Development of a new subgrid PDF shape for E3SM: Current status

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The current version of E3SM's subgrid PDF (i.e. CLUBB's "ADG1" PDF) is excessively bimodal in vertical velocity, w.

This means that the strongest updrafts are under-represented.

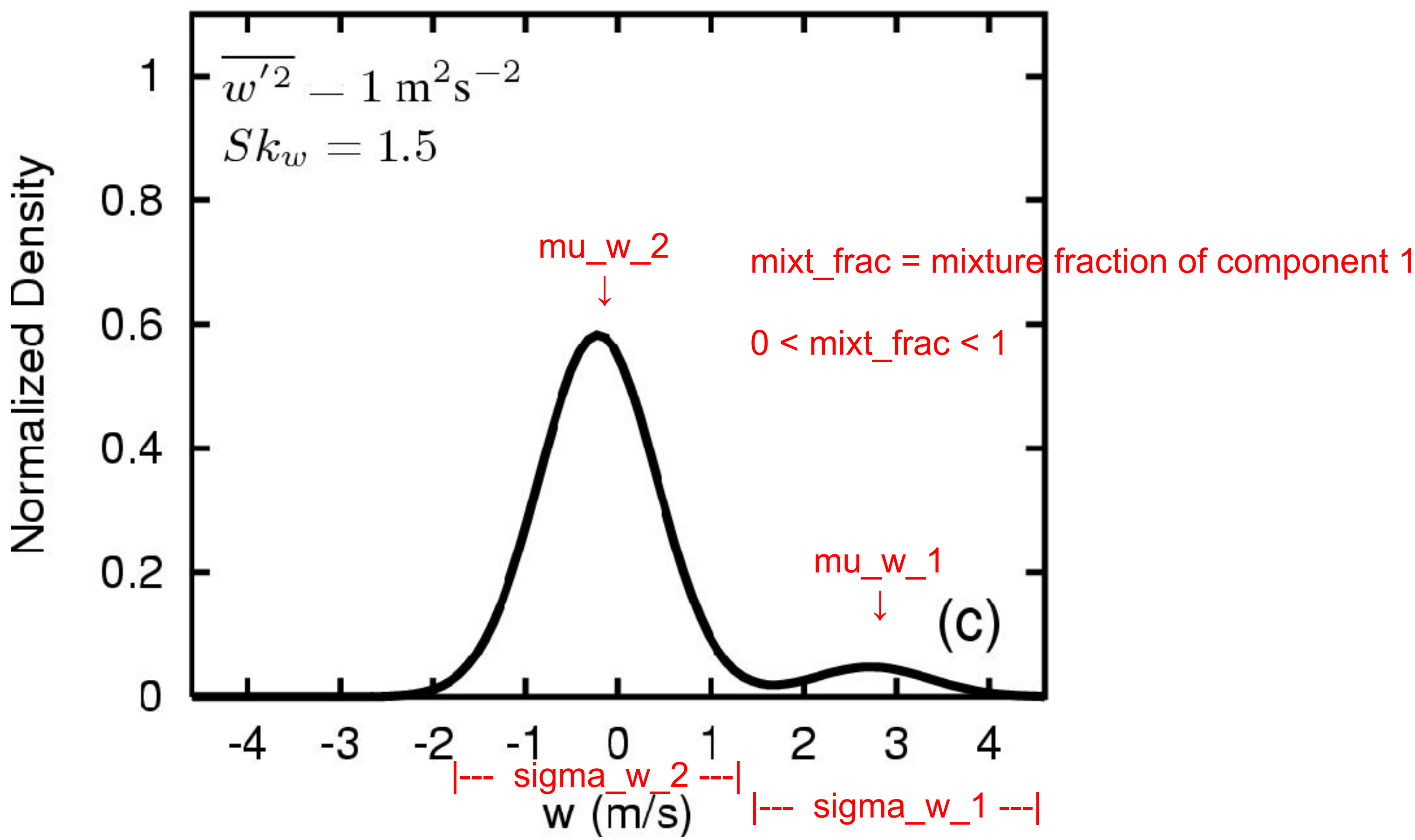
This, in turn, means that not enough droplets are activated in cumulus clouds, all else equal.

We want to revise CLUBB's particular double Gaussian PDF shape but stay within the double Gaussian family

Why stick with a double Gaussian?:

- A double Gaussian is a flexible shape that can be skewed to the left or the right.
- Also, generalizing a double Gaussian to a multi-variate form is tractable.
- A double Gaussian will work with existing versions of CLUBB or SHOC.

A univariate double Gaussian has 5 PDF parameters: the mean and standard dev of each Gaussian component, plus the probability mass (“mixt_frac”) in the first component:



Golaz et al. (2002)

As compared with E3SM's current PDF ("ADG1"), the new PDF introduces an extra parameter to play with

ADG1 has `gamma_coef`. `gamma_coef=0` yields a double-delta PDF in `w`; `gamma_coef=1` yields a single Gaussian.

The new PDF replaces `gamma_coef` with `F_w` and `varnce_ratio`.

For the new PDF, we create one additional equation that tells us whether the PDF is shaped more like a Gaussian or double-delta:

```
| mu_w_1 - <w> | / sqrt( <w'^2> )
     = sqrt(F_w) *
          ( sqrt( 1 - mixt_frac ) / sqrt( mixt_frac ) )
```

where $0 <= F_w <= 1$.

If $F_w = 1$, then our PDF is a double delta fnc.

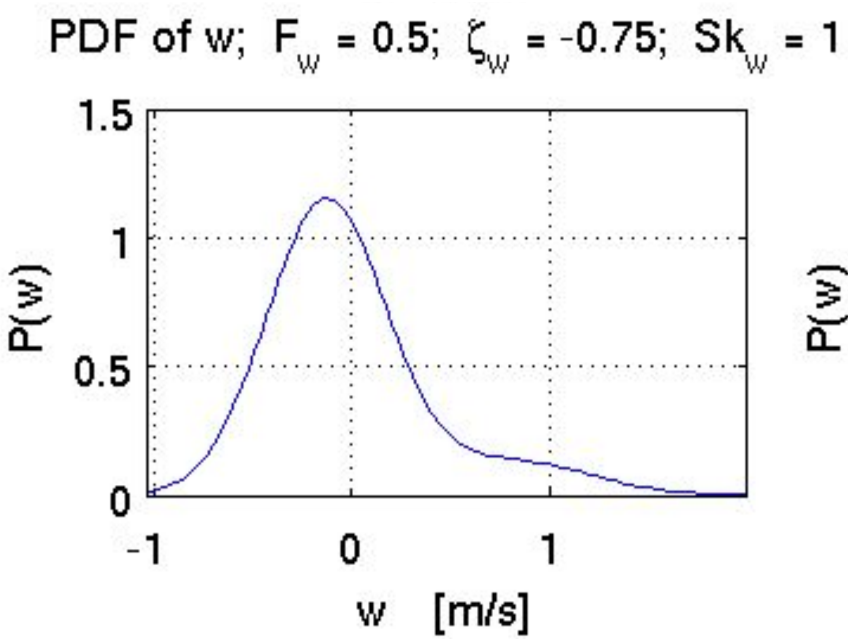
If $F_w = 0$, then our PDF is a single Gaussian.

Also for the new PDF, we create a 2nd extra equation that tells us about the relative strength of the tails of the PDF

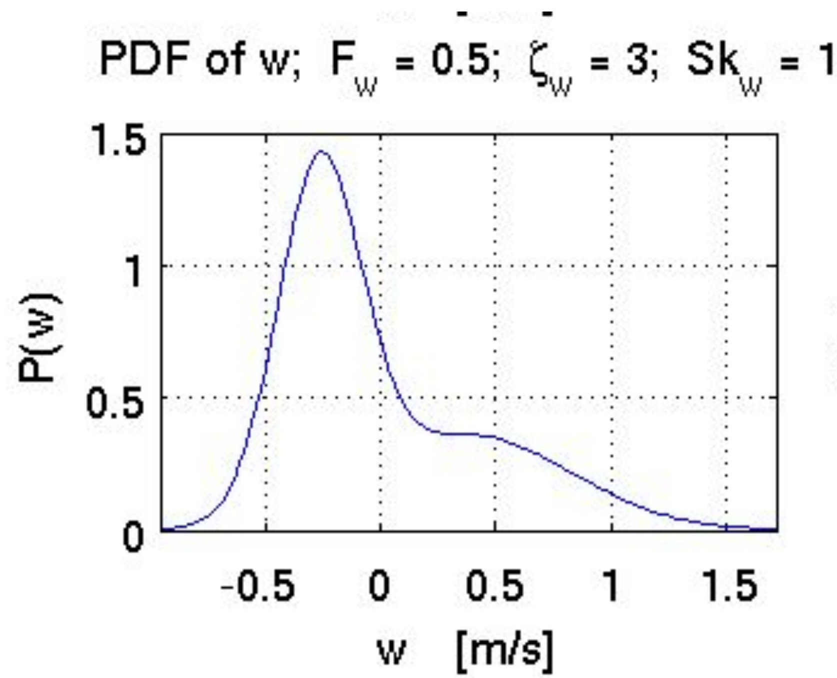
```
varnce_ratio = ( mixt_frac * sigma_w_1^2 )
               / ( ( 1 - mixt_frac ) * sigma_w_2^2 )
```

```
where varnce_ratio > 0.
```

By increasing `varnce_ratio`, the right-hand tail grows longer:

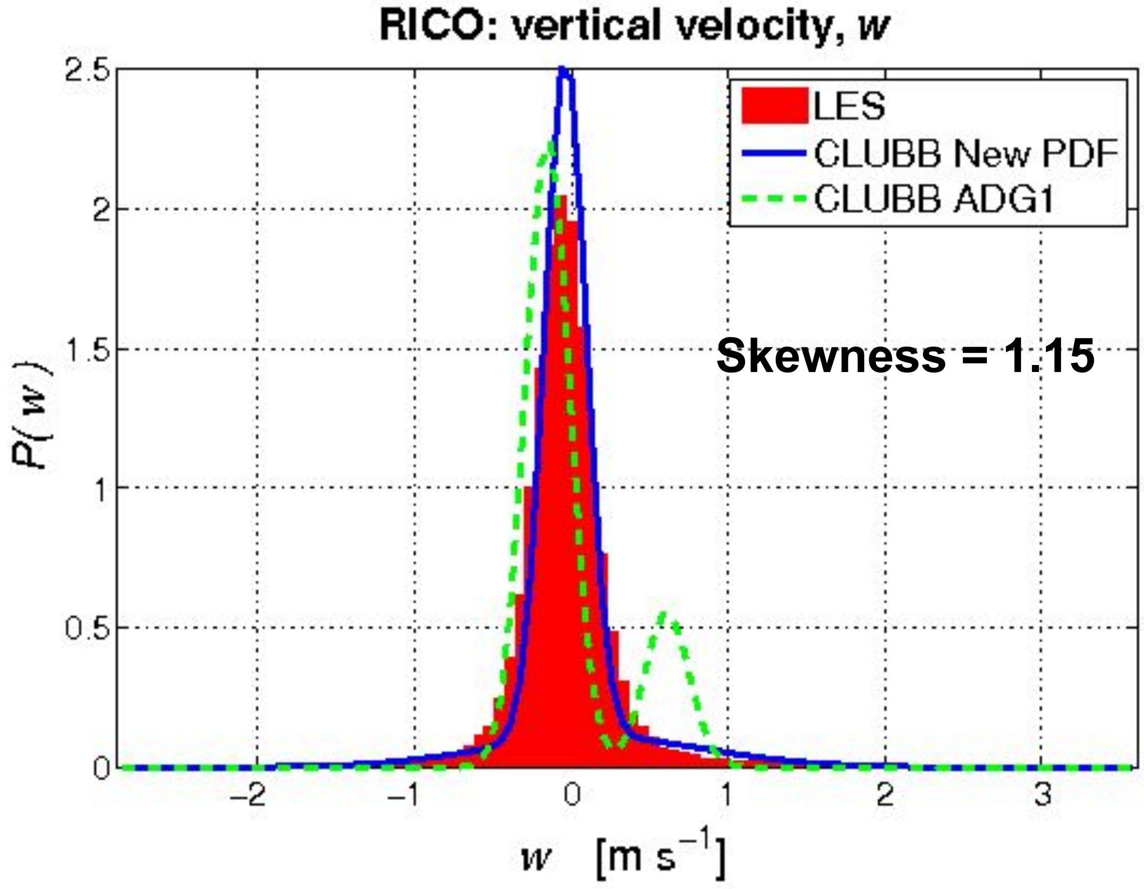


varnce_ratio = 0.25



varnce_ratio = 4

The new PDF of *w* compares better with LES



We hope that someday, the improved PDF of *w* will help with aerosol activation.

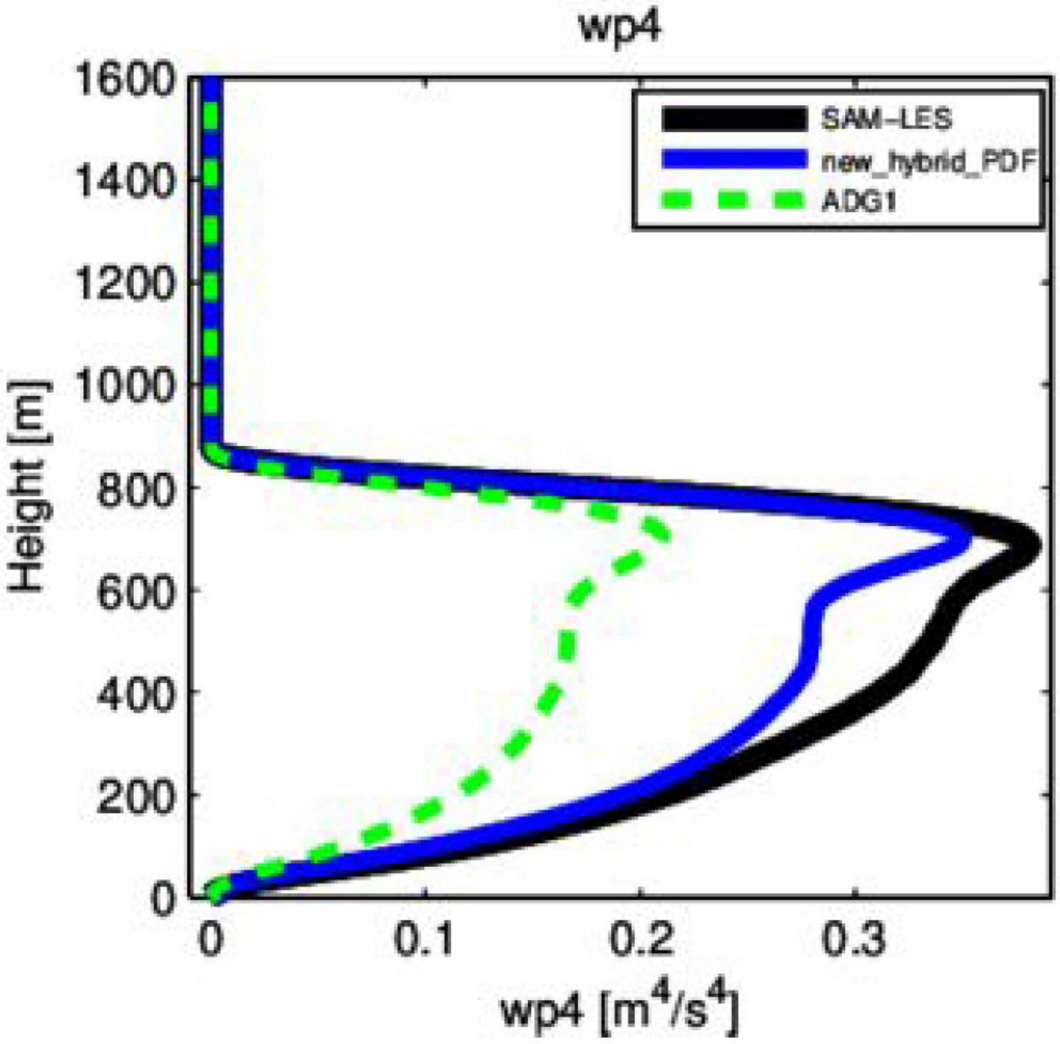
One metric for evaluation: the 4th-order moment of `w.` This is a measure of the intensity of strong updrafts and downdrafts

Just as radar reflectivity is sensitive to large hydrometeors (radius^6), <w’^4> is sensitive to extreme drafts.

Both have large exponents.

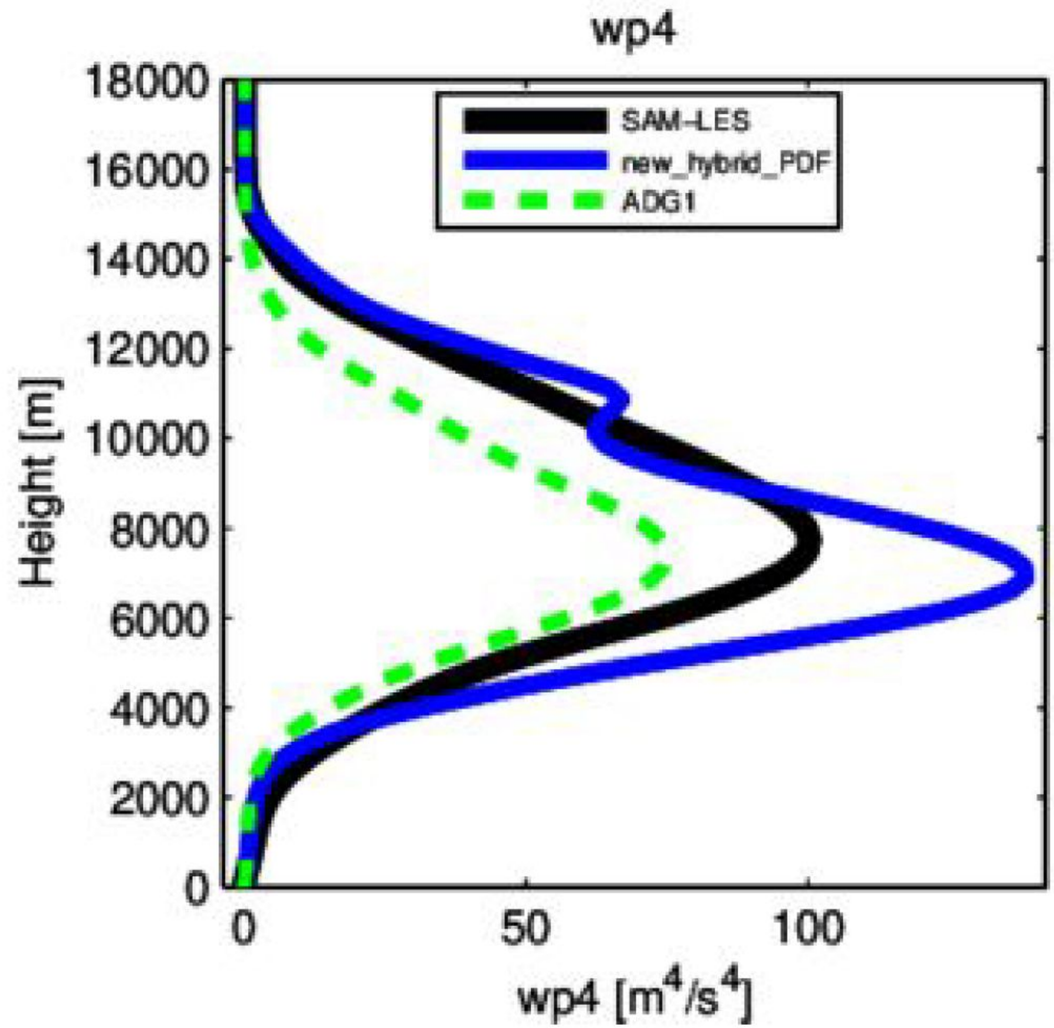
Let’s evaluate the new PDF using LES.

In the DYCOMS-II RF01 case, the new (here labeled "new_hybrid") PDF underpredicts the strong drafts:



In the ARM 97 deep convective case, the new PDF overpredicts the strong drafts:

Perhaps the PDF formula is fooled by the strong skewness in ARM 97?



In the GCSS ARM shallow cumulus case, the new PDF underpredicts the strong drafts in the cloud layer and overpredicts them in the subcloud layer: