Comparison of Cloud Size Distribution from a Regional Atmospheric Model with Satellite Observations for GCM Cloud Parameterization

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Background

The spatial and temporal characteristics of clouds can significantly affect the atmospheric radiation budget. These characteristics, when determined from observations, can serve as an important observational constraint for evaluating and improving cloud parameterization in global and regional climate models. Recently, Boer and Ramanathan (1997) developed an algorithm to determine these cloud characteristics and applied it to the satellite data over the tropical western and central Pacific.

In this study, we will use the results from Boer and Ramanathan (1997) to evaluate a widely used cloud parameterization in global climate models (GCMs). We apply the same algorithm as they used for their satellite data to the model-simulated cloud fields and compare the results of the model cloud spatial characteristics with their observational results.

Model and Simulation of Cloud Systems

The model used for this study is a high-resolution limited area model (HIRLAM) from Stockholm University. The dynamic framework of the model is based on the European Centre for Medium Range Weather Forecasting (ECMWF) regional gridpoint model, and the physical parameterization package is also similar in many aspects to that of the ECMWF. The model has 16 vertical levels in a hybrid coordinate system extending from the surface to 25 mb, and a horizontal dimension of 110 x 100 gridpoints at a resolution of 0.5°. Of particular interest to this study is the cloud parameterization, which uses the prognostic cloud water parameterization scheme developed by Sundqvist et al. (1989). This parameterization scheme has been used in various forms by many GCM groups worldwide.

The model is run over the tropical western and central Pacific, covering (115° E, 150° W) and (30° S, 20° N). The period of simulation is 30 days from March 7 to April 5, 1993, the same period as studied by Boer and Ramanathan so that the satellite results are readily available for comparison. Since HIRLAM is a forecast model, we performed a 36-h forecast for each of the 30 days starting from 00 Greenwich mean time (GMT). To allow for model spin-up, the first 12-h model output is discarded and only the last 24 h of data are used to represent the simulation day. The data are saved every 6 h. The analyzed atmospheric fields and sea surface temperature from ECMWF are used for the model's initial and lateral boundary conditions.

The size distribution of the simulated cloud is determined using the cloud classification algorithm of Boer and Ramanathan (1997), with the cloud top temperature and the fractional cloud cover as input. The clouds are divided into three categories: deep convective systems with cloud top temperatures less than 240K, mid-top clouds with cloud top temperature between 240K and 270K, and low clouds with cloud top temperature greater than 270K. The deep clouds roughly correspond to those with cloud tops above 300 mb, the mid-top clouds have their tops between 600 mb and 300 mb, and the low clouds have their tops below the 600 mb level. Within the deep cloud category, the cloud systems are further divided into mesoscale convective systems (MCSs) and non-mesoscale systems (non-MCSs) using the criterion set by Boer and Ramanathan (1997).

Results

Figure 1 compares the cumulative distribution of the fractional cloud cover between the satellite observations and the model simulation for different cloud types. The area contribution from the smaller cloud systems in the model is significantly less than observed. On the other hand, the total contribution to the cloud cover by the deep clouds of all

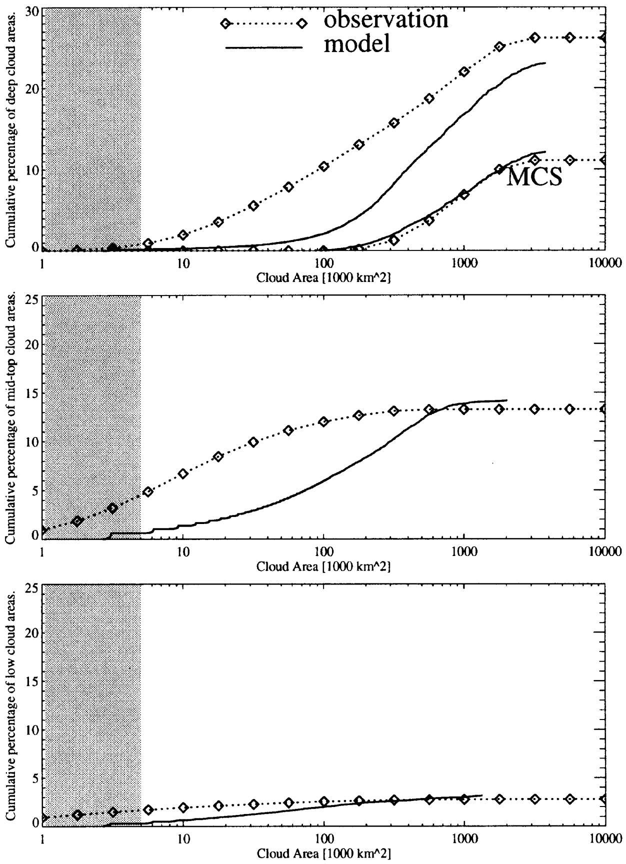

Figure 1. Cumulative contribution from different cloud types to the total cloud cover as functions of the cloud area. The monthly mean total cloud cover is 42% from the satellite and 40% from the model.

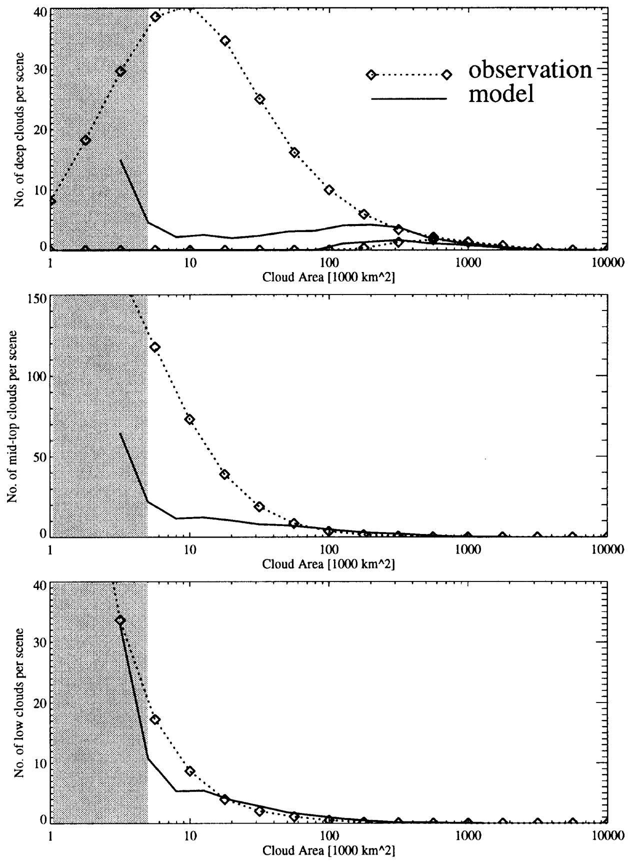

Figure 2. Number distribution types of clouds as functions of their area. The dashed line is based on the satellite results of Boer and Ramanathan (1997).

sizes from the model is only slightly less than observed, suggesting that the model clouds are biased toward larger cloud sizes. Within the deep clouds, the cumulative contribution from MCSs to the fractional cloud area is very well simulated. The cloud cover from MCSs accounts for about half of the total cloud cover from all deep cloud systems.

The simulation of the area contribution from the mid-top clouds is qualitatively similar to the deep clouds; that is, the contribution from the smaller cloud systems is under-simulated. But the total contribution from this cloud type of all sizes in the model is in good agreement with the observations. The low-level clouds contribute about 3% cloud cover, and this is well simulated in the model.

The number distribution of the different cloud types is shown in Figure 2. Consistent with the cloud cover, the model significantly under-simulates the number of clouds with areas of less than 10^5 km^2 for deep convective systems and 3 x 10^4 for mid-top clouds. The number distribution of the larger systems is much better simulated, with the model producing slightly more clouds. Similar features are seen for the mid-top clouds. On the other hand, the number distribution of the low clouds is well simulated by the model. The cloud population is dominated by clouds of relatively small sizes for all cloud types, although the large clouds account for a significant portion of the cloud cover. For instance, there are only a few MCSs per scene, but they contribute to almost half of the total deep cloud cover.

The diurnal variation of the cloud population and area for the deep clouds is demonstrated in Figure 3. Here the number and area are normalized by the maximum within the 24-h period. The total number of deep convective systems shows little diurnal variation in the model, while the observations show a maximum pre-dawn and a secondary maximum in the afternoon. However, for the MCSs the observed pre-dawn maximum is reasonably well reproduced

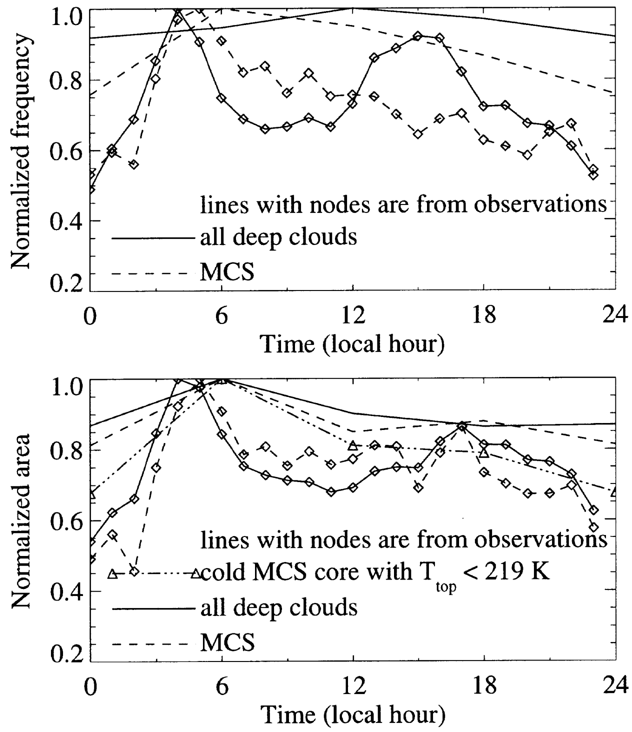

Figure 3. Diurnal variation of number of deep clouds normalized by the maximum number of these clouds across the 24-h bins. Note that the model output is available 4 times a day.

by the model, although the amplitude of variation is less than observed. The modeled total area for all deep clouds exhibits a maximum in the early morning, in agreement with the satellite observations. But the late afternoon secondary maximum is missing in the model. The area of the modeled MCSs has a primary maximum in the early morning and a weak secondary maximum in the late afternoon, in qualitative agreement with the satellite observations.

The area cover of the very cold cores of the cloud systems in the tropical Pacific warm pool was found to exhibit a single peak in the early morning by Mapes and Houze (1993) using satellite data. Similar features are seen from the modeled MCSs here. From Figure 3, it is shown that the area of the very cold cores of the MCSs (areas with cloud top temperature < 219K) reaches maximum in the early morning and decreases as the day progresses.

Summary and Future Plans

The cloud classification algorithm by Boer and Ramanathan (1997) is applied to the cloud fields from a regional central and western Pacific region. It is shown that the area contribution from the different types of the model clouds to the total cloud cover is in good agreement with the satellite observations. However, the size distribution of the model clouds is biased toward the larger clouds. The diurnal variation of the number and area of the mesoscale convective systems is also reasonably well simulated compared to the satellite results. We plan to improve the algorithm for application to the Southern Great Plains (SGP) site. While the oceanic convective systems are reasonably well simulated in its area contribution from different cloud types and the diurnal cycle, the continental convective systems may possess different characteristics and the model's ability to reproduce them is not known. We will use the observations from the SGP site, together with the improved cloud classification algorithm, to evaluate the cloud parameterization for continental cloud systems. These results together will serve as a testbed for improving the model cloud parameterization.

References

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