A new double Gaussian subgrid PDF for CLUB
A work in progress

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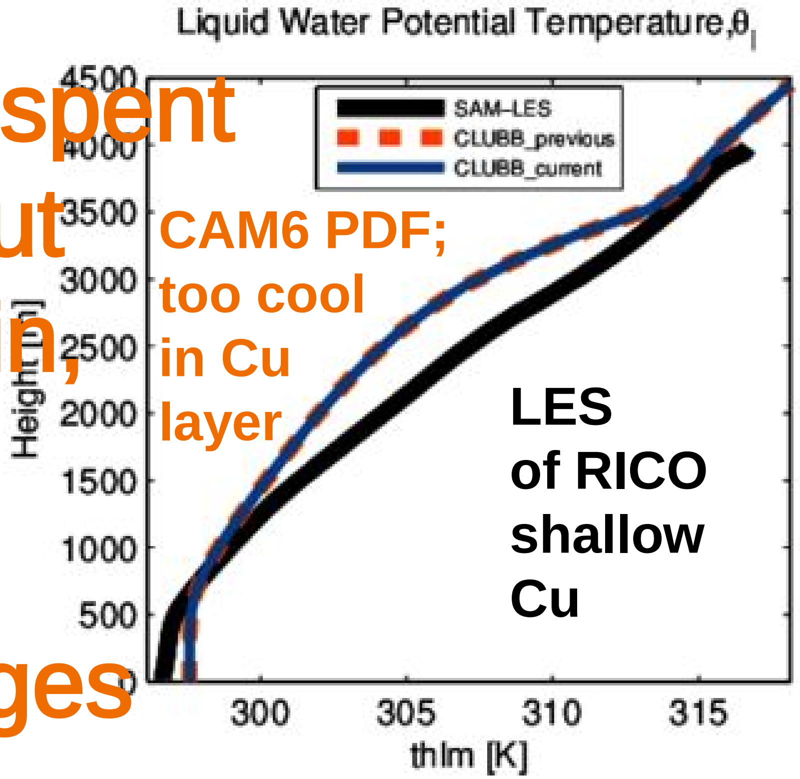
Introduction

- CLUBB is a parameterization of shallow clouds and turbulence. It’s in CAM6.
- CLUBB is based on subgrid PDFs. A central feature of PDF parameterizations is an assumption about subgrid PDF shape.
- CAM6’s PDF shape is mathematically simple but makes some sub-optimal assumptions.
- A revised PDF shape is being developed by Brian Griffin at UW--Milwaukee (UWM).
- Sample results from a single -column case will be shown.

Motivation: UWM has spent time tuning CLUBB, but stubborn biases remain, and so UWM is implementing some structural model changes



E.g., stratocumuli and cumuli are not distinct enough in this variant of CLUBB, in part because the cumuli are too well mixed in the vertical.

Background: CLUBB is a higher-order closure model

That means: CLUBB contains Reynolds -averaged equations for grid means, subgrid variances, covariances, etc.

These equations contain terms that need to be closed (parameterized).

(Nota bene: This talk will discuss a variant of CLUBB that integrates the microphysics analytically over the PDF. CAM6 uses cruder assumptions for this coupling.)

CLUBB’s prognostic higher order equations:

$$\text{Means}: \quad \frac{\partial \overline{u}}{\partial t} = \ldots \quad \frac{\partial \overline{v}}{\partial t} = \ldots \quad \frac{\partial \overline{r_t}}{\partial t} = \ldots \quad \frac{\partial \overline{\theta_l}}{\partial t} = \ldots$$

$$\text{2nd}-\text{order}: \quad \frac{\partial \overline{w' r_t'}}{\partial t} = \ldots \quad \frac{\partial \overline{w' \theta_l'}}{\partial t} = \ldots \quad \frac{\partial \overline{w'^2}}{\partial t} = \ldots$$

$$\frac{\partial \overline{r_t'^2}}{\partial t} = \ldots \quad \frac{\partial \overline{\theta_l'^2}}{\partial t} = \ldots \quad \frac{\partial \overline{r_t' \theta_l'}}{\partial t} = \ldots$$

$$\text{3rd}-\text{order}: \quad \frac{\partial \overline{w'^3}}{\partial t} = \ldots$$

$w = \text{vertical velocity}$ $\qquad$ $r_t = \text{total water mixing ratio}$

$\theta_l = \text{liquid water potential temperature}$

Why is the PDF shape important?

The PDF is used to close:

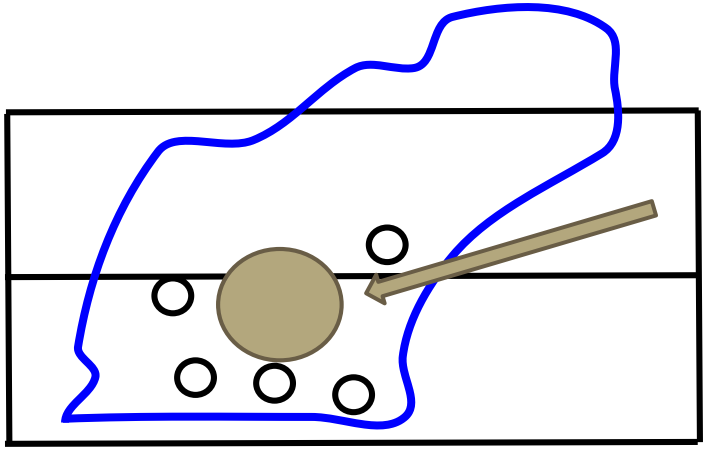
- turbulent advection terms
- buoyancy terms
- microphysical terms (we’ll discuss a version of CLUBB that integrates analytically over the PDF).

In particular, the PDF shape is crucial for diagnosing latent heating:

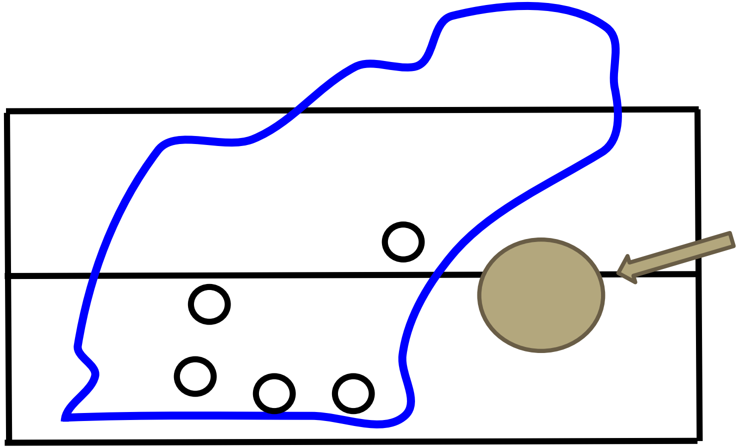
$$\frac{\partial \overline{\theta_l}}{\partial t} = \underbrace{-\overline{w}\frac{\partial \overline{\theta_l}}{\partial z}}_{\text{mean adv}} \underbrace{-\frac{1}{\rho_s}\frac{\partial \rho_s \overline{w'\theta_l'}}{\partial z}}_{\text{turb adv}} + \underbrace{\overline{\left.\frac{\partial \theta_l}{\partial t}\right|_{\text{RT}}}}_{\text{radiation}} + \underbrace{\overline{\left.\frac{\partial \theta_l}{\partial t}\right|_{\text{mc}}}}_{\text{microphys}}$$

Latent heating due to microphysics is needed to balance radiative cooling and turbulent advection of heat.

Latent heating and evaporation of rain depend on the covariability of cloud and rain:



This rain drop will collect cloud drops:



This rain drop will evaporate:

CLUBB uses a double Gaussian PDF funct

CAM6 version:

P(w,rt,thl,rain) = a G1(w) G1(rt,thl,rain)

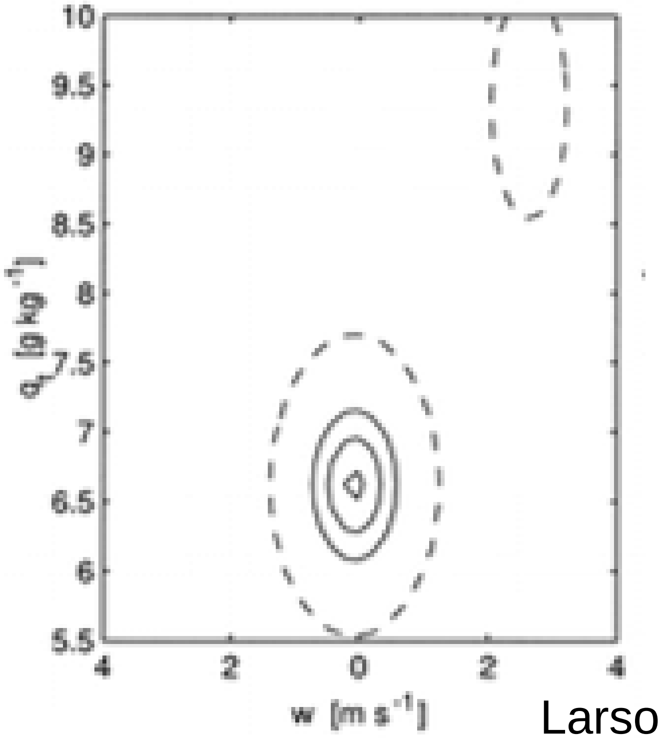
+ (1-a) G2(w) G2(rt, thl,rain)

Brian's new version:

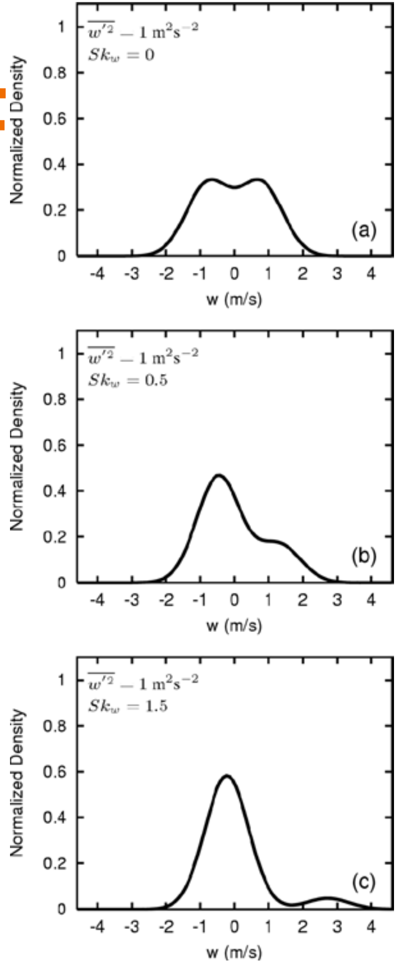
P(w,rt,thl,rain) = a G1(w,rt,thl,rain) + (1 -a) G2(w,rt, thl,rain)

2 shortcomings of CAM6’s PDF

1. Vertical velocity and scalars are uncorrelated within a component:



2. The PDF of vertical velocity does not approach a single Gaussian when skewness is zero:



Larson et al. (2002)

How is Brian's new PDF different from CAM PDF?

	CAM6's PDF	**Brian's New PDF**
Is it a double Gaussian?	Yes	Yes
Is it analytic (i.e., involves no iteration)?	Yes	Yes
Does it approach a single Gaussian in vertical velocity, *w*, as skewness → 0?	No	Yes
Does it allow non-zero within-Gaussian correlations between *w* and scalars?	No	Yes

As an initial test, we simulate the RICO sha cumulus case

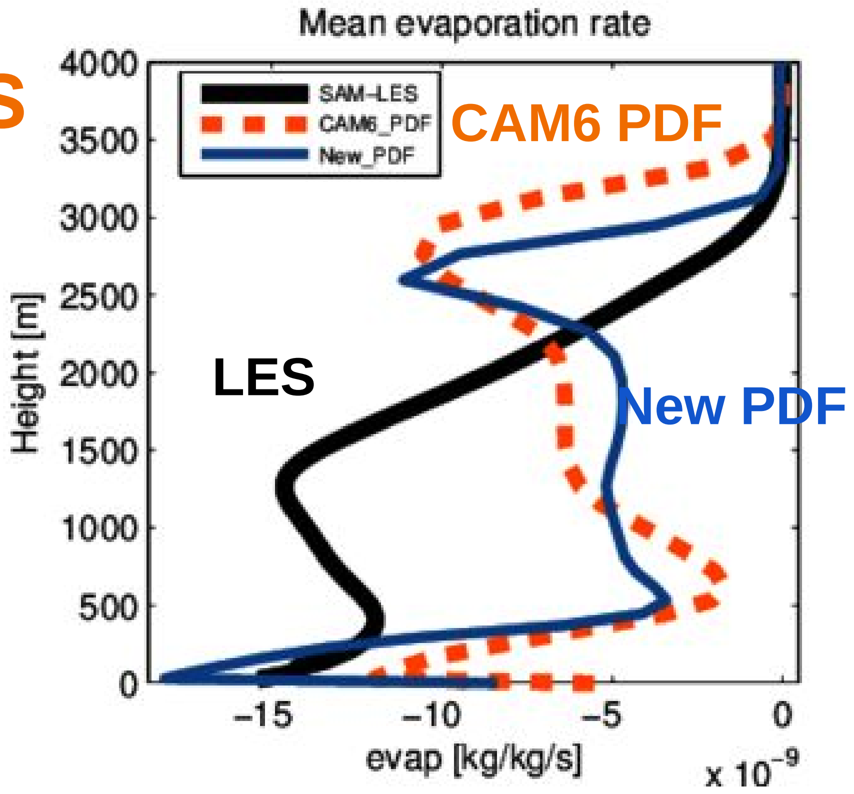
The runs are interactive, as compared to the non -interactive results that Brian showed at AMWG.

The microphysics scheme is Khairoutdinov -Kogan.

Unlike in CAM6, the microphysics is integrated over CLUBB's PDF.

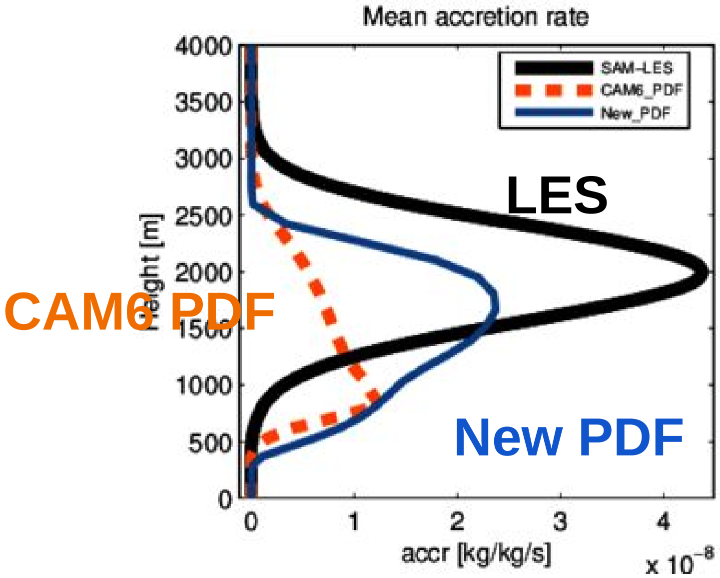
In a higher -order closure model, we can see how an error propagates through the model.

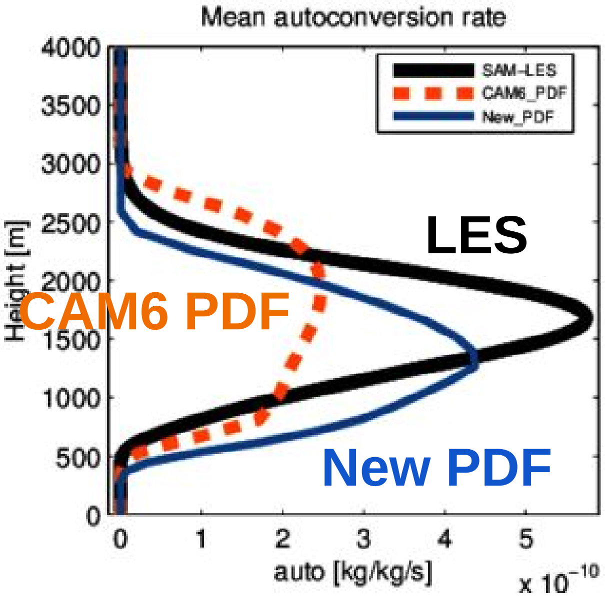
When the new PDF is used, evaporation is still overpredicted aloft



This is because near cloud top too much rain is placed outside of cloud.

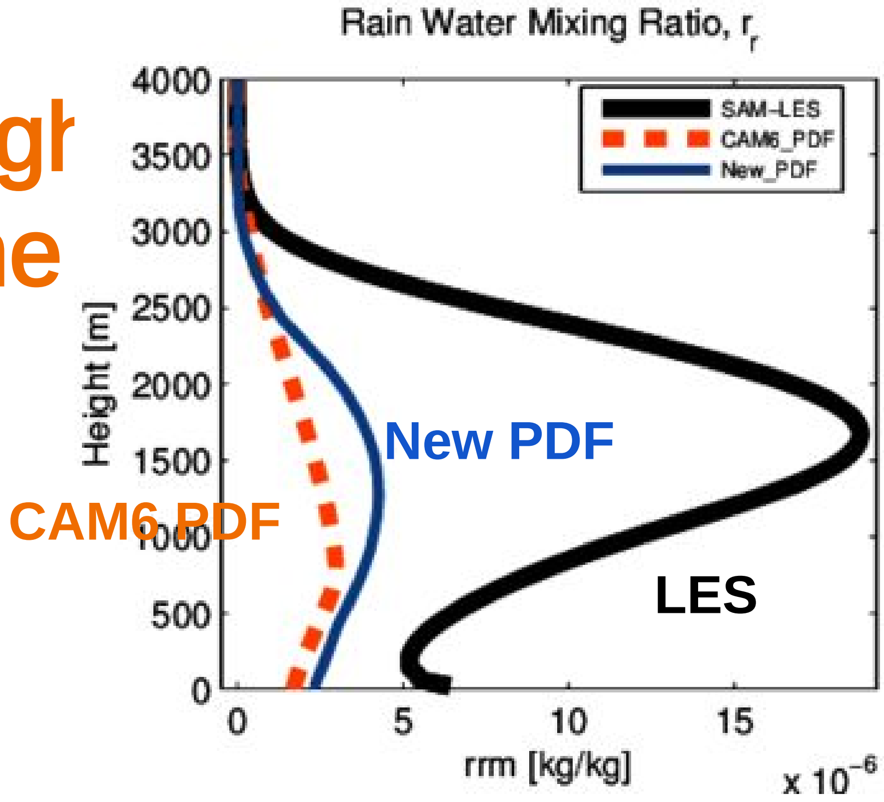
But accretion and autoconversion are impro





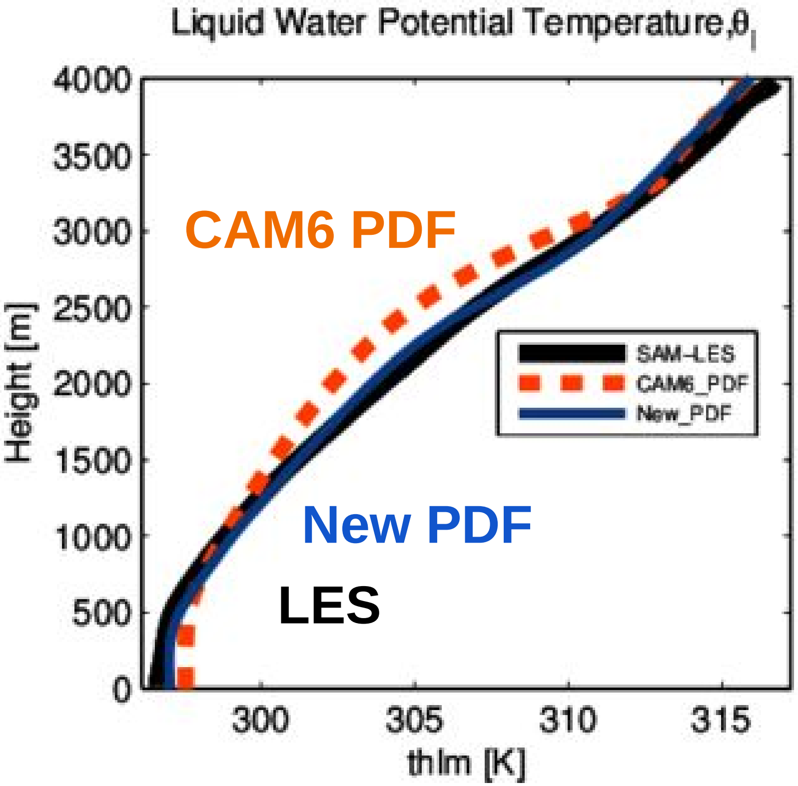
The altitude of maximum accretion is improved because the new PDF is able to place more rain within cloud.

The net result is a sligh improved shape of the rain profile



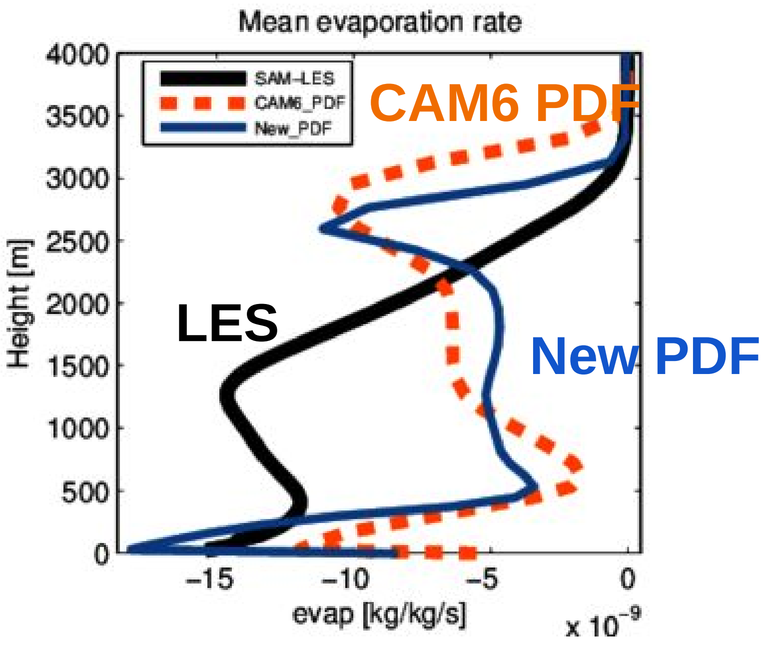
In particular, the rain mixing ratio peaks at a higher (improved) altitude.

The increased rain leac increased latent heating aloft and an improved temperature profile

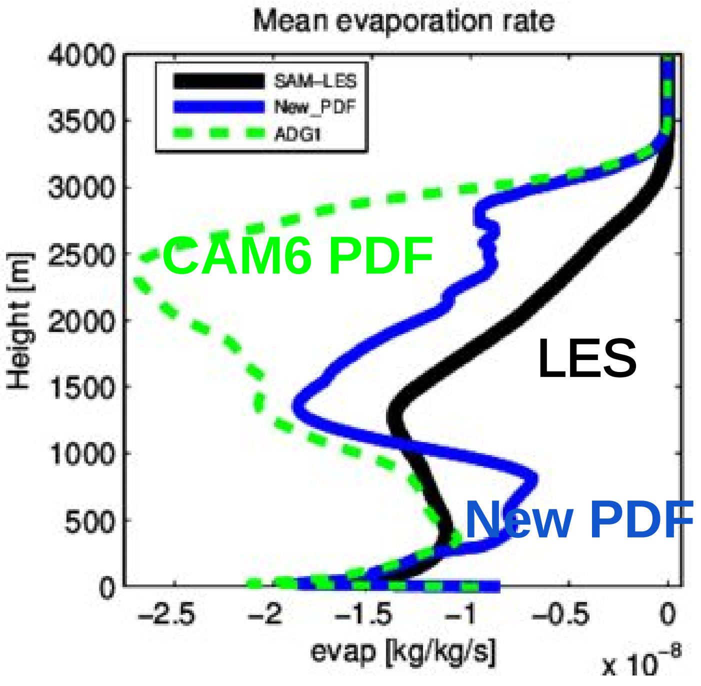


This is important to prevent well -mixed layers from forming in cumulus regions.

Rain evaporation was better simulated in a *interactive* simulation:



Interactive simulation



Non-interactive simulation

This indicates that the inputs to the PDF are inaccurate

Perhaps this is because:

1) the scalar skewness is inadequately predicted; or

2) the scalar variance is inadequately predicted.

Conclusions

- A more realistic PDF shape has been implemented in CLUBB.
- The new PDF shows minor but encouraging improvements to the latent heating in shallow cumulus.
- Further improvements will be sought in the inputs to the PDF

Thanks for your time!