

# How and Why to Upgrade Cloud Microphysics in GCMs

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## Why do GCMs need comprehensive microphysics?

The old reason is still valid: cloud-radiation feedbacks are critical for modeling climate sensitivity, and microphysics has a major effect on cloud radiative properties.

Meanwhile, several newer reasons have come up:

1. Regional climate change can depend on cloud feedbacks.
2. Precipitation is an important facet of climate change.
3. Cloud-aerosol interactions are inherently microphysical.
4. Numerical weather prediction can provide synergies.

**There are several key elements in this research:**

We build parameterizations incorporating recent research on cloud microphysics.

We evaluate parameterizations against ARM observations using a single-column model.

We put the parameterizations in CAM3/CCSM and investigate their influence on the model climate.

We examine the parameterizations for their effect in NCEP numerical weather prediction models.

We develop and test stochastic parameterizations as a generalization of this approach.

## **SCM radiation, convection, and cloud parameterizations:**

Longwave: Mlawer et al. 1997 (ECMWF)

Shortwave: Briegleb 1992 (CAM3)

Convection: Zhang & McFarlane 1995, Hack 1994 (CAM3)

Prognostic cloud: Tiedtke 1993 (ECMWF)

## **SCM interactive microphysics parameterizations:**

Ice fallout: Mitchell 1996, Ivanova et al. 2001

Optical: Slingo 1989, McFarquhar et al. 2002

Radius: Bower et al. 1994, McFarquhar 2001

# SINGLE-COLUMN MODEL

## Input:

- Initial profiles of  $T$  and  $q$
- Advective fluxes of heat and moisture
- Vertical velocity

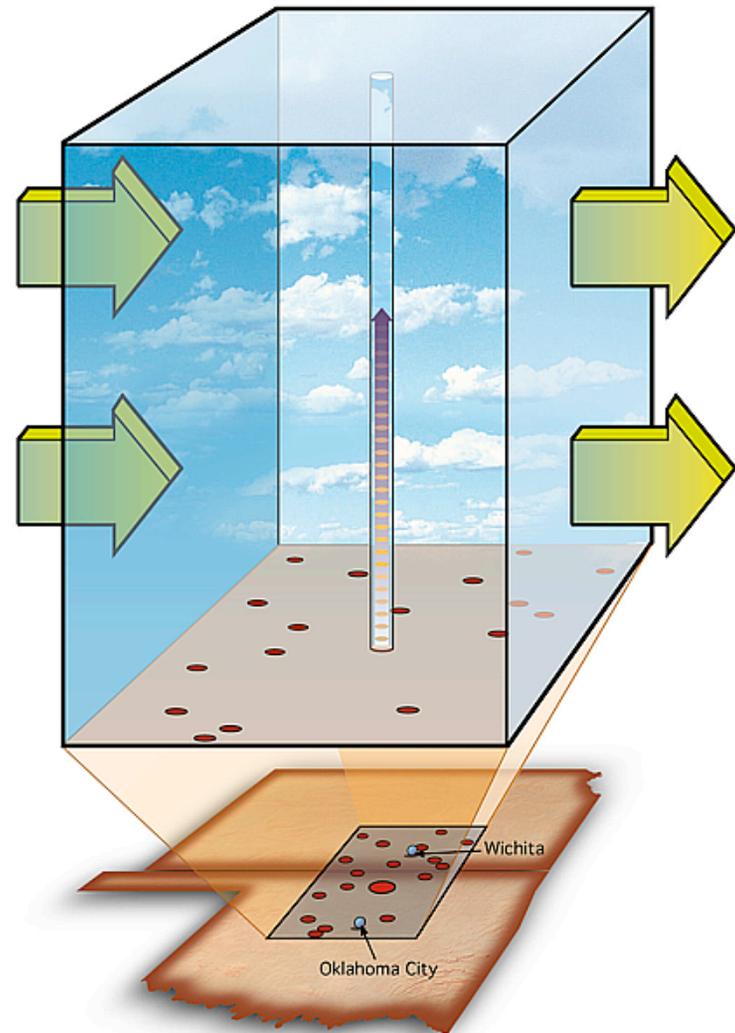
## Output:

### Large-Scale Variables

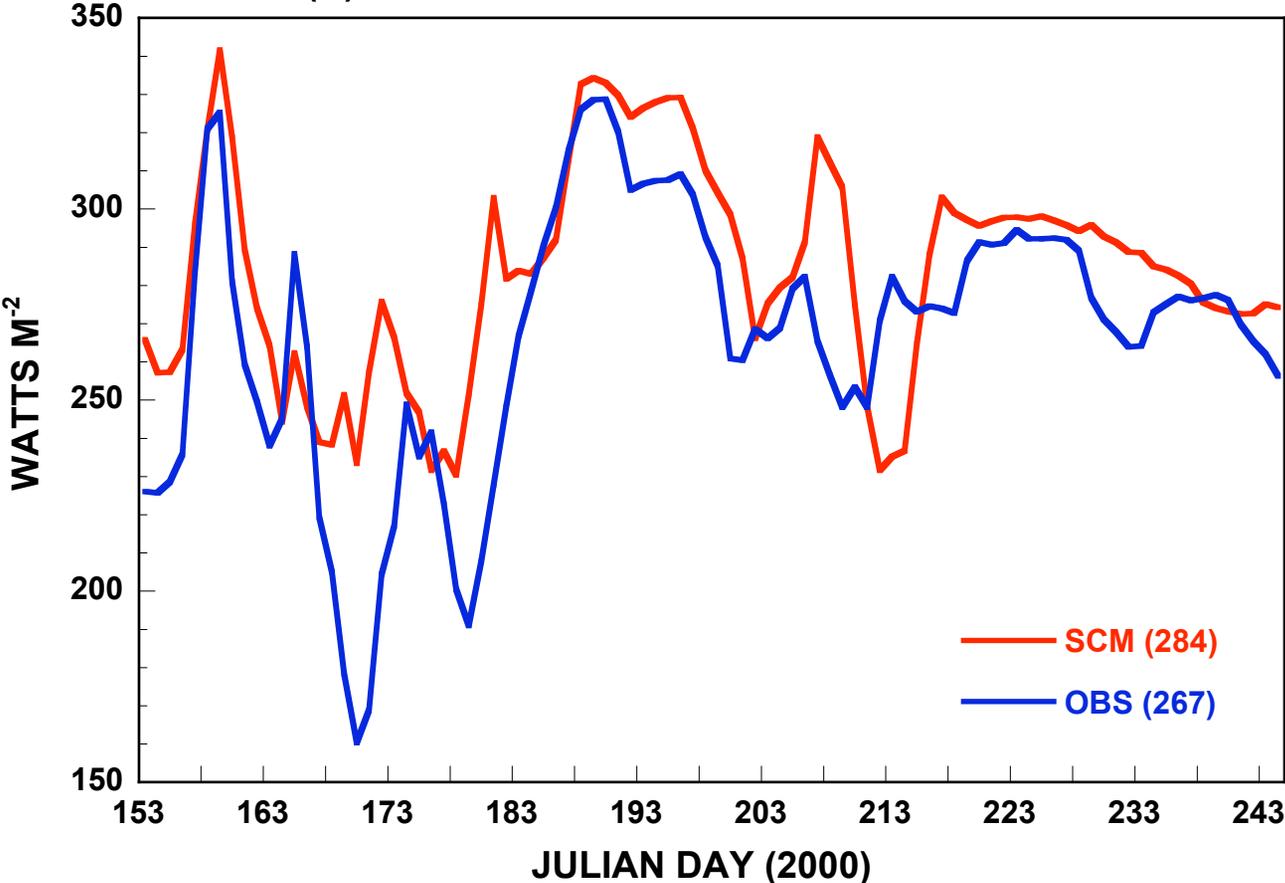
- Temperature,  $T(t,z)$
- Humidity,  $q(t,z)$
- Cloud water/ice,  $q_c(t,z)$

### Diagnostics

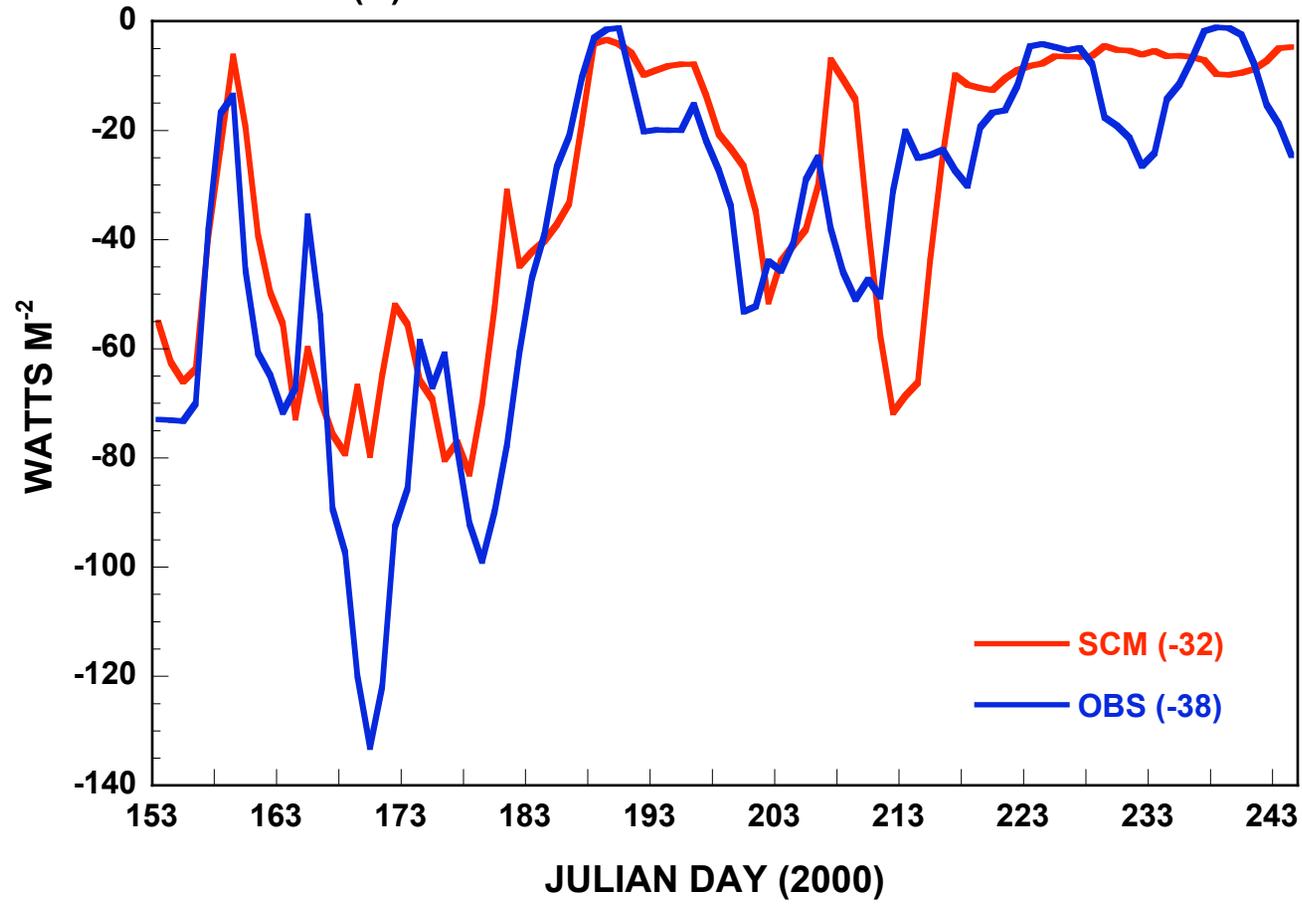
- Precipitation
- Radiative Fluxes
- Cloud properties



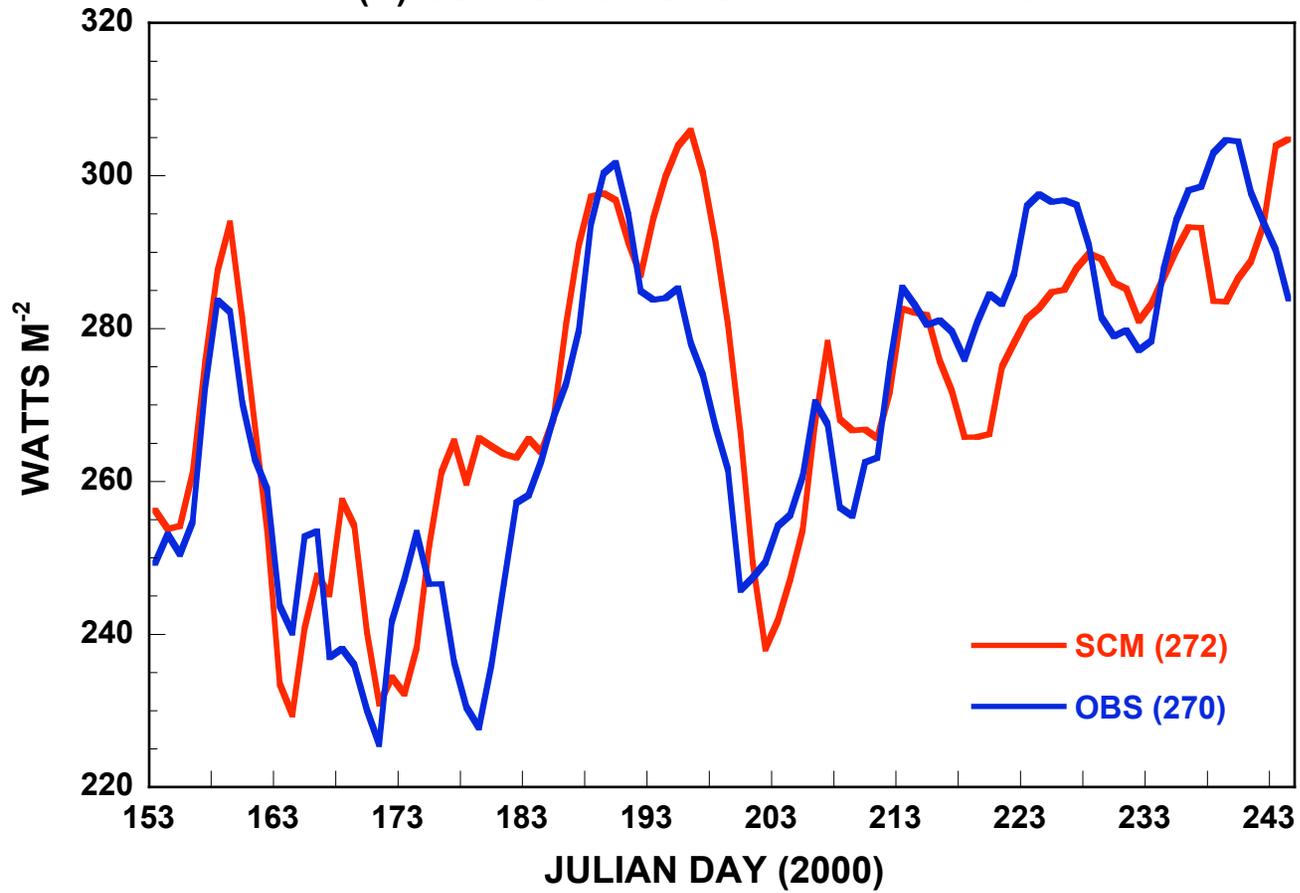
(A) DOWNWELLING SURFACE SHORTWAVE



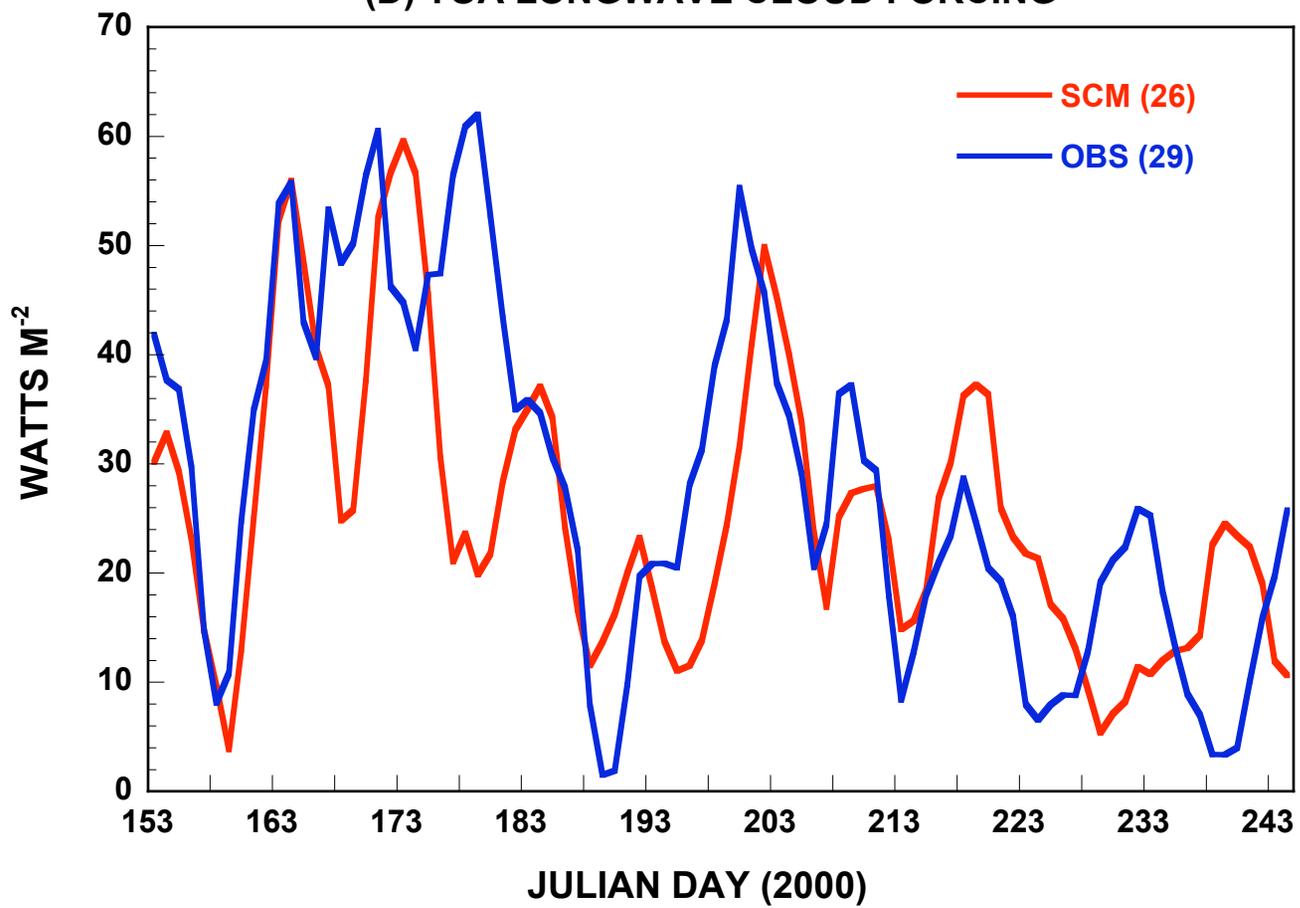
(B) TOA SHORTWAVE CLOUD FORCING



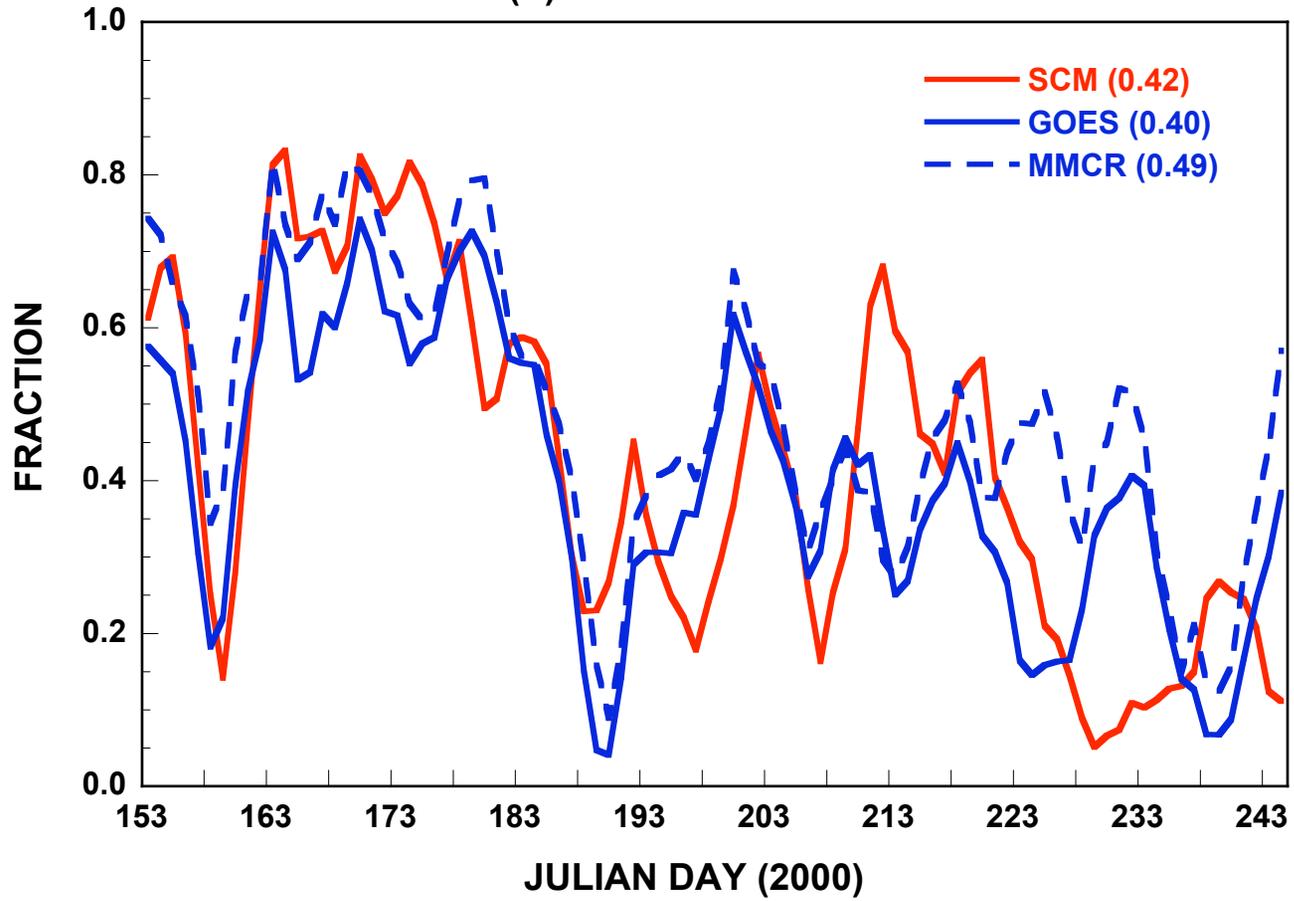
(C) OUTGOING LONGWAVE RADIATION



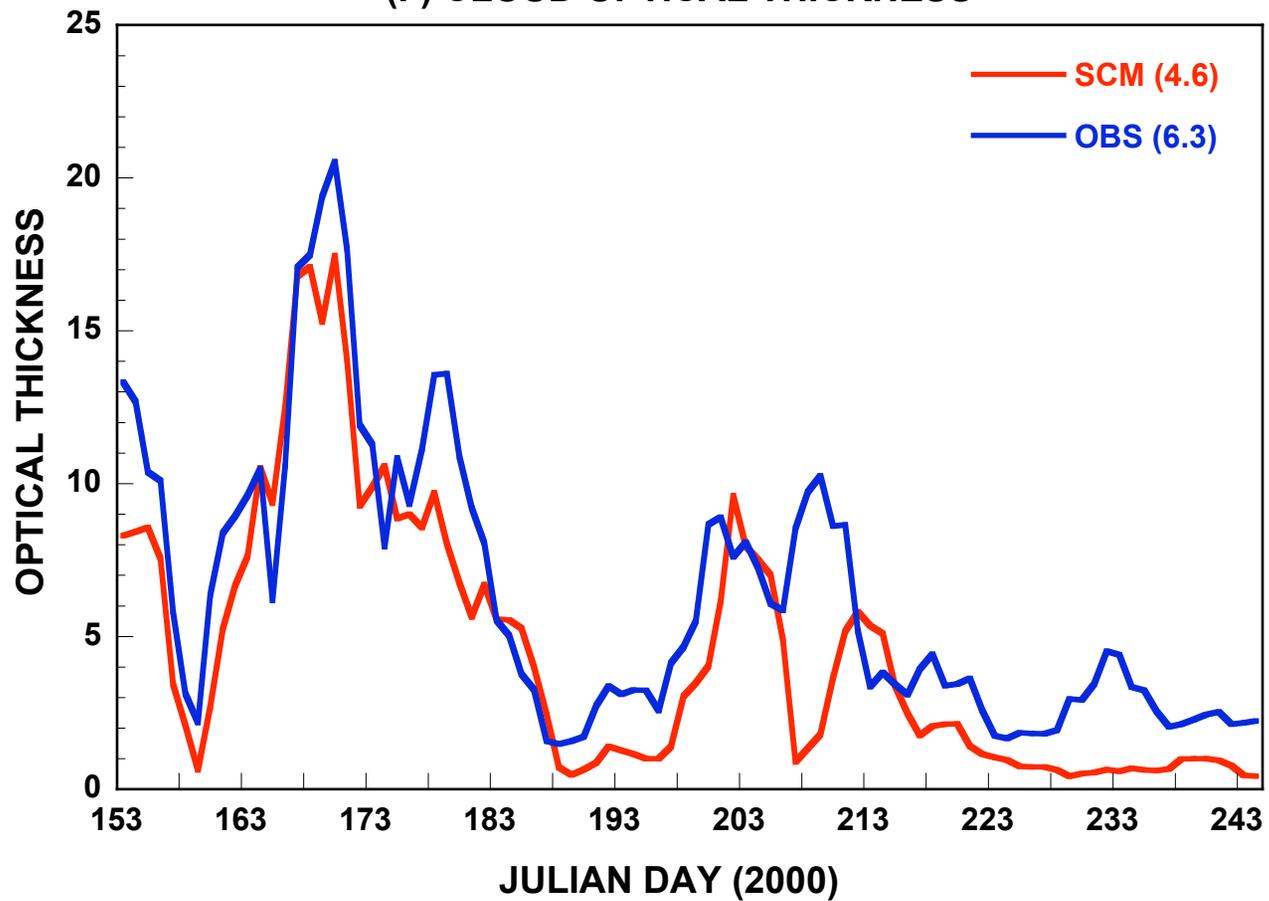
(D) TOA LONGWAVE CLOUD FORCING



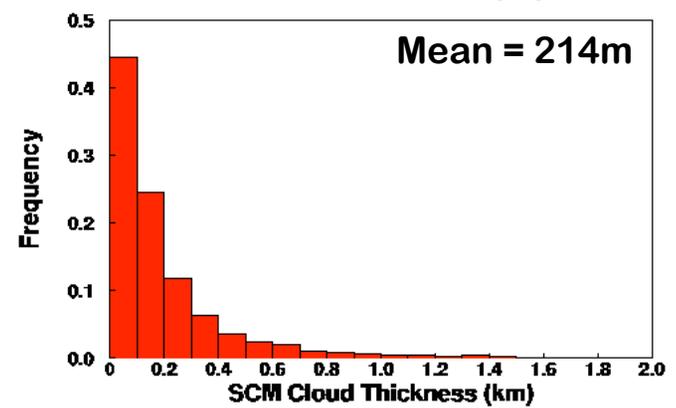
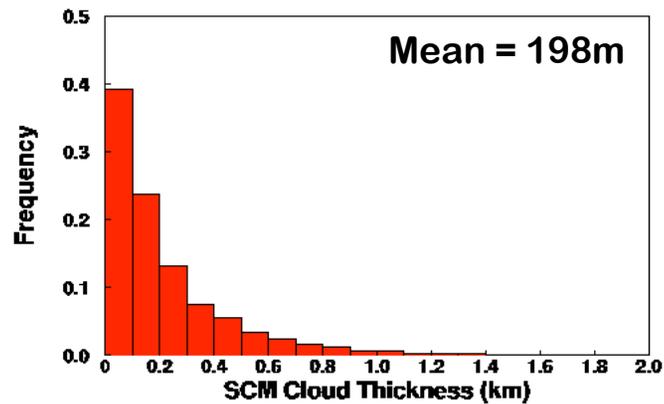
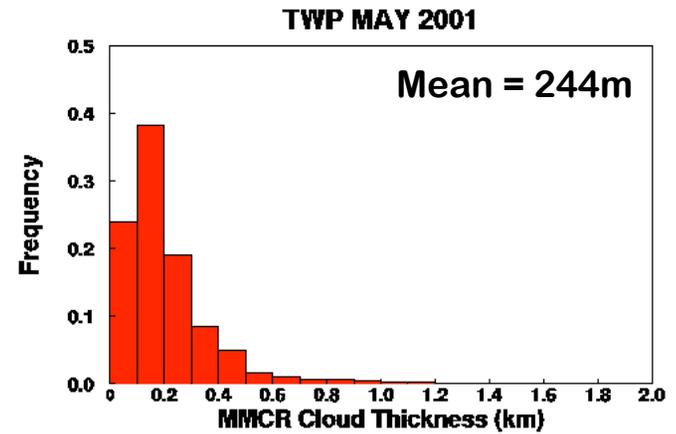
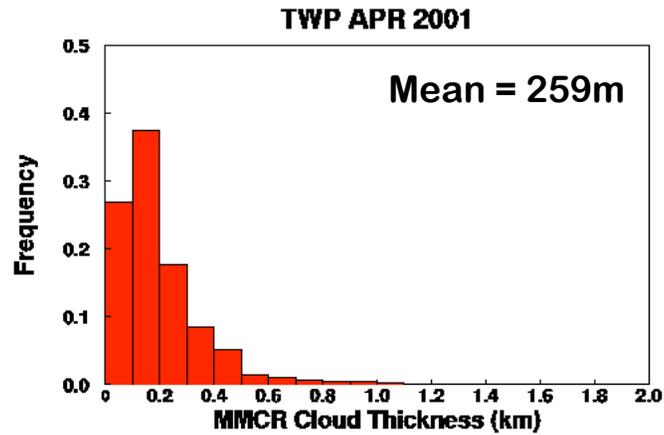
(E) CLOUD FRACTION



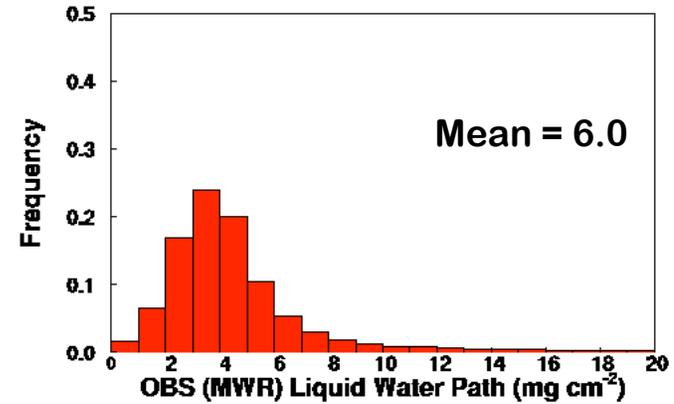
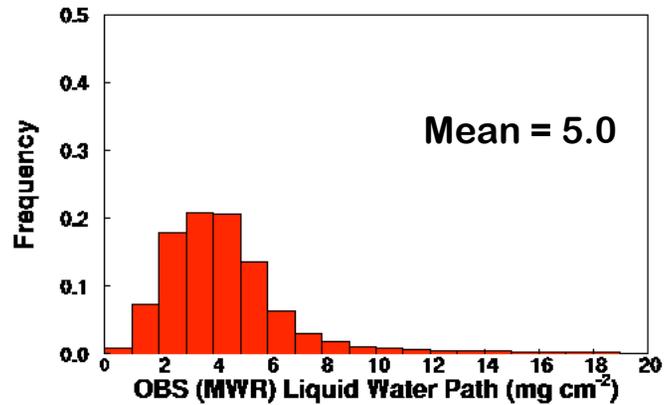
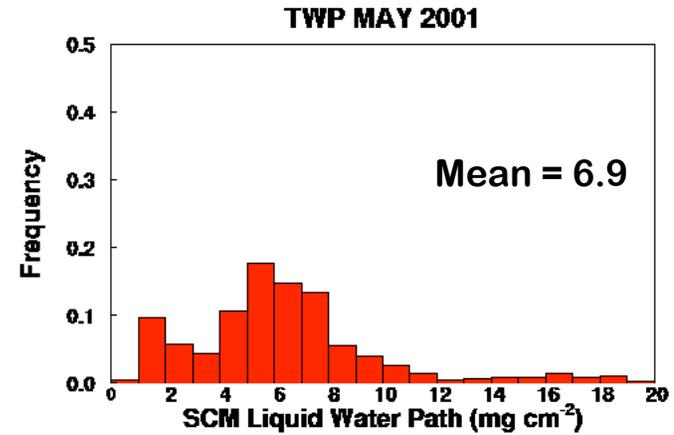
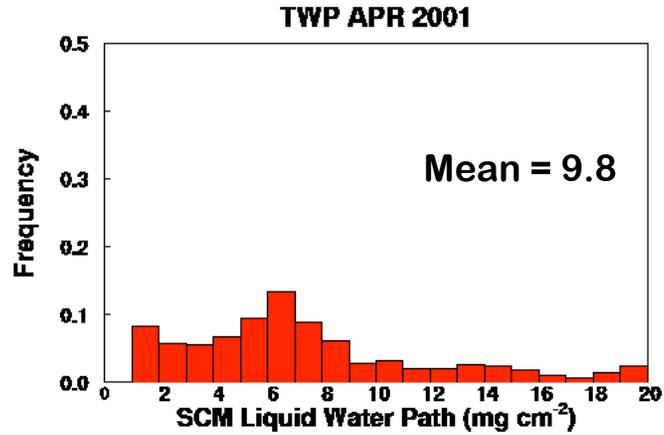
(F) CLOUD OPTICAL THICKNESS



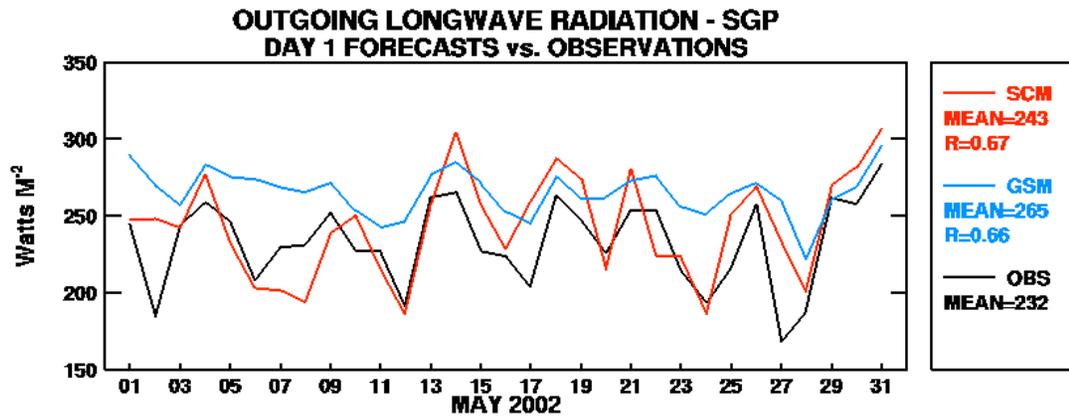
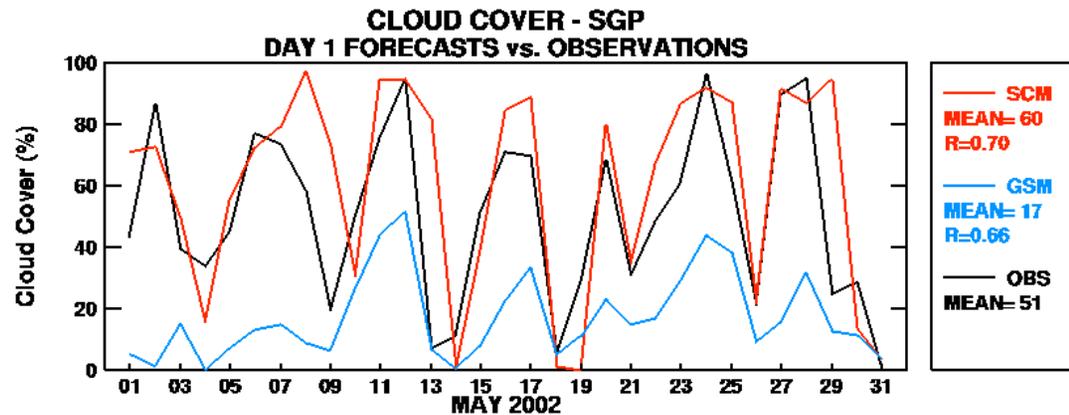
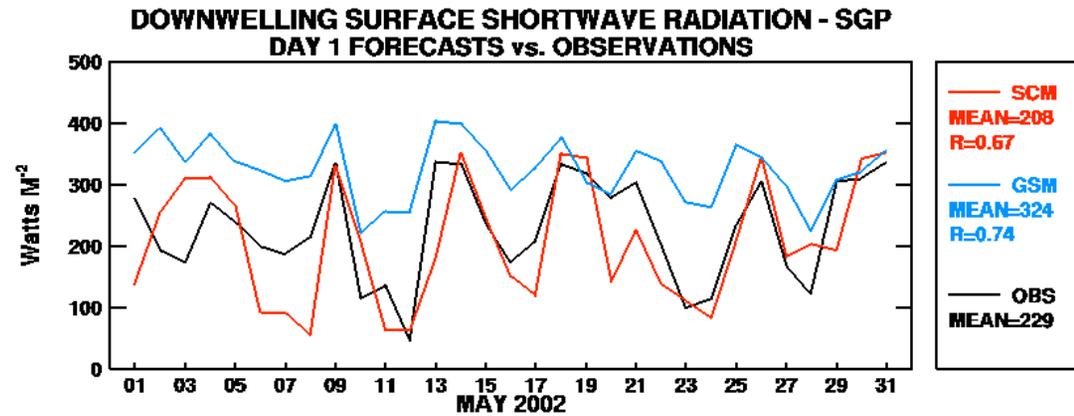
# Cloud Thickness (Lowest 2km Only)



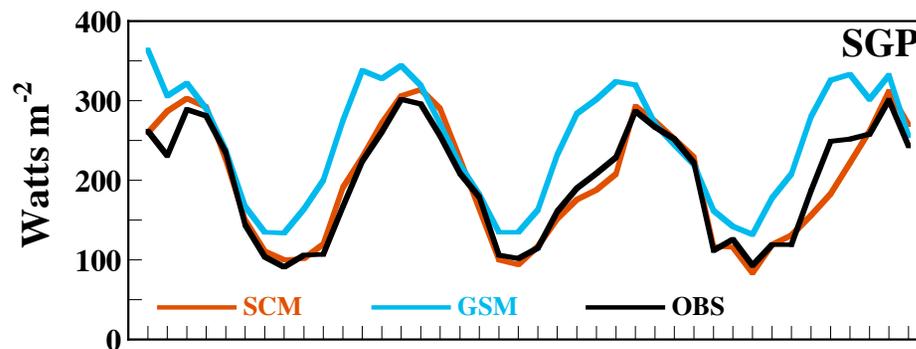
# Liquid Water Path



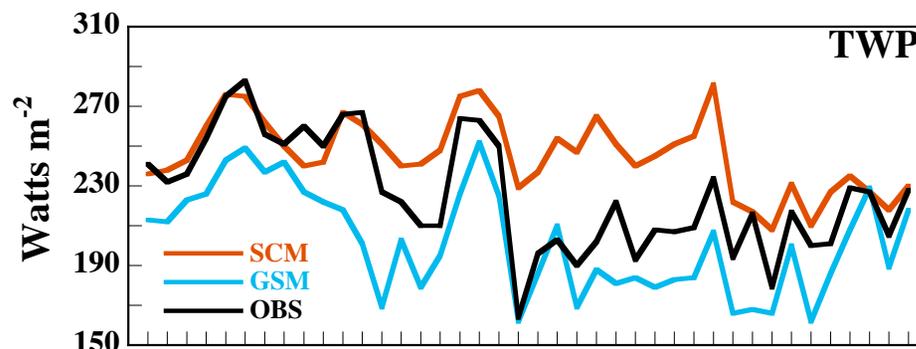
# Model Performance for Individual Month



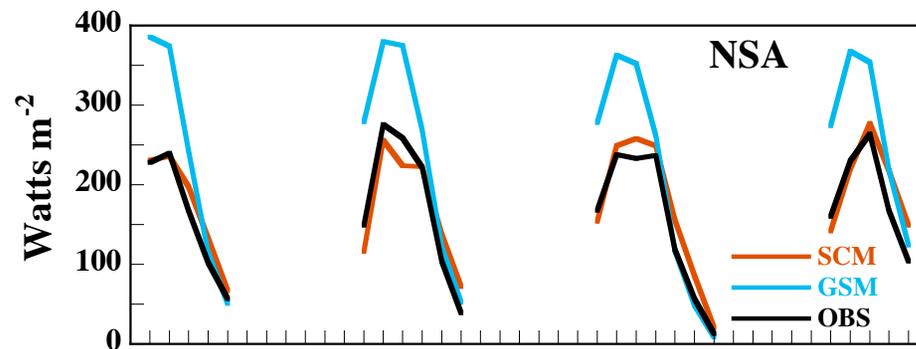
# Monthly Mean Downwelling Surface Shortwave Radiation



Southern Great Plains



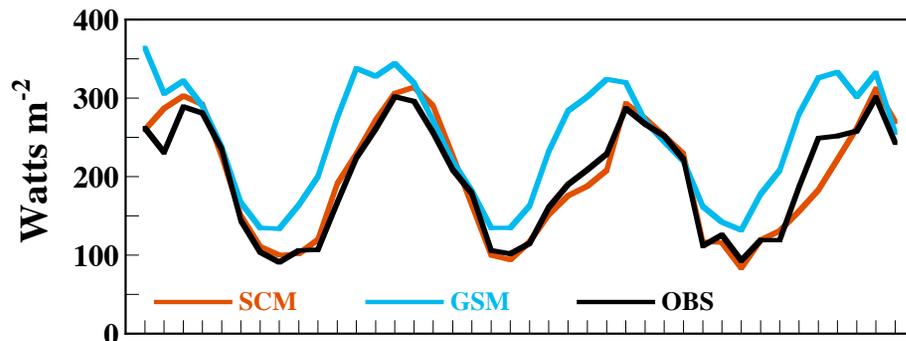
Tropical West Pacific



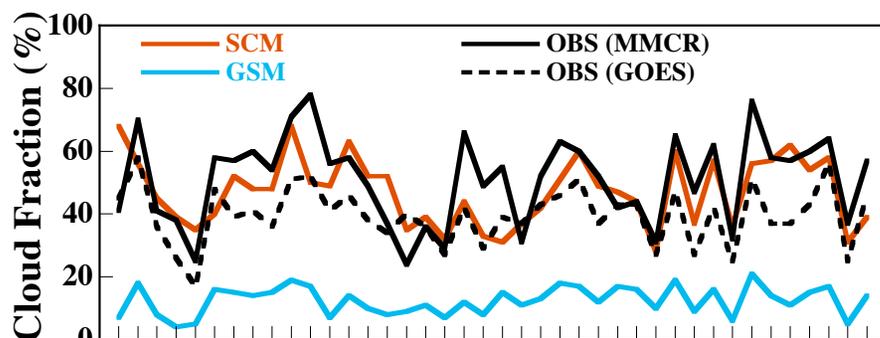
North Slope of Alaska

Month (2000-2003)

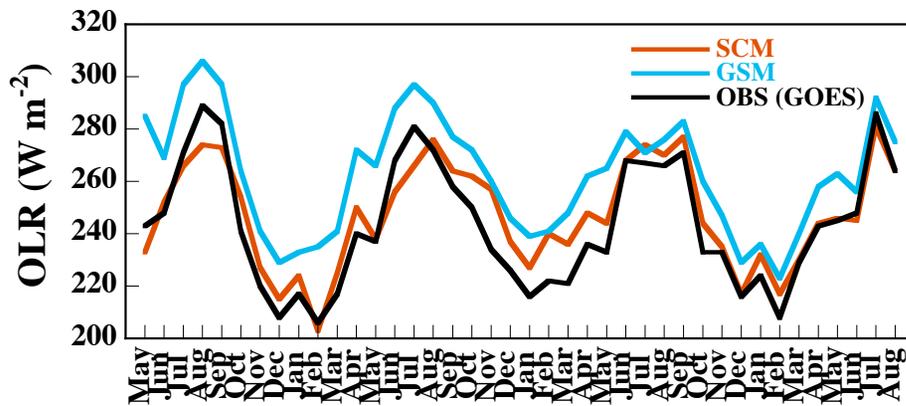
# Monthly Means at ARM Southern Great Plains Site



Downwelling Surface  
Shortwave Radiation



Cloud Fraction



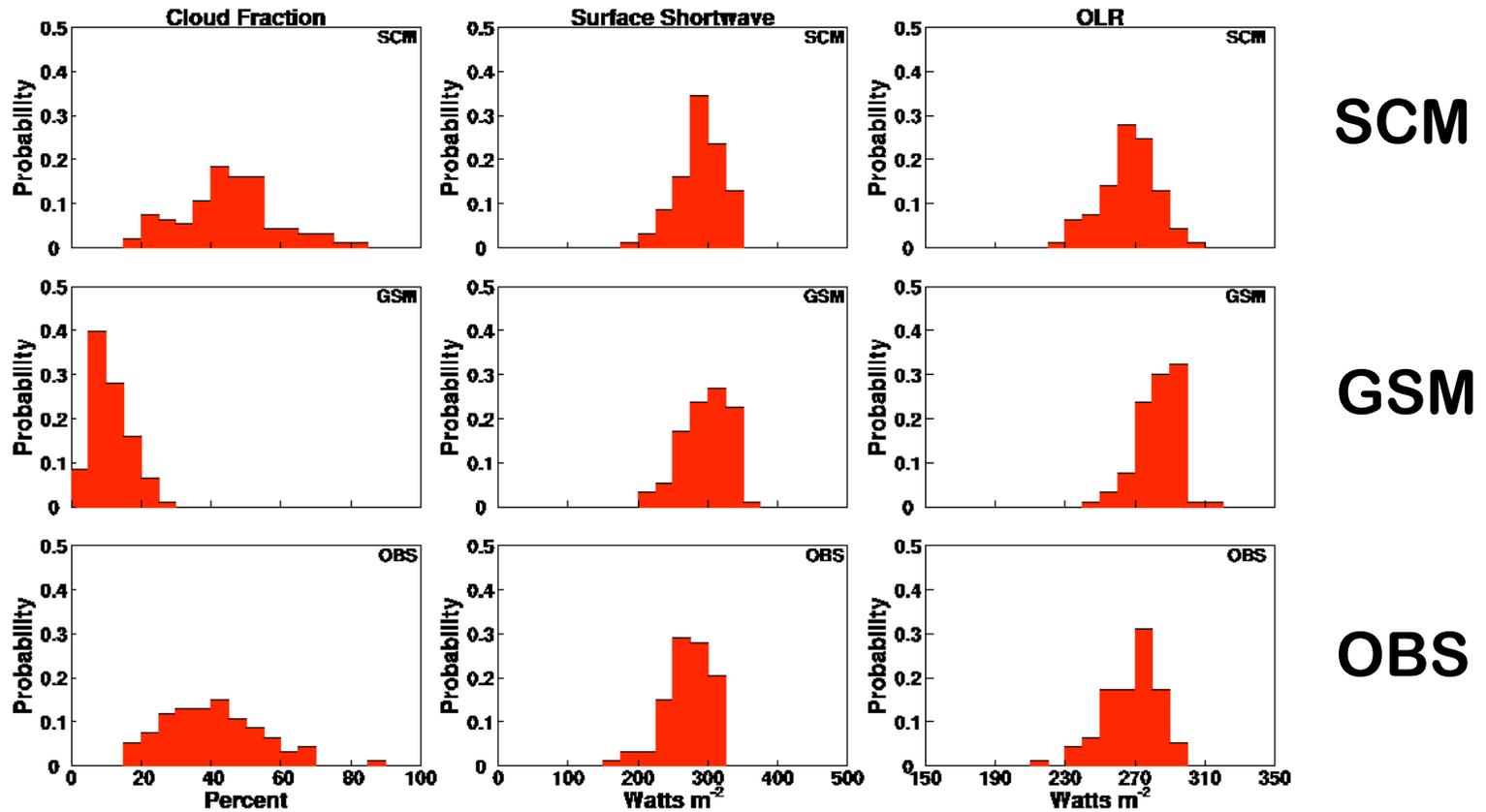
Outgoing Longwave  
Radiation

Month (2000-2003)

# Daily Mean Statistics at SGP

## PROBABILITY DISTRIBUTION OF DAILY MEAN VALUES AT SGP

JUN-AUG 2000-03

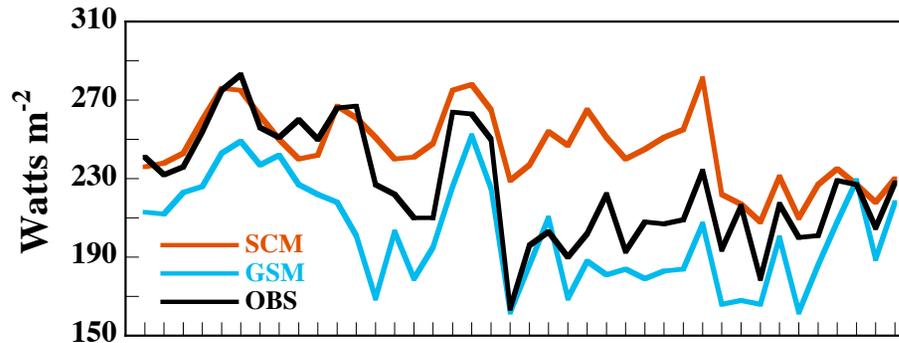


SCM

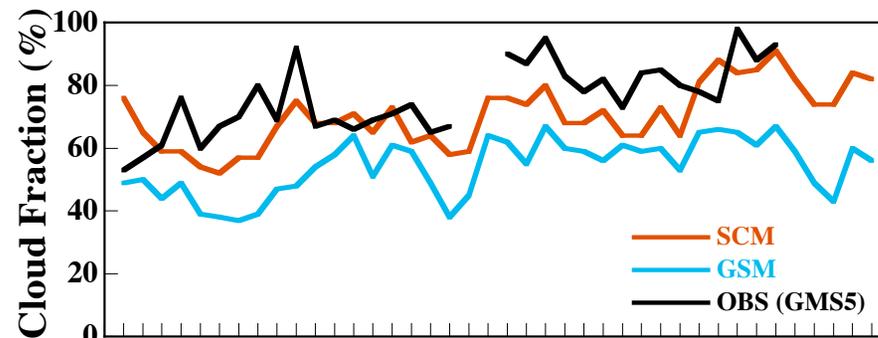
GSM

OBS

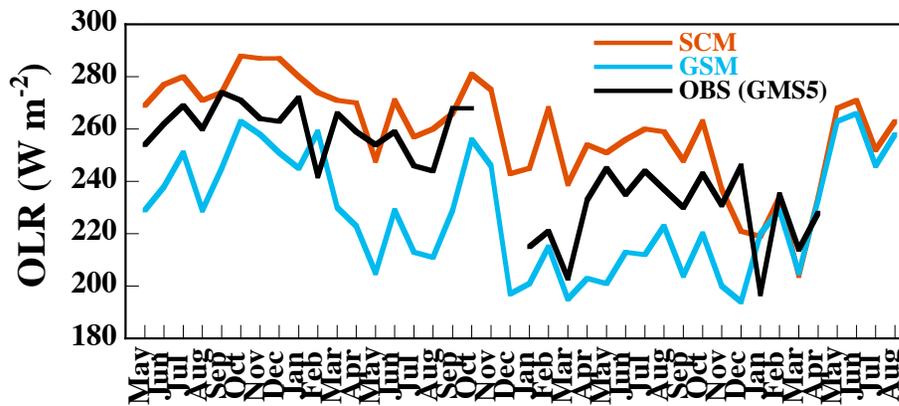
# Monthly Means at ARM Tropical West Pacific Site



Downwelling Surface  
Shortwave Radiation



Cloud Fraction



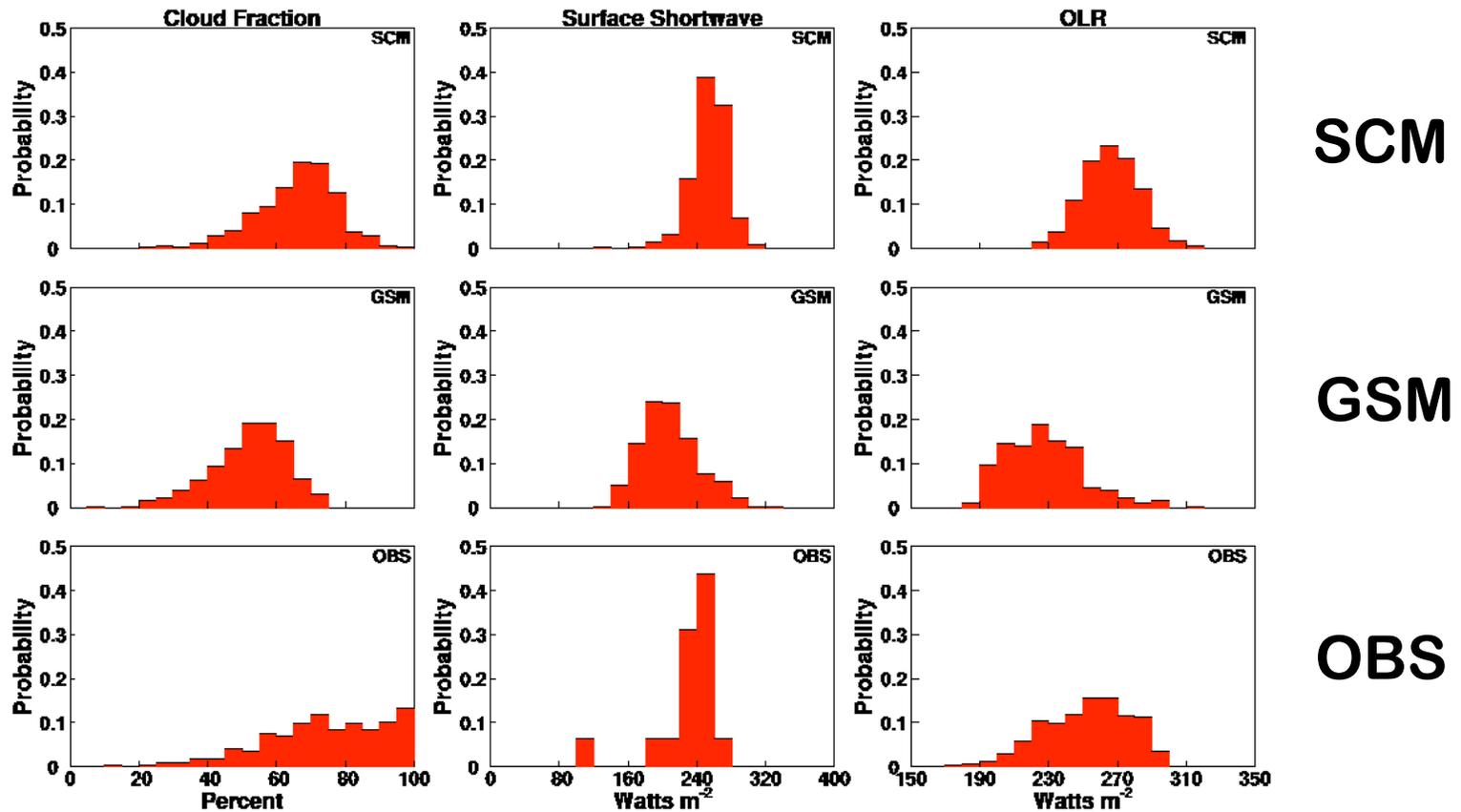
Outgoing Longwave  
Radiation

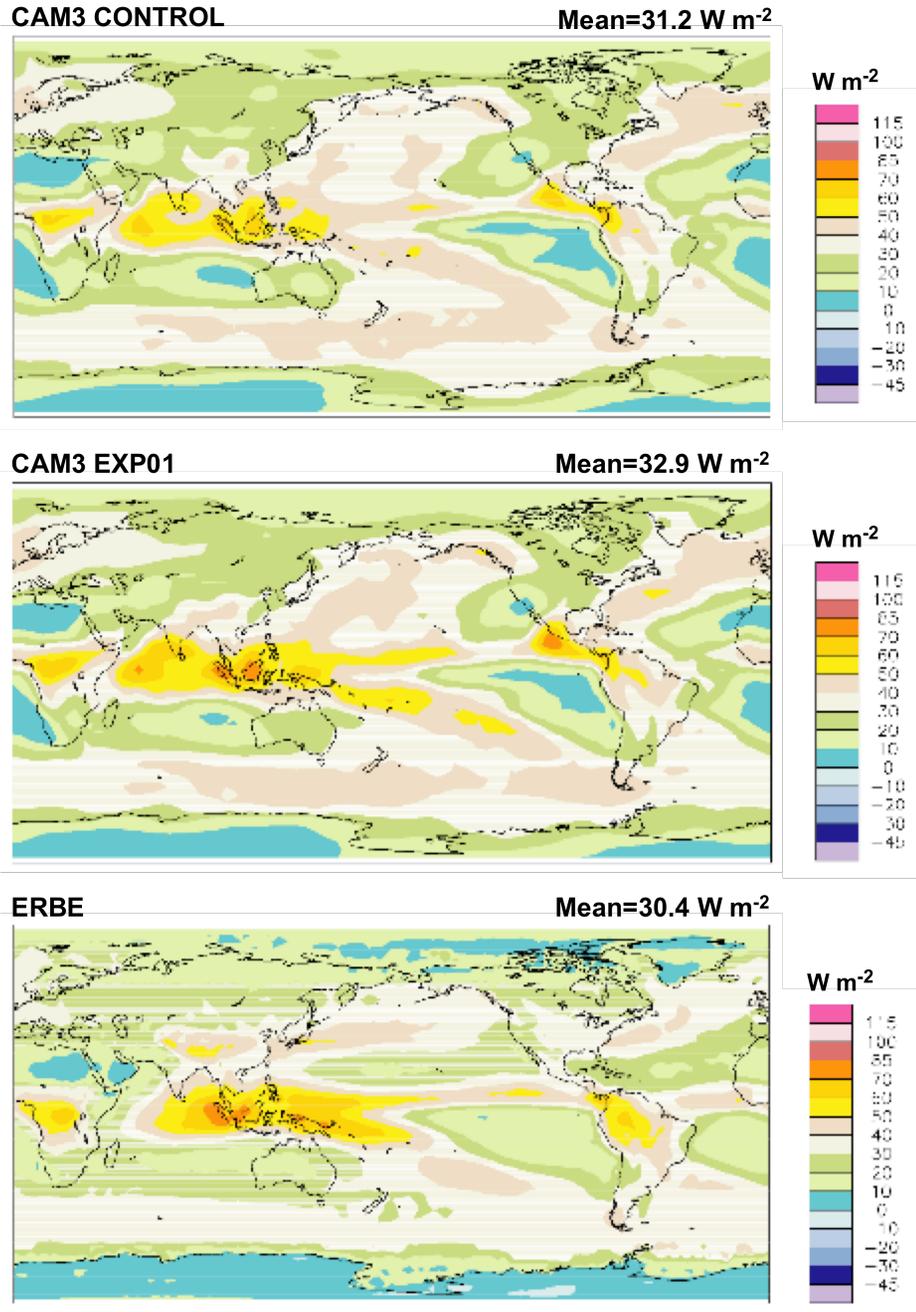
Month (2000-2003)

# Daily Mean Statistics at TWP

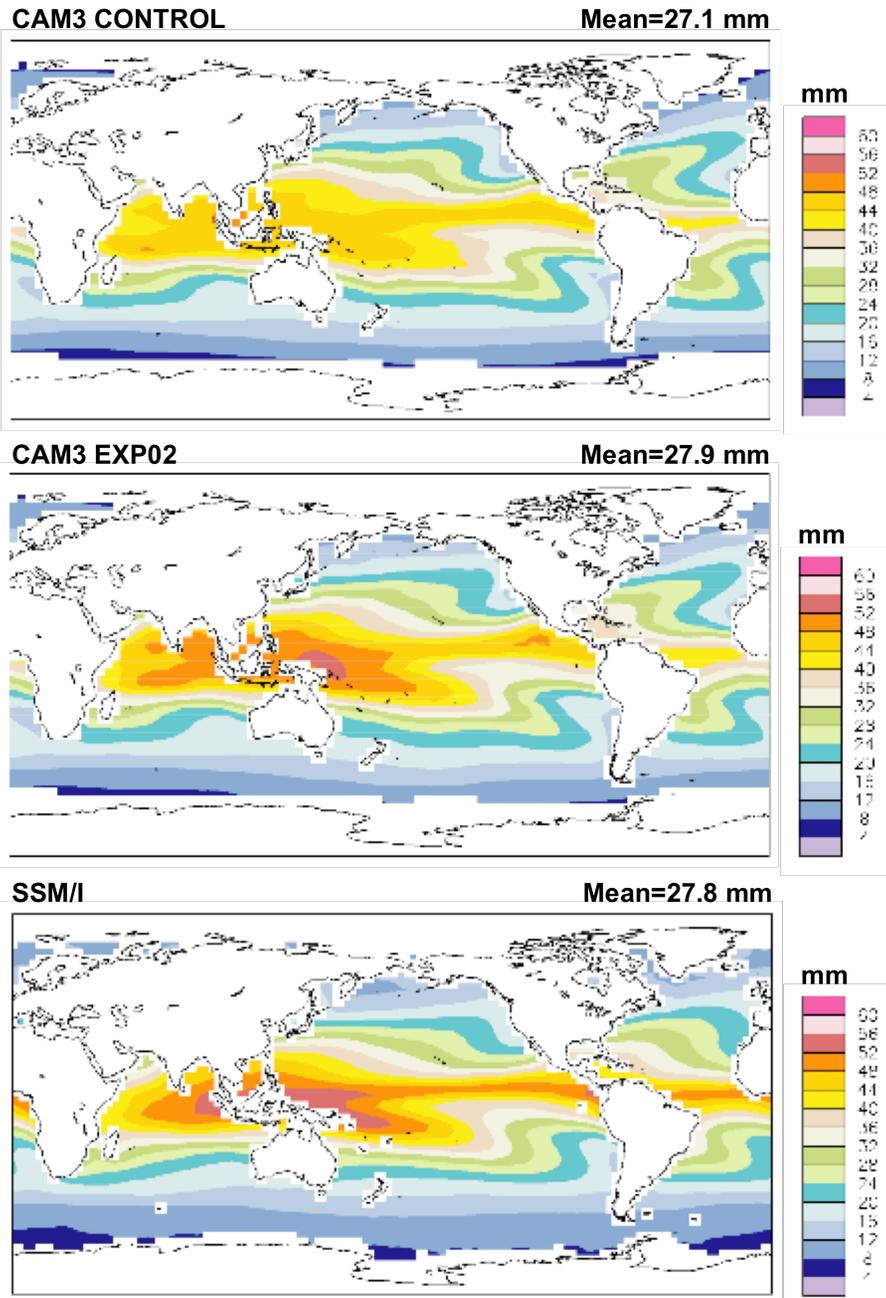
PROBABILITY DISTRIBUTION OF DAILY MEAN VALUES AT TWP

JUN-AUG 2000-02

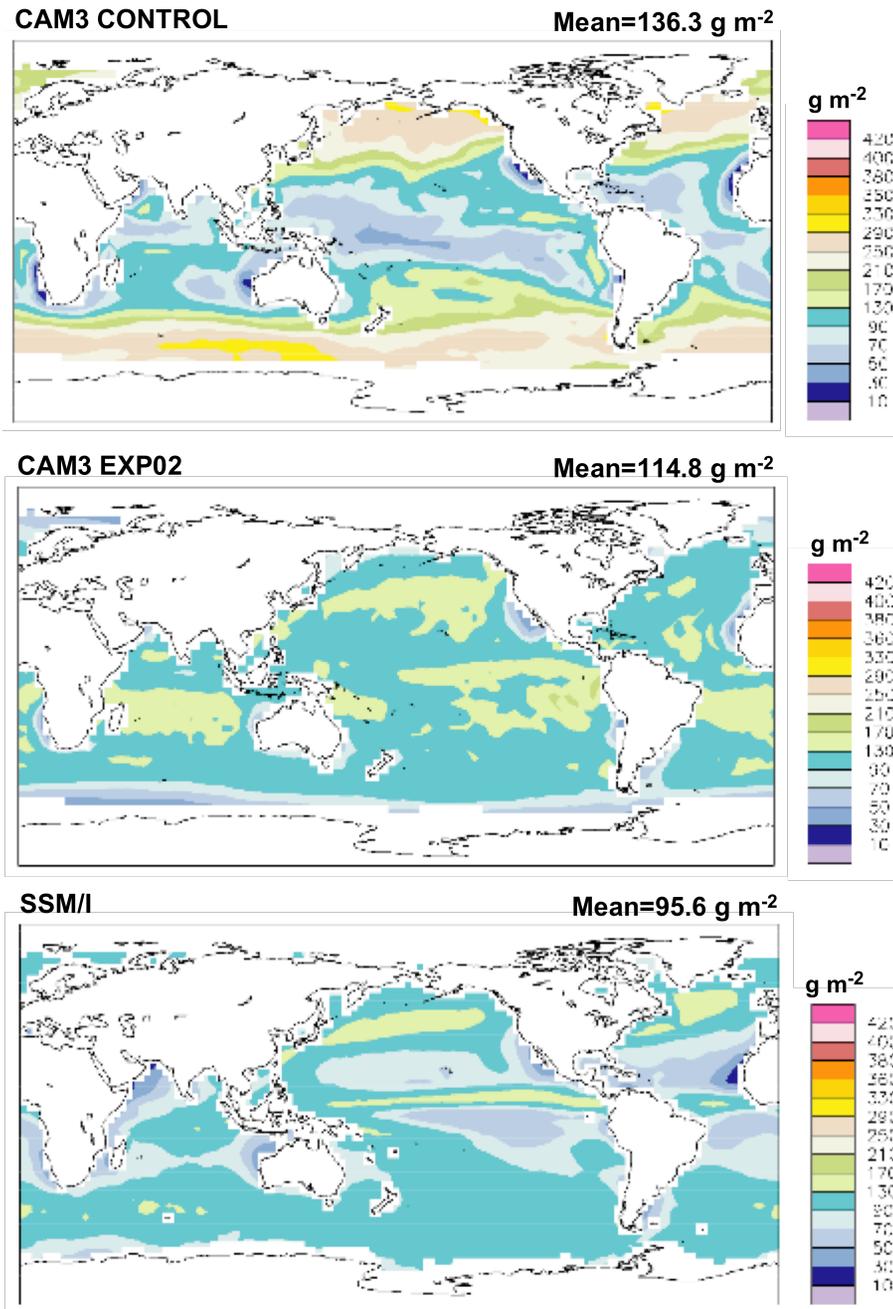




**Figure 9.** Annual mean longwave cloud forcing from run CONTROL (top panel), EXP01 (middle panel) and ERBE data (bottom panel). Run EXP01 using the McFarquhar ice cloud parameterizations (particle radius and cloud optical properties) produces more realistic values of longwave cloud forcing in the Tropical West Pacific region.



**Figure 11.** Annual mean precipitable water from run CONTROL (top panel), EXP02 (middle panel) and SSM/I data (bottom panel). Run EXP02 using the Tiedtke prognostic cloud/cloud water parameterization produces more realistic values of precipitable water, particularly in the tropical Pacific and Indian Ocean regions.



**Figure 12.** Annual mean cloud liquid water from run CONTROL (top panel), EXP02 (middle panel) and SSM/I data (bottom panel). Run EXP02 using the Tiedtke prognostic cloud/cloud water parameterization produces more realistic values of cloud liquid water, particularly in the mid-latitude storm tracks of both the northern and southern hemispheres.

## Conclusions

We have built new parameterizations with detailed cloud microphysics and evaluated them with ARM data, using a single column model.

In our single column model, the new parameterizations are more realistic than the cloud-radiation algorithms in a recent version of the NCEP operational global numerical weather prediction model.

Preliminary tests of these parameterizations in a leading GCM (CAM3) appear to confirm these results.

By using a combination of models, and testing against observations, we can diagnose causes of model errors.

## Keeping the big picture in mind:

Why are we interested in cloud-climate interactions?

1. Cloud effects still dominate climate sensitivity.
2. Radiative transfer in models needs improvement.
3. Aerosol effects are especially poorly understood.

Recent research and the requirements of IPCC suggest:

- A. Cloud parameterizations require new approaches.
- B. To be acceptable to IPCC, models must pass tests.
- C. Climate sensitivity cannot be only 1 global number.

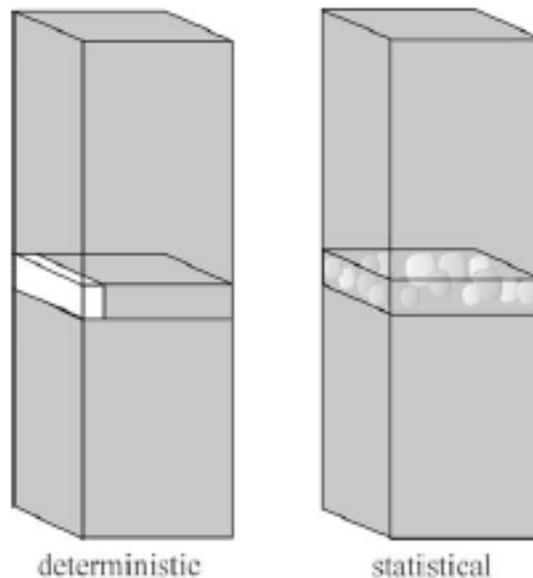
## Stochastic parameterizations: a promising approach:

GCMs usually treat cloud-radiation interactions by first predicting cloud amount in some crude way. Then they weight clear & overcast radiative transfer calculations .

Would it not be better to treat the entire problem stochastically? Why not ask the GCM to predict the probability distribution functions of cloud properties?

Such a treatment could incorporate observed statistical characteristics of cloud fields (and some cool theory).

This is what we plan to do in SCM, GCMs and (we hope) in MMAP (Lane-Veron and Somerville, JGR, 2004).



## Stochastic theory of radiative transfer through generalized cloud fields

Dana E. Lane-Veron and Richard C. J. Somerville

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D18113, doi:10.1029/2004JD004524, 2004