One PDF to Rule Them All:
A Quest for Subgrid Physics Consistency

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AMWG Meeting

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Chapters:

1. **Macrophysics**
   a. **Cloud fraction**
   b. **Condensation/evaporation**
2. **Microphysics**
3. **Radiation subcolumns**

Macrophysics Concept:

Define the saturation excess $s = q_w - q_s(T,p)$.

liquid + vapor mixing ratio ↑

↑ saturation mixing ratio at temperature *T* and pressure *p*.

If condensation/evaporation are instantaneous and the shape and moments of the s PDF are known,

$$\text{Cloud Fraction} = \int_0^\infty PDF(s)\,ds$$

$$\text{Cloud Mass} = \int_0^\infty s \cdot PDF(s)\,ds$$

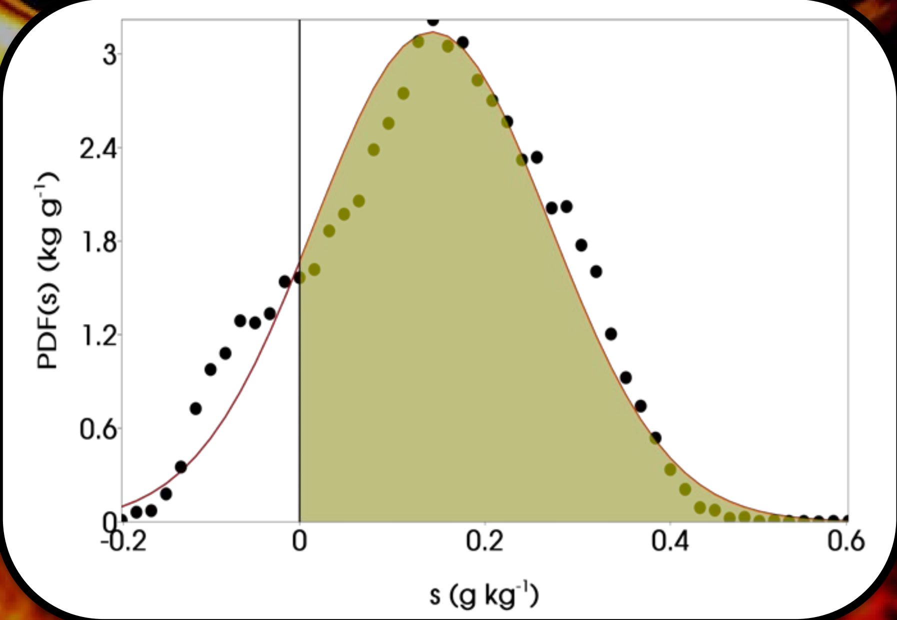


Fig: Example PDF from ASTEX (dots) with Gaussian fit (line) and cloud fraction (shaded area).

Details:

Define the saturation excess $s = q_w - q_s(T,p)$.

liquid + vapor mixing ratio ↑

↑ saturation mixing ratio at temperature *T* and pressure *p.*

If condensation/evaporation are instantaneous and the shape and moments of the s PDF are known,

$$\text{Cloud Fraction} = \int_0^{\infty} PDF(s)\,ds$$

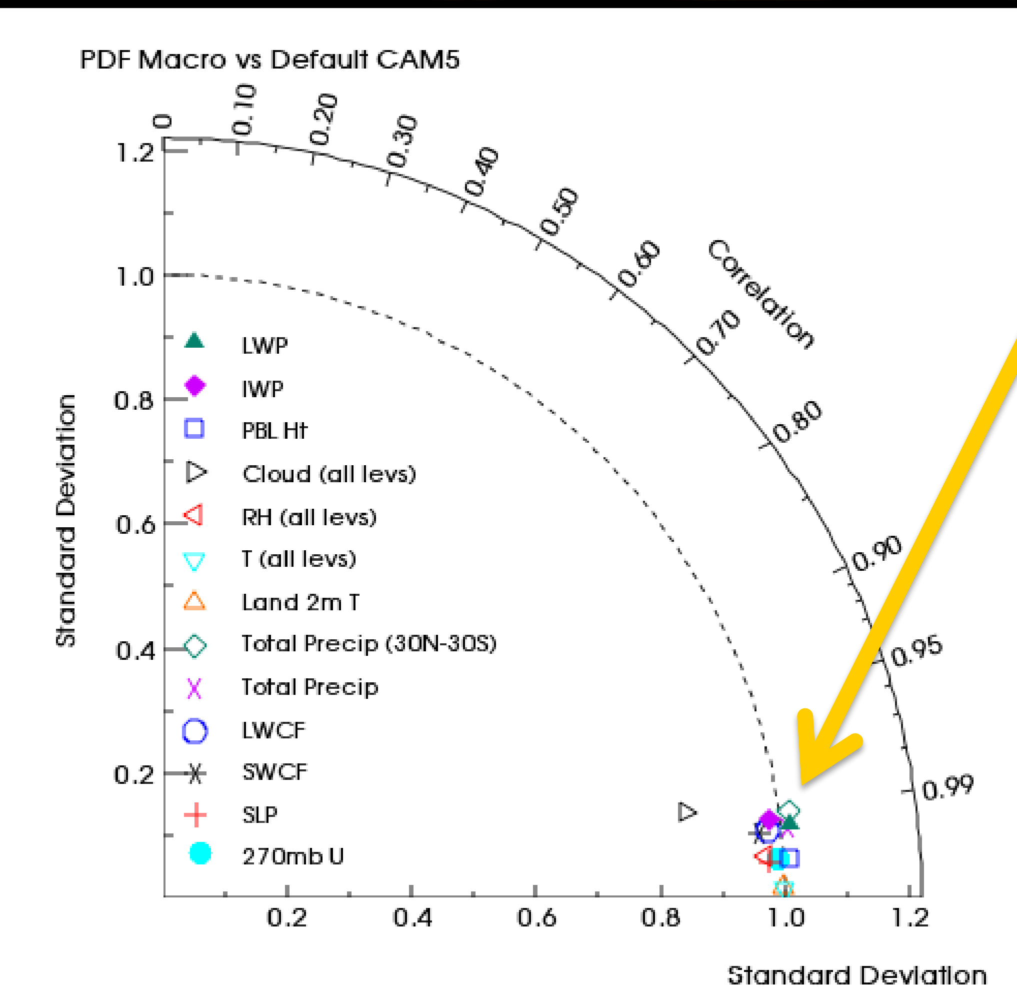
$$\text{Cloud Mass} = \int_0^{\infty} s \cdot PDF(s)\,ds$$

1. Imposes consistency between fraction and mass.
2. Not new – Sommeria and Deardorf (1977) and Mellor (1977) proposed very similar parameterizations.
3. Handling ice independently and subtracting it from the PDF is new and largely avoids ice supersaturation problems (but still permits inconsistencies).
4. Currently choosing PDF width to mimic CAM5

Macrophysics Results I: Summary

Based on 10 yr 2º climo SST runs on hera (AMD Opteron) @ LLNL

1. Our macrophysics scheme increases throughput by 7+%



2. but produces a climate very similar to CAM5!

3. Only cloud *fraction* changes enough to warrant further study

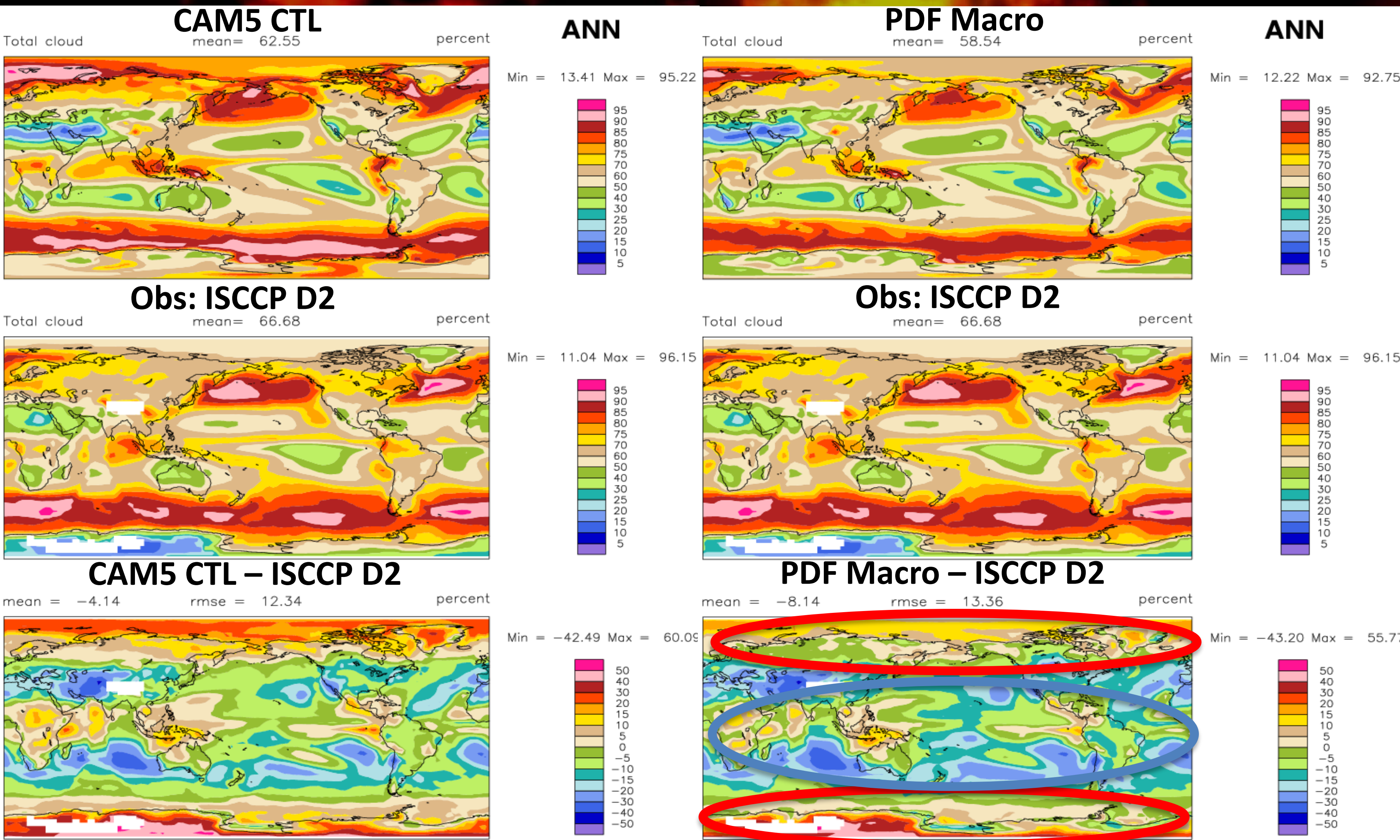
Taylor diagram showing relative standard deviation (radial distance), correlation (angle), and RMS error (distance from (1,1)) using our macrophysics scheme versus default CAM5.

Macro Results II: Global Averages

Based on 10 yr 2° climo SST runs (observation period varies)

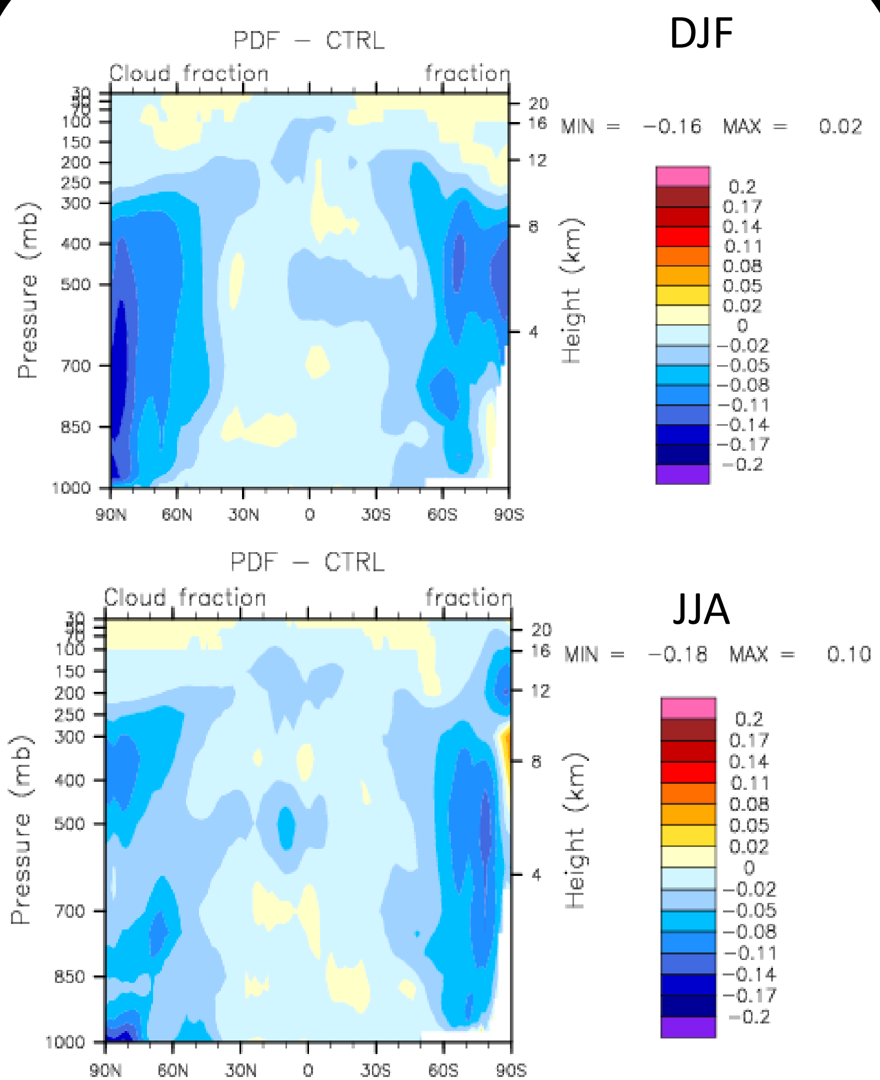
	OBSERVATION	CAM5 CTL	PDF Macro
RESTOM [Wm-2]	0	1.94	2.59
TS	287.7 (NCEP)	287.7	287.7
SHFLX	19.4 (JRA25)	18.5	18.5
LHFLX	87.9 (JRA25)	86.2	86.9
PRECT	2.61 (GPCP)	2.9	3.0
PREH2O	24.6 (NVAP)	25.8	25.9
CLDTOT	66.8 (ISCCP)	62.5	58.6
TGCLDLWP	79.9 (NVAP. Ocean)	44.5	44.9
SWCF	-47.1 (CERES2)	-50.2	-48.3
LWCF	29.9 (CERES2)	21.9	21.7

Macro Results III: CLDTOT Climo Maps



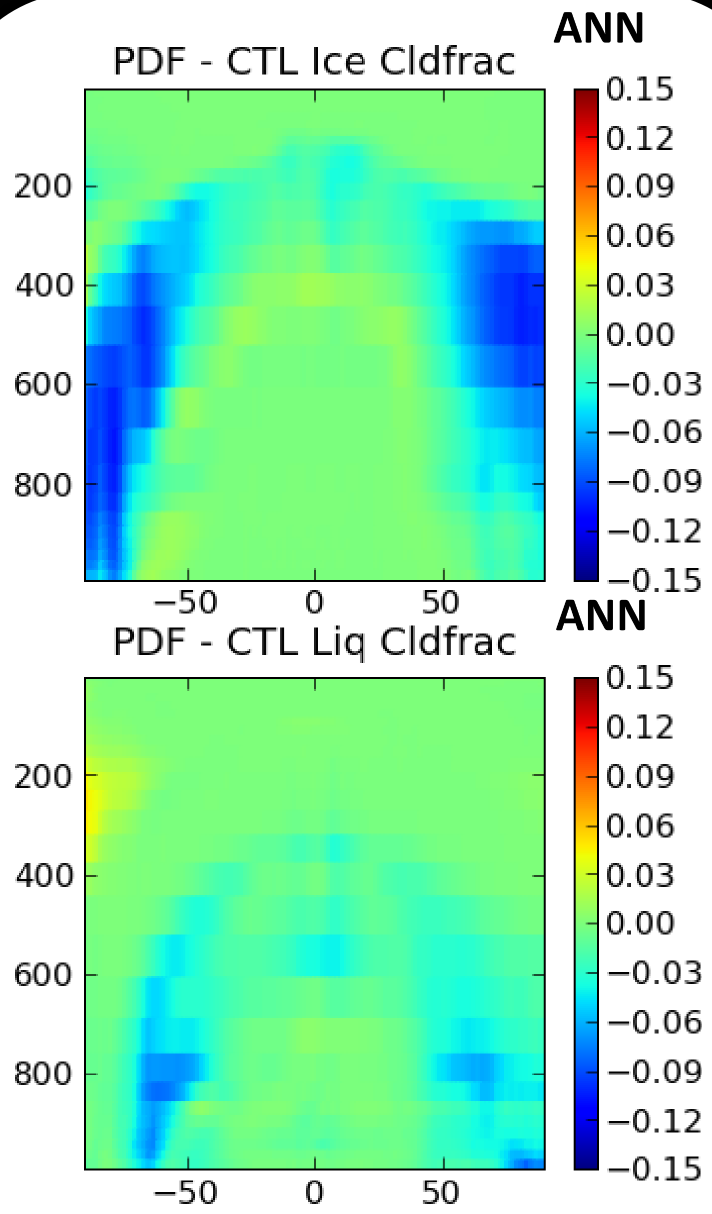
- CLDTOT decreases at high latitudes, *improving* agreement with obs
- Underprediction in storm tracks is increased, resulting in higher RMS.

Macro Results IV: CLOUD Zonal X-Sections



- **Cloud decreases are fairly uniform with height**
- **Decreases are slightly stronger in winter hemisphere**
- **Changes at high lat + elevation suggest ice clouds?**

Macro Results V: Liquid vs Ice Cloud Frac



- Changes *are* mostly in the ice phase
  - Odd since we didn't change ice parameterization
  - Due to changes in condensational heating?
- Slight increase in liquid cloud at high elevations near S pole (not good!)
  - because Gaussian PDF always has finite cloud frac?

Microphysics: Concept

(liquid water content)

For microphysical process w/ local rate $R = x\, q_l^y$:

autoconversion, accretion, immersion freezing, contact freezing, ~~sedimentation~~

- CAM5:
  - assumes SGS q_l variability follows Γ distn
    - Impossible to make consistent with q_t or s PDF
- Gaussian PDF:
  - Implies q_l follows a truncated Gaussian distn
    - Implemented as a 1-D table lookup

Issues:

1. Subgrid effects on sedimentation should be added
2. Sequential macro, micro (with substepping), and radiation apply processes to unnatural states

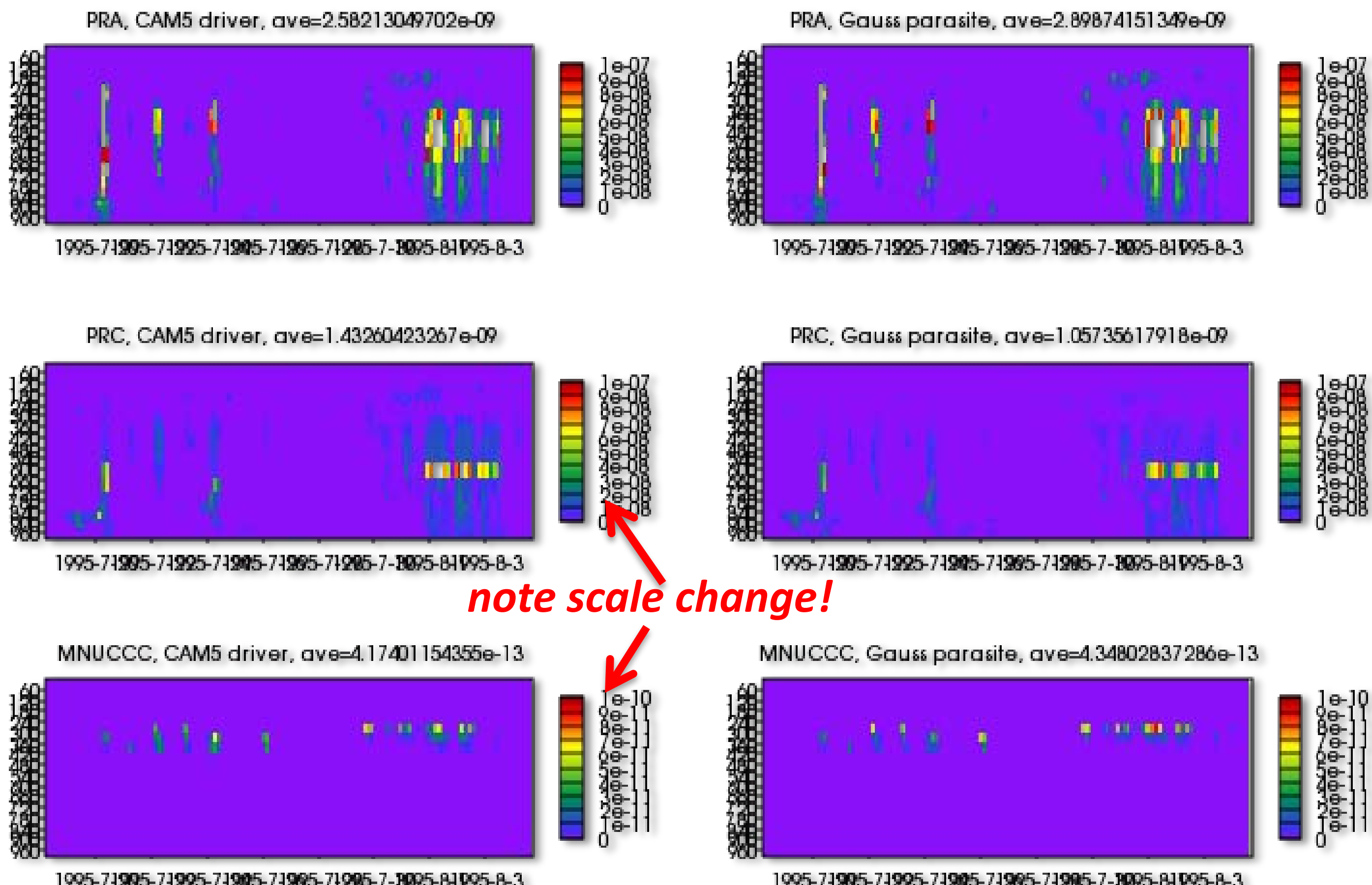
Microphysics: Results

SCAM results from ARM SGP July 1995 IOP: summertime convection.

Accretion:

Autoconversion:

Immersion Freezing:

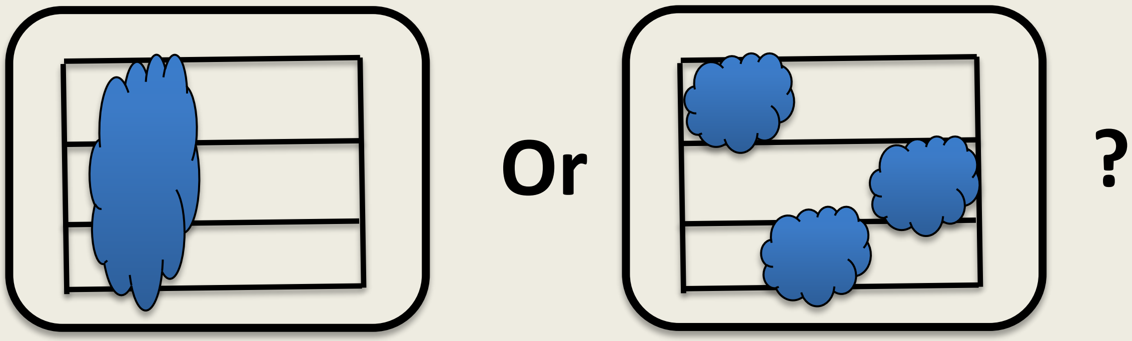


(Contact freezing always 0)

- Using old/new agreement to test for bugs
- At first glance, scheme looks reasonable!

Radiation Subgrid Variability

Vertical alignment of cloud between partially-cloudy cells (aka *cloud overlap*) has a huge influence on radiation:



CAM uses the Monte-Carlo Independent Column Approximation (McICA) to handle overlap. This uses random numbers to choose a different subcolumn for each radiation k-band.

<u>Issues:</u>

1. Currently handles cloud fraction, but assumes uniform q_l
2. Merges convective and stratiform cloud, resulting in unrealistic cloud properties

Conclusions and Plans:

1. Macro is done, runs 7+% faster, and improves AMIP climatology
   – Only cloud fraction changes significantly (due to ice-phase… needs exploration)
2. Micro is coded, needs testing
   – Sedimentation and process sequencing need work
3. Radiation should use subgrid q_l variability
4. Long-term goals include ice-phase PDF and process-based variance

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Thanks!

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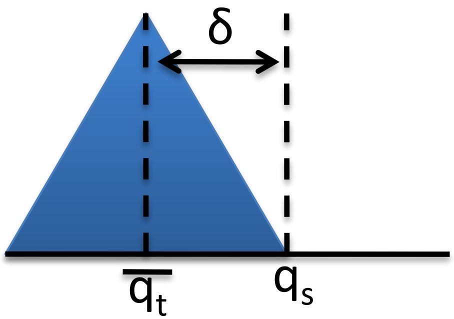
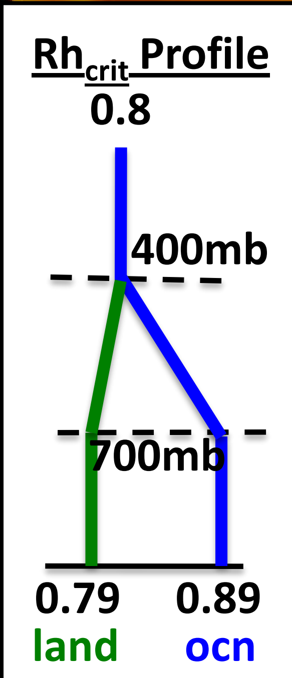
Variance Calculation

PDF width parameterization is important… and hard.

- CAM5 cloud frac uses triangular PDF in q_t with half-width (δ) $\propto$ Rh_{crit} from CAM4



$$\overline{q}_t + \delta = q_s \text{ and } RH_{crit} = \overline{q}_t / q_s$$
$$\Rightarrow \delta = (1 - RH_{crit}) q_s$$



- Currently spoof CAM5 by using triangle's variance.
  - Future work=diagnostic, process-based variance.

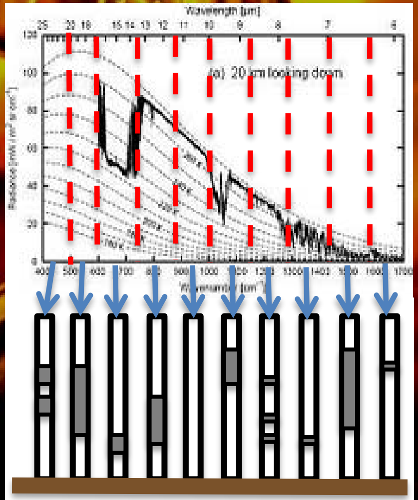
Our initial goal is to add PDF consistency with as little simulation impact as possible

Radiation Subgrid Variability

- CAM5 uses *Monte Carlo-Independent Column Approximation* (McICA):

Radiation codes typically compute fluxes as the sum of calculations for a series of spectral bands

- McICA chooses a different cloud state for each band
- makes summing over bands ≈ Monte Carlo integration over cloud states.
- noisy for 1 timestep, but quickly damps
- allows for arbitrary cloud overlap



$$\Rightarrow F_{net} = \sum_k I(\lambda_k) F(\text{state}_k, \lambda_k)$$

McICA in CAM5:

1. Handles cloud fraction consistently
2. Assumes uniform liquid water content (inconsistent)
3. Merges convective and stratiform cloud, causing unrealistic properties