How Does CLUBB's New Prognostic Momentum Flux Formulation Impact the Mean Climate in CAM6?

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In collaboration with the Momentum Flux CPT team

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The momentum flux CPT has worked to implement a new prognostic momentum flux formulation in CLUBB

$$\frac{\partial \overline{u'w'}}{\partial t} = -\overline{w}\frac{\partial \overline{u'w'}}{\partial z} - \frac{1}{\rho}\frac{\partial \overline{\rho w'^2 u'}}{\partial z} - (1-C_{uu\_shr})\overline{w'^2}\frac{\partial \overline{u}}{\partial z} - (1-C_7)\overline{u'w'}\frac{\partial \overline{w}}{\partial z} + (1-C_7)\frac{g}{\theta_{vs}}\overline{u'\theta_v'} - \frac{C_6}{\tau}\overline{u'w'} - \epsilon_{uw}$$

Advection of momentum flux by the mean vertical wind

Turbulent production

- Replaces the diagnostic "eddy diffusivity" formulation:

$$\overline{u'w'} = -K_m \frac{\partial \overline{u}}{\partial z}$$

- **Prognostic formulation allows for countergradient fluxes**

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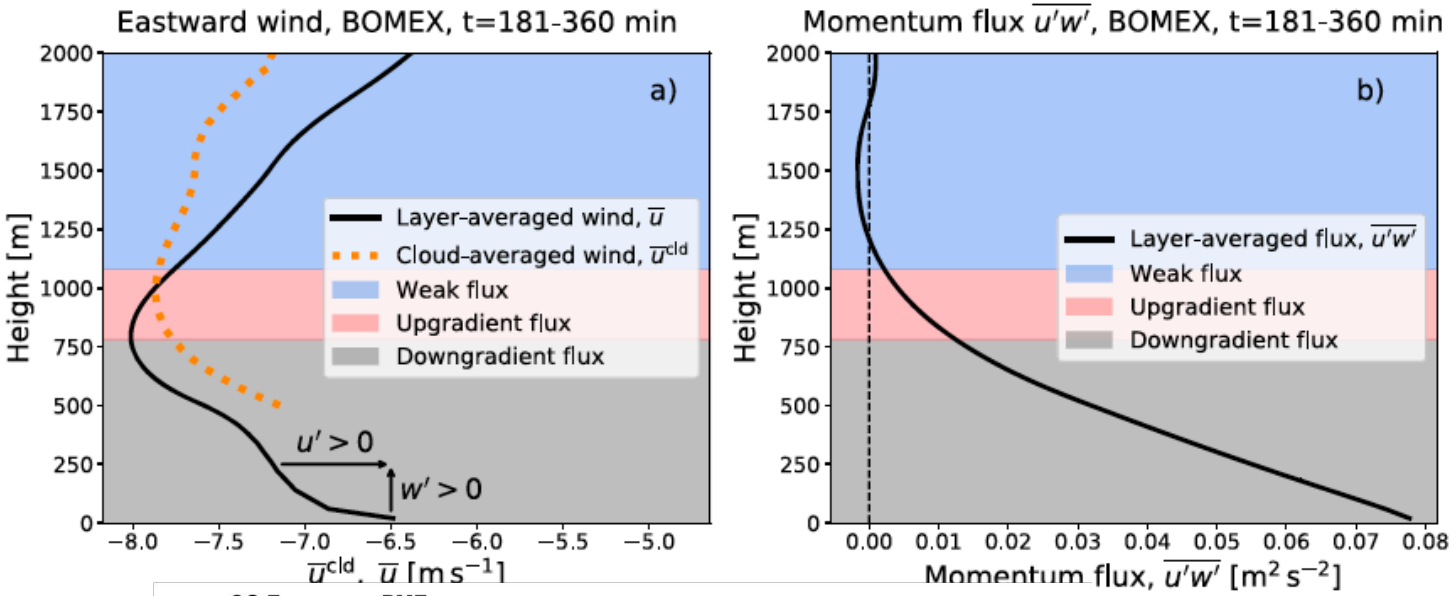
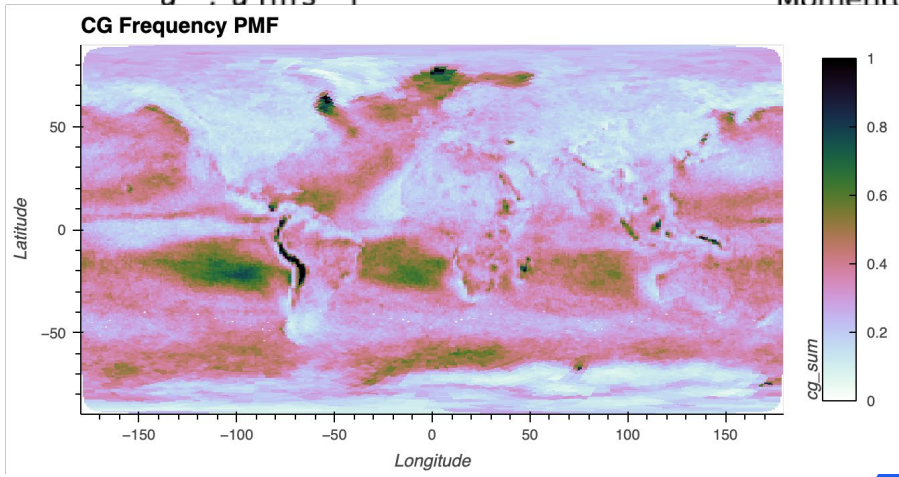
Countergradient fluxes have been shown to manifest in shallow cumulus regions



Larson et al. (2019) and Graap and Zarzycki (2023) found countergradient fluxes in the tropics

(Figure from Larson et al. 2019)



Preliminary analysis using prognostic momentum flux in CAM6 indicates countergradient fluxes elsewhere across the globe

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We want to ask the question: how does implementing prognostic momentum flux impact the general circulation in CAM6?

- 10-year aquaplanet (*QPC6*) simulations
  - CLUBB settings from *f.cam6_3_132.FLTHIST_ne30.001* (CK10 = 0.5)
- Run one simulation with prognostic momentum flux and one with the legacy diagnostic formulation (all else constant)
- Compare mean general circulation for years 2 through 10

- **At the very early stages of tackling this question**
- **Not focused on tuning or bias reduction at the moment**
- **Want to first see how a reasonable CAM6 configuration changes when turning on prognostic momentum**

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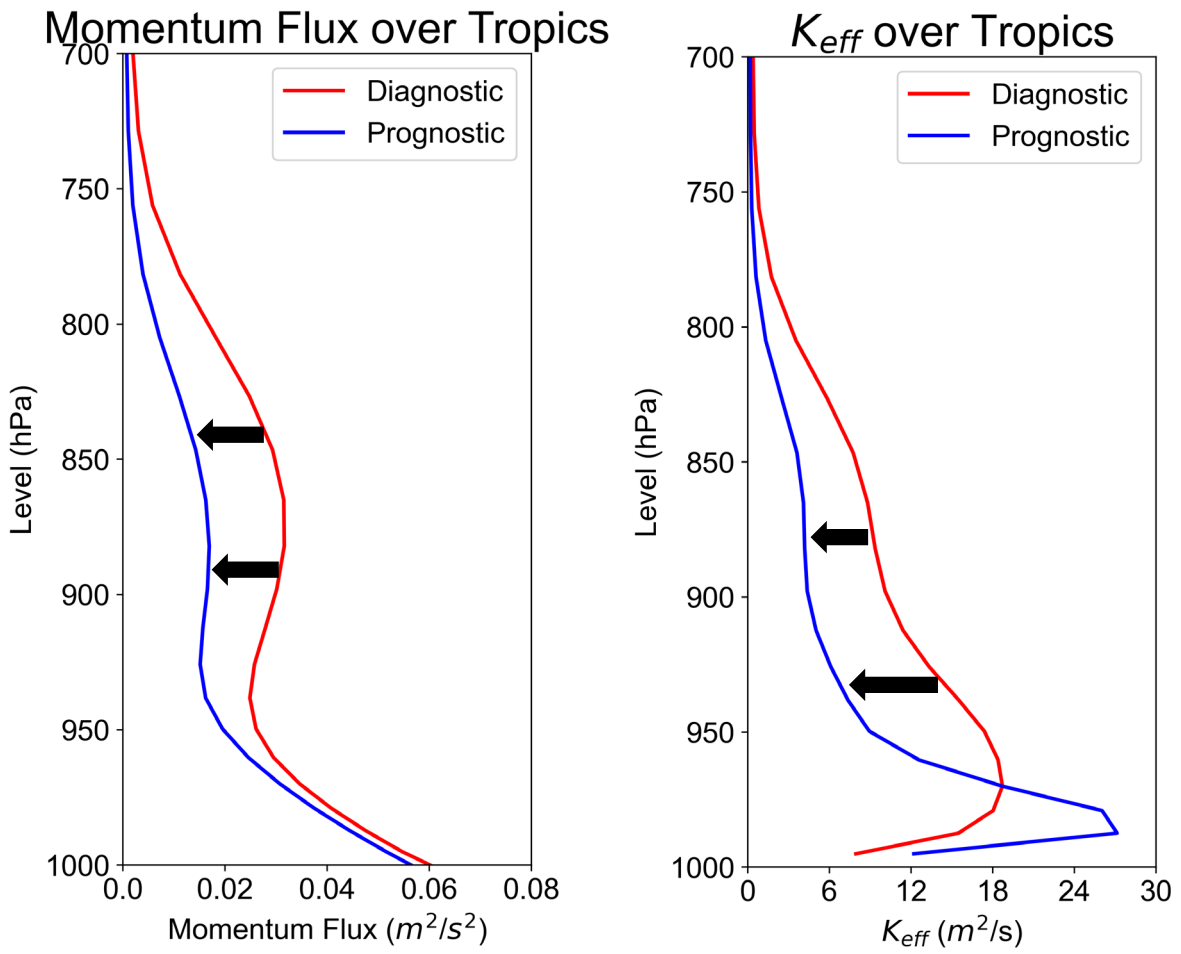
Implementing prognostic momentum flux in this CLUBB configuration reduces momentum flux and effective eddy diffusivity

- The atmosphere becomes less diffusive, with reduced momentum flux
- With diagnostic momentum flux, the red curve can be adjusted by tuning the CK10 parameter in CLUBB
- **NOTE: Without prognostic momentum, CK10 is the primary mechanism for reducing momentum diffusivity**



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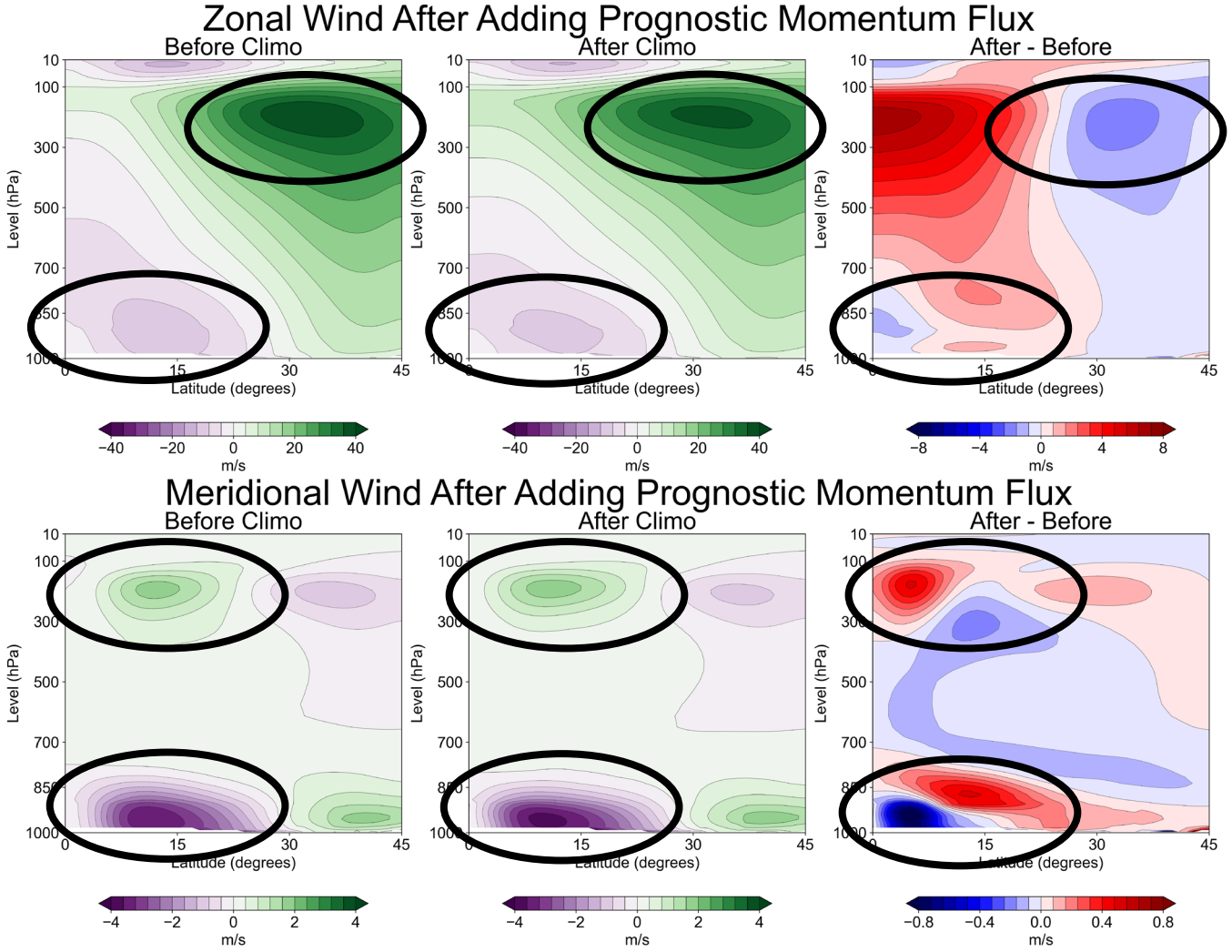
Circulation responses manifest in the mean climate's response to reduced diffusivity



- Decreased magnitude of the westerly jet and low-level easterlies
- Core of low-level equatorward flow strengthens and contracts downward and equatorward
- Poleward flow aloft increases in magnitude and shifts equatorward

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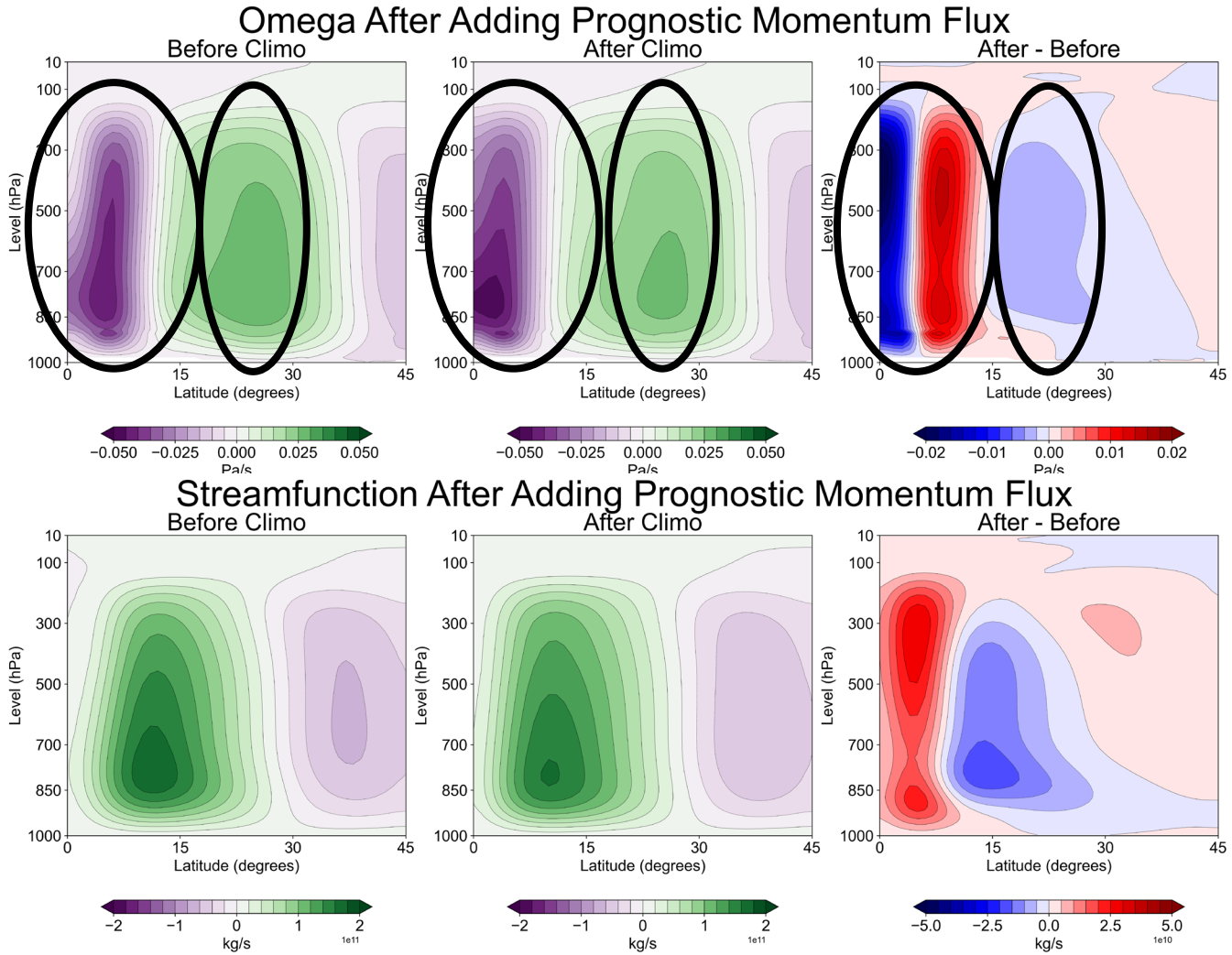
Circulation responses manifest in the mean climate's response to reduced diffusivity

- Upward motion at low latitudes strengthens and shifts equatorward
- Downward motion in the subtropics is weakened and shifts equatorward
- The streamfunction response also indicates a weakening of the Hadley circulation and an equatorward contraction



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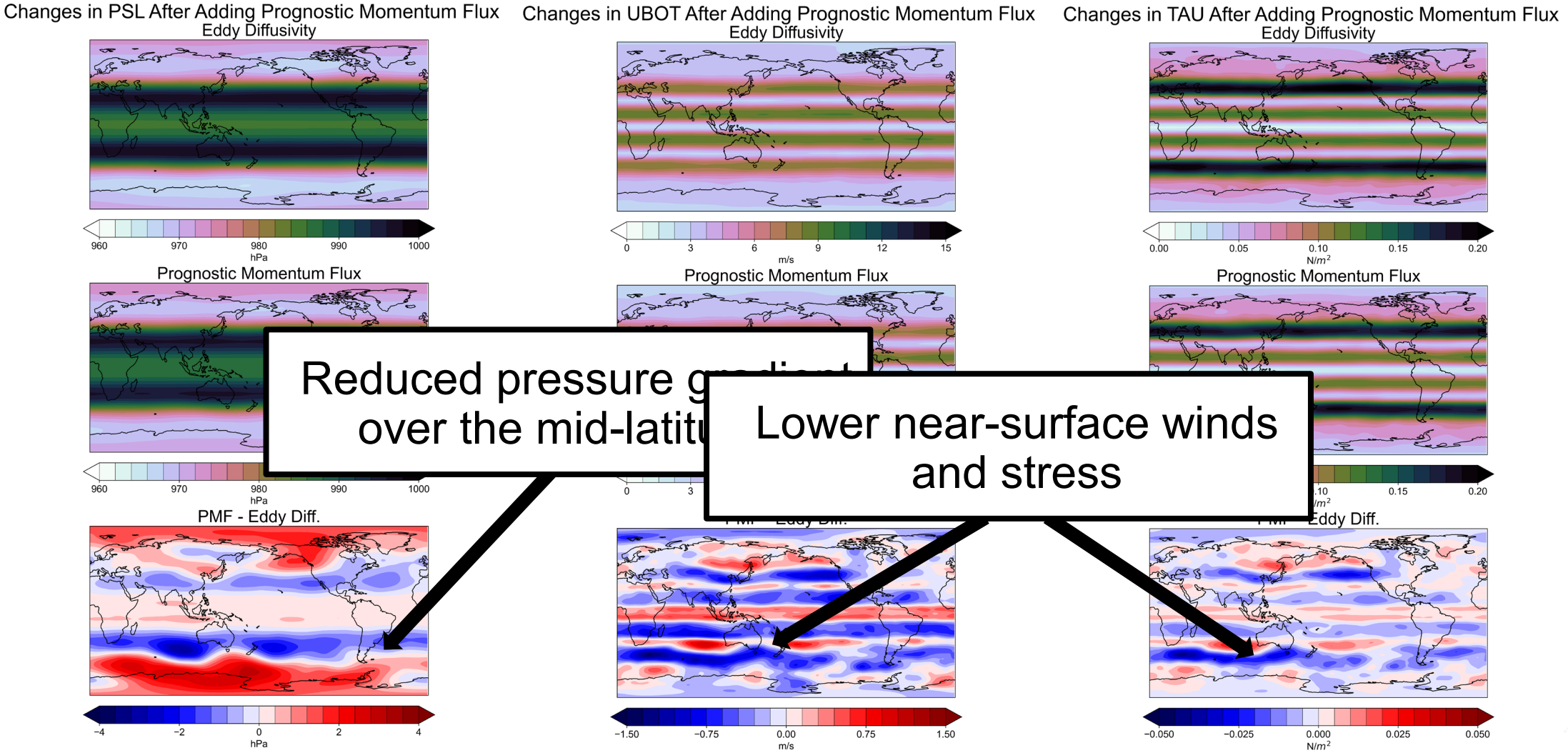
Adding prognostic momentum flux has the potential to impact low-level winds



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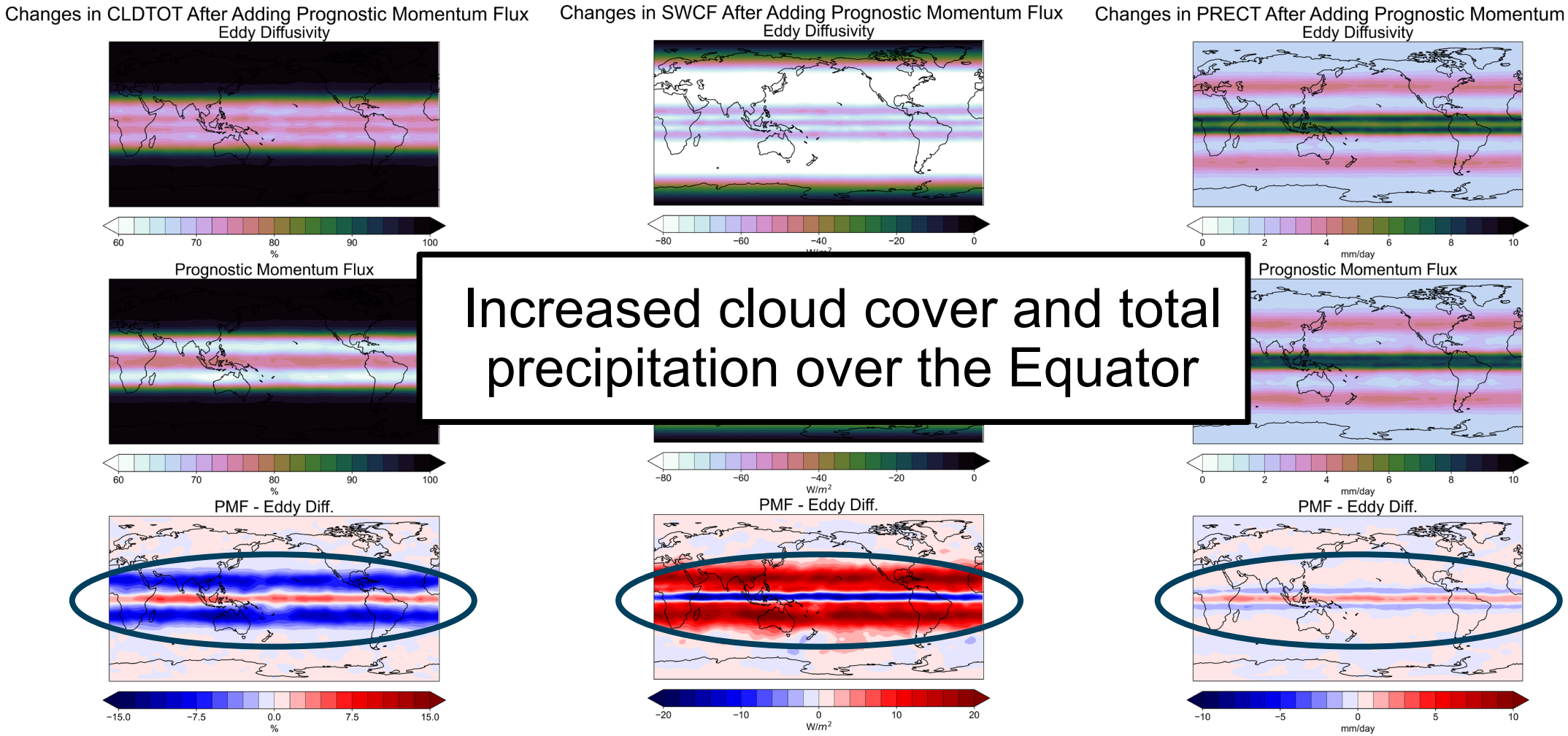
Adding prognostic momentum flux also has the potential to influence clouds



Increased cloud cover and total precipitation over the Equator

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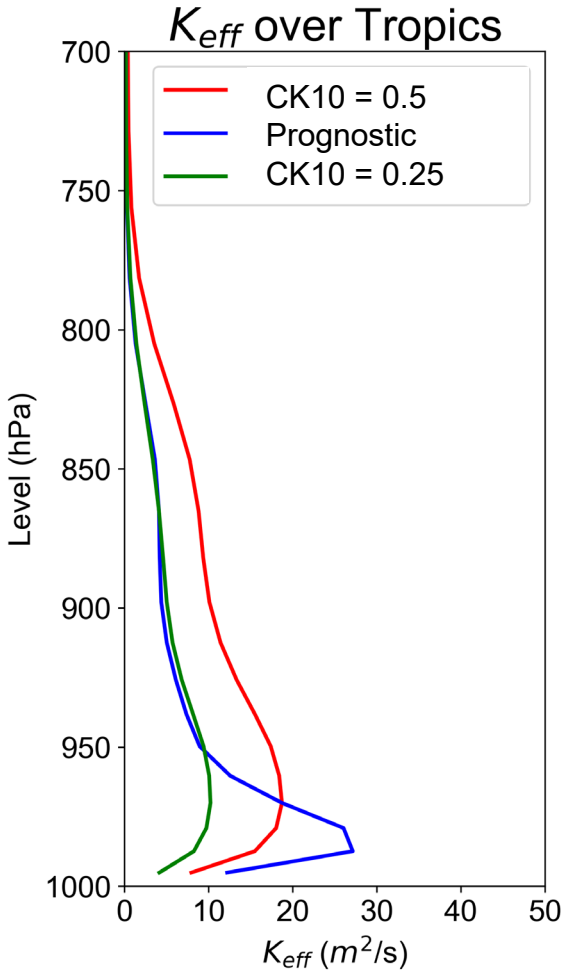
This work is in the early stages, and we're still determining how to best answer the question of how prognostic momentum flux affects the mean climate

- Response to adding prognostic momentum flux will vary depending on the baseline CLUBB parameter settings
- What if we choose a less diffusive baseline configuration?
- How do we better understand the bulk impact of vertically integrated diffusivity + more subtle differences such as countergradient fluxes and profile shape changes?



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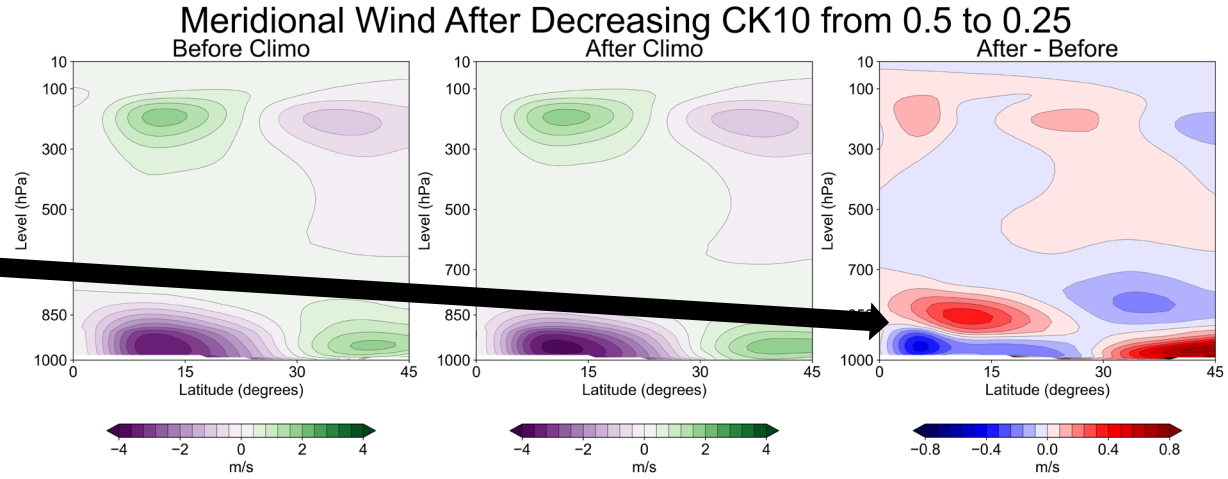
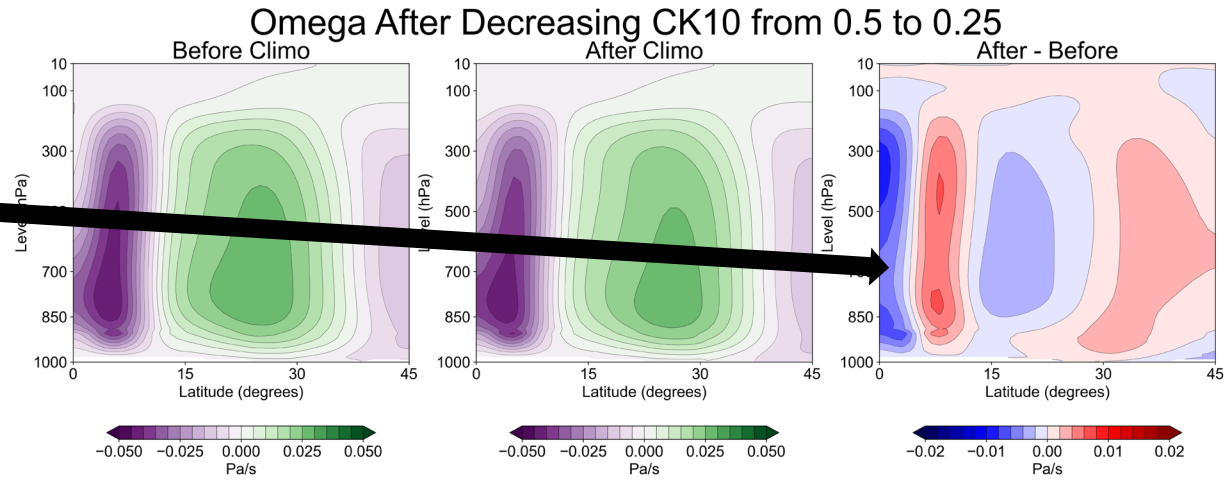
When we keep diagnostic momentum flux but decrease the CK10 parameter, we get a response that's qualitatively like adding PMF

Strengthened meridional winds and a downward + equatorward contraction



Strengthened upward motions and equatorward shift



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Main takeaways

- Adding prognostic momentum flux to a reasonable CAM6-CLUBB baseline configuration reduces integrated diffusivity
- With reduced diffusivity, the Hadley circulation appears to weaken and contract toward the Equator
- Meridional winds are strengthened in the tropics
- Over the mid-latitudes, there's a reduced sea-level pressure gradient
- **What are the physical mechanisms driving these responses?**
- **What are the influences of reducing integrated diffusivity vs. adding countergradient fluxes + profile shape changes?**

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We thank our partners in this work

Additional Questions?
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Main takeaways

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