IMPACT OF CLOUD RADIATIVE EFFECTS ON THE SIMULATION OF THE TROPICAL PACIFIC CLIMATE

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1. Introduction

Clouds affect the global energy balance and are an important component of the Earth climate system. In this study, we conduct sensitivity experiments to explore the impact of cloud representations on the simulation of the Tropical Pacific climate with the UCLA coupled GCM. One such sensitive study has focused on the impact of cloud optical properties on the simulations. Other sensitivity studies have addressed the impact of stratus cloudiness on the latitudinal asymmetry and annual cycle of the eastern Equatorial Pacific.

2. Model Description

The UCLA coupled GCM consists of the UCLA global atmospheric GCM (AGCM) (Kim 1996, and references therein) and the GFDL oceanic GCM (OGCM), which is the Modular Ocean Model (MOM) (Bryan, 1969; Cox, 1984). The results presented in this paper were obtained with the AGCM coupled to the tropical Pacific version of MOM (Ma et al. 1996).

3. Sensitivity to Cloud Emissivity

The emissivity of clouds in the AGCM is determined by their optical thickness (τ), which is parameterized in the longwave radiation scheme. For large-scale condensation clouds, τ is determined using the following formulation:

$$\tau = a \times (T_c - T_0)^2 \times \Delta p \quad \text{if } T_c \le 263^\circ\text{K} \qquad (1)$$

$$= b \times \Delta p \quad \text{if } T_c \ge 273^\circ\text{K},$$

where Δp and T_c are pressure thickness and temperature of the cloud, respectively, T_0=191°K, a=2x10^{-6} K^{-2}mb^{-1}, and b=0.08 mb^{-1}. The optical thickness for clouds with temperatures between 263°K and 273°K is linearly interpolated between the values corresponding to T_c=263°K and T_c=273°K.

We carried out several one-year long uncoupled AGCM simulations in which SSTs are prescribed from an observed climatology. In these simulations, the emissivity of high-clouds was modified by increasing the value of the coefficient a in equation (1) to 3, 5, and 7 times its control value. The results show that surface evaporation in the tropical Pacific is decreased when the emissivity of high clouds is increased. Analyses of these results indicate that increasing cloud emissivity results in a warmer upper troposphere due to lower longwave cooling. Static stability in the troposphere, therefore, is increased and cumulus activity is thus reduced. Since there is less moisture being transported upward by cumulus convection, the planetary boundary layer (PBL) is moister and latent heat flux from ocean surface is smaller.

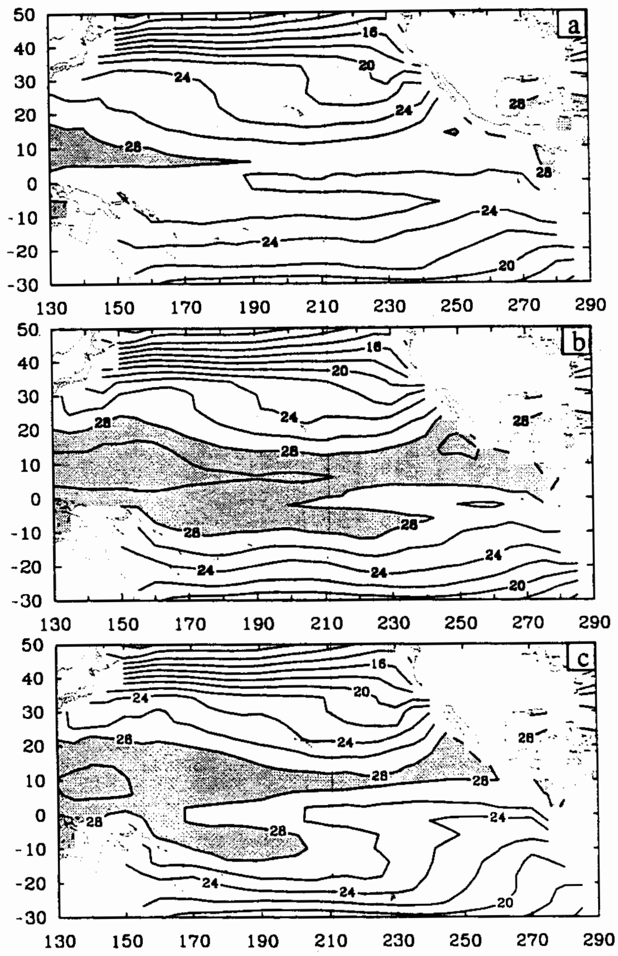

FIG.1. October SST produced by the coupled GCM in the: (a) control simulation, (b) the simulation with increased cloud emissivity, and (c) the simulation with enhanced Peruvian stratus.

A similar set of experiments with the coupled GCM show that increasing the emissivity of high clouds results in warmer SSTs (Fig. 1a and b). Warming is particularly clear in the subtropical Pacific where the cold bias in the UCLA coupled GCM was the largest (see Yu and Mechoso 1996). Refinements in cloud properties, particularly for high-clouds, do improve the performance of the coupled GCM.

3. Sensitivity to Peruvian Stratus

To assess the impact of Peruvian stratus clouds on the simulation of the tropical Pacific climate, we prescribed a permanent stratus cover over the ocean from 10°S to 30°S and east of 90°W up to the coast of South America. The pressure thickness of the prescribed stratus is 30 mb or the PBL depth if this is less than 30 mb thick.

After this artificial stratus enhancement was incorporated into the coupled GCM with an increased cloud emissivity, the too-weak equatorial cold tongue produced by the emissivity experiment is intensified (Fig. 1c). Overall, this experiment produces more realistic values of SST. The latitudinal asymmetry in the eastern Pacific, where the ITCZ appears mainly to the north of the equator, is better simulated. Similar to the study of Ma et al. (1996), the prescribed stratus affect SSTs locally by reducing the shortwave radiative flux reaching the surface, and remotely through ocean advection and an enhanced Hadley circulation (Ma et al. 1996). Enhanced evaporation cools the SSTs from the Peruvian coast westward and northward toward the equator, and ocean advection cools down SSTs in the central equatorial Pacific.

To investigate the influence of the seasonal cycle of Peruvian stratus cloudiness on the annual cycle of the equatorial cold tongue, we conducted two additional experiments in which Peruvian stratus are prescribed only in either the first or second half of the calendar year. We found that when Peruvian stratus are prescribed only in the second half of the year, which is more realistic than the alternative option, the cold phase of the cold tongue lasts longer. The observed asymmetric characteristics of the annual cycle of the cold tongue are also better simulated in this experiment (Fig. 2). One such characteristic is that only the warm phase of the seasonal cycle shows a westward propagation; another is that the warm phase has a larger amplitude than the cold phase.

4. Conclusions

Our stratus experiments suggest that (1) cloud radiative properties specified in the model can have a strong influence on the overall quality of the simulated climate, (2) Peruvian stratus decks have a significant influence on the local and remote SSTs in the tropical Pacific, and (3) the seasonal variation of these clouds contributes to several asymmetric features of the annual cycle in the eastern equatorial Pacific.

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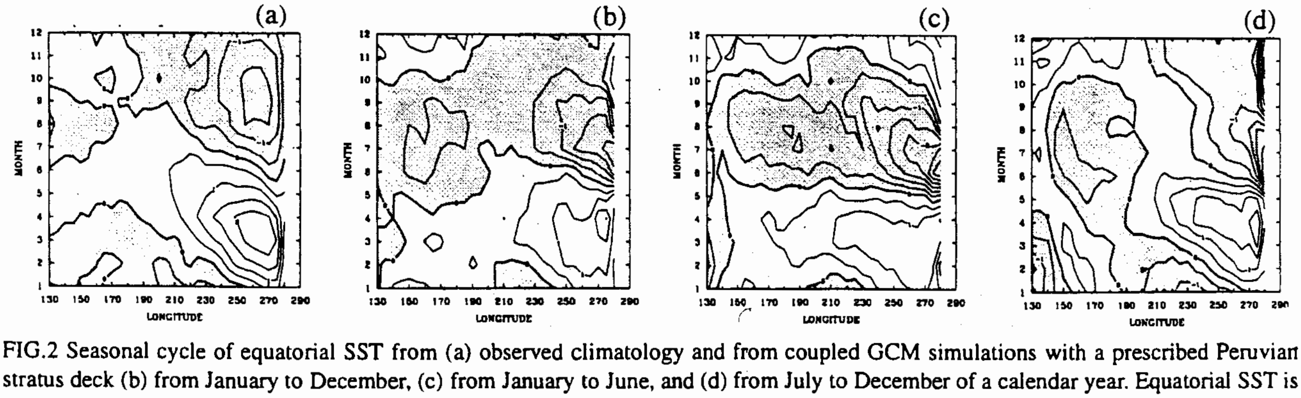

FIG.2 Seasonal cycle of equatorial SST from (a) observed climatology and from coupled GCM simulations with a prescribed Peruvian stratus deck (b) from January to December, (c) from January to June, and (d) from July to December of a calendar year. Equatorial SST is averaged from 4°S and 4°N. Annual means are removed from all fields shown in the figure.

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