Cloud Ensemble Simulation with Data from the Atmospheric Radiation Measurement Intensive Observation Period

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Introduction

The main objective of this study is to use Atmospheric Radiation Measurement (ARM) intensive observation period (IOP) data to refine a cloudiness parameterization, as proposed by Xu and Randall (1996a). The cloudiness parameterization uses the large-scale average condensate (cloud water and cloud ice) mixing ratio as the primary predictor. The large-scale relative humidity and cumulus mass flux are also used in the parameterization as secondary predictors. The cloud amount is assumed to vary exponentially with the large-scale average condensate mixing ratio. The rate of variation is, however, a function of large-scale relative humidity and the intensity of convective circulations. In the version of the parameterization presented by Xu and Randall (1996a), the intensity of convective circulations was yet to be included; that is, only the condensate mixing ratio and large-scale relative humidity were used as predictors.

In this study, cloud-resolving modeling is adopted to supplement bulk cloud properties such as cloud fraction and condensate mixing ratio, which were not reliably observed during ARM IOP. The UCLA cloud ensemble model (CEM) is used. CEMs cover a large horizontal area with a sufficiently small horizontal grid size to resolve individual clouds. They can provide many valuable data sets by simulating different cloud regimes in the atmosphere (e.g., Tao et al. 1987; Xu and Krueger 1991; Xu and Randall 1996b). Moreover, variables associated with statistical properties of clouds are inherently consistent.

Preliminary Results

The July 1995 IOP (July 18 - August 4) data are used in the simulation presented here. Other IOPs have also been simulated (not shown here). The large-scale input data include the vertical velocity, the horizontal advective tendency of temperature and moisture, as analyzed by the Livermore group (see Cripe and Randall [1997, this volume]). The observed surface sensible and latent heat fluxes are prescribed in the simulation. The remaining aspects of the design of the numerical simulation are identical to those described by Xu and Randall (1996b), which simulated cumulus ensembles over the tropical Atlantic with observed large-scale data. The only exception is that the domain size is half as large (256 km).

The simulation with the July 1995 IOP data captures observed precipitation events (Figure 1) on July 20 (day 3), 26 (day 9), and August 1, 2 and 3 (days 15, 16, and 17). Observed surface precipitation on July 22 (day 5) and 24 (day 7) is not simulated, although upper-level cloudiness is produced on day 5 (Figure 2). Only a small cloudy area in the middle troposphere is simulated on day 7, even though heavy precipitation was observed at ground (Figure 1). Thus, the simulated results compare with observations reasonably well. Some deficiencies exist, however.

The time-height cross section of simulated cloud fraction for July 1995 IOP is shown in Figure 2. The most striking feature shown in Figure 2 is that, unlike in the tropics, the occurrence of clouds is intermittent except for the last four days of the simulation. The timing of cloudy sky is basically consistent

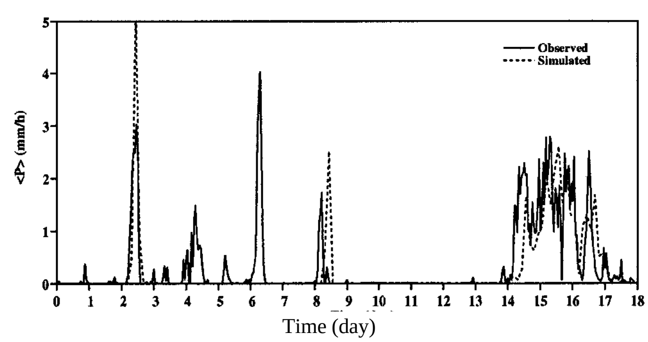

Figure 1. Time series of observed and simulated surface precipitation rates for July 1995 IOP.

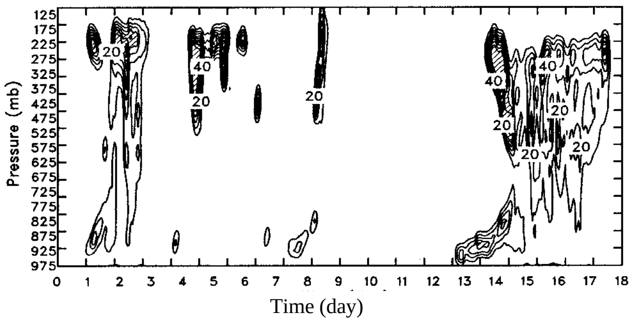

Figure 2. Time-height cross section of simulated cloud fraction for July 1995 IOP. The contour interval is 10%. Shaded are the areas with over 50% cloudiness.

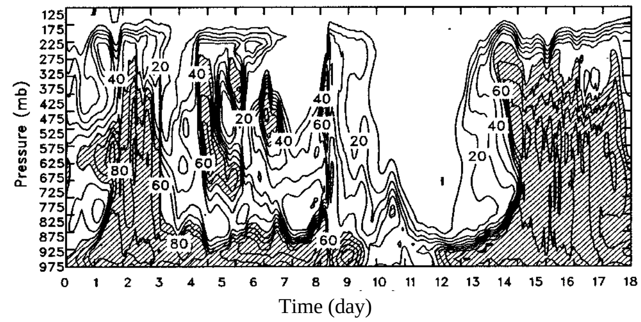

Figure 4. Time-height cross section of simulated large-scale relative humidity for July 1995 IOP. The contour interval is 10%. RHs over 60% are hatched.

with the observed surface precipitation events. As noted earlier, the simulated clouds are not always precipitating (compare Figures 1 and 2). Nevertheless, the upper-level clouds are usually more abundant than the low-level clouds during the IOP. The upper-level cloud fraction exceeds 80% at selected periods, for example, at days 5 and 15. The low-level cloudiness is usually far less than 50% except for days 14 and 15.

Figure 3 shows the time-height cross section of a simulated cloud water + cloud ice (condensate) mixing ratio. It is apparent that the regions with condensate are overlapped with the cloudy regions shown in Figure 2. It is also apparent that the regions with high concentrations of condensate are correlated with higher cloud fraction regions. This suggests that the mixing ratio of condensate is closely related to cloud fraction, as in the tropical stratiform anvils and subtropical stratocumuli (see Xu and Randall 1996a).

The time-height cross section of the simulated large-scale relative humidity (RH) is shown in Figure 4. The areas with RHs greater than 60% are hatched in Figure 4. It can be seen that the cloudy regions are always associated with higher RHs (compare Figures 2 and 4). In other words, the presence of clouds is associated with a more humid large-scale environment. The opposite is not true, however. For instance, the RH is always high in the lower troposphere, whether or not any cloud is present.

Finally, the cloud fraction is diagnosed with the parameterization of Xu and Randall (1996a) using the simulated mixing ratio of condensate (Figure 3) and relative humidity (Figure 4). It should be emphasized that the coefficients in the parameterization were based on the tropical stratiform clouds (Xu and Randall 1996a). Their suitability for the midlatitude cloud systems is not guaranteed. The diagnosed cloud fraction is shown in Figure 5. Comparing Figure 5 with Figure 2, it can be seen that the cloudy regions are virtually identical between simulation and parameterization.

There are, however, some underestimates in the upper troposphere (e.g., days 2, 5, and 15) and some overestimates in the lower troposphere (e.g., days 2 and 14). The reason for overestimates in the lower troposphere is that convective clouds are not excluded in the cloud fraction. These clouds

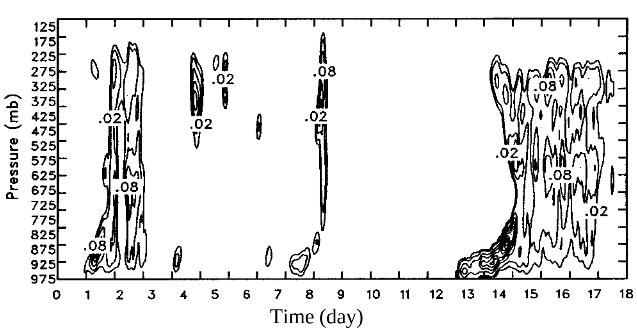

Figure 3. Time-height cross section of simulated mixing ratio of condensate for July 1995 IOP. The contour interval is 0.02 g kg^{-1}.

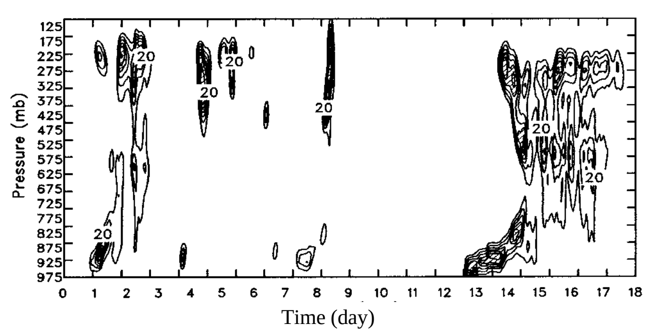

Figure 5. Time-height cross section of diagnosed cloud fraction for July 1995 IOP. The contour interval is 10%. Shaded are the areas with over 50% cloudiness.

have high concentrations of condensate (Figure 3) but small areas. The underestimates in the upper troposphere are more difficult to explain. It is possible that the exclusion of the intensity of convective circulations affects the diagnosed cloud fraction. Inclusion of this additional predictor may improve the performance of the parameterization under different cloud regimes. Further study is under way to investigate this possibility.

Summary

In summary, the ARM IOP data have been successfully used to simulated the bulk properties of clouds with a cloud ensemble model although some deficiencies exist in the simulation. The simulated cloud properties and large-scale environment variables are used to evaluate a cloudiness parameterization proposed by Xu and Randall (1996a). The performance of this parameterization in its preliminary version is acceptable to some extent. There is room for further improvement, for example, by including the intensity of convective circulations as a secondary predictor. In addition, measurement of cloud properties during IOPs is also helpful to verify the parameterization. Simulations of other IOPs will also be helpful to refine the cloudiness parameterization.

Acknowledgments

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