Comparing the CLUBB-L and CLUBB-taus damping algorithms in CAM and CESM experiments

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Colin Zarzycki, Adam Herrington for help with figures & comments

Improved CLUBB going into CAM7

- One important improvement (goal of momentum CPT): prognostic momentum fluxes (u'w', v'w' equations) replacing old diagnostic downgradient formulation.
- Two candidates for calculating dissipation terms:
  - CLUBB-L: Continues using **"Lscale" algorithm to calculate dissipation time-scales**. Includes extra eddy diffusivity on thlm, rtm.
  - CLUBB-taus: Uses **new "taus" scheme to calculate dissipation time-scales**. No extra diffusion.

CLUBB has a number of prognostic equations with timescale-dependent (tau-dependent) dissipation terms (sometimes more than one):

Momentum flux equation:

$$\frac{\partial \overline{u'_h w'}}{\partial t} = \underbrace{-\overline{w}\frac{\partial \overline{u'_h w'}}{\partial z}}_{ma} \underbrace{-\frac{1}{\rho_s}\frac{\partial \rho_s \overline{w'^2 u'_h}}{\partial z}}_{ta} \underbrace{-\overline{w'^2}\frac{\partial \overline{u_h}}{\partial z}}_{tp} \underbrace{-\overline{u'_h w'}\frac{\partial \overline{w}}{\partial z}}_{ac} \underbrace{+\frac{g}{\theta_{vs}}\overline{u'_h \theta'_v}}_{bp}$$

$$\underbrace{-\frac{C_6}{\tau}\overline{u'_h w'}}_{pr1} \underbrace{+C_7 \overline{u'_h w'}\frac{\partial \overline{w}}{\partial z}}_{pr2} \underbrace{-C_7 \frac{g}{\theta_{vs}}\overline{u'_h \theta'_v}}_{pr3} \underbrace{+C_7 \overline{w'^2}\frac{\partial \overline{u_h}}{\partial z}}_{pr4}$$

$$\underbrace{+\frac{\partial}{\partial z}\left[\left(K_{w6}+\nu_6\right)\frac{\partial}{\partial z}\overline{u'_h w'}\right]}_{dp1}$$

In CLUBB-L, these dissipation terms have the form
- C / tau * X, where…

$$\tau = \begin{cases} \frac{L}{\sqrt{\overline{e}}}; & L/\sqrt{\overline{e}} \leqslant \tau_{\max} \\ \tau_{\max}; & L/\sqrt{\overline{e}} > \tau_{\max} \end{cases}$$

L = Lscale; *e* = TKE. Lscale is basically the distance a parcel would travel to reach neutral buoyancy. **Nonlocal; more expensive; buoyancy-based; less flexible…**

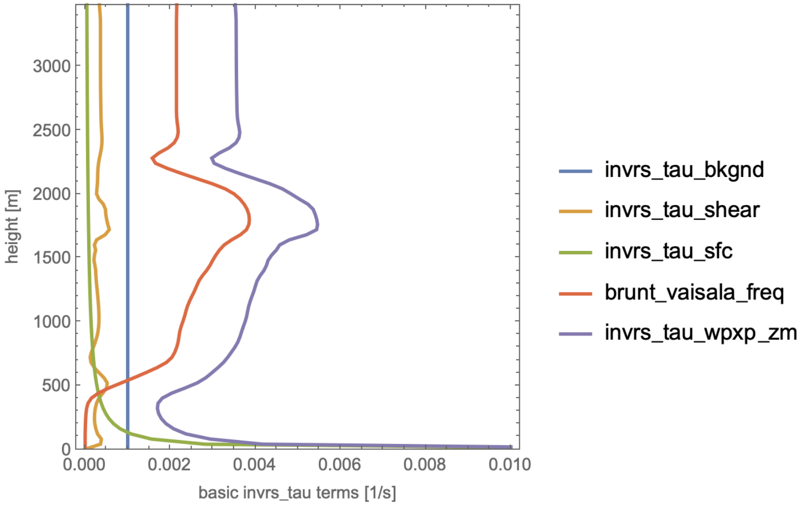
In CLUBB-taus, we trade the tunable parameters C1, C4, C8, etc. for a number of different 1/tau profiles tailored for each dissipation term (and still tunable). Example:

$$\frac{C}{\tau} \longrightarrow \frac{1}{\tau'} = \boxed{\frac{1}{\tau_{\mathrm{noN}}}} + \boxed{\frac{1}{\tau_{\mathrm{N}}}}$$

N = BV frequency

$$\frac{1}{\tau_{\mathrm{noN}}} = \underbrace{C_{i\tau\mathrm{sfc}} \frac{u_*}{\kappa\left(z + z_{\mathrm{displace}}\right)}}_{\text{surface}} \underbrace{+ C_{i\tau\mathrm{shear}} \sqrt{\left(\frac{\partial \bar{u}}{\partial z}\right)^2 + \left(\frac{\partial \bar{v}}{\partial z}\right)^2}}_{\text{shear}} \underbrace{+ C_{i\tau\mathrm{bkgnd}} \frac{1}{\tau_{\mathrm{const}}}}_{\text{background}}$$

BV-independent part



$$\frac{1}{\tau_{\mathrm{N}}} = C_{i\tau\mathrm{N}} \max\left(0, N\right) H\left(z - z_s\right)$$

BV-dependent part: the coefficient can be tuned for specific eq.

C_bkgnd = 1
C_shear = C_sfc = 0.2
C_N = 0.2

Local; cheaper; includes shear; more flexible (in theory).

- Fluxes and variances can in theory be damped differently in CLUBB-taus. A primary motivation of CLUBB-taus is to be able to damp fluxes (e.g. w’thl’) in stably stratified inversions without having to damp variances (e.g. thl’^2) in the same way.

BOMEX LES heat flux (w’thl’) and variance (thl’^2).
The flux = ~0 (left) above 2000m cloud top, but variance (right) remains nonzero above.

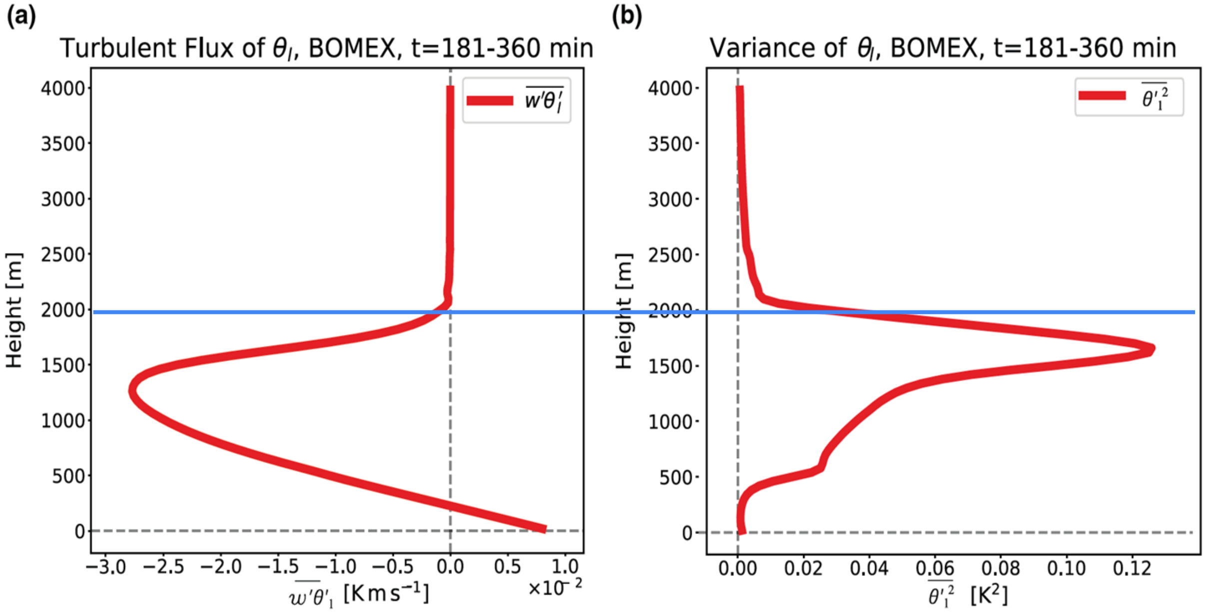
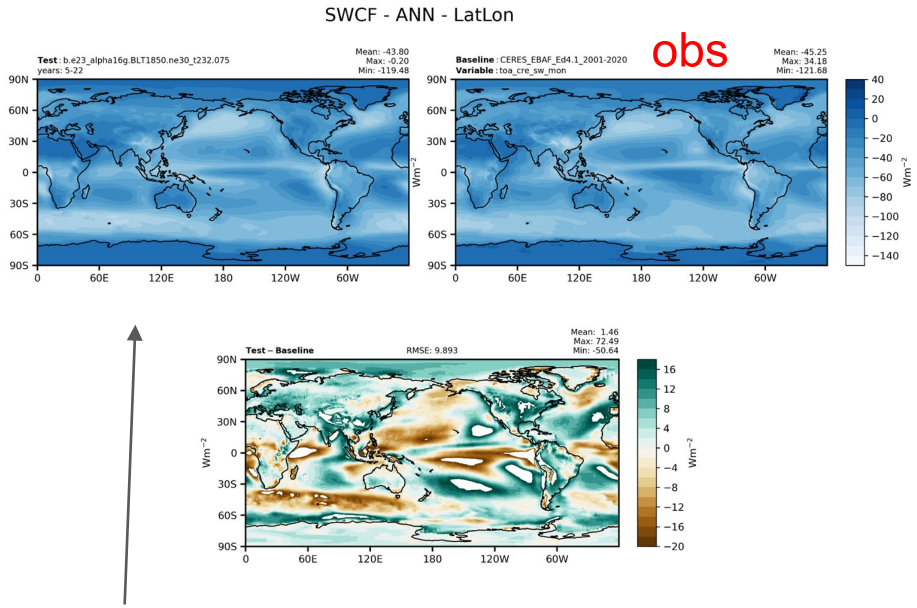


Figure from Guo et al. 2021; 2000m line added for clarity

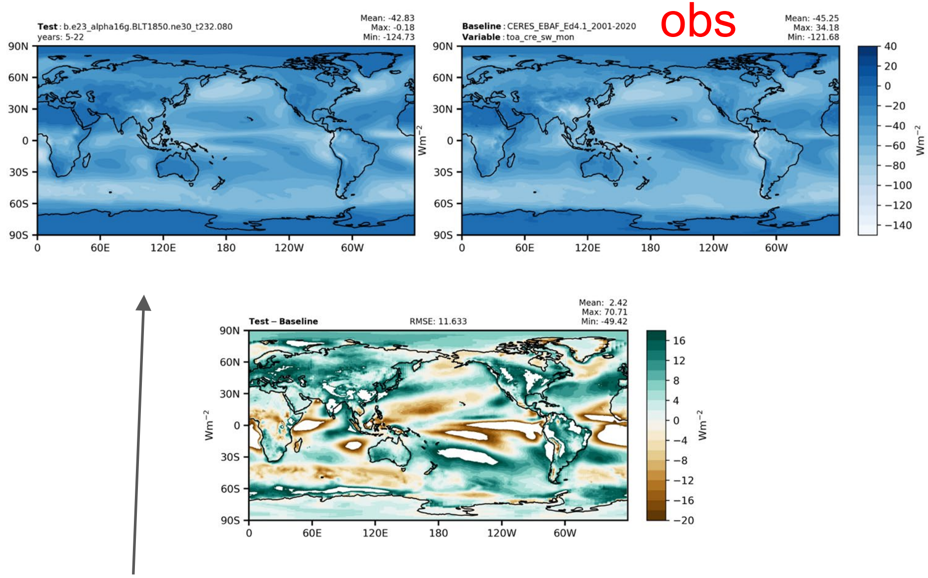
Tuning taus in CAM/CESM

- Decent progress with the spatial patterns of SWCF and LWCF
- RESTOM near zero in recent B1850 experiments.
- Magnitudes of SWCF and LWCF are still low (but low LWCF is pretty typical in CAM)



CLUBB-L

Mean: -43.8
RMSE: 9.89



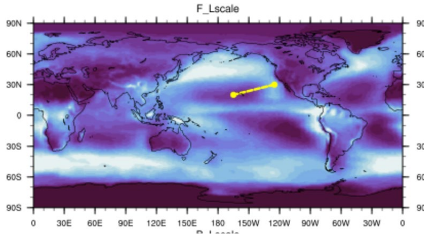
CLUBB-taus

Mean: -42.8
RMSE: 11.6

Some remaining questions/challenges

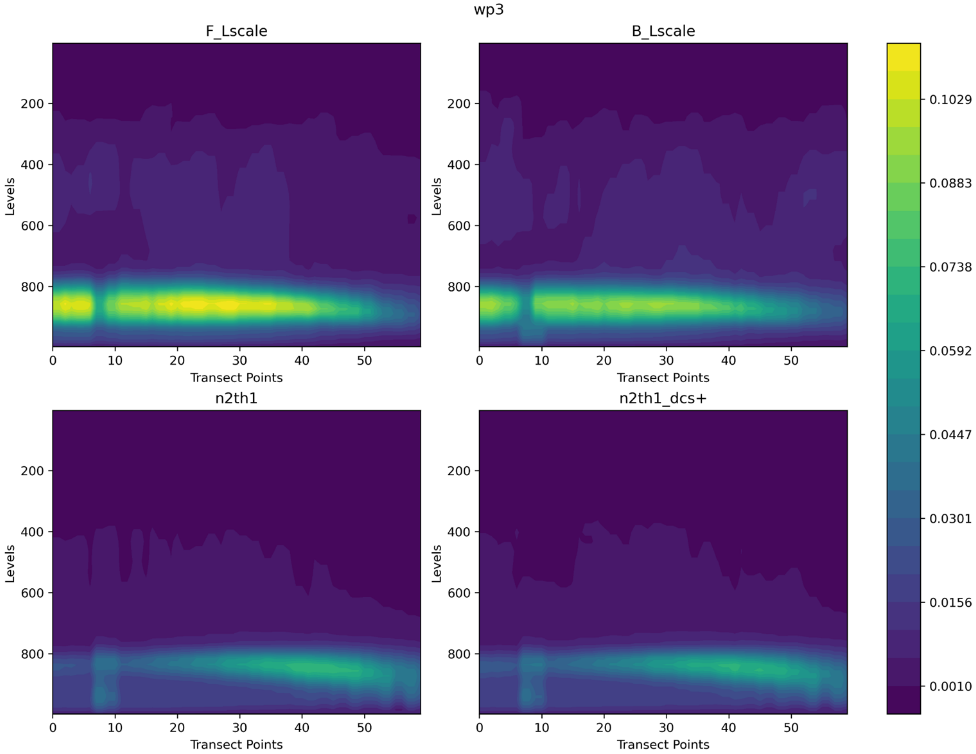
1. w’3 ~ skewness(w) seems degraded in CLUBB-taus, when looking at a transect from Hawaii to California.

Pacific transect

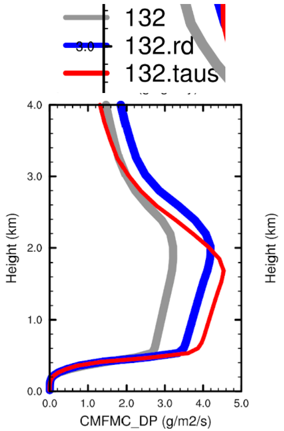


Thanks to Colin Z. & Adam H. for plots/scripts.

Top rows: CLUBB-L
Bottom rows: CLUBB-taus



Is CLUBB-taus giving a “strong ZM” solution?



(Some of the) Remaining questions/challenges

2. Stability of CLUBB-taus?
   - Some taus runs have shown instability. An increased value of se_nsplit=6 has improved this behavior in some circumstances.
3. Longer-term phenomena (ENSO, MJO, etc.)
   - Thanks to Adam Phillips for analyzing recent CLUBB-L vs CLUBB-taus tests. Adam summarizes:
     - CLUBB-L: Improvements in SST/PR variability and ENSO amplitude which now compare favorably to obs. La Nina’s do not regularly follow El Ninos.
     - CLUBB-taus: Looks very similar to CESM2. La Ninas are stronger and more persistent than in CESM2. ENSO teleconnection to NA too weak.
     - Both: The dry slot over Eq. Pac cold tongue still present, and variability in trop. Pac. extends too far wenst over the maritime continent.