Analysis of Subgrid Cloud Variability in a Year-long CRM Simulation over the ARM SGP

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1. Introduction

General circulation models (GCMs) predict cloud cover fractions and hydrometeor concentrations only in discrete vertical layers where clouds are assumed to be horizontally homogeneous in a coarse grid. They do not explicitly specify vertical geometric associations or horizontal optical variations of clouds. Subsequently, clouds within a GCM grid are simulated as a single effective volume that impacts radiation using various vertical overlap assumptions. The parameterization of cloud vertical overlap and horizontal inhomogeneity in the radiation schemes of GCMs has been a long-standing challenge problem. The inclusion of subgrid cloud variability in the radiation calculation for GCMs requires the knowledge of cloud distribution under different climate regimes, which is not yet available from observations. The year-long cloud-resolving model (CRM) simulation forced with the ARM large-scale forcing provides a unique data set to document the characteristics of cloud horizontal inhomogeneity and vertical overlap and to evaluate and represent their effects on the radiative fluxes and heating rates over a GCM grid. The objectives of this poster are to investigate the characteristics of cloud horizontal inhomogeneity and vertical overlap from the CRM, and to estimate the effect of subgrid cloud variability on radiative properties.

2. Cloud horizontal inhomogeneity

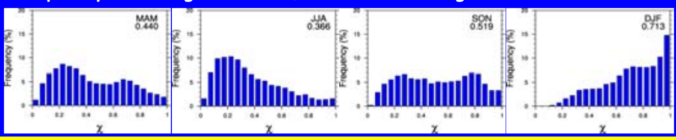
Cloud inhomogeneity parameter (i.e., reduction factor χ):

$$\chi = \frac{e^{\overline{\ln \tau}}}{\overline{\tau}}$$

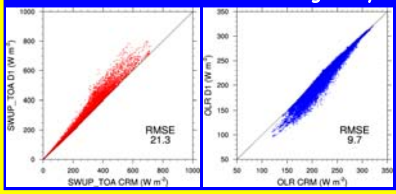
Cloudy grid box: LWP+IWP > 0.5 g m^{-2}
Cloud optical depth (τ): calculated from LWP and IWP.

(Cahalan et al. 1994, JAS)

Frequency distributions and mean values of the inhomogeneity parameter considering the vertically integrated cloudy column show inhomogeneous clouds more frequently occurring in summer, while more homogeneous clouds in winter.



Radiative effects of cloud inhomogeneity:

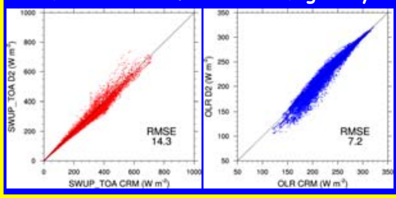


Scatter diagrams of CRM vs. D1 (diagnostic radiation calculation with homogeneous clouds) for the upward SW flux and OLR at the top of the atmosphere (TOA) during year 2000 indicate that the inhomogeneity effects decrease the SW reflection and increase the outgoing LW at the TOA.

Parameterization of cloud inhomogeneity:

Regression between χ and total cloud fraction (TC) from the CRM:

$$\chi = 1.101\mathrm{TC}^2 - 1.338\mathrm{TC} + 0.792$$



Scatter diagrams of CRM vs. D2 which applies the reduction factor χ to cloud water paths demonstrate that the biases in D1 are reduced in D2.

3. Cloud vertical overlap

Maximum (MAX), minimum (MIN) and random (RAN) overlap assumptions:

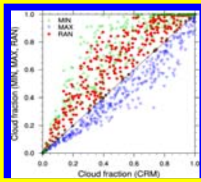
$$\mathrm{TC}_{max} = \mathrm{Max}(A_1, A_2, \ldots, A_n)$$

$$\mathrm{TC}_{min} = \mathrm{Min}\left(\sum_{k=1}^{n} A_k, 1\right)$$

$$\mathrm{TC}_{ran} = 1-(1-A_1)(1-A_2)\ldots(1-A_n)$$

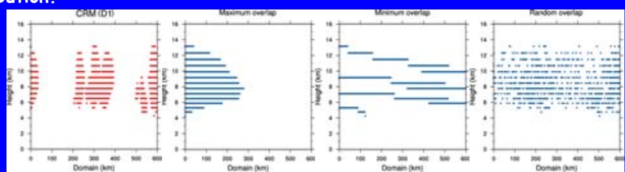
A_1, A_2, …, A_n are fractional cloud cover for each CRM level.

(Tian and Curry 1989, JGR)

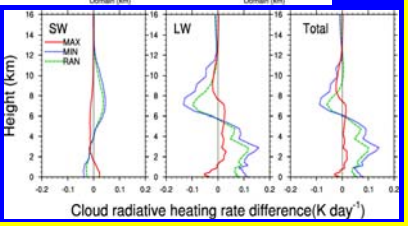


Scatter diagrams of total cloud fraction between the CRM and three cloud overlap assumptions for the whole year based on daily mean indicates that the maximum overlap systematically underestimates the total cloud fraction, while the random and minimum overlaps overestimate the total cloud fraction.

Cloudy grid boxes are redistributed from the cloud fraction profile using three overlap assumptions in the CRM domain with the removal of horizontal inhomogeneity, and the radiation calculations are then conducted for each distribution.



As compared with D1, MAX produces smaller SW heating and LW cooling between 2-8 km, and larger SW heating and smaller LW warming below 2 km. MIN and RAN increase SW heating above 4 km and reduce it below 4 km. LW cooling above 6 km and LW warming below 6 km is greater for MIN and RAN than D1.



4. Summary

* The analysis of Cahalan's inhomogeneity parameter using the year-long CRM simulation demonstrates seasonally varied cloud inhomogeneity with more inhomogeneous clouds in summer but more homogeneous clouds in winter. It is evident that the within-cloud variance must be incorporated for determining inhomogeneous corrections to plane-parallel cloud albedo and cloud emissivity estimates in GCMs. The parameterization of reduction factor in terms of total cloud fraction derived from the CRM simulations can capture the dominant radiative effects of cloud inhomogeneity which reduce the SW reflection and enhance the outgoing LW at the TOA.
* The maximum, minimum and random vertical overlap assumptions cannot properly represent the CRM cloud overlaps. Large biases show in the total cloud fractions, radiative fluxes at the surface and TOA, and the radiative heating rates. It suggests that the physically based vertical overlap which treats characteristic structure differences between major cloud types (e.g., convective, anvil and stratiform) is needed to incorporate the cloud geometric association and optical inhomogeneity effects in the radiation calculation.