Modeling of Clouds and Aerosols toward Long-Range Forecasts of Asian Summer Monsoon

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1. INTRODUCTION

The Asian summer monsoon is an important forecast objective of medium-and extended-range numerical weather prediction (NWP) in the East Asian countries. Performance of the monsoon prediction is very sensitive to parameterization schemes for various physical processes. Among them, the cloud-radiation interactions are of great interest. Here, we show some sensitivity studies of JMA's global NWP to cloud- and aerosol-radiation and discuss their roles in the atmospheric general circulation.

2. LINK of CLOUDS and AEROSOLS to ASIAN SUMMER MONSOON

The solar insolation generates the land-ocean heat contrast because of large difference in the heat capacity and initiates the Asian summer monsoon. JMA's NWP model which had been operational until 1999 (Sugi et al., 1990) underestimated the cloud fractions averaging over the continent and overestimated the absorbed solar radiation. To assess the systematic impacts of the cloud and aerosol radiation on monsoon forecasts, a series of one month forecast experiments was carried out (Iwasaki and Kitagawa, 1998).

The control model diagnostically parameterizes the cloud optical parameters from relative humidity and static stability but does not consider any effect of aerosols. The model is modified to enhance the cloudiness over the land in contrast with that over the ocean and to include the direct and indirect effects of aerosols. The heat capacity of the land is so small that the enhanced clouds and aerosols fairly reduce the surface temperature over the land and suppress the monsoon circulation. Figure 1 shows the vertically integrated horizontal moisture flux averaging over 5 one-month forecasts, which are run from initial states at the 31st of May, 1991-1995. The modified scheme enhances eastward moisture flux in low latitudes but reduces it toward the Meiyu-Changma-Baiu front over China, Korea and Japan. We can expect that precipitation is enhanced in the south of India and the South China Sea, where cyclonic impact appears. On the contrary, precipitation decreases in the region of anticyclonic impact, north of India and the Far East. Concerning onsets of the monsoon, the modifications of the model considerably delay the northward migration of the East-Asian heavy precipitation

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band, i.e., Meiyu-Changma-Baiu fronts in early summer. According to Murakami and Matsumoto (1994), the heavy precipitation band jumps from the western North Pacific monsoon (WNPM) area around the Indochina and Philippine to the Meiyu-Changma-Baiu bands. We can say that cloud and aerosol schemes significantly control the jump of precipitation band.

The cloud enhancement was introduced by Sundqvist et al. (1989), but its physical reasoning is still unclear. Possible candidates are the local circulation and 'the second Twomey effects'. The latter is that the smaller cloud droplets tend to stay longer in the atmosphere and accordingly to give more cloudiness under the same humidity and stability conditions. Other possibilities are degradations resulting from other insufficient parameterization schemes, such as, cumulus parameterization and/or turbulent mixing schemes. Although aerosols are known to have direct and indirect effects on the solar insolation (Twomey, 1977), their understandings are not enough to be accurately modeled. Further studies are needed for the cloud formations and cloud-aerosol interactions.

It is to be noted that the modification of the model was not preferable for precipitation forecasts although it considerably reduced the systematic error of the radiation. The systematic error of the precipitation may be attributed to the cumulus parameterization scheme. All of the physics parameterization schemes are being reconsidered focussing on the monsoon forecasts at JMA (Kuma et al., private communication).

3. DIURNAL VARIATION of OCEANIC LOW-LEVEL CLOUDS

Oceanic stratocumulus gives large effects to the static stability of the atmosphere. The activity of cumulus convection is very sensitive to the low-level moist static stability and it is under strong influence of the low-level cloud distributions.

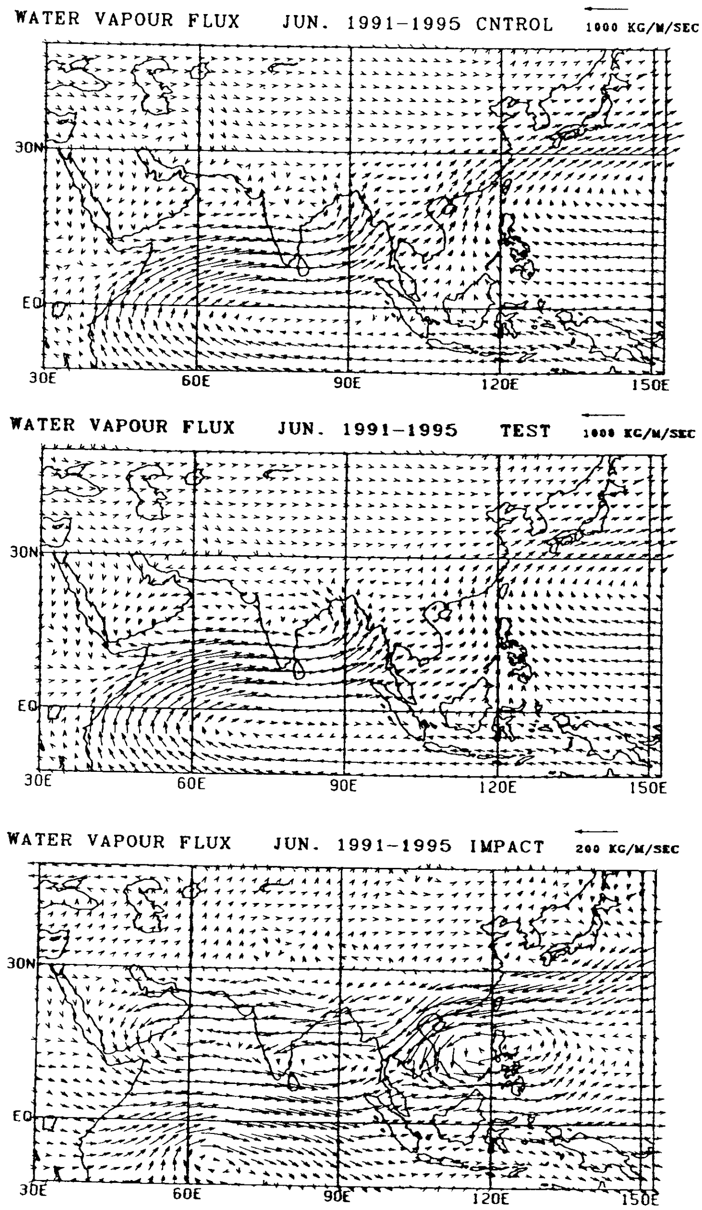

Fig.1 Vertically integrated horizontal moisture fluxes averaged over 5 one-month forecasts for June. Initial conditions are the 31st of May, 1991-1995. Top, middle and bottom panels indicate results of the control model, the modified model and impact. The scale of arrows is given at the upper-right corner of each panel (Iwasaki & Kitagawa, 1998).

The geographical distribution of low-level clouds, however, is not easy for the model to reproduce, because the oceanic low-level clouds have strong feedback through the infrared cooling and the turbulent mixing and negative feedback through solar heating. That is, the low-level clouds enhance the infrared cooling around the cloud top and the turbulent mixing and accelerate cloud formations. On the other hand, the short wave radiation heats up the clouds and decelerates the cloud formation. As a result, the cloud fraction reproduced in the model is very sensitive to the cloud optical parameters.

We study the sensitivity of the simulated diurnal variation of cloud fraction to the optical parameters, where the model results agree with the observation. The long wave cooling is more sensitive to the cloud fraction than the cloud water content, while the short wave heating is sensitive to the cloud water content. Such difference is related to the single scattering albedo and the anisotropy factor which control the cloud penetration depth. The middle panel is the sensitivity to effective radius. The increase in the effective radius enhances the single scattering coalbedo (absorption) and reduces the cloud fractions during the day. The bottom is the sensitivity of the cloud fraction to the coalbedo assuming the cloud absorption anomaly problem (e.g., Stephen and Tsay, 1990). We can expect that the cloud absorption anomaly reduces planetary albedo through the decrease in the cloudiness.

The low-level clouds tend to enhance stable rain but suppress the deep cumulus convection over the ocean which is the major driving force of the general circulation. Roughly speaking, the low-level clouds excite the Monsoon type circulation but suppress the Hadley type circulation. Of course, the actual response must depend on the detailed distributions of the clouds.

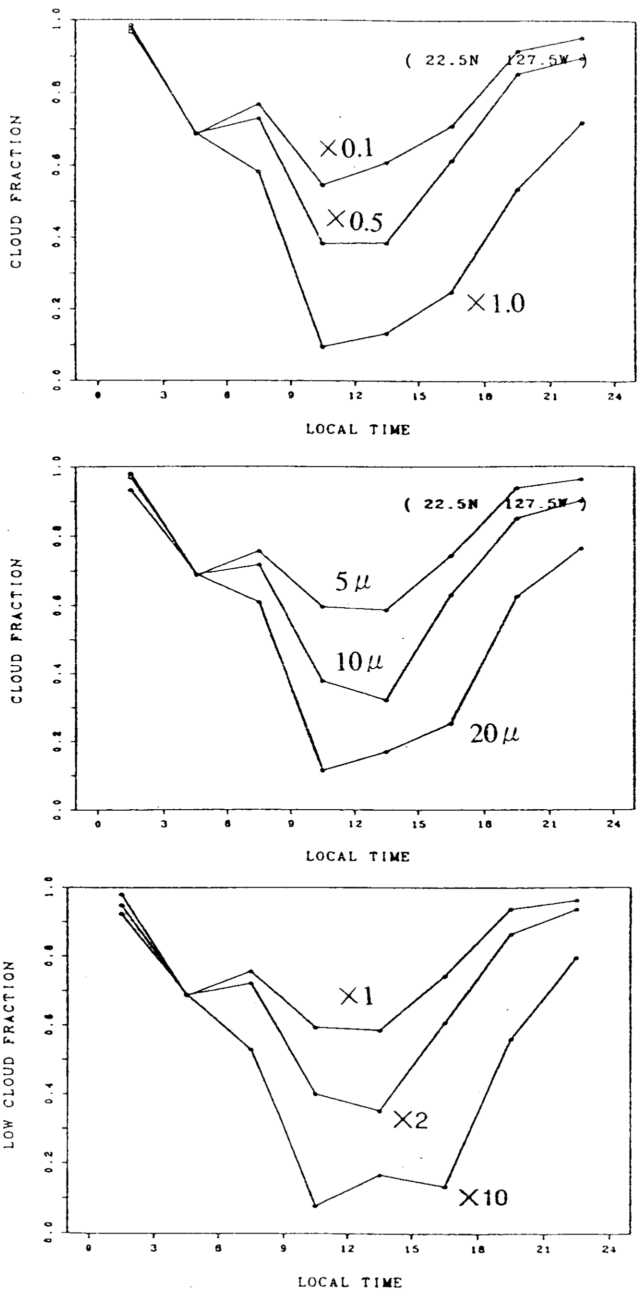

Fig. 2 Sensitivity of diurnal variation of cloudiness to optical parameters at (24W, 28N) reproduced by JMA's global NWP. The control value of cloud water content as a function of temperature is taken from Heymsfield (1977). Those of effective radius are

Top: Sensitivity to the cloud water content. Multiple factors to the control are shown in the figure.

Middle: Sensitivity to the effective radius.

Bottom: Sensitivity to the coalbedo. Multiple factors to the control are shown in the figure.

4. REMARKS

The parameterization scheme for cloud formation, which is sensitive even to cloud optical parameters and to aerosol-cloud interactions, is one of the most difficult things in GCM. We showed that ambiguity of its parameterization considerably affects the extended forecasts and the climate predictions. Intensive observations should focus on accurate descriptions on cloud-aerosol-radiation interactions. Those will be very helpful for improving the GCM and NWP models.

References

Heimsfield, A. J., 1977: Precipitation development in stratiform ice clouds: A microphysical and dynamical study. *J. Atmos. Sci.*, **34**, 367-381.

Iwasaki, T. and H. Kitagawa, 1998: A possible link of aerosols and cloud radiations to Asian summer monsoon and its implication in long-range numerical weather prediction. *J. Meteor. Soc. Japan.* **76**, 965-982

Murakami, T. and J. Matsumoto, 1994: Summer monsoon over the Asian continent and western North Pacific. *J. Meteor. Soc. Japan.***72**, 719-745.

Stephens, G. L. and S.-C. Tsay, 1990: On the cloud absorption anomaly. *Quart. J. Roy. Meteor. Soc.* **116**, 671-704.

Sugi, M., K. Kuma, K. Tada, K. Tamiya, N. Hasegawa, T. Iwasaki, S.Yamada and T. Kitade, 1990: Description and performance of the JMA operational global spectral model (JMA-GSM88). *Geophys. Mag.*, **43**, 105-130.

Sundqvist, H., E. Berge and J, E. Kristjansson, 1989: Condensation and cloud parameterization studies with a mesoscale numerical weather prediction model. *Mon. Wea. Rev.*, **117**.1641-1657.

Twomey, S. A., 1977: The influence of pollution on the short-wave albedo of clouds. *J. Atmos. Sci.*, **34**, 1149-1152.