

Influence of Cloud-Radiation Interaction in AGCM Simulations of tropical intraseasonal oscillation

Myong-In Lee

*Climate and Environment System Research Center (CES)
Seoul National University, Seoul 151-742, Korea
E-mail: milee@climate.snu.ac.kr*

1. Introduction

The simulation of tropical intraseasonal oscillation (ISO, Madden and Julian, 1971) remains one of the common problems in climate modeling, though it has been regarded as an important component especially for the medium-and long-range forecasts of Asian monsoon. In particular, using the intercomparison of atmospheric general circulation models (AGCMs), Slingo et al. (1996) pointed out that most models simulated weaker ISO variability and could not reproduce the dominance of wavenumber 1, planetary scale structures as observed. Instead, the ISO was masked by the waves of relatively fast propagation. These problems are pointed out again in the recent CLIVAR/Monsoon AGCM intercomparison study with current AGCMs.

Many previous studies have emphasized that the physical parameterizations in climate models should be improved for a reasonable simulation of ISO, particularly focusing on the cumulus schemes (Tokioka et al., 1988; Wang and Schlesinger, 1999; Lee et al., 2001). We simply increased the horizontal resolution of the model from T31 ($3.75^\circ \times 3.75^\circ$) to T106 ($1.125^\circ \times 1.125^\circ$) to find that the dependence on it seems to be less critical and low-frequency variabilities are not essentially changed. This suggests that the failure of the most AGCMs is mainly due to the physical processes, not the hori-

zontal resolution.

The cloud-radiation interaction may have a significant role in the ISO simulation by influencing the vertical diabatic heating distribution and static stability. The vertical distribution of diabatic heating is not only dependent on the latent heating by convective processes but also the radiation process, which is, in turn, affected by clouds. In spite of its possible role, the influence of cloud-radiation interaction on the tropical ISO is poorly understood and even the parameterization of the influence of cloud itself remains a difficult area in climate modeling. In the present work, the

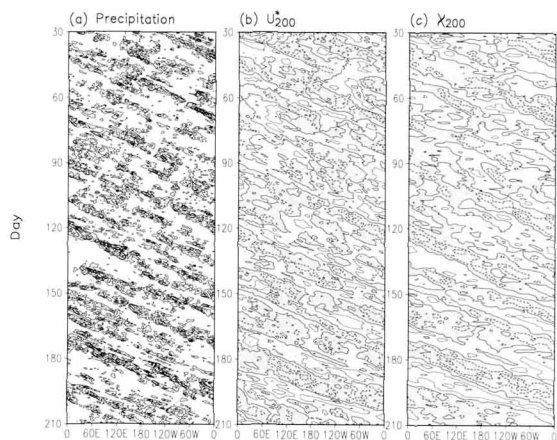


Fig. 1. Longitude-time diagrams of (a) precipitation rate ($2^\circ\text{S} - 2^\circ\text{N}$), (b) 200 hPa u-wind ($10^\circ\text{S} - 10^\circ\text{N}$), and (c) 200 hPa velocity potential ($10^\circ\text{S} - 10^\circ\text{N}$) for the fixed radiation case. Zonal mean removed in (b). Shaded are more than 10 mm day^{-1} in (a) and negative values in (b) and (c). The contour intervals are 10 mm day^{-1} in (a), 10 m s^{-1} in (b), and $10^7 \text{ m}^2 \text{ s}^{-1}$ in (c).

influence of cloud-radiation interaction on ISO simulation is examined especially by focusing on the feedback processes involving cloud, radiation and large-scale circulation.

2. Model and Experiments

The model used is the SNUGCM (Kim *et al.*, 1998) developed in Seoul National University and it is a global spectral model with the primitive equation system. It has 20 sigma levels in vertical and T31 truncation is used horizontally for this work. The model is originally based on the CCSR/NIES AGCM in Tokyo University (Numaguti *et al.*, 1995), but has several major changes including the land surface process, shallow convection, and PBL processes. The radiation process is parameterized by the 2-stream k-distribution scheme. The cumulus scheme is simplified based on the Relaxed Arakawa-Schubert scheme and modified following Tokioka *et al.* (1988) for the improvement of tropical ISO simulation in the model (Lee *et al.*, 2001a). The large-scale condensation process is parameterized based on Le Treut and Li (1991).

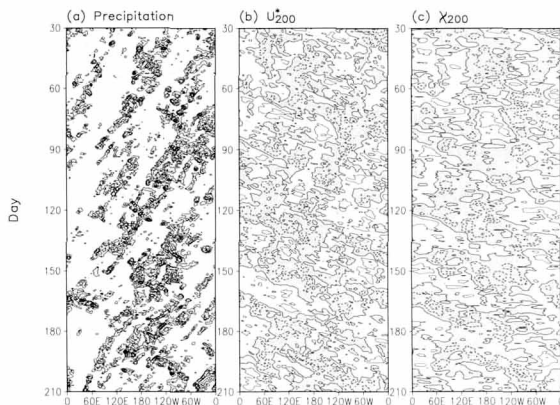


Fig. 2. Same as Fig. 1 except for the fully interactive case.

We have done two types of aqua planet perpetual AGCM simulation in which the zonally varying component of boundary condition is excluded. Aqua planet simulations can help obtain a clearer relation between the cloud-radiation interaction and the simulated intraseasonal variability. By prescribing zonal mean radiative cooling rate, the radiation is fixed and no cloud-radiation interaction is allowed in the one simulation. The other is fully interactive by adjusting radiative fluxes to the calculated cloud distribution instantaneously. By contrasting the two simulations, we carefully examined the influence of cloud-radiation feedback processes.

3. Discussions

The simulated intraseasonal variability is largely sensitive to the cloud-radiation interaction and its feedback processes parameterized in the model. With fixed radiation (Fig. 1), eastward-propagating moist equatorial Kelvin waves, mainly zonal wavenumbers 1-2, are simulated. With interactive radiation (Fig. 2), on the other hand, the eastward propagation is significantly inhibited, as small-

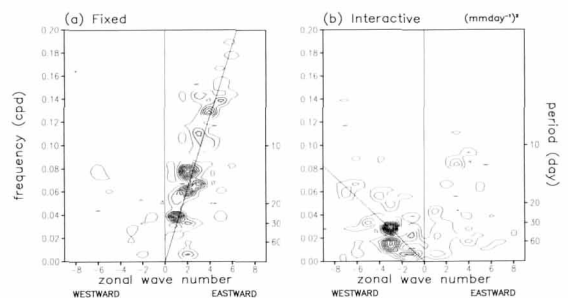


Fig. 3. Space-time power spectra of precipitation in (a) cloud-radiation fixed case and (b) interactive case. The symmetric component of precipitation between $10^{\circ}\text{S} - 10^{\circ}\text{N}$ are analyzed and the power has been summed over the latitude. Contour interval is $0.03 \text{ mm}^2 \text{ day}^{-2}$. The slant lines correspond to the phase speed of 15.4 ms^{-1} in (a) and -5 ms^{-1} in (b).

scale disturbances move westward following the basic easterly winds. This is convinced by the space-time power spectrum (Fig. 3) in which the westward variances are roughly centered on the -5 ms^{-1} phase speed line that corresponds to the direction and magnitude of background wind appearing in the interactive case.

The persistent excitations of small-scale disturbances are explained by a positive feedback mechanism involving clouds, radiation, dynamics, and convection. The mechanisms are examined using composite vertical profiles of diabatic heating rate in rainy regions. Anvil clouds formed in the upper troposphere by cumulus detrainment reduce the longwave cooling significantly in the lower troposphere, while releasing large-scale latent

heating in the upper troposphere. The resulting heating produces a strong diabatic circulation with enhanced moisture convergence and rising motions in convective regions. This persistent cumulus-anvil cloud system appears to suppress the large-scale moist Kelvin wave propagating eastward.

To moderate the strong cloud radiation feedback, we modified the large-scale condensation scheme by reducing the parameterized characteristic precipitation time scale needed for cloud condensates to grow up to rain drops. In addition to this, upper-air ice cloud contents were reduced (replaced with liquid water contents) to change the cloud albedo. The parameterized precipitation time scale determines the cloud life-time and it can possibly affect the cloud-radiation interaction time scale and the magnitude of feedback. Gradually decreasing precipitation time scale, these modified processes make a wavenumber 1, eastward propagating waves with a period about 30 days, similar to those simulated in the fixed radiation case (Fig. 4).

The modified processes were applied to a simulation with realistic land-ocean distribution and SST. Compared with observations, the eastward propagation characteristics are significantly improved after modification, but at the cost of a worse planetary radiation budget (Lee *et al.*, 2001b), indicating that more efforts are needed to improve the cloud-radiation interaction parameterizations in GCMs.

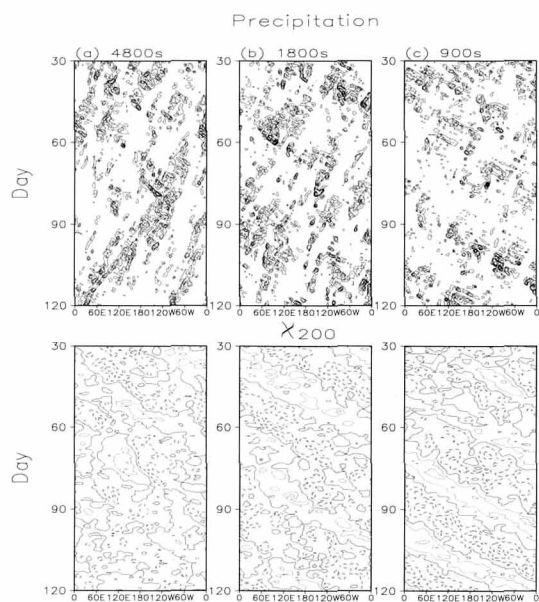


Fig. 4. Longitude-time diagrams of precipitation rate (upper panel) and 200hPa velocity potential (lower panel) when the autoconversion rate are reduced from 9600 seconds to (a) 4800, (b) 1800, and (c) 900 seconds in the fully interactive case. Shaded are more than 10 mm day^{-1} in (a) and negative values in (b) and (c). The contour interval is 10 mm day^{-1} in precipitation and $10^7 \text{ m}^2 \text{ s}^{-1}$ in velocity potential.

4. Conclusions

This study suggests the continuing need for the improvement of cloud-radiation interaction parameterization in GCMs. Based on our results, cloud has a large influence on the radiation field

and cloud-radiation interaction affects the ISO simulation significantly. In this work, we modified the cloud by changing the characteristic precipitation time scale and the phase of the cloud water, which affects cloud albedo. However, more comprehensive and reasonable treatment of clouds is needed and studying dynamic variability is regarded as one of the appropriate ways toward improvement. Moreover, the cloudiness, its distribution and the radiative forcings simulated in the model should ultimately be validated by observations.

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