A new and improved analytic double Gaussian PDF

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Cloud Layers Unified By Binormals (CLUBB)

CLUBB is a model or parameterization that uses a multivariate probability density function (PDF) in order to represent subgrid-scale variability.

CLUBB predicts means, variances, covariances (e.g. fluxes), and third-order moments of various model fields and then uses them to create the PDF.

What does CLUBB use the subgrid PDF for?

CLUBB's PDF can be integrated over to calculate grid-box averages of fields such as:

1. Cloud water and cloud fraction
2. Buoyancy fluxes
3. Higher-order moments (3rd and 4th order moments)
4. Microphysics process rates

CLUBB’s traditional double Gaussian PDF (used in CAM6)

- Known as Analytic Double Gaussian 1 (ADG1).
- ADG1 is the method by which CLUBB calculates the mean and variance of each Gaussian for a given variable, as well as the weight of each Gaussian in the multivariate PDF.

What variables does ADG1 control in the multivariate PDF?

$$P(\mathbf{w}, r_t, \boldsymbol{\theta}_l, \mathbf{h}) = a * P_1(\mathbf{w}, r_t, \boldsymbol{\theta}_l, \mathbf{h}) + (1 - a) * P_2(\mathbf{w}, r_t, \boldsymbol{\theta}_l, \mathbf{h})$$

Note: Bold **h** stands for a vector of hydrometeor species.

The variable “a” stands for the mixture fraction, which is the weight of each PDF component.

ADG1 directly controls the variables listed in blue.

Some problems with ADG1

- Excessive evaporation compared to LES higher in the domain (alongside cloud) in a precipitating cumulus case.
- Insufficient turbulent advection of higher-order moments.
- Excessively bimodal PDF of vertical velocity.

The new PDF in words

Like ADG1, it is analytic (in other words, no iterative root finders) and it is also double Gaussian.

Unlike ADG1, it goes toward a single Gaussian when skewness approaches 0 and towards a double delta as skewness approaches ±∞. The degree to which it does so is tunable.

Unlike ADG1, it accounts for within-component (or within-Gaussian) correlations of w and rt, as well as w and $\boldsymbol{\theta}_{\mathrm{I}}$. (ADG1 hard wires these to 0).

What variables are used to make the PDF?

In other words, what are the inputs?

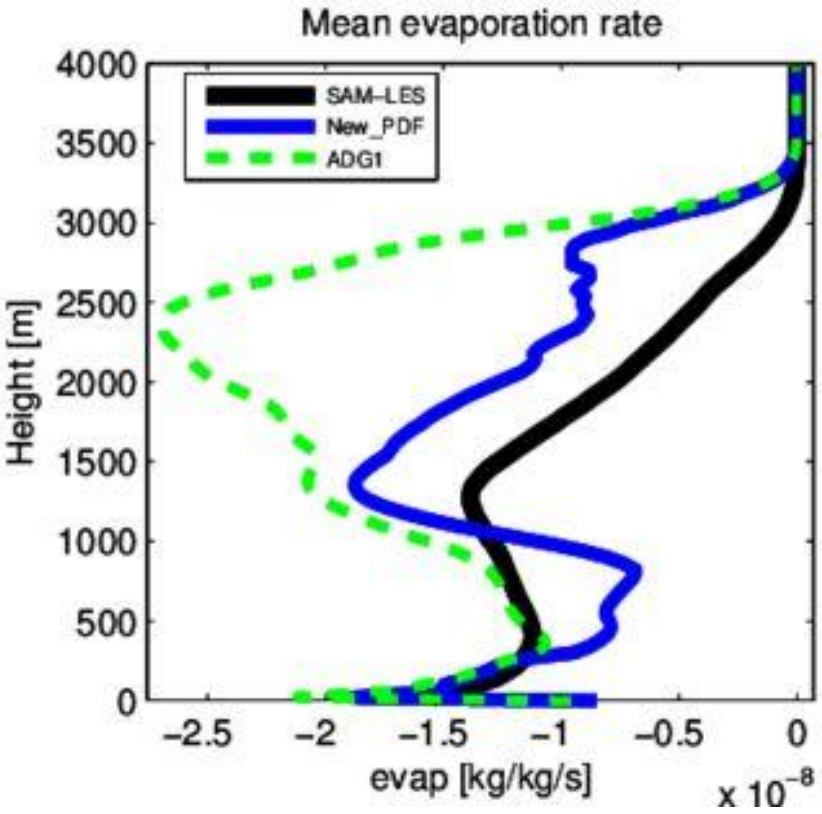
Overall (grid box) means: $\langle w \rangle$, $\langle r_t \rangle$, $\langle \boldsymbol{\theta}_l \rangle$

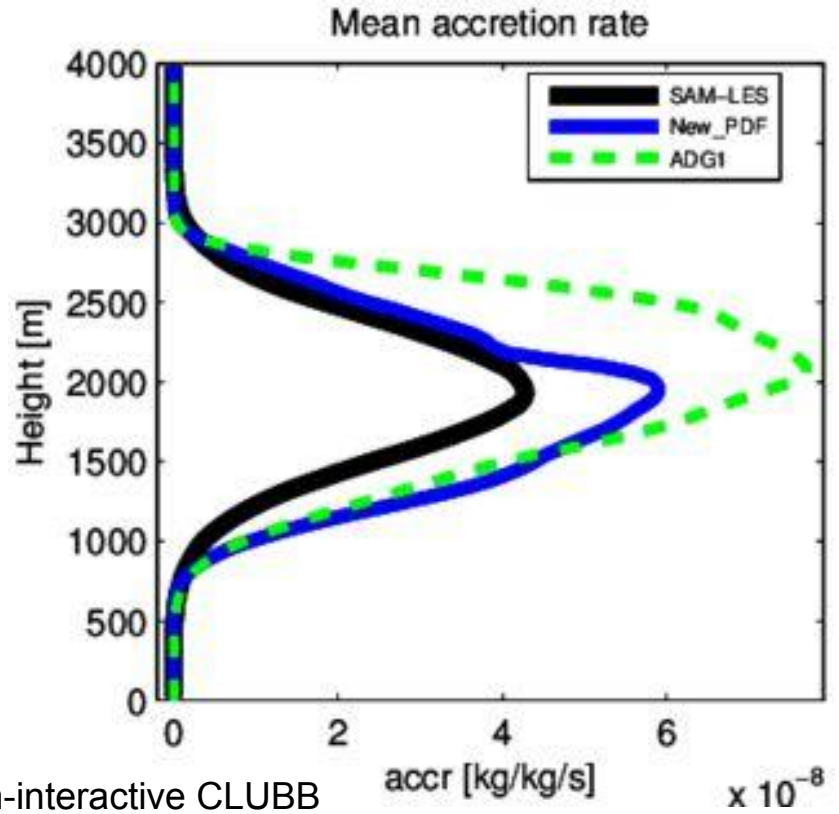
Overall variances: $\langle w'^2 \rangle$, $\langle r_t'^2 \rangle$, $\langle \boldsymbol{\theta}_l'^2 \rangle$

Third-order moments (skewness): $\langle w'^3 \rangle$, $\langle r_t'^3 \rangle$, $\langle \boldsymbol{\theta}_l'^3 \rangle$

Covariances: $\langle w' r_t' \rangle$, $\langle w' \boldsymbol{\theta}_l' \rangle$, $\langle r_t' \boldsymbol{\theta}_l' \rangle$

Microphysics process rates: RICO precipitating shallow cumulus case





Non-interactive CLUBB

Why do we care about higher-order moments?

The 3rd and 4th order moments, as calculated by integrating over the PDF, are used to close the predictive equation set as part of the *turbulent advection* term.

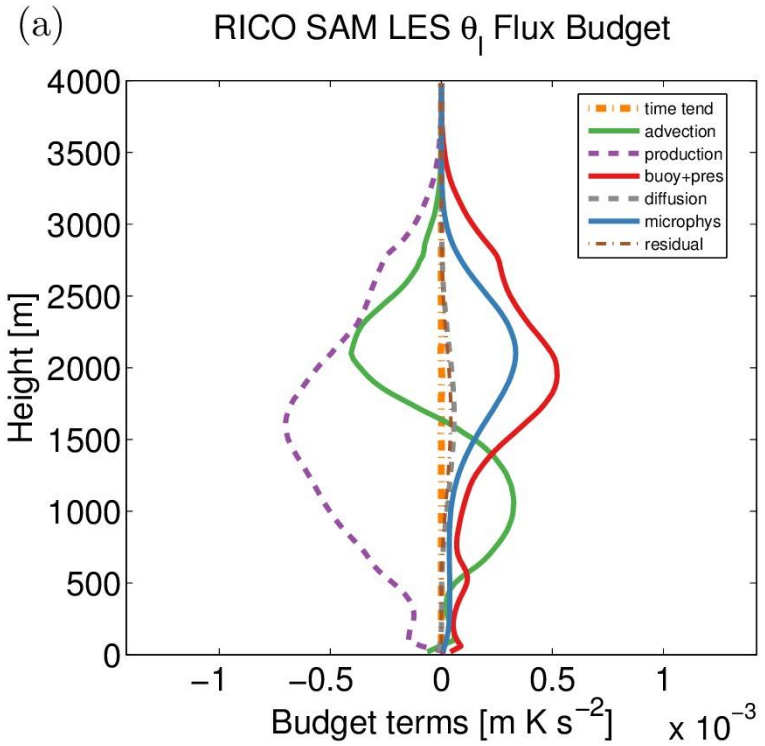
Some examples:

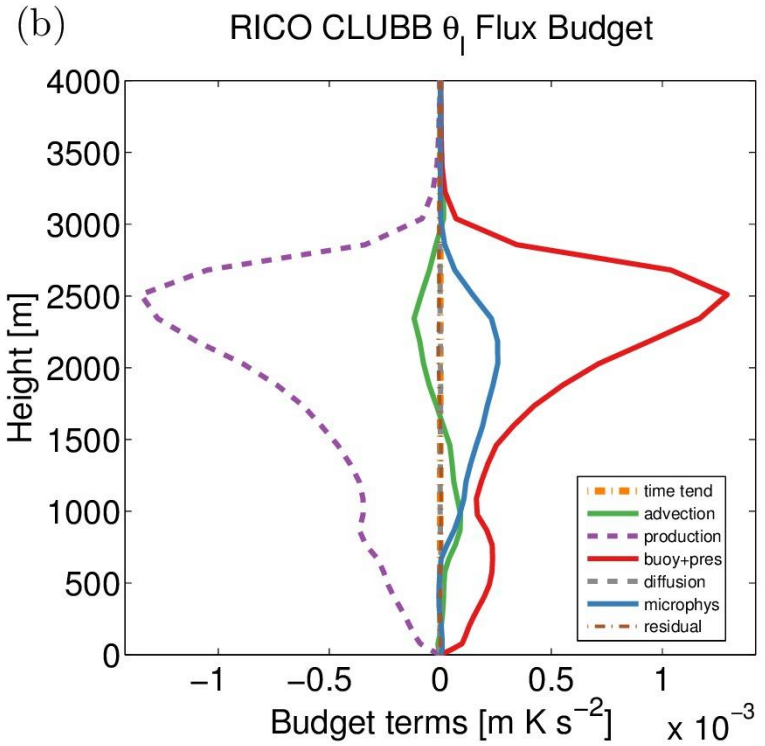
$$\frac{\partial \overline{w'^3}}{\partial t} = \ldots - \frac{1}{\rho_s}\frac{\partial \rho_s \overline{w'^4}}{\partial z} + \ldots$$

$$\frac{\partial \overline{w' r_t'}}{\partial t} = \ldots - \frac{1}{\rho_s}\frac{\partial \rho_s \overline{w'^2 r_t'}}{\partial z} + \ldots$$

$$\frac{\partial \overline{w' \theta_l'}}{\partial t} = \ldots - \frac{1}{\rho_s}\frac{\partial \rho_s \overline{w'^2 \theta_l'}}{\partial z} + \ldots$$

Problem: CLUBB usually underpredicts turbulent advection

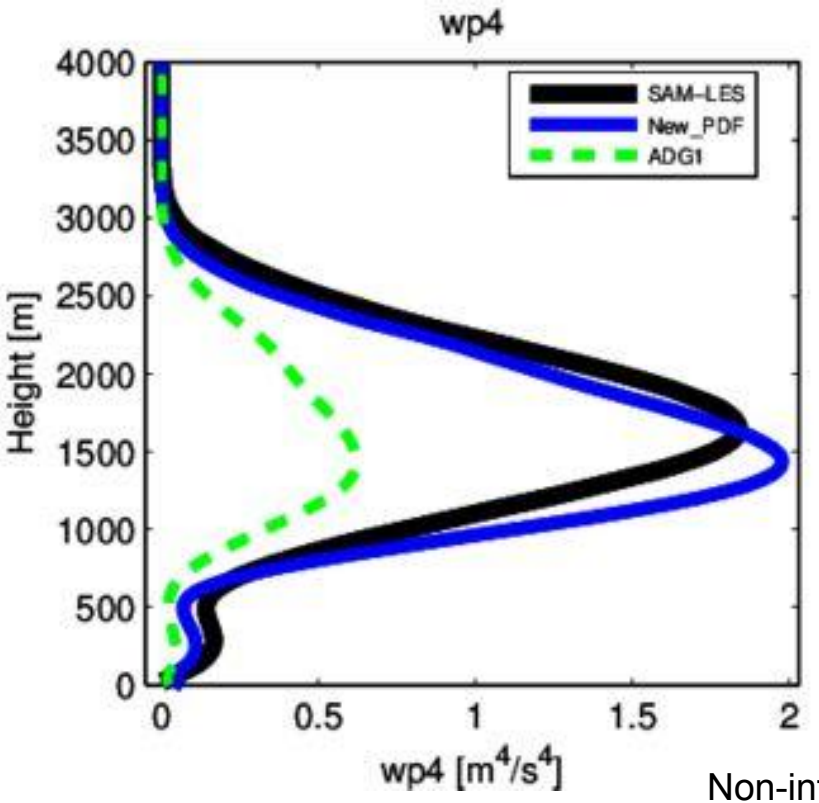


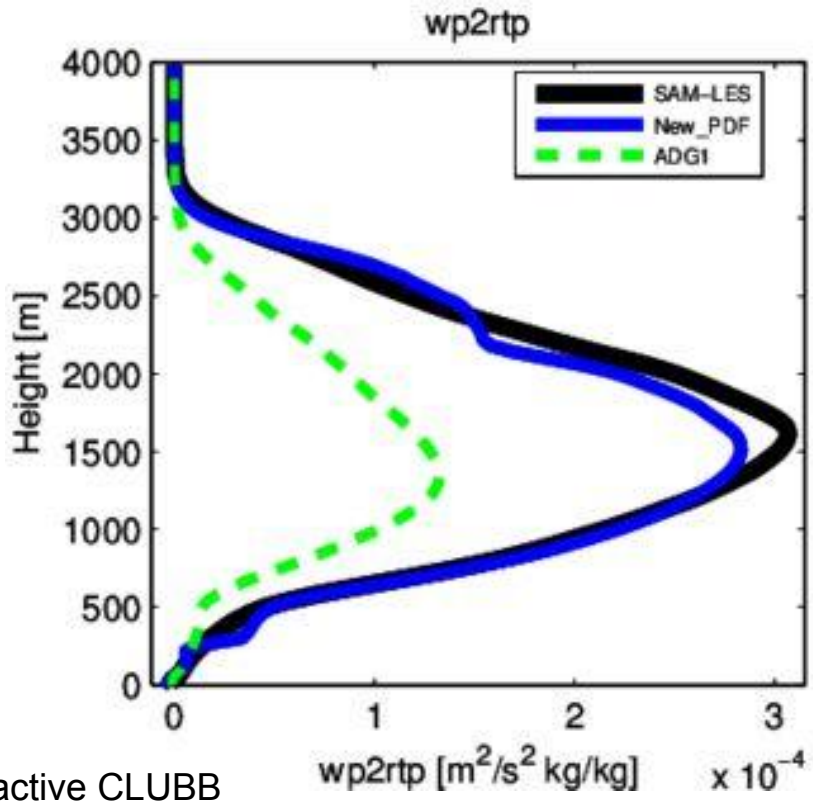


Griffin and Larson (2016)

Fully interactive CLUBB simulation with ADG1

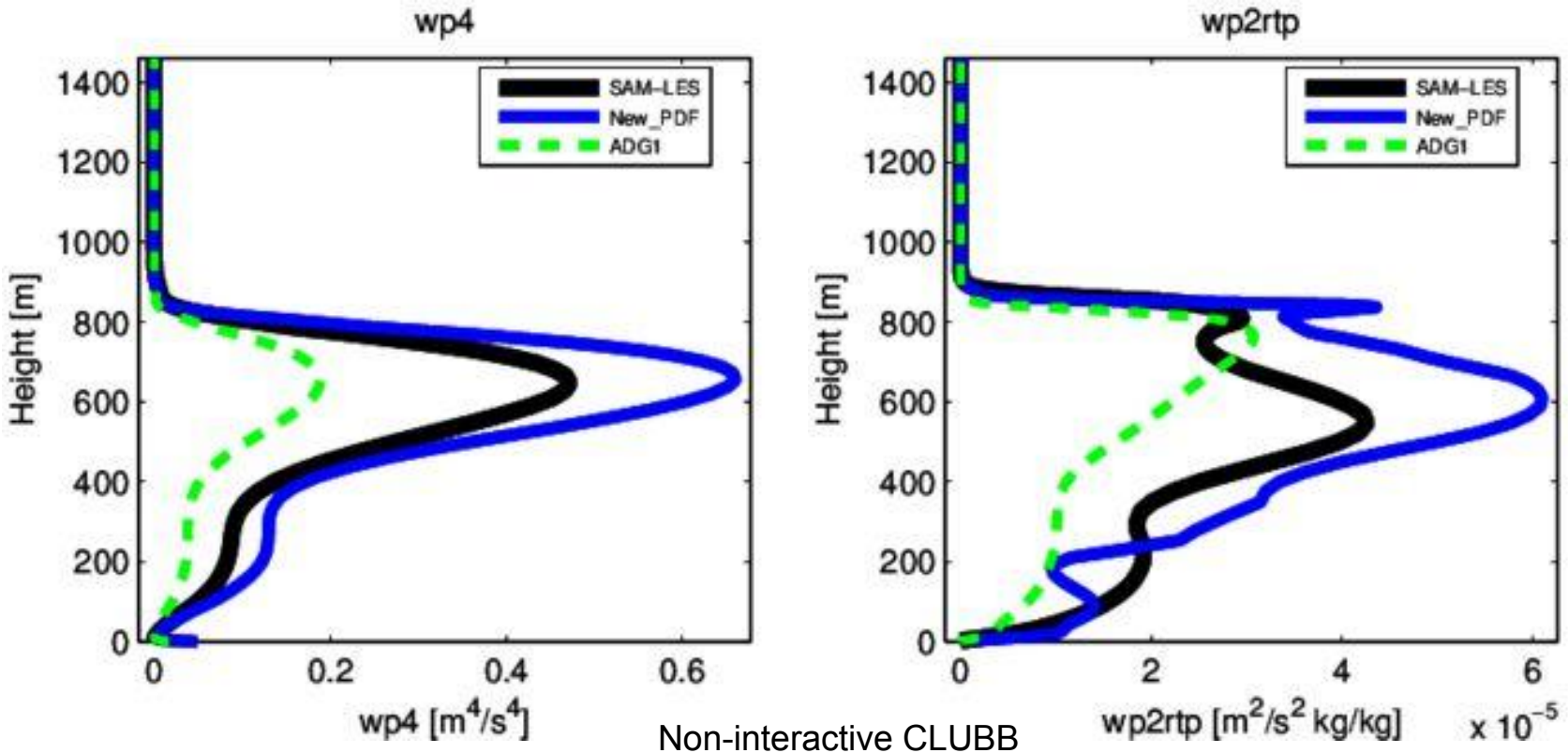
Examples of higher-order moments from the RICO precipitating cumulus case





Non-interactive CLUBB

Examples of higher-order moments from the DYCOMS-II RF02 drizzling stratocumulus case



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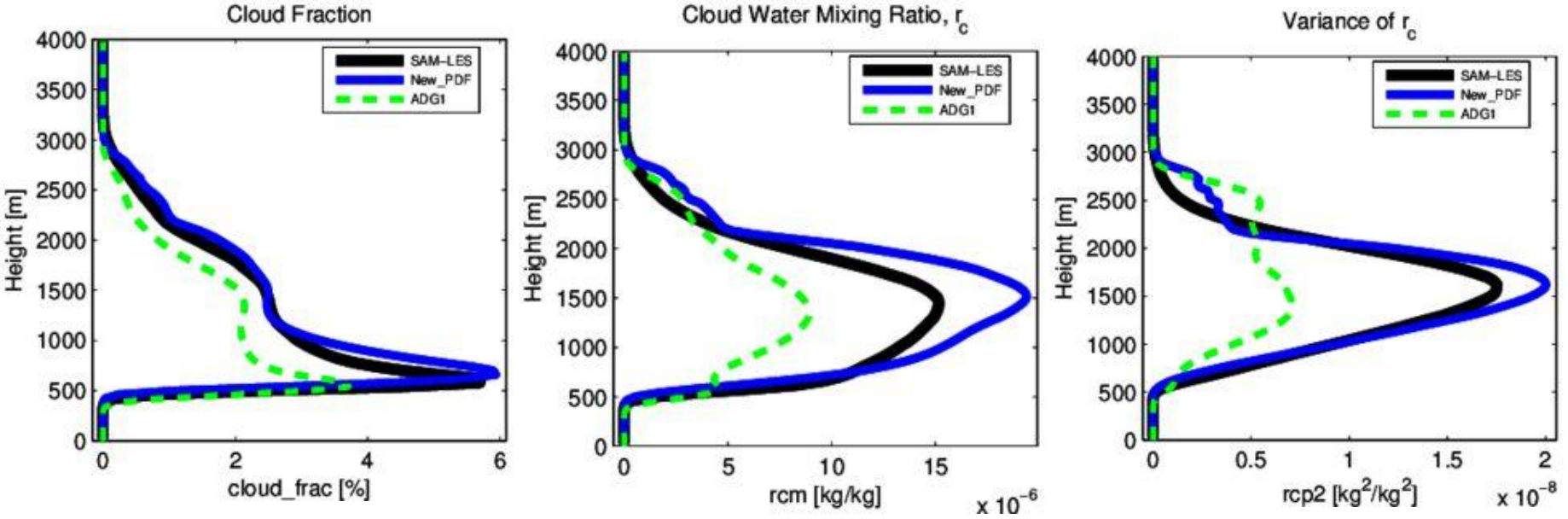
Cloud fields: RICO



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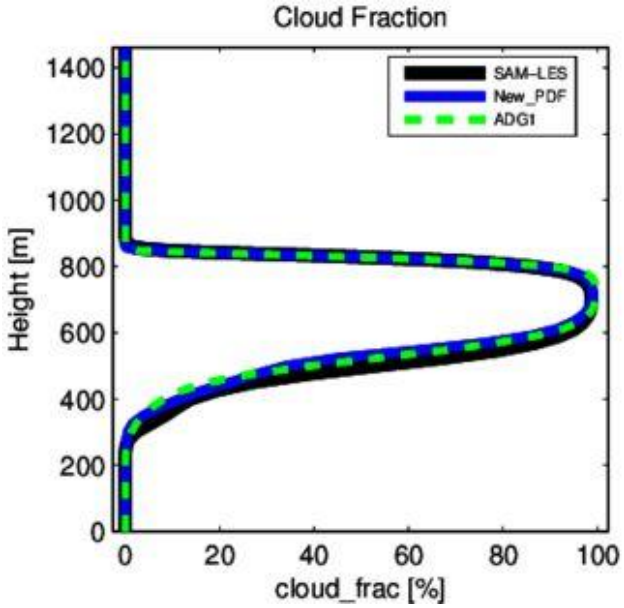
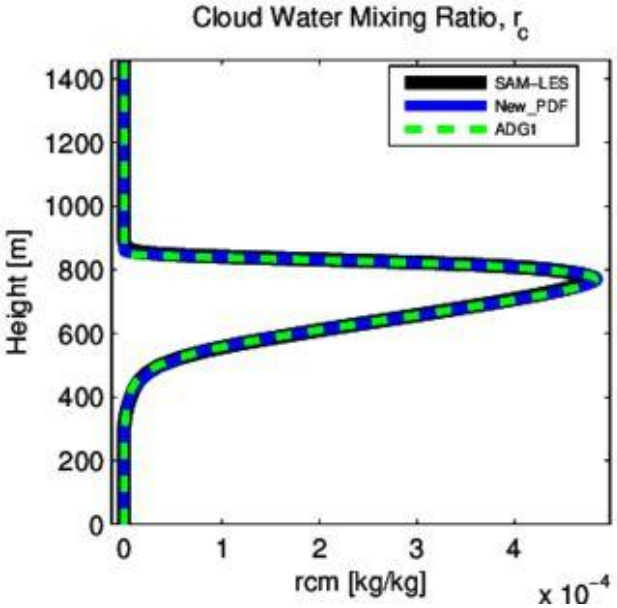
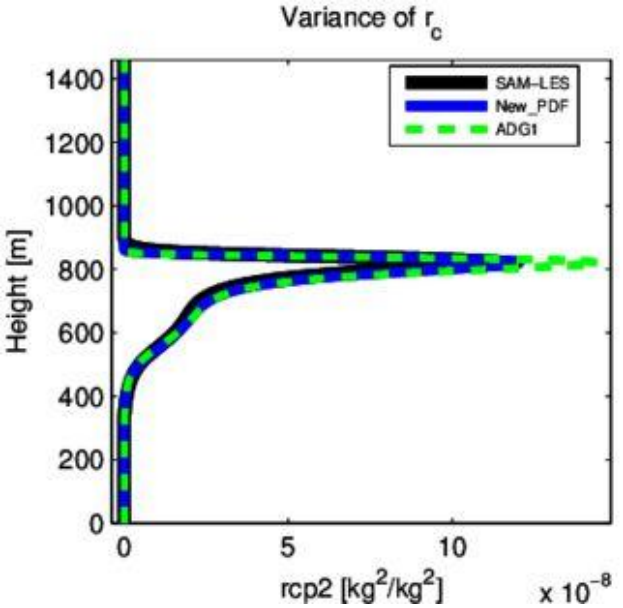
Cloud fields: DYCOMS-II RF02







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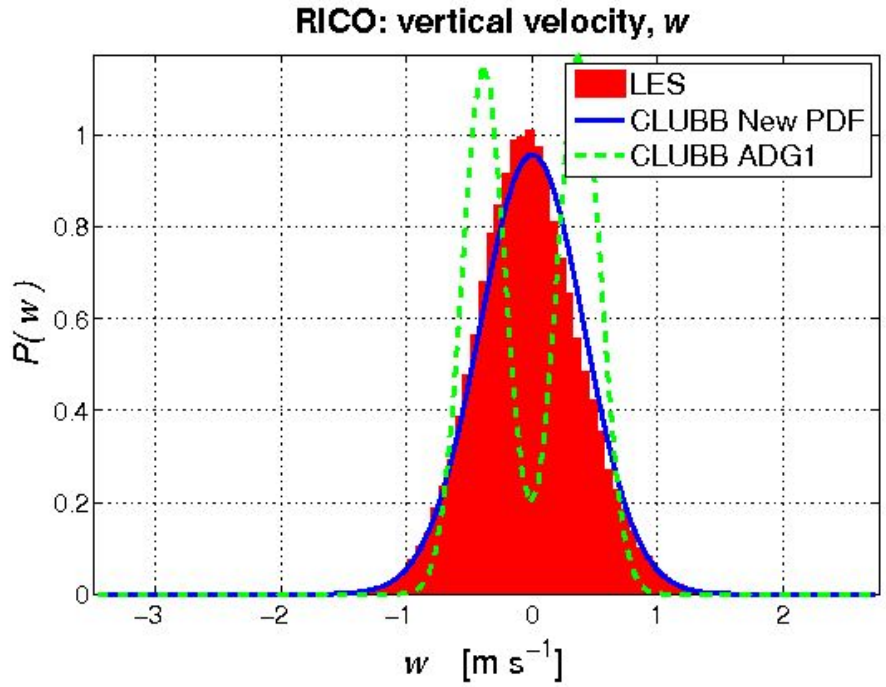
Possible future use of CLUBB's PDF

Use the PDF of vertical velocity for activating aerosol.

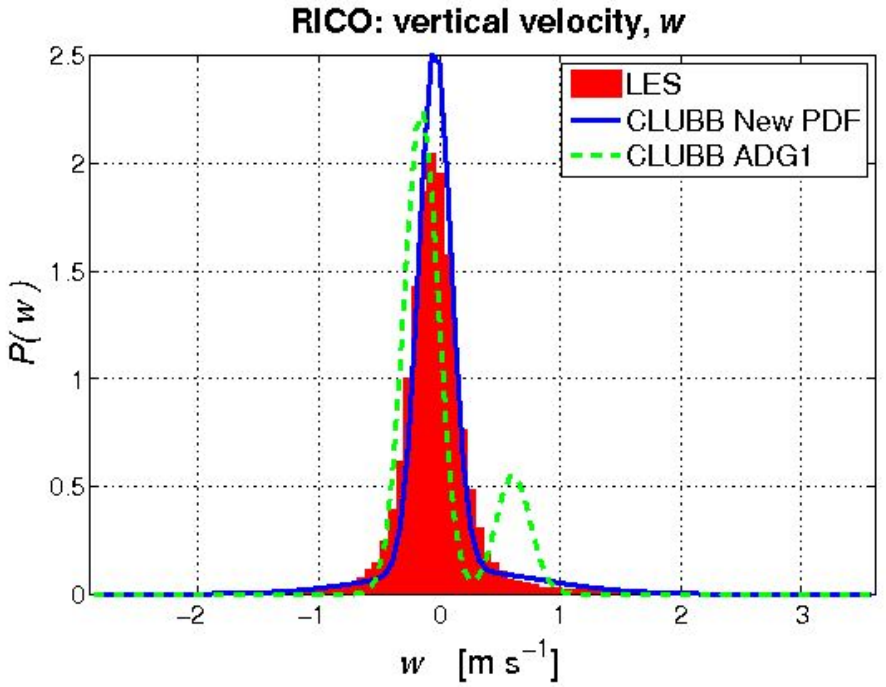
This would require a realistic PDF of vertical velocity.

The following slides illustrate the differences between ADG1 and the new PDF.

PDFs of vertical velocity



Skewness of w roughly 0



Skewness of w mildly positive (1.15)

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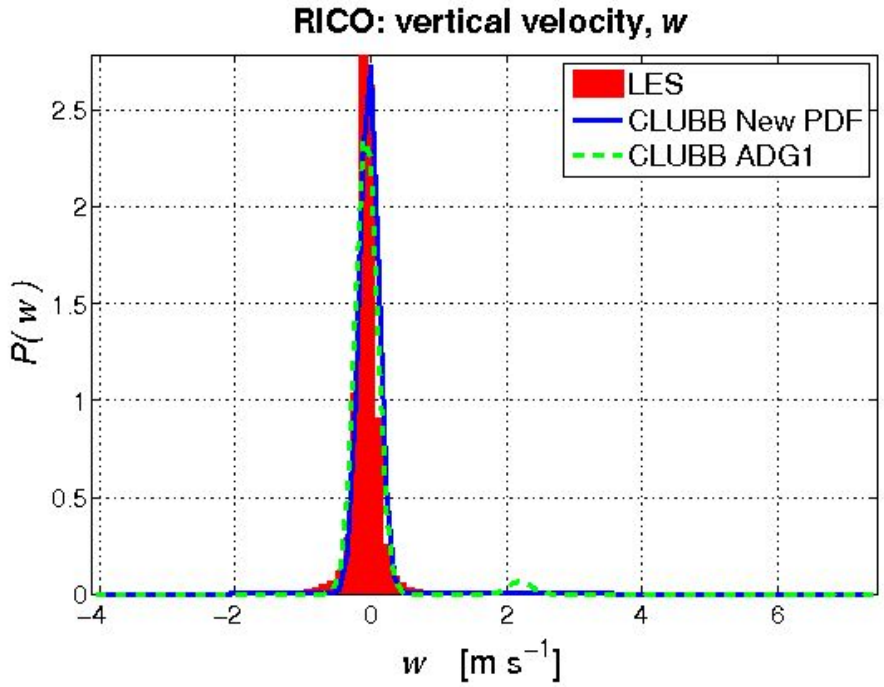
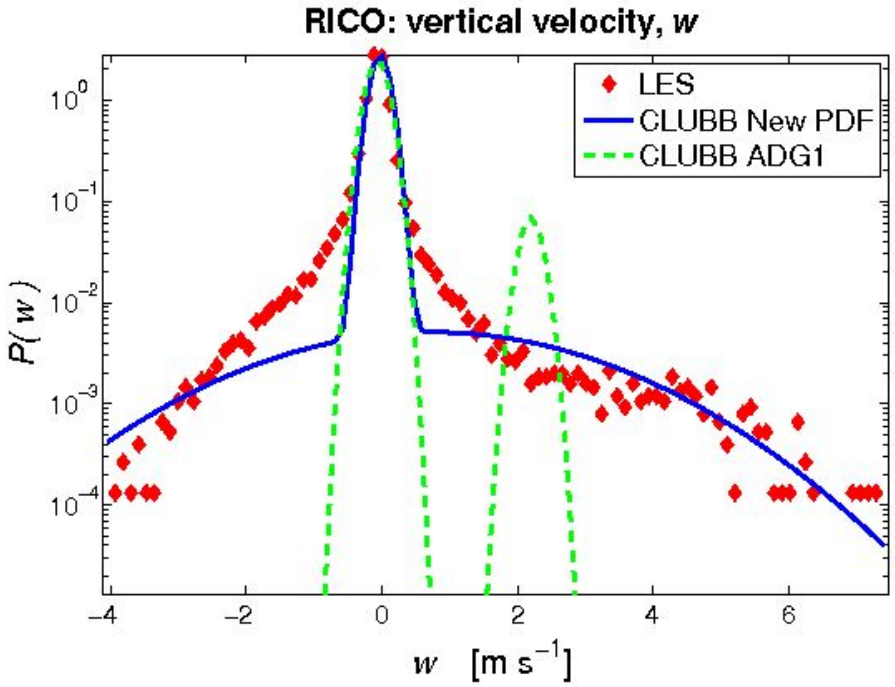
Highly skewed PDFs of vertical velocity



Skewness of w is 4.5



Same plot; log-scaled y-axis

Non-interactive CLUBB

Upcoming Work

- Fully interactive standalone CLUBB runs using the new PDF.
  - This will require some additional coding.
  - This will also require re-tuning.
- Test the new PDF in global runs.

Questions