A Lagrangian Examination of the Cloud Physical and Radiative Properties in the ARM SGP Site from Satellite Observations

G. J. Zhang and V. Ramanathan
Center for Atmospheric Sciences
Scripps Institution of Oceanography
La Jolla, California

Introduction

The conventional approach to studying clouds examines cloud properties, such as the fractional cloud cover, at a fixed location. One of the drawbacks of this approach is that the results depend upon resolution of the grid mesh on which the cloud field is projected. On the other hand, a Lagrangian approach follows individual cloud systems. As such, results based on this approach are resolution independent. Furthermore, it can determine the spatial and temporal characteristics of the cloud systems and the scale dependence of cloud physical and radiative properties. The statistics of the cloud properties for different cloud types and under different climate regimes can be used to evaluate the model cloud parameterization in regional and global climate models. Recently, Boer and Ramanathan (1997) developed a Lagrangian cloud classification algorithm and applied it to the convective cloud systems in the Tropical Western Pacific (TWP). They found that for tropical oceanic convective cloud systems, clouds with area greater than 50 km x 50 km (approximately at T213 general circulation model [GCM] resolution) account for about 95% of the total cloud area cover. Cloud radiative properties including cloud albedo and brightness temperature have considerable scale dependence.

To compare the tropical oceanic cloud systems with midlatitude continental cloud systems, this study examines the spatial characteristics and the scale dependence of the cloud physical and radiative properties in the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site using satellite observations. We apply the Lagrangian cloud classification scheme of Boer and Ramanathan (1997) to the Minnis satellite cloud product. The objective is to determine which cloud scales are important for cloud-radiation parameterization, and to provide an observational basis for developing and evaluating cloud parameterization.

Data and Analysis Method

The gridded Minnis cloud product using Geostationary Operational Environmental Satellite (GOES)-8 satellite observations for the June/July 1997 Intensive Observation Period (IOP) at the ARM SGP site are analyzed in this study. The analysis domain covers an area of 9.5° in latitude and 13.5° in longitude for (32.25 °N, 41.75 °N) and (91.25 °W, 104.75 °W) with 0.5° resolution. The data is available hourly from June 18 to July 18, 1997. The observed clouds are classified as being high, middle, and low clouds. The original Boer and Ramanathan (1997) cloud classification algorithm uses the brightness temperature as input to track individual clouds. Later, Zhang et al. (1999) modified the algorithm to use fractional cloud cover and cloud top temperature as input when applying it to the model cloud fields. In this study, we will use the same method as in Zhang et al. (1999) to identify individual clouds.

Results

Using the Boer and Ramanathan cloud classification scheme, we determined the contribution to the total cloud cover from clouds of different scales for each cloud type. Figure 1 shows the cumulative fractional area contribution for each cloud type and the contribution from each size bin. The total cloud cover over the analysis domain for the month-long period is 42%, of which 24% is from high clouds, 15% is from middle clouds, and 3% is from low clouds. Clouds with an area larger than 10^4 km^2 (T106) account for over 90% of the total high cloud cover, 75% of the total middle cloud cover, and 50% of the total low cloud cover, respectively. The dominant contributors are high clouds with area from 4×10^4 km^2 (T63) to 4×10^5 km^2 (T21). These results suggest that as far as cloud area is concerned, GCMs with 100-km resolution should be able to resolve most of the high clouds while resolving middle and low clouds may require higher model resolution.

Similar to the oceanic cloud systems, the cloud radiative properties of the midlatitude continental cloud systems at the ARM SGP site also have a strong dependence on cloud scale. Figure 2 shows the broadband cloud albedo, outgoing longwave radiation (OLR), shortwave and longwave cloud radiative forcing averaged over the cloud area as functions of cloud area. Larger clouds are brighter and have lower OLR. The cloud albedo and shortwave radiative forcing are comparable in magnitude for high, middle, and low clouds, while the OLR and longwave radiative forcing are the largest for high clouds and the smallest for low clouds. Larger clouds in general have larger shortwave and longwave radiative forcing (per unit cloud area) except for high clouds with area greater than 2×10^5 km^2. Large high clouds were observed in the late afternoon when the sun was at high zenith angle, and thus have small shortwave radiative forcing.

The cumulative distribution of the domain-averaged cloud cover, together with the cloud-mean cloud radiative forcing as functions of cloud area, yields the cumulative distribution of the domain-averaged longwave and shortwave cloud radiative forcing (Figure 3). The total longwave cloud radiative forcing is about 28 W/m^2, of which 22 W/m^2 is from high clouds. About 90% of the longwave cloud radiative forcing by the high clouds come from clouds with an area larger than 4×10^4 km^2. The contribution to shortwave cloud radiative forcing from different cloud types and scales is qualitatively similar. The total shortwave cloud radiative forcing from all cloud types and scales is about -29 W/m^2, comparable in magnitude to the total longwave cloud radiative forcing.

Summary and Conclusions

Most of the clouds that have significant contribution to the total cloud cover have area > 10^4 km^2. At current GCM resolutions (typically T42), models can only resolve about 50% of the clouds, and the other 50% in terms of area are of subgrid scale, and thus require parameterization for fractional cloud cover. At T106 (100-km) resolution, most of the clouds are resolvable except some middle and low clouds.

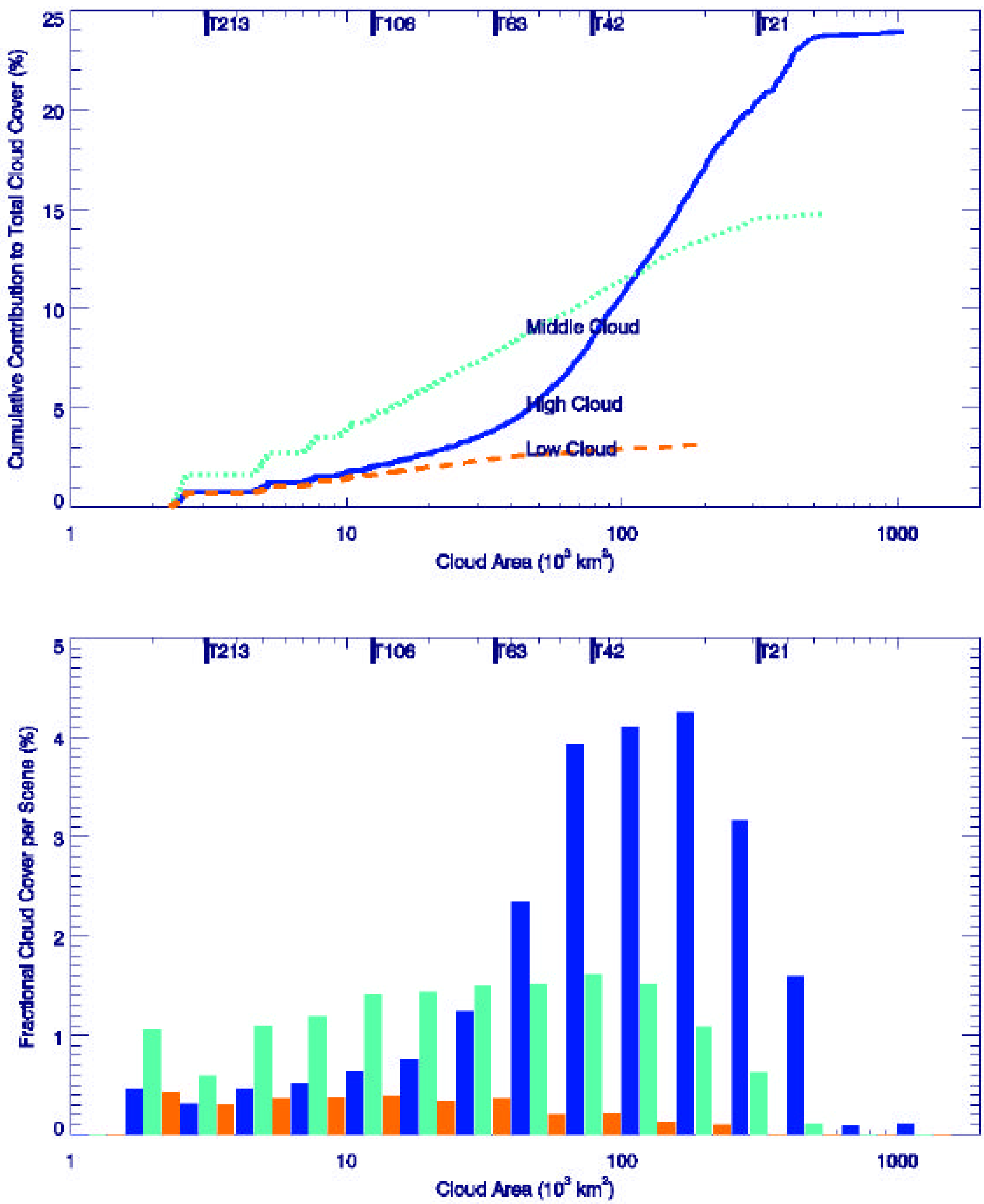

Figure 1. Cumulative contribution to the total fractional cloud area over the analysis domain from different cloud sizes for high, middle, and low clouds (top), and the decomposition to contribution from each size bin (bottom) for high (dark shade), middle (light shade), and low (medium shade) clouds.

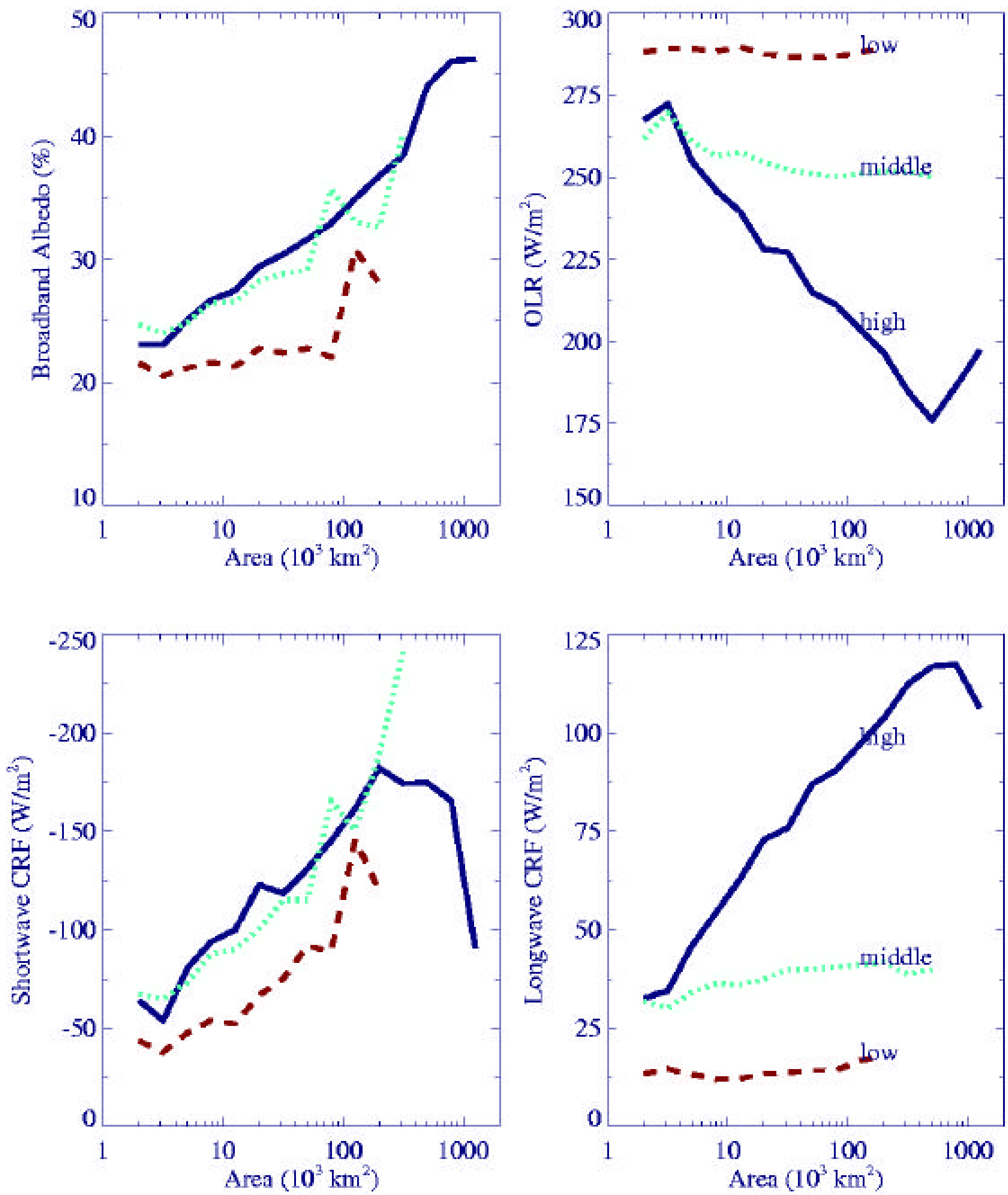

Figure 2. Cloud-mean broadband albedo, OLR, shortwave, and longwave cloud radiative forcing as functions of cloud area for high (solid line), middle (dotted line), and low (dashed line) clouds.

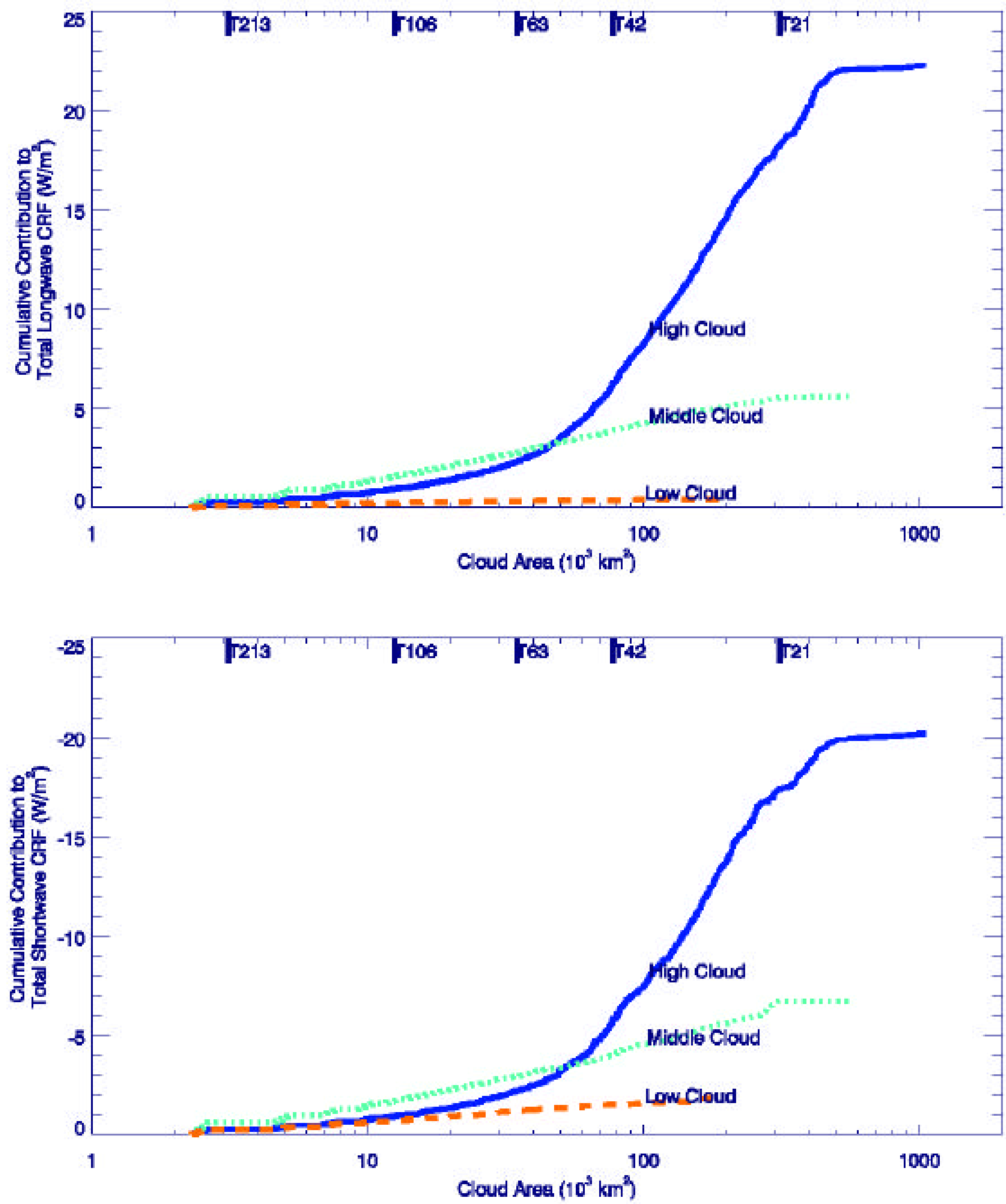

Figure 3. Cumulative contribution to the total longwave and shortwave radiative forcing averaged over the analysis domain from high, middle, and low clouds.

The strong scale dependence of cloud radiative forcing per unit cloud area implies that for the same cloud amount, if it is composed of small clouds, the radiative properties including the cloud radiative forcing would be very different from those of large clouds. Therefore, cloud scale is an important parameter in cloud radiation calculation, and should be included in cloud parameterization.

The observed cloud radiative forcing is dominated by large cloud systems. The characteristic scales for cloud radiative forcing are similar to those for cloud cover. The major contributors to cloud radiative forcing are deep clouds with an area between 4 x 10^4 km^2 (T63) and 4 x 10^5 km^2 (T21). Middle clouds contribute about 20% to the total longwave and shortwave cloud radiative forcing. Due to the small low cloud amount, and the high effective temperature, the cloud radiative forcing by low clouds is insignificant.

References

Boer, E. R., and V. Ramanathan, 1997: Lagrangian approach for deriving cloud characteristics from satellite observations and its implications to cloud parameterization. *J. Geophys. Res.*, **102**, 21,383-21,399.

Zhang, G. J., D. Zurovac-Jevtic, and E. R. Boer, 1999: Spatial characteristics of the tropical cloud systems: Comparison between model simulation and satellite observations. *Tellus*. In press.