Verification of Cirrus Cloud Parameterizations Using Southern Great Plains Data

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Introduction

An evaluation of several diagnostic cirrus cloud parameterizations is presented in this study using data from the Department of Energy's Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site. We consider three parameterizations of ice water content (IWC) proposed by Heymsfield and Donner (HD 1990), Stephens et al. (ST 1990), and Slingo and Slingo (SL 1991), each coupled with parameterizations of the ice particle size characteristics by Heymsfield and Platt (HP 1984), Mitchell (MI 1994) and Platt (PL 1997) and cirrus optical properties by Ebert and Curry (EC 1992) and Fu and Liou (FL 1993). The total possible combinations create 18 different simple cirrus coupled parameterizations for evaluation.

Methodology

This study uses a single-column, diagnostic approach similar to that described in Mace et al. (1995). The specified dimensions of 200 x 200 km in the horizontal and 16 km in the vertical are comparable to a single general circulation model grid. The column is centered on the ARM SGP central facility in north-central Oklahoma. We consider cirrus events at the SGP site from November 1, 1994, to April 30, 1995. Cirrus cloud events were determined from the SGP Micropulse LIDAR (MPL) data.

We define cirrus clouds as any cloud having a base temperature colder than -20°. Liou (1986) defines this temperature as a general cut-off for the cloud base temperature of cirrus. A cloud is considered for study only if it occurs during daylight hours, is the only cloud layer present, and is overcast over the entire column. We determine an overcast sky by examining half-hour averages of the MPL data from 15 minutes before the top of the hour to 15 minutes after the hour. If the MPL detects a cirrus cloud for at least 25 of the 30 minutes, then the column is considered overcast for that period. These constraints ensure that only single-layered overcast cirrus cases are examined.

The cloud boundaries are retrieved from the MPL data using a cloud mask scheme, which is similar to that presented in Clothiaux et al. (1995). The large-scale meteorological variables acquired from the Mesoscale Analysis and Prediction System (MAPS) output (Benjamin 1989), as well as the cloud boundaries, are required to drive the IWC parameterizations. The MAPS output is averaged from 60-km horizontal resolution to 200 km.

The variables required are temperature (T), specific humidity (q), and the large-scale vertical velocity (w). The HD scheme is dependent on T, q, and w. The ST parameterization depends on cloud temperature and the cloud boundaries. The SL parameterization requires only cloud boundaries and then uses a vertical profile of typical IWC values. These IWC values are entered into the HP, MI and PL parameterizations to evaluate the ice particle size characteristics. HP and MI predict a size distribution (n), while PL calculates an effective radius (r_{Platt}). The values n, r_{Platt}, and IWC are then incorporated into EC and FL to evaluate the visible cloud optical properties such as optical depth (τ), asymmetry parameter (g), and single-scatter albedo (ω). The EC parameterization uses n to calculate an effective radius, r_e, of the ice particles. If the PL effective radius is entered, then EC simply uses r_{Platt} in place of r_e. The effective radius along with IWC produces the cloud optical properties. The FL scheme requires n or r_{Platt} to calculate a mean effective size (or width), D, for assumed hexagonal columns. The mean effective size and the IWC are then used to calculate the optical properties. The optical properties serve as input to the δ2-stream solar radiative transfer code to compute the cloud radiative forcing at the surface.

Results

The results compare the modeled shortwave cloud forcing at the earth's surface to the observed forcing. The modeled cloud forcing fraction is calculated using the following equation:

$$CF = (M_{cld} - M_{clr}) / M_{clr}, \quad (1)$$

where CF is the modeled cloud forcing, M_{cld} is the modeled cloudy flux at the surface, and M_{clr} is the modeled clear sky flux. The observed cloud forcing value (CF_{obs}) is found in a similar calculation:

$$CF_{obs} = (O_{cld} - C_{clr}) / C_{clr} \quad (2)$$

where O_{cld} is the observed cloudy sky flux and C_{clr} is the calculated clear sky flux using an empirical method by Long (1996).

A scatter plot of modeled cloud forcing fraction versus observed cloud forcing fraction was generated for each of the 18 different coupled parameterizations considered. All of the scatter plots displayed sufficient scatter and unsatisfactory agreement between model and observations.

A statistical analysis of the plots yielded the correlation coefficient, bias, bias standard deviation, and the slope of the linear regression line (see Table 1). The correlation coefficient values were very low, ranging from 0.07 to 0.48. The parameterization schemes that were coupled with the ST IWC values produced the best correlation values. The bias standard deviation values (which yield an approximate measure of the amount of scatter) were high for all plots. The slope of the linear regression lines was too shallow for all plots with values never exceeding 0.50.

In general, the parameterization schemes coupled with EC optical properties produced higher bias standard deviation values (i.e., more scatter) and greater slopes. The parameterization schemes coupled with FL optical properties yielded lower bias standard deviation values (i.e., less scatter) and shallower slopes. The ST-PL-FL scheme (Figure 1) performed the best with the highest correlation (0.48) and the lowest bias standard deviation (0.14).

Summary

In this paper, we have outlined a methodology for using the routine data stream from the ARM SGP site for validation of several cirrus cloud parameterizations. Preliminary results are presented. A 6-month evaluation of cirrus cases at the site is conducted for the period from November 1, 1994, to April 30, 1995. This reveals that ARM SGP data, available on a daily basis, are adequate to run parameterization tests. Thus, it is conceivable that an operational validation scheme could be implemented, providing daily statistics on the performance of the cloud parameterizations. Such information will be crucial for determining how certain parameterizations perform during different meteorological situations. Ideas for improvement upon the schemes will likely follow. We are confident that this methodology will render a better understanding of the representation of cirrus clouds in computer models and make such improvements possible.

Table 1. Statistics calculated for the scatter plots of the modeled shortwave cloud forcing versus the observed forcing.

Parameterization Scheme	Correlation	Bias Standard Deviation	Slope
HD-HP-EC	0.08	0.18	0.06
HD-MI-EC	0.15	0.17	0.11
HD-PL-EC	0.15	0.18	0.12
HD-HP-FL	0.08	0.15	0.02
HD-MI-FL	0.17	0.15	0.03
HD-PL-FL	0.16	0.15	0.04
SL-HP-EC	0.25	0.18	0.23
SL-MI-EC	0.31	0.17	0.24
SL-PL-EC	0.40	0.16	0.34
SL-HP-FL	0.34	0.15	0.10
SL-MI-FL	0.35	0.15	0.08
SL-PL-FL	0.41	0.14	0.13
ST-HP-EC	0.40	0.19	0.48
ST-MI-EC	0.45	0.17	0.47
ST-PL-EC	0.48	0.16	0.48
ST-HP-FL	0.43	0.14	0.18
ST-MI-FL	0.46	0.14	0.16
ST-PL-FL	0.48	0.14	0.20

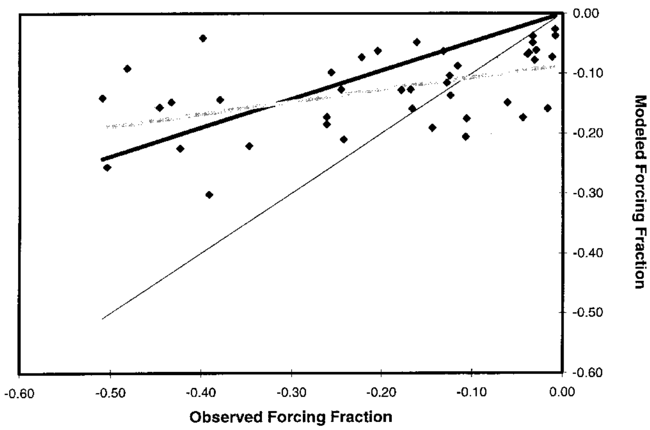

Figure 1. Plot of ST-PL-FL scheme solar forcing at the surface versus the solar forcing observed at the ARM SGP. The heavy line is the linear regression, the thin line is the 1:1 ratio, and the gray line is the linear regression forced through the origin (0,0).

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