Coupled Interactions of Organized Deep Convection Over the Tropical Western Pacific

X. Hong and S. Raman
Department of Marine, Earth, and Atmospheric Sciences
North Carolina State University
Raleigh, North Carolina

Introduction

The relationship between sea surface temperature (SST) and deep convection is complex. In general, deep convection occurs more frequently and with more intensity as SSTs become higher. This theory assumes that the atmospheric stability is sufficiently reduced to allow the onset of moist convection. However, the amount and intensity of convection observed tends to decrease with increasing SST because very warm SSTs may occur only under conditions of diminished convection. This indicates that convection acts to decrease SSTs. A reason for such decrease is the enhancements to surface fluxes of heat and moisture out of the ocean surface because of the vertical overturning associated with deep convection. Early studies used the radiative-convective models of the atmosphere to examine the role of the convective exchange of heat and moisture in maintaining the vertical temperature profile. In this paper we use a Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) to simulate a squall line over a tropical ocean global atmosphere/coupled ocean atmosphere response experiment (TOGA/COARE) area and to investigate how the ocean cooling mechanisms associated with organized deep convection act to limit tropical SSTs.

Model Description

The three-dimensional COAMPS consists of a non-hydrostatic atmospheric model and a hydrostatic ocean model (Hodur 1993). The models can be integrated simultaneously so that the surface fluxes of heat, momentum, and moisture are exchanged across the air-sea interface every time step. The models have been coupled at the interface by vertical mixing. Both the atmospheric model and the ocean model have used a time-splitting technique for computational efficiency. Short time steps have been used for the terms that govern the sound waves in the atmospheric dynamic equations and for the barotropic mode in the ocean model. Longer time steps have been used for all other terms in the atmospheric model and for the internal modes in the ocean model.

The model domain is 120 x 120 x 17.5 km with 61 x 61 x 50 grid points in the horizontal and vertical, respectively. It includes 30 layers for the atmosphere and 20 layers for the ocean. Model resolution is 2 km for horizontal and variable resolution for vertical, stretching from 150 m for the lowest layer smoothly to 1000 m for the upper layer. For the atmospheric model, large time step is 6 seconds and the small time step 0.6 seconds. For the ocean model, large time step is 240 seconds and the small time step 6 seconds. The model is started at 1800 UTC before squall line develops. The initial thermodynamic field and the wind field used composite sounding derived from P-3 flight level data and rawinsonde data at Honiara, Guadalcanal (~9°S, 160°E) for 1800 UTC on February 22, 1993 (Trier et al. 1994). Initial thermal perturbation is oriented in the along-line direction, with a radius of 20 km in the along squall line direction, 5 km in the perpendicular squall line direction, and 1600 m in the vertical direction. Maximum magnitude of thermal is 2°K at the center, decreasing to 0°K at the edges. Two simulations are performed: 1) without the atmosphere/ocean coupling and 2) with the atmosphere/ocean coupling.

Results

Simulation without Atmosphere/Ocean Coupling

Without the atmosphere/ocean coupling, the sea surface temperature is fixed in the model. Therefore, effects of the ocean on the deep convection are not included because surface fluxes related to SSTs were not represented correctly. However, the squall line can be simulated using the atmospheric model alone since it is driven by the atmospheric instabilities. However, the atmospheric instabilities are affected by the surface forcing. Horizontal cross sections of wind vectors and model-calculated radar reflectivity at an altitude of 1 km from a 4-hour simulation are shown in Figure 1. Squall line has been simulated with a pronounced "bow-shaped" bulge in the leading convective line, which is consistent with the observations. A low-level cyclonic gyre near the North (equator ward) end of the convective line has appeared. The cross section of vertical velocity from grid point (0, 31) to (120, 31) shows two updrafts (figure is not shown). One has a maximum velocity of 7.7 ms^{-1} at about 9 km and another has a maximum velocity of 4.86 ms^{-1} at about 4 km. Observations indicate similar features. Figure 2 is the vertical cross section of radar reflectivity from grid point (0, 31) to (120, 31) at hour 5. The squall line with anvil stratus precipitation in the upshear direction and convective precipitation in the downshear direction are shown. The new convective cell in the leading edge maintains the squall line development.

Simulation with Atmosphere/Ocean Coupling

When the simulation was made with coupled atmosphere/ocean model, the maximum surface fluxes were different from uncoupled simulation because of the surface cooling by precipitation and evaporation. Figure 3 shows the time changes of the domain averaged latent heat and sensible heat fluxes. Solid lines represent uncoupled simulation and dashed lines represent coupled simulation. In the early stages, surface latent heat flux shows no difference between the two simulations. After precipitation, less surface latent heat flux appears in the coupled simulation. Because SST has been fixed in the uncoupled simulation,

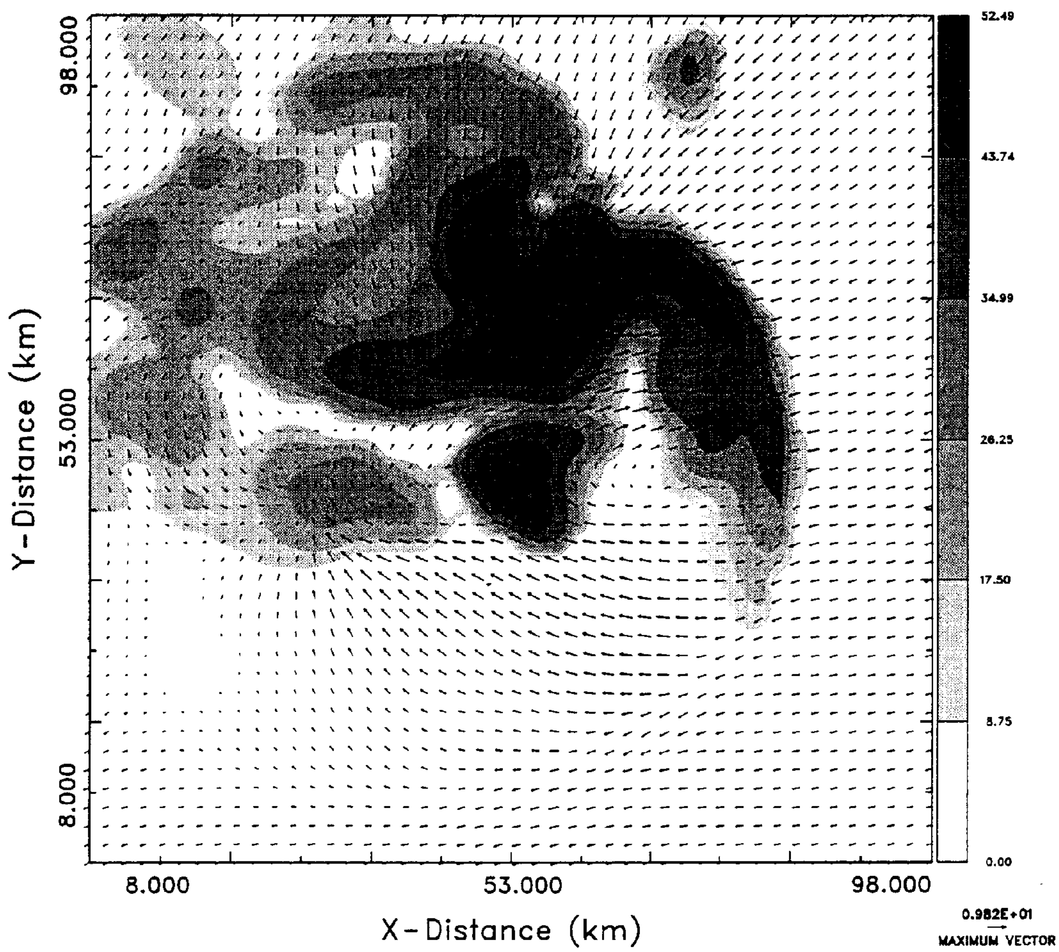

Figure 1. Horizontal cross section at 4 hrs showing the model-calculated radar reflectivity (dBz) and wind vectors at z = 1000 m. Only a 90-km portion of the domain is displayed.

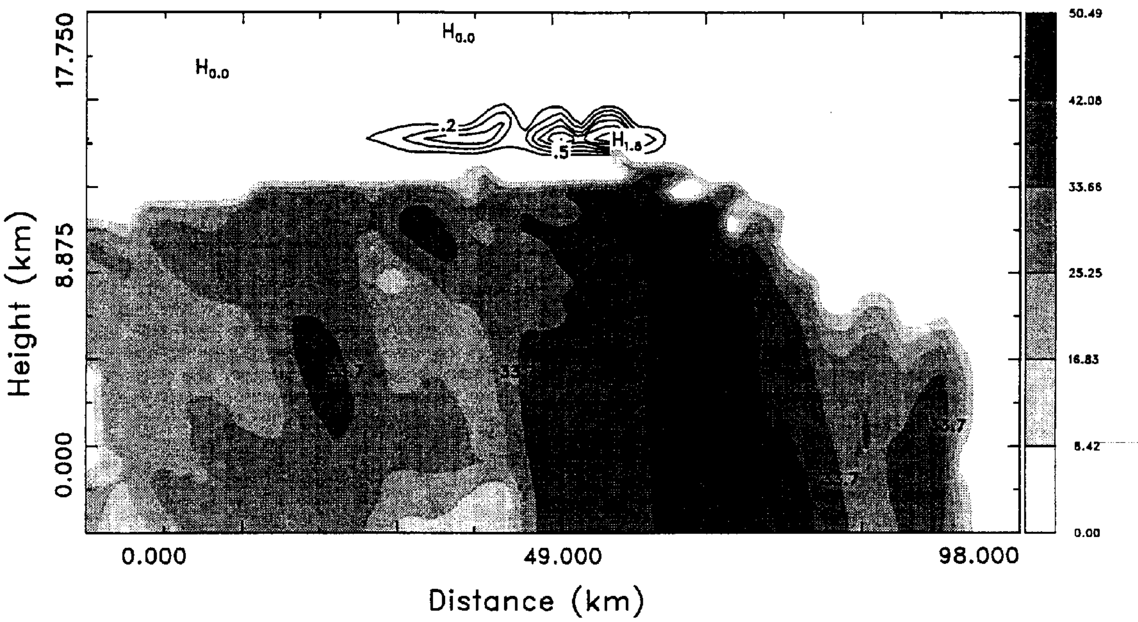

Figure 2. The vertical cross section at 5 hrs showing the model-calculated radar reflectivity (dBz) and ice crystals (g/kg). The gray scale bar indicates the range and values for the radar reflectivity and contours represent ice crystals. The cross section is taken at y = 31.

unchanged SST overestimates surface heat fluxes due to a larger gradient of temperature between the surface and the first layer of the atmospheric model. Feedback from the deep convection decreases the SSTs because of evaporative cooling (figure is not shown). This indicates that the convective exchange of the heat and moisture can change the vertical temperature profile. The ocean cooling mechanisms associated with organized deep convection can act to limit tropical SSTs.

Acknowledgments

This work was supported by the Department of Energy under Contract 091575-A-Q1 with Pacific Northwest National Laboratories. The computations for this work were performed at the National Supercomputer Center for Energy and the North Carolina Supercomputing Center.

References

Hodur, R. M. 1993. Development and testing of the coupled ocean/atmosphere mesoscale prediction system (COAMPS), Naval Research Laboratory, Monterey, NRL/MR/7533-93-7213, pp. 81.

Trier, S. B., D. B. Parson, and M. A. LeMone. 1994. A three-dimensional numerical simulation of a tropical squall line observed during TOGA-COARE. In *Proceedings of Sixth Conference on Mesoscale Processes*, Portland, Oregon, pp. 45-48.

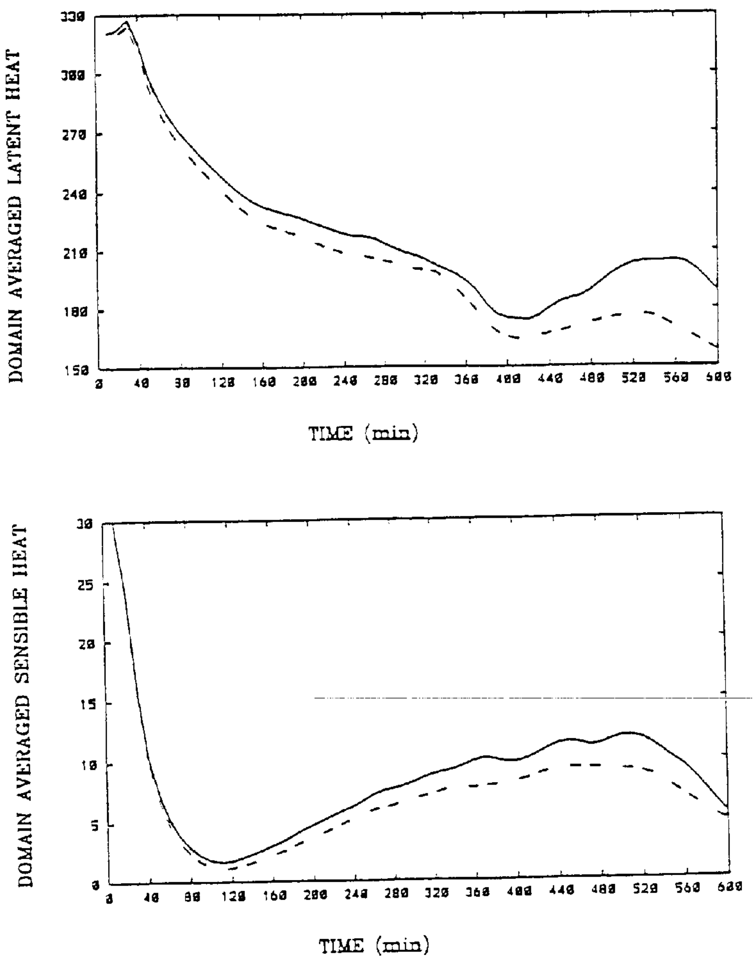

Figure 3. The time changes of domain averaged latent heat and sensible heat fluxes for the uncoupled and coupled simulations. The solid lines indicate uncoupled simulation and dashed lines indicate coupled simulation.