13.6 PRECIPITATION VARIABILITY AND BARRIER-LAYER FORMATION IN THE NORTH INDIAN OCEAN

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1. INTRODUCTION

The Southwest Monsoon, occurring from the months of June through September, greatly affects and alters the air-sea exchanges in the Indian Ocean. The monsoon changes the wind and precipitation patterns over both the Arabian Sea and the Bay of Bengal. The Arabian Sea experiences stronger southwesterly winds and drier periods interspersed with intense short-lived precipitation events while the Bay of Bengal encounters a decrease in winds but a much greater amount of precipitation during the monsoon season. As a result, these two areas undergo temperature and salinity variations in the ocean structure due to changes in the surface heat, moisture, and momentum fluxes associated with the monsoon (Sprintall and Tomczak, 1992).

The importance of salinity variability on the thermodynamics and dynamics of the upper ocean has gained an increased appreciation in the last few years due to a phenomenon called the barrier layer. Much of the interest was initiated by the recognition of the barrier layer feature in the tropical Pacific (e.g. Lukas and Lindstrom 1991), and has more recently been identified from climatological data in the Indian Ocean as well (e.g. Sprintall and Tomczak, 1992). The barrier layer is a stable salinity-stratified but isothermal region at the bottom of the surface mixed layer and is perceived to be an inhibitor of entrainment due to its stability (Anderson et al., 1996). Barrier layer depths in the western Pacific are estimated to be on the order of 30 meters (Lukas and Lindstrom, 1991).

Barrier layers have been found to affect not only mixing and entrainment, but also sea surface temperature (SST) (Anderson et al., 1996). The theory is that when a barrier layer exists, mixing is restricted to the near-surface water that is of nearly the same temperature, rather than the deeper cooler water. With a lack of cooling but simultaneous warming through solar radiation, the mixed layer warms up, effectively increasing SST as well. In the western Pacific, isolated strong wind events such as westerly wind bursts are then thought to "punch through" this stable layer and induce entrainment cooling (Lukas and Lindstrom, 1991).

This study investigates the variability in the creation of barrier layers due to monsoonal-induced variations in the surface heat, moisture and momentum fluxes. We then further investigate whether these barriers truly act as barriers to deeper mixing and entrainment, and if so under what conditions.

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2. DATA, MODEL, AND METHODS

Data used for initialization and forcing of the model as well as validation come from several sources. Ocean and surface flux data for the western Pacific comes from the WHOI IMET buoy data (Anderson et al. 1996) during the TOGA COARE Intensive Observation Period (November 1992-February 1993). Surface flux data for the Indian Ocean region comes from the ECMWF (European Centre for Medium-Range Weather Forecasts) model analyses and TRMM (Tropical Rainfall Measuring Mission) precipitation data. The time period of this portion of the study is the monsoon season of May-September 2000. The TRMM precipitation data is the NASA DAAC daily 3B42 product, which is a 1°x1° gridded product. The ECMWF model analyses used for all other surface fluxes have a resolution of roughly 1.25° x 1.25° and provides data four times a day. Both data sets are interpolated to 15 minutes resolutions for forcing of the ocean model. Initial temperature and salinity profiles for the Indian Ocean region come from the Levitus 1994 climatology.

A second-moment turbulence closure-based 1-D mixed layer model (Kantha and Clayson 1994) is used to study the ocean surface and subsurface responses. The model includes the skin surface temperature parameterization developed by Wick (1995), modified by Schluessel et al. (1997) to include the effects of precipitation. The model has a vertical resolution of 1 m (maximum depth is 150 m) and a temporal resolution of 15 min. Temperature profiles have been validated over many time scales and in many locations (Kantha and Clayson, 1994); turbulence characteristics have also been validated (Clayson and Kantha, 1999).

3. METHODS

The turbulent mixing, salinity, and temperature profiles are evaluated from model simulations as the model explicitly calculates turbulence properties in the water column. The validity of the model results presented in this talk rest on the ability of the ocean model to accurately simulate variability in the temperature and salinity fields based on local surface heat flux observations. The model simulation shown here uses the western Pacific data. In order to compare the simulation results and the buoy data, the buoy and model data are interpolated to every 0.5 m.

Only values from the model simulations at the same depths as the buoy data are retained before interpolation. The results shown in the talk will only use the model data at the 1 m resolution.

The barrier layer is identified as occurring when the isothermal layer is deeper than the isohaline layer. Mixed layer depths are calculated using the Anderson et al. (1996) methods. The isothermal layer depth is calculated by finding the point of maximum temperature in the top 20 m and then calculating the differences downward until $\Delta\theta = -0.030$°C. The isohaline layer depth is calculated by finding the point of minimum salinity in the top 20 m and calculating the differences downward until $\Delta S=0.0133$ psu.

4. MODEL VALIDATION

Sea surface temperatures and salinities from the buoy and the model simulations are shown in Fig. 1 and 2, and halocline and daily-maximum thermocline depths are shown in Fig. 3 and 4. The model simulations show reasonable variations when compared with the buoy data. The use of a one-dimensional model precludes advection, which also plays a role in the heat and salt balances in this region. Observations during this time period showed that advection had been a minor factor in the upper ocean heat content until roughly December 20 (Feng et al. 1998). Similarly the only time period prior to the December westerly wind burst in which the upper ocean salt content is strongly affected by advection is early November; advection contributes to a freshening of the upper ocean (Cronin and McPhaden, 1998). As with the upper ocean heat content, the upper ocean salt content is strongly affected by advection during the westerly wind burst (Feng et al. 1998). Anderson el al. (1996) also demonstrated that the salt and heat budgets were strongly affected by advection, entrainment, and errors in the prescribed fluxes during the westerly wind burst in mid-December.

5. FURTHER REMARKS

Our presentation will focus on model results during both the TOGA COARE IOP and the North Indian Ocean during 2000. Results of the variability of the barrier layer formation and its role in inhibiting mixing will be presented.

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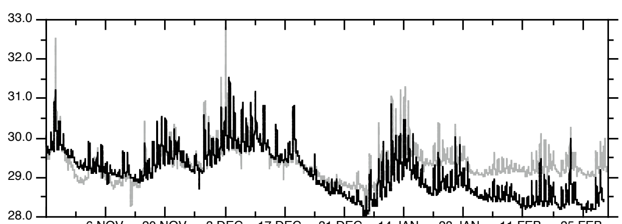

Fig 1. SSTs (buoy values in grey, model in black).

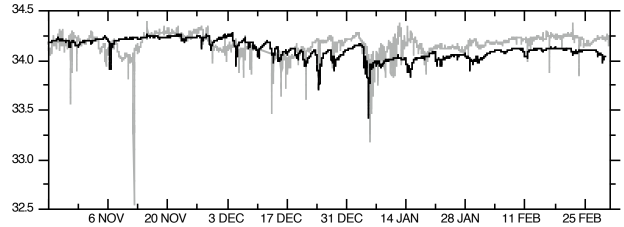

Fig 2. As in Fig. 1 but with sea surface salinities.

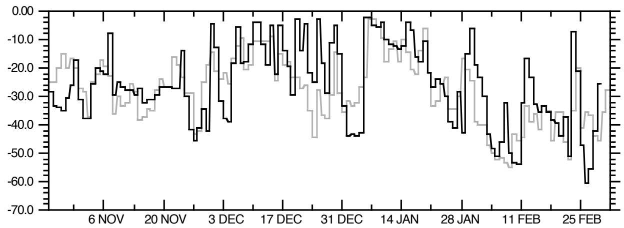

Fig 3. As in Fig 1. but with halocline depths.

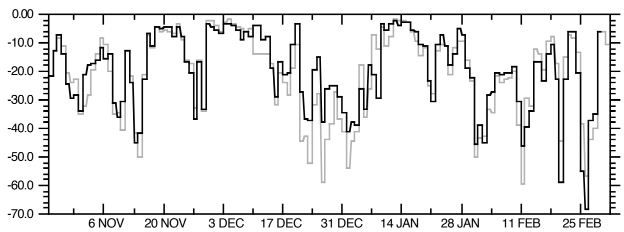

Fig 4. As in Fig. 1. but with thermocline depths.

6. REFERENCES

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