Spain - WHOI	1	Joyce, WHOI
summer 2004	P2 (two legs)	66	San Diego-Honolulu-Yokohama	2	Swift/Robbins, SIO
austral summer 05	A16S	44	Montevideo-Fortaleza Brazil	3	
austral summer 05	P16S	40	Wellington-Tahiti	3	
2006	P16N	57	Tahiti-Alaska	4	
austral summer 07	S4P/P16S	25.5	Wellington-Perth	5	
austral summer 07		25.5	Wellington-Perth	5	
2008	P18	32	Punta Arenas-Easter Island	6	
2008		35	Easter Island- San Diego	6	
2008	I6S	42	Cape Town	6	
2009	I7N	47	Port Louis/Muscat	7	future planning
2009	I8S	38	Perth- Perth	7	future planning
2009	I9N	34	Perth- Calcutta	7	future planning
2010	I5	43	Perth - Durban	8	future planning
2010	A13.5	62	Abidjan-Cape Town	8	future planning
2011	A5	30	Tenerife-Miami	9	future planning
2011	A21/S04A	42	Punta Arenas-Cape Town	9	future planning
2012	A10	29	Rio de Janeiro-Cape Town	10	future planning
2012	A20/A22	29	Woods Hole-Port of Spain-Woods Hole	10	future planning

Years 1-6 are funded.

The cruise ran from Iceland southward past the equator and repeated an oceanographic section occupied in 1988, and again in 1993, looking for possible changes in the physics, chemistry and biology of the ocean in this region. All of the major goals of this expedition were met. The sampling rosette/CTD system worked without a failure for 150 deep ocean casts, providing ~5000 water samples for 1 analysis. Such 100% instrument performance is rare in the hostile ocean environment where 90% data return is considered outstanding.

Participating scientists from PMEL, AOML and 13 other scientific institutions made a wide variety of atmospheric and oceanic measurements. Atmospheric (CO_2, chlorofluorocarbons, aerosols) and near surface seawater (temperature, salinity, pCO_2, fluorescence, ADCP) measurements were made while underway along the cruise track. Six ALACE profiling floats were deployed along the section, along with 3 newly developed 'Carbon Explorer' profiling floats designed to measure particulate inorganic carbon (PIC). Full water column CTD/rosette casts were made at 150 stations, with ~5000 discrete seawater samples collected using a specially designed 36 position 12 liter rosette package, In addition to the CTD, the rosette frame held a lowered ADCP, transmissometer and particulate inorganic carbon sensor. The new PMEL-designed rosette and sample bottles worked extraordinarily well, with only 1 known bottle misfire and almost no samples lost due to bottle leakage or other problems.

Because of potential contamination problems in sampling for iron and aluminum, separate trace metal casts were made at ~60 stations along the section using a trace-metal clean winch with a Kevlar wire. This was the largest-scale study ever done of the distribution of dissolved iron and aluminum in the ocean. Aerosol samples were collected along the cruise track to better determine the impact of atmospheric transport and deposition of dust, especially from northern Africa, on the levels of dissolved iron and aluminum in the surface waters in this region, and the importance of this process on the global carbon cycle.

Seawater samples were analyzed on board ship for salinity, dissolved oxygen, nutrients, Total CO_2 (DIC), Total Alkalinity (TAlk), pCO_2, pH, chlorofluorocarbons (CFCs), HCFCs, iron and aluminum and alkyl nitrate. Water samples were collected for shore-based analyses of helium, tritium, dissolved organic carbon, particulate organic and inorganic carbon, ^{13}C and ^{14}C. As the samples were analyzed on board, the data were collected and compiled by the data manager, allowing near real-time examination and comparison of the data sets as they were generated. Preliminary evaluation of the shipboard data indicates they are of high quality and should meet or exceed WOCE guidelines. The preliminary A16N CTD and bottle set is publicly accessible on line at: http://whpo.ucsd.edu/data/co2clivar/atlantic/a16/a16n_2003/index.htm. Final calibration and processing of the cruise data set is underway and we anticipate completing this process in early 2004.

One of the central goals of this program is to better understand the rate at which anthropogenic CO_2 from the atmosphere is taken up and transported into the ocean's interior. In addition to dissolved CO_2 measurements, simultaneous measurements of other tracers, such as CFCs, nutrients and dissolved oxygen, can aid in this study. Preliminary sections of CFC-12 from the A16N cruise are shown in Fig. 2, along with previous sections occupied in 1993 and 1988. The increases in CFC-12 between 1988 and 2003 indicate that the upper and mid depth waters in this region of the northern North Atlantic are rapidly ventilated with atmospheric gases on decadal time scales. The strong CFC signal in waters from 1000-2000m depth north of ~ 40°N reflect the rapid ventilation and transport of Labrador Sea Water into this region. A significant CFC signal is also present in abyssal waters at the northern end of the section, associated with the formation and outflow of North Atlantic Deep Waters, a key component of the global thermohaline circulation. Of particular interest is the development and evolution of a CFC-12 maximum near the equator at a depths of ~1000-2000m (Fig. 2) associated with upper North Atlantic Deep Water. This maximum demonstrates that ocean circulation processes are rapid enough to carry these compounds, absorbed in surface waters in the high latitude North Atlantic, to the tropics on decadal time scales. CFCs are key tracers for studying the rates and pathways of ocean ventilation processes and can be used to help estimate the rate of uptake of anthropogenic carbon dioxide in the ocean. The CFC data will be of use in testing numerical models for circulation and transport along this section.

Preliminary results from the cruise also indicate that the apparent oxygen utilization (AOU; see Fig. 3) at a depth range of 400-800m between 60°-40°N in this region of the North Atlantic has increased significantly between 1988 and 2003. Similar increases in mid-depth AOU have also been observed in the North Pacific (Emerson et al., 2001), and may be due to a slowdown in the rate of ocean circulation, an increase in the rate of export of organic carbon from the overlying waters, or to a combination of these factors over the past 15 years.

A detailed analysis of these and other findings from this cruise should greatly improve our understanding of key ocean processes in this region and how they may be changing on decadal timescales. The results will be presented at a special session of the 2004 Fall AGU meeting and significant findings will be published in the scientific literature.

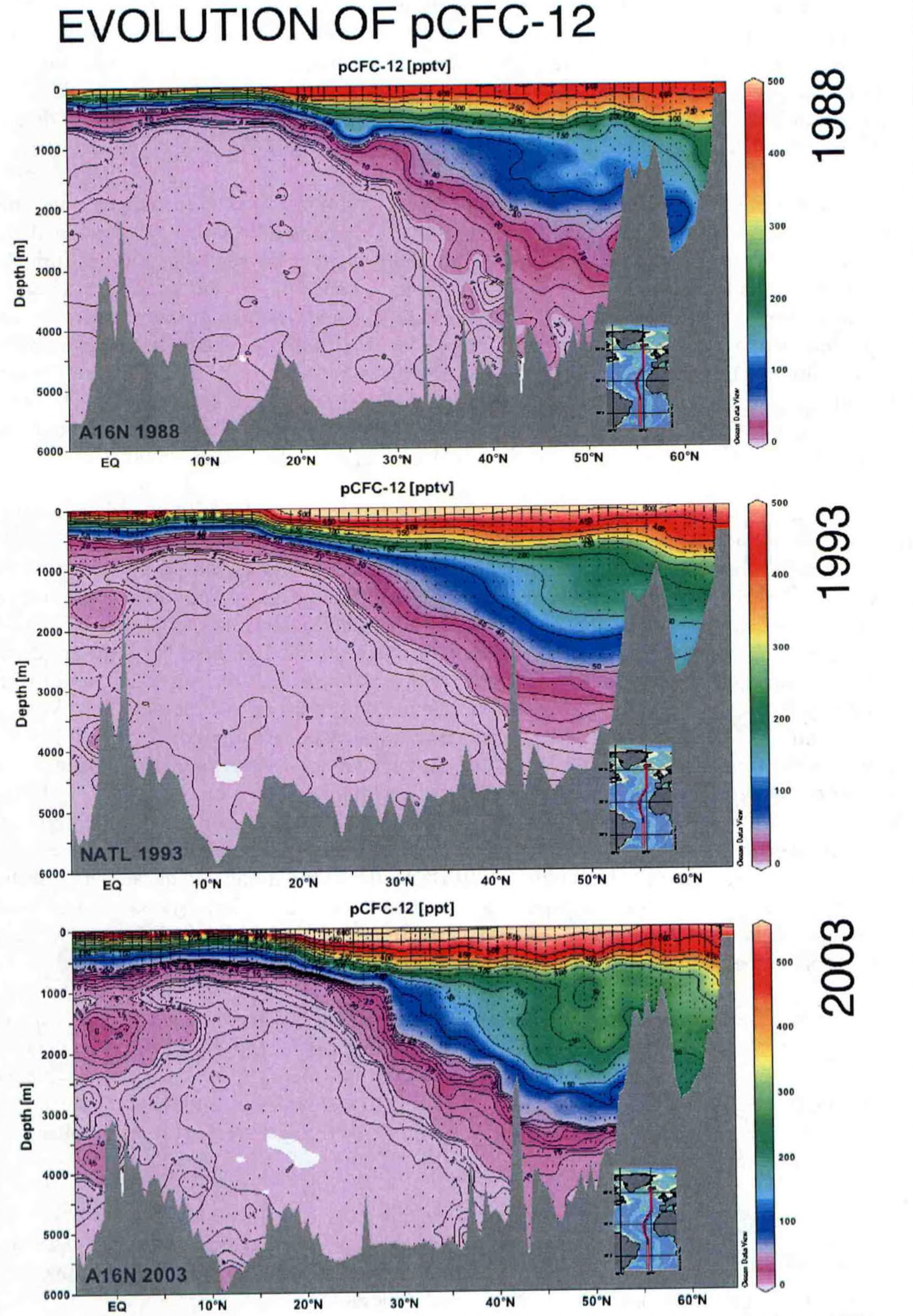


Figure 2. Distribution of: CFC-12 in pptv for: A) 1988; B) 1993; and C) preliminary 2003 results in the North Atlantic Ocean. The increases in CFC-12 between 1988 and 2003 indicate that the upper and mid depth waters in this region of the northern North Atlantic are rapidly ventilated with atmospheric gases on decadal time scales (provided by J. Bullister, PMEL).

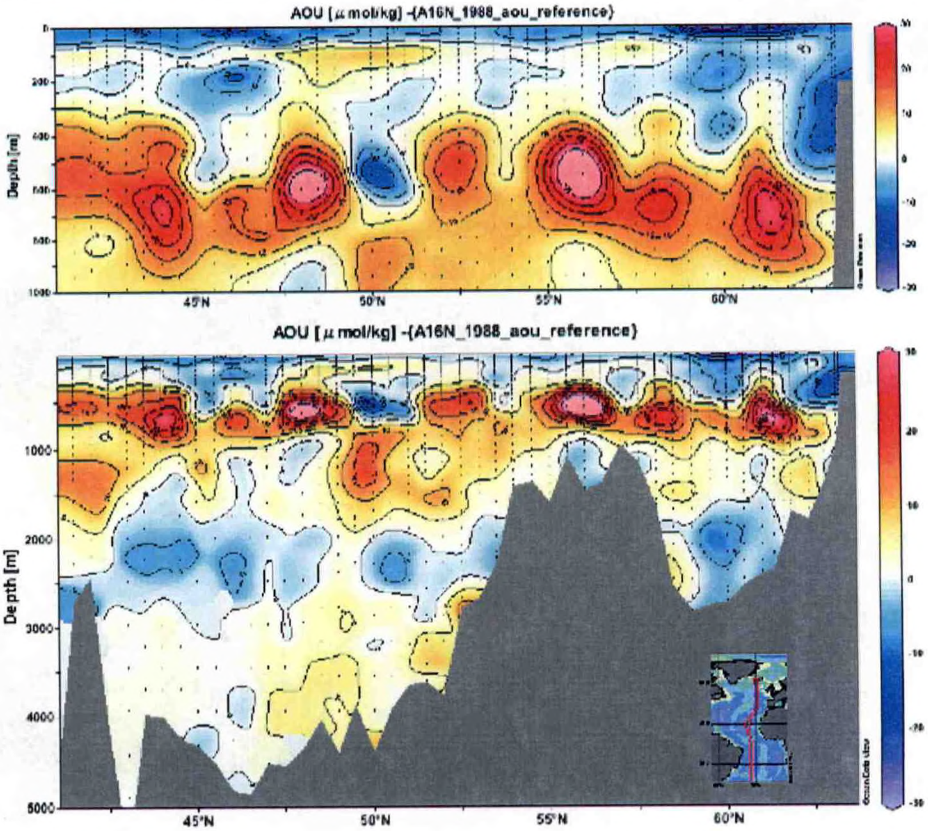


Figure 3. Preliminary results of the distribution of the AOU 2003 – 1988 difference (μmol kg^{-1}) in the North Atlantic Ocean along A16N. Note the large differences between 400 – 800 m in the water column (provided by J. Bullister, PMEL).

A20/A22 Cruise in the North Atlantic

The A20/A22 cruise commenced in September aboard the *R/V Knorr* from Woods Hole, MA and will be completed in November. The first leg (A20) was along 52°W and all stations were successfully occupied. The second leg (A22) is presently underway. Seawater samples are being analyzed on board ship for salinity, dissolved oxygen, nutrients, DIC, TAlk, and CFCs. Water samples were collected for shore-based analyses of helium, tritium, dissolved organic carbon, ^{13}C and ^{14}C. As the samples are analyzed on board, the data are collected and compiled by the data manager, allowing near real-time examination and comparison of the data sets as they are generated. Preliminary evaluation of the shipboard data indicates that they are of high quality and should meet or exceed WOCE guidelines.

The preliminary DIC results from the A20 cruise (Figure 4) along 52°W can be compared to previous cruise results from the WOCE era. The results indicate significant increases in the shallow waters masses over the depth range of 100 – 600m between the last occupation of these stations during the WOCE era (1997) and the 2003 occupation. For example, along the 26.0 – 26.6 neutral density field, DIC increases on the order of 2 – 20 μmol kg^{-1} were observed over the six year period between the two cruises (Figure 5a). In contrast, the DIC changes at a deeper density horizon (27.80 – 27.93) showed very little change (Figure 5b). These increases of DIC in the Subtropical Mode Water (STMW) may be the result of decadal changes in the local circulation, invasion of anthropogenic CO_2 into the interior North Atlantic, and/or changes in new production and remineralization of organic matter along the flow path. As we continue to process the physical and biogeochemical results from these cruises, we should be able to determine the large-scale changes in the carbon content of the Atlantic Ocean.

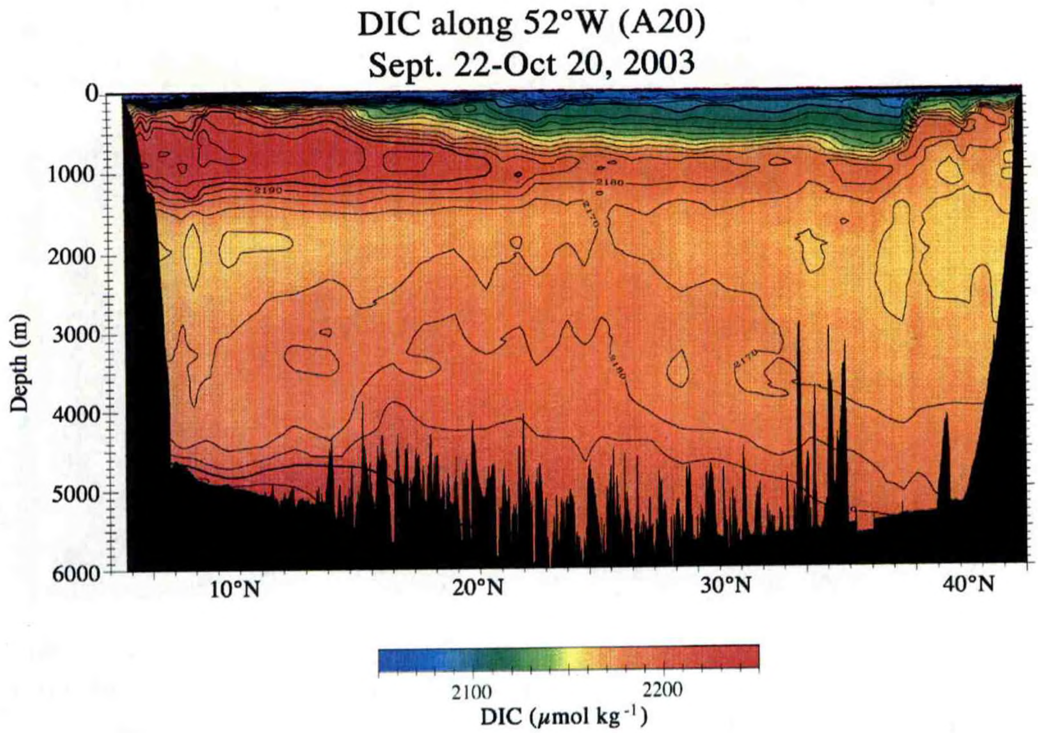


Figure 4. Distribution of DIC (μmol kg^{-1}) along 52°W in the western North Atlantic between September 22 – 20 October 2003 (provided by M. Roberts, PMEL).

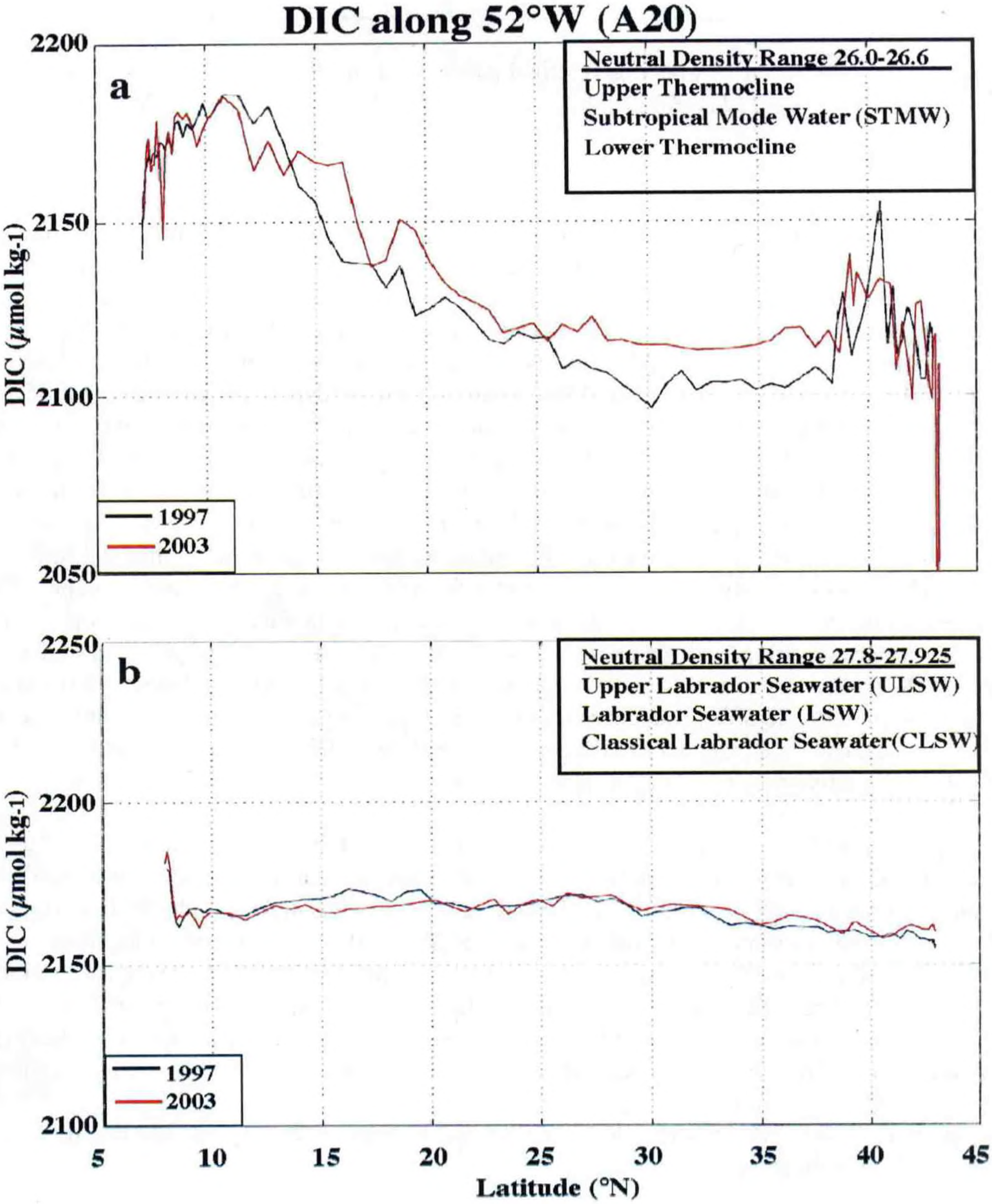


Figure 5. Preliminary comparison of the mean DIC concentrations along the a) 26.0 – 26.6; and b) 27.80 – 27.93 neutral density surfaces for 1997 and 2003 in the western North Atlantic. The DIC concentrations were weighted averages for each neutral density layer based on the 2-m interpolated DIC profiles from each station (provided by J. Toole, WHOI).

Tropical and sub-tropical Atlantic upper layer studies
by Silvia L. Garzoli, Rick Lumpkin, Mayra Pazos and Craig Engler

PROJECT SUMMARY

General overview of the project, including brief scientific rationale

Large-scale SST distributions drive the response of the climate in the tropical Atlantic sector, and even over land areas as distant as the southern and eastern Unites States. In spite of its importance, no dynamical model has successfully predicted Atlantic SST one-to-several seasons in advance. The current generation of coupled ocean-atmospheric models cannot reproduce much less predict the SST in the tropics. A recent comparison of 23 GCM results (Davey et al., 2002) concentrated on simulated fields from the tropical oceans (i.e. SST, zonal wind stress and upper layer depth averaged temperature). In the Atlantic Ocean, discrepancies between the model and observed mean states were dramatic. Specifically, in the equatorial Atlantic, the simulated zonal temperature gradient was wrong, with cold temperatures in the west and warm temperature in the east (Figure 4, Davey et al., 2002). The variability of the sub-tropical Atlantic and its interaction with the tropics is far from understood. This is primarily due to the paucity of data that for years has been mainly collected along not very frequent commercial lines. Products of SST are considerably deficient in particular, in the center of the basin and between 20°S to 40°S. A recent paper (Kushnir et al., 2003) demonstrated that the variability of the inter-tropical converge zone (ITCZ) is highly sensitive to changes in SST gradients within the broader tropical Atlantic region, particularly in the meridional direction and during the boreal spring. To better understand this variability, it is necessary to improve the SST products south of the equator. The development and future success of such models will depend on understanding the processes driving SST changes and providing products based on observations that models can attempt to simulate.

The main objectives of this program, a joint effort between SIO and the AOML that started in 1997, is to deploy and maintain an array of SVP drifting buoys in the tropical Atlantic, within 20 degrees of latitude of the equator, for the purpose of observing a basin-wide scale tropical current and SST fields on time scales of the inter-annual variations of tropical Atlantic SST. Additionally, to support hurricane predictions, ten wind drifters (WOTAN) were purchased per year. Drifters are to be deployed in a joint program with the Hurricane Division of AOML during hurricane season. Some of the drifters will be air deployed in front of developing hurricanes to provide observations of the ocean response. Other drifters will be deployed in the "hurricane alley" to provide marine observations for the NOAA Hurricane Center.

Since the program started approximately 360 drifters were deployed in the region. The drastic change in data coverage can be seen in figure 1.

In FY03, a new component of this program started to partially solve the problem of data scarcity in the south tropical Atlantic (20°S to 40°S). As mentioned before, a good coverage of SST data is needed to resolve the meridional modes of variability of the tropical Atlantic. Funds were provided to deploy 20 additional floats in the region.

Statement about how your project addresses NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate

This program is a direct component of the NOAA's Program Plan for *Building a Sustained Ocean Observing System for Climate*. The first milestones for the *in situ* networks is: "Deploy an array of 1250 drifting buoys for sea surface temperature, pressure, and current measurement, by 2004."

Statement about how your project is managed in cooperation with the international implementation panels, in particular the JCOMM panels

This program is managed by the AOML/ Global Ocean Observing System (GOOS) Center. AOML/GOOS in cooperation with steering committees at the national and international levels, was created at NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) and housed within the Physical Oceanography Division for the purpose of providing an administrative umbrella that coordinates several operational oceanographic data collection networks. GOOS and international GOOS are important components of JCOMM.

Responsible institutions for all aspects of project

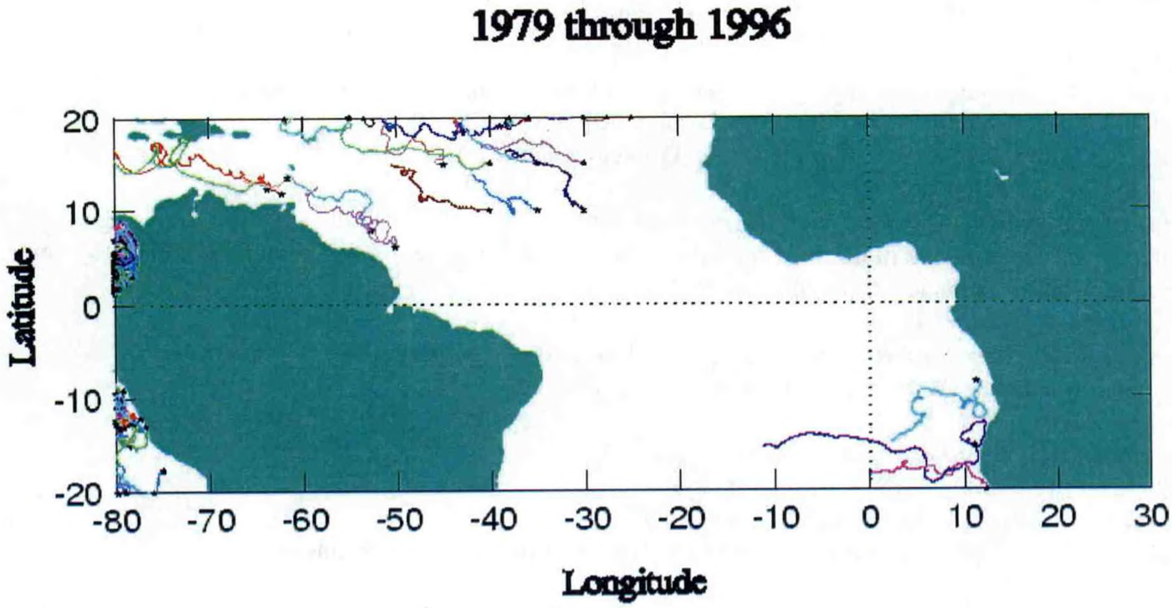
This program is a joint effort between SIO and the AOML. SVP drifters are purchased by SIO and deployed by AOML. The data are placed on GTS by Service Argos by Etienne Charpentier, the Executive Secretary of the DBCP, for operational use. AOML, under the direction of Mayra Pazos, quality controls and processes this data to regular time intervals and on six-month intervals sends it to Marine Environmental Data Service (MEDS)/Canada for international distribution. This is a component of the Global Drifter Center and the Drifting Buoy Data Assembly Center (DAC).

Project web site URL and pertinent web sites for your project and associated projects

The program web site is maintained and updated by Mayra Pazos, DAC manager.
www.aoml.noaa.gov/phod/dac/

Interagency and international partnerships

Drifters are launched using the AOML/GOOS infrastructure of NOAA interagency and international partners.



1997 Through June 2003

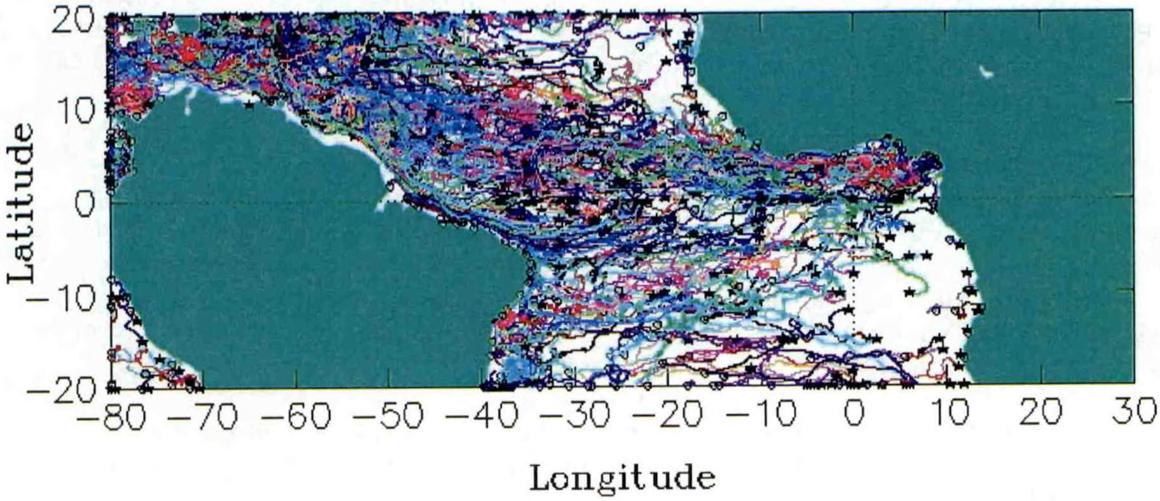


Figure 1: Evolution of the tropical Atlantic surface drifters array. Top: trajectories of drifters deployed in or entering the region from 1979 trough 1997 (18 years); Bottom: trajectories of drifters deployed in or entering the region, funded under the present project (20°N - 20°S) from 1997 trough June 2003 (6 years).

Statement that your project is managed in accordance with the Ten Climate Monitoring Principles
This program is managed in accordance with the Ten Climate Monitoring Principles (Program Plan Mike Johnson, 2003).

FY 2003 PROGRESS

Instrument/platform acquisitions for fiscal year and where equipment was deployed
A total of 79 buoys were deployed within the tropical Atlantic (20°N – 20°S)
A total of 13 buoys were deployed in the Extra -Tropical Atlantic (20°S- 40°S)

Number of deployments – compared to the previous year
The number of deployments in the tropical Atlantic remained the same (79). The number of deployments in the south-tropical Atlantic was augmented by 13.

Percentage data return for fiscal year and 'lifetime' statistics – compare to the previous year
The following statistics are for the global array.
In the last decade:
- Transmitter time improved from 296 to 453 days
- SST sensor life improved from 281 to 424 days
- Drogue life improved from 161 to 308 days
- Deployments have increased every year while failure upon deployment remains at 2%.

Measurements taken, where data are stored, data distribution, availability and access to data
All data (velocity vectors and SST) are transmitted in real time via GTS. Data is stored, quality controlled and distributed through the AOML DAC center: www.aoml.noaa.gov/phod/dac/

How data are currently being used and shared

Data are used in real time by the international prediction community to initialize the prediction models (i.e. NCSP, US Navy, European Community Center for weather forecast, British and French Meteorological Offices, etc.)

Quality is made available to the international research community via the web site mentioned above.

Where the data are archived

Data are processed, archived and made available through the Web at AOML. Data are also archived and available from MEDS.

Problems encountered

Two main problems arose:

1. Due to delays in disbursement of funds (funds arrived to AOML in late May, we were unable to buy and deploy all the drifters that were funded for FY03. The reminders will be deployed during FY04. Delay in disbursement of funds also resulted in a large increase in shipping costs. Many drifters had to be shipped by air due to the delay.
2. Due to war related issues, the US Navy stopped air deployments. As a consequence, all deployments are made now from ships. This limits our capability to seed regions not attended by ships (VOS or research vessels)

Logical considerations (e.g., ship time utilized)

The program is based on deploying the drifters through VOS and R/V available in the region. This limits our capability of filling up gaps not transited by either of these vessels.

Research highlights

One year of analysis of the data collected in this program was funded by OGP grant GC03-256. In this effort, the tropical Atlantic surface drifting buoy observations were used to determine time-mean near-surface currents and sea surface temperature (SST) and their seasonal variations. A novel decomposition technique was developed for these data, which simultaneously resolves the time mean, seasonal harmonics (annual and semiannual) and a residual eddy field described by a nonzero Lagrangian integral time scale (Lumpkin, 2003).

As a consequence of this technique, and of the considerable increase of available data due to this program, biases in the decomposition are substantially reduced in regions with strong mean currents or strong seasonal variations (Lumpkin et al., 2003). Thus, in the tropical Atlantic (where both conditions are met), the method produces significantly improved estimates of the near-surface currents and concurrent SST (Figure 2). The resulting analysis (Lumpkin and Garzoli, 2003) had identified the pathways of the major near-surface currents, including and excluding the directly wind-driven (Ekman) component, and has quantified the major mechanisms that force the primary modes of seasonal variability. Ongoing extensions of this study, also heavily dependent upon the drifter observations, are examining the distribution and possible rectification of mesoscale variability and are providing estimates of the role of lateral heat advection in modulating/controlling observed SST variations.

A new climatology of near-surface currents and SST, derived from the drifter observations using the methodology of Lumpkin et. al (2003), has been made available from the Drifting Buoy Data Assembly Center (www.aoml.noaa.gov/phod/dac/).

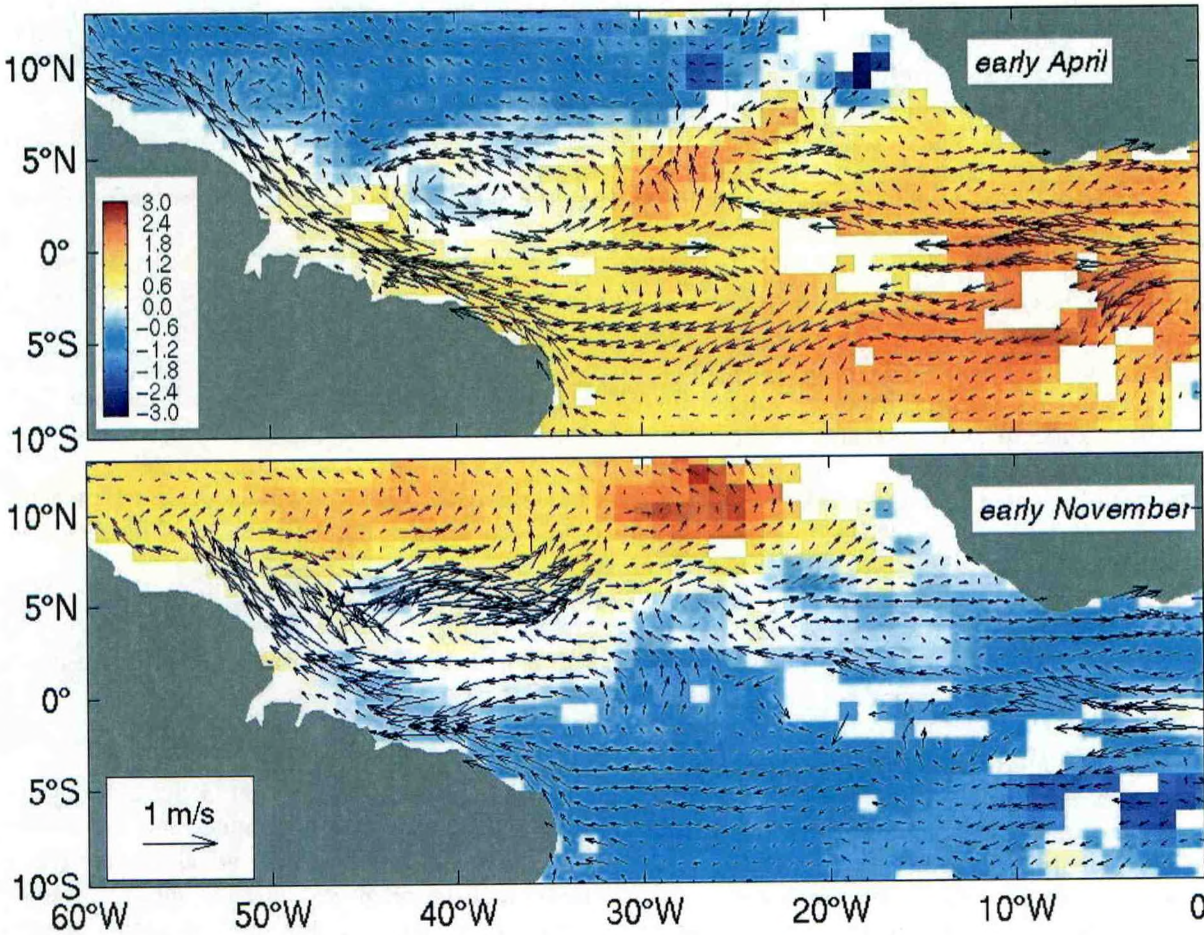


Figure 2: Climatological near-surface currents (arrows) and SST anomaly (shading, degrees Celsius), derived from surface drifting buoy observations (Lumpkin and Garzoli, 2003).

Implementation of High Density XBT Lines in the Atlantic Ocean

by Silvia Garzoli, Gustavo Goni, Molly Baringer and Robert Molinari

Project Overview

The Atlantic Ocean plays an important role within the global ocean thermohaline circulation, through the interocean and interhemispheric exchanges of water, heat, salt and vorticity. The Meridional Overturning Circulation (MOC) in the subpolar North Atlantic is driven by the formation of the North Atlantic Deep Water (NADW), with a formation rate and properties that are highly influenced by climate changes on the decadal and interdecadal time scales. These climate changes affect the air-sea buoyancy flux in the subpolar basin, where warm-to-cold water transformation processes take place. Recent results indicate that the formation of the NADW is the cause of strong traces of the North Atlantic Oscillation (NAO), a leading signal in decadal time scale climate changes in the Atlantic. The MOC in the subtropical North Atlantic is mostly affected by changes in momentum, air-sea fluxes and salinity. However, the processes by which they cause changes in the ocean dynamics are not completely known, particularly at decadal and longer time scales.

The upper limb of the MOC carries warm waters from the South Atlantic into the North Atlantic subtropical gyre through pathways and mechanisms that are not completely understood and need to be investigated further. This connection between the upper limbs of the gyres in the southern and northern hemispheres in the tropical Atlantic is primarily composed by zonal currents, which are forced by the wind field, primarily by the position and intensity of the Inter-Tropical Convergence Zone (ITCZ). Therefore, the tropical Atlantic is of critical interest for the large-scale ocean circulation since it is where strong western boundary currents contribute to inter-hemispheric transport of properties. The MOC carries warm water from the South Atlantic to the North Atlantic off the coast of Brazil within a western boundary current, the North Brazil Current (NBC). Below the NBC, colder, fresher Antarctic Intermediate water flows north in the North Brazil Undercurrent. In addition to the northward flow of the NBC a shallow Subtropical Cell (STC) carries subducted surface water from the southern subtropics to the equator, where it is upwelled to the surface.

While time scales of decades or more characterize the deep flows, the time scales of the boundary currents and STCs are of months to several years. Monitoring water mass properties as well as the velocity structure of the hypothesized pathways between the subtropics and the tropics provides the tools to characterize both the mean and the time-dependent properties of the tropical portion of the MOC and the Atlantic STC. The role of the South Atlantic in the Meridional Overturning Circulation (MOC) can be better understood by reducing the uncertainty in the meridional heat flux through the subtropical band.

This program is designed to measure the upper ocean thermal structure in key regions of the Atlantic Ocean (Figure 1). The seasonal to interannual variability in upper ocean heat content and transport is monitored to understand how the ocean responds to changes in atmospheric and oceanic conditions and how the ocean response may feedback to the important climate fluctuations such as the NAO. This increased understanding is crucial to improving climate prediction models. Within this context, four XBT lines have been chosen to monitor properties in the upper layers of the Atlantic Ocean.

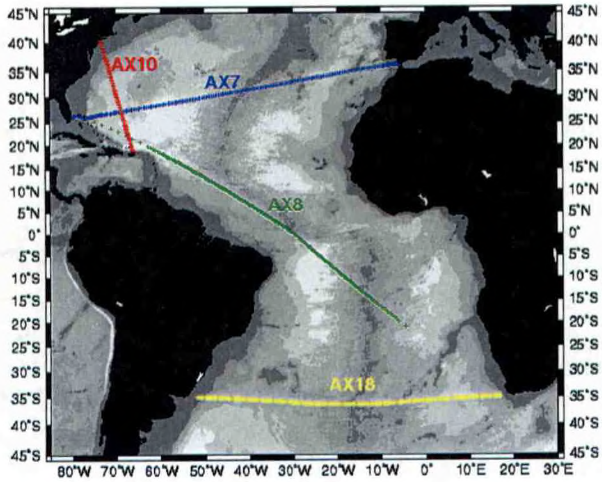


Figure 1. Location of high density XBT lines AX07, AX08, AX10 and AX18.

The high-density line AX07 is located nominally along 30°N extending from the Straits of Gibraltar in the eastern Atlantic to the east coast of the United States at Miami, Florida. This latitude is ideal for monitoring heat flux variability in the Atlantic because it lies near the center of the subtropical gyre, which has been shown to be the latitude of the maximum heat flux in the ocean.

The high-density line AX10 is located between the New York City and Puerto Rico. This line closes off the United States eastern seaboard, where subtropical temperature anomalies could have the greatest interaction with the atmosphere. This line was chosen to monitor the location of the Gulf Stream and its link to the NAO.

The high-density line AX08, part of the Tropical Atlantic Observing System, crosses the tropical Atlantic in a NW-SE direction between North America and South Africa. Historical data along AX08 and other historical temperature observations in the tropics exhibit decadal and multi-decadal signals. It has been hypothesized that this large time scale signal may cause atmospheric variability. Given the importance of the tropical Atlantic in climate variability, and the scarcity of observations in this region, data obtained from the measurements along this line are key to improving climate forecast. Temperature profiles obtained from this line will help to monitor the main zonal currents and undercurrents in the tropical Atlantic and to investigate their spatial and temporal variability.

The high-density XBT line AX18, which runs between Cape Town and South America (Montevideo, Uruguay, or Buenos Aires, Argentina) is geared towards improving the current climate observing system in the South Atlantic, a region of poor data coverage. The main objective of this line is to monitor the meridional heat transport in the upper 800 m across 30S. Given the importance of the South Atlantic and the scarcity of observations in this region, data obtained from the measurements along this line will be critical to improving the climate forecasts.

Statement about how your project addresses NOAA's Program Plan for *Building a Sustained Ocean Observing System for Climate*

The global atmospheric and oceanic data from Ships of Opportunity (SOOP) have been the foundation for understanding long-term changes in marine climate. This program is a direct component of the NOAA's

Program Plan for building a sustained Ocean Observing System for Climate and directly addresses one of its *milestones:*

- Occupy 41 volunteer observing ship (VOS) lines for high accuracy upper ocean and surface meteorological observations, by 2007 (Figure 2).

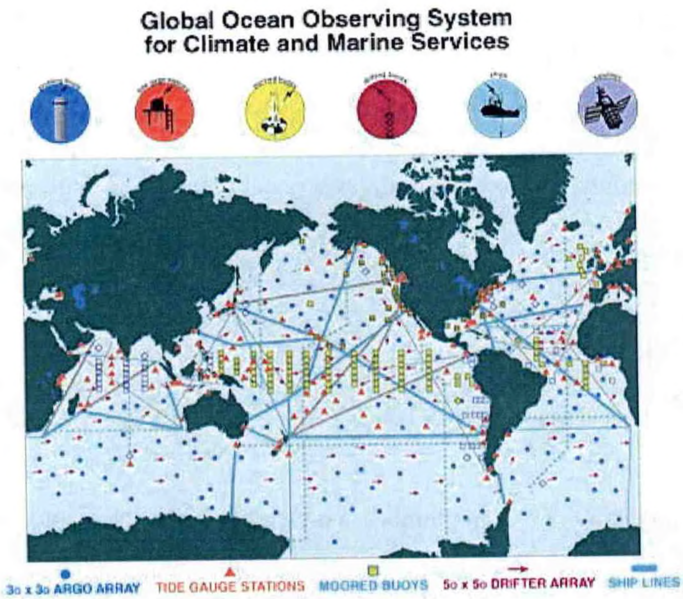


Figure 2. NOAA's Global Observing System for Climate.

Statement about how your project is managed in cooperation with the international implementation panels, in particular the JCOMM (Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology) panels

The Global Ocean Observing System (GOOS) Center and its integral components, the Global Drifter Program (GDP) and Voluntary Observing Ship (VOS) XBT Program are both participating members of JCOMM and JCOMMOPS. The VOS XBT program is represented annually at the WMO/IOC Ship Observations Team (SOT) meeting. We presently Chair the Ship of Opportunity Implementation Panel (SOOPIP).

Responsible institutions for all aspects of project
NOAA/AOML is solely responsible for all aspects of this project. International partners collaborate in maintaining these lines: The Hydrographic Naval Office (SHN) of Argentina, and the South African Weather Service are currently collaborating with this program.

Project web site URL and pertinent web sites for your project and associated projects
http://www.aoml.noaa.gov/phod/hdenxbt/

Interagency and international partnerships
Several agencies are currently collaborating with this project. The Argentine Hydrographic Office (SHN) provides the personnel to deploy the XBTs in AX18. The South African Meteorological Service is our contact in Cape Town and Durban to store the equipment in between transects.

Statement that your project is managed in accordance with the Ten Climate Monitoring Principles (reference attached Program Plan)

High-density line AX07 and AX10 have been maintained since 1994 and 1996, respectively, providing a homogeneous data set for almost a decade. Sustained observations from these and the other two high-density lines are required to have observations with adequate spatial and temporal resolution for climate studies. High-density observations in AX08 and AX18 provide data in poorly surveyed regions. Data are of easy access, interpretation and visualization. AOML has the facilities, personnel and infrastructure to maintain a stable, long-term commitment to these observations.

FY 2003 PROGRESS

Instrument/platform acquisitions for fiscal year and where equipment was deployed

Number of XBTs deployed:

Line	2002	2003
AX07	911	945
AX08	735	775*
AX10	465	439
AX18	183	371

*There is one transect underway during September and October 2003. No data available at the moment of writing this report.

The exact locations of XBT deployments are shown on the web page corresponding to each line (Figure 3).

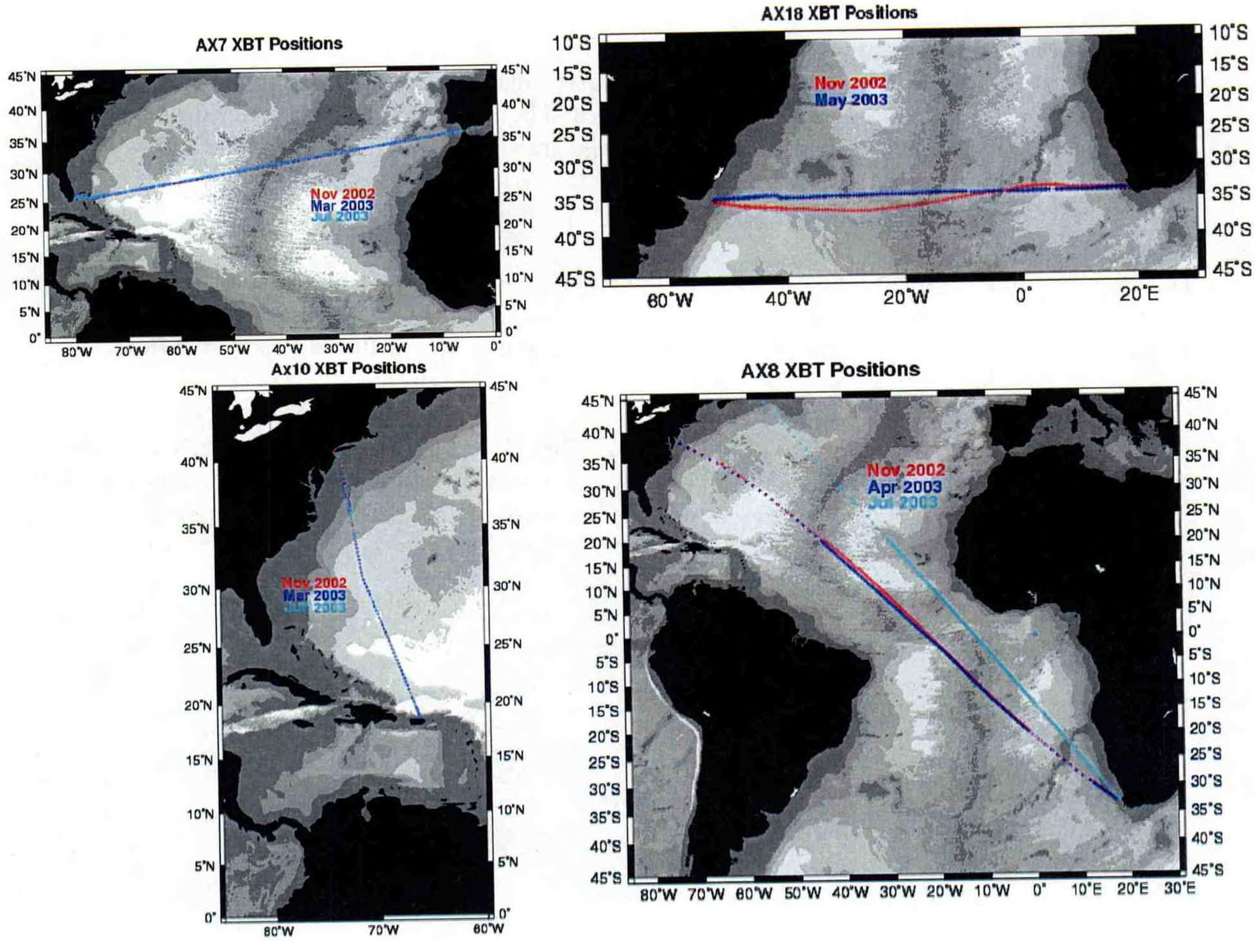


Figure 3. Location of XBT deployment for XBT lines AX07, AX08, AX10 and AX18.

Percentage data return for fiscal year and 'lifetime' statistics – compare to the previous year:

Line	2002	2003
AX07	93	89
AX08	91	94
AX10	90	87*
AX18	98	96

* High failure rate due to suspect batch of Sippican probes with wires that failed to separate from deployed probe.

Measurements taken, where data are stored, data distribution, availability and access to data

The temperature profiles specifications include depths from 0 to 700 m. Generally, temperatures can be recorded as deep as 800 m. Data are stored on the computer system on the ships on which we have installed Shipboard Environmental data Acquisition (SEAS) Systems. The real-time data are transmitted via Standard C and are distributed on the GTS and the delayed mode or full resolution data are stored at the National Oceanographic Data Center (NODC). Data are also kept at AOML and provided through a web page.

How data are currently being used and shared
Raw data is transmitted in real-time via GOES. Processed data is available through the web approximately two weeks after each transect is finished. High density XBT data are critical to understanding long-term changes in marine climate and are an essential input to climate and weather forecast models.

Problems encountered
The search for ships of opportunity remains an issue as ships constantly change routes. A major effort is required to contact Shipping Lines that cover the lines. The coordination necessary among multiple groups using ship facilities is handled by high-density personnel, e.g. drifters and profiling floats.

Logical considerations (e.g., ship time utilized)
These transects are occupied by *ships of opportunity.* The AX07, AX08, AX10 and AX18 transects last, in average, approximately 10, 17, 3 and 11 days. We also provide information to them on how the data obtained from these high-density cruises are used to improve weather and climate forecast.

Research Highlights

High density XBT data allows us to compute statistical information about the independent spatial scales that is necessary for data assimilation and mapping. Below is an example (Figure 4) of the independence length scale determined along AX07 indicating that the spatial scales are depth dependent.

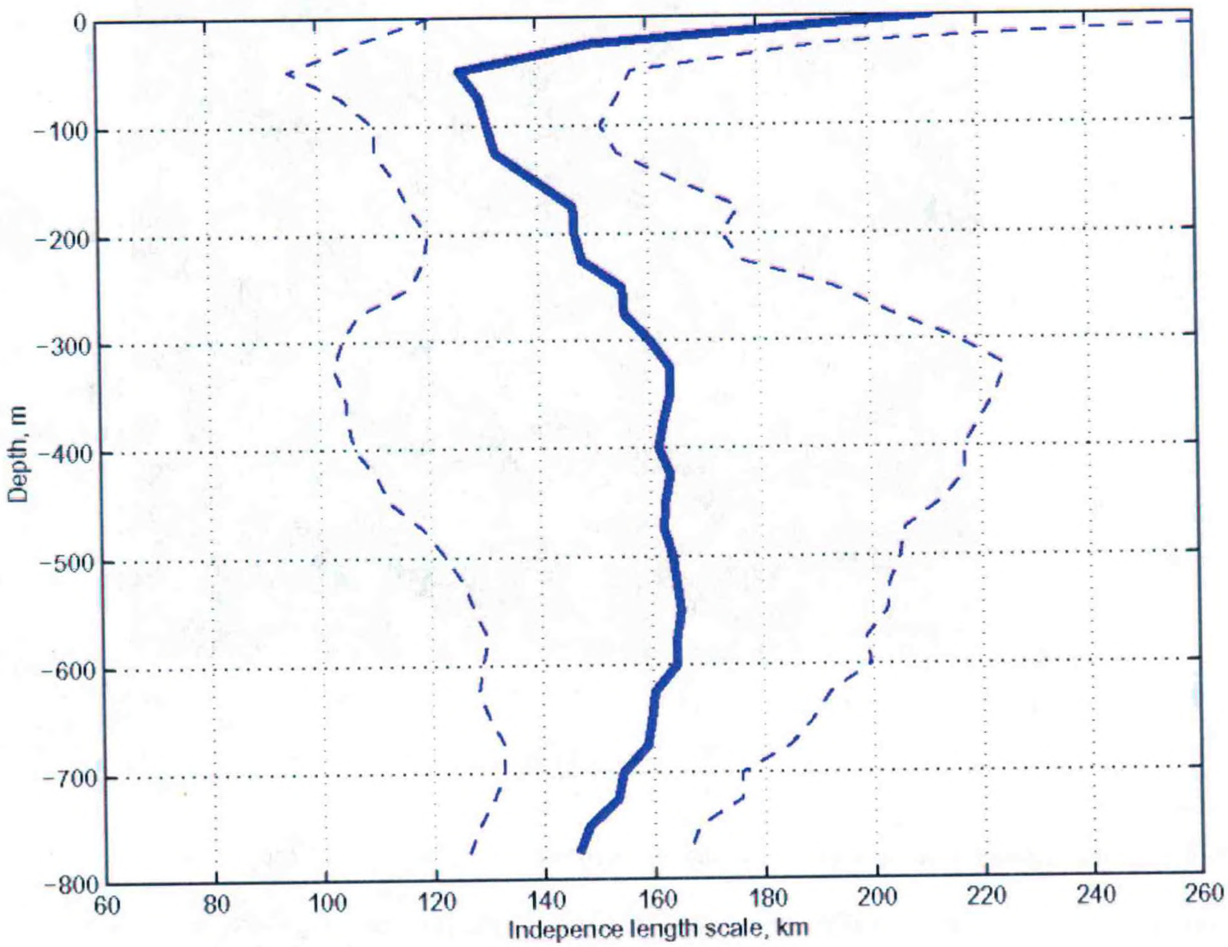


Figure 4. Independence length scale (in km) as a function of depth for AX07. The solid line is the mean and the dotted line is the standard deviation.

The long time series available along some of the high density XBT lines allows us to examine decadal trends in subsurface (and surface) temperature anomalies. Below we show an example from AX10 of the temperature anomalies at 150 meters smoothed using a three-year running mean (Figure 5).

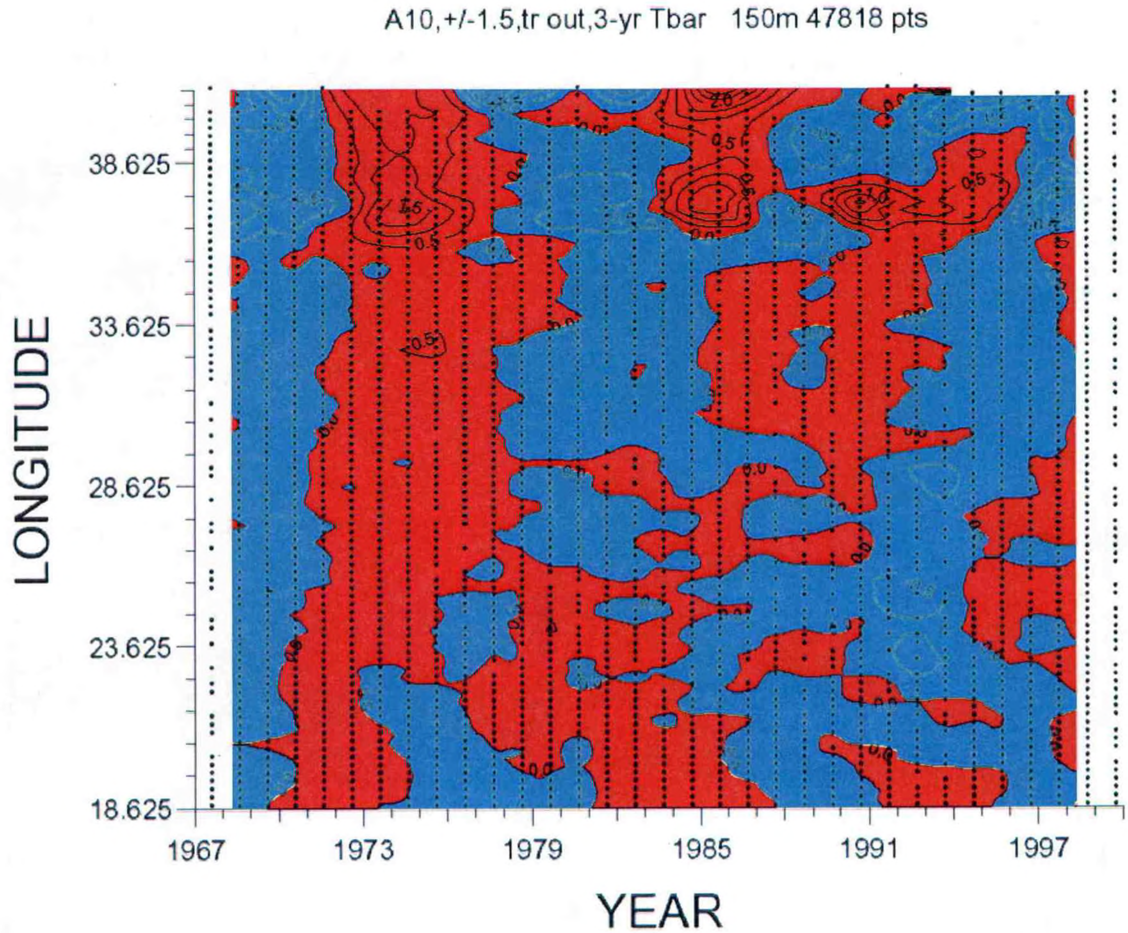


Figure 5. Sea surface temperature anomalies along AX10 showing a long time (decadal) signal.

Temperature sections from the AX08 transect are used to investigate the location, geostrophic transport and their variability of the main zonal upper ocean currents in the tropical Atlantic (Table I).

	December 2000		September 2001		January 2002	
Current	Location	Sv	Location	Sv	Location	Sv
1. NEC	19.7–9.7°N	23	19–13.1°N	15	19.8–11.1°N	22
2. NECC	7.2–4.9°N	25	9.7–5.6°N	22	9.3–7°N	16
3. nSBC	4.9–3.7°N	20	5.6–3.2°N	20	7–5.5°N	14
4. NEUC	3.7–3.0°N	14	–	–	5.5–3.9°N	18
5. nSBC	3.0–1.7°N	37	–	–	3.9–2.2°N	30
6. eSEC	1.5–3.6°S	36	1.7–4.3°S	5	1.8–4.2°S	13
7. SEUC	3.6–5.2°S	17	4.3–5.4°S	11	4.2–4.7°S	14
8. cSEC	5.2–6.8°S	13	5.4–6.9°S	11	4.7–8.0°S	6
9. SBCC	10–12.9°S	6	6.7–9.5°S	11	8.0–9.3°S	7
10. sSBC	12.9–19.9°S	7	9.5–15.3°S	10	9.3–20°S	8

Negative values indicate transports towards the west. All transports are integrals to 800 m of geostrophic velocities assuming a level of no motion at 800 m, the deepest level of XBT temperature observations.

Table 1. Upper ocean currents in the tropical Atlantic during the first three AX08 transects.

Data from the AX18 transect is currently being used to estimate the transport of the major western boundary currents (Brazil and Agulhas) and of rings shed by these current systems (Figure 6a). These values are being compared with altimeter-based estimates. We have also computed the meridional heat transport using data from the first two AX18 transects. The two red stars in Figure 6b show our first results, which are superimposed to other estimates of this parameter at different latitudes in the Atlantic basin.

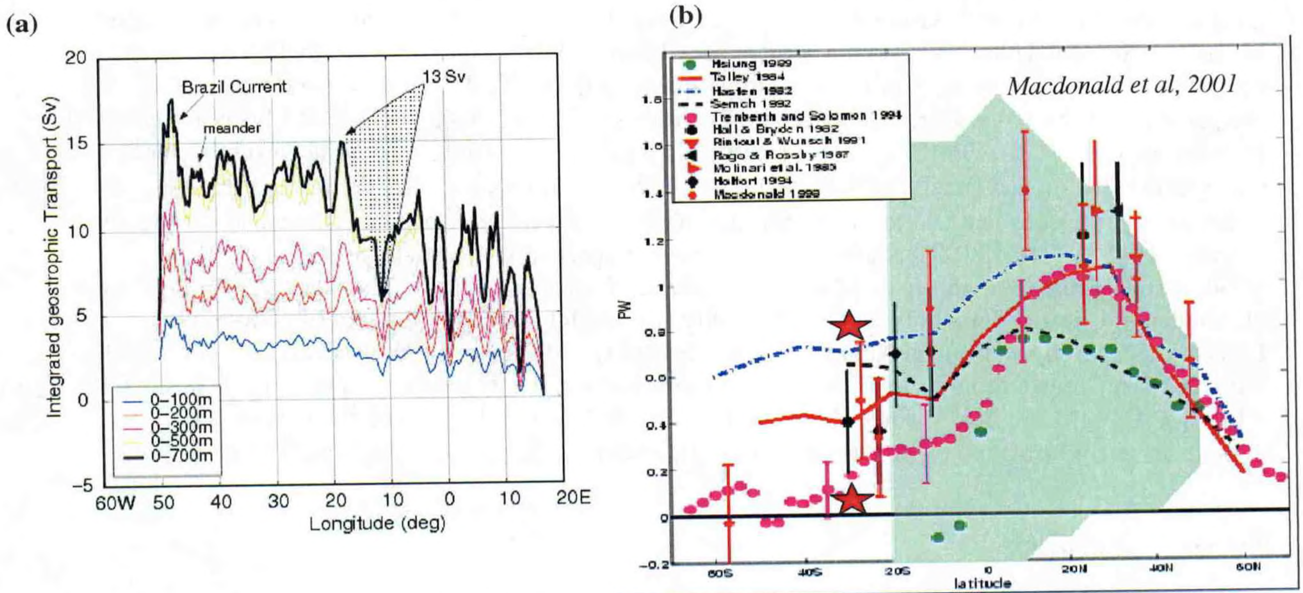


Figure 6. (a) The integrated water mass transport from West to East is computed for the July 2002 AX18 transect. The contribution from 5 layers from the surface to 100, 200, 300, 500, and 700 m relative to a zero flow at 800 m are shown. (b) Meridional heat flux in the Atlantic Ocean from models and observations. The two red stars indicate the estimates from the first two AX18 transects.

TAO/TRITON Array
by Michael McPhaden

PROJECT SUMMARY

This continuation proposal requests funds to maintain of the Tropical Atmosphere Ocean (TAO) array and the Pilot Research Moored Array in the Tropical Atlantic (PIRATA) as part of NOAA's effort to "Build a Sustained Ocean Observing System for Climate". TAO is the U.S. contribution to the TAO/TRITON array, a network of moored buoys spanning the tropical Pacific Ocean maintained in partnership with the Japan Marine Science and Technology Center (JAMSTEC). PIRATA is a joint effort between the U.S. (NOAA/PMEL), France (Institut de Recherche Scientifique pour le Développement on Coopération [IRD]), and Brazil (Instituto Nacional de Pesquisas Espaciais [INPE] which is the the Brazilian space agency and Diretoria de Hidrografia e Navegacao [DHN] which is the naval hydrographic service). Both the TAO/TRITON and PIRATA arrays support NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." They also underpin Climate Variability and Predictability (CLIVAR) research efforts on El Niño/Southern Oscillation (ENSO) and tropical Atlantic climate variability. Management of these arrays is consistent with the "Ten Climate Monitoring Principles". Program oversight at the international level is through the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A web site containing comprehensive information on both programs can be found at http://www.pmel.noaa.gov/tao/.

FY 2003 PROGRESS

TAO/TRITON Array

Background

FY 03 was the third full year of the combined TAO/TRITON array and the partnership with JAMSTEC is working well. NOAA maintains the portion of the array between 95°W and 165°E, while JAMSTEC maintains sites between 156°E to 138°W. JAMSTEC added three moorings along 130°E for its own purposes in FY2002, though these moorings complement those of the TAO/TRITON array proper. Basic measurements from ATLAS and TRITON buoys are transmitted on the GTS and are merged into a unified data set available on the World Wide Web at PMEL (http://www.pmel.noaa.gov/tao/) and a mirror site in Japan (http://www.jamstec.go.jp/jamstec/TRITON).

TAO Project Highlights

A moderate El Niño developed in the tropical Pacific in 2002-03. TAO/TRITON data were used extensively at NCEP and other operational centers for tropical Pacific Ocean analyses and ENSO forecasts, and for guiding the issuance of El Niño advisories. A publication is now in press in the *Bulletin of the American Meteorological Society* describing the event using TAO/TRITION data and other data from the ENSO Observing System:

McPhaden, M.J., 2003: Evolution of the 2002-03 El Niño. *Bull. Am. Meteorol. Soc.*, in press.

The abstract of this article is reads:

"An El Niño of moderate intensity developed in the tropical Pacific in 2002–03. This event, though not as strong as the 1997–98 El Niño, had significant impacts on patterns of weather variability worldwide. The evolution of the 2002–03 El Niño is documented through comprehensive satellite and *in situ* observations from the El Niño/Southern Oscillation (ENSO) Observing System. These observations underscore the importance of both episodic atmospheric forcing and large-scale low frequency ocean-atmosphere interactions in the development of the event."

Also, this year the TAO Project Office was awarded the 2003 Grace Hopper Government Technology Award ("Gracie Award") for "Leadership in the innovative application of information technology that contributes to the advancement of scientific knowledge and its application." The Grace Hopper Government Technology Leadership Awards are sponsored by Government Executive magazine and selected by a panel comprised of leading experts on the federal government's use of technology, drawn from government, prominent federal contractors and the academic community.

Fieldwork

As a result of the TAO/TRITON transition, PMEL is responsible for maintaining 55 ATLAS sites at and east of 165°E. At four of these sites (165°E, 170°W, 140°W, 110°W along the equator) current meters are attached to the ATLAS mooring lines and a nearby subsurface ADCP mooring is deployed. An ADCP mooring is maintained by JAMSTEC at 0°, 147°E. During the past year, the TAO project deployed 71 ATLAS moorings (3 of which were for the PACS/EPIC program) and 5 subsurface ADCP current meter moorings. The number of ATLAS deployments exceeds the number of ATLAS sites in the array because of mooring system failures or losses during the year, because some sites (like the equatorial current meter mooring sites at 110°W and 140°W) are turned around regularly on a 6-month rather than 12-month schedule and because cruise schedules are such that some moorings are deployed for slightly shorter than their 12-month design lifetime. There was also one ATLAS and one ADCP deployment for engineering development purposes included in these totals (see Section 2.1.7). For comparison, in FY 02, 63 ATLAS and 4 subsurface current meter moorings were deployed in the TAO array.

Ship Time and Sea Time

In FY 03, 267 days at sea were required to support the TAO portion of the TAO/TRITON array (232 days on the Ka'imimoana and 35 on the Ron Brown) a total of 658 PMEL person days at sea (number of people times days at sea) in support of TAO field work were required during FY 03. For comparison, in FY 02, 264 days at sea were required to support the TAO portion of the TAO/TRITON array (226 days on the Ka'imimoana and 38 on the Ron Brown) a total of 742 PMEL person days at sea (number of people times days at sea) in support of TAO field work were required during FY 02. Fewer person days at sea were logged in FY 03 than the previous year because there was less need for training of new personnel and because the PI did not go to sea in FY 03.

Real-time Data Return

Percentage data return for primary TAO variables integrated over all 55 sites (plus the 3 TAO/EPIC sites along 95°W) for FY 2003 was as follows:

	AIRT	SST	T(Z)	WIND	RH	ALL
FY 03	90	88	85	75	88	85
FY 02	87	90	86	76	87	85

Data return for the entire TAO/TRITON array (including JAMSTEC TRITON moorings) was 87% for primary variables. Data return from the most recently recovered PMEL ADCPs in FY 03 was effectively 100% at the four equatorial sites.

For comparison, ATLAS data return from FY 02 is shown in the above table. The returns are comparable, with relatively insignificant changes of a 1-2% between variables and totals.

Wind data return is lower than that for other sensors due to two factors. First, the sensor's placement at the top of the mooring exposes it to increased vandalism potential. Secondly, the wind sensors have a higher failure rate compared to other instruments. The failure is mainly in the vane circuitry and has been isolated to a single component. Consultation with the manufacturer has revealed no recent changes in design or construction, but has suggested that the grounding the sensor may improve reliability. Redesign and testing of the ATLAS wind system to provide grounding is underway.

In addition to primary ATLAS variables, additional measurements were made as part of research efforts supported by programs such as PACS/EPIC, NASA/TRMM, DOE/ARM, and others. These measurements include ocean velocities, rain rate, salinity, short wave and long wave radiation, and barometric pressure. These data are distributed via TAO web pages. TRITON sites also measure rain rate, shortwave radiation, and ocean velocity (at 10 m).

Shipboard Measurements

CTD casts, and underway ADCP and thermosalinograph measurements, are conducted from mooring servicing cruises on the Ka'imimoana and Ron Brown. These data are an integral part of the TAO project, providing *in situ* calibration checks on mooring sensor performance. They also provide hydrographic and current field information that helps to put the moored time series measurements into a broad scale hydrodynamic context. The data are a valuable resource for climate model development and climate analyses, and are frequently used together with moored times series data in scientific publications.

A total of 383 CTD casts (338 on the Ka'imimoana and 45 on the Ron Brown) were made on TAO cruises in FY 03. Fewer casts were made in FY 03 than in FY 02 (424, with 358 from the Ka'imimoana and 66 from the Ron Brown) due to 1) additional mooring work on the Ron Brown, which resulted in less time available for CTD casts and 2) a mechanical failure on the Ka'imimoana which required in a change in cruise track. The shipboard ADCP data are forwarded to, processed, archived, and distributed by Eric Firing and colleagues at the University of Hawaii. Underway sea surface salinity measurements are processed at PMEL, then forwarded regularly to the IRD laboratory in Noumea for distribution (by CD-ROM) with other sea surface salinity data.

In FY 03, with the assistance of Eric Firing and colleagues, we brought problems with the shipboard ADCP system to the attention of the NOAA/Marine Operations Center. In particular, ADCP data from the Ka'imimoana revealed serious degradation of heading information, which had negatively impacted data quality, and in some cases resulted in data loss. In addition, the ADCP on Ka'imimoana was obsolescent and had not been supported by the manufacturer for years. We therefore recommended that the ADCP and its GPS navigation system be replaced with new units. We are pleased to report that in response to our memo to NMAO outlining these problems, the existing systems will be replaced with a new 75 kHz RDI Ocean Surveyor and a POS/MV attitude sensor. We are hopeful that these units will be installed during the ship's scheduled dry-dock in January 2004.

In July 2002, the TAO-owned CTD, CTD frame, Niskin bottles, and some sensors were lost at sea. The TAO project replaced all these and other system components, but not the CTD itself. As a consequence, TAO is now relying on the Ka'imimoana to supply both primary and backup CTD systems.

Engineering Tests

After several years of tests going back to 1995, the Sontek Argonuat-MD point Doppler current meter was finally phased into service with confidence this year on TAO equatorial current meter moorings. The solution to eliminating significant biases in speed between the Sontek and proven ADCP measurements was to vane the Sontek so that it would orient into the flow. The history of the problem and the solution to it can be found in Freitag et al (2003), full citation of which can be found in Section 2.6.2. Paul Freitag, TAO project manager, presented the results of this engineering effort at the IEEE Current Meter Technology Conference held in San Diego in March 2003.

There was one ATLAS deployment for engineering development purposes at 5°N, 140°W in September 2003. This mooring was deployed to test two types of sonic anemometers for possible replacement of the RM Young propeller and vane assembly, namely the Handar WS425 Ultrasonic and the Gill model Windsonic. The field test also includes a standard wind RM Young wind sensor for comparison. The mooring is scheduled for recovery in May 2004.

One test subsurface ADCP mooring was also deployed at 0°, 110°W in April 2003. This mooring, deployed in proximity to the operational 150 kHz ADCP at 110°W, was equipped with a 75 kHz RDI Workhorse Long Ranger. The purpose was to compare performance of the two instruments since the present 150 kHz systems have not be supported by the manufacturer for years, and present generation systems will soon need to be introduced into the array. The test mooring was recovered in November 2003.

The project participated with the University of Washington and Aeromet, Inc., to compare several precipitation gauges on Kwajalein Atoll. The experiment, which began in July 2003 and continued through December 2003, will compare the sensor used on TAO and PIRATA moorings (R.M. Young model 50203-34, modified for use with the ATLAS system) with other gauges (Hasse, Disdrometer) and attempt to quantify wind affects on each type gauge. PMEL is also testing a modified TAO rain gauge designed to decrease spiking found in the present version gauge.

Guest Investigator Research Projects Using TAO Moorings and TAO Cruises

The primary mission of the TAO/TRITON array is to provide real-time data for improved detection, understanding, and prediction of El Niño and La Niña. The primary function of the NOAA Ship Ka'imimoana is to service buoys of the TAO/TRITON array. However, the TAO Project Office actively promotes use of the Ka'imimoana and, when it is used for TAO cruises, the Ron Brown for other meritorious scientific investigations that are of relevance to NOAA's mission. These projects are developed, funded, and lead by investigators from NOAA laboratories, other national research laboratories, and academia. Two categories of ancillary projects are described which are (a) ongoing and (b) one-time. An ongoing project is either planned or has been onboard already for more than one year. A list of PIs, their institutions and project titles are itemized below. The name of the ship from which the work is done (KA or BROWN) is indicated in parentheses.

a. Ongoing ancillary projects on TAO cruises for FY03:

Project, Principal Investigator, Institution (Ship)
Underway CO_2, Richard Feely, NOAA/PMEL (KA and BROWN)
Turbulent flux measurements, Chris Fairall and Jeff Hare, NOAA/ETL (BROWN)
Atmospheric monitoring, balloon radiosonde profiles, Nick Bond, NOAA/PMEL (BROWN)
Barnacle Project, Cynthia Venn, Bloomsburg University (KA and BROWN)
Carbon cycle, Michael Bender, Princeton University (BROWN)
Dissolved Inorganic Carbon (DIC) Analysis, Andrew Dickson, Scripps Institution of Oceanography (KA)
Argo float deployments, Dean Roemmich, Scripps Institution of Oceanography (KA)
Global Drifter Program, Robert Molinari, NOAA/AOML (KA and BROWN)
Iron limitation, Mike Behrenfeld, NASA/Goddard (BROWN)
CO2 moorings, Chris Sabine, NOAA/PMEL (KA)
Bio-optical measurement and nutrient analysis, Francisco Chavez, MBARI (KA)
Haruphone mooring recoveries/deployments, Robert Dziak, NOAA/PMEL (BROWN)
Tsunami/DART mooring recovery deployment at 8.5°S, 140°W, NOAA/NDBC (KA)
Bigeye mooring deployments, Rusty Brainard, NOAA/NMFS (KA)
Acoustic rain gauges on ATLAS moorings, Jeff Nystuen, University of Washington (KA and BROWN)
Atmospheric radiation, Mike Reynolds, Brookhaven National Laboratory (BROWN)

Underway ADCP, Eric Firing, University of Hawaii (KA and BROWN)
Underway pO_2/pN_2- Gas Tension device and O_2 probe, Craig McNeil, University of Rhode Island (BROWN)
Underway CIRIMS skin temperature device, Andy Jessup, UW/APL (BROWN)

b. One-time ancillary projects on TAO cruises for FY03:

Project, Principal Investigator, Institution (Ship)
Underway CO_2 measurements, Robert Byrne, University of South Florida (BROWN)
Wire-walker experiment, Robert Pinkel, Scripps Institute of Oceanography (KA)
Radiometer measurements, Tom Nolan, NASA/JPL (KA)

NOAA Teacher-at-Sea Program

The TAO project supports NOAA's Teacher-at-Sea program in coordination with NOAA's Office of Global Programs. In FY 03, three individuals participated in the program on a cruise of the Ka'imimoana in August-September 2003:

Nancy Lewis, Naalehu Elementary and Intermediate School in Naalehu on the island of Hawaii
Tom Nolan, NASA/JPL
Tetsoro Isono, JAMSTEC

PIRATA

Background

During FY 03, the PIRATA array was maintained in a 10-mooring configuration as agreed upon for the consolidation phase of the program (2001-2006). France and Brazil provide ship time and some technical support. Bases of operations are located in Natal, Brazil and Abidjan, Ivory Coast. Political unrest in the Ivory Coast in the past two years has required some shifting of ports-of-call and revision of logistical arrangements. The program has proceeded however without any major interruptions in service. The PIRATA web site is http://www.pmel.noaa.gov/pirata/, with mirror sites maintained in France and Brazil.

Unlike in TAO, shipboard CTD and ADCP data collection and processing are the responsibility of France and Brazil. PMEL is charged with providing equipment, technical support for moorings and instrumentation, and support for data processing, dissemination, and display. Also unlike TAO, PIRATA primary variables by design include a surface salinity and 3 subsurface salinities in the upper 120 m, shortwave radiation, and rainfall.

Real-time Data Return

Real-time data return was 68% overall for FY 03. This is lower than the last two years' returns of 71% (FY 02) and 75% (FY01). It is also significantly lower than Pacific data return for TAO/TRITON of 87%. The difference between the two basins relates to the greater susceptibility of the smaller PIRATA array to fishing vandalism and to a less frequent servicing schedule (one per year vs. twice per year for much of the Pacific). The good news in the Atlantic is that no moorings were completely lost and sites in the Gulf of Guinea at 0°, 10°W and 0°, 0° returned 71% and 72% data respectively for the year. Also, delayed mode data return is expected to be higher by several percent once internally recorded data are recovered and processed. In at least one instance, telemetry of subsurface temperatures failed for several months because of a faulty electrical connection between the mooring line and the buoy-mounted microprocessor. These data were recorded internally and recovered with the mooring.

Ship Time and Sea Time

In all, 10 new ATLAS moorings were deployed on 2 cruises. A total of 55 sea days (31 on the French R/V Suroit and 24 on the Brazilian R/V Antares) were required to service the array, comparable to the 53 sea days used in FY 02. PMEL personnel spent 84 person-days at sea on these cruises, up from 56 person-day in FY 02. The increase was because in FY 02, the second leg of the French cruise was staffed entirely by IRD personnel with shore side support from PMEL.

Real-time Data Return

Real-time PIRATA data return by variable for FY 03 and (for comparison, FY 02) are shown below.

	AIRT	SST	T(Z)	WIND	RH	Rain	SWR	SAL	ALL
FY 03	83	72	66	73	87	65	84	60	68
FY 02	83	68	71	65	84	72	78	64	71

TAO Project Web Pages

The TAO project continues to update the content and functionality of its web site (http://www.pmel.noaa.gov/tao/). This site provides easy access to TAO/TRITON and PIRATA data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. For FY 03, TAO web pages received a total of 22,136,074 hits, about the same as in FY 02 (22,441,908). Also during FY 03, a total of 11,961 separate user requests delivered 118,773 data files for TAO and PIRATA combined. These numbers are up 21% and 9%, respectively from the year before. TAO accounted for the bulk of the data delivered in FY 03, i.e. 89% of the requests and 86% of the delivered files.

Operational Use of TAO/TRITON and PIRATA Data

TAO/TRITON and PIRATA data are distributed to operational centers such as NCEP via the GTS. These data are used routinely in climate forecasting and analyses. The data are also used for weather and severe tropical Pacific storm forecasting. A weekly ftp transfer is routinely made to the NCEP coupled modeling project so as to ensure maximum ocean data availability for coupled model ENSO forecasts. TAO and PIRATA data placed on the GTS include spot hourly values of wind speed and direction, air temperature, relative humidity, barometric pressure, and sea surface temperature. Daily averaged subsurface temperature data are also transmitted on the GTS.

Vandalism

Vandalism continues to plague portions of the TAO/TRITON and PIRATA arrays. Data and equipment return are generally lower in regions of high tuna catch in the eastern and western equatorial Pacific, and in the Gulf of Guinea in the Atlantic. In addition to partial mooring hardware and instrumentation losses, 7 complete moorings systems were lost in the Pacific due to the effects of vandalism. This is the same number as in FY 02. Fortunately, no complete mooring systems were lost in the Atlantic, which is an improvement over the one loss in FY 02.

Efforts to combat vandalism continue, though it is not clear they are making much impact. These efforts include distribution of information brochures to national fishing agencies, fishing boats in ports of call, and industry representatives. We also hope to replace the attractive RM Young wind sensor with a less conspicuous sonic anemometer if tests of the latter prove encouraging (see Section 2.1.7).

The University of Hawaii Sea Level Center
by Mark Merrifield

PROJECT SUMMARY

The University of Hawaii Sea Level Center (UHSLC) collects, processes, and distributes tide gauge information from around the world in support of various climate research activities. The measurements are used for the evaluation of numerical models (e.g., those in operation at NCEP), joint analyses with satellite altimeter datasets, the calibration of altimeter data, the production of oceanographic products through the WMO/IOC JCOMM Sea Level Program in the Pacific (SLP-Pac) program, and research on interannual to decadal climate fluctuations. Also, in support of satellite altimeter calibration and validation and for absolute sea level rise monitoring, the UHSLC and the Pacific GPS Facility maintain co-located GPS systems at select tide gauge stations (GPS@TG). Over the years the UHSLC has participated in various national and international programs including NORPAX, TOGA and WOCE, and currently is a designated CLIVAR data assembly center and an IOC GLOSS data archive center. Data collected by the UHSLC is managed to meet both the requirements of GLOSS and NCDC's Ten Climate Monitoring Principles. The UHSLC distributes in situ sea level directly from its dedicated web site, http://uhslc.soest.hawaii.edu, through a dedicated OPeNDAP server, and through the NOPP sponsored NVODS project. We also expect to redistribute the *in situ* sea level data through the GODAE data servers.

The UHSLC collaborates with NODC to maintain the Joint Archive for Sea Level (JASL), which is a quality assured database of hourly sea level from selected stations from around the world, and we continue to work with PMEL on data distribution formats and methods.

The primary UHSLC operations are administered under the Joint Institute for Marine and Atmospheric Research co-operative agreement, and funded by the Office of Global Programs. GPS@TG projects are supported by OGP in the Atlantic Ocean, and by NASA for stations in the Pacific and Indian Oceans. We are working with other groups associated with the global observing system to provide syntheses of various datasets and to compile and distribute associated products.

FY 2003 PROGRESS

Tide Gauge Operations

The UHSLC operates 37 tide gauge stations in the global sea level network and collaborates with host countries in the operation of 7 more stations. In the past fiscal year we serviced 14 sites, installed 3 new stations, installed one new GPS@TG, and serviced 6 sites remotely. In the 2002 fiscal year, the UHSLC technicians serviced 7 sites directly and 7 sites remotely. Station maintenance during FY2003 included site visits to Settlement Point, where the tide gauge and GPS were relocated due to harbor construction, and Johnston Atoll and Hanimadoo where new equipment was installed. Routine service trips were made to Port Louis, Rodrigues, Point LaRue, Zanzibar, Mombasa, Lamu, Santa Cruz, French Frigate Shoals, Cape Verde, Saipan, Malakal, Hanimadoo, Hulele, and Baltra. Stations that developed problems that our technicians were able to solve remotely during FY2003 included Cape Verde, Esperanza, Easter Island, Manzanillo, Port Louis, and Cabo San Lucas. During a maintenance visit to the western Indian Ocean, we conducted site reconnaissance visits at Madagascar and Aldabra in anticipation of an expansion of our African network.

The historical data return for the UHSLC network is 93.8%, the current year's return is 95.3%, and the previous year's return 96.8%.

The UHSLC provided partial support for a visit by Charles Magori of Kenya to discuss the feasibility of establishing a coordinated sea level network in Africa. Mr. Magori has assisted us in the operation of our 2 Kenyan stations, and he is well placed to lead a regional effort. Several operational models were discussed with the most likely outcome being three regional centers covering Eastern, Western, and Southern Africa (Magori would direct the Eastern Africa center). In this model, the UHSLC would provide technical support for all three centers and conduct regular maintenance visits to ensure network stability and data quality. During Magori's visit, UHSLC sea level processing and analysis techniques were discussed.

Dataset Holdings

The Joint Archive for Sea Level is a collaborative arrangement between NODC, the World Data Center-A for Oceanography, and the UHSLC. Beginning in the fall of 2000, the JASL is supported by NOAA's NCDDC. The JASL is responsible for the archive referred to as the Research Quality Dataset, which is a quality assured database of hourly sea level from select stations from around the world. In the past year, the UHSLC increased its JASL holdings to 9213 station-years, including 5103 station-years at 195 GLOSS sites. Of the 101 GLOSS stations that are presently operating on islands, 93 are available through the JASL. The 2002 submission of the JASL data to the World Data Center-A for Oceanography included 105 series that contained measurements through the year 2001.

The UHSLC maintains a fast delivery database in support of various national and international programs (e.g., GODAE, CLIVAR). To ensure active participation and coordination with the international community, the database has been designated by the IOC as a component of the GLOSS program. The fast delivery data also are used extensively by the altimeter community for ongoing assessment and calibration of satellite altimeter datasets. In particular, fast delivery data are used for monitoring the latest JASON altimeter and for the tie between JASON, TOPEX/Poseidon, ERS, and GEOSAT satellites. The fast delivery sea level dataset now includes 141 stations, 113 of which are located at GLOSS sites. The historical data return for the fast delivery dataset is 94.0%, the current year's return is 94.8%, and the previous year's return 95.5%

The UHSLC continued development of a quasi-real time dataset of hourly (collection + up to a three hour delay, H-3 delay) and daily filtered values (J-2 delay) in support of GODAE. Approximately 50 stations currently are available in real-time with plans for ongoing expansion. We will distribute this product through our web site, and make it available in a netCDF format via an OPeNDAP (formerly DODS) server.

The UHSLC helped construct the WOCE V3 DVD, distributed in November 2002. UHSLC also produced CDROMS that were distributed with the JASL annual data report. These CDROMS are shared with all data originators and sent to other users upon request. Over 100 were distributed again last year.

As part of the JCOMM SLP-Pac, the UHSLC operates a Specialized Oceanographic Center that produces sea surface topography maps (monthly) and diagnostic time series (quarterly) for the Pacific Ocean. This activity is a continuation of one of the earliest examples of operational oceanography. The UHSLC presently distributes these products through the Internet and by mail to users. The net result is that approximately five weeks after the end of a month, hundreds of users throughout the world receive an analysis of the state of the Pacific Ocean sea surface topography for that month. The analysis includes comparisons of tide gauge and altimeter sea surface elevations that are available through the UHSLC web site.

Research Highlights

Interannual and decadal changes and sea level rise have been our primary research focus areas during FY2003. A manuscript describing decadal oscillations in sea level in the eastern Pacific has been submitted to the Journal of Physical Oceanography. We have described how the long sea level record collected at the Honolulu tide gauge is connected to Pacific North America (PNA) related fluctuations in winds and surface pressure. Possible heat flux contributions to this signal are being examined as nearly one-half of the decadal variability in sea level is contributed by heat changes in the upper 60m of the water column.

As part of our commitment to provide absolute sea level estimates at selected sites, we are examining signal-to-noise ratios that limit the accuracy of GPS-derived ground motion rates. By identifying and removing noise from the data, we hope to reduce the time necessary to resolve absolute sea level trends of the order of 1 mm/year. We have collected bottom pressure data from around the Hawaiian Islands and are we are now investigating whether oceanic loading signals at low frequencies contribute to the GPS variations on the islands.

We are finishing our case history of sea level variability and sea level rise at the Funafuti atoll in Tuvalu. Reports of flooding due to global sea level rise have appeared in the popular press. The UHSLC maintained a station at Funafuti for nearly 20 years, which is now being extended forward by the National Tidal Facility, Australia. We find that annual extrema have increased more rapidly than annual mean sea level, suggesting that flooding occurrences are tied to changes in weather patterns near the island rather than eustatic sea level rise.

A study of island sinking rates along the Hawaiian island chain is nearing completion. Differences in sea level rise rates recorded at Hilo and Honolulu have long been attributed to variable subsidence rates associated with volcanic activity. Continuous GPS measurements indicate that the rates are more similar between the islands. We are investigating whether the sea level rate difference may be due in part to steric variations associated with large-scale wind patterns.

We participated in an overview of sea level research using tide gauges made during the WOCE program (Woodworth et al., 2002).

We continued to work with Pacific Marine Environmental Laboratory (PMEL) and the NODC to support the Climate Data Portal (CDP), consisting of a networked system connecting diverse, distributed servers at PMEL (TAO El Nino buoys), UHSLC, and NODC (the Global Temperature-Salinity Profile Program or GTSPP dataset). Although not directly supported by the OGP, we mention our participation in the CDP in this report to convey that we are making every effort to ensure that the information collected by the UHSLC are made available to the widest range of users. The CDP enables researchers and others to access the products developed by the various elements of the ENSO Observing System over the Internet without having to log on to multiple web sites. The technology developed in this project ultimately may be useful for other NOAA servers in an operational sense. This program has also produced ncBrowse, a graphical netCDF file browser that can be used to preview the UHSLC CLIVAR/GLOSS fast delivery dataset.

The CLIVAR/GLOSS dataset was added to the NOPP's National Virtual Ocean Data System (NVODS). Our participation in the NVODS is to promote wider dissemination of UHSLC products and to stay current with evolving distribution strategies. Given our existing infrastructure, we were able to implement this task without significant expense to the project. To add this dataset to the NVODS, netCDF files were developed and an OPeNDAP server for these files installed at the UHSLC.

Program Support through the Assimilation, Analysis and Dissemination of Global Raingauge Data

by Mark Morrissey, Susan Postawko, and Scott Greene

PROJECT SUMMARY

This project supports the goals of the Climate Observations element of the NOAA's Office of Global Programs through the assimilation of hard-to-find raingauge dataset, especially over open ocean regions. We also support the Global Precipitation Climatology Project (GPCP) in a continuing role as the Surface Reference Data Center (SRDC). Our mission includes the collection, analyze and dissemination of global rainfall data sets and products deemed useful for Operational Forecast Centers, International Research Programs and individual researchers in their scientific endeavors. Housed in the Environmental Verification and Analysis Center (EVAC) at the University of Oklahoma, the EVAC/SRDC has built upon work from past NOAA-supported projects to become a unique location for scientists to obtain scarce raingauge data and to conduct research into verification activities. These data are continually analyzed to produce error-assessed rainfall products. Scientists need only to access the EVAC/SRDC web site (http://www.evac.ou.edu/srdc or http://srdc.evac.ou.edu) to obtain critical global raingauge data sets. Many of these data sets are impossible to obtain elsewhere. The EVAC/SRDC serves the research community by actively working with individually countries in environmentally important locations to help provide them with infrastructure, education and other support. The return on this investment by NOAA has been significant in terms of enabling EVAC/SRDC to provide the scientific community with critical, one-of-a-kind raingauge data sets. Past successes with this strategy have proven very worthwhile on a cost-benefit basis.

The above strategy set forth during last year was to expand our efforts to increase the raingauge climate-observing database for specific, environmentally critical locations. It is not our intention to collect all raingauge data worldwide, but to assimilate raingauge data 1) in environmentally critical locations, 2) where dense raingauge networks exist and 3) where agreements can be made to help construct raingauge networks in these critical locations. An experimental effort focused on the latter objective with the government of Niue, Kiribati and Vanuatu has resulted in a network of approximately 25 new raingauges located on many atolls and islands managed by the local Meteorological Services. The success of this effort has motivated us to expand this effort to other environmentally important countries. It is also our intention to experiment with new and innovative verification methods, which attempt to extract as much information from a data set as possible. These 'data mining' methods are currently being utilized in many fields and are still being developed.

Rainfall data is particularly important in the tropics. Not only is it a tracer of latent heat, it is vitally important to the understanding of ocean properties as well, such as latent and sensible heat flux, salinity changes and attendant local ocean circulation changes. In addition, raingauge observations from low-lying atolls are required to conduct verification exercises of nearby buoy-mounted raingauges.

PROJECT GOALS AND METHODOLOGY

The overall goal of the EVAC/ SRDC is to provide ocean-raingauge data sets to the global research community. These data are use for a variety of purposes, including trend analysis, ocean modeling, and model/satellite verification. The primary data set of interest is the Comprehensive Pacific Raingauge Data Base (CPRDB), which is the largest and most comprehensive set of raingauge data for the Pacific region in existence. As part of our task for the Global Precipitation Climatology Project (GPCP) we also produce gridded in-situ rainfall products within global land regions where rain gauges are abundant. Once these products are gridded at the scales coincident with the GPCP product (2.5 x 2.5 degree monthly and daily; and 1 x 1 degree daily), they are made available to the research community for use in validating both the GPCP product and other independent algorithms that could provide value-added information to the product. Additional activities include:

- pursuing arrangements internationally to enhance through collaboration the collection, quality and maintenance of extremely important oceanic raingauge data.
- archiving and make available to the research community these data;
- providing a validated GPCP product using existing, new and still to be developed validation methodologies and new data sources;
- analyzing selected raingauge networks and using the results to perform verification studies on GPCP satellite rainfall products;
- expanding, developing and distributing the CPRDB to all researchers; and to conduct basic research on new validation technology.
- continuing the Schools of the Pacific Rainfall Climatology Experiment (SPaRCE) as a synergistic effort to enhance the SRDC.
- reporting GPCP verification results through a bi-monthly email newsletter.

DATA COLLECTION AND ANALYSIS

Both 2.5 x 2.5 and 1.0 x 1.0 degree daily, pentad, monthly averaged grid cells are desired by GPCP scientists. To accommodate this new requirement, the SRDC has expanded the current data sets to include daily raingauge datasets to match the temporal resolution of the GPCP gridded rainfall products. This year we have analyzed several daily raingauge data sets, include the NASA Tropical Rainfall Measuring Mission Ground Validation gauge sites, the Oklahoma Mesonet and daily Pacific reports from regions of reasonably high gauge site density. In addition, new data from the islands of Kiribati, Niue, Tuvalu, Cook Islands, Pitcairn Island and Vanuatu are either in the process of establishment or are operational with data being currently collected, analyzed and archived. It should be noted that the University of Oklahoma provided $6,000 to supplement this NOAA project to purchase additional raingauges from Vanuatu. Several additional data sets have been collected and are currently being analyzed. These data include the national Republic of Korea raingauge data set, which is an extremely valuable data set containing high temporal and spatial gauge data, the daily U.S COOP rainfall summaries and data sets archived by the U.S. Environmental Protection Agency (EPA).

Data analysis techniques used by EVAC scientists to derive gridded products include simple areal averaging and error estimation. Data sets selected for satellite rainfall algorithm verification must have errors less than a given threshold. The statistical methodology for this activity has been developed by EVAC scientists.

RESULTS AND ACCOMPLISHMENTS (2002-2003)

Data Collection and Analysis:

We have exceeded our objectives for this year. The primary focus of this year's work was to compute daily averaged rainfall for 1 x 1 degree boxes for the Tropical Rainfall Measuring Mission (TRMM) Florida validation sites. The task, which included construction of box averages and error statistics, has been completed and is on our web site (www.evac.ou.edu/srdc). The error statistics include the standard error and the signal to noise ratio for each box for the years 1997 through 2001. The results indicate that, due to poor gauge instrumentation and data maintenance, only several boxes in Florida are reliable enough to use as validation sites. Data for Hawaii, Guam, Taiwan, Thailand and Israel, while shown on the web site, turned out to not be available.

After contacting the Environmental Protection Agency (EPA), we discovered that they archived a very large database of raingauge data from many watershed around the country. These data are not included in the GPCP product and may be very useful as validation data. We now have these data and are currently investigating their usefulness.

A collaborative effort with the Meteorological Director of Niue Island in the south Pacific has resulted in the placement and recording of 6 new manual read gauges spanning the island. Niue is located within the climatological average position of Southern Pacific Convergence Zone and is very isolated. Thus, these data are extremely important. We are receiving monthly reports of daily data. These data are analyzed and incorporated into the Comprehensive Pacific Rainfall (PACRAIN; http://srdc.evac.ou.edu)) http://www.evac.ou.edu/pacrain).

In addition, 10 raingauges and related material have requested by the Meteorological Director of the country of Tuvalu. Tuvalu consists of 3 main atolls located in the primary climatological rain zone in the Pacific. The gauges and material are currently being sent to Tuvalu for set up. This collaboration is a direct results of efforts made by the SPaRCE program.

Our collaborative arrangement with Mr. William Christian on Pitcairn Island is going quite well. We are receiving regular reports of daily data from this isolated island. To our knowledge these data exist nowhere else.

Dr. Morrissey is now on the Committee for funding the *Pacific Island Meteorological Needs Analysis*. As a result, a trip to the American Samoan Representative in Washington, D.C. was made in an effort to solicit support for this project. The *Needs Analysis* project's goals, if achieved, will enhancement the Pacific raingauge network significantly.

Research

Validation Methodolgy:

We developed a new mathematical expression for the signal to noise ratio for areal averaged rainfall. This statistic relates the time variance of box averages (with zero sampling error) to the error variance. A journal paper is being prepared for journal submission (e.g., the standard error expression is given below).

Newly developed and existing validation technology has been derived using the *Mathematica* symbolic software package. Several techniques have been developed and the *Mathematica* notebooks are available for downloading on our web page. Two examples are ordinary kriging and the signal to noise ratio.

NOAA Polar Orbitor/Mesosat Rainfall Comparison over the Indian Ocean

An additional research effort was to assess the impact of Meteosat 5 on precipitation estimates over the Indian Ocean compared to low orbit satellite data, i.e., polar orbiters, which was used prior to obtaining Meteosat 5 data. This work consisted of two main objectives. First, to determine the standard error associated with different temporal sampling rates, and second, to compute and analyze the difference in precipitation estimates between satellites. The temporal standard error was computed using the formula above. Results show that the standard error increases approximately 0.2 mm based on the difference in the temporal sampling. A spatial analysis of the mean values, conditional amounts, and frequency of occurrence of precipitation as measured by the two different satellites illustrate regional differences. This difference in the frequency and amount of precipitation between satellites can perhaps be explained by a difference in the estimation of diurnal variability. Our plan for the future is to expand this analysis and to perform validation over areas with surface data (e.g., GAME data).

DataBase Development

The SRDC database work is now operational. Users can now log on to our web site select and download data of interest. This allows users to access SRDC reference data sets scaled to their needs.

Other Actions Items Completed

Progress reports concerning the SRDC were presented by Mark Morrissey, Mike Klatt, Susan Postawko, and Scott Greene at the annual WGDM meeting held in Tokyo during May. Mark Morrissey reported on result of analysis of the TRMM Florida gauge data. Mike Klatt discussed the progress obtained with the new database system, Susan Postawko discussed the useful for the SRDC of new, unconventional raingauge data sets, and Scott Greene showed results on the development of improved error characterization, and on the NOAA Polar Orbitor/Mesosat Rainfall Comparison over the Indian Ocean. In addition, below is a partial list of the tasks completed during the previous year:

Taylor's Atlas, which contains monthly gauge totals from many Pacific islands prior to 1970 has been digitized and posted on our web page and is available for downloading. SRDC project was combined with the Schools of the Pacific Rainfall Climate

A special thanks goes out to Meteo France for supplying the SRDC with important French Polynesian gauge data, which will be analyzed during the next quarter.

A list of actions items obtained at the WGDM meeting identified a need for the SRDC to call attention to the SRDC's capability to not only provide data products, but to also product technical expertise on the difficult task of verification of satellite rainfall algorithms. To this end we are currently writing an article for the GEWEX newsletter and the AMS Bulletin describing the role of the SRDC in its support of the GPCP and the scientific community at large.

The Schools of the Pacific Raingauge Climate Experiment (SPaRCE), funded initially by NOAA, has over 200 schools across the Pacific equipped with a direct read raingauge. Each school takes daily raingauge measurements and these measurements are then provided to the research community (http://www.evac.ou.edu/sparce/). In return for taking raingauge measurements, the schools are supplied with equipment and educational materials.

PROJECT SUMMARY AND FY 2003 PROGRESS

The "Global Drifter Program"

Drifter Measurements of Surface Velocity, SST and Atmospheric Pressure

by Peter Niiler

Combined report for the NOAA grants to JIMO under NOAA/NA-17RJ1231:

1) "Global Drifter Measurements of Velocity, SST and Atmospheric Pressure in the ENSO Observing System"
2) "Surface Drifter Observations in CORC"
3) "Mixed Layer Heat Transport in the Tropical Atlantic"
4) "Enhancements of Drifter Observations in the South Atlantic"
5) "Enhancements of Drifter Observations in the South Pacific"
6) "Enhancements of Atmospheric Pressure Observations in the North Pacific"

PROJECT SUMMARY

Rationale:

The oceans have a profound effect on the atmosphere and changes of the habitability of the globe because they are the earth's principal time-varying reservoirs of thermal energy, moisture and accessible carbon. If the temperature of the lower layers of the atmosphere over the oceans departs form SST, there is a vigorous exchange of heat and moisture between the two fluids and the temperature of the atmosphere, because of its low heat capacity, adjusts to SST. The changes of the rates at which the oceans sequester CO_2 directly affect the changes of the global distribution of CO_2 in the atmosphere and its greenhouse radiation balance.

SST depends crucially upon ocean circulation patterns. This is most vividly demonstrated by the observation that a thermocline separates the warm surface layers of the tropical and subtropical oceans from the cold deeper layers. Such a vertical distribution of temperature cannot be maintained over many centuries unless a volume flux of cold water is supplied to the lower layers and a net heating or a volume flux of warm water is supplied to the surface layers. Via the overturning circulation of the oceans, the thermal energy absorbed in the ocean in low latitudes is transported poleward where it is given back to the atmosphere and cold water sinks. If a near-surface fresh water layers from ice melt flow over regions where heat is given back to the atmosphere, cold water cannot sink and the overturning circulation of the oceans, or transport of heat from the tropics to the polar oceans, is much reduced. The climate change of the atmosphere cannot be understood without understanding the general circulation, or property transports, of the oceans.

Because there has been a paucity of direct ocean circulation, or property transport, observations, oceanographers rely on ocean general circulation models to study and predict the circulation processes that cause climate change. To make the current climate models more realistic, model parameters and air-sea fluxes are adjusted so that the short time evolving structure of ocean currents, temperature and salinity observations are faithfully reproduced in models. If models replicate the present short-term climate changes it is though that they can also be used to predict longer time scale changes.

Climate scale spatial and temporal changes of the ocean and atmospheric temperature can occur when net surface heat, fresh water and CO_2 flux distributions between the ocean and atmosphere are disturbed or when ocean circulation changes. These spatial scales can be several tens of kilometers, as characterize present bottom and deep-water formation and equatorial upwelling regions, or many thousands of kilometers, as characterize the global ENSO phenomena. Most temporal characterizations of ocean property distributions from instrumental records appear spectrally "red" so we do not know if useful large time scale bounds can be established. Observing the ocean is a taunting because many space scales must be sampled and we must observe the oceans longer than the lifetime of any known civilization.

The principal scientific questions of the role of the ocean in climate change are how well can we describe or model the ocean circulation today and how well can these descriptions or models predict the evolution of future climates.

It is an important societal task to predict the effects of climate change, whether anthropogenic or natural. Whether CO_2 sequestration by oceans can retard the greenhouse effects of anthropogenic sources can by only be answered by ocean circulation models that, in addition to correct circulation physics, have realistic biochemical cycles. An assessment of the limits of El Nino prediction can only be done in context of ocean circulation models that embody accurate simulations of both time mean and time dependents circulation as well as realistic initial conditions of the ocean state.

It is important to the assessment of the health, and perhaps even survival, of today's civilizations that predictions of the effects of climate change are made with realistic ocean circulation models. The reality of ocean circulation models can only be determined with spatially and temporally extensive data sets of the state of the circulation and property distributions of the global oceans. Drifter data is central to the description of the circulation and property distribution of the upper layers of the oceans. These data are necessary for documenting the fate of carbon sources and sinks, the thermal energy uptake, transport, and release by the ocean and the air-sea exchange of water and the ocean's overturning circulation.

***Objectives of the Global Drifter Program*:**

The "Global Drifter Program" (*GDP*) is the principal component of the *"Global Surface Drifting Buoy Array"* of the NOAA Ocean Observing System for Climate and a scientific project of the Data Buoy Cooperation Panel (DBCP) of the World Meteorological Organization (WMO) and the International Oceanographic Commission (IOC). It is a near-operational ocean-observing network of drifters that, through ARGOS satellite system, returns data on ocean currents, SST and atmospheric pressure (and winds and salinity) and provides a data processing system for scientific utilization of that data.

The scientific objectives of the *GDP* are to:

1) Provide an operational, near-real time data stream of SST, sea level pressure and surface velocity.

2) Observe the mixed layer velocity on a global basis with 5° resolution and produce new charts of the seasonal and interannual changing circulation of the world ocean (Figure 1).

3) Develop and introduce into the drifter construction technological advances in sensors, electronics, power, methods of assembly and deployment packaging.

4) Provide enhanced data sets of ocean circulation that include drifter data from individual research programs, historical data from instruments different from the Surface Velocity Program (SVP) Lagrangian Drifter and the corrected data sets for wind-produced slip of drifter velocity. In this latter context, *GDP*:

- Provides to the coupled ocean-atmosphere climate models gridded, global data sets for assimilation of SST and surface velocity and for the verification of the parameterized processes, such as wind-driven currents.

• Provides the Lagrangian data sets for the computation of dispersal of ocean pollutants, the enhancement of models of fisheries recruitment and improvement of air-sea rescue.

• Obtains high-resolution coverage of ocean variability and time mean circulation in support of ENSO prediction model assimilation and verification in the tropical Oceans and supports short-term research projects that require enhanced upper ocean velocity observations.

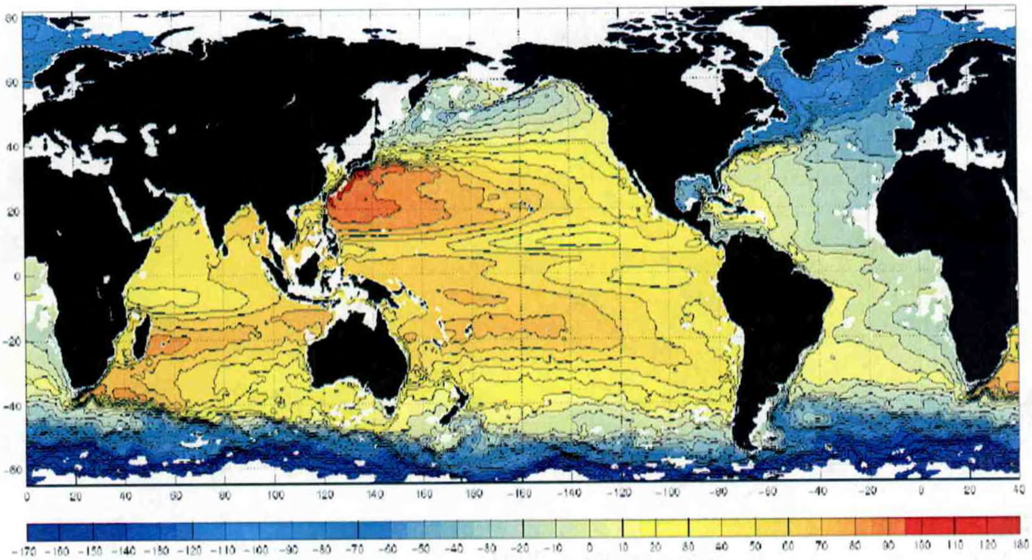


Figure 1. The absolute sea level derived from the 1992-2002 time-mean drifter observed currents on a 0.5° resolution. The time average surface geostrophic velocity is parallel to the sea level contours.

GDP Status and the Required Observations

At the present time the global drifter network is not fully implemented, for which 1250 drifters are required (Figure 1). This array size is based on the need to maintain high quality instrumental observations (+/- 0.1°C) over the global ocean at the resolution of the error covariance function of satellite SST sensors. Urgent action to address this deficiency has been proposed and is the basis for NOAA's plan for *Building a Sustained Ocean Observing System for Climate*. *GDP* is the principal project by which the *"Global Surface Drifting Buoy Array"* component of this *System* will accomplish full implementation, together with its associated data, analysis and product capabilities.

The full implementation of the drifter array is feasible now because over the past 10 years its principal instrument, the SVP Lagrangian Drifter and its barometer attachment (SVP-B), has proven to be reliable and affordable. A drifter array provides data for more than 450 days of operation at sea, is easily deployed from ships or aircraft and is manufactured commercially by three US firms at a cost of 1/3rd of what it was ten years ago.

International operational oceanographic and meteorological agencies contribute significantly to the purchase and deployment of the global SVP drifter array because *GDP* has developed a close working relationship with them both individually and through DBCP. DBCP reports on the activities of the *GDP* directly to IOC and WMO, via its membership in the Joint IOC/WMO Technical Commission for Oceanography and Marine Meteorology (JCOMM). The *GDP* operational partners are the meteorological agencies of New Zealand, Australia, South Africa, Great Britain, France, India, Korea, Canada, US and Brazil and the International Ice Patrol, NAVOCEANO and CICESE/ Mexico. Working with these partners through DBCP (and JCOMM), a 100% completion of the *"Global Surface Drifting Buoy Array"* is planned by 2005-06.

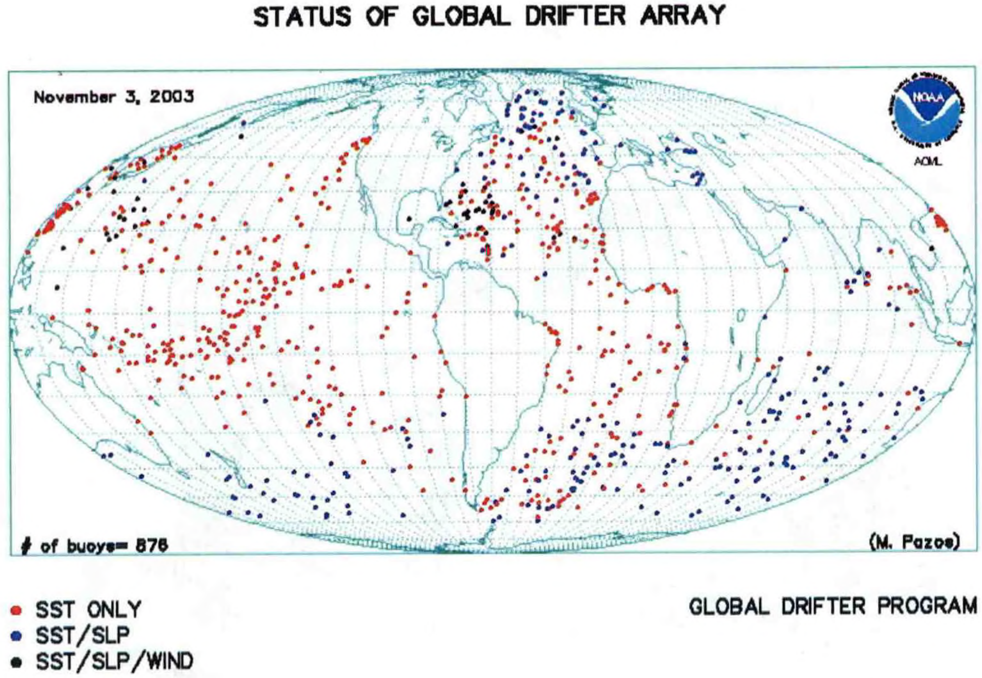


Figure 2. The global distribution of drifters on November 3, 2003.

***Management*:**

GDP is managed according to the *"Ten Climate Monitoring Principles"* established by JCOMM. In this task, there is close coordination between:

• US manufacturers in private industry (*Technocean, Inc.* of Cape Coral, FL; *Clearwater, Inc.* of Watertown, MA; *Pacific Gyre, Inc.* of Carlsbad, CA) who build the SVP drifters according to closely monitored specifications,

• Atlantic Oceanographic and Marine Laboratory (AOML) who carries out the deployments at sea, processes the data and archives these at MEDS, Canada, maintains the META file on the description of each drifter deployed, and the upgrades the *GDP* website,

• Joint Institute of Marine Observations (JIMO) who supervises the industry, acquires the drifters, upgrades the technology, develops sensors and enhanced data sets and maintains liaison with individual research programs that deploy SVP drifters.

Since 1992, an array between 600 – 900 SVP drifters has been maintained in the global ocean, depending upon the contributions of individual research projects to the global data sets. On a yearly basis a peer-reviewed literature survey is carried out. The scientific papers using drifter data can be viewed at the AOML website: http://www.aoml.noaa.gov/phod/dac/drifter_bibliography.html.

FY 2003 Progress

This is a review of the activities of JIMO in the acquisitions, technology, coordination and enhanced data sets of *GDP*. Separate reports on the number of drifters deployed, the number of observations and the status of the data files have been filed by the coordinated drifter projects at AOML.

Drifter Acquisitions
In 2003 JIMO wrote purchase orders for 666 SVP-Mini drifters, with 115 upgrades to SVP-Bs. These are now being delivered at AOML for deployment. In addition, AOML purchased 41 SVP-Mini drifters. With cooperation of the Office of Naval Research (ONR) and the Busan National University in Korea, 80 SVP-Mini drifters and 14 Minimet wind-sensing drifters were acquired. With the transfer of SVP construction technology from JIMO to CICESE/Mexico, an additional 90 SVP-mini drifters will be built from Mexican funds for deployment into the Gulf of California.

The 2003 *GDP* contribution to the "Global Surface Drifter Array" will be 720 SVP drifters, a significant increase over acquisitions in 2002; an additional 170 SVP drifters will be deployed in the marginal seas of the Pacific.

In 2002, JIMO purchased 467 SVP drifters (with 36 barometer upgrades) and 16 Minimet drifters. AOML, in addition, purchased 10 Wind drifters, for a total of 493 drifters. The 2003 drifter acquisitions are 48% larger than the 2002 purchases and a three-fold increase in upgrades to barometer sensors. There will be a significant increase of drifter data in 2004 due to: 1) Office of Global Program (OGP) funding for enhancements of the observing system for the South Atlantic and the North and South Pacific Oceans, 2) the inclusion of research projects that agreed to allow their data to become part of the *GDP* operational data file and 3) technology developments of drifter construction which lowered the per-unit price, as discussed below.

Technical Developments
In 2002-03, the configuration of the SVP drifter was redesigned at JIMO by reducing its size by about 40%, but keeping the same water-following capability of 40 for the drag area ratio, as it was in the past 14 years. In 2002, the SVP price was reduced from $2150 to $1950 and reduced further to $1800 in 2003. The anticipated cost of 2004 will be $1700 per drifter, resulting in 26% increase in acquisitions. The following technology will have been implemented in 2002-03-04 as the SVP-Mini drifters are brought on line:

1) Reduction of the size of drifter components by 40% resulted in materials savings in packing material, floats, attachments of tether and drogue, etc.
2) Redesign of ARGOS transmitters to lower voltage from 14v to 4v that requires lower standby and transmission power drains.
3) Redesign and change in manufacturing techniques of the drogue, tether and the attachment techniques.
4) Reduction in labor costs in assembly.
5) In 2003, *GDP* designed a kit of SVP parts that costs about $1100. The kit consists of a preassembled electronics/power package, a float/tether assembly and drogue. Several ocean research laboratories have purchased these and are assembling and testing them using labor provided by graduate students or technicians on the permanents staff.
6) Surface salinity sensors were added to the for SVP drifters and these have been under test in turgid waters of the East China Sea for the past three years: (Figure 3)
7) Air-deployment containers for Minimet wind-sensing drifters were developed for deployments into hurricanes: (Figure 4)

It is important to understand that the technology changes for the cost reduction could be instituted only because JIMO purchases drifters with the full knowledge of how much each component costs, how long it takes to assemble a drifter and what the profit margins in the companies that build the drifters were. In a government purchasing method the overall performance specifications are set and the lowest quoted price wins the contract. The choices of specific components, materials and methods are left to the competing manufacturers. The desired lower quotes in the past three years would not have resulted in such a bidding process because no changes of the overall specification of the performance of drifters were required. SVP drifters built in 2001 at a cost of $2150 worked well at sea. Before writing the purchase orders with the realizable 26% unit price reduction, JIMO gave the US manufacturers the new drifter assembly drawings, new sources of supply for mechanical and electronic parts, new methods of labor saving assembly and new packaging methods. By introducing the same new technology to all US manufacturers at the same time, the unit price was lowered with the full cooperation of all.

Figure 3. The SeaBird Microcats adapted to observe sea surface salinity (SSS) at the bottom of the SVP drifter float in the SIO test pool; 20 SVP-SSS test drifters have been deployed in the East China Sea to study the effects of the decreasing flow of the Yangtze on the ecology of South Korea.

Figure 4. The JIMO/Minimet wind-sensing air-deployment container during tests at Keesler AFB in July 2003. A parachute is on top of the container and 2 Minimet drifters are inside the container. Upon deployment at sea, salt pills at the bottom of the straps dissolve in seawater in 20 minutes, releasing the parachute harness.

Coordination with Individual Research Projects
GDP is cooperating with the following individual research projects to assist in the assembly of drifter components and/or deployment of GDP drifters in their study areas.

• Busan National University assembles and deploys SVP-Mini drifters in research projects sponsored by the Korean Fisheries Research Agency and the US Office of Naval Research (80 drifters in 2003). These are deployed in the East Korea Current and the Luzon Strait (Figure 5).

• CICESE in Ensenada, Mexico trained technicians at JIMO for the assembly of SVP-Mini drifters (90 drifters in 2004). These will be deployed across the entrance to the Gulf of California.

• NOAA Antarctic Marine Live Resource Program (AMLR) requested to deploy 20 *GDP* SVP drifters in January 2003 and will deploy 40 SVP drifters in January 2004. These will quickly disperse from the Antarctic Peninsula and become part the Southern Ocean *GDP* array.

• Every year since 1998 Oregon State University (OSU) research projects have released 20 SVP drifters off the central Oregon coast and has shared their data with *GDP*. OSU has requested to continue releasing *GDP* drifters on a quarterly basis. *GDP* is very pleased to provide the drifters for this activity because these drifters very quickly leave the Oregon coast to the eastern North Pacific and these provide valuable data in the effects of North Pacific climate change on fisheries recruitment.

Enhancements of Data Sets
On a six monthly basis, JIMO interpolates the NCEP reanalysis winds on to the processed data files produced by AOML Global Drifter Data Center. The winds are used to calculate the wind-produced slip of the SVP drifters and an additional slip of the drifters that have lost their drogue (Pazan and Niiler, 2001). JIMO continues to maintain a complete file of all of the historical drifter data that, including the

southern ocean FGGE-era drifters (842 data files), PMEL drifters that are drogued to 40 m (240 data files and increasing each year) and the International Ice Patrol drifters with drogues at various depths before 1997 (114 data files). Inclusion of the corrected SVP drifter data that have lost drogues increases the usable global data file for ocean circulation studies by 42%.

The complete, wind slip corrected data file is available to anyone who requests it. Further requests can be made for binning on specific space and time scales or specific locations. Availability of these data will shortly be announced in EOS: Pazan. S and P. Niiler, 2003: A new global drifter data set (*EOS*, in press).

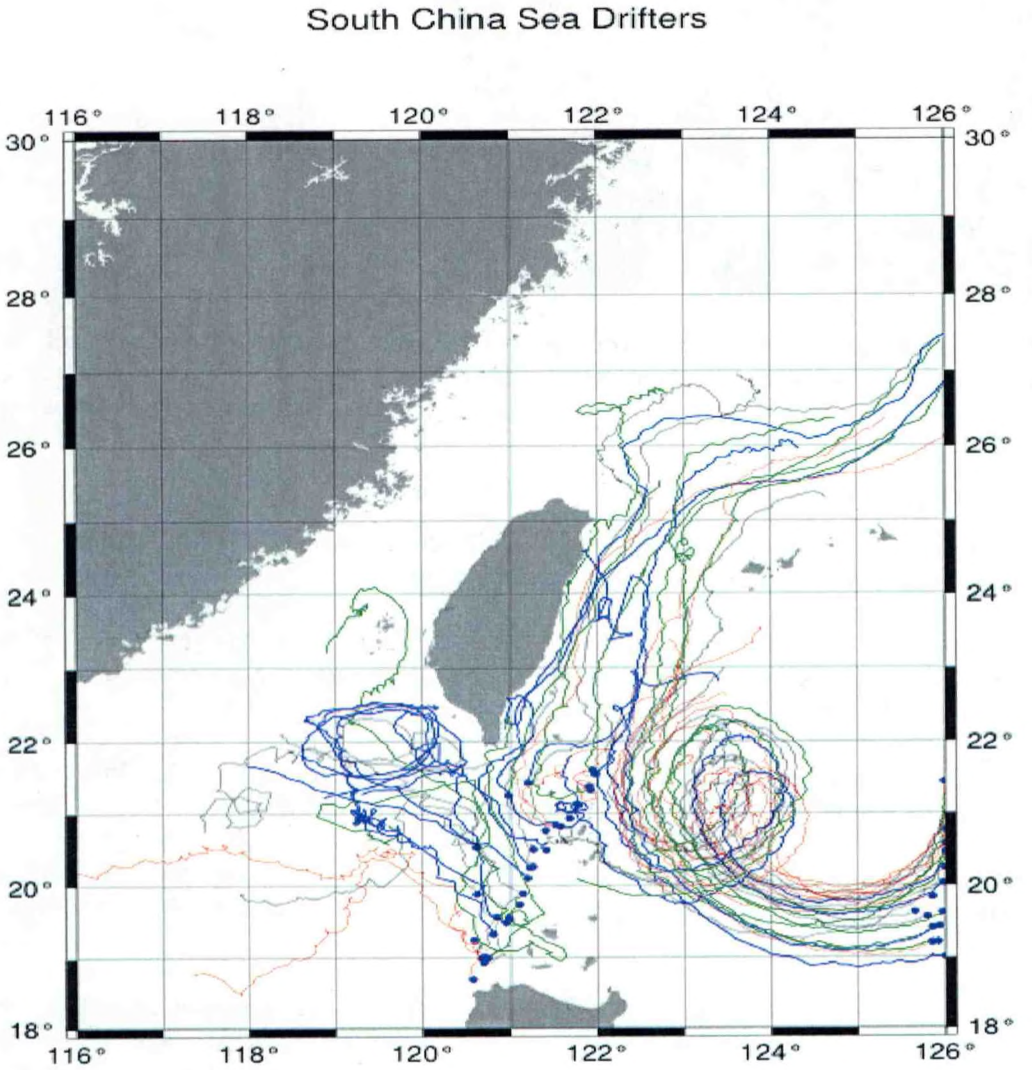


Figure 5. Track of drifters deployed in early October 2003 near the Luzon Strait in the JIMO/ONR joint research program for the study of the flow of Pacific surface water into the South China Sea. Blue dots mark the deployment locations and data is about 30 days with last fix on November 11, 2003.

The following investigators asked for and received the wind-corrected, gridded data files during the past 12 months on velocity:

Lynne Talley	Scripps Institution of Oceanography
Sarah Gille	Scripps Institution of Oceanography
Detlef Stammer	University of Hamburg, Germany
Meng Zhou	University of Massachusetts, Boston
Nikolai Maximenko	University of Hawaii
Carter Ohlman	University of California at Santa Barbara
Jian Weiqing	University of Colorado, Boulder
Julie McClean	Naval Post Graduate School
Jan Morzel	Colorado Research Associates, Boulder

Every year JIMO updates the file on peer-reviewed publications in the major oceanographic journals that have used drifter data for research results. The publication file, updated in February 2003, contains 167 peer-reviewed publications.

Climate Variability in Ocean Surface Turbulent Fluxes
by James J. O'Brien, Mark A. Bourassa and Shawn R. Smith

PROJECT SUMMARY

Ocean surface turbulent fluxes will be examined for climate-related variability. Typically SSTs, winds, and pressures are examined in such studies. The observed changes in winds (speed and direction) and SSTs alter turbulent surface fluxes, which have a far-reaching influence on regional climatologies. It is expected that surface turbulent fluxes (stress, sensible heat, and latent heat) are more directly linked to climate-related changes than winds and pressures. Similar approaches will be applied to two overlapping periods. We are objectively deriving a high quality set of monthly surface fluxes (and related fields), covering 1950 to 2005, for the global oceans north of ~30°S to examine variability on a wide range of spatial and temporal scales (seasonal to decadal). Similar daily fields (including surface radiative fluxes) are under development from July 22, 1999 through 2005, with greater spatial resolution. Our goal is to produce the most accurate flux fields available.

Reanalysis surface fields have large biases and systematic errors in comparison to surface truth (Cotton et al. 1999, Renfrew et al. 2000, Smith et al. 2001). The physics of the boundary layer are not well modeled in NWP reanalyses, resulting in poor surface fields. The errors are sufficiently large to bias climate-related studies (Cotton et al. 1999, Smith et al. 2001); therefore, in-situ (ship and buoy) observations are being objectively combined to create a better turbulent-flux product. Comparing subjectively-derived, in-situ based, Equatorial Pacific surface wind products (the FSU winds) to the NCEP/NCAR Reanalysis clearly verified the above mentioned shortcomings (Putman et al. 2000). However, the FSU wind fields are excellent matches to satellite ocean surface vector wind fields (Pegion et al. 2000), thereby confirming the accuracy of the in-situ based products. The surface flux fields developed though this study can be used to help validate flux fields created with couple ocean-atmospheric models (after the removal of the above short comings). The techniques developed in this study will also be of use for programs such as GODAE and SEAFLUX (which require the assimilation of data from multiple platforms), as well as energy budget studies based on WOCE and GOOS observations.

An objective analysis technique (Bourassa et al. 2003) has been developed to produce fields of surface turbulent fluxes (momentum, latent heat, and sensible heat fluxes) and the fields used to create the fluxes (vector wind, scalar wind, near-surface air temperature and humidity, SST, and pressure. This approach treats the various types of observations (volunteer observing ships, buoys, different satellites) as independent, and objectively determines weights for each type of observation. The weights for each type of observation are objectively determined.

The flux project at FSU targets the data assimilation milestones within the Program Plan. Our assimilation efforts combine ocean surface data from multiple Ocean Observing System networks (e.g., VOS, moored and drifting buoys, and satellites). One set of performance measures targeted in the Program Plan is the air-sea exchange of heat, momentum, and fresh water. When are products are combined with ocean models (either at FSU or other institutes), performance measures relating to surface circulation and ocean transports can be addressed. The FSU flux project also focuses on the task of evaluating operational assimilation systems (e.g., NCEP and ECMWF reanalyses) and continues to provide timely data products that are used for a wide range of ENSO forecast systems.

All development of the objective flux system and operational production of the FSU winds and fluxes are the responsibility of COAPS. Our satellite partners include Gary Wick (NOAA-ETL; satellite SST), Frank Wentz and Deborah Smith (Remote Sensing Systems; scatterometer winds, passive microwave scalar winds, passive microwave SST), and Bill Rossow and Yuanchong Zhang (NASA; radiative fluxes). We maintain a long-term collaboration with Dr. Jacques Servain (IRD, France) who focuses on data and products for the tropical Atlantic Ocean. We also continue to collaborate with U. S. and international partners in the CLIVAR program, SEAFLUX, and GODAE to provide the wind and flux products needed to achieve these projects goals. All the FSU wind (and eventually flux) products are freely available at: http://www.coaps.fsu.edu/RVSMDC/SAC/.

The FSU flux project began managing its operation in accordance with many of the Ten Climate Monitoring Principles long before they were spelled out by the NRC. We continue to fully document and provide free access to all of the FSU wind and flux products. The FSU Pacific and Indian Ocean winds have been continuously produced and distributed since the mid-1970s (Smith et al. 2003c). We endeavor to maintain a consistent product over many years and are careful to include parallel testing whenever possible before changing analysis methods. When a former product is discontinued, we provide a comparative assessment of the new and old products to aid the users transition (e.g., Bourassa et al. 2003). Finally, we continually evolve our data access and distribution system to take advantage of new distribution formats (e.g., netCDF) and access technology (e.g., DODS). This evolution will continue in the future to achieve the goals of new data management programs (e.g., Ocean.US IOOS-DMAC).

FY 2003 PROGRESS

The objective method for producing turbulent fluxes (Bourassa et al. 2003) continues to be refined to improve the quality of objective fields near coastal regions and to begin heat flux calculations. Advancements in the method include:

- Modifying the method to produce one by one degree *in situ* based gridded fields
- Improved background fields, that better capture climate variability, and induce fewer suspect features.

The code for the one-degree *in situ* wind (pseudo-stress) fields has undergone testing and analysis of one-degree fields for the tropical Indian and Pacific Oceans are now underway.

In a parallel effort, the objective method is now fully operational for production of two-degree tropical Pacific Ocean pseudo-stress fields based on *in situ* data input. Quick-look two-degree gridded pseudo-stress fields are produced at the beginning of each month using the previous month's GTS-transmitted data, and a research product for the preceding year is produced each summer using delayed-mode GTS data from NCDC. Two-degree fields for the objective Pacific FSU winds are available at http://www.coaps.fsu.edu/RVSMDC/html/winds.shtml for 1978-2000 (research) and Jan. - Sept. 2003 (quick-looks). These new products (known as the FSU2) for the tropical Pacific have now replaced the subjectively analyzed FSU wind fields (Smith et al. 2003c).

There have also been considerable improvements to our modern era, satellite-based products.

- The high resolution, satellite-based, fields are being greatly improved to better capture episodic events.
- The satellite product is being modified to process data from additional satellite sensors.
- Improvements to our knowledge of converting winds to stress are in the process of being coded.

Comparisons between the two-degree FSU2 winds and the wind fields from the first and second NCEP reanalysis (NCEPR1 and NCEPR2 respectively) are underway for the tropical Pacific (Smith et al 2003a, 2003b). Monthly wind averages over the equatorial Pacific (11°N - 11°S, 122 - 290°E) reveal large differences in the three products (Figure 1). When comparing long-term means, the FSU2 winds are stronger (5.6 ms^{-1}) than either the NCEPR1 (4.1 ms^{-1}) or the NCEPR2 (4.6 ms^{-1}). The 1.5 ms^{-1} difference in the mean between FSU2 and NCEPR1 is consistent with Smith et al. (2001), in which they compared wind observations from research vessels (R/V) to the NCEPR1 and found the NCEPR1 winds in the tropics to be consistently lower (mean bias 0.7 ms^{-1}) than the R/V winds. Since the R/V winds are rarely included in the NCEPR1 and are not used in the FSU2 products, they provide a largely independent reference for the FSU2 and NCEP wind fields. The difference between the NCEPR2 and FSU2 is smaller

(1.0 ms^{-1}) than for NCEPR1 and the reduction is believed to be due to either improvements in the data inputs to NCEPR2 or changes in the NCEPR2 flux or convective parameterizations.

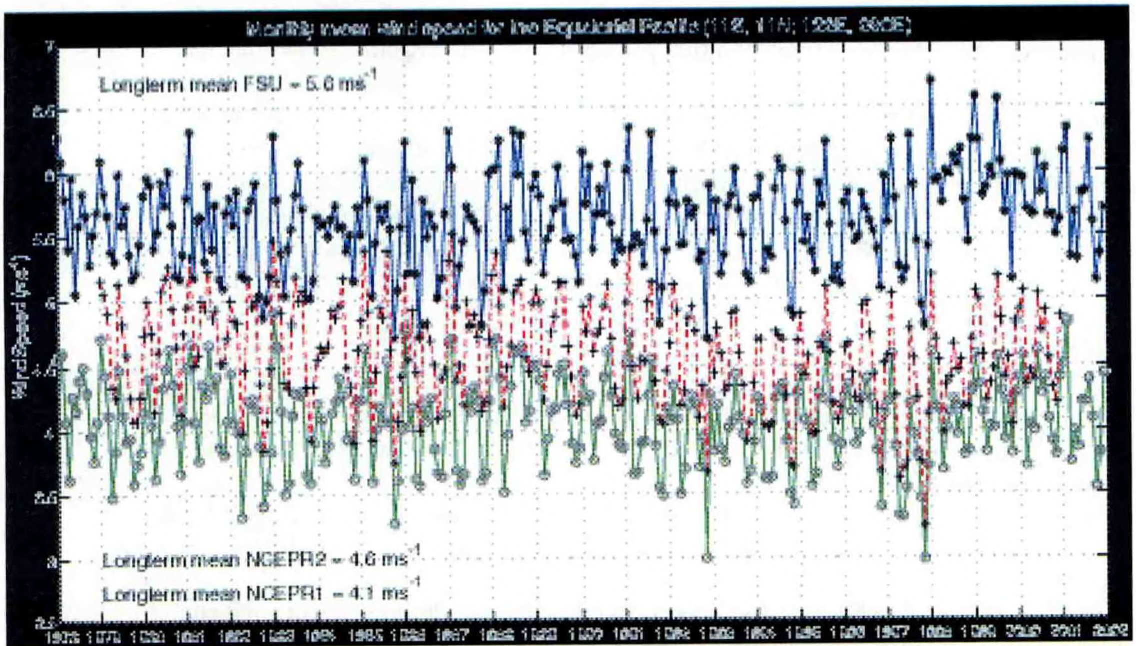


Figure 1: Monthly mean wind speed (ms^{-1}) averaged over the Equatorial Pacific from 11°S to 11°N, 122 to 290°E for the objective FSU2 (*, blue solid line), NCEP Reanalysis 1 (▪ , green solid line), and NCEP Reanalysis 2 (+, red dashed line).

As noted earlier, the FSU2 winds are being freely distributed via the web. The operational Pacific FSU2 pseudostress fields continue to be used by U. S. government agencies (e.g., NCEP, NOAA/AOML, NASA/JPL) and universities (e.g., Columbia University, New York University, UCLA, UCSD, FSU). International users include ECMWF, the Royal Netherlands Meteorological Institute, CSIRO (Australia), and the Shanghai Typhoon Institute. The quick-look Pacific fields are also reproduced on a monthly basis in the Climate Diagnostics Bulletin distributed by NOAA.

Quality-Evaluated Meteorological Data from Research Vessels
by James J. O'Brien, Mark A. Bourassa and Shawn R. Smith

PROJECT SUMMARY

Accurate estimates of turbulent air-sea fluxes over the global oceans are necessary for ocean modeling, climate modeling, and are a key component of the Climate Observation Program. The project continues to evaluate the accuracy of turbulent fluxes from in-situ observations, satellite observations, and globally gridded flux fields (e.g., FSU fluxes, national meteorological center reanalyses). These activities specifically target performance measures related to sea surface temperature, sea-level pressure, and air-sea exchanges of heat, momentum, and fresh water as outlined in the Program Plan.

The unique component of this study is the source of in-situ data: quality-evaluated, automated meteorological observations collected by research vessels (R/Vs). The present project is augmenting the R/V data holdings at COAPS with observations from the NOAA vessels *Ronald Brown* and *Ka'imimoana.* We will begin working with initial IMET (Hosom 1995) equipped VOS vessels in the near future. Production of quality-evaluated R/V meteorological observations and turbulent fluxes provide an important data source for validation of the analyses (sea surface pressure, winds, precipitation, sea temperature, and air-sea fluxes) desired by the Climate Observation Program. Benefits of our R/V flux evaluations include uncertainty estimates that will allow future improvements of global flux fields. R/V observations are too sparse in space-time to validate monthly products, such as an objective version of the FSU winds (Bourassa et al. 2003); however, the R/V observations can be used to validate satellite observations, which can then be used to validate the monthly products. Directly or indirectly, R/V data are an excellent source of comparison data for surface reanalyses (e. g., Smith et al. 2001).

All R/V observations are evaluated using an improved automated and visual quality processing system. In addition a focused evaluation of atmospheric pressure measurements from the R/Vs is underway to improve the quality of comparison data for future validation studies. Systematic errors in reanalysis winds (and hence turbulent surface fluxes) appear to be closely related to errors in surface pressure (Smith et al. 2001); understanding the systematic errors in winds and pressure will lead to a better understanding of the systematic errors in reanalysis fluxes. Prior wind-related feedback to R/V operators and the IMET program has resulted in higher quality automated weather observations. We will continue our interaction with R/V operators, and anticipate improvements in accuracy of pressure and wind. Free distribution of our quality evaluated R/V data (http://www.coaps.fsu.edu/RVSMDC/) continues to benefit U. S. and international scientists. Expanding access to quality-evaluated R/V meteorological data is a primary mission of our data center and this activity addresses the Milestones for Dedicated Ship Time and Data and Assimilation Subsystems outlined in the Program Plan.

All activities of this project are the responsibility of personnel at COAPS. To complete the activities, we directly coordinate data receipt from the ship technicians onboard the *Ronald Brown* and *Ka'imimoana.* Collaboration continues with Robert Weller, David Hosom, and Frank Bahr at the Woods Hole Oceanographic Institute in regards to the VOS IMET program. During FY 2003, we extended our collaboration with members of several JCOMM panels through the Workshop on High-Resolution Marine Meteorology (Smith 2003). We are building further partnerships with the WMO VOSClim program, both the U. S. and international CLIVAR program, GOOS, and the Ocean.US IOOS-DMAC.

Data center activities are managed in accordance to the Ten Climate Monitoring Principles outlined by the NRC. Since our inception with WOCE and TOGA-COARE, the COAPS R/V data center has emphasized the importance of metadata to fully document our data sets. We have a clear focus on data quality and have applied a number of innovative QC techniques for R/V data. Since the end of WOCE, the data center has been a strong advocate for continued data stewardship for R/V meteorological observations. We continue to call for additional resources to be applied to the remote regions of the oceans (e.g., Southern Oceans), where R/Vs can serve as a vital component of an ocean observing system.

Finally, we continue to provide free and open access to all R/V data, metadata, and documentation at the COAPS surface meteorology data center.

FY 2003 PROGRESS

FY 2003 activities were focused on three areas: (1) implementing improvements to automated and visual quality control (QC) systems, (2) beginning QC of NOAA R/V and VOS-IMET meteorological observations, and (3) beginning an evaluation of atmospheric pressure sensors on R/Vs. In addition, the year one task of hosting a workshop to discuss VOS-IMET data processing was completed.

Multiple improvements were made to our operational automated and visual QC tools, and testing of a new automated method for identifying spikes, steps, and statistically suspect values is continuing. The first step in our QC system, an automated preprocessor, was enhanced by

- Adding latitude dependent range checks for air, wet-bulb, dew point, and sea temperature
- Improving computational efficiency of water versus land position check
- Adding a minimum standard deviation to statistical test to reduce unnecessary flagging
- Streamlining program I/O and allowing single variable processing (as opposed to processing all variables in a file)
- Improved error handling.

These modifications greatly reduce the run-time of the preprocessor and reduce the man-hours our visual data analyst must spend altering preprocessor applied flags.

Testing of a new automated process to identify spikes, steps, and statistically suspect values continues and a beta version is now implemented as the second stage of our QC system. Development of the technique (Smith et al. 2003b) was motivated by a desire to process much larger volumes of automated marine weather observations during each man-hour of quality evaluation. Spikes and steps are currently identified through visual inspection. A decade of experience quality controlling automated research vessel data revealed the flagging of spikes and steps to be extremely time consuming and the potential for automation was realized. The new technique focuses on the detection of spikes and steps primarily because they tend to be systematic and their existence can be identified using a statistical approach. Once this technique is applied, our visual analyst can focus his valuable man-hours on identifying conditions that caused these spikes and steps, as well as more subtle systematic errors.

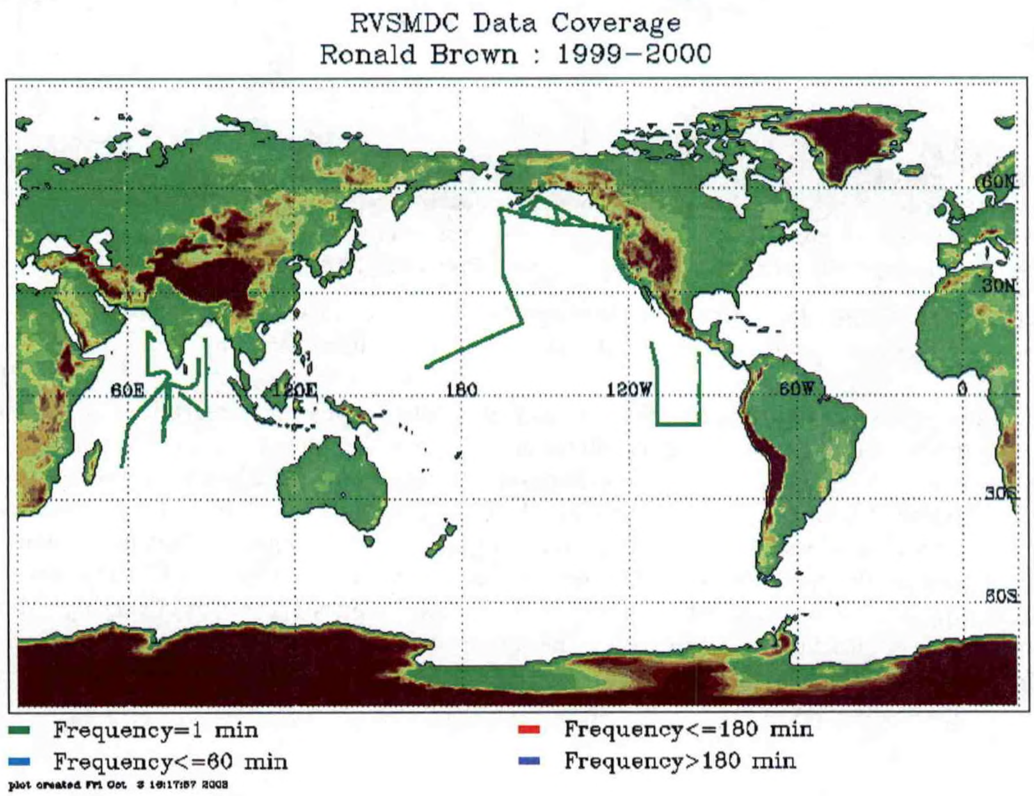
The final stage of our QC system, visual inspection, has been improved through upgrades to our VIsual Data Assessment Tool (VIDAT). VIDAT enhancements include:

- More efficient file handling (analyst needs fewer mouse clicks to load data)
- Added ability to view up to 15 variables at one time (up from 6 in old version)
- Use of string box for zoom on data plots (earlier system required multiple command entries by analyst)
- An ability to flag multiple variables at one time

These enhancements greatly improve the analyst's efficiency. For example, VIDAT now allows the analyst to view all seven variables necessary to assess quality of true (earth-relative) winds at one time. Previously, two plots would be needed. Overall, improvements to the entire QC system allow data to be processed more efficiently.

The enhanced QC system has been applied to historical data from the NOAA vessels *Ronald Brown* and *Ka'imimoana*. Quality evaluation is complete for 1999, 2000, and most of 2002 for the *Ronald Brown* and for 1999-2001 for the *Ka'imimoana.* The gap in the *Ronald Brown* data was caused by problems in the data delivery, which have been resolved for the subsequent years. These data cover a wide range of ocean regions (Figure 1). Data from these vessels are typically sampled at one-minute intervals and include the ship's position, speed, course, and heading along with standard meteorological parameters (e.g., ship- and earth-relative winds, air and sea temperature, atmospheric pressure, humidity, and shortwave and longwave radiation). Both the ships have the ability to record rainfall, but these data were unreliable or not available for all cruises. Earth-relative winds for the *Ronald Brown* were found to be of poor quality, most likely due to severe flow distortion, and were removed from 30% of the data for 1999 and 2000. The *Ronald Brown* data for 1999 and 2000 also had frequent problems in the temperature and relative humidity, which are suspected to be due to poor sensor ventilation. Data from the *Ka'imimoana* were generally of good quality, although half the cruises exhibited some sensor ventilation problems. In addition, the longwave radiation sensor failed for 30% of the 1999-2001 cruises. We will continue to seek additional data from the NOAA vessels in FY 2004. We anticipate receiving data from one or two VOS-IMET vessels by the end of 2003 (D. Hosom, WHOI, personal communication, 2003). The delivery of VOS-IMET data has been delayed as WHOI shifts from the ASIMET system to the AutoIMET on their test VOS. The AutoIMET solves several problems that limited the research applications of the initial ASIMET data.

The value-added data and QC reports (Rolph and Smith 2003a, b) are available from our center at http://www.coaps.fsu.edu/RVSMDC/. We are committed to an open data sharing policy so data access is not restricted. Arrangements will be made to archive these data at one of the national archive centers. In addition, funding is pending (NOAA-ESDIM) that will allow for a subset of these data to be included in I-COADS.



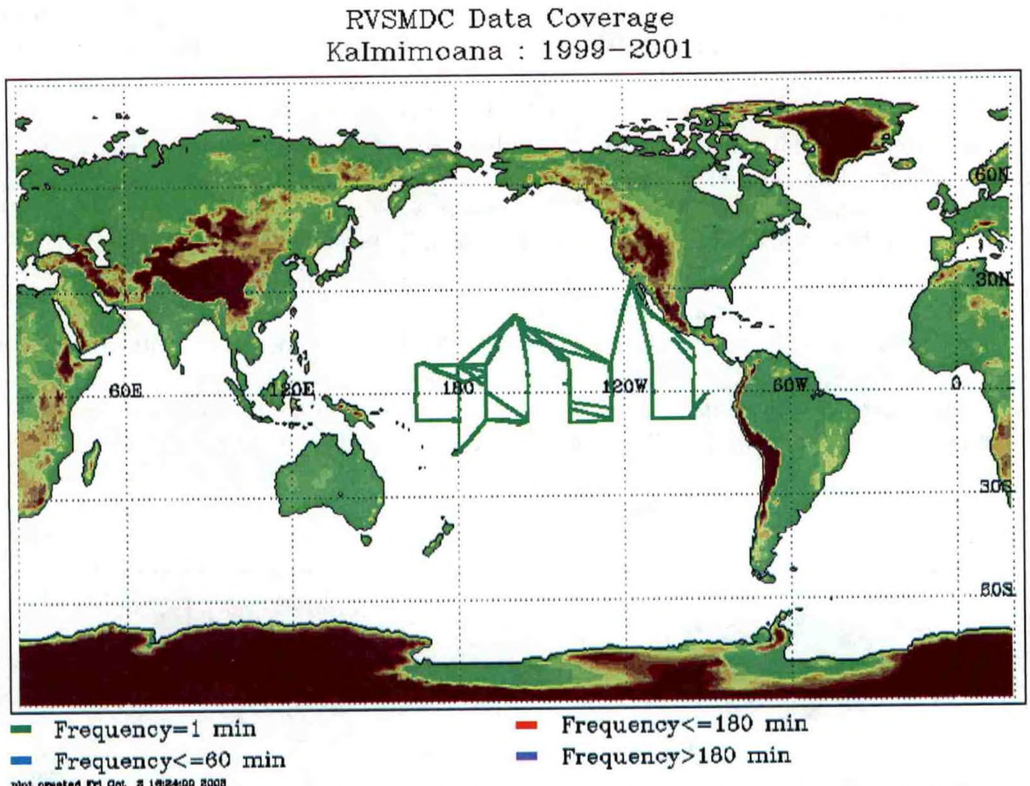


Figure 1: Coverage of controlled surface meteorology data available at COAPS for the NOAA vessels *Ronald Brown* (top) and *Ka'imimoana* (bottom). All data are one minute sampling.

Our data analysts noticed systematic problems with atmospheric pressure observations on several vessels during the WOCE program. These problems are thought to be related to either the citing of the pressure gauges or the orientation/exposure of the sensor's pressure port. Initial investigation into this problem in underway. Suspect pressure observations from several ships occur when the ship-relative wind direction are within a limited range of values (Figure 2). To date the investigation has shown no consistency in these angles from ship-to-ship or for different cruises on a single vessel. The expectation is that certain exposures or locations for the pressure sensor may be place the sensor in varying airflow regimes that adversely affect the pressure port on the sensor. Further investigations are planned but some will require additional, hard to locate, metadata.

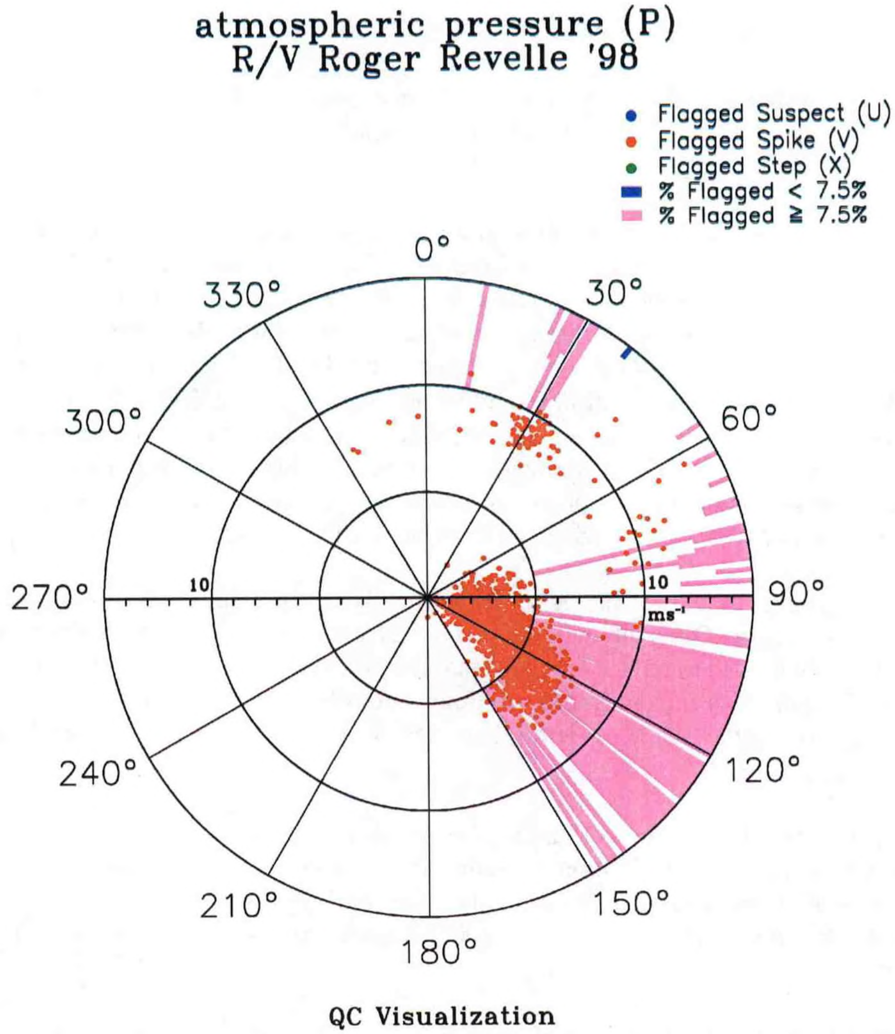


Figure 2: Spikes in the atmospheric pressure data collected by the R/V *Roger Revelle* occur most frequently when the ship-relative wind direction is blowing from between 75 and 150 degrees. In the plot, pressure data flagged as suspect, spike, or step are plotted at their corresponding ship-relative wind direction. Bars on the outer ring denote the percentage of pressure data flagged in each one-degree ship-relative wind bin (see legend).

Finally, on 3-5 March 2003, COAPS hosted a "Workshop on High-Resolution Marine Meteorology" (Smith 2003, Smith et al. 2003a). Initially this workshop was anticipated to focus on planning data management for the VOS-IMET program, but interest in the topic greatly expanded the focus to many U.S. sponsored high-resolution (sampling periods 1hr) marine meteorological observing programs. Original expectations of only a dozen participants quickly grew to nearly 30 representatives from NOAA labs, government agencies, universities, and even two international institutions. With supplemental funding from NOAA-OGP, the workshop was a resounding success. The workshop participants agreed to a number of recommendations and initiatives. The recommendations are being circulated around the scientific and operational marine communities. Further details on the workshop are available at: http://www.coaps.fsu.edu/RVSMDC/marine_workshop/Workshop.html.

In situ and Satellite Sea Surface Temperature (SST) Analyses

by Richard W. Reynolds

PROJECT SUMMARY

The overall purpose of this project is to focus on improvements to the climate-scale SST analyses produced at NOAA as described by Reynolds and Smith (1994) and Reynolds et al. (2002). This effort is designed to support the development of an ocean climate observing system. The analysis is done by optimum interpolation (OI) with a separate step to correct any large-scale satellite biases relative to the *in situ* data. The analysis uses infrared (IR) satellite data from the Advanced Very High Resolution Radiometer (AVHRR) and *in situ* data from ships and buoys. Reynolds et al. (2002, 2003) showed that satellite bias correction is necessary for climate SSTs. In this proposal we discuss our progress and our plans to improve these analyses. The improvements include the development of better bias corrections, the use of new SST data sets and the development of better error statistics. We also present our efforts to develop an objective method to determine where addition buoy data are needed for improved SST.

One of the important goals of the Sustained Ocean Observing System for Climate is to improve the SST accuracy over the global ocean. Our study will define the SST accuracy and determine where additional surface drifting buoys are needed to reduce potential satellite bias errors. With the current *in situ* data distribution, this will require approximately 250 additional buoys between 60°S and 60°N. Because of limited *in situ* observations in the Southern Hemisphere, 150 of these buoys are needed between 60°S and 30°S.

Richard W. Reynolds is the chair of the SST and sea ice working group which is shared by two GCOS panels: the Ocean Observation Panel of Climate and the Atmosphere Observation Panel of Climate. This proposed work is part of the work of the working group. The working group membership is a broad group of interested national and international scientists. All work presented here follows the Ten Climate Monitoring Principles.

All the funds requested for this proposal support work at NCDC. However, two other groups are involved. The first group is the National Center for Environmental Prediction (NCEP), which runs the OI analysis operationally. Information on the analyses and the analyzed fields themselves can be found at: http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/. We hope to bring the operations to NCDC by the end of FY2004 so that improvements can be implemented. The second group is at North Carolina State University under the direction of Professor Fuentes. Professor Fuentes plans to integrate the satellite bias correction into the OI procedure instead of the present method of correcting the bias in a preliminary step. Neither group uses any funds requested in this proposal. (The work at North Carolina State University is funded under the Climate and Weather Impacts on Society and the Environment, CWISE, program.)

FY 2003 PROGRESS

During FY2003, we have made significant progress in two main areas.

Study of the impact of microwave satellite SSTs

The first area of progress is an examination of the impact of satellite SSTs from the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) on the NOAA OI analysis. Microwave satellite SSTs have a significant coverage advantage over satellite IR SSTs, because microwave SSTs can be retrieved in cloud-covered regions while IR SSTs cannot.

The operational version of the OI analysis uses *in situ* (ship and buoy) and IR satellite data from the AVHRR instrument. For this study, six different versions of the OI were produced weekly from 10 December 1997 through 1 January 2003 using different combinations of AVHRR and TMI data and including versions with and without a bias correction of the satellite data. To make the results more objective, 20 percent of the buoys were randomly selected and the SSTs from these buoys were withheld from the OI for independent verification.

A summary of the results is shown in Figure 1. The figure shows time series of the smoothed weekly averaged difference of three OI analyses minus collocated buoys between 35°S and 35°N. Only the withheld (independent) drifting and moored buoys are used in the differences. The three versions do not have satellite bias correction. The versions are: the OI using TMI only, the OI using AVHRR only, and the OI using both TMI and AVHRR (TMI + AVHRR). The results show that the TMI only OI analysis is biased warm while the AVHRR only OI is biased cold relative to the buoys. Thus, both AVHRR and TMI data have biases that must be corrected for climate studies. These biases change with time as physical properties of the atmosphere change and as satellite instruments and the orbits of the satellites, themselves, change. It is critical to monitor differences between satellite and other products to quickly diagnose any of these changes. The figure also shows that the combined TMI + AVHRR OI analysis tends to have a reduced bias compared to the other two analyses. This is because the sources of errors in microwave and IR instruments are independent and may tend to cancel.

A complete report on the results has been submitted to the Journal of Climate (Reynolds, et al., 2003). The results presented there show that it is difficult to clearly demonstrate that there is a significant advantage in adding TMI data for the OI analyses with bias correction. However, the advantage of TMI data is clearly shown in the OI analyses without bias correction. The use of both TMI and AVHRR data improves the OI analysis without bias correction and does not negatively impact the OI analyses with bias correction. Because there are many areas of the ocean with limited *in situ* data and restricted AVHRR coverage due to cloud cover, the use of both TMI and AVHRR should improve the accuracy of the analysis in these regions. In addition, the use of more than one satellite product is helpful in diagnosing problems in these products.

Buoy need network

Our second area of progress is the method to design an effective and efficient Buoy Need Network, which is capable of reducing biases in satellite sea surface temperatures (SST). To do this we first determined a maximum acceptable error. Following Needler et al. (1999) we specify that the monthly SST error must be less than or equal to 0.5°C on a 5° spatial grid. This error must include random, sampling and bias errors.

The random and sampling error can be determined directly from the OI or from an optimum average (OA) procedure. We found that the sampling and random errors using *in situ* and AVHRR data were always less than 0.3°C on a monthly 5° grid. These errors were low because of the high density and full coverage of satellite data. The regions with the largest errors were cloud-covered regions where IR data are limited. The use of global microwave data would further reduce the errors. These microwave data are now available from the Advanced Microwave Scanning Radiometer (AMSR), which is now available from two different satellites. Thus, we already have acceptable random and sampling errors.

Biases occur with all satellite data due to instrument and algorithm problems. For AVHRR typical biases are 0.2 to 0.5°C. However, AVHRR biases have reached between 2 to 3°C over the tropical oceans following the 1982 volcanic eruptions of El Chichón and the 1991 eruptions of Mt. Pinatubo. Unfortunately, it is not possible to predict when biases of this size will occur. Thus, it is necessary to have an *in situ* network that will ensure a final product with acceptable bias errors.

Because there is no convenient algorithm to estimate bias errors, we needed to simulate them. This was done using the monthly OI analysis. The first step was to determine the spatial scales of typical biases. The OI analysis was computed with and without bias correction monthly from January 1990 to December 2002. The monthly difference between the two analyses represents the bias error. Spatial empirical orthogonal functions (EOFs) were computed from the differences. The first pattern showed the large-scale tropical biases typical of the aerosols for Mt. Pinatubo or El Chichón. The next five EOFs showed smaller scale biases which together sampled most of the world ocean. Taken together the first six EOFs represented 52.7% of the variance.

The next step was to use these EOF patterns to simulate large biases and determine how well the *in situ* data could correct these biases. This was also done using the OI analysis with a climatological first guess. The analysis was run monthly for the 1990 - 2002 period with simulated SSTs. For the satellite data, the locations of the SST data were preserved but the SST values were changed. The satellite SST values were the first guesses plus one of the six EOF functions multiplied by Gaussian noise. The buoy locations and SST values were both simulated. The buoy SST positions were placed on a regular grid. The buoy SST values were set to the first guess plus Gaussian random noise. The OI was analyzed for each of the six EOFs with buoy grid resolutions of 20°, 15°, 10°, 5° and 2°. For each OI analysis, a spatial map of the root mean square (RMS) difference over time was computed between the OI and the first guess. If there were no *in situ* data, the bias would not be corrected and the RMS difference would equal the absolute value of each EOF. If there were adequate *in situ* data, the satellite biases would be corrected and the RMS difference would approach zero.

The results of these simulations showed that bias errors could be reduced below 0.5°C if there were at least two buoys on a 10° grid. To include the impact of ship data, we used the random ship (1.3°C) and buoy (0.5°C) errors determined by Reynolds and Smith (1994). Because these errors are random, 6.76 ship observations are necessary to reduce the ship error to the value of error of one buoy observation. Using 6 ships as an estimate, an equivalent number, n_e, of buoy observations would be equal to: $n_e = n_b + n_s/6$ where n_b is the number of buoy observations and n_s is the number of ship observations. Using actual ship and buoy observations, it is now easy to estimate the number of equivalent buoys in the present observing system and to determine how many additional buoys are needed to bring the number of equivalent buoys to two. Figure 2 shows the average density of the number of buoy equivalent observations on a 10° grid from January 2000 to December 2002 in the top panel. The middle panel shows the optimum density distribution in which the buoy density has been increased to two between 60°S and 60°N. The lower panel shows a time series of the number of buoys, which must be added each month to reach the optimum distribution. Here the average number of additional buoys is roughly 250. Because of limited *in situ* observations in the Southern Hemisphere, roughly 150 of these buoys are needed between 60°S and 30°S as shown by an additional curve in the lower panel. A document describing these results is in preparation.

Ocean Reference Stations

and

Northwest Tropical Atlantic Station for Flux Measurement (NTAS)

(*Project Period:* 01 July 2003 – 30 June 2004)

by Robert A. Weller and Albert J. Plueddemann

PROJECT SUMMARY

Overview

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

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

Addressing NOAA's Program Plan:

The program directly addresses the sixth element of the Program Plan for Building a Sustained Ocean Observing System for Climate, Ocean Reference Stations. It works in synergy with many of the other elements (Global Surface Drifting Buoy Network, Global Ships of Opportunity, Argo Profiling Float Array, Satellites for Sea Surface Temperature, Sea Surface Height, and Surface Vector Winds) by providing high temporal resolution at fixed point to complement the Lagrangian or spatial sampling of the other elements. It is also an important element of Assimilation efforts, as surface fluxes can be diagnosed from the ocean and provide a means to assess the models being used for assimilation.

Management in Cooperation with International Panels:

The Ocean Reference Station project is managed in cooperation with the International Time Series Science Team (co-chaired by R. Weller), a joint planning effort that involves the climate, carbon, and other disciplinary communities interested in long time series and that reports to the Ocean Observations Panel for Climate (OOPC) and to the Partnership for Ocean Global Observations (POGO, an international consortium of directors of oceanographic institutions). The link to JCOMM observations is through the OOPC. The Ocean Reference Station project, and more generally the International Time Series Science Team, because of its importance to and emphasis on air-sea fluxes, has also reported to the WCRP Working Group on Numerical Experimentation (WGNE) to develop explicit links to the weather and climate modeling centers. An outcome of this is the SURFA project, where time series we collect are provided to Peter Gleckler at PCMDI for inclusion in the AMIP (Atmospheric Model Intercomparison Project). We will participate in a new WCRP/CLIVAR oversight group on air-sea fluxes being formed now with Chris Fairall as the Chair. We have participated in planning for CLIVAR and for the Carbon Cycle Science Plan implementation, working to see that the Ocean Reference Sites develop to serve the needs of the research programs.

Responsible Institution:

The Woods Hole Oceanographic Institution is the responsible institution for this project.

Websites:

WHOI's website:	http://www.whoi.edu
UOP Group's site:	http://uop.whoi.edu
Stratus Project site:	http://uop.whoi.edu/stratus
NTAS Project site:	http://uop.whoi.edu/ntas

Partnerships:

Planning and implementation of the Ocean Reference Stations includes a number of partnerships. The Hawaii site will be equipped with ocean instrumentation through a National Science Foundation grant to Roger Lukas of the University of Hawaii. The siting of the Stratus site was done in collaboration with the Chilean Navy Hydrographic and Oceanographic Service (SHOA), and trips to the Stratus site have involved Chilean (SHOA and also the University of Concepcion) and Ecuadorian (Navy oceanographic office, INOCAR) participation. The Stratus site provided the focal point for the stratus component of the multi-agency cooperative EPIC 2001 field program and is included as a focal point for a CLIVAR VOCALS (Vamos Ocean Cloud Atmosphere Land Study) process study in 2006 or 2007. The NTAS site may similarly provide a focal point for a field study (RICO) of tropical convection and clouds now under discussion by Chris Bretherton and Bjorn Stevens. Surface meteorological and air-sea flux data from our sites are made available to various national/international centers (NCEP in the U.S., ECMWF in Europe). There is strong synergy between our program and the National Science Foundation program on Ocean Observatories, and the NSF effort is looked to as the means to develop observatory hardware capable of extending the Ocean Reference Sites to higher latitude sites of high scientific and operational climate interest.

Monitoring Principles:

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

Progress, Plans, Budgets, and Add Tasks

A description of FY 2003 progress, FY 2004 plans, FY 2004 budgets, and Add Tasks are presented by Task, including details for the two Ocean Reference Sites now occupied, Stratus and NTAS. A representative publication from the Stratus project is included in an Appendix.

Task I Engineering, oversight and data:

FY2003 Progress:

Design of a new buoy for use at the Ocean Reference Stations is complete, and fabrication of the first buoy hull and tower top has begun and will be completed this year. These new buoys will replace the 15-20 year old hulls presently used which are degrading (corrosion of the welded aluminum) and are expensive to ship as they do not fit inside a sea container like the new hulls. Hull construction is going slower than planned; funds for the six buoys were in the first year of funding (7/1/2002-6/30/2003). This was done to allow the design to mature and for us to benefit from lessons learned in the construction and subsequent deployment in early 2003 of the first such hull at the Bermuda Time Series Site. That hull recently survived Hurricane Fabian. Construction of our remaining five hulls will be re-scheduled for this year (7/1/2003-6/30/2004). Acquisition of four meteorological sensor systems to be used to support the three sites has begun; these will be acquired, tested and burned-in this year, then integrated with the new tower tops and tested again. Data processing continues on schedule.

Acquisitions: 6 buoy hulls being fabricated. To be used for Tasks II (Stratus), III (NTAS), and IV (Hawaii).

Deployments, Data Return, Measurements, Data Sharing, Logistical Considerations, Research Highlights, Publications, Conferences, Meetings, Outreach: See Task II, III below.

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

Anticipated and unanticipated project costs: We are moving forward faster than planned to occupy the third site; all other costs are as in the budget.

Problems: None significant. Buoy hull construction is slower than anticipated but we are making do with the older hulls for now.

Community service: We provided preliminary design feasibility assessment of placing surface moorings in the Kursohio Extension region to Meghan Cronin, PMEL.

Task II Stratus Site:

Stratus FY2003 Progress:

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

Work this year included down-cruising hardware and instruments recovered in October 2002, doing post-calibrations, data processing, writing cruise and data reports, preparing the mooring and instrumentation for the next deployment, scheduled for November 2003 on board the *RV Revelle*, starting in Manta, Ecuador and ending in Arica, Chile, and coordinating that cruise. Work on this task is on schedule.

Acquisitions

We did not acquire instruments. On our cruise on *RV Roger Revelle* we will deploy 45 surface drifters and 9 Argo float (Fig II-1) to bolster sampling in the southeastern Pacific.

Deployments

The Stratus site is visited once per year, in October or November, as required by battery and calibration life. The surface mooring there is recovered and a new mooring deployed. This year we will also deploy a DART mooring for NOAA/PMEL and the Chilean Navy (SHOA).

Measurements

On the buoy: air temperature, sea surface temperature, relative humidity, incoming shortwave and longwave radiation, wind speed and direction, rain rate, and barometric pressure. On the mooring line: concentrated in the upper 300m, temperature, salinity, and velocity. During the deployment, high data rate (up to 1 sample per minute) data are stored in each instrument. Hourly-averaged surface meteorology is telemetered via Service ARGOS; the telemetered data are stored a WHOI on a workstation. The telemetered data are available on the website (http://uop.whoi.edu/stratus) in near real time; it is also set up to be FTP'd to collaborators and those who request it. The internally recorded data goes through processing, has calibration information applied, and is subject to preliminary analyses before being made publicly available on our website. In the interim, preliminary versions are made available upon request.

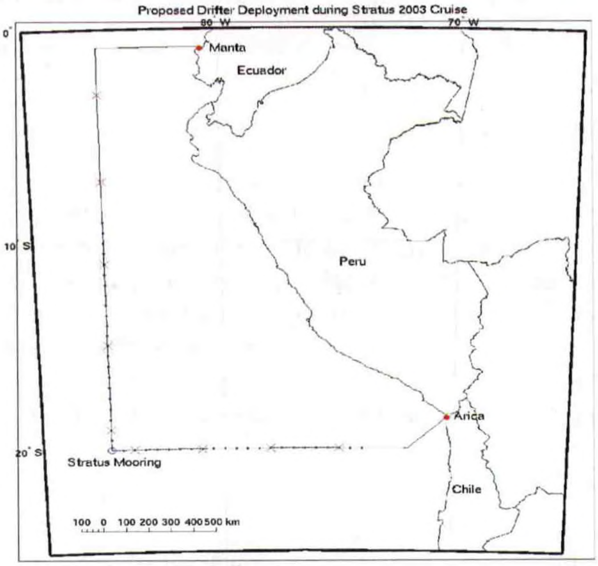


Figure II-1. Cruise track planned for RV Revelle in November 2003 during cruise to service the Stratus site. Forty-five surface drifters and nine Argo floats will be deployed.

Data use and sharing

Hourly surface meteorological data archived at WHOI, arriving within hours of when it was observed. These data are exchanged in near real time with ECMWF and NCEP; they in turn provide operational data at the grid point nearest the model. It is also shared with the Chilean Navy (SHOA). The same data are shared with CLIVAR investigators, especially modelers interested in the Stratus region, with VAMOS investigators in the U.S. and in South America. It is also sent to Peter Glecker at PCMDI for use in the SURFA project. This meteorological data are used to access the realism of operational atmospheric models in the stratus region. Once per minute as well as hourly surface meteorological time series are provided to the EPIC and VEPIC investigator communities (including Sandra Yuter, Chris Bretherton, Meghan Cronin). The surface meteorological data have been made available to the satellite community (including radiation – Langley, winds – Remote Sensing Systems and JPL, SST – Dick Reynolds, all variables – the SEAFLUX project). The oceanographic data are being used by Weller and a Postdoctoral Investigator at WHOI to investigate air-sea coupling and upper ocean variability under the stratus deck. In parallel it will be compared with ocean models results (with Ragu Murtugudde, Univ. of Maryland).

Data archive

The initial archive is that maintained by the Upper Ocean Processes Group at WHOI, which maintains a public access server of their mooring data. We are working with the International Time Series Science Team to develop a number of sites that will maintain as many records of time series stations as can be collected to facilitate access to such data.

Costs

A great unknown continues to be the ports of call and length of the cruises to service the mooring; because of this labor costs for days at sea and shipping and agent's fees in foreign ports can exceed budgeted figures. We plan for roughly 16 days at sea. If we are assigned a longer cruise, the labor costs are beyond the budgeted amounts. Besides these costs we have been on track, with costs as laid out in the budget.

Problems

Availability of ship time continues to be a first order problem, as do the uncertainties of whether or not the ship costs will be covered by NOAA. Because of the high demand on Class 1 ships, we are often, as this year, on a UNOLS vessel. There are difficulties of coordination between NOAA and UNOLS. There are also continuing issues about the UNOLS operators getting payment in a timely fashion. The performance of the RDI Acoustic Doppler Current Profilers deployed on this mooring has not been as expected. Range has been less than anticipated; additional Vector Measuring Current Meters have been added to fill the gaps left by the RDI ADCP's short range. One of two units was returned to the manufacturer after failing to run for a full year; it was found to have excessive power consumption.

Logistical considerations

We need to return every 12 months with about 2-4 weeks margin because of the lifetime of the batteries powering the instrumentation. Getting a Class 1 ship to the site every 12 months has become a major challenge,

We need 6 days on station with the ship at the mooring site. The work includes comprehensive comparison of ship and buoy meteorological sensors (Fig. II-2), which is critical to determining and demonstrating the accuracy of the moored sensors. The addition of air-sea flux studies at the Stratus site by Fairall (NOAA ETL) and others (such as cloud radar work by Yuter, Univ. of Washington) adds to the need, so that 10 days at site could be used. Every effort is made to work out of ports of call close to the site, but at times the ship opportunities that have been suggested have been as far as 20 steaming days away, which would cause a large increase in labor costs.

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

Research highlights:

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

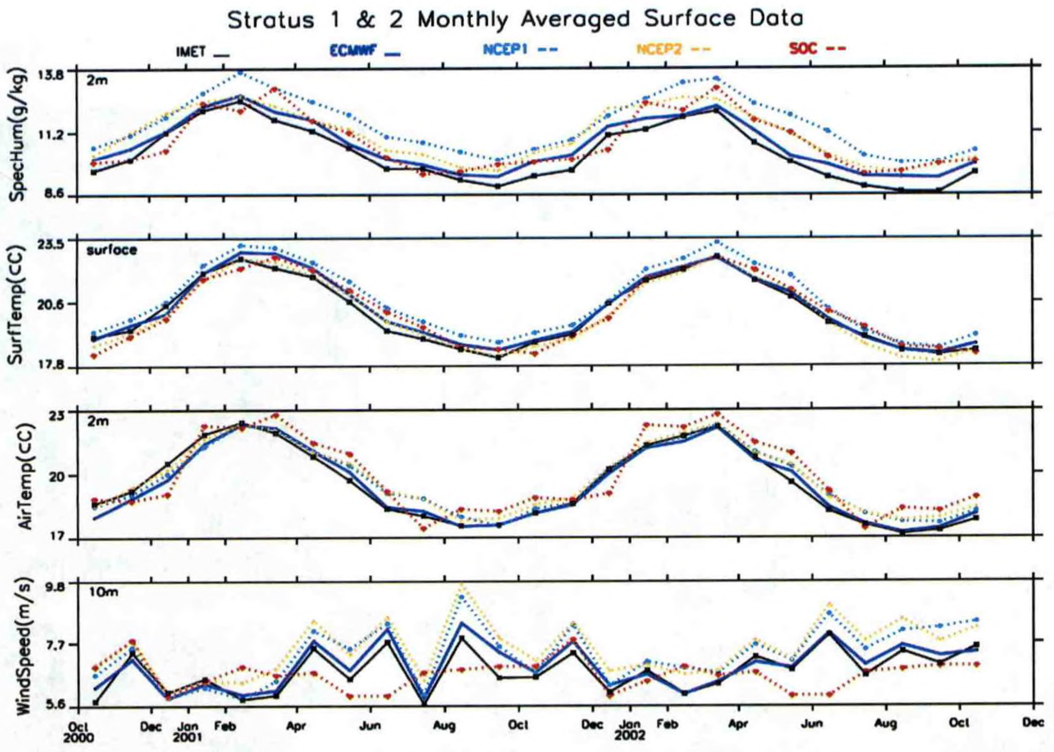


Figure II-3: Comparison of stratus buoy meteorological data with atmospheric model reanalyses (ECMWF ERA-15, NCEP1, and NCEP2) and COADS climatologies.

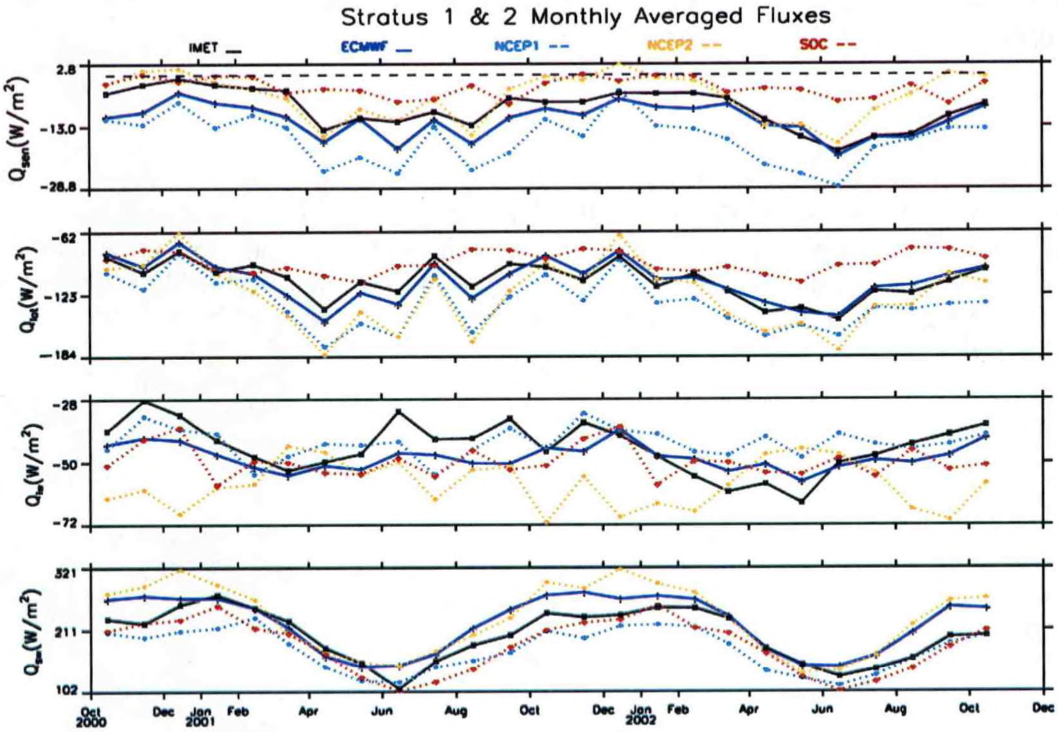


Figure II-4: Comparison of the air-sea fluxes at the Stratus buoy for two years with reanalysis and climatological data as in Fig. II-2.

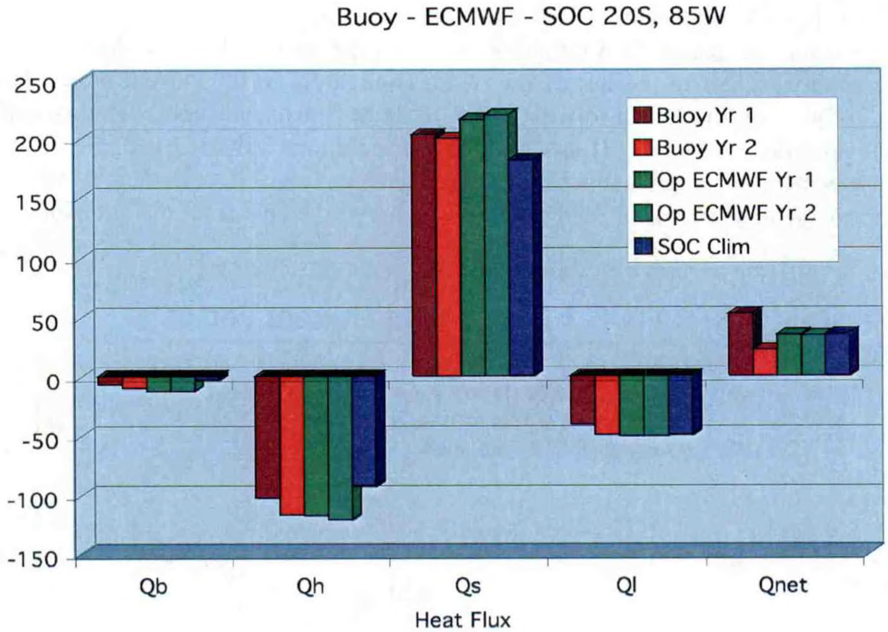


Figure II-5: Comparison of annual means of the heat flux components (sensible – Q_b, latent – Q_h, shortwave – Q_s, longwave – Q_l, and net heat – Q_{net}) for the first two years of data from the Stratus buoy with operational ECMWF model and SOC climatological heat fluxes.

Another unique achievement of the Stratus mooring is the collection of the first record of upper ocean variability under the stratus clouds (Fig. II-6). Because these data have coincident

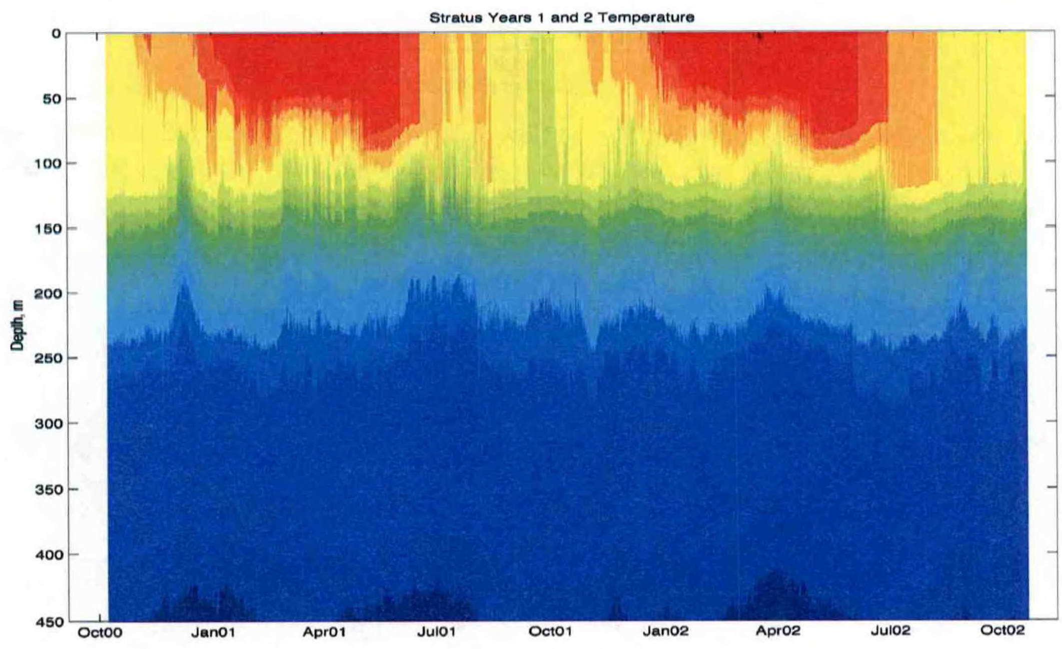


Figure II-6: Two years of temperature data from the upper 450 m at Stratus site.

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

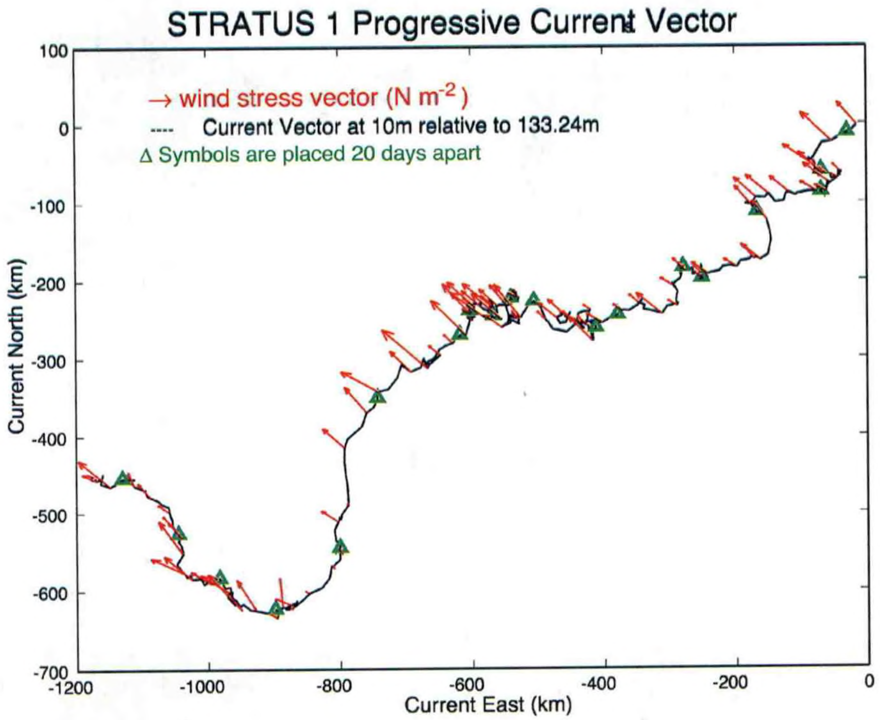


Figure II-7. The progressive vector diagram for the flow at 10 m relative to that at 133 m is plotted in black. Green triangles are spaced 20 days apart. Weekly-averaged wind stress vectors are shown as red arrows. The southeast Trades drive flow to the southwest in the upper ocean.

FY 2004 Plans

Office of Climate Observation, Climate Observation Program,
The Ocean Component
by Mike Johnson

FY 2004 PLANS

The new office space for the Office of Climate Observation (OCO) will be completed and will include an Observing System Monitoring Center room for real-time tracking of the global system. A representative from JAMSTEC will begin a one-year TDY assignment to OCO to assist with development of international system tracking and reporting capabilities.

The second Annual System Review will be held in Silver Spring, April 13-15.

Planned system advancements in FY 2004 include:

- *Documenting long-term trends in sea level change*: Upgrade 4 tide gauge stations and the data management subsystem for real-time reporting. Begin transition from NASA to NOAA responsibility for the long-term support for sustained operation of the Harvest Platform altimeter calibration station.
- *Documenting the ocean's heat exchange with the atmosphere*: Add 240 drifting buoys to the global array to improve satellite corrections and reduce the uncertainty in analyses of global sea surface temperature. Begin planning with international partners for implementation of a pilot array of tropical moored buoys in the Indian Ocean. The Indian Ocean will extend TAO/TRITON in the Pacific and PIRATA in the Atlantic and thus complete global monitoring for the Earth's tropics -- the major ocean capacity for heat and water exchange with the atmosphere.
- *Documenting the ocean's storage and transport of heat*: Upgrade one existing high-resolution ships-of-opportunity trans-oceanic expendable bathythermograph (XBT) line and add one new line to the global network for long-term monitoring of the ocean's transport of heat. Additionally, NOAA and NSF will begin transition to operational status six Indo-Pacific high-resolution lines – over the next two years NOAA will assume long-term support for this component of the observing system thus freeing up resources at NSF for new CLIVAR research.
- *Documenting carbon sources and sinks*: A global inventory of ocean carbon is needed at least once every 10 years. Systematic surveying of the ocean has been initiated in partnership with NSF but the present level of funding is only adequate for NOAA to complete its contribution to the global effort in at best 14 years. In FY04 (and continuing in FY05) NOAA will augment the present effort to bring the rate of survey up to the required 10-year cycle.

NOAA Observing System Monitoring Center

by Landry Bernard, Steve Hankin, James Hall, Kevin O'Brien, Cheryl Demers
(for project period June – December 2003)

FY 2004 PLANS

Executive Summary

This is the FY2004 work plan for the Observing System Monitoring Center (OSMC) system, an information gathering, decision support, and display system for the Office of Climate Programs at National Oceanic and Atmospheric Administration (NOAA) Headquarters in Silver Spring, MD. The OSMC system will display current and historical status of globally distributed data collection systems. The OSMC system will provide the data visualization tools necessary to identify the coverage of any given collection of platforms and parameters. These visualization tools will be available as needed to present this information to other NOAA centers, national partners, and international partners through an Internet web site. The OSMC system will be accessed through the use of a conventional web browser. One aspect of this project was to outfit a command center and briefing area at Silver Spring with large screen displays of these web browser windows, recommendations were provided in FY2003.

A rapid prototyping process will be used to produce a prototype system that implements the top-level system requirements for a subset of the total number of platforms and parameters. This will include the selection of a region, set of parameters, timeframe, spatial resolution, display format, and statistics format. As the display functionality, user interface, and data repository issues are resolved, additional platforms and parameters will be added to the system.

The deliverables will include Architecture Design Document, Data Management Software Requirements Specification, and a prototype OSMC system based on the Pacific Marine Environmental Laboratory (PMEL) Live Access Server (LAS) data visualization web server capability and the Ferret data acquisition utility.

Authorized users will be able to access the system from anywhere on the Internet, but the initial focus is on developing the command center view of each platform for display in Silver Spring, MD. The web-based interface will be the front-end of the system. The back-end server components of the prototype system will be hosted by PMEL in Seattle, WA, and accessed remotely from the newly assembled OSMC in Silver Spring, MD. The remaining deliverables will incrementally add capacity and transition the back-end server components of the system to a production environment that will be provided by the National Data Buoy Center (NDBC) at Stennis Space Center, MS.

Background

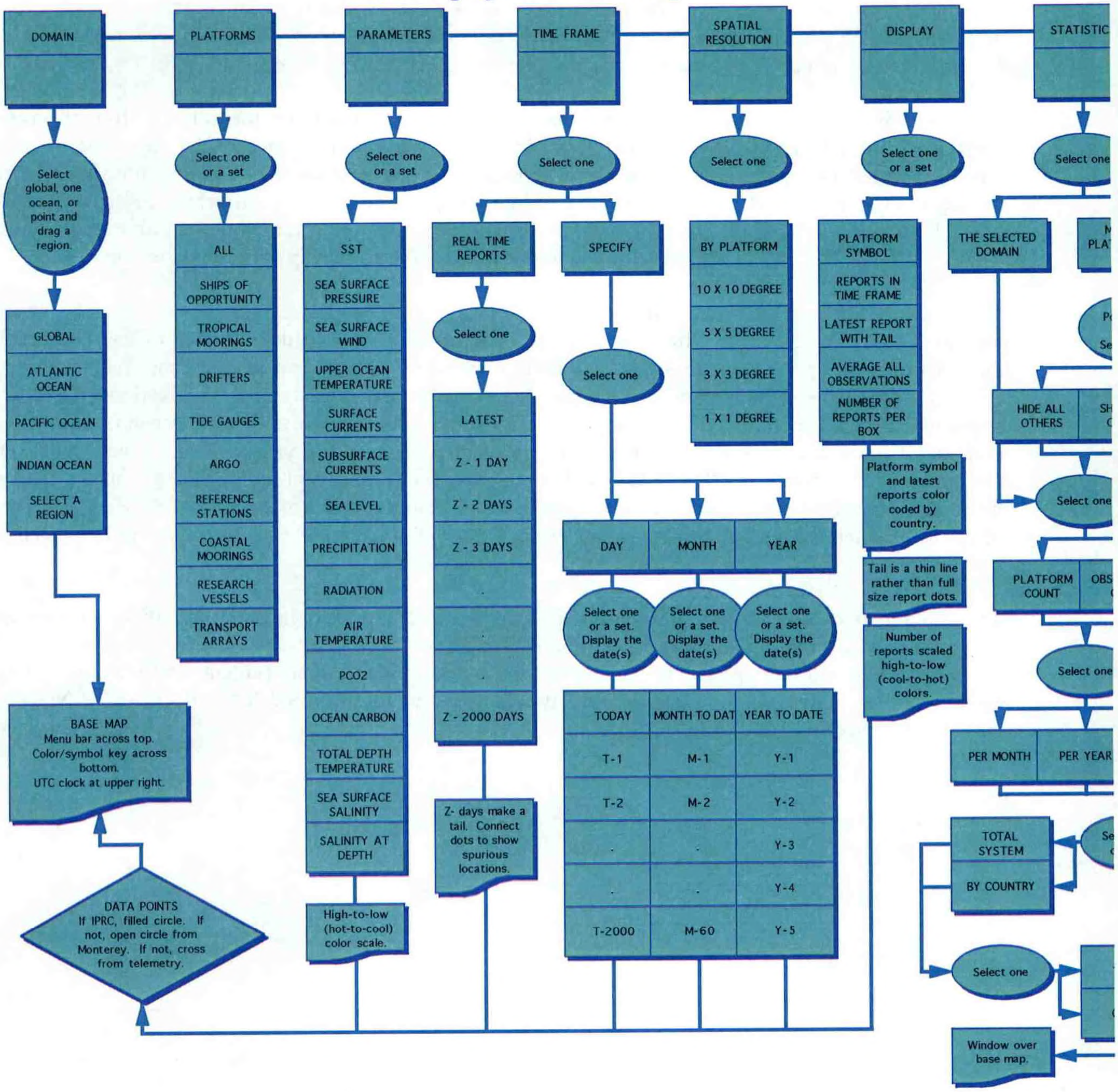
There is a clear need for software for real-time overseeing of the global ocean climate observing system. In order for such software to be successful orderly ocean databases need to be developed and maintained. This project plan covers both activities, as a coordinated effort between NDBC and PMEL.

The observing system for climatic data consists of a variety of sensors measuring different physical variables from a range of different platforms. In order for the performance of the observing system to reach its called for specifications, software and data systems are needed to permit observing system managers to keep track of the type, location and performance of all of the different sensors, in near-real time. Even though the objective is climate assessment, research and forecasting, real time information is needed so that action can be taken in a timely manner to rectify shortcomings of the observing system.

Some of the data are reported back to users in near-real time, while other data has to be handled separately and turned over to climate users later. The marine real time data are part of the 'fire hose' of information making its way through the World Weather Watch system all the time; they have to be extracted from the data stream for marine use. Operational centers like the National Center for Environmental Prediction (NCEP) and the Fleet Numerical Meteorology and Oceanography Center (FNMOC) have been extracting marine data for their purposes for years. The Global Ocean Data Assimilation Experiment (GODAE) has established servers in France and in the United States to store and make available these same data to all interested parties. Another server is being established at University of Hawaii's International Pacific Research Center (IPRC) with a particular focus on delayed mode climate data.

The remainder of this project plan lays out an approach for developing and deploying an automated system that will serve to address the needs identified above. The project plan defines the architecture of the proposed system along with an overview of the development, management, and teaming approach being used to implement the system. Finally, estimates of the cost and level of effort for NDBC for FY2004 are provided.

Observing System Monitoring



Approach

This plan is a continuation of the effort started in FY2003 and addresses the development of the system that is planned to occur during FY2004.

Development

Delivery 1. (Enhanced Prototype – December 2003)

Tasks:

- Add winds, waves, and other parameters to prototype system (PMEL).
- Initial Install & configure Live Application Server (LAS) at NDBC (NDBC Contractor)
- Initial configuration of OPG Portal (Ops Officer).
- Updated Architecture Design
- Updated Requirements Documents

Deliverables:

- Enhanced prototype operational
- Draft Architecture Design document (target system h/w, s/w. & telecommunications)
- Draft Data Migration/IO Requirements Document

Activities:

- The prototype will continue to evolve and additional functionality will be introduced. (PMEL & SAIC)

- In parallel with efforts to complete the initial prototype at PMEL, work will begin at NDBC to install a production LAS Server.

- The OSMC Operations Officer will participate in the development of the prototype system, the development of the requirements of the data repository, and, primarily, the configuration of a Web Portal for OGP to tie the OSMC system together with other information and reporting requirements that develop during this period of time.

- An architectural diagram will be constructed showing each major component along with a brief description of its requirements and more detail on the interfaces between components.

Delivery 2. (Additional Parameters and Platforms - June 2004)

Tasks:

- Incorporate bulk of remaining parameters & platforms (PMEL)
- Additional configuration of OGP Portal (Ops Officer)
- Additional data repository fields to support additional parameters & platforms (NDBC)
- Additional data repository capabilities to support advanced queries (NDBC)
- Final Architecture Design Document (NDBC Contractor)
- Final Data Management I/O Requirements Document (NDBC Contractor)
- Proof of Concept of operational data repository (NDBC)

Deliverables:

- Enhanced operational software
- Operational LAS Server at NDBC
- Initial data repository capability (Proof of Concept)

- Final User Interface Requirements Document
- Final Data Management/IO Requirements Document
- Final Architecture Design Document

Activities:

- The purpose of this phase is to proceed with full-scale development of the remaining system in an incremental fashion.
- The requirements analysis efforts during the prototyping phase will provide insight on how to prioritize the addition of platforms and parameters to the OSMC system during Delivery 3.
- Considerable focus will be placed on the implementation of data visualization tools and generating statistical reports.
- The implementation of the data repository will begin along with data ingestion from a limited number of data sources. (NDBC)
- The OSMC system will shift from PMEL's development environment to NDBC's operational environment.

Delivery 3. Initial Statistical Analysis (December - 2004)

Tasks:
- Incorporate all remaining parameters & platforms (PMEL).
- Additional configuration of OGP Portal (Ops Officer).
- Additional data repository fields to support additional parameters & platforms (NDBC).
- Incorporate initial statistical analysis capabilities (Ops Officer).

Deliverables:
- Enhanced operational software.
- Test plan.
- Test report.

Activity:
- Delivery 3 represents an OSMC decision support system with full access to the required data and a wider range of visualization capabilities.

System Architecture

The OSMC system is described in 4 major layers or components (Figure 1). Each layer is summarized here working through the diagram from the bottom up.

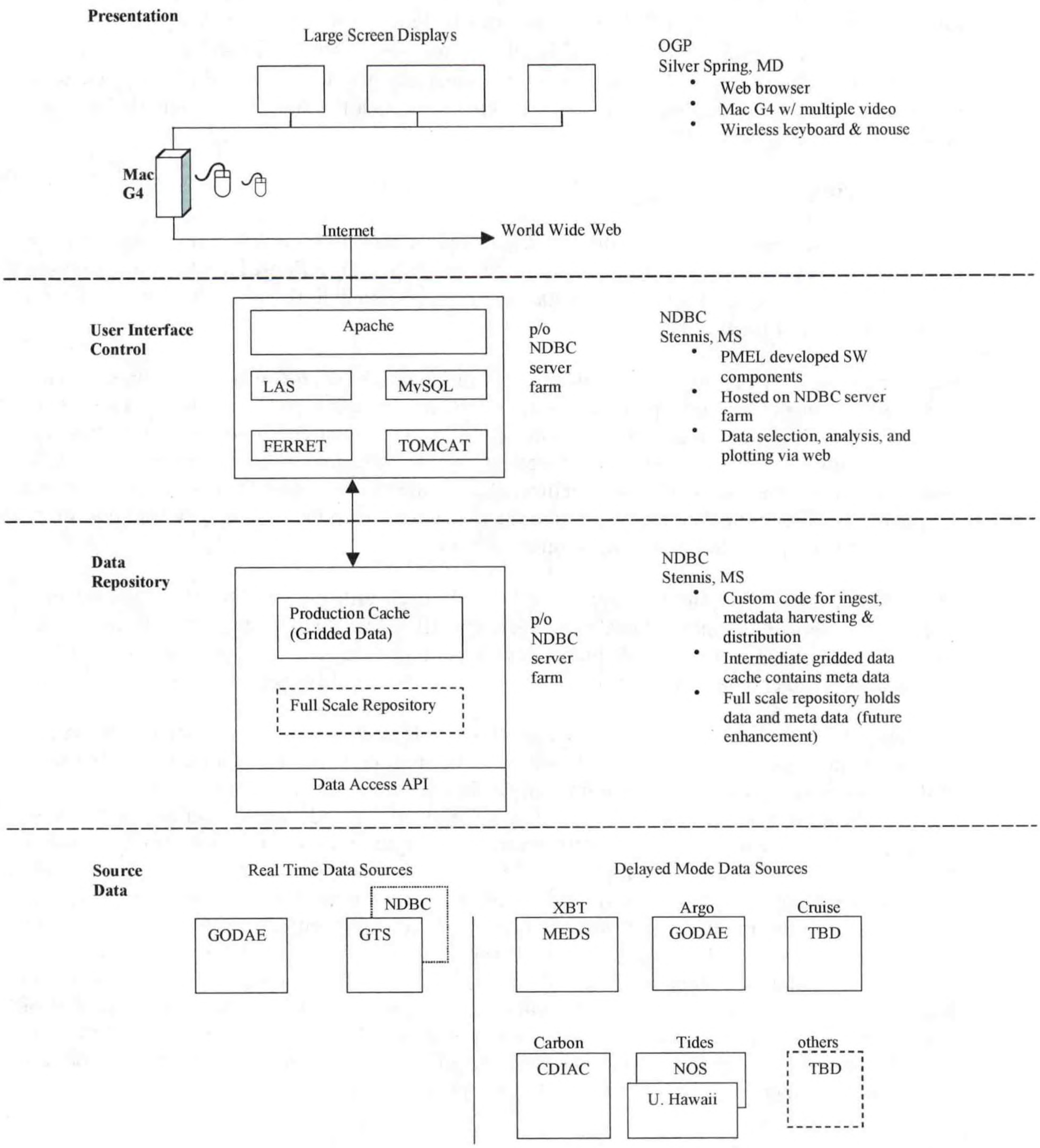


Figure 1. System Architecture

Source Data

This layer represents the data that already exists on data servers such as GODAE, NCEP, National Ocean Service (NOS), Carbon Dioxide Information Analysis Center (CDIAC), NDBC, etc. The source data layer is shown here for completeness but no development effort is anticipated for this layer by the NDBC/PMEL team. There may be some level of effort on the part of the data providers to enhance their system to provide information needed for the OSMC. For example, the US GODAE group has agreed to make available metadata which is not routinely kept on their server. In return for their assistance this project will ensure that the databases which are built will be available, through the US GODAE server interfaces.

Data Repository

This layer is comprised of three components, a full-scale repository, a production cache, and an applications programming interface (API) to source data. The API will provide a consistent means of collecting data from various data providers, to populate the production cache with a gridded summary of the statistics and meta-data.

Implementation of a full-scale data repository is one possible course of action to make source data available locally for high-speed access by OSMC display and reporting systems. This would allow more sophisticated analysis from the data sets that, when combined with statistics and meta-data, provides more insight to data collection efforts as they relate to meeting scientific goals. An alternative course of action includes the installation of a local DODS server to support the interface between the data repository and the user interface control layer. The data repository design is a key output of the requirements analysis work.

The focus at the data repository layer is to provide data, either as a relational database or a collection of network Common Data Form (netCDF) files, that directly support plots needed for the presentation layer and to provide that data with good performance. The goal here is to collect and cache data rather to recollect data each time it is needed to build a plot.

The components of the data repository layer will be implemented on servers located at NDBC. It is expected that this data repository layer will be comprised of scripts and data files, but the scale of the data repository may require a relational database system. Regardless of the implementation decision about the use of a database system or a file system, the OSMC system data subsystems will require significant amounts of server processor time and disk space. Disk space can easily and cost effectively be added to database or file servers, as required. The availability of the high-performance Oracle 9i database system at NDBC is an important data repository design consideration. Leveraging the existing Oracle database server infrastructure would be a cost effective means of providing access to a high capacity database system with native support for Extensible Markup Language (XML) technology. The OSMC data repository is expected to include an XML Repository, which is a technology that supports the centralized management of content (preprocessed information stored for retrieval and display). The major benefits of an XML Repository are realized through its ability to allow you to organize the content, annotate it for purposes of quick retrieval, and manage the complex relationships and interdependencies.

User Interface Control

The components in this layer already exist and are in use at PMEL and other institutions. These components will be installed on servers at NDBC (possibly the same hosts used for the data repository). Architecturally the Data Repository and User Interface Control functions are separated to allow future scalability, but they can be implemented on the same physical server.

The Live Access Server (LAS) is a general purpose Web server for geo-science data sets. LAS consist of a set of modular components in a three-tiered architecture which interact to provide user interface, business logic and data access functionality. Because of the modular design, custom geo-science data servers can be built by substituting or adding to the core LAS components. Key software components of the LAS system include LAS, Ferret, Tomcat, Apache and MySQL.

The strategy adopted by PMEL in the development of the LAS system has been to choose open-source, off-the-shelf software for general capabilities and to develop in-house tools only when necessary. Apache, MySQL and Tomcat are all freely available without software licensing fees and very widely adopted in both private and public enterprises. Each has an established track record and a very dedicated user community. NDBC uses the Apache web server for the existing NDBC Internet web site, publishing station data reliably – even under enormous loads during peak periods such as hurricanes. Ferret has been developed at PMEL over the last 20 years, initially to deal with large gridded model output, but has matured to work well with a wide variety of climate data. It is used by a broad community of oceanographers of varying stripes as it has many highly developed tools that meet the needs of climate scientists. The Live Access Server addresses a broad need for access to dispersed climate data. Many details associated with individual datasets are hidden by the LAS interface, allowing users to interact with data regardless of location and native format. We are not aware of any other tool that provides the functionality available through LAS.

Presentation Layer

The user interface is built on web pages served from the user interface layer at NDBC, and since it is a simple web interface, it can be made available to NOAA partners on the World Wide Web. To add more interactivity in the user interface than a web based LAS interface allows, custom Java applications can be built to address this need. Such an approach to user interface development retains the desirable property of being portable to other platforms (PCs or Unix desktops) and free to distribute

For the OSMC command center, the presentation layer will be implemented on several large format screens driven by an Apple Macintosh G4 computer system. There are several reasons for selecting the G4 as the display system. First, the system uses all of the monitors on the display wall to create one virtually large desktop. Windows may be dragged between displays without any special commands or user training. Second, the G4 will integrate nicely with the other Macintosh computer at the OSMC and NOAA HQ. For instance, PowerPoint files from any of the desktop computers are readily moved through the network to the display G4 for presentation. Third, Virtual PC may be run on the G4 so that a Windows environment can be made available to visitors wishing to present via a Windows environment or to demonstrate Windows based software.

Verification, Validation, and Testing

Test schedule and process: The features developed during each build will be tested using a formal integration and test process. Once the requirements are documented a set of detailed test cases will be generated for each feature. The test cases will identify the purpose of the test, the scenarios that the test is intended to exercise, the test data that will be used to conduct the test, and the pass/fail criteria. The test cases will be documented in a test plan and presented to OGP for their review and concurrence prior to conducting the tests. Once the implementation is completed for each build, the complete set of code developed during the build will be integrated and tested using the test cases described above.

The System Engineer/Technical Lead will be responsible for developing, documenting, and conducting the test cases for each build. This individual will obtain help from the developers in creating the test cases, executing the tests, and analyzing the results.

Peer Reviews: In addition to the formal build level tests, all software modules identified as critical will be peer reviewed. Modules that are particularly complex are re-used in multiple subsystems, or that support a critical algorithm are candidates for peer review. The members of the peer review panel will include developers from the SAIC team and the PMEL team where appropriate.

Acceptance Criteria: Each test case will have the appropriate pass/fail criteria identified. When the test cases are executed, all of the results will be saved and archived. The results obtained from each test case and any data analysis results will be documented in the test report at the end of each build. The test plan will be reviewed with the OGP and will be approved by the principal investigator.

Methods and Tools: Compliance with requirements will be demonstrated via functional testing to the greatest extent possible. In cases where requirements cannot be verified by conducting specific test cases, they may be verified using analysis or demonstration techniques.

Deployment, Operations, and Maintenance

The server resources necessary to host LAS, Ferret, and the data repository will be located at NDBC, unless Internet performance becomes an issue. The advantage of locating the server resources at NDBC is that existing systems administration, monitoring, and high-availability infrastructure can be leveraged. This is expected to result in less hardware, administration, backup, and monitoring responsibilities for OSMC staff. NDBC is a tenant activity aboard Stennis Space Center and benefits from access to very-high speed access to the Internet and Government networks. If performance is an issue due to a network bottleneck serving up pages from MS to DC, consideration will need to be given to an additional LAS server at OGP HQ for local network use only. If a web server is ultimately required at OGP HQ, it can be a clone of the LAS server at NDBC, representing a relatively minor maintenance burden for the Operations Officer. The remainder of the OSMC user community is expected to access identical information from an NDBC mirror server.

The data repository server will also be deployed at NDBC, absorbed in existing capacity if possible. However, OSMC data storage requirements may require some incremental increase in capacity at NDBC (e.g., an additional server node, Oracle licenses, and/or disk storage). While not required in Phase 1, the Oracle relational database server, Oracle Application Server, and (especially) the Oracle Enterprise Portal server can provide the infrastructure necessary to quickly assemble a comprehensive OSMC decision support system. Incremental additions to existing NDBC Oracle licenses and the use of existing, high-performance server infrastructure presents a cost-effective and rapid means to provide the infrastructure necessary for the OGP HQ to build the necessary information systems required to support operations.

Program Management

The OSMC program uses the spiral life cycle model with several major deliveries. The initial delivery will be the initial operational prototype that can be used to demonstrate a broad set of functionality using two to three parameters. During this production of the OSMC prototype, we will also test alternative architectural approaches for the data repository in order to select the best approach. The remaining deliveries will add functionality in an incremental fashion where additional parameters, platforms, analysis and plotting routines, and data sources are added to the system according to priorities set by program management personnel.

Starting with the Proof of Concept each delivery will begin with the identification of a feature list. Detailed manpower estimates and priorities will be developed for each feature and the build plan will be submitted to OGP for their concurrence. Features or tasks will then be assigned to individual developers for analysis, design, and coding. During the early portion of the build, developers will work to fully define the detailed requirements for all features being addressed in the current delivery. Once the requirements are well understood, the architecture will be evaluated and updated if required to accommodate the new requirements. At this point, the detailed design for new features will be created and the code to implement the features will be written, tested, and peer reviewed if appropriate.

Once the requirements are identified and documented, test cases and test data sets will be identified and documented in the test plan. The test plan will be developed in parallel with the feature implementation (e.g. detail design, code, test). Upon completion, the test plan will also be submitted to OGP for their concurrence. At the conclusion of each build integrated testing will be performed and the results will be documented in a build test report. The results of the integration testing will be submitted to the OGP team for their approval.

Organizational Structure

Figure 2 depicts the primary interfaces between the various members of the team responsible for developing the OSMC.

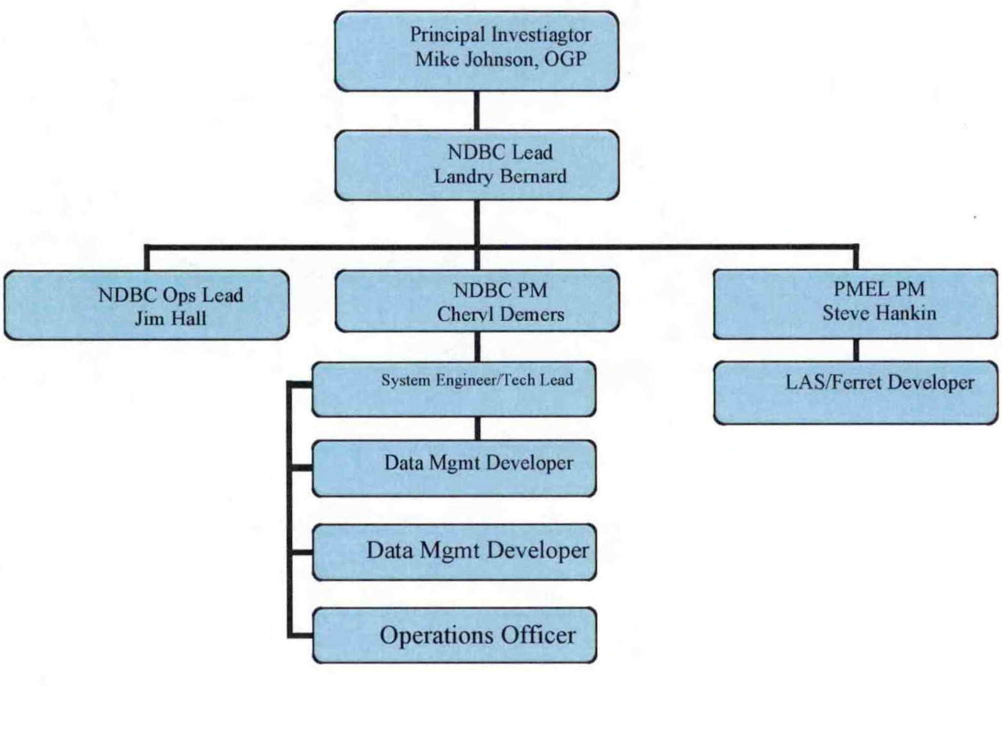


Figure 2 Organizational Interfaces

The Principal Investigator (PI) will be responsible for establishing the overall program goals and top-level requirements and for approving each delivery. The NDBC Operations Lead will be primarily responsible for liaison with the OGP PI and for overall management of the system development. The NDBC and PMEL Program Managers (PMs) will be responsible for managing all of the work in their respective organizations and will work together to ensure that all technical or programmatic issues are identified and resolved. The SAIC Systems Engineer/Technical Lead will be responsible for daily leadership of and technical guidance to the SAIC development team. The NDBC Operations Lead will be responsible for managing the server farms and OSMC software installed at NDBC.

Western Boundary Time Series in the Atlantic Ocean

by Molly Baringer, Elizabeth Johns, Christopher Meinen,
Silvia Garzoli, and Agusta Flosadottir

FY 2004 PLANS

<u>*Task 1, Continuous transport of the Florida Current*</u>

- Continuous Cable recording will continue. Assessment of current recording equipment configuration will continue.
- Four RV Walton Smith calibration cruises are planned.
- Tentative dates for calibration cruises are December 2003, March 2004, June 2004 and September 2004
- Three new dropsondes will be built: one including a self-recording CTD sensor for temperature, salinity and pressure measurements, and two dropsondes including just GPS information.
- A minimum of ten dropsonde cruises will be conducted: two cruises in October with the remainder closely timed near the Walton Smith cruises and the AX7 high density XBT line.
- Web site will be made operational once data quality stabilizes.

<u>*Task 2: Deep Western Boundary Current Time Series*</u>

The RV Ronald H. Brown will be used for the next Deep Western Boundary Current cruise, currently scheduled for summer of 2004. Station locations as shown in Figure 2 will be sampled time permitting: first priority will be to the station east of the Bahamas, second priority to the stations at 27N in the Florida Straits.

<u>*Task 3: Quality Control of Continuous Cable Transports*</u>

- Evaluate the quality of the data now beginning to come in.
- Evaluate, in light of the information regarding ground loops and the electrode failure, whether corrections can be applied to rescue some of the past year's data, and if possible, make corrections.
- Participate in working out changes in the observational setup to minimize the chance of future problems, to make system fault tolerant.
- Continue to watch for future problems and if any occur, contribute to their diagnosis and resolution.
- Cable protection activities.
- Participate in planning for long-range maintenance of cross-stream voltage observations.

<u>*Task 4: Deep Western Boundary Current Inverted Echo Sounders*</u>

Three inverted echo sounders equipped with pressure gauges will be deployed spanning the deep current on the next Deep Western Boundary Current cruise (summer of 2004). One inverted echo sounder without deep pressure will be deployed along the shallow slope in 1000m to monitor the Antilles Current. Echo sounders will remain in place for two years: recovery expected summer of 2006.

Anticipated requirements to maintain the network at status quo

<u>*Task 1:*</u> $81,170 is needed to maintain the network for FY04; $51,800 was provided in FY03 (see attached budget).

Task 2: $122,874 is needed continue the work in FY04; $120,000 was provided in FY03 (see attached budget).

Task 3: $24,222 is needed to continue the present work; $22,835 was provided in FY03 (see attached budget).

Task 4: No funding augmentation required (see attached budget).

Logistics requirements (e.g., ship time)
Current levels of clearance and ship time are needed.

New data collection methods
We request an "Add Task" to purchase backup recording equipment and instrument a second cable to assure continuity of measurements.

Expected scientific results
This proposal is funded to conduct fieldwork and data collection. Nevertheless, continued measurements of the western boundary currents will help scientists

- Monitor for abrupt climate change
- Understand natural climate variability
- Determine heat, fresh water and volume transports of two major components of the thermohaline circulation

ENSO Observing System

by Steven K. Cook and Dr. Robert L. Molinari (PI) with
Silvia Garzoli, Craig Engler, Mayra Pazos, Jim Farrington, Paul Chinn,
Gary Soneira and Janet Brocket

FY 2004 PLANS

Anticipated requirements to maintain the network at status quo

- Drifters –
    - Drifters are purchased by SIO but we expect an increase in the number of drifters deployed because of a less expensive design.
    - We expect to deploy over 700 Drifters, which will increase our shipping costs by about 50% or $25K for a total of $72K.

- XBTs –
    - Anticipated increase in the price of XBTs will require $595K to maintain the present LD and FS network. (See Table 1.)
    - Note: *To maintain the international XBT network recommended by the Upper Ocean Thermal Review committee will require an additional $468K. (See Table 1.)*

Logistical requirements (e.g., ship time)

- Not applicable.

New data collection methods

- Implementation of SEAS 2000 configured with the Sippican Mk-21 XBT data collection system will upgrade the fleet to a Windows based PC system and allow for the real-time transmission of full resolution XBT data.
- Integration of the Autolauncher XBT systems with SEAS 2000 will result in the successful merging of two separate existing software and data processing packages into a single process.
- Integration of automated meteorological systems (AWS), Thermosalinographs (TSG), and pCO2 systems into SEAS 2000 will result in the capability of transmitting of full resolution data sets thereby increasing the data flow of climate quality observations and reducing the possibility of the loss of delayed mode data.
- Developing real-time plotting packages for XBT data that will be implemented via Web access. (See Figures 1 & 2.)

Expected scientific results

- Analysis of drifter observations in the tropical Atlantic will continue, focusing upon the impact of heat advection in regional heat budgets and the role of seasonal variability and eddy fluxes in setting SST anomalies. A related study will use the drifter observations to quantify time and space scales of dispersion and eddy momentum fluxes, with the goal of improving our understanding of the large-scale advective pathways in the tropical Atlantic. Drifter trajectories in the South Atlantic will be examined, with particular focus on the time mean and seasonal variations of the boundary currents (Brazil/Malvinas confluence, Agulhas/Benguela system) and the variations of tropical/subtropical exchanges associated with meanders in the South Equatorial Current.

- Analysis of XBT data collected along lines occupied for multiple decades will continue. The studies will be directed at decadal variability of the Gulf Stream and subtropical gyre of the North Atlantic and the relation of this variability to atmospheric climate. In addition, track line data collected in the tropical Atlantic will be reviewed to identify scales of variability and potential exchanges between the tropics and subtropics.

CONSORTIUM ON THE OCEAN'S ROLE IN CLIMATE

Project Infrastructure

by Russ E. Davis

FY 2004 PLANS

SIO plans to add some expertise to its staff in the area of data assimilating modeling. We hope that this will allow us to accelerate progress in the data-assimilation effort.

The Infrastructure component proposes to shift its educational support effort from graduate students, where we typically have adequate funding in individual grants, to supporting a post-doctoral scholar who will work within a CORC project of his/her own choosing.

High Resolution XBT/XCTD (HRX) Transects

by Dean Roemmich

FY 2004 PLANS

FY2004 funds (July 2004 – June 2005) will be the fourth and final year of the CORC-III project. It will also be the final year for the NSF-funded Scripps HRX transects. We will continue quarterly sampling along all lines (NOAA/CORC transects IX15/21, PX81, and PX08 New Zealand – Panama) while evaluating the future prospects for ship routes in the South Pacific. We will also plan for the transition of the NSF-funded transects to NOAA.

It is now four years since the Upper Ocean Thermal Review and OceanObs99. The international CLIVAR SSG has recently commissioned a Global Synthesis and Observations Panel (D. Stammer and D. Roemmich, co-chairs; GSOP replaces COOP). This panel will review progress of observing system elements, including HRX, and will be an appropriate forum for assessing and planning for the future of the overall HRX program.

From the standpoint of scientific analysis, the implementation of Argo is an exciting complement to the HRX sampling. By providing enhanced broadscale coverage, salinity measurements, and reference velocities, Argo will substantially reduce the error bounds on both heat storage and transport in large regions. Subsequent regional and basin-wide heat budget studies similar to Roemmich *et al* (2003) in the Tasman Box will have a much improved signal-to-noise ratio in the estimation of interannual variability.

Budget and responsibilities

Scientific oversight for the Scripps HRX program is provided by D. Roemmich, in collaboration with B. Cornuelle and J. Sprintall. The team of PIs guides selection and maintenance of routes according to international priorities, supervises the operations management, participates in data collection and is responsible for final quality control and scientific analysis. The HRX program provides a primary dataset for the PhD dissertation research of student Josh Willis.

The operations manager is G. Pezzoli (maring technician). He is responsible for liaison with ships and shipping companies, maintenance and upgrades of XBT auto-launcher hardware, scheduling of cruises, and logistical support for cruises. He participates in cruises as well as training and overseeing a roster of ship-riders, including full-time (J. Afghan) and part-time (D. Cutchin and others) marine technicians, students and scientists. The ship riders' job includes interaction with ships' personnel, XBT/XCTD data collection, quality control of data, and technical support for ancillary projects such as the CORC IMET systems.

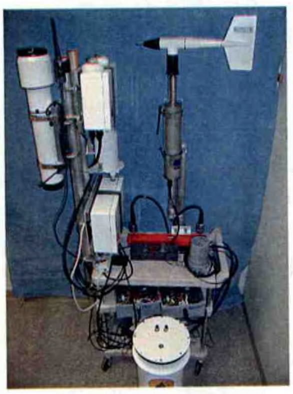
J. Gilson (Specialist) carries out scientific programming and data analysis, and is a frequent author/co-author with the PIs in published work. L. Lehmann (programmer/analyst) is responsible for XBT autolauncher software, and for maintaining the HRX dataset and web site, as well as for updating ancillary datasets, such as satellite altimetry and operational air-sea fluxes, needed for scientific analysis.

Observations of Air-Sea Fluxes and the Surface of the Ocean
by Robert A. Weller and David S. Hosom

FY 2004 PLANS

A change of the ASIMET modules to the AutoIMET system on the Horizon Enterprise plus a turnaround of the AutoIMET system on the Columbus Florida will take place in December 2003.

The original stand-alone ASIMET modules will all have been converted to the new Auto-IMET systems and these will have been installed on the three active ships, Horizon Enterprise, Columbus Florida, and Sealand Express. A third Pacific ship is scheduled to have a system installed in 2004 making a total of four VOS with Auto-IMET / NOAA SEAS systems that report via Inmarsat C in real time and store one minute data for retrieval every six months. This program is in an operational support mode for the current ships.



Auto-IMET system showing the data logger, battery container, acoustic modem for wireless acquisition of inside-hull-mounted SST, and the flux suite of sensors including: wind speed and direction, relative humidity and air temperature, sea surface temperature, precipitation, barometric pressure, shortwave radiation, and longwave radiation. A complete meteorological message is transmitted to the bridge via radio every six minutes to the NOAA SEAS system. The NOAA SEAS system returns GPS to the AutoIMET for later processing of real wind. Real wind is computed by the NOAA SEAS system. All of the data recording and sensor units are replaced every six months for repair, calibration, and one-minute data retrieval. This is a critical part of obtaining climate quality data.

Drifter Observations
by Pearn P. Niiler

FY 2004 PLANS

Enhancements of drifter deployments in the tropical Pacific will continue. We plan to support the continuation of studies of the connection of the Philippine Sea and the South China Sea with 40 SVP-Mini drifters per year. In June 2004 we will endeavor to support a study of the patchiness of detritus that is sampled by sediment traps near Oahu with 25 drifters as requested by UC Santa Barbara. All of these drifters will disperse and become part of the Global Drifter Array after they have been utilized for research purposes on the early stages of their life at sea.

The construction and evaluation of SSS sensors will continue. Plans are to construct at least 5 SVP drifters with both new SSS sensors developed by Ray Schmitt and Niel Brown at WHOI and the SeaBird Microcats we have been using. A comparison study with both sensors on the same drifter will be done near the near Bermuda, with recoveries from the tending vessel at the HOME site several months to several seasons after deployment. Additional SeaBird Microcats will be deployed in the North Atlantic with the cooperation of the French Meteorological Service in the Bay of Biscay, who have offered to retrieve these for post-calibration during their regular cruises to service moored buoys in the deep ocean. The principal technical issues are how quickly will the SSS sensors foul and how can their life be extended.

Analysis will continue of the circulation and vorticity dynamics of the North Pacific Countercurrent and the circulation of the Yangtze River plume. We will embark upon analysis to describe of the convergences of mass, vorticity and thermal energy of the tropical Pacific, a project that has been in abeyance since the time of TOGA because of the dearth of velocity observations, which CORC has subsequently remedied.

Underwater Gliders for Monitoring Ocean Climate
by Russ E. Davis

FY 2004 PLANS

Work for the coming period will follow three simultaneous and closely related threads:

(1) technical development to improve glider reliability and to fit them with a CTD system that will provide stable long-term measurements and an ADCP so that measured shear can be combined with vertically averaged absolute velocity to produce velocity profiles;

(2) initiation of a repeated survey line offshore off San Diego as a cost-effective pilot test of glider capabilities to monitor boundary currents; and

(3) collaboration with Billy Kessler (PMEL) and Yoshifume Kuroda (JAMSTEC) on a pilot exploration using gliders to monitor the Mindanao Current.

Technical Development. The Monterey field trial showed that Spray is nearly ready for operational use but that continued technical development is required to work out the remaining bugs. Priority for technical development will be on (a) improving the hydraulic system to avoid pump failure in the presence of ubiquitous air bubbles in the hydraulic system, (b) implementing an improved conductivity sensor to avoid biological contamination both from particle impact and from growth on the sensor, and (c) implementation of an ADCP for direct measurement of shear. We are now evaluating a new dual-stage pump for hydraulic system modifications, are designing a system to used a pumped Sea Bird conductivity cell with internal poisons, and are preparing the first field tests of the Sontek ADCP purchased previously.

Pilot Repeat Section in the California Current. The planned development work requires long-term field tests and it would be foolish not to use this field time to add to the climate record. One of the longest extant ocean climate time series is the CalCOFI program's 54 year sampling of the California Current System (CCS). This record clearly shows how climate variability, most notably connected to the ENSO and PDO cycles, influences the physical structure of the CCS and the structure and abundance of biological communities that live in it. NOAA Fisheries is in the process of proposing for FY 2006 a Pacific Coastal Observing System (PaCOS) that would combine and coordinate stock assessment surveys, extended sampling of the CalCOFI type, and more modern methods to monitor the CCS along the entire west coast of the U.S.

Today's CalCOFI surveys are relatively low resolution in time (quarterly) and space (71 km), better suited for providing many independent samples of biology than for characterizing the important mass, heat, nutrient and freshwater transports of the upwelling cell, the poleward California Undercurrent and the equatorward California Current. In the spirit of an Integrated Ocean Observing System, one would hope that this NOAA Fisheries effort will be integrated with the Climate Observing Program in the CCS and that the goals of the latter will expand a bit to include describing and predicting physical climate changes in the ocean that affect ecosystem function, fisheries management, and protection of endangered species. As a small step in this direction, we propose to configure our field tests to increase the sampling density (in time and space) along CalCOFI line 93, which extends about 500 km southwest from La Jolla. Initially we will restrict tests to month long tests along the first 250 km of this line but as capabilities develop we will extend to the end of the line CalCOFI usually samples.

Mindanao Current. While the climate variability in the CCS may have little influence on variability of atmospheric climate, variability in the Low Latitude Western Boundary Currents (LLWBCs) of the tropical Pacific are strong candidates to modulate the strength and timing of ENSO (and perhaps PDO) by affecting the temperature, salinity and stratification of the Pacific Equatorial Undercurrent. In the southern and northern hemispheres, respectively, the New Guinea Coastal Undercurrent and the Mindanao Current have sources in the interior currents that separate subtropical gyres from the tropical circulation. These LLWBCs feed the Equatorial Undercurrent, which is, itself, the source for equatorial upwelling that so strongly influences SST during ENSO cycles. Variations in LLWBC transport or its properties may well influence stratification along the equator and, thereby, the ocean's SST response to equatorial winds, which is a central process in the feedback that maintains equatorial anomalies.

Billy Kessler has organized collaboration between PMEL, our effort, and Yoshifume Kuroda of JAMSTEC to carry out a pilot study to see how effectively gliders can monitor the Mindanao Current. Our original CORC plan proposed to make our first pilot climate observations in the equatorial Pacific and we are still aimed to do that. But because the LLWBCs of the Pacific appear to be as potentially important to climate variability, because they are much less well measured in today's observing system, and because the PMEL/ JAMSTEC collaboration provides such strong logistic leverage, we plan to place our initial effort on supporting this Mindanao

Current effort. We will prepare a glider for the first pilot study in FY 2004 and probably two for the follow-on now scheduled for FY 2005.

Development of an Underway CTD
by Daniel L. Rudnick

FY 2004 PLANS

The main design goal of the coming year is to improve ease of use through redesign of the shipboard winch. We are now using a commercial fishing reel equipped with a motor. Our plan is to construct a custom winch with more capacity and power than our current system.

We will continue our documentation of sensor accuracy through repeated use in the field. For example, a fully operational use of UCTD is planned on an ONR-funded cruise in May/June 2004.We expect to establish firm sensor accuracies by the end of the year. The UCTD system will then be documented in a refereed publication.

During the coming year we will begin deployment of UCTD on NOAA cruises. Possibilities include cruises conducted for Southwest Fisheries, TAO mooring turnaround, and the CORC high-resolution XBT network.

Budget and responsibilities
PI D. Rudnick is responsible for oversight of UCTD development. Rudnick establishes priorities in development, sensor accuracies based on scientific needs, and guidelines for operations.

Specialist J. Klinke facilitates all operations in the lab and at sea. Klinke does calibrations, prepares instruments, and participates in field deployments. Klinke also writes software to make communication and initial data analysis available to the user.

Design tasks are done by the Instrument Development Group (IDG) at SIO, including Jim Dufour and Lloyd Regier. IDG takes the lead in both mechanical and electronic design.

Lagrangian Salinity Profiling: Evaluation of Sensor Performance
by Ray Schmitt

FY 2004 PLANS

For FY 2004 (July 2004-June 2005) the main task will be to monitor and evaluate the performance of the nine FSI-equipped ARGO floats in the Eastern Tropical Pacific. Evaluations of drift and dynamic response of these floats will be compared against previously deployed SeaBird floats in the area. In addition, dynamic response tests of the SeaBird float CTD will be made in our double-diffusive interface tank (pending completion of modifications to the lowering rate mechanism). Both these efforts will help in quality assurance of salinity measurements for the ARGO program.

Our overall goal for improved monitoring of the salinity field is to assess the patterns strength and variability of the water cycle over the ocean. We have been supported by NSF to deploy salinity floats in the tropical Atlantic and have been able to connect variability in the float salinity data with Amazon river discharges using SeaWifs color imagery (Hu et al, 2003). We plan to seek support in 2004 from NSF for scientific analysis of the growing salinity database to complement the technical advances made possible through our CORC support. In the following "Add Task" we request support for test deployments of a new foul-proof salinity sensor designed for surface drifters.

Budget-

Scientific oversight, publications and dynamic response testing will be the responsibility of PI R. Schmitt. He will receive modest assistance in these tasks from programmer E. Montgomery.

Data Assimilation

by Bruce Cornuelle, Detlef Stammer and Art Miller

FY 2004 PLANS

The adjoint data assimilation approach will be carried out in the tropical Pacific region over as long a period as the nonlinearities will allow. The sources of the limits of predictability in the tropical Pacific will be also identified in the context of the adjoint approach in order to consider different methods that allow the extension of the assimilation period length. Once the assimilation system is validated all the available data sets in the tropical Pacific will be included to improve the quality of the analysis. This work will produce a time-evolving ocean state estimate and an improved set of forcing and boundary conditions. These products will be analyzed to quantify forcing errors and to examine the detailed ocean structure and dynamical evolution through several ENSO cycles. The complete set of products (ocean state, forcings and boundary conditions) will be made available to the community for general scientific studies in tropical Pacific.

The MIT model will be coupled with the biological model and run in the tropical Pacific domain to determine the influence of biology on the physical flow fields. This will involve continuing the process of testing the ROMS biology code, and importing it into the MIT model. Once this is finished, initial short-term (10 years) and long-term (50 years) runs will performed with both models using realistic wind variations from 1950-present to examine how much of the seasonal, annual and interdecadal variability (biological and physical) are captured by each of the models. Once final tuning the
MIT model will be ready to run with biology in the tropical domain.

Budget and Responsibilities

I. Hoteit (Ph.D. in data assimilation) has primary responsibility for the model and assimilation, in consultation with Stammer and Cornuelle. He will also examine the quality of the assimilation estimates and analyze the adjustments of the adjoint method to the forcings and boundary conditions. A. Miller and D. Neilson (Ph.D. in biological oceanography) will work together with Hoteit, Cornuelle and Stammer in implementing the biological model in the MIT ocean model, installing it on the COMPAS cluster, setting up the runs and doing the analysis. G. Auad (Ph.D. in physical oceanography) will also contribute to this work by helping to run and analyze the ROMS model for the same forcing and boundary conditions to determine the differences and similarities in the physical and biological response for the MIT and ROMS models.

6 Figures

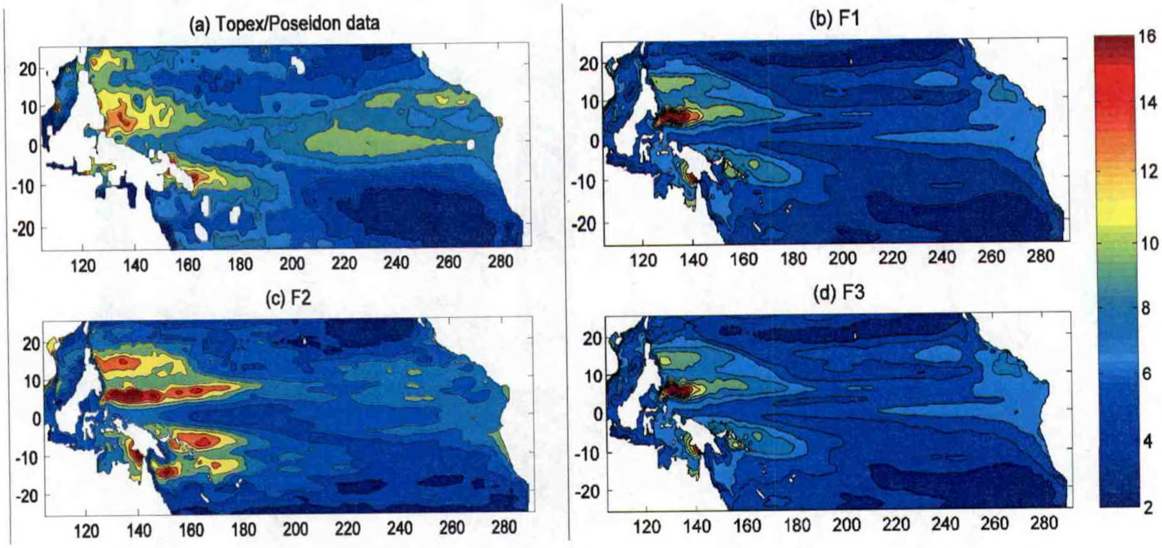


Figure 1. Standard deviation of the sea surface height (monthly averaged fields) from (a) Topex/Poseidon data, (b) run with NCEP forcings, (c) run with ECCO forcings, and (d) run with ECCO forcings but NCEP wind. This shows how the high-resolution tropical model responds to the forcings optimized in the global model (ECCO). The ECCO product seems to produce the best agreement.

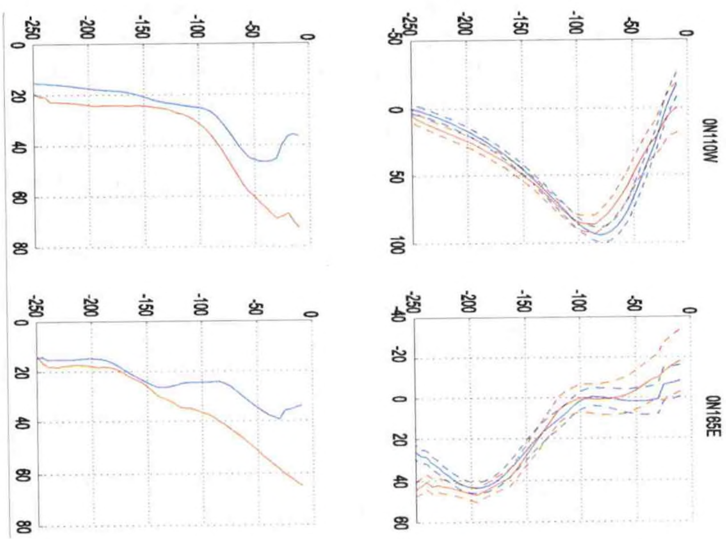


Figure 2. Profiles of the mean (upper panel) and standard deviation (lower panel) for the zonal velocity estimated from the model forced with ECCO forcings (red curve) and from ADCP measurements (blue curve) along the equator at 110°W and 165°E. The dashed-lines correspond to the 95% confidence interval. We see satisfying agreement between the mean zonal currents, but the rms is too large near the surface. We attribute this to errors in the wind forcing, and expect that the assimilation can reduce these differences.

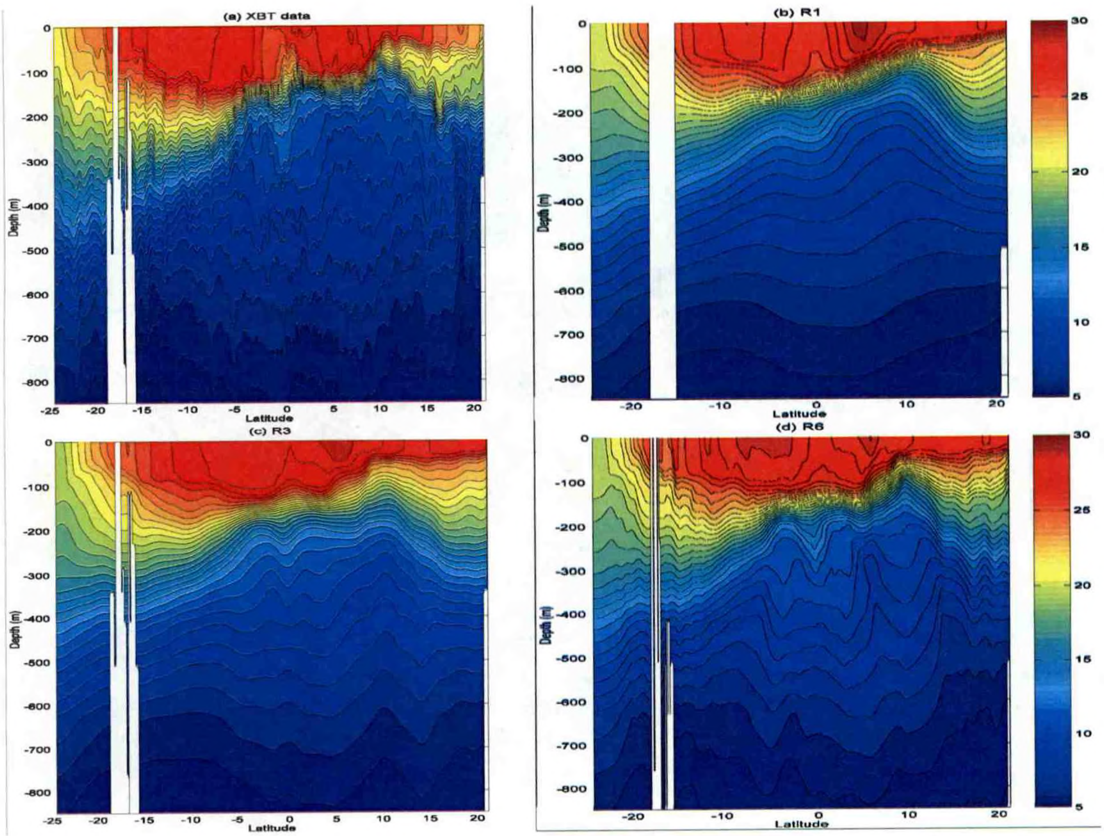


Figure 3. Latitude-depth cross-sections of temperature for September 1999 from (a) XBT measurements, (b) 1° run, (c) 1/3° run, and (d) 1/6° run. Shows how increased resolution improves the comparison to the HR XBT sections, even though this is without assimilation in the tropical model. The 1/3° model does significantly better than the 1° run, but the 1/6° model is not much better than the 1/3° model, except for the NECC thermocline strength and slope.

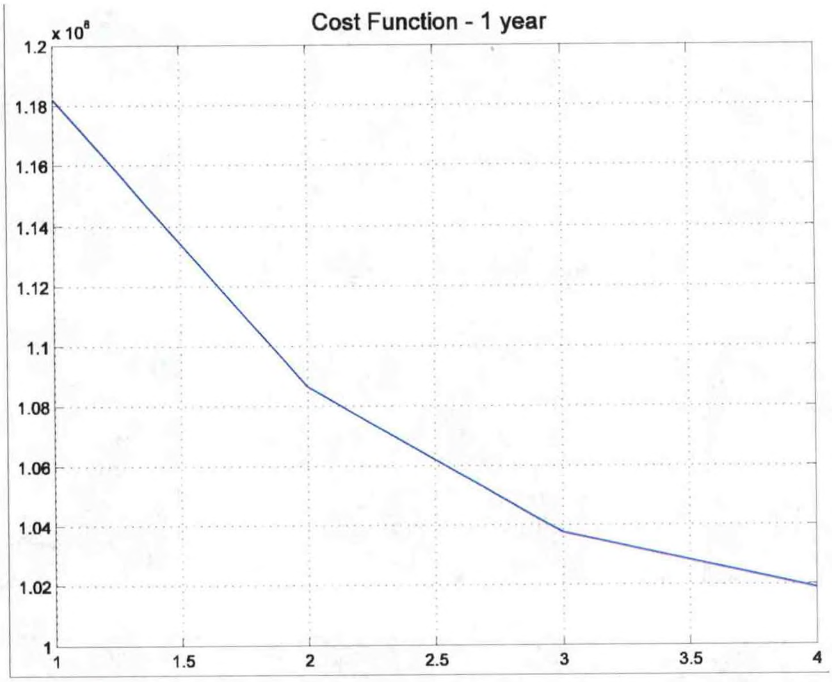


Figure 4. Evolution of the cost function (over 1 year assimilation period) as function of the number of iterations. As a first step, the model is constrained with monthly Levitus salinity and temperature data, Reynolds sea surface temperature data and Topex/Poseidon sea surface height data. Other data sources (TAO's, XBT's, Drifters', etc.) will be assimilated in the near future.

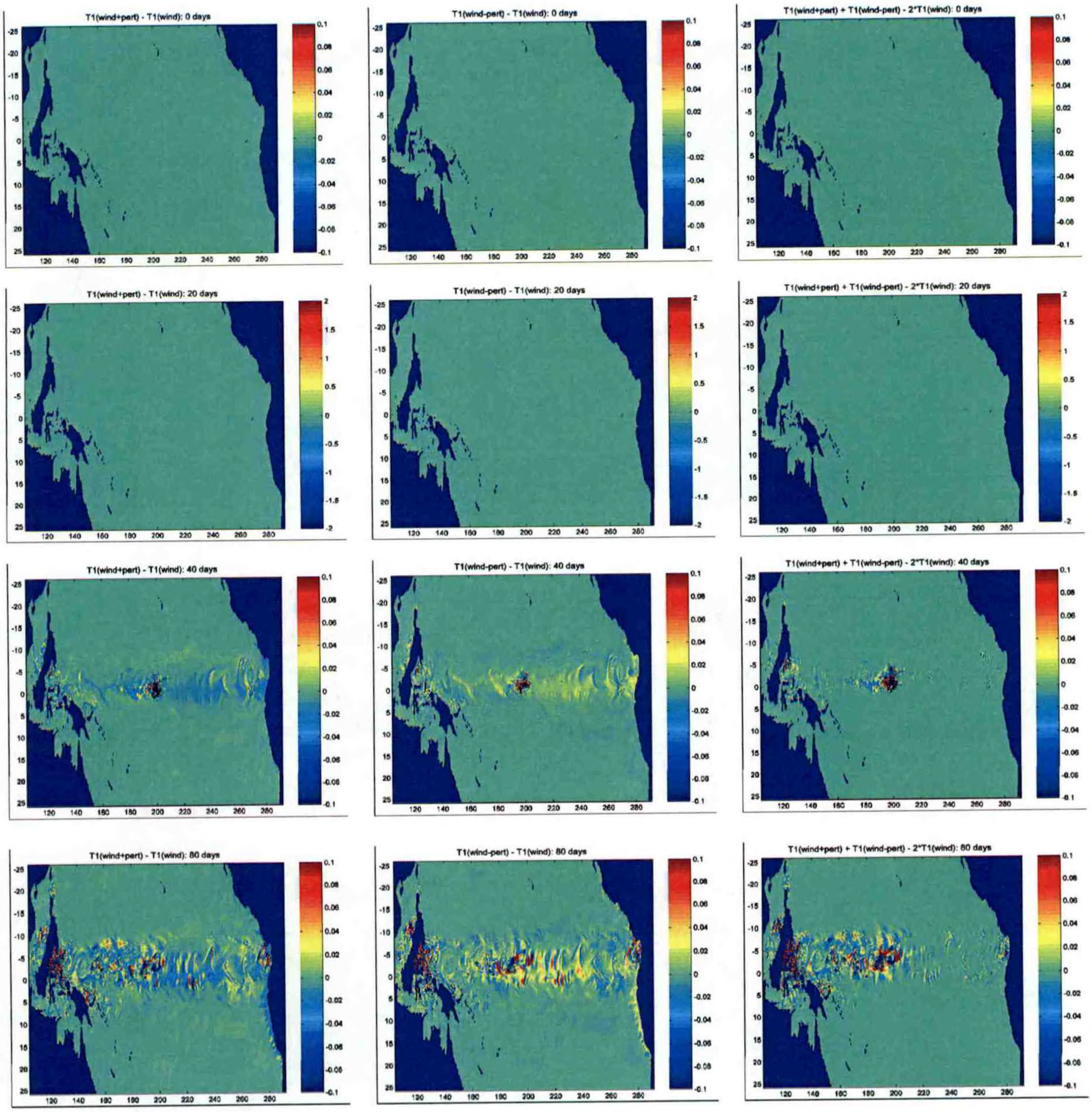


Figure 5. The first two panels show the evolution as a function of time of the positive (*eps*>0) and negative (*-eps*) perturbation on the wind stress. The evolution of the second derivative to the wind stress as function of time is shown in the rightmost panel. Strong nonlinearities appear after only a few weeks.

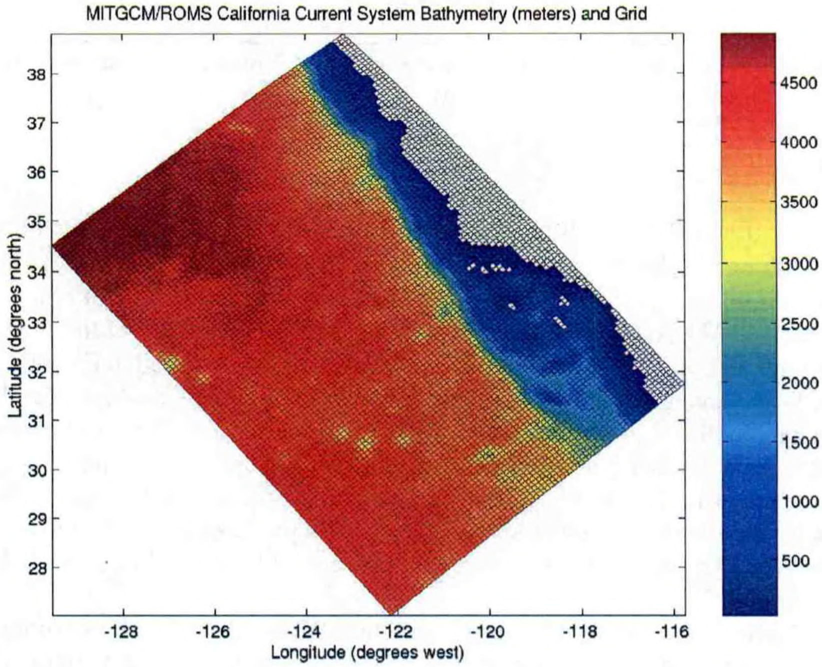


Figure 6. Topography (meters) and grid of the MITGCM/ROMS California current system.

High Resolution Climate Data From Research and Volunteer Observing Ships
by C. W. Fairall

FY2004 PLANS

The major effort in FY04 will be execution of the TAO and WHOI climate buoy cruises plus continued work on the *Ronald Brown* C-band radar. Approximately 40 days of air-sea flux data will be obtained on the TAO cruise and about 15 days of data on the WHOI cruise. A second component will be planning for construction (beginning in FY2005) of the roving flux standard. Ship time will be in piggyback mode. The new sensors acquired in FY2003 (with the exception of the laser wave gauges, which did not arrive in time) will be deployed for the first time. Besides collecting the high resolution flux data, we will be doing pilot study evaluation of a UNOLS ship (R/V *Revelle*) IMET system as part of our plans to upgrade research vessel climate data. The *Revelle* is the ship for the WHOI buoy cruise and the present ETL seagoing flux system will provide the roving standard. Construction will begin on the High Resolution Climate Observations website. The first task will be compiling material for the online handbook for flux observations.

For the Ronald Brown radar systems project, installation of the two new computers needs to be done while the ship is in port. Laser leveling of the antenna motion stabilization (INU) should be done in port also. It has been suggested that this should be done every few years. Routine maintenance, such as calibrations, will need to be done to have the system functional for upcoming experiments. The Sigmet software licenses and maintenance will also need to be continued (this is k$9 per year).

Outreach efforts this project center on educational contacts through the University of Colorado Outreach program and the NOAA Teacher-at-Sea program. For the TAO cruise a link has been set up for twice-weekly exchanges with 10 middle school classes around the US. The WHOI climate buoy cruise will have two Teachers-at-Sea on board.

Document Ocean Carbon Sources and Sinks

Encompassing the proposals:

Initial Steps Towards a Global Surface Water pCO_2 Observing System.

and:

Underway CO_2 Measurements on the NOAA Ships *Ka'imimoana* and *Ron Brown* and RVIB *Palmer* and *Explorer of the Seas*

by Richard A. Feely and Rik Wanninkhof,
with Nicolas R. Bates, Frank Millero, Taro Takahashi, Steven Cook

FY 2004 PLANS

Requirements to maintain the network at status quo:
pCO_2 on research ships: requested funding level can maintain status quo but focus will have to be on upgrading instrumentation that is at end of useful lifespan. The added instrumentation cost will be recovered through reduced personnel cost currently expended on emergency repairs. Some of the auxiliary measurements proposed (O_2, DIC, nitrate, and chlorophyll) might have to be decreased to cover the equipment costs.
VOS: This effort is not yet operational and is about 6-mo to 1-year behind schedule in outfitting as proposed because of late receipt of funds and longer lead times for instrument development and procurement. Scheduled outfitting can be completed with funds requested but without the proposed Seakeepers models for auxiliary measurements. See add task for requested augmentations.

Logistical requirements:
Research ships: The underway CO_2 efforts have been one of the first chemical measurements to run nearly unattended on the research ships. However, several of the ships have instrumentation for other projects. This has put a strain on space and ship resources. Since these measurements are not an integral part of the ship's projects there have been increasing pressures maintaining the efforts. More formal arrangements regarding sustained operations on research ships should be implemented.
VOS: Installation and maintenance of pCO_2 systems on VOS has proven to be a more substantial task than anticipated. There are a significant amount of uncertainties regarding interactions with ship's command, space availability, access to ship's etc that make the effort more time consuming and costly than originally anticipated. Despite this, ships have been found to carry our equipment on the proposed lines. For these efforts, auxiliary measurements (air flask measurements, XBT, fluorometry, plankton recorders, meteorology) are very beneficial for interpretation of results. In some cases this is becoming problematic because of overburdening the ships with projects.

New data collection methods:
A new autonomous pCO_2 system has been designed and built which, in time, will be capable of operating autonomously on VOS. The system has been designed such that data can be telemetered to shore and instrument commands can be sent to the instruments on the ships. Systems on the research ships will be upgraded to this new system when funding allows.

Expected scientific results:
The work is in support of creating:

1. Seasonal flux maps

2. Improve mechanistic understanding of the controls on pCO_2.
3. Increase data coverage in regions with limited observations to improve the global pCO_2 climatology.

The mechanistic studies have a focus on providing input for modeling and empirical studies to improve methods of extrapolating/interpolating pCO_2 data in time and space.

Global Repeat Hydrographic/Co_2/Tracer Surveys In Support Of CLIVAR and Global Carbon Cycle Objectives

by Richard A. Feely and Rik Wanninkhof,
with Christopher Sabine, Gregory Johnson,
Molly Baringer, John Bullister, Calvin W. Mordy, and Jia-Zhong Zhang

FY 2004 PLANS

Anticipated Requirements to Maintain the Network at Status Quo:

The A20/A22 cruises will be completed in November and subsequent repairs will be needed to the shipboard vans and CO_2 instrumentation before the upcoming Pacific P2 and Atlantic A16S cruises. The NOAA hydrography budget for FY04 covers costs required to finalize the data from the 2003 reoccupation of WOCE Section A16N and to pay for outstanding costs for that section that were incurred in FY03. While the U. S. Repeat Hydrography CO_2/tracer Program plan calls for the NOAA CO_2 groups to go to sea for this program in FY04, the NOAA hydrography group is not on the schedule for FY04. But in FY05 when the 2005 reoccupation of A16S is scheduled, the NOAA hydrography group will again go to sea and the funds required by this group will increase.

Logistics Requirements (e.g., ship time):

We will be requesting 5-6 additional days to the 60 ship time days for the P2 cruise through the NSF-supported UNOLS process. We will be requesting 60 days of NOAA ship *Ronald H. Brown* ship time for the A16S cruise in the South Atlantic in 2005. We need new support for underway pCO_2 measurements (see Sec 5.1).

New Data Collection Methods:

New CTD oxygen sensors (SeaBird Electronics model 43) were used on this cruise. Two of the three new oxygen sensors used were more stable than the older Beckman sensors used previously. With these two sensors, preliminary calibrations had typical standard deviations between sensors and water samples of 1 μmol kg^{-1} (0.5%). Also new (refined design) water sample bottles fabricated at PMEL for the 2003 A16N reoccupation worked very well, with effectively no evidence of leaking bottles.

Expected Scientific Results:

The P2 and A16N and A20/A22 cruises will provide the necessary data required to assess changes in the Pacific and Atlantic ocean of anthropogenic carbon and biogeochemical cycles in response to natural and/or man-induced activity. Global warming-induced changes in the ocean's transport of heat and freshwater, which could affect the circulation by decreasing or shutting down the thermohaline overturning, can be determined from the long-term observations derived from these cruises. The A16N cruise is a meridional section extending from Iceland down the eastern basin of the North Atlantic, and crossing into the western basin at the equator. Preliminary comparisons of water properties measured between the 1988 occupation and 2003 reoccupation suggest a lessening of mode water densities. An increase in AOU within and below that mode water, along with other changes (colder, fresher, more oxygen-rich Labrador Sea Water in 2003) was also observed. These rather striking findings have implications for heat, freshwater, and biogeochemical cycling that should be explored in more detail once the data are finalized and the 2003 reoccupations of A20 and A22 in the western basin of the North Atlantic are complete.

Tropical and Sub-tropical Atlantic Upper Layer Studies
by Silvia L. Garzoli, Rick Lumpkin, Mayra Pazos and Craig Engler

FY 2004 PLANS

This proposal is funded to conduct fieldwork and data collection. Nevertheless, use of the data for scientific purposes by AOML scientist is expected. Science plans are as follows:

1. Submission of paper "Eddy statistics in the Tropical Atlantic Ocean." This paper will map the distribution of eddy energy, examine Lagrangian spectra at time scales of mesoscale fluctuations, map and explain the distribution of Lagrangian length and time scales which characterize oceanic dispersion, and explore the role of eddy flux terms in the time-mean momentum budgets of the tropical Atlantic ocean. This study will rely primarily on the drifting buoy observations.

2. Submission of paper "Near-surface circulation in the South Atlantic Ocean". In an approach similar to Lumpkin and Garzoli (2003), the augmented number of drifting buoy observations will be examined in the South Atlantic Ocean, including the Atlantic sector of the Southern Ocean. Particular focus will be on the time-mean pathways of the boundary currents (Confluence of Brazil and Malvinas; the Agulhas/Benguela system) and the variations of the upper ocean exchanges associated with meanders in the South Equatorial Current's bifurcation against the coast of Brazil.

Implementation of High Density XBT Lines in the Atlantic Ocean
by Silvia Garzoli, Gustavo Goni, Molly Baringer and Robert Molinari

FY 2004 PLANS

We plan to carry out four transects along AX07, AX10 and AX08, and a minimum of two transects along AX18.

Anticipated requirements to maintain the network at status quo
Augmented funding to cover increased costs of XBTs, now $32 to $45 per probe.

Logistics requirements (e.g., shiptime)
Current levels of ship availability are needed.

New data collection methods
We are currently testing a new 8-probe autolauncher and utilizing the new SEAS 2000 software for data collection.

Expected scientific results
AX08: Submission of manuscript: "Zonal Currents in the Tropical Atlantic Ocean". We intend to identify the surface signal of each zonal current in the upper 800m by combining the XBT-derived temperature sections and the sea height anomaly fields from altimetry.

AX18 and AX07: We intend to continue the estimates of the meridional heat fluxes across 30°S (AX08) and 30°N (AX07) and combine these results with satellite observations to produce estimates when XBT observations are not available.

TAO/TRITON Array
by Michael McPhaden

TAO Transition Plan

In a memo dated 13 August 2002, the Deputy Directors for OAR and the National Weather Service instructed the directors of PMEL and NDBC to develop a plan by 15 January 2003 for transferring PMEL operations to NDBC. The memo was in response to the Administrator of NOAA's endorsement of a recommendation by the NOAA Program Review Team that TAO mooring operations be consolidated with those at NDBC. A TAO transition plan, with two options, was submitted to the NOAA Administrator on schedule. The first option was to proceed immediately as requested with the transfer of TAO, albeit the expense would be great because of training, relocation, and capital equipment costs to move operations to Mississippi. The second option emphasized the need to both develop operational observing system requirements first and to consider TAO in the broader context of the overall ocean observing system for climate. This second option was endorsed by the NOAA Executive Council (NEC) and agreed to by the NOAA Administrator in March 2003. Subsequently, PMEL, NDBC, and OGP began establishing committees and procedures guided by NOAA's new matrix management principles to meet milestones requested by the NEC under the second option.

In July 2003, the NOAA Administrator reversed his decision made 3 months earlier and requested development of a new TAO transition plan. This new plan, due at NOAA headquarters on15 February 2004, requires the transfer of TAO and PIRATA operations from PMEL to NDBC to be completed by October 2005. The guidelines for the transfer are that it 1) be accomplished at minimal cost; 2) be transparent to users; and 3) preserve international partnerships. Achieving these goals in the allotted time frame while still maintaining the high standards of excellence that the research community is accustomed to will be a challenge. The rationale for transferring TAO and PIRATA to NDBC is that these buoy programs are presumed to be operational and so they should be run by the National Weather Service (the parent of NDBC) which is trying to establish an operational climate service in NOAA. Responsibility for management of PIRATA operations in the Atlantic will also be transferred to NDBC from PMEL as part of this transition.

FY 2004 PLANS

Plans in FY 04 call for maintaining 55 ATLAS mooring sites and 4 ADCP mooring sites between 95°W and 165°E. We anticipate that NOAA ship time requirements to maintain the TAO portion of the TAO/TRITON array in FY 04 will be similar to those in FY 03, namely 265 days. Most of this ship time will be on the Ka'imimoana (230 days), with additional time provided by the Ron Brown (35 days).

FY 04 will be the third year of the 5-year PIRATA consolidation phase. During the consolidation phase, France and Brazil have agreed to provide all ship time and cover all shipping costs for ATLAS moorings between PMEL and the theater of operations. These countries will also provide storage facilities for ATLAS mooring hardware. The U.S. (PMEL) will provide all ATLAS mooring equipment and refurbishment costs. PMEL will also provide all ATLAS mooring data processing, will maintain a website for mooring display and distribution, and will provide mooring technical support on cruises. PMEL will provide ATLAS mooring training for Brazilian and French technicians both at PMEL and in the field as needed. Travel costs for training at PMEL will be the responsibility of the trainee's organizations. PIRATA cruises in FY 04 will be conducted on the French R/V Suroit in January-February 2004 and on the Brazilian

R/V Antares in July 2004.

The TAO project will continue to improve upon its web pages for data dissemination and display. Specifically, we intend to introduce the TRITON salinities, radiation, rainfall, and currents to the TAO/TRITON web pages. Web dissemination of these data is expected to begin in the third quarter of FY 04.

We expect to get TAO and PIRATA salinity data on the GTS in FY 04 by working with Service Argos to develop necessary algorithms. TRITON salinity data are already on the GTS.

We will continue to pursue engineering improvements to the array, specifically those that relate to improved compass accuracy, wind sensor reliability, and improved velocity measurements. We will also investigate the possibility of measuring a high vertical resolution current profile in the upper 50m from an ATLAS mooring.

TAO project staff will participate in the drafting of technical reports. These will include finalizing the results on upward-looking ADCP data processing. The PI will continue his analysis of TAO and related data sets, and his public service. Paul Freitag will continue his service as TAO representative to the DBCP and has already represented the project at the October 2003 meeting of the DBCP in Angra dos Reis, Brazil. He has likewise already represented TAO in FY 04 at the Quality Assurance of Real-Time Ocean Data (QARTOD - I) meeting held in December 2003 at NDBC in Mississippi.

This year, increased effort will be devoted to developing a moored buoy array component as part of an integrated ocean observing array for climate in the Indian Ocean. The PI is a member of the newly formed CLIVAR Indian Ocean Panel and will attend its first meeting (and related meetings) in Pune, India in February 2004.

We expect to accommodate three new ancillary projects on TAO cruises aboard the Ron Brown in FY 04. These are:

- Underway O2 measurements, Jan Kaiser and Michael Bender, Princeton University (BROWN)
- Underway Dimethylsulphide (DMS), Timothy Bates and James Johnson, NOAA/PMEL
- Dimethysulphide (DMS) flux measurements, Barry Huebert and Byron Bloomquist, University of Hawaii

The University of Hawaii Sea Level Center
by Mark Merrifield

FY 2004 PLANS

We will continue the operation and maintenance of our tide gauge network. Planned station visits during FY2004 include Diego Garcia, Kanton, Kapingamarangi, Penhryn (will require major construction or moving the station), Christmas Island (again will require major construction or moving the station), French Frigate Shoals (will require installing a new station when sea wall is ready), Dakar, Salalah, and Masirah.

We are slowly upgrading key network sites to acoustic Aquatrak sensors in place of the older float gauges. An on-site data storage device has also been in development as a back-up system when satellite transmissions fail. This transition could accelerate with more resources (see add task 2).

We have completed 7 GPS installations to date, but we will continue to explore opportunities for further expansion in this area. For example, we have contacted the Azores about a possible installation and the initial response has been quite positive. Similar discussions are being held with the National Tidal Facility concerning their South Pacific gauges, and with agencies in Brazil.

We will continue to explore ways to expand the CLIVAR/GLOSS fast delivery dataset. Our ultimate goal is to provide the entire GLOSS tide gauge network in near-real time. It is this dataset that is used extensively for altimeter calibration and model verification

Real-time applications of tide gauge data are evolving with the advent of GODAE. We are working with the GODAE steering committee to ensure that tide gauge information on this time frame is available through the UHSLC. Given appropriate resources we hope to fully implement the real-time dataset and user interface (see task 3). We will also work with IPRC to ensure that the JASL delayed mode observations are available through the APDRC servers.

We will continue to work on the ncBrowse and Climate Data Portal projects with the goal of integrating all of our datasets and products into these systems. We will also continue to integrate the UHSLC datasets and products into the NVODS, and distribute them through a separate OPeNDAP server at the UHSLC web site. We expect that these efforts will provide the UHSLC datasets in common and easy to access formats for researchers and modeling centers.

The UHSLC proposes working with the *in situ* sea level community as a partner in the GLOSS Development in the Atlantic and Indian Oceans (GAINS) project. In our estimation, a major effort in Africa would be problematic without a pilot program to build infrastructure in at least one or two regions. South Africa appears to be ready to take on the southern region. We believe that Charles Magori of Kenya can lead an initiative in East Africa. Funding to assist with the installation of on the order of 5 new stations for a pilot program might encourage more sustainable funding from outside sources (see Task 5).

Our research effort will focus on understanding the GPS ground motion dataset at each of our tide gauges. Absolute sea level trends will be provided at all GPS@TG stations.

We will continue to work on defining secular and other relative sea level trends at in-situ stations, including trends of various maxima values. This work includes the calculation and correction for any local network trends identified by benchmark surveys.

Program Support for the Assimilation, Analysis and Dissemination of Pacific Rain Gauge Data: PACRAIN

by Mark L. Morrissey, Susan Postawko, and J. Scott Greene

Results from Prior NOAA OGP Climate Observations Projects

- The PACRAIN rainfall database http://www.evac.ou.edu/pacrain/ consists of daily and monthly raingauge data from 643 stations throughout the tropical Pacific, with some records going back into the 1800's. Much of these data have been collected through arrangements with local Pacific meteorological services, as well as New Zealand's National Institute of Water and Atmospheric Research, Meteo-France, and the U.S. National Climatic Data Center. There is no other such comprehensive and up-to-date rainfall database in existence. It has taken over 15 years to compile these data with support from NOAA.
- The Surface Reference Data Center (SRDC), which is a sub-program of the Global Precipitation Climatology Project (GPCP), has been funded by the Climate Observation program for several years. This quasi-operational, quasi-research center produces surface precipitation products from raingauge networks of sufficient density world-wide to be useful for comparisons with satellite rainfall estimates for verification purposes. The products are placed on the internet (http://www.evac.ou.edu/srdc/) for easy download by the research community. In addition, the SRDC develops and implements new statistical methodologies to facilitate satellite rainfall verification experiments. The SRDC is housed at the Environmental Verification and Analysis Center (EVAC) at the University of Oklahoma.
- The Schools of the Pacific Rainfall Climate Experiment (SPaRCE; http://www.evac.ou.edu/sparce/).), funded initially by NOAA, has over 200 schools, technical centers and other local organizations across the Pacific interested in taking part in the global climate research effort. Each organization is equipped with a direct read raingauge, a GPS, a camera, and detailed instructions on setup and maintenance of a professional weather observation site. Several sites are equipped with instruments in addition to raingauges, such as thermistors and hygrometers. Each local participant group takes daily rainfall measurements, which are quality controlled and then provided to the research community through inclusion in the PACRAIN database. The SPaRCE program also supplies participants with education materials (e.g. books, video tapes) and workshops in an effort to increase awareness of the necessity of enhancing the quality and quantity of Pacific environmental data. It is extremely important to the participants that their efforts make a direct and vital contribution to the global effort of understanding climate change and the potential effects of such a change on their specific locales. The SPaRCE program is an internationally recognized program, and just received an excellent review from the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) (http://www.unescap.org/drpad/vc/conference/ex_pi_167_spr.htm)

Statement of Work

Introduction

The goals of the proposed project are: 1) to facilitate the collection and analysis of raingauge data in environmentally critical locations in a cost-effective manner; 2) to assimilate and disseminate these data and information management support activities needed to assure the availability of critical data sets to a variety of national and international programs of primary interest to the Office of Global Programs (OGP; especially the Global Precipitation Climatology Project, GPCP) and PI-GCOS (Pacific Island Global Climate Observing System); 3) to provide data and information management support related to cross-cutting science efforts necessary to assess long term climate changes; 4) to conduct research into new seasonal forecast methodologies using artificial intelligence; and 5) to utilize new and existing methodologies in conjunction with the research community to provide a solid foundation for establishing confidence in various satellite rainfall algorithms, especially those to be utilized by the GPCP for estimating global precipitation.

The key to understanding the world's climate lies primarily within the Pacific Ocean. While the Climate Observation element of OGP is focusing on monitoring ocean properties, they also recognize the important physical links between oceans and the atmosphere, especially the rainfall process. Rainfall influences many ocean properties, such as salinity and concurrent density changes, sea surface temperature, and local ocean circulation. The understanding of these physical links is especially vital within the tropical Pacific because of the tremendous amount of heat energy stored in that ocean, and the resultant catastrophic release of this energy through phenomenon like the El Niño/Southern Oscillation. Current hypotheses suggest that the initial signs of global warming will, or are, happening within the tropical Pacific. For example, one specific hypothesis suggests that global warming may be producing a multi-decadal scale change in the Pacific regional hydrologic cycle (Morrissey and Graham, 1996). Thus, to model interannual and longer-term climate change, tropical rainfall measurements are essential.

Rainfall measurements on islands alone will be insufficient to meet model requirements. Many models require spatial and temporal densities of measurements that can only be obtained by using satellite data. However, without surface island raingauge observations, the satellite rainfall estimates are of unknown accuracy. Even radar measurements, due to their indirect inference of rainfall from active microwave reception, require raingauge measurements to assess their accuracy. In addition, with the exception of the radar located on Kwajalein atoll, all other current radar sites in the Pacific are located inland or along coastal regions. Programs such as NASA's Tropical Rainfall Measuring Mission (TRMM, Simpson et al., 1988), whose goal is to measure tropical rainfall from a dedicated satellite, must have their rainfall algorithms validated in order to understand the validity of the underlying physics associated with the construction of these algorithms. However, besides the tropics, there are other regions of the world where rainfall estimation through satellite observation is just as important for climate assessment and satellite verification (e.g., the GEWEX America Prediction Project regions). Thus, it is imperative that raingauge data sets be obtained for these regions as well. While island-based raingauges cannot measure open ocean conditions directly, gauges located on atolls have been shown to be fairly representative of open ocean conditions (Lavoie, 1963). Nearby buoy rainfall measurements, such as those taken from siphon gauges on the TAO/TRITON array (Payne et al., 2002), can be compared using statistical measures (Morrissey et al., 1994) to atoll-site gauges. Thus, there is a direct link to atoll-based rainfall measurements on low-lying atolls and rainfall measurements made on buoys where the accuracy needs to be assessed.

The Environmental Verification and Analysis Center (EVAC) at the University of Oklahoma currently houses the Surface Reference Data Center (SRDC), a GPCP program. The SRDC's primary mission, in support of the GPCP specifically and the research community in general, is the assimilation, analysis and dissemination of global raingauge data sets for the purpose of validating satellite rainfall algorithms. EVAC has a history of providing raingauge data sets to the research community. For example, the comprehensive Pacific rainfall database (PACRAIN, Morrissey et al., 1995), which is part of the SRDC data base, is the most extensive Pacific island raingauge data base in the world. Data have been collected from hundreds of Pacific island stations, with some records going back as far as the 1800's. It is currently available to scientists on-line (www.evac.ou.edu/pacrain). Data analysis and quality control of these data is essential and is considered an operational task since data collection in the Pacific is a variable and sometimes inconsistent process.

Unfortunately, for many reasons (primarily economic) the developing Pacific Island nations do not have the resources to sustain, much less build upon, the observational weather and climate networks within the Pacific. Given that the Pacific Ocean represents one-third of the global surface area, this presents a tremendous gap in the global observational network. This deficiency has been recognized by the international community, and as a consequence the Global Climate Observing System (GCOS) and in particular the PI-GCOS (i.e. Pacific Island Global Climate Observing System, Salinger et al., 2002) programs have been put together to help maintain and enhance the observing capabilities of the developing countries, benefits of which feed back to more developed countries.

Proposed Work

a) Expansion of Pacific Rainfall Network (PACRAIN) and the Schools of the Pacific Rainfall Climate Program (SPaRCE) in Support of OGP Climate Observations and PI-GCOS

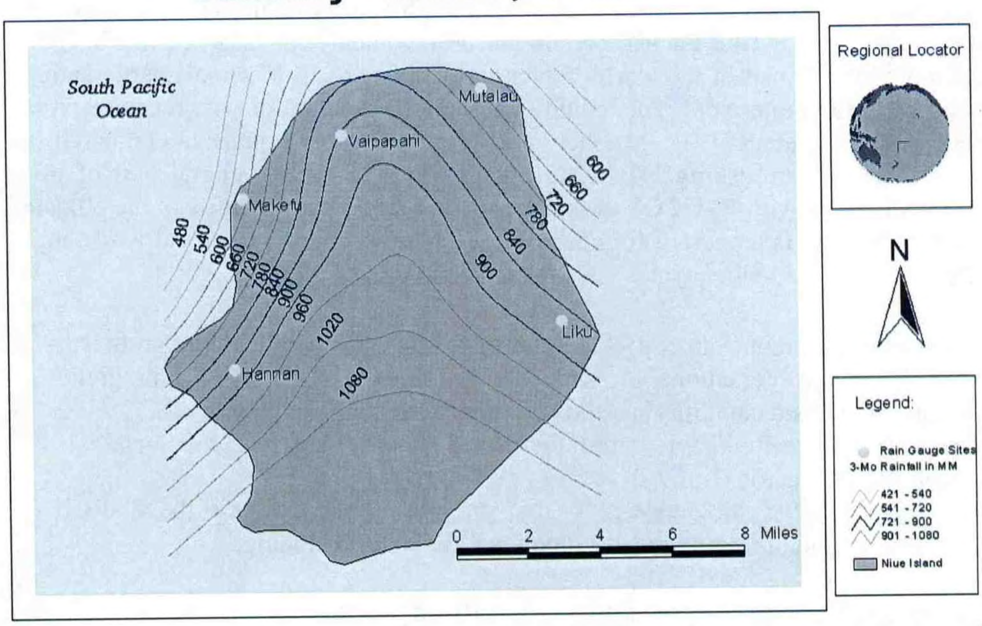
Relationship to PI-GCOS

The Pacific Island Global Climate Observing System (Salinger et al., 2002) is a multinational approach to enhancing the weather and climate observational network in the critically important tropical Pacific region. Presently, NOAA has taken the lead in this activity through an administration initiative called the Climate Change Research Initiative (CCRI). However, the intent is obtain support for developing nations from many other nations and NGO's. As PI-GCOS and OGP's Climate Observation's program are closely related, we intend through our proposed work to help meet some of the objectives of both programs through a cost-effective manner of leveraging work accomplished and work proposed.

Our future work will primarily address items of relevance to the Climate Observation Element and PI-GCOS. We are requesting support for expanded activities of the EVAC/SRDC and support for the enhancement of the PACRAIN database through collaborative ventures with Pacific Island Meteorological Services and work through the SPaRCE program. Several experimental collaborative projects (i.e. pilot projects) are already ongoing. They include collaboration with the Kiribati, Vanuatu, Niue and Tuvalu Meteorological Services. In addition, several other projects are being proposed. This collaboration has resulted in raingauge sites on 15 atolls in Kiribati that previously had no raingauges located on them. This was accomplished by supplying training, data analysis and minimal logistical support to the Kiribati Meteorological Service. The Kiribati Meteorological Service obtains a much-needed local raingauge network and the research community obtains a much needed enhancement of the Pacific raingauge climate network. We are now obtaining rainfall data from these atolls on a regular basis. Discussions with other Pacific Island Meteorological Directors have resulted in a strong willingness on their part to also be included in this collaborative effort. An example of a successful collaboration is shown below, where the Niue Meteorological Service recently installed six new raingauges around the island (the figure below does not show the 6th gauge, which was installed on the southern portion of the island). These pilot projects cost approximately \$3,000-\$5,000 USD /year/met service. While PI-GCOS includes activities to enhance the overall climate and weather networks in the Pacific (i.e. not just rainfall), we consider our proposed effort as a way to initiate some of the proposed projects in the PI-GCOS action plan (Salinger et al., 2002). For example, Section 2 of the PI-GCOS action plan is to advocate the social, cultural and economic importance of climate observing systems to local governments and users of such observing systems. This is the basic tenet of the SPaRCE program itself. In addition, the PI-GCOS action plan suggests pilot projects which should lead, through learning, to self sustaining larger scale projects. As mentioned above, we are already doing this in part and hope to facilitate PI-GCOS plans through collaboration.

Island nations currently interested in working with us in this venture include the Cook Islands, Vanuatu, Niue, Tuvalu, the Federated States of Micronesia, and Kiribati. The strategy includes close cooperation and collaboration among all entities in sharing information and resources. This also includes the U.S. National Weather Service, which supports various operations on many of these islands.

Niue 3-Month Rainfall Accumulations
January - March, 2002



We have also established strong links to NCDC, New Zealand Institute of Water and Atmosphere (NIWA) and the French Polynesian Meteorological Service in order to reduce the time it takes to get data merged and available to the research community. These links are also crucial for the successful implementation of the PI-GCOS program. One of tasks recently accomplished is the updating of the metadata catalog. For example, there are several stations for which station location, time of observation, or gauge elevation had not been identified. In addition, the maximum elevation of the island or atoll was not included. These tasks have been completed which now allow researchers to filter out potential orographic influences on precipitation from the open-ocean data set. Most of this metadata information has come directly from the local meteorological services in the Pacific.

The School of the Pacific Rainfall Climate Experiment (SPaRCE, Postawko et al., 1994), initially funded by NOAA's OGP in 1992, contributes a significant portion of the rainfall data available on atolls and islands to the SRDC. One of the primary concerns of scientists with student-collected data is data quality. Thus, our protocols for siting, maintaining and collecting data are very stringent. As a check of the site, each school is required to photograph their site and setup, plus provide a map of the surroundings. This gives us a qualitative assessment of the site setup. All the data is passed through the same quality control programs as the data from the standard meteorological station data.

Since this program started we've discovered some very interesting facts concerning people living on small islands in the Pacific. Having extremely little means of educational support, students and teachers tend to take ownership of their meteorological equipment. In many cases the school is better equipped than the local meteorological station. Because of this we strive to strengthen connections between each school and their local meteorological office. This has been successful in the sense that the local meteorologists take an active interest in the student's activities and, in most cases, help out with recruitment. The local governments and meteorologists see SPaRCE as the most efficient and cost effective way to enhance their own local weather networks. SPaRCE has approximately 200-300 schools and other organizations across the Pacific participating in the program.

The SPaRCE program provides both educational material and equipment to the schools free of charge. In return, the scientists receive daily data and plus many intangible assets, one of which is a better appreciation by the Pacific people and governments for large scientific field experiments carried out in their part of the world. Potentially, the number of schools participating in the Pacific could be in the thousands. This could quadruple the amount of data received from this very important location. SPaRCE is extremely cost effective and inexpensive compared to similar programs. Thus, we are asking NOAA to regard SPaRCE as an integral part of this proposal and it's collaboration with PI-GCOS in that it provides significant benefits to the climate research community. Funding is requested for educational materials and several local workshops to be given throughout the next funding cycle.

SPaRCE has been operational since 1992. Funding for such an operational program is usually difficult. However, the international recognition of the benefits of the SPaRCE program to both developing and developed countries has allowed funding to continue. The SPaRCE program has just received an excellent review from the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) (http://www.unescap.org/drpad/vc/conference/ex_pi_167_spr.htm). Descriptions of the SPaRCE program can found on a myriad of international and national web sites including:

http://www.unescap.org/mced2000/pacific/background/sparce.htm

http://unfccc.int/resource/ccsites/marshall/activity/sparce.htm

http://www.bom.gov.au/info/weatherkit/section4/prog.shtml

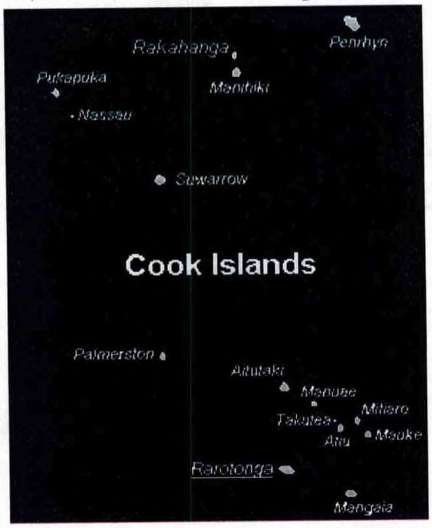
http://www.nsf.gov/sbe/nuggets/006/nugget.htm

b) Proposed Pilots by Pacific Country

Cook Islands

The Cook Islands are made up of two sets of islands: the Southern Cooks, a group of moderately large islands; and the Northern Cooks which are all low lying atolls. The Northern Cooks would be invaluable for data collection given that they are isolated, located in an environmentally important region of the Pacific just south of the equator, and are likely to well represent open ocean conditions. They are also quite close to the TAO/TRITON buoy array containing siphon raingauges. The Cook Island Meteorological Service is located on Rarotonga, one of the Southern Cook Islands, and thus have little real time communication with the Northern Cook Islands. The

Meteorological Director, Mr. Arona Ngari, intends to utilize the pilot funds to install at least one raingauge site at each school in the Northern Cooks. This will be accomplished in conjunction with the Cook Island Education Department. Quoting from Mr. Ngari "I can arrange with the Education Department for an approval of sights on the school grounds and then have an officer from the office install and educate the schools on how to read and operate the programme".



In addition, Mr. Ngari plans to install FM radio sets through a program that the Cook Island Telecom has already put in place. The Telecom group has quoted a figure of $750 per transmitter. Thus, if this proposal is funded each island could report rainfall to the Meteorological Service on a daily basis. The funding would allow for 6 systems. Considering the remoteness of these islands, some of which are close enough together to share one node, only 7 are required for the outer islands. Thus, for a relatively small amount of funds a huge area of the Pacific could soon be collecting climate and weather observations through which proof of concept can be used to justify larger projects such as PI-GCOS.

Vanuatu

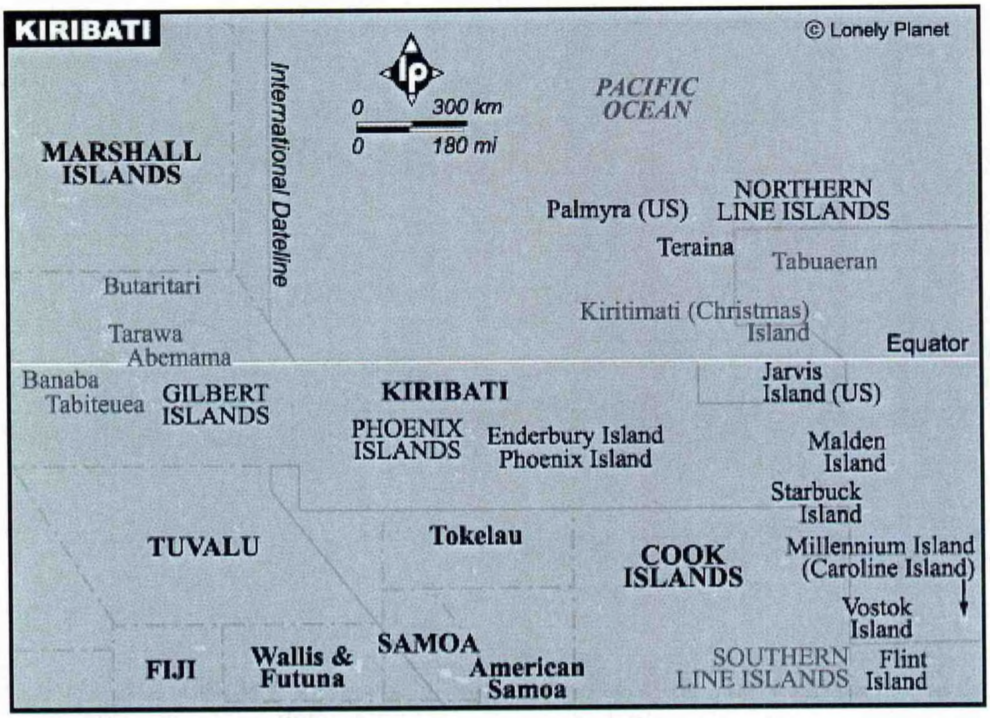
Vanuatu, located in the southwest tropical Pacific, consists of a very large set of islands and is located near the rainfall maximum in the Pacific (Morrissey and Graham, 1996). Presently, Mr. Jotham Napat, the Director of the Vanuatu Meteorological Service has 100 raingauges that were sent to him from us through an internal University of Oklahoma Grant. Given the size of Vanuatu (87 islands), Mr. Napat says, "One island could have about 5 to 10 sites or more". They are also in need of a real time communication system. At some locales FM transmitters may be appropriate. However, this need is currently being addressed by the Pacific Communications Exploratory Workshop Steering Committee, which is working in collaboration with PI-GCOS to establish timely communication setups with remote villages. Mr. Napat plans to utilize the pilot project funds to purchase additional gauges, GPS units (for siting) and possibly a computer for data assimilation and communication. They also intend to collaborate with the Vanuatu Hydrology Department who are also establishing gauge sites. The collaboration will strengthen both educational and data exchange links not only within Vanuatu, but with the global research community as well.

Country of Vanuatu

Kiribati

Kiribati is one of the largest counties in the world in terms of total ocean area. It extends from just west of the dateline on the equator, eastward to about 140W, and roughly from 10N to 10S. The nation is totally composed of low-lying atolls in the critical central equatorial Pacific where the El Niño signal is strongest. Thus, it can potentially provide an extremely valuable set of observing platforms for climate study. The Meteorological Director, Mr. Tekena Teitiba, intends to utilize funds from the pilot project to acquire 20 additional raingauges, several maximum and minimum thermometers, one complete anemometer for wind speed and direction, and the remainder of the funds are to be used for airfare and subsistence for site installation.

It should be noted that there are almost no observations currently made on many of the outlying islands. Mr. Teitiba intends to partially rectify this problem in a very cost effective manner. The benefits to the research community from long-term observations from these atolls would be tremendous.

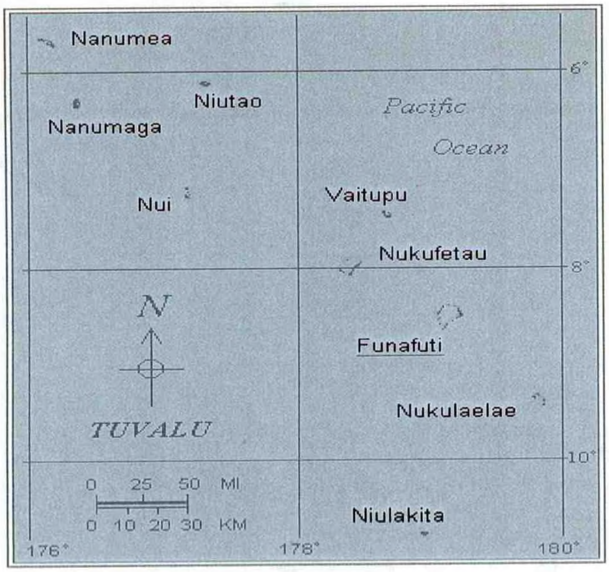


Niue

Niue is a small raised atoll located south of Samoa just east of the dateline. The Meteorological Director of Niue, Mr. Sionetasi Pulehetoa, is in need of a Climate Trainee to help maintain the SPaRCE program in Niue. In his words "I am thinking of establishing a local post for a Climate Trainee in the Niue Met Service. The person may be required to input all rainfall data for Niue under SPaRCE and transmit electronically to your office on a monthly basis. This will be a quicker way of getting the data rather than by postage. All we have to do is to prepare an Exel spreadsheet for each station into one of our computers for this purpose. The person may also be required to record the climate data for all climate and rainfall stations in Niue and other met duties. This extra staff may be very helpful to assist the Niue Met Service duties. The annual salary for the Climate Trainee is $9,000 per annum. The employment will depend on the funding. If not fully funded the person can be employed on a part-time basis. Very much appreciate your experience and assistance with this request."

Tuvalu

The Director of the Tuvalu Meteorological Service, Ms. Hilia Vavae, intends to utilize funds from the pilot project to hire a climate officer to collect and maintain records on these important low-lying atolls. In addition, she plans to use some of the funds for needed communication costs to bring data to Funafuti from the other eight atolls. It should be noted that Tuvalu is located in the middle the climatological rainfall maximum in the Pacific (Morrissey and Greene, 1991) and that quality rainfall data from these atolls are especially crucial to monitoring ocean and atmospheric conditions in the physically significant heart of the Pacific, specifically the El Niño phenomenon.



Summary of Pilot Projects

It should be emphasized that the total annual cost of the proposed pilot projects is approximately \$32,000 per year. Compared with other network implementation projects, especially some automated projects, this is an extremely cost effective method of initiating a climate network, not to mention the important, but often over-looked, component of building international partnerships required for the effective maintenance and sustainability of such climate networks. The data obtained will be incorporated into the PACRAIN database, where it can be easily accessed through our web site. In the long-term, it is expected that all weather data collected will be incorporated into a GCOS (or PI-GCOS) database.

We should also mention that a completely outfitted island-based climate network will not substitute for planned and automated network atmosphere and ocean observing systems. The Pacific Ocean is simply too big to expect full coverage through island-based sites. However, islands, especially atolls, have the advantage of being stable platforms and, depending on the variable measured, relatively representative of open ocean conditions. Thus, they make an excellent and necessary compliment to automated observing systems.

c) Operational Support of the GPCP and related programs

Another important component of this proposal is our role as the GEWEX/GPCP validation center referred to as the Surface Reference Data Center (SRDC). As part of the effort to expand the activities of the SRDC, we will continue to collect, quality-assure, and disseminate the PACRAIN database, as well as sample data sets from around the world. The data will be made available through our new web-based retrieval routine. An interactive page has been developed and is on the worldwide web at http://www.evac.ou.edu/srdc/.

We will continue to work on the raw data sets that are ingested into the SRDC. These data sets are from dense networks from both the tropics and the mid-latitudes. Approximately 25 different networks are currently being analyzed. The South Korean Meteorological Service has kindly submitted data from their excellent high temporal and spatial gauge network to the SRDC. Detailed quality-assurance techniques are applied to identify potential outliers. Initial work has revealed inconsistencies in the frequency of rainfall from daily reports in some data sets. For example, some locations report more rainfall on Mondays than during the weekends. These data will to be flagged as suspicious.

The GPCP produces satellite rainfall products on two scales, 1 x 1 degree daily and 2.5 x 2.5 degree monthly. Given the data sets currently in our archive, plus those yet to be obtained, we will produce areal averaged rainfall products at scales corresponding to the comparative satellite products (i.e., at these two scales). One data set of particular interest was provided by the Oklahoma Mesonetwork, operated in collaboration between the Oklahoma Climatological Survey and the Oklahoma State University (Brock et al., 1995; Morrissey and Greene, 1998) which contains well over 100 stations throughout Oklahoma, with a raingauge resolution of 5 minutes. This resolution minimizes temporal sampling error when constructing averages. These data have already been analyzed and areal averages are available on the SRDC web site. Also available is a network of fifty 5-minute resolution gauges (i.e., the piconet) located within a 3 x 3 km^2 area in central Oklahoma. All SRDC products and research results are made available through the worldwide web and our quarterly newsletter, which provides the research community with up-to-date verification-related news and comments from researchers.

We also intend to work collaboratively with Dr. Elizabeth Ebert from the Australian Bureau of Meteorology in producing an interactive web page consisting of preliminary verification results of several satellite rainfall algorithms of relevance to the GPCP. Dr. Ebert pioneered this approach.

d) Research: Development of a Region Specific Seasonal Precipitation Forecast Scheme

A forecasting algorithm for seasonal rainfall at specific locales within the Pacific region would provide a needed tool for local and regional forecasters. The benefits to developing nations would be tremendous, especially in terms of agricultural and water resource management. Another incentive to develop such a scheme is that it would empower local meteorological services within their own governments and facilitate the task of PI-GCOS and the collection of climate observations for the research as a whole.

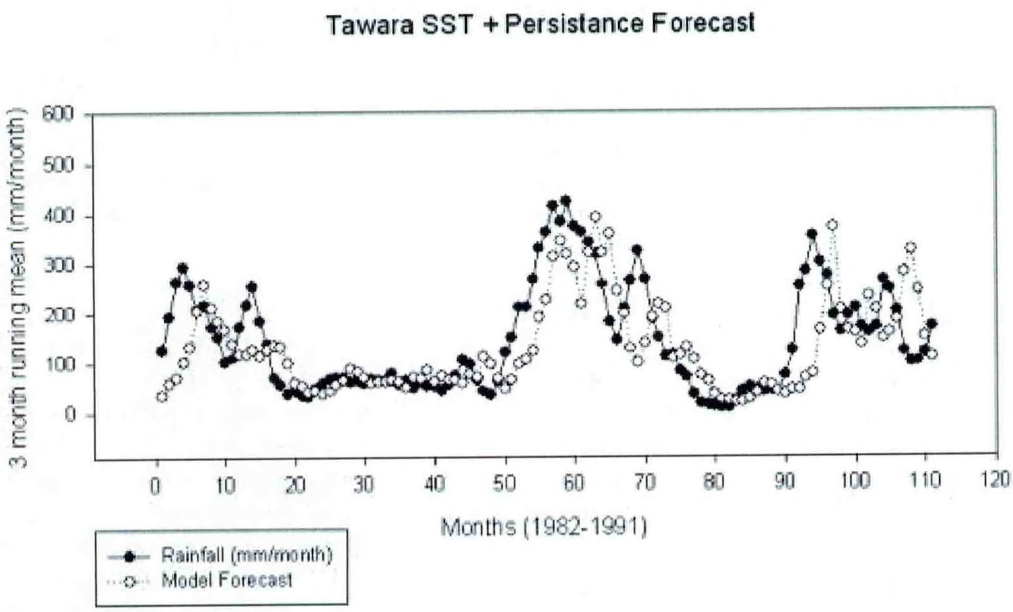
Presently such forecasts are made by the Pacific ENSO Application Center (PEAC) located at the University of Hawaii and the National Weather Service in Honolulu. PEAC produces forecasts for US affiliated islands in the Pacific, and New Zealand's National Institute for Water and Atmospheric Research (NIWA) publishes a quarterly newsletter with seasonal rainfall forecasts for most of the tropical Pacific. Efforts are also on-going at the Australian Bureau of Meteorology. A few years ago PEAC used an objective canonical correlation scheme produced by He and Barston (1996) to predict seasonal, regional rainfall. Presently, both PEAC and NIWA utilize subjective and large model forecasts to regionalize their own forecasts. We intend to work collaboratively with these organizations in producing an objective regional model(s) which then could be ported to each local meteorological service to run on a personal computer.

Forecast Methodology

The term 'exploratory data analysis' was coined largely by John Tukey and colleagues (Chambers et al. 1983). The basic idea was to 'let the data do the talking'. This implies that mathematical/statistical methods can be developed which extract important information from data. This information may not be obvious to the human eye at first, especially non-linear processes. The early Tukey et al. methods were very simple. But now we have a whole range of sophisticated techniques for 'exploring data'. One of the confusing aspects about data mining is the myriad of different approaches to it. However, they can be roughly categorized into 2 approaches; 1) Geographical Information System techniques, which are basically graphical approaches (using computer animation to illustrate data in ways to demonstrate non-obvious relationships among variables) and 2) the use of artificial intelligence (AI) methods. It is the latter that we've had the most experience with and feel may be more useful for the scientific problem of discovering important relationships within data sets. Data mining is relevant to precipitation forecasting when the physical mechanisms pertinent to producing rainfall are unknown. If the relationships do not turn out to be simple, linear ones, but appear to be more complex, then certain AI methods can then be utilized to determine the mathematical nature of this relationship. From the results it is hoped that the physical relationship(s) can be more easily identified and a forecast scheme developed to account for unforeseen physical effects. Two of the increasingly more common AI methods of choice are neural networks (Hagan et al., 1996) and genetic algorithms (Coley, 1999). Our preliminary work suggests that genetic algorithms or its variant, genetic programming, may prove useful in the development of a regional forecast scheme.

The proposed method is based largely on a Genetic Programming (Koza, 1992) approach which incorporates sea surface temperature (SST) and 700 mb geopotential heights to produce local forecasts in the tropical Pacific. He and Barston (1996) demonstrated that these two variables, especially SST, contained information predictive of seasonal weather/climate change in the Pacific. Our goal is to not only identify this information, but to maximize its use in a seasonal rainfall forecasting scheme. Our approach is similar to data mining in that regions where SST is important, and its functional relationships to island rainfall are *not* known *a priori*, can be identified and used to produce a forecast scheme. The scheme basically performs a parallel search to seek out time-space locales related to rainfall for a specific island location and *their functional relationships*. Of course, pertinent information has to be assumed to exist in the data before hand.

After these relationships are discovered, then the physical relationships can be explored in depth. The genetic programming/algorithm search method(s) are based on evolutionary concepts first developed by Holland (1973) and further developed by many other (see Goldberg, 1989). The methodology has since been applied to many different fields; however, we are not aware of any application of genetic programming to date in meteorology. We have developed a prototype model using SST only for rainfall forecasts in Tawara. A preliminary forecast for the island of Tarawa is shown below. Since the prototype model is in the early stages of development an analysis of its result is premature.



Preliminary seasonal rainfall forecast for Tawara (1982-1991). The model was trained using data from 1992-2000.

Once developed, and sufficient skill achieved, we plan to share our development work under the auspices of PI-GCOS with the above mentioned organizations and local meteorological services. The overriding objective is to work with the local Pacific Meteorological services in developing their skill at local forecasts. This will hopefully have the benefit of empowering their services within their own local government infrastructure. This will, we hope, lead to more local support of their activities and thus ultimately lead to a sustainable weather/climate network.

e) Proposed Enhancements of, and Ongoing Work on, the PACRAIN Database

- PACRAIN is being migrated from a simple flat file database to a comprehensive database management system (DBMS). The advantages of a DBMS include better scalability, data integrity and security, and built-in querying and management tools.
- An improved data scheme has been developed. The new scheme is more flexible and allows observations and aggregations at any time scale to be stored. Each record will have more detailed metadata associated with it.
- A new web-based interface is being created. The interface will work with a standard web browser, so anyone with Internet access will be able to download data. Data retrieval will be more flexible and robust than with the current interface.
- Rainfall records are being standardized. Each data source has different conventions for how observations are recorded. The most significant difference is the meaning of the date of record, but there are also differences in the handling of trace accumulations and accumulations which span more than one observation period.
- Historical data (prior to 1971) from Richard C. Taylor's *An Atlas of Pacific Island Rainfall* are being merged with contemporary PACRAIN data. To date, 42 sites have been combined. The period of record for many of these sites is from well before 1971 to the present. For several sites the period of record extends back to the late Nineteenth Century.
- Rainfall data within the database is being checked against source data to eliminate inconsistencies and missing records. Site metadata is also being reviewed and corrected.
- A methodology will be developed for detecting statistical outliers and other anomalies in the data. These will be flagged as part of the metadata.
- Individual sites will be examined to identify patterns of anomalous data which indicate that there is a problem with a site, and that site will be flagged as necessary. For SPaRCE sites it may be possible to correct the problem through correspondence with the observer.

The "Global Drifter Program"

Drifter Measurements of Surface Velocity, SST and Atmospheric Pressure

by Peter Niiler

The motivation for the activities in the period July 2004 - June 2005 is provided by the NOAA Program Plan for Ocean Climate Observations which states that:

" Data sparse regions of the global ocean are a major source of uncertainty in the seasonal forecasts and are also a major uncertainty in the detection of long-term trends in global sea surface temperature, which in turn is an indicator of global change. Data gaps must be filled by surface drifting buoys to reduce these sources of error to acceptable limits. NOAA, together with international partners, will extend the global SST/velocity drifting buoy array to data sparse regions, increasing from 800 *in 2004* * to 1250 buoys by 2005, while adding wind, pressure, and precipitation measurement capabilities to serve short term forecasting as well as climate research, seasonal forecasting, and assessment of long term trends" (*added by JIMO).

Anticipated requirements to maintain the "Global Surface Drifting Buoys Array at status quo:
With the current attrition rate of the global drifter array due to all causes (e.g. deployment failures, picked up, gone ashore, stopped working, etc.), the array needs effectively to be replaced every year. This conclusion is based on the observation that a global array of about 600-650 drifters was in the ocean during 1997-2002. During this time about 420 drifters per year were acquired by *GDP*, 100 drifters from individual research proposals and 120 drifters from the operational meteorological community, or a total of about 640 drifters each year were deployed. Thus the FY'03 purchases of 720 drifters and the expected international contributions of 180 drifters (DBCP-19), an array of 900 drifters would be in placed into the ocean by the end of 2004 or early 2005.

To keep the status quo of a 900-element drifter array in the ocean in 2005, GDP needs to acquire 740 drifters in FY'2004.

To increase this array to 1250 by 2005, as called for by the NOAA plan, an additional 350 drifters need to be deployed over what is required for the status quo. Since it is reasonable to expect that the international and research communities will to acquire 60-80 SVP drifters in addition to what they now deploy (e.g. Australia stated in DBCP-19 that funds will accrue in 2004 for such an endeavor), *GDP* will need to purchase an additional 270-290 drifters in FY 2004. A budget for 274 additional drifters is presented below.

The complete SST/Velocity array of 1250, the required drifters can be acquired within the expected funding levels of the NOAA climate observing system for FY'2004 (an additional $530,000 for drifters and deployment costs). The addition of barometers and wind sensors will require significant increases in funding. To place barometers on every GDP drifter requires additional barometers (@$1100), at an additional yearly cost of $1,100,00. To place wind sensors on every GDP drifter requires an additional WOTANs (@$3500) at an additional yearly cost of $3,800,000.

Logistical Requirements
Presently, most of the global drifter array is deployed from the "Volunteer Observing Ships" (VOS) and research vessels. Requirements are also to deploy Minimet drifters in front of major hurricanes that threaten the US mainland. The VOS and research fleet do not cover large areas of

the ocean and ships avoid hurricanes. To meet the objective of global coverage, *GDP* (and Argo) requires the use of long range C-130 aircraft for air-deployment. Between 1994 and 2002 the Mississippi Air National Guard provided air-deployments as part of their training missions on irregular intervals. With their commitments to the extended conflicts in the Middle East, they are no longer able to do so.

It is proposed that the NOAA Ocean Climate Observations Program acquire the use of a C-130 aircraft for the purpose of air-deployment of drifters and floats, especially in the Southern Oceans or where sensors leave quickly. Arrangements for deployments from air in front of hurricanes have been arranged through cooperation with the NOAA/Hurricane Center at AOML and the 53rd Wing of the Air Force Reserve, stationed in Keesler AFB, MS. The required number of hours and flight times should be coordinated between the *GDP* and Argo programs. OGP should call together a small workshop to discuss and plan for the coordinated needs of remote deployments of autonomous systems for the Global Ocean Observing System and present the requirements to NOAA Administrator.

Technical Developments and Data Enhancements

In 2004 we will continue to pursue the construction and evaluation of SSS sensors. Plans are to construct at least 5 SVP drifters with new SSS sensors developed by Ray Schmitt and Niel Brown at WHOI and the SeaBird Microcats we have been using. A comparison experiment will be done near the near Bermuda with recoveries from with the HOME site vessel several months to several seasons after deployment. Additional SeaBird Microcats will be deployed in the North Atlantic with the cooperation of the French Meteorological Service in the Bay of Biscay, who have offered to retrieve these for post-calibration during their regular cruises to service moored buoys in the deep ocean. Presently, we have had two recoveries of SSS sensors in the western Pacific and more are needed. The principal technical issues are how quickly will the SSS sensors foul and how can their life be extended.

Since 1998, 8-10 wind-sensing drifters had been deployed by AOML into the "hurricane alley" of the North Atlantic before the hurricane season started. Our study of these data showed that none had experienced even gale force winds. We are in the midst of learning how to air-deploy Minimet wind-sensing drifters more directly into hurricanes. With the cooperation of ONR/CBLAST program, the NOAA/AOML Hurricane Center and the Air National Guard 53rd Squadron "Hurricane Hunters" we successfully deployed 14 Minimet drifters in front of "*Fabian*", a class 4 hurricane in September, 2003; 8 Minimets provided good atmospheric pressure and wind-direction data through the central "eye" of "*Fabian*". In 2004, we plan to place a coherent array of 38 drifters in front of a mature Atlantic hurricane. The principal technical issues are how well can a WOTAN, or ambient noise, measure gale force and higher winds and can hurricane area rain rates be determined from these sensors.

Drifter velocity data enhancements will continue. We propose to continue the wind-slip corrections to the drifter velocity data set on a six-month basis and make requested gridded data available to the scientific community. We have now received the PMEL raw ARGOS data set from over 240 drifters near Alaska and in the Bering Sea and will process these so scientific use can be made more easily. These have large drogues centered at 40m so interpretations will require a different tack than we use with SVP drifters.

Climate Variability in Ocean Surface Turbulent Fluxes
by James J. O'Brien, Mark A. Bourassa, Shawn R. Smith

FY 2004 PLANS

- Complete 1978-present 1° wind analyses for Pacific and Indian Oceans
- Evaluated methods for extending Pacific and Indian Ocean fields prior to 1978
- Begin wind fields for tropical Atlantic Ocean
- Begin flux field production
- Begin calculation of wind uncertainty fields
- Continue comparisons of FSU winds and fluxes to available products
- Complete development process for of satellite scalar winds
- Begin development process of satellite SST
- An objective technique for determining appropriate periods for temporal averaging of satellite data.

The extension of our technique to produce 1° fields north of 30°S was not anticipated during our initial proposal. The higher resolution fields provide greater detail in atmospheric fields (e.g., Somali Jet), but also result in a new set of challenges. We are working on more sophisticated automated quality control procedures to simplify the visual data editing. There are physically significant differences between the characteristics of SST observations from different satellite instruments and times of day. We are collaborating with members of the GODAE GHRSST team to aid in a timely solution to these issues.

Quality-Evaluated Meteorological Data from Research Vessels
by James J. O'Brien, Mark A. Bourassa, Shawn R. Smith

FY 2004 PLANS

- Continue QC for specified NOAA ships
- Download and QC AutoIMET data sets from two VOS
- Evaluate and improve QC system in light of experience with NOAA and VOS-IMET data
- Create data sets of co-located R/V, satellite, and gridded (FSU and reanalysis) turbulent fluxes
- Statistical analysis of co-located flux data
- Evaluate pressure sensors problems

Collection and quality evaluation of the AutoIMET data from VOS will likely reveal new problems and challenges associated with high-temporal frequency meteorological measurements on merchant vessels. Past experience has shown that each new ship installation, even on R/Vs, introduces new and unexpected problems. These problems can be related to differing installation locations, variations in flow distortion, and differing operating environments for each vessel.

We anticipate some exciting new results as we begin comparing R/V observations to the meteorological and flux fields from the new ECMWF 40 year reanalysis (ERA40) and the 2nd NCEP reanalysis. This work has been delayed by the slow release of ERA40 to the research community. We anticipate access to the flux fields by early 2004.

In situ and Satellite Sea Surface Temperature (SST) Analyses
by Richard W. Reynolds

FY 2004 PLANS

During FY2004 we plan on working on three topics funded by this proposal. The first is to use more satellite SST data sets in the OI. These sets will include the new microwave products from AMSR and from WindSat. These data will be available through Remote Sensing Systems (Santa Rosa, CA). In addition IR data from the Moderate Resolution Imaging Spectroradiometer (MODIS) will be used. The MODIS work will be delayed until the early 2004 when the current algorithm recalibration will be complete. The MODIS data will be available from JPL.

Our second task is to complete the buoy need product. Our highest priority is to work with AOML to fine tune a product like the results shown in figure 2. This would most likely be a seasonal product, which would be made available operationally. This product and previous products beginning in 2000 would be kept on line for interested users. In addition, a research paper on the results will be prepared for the Journal of Climate.

Our third topic is to produce a better SST metric. This metric is an indicator of SST accuracy. Initially, this seemed like an easy task. However, as discussed above, the SST accuracy is already acceptable if there are no satellite biases. Because we don't know when these biases may occur, we must have an *in situ* network in place that corrects any satellite biases. Thus, we plan to design the metric from the buoy need work. From the buoy need work we defined the potential SST bias error based on satellite SST biases simulated by six EOFs with different buoy densities. The metric will be defined from the potential SST bias error. Then, the individual 10° values will be converted to a global value.

Ocean Reference Stations and

Northwest Tropical Atlantic Station for Flux Measurement (NTAS)

(Project Period: 01 July 2003 – 30 June 2004)

by Robert A. Weller and Albert J. Plueddemann

FY2004 PLANS

We plan to acquire four acoustic releases in this year to facilitate and control costs in maintaining the three sites. We will likely deploy the Hawaii site early in FY2004, probably in July 2004, moving ahead in consultation with the program manager and because of our readiness to do so. This is an advancement of our original plan, which had the Hawaii site starting in the summer of 2005.

Maintaining three sites will require a pool of hardware (buoy hulls) and instrumentation, ongoing maintenance of the buoy hull and meteorological and oceanographic instrumentation, fabrication of mooring components, ship time (detailed further under each task), labor for preparation and work at sea, calibrations support, ARGOS telemetry costs, work station and disk support, repair, and replacement, and support of data recovery from the instrumentation, processing, sharing. We are examining shifting from Service Argos to IRIDIUM for data telemetry.

<u>FY 2004 Add Tasks</u>:

We have advanced the schedule for building and testing the hardware for the Hawaii site; we plan to deploy there if funds are available. If funds are insufficient or if ship scheduling difficulties arise so that we cannot get a vessel for Hawaii in July 2004, or if we have to trade off funding for that ship to ensure we can get funded for the ship time needed to continue Stratus or NTAS, then we would defer the Hawaii deployment to 2005.

The rationale to do the deployment in FY2004 so is that we will have the meteorological instrumentation and hardware ready, the cooperating PI (Lukas) will have the ocean instrumentation ready, and that we would thus move faster toward engagement with the communities that use the data from the Ocean Reference Stations.

CHAPTER 4

STATE OF THE SCIENCE

This final chapter contains selected abstracts and a bibliography of FY 2003 publications from scientific journals treating the global observation of ocean heat, carbon, fresh water, and sea level change. A select number of abstracts of particularly relevant scientific papers are presented first, chosen by the principal investigators (PI) of the science projects funded by NOAA's Office of Climate Observation. Website urls follow the bibliographic reference if the publication and expanded abstract can be found online.

4.1 Selected Abstracts

Bourassa, M. A., D. M. Legler, J. J. O'Brien, and S. R. Smith, SeaWinds validation with research vessels, *Journal of Geophysical Research, 108(C2),* doi:10.1029/2001JC001028, 2003. http://www.coaps.fsu.edu/~bourassa/publications.shtml (6th from top of page)

ABSTRACT

The accuracy of vector winds from the SeaWinds scatterometer on the QuikSCAT satellite is assessed, for rain-free conditions, through comparison with observations from research vessels. Several factors that contribute to uncertainty in scatterometer winds are isolated and examined as functions of wind speed. The independent sources of uncertainty considered herein are ambiguity selection, wind speed, wind direction (for correctly selected ambiguities), variability associated with spatial separation between scatterometer and ship observations, and random errors in the ship observations. Rain-related errors, which are functions of wind speed and rain rate (hence varying on an event to event basis), are not examined. Ambiguity selection refers to the selection of a unique scatterometer wind direction from multiple likely solutions. For SeaWinds on QuikSCAT, in rain free conditions, ambiguity selection is found to be near perfect for surface wind speed (w) > 8 ms^{-1}; however, ambiguity selection errors cause the directional uncertainty to exceed 20° for $w < \sim 5$ ms^{-1}. Improved statistical methods that account for the spatial variability in the winds and uncertainty in the ship data are applied to determine uncertainties in speed and direction separately for correctly selected ambiguities. These uncertainties (averaged over the full comparison set) are found to be 0.45 ms^{-1} and 5° for the QSCAT-1 model function and 0.3 ms^{-1} and 3° for the Ku-2000 model function.

The QuikSCAT winds are examined as vectors through two new approaches. The first is a method for determining vector correlations that considers uncertainty in the comparison data set. The second approach is a wind speed dependent model for the uncertainty in the magnitude of vector errors. For the QSCAT-1 (Ku-2000) model function, this approach shows ambiguity selection dominates uncertainty for $2.5 < w < 5.5$ ms^{-1} ($0.6 < w < 5.5$ ms^{-1}), uncertainty in wind speed dominates for $w < 2.5$ ms^{-1} and $5.5 < w < 7.5$ ms^{-1} ($w < 0.6$ ms^{-1} and $5.5 < w < 18$ ms^{-1}), and uncertainty in wind direction (for correctly selected ambiguities) dominates for $w > 7.5$ ms^{-1} ($w > 18$ ms^{-1}). This approach also shows that spatial variability in the wind direction, related to inexact spatial co-location, is likely to dominate rms differences between scatterometer wind vectors and in-situ comparison measurements for $w > 4.5$ ms^{-1}. Similar problems will exist with many validation efforts. The techniques used herein are applicable to any validation effort with uncertainty in the comparison data set or with inexact co-location. Application of these techniques leads to more accurate estimates of observational uncertainty.

Bretherton, C. S., T. Uttal, C. W. Fairall, S. E. Yuter, R. A. Weller, D. Baumgardner, K. Comstock, and R. Wood, The EPIC 2001 Stratocumulus Study, *Bulletin of the American Meteorological Society*, to appear, 2003. http://www.ofps.ucar.edu/epic/publications/publication_refs.html (2nd from top of page)

ABSTRACT

Overlaying the cool southeast Pacific Ocean is the most persistent subtropical stratocumulus cloud deck in the world. It produces a profound affect on tropical climate by shading the underlying ocean and by radiatively cooling and stirring up turbulence in the atmosphere. In October 2001, the East Pacific Investigation of Climate undertook an exploratory cruise from the Galapagos Islands to Chile. The cruise gathered an unprecedented dataset integrating radiosonde, surface, cloud remote sensing, aerosol, and ocean measurements. Scientific objectives included measuring the vertical structure of the ABL in this region, understanding what physical processes are determining the stratocumulus cloud albedo, and understanding the fluxes of heat and water that couple the atmosphere and the ocean in this region.

An unexpectedly well-mixed stratocumulus-capped boundary layer capped by a strong inversion was encountered throughout. A strong diurnal cycle was observed, with thicker clouds and substantial drizzle (mainly evaporating above the sea surface) during the late night and early morning. This was driven in part by local diabatic processes but was reinforced by a surprisingly pronounced diurnal cycle of vertical motion. The vertical motion appears to be an inertia-gravity wave driven by daytime heating over South America that propagates over 1000 km offshore. Much more nocturnal drizzle and pronounced mesoscale cellularity were observed in 'clean' conditions when cloud droplet concentrations and aerosol concentrations were low. Entrainment of dry, warm air is inferred to be the primary regulator of cloud thickness in this region, but drizzle also appears to have a large indirect impact by inhibiting and changing the spatial organization of turbulence.

Brunke, M. A., C. W. Fairall, X. Zeng, L. Eymard, and J. A. Curry, Which bulk aerodynamic algorithms are least problematic in computing ocean surface turbulent fluxes?, *Journal of Climate*, *16*, 619-635, 2003. http://ams.allenpress.com/amsonline/?request=get-abstract&issn=1520-0442&volume=016&issue=04&page=0619 (abstract only)

ABSTRACT

Bulk aerodynamic algorithms are needed to compute ocean surface turbulent fluxes in weather forecasting and climate models and in the development of global surface flux datasets. Twelve such algorithms are evaluated and ranked using direct turbulent flux measurements determined from covariance and inertial-dissipation methods from 12 ship cruises over the tropical and midlatitude oceans (from about 5°S to 60°N). The four least problematic of these 12 algorithms based upon the overall ranking for this data include the Coupled Ocean–Atmosphere Response Experiment (COARE) version 3.0 and The University of Arizona (UA) schemes as well as those used at the European Centre for Medium-Range Weather Forecasts (ECMWF) and the National Aeronautics and Space Administration (NASA) Data Assimilation Office for version 1 of the Goddard Earth Observing System reanalysis (GEOS-1). Furthermore, the four most problematic of these algorithms are also identified along with possible explanations. The overall ranking is not substantially affected by the use of the average of covariance and inertial-dissipation flux measurements or by taking into consideration measurement uncertainties. The differences between computed and observed fluxes are further evaluated as a function of near-surface wind speed and sea surface temperature to understand the rankings. Finally, several unresolved issues in terms of measurement and algorithm uncertainties are raised.

Colbo, K. and R. Weller, Mooring observations from the eastern subtropical Pacific, *EOS Transactions AGU*, *84(52)*, Ocean Sciences Meeting Supplement, Abstract, S31E-10, 2003. http://www.agu.org/cgi-bin/SFgate/SFgate?&listenv=table&multiple=1&range=1&directget=1&application=os04&database=%2Fdata%2Fepubs%2Fwais%2Findexes%2Fos04%2Fos04&maxhits=200&=%22OS31E-10%22 (abstract only)

ABSTRACT

As part of the East Pacific Investigation of Climate (EPIC), a buoy was moored at 20°S, 85°W in October 2000. The buoy has now returned three years of both surface meteorology and upper ocean density and velocity. Aside from providing a unique data set from this poorly sampled portion of the oceans, the data sets also allow us to investigate some specific processes of importance to all of the oceanic eastern boundary regions. Westward propagating Rossby waves are known to be generated by sea surface height anomalies, due to Coastally Trapped Waves traveling poleward along the South American coast. The open ocean signature of interannual scale disturbances has been seen in TOPEX data, but the signature of the interseasonal waves has not been as well studied. Our data provides a clear data set from which to study these higher frequency Rossby waves. The mooring is also located in a region of high evaporation and almost no precipitation leading to a mixed layer that is strongly destabilized by salinity. The resulting gradients at the thermocline are strongly susceptible to salt fingering. This salt fingering provides a mechanism to inject salt onto the equatorward traveling salinity minima, and hence alter Mode water properties.

Cosca, C. E., R. A. Feely, J. Boutin, J. Etcheto, M. J. McPhaden, F. P. Chavez, and P. G. Strutton, Seasonal and interannual CO_2 fluxes for the Central and Eastern Equatorial Pacific Ocean as determined from fCO_2-SST relationships, *Journal of Geophysical Research*, *108(C8)*, 3278, doi: 10.1029/2000JC000677, 2003.
http://www.agu.org/journals/jc/jc0308/2000JC000677/2000JC000677.pdf (PDF)

ABSTRACT

In order to determine high-resolution variations of CO_2 distributions in the equatorial Pacific, we have developed seasonal and interannual fCO_2-SST relationships from shipboard data. The data were gathered onboard NOAA ships from 1992 through 2001. The cruises during the 10-year period included 89 transects of the equatorial Pacific between 95°W and 165°E, and spanned two El Niño events (1992–1994 and 1997–1998). Data were collected during the equatorial warm season (January–June) and cool season (July–December) as well as during all phases of the ENSO cycle, making it possible to examine the interannual and seasonal variability of the fCO_2-SST relationship. There is a significant difference between the regression lines for El Niño versus non-El Niño data sets. During both non-El Niño and El Niño periods we observed seasonal differences in the fCO_2-temperature relationship. With respect to the non-El Niño period, the seasonal regression lines have lower root mean square (rms) deviations than the composite non-El Niño regression line, and the slopes are significantly different at the 95% confidence level. The slope for the cool season is less negative than the slope for the warm season, suggesting higher biological productivity occurs during the latter half of the year. The derived fCO_2-SST relationships have been combined with satellite-based temperature data to provide a composite time-space map of fCO_2 in the central and eastern equatorial Pacific and corresponding fluxes for the period between 1985 and 2001. The mean flux for the 16-year record is 0.3 ± 0.1 PgC yr^{-1} for an area that covers approximately half of the Pacific equatorial belt.

Keywords: CO_2 flux, equatorial Pacific oceanography, fCO_2-SST relationships, CO_2 modeling, seasonal CO_2 flux, interannual CO_2 flux

Cronin, M. F., N. Bond, C. Fairall, J. Hare, M. J. McPhaden, and R. A. Weller, Enhanced oceanic and atmospheric monitoring for the eastern Pacific, *EOS Transactions AGU, 83(19)*, 205, 210-211, 2002. http://www.pmel.noaa.gov/~cronin/EPIC/cron2442.pdf (PDF)

ABSTRACT

The Eastern Pacific Investigation of Climate Processes (EPIC) is a five-year experiment to improve the understanding of the intertropical convergence zone (ITCZ), its interaction with the cool water that upwells along the equator in the eastern Pacific, and the physics of the stratus cloud deck that forms over the cool waters off South America. EPIC fieldwork began in 1999 and involves short-term process studies, embedded within longer-term enhanced monitoring built on the El Niño Southern Oscillation (ENSO) observing system. At this writing, we are halfway through the enhanced monitoring portion of the experiment and have just completed the two-month process study EPIC2001. In this report, we review the status of the EPIC program and present some preliminary scientific results from the enhanced monitoring data set.

Fairall, C. W., E. F. Bradley, J. E. Hare, A. A. Grachev, and J. B. Edson, Bulk parameterization of air-sea fluxes: Updates and verification for the COARE algorithm, *Journal of Climate, 16*, 571-591, 2003. http://ams.allenpress.com/amsonline/?request=get-document&issn=1520-0442&volume=016&issue=04&page=0571

ABSTRACT

In 1996, version 2.5 of the Coupled Ocean–Atmosphere Response Experiment (COARE) bulk algorithm was published, and it has become one of the most frequently used algorithms in the air–sea interaction community. This paper describes steps taken to improve the algorithm in several ways. The number of iterations to solve for stability has been shortened from 20 to 3, and adjustments have been made to the basic profile stability functions. The scalar transfer coefficients have been redefined in terms of the mixing ratio, which is the fundamentally conserved quantity, rather than the measured water vapor mass concentration. Both the velocity and scalar roughness lengths have been changed. For the velocity roughness, the original fixed value of the Charnock parameter has been replaced by one that increases with wind speeds of between 10 and 18 m s^{-1}. The scalar roughness length parameterization has been simplified to fit both an early set of NOAA/Environmental Technology Laboratory (ETL) experiments and the Humidity Exchange Over the Sea (HEXOS) program. These changes slightly increase the fluxes for wind speeds exceeding 10 m s^{-1}. For interested users, two simple parameterizations of the surface gravity wave influence on fluxes have been added (but not evaluated).

This new version of the algorithm (COARE 3.0) was based on published results and 2777 1-h covariance flux measurements in the ETL inventory. To test it, 4439 new values from field experiments between 1997 and 1999 were added, which now dominate the database, especially in the wind speed regime beyond 10 m s^{-1}, where the number of observations increased from 67 to about 800. After applying various quality controls, the database was used to evaluate the algorithm in several ways. For an overall mean, the algorithm agrees with the data to within a few percent for stress and latent heat flux. The agreement is also excellent when the bulk and directly measured fluxes are averaged in bins of 10-m neutral wind speed. For a more stringent test, the average 10-m neutral transfer coefficients were computed for stress and moisture in wind speed bins, using different averaging schemes with fairly similar results. The average (mean and median) model results agreed with the measurements to within about 5% for moisture from 0 to

20 m s^{-1}. For stress, the covariance measurements were about 10% higher than the model at wind speeds over 15 m s^{-1}, while inertial-dissipation measurements agreed closely at all wind speeds. The values for stress are between 8% (for inertial dissipation) and 18% (for covariance) higher at 20 m s^{-1} than two other classic results. Twenty years ago, bulk flux schemes were considered to be uncertain by about 30%; the authors find COARE 3.0 to be accurate within 5% for wind speeds of 0–10 m s^{-1} and 10% for wind speeds of between 10 and 20 m s^{-1}.

Feely, R. A., C. L. Sabine, K. Lee, F. J. Millero, M. F. Lamb, D. Greeley, J. L. Bullister, R. M. Key, T. - H. Peng, A. Kozyr, T. Ono, and C. S. Wong, In situ calcium carbonate dissolution in the Pacific Ocean, *Global Biogeochemical Cycles, 16(4)*, 1144, doi: 10.1029/2002GB001866, 2002.
http://www.agu.org/pubs/crossref/2002/2002GB001866.shtml (abstract only)

ABSTRACT

Over the past several years researchers have been working to synthesize the WOCE/JGOFS global CO_2 survey data to better understand carbon cycling processes in the oceans. The Pacific Ocean data set has over 35,000 sample locations with at least two carbon parameters, oxygen, nutrients, CFC tracers, and hydrographic parameters. In this paper we estimate the in situ $CaCO_3$ dissolution rates in the Pacific Ocean water column. Calcium carbonate dissolution rates ranging from 0.01–1.1 Δmol kg^{-1} yr^{-1} are observed in intermediate and deepwater beginning near the aragonite saturation horizon. In the North Pacific Intermediate Water between 400 and 800 m, $CaCO_3$ dissolution rates are more than 7 times faster than observed in middle and deep water depths (average = 0.051 Δmol kg^{-1} yr^{-1}). The total amount of $CaCO_3$ that is dissolved within the Pacific is determined by integrating excess alkalinity throughout the water column. The total inventory of $CaCO_3$ added by particle dissolution in the Pacific Ocean, north of 40°S, is 157 Pg C. This amounts to an average dissolution rate of approximately 0.31 Pg C yr^{-1}. This estimate is approximately 74% of the export production of $CaCO_3$ estimated for the Pacific Ocean. These estimates should be considered to be upper limits for in situ carbonate dissolution in the Pacific Ocean, since a portion of the alkalinity increase results from inputs from sediments.
Keywords: $CaCO_3$ dissolution, anthropogenic CO_2, Pacific Ocean, aragonite saturation, calcite saturation, carbonate lysocline

Foltz, G. R., S. A. Grodsky, J. A. Carton, and M. J. McPhaden, Seasonal mixed layer salt budget of the tropical Atlantic Ocean, *Journal of Geophysical Research, 108(C5)*, 3146, doi:10.1029/2002JC001584, 2003.
http://www.atmos.umd.edu/~senya/HTML/pirata_salt/abstract.html (abstract only)

ABSTRACT

This paper addresses the atmospheric and oceanic causes of the seasonal cycle of mixed layer salinity in the tropical Atlantic based on direct observations and model data. Data sets include up to five years (September 1997 - December 2002) of measurements from moored buoys of the Pilot Research Array in the Tropical Atlantic (PIRATA), near-surface drifting buoys, and a numerical ocean model reanalysis. We analyze the mixed layer salt balance at nine PIRATA mooring locations and find that the seasonal cycles of evaporation, precipitation, entrainment, and mean horizontal salt advection all contribute to seasonal mixed layer salinity variability in the northwest (4°N - 15°N along 38°W). The balance is similarly complex along the equator. Here precipitation decreases eastward (between 35°W and 10°W), while freshening from zonal advection increases eastward. Horizontal eddy advection provides an important source of freshening along the equator during boreal summer and fall, when tropical instability waves are present. Meridional advection, combined with entrainment and vertical turbulent diffusion (we suspect), opposes the freshening effects of precipitation, mean zonal advection, and eddy advection, resulting in a weak seasonal cycle of mixed layer salinity. The balance in the southeast (6°S - 10°S along 10°W) includes significant contributions from mean horizontal advection. Here our estimates are highly uncertain due to a lack of knowledge of horizontal salinity transport.

Freitag, H. P., M. J. McPhaden, C. Meinig, and P. Plimpton, Mooring motion bias of point Doppler current meter measurements, In: *Proceedings of the IEEE Seventh Working Conference on Current Measurement Technology*, San Diego, CA, 13-15 March 2003, IEEE, Piscataway, NJ, 155-160, 2003.
http://www.pmel.noaa.gov/tao/proj_over/frei2539_v5.pdf (PDF)

ABSTRACT

Upper-ocean current measurements have been made for more than 20 years from taut-line surface moorings deployed in the equatorial Pacific by NOAA's Pacific Marine Environmental Laboratory (PMEL). Until 1998 the moorings were instrumented with mechanical current meters (MCMs, either Vector Averaging Current Meters (VACM) or Vector Measuring Current Meters (VMCM)). Comparison with nearby subsurface 150 kHz Acoustic Doppler Current Profilers (ADCP) indicated that differences between the two measurement systems were generally small (i.e., mean differences of 5 cm s^{-1} or less). By the early-1990's, maintenance of the aging MCMs (designed in the 1960s and 1970s) was difficult, time consuming and expensive. Early tests of the Sontek Argonaut-MD current meters by PMEL indicated that it was a good candidate for replacement of the MCMs. Subsequent comparisons between Argonaut-MD data and nearby ADCPs revealed significant bias between the two, with the Argonaut-MD reporting lower horizontal current speed. Further investigation, including the analysis of high-frequency output from the Argonaut-MD compass/tilt-sensor (Precision Navigation model TCM2), found that the source of the bias was the inability of the compass/tilt sensor to function properly in response to extreme lateral and rotational accelerations experienced by the instruments in high current speed regimes. A solution to this problem was to reduce the acceleration of the current meters by attaching vanes to each instrument. Since PMEL introduced this modification, differences between Argonaut-MD and ADCP data are comparable to those found previously between MCM and ADCP.

Garzoli, S. L., and J. Servain, CLIVAR workshop on tropical Atlantic variability, *Geophysical Research Letters, 30(5)*, 8001, doi:10.1029/2002GL016823, 2003.
http://www.agu.org/journals/gl/gl0305/2002GL016823/2002GL016823.pdf (PDF)

INTRODUCTION (partial)

Climate variability in the tropical Atlantic region and the land that surrounds it represents a difficult problem in terms of large-scale circulation and ocean-atmosphere-land interactions, with important economic and social impacts (CLIVAR Initial Implementation Plan, June 1998). During recent decades a large multi-decadal swing in the Atlantic climate has been observed and it is believed to be caused by interactions between the Atlantic Ocean and the overlaying atmosphere. These climate swings are directly or indirectly related to the tropical Atlantic region where surface temperature variability and the associated changes in winds, sea level pressure, intertropical convergence zone (ITCZ), and the Hadley circulation occur on interannual to decadal time scales. These covariant fluctuations are collectively called Tropical Atlantic Variability (TAV).

Gibson, B. A., S. E. Postawko, J. Ensworth, M. L. Morrissey, J. Wurman, and S. Ellis, Introducing high-tech and low-tech geoscience-related technology to disadvantaged schools in the Tropical Pacific, *Journal of Geoscience Education*, *51*, 2003. http://www.nagt.org/Mar03/March03-06.html (abstract only)

ABSTRACT

The Schools of the Pacific Rainfall Climate Experiment (SPaRCE) is a cooperative educational and research project that involves elementary, middle, and high schools, trade schools, colleges, and meteorological services from various Pacific Islands, atolls, and the U.S. The educational materials that the program provides to Pacific area schools involve mostly the use of non-technical, simple equipment and experiments. This is due to the cost of materials and postage, and the fact that most schools are isolated, lack funds, or do not have reliable electricity. The material sent to participants includes plastic direct-read rain gauges, workbooks, and videos that discuss tropical Pacific related weather phenomenon. Recently, the SPaRCE program was able to deploy automated weather stations to a limited number of participants. In addition, the SPaRCE program had also supplied four Pacific-area schools with Micro-Tops devices, a hand-held radiometer which measures total column ozone. The SPaRCE program hopes to continue providing the participating educators with more opportunities to use technology in their geoscience curriculum.

Gilson, J. and D. Roemmich, Mean and temporal variability in Kuroshio geostrophic transport south of Taiwan (1993-2001), *Journal of Oceanography, 58*, 183-195, 2002. http://www.terrapub.co.jp/journals/JO/abstract/5801/58010183.html (abstract only)

ABSTRACT

Observations of the Kuroshio south of Taiwan have been carried out on a quarterly basis since late 1992 as part of the basin-wide High Resolution expendable bathythermograph/expendable conductivity-temperature-depth (XBT/XCTD) network. Mean geostrophic transport in the Kuroshio, 0-800 m, from 34 cruises is 22.0 Sv ± 1.5, consistent with previous results from moorings and geostrophic calculations in the upstream Kuroshio region. The mean core of the current has speed about 90 cm s^{-1} and is located close to Taiwan. At this location the Kuroshio appears to be confined mainly to the upper 700 m, and there is no evident tight recirculation of the current. Eddy variability is substantial, and large eddies can be seen propagating westward for thousands of kilometers in TOPEX/Poseidon altimetric data, impinging on the current and altering its structure and transport. The annual range in transport is about 8 Sv ± 6, with maximum in summer. Interannual variability is about 12 Sv ± 6, with transport maxima in 1995 and 2000 and a minimum in 1997-1998. Interannual variability in the upstream Kuroshio may be uncorrelated with that in the downstream region south of Japan, where the transport is much greater. Our quarterly sampling aliases high frequency variability of the current, and an improved boundary-current observation program would include more frequent transects and occasional deeper measurements.

Gloor, M., N. Gruber, J. L. Sarmiento, C. L. Sabine, R. A. Feely, and C. Rödenbeck, A first estimate of present and preindustrial air-sea CO_2 flux patterns based on ocean interior carbon measurements and models, *Geophysical Research Letters, 30(1),* 1010, doi: 10.1029/2002GL015594, 2003.
http://www.agu.org/journals/gl/gl0301/2002GL015594/2002GL015594.pdf (PDF)

ABSTRACT

The exchange of CO_2 across the air-sea interface is a main determinant of the distribution of atmospheric CO_2 from which major conclusions about the carbon cycle are drawn, yet our knowledge of atmosphere-ocean fluxes still has major gaps. A new analysis based on recent ocean dissolved inorganic carbon data and on models permits us to separately estimate the pre-industrial and present air-sea CO_2 flux distributions without requiring knowledge of the gas exchange coefficient. We find a smaller carbon sink at mid to high latitudes of the southern hemisphere than previous data based estimates and a shift of ocean uptake to lower latitude regions compared to estimates and simulations. The total uptake of anthropogenic CO_2 for 1990 is 1.8 (±0.4) Pg C yr^{-1}. Our ocean-based results support the interpretation of the latitudinal distribution of atmospheric CO_2 data as evidence for a large northern hemisphere land carbon sink.

Goni, G., and M. Baringer, Surface currents in the tropical Atlantic across high density XBT line AX08, *Geophysical Research Letters, 29 (24),* 2002.
http://www.agu.org/journals/gl/gl0224/2002GL015873/2002GL015873.pdf (PDF)

ABSTRACT

Three temperature sections that cross the tropical Atlantic obtained from high density XBT transects are used to identify the major surface currents and to compute their water mass transports. The dynamic heights are computed using XBT temperature profiles with salinity derived from historical T-S relationships. The values of dynamic height estimated from altimeter data used in conjunction with climatological dynamic height fields are within 3 cm of the XBT-derived values. The error in XBT-derived dynamic height introduced by using historical T-S relationships instead of actual salinity values are estimated to be of the order of 1.5 cm. Dynamic height estimates using the actual salinity values underestimate those obtained using historical T-S relationships. The structure exhibited in the dynamic height and altimeter-derived sea height fields do not reveal all the upper ocean currents, making these temperature sections presented here critical for computing transports and identifying currents in this region.

Goni, G. and P. Rizzoli (editors), *Interhemispheric Water Exchange in the Atlantic Ocean,* Elsevier Oceanographic Series, Vol. 68, 2003.
http://www.elsevier.com/wps/find/bookdescription.cws_home/699546/description#description (BOOK)

DESCRIPTION

Recent results from modeling and observational studies demonstrate that the tropical Atlantic is a critical region for processes that maintain the meridional overturning circulation, such as cross-equatorial exchanges, and for sea surface temperature variability that impacts on climate variability of the coupled tropical ocean/atmosphere system.

The theme of this book is the inter-hemispheric and inter-gyre exchanges of heat, salt and fresh water, while its goal is to improve the knowledge of the tropical Atlantic dynamics and how it affects the global ocean. A clear understanding of the dynamics of processes that affect the flow of mass and heat between the southern and the northern hemispheres in the upper few hundred meters in the tropical Atlantic and of those associated to the ocean circulation or to surface signals, from decadal, inter-annual to mesoscale periods, becomes necessary to better evaluate their contribution to the interhemispheric mass exchange. These processes are believed to be largely responsible in driving the sea surface temperature, which in turn, is a critical parameter to investigate ocean-atmospheric interactions. Output produced by regional models is also used to complement the observations and to provide additional information on their spatial and temporal variability. The subtropical cells, by bringing water masses subducted in the subtropics to the equator, and zonal currents investigated here contribute to the interhemispheric water exchange.

Special attention is also given to the warm and salty anticyclonic rings shed by the North Brazil Current, which are now known to have a much broader impact, not only on interhemispheric water mass transfer, but also on the environment of remote regions. Observations from different sources are blended together, are used to validate model outputs and are also assimilated into models to obtain a more complete and accurate picture of the oceanic circulation and of its time evolution.

Grebremichael, M, W. F. Krajewski, M. Morrissey, D. Langerud, G. J. Huffman, R. Adler, Error uncertainty analysis of GPCP monthly rainfall products: A data based simulation study, *Journal of Applied Meteorology*, *42*, 1837-1848, 2003. http://ams.allenpress.com/pdfserv/i1520-0450-042-12-1837.pdf (PDF)

ABSTRACT

This paper focuses on estimating the error uncertainty of the monthly 2.5° x 2.5° rainfall products of the Global Precipitation Climatology Project (GPCP) using rain gauge observations. Two kinds of GPCP products are evaluated: the satellite-only (MS) product, and the satellite–gauge (SG) merged product. The error variance separation (EVS) method has been proposed previously as a means of estimating the error uncertainty of the GPCP products. In this paper, the accuracy of the EVS results is examined for a variety of gauge densities. Three validation sites—two in North Dakota and one in Thailand—all with a large number of rain gauges, were selected. The very high density of the selected sites justifies the assumption that the errors are negligible if all gauges are used. Monte Carlo simulation studies were performed to evaluate sampling uncertainty for selected rain gauge network densities. Results are presented in terms of EVS error uncertainty normalized by the true error uncertainty. These results show that the accuracy of the EVS error uncertainty estimates for the SG product differs from that of the MS product. The key factors that affect the errors of the EVS results, such as the gauge density, the gauge network, and the sample size, have been identified and their influence has been quantified. One major finding of this study is that 8–10 gauges, at the 2.5° scale, are required as a minimum to get good error uncertainty estimates for the SG products from the EVS method. For eight or more gauges, the normalized error uncertainty is about 0.86 ± 0.10 (North Dakota: box 1) and 0.95 ± 0.10 (North Dakota: box 2). Results show that, despite its error, the EVS method performs better than the root-mean-square error (rmse) approach that ignores the rain gauge sampling error. For the MS products, both the EVS method and the rmse approach give negligible bias. As expected, results show that the SG products give better rainfall estimates than the MS products, according to most of the criteria used.

Lamb, M. F., C. L. Sabine, R. A. Feely, R. Wanninkhof, R. M. Key, G. C. Johnson, F. J. Millero, K. Lee, T. – H. Peng, A. Kozyr, J. L. Bullister, D. Greeley, R. H. Byrne, D. W. Chipman, A. G. Dickson, C. Goyet, P. R. Guenther, M. Ishii, K. M. Johnson, C. D. keeling, T. Ono, K. Shitashima, B. Tilbrook, T. Takahashi, D. W. R. Wallace, Y. W. Watanabe, C. Winn and C. S. Wong, Consistency and synthesis of Pacific Ocean CO_2 survey data, *Deep-Sea Research II, 49 (1-3)*, 21-58, 2002. http://jelly.pmel.noaa.gov/admin/scripts/Publications.asp?ABSTRACT_REQUEST=2201 (abstract only)

ABSTRACT

Between 1991 and 1999, carbon measurements were made on twenty-five WOCE/JGOFS/OACES cruises in the Pacific Ocean. Investigators from 15 different laboratories and four countries analyzed at least two of the four measurable ocean carbon parameters (DIC, TAlk, fCO_2, and pH) on almost all cruises. The goal of this work is to assess the quality of the Pacific carbon survey data and to make recommendations for generating a unified data set that is consistent between cruises. Several different lines of evidence were used to examine the consistency, including comparison of calibration techniques, results from certified reference material analyses, precision of at-sea replicate analyses, agreement between shipboard analyses and replicate shore based analyses, comparison of deep water values at locations where two or more cruises overlapped or crossed, consistency with other hydrographic parameters, and internal consistency with multiple carbon parameter measurements. With the adjustments proposed here, the data can be combined to generate a Pacific Ocean data set, with over 36,000 unique sample locations analyzed for at least two carbon parameters in most cases. The best data coverage was for DIC, which has an estimated overall accuracy of ~3 Δmol kg^{-1}. TAlk, the second most common carbon parameter analyzed, had an estimated overall accuracy of ~5 Δmol kg^{-1}. To obtain additional details on this study, including detailed crossover plots and information on the availability of the compiled, adjusted data set, visit the Global Data Analysis Project web site at: http://cdiac.esd.ornl.gov/oceans/glodap.

McNeil, B. I., R. J. Matear, R. M. Key, J. L. Bullister and J. L. Sarmiento, Anthropogenic CO_2 uptake by the ocean based on the global chlorofluorocarbon dataset, *Science, 299*, 235-239, 2003. http://www.sciencemag.org/cgi/content/full/299/5604/235

ABSTRACT

We estimated the oceanic inventory of anthropogenic carbon dioxide (CO_2) from 1980 to 1999 using a technique based on the global chlorofluorocarbon data set. Our analysis suggests that the ocean stored 14.8 petagrams of anthropogenic carbon from mid-1980 to mid-1989 and 17.9 petagrams of carbon from mid-1990 to mid-1999, indicating an ocean wide net uptake of 1.6 and 2.0 +/- 0.4 petagrams of carbon per year, respectively. Our results provide an upper limit on the solubility-driven anthropogenic CO_2 flux into the ocean, and they suggest that most ocean general circulation models are overestimating oceanic anthropogenic CO_2 uptake over the past two decades.

McPhaden, M. J., Tropical Pacific Ocean heat content variations and ENSO persistence barriers, *Geophysical Research Letters, 30(9),* 1480, doi:10.1029/2003GL016872, 2003. http://www.agu.org/pubs/crossref/2003/2003GL016872.shtml

ABSTRACT

Data from the tropical Pacific Ocean for the period 1980–2002 are used to examine the persistence of sea surface temperature (SST) and upper ocean heat content variations in relation to El Niño and the Southern Oscillation (ENSO). The present study demonstrates that, unlike for SST, there is no spring persistence barrier when considering upper ocean heat content. Conversely, there is a persistence barrier for heat content in boreal winter related to a seasonal reduction in variance. These results are consistent with ENSO forecast model studies indicating that accurate initialization of upper ocean heat content often reduces the prominence of the spring prediction barrier for SST. They also suggest that initialization of upper ocean heat content variations may lead to seasonally varying enhancements of forecast skill, with the most pronounced enhancements for forecasts starting early and late in the development of ENSO events.

Niiler, P. P., N. A. Maximenko, and J. C. McWilliams, Dynamically balanced absolute sea level of the global ocean derived from near-surface velocity observations, *Geophysical Research Letters, 30(22)*: 2164-2167, 2003. http://www.agu.org/pubs/crossref/2003/2003GL018628.shtml

ABSTRACT

The 1992–2002 time-mean absolute sea level distribution of the global ocean is computed for the first time from observations of near-surface velocity. For this computation, we use the near-surface horizontal momentum balance. The velocity observed by drifters is used to compute the Coriolis force and the force due to acceleration of water parcels. The anomaly of horizontal pressure gradient is derived from satellite altimetry and corrects the temporal bias in drifter data distribution. NCEP reanalysis winds are used to compute the force due to Ekman currents. The mean sea level gradient force, which closes the momentum balance, is integrated for mean sea level. We find that our computation agrees, within uncertainties, with the sea level computed from the geostrophic, hydrostatic momentum balance using historical mean density, except in the Antarctic Circumpolar Current. A consistent horizontally and vertically dynamically balanced, near-surface, global pressure field has now been derived from observations.

O'Brien, K., K. McHugh, G. Vecchi, E. Harrison, S. Hankin, and A. Manke, The Observing System Monitoring Center: A Tool for Evaluation of the Global Ocean Observing System, *Proceedings of the 20th International Conference on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*, 2004 AMS Annual Meeting, Seattle, WA, 12–15 January 2004, paper P1.35, 2004. http://ams.confex.com/ams/84Annual/techprogram/paper_73535.htm (PDF)

INTRODUCTION

In order to properly understand climate variability, the development, evaluation and maintenance of a sustained global observing system is required. As the Intergovernmental Panel on Climate Change (IPCC 2001) states, "Concern has been expressed about the present condition of the observational networks." Kevin Trenberth adds, "To advance the understanding of climate change and its forcings, it will be necessary to have a comprehensive global observing system reliably producing high-quality data and products." (Trenberth 2002). The Observing System

Monitoring Center (OSMC) is being constructed in order to assess the effectiveness of the current global ocean observing system as well as to aid in the planning and evaluation of new observing system components. Currently, the observing system for climatic data consists of a variety of sensors measuring a multeity of physical variables from numerous platforms. Ensuring the effectiveness of the observing system requires software and data systems to keep track of the performance of the different sensors in near-real time. The near-real time data access is critical to promptly overcome any shortcomings of the observing system. The goal of the OSMC is to fill the clear need for near-real time overseeing of the global ocean climate observing system. The OSMC will be an information gathering, decision support and display system and will also display current historical status of globally distributed data collection systems. In addition, the OSMC will provide the data visualization tools necessary to identify the coverage of any given collection of platforms and parameters.

Petersen, W. A., R. Cifelli, D. J. Bocippio, S. A. Rutledge, and C. W. Fairall, Convection and easterly wave structure observed in the Eastern Pacific warm-pool during EPIC-2001, *Journal of the Atmospheric Sciences*, *60*, 1754-1773, 2003. http://olympic.atmos.colostate.edu/epic/epic_pdf/petersen_2003.pdf (PDF)

ABSTRACT

During September–October 2001, the East Pacific Investigation of Climate Processes in the Coupled Ocean–Atmosphere System (EPIC-2001) intertropical convergence zone (ITCZ) field campaign focused on studies of deep convection in the warm-pool region of the eastern Pacific. This study combines C-band Doppler radar, sounding, and surface heat flux data collected aboard the R/V *Ronald H. Brown* during EPIC to describe the kinematic and thermodynamic states of the ITCZ environment, together with tendencies in convective structure, lightning, rainfall, and surface heat fluxes as a function of 3–5-day easterly wave phase.

Three easterly waves were observed at the location of the R/V *Brown* during EPIC-2001. Wind and thermodynamic data reveal that the wave trough axes exhibited positively correlated *u* and y winds, a slight westward phase tilt with height, and relatively strong (weak) northeasterly tropospheric shear following the trough (ridge) axis. Temperature and humidity perturbations exhibited mid- to upper-level cooling (warming) and drying (moistening) in the northerly (trough and southerly) phase. At low levels, warming (cooling) and moistening (drying) occurred in the northerly (southerly) phase.

Composited radar, sounding, lightning, and surface heat flux observations suggest the following systematic behavior as a function of wave phase: zero to one-quarter wavelength ahead of (behind) the wave trough in northerly (southerly) flow, larger (smaller) convective available potential energy (CAPE), lower (higher) convective inhibition (CIN), weaker (stronger) tropospheric shear, larger (smaller) convective rain fractions, higher (lower) conditional mean rain rates, higher (lower) lightning flash densities, and more (less) robust convective vertical structure occurred. Latent and sensible heat fluxes reached a minimum in the northerly phase and then increased through the trough, reaching a peak during the ridge phase (leading the peak in CAPE). Larger areas of light convective and stratiform rain and slightly larger (10%) area-averaged rain rates occurred in the vicinity of, and just behind, the trough axes in southerly and ridge flow. Importantly, the transition in convective structure observed across the trough axes when considered with the relatively small change in area mean rain rates suggests the presence of a transition in the vertical structure of diabatic heating across the easterly waves examined. The inferred transition in heating structure is supported by radar-diagnosed divergence profiles that exhibit convective (stratiform) characteristics ahead of (behind) the trough.

Rudnick, D. L. and R. E. Davis, Red noise and regime shifts, *Deep-Sea Research I, 50(6)*, 691-699, 2003.

ABSTRACT

The analysis of interdecadal physical and biological variability is made challenging by the relative shortness of available time series. It has been suggested that rapid temporal changes of the most energetic empirical orthogonal function of North Pacific sea surface temperature (sometimes called the Pacific Decadal Oscillation or PDO) represents a ''regime shift'' between states with otherwise stable statistics. Using random independent time series generated to have the same frequency content as the PDO, we show that a composite analysis of climatic records recently used to identify regime shifts is likely to find them in Gaussian, red noise with stationary statistics. Detection of a shift by this procedure is not evidence of nonlinear processes leading to bi-stable behavior or any other meaningful regime shift.

Keywords: Climatic changes; Statistical analysis; Regime shifts; Pacific Decadal Oscillation

Sabine, C.L., and M. Hood, Ocean carbon scientists organize to achieve better coordination, cooperation, *Eos, Transactions AGU, 84(23)*, 218–220, 2003. http://www.globalcarbonproject.org/PRODUCTS/Sabine&Hood.2003.pdf (PDF)

INTRODUCTION

Studies of the global carbon cycle and climate change necessarily involve investigations across regional and political boundaries. Recognizing the need to develop an international research framework, various working groups of programs such as the International Geosphere-Biosphere Programme (IGBP) have developed research strategies for global carbon cycle studies.

Based on recommendations from these programs, several nations are now moving ahead with plans for large-scale ocean carbon observations. Many of these national and regional studies are similar in focus, and have been designed to complement studies in other countries. However, there is an immediate need for global-scale coordination of these carbon observations and research efforts. There is also an urgent need to critically assess the overall network of planned observations to ensure that the results, when combined, will meet the requirements of the research community.

As part of a new pilot project, the Global Carbon Project (GCP) and the Ocean CO_2 Panel have joined forces to coordinate ongoing, large-scale ocean carbon observations over the next decade. This project coordination draws upon the long-term experience of the Ocean CO_2 Panel parent organizations; the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC). It also draws on the carbon focus, and ties to the scientific community of the GCP parent organizations; the IGBP, the International Human Dimensions Programme (IHDP), and the World Climate Research Programme (WCRP). The International Ocean Carbon Coordination Project (IOCCP) has been organized to:

- gather information about ongoing and planned ocean carbon research and observation activities;
- identify gaps and duplications in ocean carbon observations;
- produce recommendations that optimize resources for international ocean carbon research and the potential scientific benefits of a coordinated observation strategy; and
- promote the integration of ocean carbon research with appropriate atmospheric and terrestrial carbon activities.

Only through a coordinated ocean sampling effort and improved basic scientific understanding of the ocean carbon cycle will the overall goal of skillful predictions of future atmospheric CO_2 be attained.

Sabine, C. L., R. A. Feely, R. M. Key, J. L. Bullister, F. J. Millero, K. Lee, T. - H. Peng, B. Tilbrook, T. Ono, and C. S. Wong, Distribution of anthropogenic CO_2 in the Pacific Ocean, *Global Biogeochemical Cycles, 16(4),* 1083, doi: 10.1029/2001GB001639, 2002. http://www.agu.org/pubs/crossref/2002/2001GB001639.shtml (abstract only)

ABSTRACT

This work presents an estimate of anthropogenic CO_2 in the Pacific Ocean based on measurements from the WOCE/JGOFS/OACES global CO_2 survey. These estimates used a modified version of the ΔC^* technique. Modifications include a revised preformed alkalinity term, a correction for denitrification, and an evaluation of the disequilibrium terms using an optimum multiparameter analysis. The total anthropogenic CO_2 inventory over an area from 120°E to 70°W and 70°S to 65°N (excluding the South China Sea, the Yellow Sea, the Japan/East Sea, and the Sea of Okhotsk) was 44.5 ± 5 Pg C in 1994. Approximately 28 Pg C was located in the Southern Hemisphere and 16.5 Pg C was located north of the equator. The deepest penetration of anthropogenic CO_2 is found at about 50°S. The shallowest penetration is found just north of the equator. Very shallow anthropogenic CO_2 penetration is also generally observed in the high-latitude Southern Ocean. One exception to this is found in the far southwestern Pacific where there is evidence of anthropogenic CO_2 in the northward moving bottom waters. In the North Pacific a strong zonal gradient is observed in the anthropogenic CO_2 penetration depth with the deepest penetration in the western Pacific. The Pacific has the largest total inventory in all of the southern latitudes despite the fact that it generally has the lowest average inventory when normalized to a unit area. The lack of deep and bottom water formation in the North Pacific means that the North Pacific inventories are smaller than the North Atlantic.

Keywords: Pacific Ocean, anthropogenic CO_2, carbon cycle, total CO_2, ΔC^*, optimum multiparameter analysis

Snowden, D. P. and R. L. Molinari, Subtropical cells in the Atlantic Ocean: An observational summary, *Elsevier Oceanography Series, 68*, 2003. http://www.aoml.noaa.gov/general/pubs/publist1.html (abstract only)

ABSTRACT

In this paper, we survey the observational literature pertaining to the shallow meridional overturning circulation cells connecting the subduction regions of the subtropical North and South Atlantic Ocean with the upwelling regions on and near the equator. These subtropical cells (STCs) exist in both hemispheres, but they are not symmetric about the equator. The southern hemisphere STC has a structure consistent with the cannonical feature (*i.e.*, subduction in the southern hemisphere subtropics, transport of the subducted water to the Equatorial Undercurrent, upwelling on the equator, and return of the upwelled water to the subtropics). However, there is no clear evidence to indicate that water subducted in the northern hemisphere subtropics reaches the equator. Rather, pathways of water subducted in the subtropical North Atlantic have been observed to the North Equatorial Countercurrent. Upwelling regions for these northern hemisphere water masses are not yet defined. Characteristics of the STCs which must be more fully explored (*e.g.*, temporal variability, transports, mixing) in order to understand their impacts on the regional climate variability of the tropical Atlantic Ocean are identified.

Sun, B., L. Yu, and R. A. Weller, Comparisons of surface meteorology and turbulent heat fluxes over the Atlantic: NWP model analyses versus moored buoy observations, *Journal of Climate, 16*, 679-695, 2003. http://ams.allenpress.com/pdfserv/i1520-0442-016-04-0679.pdf (PDF)

ABSTRACT

Surface meteorological variables and turbulent heat fluxes in the National Centers for Environmental Prediction–National Center for Atmospheric Research reanalyses 1 and 2 (NCEP1 and NCEP2) and the analysis from the operational system of the European Centre for Medium-Range Weather Forecasts (ECMWF) are compared with high-quality moored buoy observations in regions of the Atlantic including the eastern North Atlantic, the coastal regions of the western North Atlantic, and the Tropics. The buoy latent and sensible heat fluxes are determined from buoy measurements using the recently improved Tropical Ocean Global Atmosphere Coupled Ocean–Atmosphere Response Experiment (TOGA COARE) flux algorithm.

The time mean oceanic heat loss from the model analyses is systematically overestimated in all the regions. The overestimation in latent heat loss ranges from about 14 W m^{-2} (13%) in the eastern subtropical North Atlantic to about 29 W m^{-2} (30%) in the Tropics to about 30 W m^{-2} (49%) in the midlatitude coastal areas, where the overestimation in sensible heat flux reaches about 20 W m^{-2} (60%). Depending upon the region and the NWP model, these systematic overestimations are either reduced, or change to underestimations, or remain unchanged when the TOGA COARE flux algorithm is used to recalculate the fluxes. The bias in surface meteorological variables, one of the major factors related to the biases in the revised NWP heat fluxes, varies with region and NWP analysis. Generally the temperature and humidity biases in the coastal regions are much larger than other regions. In the extratropical regions, NCEP1 and NCEP2 generally show a wet bias, which is mainly responsible for the underestimation in the revised NWP latent heat loss. In the Tropics a dry bias is found in the NWP analyses, particularly in ECMWF and NCEP2, which contributes to the overestimation in the revised NWP latent heat loss. Compared to NCEP1, NCEP2 shows less cold bias in 2-m air temperature and thus less biased sensible heat flux; NCEP2 also shows less humid bias in 2-m humidity in the extratropical regions but more dry bias in 2-m humidity in the Tropics, either of which leads to a more biased latent heat flux in NCEP2.

Despite the significant biases in the NWP surface fields and the poor representation of short-time sea surface temperature variability, the NWP models are able to represent the dominant short-time variability in other basic variables and thus the variability in heat fluxes in the wintertime coastal regions of the western North Atlantic (on timescales of 3–4 days and 1 week) and the northern and southern subtropical regions (on a timescale of about 2 weeks), but ECMWF and particularly the NCEP analyses do not represent well the 2–3-week variability in the tropical Atlantic.

Takahashi, T., S. C. Sutherland, R. A. Feely, and C. E. Cosca, Decadal variation of surface water pCO_2 in the Western and Central Equatorial Pacific, *Science*, *302*, 852-856, 2003. http://clickit.go2net.com/search?pos=4&ppos=0&plnks=0&uplnks=20&cat=web&cid=239171&site=srch&area=srch.noncomm.google&shape=textlink&cp=info.dogpl&cluster-click=0&pd=0&coll=1&query=takahashi+decadal+variation+of+surface+water+pco2+in+the+western+and+central+equatorial+pacific&qq=ee_IY!60DpnrXIWhvGymmem70_NrZUR4qrMS2MLDMWVPTem)!2CrQogoR+M_P (PDF)

ABSTRACT

The equatorial Pacific Ocean is one of the most important yet highly variable oceanic source areas for atmospheric carbon dioxide (CO_2). Here, we used the partial pressure of CO_2 (PCO_2), measured in surface waters from 1979 through early 2001, to examine the effect on the equatorial Pacific CO_2 chemistry of the Pacific Decadal Oscillation phase shift, which occurred around 1988 to 1992. During the decade before the shift, the surface water PCO_2 (corrected for temperature changes and atmospheric CO_2 uptake) in the central and western equatorial Pacific decreased at a mean rate of about –20 Δatm per decade, whereas after the shift, it increased at

about +15 Δatm per decade. These changes altered the CO_2 sink and source flux of the equatorial Pacific significantly.

Vallée, C., R. A. Weller, P. R. Bouchard, W. M. Ostrom, J. Lord, J. Gobat, M. Pritchard, T. Westberry, J. Hare, T. Uttal, S. Yuter, D. Rivas, D. Baumgardner, B. McCarty, J. Shannahoff, M.A. Walsh, F. Bahr, Long-Term Evolution of the Coupled Boundary Layers (STRATUS) Mooring Recovery and Deployment Cruise Report, NOAA Research Vessel *R H Brown*, Cruise RB-01-08, 9 October – 25 October 2001, *Technical Report*, WHOI-2002-02, UOP-2002-01, 2002.
http://uop.whoi.edu/stratus/images/Stratus2Cruise.pdf (PDF)

ABSTRACT

This report documents the work done on cruise RB-01-08 of the NOAA R/V *Ron Brown*. This was Leg 2 of R/V *Ron Brown's* participation in Eastern Pacific Investigation of Climate (EPIC) 2001, a study of air-sea interaction, the atmosphere, and the upper ocean in the eastern tropical Pacific. The science party included groups from the Woods Hole Oceanographic Institution (WHOI), NOAA Environmental Technology Laboratory (ETL), the University of Washington (UW), the University of California, Santa Barbara (UCSB), and the University Nacional Autonoma de Mexico (UNAM). The work done by these groups is summarized in this report. In addition, the routine underway data collected while aboard R/V *Ron Brown* is also summarized here.

Willis, J., D. Roemmich and B. Cornuelle, Combining altimetric height with broadscale profile data to estimate steric height, heat storage, subsurface temperature and SST variability, *Journal of Geophysical Research, 108(C9)*, 3292-3303, doi:10.1029/2002JC001755, 2003.
http://www.agu.org/journals/jc/jc0309/2002JC001755/2002JC001755.pdf (PDF)

ABSTRACT

A new technique is demonstrated for combining altimetric height (AH) and seasurface temperature (SST) with in situ data to produce improved estimates of 0/800 m steric height (SH), heat content, and temperature variability. The technique uses a linear regression onto AH to construct an initial guess for the subsurface quantity. This guess is then corrected toward the in situ data creating an estimate with substantially less error than could be achieved using either data set alone. Inclusion of the SST data further improves the estimates and illustrates how the procedure can be generalized to allow inclusion of additional data sets. The technique is demonstrated over a region in the southwestern Pacific enclosing the Tasman Sea. Nine-year time series of heat storage and temperature variability, averaged over 4° latitude and longitude and 1 year in time, are calculated. The estimates have RMS errors of approximately 4.6 W/m^2 in heat storage, 0.10°C in subsurface temperature and 0.11°C in surface temperature, and fractional errors of 20, 28, and 18%, respectively, relative to the total variance overall spatial and temporal scales considered. These represent significant improvements over previous estimates of these quantities. All the time series show strong interannual variability including the El Nino event of 1997. Application of these techniques on a global scale could provide new insight into the variability of the general circulation and heat budget of the upper ocean.

4.2 Bibliography of Science Articles and Reports Published by OCO-funded Scientists During FY 2003

A bibliography of all science publications published during FY 2003 is found below. Articles are separated into published articles and articles in press, books and book chapter, submitted articles, articles in preparation, reports and memos, proceedings, abstracts, encyclopedia entries, newsletters, and brochures and pamphlets.

Legend for projects affiliated with publications

A key is provided to show the affiliation between each published article and the science projects shown below (PI = Principal Investigator; co-PI = co-Principal Investigator; PM = Project Manager; PL = Project Leader).

A. Western Boundary Time Series in the Atlantic Ocean (PMs: Baringer, Johns, Meinen, Garzoli, Flosadottir)
B. ENSO Observing System (PM / PI: Cook / Molinari)
C. High Resolution XBT/XCTD (HRX) Transects (PI / PL: Kennel / Davis)
D. Drifter Observations (PI / PL: Kennel / Niiler)
E. Underwater Gliders for Monitoring Ocean Climate (PI / PL: Kennel / Davis)
F. Lagrangian Salinity Profiling: Evaluation of Sensor Performance (PI / PL: Kennel / Schmitt)
G. Development of an Underway CTD (PI / PL: Kennel / Rudnick)
H. Data Assimilation (PI / PLs: Kennel / Cornuelle, Stammer, Miller)
I. High Resolution Climate Data from Research and Volunteer Observing Ships (PM: Fairall)
J. Global Repeat Hydrographic/CO_2/Tracer Surveys in Support of CLIVAR and Global Carbon Cycle Objectives (PIs: Feely, Wanninkhof)
K. Document Ocean Carbon Sources and Sinks: Initial Steps Towards a Global Surface Water pCO_2 Observing System Underway CO_2 Measurements on the NOAA ships Ka'imimoana and Ron Brown and RVIB Palmer and Explorer of the Seas (PMs / co-PIs: Feely, Wanninkhof / Sabine, G. Johnson, Baringer, Bullister, Mordy, Zhang)
L. Tropical and Sub-tropical Atlantic Surface Drifters Array (PM: Garzoli)
M. Implementation of High Density XBT Lines in the Atlantic Ocean (PMs: Garzoli, Goni, Baringer, Molinari)
N. TAO Array and PIRATA (PI: McPhaden)
O. Global Sea Level Center: In-Situ Sea Level, The University of Hawaii Sea Level Center (PM: Merrifield)
P. Program Support through the Assimilation, Analysis and Dissemination of Global Raingauge Data (PI / co-PIs: Morrissey / Postawko, Greene)
Q. The "Global Drifter Program" (PI: Niiler)
R. Climate Variability in Ocean Surface Turbulent Fluxes (PI / co-PIs: O'Brien / Bourassa, Smith)
S. Quality-Evaluated Meteorological Data from Research Vessels (PI / co-PIs: O'Brien / Bourassa, Smith)
T. *In situ* and Satellite Sea Surface Temperature (SST) Analyses (PM: Reynolds)
U. Ocean Reference Stations and Northwest Tropical Atlantic Station for Flux Measurement (NTAS) (PMs: Weller, Plueddemann)
V. Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic (Atlantic VOS) (PIs: Weller, Hosom)

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Beron-Veron, F. and M. Olascoaga, Spectral, formal, and nonlinear stability in a layered quasigeostrophic with application to the Atlantic North Equatorial Current, *Interhemispheric Water Exchange in the Atlantic Ocean, Elsevier Oceanographic Series, 68*, Elsevier Science, 2003. (M)

Bishop, J. K. B., R. E. Davis and J. T. Sherman, Robotic observations of dust storm enhancement of carbon biomass in the North Pacific, *Science, 298*, 817-821, 2002. (E)

Bourassa, M. A., D. M. Legler, J. J. O'Brien, and S. R. Smith, SeaWinds validation with research vessels, *Journal of Geophysical Research, 108(C2),* doi:10.1029/2001JC001028, 2003. (S)

Bretherton, C. S., T. Uttal, C. W. Fairall, S. E. Yuter, R. A. Weller, D. Baumgardner, K. Comstock, and R. Wood, The EPIC 2001 Stratocumulus Study, *Bulletin of the American Meteorological Society*, to appear, 2003. (I)

Brunke, M. A., C W. Fairall, and X. Zeng, Which bulk aerodynamic algorithms are least problematic in computing ocean surface turbulent fluxes?, *Journal of Climate, 16*, 619-635, 2003. (I)

Cai, W., M. J. McPhaden, and M. A. Collier, Multidecadal fluctuations in the relationship between equatorial Pacific heat content anomalies and ENSO amplitude, *Geophysical Research Letters,* in press, 2003. (N)

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APPENDIX A

FY 2003 Accounting and Preliminary FY 2004 Budget Planning (prior to final allocations)

Michael Johnson
Director, Office of Climate Observation

FY 2003 Accounting and
Preliminary FY 2004 Budget Planning (prior to final allocations)

Climate Observation Program
Preliminary FY 04 Budget Planning ($ K)

	System total			C&GC		COSP Ocean		COSP Carbon		Lab Base		Other	
Network	**FY03**	**FY04**	**Change**	FY03	FY04	FY03	FY04	FY03	FY04	FY03	FY04	FY03	FY04
Tide Gauges	**710**	**946**	**236**	0	25	0	271	0	0	710	650	0	0
Drifting Buoys	**2077**	**2679**	**602**	756	627	271	1102	0	0	1050	950	0	0
Ships of Opportunity	**1903**	**2452**	**549**	995	773	301	1149	0	0	607	530	0	0
Tropical Moored Buoys	**3175**	**3625**	**450**	600	600	0	450	0	0	2575	2575	0	0
Argo	**275**	**273**	**-2**	275	273	0	0	0	0	0	0	0	0
Ocean Reference Stations	**1943**	**2632**	**689**	1101	0	788	2632	0	0	54	0	0	0
Ocean Carbon Monitoring	**2204**	**2874**	**670**	0	0	1060	1747	1127	1127	0	0	17	0
SURFRAD	**210**	**210**	**0**	210	105	0	0	0	0	0	0	0	105
Rain Gauges	**139**	**179**	**40**	139	149	0	0	0	0	0	0	0	30
Dedicated Ship Time	**626**	**617**	**-9**	0	150							626	467
Data & Assimilation Subsystems	**1017**	**1455**	**438**	464	578	70	203	0	0	393	674	90	0
Management & Product Delivery	**853**	**1398**	**545**	438	886	110	197	0	0	305	315	0	0
Overhead - Admin Services	**187**	**729**	**542**	187	729 *	0	0	0	0	0	0	0	0
	15319	**20069**	**4750**	5165	4895	2600	7751	1127	1127	5694	5694	733	602

Notes:
*The FY04 C&GC value for "Overhead" is the 5% administrative fee for processing all non-C&GC funding. This supports salaries, office space, supplies, etc.
The "Other" column is partnerships with other programs.
In FY03 GCC paid $17 K to augment the pCO2 project; Master paid $90 K for OCO database management.
In FY04 COSP will pay $105 K in the phase-out of SURFRAD from ocean to atmospheric obs; GCOS will pay $30 K partnership in Pacific rain gauges.

APPENDIX B

Program Plan for Building a Sustained Ocean Observing System for Climate

Michael Johnson
Director, Office of Climate Observation

Program Plan
For
Building a Sustained Ocean Observing System for Climate

Updated: March 2004

Overall Summary

The Climate Change Science Program (CCSP) has identified the critical need for the federal government to begin delivering regular reports documenting the present state of the climate system components. Yet an observing system does not presently exist that is capable of accurately documenting climate variability and change in the Earth's oceans, atmosphere, cryosphere, and land surface. Through this program plan NOAA will develop the infrastructure necessary to build, with national and international partners, the ocean component of a global climate observing system and to deliver regular reports on the ocean's contribution to the state of the climate and on the adequacy of the observing system.

1.0 Base Program

1.1 Key activities currently carried out by NOAA for this strategy area: Over the past decade NOAA has worked with national and international partners to begin building a sustained global ocean system for climate, focusing first on the tropical Pacific, expanding to the Atlantic, and promoting future research in the Indian Ocean. It is now well understood that documenting and forecasting climate will require continuous measurements from space along with the instrumenting of the entire global ocean. The present international effort is about 45% of what will ultimately be needed for the global system. NOAA presently maintains approximately 60% of the *in situ* networks and 30% of the space components and is committed to the goal of providing at least 50% of the composite system over the long term.

The existing foundation is comprised of eleven complementary *in situ*, space based, data and assimilation subsystems: 1) Global Tide Gauge Network; 2) Global Surface Drifting Buoy Array; 3) Global Ships of Opportunity Network; 4) Tropical Moored Buoy Network; 5) Argo Profiling Float Array; 6) Ocean Reference Stations; 7) Coastal Moorings; 8) Ocean Carbon Monitoring Network; 9) Dedicated Ship Operations; 10) Satellites for Sea Surface Temperature, Sea Surface Height, Surface Vector Winds, and Ocean Color; 11) Data and Assimilation Systems and their products (the Global Ocean Data Assimilation Experiment – GODAE). The system design is illustrated in Figure 1. This is an international effort. NOAA's plan includes a twelfth element – 12) System Management and Product Delivery – to focus program resources on answering the nation's highest priority policy - and economically-relevant questions. In addition, complementary atmospheric observations and analyses, including precipitation and radiation, as well as a global analysis of winds using satellite and surface data help complete the system.

The plan is being advanced via matrix management within the NOAA Climate Program. Implementation of the in situ networks is through distributed centers of expertise at the NOAA Research laboratories, the National Ocean Service Center for Operational Oceanographic Products and Services, the National Data Buoy Center, and the university laboratories that have developed the instruments and techniques. The space components are centered in the National Environmental Satellite, Data and Information Service; the space components are being advanced via other NOAA program planning; they are noted here because of their central role in global observation but they are not detailed in this plan. The focal point for developing global ocean data assimilation capabilities will be the Geophysical Fluid Dynamics Laboratory in partnership with the National Centers for Environmental Prediction and university-based applied research centers. The system management functions are focused in the Office of Global Programs.

1.2 Matrix document showing key activities and current status: Illustrated in Figure 2 and detailed below in Section 6.

1.3 Current out-year performance measures based on current funding levels: The performance measures are given in Section 5. At current funding levels the out-year accomplishments will be frozen at the deliverables indicated for FY05.

1.4 Current budget for each of the major activities (FY 2004):

Tide Gauge Network	\$1.7 M
Drifting Buoy Array	\$2.8 M
Tropical Moored Buoy Network	\$4.2 M
Ships-of-Opportunity Network	\$4.1 M
Argo Array of Profiling Floats	\$10.9 M
Ocean Reference Stations	\$3.8 M
Ocean Carbon Monitoring	\$2.9 M
Integrated Arctic Observing System	\$2.6 M
Dedicated Ship Time	\$10.7 M
Data and Assimilation Subsystems	\$4.6 M
Management and Product Delivery	\$2.4 M
	\$50.7 M

2.0 Statement of Need

The *Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCCC* concludes "there has been progress and improvement in the implementation of global climate observing systems since the first report, especially in the use of satellite information and in the provision of some ocean observations. At the same time, the Report notes that the global terrestrial networks remain to be fully implemented; the ocean networks lack global coverage and commitment to sustained operations; and the atmospheric networks are not operating with the required global coverage and quality. The Report concludes, in agreement with the IPCC, that there remain serious deficiencies in the ability of the current global observing systems for climate to meet the observational needs of the UNFCCC. ...Without urgent action to address these findings, the Parties will lack the information necessary to effectively plan for and manage their response to climate change."

The Report goes on to note "new technology developed and proven by the ocean climate programs of the 1990s has allowed the ocean community to design and commence implementation of an initial ocean climate observing system that is well focused on the UNFCCC needs. The first priority is the full implementation of this system together with its associated data, analysis and product capabilities."

This program plan is founded on the international design noted in the Report; it is illustrated in Figure 1. Other requirement drivers include the CCSP Strategic Plan expressing need for "complete global coverage of the oceans with moored, drifting, and ship-based networks," and the OCEAN.US *Implementation of the Initial U.S. IOOS* specifying "the highest priority for the global component of the IOOS is sustained, global coverage." NOAA's contribution to the commencement of global implementation is represented in the current program budget and the progress to date is illustrated in Figure 2. Implementation of this program plan will demonstrate to the world community that the United States is intent on taking immediate action to address the Report findings, is willing to play a leadership role in achieving global coverage of the ocean networks, and is committed to sustained operations.

2.1 Program Office requirements to be met: The NOAA Office of Global Programs is organized around four strategic objectives: 1) Development of an Earth System Model for climate change projections at GFDL; 2) Improvement of NWS operational seasonal to international climate forecasts; 3) Development of the in situ ocean component of the global climate observing system; and 4) Development of decision support tools. This plan describes the program for meeting the third objective.

2.2 Input from NOAA leadership, internal councils, and crosscut teams related to this strategy: VADM Lautenbacher has announced as one of his top priorities the building of a global climate observing system, particularly the ocean component. The NOAA Council on Long Term Climate Monitoring (CLTCM) has prioritized elements of ocean observation for their feasibility, impact and timeliness for reducing uncertainty in the role of the ocean in climate variability and change. A cross-cut team has been established in response to the recommendations of the NOAA Performance Review for developing an observing system architecture that will a) determine the adequacy of the state of the system today and in the future; b) address utilization of the data and archival; and c) consider other systems as well. This program plan is directed toward achieving VADM Lautenbacher's vision, the priorities of the CLTCM, and the three aspects of the observing system architecture for ocean climate.

2.3 External constituent input related to the strategy area: In 2001 the U.S. GOOS Steering Committee conducted a formal review of the 2001 version of this program plan. The review panel included international representatives of the IOC, IGOS, CLIVAR, WOCE, OOPC, GODAE, and JCOMM as well as partner agencies within the United States – NASA and NAVOCEANO. The seven summary recommendations of the review are paraphrased below.

1. Strong overall support for the plan. U.S. GOOS urged NOAA to implement the plan with the following additional recommendations:
2. The need for a management plan – An effort of the proposed magnitude must be integrated, organized, and managed as a system in order to be effective. The management plan should define an orderly decision making process with management accountability that is understood by other agencies and by customers. A single NOAA point of responsibility and authority is very desirable. Sections 7.0–7.7 achieve this recommendation.
3. The need for a data and information management budget. Section 6.12 achieves this recommendation.
4. The need for improved ocean products – evaluation and delivery. Section 7.6 achieves this recommendation.
5. The need for transition to operations of precision altimetry. Section 6.11 achieves this recommendation.
6. The need for ocean carbon monitoring to be better defined. Section 6.8 achieves this recommendation.
7. The need to deal with dedicated ship time issues. Section 6.10 has been revised to achieve this recommendation.

2.4 Relevant Congressional input or guidance related to the strategy area: The FY03 Senate Committee on Appropriations Report "reaffirms its support for the establishment of an integrated, interagency ocean and coastal observing system ... and requests the submission of a plan to implement such a system." The National Oceanographic

Partnership Program's Ocean.US office is responding to this Congressional request on behalf of the contributing agencies. The climate system detailed below forms the nucleus of the global component of the U.S. Integrated Ocean Observing System.

2.5 Known impediments (legal, fiscal, policy) towards achieving performance targets and objectives: None.

3.0 Program Initiative

3.1 Overall strategy for addressing deficiencies outlined in the Statement of Need Section. The strategic approach underlying this program plan is as follows:

- Build the long-term ocean component of the observing system in the context of a comprehensive, multi-year, climate services initiative. Improved marine and coastal forecast services will be immediate byproducts.
- Set a 2000-2010 timeline for phased implementation.
- Establish accountability by defining specific objectives and performance measures.
- Define an "initial observing system design" that will accomplish the objectives and performance measures. Identify annual milestones to complete the initial system over the ten-year time line. Emphasize that the initial design is our best guess at this time – it must be evolutionary as knowledge and technology advance.
- State the obvious – a global observing system cannot be built with existing budgets.
- Estimate the annual funding needed to achieve the identified milestones. Estimate that NOAA will implement about 50% of the global system.
- Work with national and international partners to achieve 100%.

Although NOAA's marine and coastal services and the mission services of the other agencies and nations will benefit from this plan, and are considered throughout, accomplishing NOAA's climate mission is the fundamental driver. The scientific foundations come from the Climate Variability and Predictability Program (CLIVAR), the Carbon Cycle Science Program, and the Global Water Cycle Program. It is not the intent of the plan to provide all of the observations needed by these programs but to provide a baseline observing system, to be sustained over the long term, that can be built upon where needed to answer specific questions. This baseline system looks for efficiencies to be gained by utilizing common platforms/sites/data infrastructure for several objectives in parallel, and seeks to foster a system approach to effective international organization of complementary in situ, satellite, data, and modeling components of climate observation.

Priorities for implementation are now in place based on the concept of extending the building blocks that have already been put in place, and on the international plan drafted by over 300 scientists from 26 nations that met in Saint Raphael, France, October 1999, at the OCEANOBS 99 Conference for design of *The Ocean Observing System for Climate*. Again, this NOAA plan does not seek to implement all aspects of the Saint-Raphael system, but only those base-line components needed to meet the design objectives (see Section 4.2), and those for which NOAA should expect to have primary mission responsibility in the United States.

3.1.1 NOAA context*:* This plan supports NOAA's strategic goal to monitor and observe: "NOAA will invest in needed climate quality observations and encourage other national and international investments to provide a comprehensive observing system in support of climate assessments and forecasts." The plan details how NOAA will achieve one element of that strategic goal – implementation of the sustained *in situ* ocean component of the climate observing system.

3.1.2 Interagency context: The observational objectives of NOAA's climate program and those of the CCSP are essentially identical and the ocean observing system architecture detailed below will be implemented by NOAA within the framework of, and as an element of, the CCSP. At the same time the observing system must be advanced in support of climate services, it must also be advanced in response to a national demand for the ocean agencies to coordinate implementation of an U.S. contribution to the global ocean observing system. It is recognized that an effective global ocean observing system can be achieved only through continuing interaction among all national (and international) partners. In this context, NOAA will provide a significant contribution to the global component of the Integrated Ocean Observing System. Implementation will be coordinated with the National Oceanographic Partnership Program agencies, just as all of NOAA's climate observation and research activities have been coordinated through the U.S. Global Change Research Program for the past decade.

3.1.3 International context: The observational component of climate services has by far the greatest opportunity and necessity for international collaboration. A global observing system by definition crosses international boundaries and the potential exists for both benefits and responsibilities to be shared by many nations. The system described below is based on the international design of, and is an U.S. contribution to, *The Ocean Observing System for Climate* (Saint-Raphael, France, 1999). The observing system projects that make up the climate component have been developed, and will continued to be evolved, organized and managed, in cooperation with the international implementation panels of the Joint IOC/WMO Technical Commission for Oceanography and Marine Meteorology (JCOMM), and with scientific guidance from the GCOS/GOOS/WCRP Ocean Observations Panel for Climate (OOPC).

3.2 Proposed out-year performance targets: See Sections 5.0-5.4.

3.3 Discussion of individual investments necessary to address shortfalls: Given in Sections 6.0-7.7.

3.4 ROM cost and schedule for each investment: Details given in Table 2. Summary:

	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
System annual operating cost ($ M)	35.2	41.2	59.2	98.1	125.7	139.3	142.6	144.5

4.0 Program Goal and Objectives

4.1 Goal
The goal of this plan is to build and sustain the ocean component of a global climate observing system that will respond to the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments.

4.2 Objectives

The ocean is the memory of the climate system and is second only to the sun in effecting variability in the seasons and long-term climate change. It is estimated that the ocean stores 1000 times more heat than the atmosphere, and 50 times more carbon. Eighty percent of the precipitation that waters our Earth comes directly from the ocean. Changing sea level is one of the most immediate impacts of climate change. Additionally, the key to possible abrupt climate change may lie in deep ocean circulation.

Accordingly, the objectives of the sustained ocean observing system for climate are to:

1) Document long-term trends in sea level change;
2) Document ocean carbon sources and sinks;
3) Document heat uptake, transport, and release by the ocean; and
4) Document the air-sea exchange of water and the ocean's overturning circulation.

This implementation plan will provide a composite global ocean observing system of complementary networks that includes: 1) deployment and maintenance of observational platforms and sensors; 2) data delivery and management; and 3) routine delivery of ocean analyses. This end-to-end ocean system will provide the critical "up-front" information needed for climate forecasting, research, and assessments – continuous, long term, climate quality, global data sets and a suite of routinely delivered ocean analyses. At the same time, the system will provide real-time data to serve the needs of NOAA's marine and coastal forecast missions and the needs of the other agencies in accomplishing their missions.

5.0 Performance Measures

In order to achieve the four objectives, the system must accurately measure: 1) sea level to identify changes resulting from climate variability; 2) ocean carbon content every ten years and the air-sea exchange seasonally; 3) sea surface temperature and surface circulation to identify significant patterns of climate variability; 4) sea surface pressure and air-sea exchanges of heat, momentum, and fresh water to identify changes in forcing functions driving ocean conditions and atmospheric conditions; 5) ocean heat and fresh water content and transports to identify where anomalies enter the ocean, how they move and are transformed, and where they re-emerge to interacting with the atmosphere; 6) identify the essential aspects of thermohaline circulation as well as the subsurface expressions of the patterns of climate variability; and 7) sea ice thickness and concentrations.

The sampling requirements for these parameters have been documented by international GOOS and GCOS. Table 1 lists the requirements as presented at the OCEANOBS 99 Conference in Saint-Raphael, France. It represents the best estimates of the international community at this time.

The Proceedings of OCEANOBS 99 and the final report from the conference, *Observing the Ocean in the 21st Century*, outline implementation strategies for achieving these sampling requirements. Additionally, for documenting sea level variability and change, the implementation strategy is further defined in the *International Sea Level Workshop Report*, 1998; and for documenting ocean carbon sources and sinks the implementation strategy is defined in the *Large Scale CO_2 Observing Plan: In Situ Oceans and Atmosphere (LSCOP)*, 2002. The latter plan is for the United States only at this time, but was developed by U.S. scientists working in collaboration with international partners. The international community met in Paris, January 2003, to advance international implementation of the ocean carbon monitoring system and the United States contribution will be updated as the international plan is formulated. These foundation documents are available from the NOAA Office of Global Programs and are listed in Appendix A.

Based on the requirements in Table 1 and the implementation strategies defined in the foundation documents listed in Appendix A, the system's effectiveness in meeting the objectives will be gauged by the performance metrics listed below. Detailed metrics are given for each objective in sections 5.1-5.4. Those detailed metrics will lead to a system that can be summarized in three overarching measures of success:

Performance Measure 1: Reduce the uncertainty in projections of sea level rise during the 21st century.

Metric: Range between credible estimates of sea level rise (centimeters):

2002	2003	2004	2005	2006	2007	2008	2009	2010
80 cm	80 cm	70 cm	60 cm	50 cm	40 cm	30 cm	25 cm	25 cm

Performance Measure 2: Reduce the uncertainty in estimates of the increase in carbon inventory in the global ocean.

Metric: Uncertainty in estimates of anthropogenic changer per decade (Gigatons):

2002	2003	2004	2005	2006	2007	2008	2009	2010
10 Gt	10 Gt	10 Gt	8 Gt	8 Gt	7 Gt	6 Gt	4 Gt	4 Gt

Performance Measure 3: Reduce the error in global measurement of sea surface temperature.

Metric: Potential satellite bias error (degrees Celsius):

2002	2003	2004	2005	2006	2007	2008	2009	2010
0.7 C	0.7 C	0.6 C	0.5 C	0.4 C	0.3 C	0.2 C	0.2 C	0.2 C

5.1 Document long-term trends in sea level change.

Performance Measure 4: Complete the installation of real-time, remote reporting tide gauges and co-located permanent GPS receivers at the international GLOSS subset of 62 stations for Long Term Trends and subset of 30 stations for altimeter drift calibration.

Performance Measure 5: Establish the permanent infrastructure necessary to process and analyze the tide gauge and GPS data and deliver routine annual sea level change reports.

Metrics:

For 62 climate reference stations worldwide, routinely deliver an annual report of the variations in relative annual mean sea level for the entire length of the instrumental record, and the monthly mean sea level trend for the past 100 years with 95% confidence interval.

Routinely deliver an annual report of global absolute sea level change to an accuracy of 1 mm per year.

5.2 Document ocean carbon sources and sinks.

Performance Measure 6: Complete the Northern Hemisphere ocean observing system to assist in determining carbon dioxide sources and sinks over the coterminous United States in partnership with the atmospheric observing system.

Performance Measure 7: Complete the expansion of the global oceanic observing system to inventory global scale oceanic uptake of excess carbon dioxide in partnership with the atmospheric observing system.

Metrics:

Report interhemispheric gradients of CO_2 constrained to 1 ppm on seasonal time scales.

Improve measurements of North Atlantic and North Pacific Ocean basin carbon dioxide fluxes to within ±0.2 Pg/C per year.

Reduce uncertainty on regional estimates of carbon sources and sinks on a global basis to ±50%.

Report the change in ocean carbon inventory over the last decade constrained to 2 Pg/C per year.
Provide publicly available, routine changes in inventory of carbon, heat, and salinity in the ocean basins on a decadal time frame to assess the effect of global change and feedbacks on the ocean

5.3 Document the ocean's storage and global transport of heat and fresh water.

Performance Measure 8: For the global ocean, complete the ocean observing system needed to measure the global variations in sea surface temperature, surface and 2000 m circulation, total heat content of the ocean, and the transport of heat across and between all ocean basins.

Performance Measure 9: Design, deploy, and implement instrument and analysis systems to provide long term integrated measures of the global thermohaline circulation and deliver yearly estimates of the state of the thermohaline circulation - intensity, properties, freshwater transport.

Metrics:
At ocean reference stations, deliver routine annual analyses of variability in average temperature at 0-1000 m depth to 0.1 C, and seasonal average temperature change to 0.1 C per three months.
Deliver analyses of the seasonal means of the surface and 2000 m ocean velocity fields on appropriate spatial resolutions that capture the major features of the overturning circulation for all the core climate variability regions (the global tropics, Pacific Decadal Oscillation, North Atlantic Oscillation, high latitude water mass formation regions both northern and southern hemispheres).
Deliver analyses of monthly mean sea surface temperature anomaly at 500 km resolution to 0.2 C accuracy, average temperature at 0-1000 m depth to 0.5 C accuracy, and annual average temperature change to 0.5 C per year.
For the sinking regions of the north Atlantic and southern hemisphere, deliver yearly estimates of the annual average temperature and salinity of the intermediate, deep, and bottom waters to 0.03 C and 0.03PSU.
Across zonal sections in the Atlantic at 24 N, 47 N, and globally at 35 S, deliver estimates of the average annual meridional heat transport from surface to bottom at 0.3PWatt accuracy.

5.3 Document the air-sea exchange of heat and fresh water.

Performance Measure 10: For the global tropical ocean belt, complete the upper ocean and surface meteorology observing system needed to measure the ocean-atmosphere exchange of heat.

Performance Measure 11: For the global ocean, complete the oceanographic, surface meteorology, and analysis system needed to measure variability in the ocean-atmosphere exchange of fresh water, i.e., precipitation and evaporation.

Metrics:
For the global ocean, deliver analyses of weekly mean sea surface temperature at 500 km resolution to 0.2 C accuracy
At ocean reference stations, deliver routine annual analyses of variability in ocean-atmosphere flux to 10 W/m^2.

For the global ocean deliver weekly analysis of precipitation and evaporation at 500 km resolution to 5 cm per month accuracy.

6.0 Milestones

In order to achieve the Performance Measures, the integrated ocean observing system will be completed according to the following schedule. The schedule is based on the initial design and projections of adequate funding. The milestones will be updated annually to reflect evolution of the design as knowledge and technology advance, and to reflect the realities of funding availability.

	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
System % Complete:	40	45	48	55	77	88	94	99	100

Although individual network priorities are described below, they must all go forward together as a system. For example, the global Argo array of profiling floats is a primary tool for documenting ocean heat content; yet deployment of the floats in the far corners of the ocean cannot be achieved without the ships-of-opportunity and dedicated ship time elements; and the Argo array cannot do its work without global over-flight by continued precision altimeter space missions; while the measurements taken by all networks will be rendered effective only through the data and assimilation subsystems.

The following sections indicate network improvements that work toward building the observing system as a whole. The ocean observing system is a composite of complementary networks, each one contributing its unique strengths; most serve multiple purposes. One of the primary goals of NOAA's Office of Climate Observation is to look for efficiencies to be gained by utilizing common platforms/sites/data infrastructure for several objectives in parallel. For these reasons it is difficult to assign the network components specifically to the climate service product lines on a one-to-one basis. In general, however, the network tasks described below will contribute to the deliverables as follows:

1) Document long-term trends in sea level change:
    - Tide Gauge Network
    - Satellites
    - Data and Assimilation Subsystems

2) Document ocean carbon sources and sinks:
    - Drifting Buoy Array
    - Tropical Moored Buoy Network
    - Ships of Opportunity
    - Argo Array
    - Ocean Reference Stations
    - Ocean Carbon Measurements
    - Coastal Moorings
    - Dedicated Ship Time
    - Data and Assimilation Subsystems

3) Document heat uptake, transport, and release by the ocean:
    - Tide Gauge Network
    - Drifting Buoy Array
    - Tropical Moored Buoy Network
    - Ships of Opportunity
    - Argo Array
    - Ocean Reference Stations

Coastal Moorings
Dedicated Ship Time
Satellites
Data and Assimilation Subsystems

4) Document the air-sea exchange of water and the ocean's overturning circulation:
Drifting Buoy Array
Tropical Moored Buoy Network
Ships of Opportunity
Argo Array
Ocean Reference Stations
Coastal Moorings
Dedicated Ship Time
Satellites
Data and Assimilation Subsystems

Priorities and milestones for the individual networks follow. For each network the several priority tasks are listed in tabular form. The bottom lines of the tables give the representative milestones that are shown graphically in Figure 2; representative milestones are used to simplify the graphic depiction of the phased implementation plan illustrated by Figure 2. Relative emphases in completing the several components of the observing system will depend on the relative priorities assigned to the network tasks in the context of the overall requirements of climate services.

6.1 Tide Gauge Network: Tide gauges are necessary for accurately measuring long-term trends in sea level change and for calibration and validation of the measurements from satellite altimeters, which are assimilated into global climate models for predicting climate variability. Many tide stations need to be upgraded with modern technology. Permanent GPS receivers will be installed at a selected subset of stations, leading to a geocentrically located subset expansion from the present 37 GPS sites to 86 sites globally by 2006. In cooperation with international partners NOAA will maintain a global climate network of 199 tide gauges stations, including the subset noted above, for validation of satellite retrievals, validation of climate model results, and documentation of seasonal to centennial variability in the El Nino Southern Oscillation, Indian Ocean and Asian-Australian monsoons, tropical Atlantic variability, North Atlantic Oscillation, North Pacific variability, high latitude circulation, western boundary currents, and circulation through narrow straits and chokepoints. This task will contribute to climate services by providing the long term records needed to 1) document sea level change: 2) document heat uptake, transport, and release by the ocean (sea surface height contributes to the measurement of ocean heat content); and 3) documents the ocean's overturning circulation (gradients of sea surface height across straights and choke-points are used to calculate large-scale ocean currents).

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational stations	57	63	63	63	63	63	63	63	107
Research stations	6	0	0	0	0	0	0	0	0
Station upgrades	0	4	10	16	26	32	32	32	199
GPS installation	5	10	14	20	40	40	40	40	86
GPS data processing			X	X	X	X	X	X	X
Technology development				X	X	X	X	X	X
International GPS/DORIS	43	55	75	86	86	86	86	86	86

6.2 Drifting Buoy Array: Data sparse regions of the global ocean are a major source of uncertainty in the seasonal forecasts and are also a major uncertainty in the detection of long-term trends in global sea surface temperature, which in turn is an indicator of global change. Data gaps must be filled by surface drifting buoys to reduce these sources of error to acceptable limits. NOAA, together with international partners, will extend the global SST/velocity drifting buoy array to data sparse regions, increasing from 787 to 1250 buoys by 2005, while adding wind, pressure, and precipitation measurement capabilities to serve short term forecasting as well as climate research, seasonal forecasting, and assessment of long term trends. This task will support climate services by providing measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks (sea surface temperature affects the rate of transfer of CO_2 between the ocean and atmosphere; 3) document the air-sea exchange of water and the ocean's overturning circulation, and 4) document sea level change by providing the sea surface atmospheric pressure measurements that are essential for calculating sea surface height from satellite altimeter measurements.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational buoys	420	670	1040	1040	1040	1040	1040	1040	1250
Research buoys	200	200	0	0	0	0	0	0	0
Add met sensors	40	40	500	670	670	670	670	670	1250
Technology development			X	X	X	X	X	X	X
International array size	787	1050	1250	1250	1250	1250	1250	1250	1250

6.3 Tropical Moored Buoy Network: Most of the heat from the sun enters the ocean in the tropical/sub-tropical belt. The advanced understanding of the role of the tropics in forcing mid-latitude weather and climate was learned primarily through the observations of the tropical moored buoy array (TAO/TRITON) in the Pacific. A similar pilot array in the Atlantic basin (PIRATA) now offers the potential of even better understanding, improved forecasts, and improved ability to discern the causes of longer-term changes in the Oceans. In addition to monitoring the air-sea exchange of heat, the moored buoys provide platforms for supporting instrumentation to measure carbon dioxide and rainfall in the tropics. The global tropical moored buoy network will be expanded from 79 to 112 stations by 2009 and will ultimately span all three oceans - Pacific, Atlantic, and Indian Ocean. This task will support climate services by providing both ocean and atmospheric observations to 1) document heat uptake, transport, and release by the ocean; 2) document carbon sources and sinks; and 3) document the air-sea exchange of fresh water.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational buoys	55	65	65	65	65	65	65	65	79
Research buoys	10	0	0	0	0	0	0	0	0
Indian Ocean expansion			3	6	15	15	15	15	30
Atlantic Ocean expansion			2	2	5	5	5	5	9
Add salinity sensors	10	10	60	65	65	65	65	65	99
Add flux capability to buoys			5	5	5	5	5	5	8
Technology development			X	X	X	X	X	X	X
International network size	79	79	82	85	89	100	112	112	112

6.4 Ships of Opportunity: The global atmospheric and oceanic data from Ships of Opportunity (SOOP) have been the foundation for understanding long-term changes in marine climate and are essential input to climate and weather forecast models. Improved instrument accuracy, automated reporting, and improved information about how the observations were taken will greatly enhance the quality of these data, reducing both systematic and random errors. NOAA will improve meteorological measurement capabilities on the global SOOP fleet for improved marine weather and climate forecasting in general, and will concentrate on a specific subset of high accuracy SOOP lines to be frequently repeated and sampled at high resolution for systematic upper ocean and atmospheric measurement. This climate-specific subset will build from 26 lines presently occupied to a designed global network of 41 lines by 2007 and will provide measurements of the upper ocean thermal structure, sea surface temperature and chemistry, and surface meteorology of high accuracy. Additionally, the SOOP fleet is the primary vehicle for deployment of the drifting arrays. This task will support climate services by providing ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; and 2) document ocean carbon sources and sinks (carbon sampling instrumentation is detailed under a separate task below); and 3) document the air-sea exchange of water and the ocean's overturning circulation.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational HRX lines	2	15	21	21	21	21	21	21	26
Research HRX lines	6	0	0	0	0	0	0	0	0
Frequently repeated lines	4	5	8	8	8	8	8	8	22
Add flux/salinity HRX	2	2	7	12	15	15	15	15	26
Auto-met package, VOSClim	0	0	40	100	200	200	200	200	200
Technology development				X	X	X	X	X	X
International lines	26	29	30	36	45	45	45	45	45

6.5 Argo array of profiling floats: The heat content of the upper 2000 meters of the world's oceans, and the transfer of that heat to and from the atmosphere, are variables central to the climate system. The Argo array of profiling floats is designed to provide essential broad-scale, basin-wide monitoring of the upper ocean heat content. Three thousand floats will be deployed worldwide by 2005. The U.S. contribution is approximately one-half of this international project. Glider technology will replace standard drifting Argo floats in the boundary currents and targeted deep circulation regions. This task will support climate services by providing measurements needed to 1) document heat uptake, transport, and release by the ocean; and 2) document the air-sea exchange of water and the ocean's overturning circulation.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational Argo floats	320	1000	1500	1485	1485	1385	1385	1385	2800
Research Argo floats	15	0	0	0	0	0	0	0	0
Operational gliders	0	0	0	0	0	100	100	100	200
Research gliders	3	3	10	20	50	0	0	0	0
Technology development				X	X	X	X	X	X
International array size	1000	2000	3000	3000	3000	3000	3000	3000	3000

6.6 Ocean Reference Stations:

6.6.1 Subtask 1: NOAA, together with international partners, will implement a global network of ocean reference station moorings, expanding from the present six pilot stations to a permanent network of 21 (plus 8 within the tropical moored buoy network) by 2008. NSF's Ocean Observatories Initiative will provide a major piece of the infrastructure needed for this network, establishing high-capability re-locatable moored buoys in remote ocean locations. NOAA will maintain climate instrumentation aboard the NSF-supplied platforms.

6.6.2 Subtask 2: Monitoring the transport within the ocean is a central element of documenting the overturning circulation of fresh water and heat and carbon uptake and release; heat and carbon generally are released to the atmosphere in regions of the ocean far distant from where they enter. Long-term monitoring of key choke points, such as the Indonesian through-flow, and of boundary currents along the continents, such as the Gulf Stream, must be established to measure the primary routes of ocean heat, carbon, and fresh water transport.

6.6.3 Subtask 3: Monitoring thermohaline circulation is a central element of documenting the ocean's overturning circulation and a critical need for helping scientists understand the role of the ocean in abrupt climate change. It is essential that the ocean observing system maintain watch at a few control points at critical locations. Key monitoring sites have been identified by an international team of scientists for deployment of long-term subsurface moored arrays and repeated temperature, salinity, and chemical tracer surveys from research vessels. NOAA will focus with Canadian partners on monitoring the Labrador Sea and upstream locations in Davis Strait and the Canadian Arctic Archipelago, while European partners will focus on the eastern north Atlantic. One exception to this is that NOAA will maintain the Greenland-Iceland-Norwegian (GIN) Seas times-series that was started in 1991. Additionally, to estimate the effect of Antarctic zone water on the global thermohaline circulation, NOAA will maintain time series moorings and repeat sections in the northwestern Weddell Sea, and will establish time series measurements in the Ross Sea. These locations are important to examine the variability of water mass transformation processes as they relate to climate variability in the Southern Ocean.

6.6.4 Summary: These three subtasks will support climate services by providing ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks (carbon sampling instrumentation is detailed under a separate task below; and 3) document the air-sea exchange of water and the ocean's overturning circulation.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Operational flux moorings	1	2	6	7	9	9	9	9	29
Research flux moorings	1	0	0	0	0	0	0	0	0
Operational full depth stations	0	0	3	5	10	10	10	10	42
Research full depth stations	1	1	0	0	0	0	0	0	0
Operational transport stations	0	0	2	4	4	5	5	5	10
Research transport stations	2	0	0	0	0	0	0	0	0
Pacific Raingauge (PACRAIN)	0	28	28	28	28	28	28	28	28
Research rain gauge network	28	0	0	0	0	0	0	0	0
Operational GIN time series	0	1	1	1	1	1	1	1	1
Research GIN time series	1	0	0	0	0	0	0	0	0
Sinking regions, operational	0	2	2	4	4	4	4	4	5

Sinking regions, research	1	1	0	0	0	0	0	0	0
S. Hemisphere sections	0	0	0	2	3	3	3	3	3
Technology development				X	X	X	X	X	X
International flux array	6	7	10	14	16	29	29	29	29

6.7 Coastal Moorings: Improved near shore measurements from moored buoys are critical to coastal forecasting as well as to linking the deep ocean to regional impacts of climate variability. The boundary currents along continental coastlines are major movers of the ocean's heat and fresh water (e.g., the Gulf Stream). Furthermore, the coastal regions are critical to the study of the role of the ocean in the intensification of storms, which are key to the global atmospheric transport of heat, momentum and water, and are a significant impact of climate on society. Coastal arrays are maintained by many nations making this a "global" network of "coastal" stations. A climate subset of NOAA's existing network will be improved by augmenting and upgrading the instrument suite to provide measurements of the upper ocean as well as the sea surface and surface meteorology. Ten of these moorings will serve as platforms-of-opportunity for the addition of carbon sampling instrumentation. This task will support climate services by providing ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks (carbon sampling instrumentation is detailed under a separate task below); and 3) document the air-sea exchange of water.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Upgrade w/climate sensors	0	0	20	65	65	65	65	65	105
Technology development				X	X	X	X	X	X
International coastal network	0	0	20	85	95	105	105	105	105

6.8 Ocean Carbon: Understanding the global carbon cycle and the accurate measurement of the regional sources and sinks of carbon are of critical importance to international policy decision making as well as to forecasting long term trends in climate. Projections of long-term global climate change are closely linked to assumptions about feedback effects between the atmosphere, the land, and the ocean. To understand how carbon is cycled through the global climate system, ocean measurements are critical. NOAA will add autonomous carbon dioxide sampling to the moored arrays and the VOS fleet to analyze the seasonal variability in carbon exchange between the ocean and atmosphere, and in cooperation with NSF will implement a program of systematic global ocean surveys that will provide a complete carbon inventory once every ten years. This task is coordinated with the Global Carbon Cycle Science program, is dependent on implementation of the ship lines and moored and drifting arrays, and will support climate services by providing measurements to document ocean carbon sources and sinks.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Inventory lines per decade	6	6	11	11	11	11	11	11	25
Time series moorings	2	2	4	6	6	6	6	6	12
Coastal flux moorings	0	0	0	11	11	11	11	11	29
Flux on ships of opportunity	4	7	12	12	12	12	12	12	21
Research flux on moorings	2	0	0	0	0	0	0	0	0

Trans rsch flux moorings to ops	0	2	2	2	2	2	2	2	2
Technology development			X	X	X	X	X	X	X
International flux array	14	17	28	38	48	62	62	62	62

6.9 Integrated Arctic Observing System: To understand the role of the Arctic on global environmental change, the amount of uncertainty in the causes and trajectories of global climate change needs to be reduced. Given the sensitivity of the Arctic environment to climate variability and change, it is in this region that early indications of the future progression of climate change are likely to be first detected.

Ocean Climate Observations in the Arctic Ocean and Northern High Latitude Seas – A program of sustained observations of this area is being conducted through dedicated and shared ship-based cruises and permanent oceanographic moorings, supplemented by acquisition and analysis of historical data sets. The long-term goal is to detect climate-driven physical and ecological change, especially due to changes in sea ice extent and duration, and in ocean density and circulation that together may lead to changes in ocean heat transport, productivity, and food web structure. International collaboration is essential for completing this program, especially with Russia and Canada. In FY2003, one new mooring was deployed in the Northern Bering Sea, a research cruise was conducted to the Chukchi Sea in collaboration with China, planning was initiated for a future Chukchi Sea cruise in collaboration with Russia, sea-glider deployments were initiated in the Labrador Sea, joint US-Canada observations were conducted in Barrow Strait, and efforts begun to discover, obtain and manage historical data sets.

Arctic Sea Ice Observations – Ice-tethered buoys and bottom-mounted moorings are deployed to monitor the drift of Arctic sea ice and to determine its thickness. The long-term goal is to provide an accurate record of changes in sea ice thickness that, together with satellite observations of sea ice extent, can provide an estimate of changes in sea ice volume. This information is critical for improvement of global climate models and development of a regional Arctic climate model. Several ice buoys and two ice thickness stations were deployed in summer 2003.

This task will support climate services by providing ocean and ice measurements needed to document heat uptake, transport, and release by the ocean.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Arctic pathway moorings	0	0	1	2	4	6	8	8	12
Arctic Ocean moorings	0	0	1	2	4	6	7	7	8
ASOF gateway mooring sets	0.5	0.5	1	1	1	1	2	2	5
Automated drifting stations	0	0	1	2	2	2	2	3	3
Ice buoys	10	10	11	20	20	20	20	20	40
Hydrographic stations	0	0	1	4	6	8	9	10	16
Bering Sea moorings	1	1	1	2	4	6	6	6	6
Western boundary sections	0	0	1	1	1	1	1	1	1
Western boundary moorings	0	0	2	2	4	4	4	4	4
Ice buoys and moored stations	10	11	13	23	25	33	43	51	51

6.10 Dedicated Ship Time:

6.10.1 Subtask 1: Climate Ship time within the UNOLS research fleet for deployment of the moored and drifting arrays, and for deep ocean surveys is an essential component of this initiative. The deep ocean cannot be reached by SOOP and Argo; yet quantification of the carbon and heat content of the entire ocean column is needed to solve the climate equations. In addition to providing the survey and deployment platforms for the autonomous arrays, the research fleet will maintain sensor suites on a small core of vessels as the highest quality calibration points for validation of the other system measurements. Annual requirements for ship time are 54 days in addition to the Ka'imimoana for TAO/TRITON maintenance, 74 days for the carbon inventory, 34 days for PIRATA in addition to the French/Brazilian support (see Subtask 2), 47 days for ocean reference stations growing to 120 days, 60 days for deployment of the drifting arrays in remote regions, and 46 days for thermohaline circulation monitoring growing to 172 days.

6.10.2 Subtask 2: The PIRATA array has been maintained by French research vessels, once per year in the east, and the Brazilian navy once per year on the western side of the Atlantic. Two maintenance visits per year to each mooring are necessary to maintain adequate operational data flow, as has been demonstrated in the Pacific with the TAO/TRITON array. The PIRATA consortium (Brazil, France, U.S.A.) has proposed a plan to establish an international ship base in Natal, Brazil, and operate cooperatively a new ship dedicated to Atlantic climate operations. The consortium has proposed that NOAA and French partners cooperate to acquire a new ship, and build the capacity in Brazil to support long-term climate operations. The new ship would support Argo and drifter deployments as well as PIRATA maintenance. The U.S. homeport for the ship, and support base for north Atlantic operations, would be Charleston, SC; Natal would support operations in the tropical and south Atlantic. This is a new concept in international collaboration and capacity building. In 2003, NOAA began feasibility study together with French and Brazilian partners to identify the best long-term solution to this issue. In the mean time, NOAA will begin supplementing the once-per-year French and Brazilian maintenance cruises with a second maintenance cruise using UNOLS or other charter operations (see Subtask 1).

6.10.3 Summary: This task will support climate services by providing multi-use platforms for the ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks; and 3) document the air-sea exchange of water and the ocean's overturning circulation.

Ship days at sea	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Ka'imimoana	276	276	276	276	276	276	276	276	276
TAO/TRITON additional	54	54	54	54	54	54	54	54	90
PIRATA	0	0	34	34	34	34	34	34	124
Carbon survey	74	74	74	74	74	74	74	74	240
Coastal flux maps	0	0	0	36	40	40	40	40	240
Reference Stations	47	47	47	60	102	120	120	120	480
Deployment of drifting arrays	0	0	0	60	60	60	60	60	100
Thermohaline circulation	46	46	46	46	90	172	172	172	340
Arctic hydrographic sections	0	0	0	60	60	60	60	60	120
NOAA total	497	497	531	700	790	890	890	890	
International fleet	550	610	750	900	1200	1620	1620	1620	1620

6.11 Satellites:

The initial ocean observing system for climate depends on space based global measurements of 1) sea surface temperature, 2) sea surface height, 3) surface vector winds, and 4) ocean color. These satellite contributions are detailed in other NOAA program plans.

6.11.1 Sea surface temperature: Satellite measurements of sea surface temperature are included in NOAA's operational satellite program and the NPOESS program. Satellite data provide high-resolution sea surface temperature data. Both infrared and microwave satellite data are important. Microwave sea surface temperature data have a significant coverage advantage over infrared sea surface temperature data, because microwave data can be retrieved in cloud-covered regions while infrared cannot. However, microwave sea surface temperatures are at a much lower spatial resolution than infrared. In addition microwave sea surface temperatures cannot be obtained within roughly 50 km of land. A combination of both infrared and microwave data are needed because they have different coverage and error properties. Drifting buoy and other *in situ* data are critically important in providing calibration and validation in satellite data as well as providing bias correction of these data. Satellite biases can occur from obit changes, satellite instrument changes and changes in physical assumptions on the physics of the atmosphere (e.g., through the addition of volcanic aerosols). Thus, drifting buoy and other *in situ* data are needed to correct for any of these changes.

6.11.2 Sea surface height: The value of spaced-based altimeter measurements of sea surface height has now been clearly demonstrated by the TOPEX/Poseidon and Jason missions. Changes in sea level during major El Nino events can now be discerned at high resolution and provide realistic model initializations for seasonal climate forecasting. The same data, when calibrated with island tide gauge observations, are also able to monitor the rate of global sea level change with an accuracy of 1 mm per year. The planned NPOESS altimeter will be adequate for shorter term forecasting, but the NPOESS altimeter will not fly in the same orbit as TOPEX/Poseidon and Jason; and for monitoring long-term sea level change, continuation of precision altimeter missions in the TOPEX/Poseidon/Jason orbit is necessary. Jason follow-on altimeter missions (Ocean Surface Topography Mission, OSTM) are necessary to continue the long-term sea level record. NASA and CNES have asked NOAA and EUMETSAT to transition the Jason-class altimeter from research to operations beginning with the OSTM. In FY2006, NOAA will assume primary U.S. responsibility for continuing this international effort. This task will contribute to climate services by providing the long term records needed to 1) document sea level change; 2) document heat uptake, transport, and release by the ocean; and 3) document the ocean's overturning circulation (sea surface height contributes to the measurement of ocean heat and fresh water content and their transport).

6.11.3 Surface vector winds and ocean color: The best methods of sustaining satellite measurement of surface vector winds and ocean color are still a research and development question; over the next five years NOAA, NASA, and NPOESS will weigh the alternatives and determine the long term strategy for maintenance of these elements.

6.12 Data and Assimilation Subsystems:

6.12.1 Subtask 1 – Long Term Stewardship: The value of the observations does not end with their initial use in detecting and forecasting climate variability. The data must be retained and made available for retrospective analyses to understand long-term climate change, and for designing observing system operations and improvements. NOAA's long history and unique expertise in environmental data management will be applied to the ocean observing system. NOAA also will include the vast holdings of historical ocean observations within the context of the integrated environmental data access and archive system. Support will also be provided for a World Ocean Database to incorporate modern data into an integrated profile system.

6.12.2 Subtask 2 – Data Management and Communications: A robust and scalable data management infrastructure is essential to the vision of a sustained ocean observing system. NOAA's ocean climate data element will contribute a global component to the Data Management and Communications System (DMAC) of the U.S. Integrated Ocean Observing System (IOOS) that is being implemented by the National Oceanographic Partnership Program agencies. The DMAC plan integrates data transport, quality control, data assembly, limited product generation, metadata management, data archeology, data archival, data discovery, and administration functions. Uniform access to data will be addressed through the concept of "middleware" connectivity – a common set of standards and protocols that connects all data sources to data users. The middleware approach shields end users from many of the traditional barriers that have been associated with climate data access, including file formats, the distributed location of data, and the large size of some data sets. The preliminary design has been developed by the National Virtual Ocean Data System (NVODS) project.

The nature of IOOS requires the DMAC to be very highly distributed, supporting both large and small data providers at Federal, regional, state, municipal and academic levels. Data assembly centers will be built into the design to add fault-tolerance and increase ease of use. The GODAE server at Navy's Fleet Numerical Modeling Operations Center (FNMOC) in Monterey will provide robust, operational access to aggregated and quality-controlled real-time data streams and will be a primary assembly center for NOAA's real-time global measurements. Delayed-mode data sources will be distributed across many institutions including the Asia-Pacific Research Data Center (APDRC) (part of the International Pacific Research Center (IPRC) at the University of Hawaii) and the NOAA Data Centers. The APDRC will provide data assembly services for delayed-mode observations in a cooperative partnership with the GODAE Server.

The Data Management and Communications component of NOAA's ocean climate observing system must also deliver the information products needed by NOAA scientists and managers for decision support. The products must provide the information needed to monitor the month-by-month effectiveness of the observing system and to diagnose problems. The products should include intelligible scientific graphics and human-readable numeric tables that provide an overview of the integrated system, selectively merging the data from all relevant measurement streams. These information products will be a component of NOAA's contribution to IOOS.

6.12.3 Subtask 3 – Four dimensional data assimilation including GODAE: For climate forecasting, the combined fields from many different networks are used as initial conditions to begin the forecast. These combined fields, or analyses, are also used to document what the ocean and atmosphere are doing at present and what they did in the past, thus providing a record of the changing climate. By routinely comparing models and data, shortcomings in the observing system can be identified and both the models and forecasts can be improved. To utilize effectively the ocean observations, NOAA will expand the current ocean analyses (presently focused on the tropical Pacific) to the global domain and will develop and implement improved assimilation subsystems that can more effectively use the new data types that are being collected. The principal vehicle for developing this capability, involving both national and international communities and producing a variety of marine products in addition to the use of these observations in forecast systems, will be the Global

Ocean Data Assimilation Experiment (GODAE). The global data and ocean product delivery will be operationalized as a contribution to, and continue as a follow-on to, GODAE through the interagency/international server infrastructure being implemented by GODAE for real-time at FNMOC and for delayed mode at the IPRC; NOAA will provide the primary U.S. support to sustain the IPRC server infrastructure over the long term (in cooperation with Japan). In addition to improving initializations for seasonal forecasting at NCEP, NOAA will implement sustained ocean data assimilation activities at GFDL to enable experimental decadal forecasts, provide ocean initial conditions for IPCC type scenarios, monitor ocean heat uptake, monitor the thermohaline circulation for abrupt changes, and develop a capability for monitoring changes in oceanic carbon sources and sinks.

6.12.4 Summary: This task will support climate services by providing the integrating data, synthesis, and analysis infrastructure for the ocean and atmosphere measurements, both *in situ* and space based, needed to: 1) document long-term trends in sea level change; 2) document heat uptake, transport, and release by the ocean; 3) document ocean carbon sources and sinks; and 3) document the air-sea exchange of water and the ocean's overturning circulation.

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
Data set development	X	X	X	X	X	X	X	X	X
World Ocean Database				X	X	X	X	X	X
Standards and protocols				X	X	X	X	X	X
Systems interoperability	X	X	X	X	X	X	X	X	X
Automated monitoring tools	X	X	X	X	X	X	X	X	X
IPRC server	X	X	X	X	X	X	X	X	X
GODAE pilot activities (JIMO)	X	X	X	X	X	X	X	X	X
Operationalize GODAE pilot		X	X	X	X	X	X	X	X
Global initialization for S-I	X	X	X	X	X	X	X	X	X
Experimental decadal forecast		X	X	X	X	X	X	X	X
Conditions for IPCC scenarios		X	X	X	X	X	X	X	X
Monitor ocean heat uptake		X	X	X	X	X	X	X	X
Monitor thermohaline circulation				X	X	X	X	X	X
Monitor carbon sources and sinks	X	X	X	X	X	X	X	X	X
Argos data processing – Drifting Buoy arrays	X	X	X	X	X	X	X	X	X
Argos data processing – Tropical Moored Buoy network	X	X	X	X	X	X	X	X	X
Argos data processing – Ocean Ref stations	X	X	X	X	X	X	X	X	X

7.0 Management Plan – System organization and product delivery

A global effort of the proposed magnitude must be integrated, organized, and managed as a system in order to be effective. Matrix management is NOAA's corporate business practice and standard protocol. This management plan will follow that protocol by capitalizing on the capabilities that presently exist across the agency while building toward the vision of a single composite system.

Implementation of the individual *in situ* networks will continue to be through distributed centers of expertise at the NOAA Research laboratories, the National Ocean Service Center for Operational Oceanographic Products and Services, the National Data Buoy Center, and the university laboratories that have developed the instruments and techniques. The space components and data management will be centered in the National Environmental Satellite Data and Information Service. The focal point for developing global ocean data assimilation capabilities will be the Geophysical Fluid Dynamics Laboratory in partnership with the National Centers for Environmental Prediction and university-based applied research centers.

To weld the distributed efforts together into the single vision, NOAA has established a project Office of Climate Observation (OCO) under the auspices of the NOAA Climate Program. Organizationally the project office is located within the Office of Global Programs (OGP). OGP embodies a global perspective and is experienced in matrix management. One of OGP's four strategic objectives is "development of the *in situ* ocean component of the global climate observing system." Additionally, for the climate observing system institutional mechanisms must be put in place to ensure continuous and close involvement of the research community. Research, operations, and management are inseparable for climate observation and OGP will hard-wire that relationship.

The Director of OGP utilizing the OCO is charged with advancing NOAA's multi-year program plan for *Building a Sustained Ocean Observing System for Climate.* The OCO is a hybrid combining the functions of a traditional program office with the functions of a center for system monitoring, evaluation, integration, and action. The individual network managers will continue to monitor and evaluate the performance of their individual networks, while the OCO will build the capability to monitor and evaluate the performance of the system as a whole, and take action to evolve the *in situ* networks for overall effectiveness and efficiency in meeting climate observation objectives.

The OCO is the management focus for the distributed ocean network operations and, utilizing the NOAA Observing System Architecture, establishes and maintains operational linkages between the networks and NOAA's other *in situ* and satellite elements and the data and modeling activities that are essential components of climate observation. The office provides a central point of contact within NOAA for coordination with the other agencies and nations involved in observing system implementation. The office receives and acts on feedback from the observing system customers - the operational forecast centers, international research programs, and major scientific assessments - and acts on their observational requirements in accordance with the NOAA Requirements-Based Management Process.

7.1 Subtask 1 – System Monitoring: The OCO monitors the status of the globally distributed networks to anticipate gaps and overlaps in their combined capabilities. Real-time reports from all platforms are being centralized so that up-to-date status can be displayed at all times. The office is working to report system statistics and metrics, routinely and on demand.

7.2 Subtask 2 – Evaluation: Expert teams of scientists both internal and external to NOAA will be established to continually evaluate the effectiveness of the networks in meeting the performance measures and the adequacy of the deliverables in meeting the system objectives. The expert teams will evaluate analysis/synthesis products, recommend product improvements, recommend where additional sampling is needed or redundancies are not needed, recommend better utilization of existing and new *in situ* and satellite data, and assess the impacts of proposed changes to the system. Figure 3 shows the draft framework for expert teams for the ocean component of the system. Three teams are at least partially established…the Air-Sea Exchange of Heat And Water "goal" team under the direction of Dick Reynolds (NCDC); the Carbon Sources and Sinks "goal" team under the direction of Richard Feely, Rik Wanninkhof, and others; and the Seasonal Forecasting "mission" team under the direction of ODASI.

7.3 Subtask 3 – Action: System monitoring and evaluation will be useless unless there is responsive action taken to build the system, fix problems, and improve sampling strategies. Decisions must be made to implement the best solutions to conflicting requirements (multiple partners and customers have differing missions and will inevitably have differing requirements), to re-deploy existing resources to best improve the system, to select the highest priorities for system extensions and funding of new ideas, and to agree on quid pro quo with interagency and international partners. The OCO is charged with advancing NOAA's multi-year program plan and with evolving the system for maximum effectiveness and efficiency along the way.

7.4 Subtask 4 – Intra-agency, Interagency, and International Coordination: National and international coordination is essential to success in building the global ocean observing system for climate. The OCO is charged with building the infrastructure necessary to organize NOAA's ocean observing efforts along three axes – 1) climate services, 2) the U.S. Integrated Ocean Observing System, and 3) international implementation.

1) For climate services the ocean observations must be available to be combined with data from the atmospheric networks, land surface networks, and cryosphere networks. The requirements from the three user communities – the forecast centers, research programs, and scientific assessments – must be received and synthesized into common requirements or prioritized if they do not resolve readily.

2) For the U.S. Integrated Ocean Observing System, NOAA's climate system will make a significant contribution to the global component where like data from the various platforms, *in situ* and space-based, must be combined to form complete fields (e.g., sea surface temperature from ships, drifting and moored buoys, and satellites). NOAA's efforts must be combined with the efforts of the other NOPP agencies into a seamless system.

3) For international implementation NOAA must work with the implementation panels of the Joint IOC/WMO Commission for Oceanography and Marine Meteorology (JCOMM) to ensure that consistent standards and formats are used by all participating nations so that data can be easily shared and that consistent quality can be expected from all platforms regardless of their national origin.

In addition to dedicated infrastructure needed for NOAA to operate an office for climate observation, dedicated infrastructure is also needed for operation of the interagency and intergovernmental planning and implementation coordination organizations. These interagency/international organizations rely on funding from the member agencies for their support. NOAA has historically provided a significant portion of the funding needed to maintain the existing international secretariats, science and implementation panels, and capacity building efforts of GOOS, GCOS, and the JCOMM. This funding support has been ad hock and in general from the research programs. As a central component of sustaining the long-term, operational global climate observing system, support for the national/international coordination/implementation infrastructure will be institutionalized via the OCO.

7.5 Subtask 5 – Annual Report on the Ocean's Role in Climate: The organizing framework to bring the multiple elements of the composite ocean observing system together is the routine delivery of an *Annual Report on the State of the Ocean and the Ocean Observing System for Climate.* The National Climate Change Science Program strategic plan has identified the critical need for regular reports documenting the present state of the climate system components. NOAA's Office of Climate Observation will lead the national effort to develop this reporting for the ocean component. The theme of the report is the

CCSP overarching question for guiding climate observations and monitoring- "What is the current state of the climate, how does it compare with the past, and how can observations be improved to better initialize and validate models for prediction or long term projections?"

The annual report synthesizes satellite and *in situ* observations integrated with models and provides the products to decision makers, the science community, and the public. This reporting framework also establishes a formal mechanism for implementing a "user-driven" observing system and for reporting on the system's performance in meeting the requirements of the operational forecast centers, international research programs, and major scientific assessments. Stakeholders are invited to provide formal recommendations for system improvement and evolution as part of the annual report process.

The annual report contains four chapters:

1) This chapter describes The Role of the Ocean in Climate and includes a description of ENSO, SST, sea ice, and sea level, and the various demands on the system incorporating seasonal, interannual, decadal, and climate change time scales. This chapter sets the context for the report and outlines common themes, including the significance of the global ocean observing system and the demands on the system.

2) The second chapter documents the State of the Ocean. The target audience is decision makers and non-scientists. This chapter will be written by the experts in the field and will be an annually updated climatology of the ocean, placed in historical context, with discussion of the present uncertainties and with pointers to products of greater detail and climate applications.

3) The third chapter documents the State of the Observing System. The target audience is NOAA management. This chapter has two sections:

a) System Progress in meeting milestones is documented by the network managers for their projects and by the OCO for the system in total. Annual statistics and status are given.
b) In the future, overall System Performance will be evaluated by the expert teams and by the users of ocean observations (the operational forecast centers, research programs, and scientific assessments). The stakeholders will be invited annually to give formal feedback to the observing system management and recommend improvements needed in the observations for delivery of climate services.

4) Chapter four recaps the State of the Science. The target audience is scientists. The final chapter of the report contains a bibliography of refereed publications from scientific journals treating the global observation of ocean heat, carbon, fresh water, and sea level change. Each year a selected number of reprints of particularly relevant scientific papers and/or abstracts will be published with the report.

7.6 Subtask 6 – External Review: The execution of this plan will be subject to normal management review in accordance with NOAA's Requirements-Based Management Process. Additionally, for specific programmatic advice and guidance, the Climate Observing System Council (COSC) has been established to review the program's contribution to the international Global Climate Observing System and to recommend effective ways for the program to respond to the long-term observational needs of the operational forecast centers, international research programs, and major scientific assessments. The Council is comprised of members both internal and external to NOAA who individually offer their expert advice; the Council is not expected to develop consensus opinions. The term of membership is two years with a renewal option for two additional terms. The Council meets at least annually to:

Advise the OCO on priorities for sustaining and enhancing components of the global climate observing system.

Review the accomplishments and future plans of specific program activities.

Recommend realignment of activities, or entirely new activities, within the program as appropriate to satisfy the evolving requirements for climate observation.

Bring to the OCO a broad view on national and international climate research and operational activities and their implications.

Provide coordinating linkages with national and international programs requiring and/or contributing to the implementation of the global climate observing system.

Advise the OCO on the balance of activities within the program in the context of NOAA's overarching climate service requirements, of other national and international requirements, and of other national and international contributions to the global climate observing system.

7.7 System management and product delivery milestones:

	NOAA Contributions								International Goal
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	
System Monitoring	X	X	X	X	X	X	X	X	X
System Evaluation:									
Seasonal forecasting		X	X	X	X	X	X		X
Decadal forecasting		X	X	X	X	X	X	X	X
Climate change				X	X	X	X	X	X
Sea level change		X	X	X	X	X	X	X	X
Carbon sources and sinks									X
Air-sea exchange,heat/water		X	X	X	X	X	X	X	X
Heat storage/thermohaline circulation		X	X	X	X	X	X	X	X
SST	X	X	X	X	X	X	X	X	X
Sea Ice		X	X	X	X	X	X	X	X
Interagency/International panels		X	X	X	X	X	X	X	X
International capacity building				X	X	X	X	X	X
Transition SST eval res to ops	X	X	X	X	X	X	X	X	X
Mgmt – wkshps & science mtgs		X	X	X	X	X	X	X	X
Mgmt – administration & finance		X	X	X	X	X	X	X	X
Mmgt ops funded from research	X	X	X	X	X	X	X	X	X
Annual Report		X	X	X	X	X	X	X	X
External review				X	X	X	X	X	X

Table 2. Tabulated Observational Data Requirements for GOOS/GCOS (from GOOS, 1999).

A summary of the sampling requirements for the global ocean, based largely on OOSDP (1995), but with revisions as appropriate. These are a statement of the required measurement network characteristics, not the characteristics of the derived field. The field estimates must factor in geophysical noise and unsampled signal. Some projections (largely unverified) have been included for GODAE.

Sampling Requirements for the Global Ocean							
Code	**Application**	**Variable**	**Hor. Res.**	**Vert. Res.**	**Time Res.**	**#samples**	**Accuracy**
A	NWP, climate, mesoscale ocean	Remote SST	10 km	-	6 hours	1	0.1-0.3°C
B	Bias correction, trends	*In situ* SST	500 km	-	1 week	25	0.2-0.5°C
C	Climate variability	Sea surface salinity	200 km	-	10 day	1	0.1
D	Climate prediction and variability	Surface wind	2°		1-2 day	1-4	0.5-1 m/s in components
E	Mesoscale, coastal	Surface wind	50 km	-	1 day	1	1-2 m/s
F	Climate	Heat flux	2° x 5°	-	month	30	Net: 10 W/m^2
G	Climate	Precip.	2° x 5°	-	daily	Several	5 cm/month
H	Climate change trends	Sea level	30-50 gauges + GPS with altimetry, or several 100 gauges + GPS	-	monthly means		1 cm, giving 0.1 mm/yr accuracy trends over 1-2 decades
I	Climate variability	Sea level anomalies	100-200 km	-	10-30 days	~ 10	2 cm
J	Mesoscale variability	Sea level anomalies	25-50 km	-	2 days	1	2-4 cm
K	Climate, short-range prediction	sea ice extent, concentration	~ 50 km	-	1 day	1	10-50 km 2-5%
L	Climate, short-range prediction	sea ice velocity	~ 200 km	-	Daily	1	~ cm/s
M	Climate	sea ice volume, thickness	500 km	-	monthly	1	~ 30 cm
N	Climate	surface pCO_2	25-100 km	-	daily	1	0.2-0.5 µatm
O	ENSO prediction	T(z)	1.5° x 15°	15 m over 500 m	5 days	4	0.2°C
P	Climate variability	T(z)	1.5° x 5°	~ 5 vertical modes	1 month	1	0.2°C
Q	Mesoscale ocean	T(z)	50 km	~ 5 modes	10 days	1	0.2°C
R	Climate	S(z)	large-scale	~ 50 m	monthly	1	0.01
S	Climate, short-range prediction	U(surface)	600 km	-	month	1	2 cm/s
T	Climate model valid.	U(z)	a few places	50 m	monthly means	30	2 cm/s

5

Table 1. From *The Action Plan for GOOS/GCOS and Sustained Observation for CLIVAR* by Needler et al. -- *OCEANOBS 99*

Appendix A

Foundation Documents

Observing the Oceans in the 21st Century, edited by Chester J. Koblinsky and Neville R. Smith, GODAE Project Office, Bureau of Meteorology, Melbourne, Australia, ISBN 0642 70618 2, 2001.

OCEANOBS 99, proceedings of the International Conference on the Ocean Observing System for Climate, GCOS/GOOS/WCRP Ocean Observations Panel for Climate and the CLIVAR Upper Ocean Panel, Saint-Raphael, France, October 1999.

International Sea Level Workshop Report, GCOS/GOOS/WCRP Ocean Observations Panel for Climate and the CLIVAR Upper Ocean Panel, GCOS #43, GOOS #55, ICPO #16, April 1998.

A Large Scale CO_2 Observing Plan: In Situ Oceans and Atmosphere (LSCOP), a contribution to the implementation of the U.S. Carbon Cycle Science Plan by the *In Situ* Large-Scale CO_2 Observations Working Group, April 2002.

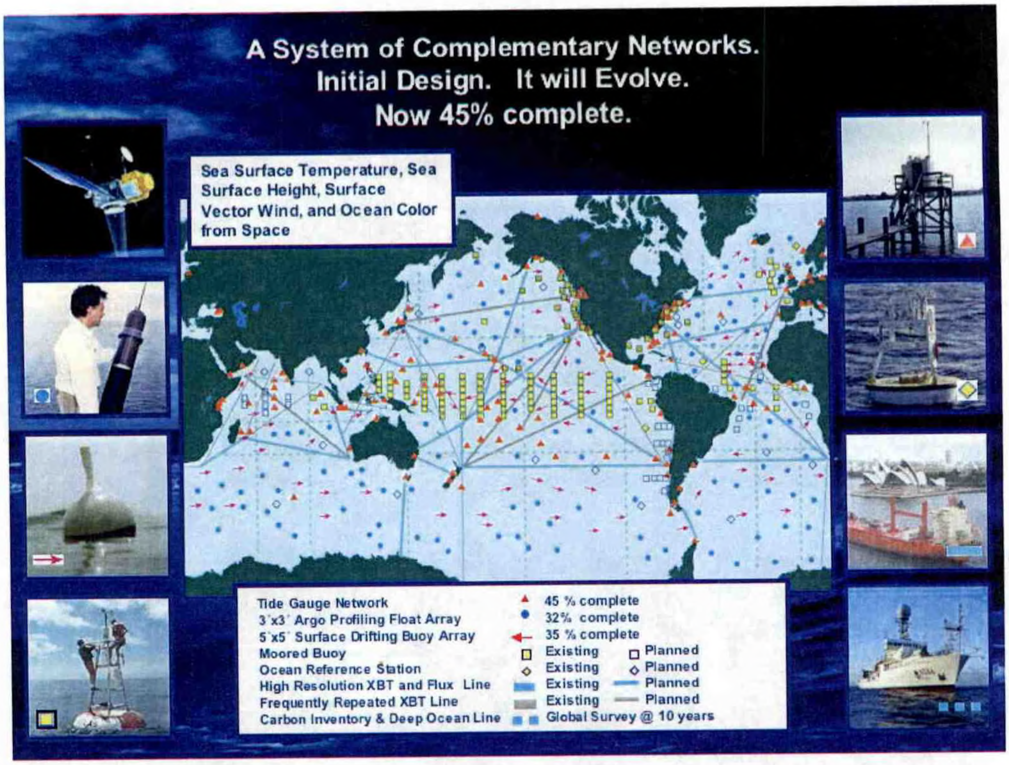

Figure 1

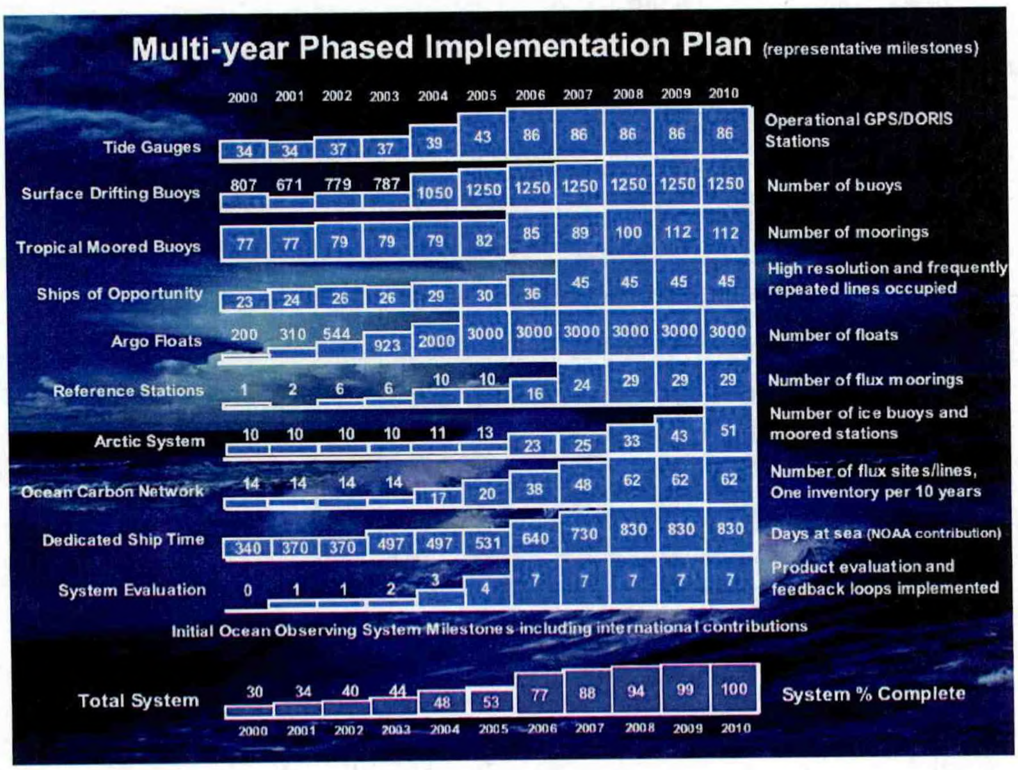

Figure 2

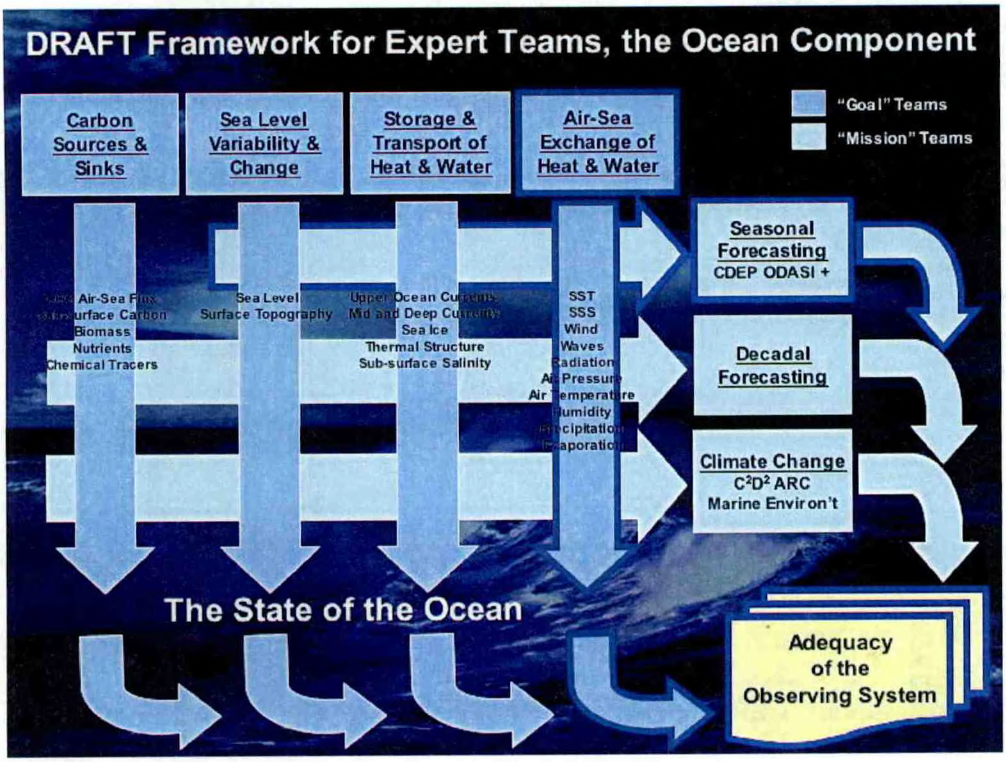

Figure 3

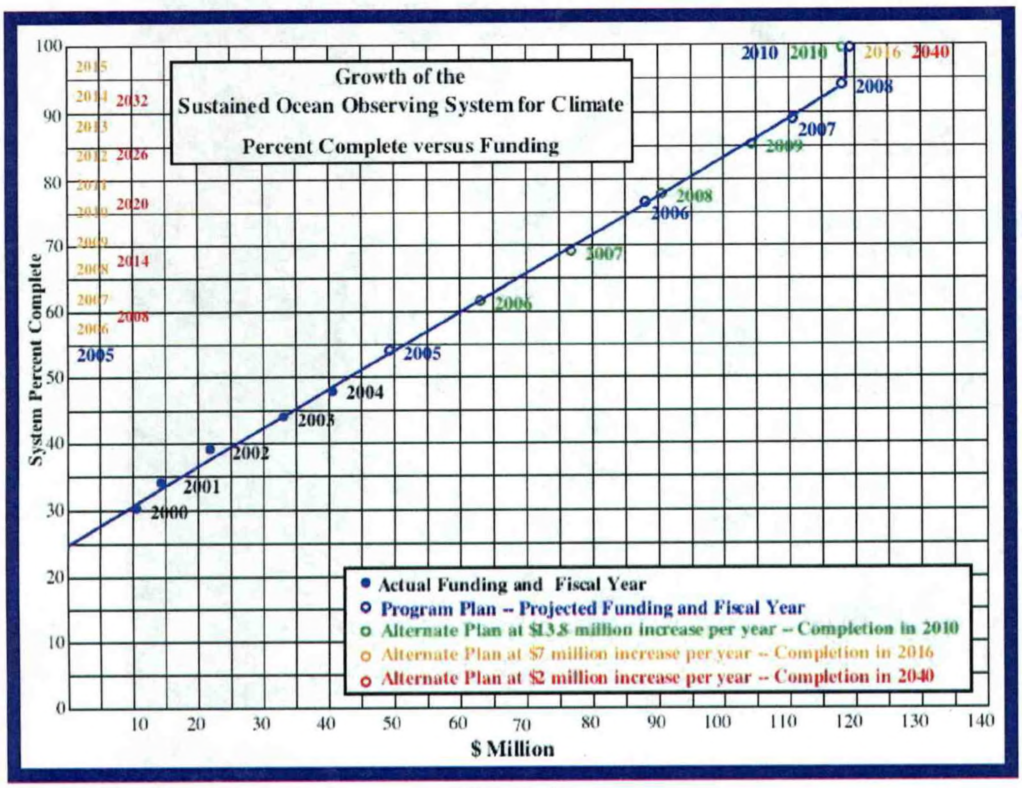

Figure 4

APPENDIX C

Professional Development and Community Service by Scientists Funded by The Office of Climate Observation

Professional Development and Community Service by Scientists funded by the Office of Climate Observation

Community Service (e.g., appointments to science and implementation panels)

Molly Baringer (NOAA/AOML/PHOD)
AGU Ocean Science Secretary, Associate member SCOR panel, Member S2O2 panel, Member NOAA/OAR ship time procurement procedure review panel, Associate Member IAPSO/SCOR Working Group 121 on Ocean Mixing.

Nicolas R. Bates (Bermuda Biological Station for Research, Inc.)
CARINA Steering Committee Member; International Advisory Member of the European CarboOcean project.

Mark A. Bourassa (COAPS)
NASA Ocean Vector Winds Science Team.

John Bullister (NOAA/PMEL)
Served on WOCE Data Products Committee.

Steven K. Cook (NOAA/AOML/PHOD)
WMO/IOC Data Buoy Cooperation Panel, GOOS Global Drifter Program, WMO/IOC Ship Observations Team, Chairman – Ship of Opportunity Implementation Panel, Convener - Task Team on VOS Recruitment and Program Promotion, Task Team on VOS Automated Systems, Expert Group on Instrument Testing.

Yeun-Ho Chong Daneshzadeh (NOAA/AOML/PHOD)
WOCE and Beyond Meeting as XBT DAC representative; Global Temperature Salinity Profile Program Committee.

Chris Fairall (NOAA/ETL)
Appointed to chair the WCRP Working Group on Surface Fluxes, Serves on the International Geophysical Union International Climate Dynamics and Meteorology Working Group A (Boundary Layers and Air-Sea Interaction).

Richard A. Feely (NOAA/PMEL)
Co-chair Repeat Hydrography CO_2/tracer Program Oversight Committee; International Ocean Carbon Coordination Project, Paris, Jan 2003; International Pacific CLIVAR Panel; Carbon Cycle Science Program Science Steering Group; Team Member of the European CarboOcean; Member of PICES Working Group 17.

Silvia Garzoli (NOAA/AOML/PHOD)
Appointed to Climate OAR Board/Team; Appointed to the NOAA Experts team to provide NOAA input to the U.S. interagency process developing a U.S. Plan on Earth Observations and the U.S. position for the ad hoc intergovernmental Group on Earth Observations.

Gregory Johnson (NOAA/PMEL)
Member, 2002-Present, U.S. CLIVAR/CO_2 Repeat Hydrography Oversight Committee; Associate Editor, 2000-Present, Journal of Physical Oceanography; Member, Organizing Committee for WOCE and Beyond Conference, San Antonio, November 2002.

Michael J. McPhaden (NOAA/PMEL)
President of the Ocean Sciences Section of the American Geophysical Union; Serves on the International CLIVAR Pacific and Indian Ocean Panels; Member of the JCOMM Observations Coordination Group; Chairs the Tropical Moored Buoy Implementation Panel (TIP) which is an action group of the Data Buoy Cooperation Panel (DBCP); Member of the OOPC/CLIVAR Global Eulerian Observatories Working Group; Served on the PIRATA Scientific Steering Group; Member of the Bulletin of the American Meteorological Society editorial board.

Frank J. Millero (University of Miami)
Committees - Oversight Committee for the Repeat Hydrography Program (CLIVAR, CO_2/SCC) 2002-2003; Board of Visitors, 2003; Clair C. Patterson Award Committee, Chair, 2003. Honors - Carnegie Mellon 2003 Alumni Distinguished Achievement Award.

Chris Sabine (NOAA/PMEL)
International CLIVAR/CLIC Southern Ocean Panel; Scientific Steering Committee for IGBP/IHDP/WCRP Global Carbon Project; International Ocean Carbon Coordination Project (IOCCP); Working Group for the Implementation of the North American Carbon Program (NACP); Member of CARbon dioxide IN the Atlantic (CARINA); Member of PICES Working Group 17.

Shawn R. Smith (COAPS)
Ocean.US IOOS Expert Team on Archival and Access, Provides Pacific FSU wind fields each month for publication in the NOAA/CDC Climate Diagnostics Bulletin.

Rik Wanninkhof (NOAA/AOML)
International Ocean Carbon Coordination Project, Paris, Jan 2003; Carbon Cycle Science Program Science Steering Group; Team Member of the European CarboOcean, Seakeepers Society Instrument Advisory Board.

Robert Weller (WHOI)
AGU, OS Section Executive Committee, Chair OS Section Awards Committee; Member, AGU-ALSO joint committee for Ocean Sciences meetings; Member, International CLIVAR SSG; Member; International CLIVAR Pacific Implementation Panel; Member CLIVAR VAMOS EPIC Science Team; Co-chair, U. S. CLIVAR Science Steering Committee; Member, UNESCO/IOC Ocean Observations Panel for Climate (OOPC); Member, UNESCO/WMO GOOS Capacity Building Panel; Member, NRC Committee on the Implementation of a Seafloor Observatory Network for Oceanographic Research, 2002-2003; Member, NRC Environmental Satellite Data Utilization Committee, 2002-present; Member, NRC Committee to Review the Climate Change Strategic Plan (CCSP), starting 2002; Member, CORE Ocean Observatories Steering Committee (OOSC); Member, DEOS (Dynamics of Earth Ocean Systems) Executive Committee; Member, NSF Scientific Cabled Observatory for Time Series Committee; NOAA: Climate Observing System Council, Climate Council; Co-chair, International Time Series Science Team; CCSP Interim Ocean Carbon Implementation Group, 2002-present; Chair of the NOAA Joint Institute Directors, starting July 2003; Member, NOAA Senior Research Council, starting July 2003.

List of conferences/workshops presented at/attended

Molly Baringer (NOAA/AOML/PhOD)
Tropical Atlantic Workshop, Miami, March 2003; NOAA/OGP Principle Investigators Meeting, May 2003; AGU fall planning meeting, San Francisco, CA June 2003; AGU fall planning meeting, Washington, DC, Sep 2003; CIMAS review presentation, Jan 2003.

Nicolas R. Bates (Bermuda Biological Station for Research, Inc.)
Meetings: OCEANS (now IMBER) and International Ocean Carbon Coordination Project, Paris, January 2003; CARINA (Carbon in the North Atlantic) meeting, Gran Canaria, March 2003 (presentation of U.S. NOAA VOS CO_2 network plans); CLIVAR North Atlantic Planning meeting, Villefranche-sur-Mer, April 2003 (presentation of U.S. NOAA VOS CO_2 network plans); JGOFS final meeting Washington DC, May 2003; JGOFS SMP Meeting, WHOI, June 2003.

Center for Ocean-Atmospheric Prediction Studies (COAPS)
Meeting attendance/participation:
Bourassa, M. A., and J. J. O'Brien, 2003: Fine resolution satellite-based winds for episodic events. Oceans 2003 Marine Technology and Ocean Science Conference, Sept. San Diego, CA; Bourassa, M. A., J. J. O'Brien, and S. R. Smith, 2003: SeaWinds validation through comparison to research vessel observations. ADEOS-II/SeaWinds Calibration/Validation meeting, Oct. Pasadena, CA; Bourassa, M. A., S. L. Morey, J. J. O'Brien, J. Zavala-Hidalgo, 2003: Satellite-based Episodic Events for Meteorology and Ocean Forcing. Symposium on Upper Ocean Circulation and Air-Sea Interaction, May, Tallahassee, FL; Lagerloef, G. S. E., R. B. Lukas, F. Bonjean, J. T. Gunn, G. T. Mitchum, M. Bourassa, T. Busalacchi: 2003, El Nino tropical Pacific Ocean surface current and temperature evolution in 2002 and outlook for La Nina in early 2003, IUGG 2003, July, Sapporo, Japan; Bourassa, M. A., J. J. O'Brien, S. R. Smith, and R. Romero, 2002: A new FSU wind and flux climatology. Abstracts from WOCE and Beyond, San Antonio, TX, 162; Bourassa, M. A., and J. J. O'Brien, 2003: Fine resolution satellite-based winds for episodic events. Oceans 2003 Marine Technology and Ocean Science Conference, Sept. San Diego, CA; O'Brien, J. J., M. A. Bourassa, and S. L. Morey, 2003: Excellent Winds from Space – SeaWinds for Ocean Models. High Resolution Marine Meteorology Workshop, March, Tallahassee, FL; O'Brien, J. J., M. A. Bourassa, X. Jia, S. L. Morey, B. Subramanyan, and J. Zavala, 2003: Gulf of Mexico Currents Driven by High-Resolution Gridded QSCAT Winds. Ocean Vector Wind Science Team Meeting, Jan. Oxnard, CA; Smith, Co-Chair, Workshop on High-Resolution Marine Meteorology, Tallahassee, FL, March 2003; Smith, Presenter, Climate Observation Program Workshop, Silver Spring, MD, May 2003; Smith, Attendee, NESDIS Data Users' Workshop, Boulder, CO, June 2003 Finally, on 3-5 March 2003, COAPS hosted a "Workshop on High-Resolution Marine Meteorology" (Smith 2003, Smith et al. 2003a); Bourassa, M. A., 2003: Application of R/V data to satellite calibration/validation. High Resolution Marine Meteorology Workshop, March, Tallahassee, FL; Bourassa, M. A., O'Brien, J. J., R. Romero, and S. R. Smith, 2003: A New Objective FSU Winds Climatology. The Oceanographic Society Meeting, June, New Orleans, LA.

Luca Centurioni (SIO)
Argo Workshop, Tokyo, Japan, November 2003; DBCP-19, Rio de Janeiro, Brazil, October 2003; The EGS/AGU Meeting, Nice, France, April 2003.

Steven K. Cook (NOAA/AOML/PhOD)
Workshop on High Resolution Marine Meteorology; WMO/IOC Data Buoy Cooperation Panel; WMO/IOC Ship Observations Team; WMO/IOC Ship of Opportunity Implementation Panel (Chaired); NOAA Marine and Aviation Operations Conference.

Yeun-Ho Chong Daneshzadeh (NOAA/AOML/PhOD)
WOCE and Beyond Meeting as XBT DAC representative; Global Temperature Salinity Profile Program Committee.

Craig Engler (NOAA/AOML/PhOD)
WMO/IOC Data Buoy Cooperation Panel.

Chris W. Fairall (NOAA/ETL)
NOAA 27th Annual Climate Diagnostics and Prediction Workshop, NOAA-OGP, Fairfax, VA, 21-25 October 2002; Twelfth Conference on Interactions of the Sea and Atmosphere, AMS, Long Beach CA, 10-14 February 2003 - Papers presented: 1) Bulk parameterization of air-sea fluxes: Updates and verification of the COARE algorithm (Invited), 2) The air-sea moisture transfer coefficient for wind speeds from 0 to 20 m/s; Workshop on High-Resolution Marine Meteorology, NOAA, Florida State University, Tallahassee, FL, 3-5 March 2003 - Paper presented: Shipboard monitoring of stratocumulus cloud properties in the PACS region; Sixth Annual Meeting of the WCRP/CLIVAR VAMOS Panel, NOAA-OGP, Miami, FL, 23-27 April, 2003; NOAA Intra-Seasonal to Interannual Prediction Program Workshop, NOAA-OGP, Silver Spring, MD, 12-13 August 2003.

Richard A. Feely (NOAA/PMEL)
International Ocean Carbon Coordination Project Invited Talk, Jan 2003; Climate Observations and Services PI Meeting, May 2003; International JGOFS North Pacific Synthesis Group Invited talk, November, 2003.

Paul Freitag (NOAA/PMEL)
TAO Project Manager representing the TAO project office on the DBCP; Reported on TAO activities at the annual DBCP workshop held in Martinique in October 2002; Reported on the details of TAO real-time and delayed mode data sets at the Workshop on High-Resolution Marine Meteorology held in Tallahassee, Florida in March 2003.

Silvia Garzoli (NOAA/AOML/PHOD)
CLIVAR/OOPC/IAI Workshop on the South Atlantic Climate Observing System, February 6 – 8, 2003 Hotel Portogalo, Angra dos Reis - Brazil (invited presentation); The first meeting of the Aquarius/SAC-D Science Team, Hotel Costa Galana, Mar del Plata, Argentina, March 18-20, 2003 (invited presentation).

Gustavo Goni (NOAA/AOML/PHOD)
CLIVAR/OOPC/IAI Workshop, Angra dos Reis, Rio de Janeiro, Brazil, February 2003; Tropical Atlantic Workshop, Miami, March 2003; IUGG Meeting, Sapporo, Japan, July 2003.

Dave Hosom (WHOI)
High Resolution Marine Meteorology Workshop, Tallahassee, March 2003; The Climate Observation Program Workshop, May 2003.

Elizabeth Johns (NOAA/AOML/PHOD)
SEACOOS meeting, Jacksonville, FL, June 2003.

Gregory Johnson (NOAA/PMEL)
WOCE and Beyond Conference, San Antonio, November 2002. (Author or co-author on 5 presentations.)

Rick Lumpkin (CIMAS/AOML)
Lagrangian Analysis and Prediction of Coastal and Ocean Dynamics, "Estimating means and seasonal variations from surface drifter observations in the Atlantic Ocean", Key Largo, FL, 12-16 December 2002.

Mike McPhaden (NOAA/PMEL)
Participated in several meetings including the IOGOOS meeting in Mauritius (November 2002), the PIRATA SSG (February 2003 in Brazil), the NOAA Climate Observations Workshop (May 2003, Washington, DC), the CLIVAR SSG-10 meeting (Victoria, BC, May 2003), the PUMP Workshop (Boulder, May 2003), and the OOPC meeting (Ottawa, Ontario, September 2003). Contributed to drafting the OOPC/CLIVAR GEO Working Group white paper and visited Peru in October 2003 to provide advice to the government on the evolving El Niño.

Frank J. Millero (University of Miami)
Meetings - Invited lecturer, "United States Carbon Dioxide Studies in the Atlantic," Carbon Dioxide in the Atlantic Ocean 2nd CARINA General Meeting and Open Science Conference, February 26 – March 1, 2003, Maspalomas, Gran Canaria, Spain; Invited lecturer, "The speciation of metals in natural waters," Annual Congress of the GTC and of the XIV Italian-Spanish Congress on the Thermodynamics of Metal Complexes, Villa Orlandi, Capri, Italy, June 2003; Invited lecturer, "The CO_2 system in the oceans," Old Dominion University, September, 2003.

Calvin W. Mordy (JISAO/UW)
WOCE and Beyond, San Antonio, TX, November 18-22, 2002; The nutrient workshop at Scripps Institute of Oceanography, March 5-7, 2002.

Mark Morrissey (University of Oklahoma)
Presented a report at the 15th annual Pacific Meteorological Director's meeting in Nadi, Fiji during March 2002; Presented results of this year's work at the 15th meeting of the Working Group on Data Management for the GPCP in Tokyo, Japan during May 2002; Work presented at the 1st Meeting of the International Precipitation Working Group held in Madrid, Spain in September 2002; Presented an update associated with the SPaRCE program at an invited talk at the National Council for Geographic Education Annual Meeting, Philadelphia, October.

Peter Niiler (SIO)
DBCP-19, Rio de Janeiro, Brazil; October 2003; NASA/Scatterometer Workshop, Pasadena, CA, September 2003; NOAA Workshop on "Ocean Climate Observations", Silver Spring, MD, June 2003; The Jet Propulsion Laboratory, Invited lecture on: "How surface circulation determines the absolute sea level of the oceans", May 2003; Scripps Institution of Oceanography, Lecture on: "How surface circulation determines the absolute sea level of the oceans", May 2003; The EGS/AGU Meeting; Nice, France, April 2003.

Mayra Pazos (NOAA/AOML/PHOD)
WOCE and Beyond Meeting as GDC DAC representative; WMO/IOC Data Buoy Cooperation Panel.

Richard W. Reynolds (NCDC)
GCOS SST/Sea-Ice Working Group - Presented at third meeting of the GODAE High Resolution (SST) Pilot Project meeting, Frascati, Italy, December 2-4, 2002; Analyzing sea surface temperatures for climate using ship, buoy and satellite data - Presented at the Satellites in Our Everyday World Workshop, North Carolina State University, Raleigh, NC,

March 13, 2003; GCOS SST/Sea-Ice Working Group progress - Presented at 8th Ocean Observations Panel for Climate Meeting, Ottawa, Canada, September 3-6, 2003; SST analysis options and methods for estimating bias and other errors in satellite input data sets and final SST products - Presented at fourth meeting of the GODAE High Resolution (SST) Pilot Project meeting, Pasadena, CA, September 22-26, 2003; A buoy need network for improved SSTs - Presented at the Climate Observing System Council's Climate Observation Program Workshop in Silver Spring, May 13-15, 2003; An operational buoy need network for climate SST - Presented at the International Union of Geodesy and Geophysics XXIII General Assembly, Sapporo, Japan, June 30 - July 11, 2003.

Christopher Sabine (NOAA/PMEL)
International Ocean Carbon Coordination Project, Paris, Jan 2003; Global Carbon Project Scientific Steering Committee, 2002; US CLIVAR Scientific Steering Committee; SCOPE/GCP Rapid Assessment of the Carbon Cycle, Brazil, 2003.

William Scuba (SIO)
DBCP-19, Rio de Janeiro, Brazil; October 2003.

University of Hawaii Sea Level Center (UH)
Meeting attendance/participation:
Attended the Western Pacific Geophysics Meeting in Wellington, New Zealand, chaired a session, and presented three papers, one jointly with PMEL and NODC; Late 2002 - served on the National Oceanographic Partnership Program Ocean.US Applications and Products Expert Team; Fall 2002, utilizing GLOSS resources, visited the Diretoria de Hidrografia e Navegacao da Marinha of Brazil; Participated in the NOAA sponsored Regional workshop on Potential Applications of Ocean Observations for the Pacific Region in Nadi, Fiji - presented on sea level rise at Tuvalu and participated in various working groups; Served at the concurrent meeting of the PacificGOOS Steering Committee; Fall 2002, the UHSLC conducted an inventory of its observation systems as part of the NOAA Observing Systems Architecture (NOSA) via the NOAA Forge online system; October 2002 - participated in the Jason-1 Science Working Team meeting in New Orleans and presented a poster on our GPS@TG network measurements; November 2002 - attended the WOCE & Beyond Conference in San Antonio; March 2003 - participated in a round table of Federal Hazard Mitigation Partners in the Pacific Islands in Honolulu, where we presented an update on extreme sea level events in the Pacific region; April 2003, utilizing GLOSS resources, UHSLC JASL coordinator, Pat Caldwell was one of three faculty in the GLOSS Training Course held at the Servicio de Hidrografia y Oceanografia de la Armada in Chile; Visited the Dirreccion de Hidrografia y Navegacion of Peru; represented the GLOSS at the International Hydrographic Organization Committee on Tides conference held in Lima on April 23, 2003; May 2003 - participated in the Climate Observation Program Workshop at Silver Spring, Maryland; July 2003 - presented a paper on decadal sea level in the Pacific at the IUGG in Sapporo, Japan.

Rik Wanninkhof (NOAA/AOML)
International Ocean Carbon Coordination Project, Paris, Jan 2003; High Resolution Marine Meteorology Workshop, Tallahassee, March 2003; JGOFS final meeting Washington DC, May 2003; Climate Observations and Services PI Meeting, Washington DC May 2003.

Robert Weller (WHOI)
NOAA Constituent Meeting, Boston, September 2002; Climate briefing for Adm. Lautenbacher, Wash DC, Sept 2002; DEOS Steering Committee, Oct 2002; State Department workshop on global oceanography, Wash DC, Nov 2002; Fall AGU, Dec 2002; NRC committee, Seafloor Observatories, Irvine, CA Dec 2002; CLIVAR SSC, San Diego, Jan 2003; NRC Committee, CCSP review, Irvine, Jan 2003; Aha Hulikoa Workshop, Hawaii, Jan 2003;

Moorings Working Group, Ocean Observatories Initiative, Santa Fe, Feb 2003; Annual AMS Meeting, Long Beach, Feb 2003; NRC Committee, Seafloor Observatories, Wash DC, Feb 2003; Pacific Decadal Variability Workshop, Wash DC, Feb 2003; High Resolution Marine Meteorology Workshop, Tallahassee, March 2003; NRC Committee, Environmental Satellite Data Utilization, Wash DC, March 2003; VAMOS Science Panel, VEPIC workshop, Miami, April 2003; International CLIVAR Science Steering Group, Victoria, BC, May 2003; NOAA Climate Observing System Council, Wash DC, May 2003; Pacific upwelling and mixing program (PUMP) workshop, Boulder, May 2003; DEOS Steering Committee, New Orleans, June 2003; NRC Committee, Environ. Satellite Data Utilization, Madison, WI, June 2003; RV Revelle precruise planning meeting, San Diego, June 2003; NOAA Senior Research Council, Boulder, July 2003; NOAA Interseasonal to Interannual Prediction workshop, Wash DC, August 2003; Climate Analysis Workshop, NCAR, Boulder, August 2003; NRC Committee, CCSP review, Wash DC, August 2003; Ocean Observations Panel for Climate (OOPC), Ottawa, Sept 2003; NRC Committee, Environmental Satellite Data Utilization, Sept 2003; PACS/EPIC Workshops, NCAR, Sept 2003; DEOS Steering Committee, San Francisco, Oct 2003; NRC Committee to Review CCSP, Irvine, CA, Oct 2003; Site Review of NOAA Joint Institute at U. Oklahoma, CIMMS, Oct 2003.

Jia-Zhong Zhang (NOAA/AOML)
The nutrient workshop at Scripps Institute of Oceanography, March 5-7, 2002.

Outreach (e.g., press/media interviews, public lectures)

Molly Baringer (NOAA/AOML/PHOD)
CIMAS review presentation, Jan 2003.

Gustavo Goni (NOAA/AOML/PHOD)
GLOSS Training Course, Valparaiso, Chile, April 2003.

Elizabeth Johns (NOAA/AOML/PHOD)
SEACOOS meeting, Jacksonville FL, June 2003.

WMO/IOC GOOS Center – Voluntary Observing Ship Recruitment
Gave presentations to Maersk-Sealand North America, Maersk Corporate Headquarters, Safmarine Shipping Headquarters.

Mayra Pazos (NOAA/AOML/PHOD)
Gave presentations at elementary schools

Tropical and sub-tropical Atlantic Surface Drifters Array (NOAA/AOML/PHOD)
Data have been used for educational purposes at the University of Miami and at public school.

Rik Wanninkhof (NOAA/AOML)
Mentored a student intern, Sabate Visconti on the Dade County Advanced Academic Internship Program on project "physical and biological controls on pCO_2 levels in the Caribbean"; hosted a post-doc, Are Olsen sponsored by the Norwegian Research Council working on project, "methods of extrapolating pCO_2 in time and space".

Robert Weller (WHOI)
Gave briefings to school children about Stratus project and mooring hardware while loading RV Revelle in San Diego, Sept 2003; NOAA Teacher-at-Sea program involved in November 2003 cruise with a teacher from San Marcos, CA and a teacher from Arica, Chile on board.

APPENDIX D

Request for Annual Progress Report
and
Report Format

Request for Annual Progress Report

29 August 2003

Dear Climate Observationalists:

Thank you for your participation in the Climate Observation Program Workshop 13-15 May in Silver Spring. It was a successful meeting and provided good direction for the continued development of a truly sustained global climate observing system. We plan to hold the Second Annual Climate Observation Program Review 19-24 April 2004. Please place this date on next year's calendar.

Based on your input during the workshop, we are requesting an annual progress report from you to document individual project outcomes, help identify system needs, and help establish the foundation for future program growth. As discussed in May, your reports will provide a major part of the information needed for our Program's *Annual Report on the State of the Ocean and the Observing System for Climate*. This information will also be used to update the Program Plan and the NOSA database.

As we move toward a sustained observing system it is anticipated that, for the established projects, the filing of the annual progress reports will replace the traditional research proposal process. Each project's annual work plan will provide the justification and accountability for funding needed to sustain existing work and/or funding increases needed to accomplish new work.

Your annual progress report should include: 1) a project summary, 2) FY 03 progress, 3) FY 04 work plan, 4) a corresponding FY 04 budget, and 5) "Add Tasks". Attachment 1 is an outline of the reporting guidelines. The guidelines are intended to provide a somewhat standard look and feel across all the projects and to allow the Project Office to extract summary information and system-wide statistics for preparing the *Annual Report*, other system reports, and for answering questions from NOAA management. It is also hoped that, using information from your annual progress reports, the Project Office will be able to accomplish a significant amount of the routine updating of the NOAA Observing System Architecture (NOSA) database in order to relieve the labs and centers of that administrative burden.

If your lab/center is implementing more than one project, please evolve toward a single annual report for each network. For example, AOML would collect all of its SOOP projects into a single report. Within each report, however, identify the various components as separate Tasks, if appropriate. For example, AOML might have separate Tasks identified for implementing the North Atlantic HRX lines, the South Atlantic HRX lines, and the Pacific broadcast XBT lines. The tasks should be based on the work plans under which you are presently operating so that scientific rationale and review can be traced back through the Project Office files.
The Project Office's *Annual Report* will summarize progress by "network" (as per the JCOMM panels and per our Program Plan). If your lab/center works across several networks, please report these separately. For example, AOML's GOOS Center would file separate annual reports for the SOOP work and for the Global Drifter Program work. It may be difficult to break out personnel costs, etc. between projects if the same people work on more than one, but please provide your best estimate of the separation.

For FY 04, it is the intent of the Climate Observation Program to sustain existing projects at the FY 03 level of funding (depending on the appropriation/allocation process, of course).

The budget sheet and cover sheet of your annual report should reflect that "base" budget level for FY 04 work.

The climate observing system must be stable but not static. Project managers should evolve their work within their "base" budget to achieve maximum effectiveness and efficiency as scientific understanding and technology advance. Any significant changes, however, must be accomplished in accordance with the Ten Climate Monitoring Principles and in cooperation with the international implementation panels, in particular the JCOMM panels. The Ten Principles are listed in the Appendix of the Program Plan, which is included with this message (Attachment 2) for your reference.

In addition to your base project Tasks, please include "Add Tasks" with your report. The Add Tasks should outline incremental expansions and improvements that you would like to accomplish if additional funding becomes available. Include a cost estimate for each Add Task. When/if new funding becomes available, the Project Office will evaluate the Add Task requests against Program priorities. For selected Add Tasks we will ask for a detailed budget sheet to document a supplement to your annual work plan. In most cases, the selected Add Tasks will then become part of the project's base funding for following years.

Add Tasks that are obvious advancements of the Program Plan can be brief and need little scientific justification. Add Tasks that are not so obvious should include scientific rationale and implementation strategy at about the same level of detail as a standard letter of intent – i.e., two pages. Cite workshops, science and/or implementation panels, and/or program steering group reports recommending the advancements proposed in each Add Task.

Budget planning values for FY 04 are attached (Attachment 3). This plan was used to document NOAA's request for a FY 04 budget increase. The values shown are "before taxes;" in the best case scenario the Program will see about 89%. You should use this as guidance in creating your Add Tasks. Of course the Federal appropriation and NOAA allocations seldom equate to the budget planning. So, if possible, develop several modestly priced Add Tasks that could build your network incrementally according to actual funding availability. Please list your Add Tasks in your recommended priority order.

The FY 04 budget planning represented in the attachment was put in place two years ago. It is subject to modification. If we are serious about building an observing system that is responsive to our customers' requirements -- and we are serious about that -- we must be prepared to adjust course according to customer feedback. The Project Office will constantly review user input and may modify planning and priorities as we move forward; so the ratios of new funding applied to the networks may vary from the attached FY 04 plan. You should use it as guidance but should not be constrained by it.

At the Program Workshop in May, NCEP identified three high priority areas for observing system evolution in support of seasonal forecasting (see Attachment 4). Where practical, explain how you can utilize your base capabilities to begin addressing these requirements, and/or target these areas with appropriate Add Tasks.

The individual project reports as well as the Project Office's *Annual Report* will be subject to peer review and to programmatic review by the Climate Observing System Council. The Program Plan and our overall Program performance are also subject to continual review by NOAA's Programming, Planning, and Budgeting System.

Please submit your annual report by 15 October so that we can move money to you as soon as possible in the fiscal year. We intend to move funding to the universities and joint institutes as well as to the labs/centers early in the year even though the official continuation dates of most joint institute cooperative agreements is 1 July.

METHOD OF SUBMISSION

Your progress report should be submitted electronically by 15 October to climate.observation@noaa.gov. Follow with hard copy to:

NOAA Office of Climate Observation
1100 Wayne Avenue
Silver Spring MD 20910
1-301-427-2089

Thank you for your continued dedication to building the sustained ocean observing system for climate.

Sincerely,

Diane Stanitski
Associate Program Manager
Climate Observation

Report Format

Please include the following information, where applicable, in your annual progress reports. Be as concise and comprehensive as possible and include the full name of all projects and acronyms used. Graphics are encouraged as a means to present your status and findings. Please provide a map(s) indicating locations instrumented or analyzed.

COVER PAGE

- Project title
- Project period – make this FY 03, if possible (Oct 1, 2002 – Sept 30, 2003)
- Project Manager(s) – name, title, affiliation, address, phone, email
- Primary contact person for finance – name, phone, email
- Signature for person(s) responsible/accountable, e.g., Lab Director

PROJECT SUMMARY

- General overview of the project, including brief scientific rationale
- Statement about how your project addresses NOAA's Program Plan for *Building a Sustained Ocean Observing System for Climate*
- Statement about how your project is managed in cooperation with the international implementation panels, in particular the JCOMM panels
- Responsible institutions for all aspects of project
- Project web site URL and pertinent web sites for your project and associated projects
- Interagency and international partnerships
- Statement that your project is managed in accordance with the Ten Climate Monitoring Principles (reference attached Program Plan)

FY 2003 PROGRESS

- Instrument/platform acquisitions for fiscal year and where equipment was deployed
- Number of deployments – compare to the previous year
- Percentage data return for fiscal year and 'lifetime' statistics – compare to the previous year
- Measurements taken, where data are stored, data distribution, availability and access to data
- How data are currently being used and shared
- Where the data are archived
- Anticipated and unanticipated project costs
- Problems encountered
- Logical considerations (e.g., ship time utilized)
- Research highlights
- List of all refereed publications, technical reports, and meeting proceedings related to your project (include a copy of one or two refereed papers in your Appendix representative of your project that could be included in the Annual Report and send one paper copy of ALL publications, reports, etc. related to the project directly to the OCO)
- Community service (e.g., appointments to science and implementation panels)
- List of conferences/workshops presented at/attended
- Outreach (e.g., press/media interviews, public lectures)

FY 2004 PLANS

Please include the following information, if applicable:

- Anticipated requirements to maintain the network at status quo
- Logistics requirements (e.g., ship time)
- New data collection methods

Expected scientific results

FY 2004 BUDGET

Show Program funding requirements
Show non-Program support for the observing system (e.g., PI salary)
Identify how much of your total budget goes toward: a) operations, b) data management, and c) R & D
Identify how many FTEs that Program funding supports – a) Federal FTEs, and b) non-Federal FTEs.
Identify how many FTEs dedicated to the project are not funded by the Program

ADD TASKS

Rationale
Proposed work
Procurements needed
Additional personnel needed
Cost estimate

APPENDICES

Copy of representative publications
A bibliography of all papers published and in press during the last fiscal year, including references to papers using data accessed through your project.

THE 10 CLIMATE MONITORING PRINCIPLES

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms, and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such IPCC assessments, should be integrated into national, regional, and global observing priorities.
6. Operation of historically uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators, and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully planned manner should be promoted.
10. Data management systems that facilitate access, use, and interpretation of data and products should be included as essential elements of climate monitoring systems.

APPENDIX E

Contributors and Reviewers: Annual Report

Contributors and Reviewers

Executive Summary – *Diane Stanitski, NOAA/OGP, Silver Spring, Maryland*

Chapter 1: The Role of the Ocean in Climate – *Kevin Trenberth, UCAR, Boulder, Colorado*

Chapter 2: The State of the Ocean
2.1 Global sea level rise – *Laury Miller and Bruce Douglas, NOAA/NESDIS, Silver Spring, Maryland; Robert Cheney, Florida International University, Miami, Florida*
2.2 Observing the global ocean carbon cycle – *Rik Wanninkhof, Atlantic Oceanographic and Marine Laboratory, Miami, Florida; Richard Feely, Pacific Marine Environmental Laboratory, Seattle, Washington*
2.3 In situ data requirements for recent situ sea surface temperature analyses – *Richard Reynolds, National Climatic Data Center, Asheville, North Carolina*
2.4 Surface currents to identify significant patterns of climate variability – *Peter Niiler, Scripps Oceanographic Institution, California; Nikolai Maximenko, International Pacific Research Center, Honolulu, Hawaii*
2.5 Sea surface pressure – *Ed Harrison, Pacific Marine Environmental Laboratory, Seattle, Washington; Authors of the Second Report on the Adequacy of the Global Observing Systems for Climate*
2.6 Air-sea exchange of heat, fresh water, momentum – *Robert Weller, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts*
2.7 El Niño and heat content variations – *Michael McPhaden, Pacific Marine Environmental Laboratory, Seattle, Washington*

Chapter 3: The State of the Observing System
There were many contributors to each FY 2003 progress report and FY 2004 planning report; please refer to authors identified in Chapter 3 under report titles.

Chapter 4: The State of the Science
Contributions were made by the authors of each bibliographic reference.

Reviewers
The following individuals reviewed all or part of this report. Their contributions are much appreciated.

Ed Harrison, *Pacific Marine Environmental Laboratory, Seattle, Washington*
Michael Johnson, *Office of Climate Observation, Silver Spring, Maryland*
Masahiko Kamei, *Office of Climate Observation, Silver Spring, Maryland*
Ed Sarachik, *University of Washington, Seattle, Washington*
Sydney Thurston, *Office of Climate Observation, Silver Spring, Maryland*

APPENDIX F

List of Acronyms

List of Acronyms

ADCP	Acoustic Doppler Current Profiler
AOML	Atlantic Oceanographic and Meteorological Laboratory
APDRC	Asia-Pacific Data Research Center
ARCs	Applied Research Centers
ARPEGE-CLIMAT	Climate Research Project on Small and Large Scales (France)
BMRC	Bureau of Meteorology Research Centre (Australia)
BoM	Bureau of Meteorology (Australia)
BPR	Bottom Pressure Recorder
BSH	Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency) (Germany)
C&GC	Climate and Global Change
CCRI	Climate Change Research Initiative
CCSP	Climate Change Science Program
CDC	Climate Diagnostics Center
CDP	Climate Data Portal
CFD	Computer Flow Dynamics
CICOR	Cooperative Institute for Climate and Ocean Research
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
CIRES	Cooperative Institute for Research in Environmental Sciences
CLIPS	Climate Information and Prediction Services Project
CLIVAR	CLImate VARiability and Predictability
COLA	Center for Ocean, Land, and Atmosphere Studies
COAPS	Center for Ocean-Atmospheric Prediction Studies
COP	Climate Observation Program
CORC	Consortium on the Ocean's Role in Climate
COSC	Climate Observing System Council
COSP	Climate Observations and Services
CLIVAR	Climate Variability and Predictability Program
CPC	Climate Prediction Center
CPRDB	Comprehensive Pacific Raingauge Database
CSIRO	Commonwealth Scientific and Industrial Research Organization
CTD	Conductivity, Temperature, Depth
DAC	Data Assembly Center
DBCP	Data Buoy Cooperation Panel
DMC	Drought Monitoring Center
DODS	Distributed Ocean Data System
DWBC	Deep Western Boundary Current
ECCO	Estimating the Circulation and Climate of the Ocean
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño-Southern Oscillation
EPIC	Eastern Pacific Investigation of Climate
ERS	Earth Remote-sensing Satellite
ETL	Environmental Technology Laboratory
EVAC	Environmental Verification and Analysis Center
FRX	Frequently Repeated XBT
FSU-COAPS	Florida State University Center for Ocean-Atmosphere Prediction Studies
GAINS	GLOSS Development in the Atlantic and Indian Oceans
GCC	Global Carbon Cycle
GCOS	Global Climate Observing System
GCTE	Global Change and Terrestrial Ecology Program
GCRMN	Global Coral Reef Monitoring Network
GDC	Global Drifter Center

GDP	Global Drifter Program
GEOSAT	Geodesy Satellite
GLOSS	Global Sea Level Observing System
GODAE	Global Ocean Data Assimilation Experiment
GOOS	Global Ocean Observing System
GPCP	Global Precipitation Climatology Project
GPS	Global Positioning System
GPS@TG	Co-located GPS systems at tide gauge stations
GTS	Global Telecommunications System
GTSPP	Global Temperature-Salinity Profile Program
HRX	High Resolution XBT
HURDAT	Atlantic Basin Hurricane Database
IAI	Inter-American Institute for Global Change Research
IOC	Intergovernmental Oceanographic Commission
IDOE	International Decade of Ocean Exploration
IES	Inverted Echo Sounder
IFREMER	Institut français de recherche pour l'exploitation de la mer (French Research Institute for Exploitation of the Sea) (France)
IMET	Improved METeorology
IOOS	Integrated Ocean Observing System
IPRC	International Pacific Research Center
IRD-Brest	L'Institut de recherché pour le developpement – Brest (France)
IRI	International Research Institute for Climate Prediction
ITCZ	Inter-Tropical Convergence Zone
IUGG	International Union of Geodesy and Geophysics
JAMSTEC	Japan Marine Science and Technology Center
JCOMM	Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology
JIMAR	Joint Institute for Marine and Atmospheric Research, University of Hawaii
JIMO	Joint Institute for Marine Observations
JISAO	Joint Institute for the Study of the Atmosphere and Ocean
JMA	Japan Meteorological Agency
JTA	Joint Tariff Agreement
MEDS	Marine Environmental Data Services
MOC	Meridional Overturning Circulation
MOCHA	Meridional Overturning, Circulation and Heat Transport Array
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NEAR-GOOS	North-East Asian Regional GOOS
NERC	National Environmental Research Council
NESDIS	National Environmental Satellite, Data, & Information Service
NGO	Non-Governmental Organization
NIC	National Ice Center
NIH	National Institutes of Health
NMFS	National Marine Fisheries Service
NMHS	National Meteorological and Hydrological Services
NMRI	Naval Medical Research Institute
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NOPP	National Ocean Partnership Program
NORPAX	North Pacific Experiment

NOS	NOAA Ocean Service
NOSA	NOAA Observing System Architecture
NSF	National Science Foundation
NWS	National Weather Service
NWS-PR	National Weather Service Pacific Region
NVODS	National Virtual Ocean Data System
OCO	Office of Climate Observation
OGP	Office of Global Programs
OMAO	Office of Marine and Aviation Operations
OOPC	Ocean Observations Panel for Climate
PacificGOOS	Pacific Global Ocean Observing System
PACIS	Pan-American Climate Information System
PDO	Pacific Decadal Oscillation
PEAC	Pacific ENSO Applications Center
PHOD	Physical Oceanography Division
PIES	Pressure Gauge Equipped Inverted Echo Sounder
PMEL	Pacific Marine Environmental Laboratory
PNA	Pacific North America
PNNL	Pacific Northwest National Laboratory
RRP	ENSO Rapid Response Project
RVIB	Research Vessel / Ice Breaker
RSMAS	Rosenstiel School of Marine and Atmospheric Science
SCPP	Seasonal-to-Interannual Climate Prediction Program
SCMI	Southern California Marine Institute
SEACOOS	Southeast Atlantic Coastal Ocean Observing System
SEARCH	Study of Environmental Arctic Change
SEAS	Shipboard Environmental data Acquisition
SI	Seasonal-to-Interannual
SIO-ECPC	Scripps Institution of Oceanography-Experimental Climate Prediction Center
SLP-PAC	Sea Level Program in the Pacific
SOC	Southampton Oceanography Centre
SOOP	Ship-of-Opportunity Program
SOOPIP	Ship-of-Opportunity Implementation Panel
SOI	Southern Oscillation Index
SOT	Ship Observations Team
SPARCE	South Pacific Rainfall Climate Experiment
SRDC	Surface Reference Data Center
SSG	Scientific Steering Group
SSP	Sea Surface Pressure
SST	Sea Surface Temperature
START	Global Change System for Analysis, Research, and Training
SURFRAD	Surface Radiation Budget Network
TAO	Tropical Atmosphere Ocean Array
TOGA	Tropical Oceans-Global Atmosphere Program
TOPEX	Ocean TOPography Experiment
TRMM	Tropical Rainfall Measuring Mission
UHSLC	University of Hawaii Sea Level Center
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
UOTC	Upper Ocean Thermal Center
URI	University of Rhode Island
USIABP	U.S. Interagency Arctic Buoy Program
USGCRP	U.S. Global Change Research Program

UW	University of Washington
VOS	Voluntary Observing Ships
WCRP	World Climate Research Program
WDC-A	World Data Center-A for Oceanography
WHO	World Health Organization
WHOI	Wood's Hole Oceanographic Institution
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWW	The World Weather Watch of WMO
XBT	Expendable Bathythermograph