

Final Report for NSF grant OCE-9525986: The Role of Upper Ocean Processes in Modulating Air-Sea Fluxes During TOGA COARE

Activities and Findings

Objectives of Project

The project primarily addressed upper ocean processes that influence vertical fluxes of heat, moisture and momentum in the climatically important western Pacific warm pool. A coordinated suite of collaborative data analysis and modeling activities was aimed at ultimately improving air-sea coupling parameterizations in 3-D coupled general circulation models (GCMs), using observations from the TOGA Coupled Ocean–Atmosphere Response Experiment (COARE). The specific tasks that were undertaken include development of an integrated upper ocean analysis for the ocean Intensive Flux Array; heat and salinity budget computations for the IFA including estimation of local and remote 3D circulation influences on vertical mixing; statistical analysis of coherent meso- and small-scale thermohaline features in the upper ocean and their contributions to vertical fluxes of heat, moisture and momentum; collaborative development of a 1-D coupled model; and collaboration with ocean and atmosphere modelers working on small-, meso- and large-scales.

These efforts have contributed substantially to achieving the following goals of COARE:

To describe and understand the principal processes responsible for the coupling of ocean and atmosphere in the western Pacific warm pool system,

To describe and understand the oceanic response to combined buoyancy and wind stress forcing in the western Pacific warm pool region, and

To describe and understand the multiple scale interactions that extend the oceanic and atmospheric influence of the western Pacific warm pool system to other regions and vice versa.

Comprehensive Overview of COARE results

The PI worked with Frank Bradley (CSIRO, Australia) to organize and conduct the final international conference for TOGA COARE. The results of COARE '98 are summarized in a World Climate Research Programme volume (Bradley and Lukas, 1999). The journal article by Godfrey et al. (1998) provides a comprehensive summary at the time of the conference. In addition to documenting the progress towards the objectives of COARE, an important objective of these efforts was to set out the research agenda that is required to capitalize fully on the substantial investment in TOGA COARE.

Comprehensive Assessment and Reconciliation of Fluxes

A manuscript by Weller, Bradley and Lukas (2001) has been completed that provides a comprehensive assessment of the errors within the COARE flux datasets and the consistency of the various estimates. Extensions of the COARE bulk flux algorithm are discussed. The implications of COARE air-sea flux results for remote sensing and numerical modeling of the coupled ocean-atmosphere exchanges are numerous. Bradley et al. (2001) addressed the remaining inconsistencies between the various methods of observing and estimating rainfall during COARE. The conclusions are that the atmospheric moisture budget of Johnson and Ciesielski (2000) is consistent with the direct ship-based measurements, and that the remote ship-based radar estimates are biased low. This impacts satellite precipitation algorithms calibrated against radars.

Coupled Scale Interactions

One of the major targets for COARE was the role of scale interactions in the coupling of ocean and atmosphere. The paper by Meehl et al. (2001) provides a framework for these nonlinear interactions, and illustrates the principles with a variety of COARE-related examples. The role of the Madden-Julian Oscillation in modulating upper ocean mixing, including impacts on the diurnal cycle, were studied by Lagerloef et al. (1998). Kemball-Cook worked on simulation of the Intraseasonal Oscillation in the ECHAM-4 model and the discernable impact of coupling with an ocean model. Wang et al. (1999, 2000) show that coupled ocean-atmosphere scale interactions play a key role in the western tropical Pacific during the transition from one phase of ENSO to the other. Zhang has been working with Wang on the air-sea interaction processes responsible for the development of the anomalous Philippine Sea high during the onset of El Niño. Wu (2000) showed that the distinct northeastward summer monsoon progression in the western North Pacific is related to the seasonal movement of a high SST tongue and that the monsoon-induced wind and surface wind changes feed back on this seasonal SST change.

Basin-Wide Currents and Thermocline Variability

Lagerloef et al. (1999) developed a model relating wind and sea surface topography to mixed layer flow in the tropics, including the equator. This model was combined with satellite altimeter and scatterometer observations to study the evolution of tropical Pacific currents, including the evolution of ENSO. Further work is underway elucidating the relative roles of horizontal advection and vertical fluxes in the evolution of mixed layer temperature during ENSO events, especially in the warm pool region. A clear result is that horizontal advection of heat is an important term in the central equatorial Pacific, and that phasing of other terms contributing to SST anomalies is regionally different. Wang et al. (2000) analyzed the annual cycle of thermocline variability in the NOAA/NCEP ocean reanalysis. Lukas (2001) provides a comprehensive overview of Pacific equatorial currents for the Encyclopedia of Oceanography.

Upper Ocean Heat and Salt Budgets

A method was developed for analyzing the R/V Wecoma Intensive Observing Period survey observations of T, S and velocity (Feng et al., 1998b) to eliminate the influence of unresolved internal tides and other internal waves (Feng et al., 1998a). This method, along with turbulent entrainment flux estimates, was used to compute the upper ocean heat and salt budgets for the Intensive Flux Array (Feng et al., 2000). The budget estimates agree with the observed heat fluxes to better than 10 W/m² and to better than 20% in freshwater flux, thus confirming the accuracy of the COARE observations and the COARE bulk air-sea flux algorithm.

Space-Time Structures of Upper Ocean T, S, and Density

Huyer et al. (1997) provided a comprehensive description of the temperature, salinity and velocity space and time structures observed during the COARE IOP from the R/V Wecoma surveys. Further efforts to describe the detailed time and space scales of upper ocean density and velocity during COARE were made by Soloviev et al. (2000, 2001c). A major conclusion is that below the mixed layer the spatial structure on scales of several km to several hundred km is consistent with the equatorial version of the random internal wave model of Garrett and Munk when the nonrandom internal tide model of Feng et al. (1998b) is included. Soloviev et al. (2001b) and Soloviev and Lukas (2001a) have elaborated on the nonlinear interaction of thermohaline fronts and winds in the warm pool, explaining the observation that the T-S relationship obeys $R \sim 0.5$ rather than the $R \sim 1$ observed by Rudnick et al. in the North Pacific subtropical gyre. This is rationalized by consideration of Stommel and Young's (1993) model, and the differences in these regions in terms of random precipitation and heating.

Feng et al. (2001) described a submesoscale eddy that was observed to spin up in the IFA during the decay of the Yoshida jet that was forced by the strong December westerly wind bursts. The vorticity dynamics of the eddy development were quantified.

Upper Ocean Mixing

Soloviev et al. (1998; 1999) documented the instruments used to obtain near-surface T, S and velocity fluctuation information during COARE, and the methods for estimating turbulence dissipation. Soloviev et al. (2001a) developed a new Richardson number-based parameterization of turbulence based on boundary layer theory. When used in a 1-D model, this parameterization leads to improved ability to simulate COARE observations over a wide range of wind speeds and stability. Soloviev and Lukas (2001b) studied surface wave-breaking enhancement of upper ocean turbulence, and developed a new parameterization for this usually neglected contribution to mixing.

D. Rowe, O. Cabanes, T. Suzuki and K. Lebedev each worked on the problem of the interaction of upper ocean mixed layer physics with variable air-sea fluxes and ocean dynamics. An unpublished report by Cabanes showed that the signature of equatorial inertia-gravity waves could be imprinted on sea surface temperature through their upwelling and shear effects on the mixed layer turbulence budget. Suzuki's work extended that of Cabanes to consider other wave types and structures. This work was not completed, as Suzuki returned to Japan to take a position with the Frontier Research System for Global Change. We hope to publish a paper on the work when he has settled in. Lebedev's work with the KPP mixing parameterization has been incorporated into an inverse model (Yaremchuk and Lebedev, 2001) that may be used for study of the western Pacific warm pool.

1-D Coupled Modeling

Bin Li worked on coupling single-column models of the atmosphere with the Price-Weller-Pinkel mixed layer model. Dail Rowe continued that effort with REU student Larry O'Neill. The NASA single-column atmospheric model exhibited strong drift when forced with COARE atmospheric observations and SST. The NCAR single column atmospheric model was able to reach equilibrium with the COARE boundary conditions. This thread of research under this grant has suffered from unfortunate personnel turnover, and research groups at several other institutions have done much of what we proposed to do.