A RESEARCH PROPOSAL
to the
NOAA OFFICE OF GLOBAL PROGRAMS

SHIPBOARD MONITORING OF AIR-SEA FLUX AND CLOUD PROCESSES IN THE ATLANTIC AND PACIFIC OCEANS

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C&GC PROGRAM TOPIC: CLIMATE OBSERVATIONS, CLIVAR PACS AND CLIVAR ATLANTIC

	FY03	FY04	FY05
REQUESTED BUDGET:	569.4 k$	659.7 k$	674.2 k$

PERIOD OF SUPPORT: 1 October 2002 through 30 September 2005

ENDORSEMENTS:

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ABSTRACT

Shipboard Monitoring of Air-sea Flux and Cloud Processes
in the Atlantic and Pacific Oceans
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Total Proposed Cost: $1,903,300 Proposed Period: 1 October 2002-30 September 2005

For the last three years ETL has conducted two cruises each year in a monitoring study of air-sea interaction and cloud properties in the tropical eastern Pacific for the NOAA CLIVAR Pan American Climate Studies (PACS) program. We now propose to continue this effort in the Pacific and to expand the project to an additional two cruises a year in the Atlantic in support of the CLIVAR Atlantic program. We seek funds from NOAAs' Climate Observations program for most of the data acquisition costs.

We propose to place a suite of instruments on NOAA (or UNOLS) ships servicing three selected buoy sites: the TAO buoys at 95W/110W in the fall, the WHOI Ocean Reference Station (ORS) buoys at 20 S 85 W and at 15 N 51 W (http://uop.whoi.edu/) . The fourth cruise is targeted for the area near the PIRATA line at 40 W. The Pacific buoy lines lie within the equatorial and the Peruvian stratocumulus zones; the Atlantic sites lie within the equatorial and the N. Atlantic tradewind cumulus cloud zones. All four cruises will field the ETL flux system and basic cloud monitoring package (a wind profiler, GPS rawinsondes, a cloud ceilometer and a an automated 2-channel microwave radiometer). We propose to expand this system to include measurements of surface wave properties, drizzle droplet spectra, and aerosol information. On the two cruises to the WHOI ORS buoys we will also field the NOAA portable cloud observatory (NPCO) which features a 35GHz cloud radar, an advanced 3-channel microwave radiometer, and an upward looking IR radiometer; the NPCO gives much more detail on cloud properties (vertical distribution of liquid water, cloud droplet sizes, etc). This combination of measurements will include all of the basic processes presently believed to significantly affect the physics of MBL clouds and air-sea interactions.

The basic objectives of these measurements are to:

*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
*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 MBL clouds, aerosols, and drizzle in cloud radiative forcing

We have established collaborations at PMEL and WHOI on buoy measurements, UW and UCLA on using the data with cloud resolving models, and at NCEP, NESDIS, and NPOESS for operational applications. An outreach plan with for Denver/Boulder area middle schools is under development.

1. Results from Prior Research

NOAA Award : Climate Global Change Program, 10/1/99-9/30/02
Amount : $419,400 K
Title : Shipboard monitoring of stratocumulus cloud properties in the PACS region, C. Fairall PI

In this project we implemented a modest ship-based cloud and flux measurement program to obtain statistics on key surface, MBL, and low-cloud macrophysical, microphysical, and radiative properties. The measurements were made as part of the PACS/EPIC monitoring program for the 95 W and 110 W TAO buoy lines in the tropical eastern Pacific (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 MBL/cloud modelers (both statistically and for specific simulations) and to improve satellite retrieval methods for deducing MBL and cloud properties on larger spatial and temporal scales.

The primary objectives were to

*Obtain new measurements of near-surface, cloud, and MBL 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, MBL and cloud parameters for ‘calibration’ of satellite retrieval techniques.

1.1 Methodology

We conducted an enhanced monitoring cloud and MBL measurement program to supplement the measurements made routinely on the NOAA ships (*R/V’s Ka’imi Moana* and *Ronald H. Brown*) servicing the TAO buoys in the PACS region. The field program is built around regularly scheduled service visits to the 95 W and the 110 W buoy lines. The 95W line is in the main stratocumulus belt and the 110W line is at the western edge. An instrument package has been developed that can be installed on either 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.

This set of instruments allows computation of low-cloud statistics (integrated liquid water content, cloud base height, and fraction) 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 six missions beginning in fall of 1999 and ending in spring of 2002. Each mission has included transects of the 95 and 110 buoy lines between 8 S and 12 N. A description of the project and preliminary analysis of the fall 99 cruise is available on the ETL website http://www.etl.noaa.gov/programs/pacs/. Our major effort so far has been in executing the cruises twice a year 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 and Meghan Cronin at PMEL on the fluxes and cloud forcing aspects. We are working to create a web-accessible database for our collaborators and other EPIC investigators. Data are archived for public use at ftp://ftp.etl.noaa.gov/et7/anonymous/cfairall/EPIC/epicmonitor/. Present status of processed data is given in the following table:

Table 1-1. Present processed data availability at the ETL PACS ftp site: D - data available on this site, I - image files only, X - available but not posted.

Mission	Flux	Radar profiler	Ceilom.	MWR	Sonde	Cloud radar	C-band radar
fall99	D	I	D	D	D	NA	X
sp00	D	X	D	D	D	NA	NA
fall00	D	X	D	D	D	I	I
sp01	D	X	D	D	D	NA	NA
fall01	D	X	D	D	D	X	X
sp02	X	X	X	X	X	NA	NA

1.3 *Publications*

Cronin, M. F., N. Bond, C. W. Fairall, J. E. Hare, M. J. McPhaden, and R. A. Weller, 2002: Enhanced oceanic and atmospheric monitoring for the Eastern Pacific Investigation of Climate Processes (EPIC) experiment. *EOS, Transactions of AGU*, **83**, 205-211.

Fairall, C. W., E. F. Bradley, J. E. Hare, A. A. Grachev, and J. B. Edson, 2002: Bulk parameterization of air-sea fluxes: Updates and verification for the COARE algorithm. *J. Clim.*, to appear.

Weller, R. A., Cronin, M. F., N. Bond, and C. W. Fairall, 2002: Enhanced oceanic and atmospheric monitoring in the south east Pacific (Parts I and II). *J. Clim.*, in preparation.

2. Statement of Work

2.1 Introduction

NOAA is entering a new era of climate research and prediction requiring a major expansion of capabilities for climate observations over the oceans (Goody et al., 2002). Improved observations are needed for operational forecast centers, international research programs, and major scientific climate assessments. Thus, NOAA is cooperating with other agencies to develop an Ocean Observing System (OOS) with a combination of *in situ* and satellite measurement components. Air-sea interaction plays a significant role in this problem and, as time scales increase from weeks, to intraseasonal, to seasonal, the importance of air-sea interaction increases. The largest mode of short term seasonal variability in the Earth's climate system (El Nino) is an air-sea interaction phenomenon. The potential societal value of intraseasonal forecasts highlights the vast importance of short-term air-sea interaction such as coastal upwelling, the North American monsoon, or the anticipated frequency of landfalling tropical cyclones.

The single most important process in air-sea interaction is the air-sea flux (in some sense, air-sea fluxes *are* air-sea interaction). Turbulent and radiative fluxes are required for virtually all aspects of research, model validation, and assessment of air-sea interaction. The importance of the turbulent fluxes was profoundly illustrated when a small change in the bulk flux parameterization on the ECMWF model totally changed the model climate of the tropics (Miller et al., 1992). Recent studies with CCM3 have shown the clear need for improvements in the representation of turbulent fluxes (Collins et al., 1997). The variability of radiative fluxes at the surface is dominated by clouds. The representation of clouds and their interactions with the Earth's radiation field are another major source of uncertainty (Cess et al. 1988; Browning 1994) in efforts to predict climate change through General Circulation Models (GCMs).

Marine boundary layer (MBL) clouds strongly influence global climate because their high albedos (compared with the ocean background) give rise to large deficits in absorbed solar radiative flux at the top of the atmosphere, while their low altitude prevents significant compensation in thermal emission (Randall *et al.* 1984). Clouds also couple directly to the surface fluxes through the winds and scalar fields (e.g., Stevens et al., 2001a). The optical properties of MBL clouds are determined by the balance of surface evaporation, entrainment and radiative cooling combined with the boundary layer aerosol properties (Albrecht, 1989; Menon et al., 2002). Aerosols enter the problem in a complicated way through influences on the size distribution of cloud droplets, which in turn influence solar radiative interactions and the drizzle production in the clouds (Albrecht, 1993; Zhu and Albrecht, 2002).

Coupled ocean-atmosphere processes in the subtropics are significantly influenced by MBL clouds (stratocumulus and trade cumulus). In the tropics, clouds generated by deep convection dominate in some regions and MBL clouds dominate in others. Coupled model studies show that the radiative effects of MBL clouds are essential in producing the observed equatorial cold tongue sea surface temperature structure (Philander et al. 1996; Li and Philander, 1996; Delecluse et al. 1998). This includes the classical subtropical stratocumulus regimes off California (NE Pacific) and Peru (SE Pacific) and equatorial stratocumulus occurring in the region of strong N-S sea surface temperature gradient around 85-110 W.

MBL clouds still present great difficulty for GCM's which must attempt to capture complex physical processes with crude spatial resolution. These "subgrid scale processes" must be highly parameterized in GCMs and they have very strong effects on the surface fluxes (Grabowski, 2000). While parameterization of deep convective processes may be eliminated within a few decades by embedding Cloud Resolving Models (CRM) in GCMs (Grabowski, 2001), MBL-scale processes, including clouds, radiative and turbulent surface fluxes, will still require parameterization in the foreseeable future.

2.2 Statement of the Problem

For the reasons discussed above, air-sea fluxes and the MBL processes (particularly clouds) that influence the fluxes are a major focus of the NOAA Climate Observations program. The NOAA/CLIVAR observational strategy involves a combination of short term but comprehensive process studies, coupled with other oceanographic and meteorological monitoring studies (Weller, 1998; Esbensen et al., 2002); it is also poised to use data from the OOS. In the realm of air-sea fluxes, the TAO buoys and specialized Ocean Reference Stations (ORS) are the primary *in situ* measurement systems for continuous high-quality flux estimations. The ORS are large discus buoys designed to obtain high quality data for estimation of air-sea fluxes. The buoy data are critical in evaluation of fluxes in various climate regimes (McPhaden et al., 1998), intercomparisons for operational forecast models (Josey et al, 2002), and several efforts to retrieve fluxes from satellite information (Jones et al., 2001; Project SEAFLUX http://paos.colorado.edu/~curryja/ocean/).

The planned use of networks of TAO-type buoys and ORS buoys is not expected to meet all air-sea flux scientific needs (Taylor, 2001; Cronin et al., 2002). There are some practical limitations associated with the nature of today's buoy systems. These are : 1) accuracy, 2) spatial representation, and 3) a lack of atmospheric profile information. The change in heat flux associated with doubling of atmospheric CO_2 concentration is a few Wm^{-2}; for seasonal time scales air-sea fluxes need to be constrained within 10 Wm^{-2} (Webster and Lukas, 1992). Air-sea interaction buoys must operate unattended for 6-12 months, so it is necessary to compromise accuracy for ruggedness. Also, turbulent fluxes are not measured directly but are estimated using bulk flux routines (Fairall et al., 1996a; 2002). The spatial limitation of fixed buoys is obvious; it can be mitigated by adding more buoys (e.g., the TAO and PIRATA arrays) with the usual tradeoffs in cost. In the short term there will be only a few ORS sites. Present instruments for monitoring of atmospheric profiles require more power than is practically available on buoys. As discussed above, atmospheric profile information is critical for interpreting surface flux measurements, comparing with operational weather models, and in improving satellite retrievals. Thus, buoy observations must be supplemented with high-quality flux and profile measurements from CLIVAR intensive field programs (such as EPIC2001) and other monitoring efforts (Weller, 1998; Taylor, 2001; Esbensen et al., 2002).

2.3 Proposed Ship-based Observation Program

CLIVAR and Climate Observing program goals can be significantly advanced by continuing and enhancing regular research-grade ship-based observations of air-sea fluxes and cloud properties. Because of accuracy limitations, Volunteer Observing Ships (VOS) require cumbersome correction procedures and are still not useful in some applications (Josey et al., 2002). Even *standard* observations from scientific research vessels have well-documented problems (Smith et al., 2001). Thus, to address the problems discussed in 2.2, we propose a series of four cruises a year (2 Atlantic and 2 Pacific) to make comprehensive flux and MBL/cloud observations to supplement NOAA buoy operations. The cruises will be done in *piggyback* mode; ETL sensors will be installed on the ships servicing the TAO, PIRATA, or ORS buoys. This work will be an extension and expansion of the twice-yearly monitoring cruises to the tropical eastern Pacific sponsored by the CLIVAR PACS program (see section 1). Collaborations with Meghan Cronin (PMEL) on TAO buoys and Bob Weller (WHOI) on the ORS buoy at 20 S 85 W will continue and collaborations with Al Plueddemann (WHOI) on the ORS buoy at 15 N 51 W is planned.

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. Fairall et al. (1996a) 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 & 2000; Curry et al., 1999; Curry et al., 2002) and have seen extensive use in research to improve bulk turbulent flux algorithms (Fairall et al., 1996a; Clayson et al., 1996; Xeng et al., 1998; Bourassa et al., 1999; Brunke et al., 2002). ETL has also recently spearheaded NOAA-sponsored intensive field programs such as JASMINE and EPIC2001.

These comprehensive observations will do more than add to the value of buoy data but will also serve to promote NOAA CLIVAR and operational interests. Contacts have ben initiated at NCEP (S. Lord), NESDIS (Andy Hall), and NPOESS (Steve Mango) to establish operational 'customers' for these data. We have an ongoing cooperation with Dr. Andy Jessup (UW/APL) 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. In recent years high-resolution MBL models such as Large Eddy Simulations (LES) and CRM have shown considerable success (e.g., Krueger et al. 1995; Stevens et al., 1998) in generating realistic subtropical cloud fields and simulating their life cycle from low stratus to trade cumulus clouds. However, a recent comparison of state of the art LES (Stevens et al., 2001b) indicates that even LES is an unreliable predictor of cloud fraction in the trades. Exactly what processes regulate cloud fraction is an outstanding issue in rational representations of the planet's albedo (and hence climate). To quote Stevens, "It is imperative that we develop a modern data base of cloud properties in an environment whose properties are well characterized: dynamically, thermodynamically and chemically. When integrated with decades of ocean weather ship data, surface monitoring, and satellite remote sensing, such a data set will be invaluable in constraining fine-scale modeling efforts to estimate factors regulating cloud fraction thereby providing closure".
Bjorn Stevens (UCLA) and Chris Bretherton (UW) await with great anticipation regular detailed observations of marine stratocumulus and trade cumulus clouds. These measurements will address scientific objectives of the CLIVAR PACS and Atlantic programs and have received the endorsement of the VAMOS East Pacific Investigations of Climate (VEPIC) panel (http://www.atmos.washington.edu/~breth/VEPIC/VEPIC_Science_Plan.pdf).

2.4 Scientific Objectives

In this proposal we outline a plan for a ship-based measurement program to obtain statistics on key surface, MBL, and low-cloud macrophysical, microphysical, and radiative properties relevant to NOAA's Climate Observations and CLIVAR programs. We propose to place a suite of instruments on NOAA (or UNOLS) ships servicing three selected buoy sites: the TAO buoys at 95W/110W in the fall, the WHOI ORS buoys at 20 S 85 W and at 15 N 51 W (http://uop.whoi.edu/) . The fourth cruise is targeted for the area near the PIRATA line at 40 W. The Pacific buoy lines lie within the equatorial and the Peruvian stratocumulus zones (Weller, 1998; Esbensen et al., 2002); the Atlantic sites lie within the equatorial and the N. Atlantic tradewind cumulus cloud zones. The basic objectives of these measurements are to:

*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
*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 MBL clouds, aerosols, and drizzle in cloud radiative forcing

2.5 Methodology

We propose a series of four cruises a year (2 Atlantic and 2 Pacific) to make comprehensive flux and MBL/cloud observations in *piggyback* mode on the ships servicing the TAO, PIRATA, or ORS buoys. All four cruises will field the ETL flux system and basic cloud monitoring package (a wind profiler, GPS rawinsondes, a cloud ceilometer and a an automated 2-channel microwave radiometer: White et al., 1995; Fairall et al., 1997). We propose to expand this system to include measurements of surface wave properties, drizzle droplet spectra, and aerosol information. On the two cruises to the WHOI ORS buoys we will also field the NOAA Portable Cloud Observatory (NPCO) which features a 35GHz cloud radar (Moran et al., 1998), an advanced 3-channel microwave radiometer (Hazen et al., 2002), 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.. When operating on the *Ronald H. Brown* we will also have use of the scanning C-band Doppler radar, which provides great detail on the spatial distribution of convection, precipitation, and clouds. This combination of measurements will include all of the basic processes presently believed to significantly affect the physics of MBL clouds and air-sea interactions.

Near-surface bulk and flux data. The ETL flux group has spent more than a decade developing techniques for accurate ship-based measurements (Fairall et al., 1996a; 1997). Wind speed is measured with a sonic anemometer with full motion corrections (Edson et al., 1998). We also correct for flow distortion by the ship's structure based on computational fluid dynamics (CFD) calculations with empirical tuning. CFD calculations have been done on the R/V's *Ronald H. Brown* (NOAA) and *Knorr* (WHOI); these results are applicable to the other sister ships likely to be used in this research (e.g., *Roger Revelle* and *Melville*). Radiative flux sensors are calibrated by E. Dutton at NOAA/CMDL and cross checked against the Brookhaven NL system deployed by Mike Reynolds. Atmospheric temperature and humidity are field checked against a hand-held Assman psychrometer standard; typical corrections are on the order of ±0.2 C and ±0.3 g/kg. Near surface ocean temperature is measured with a specially developed floating temperature sensor (called a 'seasnake') which samples at a depth of about 5 cm. This sensor fully resolves all diurnal warm layers; true interface temperature is obtained by subtracting a cool-skin correction (Fairall et al., 1996b). A sonic anemometer/thermometer and a high-speed infrared H_2O/CO_2 sensor are used to make measurements of turbulent fluxes. Platform motion corrections were made as described by Edson et al (1998). Direct covariance and inertial-dissipation fluxes are computed at 10-min and 1-hr time intervals. The measurement of direct covariance CO2 fluxes is a recent breakthrough (Fairall et al., 2000; McGillis et al., 2001) that links these observations to NOAA's Carbon Cycle program. In FY04 Dr. Barry Huebert (University Hawaii) will add a high speed dimethysulfide (DMS) sensor to this package to measure direct covariance DMS fluxes. DMS flux is associated with a possible link between ocean biology and aerosols in the MBL; it also provides a new method to estimate MBL entrainment velocity (Stevens and Lenschow, 2000).

NOAA Portable Cloud Observing system. The NPCO comprises a package of instruments [35 GHz Doppler radar, microwave (20.6, 31.65 and 90.0 GHz) radiometers and an IR (9.9-11.4 or 10.6-11.3

μm) radiometer]. As well the instruments, a key component of the package is a number of state-of-the-art retrieval techniques that are utilized in the internal internet system connecting instrument computers

Table 1. Instruments and measurements deployed by ETL for the ship-based cloud/MBL 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, MBL microturbulence
8	Rawinsonde	MBL 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	Precipitation spectrometer	Drizzle droplet size spectra
12	CN counter, aerosol spectrometer	Aerosol size spectra
13	BNL rotating shadowband radiometer	Direct/diffuse solar
14	35 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

and processing computers to produce real-time information on advanced cloud properties. Retrievals are available for all-liquid clouds such as marine stratus, all-ice clouds such as anvils from deep convective systems and mixed scenes when ice and water clouds are simultaneously present. The instruments, data processing, visualization and archiving computers have been installed in a portable seatainer which makes the facility suitable for deployment on ship; the system has already had successful research cruises on the NOAA ship *Ronald H. Brown* in the tropical western Pacific, the Bay of Bengal, in the Southern Pacific, and in coastal U.S. waters. With suitable satellite internet access, data images and samples are available on shore in near real time. The data products from this unique system includes high resolution

(9 second, 45-meter) measurements of cloud boundaries, cloud top temperatures, number of cloud layers, cloud water contents, cloud particle sizes, and cloud optical depths which are key components for understanding how clouds moderate atmospheric heating budgets and long-term climate. It should be noted that the NOAA Cloud Observatory is the only fully operational portable system of it's kind presently in existence, and is also the only system with real-time data processing capabilities for producing the cloud properties of interest. The technologies utilized by the system have received the 1997 NOAA Administrator's Award, and the 2001 NOAA Technology Transfer Awards.

Turbulent flux parameterization. Developing and improving assessments of turbulent fluxes at the surface are critical to the CLIVAR program. Bulk algorithms are widely used to estimate surface fluxes in numerical models and in applications (e.g., satellite retrievals) where highly detailed local information is not available. These are based upon similarity representations of the fluxes in terms of mean quantities

$$<w'x'> = C_x \Delta X\, S = C_x \Delta X\, (U^2 + U_g^2)^{1/2}$$

where x can be the u, v wind components, the potential temperature, θ, the water vapor mixing ratio, q, etc, and C_x is the total transfer coefficient. ΔX is the sea-air difference in the mean value of x and S is the mean wind speed which is composed of a mean vector part (U and V components) and a gustiness part (U_g) to account for subgrid-scale variability. The COARE bulk algorithm is still being improved and version 3.0 was just released (Fairall et al., 2002).

Fairall et al. (2002) discuss two important research issues for bulk flux parameterizations: 1) treating subgrid-scale variability in model applications and 2) accounting for variations in surface wave properties. Item 1 involves relating U_g to resolved-scale convective forcing and variability. Large scale models (i.e., one that do not explicitly resolve convection), must account for variability associated with mesoscale convection (Vickers and Esbensen, 1998). Numerical modeling work has suggested that U_g can be additionally parameterized in terms of rainrate or cumulus convective mass flux (Krueger and Zulauf, 1997). The combination of the C-band Doppler radar, the vertically pointing precipitation profiler, and the direct flux measurements offer us a unique opportunity to examine such parameterizations with atmospheric data. Item 2 involves the controversial effect of wave properties such as wave steepness or period on the turbulent fluxes. The present version of the COARE flux model has two different user-selectable options for representation of wave effects. For waves near typical wind-wave equilibrium the two parameterizaitons give similar results, but for waves that are out of equilibrium they give much different results. Direct flux measurements with corresponding wave information in the open ocean are required to evaluate these parameterizations. Because of large sampling variability inherent in flux measurements, a very large data based is required to resolve both of these issues. Thus, a regular series of monitoring cruises is the ideal venue for this study.

Cloud radiative forcing. One emphasis of our proposed work will be to use the 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 (e.g., Ramanathan et al., 1995 for the tropics; Walsh and Chapman, 1998 for the Arctic). CF yields valuable information about cloud dynamics (Pincus et al., 1997) and offers an important tool for diagnosing GCM treatments of cloud/radiative processes. Ramanathan et al. (1995) showed direct linkage between SFC and oceanic dynamics. Furthermore, Tian and Ramanathan (2002) have shown that CF is much more directly linked to atmospheric regional dynamics and moisture transports than, say, surface turbulent fluxes.

Cloud forcing can be inferred globally using satellite data at the top of the atmosphere (TOA, Ramanathan et al., 1989) and, although it is more indirect, at the surface. For surface cloud forcing (SCF), surface-based methods are more direct and more accurate, but provide limited sampling. Previous studies in the tropics have shown that the heavy water vapor burden in the boundary layer masks the longwave (LW) signal from clouds and SCF is dominated by the solar flux (LW SCF is about 5 to10 Wm^{-2} while shortwave (SW) SCF is -70 to -110 Wm^{-2}). In subtropical stratocumulus regimes, the solar component is more nearly balanced by the LW component and total SCF is perhaps closer to -30 Wm^{-2}.

The PACS enhanced monitoring program (Cronin et al., 2002) is expected to give good estimates from simple surface measurements of the annual cycle of SCF along 95 W and at the WHOI buoy site at 20 S 85 W. Similar methods can be applied to the CLIVAR Atlantic buoy program. The observations proposed here will link observed radiative SCF with cloud properties following the approach Intrieri et al. (2002) used for the Arctic. Our results will also be useful for improving satellite-based methods for deducing SCF.

A examples of the utility of more complete observations is illustrated in Figs. 1-3. For example, when clouds occur their effect on the surface fluxes is dependent on cloud base height and cloud liquid water content. Figure 1 shows results of our ship measurements from the PACS monitoring program. Cloud fraction and cloud integrated liquid water path (LWP) are shown as a function of latitude for spring and fall seasons. The higher cloud fractions and LWP between 5-10 N are associated with the ITCZ; south of 3 N we see typical LWP values (50 -200 gm^{-2}) for stratocumulus/tradecumulus clouds. Also, to compute CF, we need a clear sky flux model (i.e., a representation of what the flux would be in the absence of clouds). Such models require information on the atmospheric column: examples include estimates of aerosol optical thickness and estimates of the total column water, IV. Buoys do not measure cloud base height or IV. To interpret variations in IR flux with latitude for the TAO buoys, we need to know if cloud base height has a systematic dependence on latitude. Also, we can obtain an estimate of IV using buoy observations of specific humidity, q, at the surface. In that case, we use a simple representation IV=b*q, where b is an empirical coefficient. Figure 2 shows averages of cloud base height and b from the first 4 PACS monitoring cruises. There is little latitudinal dependence in the fall. The spring measurements show lower cloud base height north of the equator with a strong dip at the equatorial cold tongue.. The coefficient b is essentially constant in spring but varies strongly with latitude in the fall. This structure is probably caused by synoptic-scale subsidence south of the equator which dries out the upper troposphere and promotes the formation of stratocumulus clouds. These values are then used in the clear sky model shown with TAO buoy observations at 10 N 95 W (Fig. 3). The clear sky model tuned with the ETL ship observations has resulted in much more accurate values for CF.

Cloud property retrievals. Historically, aircraft cloud measurements were used to find microphysical relationships for GCM parameterizations (e.g., Gultepe, 1996). In the last decade, there has been great advancement in techniques to obtain the same information from surface-based remote sensors (White et al., 1995). Much of what we know about the statistics of marine cloud liquid water contents comes from surface-based data (Snider et al., 1998). Retrievals of cloud or drizzle microphysics using a combination of a cloud radar and microwave radiometer were first demonstrated by Frisch et al. (1995). The method is based on relating measurements to three parameters that characterize the cloud droplet spectrum as a lognormal distribution. Subsequent explicit modeling studies (Frisch et al. 1998) have shown the method is well-founded (essentially there is strong correlation between the 3rd and 6th moments of the distribution) and that the retrieval of the profile of liquid water is independent of the assumed distribution width. Frisch et al. (2000) have developed a method to reduce the sensitivity of the retrievals to the assumed value of the droplet distribution normalized width. They compared their liquid water retrieval with *in situ* aircraft measurements and found a standard estimate of the error to be 0.03

gm^{-3} . Recent work by Frisch et al. (2002) shows that a good retrieval can be done without the use of the microwave radiometer integrated liquid water measurements for retrieving the droplet effective radius. This relies on the reflectivity alone and is not very sensitive to the cloud droplet concentration nor the spread of the droplet spectra.. The Frisch method gives complete characterization of profiles of drizzle size and number concentration which, combined with the surveys of the C-band radar, give a unique view of drizzle in marine stratocumulus. The addition of the ship-based aerosol and drizzle information examine relationships between aerosol, drizzle droplet concentrations, cloud radiative properties, and stratocumulus/trade cumulus dynamics.

Fig. 4 gives an example of remote sensing of cloud properties at the WHOI ORS buoy at 20 S 85 W from EPIC2001. The liquid water path (upper panel) in the cloud is measured by two independent microwave radiometers. One is the ARM program standard 2-channel (23 and 31 GHz) system that we refer to as the *MAILBOX*: the other is a 3-channel (21, 31 and 90 GHz) ETL system referred to as *MMCR*. The lower panel shows backscatter intensity from the cloud radar with the cloud base height from the ceilometer. This particular example shows moderate drizzle during the night and periods of clearing during the day. Spikes in the 2-channel values at 291.58 and 291.65 are artifacts caused by rain wetting of the radiometer window. Figure 5 illustrates a retrieval of an important cloud property from EPIC2001, the concentration of cloud droplets (number of droplets per unit volume). In this example, the number of cloud droplets increased dramatically as the ship approached the coast (presumably caused by increasing aerosol concentration near the coast). There was a corresponding increase in the albedo of these clouds and a reduction in the solar flux reaching the ocean surface. This example nicely illustrates the value of spatial information and the need for aerosol measurements to aid in the interpretation of the results.

2.6 Outreach

On the JASMINE cruise in 1999 ETL developed an outreach relationship with Jim Cronin at Thunder Ridge middle school in Cherry Creek, CO. Using email, meteorological and oceanographic observations were integrated into a science class work unit over a 3 week period. This involved the transmission of data samples and photographs from the ship. The students evaluated the data, made weather forecasts (for the Indian Ocean), and asked questions. On the EPIC2001 cruise, we hosted two different onboard visitors as part of NOAA’s Teacher at Sea program. With 4 cruises a year for this proposal (all during the school year) continuing for at least 3 years, we have a unique opportunity to greatly expand this effort. We now have informal agreements with Thunder Ridge MS and Monarch K-8 (Louisville, CO) to develop much more comprehensive connection of science teaching units and these proposed research cruises. Mr. Cronin has contacted other science teachers in the Cherry Creek school district. In the first year we will do a pilot study with a single class from each of the two schools. If that is succeessful, it will form the basis to expand the effort to more schools and more grade levels. We also plan to allocate travel funds to allow a teacher go on each of the WHOI ORS buoy cruises.

2.7 Work Timetable

Year-1

*Complete processing and posting of data from existing PACS monitoring cruises
*Complete two publications with PMEL, UW, and WHOI on monitoring results
*Order Laser wave instruments and integrate with flux system
*Order aerosol systems and set up data acquisition

*Complete upgrades to cloud radar
*Deploy basic monitoring system on R/V Ron Brown in October 2002 TAO buoy servicing cruise to 95/110 W
*Deploy basic monitoring system and NPCO on R/V Ron Brown for WHOI buoy servicing cruise to 15 N 51 W, spring 2003
*Deploy basic monitoring system on R/V Ron Brown for cruise near PIRATA buoys at 40W, spring 2003
*Complete basic processing for all cruises this FY
*Begin cloud microphysics retrievals

Year-2

*Deploy basic monitoring system and NPCO on R/V Mellville for WHOI buoy servicing cruise to 20 S 85 W, fall 2003
*Deploy basic monitoring system on R/V Ron Brown in October 2003 TAO buoy servicing cruise to 95/110 W
*Deploy basic monitoring system and NPCO on R/V Ron Brown for WHOI buoy servicing cruise to 15 N 51 W, spring 2004
*Deploy basic monitoring system on R/V Ron Brown for cruise near PIRATA buoys at 40W, spring 2004
*Complete basic processing for all cruises this FY
*Continue cloud microphysics retrievals; combine with cloud forcing studies
*Begin flux parameterization studies

Year-3

*Deploy basic monitoring system and NPCO on R/V Mellville for WHOI buoy servicing cruise to 20 S 85 W, fall 2004
*Deploy basic monitoring system on R/V Ron Brown in October 2004 TAO buoy servicing cruise to 95/110 W
*Deploy basic monitoring system and NPCO on R/V Ron Brown for WHOI buoy servicing cruise to 15 N 51 W, spring 2005
*Deploy basic monitoring system on R/V Ron Brown for cruise near PIRATA buoys at 40W, spring 2005
*Complete basic processing for all cruises this FY
*Continue cloud microphysics retrievals; combine with cloud forcing studies
*Continue flux parameterization studies

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2.9 Figures

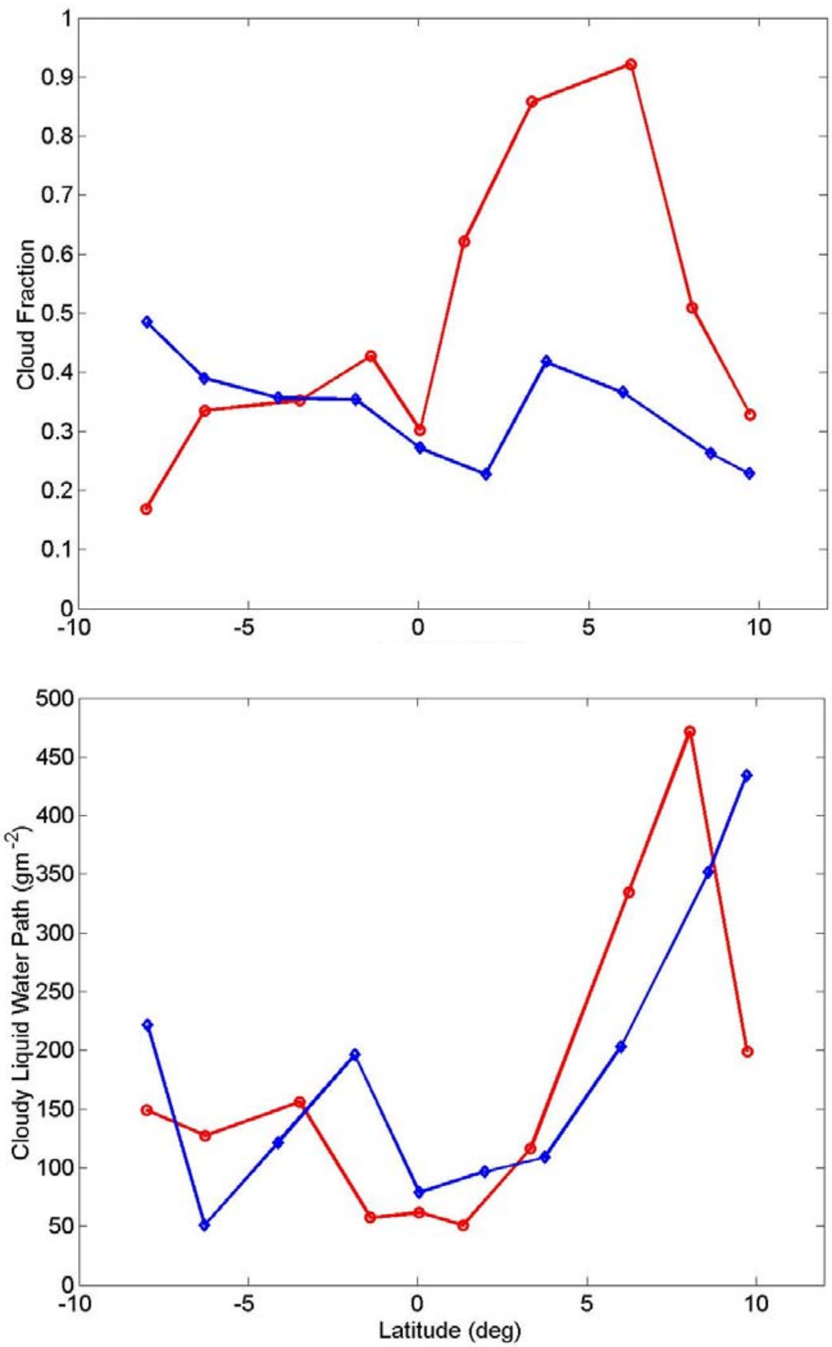

Figure 1. Bin-averaged measurements of atmospheric properties from 4 PACS monitoring cruises. Upper pane: low-cloud fraction; lower panel: integrated cloud liquid water content when clouds are present. Red circles for are fall and blue diamonds are spring.

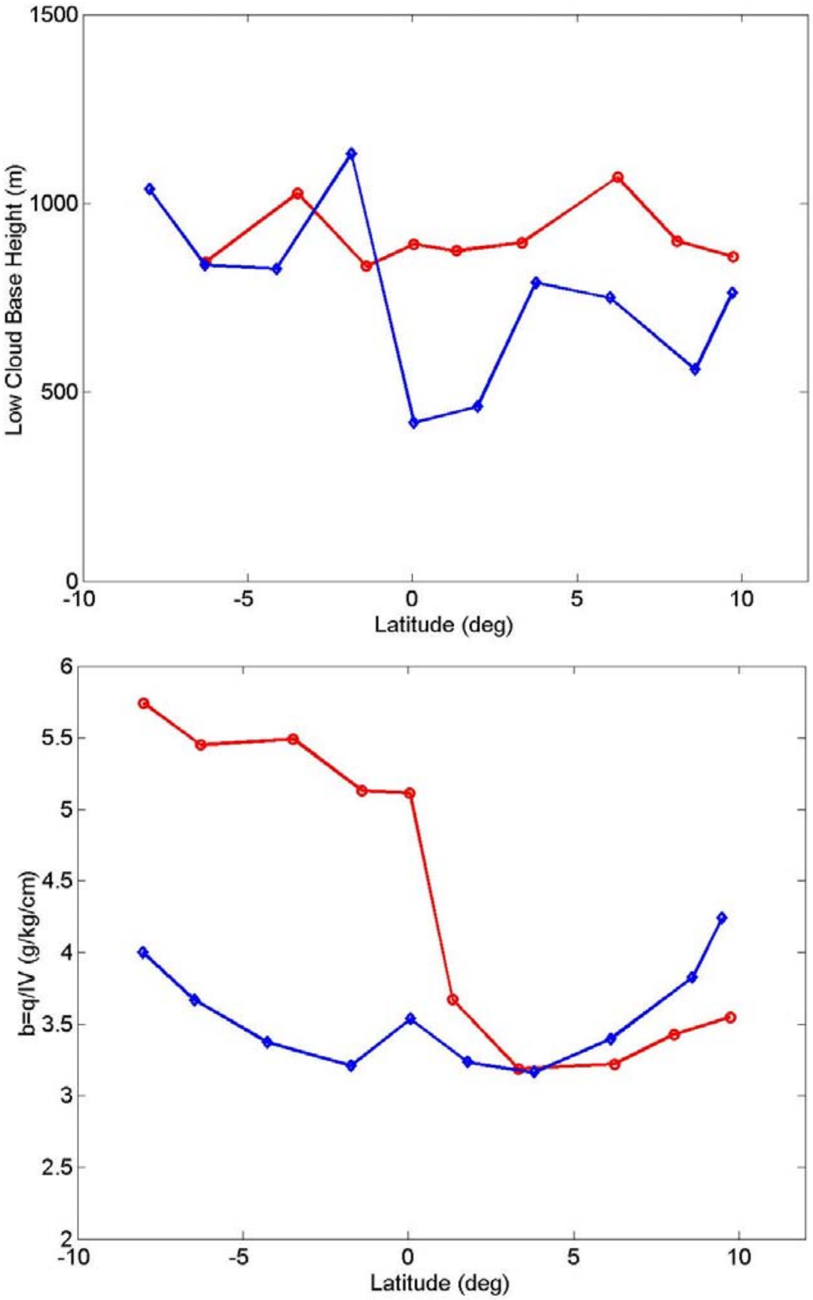

Figure 2. Daily-averaged measurements of atmospheric properties from 4 PACS monitoring cruises. Upper pane: low cloud base height; lower panel: ratio of MBL specific humidity, q, to total column integrated water vapor, IV. Red circles for are fall and blue diamonds are spring.

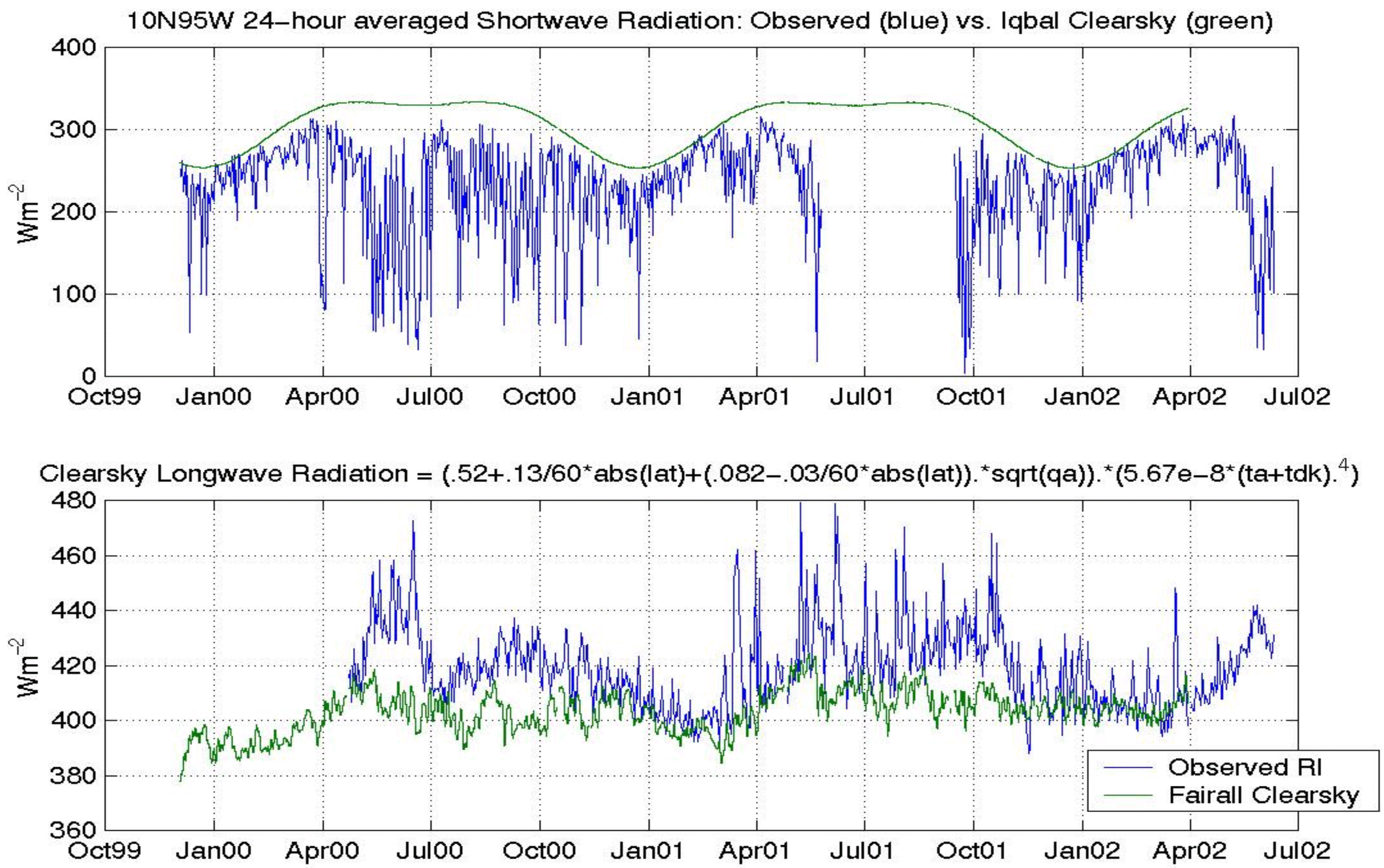

Figure 3. Daily averaged downward solar (upper panel) and IR (lower panel) flux time series for 10 N 95 W. The blue lines are TAO buoy data; the green line clear sky model values based on ETL PACS cruise information. The difference in the two lines is the cloud radiative forcing at the surface. Strong forcing in the May-October period is caused by migration of the ITCZ to 10 N.

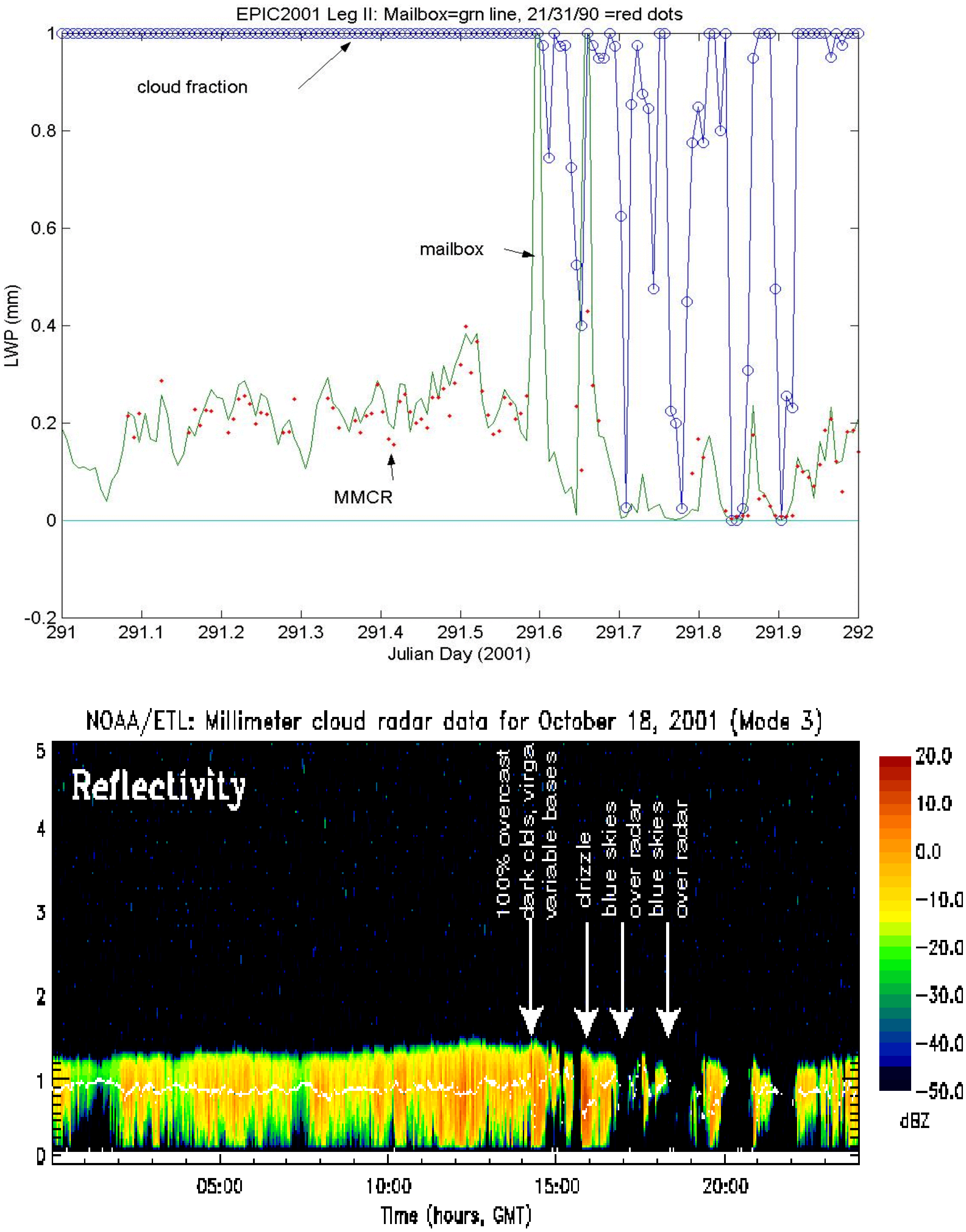

Figure 4. Stratocumulus cloud characteristics on Oct. 18, 2001. Upper panel: total liquid water path (LWP) from two microwave radiometer systems (green line and red dots) and cloud fraction from a ceilometer (blue circles). Lower panel: cloud radar backscatter intensity (color contours) and ceilometer cloud base heights (white dots).

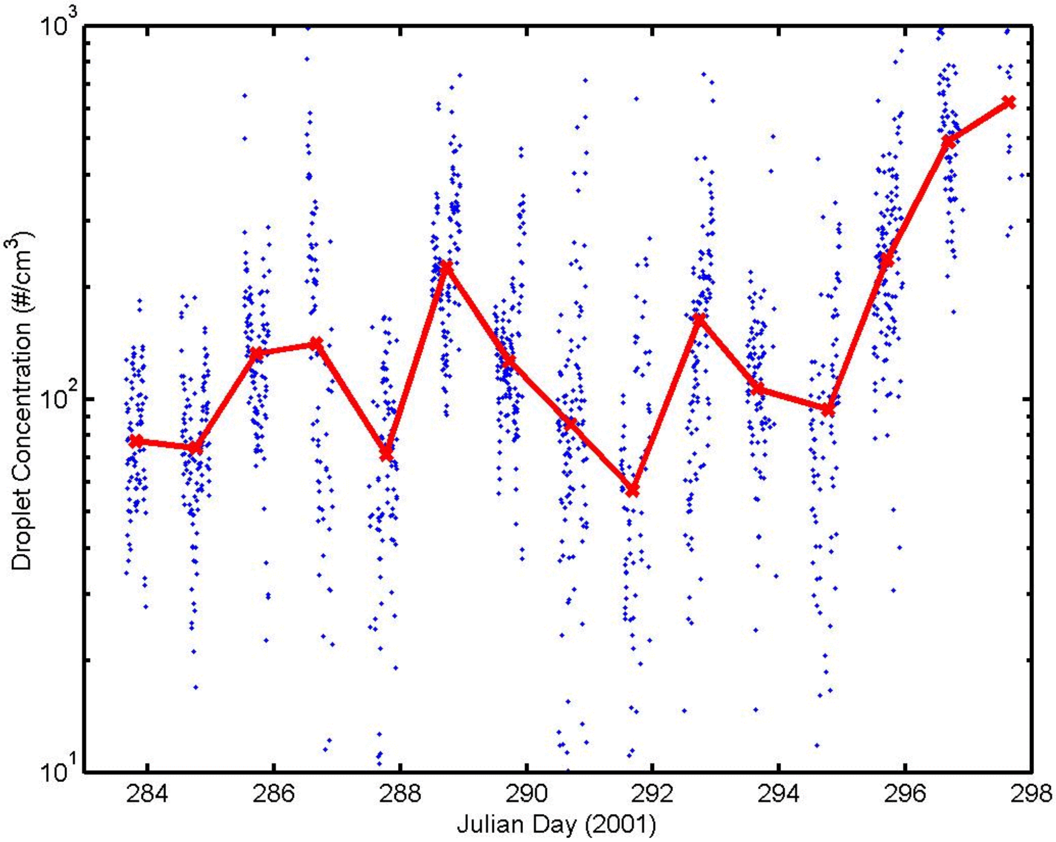

Figure 5. Time series from EPIC2001 of stratocumulus cloud droplet concentration inferred from solar radiative flux measurements using the method of Dong et al. 1998. Blue dots are individual half-hour values; red x's are the daily median. Days 286-295 correspond to *Ronald H. Brown* observations at the WHOI ORS buoy at 20 S 85 W. After day 295 the ship departed the area and headed East toward the coast of Chile. The increase in cloud droplet concentration associated with lower cloud solar transmission coefficient (higher albedo) are presumed to be caused by increasing aerosol concentration near the coast.

3. Budget Details

3.1 Background on Cruise Costs

For the last three years ETL has received funding from PACS/EPIC program for 'monitoring' studies of air-sea fluxes and cloud radiative properties. We have been installing the ETL seagoing system on the TAO tender ship (twice yearly at 95 and 110 W). The measurements included the ETL flux system, a wind profiler, GPS rawinsondes, a cloud ceilometer and a microwave radiometer to measure fluxes, PBL properties, and clouds. Nick Bond at PMEL has been collaborating on the sonde launches. The NPCO went on two of those cruises. We now have 6 of those cruises plus Epic2001.

We are now proposing to do 2 cruises a year with the basic flux/cloud system and 1 (Fy03) or 2 (FY04 and FY05) cruises a year with fluxes and the NPCO. All cruises will be in piggy-back mode (i.e., as addenda to buoy servicing, etc). The cloud radar would be deployed on the WHOI reference buoy change outs in the Pacific (Weller) and Atlantic (Plueddeman). Based on experience gained in the previous cruises, we have done a study of the data acquisition costs for a 30-40 day cruise, which are summarized (a detailed spreadsheet is available) in Table 2. These are just typical costs with variations occurring because of shipping ports and how many sensors happen to fail. Costs do not include scientific analysis, modeling, papers, etc.

Table 2. Costs (k$) of fielding specific ETL ship-based measurement systems from installation through basic data processing.

Task	**Flux/bulk-cloud**	**NPCO**	**Rawinsondes**
setup/teardown	30	37	5
cruise	28	43	0
supplies	5	5	25 (4/day @30 days)
processing	15	22	2
total	78	107	32

The NPCO is self-contained in its own seatainer; the flux system is in components that must be assembled on the ship. Previously, sonde costs were not part of our budget; we understand Nick Bond is interested in continuing the sonde work on the TAO line. Note that 30%-40% of the costs (i.e., setup/teardown) can be saved if two consecutive cruises are done on the same ship. We plan to target the *Ronald H. Brown* as a key R/V where most of the flux system (i.e., the time-consuming parts to install and expensive parts to ship) is left on board (particularly the long cable runs, etc).

The following is a planned scenario for FY03. Because of timing, we will not be able to do the September 2002 change out of the Weller buoy at 20 S 85 W. The regular fall PACS cruise on the *Ronald H. Brown* will be done. The Plueddeman WHOI buoy will be done spring 2003 on *Ronald Brown*; that would be immediately followed or preceded by a second Atlantic cruise (which saves installation costs). Finally, some funds will be needed to prepare for the Weller buoy in the fall of 2003. In FY 04 and 05 we will do all four cruises.

3.2 Equipment Costs

In FY03 we are requesting funds for acquisition of key equipment. The measurements that we wish to add to the present ETL system are:

Instrument	Vendor/Model	Unit cost (k$)	Num	Request
Drizzle droplet spectrometer	Drop Meas. Tech. Cloud Imaging Probe	60	1	0*
Wave height and period	Riegl LD90 Laser	15	2	30
Aerosol spectrometer	Part. Meas. Sys. Lasair 1510	20	1	20
Total aerosol conden-sation nuclei counter	Therm. Sys. Inc. 3010 CN counter	15	1	15
Cloud radar upgrade	ETL	15	1	15
Total Cost				80

We just acquired the DMT cloud imaging probe with other funds, so there is no request. The addition of ocean surface waves will increase our capability to parameterize fluxes and aid in satellite interpretations. One wave measurement system will be ordered in FY03 and one in FY04;The two aerosols systems will cover the production mode (total CN) and the accumulation mode (0.1 to 5.0 µm diameter) which is principally responsible for cloud condensation nuclei. This is essential to related MBL aerosol properties and cloud optical properties. The cloud radar upgrade will double processing speed and improve sensitivity; ETL will contribute 45 k$ of components.

3.3 Scientific Analysis Costs

The total proposed costs for this project include significant scientific research efforts as part of the CLIVAR PACS and Atlantic programs. In the second and third year of the project, ETL base funds will be used for a university graduate student in CRM or LES modeling (UW or UCLA) to work with this data.

4. Abbreviated Vita

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PROFESSIONAL PREPARATION:

NRC Postdoctoral Research Associate, Naval Postgraduate School, 1971
Ph.D., Solid State Physics, Michigan State University, 1970.
B.S., Physics and Mathematics, Florida State University, 1966.

RESEARCH AREAS:
Air-sea interaction, measurements of fluxes, remote sensing of boundary layer and cloud properties, atmospheric turbulence, cloud-radiative coupling, parameterizations of turbulent and cloud properties, atmospheric dispersion.

PROFESSIONAL APPOINTMENTS:

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.
1989-Pres.	NOAA/ERL Environmental Technology Laboratory, Boulder, CO.

RECENT and RELEVANT PUBLICATIONS:

Fairall, C. W., J. E. Hare, and J. B. Snider, 1990: An eight-month sample of marine stratocumulus cloud fraction, albedo, and integrated liquid water. *J. Clim.*, **3**, 847-864.

Chertock, B., C. W. Fairall, and A. B. White, 1993: Surface-based measurements and satellite retrievals of broken cloud properties in the equatorial Pacific. *J. Geophys. Res.*, **98**, 18,489-18,500.

Frisch, A. S., D. H. Lenschow, C. W. Fairall, W. H. Schubert, and J. S. Gibson, 1995: Doppler radar measurements of turbulence in marine stratocumulus cloud during ASTEX. *J. Atmos. Sci.*, **52**, 2800-2808.

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., E.F. Bradley, D.P. Rogers, J.B. Edson, and G.S. Young, 1996: Bulk parameterization of air-sea fluxes for TOGA COARE. *J. Geophys. Res.*,**101**, 3747-3767.

White, A. B., C W. Fairall, A. S. Frisch, B. W. Orr, and J. B. Snider, 1996: Recent measurements of turbulence and microphysical parameters in marine boundary layer clouds. *Atmos. Res.*, **40**, 177-221.

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.

Curry, J. A., and 21 coauthors, 2000: FIRE arctic clouds experiment. *Bull. Am. Met. Soc.,* **81**, 5-29.

Fairall, C. W., J. E. Hare, J. B. Edson, and W. McGillis, 2000: Parameterization and measurement of air-sea gas transfer. *Bound.-Layer Meteorol.*, **96**, 63-105.

Cronin, M. F., N. Bond, C. W. Fairall, J. E. Hare, M. J. McPhaden, and R. A. Weller, 2002: Enhanced oceanic and atmospheric monitoring for the Eastern Pacific Investigation of Climate Processes (EPIC) experiment. *EOS, Transactions of AGU*, **83**, 205-211.

Webster, P. J., C. W. Fairall, P. W. Hacker, R. Lukas, E. F. Bradley, and S. Godfrey, 2002: The Joint Air-Sea Monsoon Interaction Experiment (JASMINE): Exploring the intraseasonal variability of the South Asian monsoon. (2) A pilot field program. *Bull. Am. Met. Soc.*, to appear.

[13 other recent publications not shown in the interest of saving paper]

SCIENCE COMMITTEES, AWARDS, ASSOCIATIONS:

SHEBA, FIRE, TOGA COARE, ARM Science Team member
Member The Oceanography Society, American Meteorological Society, and American Geophysical Union
Chairman, AMS Committee on Boundary Layers and Turbulence: 1987-1990
Member of the National Academy of Sciences Committee on Coastal Meteorology: 1990-1993
General Co-Chairman of the 3rd International Symposium on Tropospheric Profiling: Hamburg, Germany, August, 1994
Associate Editor of Journal of the Atmospheric Sciences: 1991-1994
Member of the NSF Coastal Ocean Processes (CoOP) advisory committee: 1991-1994
Member, International Geophysical Union International Climate Dynamics and Meteorology Working Group A (Boundary Layers and Air-Sea Interaction), 1996-Present.
NOAA outstanding paper award 1997
Fellow, Cooperative Institute for Research in Environmental Sciences, 1999
Fellow, American Meteorological Society, elected 2000

COLLABORATORS AND AFFILIATIONS:

Peter Webster - University Colorado/Georgia Tech
Chris Bretherton - University of Washington
Robert Weller -WHOI
James Edson -WHOI
Bjorn Stevens - UCLA
Mike Banner - UNSW, Australia

TANEIL UTTAL
Research Meteorologist/Group Leader
Clouds and Arctic Research Group
NOAA Environmental Technology Laboratory
Boulder, DO

PROFESSIONAL PREPARATION:
B.S. Physics Colorado College - 1979
M.S. Atmospheric Science - Colorado State University - 1985

RESEARCH AREAS:
Cloud radiation and microphysical studies with radars and radiometers, cloud parameterizations, and validation of satellite retrievals of cloud properties.

PROFESSIONAL APPOINTMENTS:
1980-1981 Colorado Climate Center
1982 - Present NOAA Environmental Technology Laboratory, Boulder CO

RECENT AND RELEVANT PUBLICATIONS:

Intrieri, J.M., M.D. Shupe, T. Uttal and B.J. McCarty, 2002: An annual cycle of Arctic cloud characteristics observed by radar and lidar at SHEBA, *J. Geophys. Res.*, accepted.

Uttal, T., and Coauthors, 2002: Surface Heat Budget of the Arctic Ocean, Bull. *Amer. Meteor. Soc.*, **83**, 255-275.

Uttal, T. and R.A. Kropfli, 2001: Effect of pulse length on radar reflectivity statistics*, J. of Atmos. and Ocean. Technology*, **18**, 947-961.

Shupe, M.D., T. Uttal, S.Y. Matrosov, and A.S. Frisch, 2001: Cloud water contents and hydrometeor sizes during the FIRE - Arctic Clouds Experiment. *J. Geophys. Res.*, **106**, 15,015-15,028.

Uttal, T., E.E. Clothiaux, W.L. Eberhard, J. Intrieri, and T. Ackerman, 1995: Cloud boundary statistics during FIRE II, 1995. *J. Atmos. Sci*., **52**, 4276-4284.

Baum, B.A., T.Uttal, M.Poellot, T.P.Ackerman, J.M. Alverez, J.Intrieri, D,O'C. Starr, J.Titlow, V.Tovinkere, and E.E. Clothiaux, 1995: Satellite remote sensing of multiple cloud layers. *J.Atmos Sci*., **52**, 4210-4230.

Intrieri, J.M., T. Uttal, W. Eberhard, J.Snider, Y.Han, B.Orr, and S. Matrosov, 1994: Multi-wavelength observations of cirrus clouds during FIRE-II, 1995. *J.Atmos. Sci.,* **52**, 4079-4093.

Uttal, T., S.Y.Matrosov, J.B.Snider, and R.A. Kropfli, 1994: Relationships between ice water path and downward longwave radiation for clouds optically thin in the infrared: Observations and model calculations, 1994. *J.Appl. Meteor*., **33**, 348-357.

Intrieri, J.M., G.L. Stephens, W.L.Eberhard, and T. Uttal, 1993: A method for estimating cirrus cloud particle sizes using a radar/lidar backscatter tecnique. *J.Appl. Meteor.*, **32**, 1074-1082.

Palmer, A.J., S.Y. Matrosov, B.E. Martner, T.Uttal, D.K. Lynch, and M.A. Chatelain, 1993: Combined infrared emission spectra and radar reflectivity studies of cirrus clouds. *IEEE Trans. Geosci. Remote Sensing*, **97**, 11567-11574.

Uttal, T., J.B. Snider, R.A. Kropfli, and B.W. Orr, 1990: A remote sensing method of measuring atmospheric vapor fluxes: Application to winter mountain storms. *J.Appl. Meteor*., **29**, 22-34.

Sassen, K., D. O'C. Starr and T. Uttal, 1989: Mesoscale and microscale structure of cirrus clouds: Three case studies. *J.Atmos Sci.*, **46**, 371-396

Uttal, T. R.M. Rauber, L.O. Grant, 1988: Distributions of Liquid, Vapor and Ice in an Orographic Cloud from Field Observations. *J.Amos. Sci*., **45**, 1110-1122.

SCIENCE COMMITTEES, AWARDS, ASSOCIATIONS
Surface Heat and Budget of the Arctic (SHEBA) Science Team
Earth Observing System (EOS) Science Team
First ISCCP Regional Experiment (FIRE) Science Team
Member - AMS Polar Meteorology and Oceanography Committee
Member - U.S. Arctic Research Support and Logistics Working Group
Member - GCSS Polar Clouds Working Group V
Member - GCSS Cirrus Working Group II

COLLABORATORS AND AFFILIATIONS:
Patrick Minnis - NASA Langley Research Center
Peter Hobbs - University of Washington
Eugene Clothiaux - Pennsylvania State University

5. Current and Pending Support

PI: C. Fairall, 1 Co-I; Amount: $419,400 for FY99-02: Status - current; NOAA PACS Program
C. Fairall: 2 mo/yr;
Title: Shipboard monitoring of stratocumulus cloud properties in the PACS region

PI: C. Fairall, 4 Co-I; Amount: $896,400 for FY00-02; Status - current; NOAA PACS Program
C. Fairall: 2 mo/yr; T. Uttal: 2.0 mo/yr
Title: Shipbased cloud and precipitation air-sea interaction studies: EPIC2001

PI: J. Hare, C. Fairall Co-I; Amount: $291,700 for FY00-02; Status - current; NOAA Carbon Cycle
C. Fairall: 1 mo/yr;
Title: Direct measurements of gas transfer over the open sea: Instrumentation and techniques

PI: C. Fairall, 1 Co-I; Amount: $379,800 for FY01-04; Status - current; Office of Naval Research
C. Fairall: 2 mo/yr
Title: Measurement of sea spray droplet distributions at high winds

PI: Taneil Uttal, 4 Co-I;Amount: $407,500 for FY98-02; Status - current
T. Uttal: 3.0/year; NASA/CIRES/EOS
Title: Validation of CERES Cloud Retrievals over the Arctic with Surface-Based Millimeter-Wave Radar

PI- Taneil Uttal - 6 Co-I; Amount: FY 99-02 $353,000; Status - current; NASA FIRE-ACE
T. Uttal: 1.3 months/year
Title: Ground Based and Remote Sensing of the Microphysical and Radiative Properties of Clouds: Comparisons with Mid-Latitude and Sub-Tropical Systems

PI: Taneil Uttal, 3 CO-I; Amount: FY01-FY03 $231,550; Status - current; NSF/SHEBA
T. Uttal: 2.0 months/year
Title: Processing of Radar, lidar and radiometer data sets to produce cloud microphysical and optical properties for the SHEBA annual cycle

PI: C. Fairall, 2 CO-I; Amount: FY03-FY05 $705,000; Status - pending: NOAA PACS program
C. Fairall: 2.0 months/year; T. Uttal: 2.0 months/year
Title: Investigation of cloud and precipitation aspects of air-sea interaction in the eastern Pacific: Analysis of ETL ship-based data from EPIC2001.