An improvement to CLUBB's modeling of subcloud vertical velocity skewness

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Preliminary points:
1. CLUBB (Cloud layers unified by binormals)

- Unified parameterization (of turbulence & clouds) avoids interactions between different parameterizations
- Accurately representing vertical velocity skewness is a challenge

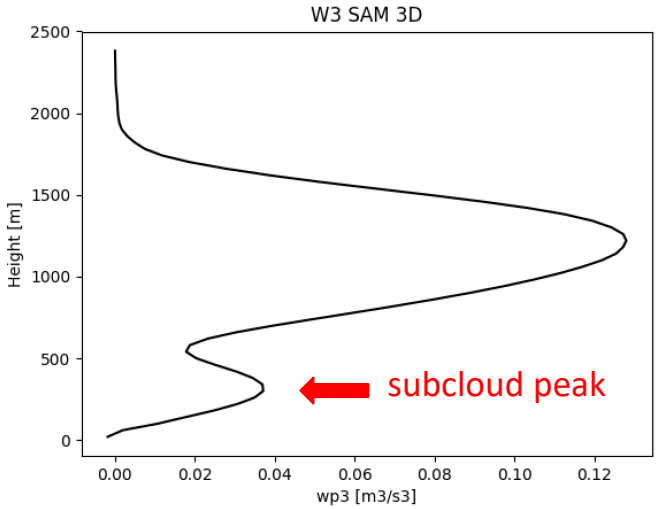
2. Skewness (w'^3) corresponds to cloud regime

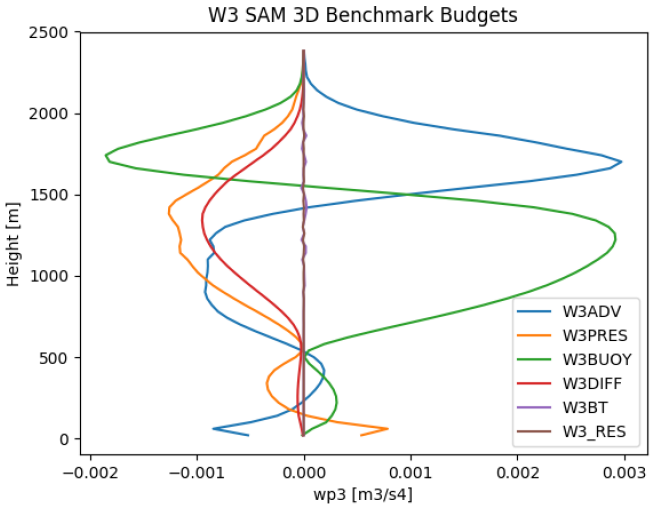
Large skewness

Small skewness

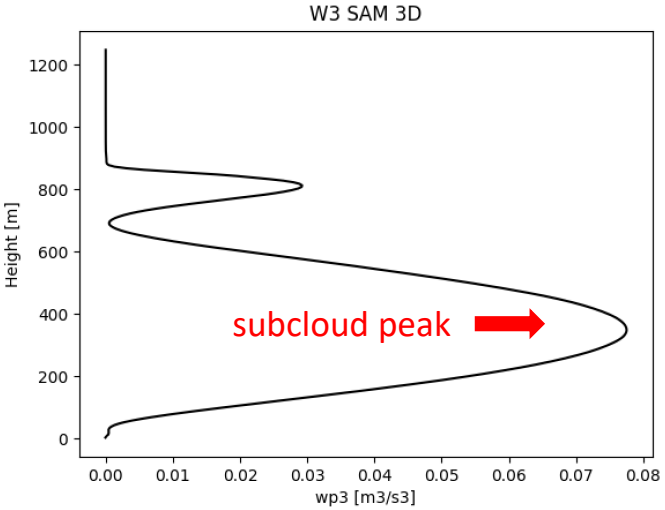
SAM-LES W3 budgets indicate a positive contribution from pressure near the surface, which is amplified by the buoyancy term.

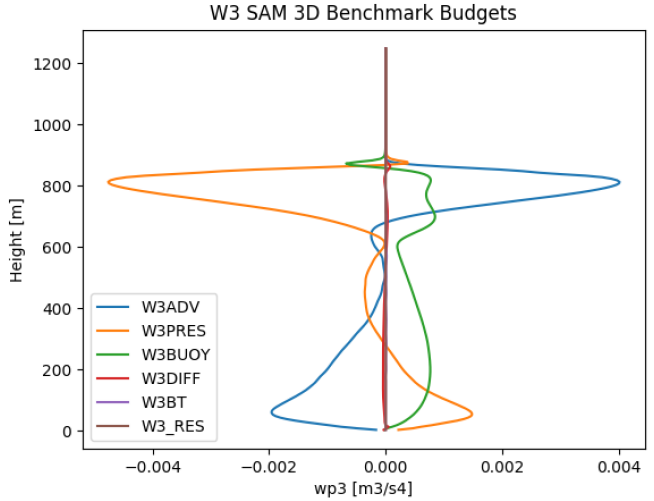
BOMEX
(trade cumulus case, averaged over last three hours)





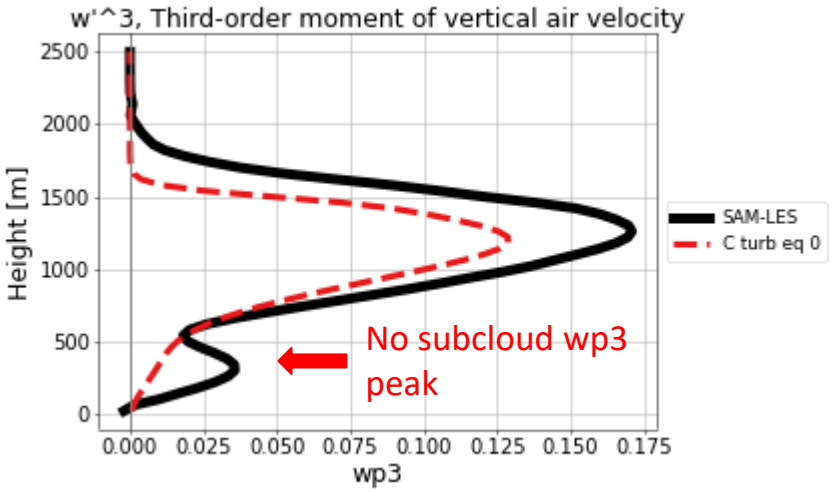
DYCOMS2_RF01
(stratocumulus case, averaged over last hour)

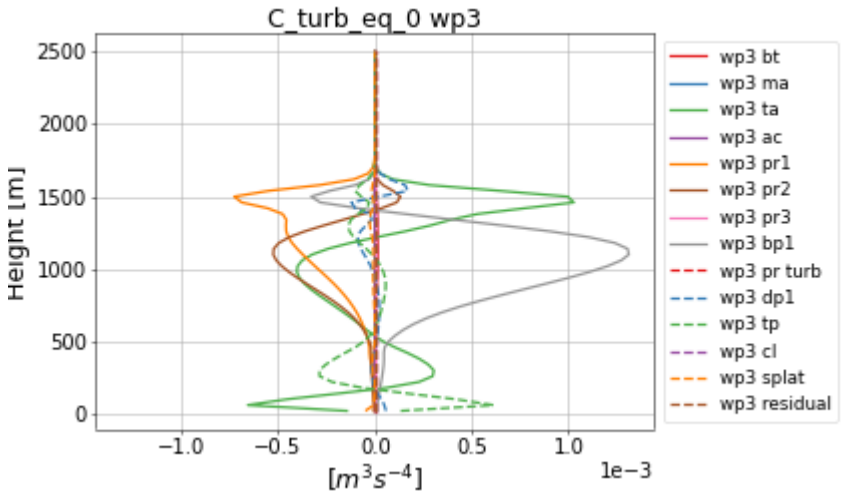




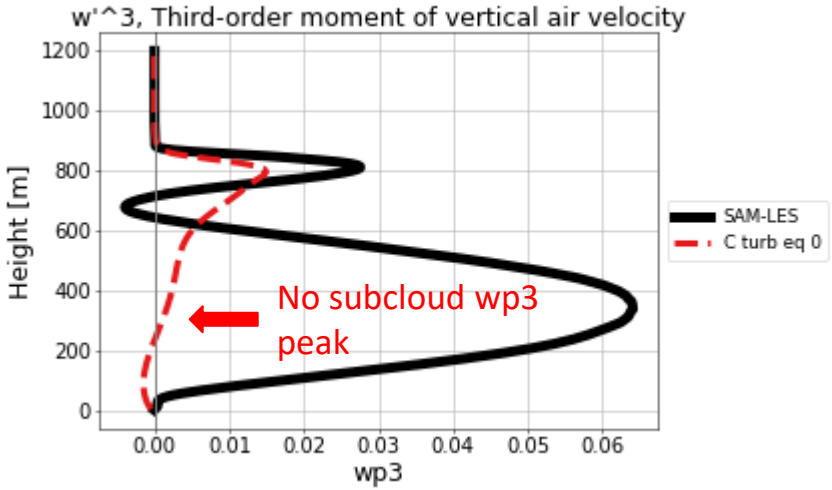
CLUBB ought to mimic the behavior of the LES. Namely, CLUBB's pressure terms ought to produce positive w'3 near the surface. Then, CLUBB's buoyancy term can amplify w'3 below cloud.

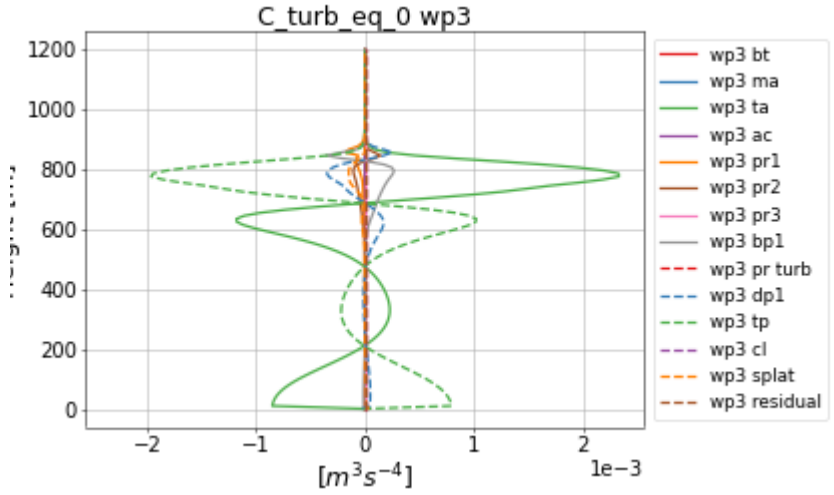
BOMEX





DYCOMS2_RF01





PROBLEM #1: CLUBB's standard pressure terms won't produce positive w'3

$$\frac{\partial \overline{w'^3}}{\partial t} \approx \underbrace{-\frac{1}{\rho_s}\frac{\partial \rho_s \overline{w'^4}}{\partial z}}_{ta} \underbrace{+3\frac{\overline{w'^2}}{\rho_s}\frac{\partial \rho_s \overline{w'^2}}{\partial z}}_{tp} \underbrace{+\frac{3g}{\theta_{vs}}\overline{w'^2\theta'_v}}_{bp}$$

$$\underbrace{-\frac{C_8}{\tau}\overline{w'^3}}_{pr1} \underbrace{-C_{11}\left(-3\overline{w'^3}\frac{\partial \overline{w}}{\partial z} + \frac{3g}{\theta_{vs}}\overline{w'^2\theta'_v}\right)}_{pr2}$$

ta = turbulent advection
tp = turbulent production
bp = buoyant production
pr1 = return-to-isotropy
pr2 = "rapid" pressure term

"pr1" only damps. "pr2" is zero if w'3 is zero.

With no pressure term that produces positive w'3 near the surface, we can't expect CLUBB's buoyancy term to produce large, positive w'3.

PROBLEM #2: CLUBB's buoyancy term won't save us either; we expect CLUBB's buoyancy term to be large only if w'3 is large

$$\underbrace{+\frac{3g}{\theta_{vs}}\overline{w'^2\theta'_v}}_{bp} \quad \Leftarrow \quad \overline{w'^2\theta'_l} \sim \frac{\overline{w'^3}}{\overline{w'^2}}\overline{w'\theta'_l}$$

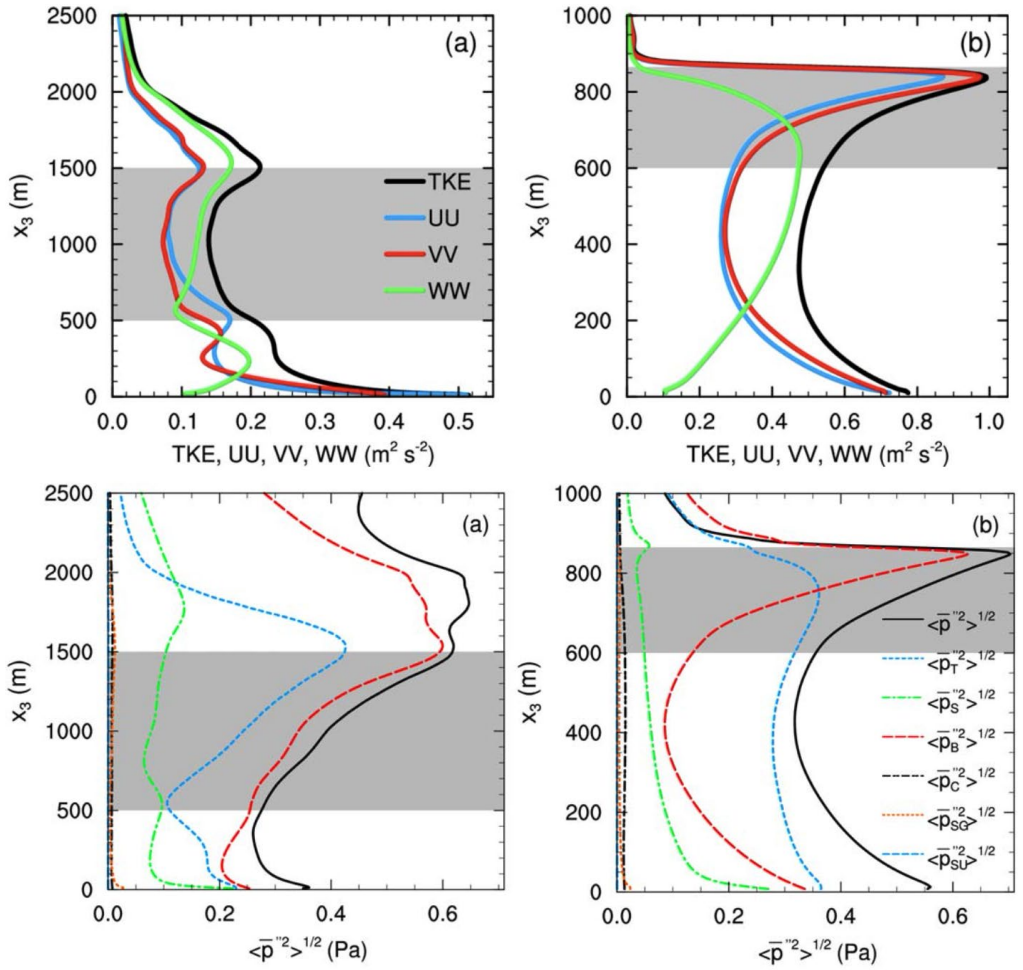
(closed using CLUBB's subgrid PDF)

$$\overline{w'^2\theta'_v} = \overline{w'^2\theta'_l}$$ in subcloud layer with w'3 = 0

CLUBB needs a new pressure term. Idea: We notice that the profile of turbulent kinetic energy (TKE) is similar to the profile of std(p').

TKE →

std(p') →



We could make use of this similarity in the generic pressure term from the d(w'3)/dt equation:

$$-3\overline{\frac{w'^2}{\rho_s}\frac{\partial p'}{\partial z}}$$

(a) BOMEX, (b) DYCOMS2_RF01.

Figures from Heinze, Mironov, & Raasch 2015 (top), 2016 (bottom).

Hence, to provide a source of positive w'3 near the surface, we add a new pressure term to CLUBB's w'^3 equation.

Assuming $p' \sim \rho_s e$, where $\overline{e} = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$ we can use the form of the generic pressure term to write a new wp3 source term:

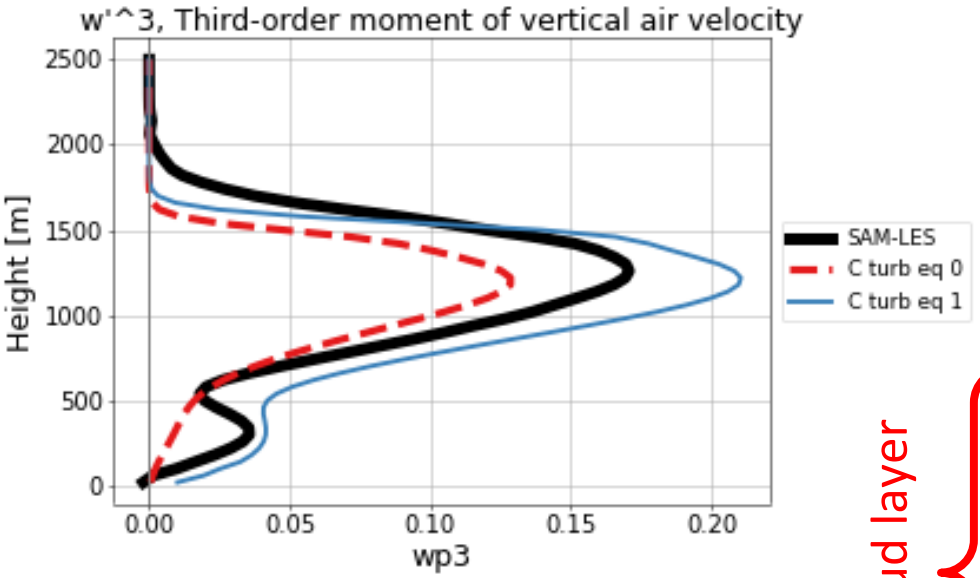
$$-3\overline{\frac{w'^2}{\rho_s}\frac{\partial p'}{\partial z}} \sim -C_{turb}\overline{\frac{w'^2}{\rho_s}\frac{\partial \rho_s e}{\partial z}}$$

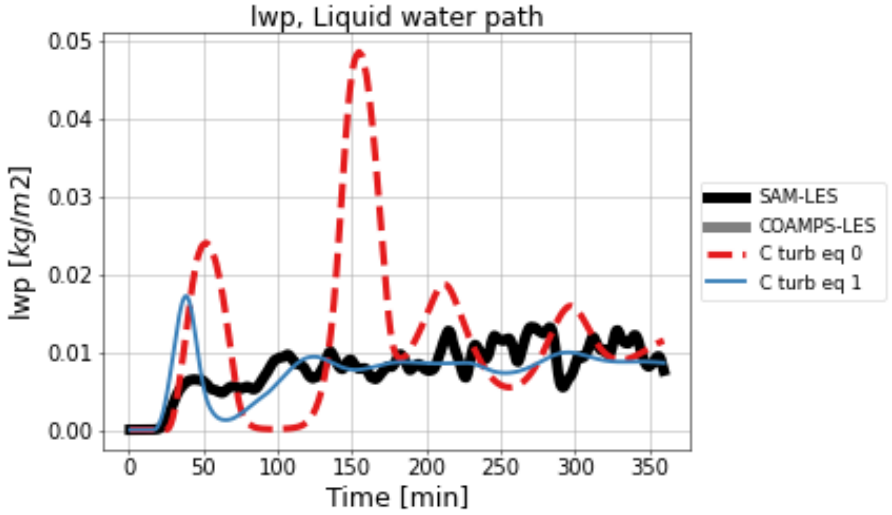
Which yields the new w'3 equation:

$$\frac{\partial \overline{w'^3}}{\partial t} \approx \underbrace{-\frac{1}{\rho_s}\frac{\partial \rho_s \overline{w'^4}}{\partial z}}_{ta} \underbrace{+3\frac{\overline{w'^2}}{\rho_s}\frac{\partial \rho_s \overline{w'^2}}{\partial z}}_{tp} \underbrace{+\frac{3g}{\theta_{vs}}\overline{w'^2\theta'_v}}_{bp}$$

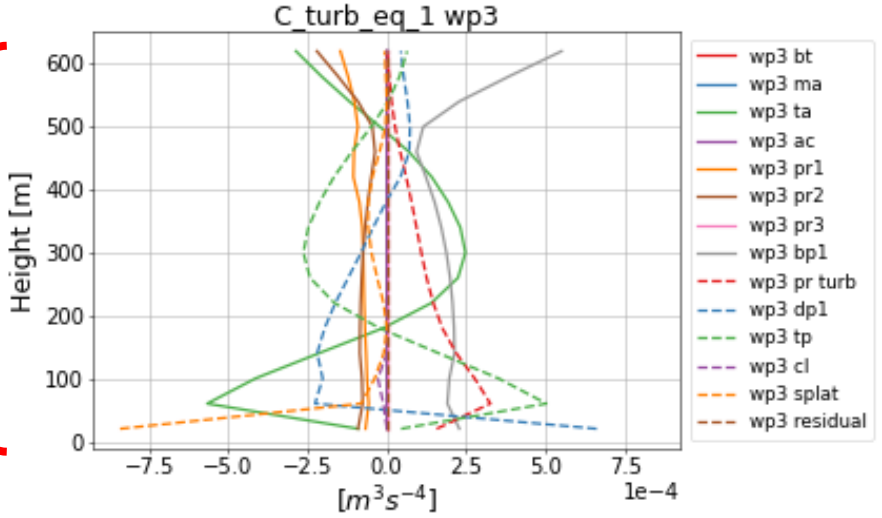
$$\underbrace{-\frac{C_8}{\tau}\overline{w'^3}}_{pr1} \underbrace{-C_{11}\left(-3\overline{w'^3}\frac{\partial \overline{w}}{\partial z} + \frac{3g}{\theta_{vs}}\overline{w'^2\theta'_v}\right)}_{pr2} \underbrace{-C_{turb}\overline{\frac{w'^2}{\rho_s}\frac{\partial \rho_s e}{\partial z}}}_{pr\_turb}$$

Improved results in CLUBB with new term: BOMEX case

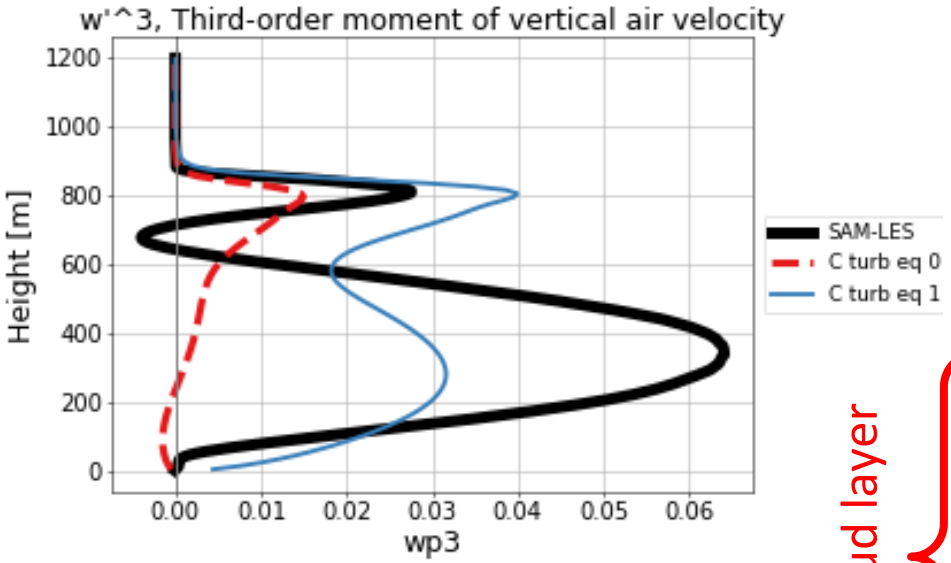


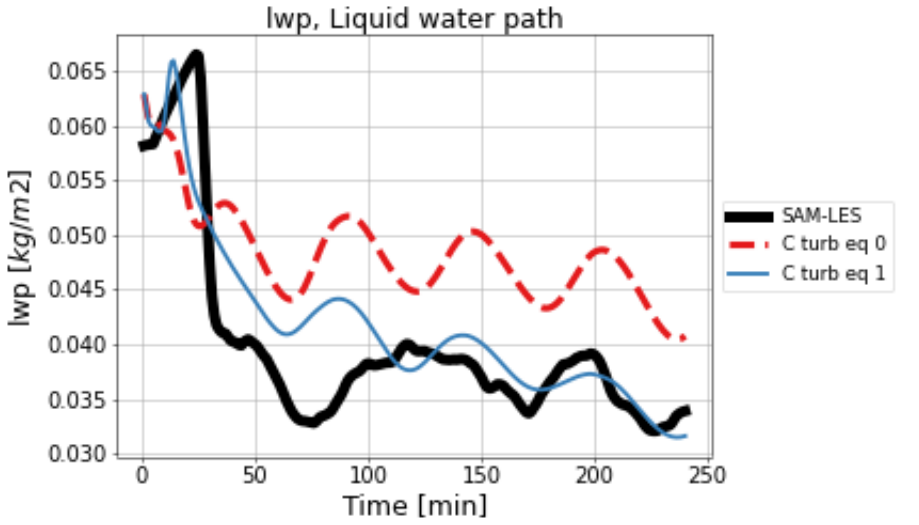


Subcloud layer

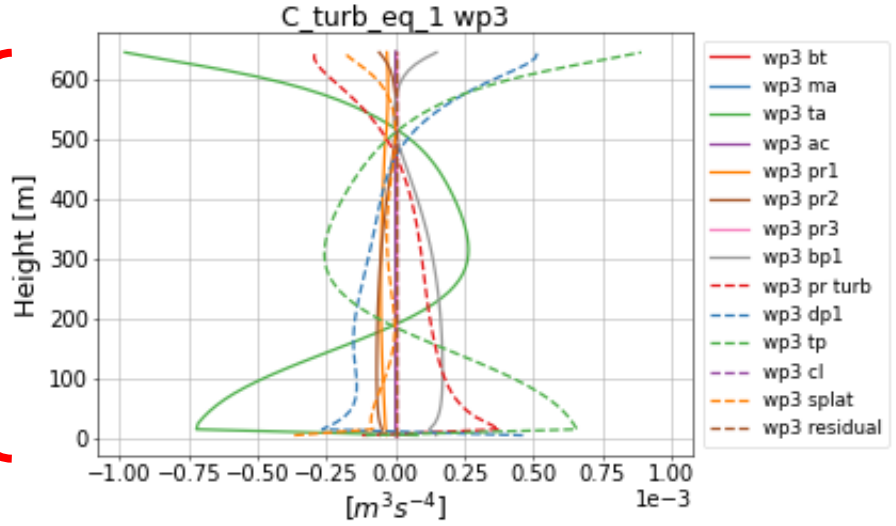


Improved results in CLUBB with new term: DYCOMS2_RF01 case





Subcloud layer



Summary

- An additional term is needed in CLUBB's w'3 equation in order to reproduce the near-surface positive contribution from pressure that shows up in LES
- We use a similarity in LES between TKE and std(p') to construct a new term for the wp3 equation.
- The new TKE term improves not only the modeled subcloud skewness, but can improve prognostic quantities as well
- Work is ongoing to better understand the link between pressure and buoyancy in LES and to better understand how the new term may be theoretically justified