Towards producing multi-year cloud properties and radiative heating rates for evaluating GCMs over ARM SGP and TWP

Xiaoqing Wu

Department of Geological and Atmospheric Sciences
Iowa State University (ISU)

Liping Deng and Sunwook Park (ISU)
Qilong Min (State University of New York at Albany)

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Clouds and humidity remain sources of significant uncertainty but there have been incremental improvements in simulations of these quantities.

----2001 IPCC Third Assessment Report

Significant uncertainties, in particular, are associated with the representation of clouds, and in the resulting cloud responses to climate change. Consequently, models continue to display a substantial range of global temperature change in response to specified greenhouse gas forcing.

----2007 IPCC Fourth Assessment Report

* The lack of observations of long-term cloud properties and radiative heating rates under different climate regimes is partly responsible for the slow progress in representing convection, cloud and radiative processes in GCMs.

* Produce thermodynamically and dynamically consistent multi-year cloud properties and radiative heating rates at ARM SGP and TWP sites with CRM simulations.

* Use the CRM and GCM that integrate ARM observations to improve the simulations of cloud systems and understand their impacts on climate mean state and variability.

I. Evaluating CRM simulations against observations

ISU Cloud-Resolving Model (CRM)

* 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)

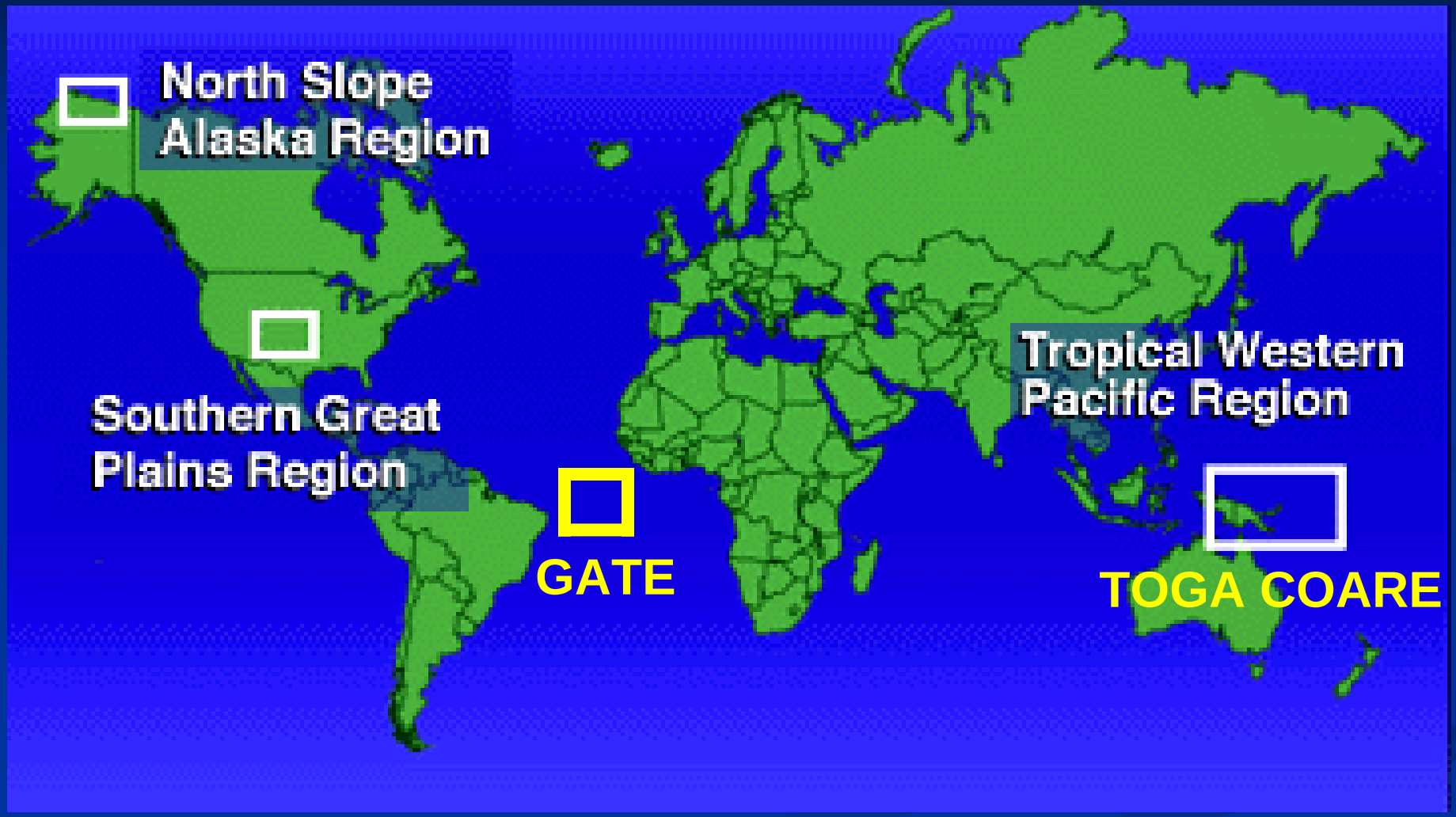
* Observed large-scale forcing:

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

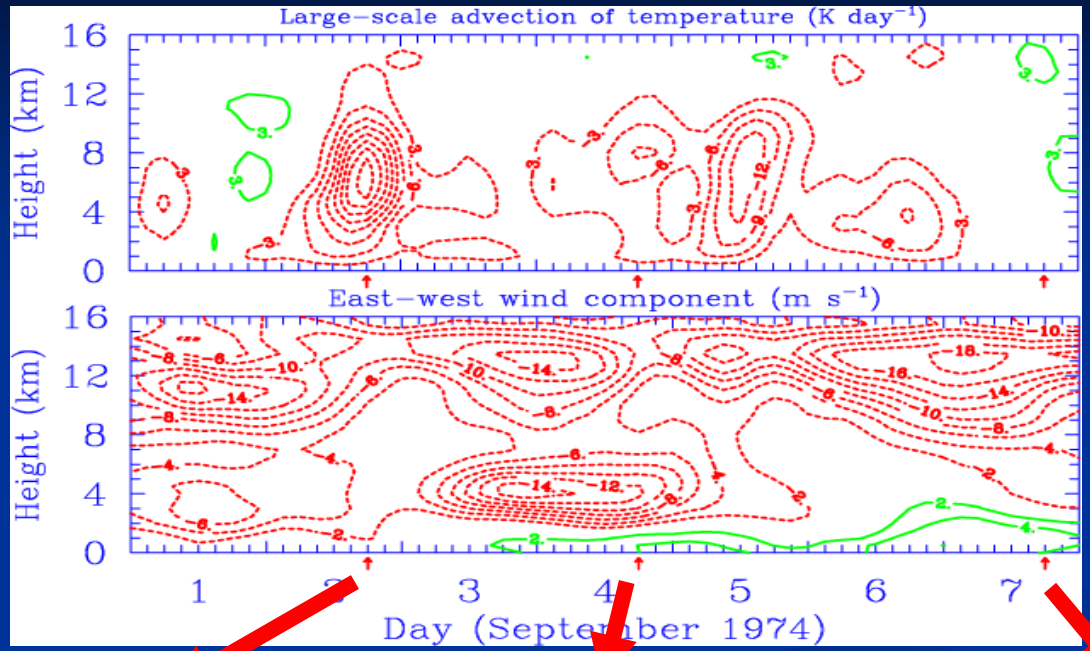
$$\left(\frac{\partial q_v}{\partial t}\right)_{lsf} = -U\frac{\partial Q_v}{\partial x} - V\frac{\partial Q_v}{\partial y} - W\frac{\partial Q_v}{\partial z}$$

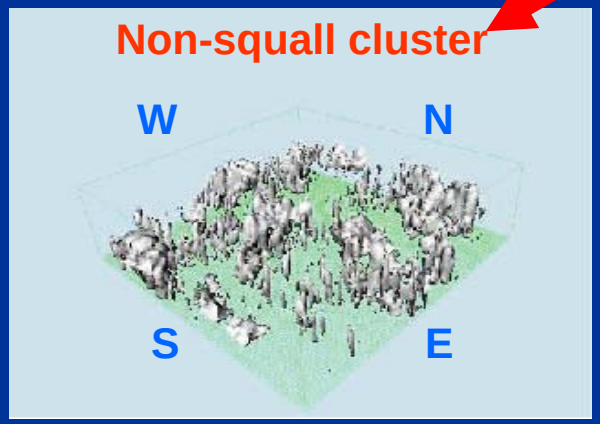
Θ, Q_v, U, V, W are observed temperature, moisture, and wind fields, respectively.

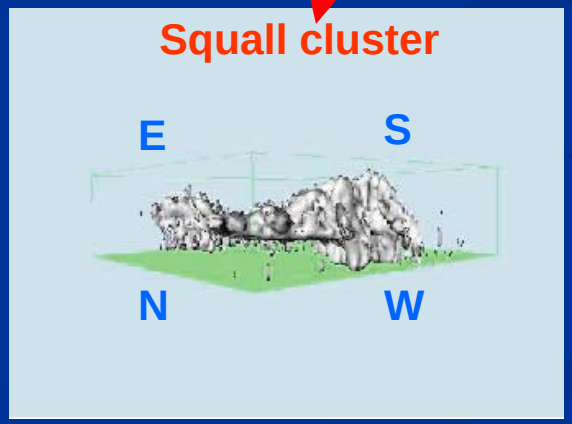
Grabowski, Wu and Moncrieff (1996, JAS)

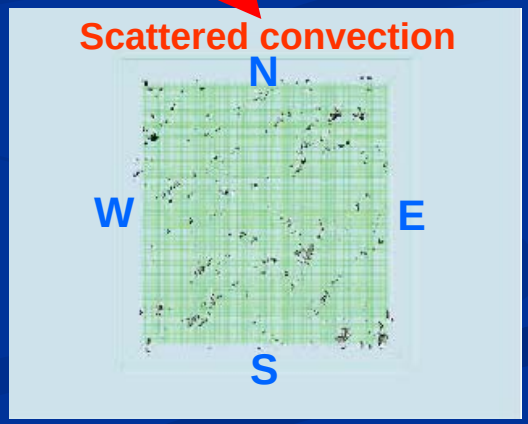

North Slope
Alaska Region
Southern Great
Plains Region
GATE
Tropical Western
Pacific Region
TOGA COARE

GATE week-long CRM simulations









400 km x 400 km domain with 2-km horizontal resolution

Wu and Moncrieff (1996), Grbowski, Wu, and Moncrieff (1998)

TOGA COARE month-long CRM simulations

W m^{-2}	FC	GMS1	GMS2	CRM	SCM
Q_{LW}(TOA)	-198.8	-200.4	-205.1	-195.8	-211.7
Q_{SW}(TOA)	269.5	294.4	274.4	274.8	312.4

30-day mean net top of the atmosphere (TOA) radiative fluxes (W m^{-2}) from observations (FC, GMS1, and GMS2), CRM and SCM.

W m^{-2}	OBS	SSMI/GMS	CRM	SCM
Q_{LW}(SFC)	-51.6	-48.2	-48.2	-57.0
Q_{SW}(SFC)	178.6	173.2	179.3	227.7

30-day mean net surface (SFC) longwave (LW) and shortwave (SW) fluxes from observations (OBS and SSMI/GMS), CRM and SCM.

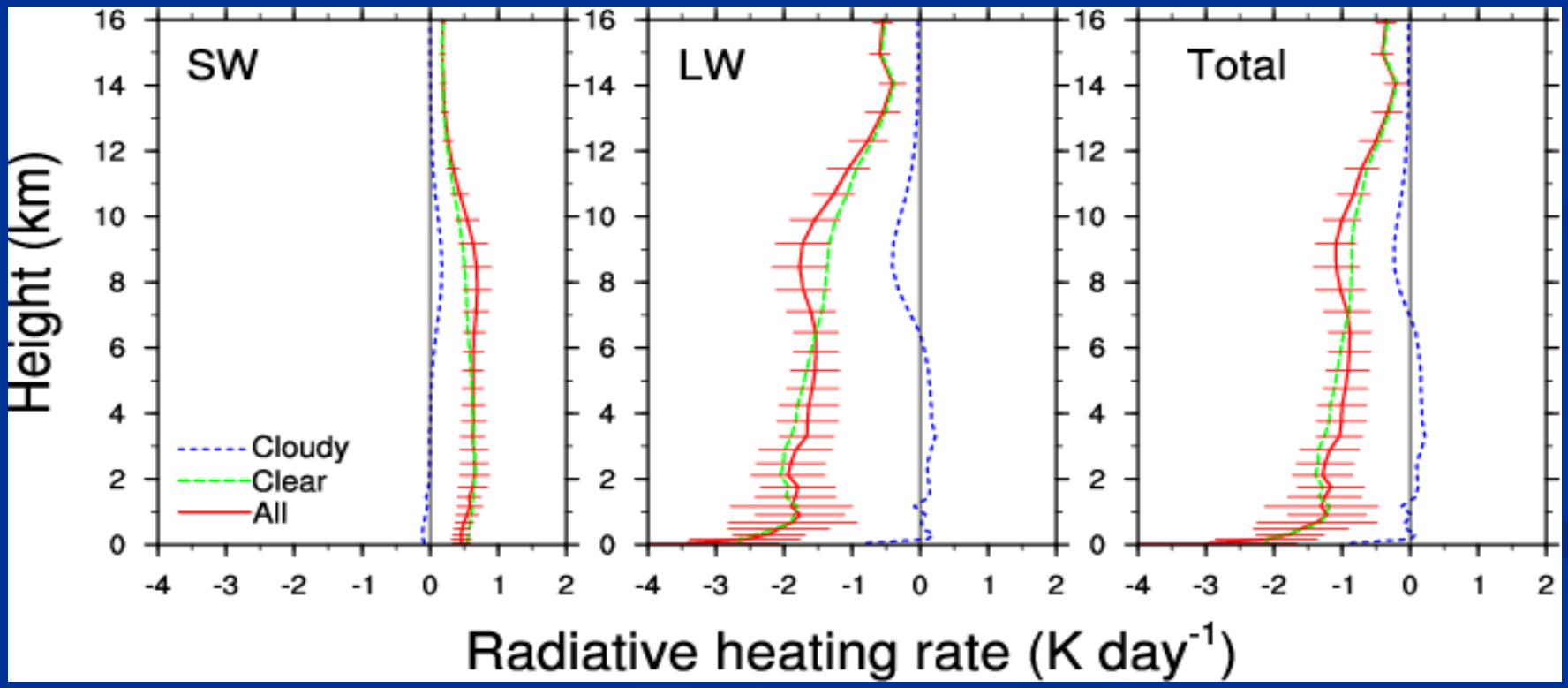
Wu and Moncrieff (2001, JAS)

ARM year-long CRM simulations

"Seasonal Variation of Cloud Systems over ARM SGP"

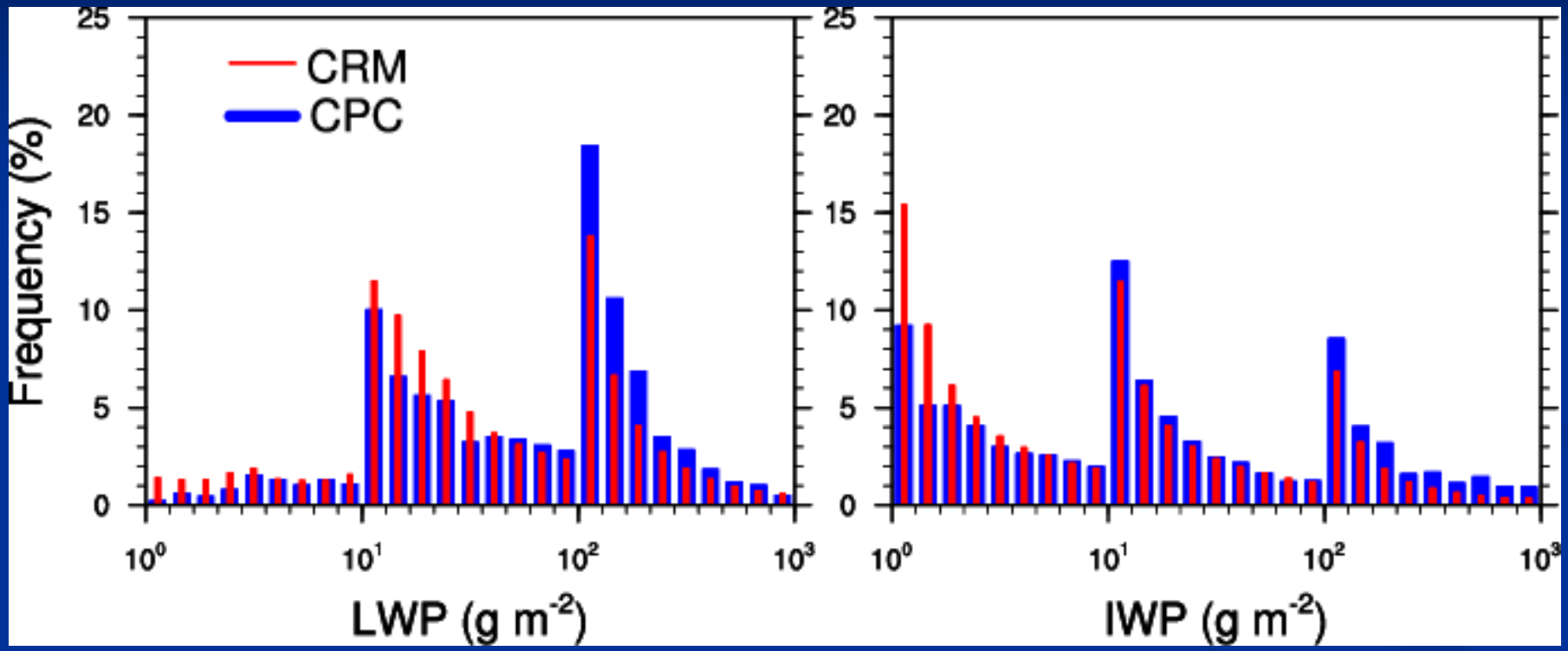
Wu, Sunwook, and Min (2008, JAS)

Year-2000 mean radiative heating rates



ARM year-long CRM simulations

Frequency histograms of hourly liquid water path (LWP) and ice water path (IWP)

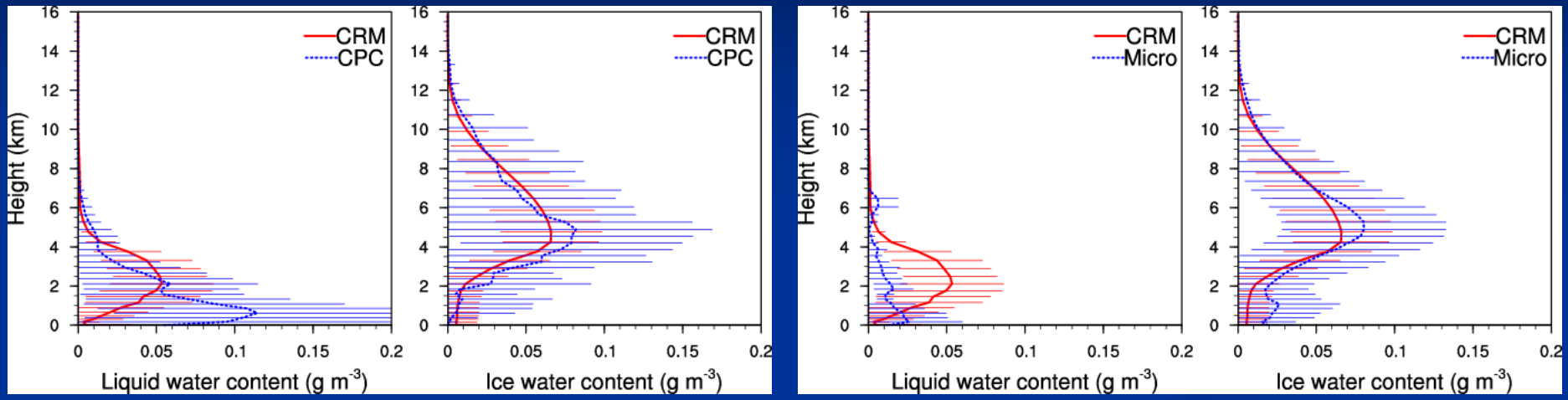


The widths of the size bins are 100 g m^{-2}, 10 g m^{-2} and 1 g m^{-2} for three categories, large size of 100-1000 g m^{-2}, medium size of 10-100 g m^{-2}, and small size of 1-10 g m^{-2}, respectively.

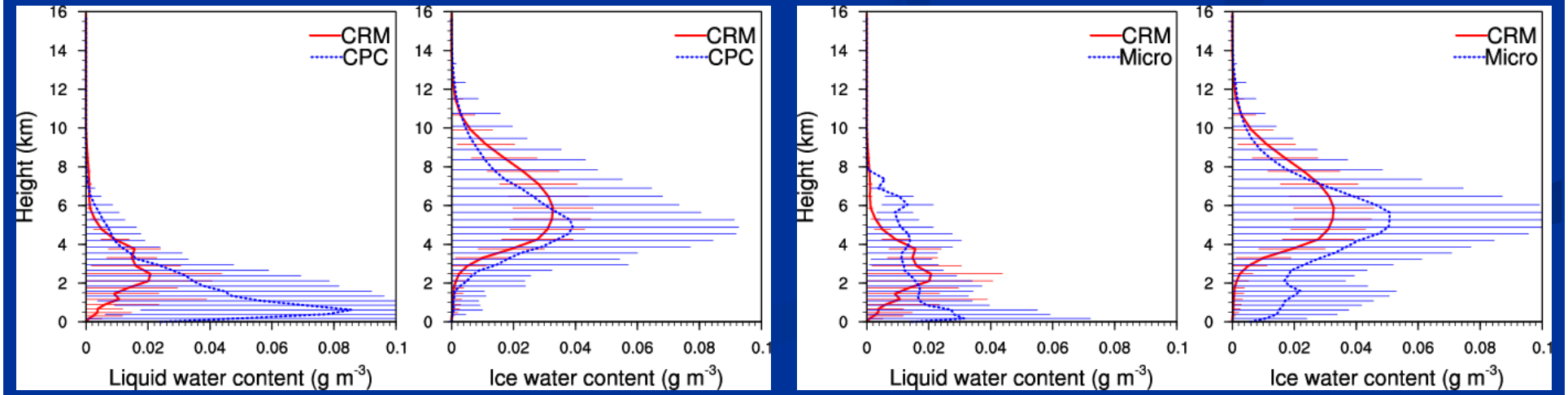
CPC: Column Physical Characterization product (Mace et al. 2006, JGR)

ARM year-long CRM simulations

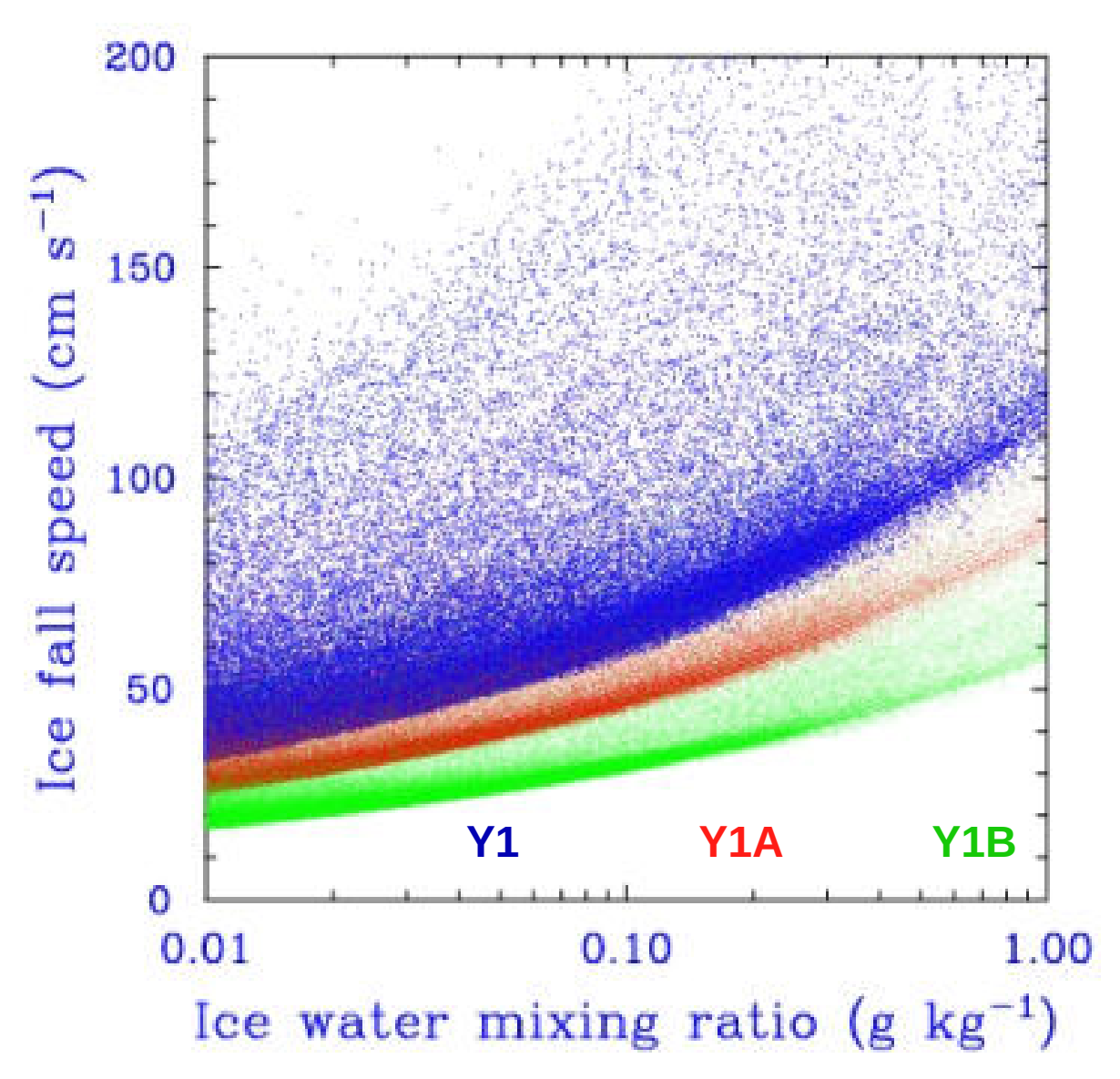
Precipitating cloud liquid and ice water content (g m^{-3}) at SGP



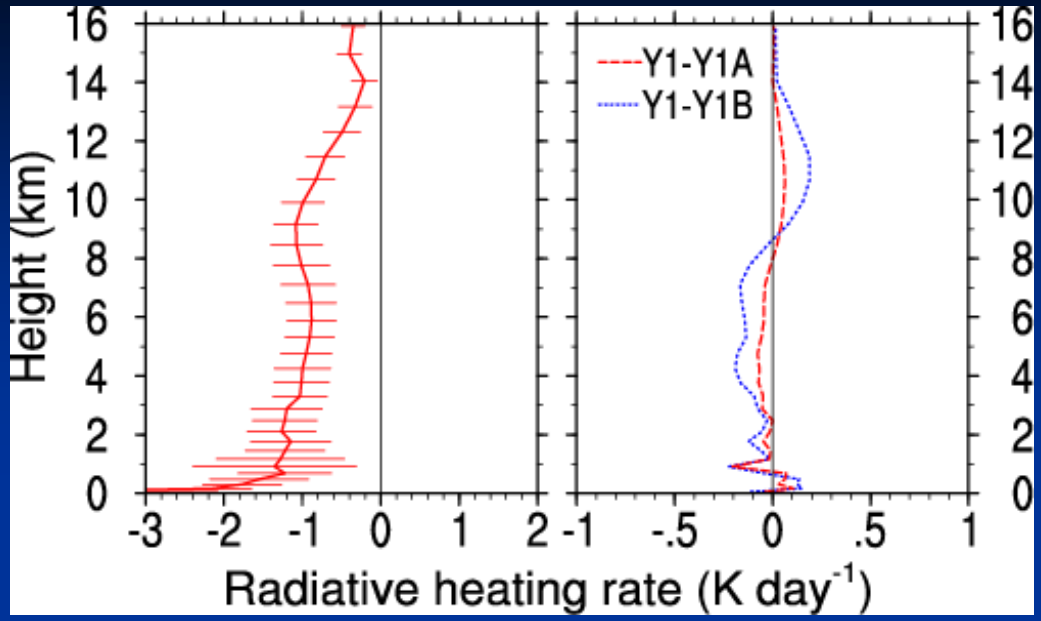
Non-precipitating cloud liquid and ice water content (g m^{-3}) at SGP



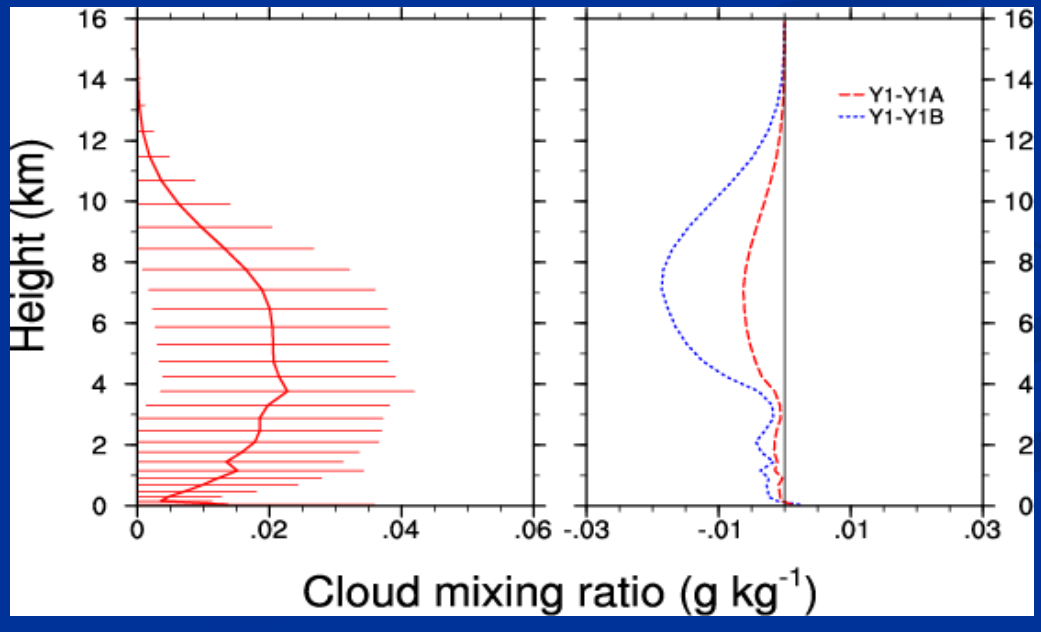
Sensitivity of year-long CRM simulations to ice fall speeds



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



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



II. Evaluating GCM simulations against CRM and ARM observations

ISU General Circulation Model (GCM)

Based on a version of NCAR Community Climate System Model, but with

*** Modified Zhang-McFarlane (ZM) Convection Scheme**

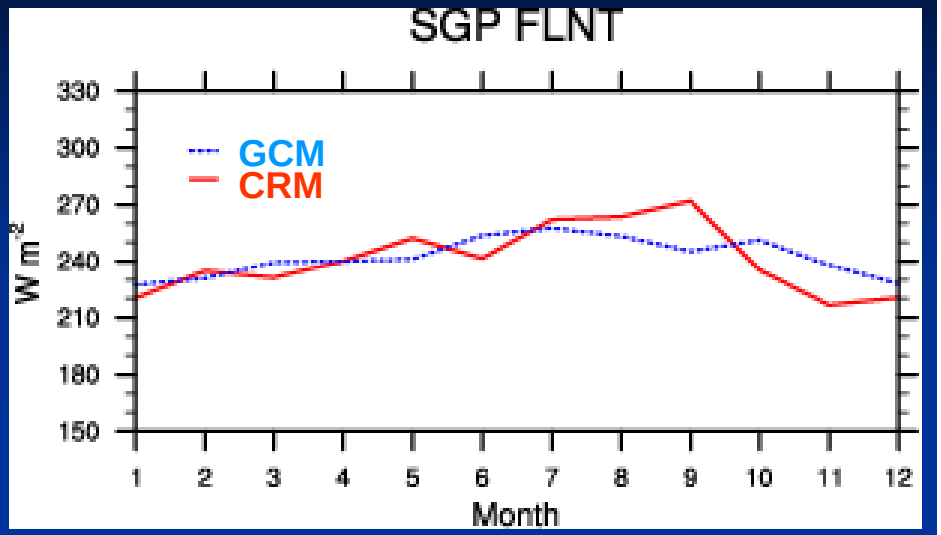
- **Revised convection closure assumption**
  Zhang (2002, 2003, JGR)
- **Trigger condition of deep convection**
  Wu et al. (2007, GRL)
- **Convective momentum transport**
  Zhang and Cho (1991, JAS), Wu and Yanai (1994, JAS), Wu et al. (2003, GRL), Zhang and Wu (2003, JAS), Wu et al. (2007, JAS), Song et al. (2008a, b, JC)

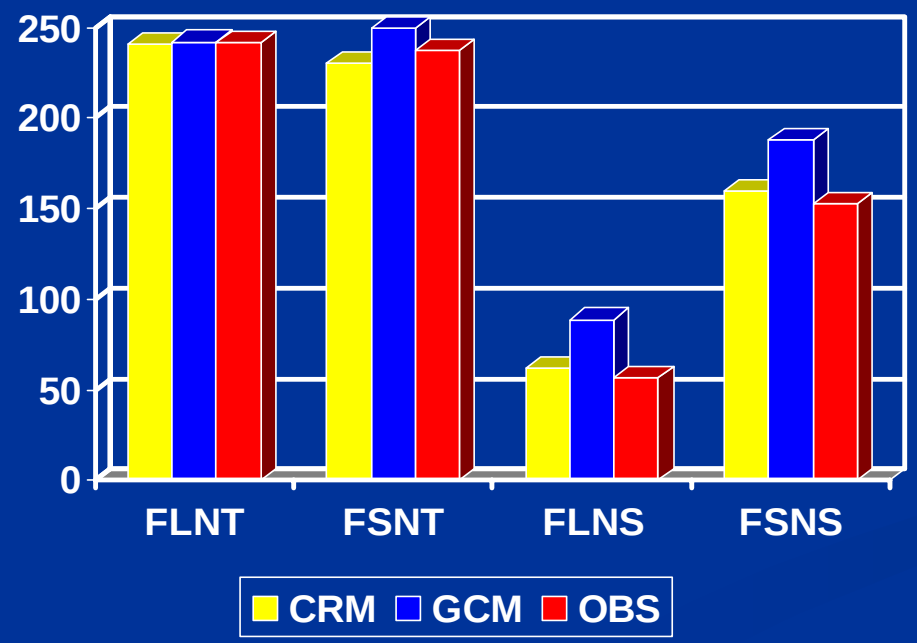
*** Mosaic treatment of subgrid cloud variability in the radiation scheme**
Liang and Wang (1997, JGR), Wu and Moncrieff (2001, JAS), Wu and Liang (2005, GRL), Liang and Wu (2005, GRL)

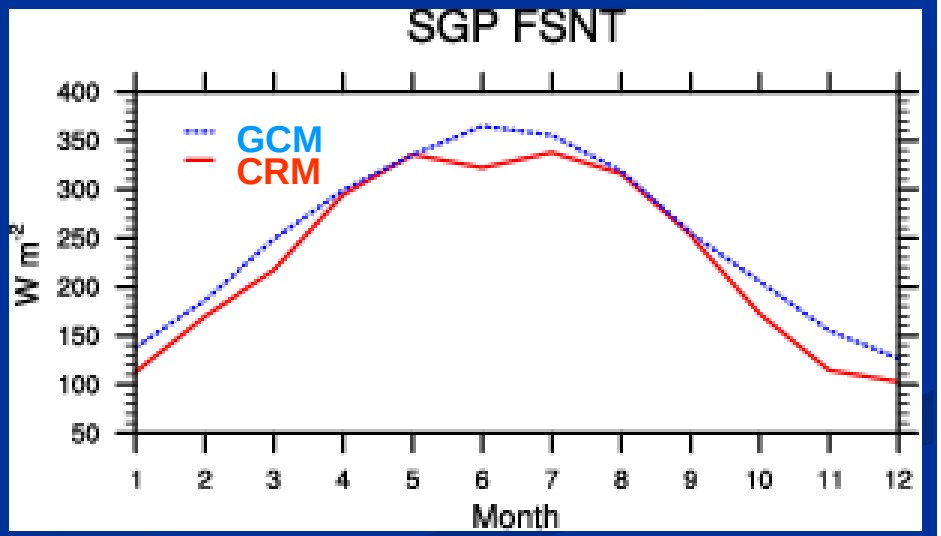
*** ……..**

Annual mean of daily net radiative fluxes at ARM SGP

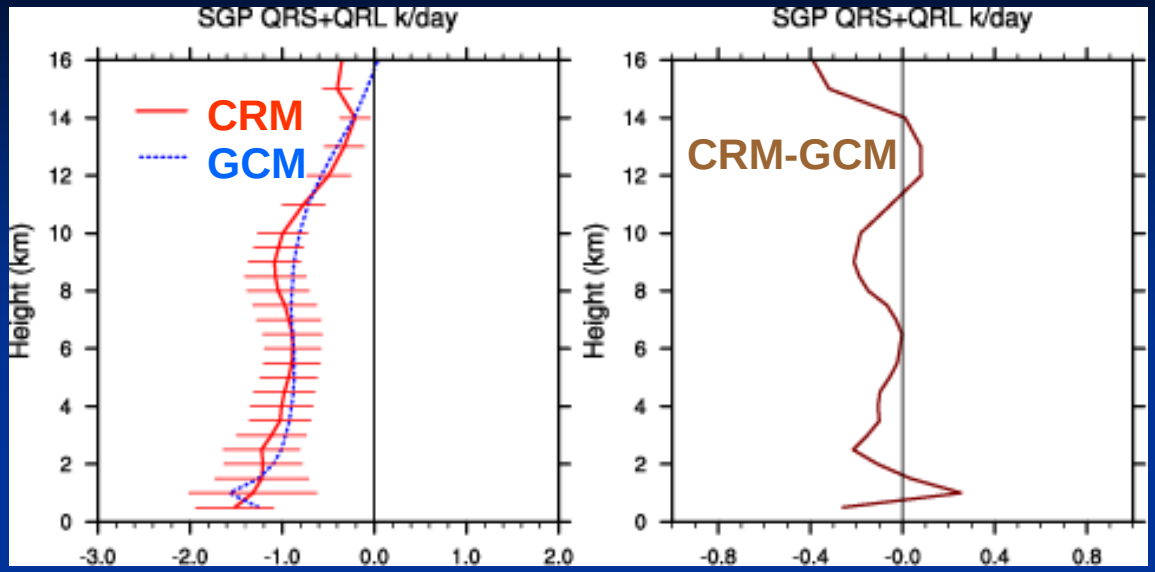
W m^{-2}		TOA		SFC	
		FLNT	FSNT	FLNS	FSNS
Mean	CRM	241.0	229.9	61.9	160.2
	GCM	242.1	249.2	88.9	188.1
	OBS	241.9	237.4	56.6	152.4
SD	CRM	28.2	95.5	31.3	78.0
	GCM	33.7	93.2	32.6	77.7
	OBS	33.1	97.9	25.3	74.8



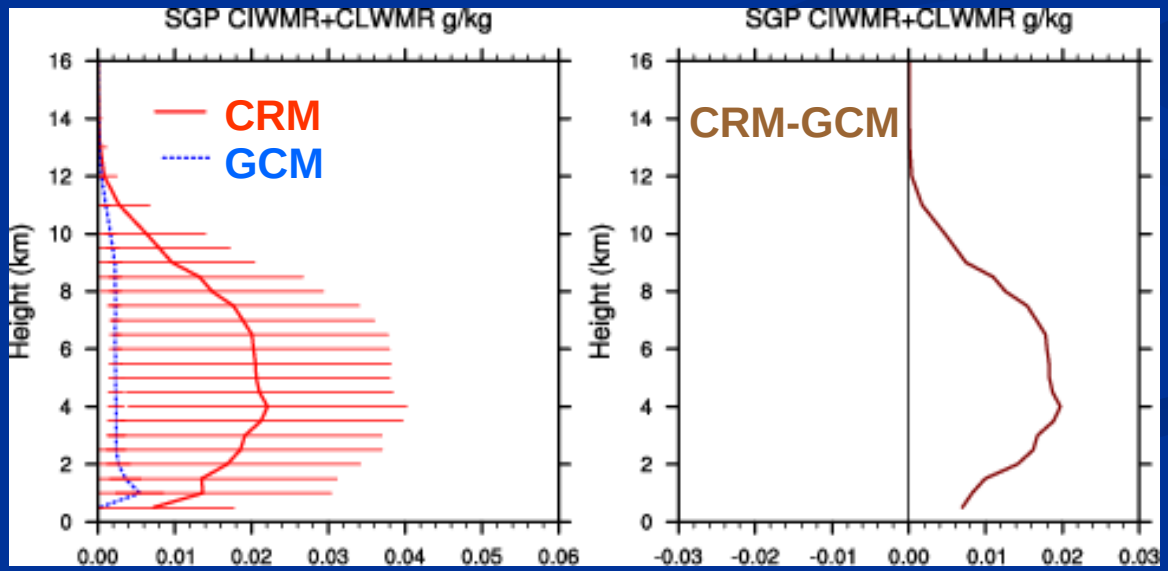




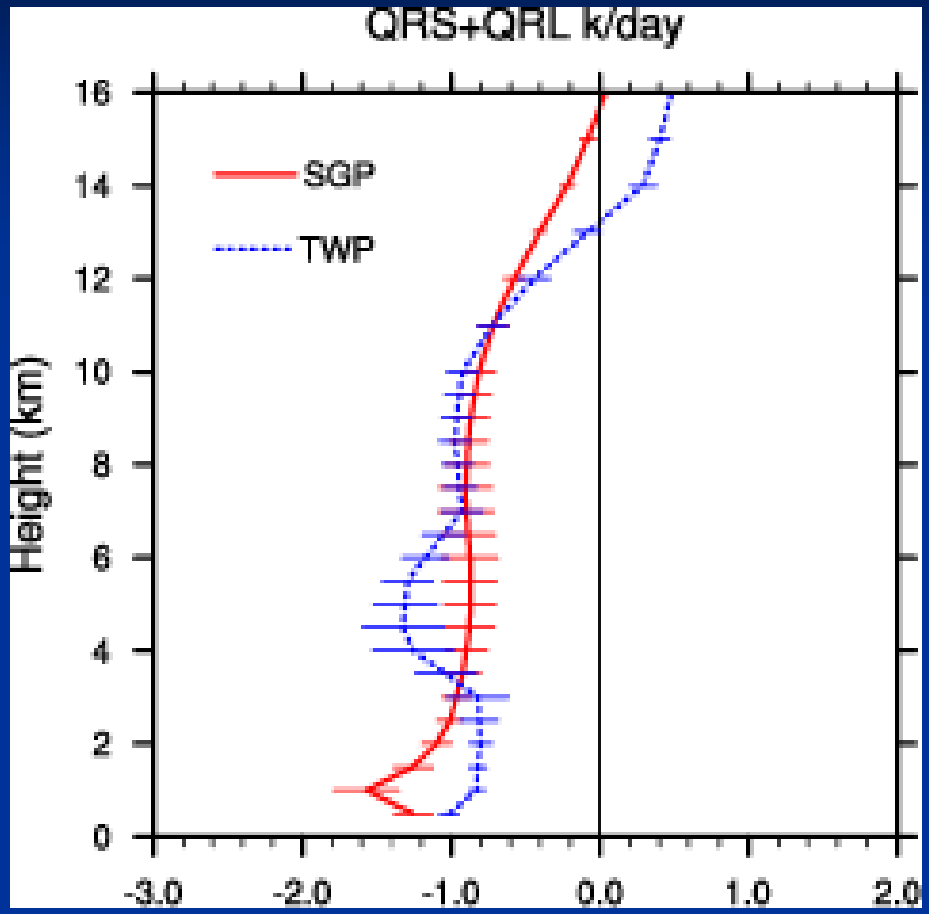
Annual mean of daily radiative heating rates (K day^{-1}) at ARM SGP

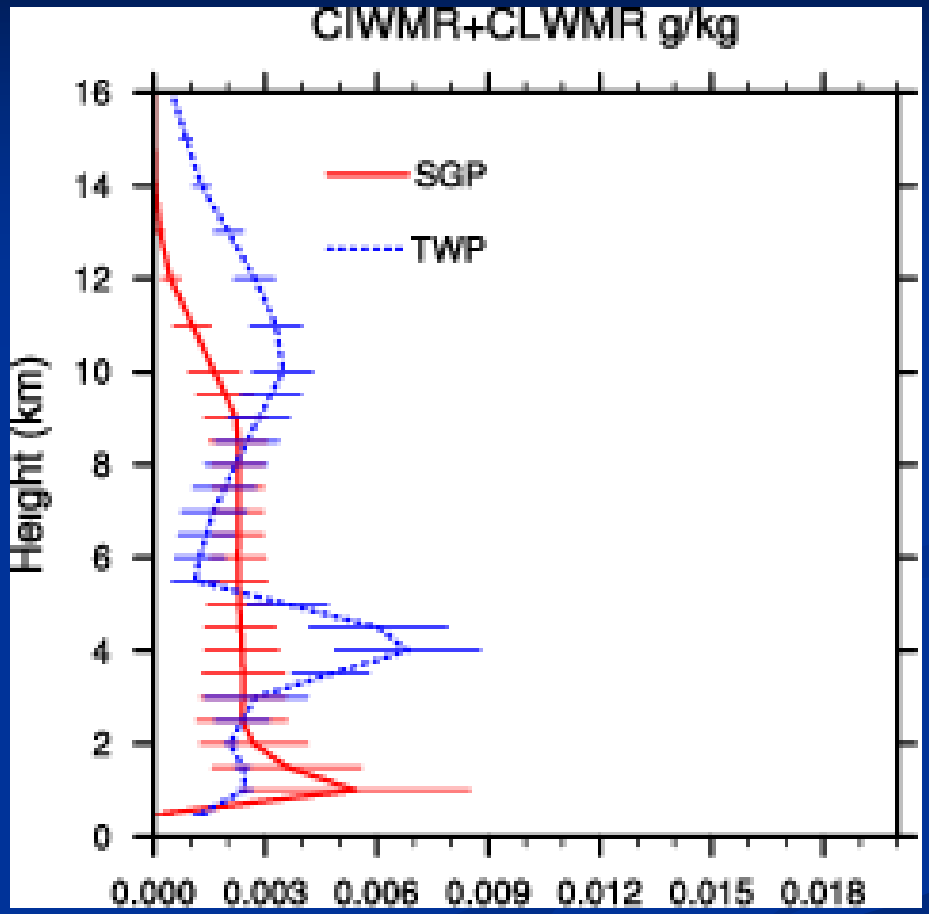


Annual mean of daily cloud (liquid and ice) water mixing ratio (g kg^{-1}) at ARM SGP



Annual mean profiles from GCM at ARM SGP and TWP





Radiative heating rates (K day^{-1})

Cloud water mixing ratio (g kg^{-1})