Annual Progress Report to
NOAA's Climate Observations Program

High Resolution Climate Data from Research and Volunteer Observing Ships

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ABSTRACT

This project focuses on the measurement of direct high-resolution air-sea fluxes on one to two cruises per year and on the development and use of a roving standard flux measuring system deployed on a series of NOAA and UNOLS research vessels to promote the improvement of climate-quality data from those platforms. Direct measurement of air-sea turbulent fluxes of sensible heat, latent heat, and momentum are critical for the development of model parameterizations of fluxes, and this project provides a strategy for maintaining regular flux observations within the climate context and provides a critical tool for providing a systematic calibration for flux observations from UNOLS and NOAA vessels.

PROJECT SUMMARY

Direct covariance air-sea fluxes are performed on several oceanic cruises each year, and ESRL has developed a roving standard flux measuring system to be deployed on research vessels on an opportunistic basis. This latter task aims to encourage the UNOLS and NOAA fleet to toward high-quality climate observations from these platforms. An adjunct task is maintenance and operation of the C-band scanning Doppler radar and the stabilized wind profiling radar on the NOAA ship *Ronald H. Brown*. Because buoys and most ships and satellites rely on bulk methods to estimate fluxes, another aspect of this project is the use of direct measurements to improve the NOAA/COARE bulk flux algorithm. Originally one cruise was the annual TAO buoy tending cruise to 95W and 110 W on the *Ronald Brown*, but after several years participation in the TAO cruise was discontinued in favor of participation in the annual cruise to the equatorial Atlantic Ocean with NOAA/AOML as part of the African Multidisciplinary Monsoon Analyses (AMMA) and Saharan Dust studies (now part of the PIRATA Northeast Extension; PNE). In 2000, a second cruise was added to participate in the annual turn-around of the Stratus climate buoy at 20S 85W. Due to the success of the Stratus cruise participation and the fruitful collaboration with WHOI, and in order to maintain a more relevant connection with the climate reference buoys, ESRL now participates in the annual turn-around of the Northwest Tropical Atlantic Station (NTAS).

A full suite of direct, inertial-dissipation, and bulk turbulent fluxes of sensible heat, latent heat, and momentum are measured along with IR and solar radiative fluxes, precipitation, and associated bulk meteorological properties. This effort represents a partial transition of research from the OGP CLIVAR PACS program to operations under the Climate Observations Program (COP).

The project development is the result of a NOAA-sponsored workshop on high-resolution marine measurements (Smith et al., 2003, *Report and Recommendations from the Workshop on High-Resolution Marine Meteorology*, COAPS Report 03-01, Florida State University, pp38) which identified three important issues with the planned NOAA air-sea observation system: 1) the need for a data quality assurance program to firmly establish that the observations meet the accuracy requirements, 2) the need for observations at high time resolution (about 1 minute), 3) and the need to more efficiently utilize research vessels, including realizing their potential for the highest quality data and their potential to provide more direct and comprehensive observations. For seasonal time scales, the net air-sea flux (sum of 5 flux components) must be constrained within 10 Wm^{-2}. Buoys and VOS systems are required to operate virtually unattended for

months, so considerations of practical issues (e.g., power availability, instrument ruggedness, or safe access) are balanced against inherent sensor accuracy and optimal sensor placement. As discussed above, an important function of the in situ measurements is to provide validation data to improve NWP and satellite flux fields. High time resolution and more direct observations are invaluable for interpreting surface flux measurements and diagnosing the source of disagreements; such information can be provided by suitably equipped research vessels (R/V). Thus, the accuracy of buoy and VOS observations must be improved and supplemented with high-quality, high time resolution measurements from the US R/V fleet (which is presently underutilized). The necessity for both high time resolution and high accuracy places extreme demands on measurements because some sources of error (such as the effect of ship flow distortion on wind speed) tend to average out over a large sample. To accomplish this task will require a careful intercomparison program to provide traceability of buoy, VOS, and RV accuracy to a set of standards.

This project directly addresses the need for accurate measures of air-sea exchange in the *Program Plan for Building a Sustained Ocean Observing System for Climate* (Sections 5.2-5.4), and it is a joint effort by ESRL and Dr. Robert Weller of the Woods Hole Oceanographic Institution (WHOI). The ESRL Air-Sea Interaction Group website can be found at: http://www.esrl.noaa.gov/psd/psd3/air-sea/. ESRL also cooperates with Dr. Andy Jessup (APL University of Washington) on radiative sea surface temperature measurements, Dr. Frank Bradley (CSIRO, Canberra Australia) on precipitation and radiative flux observations, Dr. M. Cronin (PMEL) on buoy-ship intercomparisons and climate variability analysis, and Dr. Wade McGillis (Univ. Columbia) on radiative fluxes. A new website is under construction for this project (High Resolution Climate Observations http://www.esrl.noaa.gov/psd/psd3/air-sea/oceanobs/). An associated website (http://www.esrl.noaa.gov/psd/psd3/wgsf/) contains a handbook on best practices for flux measurements plus a database of high-resolution flux data. This work will be closely monitored by the WCRP Working Group on Surface Fluxes (WGSF) which is chaired by C. Fairall. This gives the project high visibility in the CLIVAR, GEWEX, and SOLAS programs. This project will be managed in cooperation with JCOMM (and other) panels as per instructions of Mike Johnson.

Users of the data from this project include numerous individual collaborators (J. Edson at UConn, B. Huebert at UHawaii, B. Ward at Galway, M. Bourassa at FSU, W. McGillis at LDEO, F. Bradley at CSIRO, M. Cronin at PMEL, R. Wanninkhof at AOML, R. Weller at WHOI, A. Beljaars at ECMWF, etc, etc) and many projects/programs worldwide (SAMOS, GOSUD, SeaFlux, USGCRP, WCRP, SOLAS, SURFA, OceanSites, CLIVAR, VOCALS, UNOLS, TAO, etc, etc). Specific application include global model algorithm development and intercomparison, satellite product intercomparison, *in situ* (buoy and ship) intercomparison studies, application of the NOAA/COARE model for flux parameterization, improved climate observation.

This project directly addresses the Climate Observation Program deliverables for improved observations of **Air-Sea Exchange**, and for accurate measurement of **Sea Surface Temperature**.

FY2009 ACCOMPLISHMENTS

ESRL completed three research cruises, including the participation in a major multi-

institutional, multi-platform experiment (VOCALS) during October-November over two cruise legs on the *Ronald H. Brown*, a climate cruise (NTAS) on the *Ronald H. Brown*, and a flux system calibration cruise on the University of Hawaii's R/V *Kilo Moana* (WHOTS). The preliminary raw and processed data from these three cruises can be found at ftp://ftp.etl.noaa.gov/et6/cruises .

Prior to VOCALS, major maintenance was performed on the C-band radar on the *Ron Brown*. Evaluations have been made on hardware and software upgrades for the system, but the level of expense is significant. The VOCALS deployment also included an intercomparison period at the WHOI Stratus buoy (20S, 85W), and the larger campaign also included W-band and X-band cloud radars on the ship, observations from multiple aircraft, and numerous floats and profiling buoys. The main VOCALS website is: http://www.eol.ucar.edu/projects/vocals/. After the VOCALS campaign ended, it was decided that the wind profiler on the Ron Brown needed to be taken down for major refurbishment at ESRL in Boulder. Funding for this instrument upgrade and re-installation has not been found to date.

In June, the ESRL turbulent flux system and C-band radar were operated on the *Ron Brown* during the WHOI climate reference Northwest Tropical Atlantic Station (NTAS) buoy near 15N, 51W. These observations are in collaboration with Al Plueddemann at WHOI.

In July, the ESRL roving flux standard was deployed on the R/V *Kilo Moana* on the WHOTS cruise in the vicinity of the Hawaii Ocean Timeseries Station (HOT) near 23N, 158W for the annual maintenance of the WHOI climate reference buoy at this location. This calibration was performed in collaboration with Al Plueddemann at WHOI and the University of Hawaii. A report is being developed from this deployment. Prior to the summer cruises, an intercalibration was performed on the ESRL Eppley and Kipp and Zonen infrared and visible broadband radiometers.

In early 2008, ESRL coordinated with the USCG icebreaker R/V Healy with the roving flux standard. Based in part on consultation with ESRL, the Healy crew installed a new instrument suite to make significant improvement to their observational systems. A report on this activity is in development.

We continue our cooperation with Dr. Huai-Min Zhang of NOAA NCDC on the SURFA project (http://www.ncdc.noaa.gov/oa/rsad/air-sea/surfa.html). The SURFA project is in an formative phase, and ESRL has downloaded surface flux fields from the ECMWF and the German DWD operational global forecast models and has begun the process of evaluating the data sets. During the next year, we will continue the data evaluation and formulate the process of comparison with in situ data. An example of this investigation is shown in the Figure below.

In the Spring of 2008, ESRL deployed the roving flux standard on the WHOI R/V Knorr for the ICEALOT cruise (http://saga.pmel.noaa.gov/Field/icealot/). This was the first deployment of the roving flux standard for intercomparison on a UNOLS vessel. The data have been archived on the ESRL website (http://www.esrl.noaa.gov/psd/psd3/cruises/) and the report is in the final stages of preparation.

Construction of the High Resolution Climate Observations website continues. A handbook for ship-based flux measurements has been developed, and it is entitled "A Guide to Making Climate Quality Meteorological and Flux Measurements at Sea" by Frank Bradley and Christopher Fairall (find it at http://www.esrl.noaa.gov/psd/psd3/wgsf/). We have updated our ship data base so that all cruises through 2008 are publicly available and this process will continue with future cruises. Joint analysis projects with WHOI and PMEL will continue as

well.

Of significance to this project is the white paper synthesis of air-sea transfer coefficients presented at the OceanObs'09 conference in Venice in September ("Observations to quantify air-sea fluxes and their role in climate variability and predictability" by C. Fairall and 17 others). This document outlines the direct observations which have led to the development of improved air-sea transfer parameterizations and outlines strategic directions for further observational systems for improved climatic prediction. A review paper (Bourassa et al., 2009) prepared by the WCRP High Latitude Flux Working Group was also submitted to the Bulletin of the American Meteorological Society.

The PI of this project has been chair the WCRP Working Group on Surface Fluxes (WGSF) since 2003. He also serves on the International Geophysical Union International Climate Dynamics and Meteorology Working Group A (Boundary Layers and Air-Sea Interaction). In 2004 he was invited to join the SOLAS Focus 2 (air-sea flux physics) Working Group to develop the Surface Ocean-Lower Atmosphere Study (SOLAS) International Implementation Plan and has been named to the US SOLAS Advisory Group. In 2008 he joined the CLIVAR High Latitude Flux Working Group (http://www.usclivar.org/hlat.php). He was awarded the 2009 Sverdrup Gold Medal by the American Meteorological Society for outstanding contributions to the scientific knowledge of interactions between the oceans and the atmosphere.

OUTREACH AND EDUCATION

Outreach efforts during the reporting period center on educational contacts through the University of Colorado CIRES Outreach program and the NOAA Teacher-at-Sea program. In mid-2009, the PI and other members of the ESRL Air-Sea Interaction Group participated in a summer workshop coordinated by the CIRES Outreach Office. The workshop focused on assisting local earth science K-12 teachers to understand the role of the world's oceans on climate, and a number of ESRL scientists presented lectures for the teachers (http://cires.colorado.edu/education/k12/cosee/). We also hosted a NOAA Teacher-in-the Laboratory; D. Stanitski spent three weeks working on calibration and comparisons of radiataive flux sensors including participating in the WHOTS cruise in July.

PUBLICATIONS (FY 2009)

De Szoeke, S.P., C.W. Fairall, and S. Pezoa, 2009: Ship observations of the tropical Pacific Ocean along the coast of South America. *J. Clim.*, **22**, 458-464.

Ghate, Virendra P., Bruce A. Albrecht, Christopher W. Fairall and Robert A. Weller, 2009: Climatology of marine stratocumulus cloud fraction in the South-East Pacific using surface longwave radiative flux observations. *J. Clim.*, **22**, 5527-5540 .

DeSzoeke, Simon P., C. W. Fairall, D.E. Wolfe, L. Bariteau, and P. Zuidema 2009: Surface flux observations in the southeastern tropical Pacific and attribution of SST errors in coupled ocean-atmosphere models. *J. Clim.*, to appear.

Bourassa, M., S. Gille, C. Bitz, D. Carlson, I. Cerovecki, M. Cronin, W. Drennan, C. Fairall, R. Hoffman, G. Magnusdottir, R. Pinker, I. Renfrew, M. Serreze, K. Speer, L. Talley, and

G. Wick, 2009: High-Latitude ocean and sea ice surface fluxes: Requirements and challenges for climate research. *Bull. Am. Met. Soc.*, submitted.

CONFERENCES (FY 2009)

The 89th American Meteorological Society Annual Meeting, Phoenix, AZ, 10-16 January, 2009. Paper presented: **Comparisons and Contrasts of Recent Shipboard Observations of Turbulent Momentum and Heat Fluxes.** J.E. Hare, C.W. Fairall, A.A. Grachev, L. Bariteau, D.E. Wolfe, S. Pezoa. http://ams.confex.com/ams/89annual/techprogram/paper_145760.htm

OceanObs09, Venice, Italy, 21-25 September, 2009. Community White Paper: **Observations to Quantify Air-Sea Fluxes and Their Role in Climate Variability and Predictability.** C. W. Fairall, and 18 coauthors. http://www.oceanobs09.net/blog/?p=73

OceanObs09, Venice, Italy, 21-25 September, 2009. Plenary Talk and White Paper: **Surface Fluxes and Processes Including Sea ice.** S. Gulev and 16 coauthors. http://www.oceanobs09.net/blog/?p=926

Attached Publications

These papers are available as .pdf files from ftp://ftp.etl.noaa.gov/user/cfairall/oceanobs/pubs/fy09/

De Szoeke, S.P., C.W. Fairall, and S. Pezoa, 2009: Ship observations of the tropical Pacific Ocean along the coast of South America. *J. Clim.*, **22**, pp 458-464.

Community White Paper: **Observations to Quantify Air-Sea Fluxes and Their Role in Climate Variability and Predictability.** C.W. Fairall, and 18 coauthors. Presented at OceanObs'09 in Venice Italy, September 2009.

Ghate, Virendra P., Bruce A. Albrecht, Christopher W. Fairall and Robert A. Weller, 2009: Climatology of marine stratocumulus cloud fraction in the South-East Pacific using surface longwave radiative flux observations. *J. Clim.*, **22**, pp 5527-5540 .

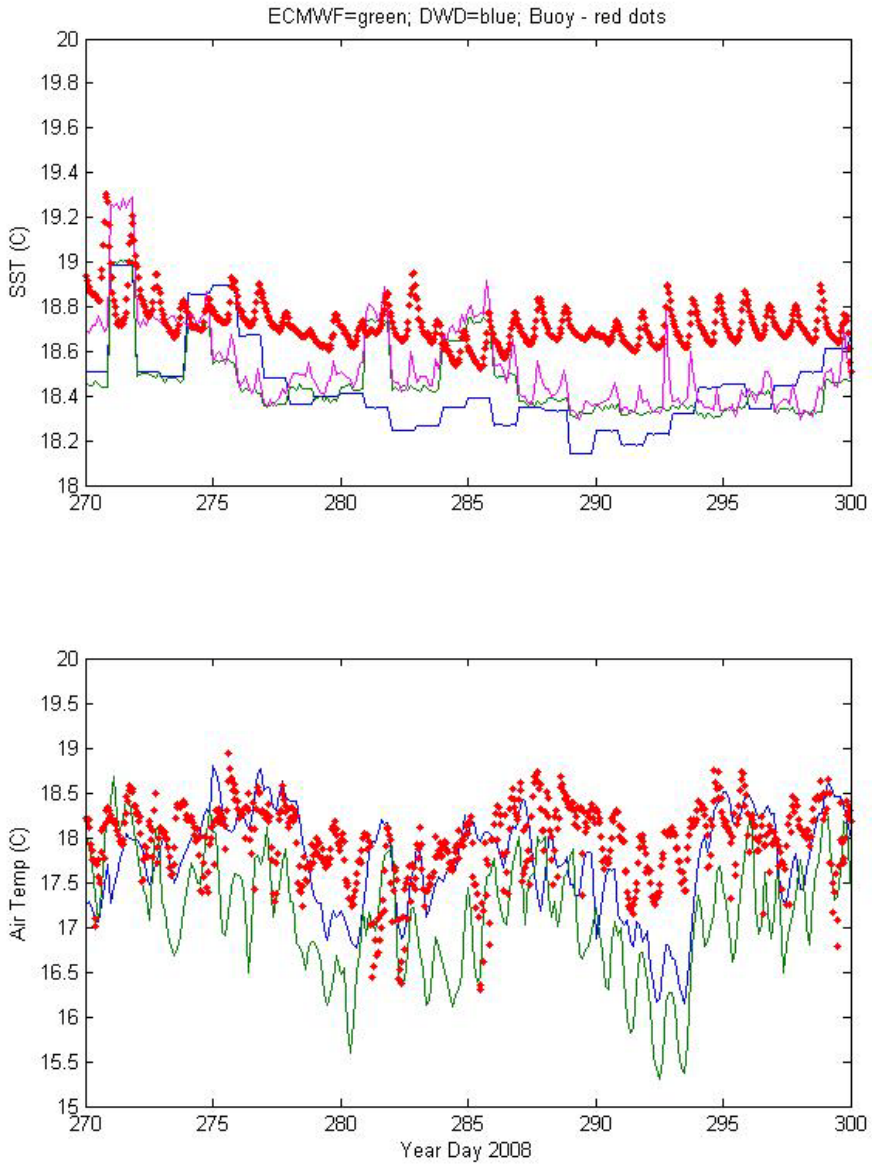

Figure 1. Time series sea and air temperature intercomparisons of two global NWP models (ECMWF=green; ECMWF with warm layer module=magenta; German DWD=blue) available from SURFA with in-situ Stratus buoy measurements (Stratus=red). The WHOI reference buoy is located at 20S 85W. Note the general cold bias of the model air and water temperatures, but also note that the new ECMWF surface algorithm (magenta) does accurately portray the surface diurnal warm layer behavior. Synoptic events that show up as drops in the observed air temperatures (e.g., between day 291-294) have some correspondence in the models. The amplitude of the synoptic variation in the models appears to be too large.