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LOW-FREQUENCY CLOUD-RADIATION INTERACTIONS

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1.Introduction

The observed 30-60 day oscillation of the tropical winds (Madden and Julian, 1971), often referred to as the Madden-Julian oscillation, has excited considerable interest in recent years, because its existence suggests the possibility that the behavior of the atmosphere is at least partially predictable on such relatively long time scales. Most theories of the Madden-Julian oscillation have been based on wave-instability theories, such as wave-CISK. As discussed by Hu and Stevens (1989; hereafter HS), these theories have not yet satisfactorily explained the observations.

Recently, HS have suggested that the Madden-Julian oscillation is actually a *forced response* to periodic heating. They suggested that the oscillatory forcing originates in the hydrologic cycle, without the active participation of large-scale dynamics. They constructed a very simple model to support their hypothesis. According to their model, the oscillation originates in a progressive build-up of atmospheric water vapor, which continues until a (prescribed) threshold is reached, after which precipitation begins and rapidly dries the atmosphere. The drying due to a precipitation episode is followed by renewed gradual moistening, and the cycle continues indefinitely in this way.

In this paper we present preliminary results from a one-dimensional (1-D) version of the UCLA / CSU GCM (Randall *et al.*, 1989), which lend further support to the ideas of HS (1989). The present 1-D results also differ in important ways from those of HS, however. In particular, *cloud-radiation effects are essential for the oscillatory behavior of our model*, although they are not essential in the model of HS.

2.Model description

The 1-D model incorporates the full radiation and moist physics parameterizations of the GCM, including interactive cloudiness (Harshvardhan *et al.*, 1989).

In some of the simulations, the 1-D atmospheric model is coupled to a slab ocean of fixed depth. For simplicity, the slab does not exchange energy with the "deep ocean;" its temperature is controlled entirely by the surface energy flux.

In each of the simulations discussed below, the daily-mean incident solar radiation at the top of the atmosphere is set to the observed globally averaged value for the Earth. The model is spun up for 1000 simulated days in order to reach statistical equilibrium, and then is run for an additional 2000 simulated days to produce results for analysis.

3.Results

When the sea surface temperature (SST) is fixed, the model produces strong oscillations of the precipitation rate, cloudiness, and surface energy flux, with a period of about 66 days. The only other spectral peak is diurnal. Figs. 1 and 2 show the time histories of the precipitation and surface solar radiation, for a particular 500 day segment. Fourier analysis (e.g., Fig. 3) shows that the 66-day spectral peak is both strong and sharp. In the following, we refer to this as the "control run."

As an experiment, we performed a simulation with fixed atmospheric radiative heating profiles, prescribed to be the same as the 2000-day average radiative heating profiles in the control run. No oscillations occurred in this "fixed-cloud" run. This indicates that cloud-radiation interactions are necessary to produce the oscillations.

To gain an understanding of the mechanism by which the oscillations are generated, we have examined in detail individual cycles of the oscillations produced in the control run. The results show that during periods of weak precipitation the upper troposphere is relatively warm, so that the static stability is relatively high. The warming of the upper troposphere is due primarily to the absorption of upwelling infrared radiation by the clouds, and to a lesser extent to the absorption of solar radiation.

When run with an ocean mixed-layer with a depth of 60 m, the model produces oscillations of the SST, with an amplitude of 0.4 K, and a period of 60 days. These are forced by the oscillations of the net surface energy flux, which are due to changes in the absorbed solar radiation; these are controlled, in turn, by the cloudiness fluctuations. The amplitude of the precipitation oscillation is slightly greater when the SST is allowed to vary. This may be because the ocean is relatively cool during the periods of weak precipitation, and relatively warm during periods of strong precipitation; the SST fluctuations thus act to reinforce the precipitation fluctuations.

4.Conclusions

Our results show that an atmospheric heating oscillation with a period of about 60 days can be generated by cloud-radiation interactions, without the participation of large-scale dynamical processes. This suggests the possibility that the observed Madden-Julian oscillation of the tropical winds is a passive dynamical response to such oscillatory forcing. A logical next step would be to explain why the observed oscillation originates near the maritime continent; there may be some reason why the oscillatory forcing is particularly strong in that region.

ACKNOWLEDGEMENTS

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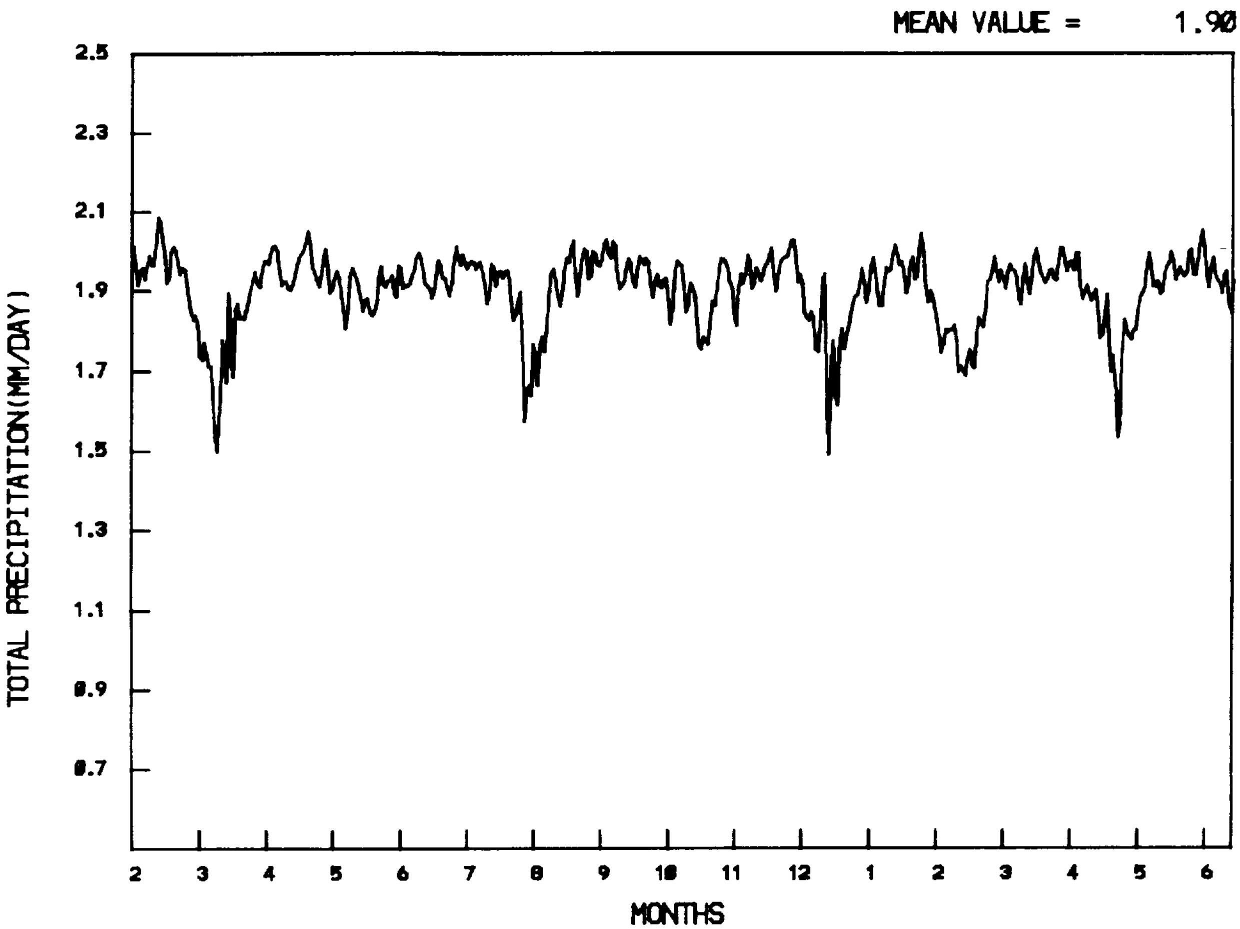

Figure 1 The time history of the precipitation, for a particular 500 day segment of the control run.

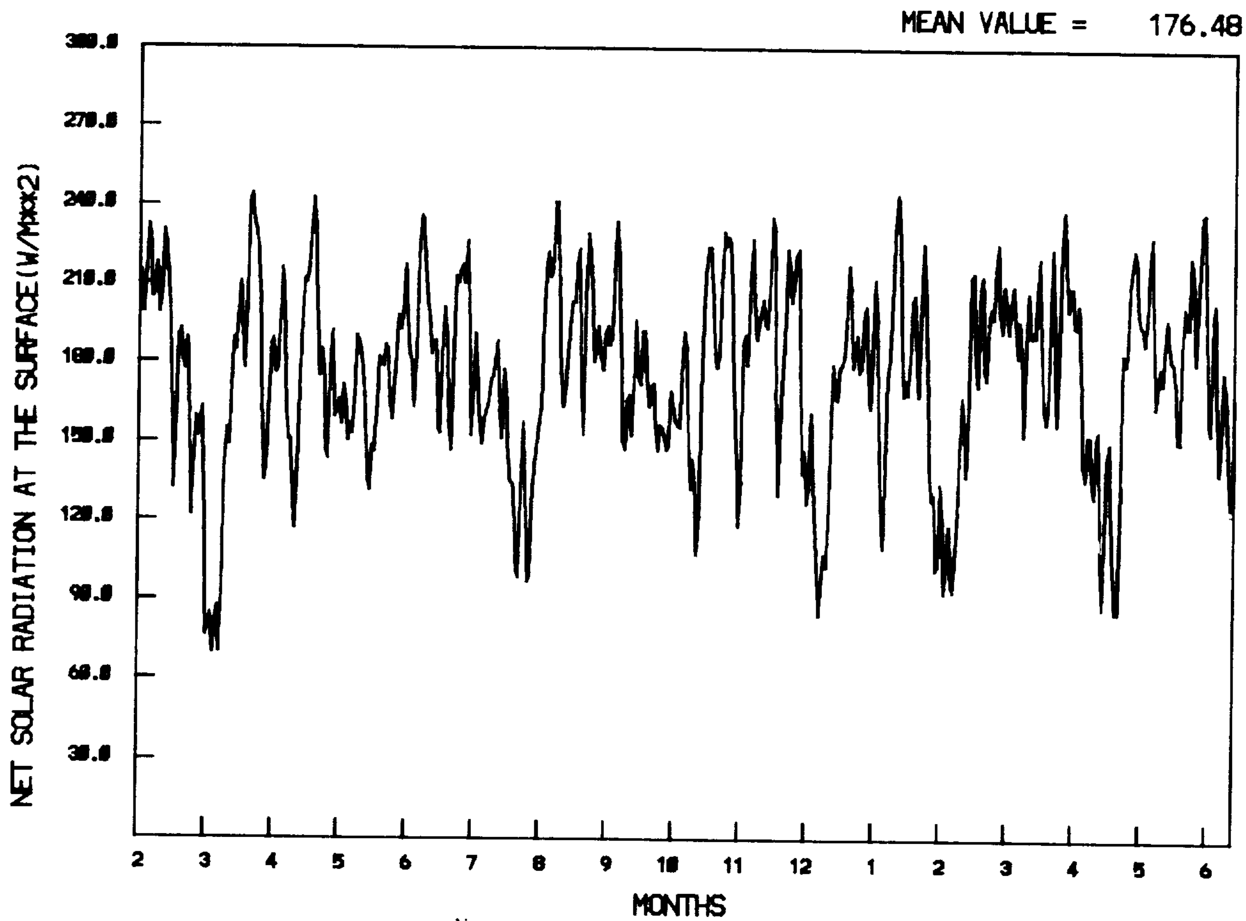

Figure 2: Same as Fig. 1, but for the solar radiation absorbed at the Earth's surface.

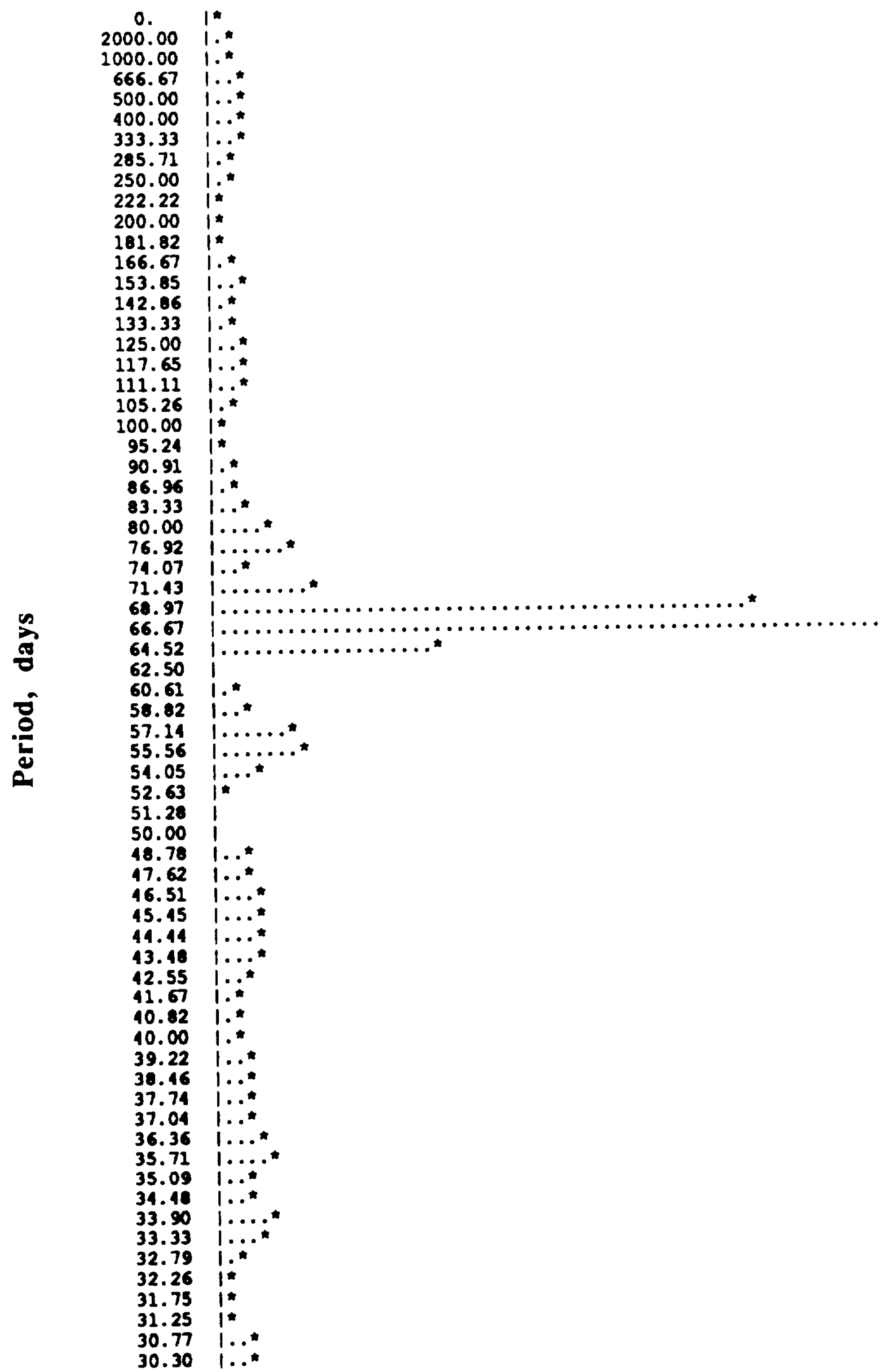

Figure 3: Square of the amplitude of the Fourier harmonics of the precipitation in the control run. The peak at about 66 days represents an amplitude of 0.3 mm day^{-1}.