Gaussian PDF Cloud Parameterization

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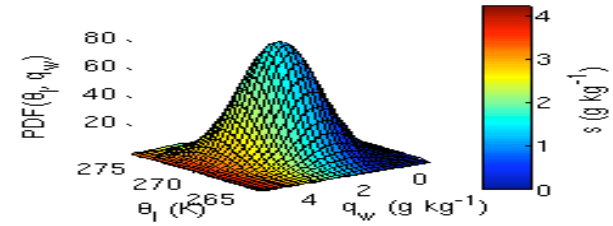
Outline:

1. The PDF
2. Macrophysics
3. Microphysics
4. Future work (radiation, ice, variance, convection)

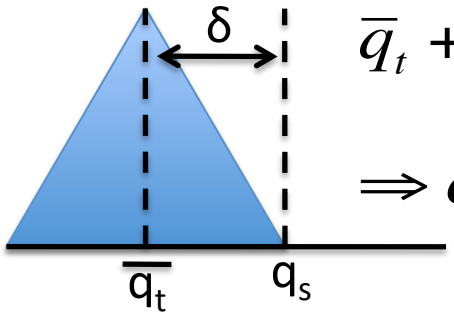
PDF: Formulation



- Using a bivariate Gaussian in T_l and $q_w=q_t-q_i$
  - follows Sommeria+Deardorff (1977), Mellor (1977)
  - q_w ➔ PDF for liquid only. Ice follows default CAM5.
    - imperfect: ice inconsistency persists, q_w not conserved.
- Can be rewritten as univariate Gaussian in $S=q_w' - B_l\, T_l'$ where $B_l=\delta q_s/\delta T|_{Tl}$
  - note if $q_l>0$, $q_l=S+Q$ where $Q=\overline{q_w}-q_s(\overline{T_l},p)$
  - univariate *always* used for calculation
  - bivariateness only meaningful if σ_{Tl} and σ_{qw} have real meaning
- Will Gaussian unboundedness cause problems for McICA?

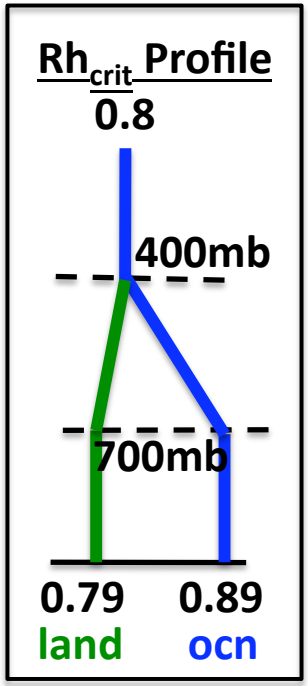
PDF: Variance

- CAM5 cloud frac uses triangular PDF in q_t with half-width $\delta \propto Rh_{crit}$



$$\overline{q}_t + \delta = q_s \text{ and } RH_{crit} = \overline{q}_t / q_s$$

$$\Rightarrow \delta = \underbrace{(1 - RH_{crit})}_{\text{CAM5}} q_s \text{ or } \delta = \frac{(1 - RH_{crit})}{\underbrace{RH_{crit}}_{\text{Our scheme}}} \overline{q}_t$$



- Currently spoof CAM5 by using triangle's variance.
  - T_l dependence requires an approximation.
  - Future work=diagnostic, process-based variance.

Macrophysics: Formulation

- Computing liquid cloud fraction A_l and cell-ave q_l from the S PDF is straightforward:

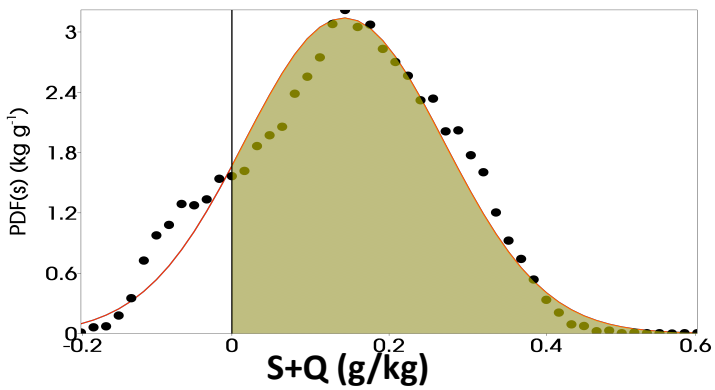


Fig: Example PDF from ASTEX (dots) with Gaussian fit (line) and cld frac (shaded).

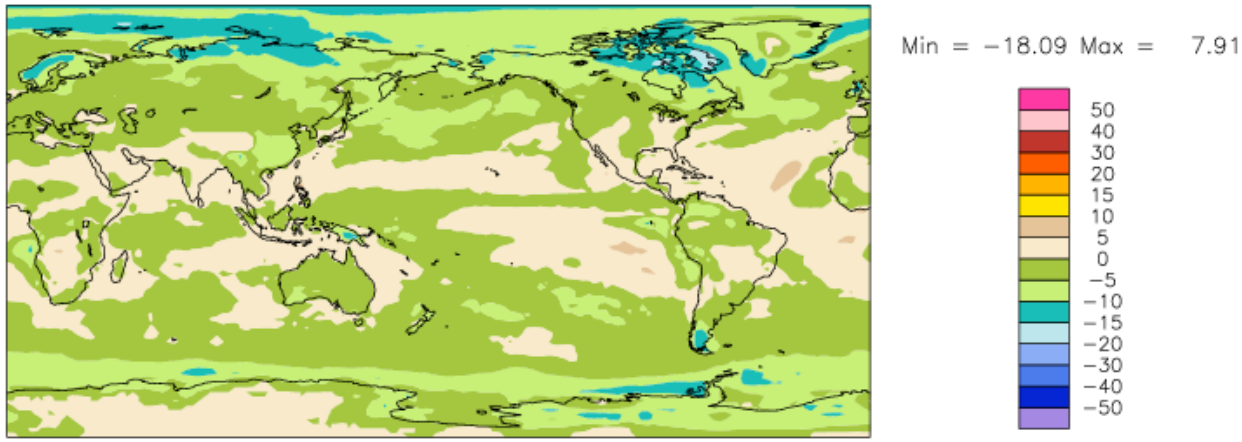
$$A_l = 0.5\left[1 + \mathrm{erf}\left(\frac{Q}{\sqrt{2}\sigma_S}\right)\right]$$

$$\overline{q}_l = \left(1 + \frac{B_l L_v}{c_p}\right)^{-1}\left[QA_l + \frac{\sigma_S}{\sqrt{2\pi}}\exp\left\{\frac{-Q}{2\sigma_S{}^2}\right\}\right]$$

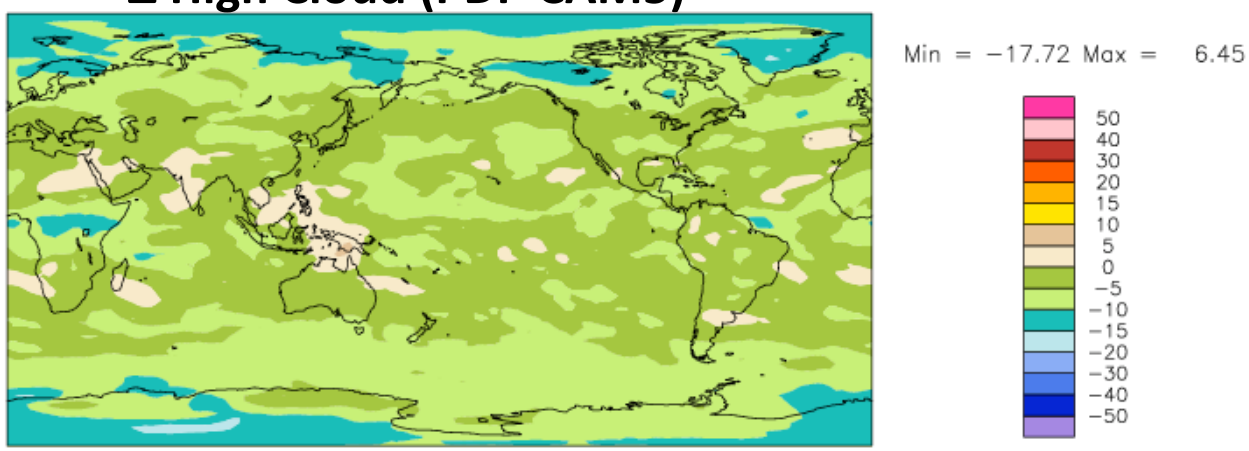
- CAM5 uses triangular distn for A_l and implicit, conserved Zhang et al (2003) for $\overline{q}_l$ (+checks).

Macrophysics: Results

Δ Low Cloud (PDF-CAM5)



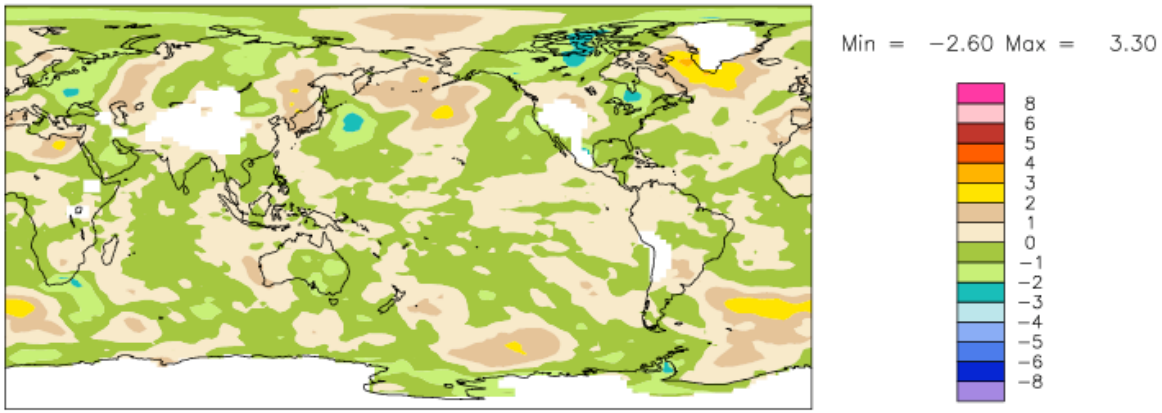
Δ High Cloud (PDF-CAM5)



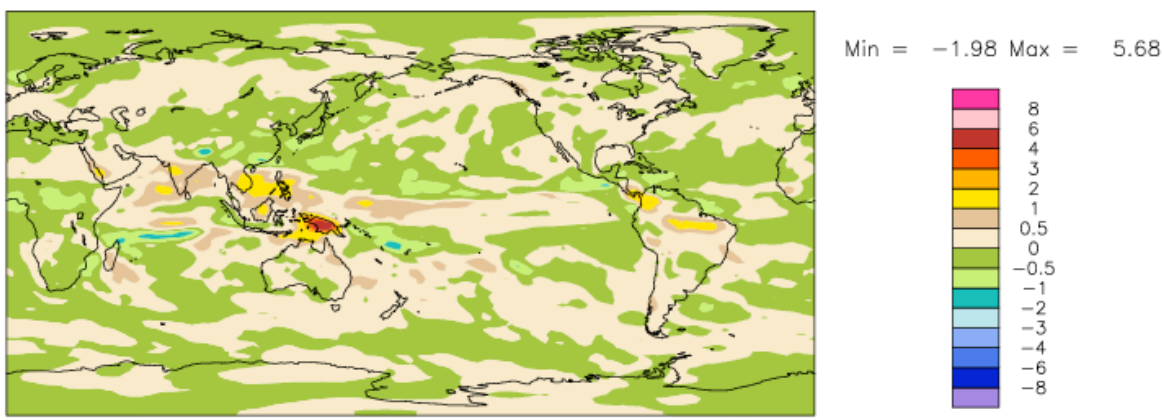
- **Cldfrac decreases at all levels**
  - **Smallest change in tropical low cloud**
  - **largest change in polar regions.**
  - **No seasonality**
- **Cell-ave LWP (not shown) increases in some coastal land regions, else unchanged**
  - **in-cld q_l must have increased**

Macrophysics: Results

Δ 850mb T (PDF-CAM5)



Δ Precip (PDF-CAM5)



- **Other aspects of the runs are remarkably similar!**
- **Remember – PDF version O(10%) faster!**

Macrophysics: Understanding Cld Frac

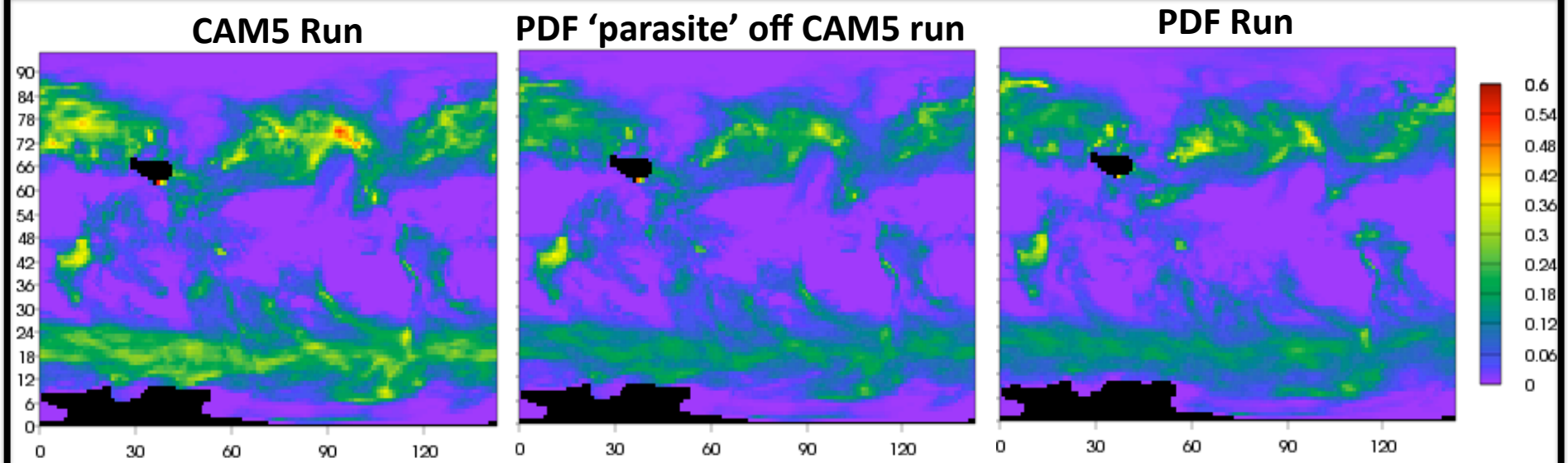


Fig: 850 mb liquid cloud fraction (LCLOUD) from 1 mo CAM simulations.

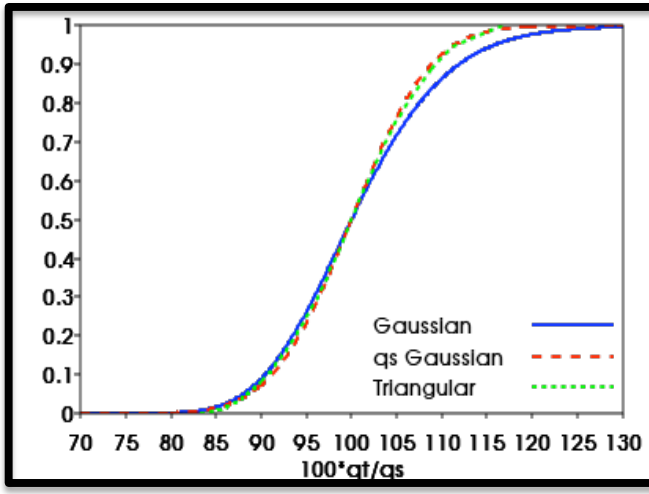


Fig: Cloud fraction vs $q_t/q_s(T,p)$ for Gaussian, CAM5 (triangular), and Gaussian using CAM5 q_s approach at p=500 mb, T=240 K.

- **PDF-forced and PDF-parasite runs similar→differences from cldfrac param**

- **Cloud fraction differences due (partly?) to making width $\propto q_w$ rather than q_s.**

Microphysics: Subgrid q_l

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
  - for given q_l, drop diameter D follows a Γ distn with params chosen to keep drop conc constant
- Gaussian PDF:
  - local q_l=S+Q ➔ q_l follows truncated Gaussian distn.

Setting $z = \left(q_l - \mu_{q_l}\right) / \left(\sqrt{2}\sigma_{q_l}\right)$ and $G = \mu_{q_l} / \left(\sqrt{2}\sigma_{q_l}\right)$,

$$\overline{R} = \frac{x}{\sqrt{\pi} A_l} \left(\sqrt{2}\sigma_{q_l}\right)^y \underbrace{\int_{-G}^{\infty} (z+G)^y \exp\left\{-z^2\right\} dz}_{\text{1d table lookup}}$$

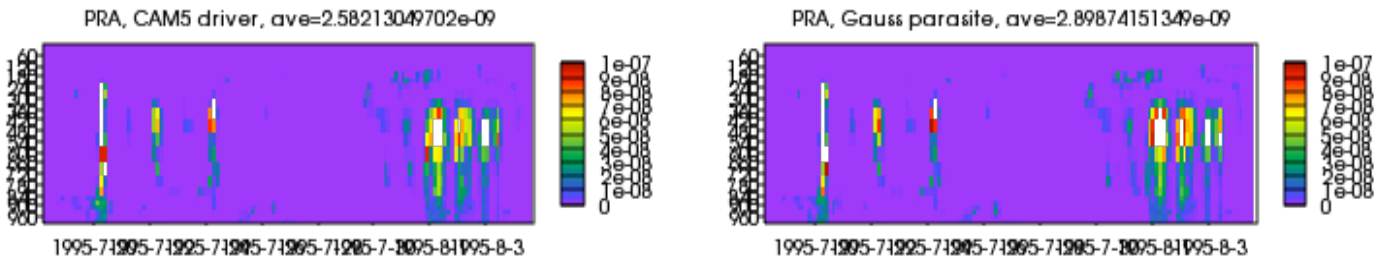
Microphysics: Substepping

- Most of CAM5 microphysics is substepped, requiring PDF updates.
  - Updated PDF is Gaussian with unchanged A_l and q_l matching that prognosed by the model.
    - this approach makes q_l pdf inconsistent with S PDF.
      - conceptually, this means that condensation/evaporation only occurs during macrophysics… which is logical.
- Updating can be done by simply scaling μ and σ by $\alpha=\overline{q_{l,new}}/\overline{q_{l,old}}$!
    - If $\overline{q_{l,old}}=0$, A_l and $\overline{q_l}$ PDF equations can back out params.
    - Updated rates could be calculated as old rate times α^y

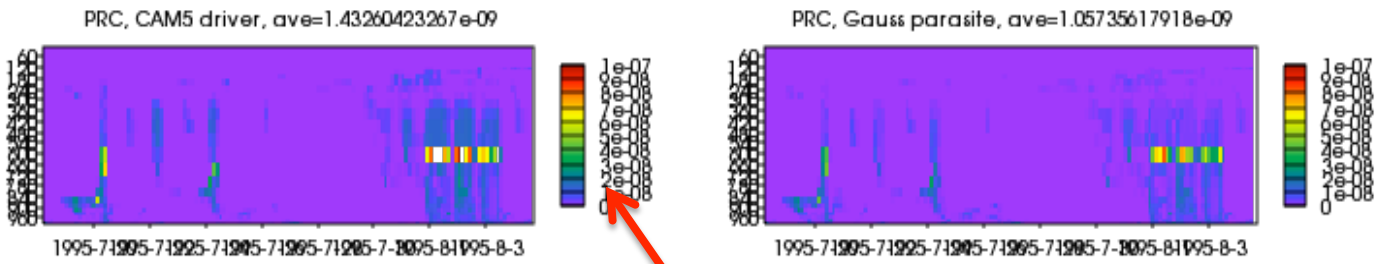
Microphysics: Results

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

Accretion:

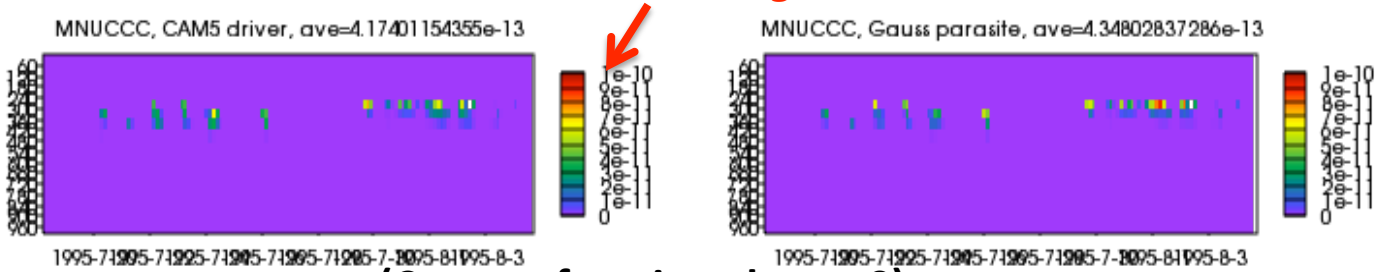


Autoconversion:



note scale change!

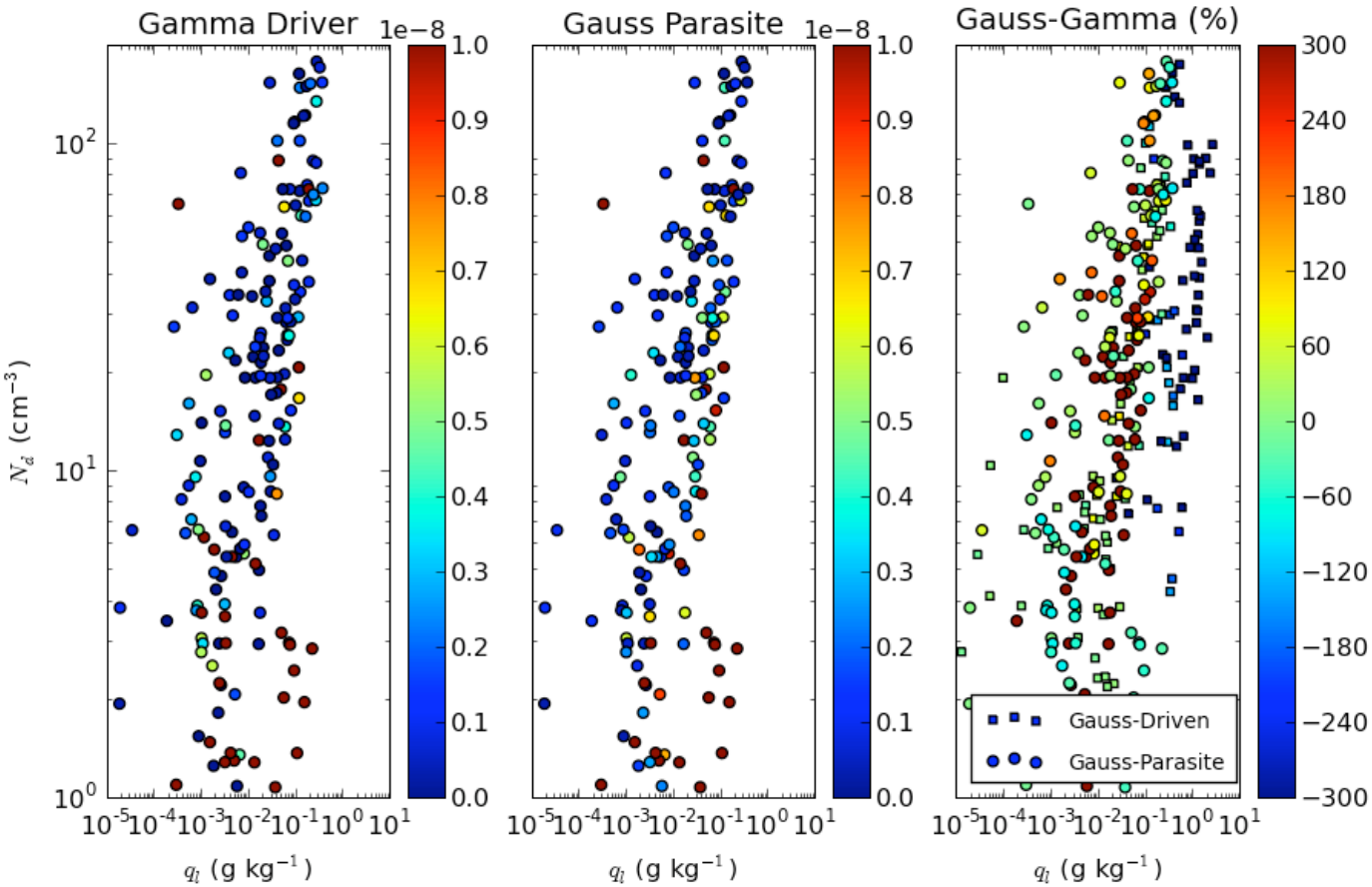
Immersion Freezing:



(Contact freezing always 0)

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

Microphysics: Results



- Rates often agree, but many cases where parasite >driver exist.

Fig: Autoconversion rates (color) as a function of q_l and N_d. The RHS panel shows % difference between Gauss and Gamma rates (with denom chosen as min{driver,parasite} to emphasize errors). The RHS panel uses 2 runs (Gauss-driven and Gamma-driven) to increase the number of data points.

Microphysics: Results

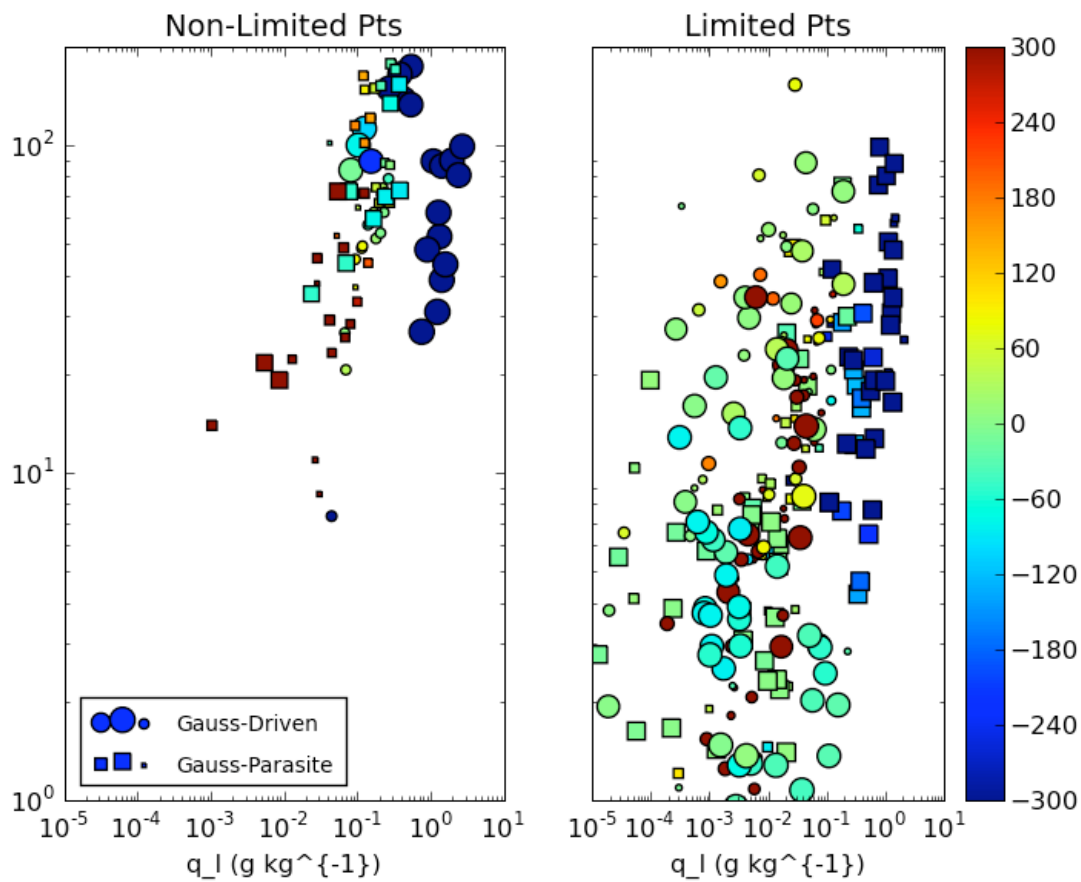


Fig: Gauss – Gamma % difference (prev slide RHS) broken into cases where microphysics depletes all q_l (so limiting is needed) or not. Symbol size ∝ pressure level.

Discrepancies aren't correlated with height or whether all water was used up in the timestep.

Microphysics: Results

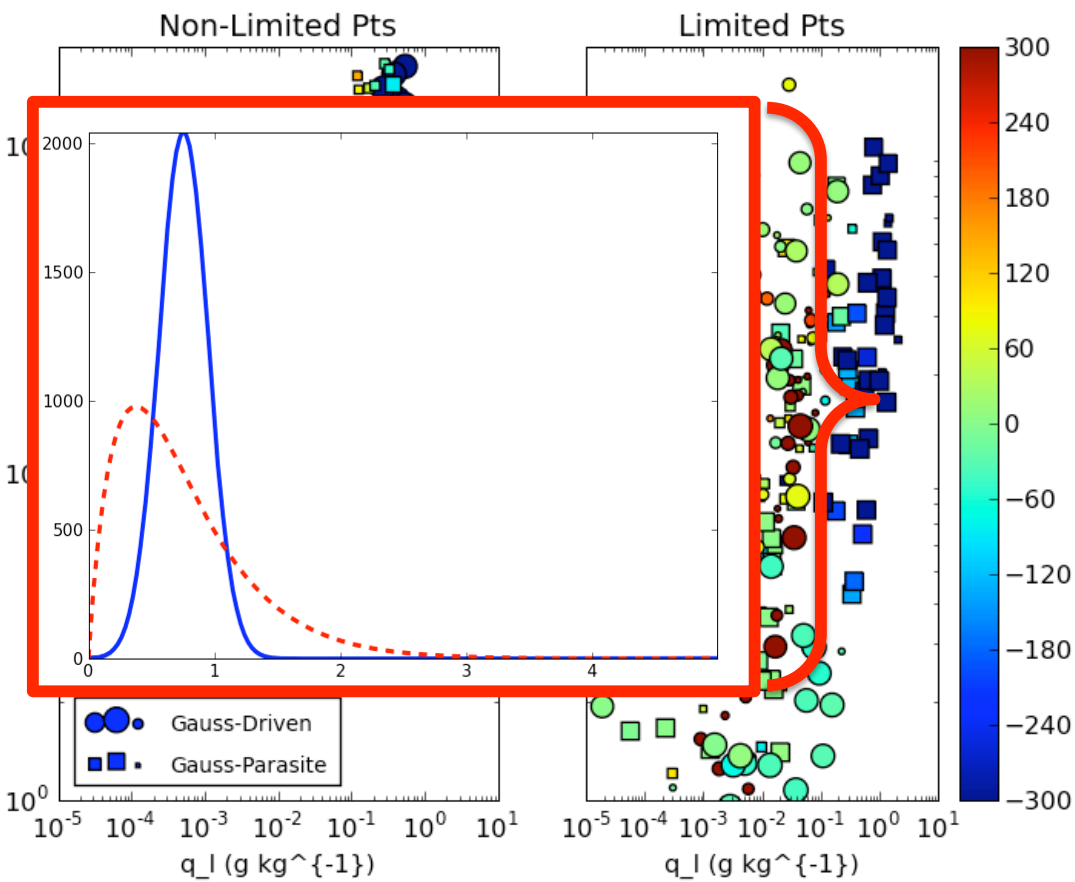


Fig: Gauss – Gamma % difference (prev slide RHS) broken into cases where microphysics depletes all q_l (so limiting is needed) or not. Symbol size ∝ pressure level.

Is difference explained by PDF shapes?

Future Work:

PHASE 1:

1. Test new parameterizations
   - use SCAM more
   - Questions: why do runs differ? Is my method robust?
2. Make connections to McICA radiation
   - A. Gettelman is "almost done" moving McICA out of radiation. Waiting for stable code.

PHASE 2 (the interesting part!):

1. Process-based diagnostic variance prediction
2. Ice/mixed phase
3. Convective detrainment