FORCING OF DEEP CONVECTION OVER TROPICAL OCEANS

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1 INTRODUCTION

One of the most difficult problems facing numerical models of weather and climate is to capture accurately the forcing of deep convection over tropical oceans. This is also referred to as the convective closure problem. The most common approach to the closure problem taken today is to assume that deep convection is a positive function of the convective available potential energy (CAPE), though some older models still relate convection to some form of low-level convergence. Though conceptually an improvement over convergence-based schemes, CAPE-based closures still have significant problems in in representing convective forcing accurately.

Recent field programs and numerical modeling have produced some insight into the convective closure problem. The purpose of this talk is to relate some of these insights.

2 EPIC2001

EPIC2001 (East Pacific Investigation of Climate, 2001 field program; Raymond et al., 2003, 2004) found that the following factors controlled convection in the east Pacific intertropical convergence zone (ITCZ): (1) Surface total heat (or moist entropy) fluxes accounted for most of the observed variance in infrared brightness temperature in a $4^\circ \times 4^\circ$ box centered at 95° W, 10° N. (2) The presence of inhibiting stable layers in the range $700 - 800$ hPa explained a significant amount of brightness temperature variance as well. Together these two factors explained 2/3 of the variance of infrared brightness temperature, and hence deep convection, during the project.

It is noteworthy that neither variations in CAPE produced by mid-level and upper level temperature changes, nor variations in environmental shear appeared to have much influence on infrared brightness temperature in this region.

3 TRMM KWAJEX

NASA's Tropical Rainfall Measuring Mission Kwajalein Experiment (Sobel et al., 2004) yielded somewhat contrasting results in comparison to EPIC2001. In particular, the single strongest predictor of rainfall (and hence deep convection) was the existence of relative humidities exceeding 80% in the lower troposphere. Upper tropospheric relative humidity was also correlated to rainfall, but lagged analyses indicate that high humidity in the upper troposphere lagged convection, whereas the reverse was true in the lower troposphere. The inference is that enhanced lower tropospheric humidity causes convection, where as upper tropospheric humidity is a result of convection. These results are in agreement with those of Sherwood (1999), who made an extensive study of soundings and associated weather in the western Pacific. It is also in agreement with observations made during TOGA COARE (Tropical Oceans Global Atmosphere Coupled Ocean Atmosphere Experiment; Webster and Lukas, 1992) of the effect of dry air intrusions into the equatorial region (Parsons et al., 2000).

Sobel et al. (2004) also noted a weak negative correlation between heavy rain and deep convection (a well-established correlation in the tropics) and a weak positive correlation between rainfall and surface wind, a surrogate for total heat flux.

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4 CUMULUS ENSEMBLE MODELS

In a cumulus ensemble model which uses weak temperature gradient approximation boundary conditions (Sobel and Bretherton, 2000), Raymond (2004) found that the convective precipitation rate is a very steep function of tropospheric relative humidity, effectively splitting the environment into two regimes. For humidities less than a critical value, there is essentially no rain and the convection responds slowly to changes in surface heat fluxes. This is because convective behavior does not change much over a broad range of humidity values. However, above the critical value, tiny changes in humidity result in large changes in the precipitation rate. In this regime the convection and precipitation rate respond almost instantly to changes in surface fluxes. Other models show a similar sensitivity.

5 CONCLUSIONS

The sensitivity of deep convection to the tropospheric humidity shown in numerical models can be used to explain the difference between the behavior of convection in the east Pacific ITCZ and the west Pacific near Kwajalein. The moisture sensitivity to convection is manifested in the latter region because it is on the edge of the subtropics, and is thus subject to inflows of dry air from higher latitudes. Furthermore, being subject to strong tradewind flows, the surface heat fluxes are always strong. Under these circumstances, the humidity of low to middle level tropospheric air is subject to large fluctuations, and is the dominant factor controlling convection. In the east Pacific, the air tends to remain moist most of the time, whereas the winds, and hence the surface heat fluxes, are highly variable. The humidity is sufficiently high that the environment exists in the moist regime discussed above, in which changes in surface fluxes drive the small changes in humidity needed to produce large changes in the convection and precipitation rate.

These results point to the importance of incorporating two factors into the closures for cumulus parameterizations: (1) Sensitivity of the closure to low to middle tropospheric humidity. (2) Sensitivity to the existence of stable layers near the top of the planetary boundary layer, which tend to suppress convection. z *Acknowledgments.* This work was supported by National Science Foundation grants ATM-0079984 and ATM-0082612.

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