Evaluation and Analysis of Long-Term CRM Simulations with ARM Observations

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The roles of cloud systems in the general circulation:

* Coupling dynamical and hydrological processes through the latent heat of condensation and evaporation and the redistribution of heat, moisture and momentum

* Coupling radiative and dynamical-hydrological processes through the reflection, absorption, and emission of radiation

* Affecting hydrological processes through precipitation

* Affecting the atmosphere-ocean coupling through modification of radiation and boundary-layer processes

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:

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

* Observed large-scale forcing:

$$\left(\frac{\partial \theta}{\partial t}\right)_{lsf} = -U\frac{\partial \Theta}{\partial x} - V\frac{\partial \Theta}{\partial y} - W\frac{\partial \Theta}{\partial z}$$

$$\left(\frac{\partial q_v}{\partial t}\right)_{lsf} = -U\frac{\partial Q_v}{\partial x} - V\frac{\partial Q_v}{\partial y} - W\frac{\partial Q_v}{\partial z}$$

Θ, Q_v, U, V, W **are observed temperature, moisture, and wind fields**

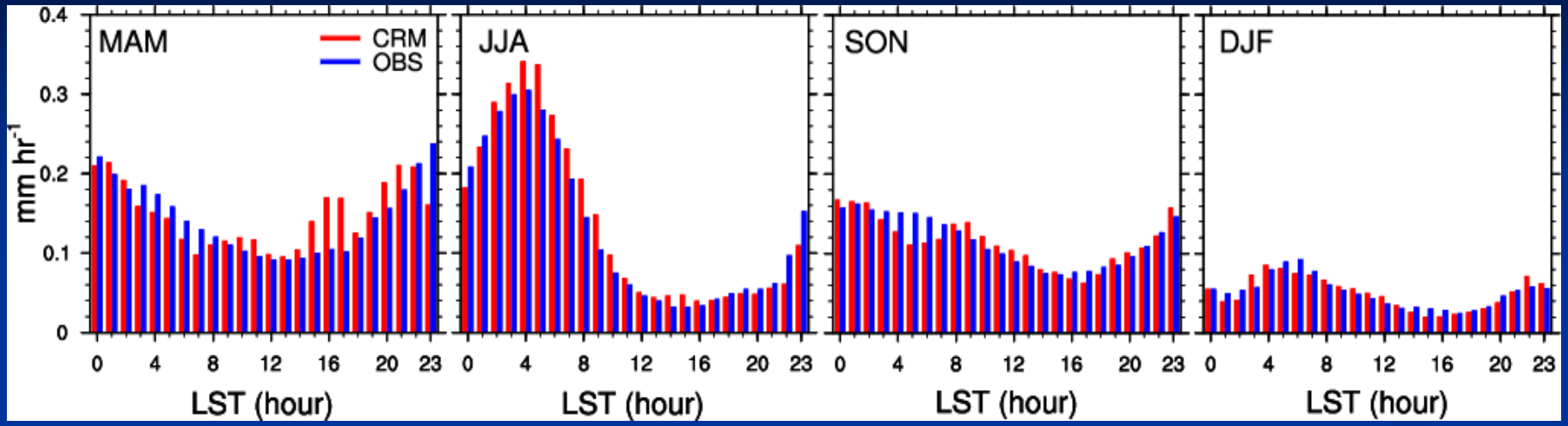
ARM value added observational products:

* Continuous forcing Data at the SGP site (Xie et al. 2004, JGR)

* Column Physical Characterization (CPC) product (Mace et al. 2006, JGR)

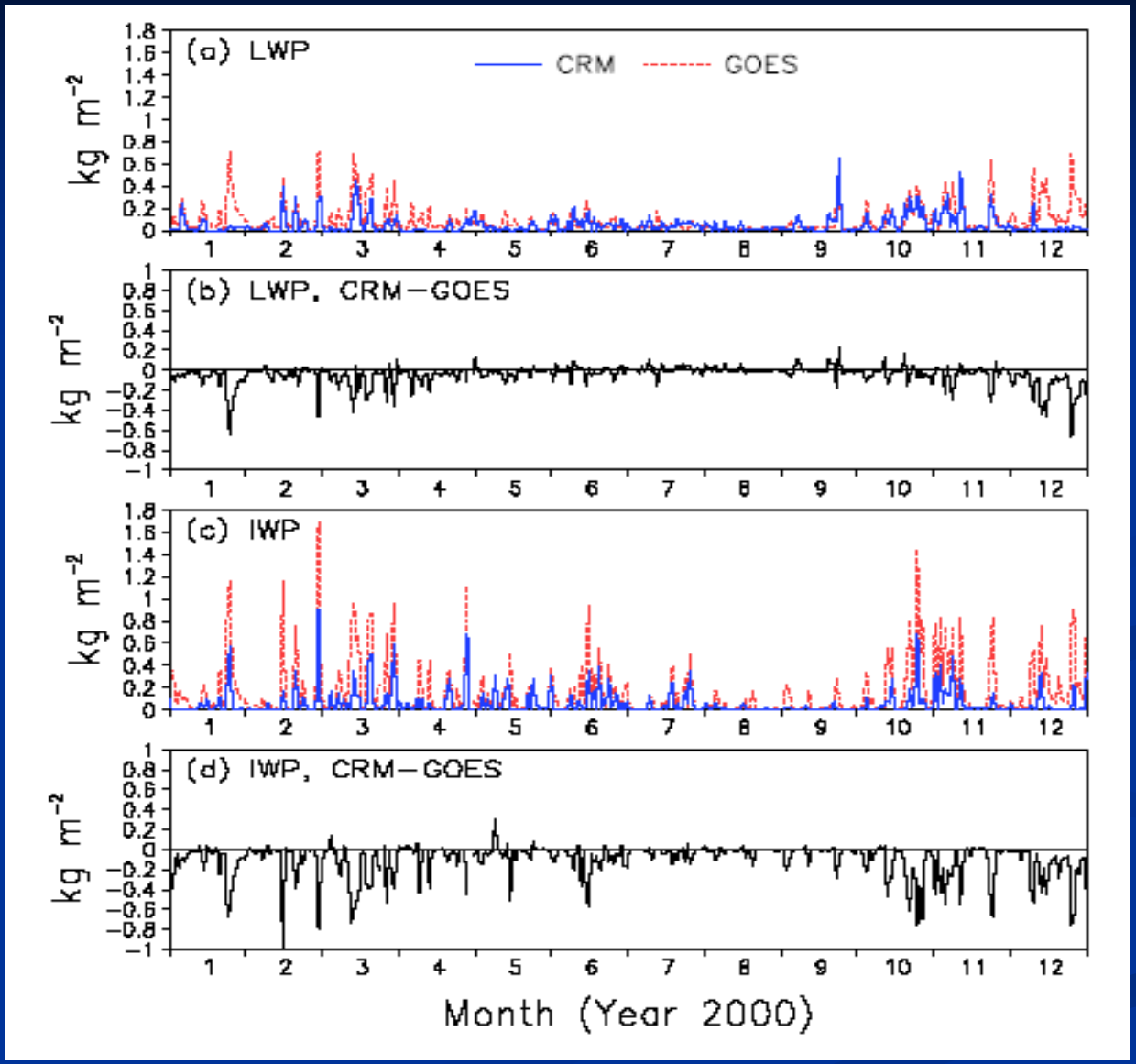
* Continuous baseline microphysical retrieval (MICROBASE) (Miller et al. 2003, Thirteenth ARM science team meeting proceedings)

* Multifilter rotating shadowband radiometer (MFRSR) (Min et al. 2004, JGR)



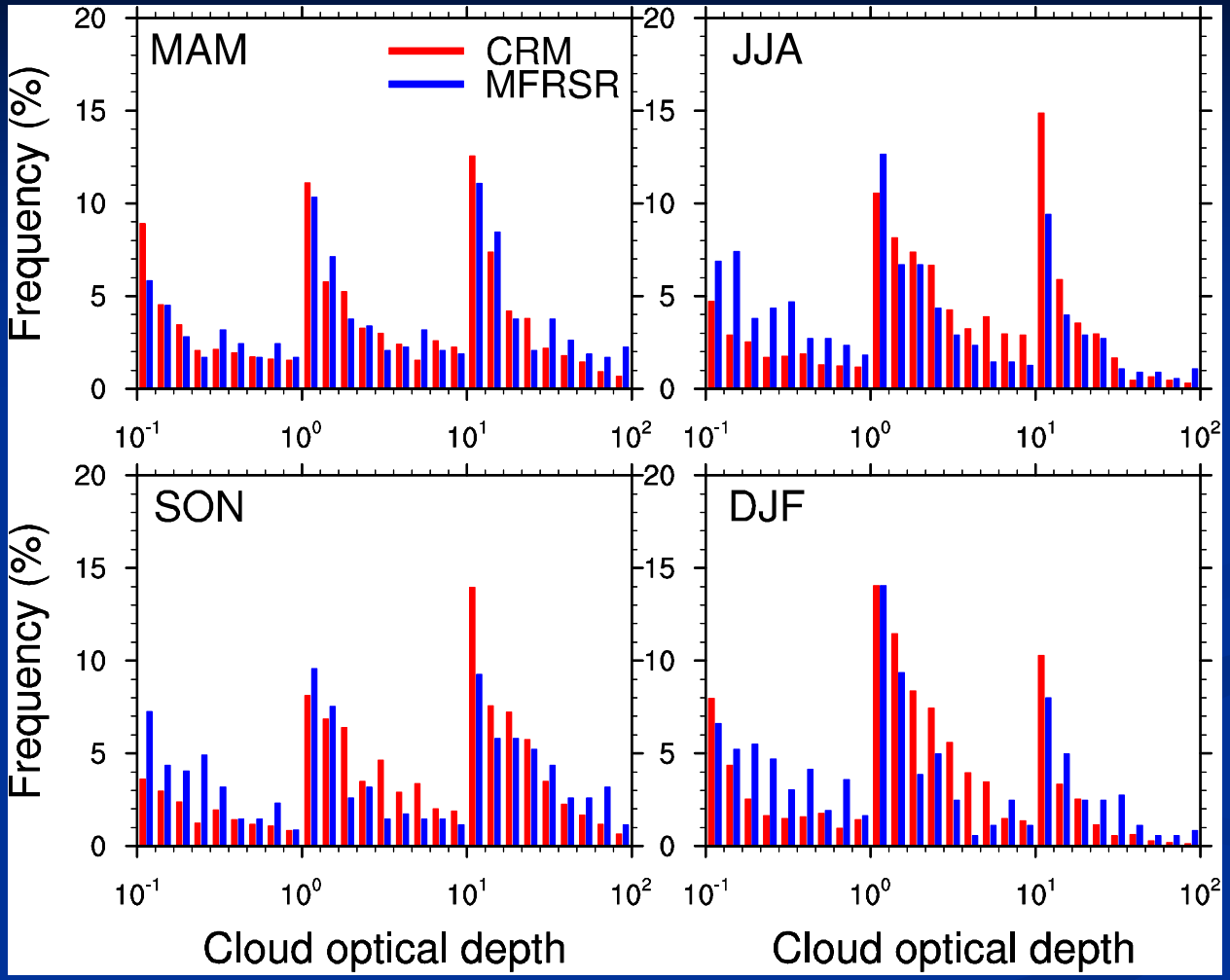
Diurnal variation of precipitation in four seasons: CRM and ARM show an early morning maximum rainfall and an afternoon minimum for summer (JJA) and winter (DJF), and a midnight maximum and an afternoon minimum for spring (MAM) and fall (SON) (Wu et al. 2008, JAS).

Liquid and ice water paths (kg m^{-2})



Wu et al. (2008, JAS), Minnis et al. (2007, JGR)

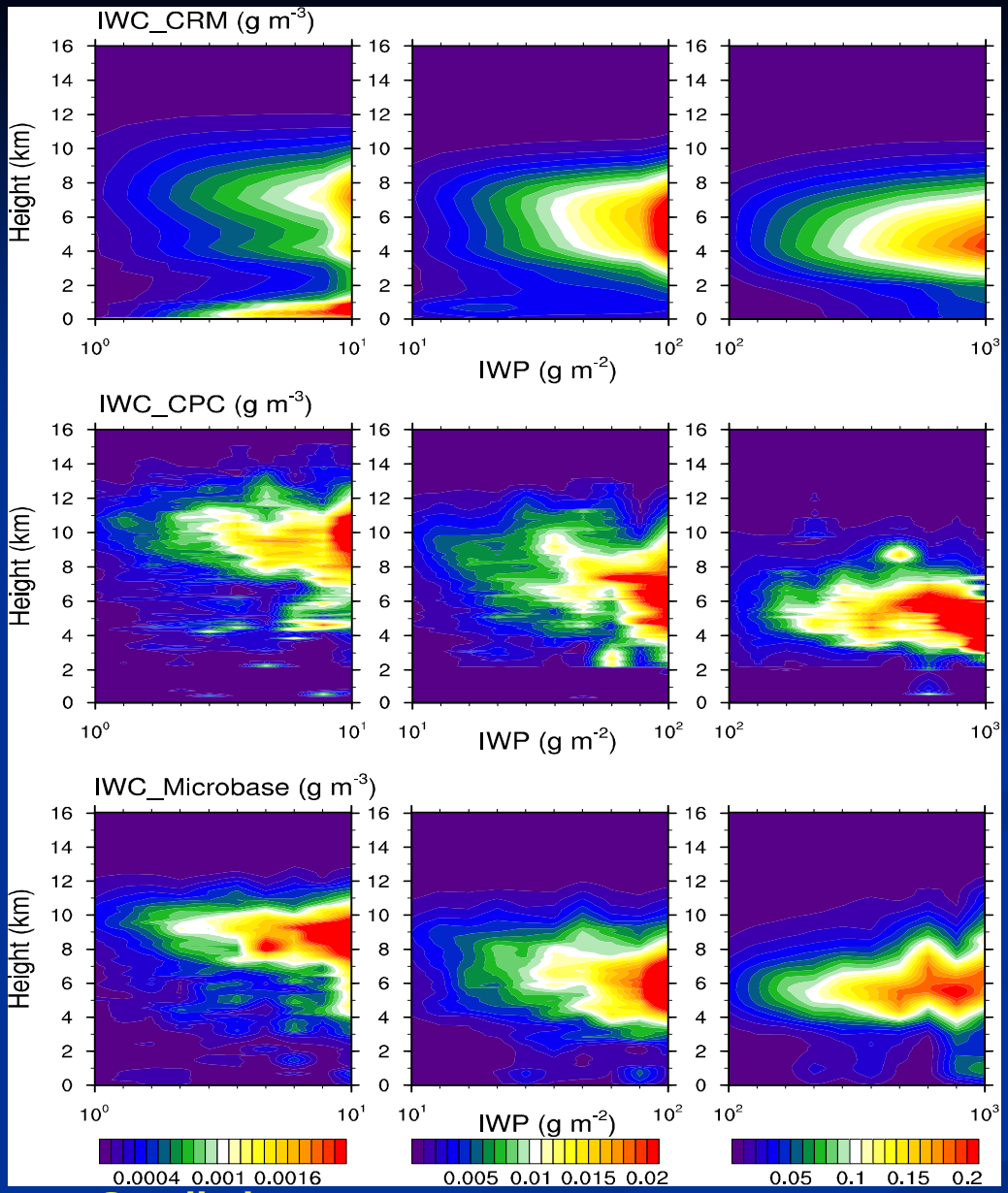
All-sky condition during daytime of year 2000



Widths of bins are 10, 1 and 0.1 for three sizes: large (10-100), medium (1-10) and small (0.1-1), respectively.

Park et al. (2010)

Vertical profiles of Ice Water Content under overcast and non-precipitating conditions during year 2000



Height (km)

CRM

CPC

MICROBASE

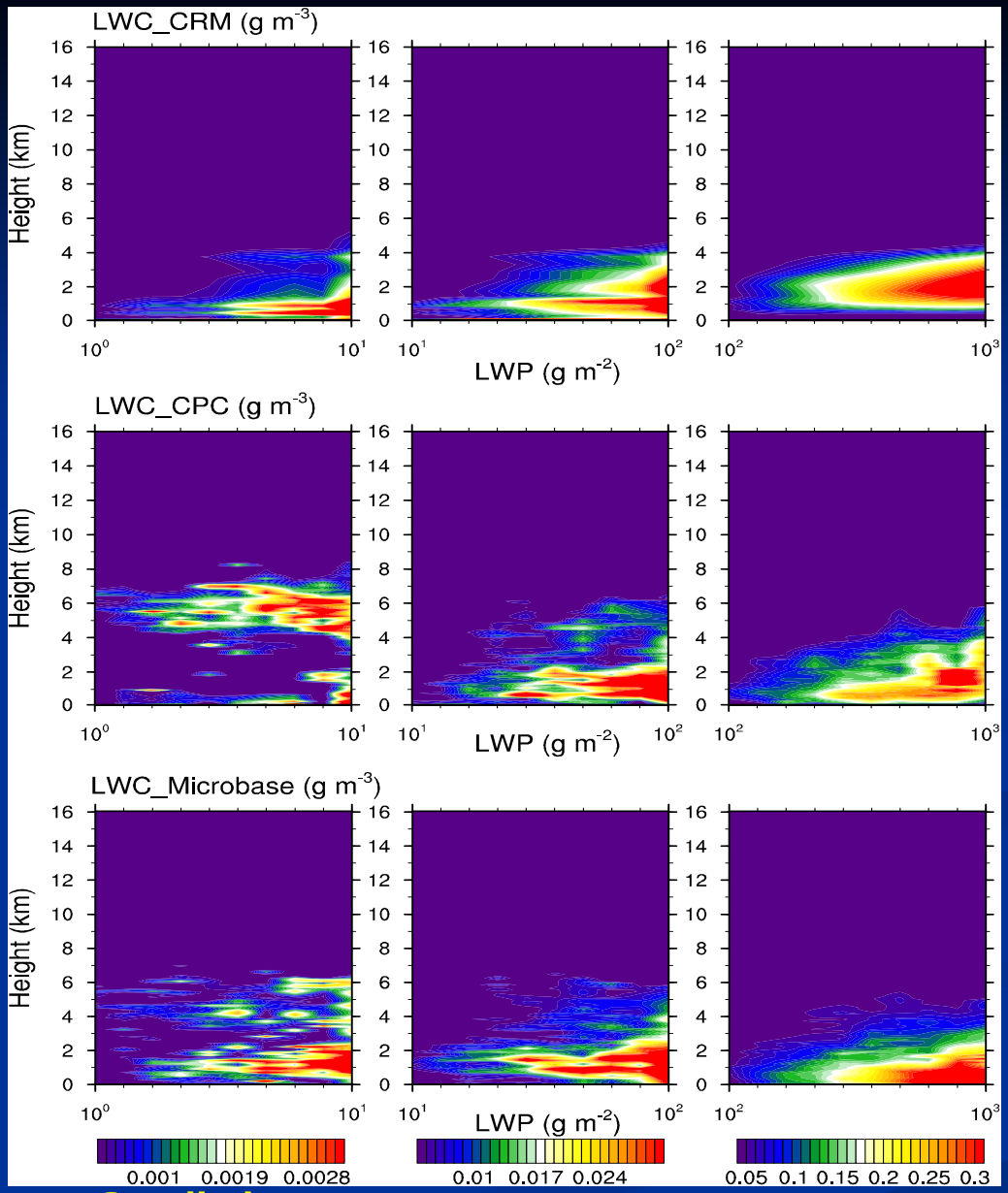
Small size (1-10 g m^{-2}) Bin width (1 g m^{-2})

Medium size (10-100 g m^{-2}) Bin width (10 g m^{-2})

Large size (100-1000 g m^{-2}) Bin width (100 g m^{-2})

Park et al. (2010)

Vertical profiles of Liquid Water Content under overcast and non-precipitating conditions during year 2000



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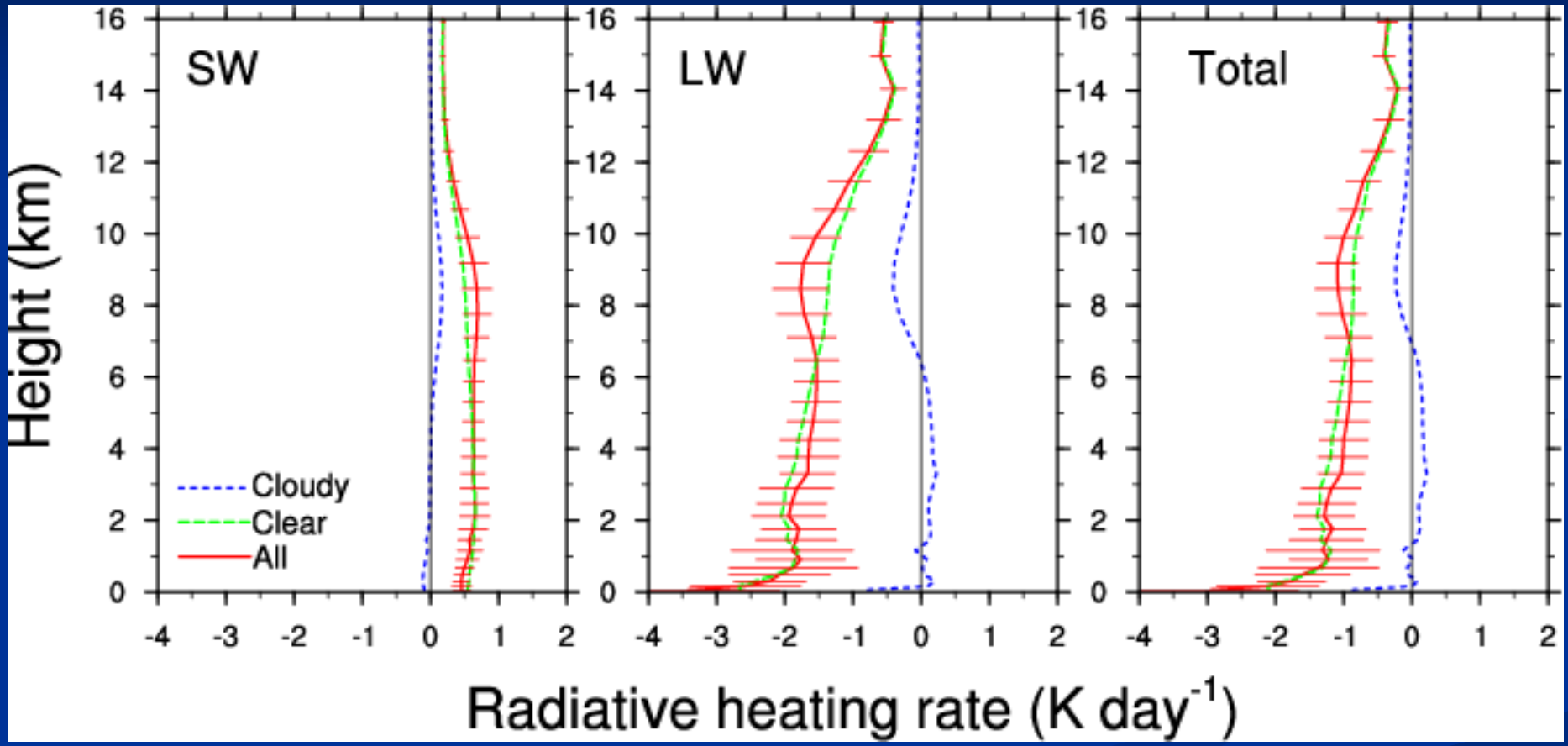
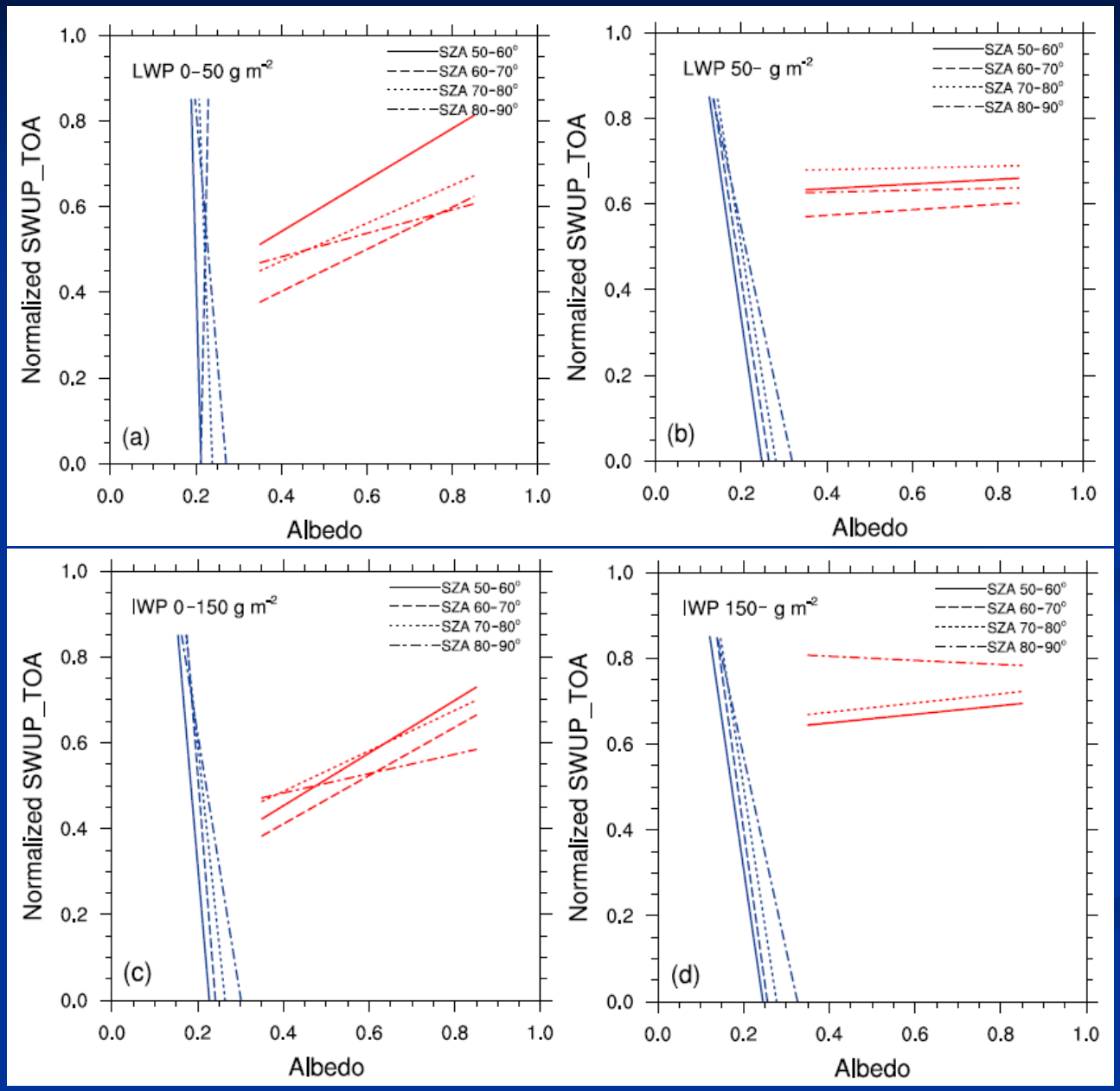
Park et al. (2010)

Year 2000 mean radiative heating rate (K day^{-1})

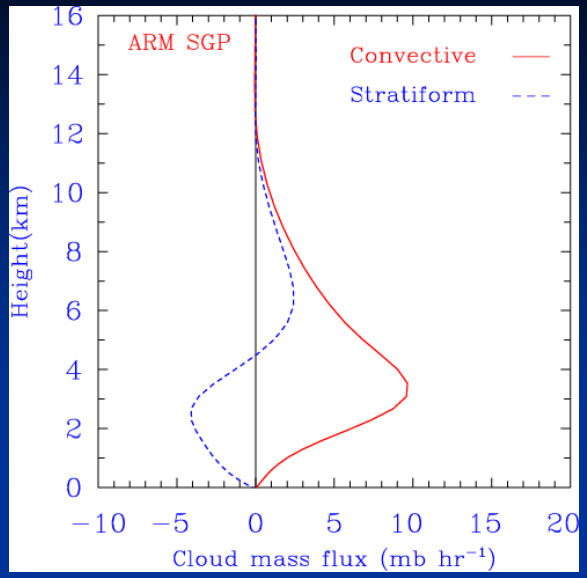


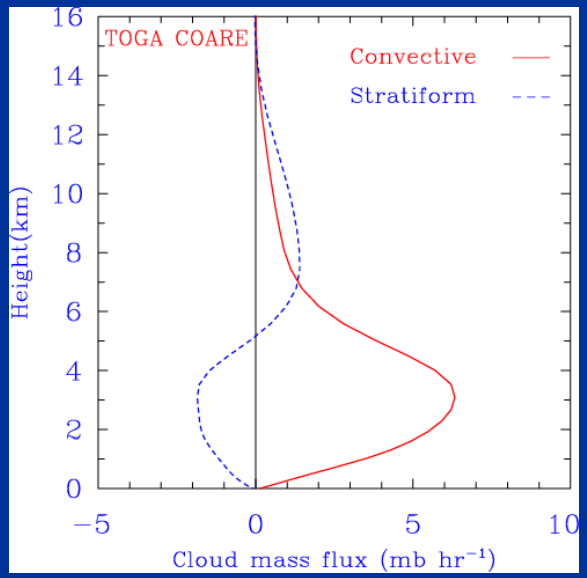
Wu et al. (2008, JAS)

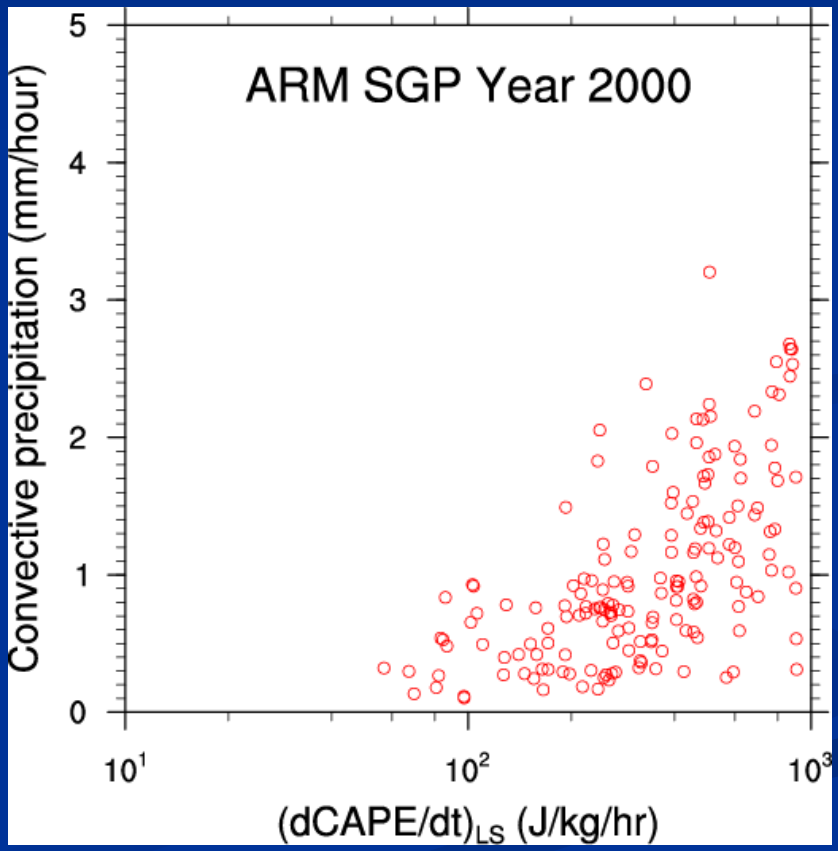
Relationship between the surface albedo, cloud properties and radiative fluxes (Park and Wu 2010, JAS)



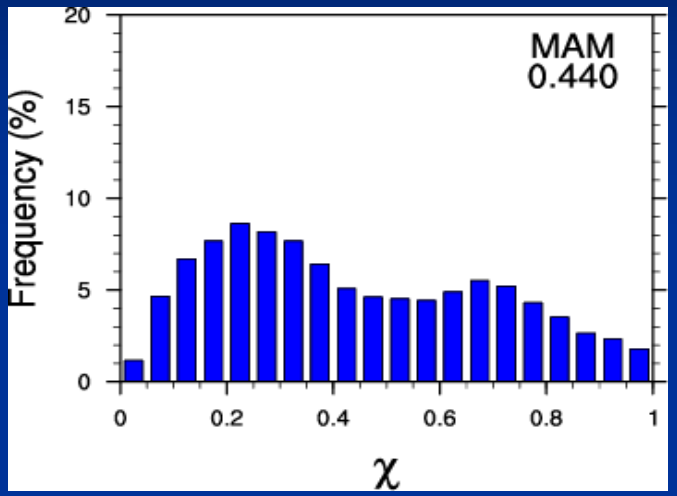
Relationship between the convective precipitation and the CAPE change due to the temperature and moisture advection

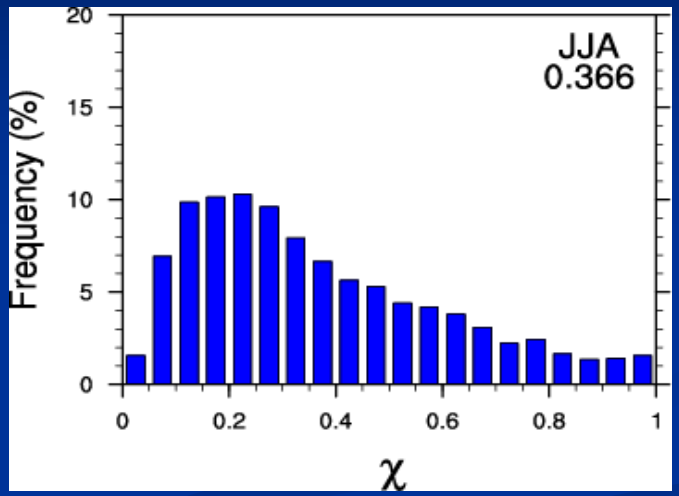


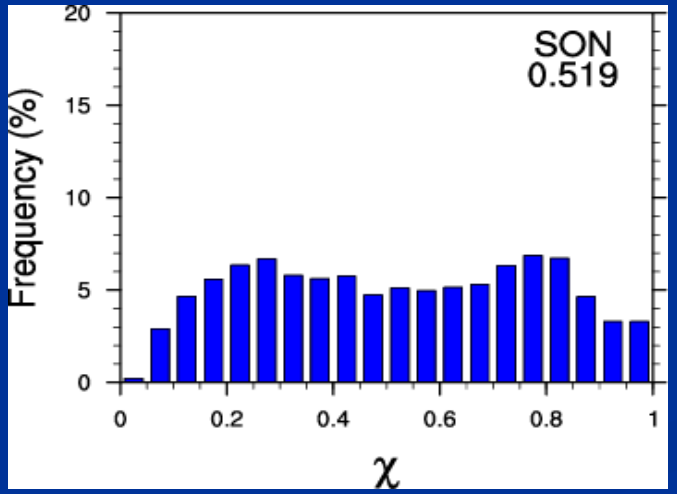


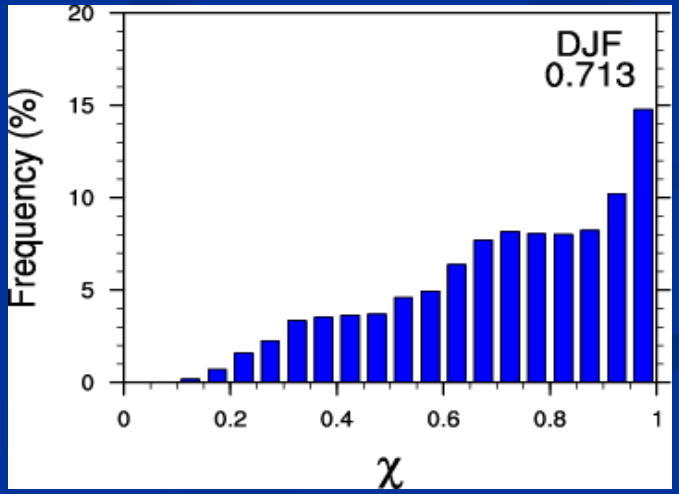


Cloud inhomogeneity parameter $\chi = e^{\overline{\ln \tau}} / \overline{\tau}$ is defined as the ratio of the logarithmic and linear average of a cloud optical depth distribution (Cahalan et al. 1994)

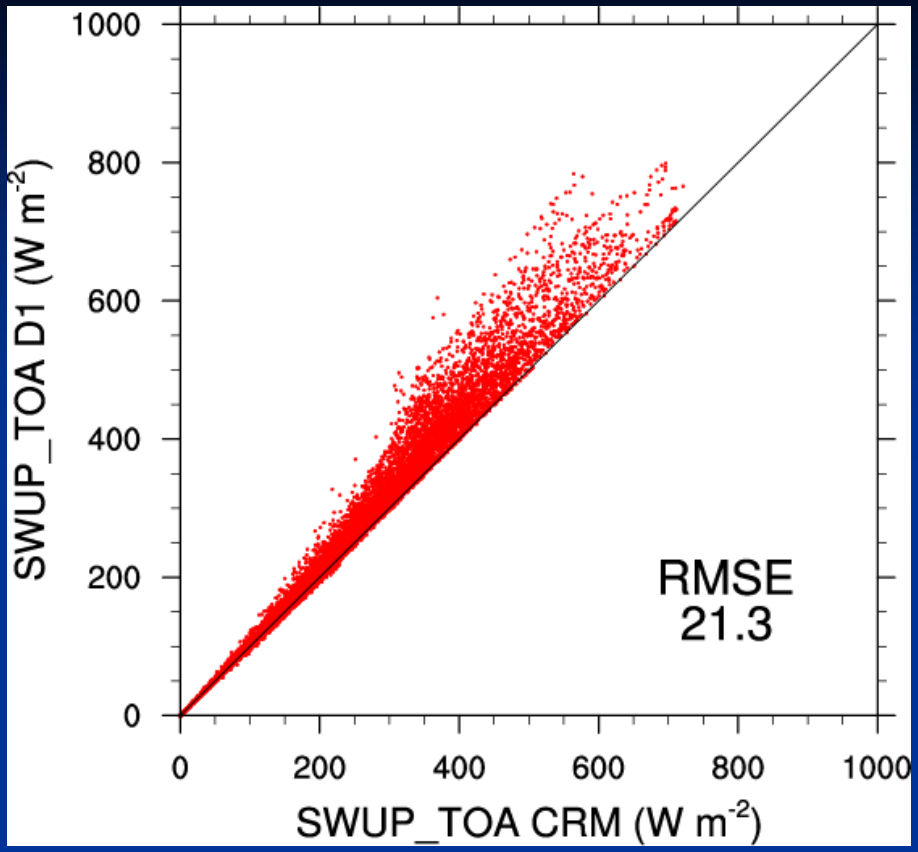


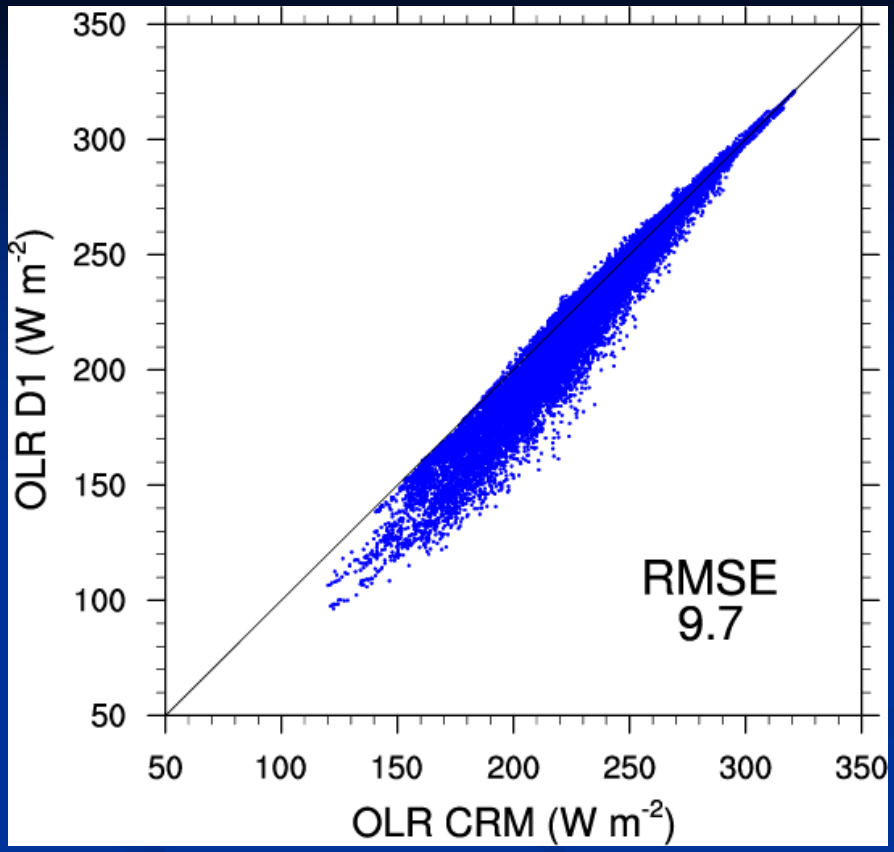






Park and Wu (2010)



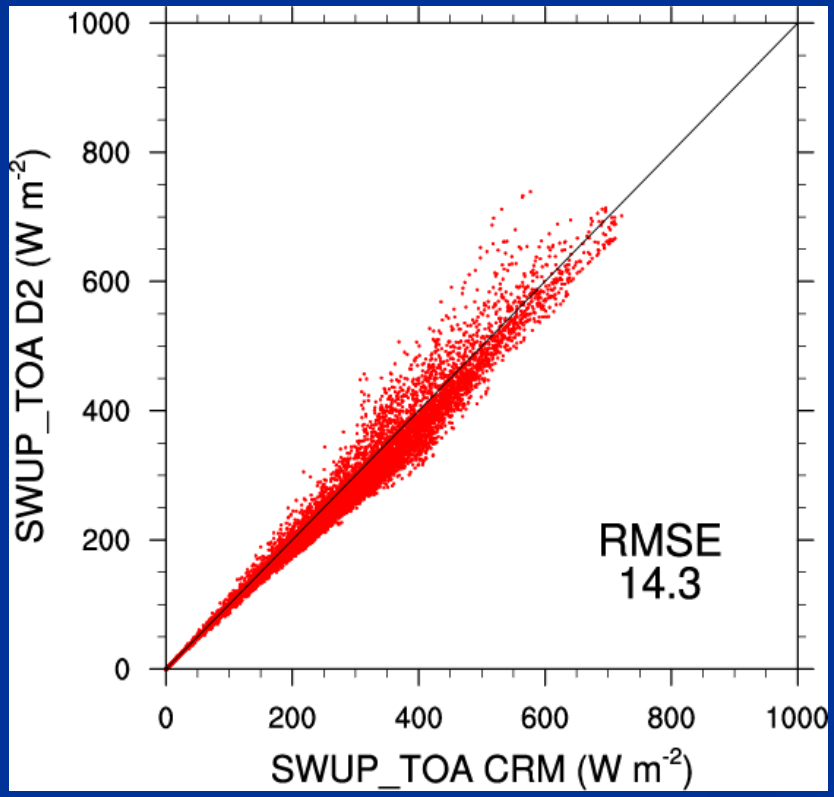


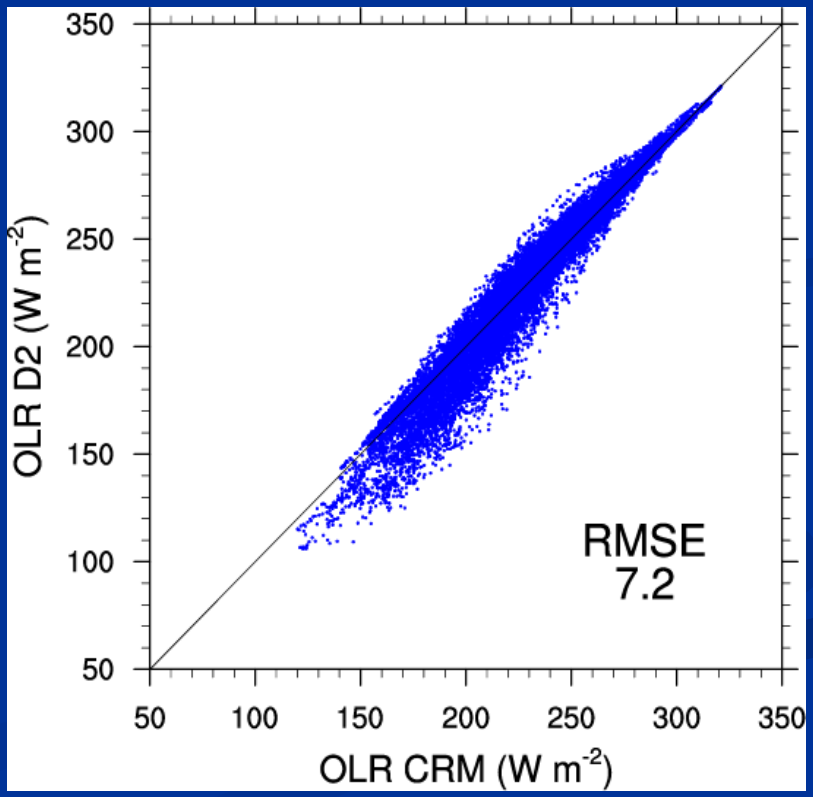
Scatter diagrams of CRM vs. D1 (diagnostic radiation calculation with homogeneous clouds) for the upward SW flux and OLR at the top of the atmosphere (TOA) during year 2000 show that the inhomogeneity effects decrease the SW reflection and increase the outgoing LW at the TOA.

Park and Wu (2010)

Parameterization of cloud inhomogeneity

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





Park and Wu (2010)

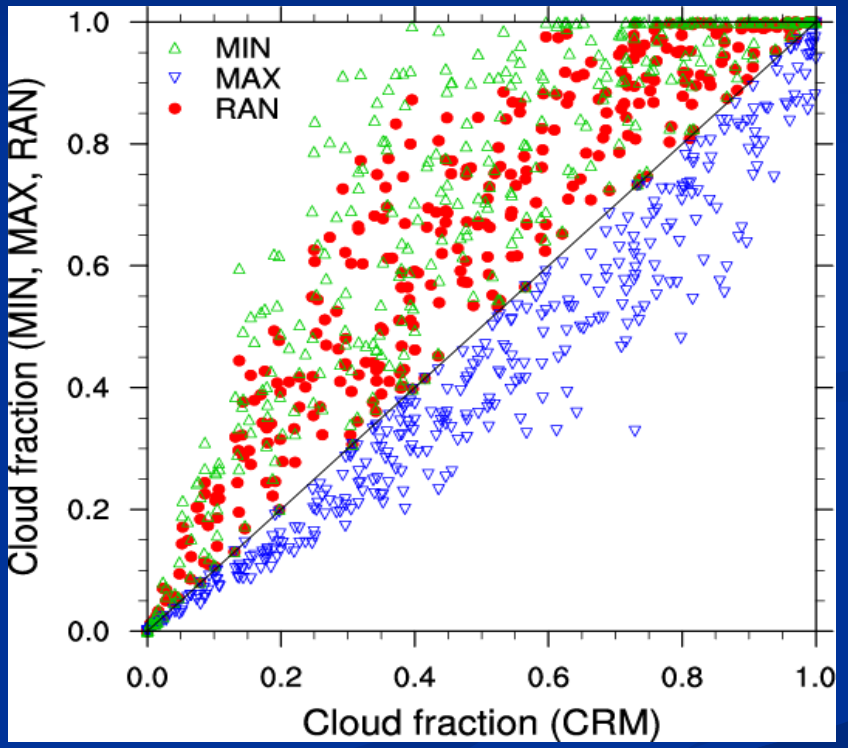
Assuming $A_1, A_2, \ldots\ldots, A_n$ are the cloud amounts for each layer, respectively, the total cloud cover (TC) computed from the minimum, maximum, and random overlap assumptions are,

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

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

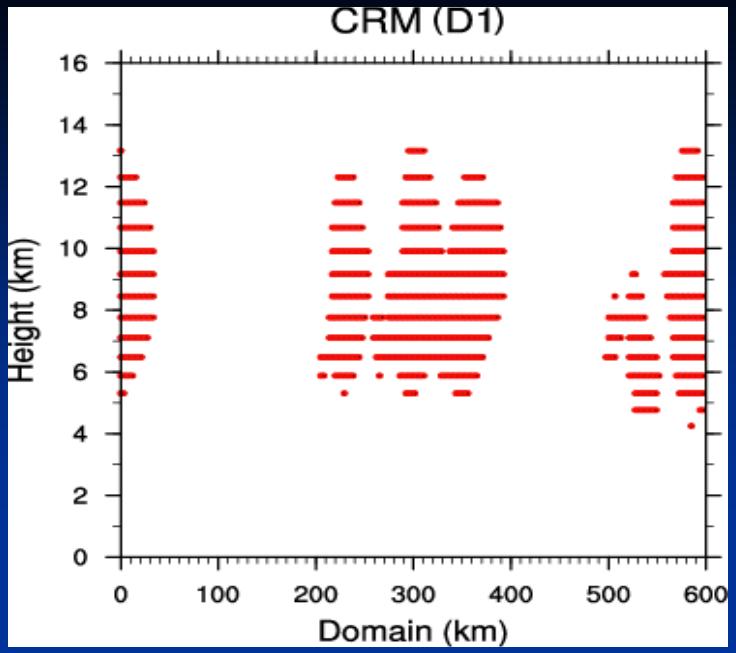
$$TC_{RAN} = 1 - (1 - A_1)(1 - A_2)\cdots(1 - A_n)$$

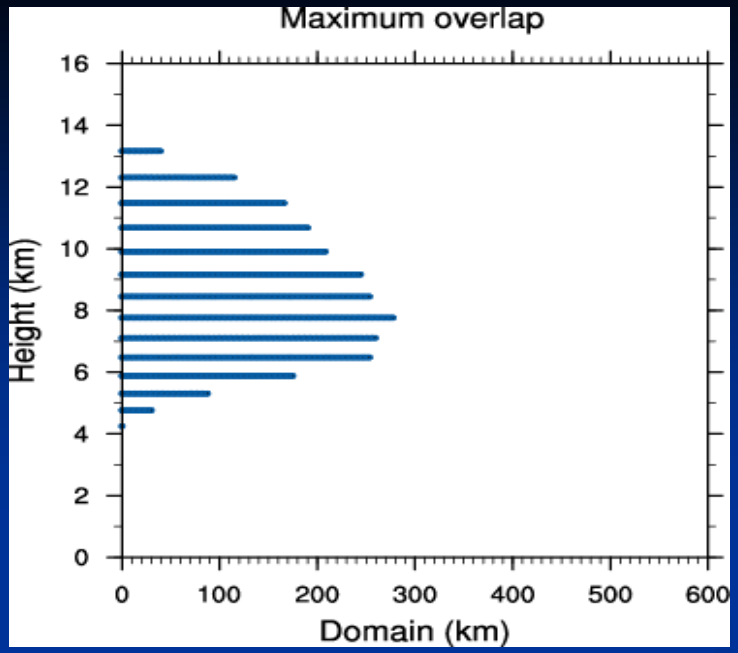
(Tian and Curry 1989)

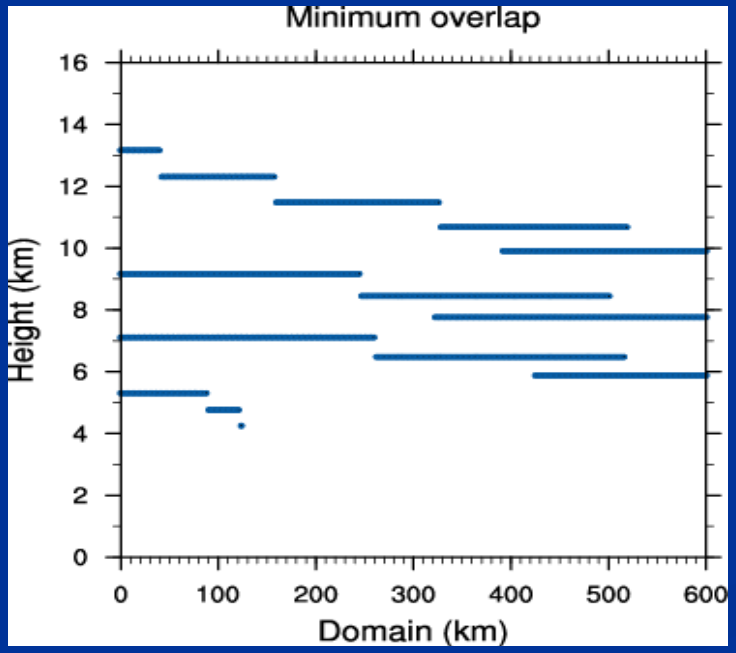


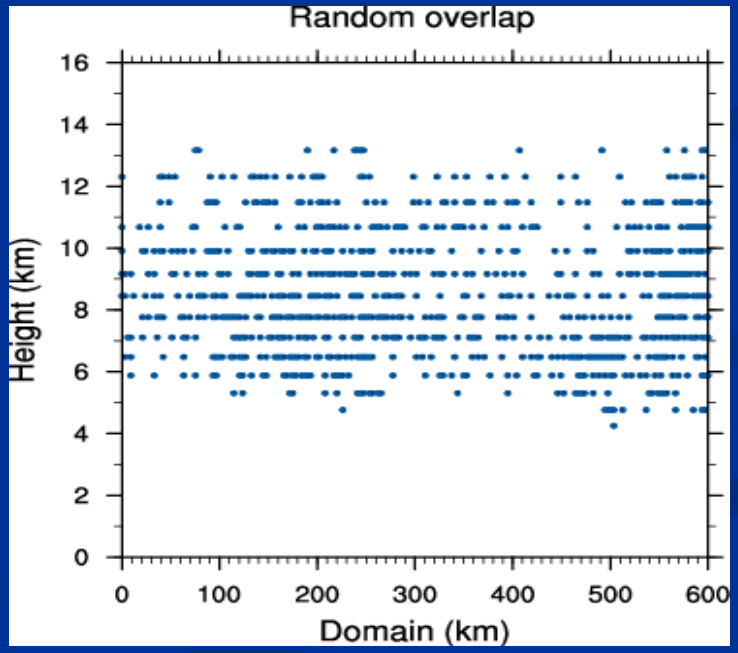
All-sky condition during year 2000

Park and Wu (2010)









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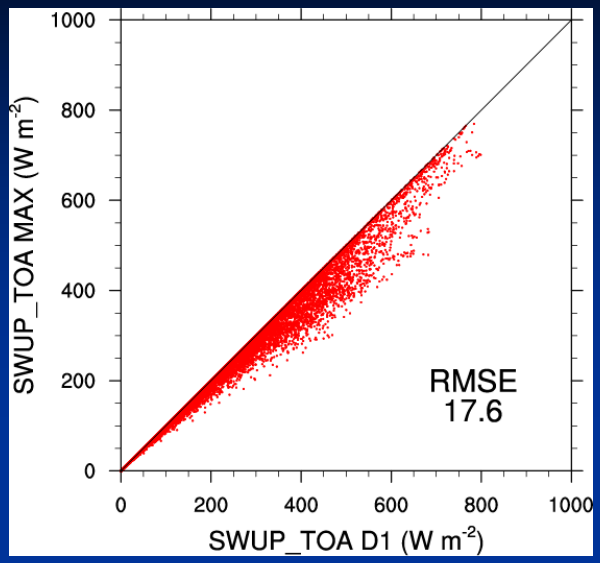
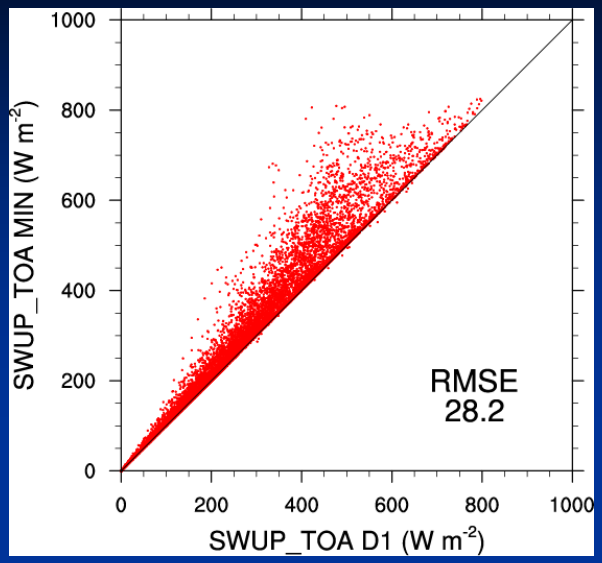
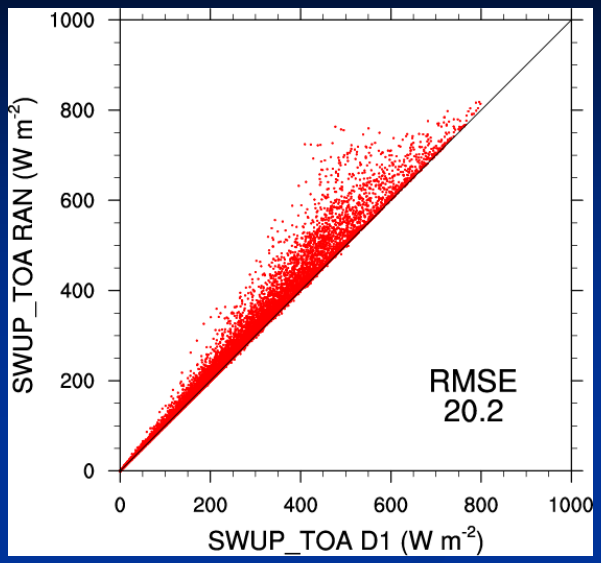
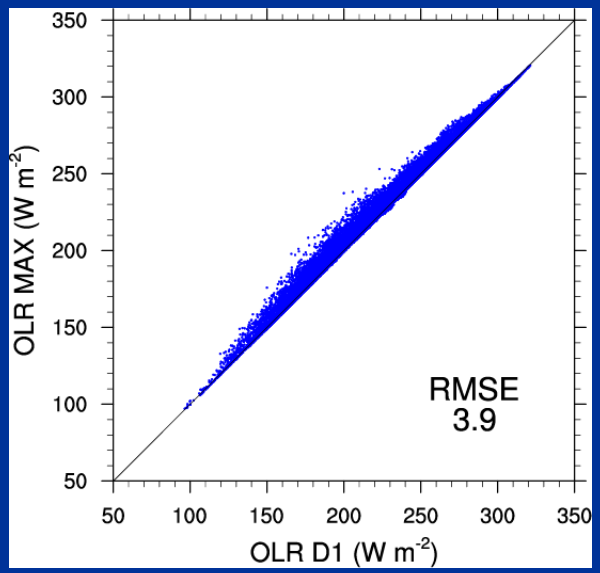
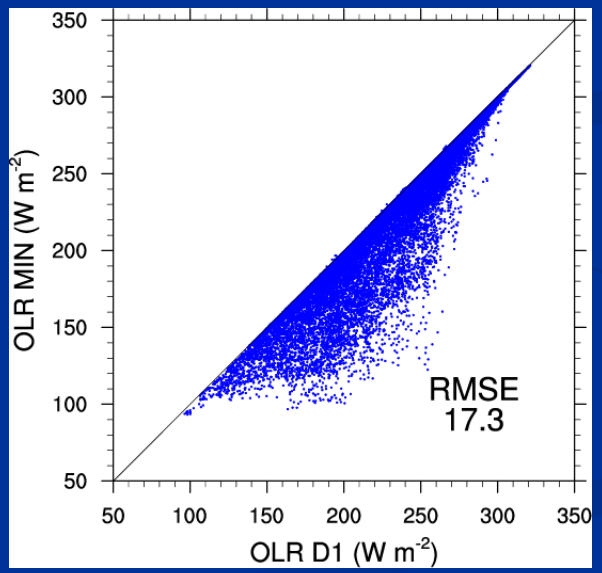
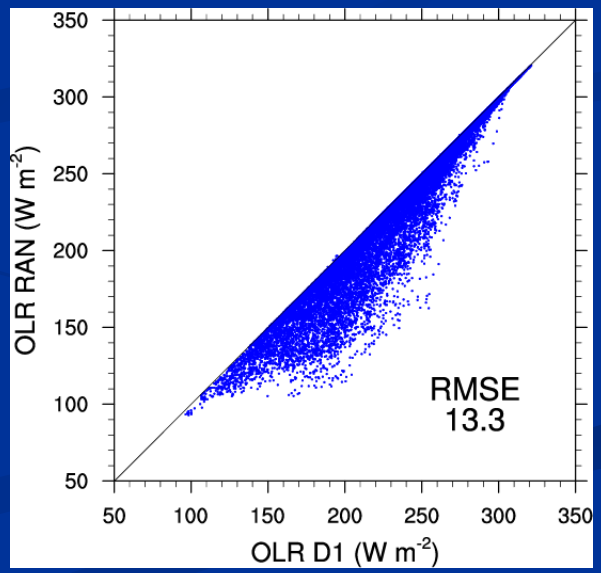






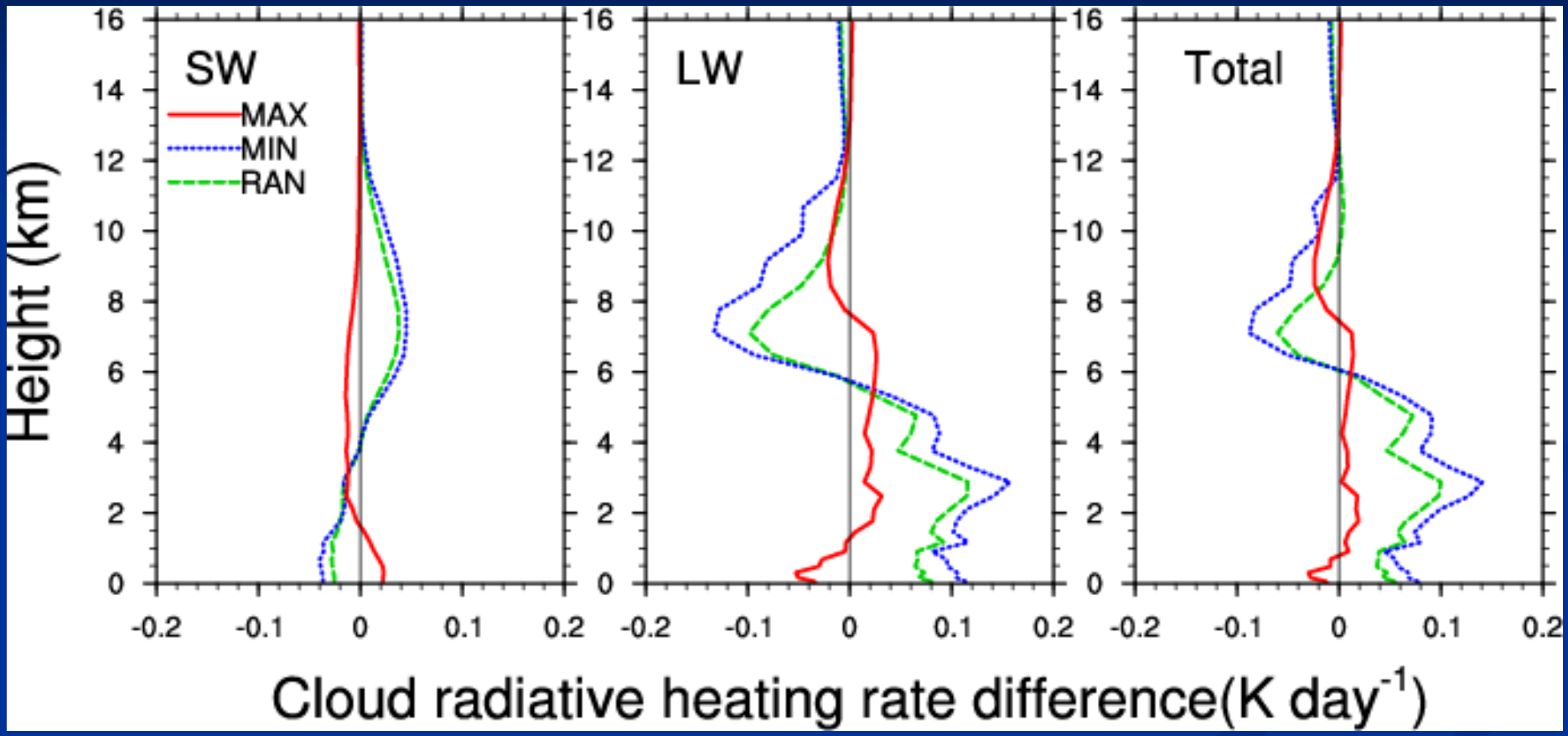






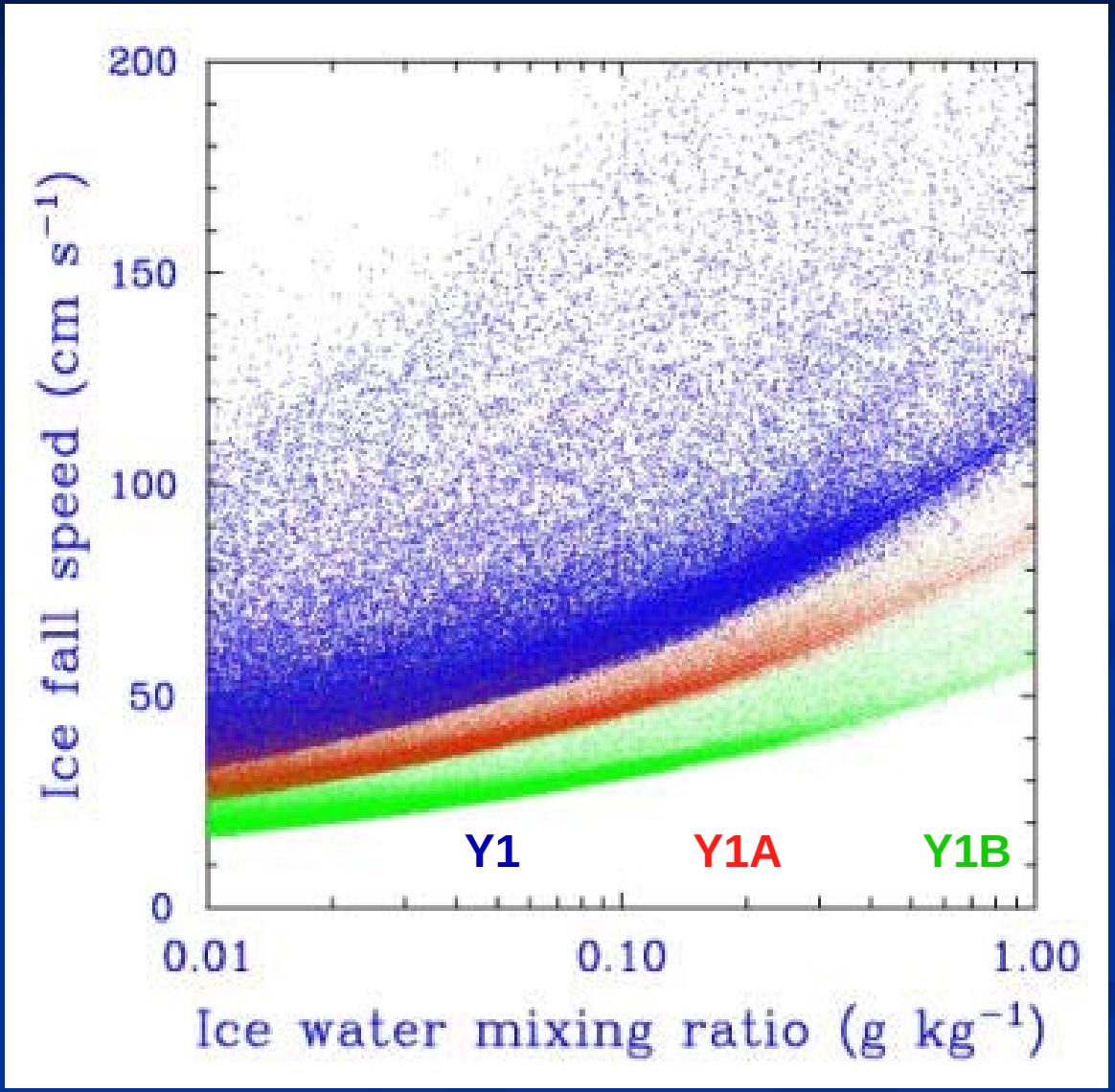
Park and Wu (2010)

Differences of heating rate between MAX, MIN, RAN and CRM (D1)

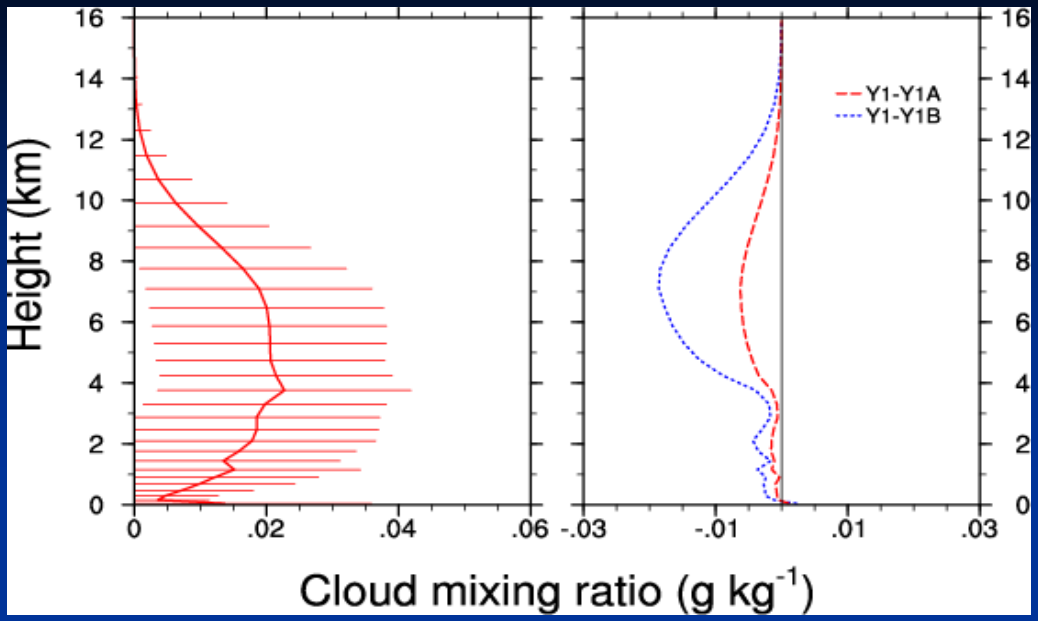


Park and Wu (2010)

Sensitivity of year-long CRM simulations to ice fall speeds



Annual mean cloud (liquid and ice) water mixing ratio (g kg^{-1}) at ARM SGP



Annual mean radiative heating rates (K day^{-1}) at ARM SGP