A Test of the Validity of Cumulus Cloud Parameterizations for Longwave Radiation Calculations

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Introduction

Longwave radiative transfer under broken cloud conditions is often treated as a problem in cloud bulk geometry, especially for cumulus clouds, because individual clouds are nearly black. However, climate models ignore cloud geometry and approximate broken clouds as black plates. Recently, we adopted the simplicity of the flat-plate approximation and extended it to include cloud geometry and cloud spatial and size distributions by defining an effective cloud fraction, N_e, that depends upon observable cloud field variables. We developed a general formulation for N_e for black clouds that can easily be tested against observations. In this study, ground-based measurements at the central facility of the Southern Great Plains (SGP) Cloud And Radiation Testbed (CART) site were used to derive N_e, absolute cloud fraction, N, and many other variables characterizing cumulus clouds. The validity of various parameterizations, developed by us and by other investigators, is tested by comparing effective amounts derived from hemispheric flux observations with absolute amounts extracted from laser ceilometer derivations and with values predicted by parameterizations.

Cloud Parameterizations

Longwave fluxes in most general circulation models (GCMs) are calculated in the form

$$F = (1 - N)\ F_c + NF_o \qquad (1)$$

where N is based on the flat-plate approximation and F_c and F_o are the fluxes that would occur if the sky were clear or completely covered by a single cloud layer of uniform optical properties. A practical and time-saving approach to account for the effect of broken clouds in a one-dimensional scheme is to use N_e instead of N. The form of the dependence of N_e on cumulus cloud parameters is described as

$$N_e = f\ (N,\beta,Zb,h,\lambda,u,\nu) \qquad (2)$$

where β is the cloud aspect ratio, Z_b is the cloud base height, h is the cloud thickness, λ is the ratio of the radiance intensities, and u and ν are the power law slopes governing the cloud spatial and size distributions. The complexity of parameterizations determines the combination of cloud parameters. Among these parameters, β is related to the cloud projection, it is defined as the ratio of h to radius for a cylinder and the ratio of h to a half side length for a cube, respectively.

We selected our fractal cube/cylinder model as well as random cylinder model (Ellingson 1982), regular cube model (Harshvandhan and Weinman 1982), and shifted-periodic array cube model (Naber and Weinman 1984) to calculate N_e in terms of other observed cloud variables from the central facility of the SGP CART site.

Derivation of Cloud Variables

At the central facility of the ARM CART site, the comprehensive ground-based measurements are routinely operated with a pyrgeometer, an Atmospheric Emitted Radiance Interferometer (AERI), a laser ceilometer, a micropulse lidar, a microwave radiometer, and a Whole Sky Imager (WSI). Additionally, radiosondes are launched by the Balloon-Borne Sounding System (BBSS) about every three hours to detect the dry and wet temperatures, which help to determine the relative humidity and to wind profile. The sky condition is also recorded in weather logs. The data used are from the period of May - July 1994.

Single-layer cumulus cloud fields are determined by the WSI, the micropulse lidar and the ceilometer. With an empirically determined optimum sampling period of 10 min., the cloud variables the instruments used for their detection and their estimated relative accuracies are as follows:

N_e	Pyrgeometer and AERI	10% - 20%
N	Ceilometer and BBSS	20% - 30%
β	Ceilometer and BBSS	20%
Z_b	Ceilometer	5%
h	Ceilometer and BBSS	10%
λ	Ceilometer and BBSS	10%
u and ν	Statistics from Other Sources	10%

In all, 436 single-layer cumulus cloud cases were used to test the validity of selected cloud models. The majority of cumulus cloud cases have β's in the range of 0.25 to 1.25 and N's varying from 0.1 to 0.5.

The distributions of fractal clouds are based on Landsat imagery analysis conducted by other investigators. Based on the investigation of the cumulus scene in Oklahoma (Sengupta et al. 1990; Zhu et al. 1992), u is set at 2.5 (Cahalan 1986) and ν is calculated to be 2.0. A relative accuracy of 10% for u and ν is assumed.

Test of the Validity of Cloud Parameterizations

The validity of selected cloud models was tested by comparing values predicted by models with effective amounts derived from the hemispheric flux observations. Figures 1-5 show cloud fraction differences, defined as $-N_e$(calculated) $-N_e$(retrieved), versus β and N and the $-N_e$(calculated) $-N_e$(retrieved), versus β and N and the sensitivity of these

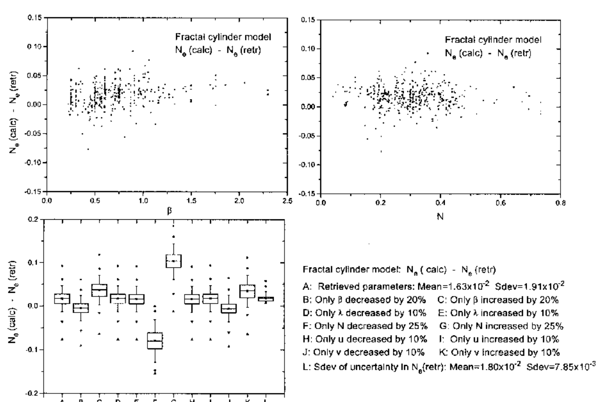

Figure 1. Cloud fraction differences using fractal cylinder model.

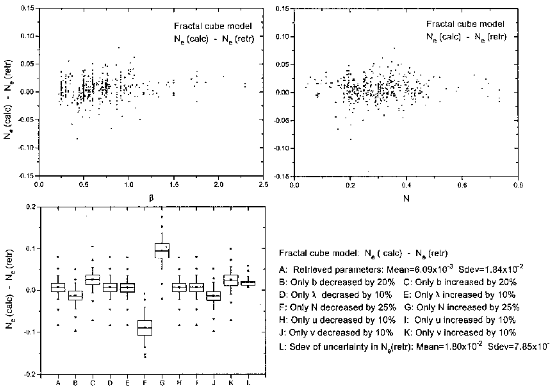

Figure 2. Cloud fraction differences using fractal cube model.

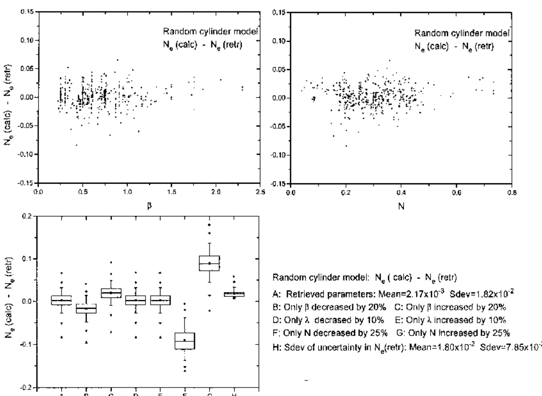

Figure 3. Cloud fraction differences using random cylinder model.

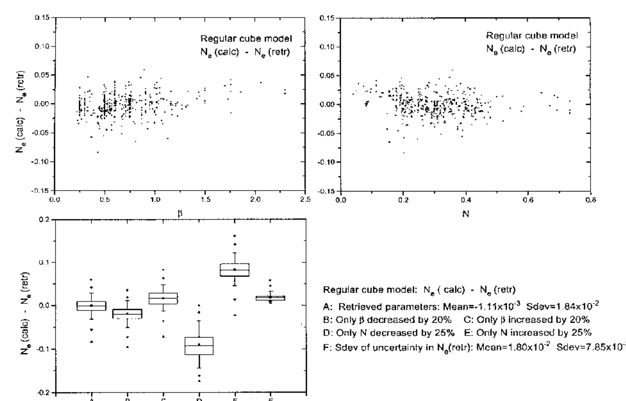

Figure 4. Cloud fraction differences using regular cube model.

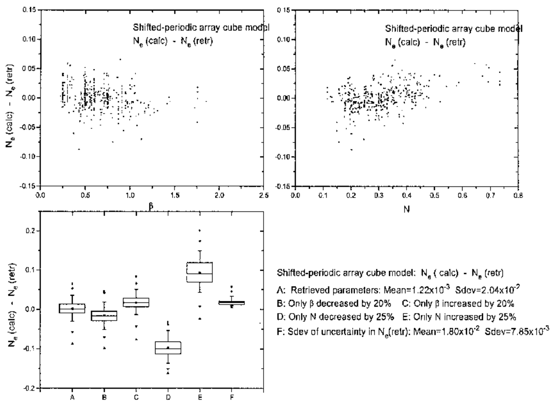

Figure 5. Cloud fraction differences using shifted-periodic array cube model.

differences to uncertainties of each model-used cloud variable. In the test range, the results tend to favor the fractal cube model, the random cylinder model, and the regular cube model. The fractal cylinder model might overestimate N_e and the shifted-periodic array cube model seems to exhibit a tendency related to β and N. However, this test does not lead to a conclusion concerning the best model for finite-sized clouds. For example, we did not have a direct observation for the cloud size distribution, while the sensitivity study indicates that the difference of N_e is sensitive to ν. If ν is set to be 1.9 instead of 2, the prediction of the fractal cylinder model agrees with observations well. Moreover, there were few cases in the range of greatest sensitivity with large β and N, in which model comparisons demonstrate larger disparity. Nevertheless, this is the first validation of the form of the dependence of N_e on bulk cloud parameters using independently measured data at the surface. The ongoing ARM program will facilitate tests over a wider range.

References

Cahalan, R.F., 1986: Nearest neighbor spacing distributions of cumulus clouds. In *Proceeding of the 2nd International Conference on Statistical Climatology*, Vienna, Austria, June 1986.

Ellingson, R.G., 1982: On the effects of cumulus dimensions on longwave irradiance and heating rate calculations, *J. Atmos. Sci.*, **39**:886-896.

Harshvandhan and J.A. Weinman, 1982: Infrared radiative transfer through a regular array of cuboidal clouds, *J. Atmos. Sci.*, **39**:431-439.

Naber, P.S., and J.A. Weinman, 1984: The Angular distribution of infrared radiances emerging from broken fields of cumulus clouds, *J. Geophys. Res.*, **89**:1249-1257.

Sengupta, S.K., R.M. Welch, M.S. Navar, T.A. Berendes, and D.W. Chen. 1990: Cumulus cloud field morphology and spatial patterns derived from high spatial resolution Landsat imagery, *J. Appl. Meteor.*, **29**:1245-1267.

Zhu, T., J. Lee, R.C. Weger, and R.M. Welch, 1992: Clustering, randomness, and regularity in cloud fields: 2. Cumulus cloud fields, *J. Geophys. Res.*, **97**:20537-20558.