Parameterizations of CRM-Simulated Subgrid Cloud Variability for GCM Radiation Schemes

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Motivation

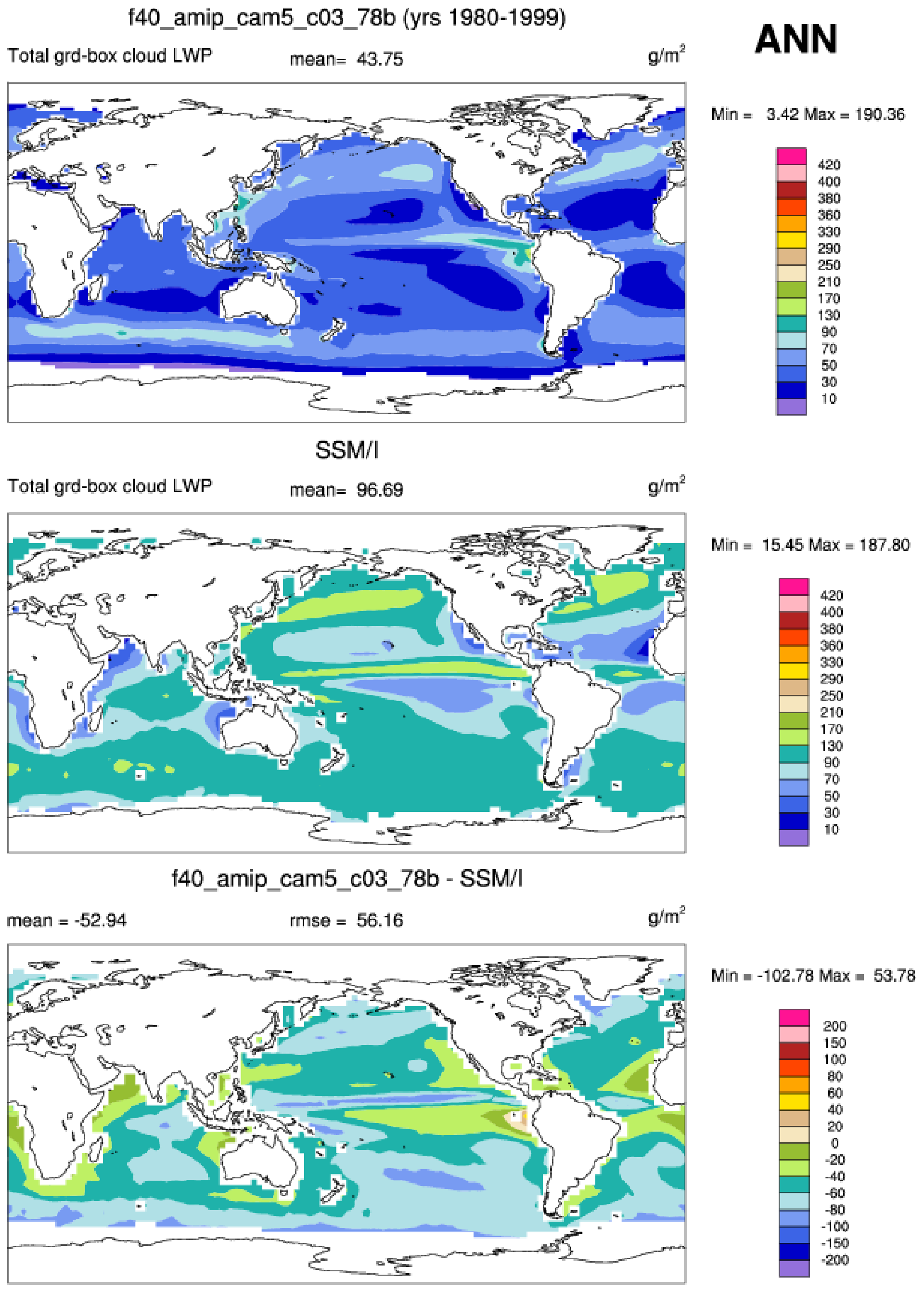
Most general circulation models (GCMs) have to use unrealistic cloud amount and/or cloud water contents in order to maintain the global radiation budget closer to satellite observations.

This long-standing problem is largely due to the difficulty in representing the effects of cloud horizontal inhomogeneity and vertical overlap on the radiation calculation.

CAM5

DIAG SET 1: ANN MEANS GLOBAL (yrs 1980-1999)

Variable	f40_amip_cam5_c03_78b
RESTOM	0.656
RESSURF	0.652



Motivation

Since complete observations of cloud systems are impossible and available measurements are limited, cloud-resolving models (CRMs) together with the ARM large-scale forcing provide a tool to simulate cloud systems under various large-scale conditions and over different regions, and to quantify and represent the subgrid cloud variability and its radiative effects.

CRM Approach

ISU Cloud-Resolving Model (CRM)

(Grabowski et al. 1996, JAS; Wu et al. 1998, 2008, JAS)

* Cloud Dynamics:

Clark-Hall finite-difference formulation of anelastic and nonhydrostatic equations (Clark et al. 1996)

* Model Physics:

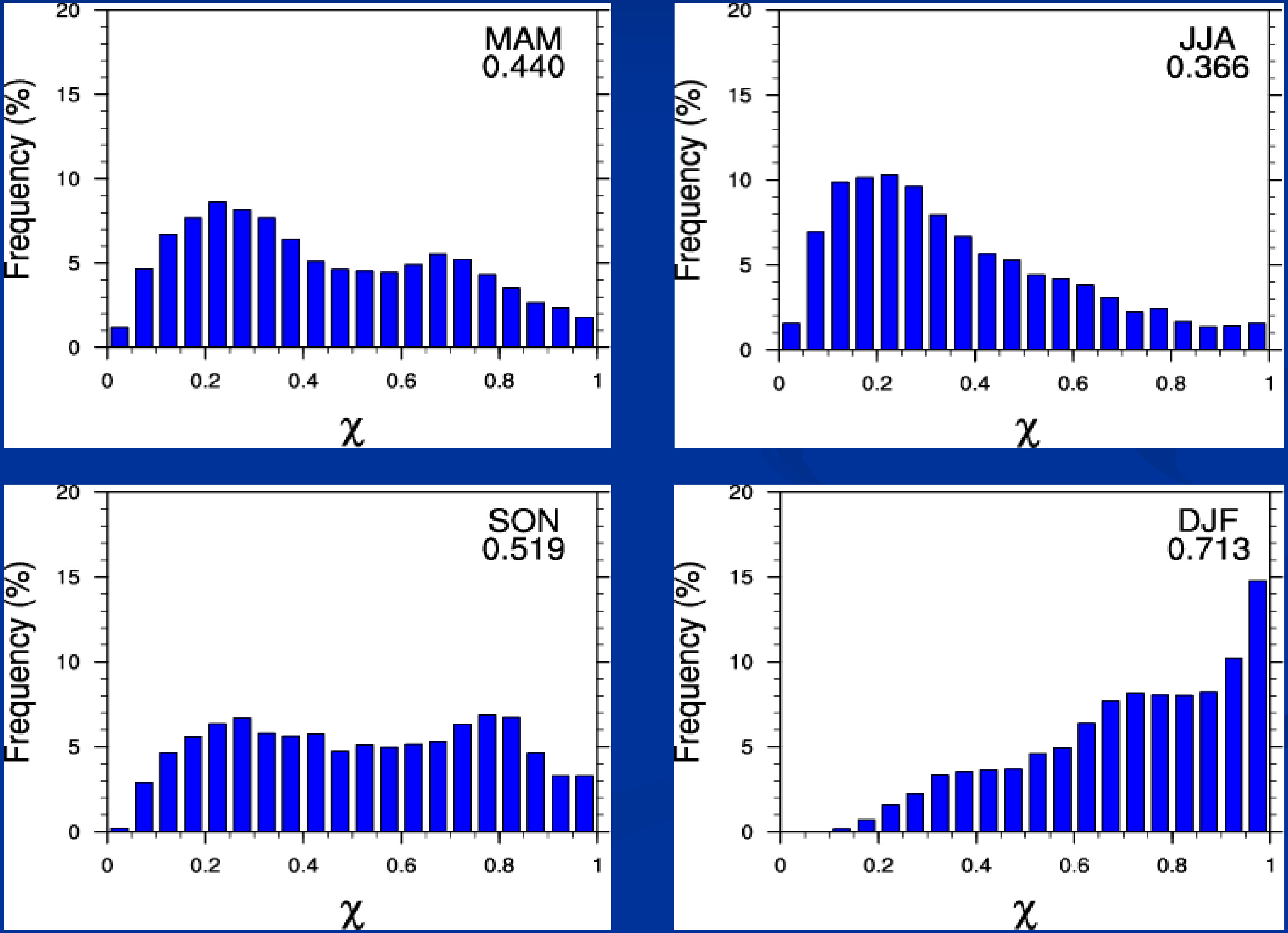
a. Cloud liquid and ice microphysical schemes
 (Kessler 1969; Koenig and Murray 1976)
b. Radiation parameterization from NCAR GCM (Kiehl et al. 1996)
c. Eddy diffusion parameterization (Smagorinsky 1963)

* Observed large-scale forcing:

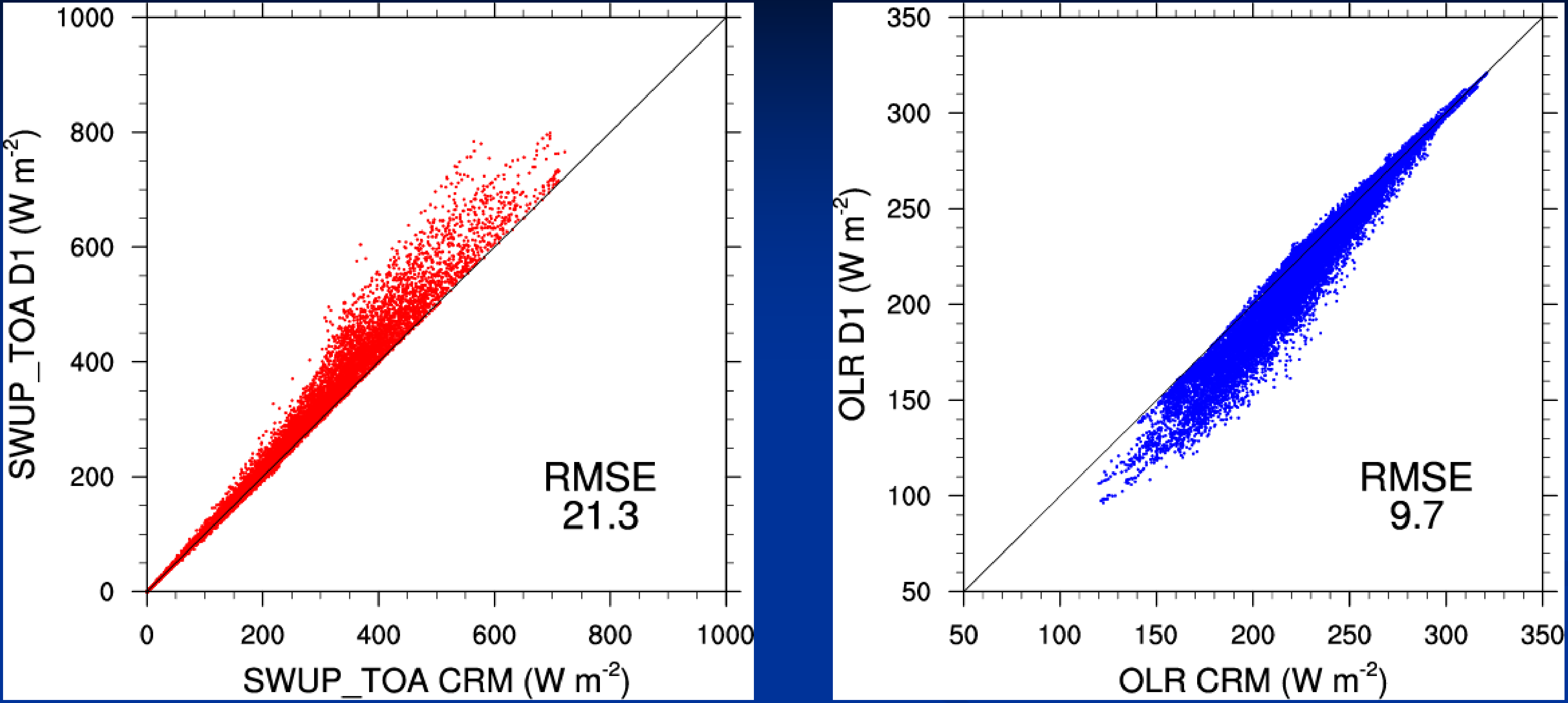
ARM value added observational products
Continuous forcing Data at the SGP site (Xie et al. 2004, JGR)

Cloud Horizontal Inhomogeneity

Cloud inhomogeneity parameter $\chi = e^{\overline{\ln \tau}} / \overline{\tau}$ is defined as the ratio of the logarithmic and linear average of a cloud optical depth distribution (Cahalan et al. 1994, JAS)



Cloud Horizontal Inhomogeneity

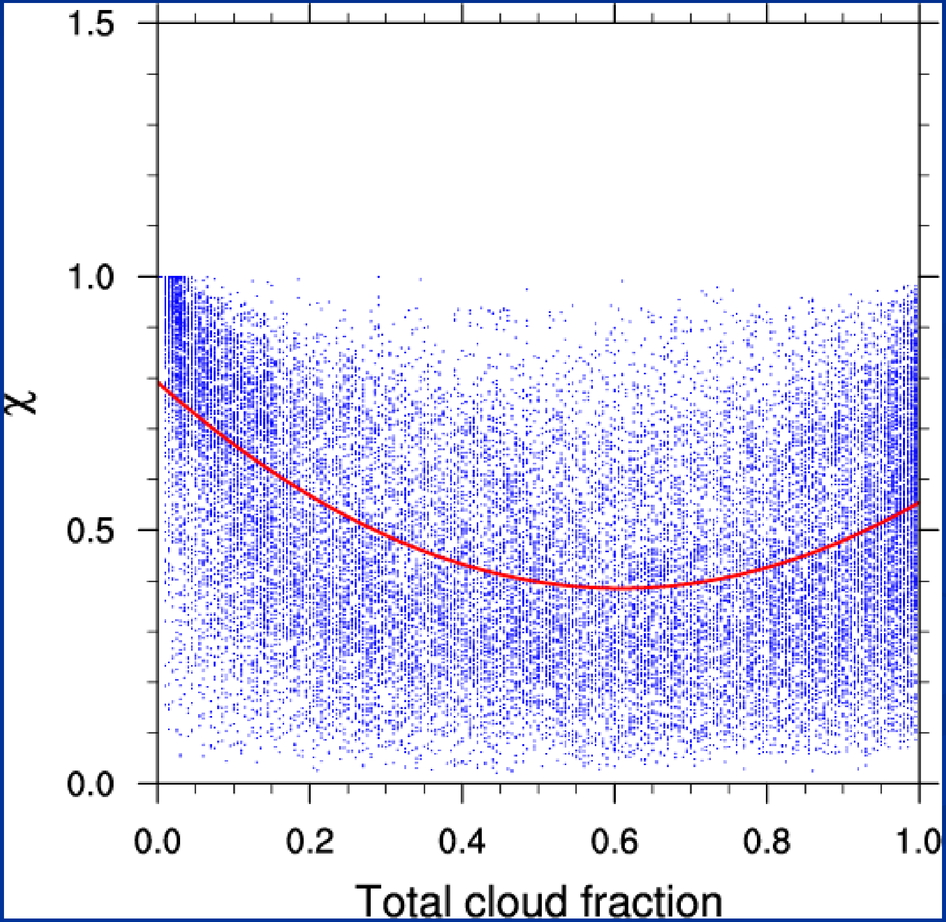


Scatter diagrams of CRM vs. D1 (diagnostic radiation calculation with homogeneous clouds) for the upward SW flux and OLR at the top of the atmosphere (TOA) during year 2000 show that the inhomogeneity effects decrease the SW reflection and increase the outgoing LW at the TOA.

Cloud Horizontal Inhomogeneity

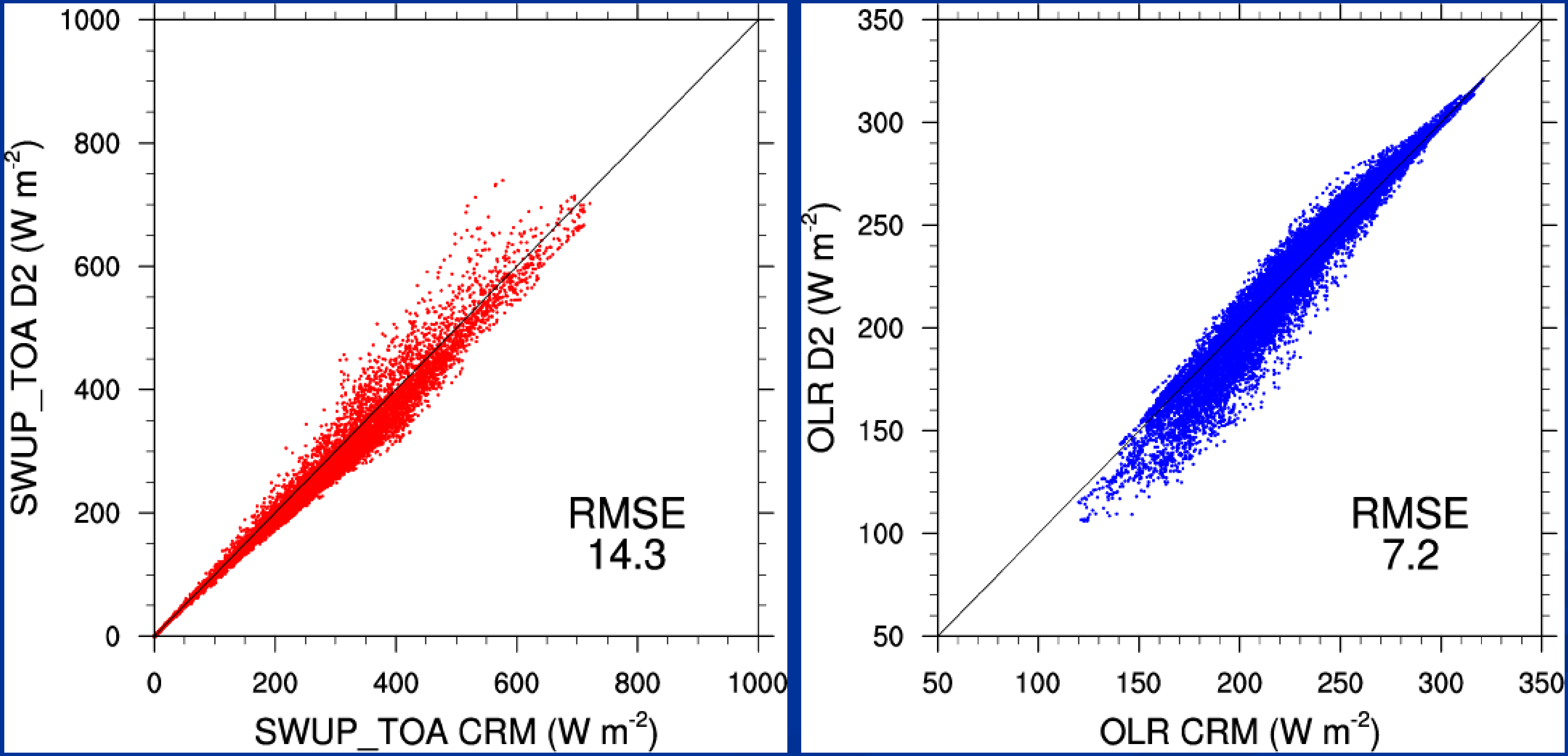
Parameterization of cloud inhomogeneity

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



Cloud Horizontal Inhomogeneity

D2: Diagnostic radiation calculation with the application of reduction factor χ in terms of total cloud fraction (TC)



Cloud Vertical Overlap

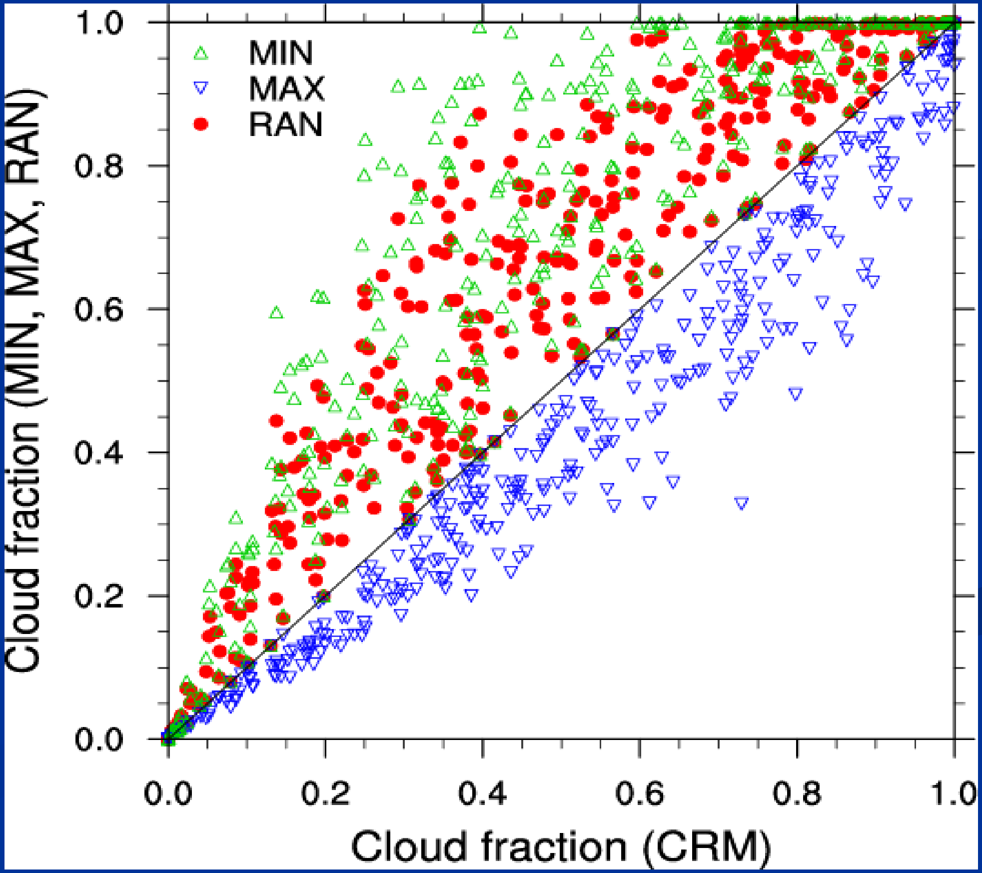
Assuming $A_1, A_2, \ldots\ldots, A_n$ are the cloud amounts for each layer, respectively, the total cloud cover (TC) computed from the minimum, maximum, and random overlap assumptions are (Tian and Curry 1989, JGR),

$$TC_{MIN} = \mathrm{Min}\left(\sum_{i=1}^{n} A_i, 1\right)$$

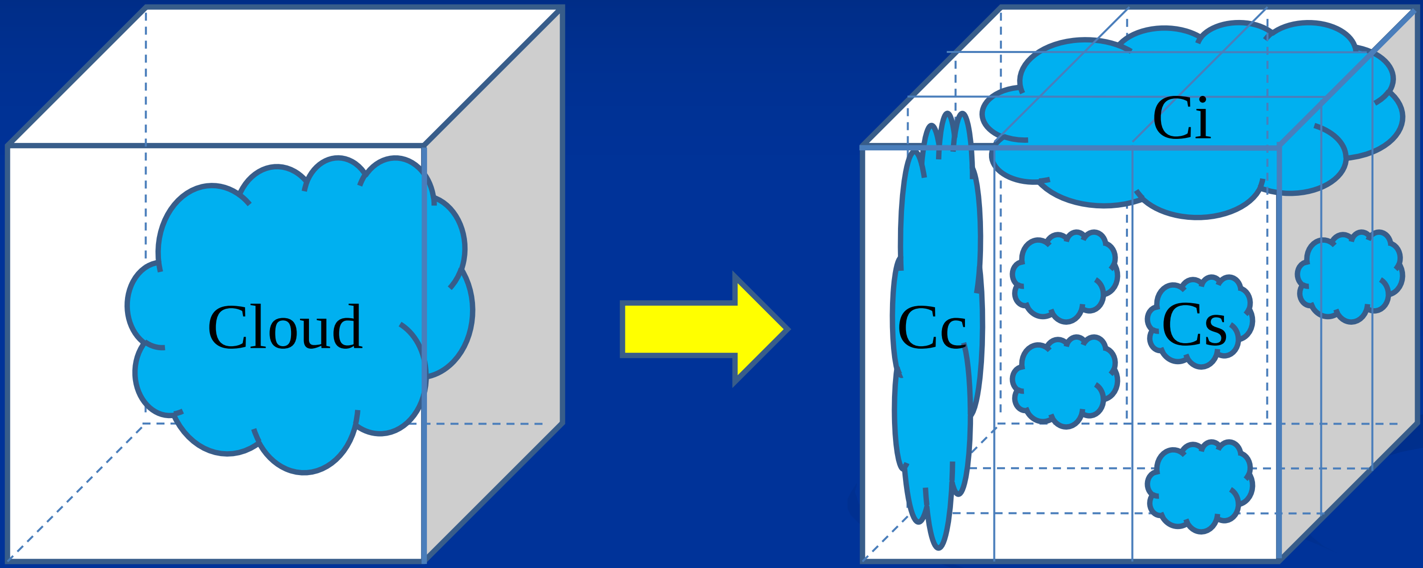
$$TC_{MAX} = \mathrm{Max}\,(A_1, A_2, \cdots, A_n)$$

$$TC_{RAN} = 1 - (1 - A_1)(1 - A_2)\cdots(1 - A_n)$$

All-sky condition during year 2000



Mosaic Treatment of Subgrid Cloud Distribution (MOS, Liang and Wang 1997, JGR; Liang and Wu 2005, GRL; Wu and Liang 2005, GRL)



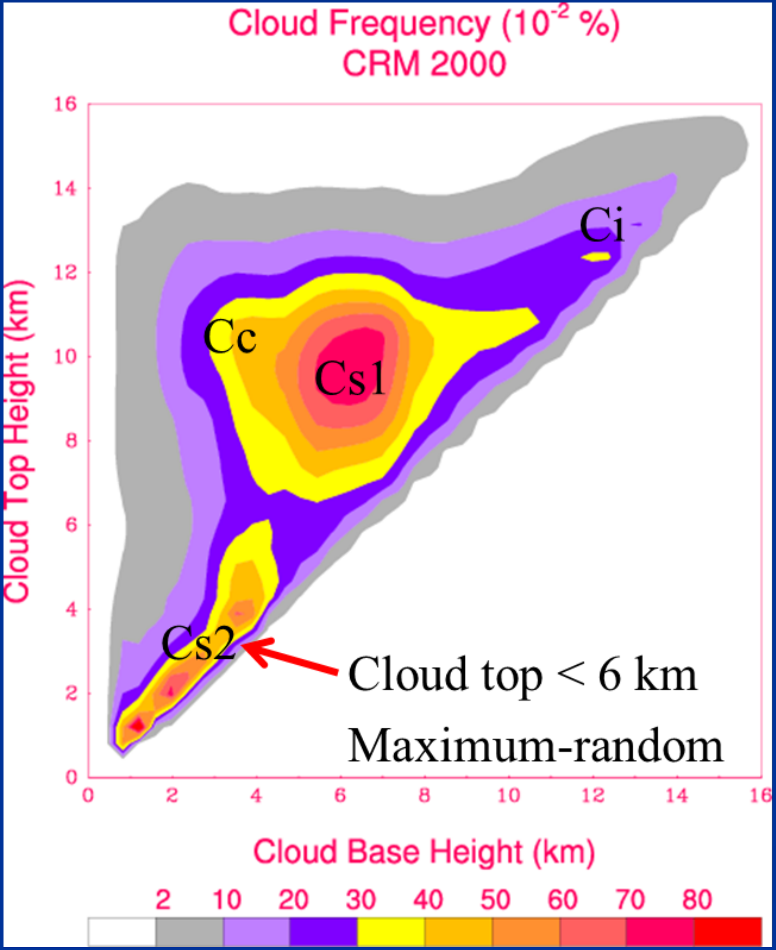
C_c: Convective clouds, maximum overlap in first subcell

C_i: Anvil clouds, continuously distributed at top level of C_c

C_s: Stratiform clouds, maximum-random overlap

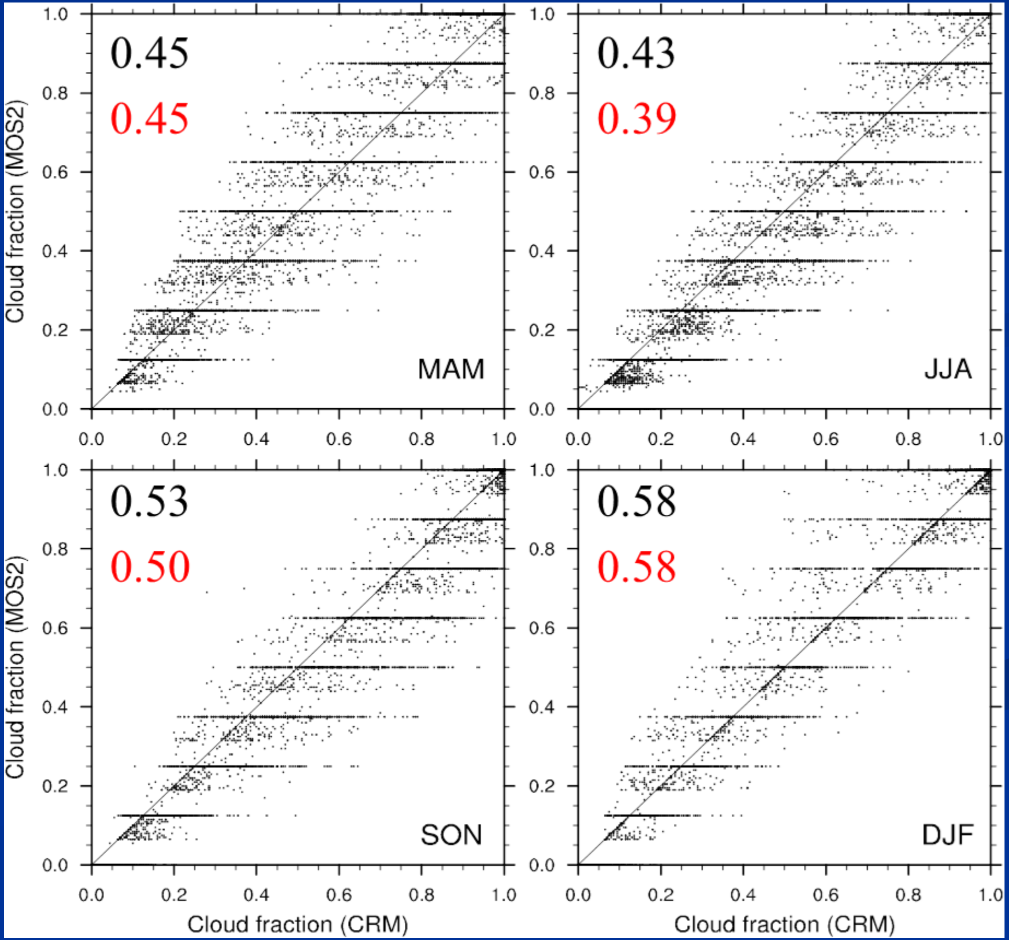
Evaluation of MOS with year-long CRM simulations

CRM
MOS2

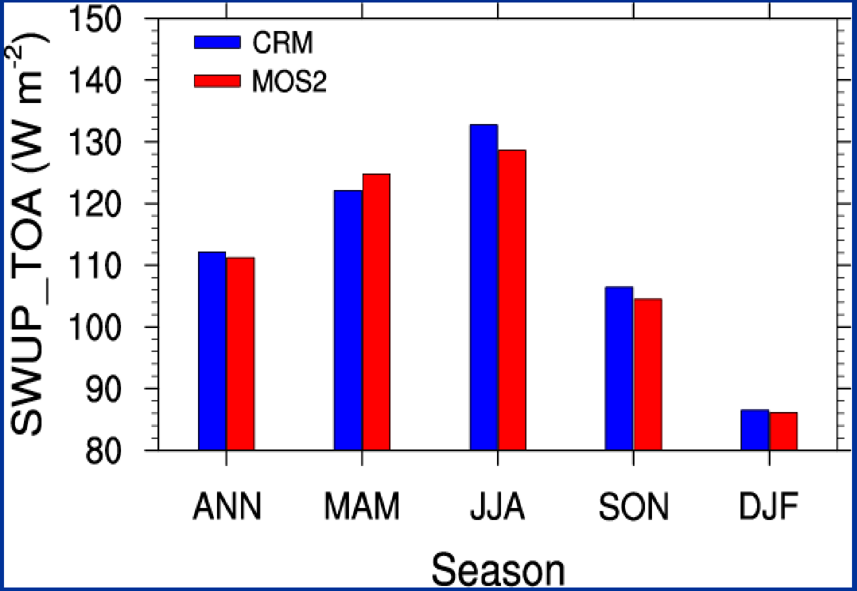


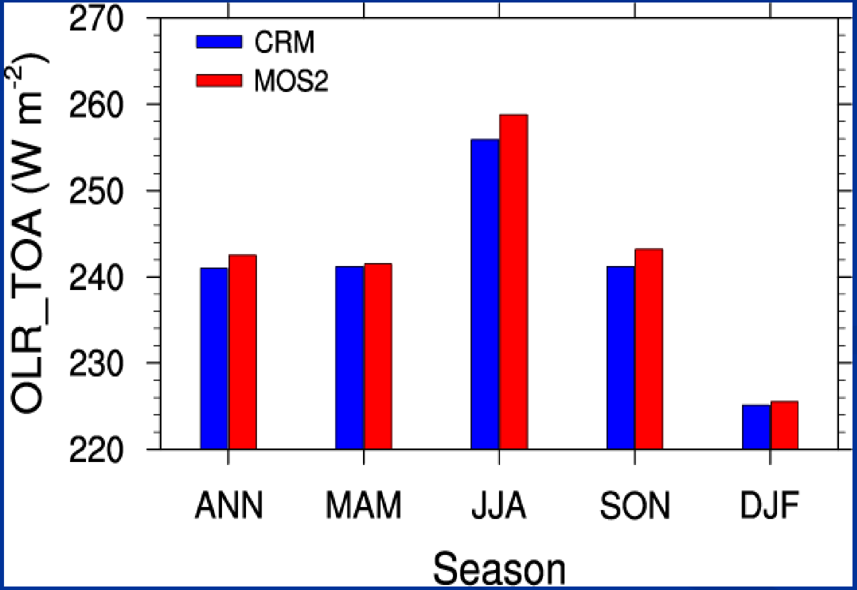
Cloud top < 6 km

Maximum-random

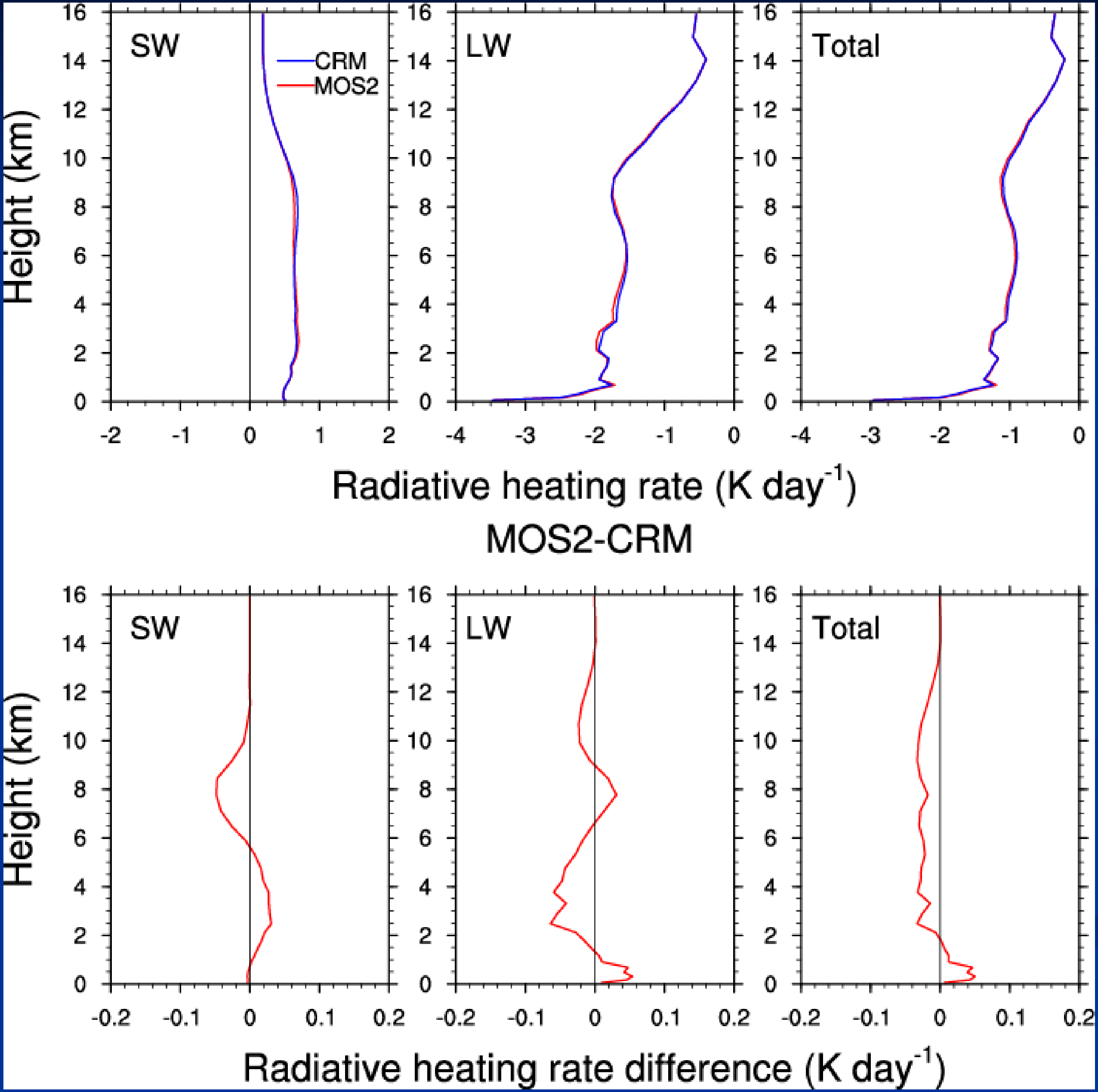


Upward shortwave and longwave fluxes at TOA during year 2000





Annual (year 2000) mean radiative heating rates



Summary

- **Seasonally varied cloud inhomogeneity in year-long CRM simulations is quantified using the reduction factor, which shows more inhomogeneous clouds in summer but more homogeneous clouds in winter.**

- **The parameterization of reduction factor in term of the total cloud fraction is able to account for the effects of cloud horizontal inhomogeneity on shortwave and longwave fluxes.**

- **Physically based mosaic approach of vertical overlap which treats characteristic structure differences between major cloud types can incorporate the cloud geometric association and optical inhomogeneity effects for the radiation calculation.**