CLUBB’s momentum fluxes

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Outline of talk

- In CAM6, two weak points are oceanic surface wind stress and sea-level pressure
- CLUBB parameterizes momentum fluxes with simple downgradient diffusion
- Momentum fluxes in nature can be upgradient, which is challenging to parameterize
- We are experimenting with various reformulations of CLUBB’s eddy diffusivity
- Single column results show hints of promise
- Global results still need work
- Conclusions
Some of the largest errors in CAM6 are related to momentum fluxes

1) Tropical oceanic surface stresses are too strong; can lead to oceanic “cold tongue.”

2) Mid-latitude cyclones are too strong (the lows are too low).
CLUBB parameterizes momentum fluxes using simple down-gradient diffusion

\[ \overline{u'w'} = -K \frac{\partial \overline{u}}{\partial z} \]

In CAM6’s atmosphere, CLUBB’s eddy diffusivity is active everywhere, including shallow convection.
Can we reduce these errors by tuning CLUBB’s eddy diffusivity?

\[ K = c_{K10} L \sqrt{tke} \]

c_K10 is the only obvious tunable parameter.
No. Improving the surface pressure degrades the oceanic surface wind stress

Although increasing $c_{K10}$ from 0.3 to 1.0 leads to “much improved skill scores for SLP, changes to subtropical surface stresses cause the sea surface temperatures to drop to unreasonable levels.” (P. Bogenschutz)
Fluxes of *moisture* are typically downgradient, which makes that parameterization problem easier.

There may be large errors in $w'r_t'$, but at the least the sign of $w'r_t'$ is easy to parameterize.
In contrast, *momentum fluxes are sometimes upgradient*

In contrast, a downgradient flux would have

\[ u'w' = -K \frac{du}{dz}. \]
An upgradient flux can be caused by non-local transport in the presence of a jet.

A plume rising from the surface will deposit counter-gradient momentum aloft.
Probably the best way to treat momentum fluxes would be to integrate the governing equation directly:

\[
\frac{\partial u'w'}{\partial t} = -w'^2 \frac{\partial \bar{u}}{\partial z} + (1 - C_5) \frac{g}{\theta_{vs}} u'\theta'_v - \frac{C_4}{\tau} u'w' - \frac{\partial w'^2u'}{\partial z}
\]

The turbulent production term is downgradient diffusion, but the buoyancy production and turbulent transport terms can lead to upgradient momentum fluxes.
However, for expediency, here we’ll simply modify CLUBB’s eddy diffusivity

In the prior eqn, drop some terms and re-arrange:

$$\bar{u}' \bar{w}' = -\frac{\tau}{C_4} \bar{w}'^2 \frac{\partial \bar{u}}{\partial z} + \frac{\tau}{C_4} (1 - C_5) \frac{g}{\theta_{vs}} \bar{u}' \bar{\theta}'_v$$

(The turbulent transport term is neglected, and so don’t get your hopes up!)
Let’s explore the effects of a counter-gradient term in single-column simulations

The counter-gradient term improves the simulation of a cumulus layer and a stably stratified layer, while leaving a well-mixed Sc layer little changed.
The zonal wind in the BOMEX shallow cumulus case is improved, but upgradient fluxes are still misrepresented.

This plot hints that new CLUBB might reduce oceanic surface stresses in shallow Cu regions.
The meridional wind is also improved a bit
The DYCOMS-II RF01 Sc case is degraded slightly.

The momentum profile is slightly less well mixed, which is not desired.
The DYCOMS-II meridional wind is also slightly degraded.

The degradation is slight because the countergradient term contributes little in a well-mixed layer.
The zonal wind in the GABLS3 stably stratified case improves.

\[ \langle u \rangle \]

\[ \langle u'w' \rangle \]
The GABLS3 meridional wind also improves
Does adding a counter-gradient term improve global simulations? Not much.

We’ll show some 2° CAM-CLUBB-SILHS simulations.

Format of the following figures

Left panels:
Default momentum eq

Right panels:
New momentum eq, with boosted c_K10
Default momentum eq

New momentum eq
Conclusions

1. Momentum fluxes can be upgradient

2. Improvements in CLUBB’s momentum fluxes may be possible if neglected terms are parameterized

3. There is only so much one can do with an eddy diffusivity approach.
Thanks for your time!