A RESEARCH PROPOSAL
to the
NOAA OFFICE OF GLOBAL PROGRAMS

Investigation of Surface Flux and Cloud/Precipitation Aspects of Air-Sea Interaction in the Tropical Eastern Atlantic

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C&GC PROGRAM TOPIC: Climate Variability and Predictability (CLIVAR)

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REQUESTED BUDGET:	81.5 k$	112.1 k$	114.2 k$

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ENDORSEMENTS:

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ABSTRACT

Investigation of Surface Flux and Cloud/Precipitation Aspects of Air-Sea Interaction in the Tropical Eastern Atlantic

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Total Proposed Cost: $307,800 Proposed Period: 1 October 2005-30 September 2008

In this project we request funds to analyze observations from a ship-based measurement program to obtain statistics on key surface, atmospheric boundary layer, cloud macrophysical and microphysical, and radiative properties relevant to NOAA's CLIVAR Atlantic Program. We plan to place a suite of instruments on NOAA ships deploying and servicing new buoys at 23W. The buoys are part of a joint NOAA AOML/PMEL project funded by NOAA's Office of Climate Observations (OCO).

The principal goal of the study is to examine the role of local air-sea interaction in the annual cycle of the Tropical Atlantic cold tongue and ITCZ complex. A second goal is to investigate modification of surface flux parameterizations in the presence of deep convection. The project will also provide comprehensive detail at a few points within a large array of *in situ* and satellite observations being used to investigate Tropical Atlantic variability.

The basic objectives of the measurements and analysis are to:

*Provide an assessment of the balance of surface fluxes and ABL structure in the TA equatorial cold tongue and ITZCZ complex.

*Advance development of bulk turbulent and radiative flux parameterizations either directly or by linking with LES and CRM research efforts.

*Advance understanding of the role of convective clouds, aerosols, and precipitation in cloud radiative forcing.

*Increase the utility of long time series buoy observations of air-sea fluxes through intercalibration, atmospheric profiles, cloud properties, and spatial context.

*Provide comprehensive information for operational weather forecast model evaluation/development and satellite calibration/validation and algorithm development

1. Results from Prior Research

NOAA Award : Climate Global Change Program, 10/1/03-9/30/05
Amount : $465,100 K
Title : Shipboard monitoring of air-sea fluxes and cloud properties in the PACS region, C. Fairall PI

As part of the EPIC monitoring and the Ocean Observations programs, ETL has conducted a series of two cruises a year in the East Pacific to make comprehensive flux and ABL/cloud observations to supplement NOAA buoy operations and to obtain baseline observations in the SE Pacific stratocumulus region. Beginning in 1999, the cruises were done in the spring and fall along 95 and 110 W. In 2002 (the start of this 3-year project), the spring cruise was supplanted by a fall cruise to the Woods Hole Ocean Reference Station (ORS) buoy at 20 S 85 W. The cruises are done in *piggyback* mode; ETL sensors are installed on the ships servicing the buoys. This work is done in collaboration with Meghan Cronin (PMEL) on TAO buoys and Bob Weller (WHOI) on the ORS buoy at 20 S 85 W. The University of Miami (cloud radars) and the Texas A&M University (aerosols) have also collaborated by deploying measurement systems.

In the current project we continued a ship-based cloud and flux measurement program to obtain statistics on key surface, ABL, and low-cloud macrophysical, microphysical, and radiative properties (Cronin et al., 2002). Our goal was to acquire a good sample of most of the relevant bulk variables that are commonly used in GCM parameterizations of these processes. These data are being compared to known relationships in other well-studied regimes. While not comprehensive, these data are useful for ABL/cloud modelers (both statistically and for specific simulations) and to improve satellite retrieval methods for deducing ABL and cloud properties on larger spatial and temporal scales.

The primary objectives were to

*Obtain new measurements of near-surface, cloud, and ABL statistics for comparison to existing data on northern hemisphere stratocumulus systems.

*Obtain quantitative information on cloud droplet and drizzle properties and probability of occurrence of drizzle and possible links to deviations from adiabatic values for integrated cloud liquid water content.

*Examine applicability of existing bulk parameterizations of stratocumulus radiative properties for the Peruvian/Equatorial regime.

*Characterize surface cloud forcing and possible ocean-atmosphere coupling through stratocumulus-SST interactions.

*Provide periodic high quality near-surface data for intercomparison with ship-based IMET and buoy-based meteorological measurements.

*Provide high quality measurements of basic surface, ABL and cloud parameters for 'calibration' of satellite retrieval techniques.

1.1 Methodology

We conducted an enhanced monitoring cloud and ABL measurement program to supplement the measurements made routinely on the NOAA ships servicing the TAO WHOI buoys in the PACS region. An instrument package has been developed that can be installed on any reasonable ship. The package includes a cloud ceilometer, an S-band cloud/precipitation Doppler radar, a water vapor/liquid microwave radiometer (MWR), and an automated air-sea flux package including a sonic anemometer, a pair of pyranometers, a pair of pyrgeometers, slow air temperature and humidity sensors, and a ship-motion package for direct turbulent flux corrections. Since 2003 deployments have included the ETL mm-wavelength cloud observing radar.

This set of instruments allows computation of low-cloud statistics (integrated liquid water content, cloud base height and fraction, cloud droplet size) and the complete surface energy budget of the oceanic and atmospheric boundary layers. The cloud statistics by themselves are of interest to cloud modelers and for scientists improving satellite retrieval methods. When combined with measurements of downward longwave and shortwave radiative fluxes, they allow computation of cloud IR and visible optical thicknesses plus the surface cloud radiative forcing, a key diagnostic variable in climate models.

1.2 *Accomplishments*

We completed five missions beginning in fall of 2002 and ending in fall of 2004 (three TAO and two stratocumulus). Each TAO mission has included transects of the 95 and 110 buoy lines between 8 S and 12 N; each stratocumulus mission included a visit to the WHOI climate reference buoy at 20 S 85 W. Our major effort so far has been in executing the cruises and processing the data from the array of sensors to produce integrated products. We have been collaborating with Nick Bond at PMEL on the atmospheric boundary layer aspects, Meghan Cronin at PMEL and Bob Weller on the fluxes and cloud forcing aspects, and Bruce Albrecht and Pavlos Kollias on cloud remote sensing. Papers have been submitted on an initial climatology from the PACS cruises (Hare et al., 2005), the annual cycle of cloud forcing from the buoy observations (Cronin et al., 2005), and cloud microphysics from the 2003 stratocumulus study (Kollias et al., 2004). Another aspect of this work is using the ship-based ETL measurements to evaluate the quality of the buoy sensors. Data are archived for public use at ftp://ftp.etl.noaa.gov/user/cfairall/. Present status of processed data is given at http://www.etl.noaa.gov/programs/pacs/

1.3 *Publications*

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2. Statement of Work

2.1 Introduction

While El Nino is the single largest mode of short-term global climate variability, Tropical Atlantic Variability (TAV) plays a major role in the Atlantic basin. TAV is a complicated mix of atmospheric (i.e.: West African Monsoon, WAM; Intertropical Convergence Zone, ITCZ; Trade Winds, African Easterly Waves, AEW; Saharan Aerosol Layer, SAL) and oceanic (i.e., Sea Surface Temperature, SST; coastal and equatorial upwelling; Tropical Instability Waves) phenomena, which interact on a range of spatial and temporal scales. These interactions have been shown to affect local, regional and basin-wide climate variability (e.g., variability in the Atlantic tropics has been implicated in poleward climate). The complexities of this system have been discussed in detail by Carton et al. (2005); a brief summary of the main points is given in this introduction.

The ability to simulate and ultimately predict these complex air-sea interactions and their larger-scale impacts on TAV and climate is limited by the lack of quantitative understanding of the processes that couple the ocean and atmosphere and modeling and observational deficiencies. For example, variability in equatorial SST in the tropical Atlantic has been attributed to a zonal mode of coupled air-sea interaction similar to El Nino in the Pacific. However, state-of-the-art coupled general circulation models (GCM) fail even to simulate accurately the mean temperature gradient along the equator in the tropical Atlantic, severely limiting their ability to provide accurate climate forecasts. A meridional mode of air-sea interaction has also been identified in the tropical Atlantic. The oceanic component of this mode is characterized by the intensity of the cross-equatorial SST gradient. Both modeling and observational studies indicate that this gradient is an integral part of the coupled air-sea system that contributes to the climatic importance of the TAV. However, the processes that control this gradient, and thus the ability to predict its intensity, are not fully understood.

The zonal and meridional SST modes impact on the WAM, ITCZ, Trade Winds, tropical cyclone development, etc. Uncertainties in the dynamics of these modes and the processes that couple the ocean to the atmosphere preclude, for example, accurate forecasts of the WAM and its associated interactions with the tropical Atlantic (e.g., quantitative definition of the processes that determine which WAM generated AEW become tropical cyclones is lacking). Similarly, the migration and intensity of the ITCZ is neither represented nor predicted accurately within existing models. As with the WAM, on time-scales ranging from annual to decadal, observational and modeling studies indicate strong coupling between the ITCZ and SST.

In summary, the ability to predict TAV and its local, regional and basin-wide affects are limited by the lack of quantitative understanding of coupled dynamical processes, modeling deficiencies and observational weaknesses. Three hypotheses have been selected to "identify sources of and mechanisms that determine predictability" of TAV. These are:

>>> On annual and interannual time-scales, the characteristics of the WAM and ITCZ are tightly coupled to upper ocean variability in the tropical eastern Atlantic. This upper ocean variability is inadequately simulated in forecast models because of deficiencies in the quality and quantity of boundary layer data as well as the limited understanding of the oceanic and air-sea exchange

processes that influence the near surface water column (e.g., diurnal heating, the skin layer). *Thus, air-sea coupling processes are a potential source of predictability to be studied in the eastern tropical Atlantic.*

>>> The inability of GCM's to simulate the ITCZ is also due to their failure to correctly reproduce the large-scale atmospheric phenomena that influence tropical convection. These deficiencies are reflected in the large disagreement in the description of the large-scale meridional atmospheric circulation in the Atlantic among current global model reanalysis products. *The large-scale atmospheric processes that control convection in the ITCZ are another source of potential predictability to be studied.*

>>> The effects of aerosols and the SAL on the atmosphere and the underlying water column, such as occur during Saharan dust outbreaks over the Main Development Region for tropical cyclones (10^{o} to 20^{o}N) control, in part, which atmospheric waves originating in the WAM develop into tropical storms. *The processes that control the impact of the SAL on atmospheric and oceanic anomalies in the eastern Atlantic are the final source of potential predictability to be studied.*

2.2 Statement of the Problem

The annual cycle of the evolution of the TA equatorial cold tongue and the ITCZ involves processes in the ocean and atmosphere that are coupled on a variety of spatial and temporal scales. Local air-sea fluxes play a prominent role in two of the hypotheses of the role of convection in TAV variability either through the 'wind-evaporation' feedback or cloud forcing of radiative fluxes. The cold tongue – ITCZ complex is strongly coupled through atmospheric boundary layer flow from south of the equator into the ITCZ. Thus, oceanic processes that affect SST south of the equator may also affect deep convection north of the equator.

It is suspected that at least part of present TAV model simulation problems have roots in of the models to resolve and simulate the cross-equatorial ABL structure, particularly in response to variability in deep convection in the ITCZ (Raymond et al., 2003; Carton et al., 2005). The ABL structure is tightly coupled to the surface fluxes that are local drivers of the ocean. Recent observational studies in the Eastern Pacific (Bond et al. 1992; Pyatt et al., 2004; DeSoeke et al. 2005; Zhang et al. 2004) have yielded insights on the vertical structure and the balance of physical processes associated with the transitional from across the cold tongue and into the ITCZ. Similar observations in the Atlantic are not available, so the applicability is unknown. A second, but related, air-sea interaction issue is the connection between turbulent air-sea fluxes and convection. This involves both the general enhancement of turbulent fluxes by subgrid-scale variability and the role the explicit spatial distribution of surface fluxes may play in the dynamics of convective systems (from relatively small warm precipitating systems to deep convective complexes). The first point deals with the difference in the magnitude of the mean wind vector and the mean wind speed in model implementations of bulk formulae where most of the 'random' variability is subgrid-scale (Young et al., 1995; Vickers and Esbensen, 1998). The second point deals with the way organized precipitating systems modify their ABL environment and create a flux footprint that affects their dynamics (Rozbicki et al. 1999; Chenet, 2004).

Ultimately, both issues must be reconciled to achieve the correct surface fluxes. Correct surface fluxes are desirable not only to drive ocean circulations but also as an approach to validate the atmospheric model performance.

2.3 Background on AMMA and AMI

A confluence of the African Multidisciplinary Monsoon Analyses (AMMA) and the Atlantic Marine ITCZ (AMI) programs are being pursued to provide the manpower resources and observing networks needed to address the three hypotheses given above (Carton et al., 2005). Field campaigns are planned in the boreal summers of 2006 and 2007 aboard the NOAA Ship *Ronald H. Brown*. NSF support is being pursued to field the NCAR aircrafts HIAPER and C130 in 2007. The oceanographic component of the field phase activities will build on the existing sustained ocean observing networks already in place in the tropical Atlantic including the PIRATA moored buoy array, the Argo profiling float array, and the Atlantic components of the global surface drifter and expendable bathythermograph networks (Fig. 1). Bob Molinari (NOAA AOML) has received funds from the NOAA Office of Climate Observations (OCO) to construct 2 TAO-like moorings. These moorings will be deployed along 23°W. In addition, the 23°W section will be occupied during 2006 and again during the maintenance cruises in following years to study the factors that control the atmospheric and oceanic impacts on the WAM and ITCZ.

High quality surface fluxes plus associated atmospheric profile, cloud, and precipitation properties related to air-sea exchange processes are planned on both deployments. Such observations are extremely valuable in evaluating and improving NWP and climate models (Collins et al., 1997; Siebesma et al., 2004). The analysis of these observations is the subject of this proposal.

2.4 Ship-based Observation Program

As part of an OCO program of data quality assurance for the ocean climate observing system, ETL is planning air-sea flux and near-surface meteorological observations for the two deployments of the R/V *Ronald H. Brown* to the Eastern Atlantic in the summers of 2006 and 2007 in association with the buoy and oceanographic section program. We propose to enhance the flux observations on the *Brown* to include measurements of cloud and precipitation processes. The *Brown* has a continuously scanning C-band Doppler radar to provide quantitative precipitation estimates and horizontal-vertical structure information on precipitation features (Webster et al., 2002; Zuidema et al., 2005a) plus a high resolution wind and precipitation profiler to provide continuous measurements of the wind and drop size distribution characteristics through the lower and mid troposphere. We propose to operate these systems and add 4-times daily rawinsondes and the NOAA cloud radar system. The strategy of this suite of observations is to provide detailed time series of profiles of wind, thermodynamics, and precipitation structure relevant to role of air-sea interaction in controlling SST and driving deep convection in the ITCZ. This approach is patterned after enhanced monitoring cruises to the tropical eastern Pacific sponsored by the CLIVAR PACS and CPPA programs (see section 1).

The ship is an ideal platform for collecting a breadth of observations which will allow *single-column* investigations of atmospheric physics in great depth. The combination of the C-band radar (convective surveillance at a radius of 200 km) will allow unusual flexibility in sampling a region around the ship. The combination of the C-band Doppler radar, the vertically pointing precipitation profilers, and the direct flux measurements proposed for the *Ronald H. Brown* will provide a firm basis for a central time series combining spatial and temporal averages.

The proposed program will provide high quality data on bulk variables, turbulent and radiative fluxes and atmospheric profiles/clouds. Spatial information will be realized from transects to and from the experimental area; seasonal information from repeat visits over the years plus the entire annual cycle from the buoy. Fairall et al. (1996) showed that with well-attended, research-quality measurements the 10 Wm^{-2} goal for net surface heat flux is attainable from a ship that can also carry a host of remote sensors for atmospheric profile measurements (Fairall et al., 1997). For this reason, NOAA/ETL shipboard measurements have been the choice of several satellite algorithm development programs (Clayson and Curry, 1996; Chou et al., 1997) and have seen extensive use in research to improve bulk turbulent flux algorithms (Fairall et al., 1996; Clayson et al., 1996; Zeng et al., 1998; Brunke et al., 2003). ETL observations from the EPIC2001 field program have already been used to validate an ECMWF model boundary-layer scheme (Martin Koehler, pers. comm.), to evaluate several stratocumulus entrainment schemes (Caldwell et al., 2005), and to construct a drizzle parameterization (Comstock et al., 2004). The enhanced monitoring data have been used to develop a new parameterization of clear-sky longwave radiative flux (Hare et al., 2005), to evaluate ECMWF and NCEP reanalysis radiative cloud forcing (Cronin et al., 2005), and to validate the NCAR Community Climate System Model PBL depth parameterization (Zeng et al., 2004).

These comprehensive observations will do more than improve understanding of local climate processes or add to the value of buoy data, but will also serve to promote NOAA CLIVAR and operational interests. Contacts have been initiated at NCEP (H. Pan), NESDIS (Andy Hall), and NPOESS (Steve Mango) to establish operational 'customers' for these data. We have an ongoing cooperation with Dr. Peter Minnett (U. Miami) who has a NASA project to operate an IR SST system on the *Ronald H. Brown*. New technologies in IR SST sensors are playing a key role in improving satellite SST products (Donlon et al., 2001). The observations will address flux and cloud parameterization issues for GCMs both directly and by coupling with ongoing research using numerical models that explicitly resolve turbulence and clouds. We will also collaborate with Drs. Chidong Zhang, Brian Mapes, and Paquita Zuidema (U. Miami) on the connections between surface fluxes, boundary layer properties, larger scale forcing, and deep convection.

2.5 Scientific Objectives

In this proposal we outline a plan to analyze ship-based measurements to obtain statistics on key surface, boundary layer, and cloud macrophysical, microphysical, and radiative properties relevant to NOAA's Climate Observations and CLIVAR programs. We propose to place a suite of instruments on the NOAA ship servicing the buoys along 23 W. The observations will be used for our research on air-sea fluxes and cloud microphysics and radiative coupling plus contribute to the broader AMMA/AMI program in several ways.

Direct observations and turbulent and radiative fluxes coupled with C-band radar characterizations of precipitating systems will allow us to examine the balance of air-sea interaction processes in various phases of the convective structures (e.g., Petersen et al., 2003; Mapes and Lin, 2005). One objective is to link convective variability and mesoscale forcing to parameterization of surface fluxes on GCM grid scales. Another focus will be the balance of various terms of the surface energy budget coupled with the evolution of the atmospheric boundary layer structure as the flow crosses the equator and moves into the ITCZ. The presence of a fairly strong sea surface temperature gradient and a spatially varying large-scale convergence/divergence pattern leads to significant variations in surface fluxes and ABL properties. Very accurate measurements of the surface heat budget and the SST will shed light on the relative roles of surface forcing and oceanic processes (advection and entrainment) in the predictability of SST in Atlantic warm pool.

The basic objectives of these measurements are to:

*Provide an assessment of the balance of surface fluxes and ABL structure in the TA equatorial cold tongue and ITZCZ complex.
*Advance development of bulk turbulent and radiative flux parameterizations either directly or by linking with LES and CRM research efforts.
*Advance understanding of the role of convective clouds, aerosols, and precipitation in cloud radiative forcing.
*Increase the utility of long time series buoy observations of air-sea fluxes through intercalibration, atmospheric profiles, cloud properties, and spatial context.
*Provide comprehensive information for operational weather forecast model evaluation/development and satellite calibration/validation and algorithm development

2.6 Details on Ship Observations

The AMMA/AMI cruises will field the ETL flux system and basic cloud monitoring package (a wind profiler, GPS rawinsondes, a cloud ceilometer and an automated 2-channel or 3-channel microwave radiometer: White et al., 1995; Fairall et al., 1997). Recent enhancements to the observations include measurements of surface wave properties, drizzle droplet spectra, and aerosol information. We will also field the NOAA Portable Cloud Observatory (NPCO) which features a 35 or 94 GHz cloud radar (Moran et al., 1998), an advanced 3-channel microwave radiometer (Zuidema et al., 2005b), and an upward looking IR radiometer; the NPCO gives much more detail on cloud properties (vertical distribution of liquid water, cloud droplet sizes, etc). A list of the instruments is given in Table 1; items 14-16 constitute the NPCO.

The primary role of the three-instrument combination (0.92 GHz wind profiler, ceilometer, flux system) is the measurement of boundary layer (PBL) structure (Fairall et al. 1997). The air-sea fluxes are fundamental drivers at the interface of both fluids. Turbulent fluxes are obtained using motion-corrected eddy covariance (Edson et al. 1998), inertial dissipation, and bulk aerodynamic methods (Fairall et al. 2003). Radiative fluxes are obtained using redundant, carefully calibration pyranometers and pyrgeometers (Fairall et al. 1998). Precipitation is obtained using redundant, carefully calibrated optical rain gauges. The wind profiler gives profiles of wind and turbulence in the lower few km, even in the absence of precipitation and below cloud base (by virtue of "clear air" refractive index Bragg scattering). The ceilometer gives continuous measurement of the cloud base height and the microwave radiometer (Snider and Hazen 1998) gives continuous measurement of total integrated column water vapor and water liquid. For the purposes of AMMA, these instruments provide information on the modulation of PBL dynamics in the presence of precipitating systems (both deep and shallow) and the contrast with suppressed and trade-cumulus conditions.

Table 1. Instruments and measurements deployed by ETL for the ship-based cloud/ABL monitoring project.

Item	System	Measurement
1	Motion/navigation package	Motion correction for turbulence
2	Sonic anemometer/thermometer	Direct covariance turbulent fluxes
3	IR fast H_2O/CO_2 sensor	Direct covariance moisture/CO2 fluxes
4	Mean SST, air temperature/RH	Bulk turbulent fluxes
5	Pyranometer/Pyrgeometer	Downward solar and IR radiative flux
6	Ceilometer	Cloud-base height
7	0.92 or 3 GHz Doppler radar profiler	Cloud-top height, ABL microturbulence
8	Rawinsonde	ABL wind, temperature, humidity prof.
9	23, 31 GHz μwave radiometer (ARM type) (MAILBOX)	Integrated cloud liquid water Integrated total water vapor
10	Riegl Laser wave sensor	Ocean surface wave height/period
11	DMT CIP Precipitation spectrometer	Drizzle droplet size spectra
12	Lasair-II aerosol spectrometer	Aerosol size spectra
13	BNL rotating shadowband radiometer	Direct/diffuse solar
14	94 GHz Doppler cloud radar	Cloud microphysical properties
15	20, 31, 90 GHz μwave radiometer (ETL) (MMCR)	Integrated cloud liquid water Integrated total water vapor

16	Upward pointed IR thermometer	Cloud-base radiative temperature
17	*Ronald H. Brown* C-band radar	Precipitation spatial structure

2.7 Examples of Cloud and ABL property observations.

The PACS enhanced monitoring program (Cronin et al., 2002) was planned to give good estimates from simple surface measurements of the annual cycle of air-sea fluxes along 95 W and at the WHOI buoy site at 20 S 85 W. The ship-based observations provide both quality assurance and broader interpretation of the buoy measurements. Using the comprehensive surface, boundary layer, and cloud information from the twice-yearly ETL observations, parameterizations of clear sky radiative fluxes have been developed that allow assessment of cloud surface forcing of radiative fluxes throughout the annual cycle.

EPIC2001 ABL Transect. On completion of the EPIC2001 ITCZ study, the *Brown* departed 10 N 95 W and headed south, stopping periodically to service TAO buoys and take CTDs. This transect from 10 N to the equator gave a very clean depiction of the PBL transformation by air mass that crosses the equator and enters the ITCZ from the south. The boundary layer transition is associated with warm air from south of the equator that is stabilized by entering the equatorial cold tongue; as this stable air moves from the equator across the temperature front at 2-3 N it undergoes a rapid transition to convection (Fig. 2). This figure shows the wind speed (upper panel), sea (circles) and air (x's) temperatures (middle panel) and the sensible (circles) and latent (x's) heat fluxes as a function of latitude between 0 and 5 N. Note the sea surface temperature gradient is a maximum at about 0.75 N while the wind speed and fluxes tend to peak near 2 N and then start to decline again. The NCAR C-130 obtained very similar results (DeSoeke et al., 2005).

Cloud Radiative Forcing Studies. One emphasis of this work has been to use marine observations to examine microphysical aspects of cloud forcing (CF) of the surface heat budget. CF, i.e., the difference in the mean flux and that which would be obtained in the absence of clouds, has seen extensive application as an index of the importance of clouds in the global heat balance. CF offers an important tool for diagnosing GCM treatments of cloud/radiative processes. Ramanathan et al. (1995) showed direct linkage between surface CF and oceanic dynamics. The contributions of clouds to the net surface heat budget computed from the ETL enhanced monitoring measurements (1999-2002) are shown in Fig. 3. The net heat flux (upper panel in Fig. 3) shows a striking symmetry difference between the spring and fall. The spring net heat flux is nearly symmetrical about the equator with a maximum (175 Wm^{-2}) at the equator decreasing to about 100 Wm^{-2} at 10 N and 8 S. The equatorial maximum is associated with lower turbulent fluxes and modestly lower cloudiness at the equator. In the fall, the maximum net heat flux (180 Wm^{-2}) is at 2 S and the minimum (essentially 0) is at 6 N. There is also a significant asymmetry away from the equator (125 Wm^{-2} at 8 S versus 75 Wm^{-2} at 10 N). Clearly the minimum CF at 6 N is primarily associated with strong solar CF (lower panel in Fig.

3) associated with the ITCZ. The maximum just south of the equator is associated with much weaker turbulent cooling and weak solar CF. Solar CF is also much more equatorially asymmetric in the fall.

Ship-buoy Intercomparisons. A second emphasis of the monitoring work has been the use of ETL measurements for quality assurance of the buoy sensors. In a simple example (Fig. 4) the ship arrives at the buoy site near the end of 289 and remains in the area until the middle of day 296. After about 1.5 days, the old buoy is pulled in and the new buoy (with fresh sensors) is deployed and reaches full operation late on day 293. The continuity of the ETL time series ensures that buoy sensor calibration corrections can be unambiguously established. In this example, the old buoy sensors show specific humidity and air temperature biases of about +0.5 g/kg and +0.3 C while the new sensors are unbiased.

2.8 Outreach

ETL has partnered with the Cooperative Institute for Research in Environmental Sciences (CIRES) Outreach program to leverage existing relationships within local school districts and with NOAA and NSF projects devoted to making research data from our projects easily useful for education at all levels (http://cires.colorado.edu/education/k12/interactions/). ETL investigator Dr. Fairall and CIRES PI Dr. Hare have long-standing interests and experience in educational outreach and will be involved in all facets of the project. The K-12 component will be supervised by Dr. Susan Buhr of the CIRES Outreach program and Ms. Genevieve Healy, a marine sciences and GIS educator. Components of the project include development of a middle and high school curriculum to be implemented within local classrooms, an onboard research experience for a teacher, career awareness activities, and scientist visits to classrooms. The curriculum to be developed will include the fundamental atmospheric and ocean science concepts that local teachers are expected to include in their classrooms, a hands-on field-based component related to CPPA science, and the use of web-based scientist logs, photos and answers to questions during the cruise to motivate students learning of the fundamental concepts. A recent focus group with secondary science teachers from around the nation indicated strong interest in using the materials to be developed, providing further participation and dissemination opportunities.

2.9 Work Timetable

Year-1
*Deploy basic monitoring system and NPCO on R/V Ron Brown for buoy servicing cruise to 22W, summer 2006.
* Complete basic processing for this cruise.

Year-2
*Deploy basic monitoring system and NPCO on R/V Ron Brown for buoy servicing cruise to

22W, summer 2007.
* Complete basic processing for this cruise.
*Begin cloud and precipitation studies
*Begin studies of coupling of deep convection and air-sea fluxes

Year-3
*Complete cloud and precipitation studies
*Complete studies of coupling of deep convection and air-sea fluxes
*Perform analysis of cloud radiative forcing and contributions to surface heat budget.

2.10 References

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2.11 Figures

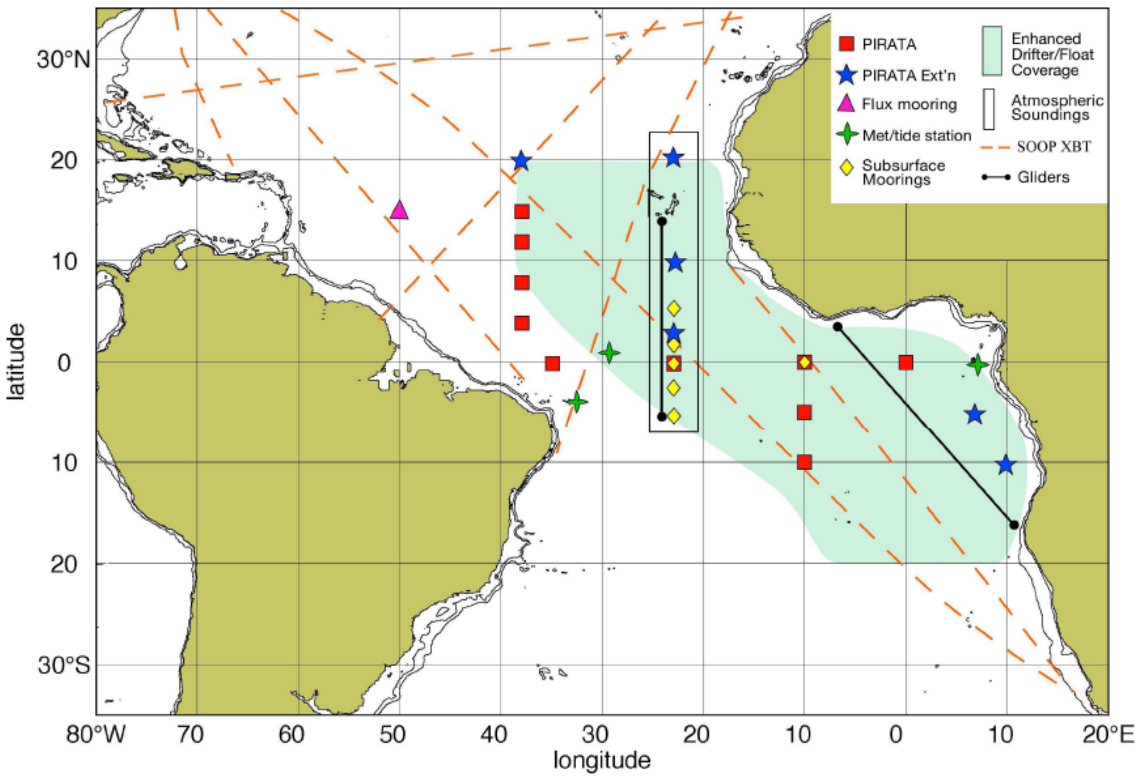


Figure 1. AMMA/AMI large scale marine observing region with designations of existing and proposed components of the measurement array. The cruises in 2006 and 2007 will target the box labeled atmospheric soundings in this figure.

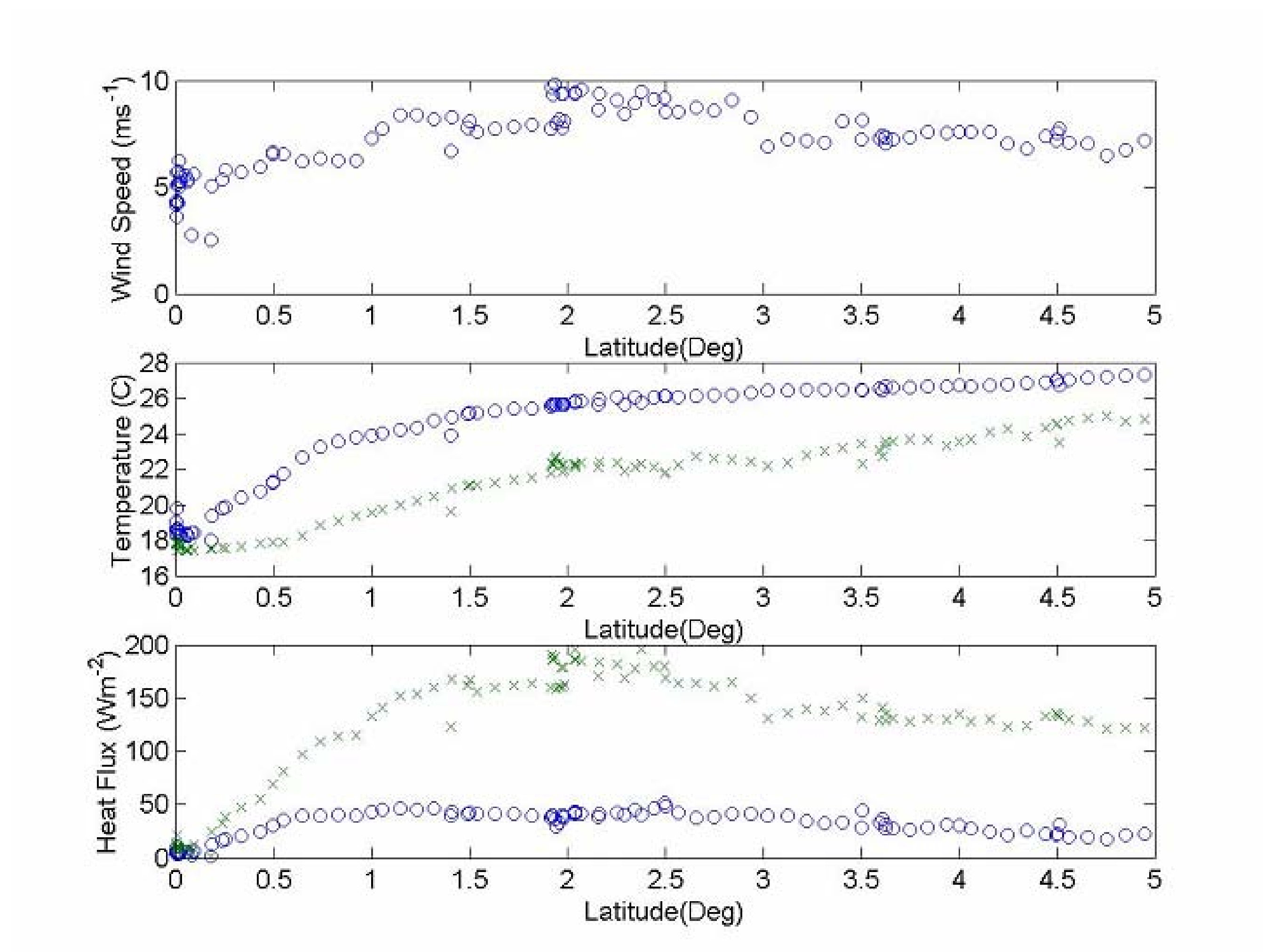


Figure 2. Near-surface properties in the Eastern Pacific cold tongue and ITCZ complex from EPIC2001 measured on the transect from the S edge of the ITCZ, through the ITCZ entry region, and into the suppressed boundary layer at the equatorial cold tongue: wind speed (upper panel); SST- blue circle and air T - green x's (middle panel); sensible heat flux - blue circles and latent heat flux - green x's (lower panel). Fluxes are suppressed in the stable boundary layer caused by warm air crossing the cold tongue from the south. The warm SST front triggers convective turbulence which increases fluxes and mixes down higher momentum (thus, the increase in wind speed).

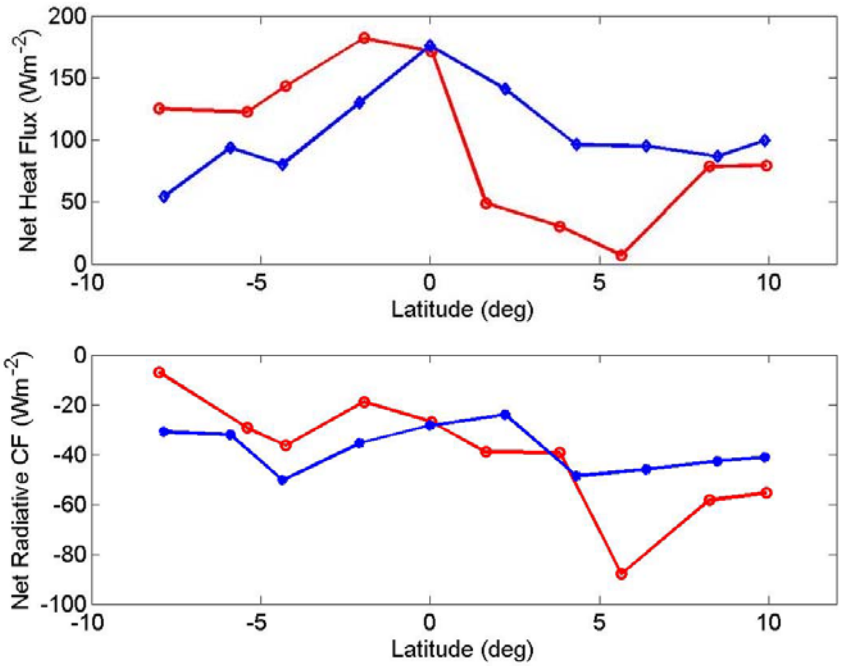
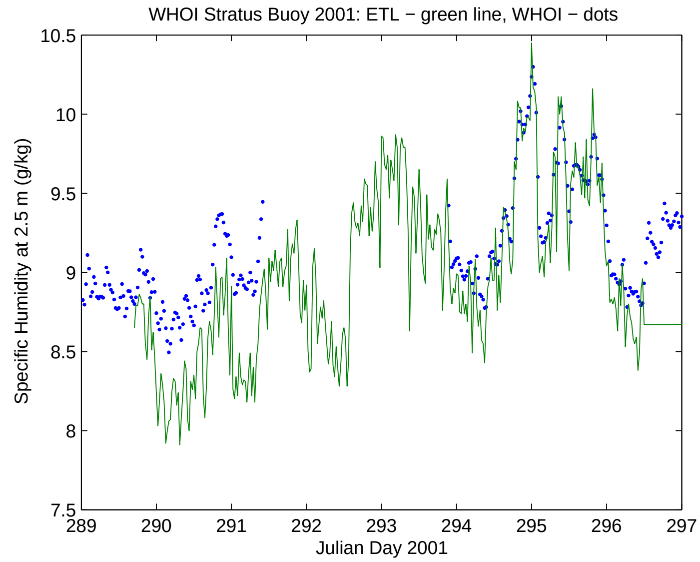


Figure 3. Latitude-averaged ship-based surface fluxes from the EPIC enhanced monitoring program (1999-2002): upper panel, net heat flux to the ocean and lower panel, the contribution to the net heat flux accounted for by surface CF (Hare et al., 2005). The circles are fall and the diamonds are spring. The net heat input tends to be a maximum in the equatorial cold tongue where cooling by turbulent surface fluxes is suppressed.



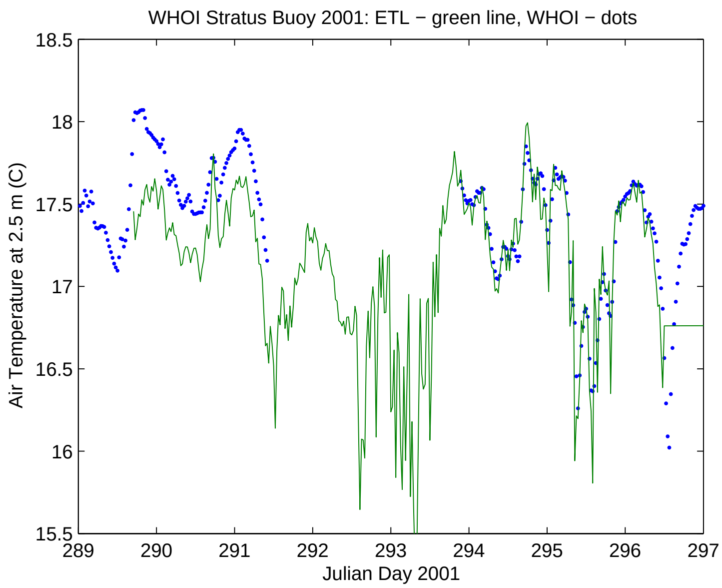


Figure 4. Intercomparison of ETL and WHOI ORS buoy measurements of near-surface meteorology (upper panel – specific humidity; lower panel – air temperature) after profile-gradient corrections. The ETL sensor is indicated by the green line and the buoy sensors by the blue dots. The old buoy sensors are removed early on day 291 and new sensors are deployed late on 293.

3. Budget Details

3.1 Background on Cruise Costs

We are now proposing to do cruises in 2006 and 2007 in the Atlantic. Funding for the basic flux and bulk cloud observing package will come from NOAA OCO. Fielding of the NPCO will be funded through ETL and other sources (this is made possible because the cruises are on the *Ronald H. Brown* so some deployment costs are covered by other field studies). Rawinsonde costs are requested in this proposal. The funds for sondes are presently placed in the 2nd and 3rd years. Rather than order sondes before the cruise we will use sondes from existing stock and replenish after the cruise. The timing of the sonde supply funds can be adjusted to accommodate other program funding priorities.

3.2 Scientific Analysis Costs

Because the measurement system deployment costs are covered by other funding sources, the principal costs proposed to CLIVAR ATLANTIC for this project are for scientific analysis of data obtained in the two cruises.

3.3 Personnel Duties

C. Fairall will be the PI. General division of duties will be as follows:

Air-Sea covariance processing:	Ludovic Bariteau
Cloud radar retrievals:	M. Shupe
Precipitation analysis:	M Ratteree
Flux parameterization:	A. Grachev, C. Fairall
ABL analysis:	D. Wolfe, C. Fairall
Data integration:	D. Wolfe

The costs of this proposal include analysis, creation of datasets for sharing with other CLIVAR investigators, scientific interpretation, and modeling. The reprocessed air-sea flux, microwave, wind profile, and precipitation radar data will be made available as quickly as possible.

TITLE: *CLIVAR Atlantic*

SPONSOR: OGP	Year: 1		P/I:		Fairall		(Level I)		(Level II & III)				
	Equivalent Calendar	Actual Budgeted	Adj Labor				Reimb Only Agency		Agency		REIMB LABOR	ETL	
A. SALARIES	* MONTHS	HOURS	BASE	+	BENEFITS	+	OVERHEAD	+	OVERHEAD	=	W/OH	Contribution	SPECIAL COMMENTS
					(22.8%)				(18%)		(162%)		
Sr. Physicist (PI) cf	1.0	174	15.4		3.5		0.0		2.8			21.7	
Sr. Meteorologist tu	0.0	0	0.0		0.0		0.0		0.0			0.0	
Meteorologist ji	0.0	0	0.0		0.0		0.0		0.0			0.0	
Sr. Meteorologist dwolfe	1.0	174	11.2		2.5		0.0		2.0		15.7		
Program Analyst lud_bar	2.0	348	8.4		1.9		0.0		1.5		11.9		
Research Scientist - Phy sfrisch	0.0	0	0.0		0.0		0.0		0.0		0.0		
Physicist Agrachev	2.0	348	14.3		3.3		0.0		2.6		20.1		
Computer Analyst mratteree	1.5	261	7.4		1.7		0.0		1.3		10.4		
RadarEng Kmoran	0.0	0	0.0		0.0		0.0		0.0		0.0		
Total Salaries		**1,131**	**$41.3**		**$9.4**		**$0.0**		**$7.4**		**$58.1**	**$21.7**	**TOTAL SALARIES**
B. LABORATORY INFRASTRUCTURE													
Facilities, Computer Services	42.1%	x ALB									**17.4**	6.5	**LAB INFRASTRUCTURE**
/Network & Lab Services													
C. CAPITAL EQUIPMENT													**CAPITAL EQUIPMENT**
D. TRAVEL													**TRAVEL**
Workshop											2.0		
Conference											2.0		
Field													
E. PARTICIPANT SUPPORT													**PARTICIPANT SUPPORT**
F. OTHER DIRECT COSTS													**OTHER DIRECT COSTS**
Sondes													
Repairs													
TWT tube													
Supplies and Materials													
Publications											2.0		
Shipping													
G. TOTAL DIRECT COSTS											**81.5**		**TOTAL DIRECT COSTS**
H. INDIRECT COSTS	*n/a*										*n/a*		
I. AMOUNT OF THIS BUDGET											**$81.5**		**TOTAL COST TO SPONSOR**
NOTE: ETL Laboratory Contribution:					**$28.1**								
			Year										
TOTAL DIRECT COSTS (K's)	**81.5**		**1**										

Labor/ Benefits	Other Obj	Agency Overhead	Laboratory Infrastructure	Sponsor Total
50.7	**6.0**	**7.4**	**17.4**	**81.5**

*NOTE: Equivalent Calendar Months include Actual Budgeted Hours plus estimated leave.

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TITLE: CLIVAR Atlantic

SPONSOR: OGP	Year: 2		P/I:	Fairall	(Level I)				
	Equivalent Calendar	Actual Budgeted	Adj Labor		Reimb Only Agency	(Level II & III) Agency	REIMB LABOR	ETL	
A. SALARIES	* MONTHS	HOURS	BASE	+ BENEFITS	+ OVERHEAD	+ OVERHEAD	= W/OH	Contribution	SPECIAL COMMENTS
				(22.8%)		(18%)	(162%)		
Sr. Physicist (PI) cf	1.0	174	15.8	3.6	0.0	2.8		22.3	
Sr. Meteorologist tu	0.0	0	0.0	0.0	0.0	0.0		0.0	
Meteorologist ji	0.0	0	0.0	0.0	0.0	0.0		0.0	
Sr. Meteorologist dwolfe	1.0	174	11.6	2.6	0.0	2.1	16.3		
Program Analyst lud_bar	2.0	348	8.7	2.0	0.0	1.6	12.3		
Research Scientist - Phy sfrisch	0.0	0	0.0	0.0	0.0	0.0	0.0		
Physicist Agrachev	2.0	348	14.8	3.4	0.0	2.7	20.8		
Computer Analyst mratteree	1.5	261	7.6	1.7	0.0	1.4	10.7		
RadarEng Kmoran	0.0	0	0.0	0.0	0.0	0.0	0.0		
Total Salaries		**1,131**	**$42.7**	**$9.7**	**$0.0**	**$7.7**	**$60.1**	$22.3	**TOTAL SALARIES**
B. LABORATORY INFRASTRUCTURE									
Facilities, Computer Services	42.1%	x ALB					**18.0**	6.7	**LAB INFRASTRUCTURE**
/Network & Lab Services									
C. CAPITAL EQUIPMENT									**CAPITAL EQUIPMENT**
D. TRAVEL									**TRAVEL**
Workshop							2.0		
Conference							2.0		
Field									
E. PARTICIPANT SUPPORT									**PARTICIPANT SUPPORT**
F. OTHER DIRECT COSTS									**OTHER DIRECT COSTS**
Sondes							25.0		
Repairs									
TWT tube									
Supplies and Materials									
Publications							5.0		
Shipping									
G. TOTAL DIRECT COSTS							**112.1**		**TOTAL DIRECT COSTS**
H. INDIRECT COSTS	*n/a*						*n/a*		
I. AMOUNT OF THIS BUDGET							**$112.1**		**TOTAL COST TO SPONSOR**
NOTE: ETL Laboratory Contribution:				**$28.9**					
			Year						
TOTAL DIRECT COSTS (K's)	**112.1**		2						

Labor/ Benefits	Other Obj	Agency Overhead	Laboratory Infrastructure	Sponsor Total
52.4	34.0	7.7	18.0	112.1

*NOTE: Equivalent Calendar Months include Actual Budgeted Hours plus estimated leave.

Reviewed: **Josephine C. Novosel**

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TITLE: *CLIVAR Atlantic*

SPONSOR: OGP	Year: 3		P/I:	Fairall	(Level I)				
A. SALARIES	Equivalent Calendar * MONTHS	Actual Budgeted HOURS	Adj Labor BASE +	BENEFITS +	Reimb Only Agency OVERHEAD +	(Level II & III) Agency OVERHEAD =	REIMB LABOR W/OH	ETL Contribution	SPECIAL COMMENTS
				(22.8%)		(18%)	(162%)		
Sr. Physicist (PI) cf	1.0	174	16.3	3.7	0.0	2.9		22.9	
Sr. Meteorologist tu	0.0	0	0.0	0.0	0.0	0.0		0.0	
Meteorologist ji	0.0	0	0.0	0.0	0.0	0.0		0.0	
Sr. Meteorologist dwolfe	1.0	174	11.9	2.7	0.0	2.1	16.7		
Program Analyst lud_bar	2.0	348	9.0	2.0	0.0	1.6	12.6		
Research Scientist - Phy sfrisch	0.0	0	0.0	0.0	0.0	0.0	0.0		
Physicist Agrachev	2.0	348	15.2	3.5	0.0	2.7	21.4		
Computer Analyst mratteree	1.5	261	7.8	1.8	0.0	1.4	11.0		
RadarEng Kmoran	0.0	0	0.0	0.0	0.0	0.0	0.0		
Total Salaries		**1,131**	**$43.9**	**$10.0**	**$0.0**	**$7.9**	**$61.8**	$22.9	**TOTAL SALARIES**
B. LABORATORY INFRASTRUCTURE									
Facilities, Computer Services /Network & Lab Services	42.1%	x ALB					**18.5**	6.9	**LAB INFRASTRUCTURE**
C. CAPITAL EQUIPMENT									**CAPITAL EQUIPMENT**
D. TRAVEL									**TRAVEL**
Workshop							2.0		
Conference							2.0		
Meeting									
E. PARTICIPANT SUPPORT									**PARTICIPANT SUPPORT**
F. OTHER DIRECT COSTS									**OTHER DIRECT COSTS**
Sondes							25.0		
Repairs									
TWT tube									
Supplies and Materials									
Publications							5.0		
Shipping									
G. TOTAL DIRECT COSTS							**114.2**		**TOTAL DIRECT COSTS**
H. INDIRECT COSTS	*n/a*						*n/a*		
I. AMOUNT OF THIS BUDGET							**$114.2**		**TOTAL COST TO SPONSOR**
NOTE: ETL Laboratory Contribution:				**$29.8**					

		Year
TOTAL DIRECT COSTS (K's)	**114.2**	**3**

Labor/ Benefits	Other Obj	Agency Overhead	Laboratory Infrastructure	Sponsor Total
53.9	34.0	7.9	18.5	114.2

*NOTE: Equivalent Calendar Months include Actual Budgeted Hours plus estimated leave.

Reviewed: **Josephine C. Novosel**

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TITLE: *CLIVAR Atlantic*

SPONSOR: OGP | Year: Total | P/I: Fairall

A. SALARIES	Equivalent Calendar * MONTHS	Actual Budgeted HOURS	Adj Labor BASE	+ BENEFITS	+ (Level I) Reimb Only Agency OVERHEAD	+ (Level II & III) Agency OVERHEAD	= REIMB LABOR W/OH	ETL Contribution	SPECIAL COMMENTS
	0.0			(22.8%)		(18%)	(162%)		
Sr. Physicist (PI) cf	3.0	522.0	47.5	10.8		8.5	0.0	66.9	
Sr. Meteorologist tu	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
Meteorologist ji	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
Sr. Meteorologist dwolfe	3.0	522.0	34.6	7.9		6.2	48.7	0.0	
Program Analyst lud_bar	6.0	1044.0	26.2	6.0		4.7	36.8	0.0	
Research Scientist - Phy sfrisch	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
Physicist Agrachev	6.0	1044.0	44.2	10.1		8.0	62.3	0.0	
Computer Analyst mratteree	4.5	783.0	22.8	5.2		4.1	32.2	0.0	
RadarEng Kmoran	0.0	0.0	0.0	0.0		0.0	0.0	0.0	
Total Salaries		**3,393**	**$127.8**	**$29.1**	**$0.0**	**$23.0**	**$180.0**	$66.9	**TOTAL SALARIES**
B. LABORATORY INFRASTRUCTURE									**LAB INFRASTRUCTURE**
Facilities, Computer Services	42.1%	x ALB					53.8	20.0	
/Network & Lab Services									
C. CAPITAL EQUIPMENT							0.0		**CAPITAL EQUIPMENT**
D. TRAVEL									**TRAVEL**
Workshop							6.0		
Conference							6.0		
Meeting							0.0		
E. PARTICIPANT SUPPORT									**PARTICIPANT SUPPORT**
F. OTHER DIRECT COSTS									**OTHER DIRECT COSTS**
Sondes							50.0		
Repairs							0.0		
TWT tube							0.0		
Supplies and Materials							0.0	0.0	
Publications							12.0	0.0	
Shipping							0.0		
G. TOTAL DIRECT COSTS							**307.8**		**TOTAL DIRECT COSTS**
H. INDIRECT COSTS	*n/a*						*n/a*		
I. AMOUNT OF THIS BUDGET							**$307.8**		**TOTAL COST TO SPONSOR**
NOTE: ETL Laboratory Contribution:				**$86.9**					

TOTAL DIRECT COSTS (K's) 307.8 — **Year Total**

Labor/ Benefits	Other Obj	Agency Overhead	Laboratory Infrastructure	Sponsor Total
157.0	74.0	23.0	53.8	307.8

*NOTE: Equivalent Calendar Months include Actual Budgeted Hours plus estimated leave.

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4. Abbreviated Vita

CHRISTOPHER W. FAIRALL
Supervisory Physicist/Chief
Clouds, Radiation, and Surface Processes Division
NOAA Environmental Technology Laboratory Boulder, CO

EDUCATION

Ph.D., Solid State Physics, Michigan State University, 1970.
B.S., Physics and Mathematics, Florida State University, 1966.

EMPLOYMENT

1971-1977	Adjunct Professor of Physics, Naval Postgraduate School, Monterey, CA.
1978-1983	Principal Staff Member, BDM Corporation, Monterey, CA.
1982	Visiting Scientist, RISO National Laboratory, Denmark.
1983-1985	Assistant Professor of Meteorology, Pennsylvania State University, University Park, PA.
1986-1989	Associate Professor of Meteorology, Pennsylvania State University, University Park, PA. Tenure awarded, 1988.
1988	Visiting Scientist, Naval Environmental Prediction Research Facility, Monterey, CA.
1989-Pres.	NOAA/ERL Environmental Technology Laboratory, Boulder, CO.

RESEARCH INTERESTS

Remote Sensing: ground-based Doppler wind profilers, Sodar and Radar, integrated sounding systems, clear-air turbulence, cloud radiative/microphysical properties.
Air/Sea Interaction: air/sea/ice flux measurements and parameterizations, sea spray, marine and Arctic boundary layers and clouds, particle and gas fluxes.
Boundary Layer Physics: mesoscale interactions, radiative transfer and closure models.

PROFESSION ACTIVITIES

Member: American Meteorological Society (Fellow 2000); American Geophysical Union; The Oceanography Society; ARM Science Team Executive Committee, 1997-2000
Associate Editor of Journal of the Atmospheric Sciences: 1991-1994
Chairman: AMS committee on Boundary Layers and Turbulence, 1987-1990
Fellow: Cooperative Institute for Research in Environmental Sciences, 1999-present.

SYNERGISTIC ACTIVITIES

First ISCCP Regional Experiment (FIRE) planning team, 1984-1987; NSF Coastal Ocean Processes (CoOP) advisory committee: 1991-1994; SHEBA Science Steering Committee: 1993-1997; Chairman, ARM Tropical Western Pacific Science Advisory Committee, 1995-2000. Chairman, WCRP Working Group on Surface Fluxes, 2003-present.

RECENT PUBLICATIONS (Last three years)

Fairall, C. W., E. F. Bradley, J. E. Hare, A. A. Grachev, and J. B. Edson, 2003: Bulk parameterization of air-sea fluxes: Updates and verification for the COARE algorithm. *J. Clim.*, **16**, 571-591.

Brunke, M. A., C W. Fairall, and X. Zeng, 2003: Which bulk aerodynamic algorithms are least problematic in computing ocean surface turbulent fluxes? *J. Clim.*, **16**, 619-635.

Petersen, Walter A., R. Cifelli, D. J. Bocippio, S. A. Rutledge, and C. W. Fairall, 2003: convection and easterly wave structure observed in the Eastern Pacific warm-pool during EPIC-2001. *J. Atmos. Sci.*, **60**, 1754-1773.

Grachev, A. A., C. W. Fairall, J. E. Hare, and J. B. Edson, 2003: Wind stress vector over ocean waves. *J. Phys. Oceanography*, **33**, 2408-2429.

Andreas, E. L., C. W. Fairall, P. O. G. Persson, and P. S. Guest, 2003: Probability distributions for the inner scale and refractive index structure parameter and their implications for flux averaging. *J. Appl. Meteorol.*, **42**, 1316-1329.

Bretherton, C. S., T. Uttal, C. W. Fairall, S. E. Yuter, R. A. Weller, D. Baumgardner, K. Comstock, and R. Wood, 2004: The EPIC 2001 Stratocumulus Study. *Bull. Am. Met. Soc*., **85**, 967-977.

Hare, J. E., C. W. Fairall, W. R. McGillis, B. Ward, and R. Wanninkhof, 2004: Evaluation of the NOAA/COARE air-sea gas transfer parameterization using GasEx data. *J. Geophys. Res*., **109** (C8): Art. No. C08S.

Curry, J. A., and 18 coauthors, 2004: SEAFLUX. *Bull. Am. Met. Soc.,* **85**, 409-424.

McGillis, W. R., and 12 coauthors, 2004: Air-sea CO2 exchange in the equatorial Pacific. *J. Geophys. Res*., **109** (C08S02)**,** doi:10.1029/2003/C002256.

Grachev, A. A., C. W. Fairall, P. O. G. Persson, E. L. Andreas, P. S. Guest, 2004: Stable boundary-layer scaling regimes: The SHEBA data. *Bound.-Layer Meteorol*., to appear.

Zeng, X., M. A. Brunke, M. Zhou, C. W. Fairall, N. A. Bond, and D. H. Lenschow, 2004: Marine atmospheric boundary layer height over the Eastern Pacific: Data analysis and model evaluation. *J. Clim*., **17**, 4159-4170.

Kollias, Pavlos, C. W. Fairall, P. Zuidema, J. Tomlinson, and G. A. Wick, 2004: Observations of marine stratocumulus in SE Pacific during the PACS 2003 Cruise. *Geophys. Res. Lett*., **31**, Art. No. L22110.

Huebert, B., B. Blomquist, J. E. Hare, C. W. Fairall, T. Bates, and J. Johnson, 2004: Measurements of the sea-air DMS flux and transfer velocity using eddy correlation. *J. Geophys. Res. Lett.*, 31 (23): Art. No. L23113.

Pyatt, Hollis, B. A. Albrecht, C. W Fairall, Nick Bond, and P. Minnis, 2005: Evolution of marine atmospheric boundary layer structure across the Cold Tongue ITCZ Complex. *J. Clim.*, **18**, 737-753.

Persson, P. O. G., J. E. Hare, C. W. Fairall, W. D. Otto, 2005: Air-sea interaction processes in warm and cold sectors of extratropical cyclonic storms observed during FASTEX. Q. *J. Roy. Met. Soc.*, **131**, 877-912.

Cronin, M. F., N. Bond, C. W. Fairall, and R. A. Weller, 2005: Surface cloud forcing in the Eastern Tropical Pacific. *J. Clim.*, accepted.

Andreas, E. L., K. J. Claffery, R. E. Jordan, C. W. Fairall, P. S. Guest, P. O. G. Persson, and A. A. Grachev, 2005: Measurements of the von Karman constant in the atmospheric surface layer. *J. Fluid. Mech.*, submitted.

Wick, Gary A., J. Carter Ohlmann, Christopher W. Fairall, and Andrew T. Jessup, 2004: Improved oceanic cool-skin corrections using a refined solar penetration model. *J. Phys. Oceanogr.*, submitted.

Hare, J. E., C. W. Fairall, T. Uttal, D. Hazen, Meghan Cronin, Nicholas A. Bond, and Dana Veron, 2005: A seven-cruise sample of clouds, radiation, and surface forcing in the Equatorial Eastern Pacific. *J. Clim*., submitted.

Zuidema, Paquita, C. W. Fairall, E. Westwater, and D. Hazen, 2005: Ship-based liquid water path estimates in marine stratus. *J. Geophys., Res*., submitted.

Zuidema, Z., B. Mapes, J. Lin, and C. W. Fairall, 2005: Cloud vertical structure in the Eastern Tropical Pacific. *J. Clim.*, submitted.

Fairall, C. W., J. E. Hare, D. Helmig, and L. Ganzveld, 2005: Water-side turbulence enhancement of ozone deposition to the ocean. *Atm. Env.*, submitted.

Fairall, C. W., W. Asher, M. Banner, and W. Peirson, 2005: Investigation of the physical scaling of sea spray spume droplet production. *J. Geophys., Res*., submitted.

FOUR OTHER RELEVANT PUBLICATIONS

Frisch, A.S., C.W. Fairall, and J.B. Snider, 1995: Measurement of stratus cloud and drizzle parameters in ASTEX with a K_α-band Doppler radar and a microwave radiometer. *J. Atmos. Sci.*, **52**, 2788-2799.

White, A. B., C. W. Fairall, and J. B. Snider, 1995: Surface-based remote sensing of marine boundary layer cloud properties. *J. Atmos. Sci.*, **52**, 2827-2838.

Fairall, C.W., A.B. White, J.B. Edson, and J.E. Hare, 1997: Integrated shipboard measurements of the marine boundary layer. *J. Atmos. Oceanic Tech.,* **14**, 338-359.

Frisch, A. S., G. Feingold, C. W. Fairall, T. Uttal, and J. B. Snider, 1998: On cloud radar and microwave radiometer measurements of stratus cloud liquid water profiles. *J. Geophys. Res.*, **103**, 23195-23197.

5. Current and Pending Support

C. Fairall Current Support

Title: A Sea Spray Droplet Parameterization for Hurricane Models
PI: C. W. Fairall, 2 Co-I; C. W. Fairall: 1 mo/yr
Amount: $290,000 for FY 05
NOAA ST&I

Title: Shipboard Monitoring of Air Sea Flux and Cloud Properties in the Atlantic and Pacific Oceans
PI: C. W. Fairall, 2 Co-I; C. W. Fairall: 2 mo/yr
Amount: $465,100 for FY 03–FY 05
NOAA OGP CPPA Program

Title: High Resolution Climate Data From Research and Volunteer Observing Ships
PI: C. W. Fairall, 1 Co-I; C. W. Fairall: 2 mo/yr
Amount: $606,100 for FY 03–FY 05
NOAA OGP OCO Program

Title: Investigation of Cloud and Precipitation Aspects of Air-Sea Interaction in the Eastern Pacific: Analysis of ETL Ship-Based Data from EPIC2001
PI: C. W. Fairall, 4 Co-I; C. W. Fairall: 2 mo/yr
Amount: $505,000 for FY 03–FY 05
NOAA CPPA Program

Title: Ship-based measurements of cloud microphysics and PBL properties in precipitating trade cumulus clouds during RICO
PI: C. Fairall + 2 other; C. Fairall: 1 mo/yr
Amount: $334,250 for FY04-FY06
NSF Physical Meteorology Program

Title: Ship-based radar, sounding, and flux observations in support of NAME
PI: S. Rutledge, 4 Co-I; C. W. Fairall: 1 mo/yr
Amount: $325,200 (ETL part) for FY 04–FY 06
NOAA CPPA Program

Title: An Ocean-Atmosphere Sensor Integration System (OASIS)
PI: J. Moisan, 4 Co-I; C. W. Fairall: 1 mo/yr
Amount: $293,000 (ETL part) for FY 04–FY 06
NOAA/NASA NOPP Program

Title: Development of an Autonomous System for Direct Measurement of the Flux of CO_2 over the Ocean
PI: J. Hare, 2 Co-I; C. W. Fairall: 1 mo/yr
Amount: $265,733 for FY 05–FY 07
NOAA Carbon Cycle Program