How do countergradient momentum fluxes in CLUBB affect the general circulation in CAM6?

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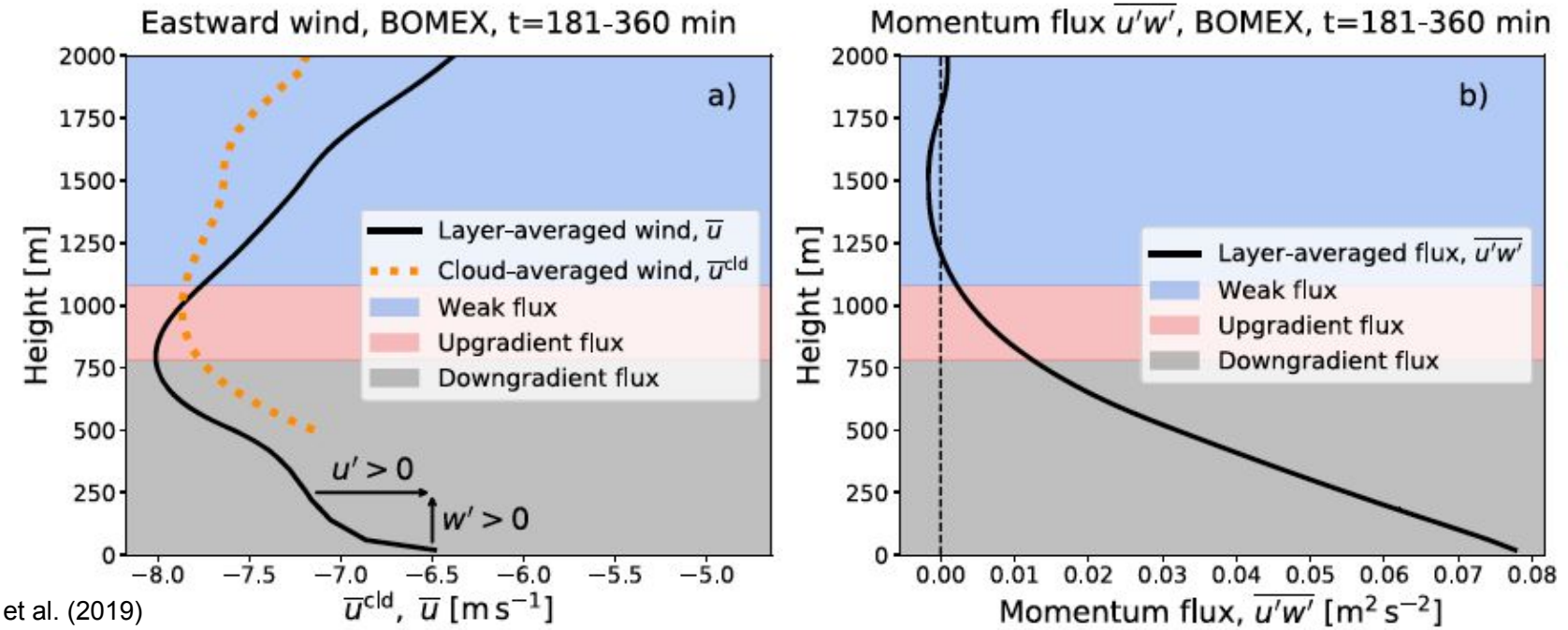
When do countergradient (CG) fluxes occur?



Larson et al. (2019)

CG momentum fluxes occur when momentum flux and wind shear are of the same sign. The prior diagnostic formulation of CLUBB didn't account for CG fluxes:

$$\overline{u'w'} \approx -K\frac{\partial \overline{u}}{\partial z}$$

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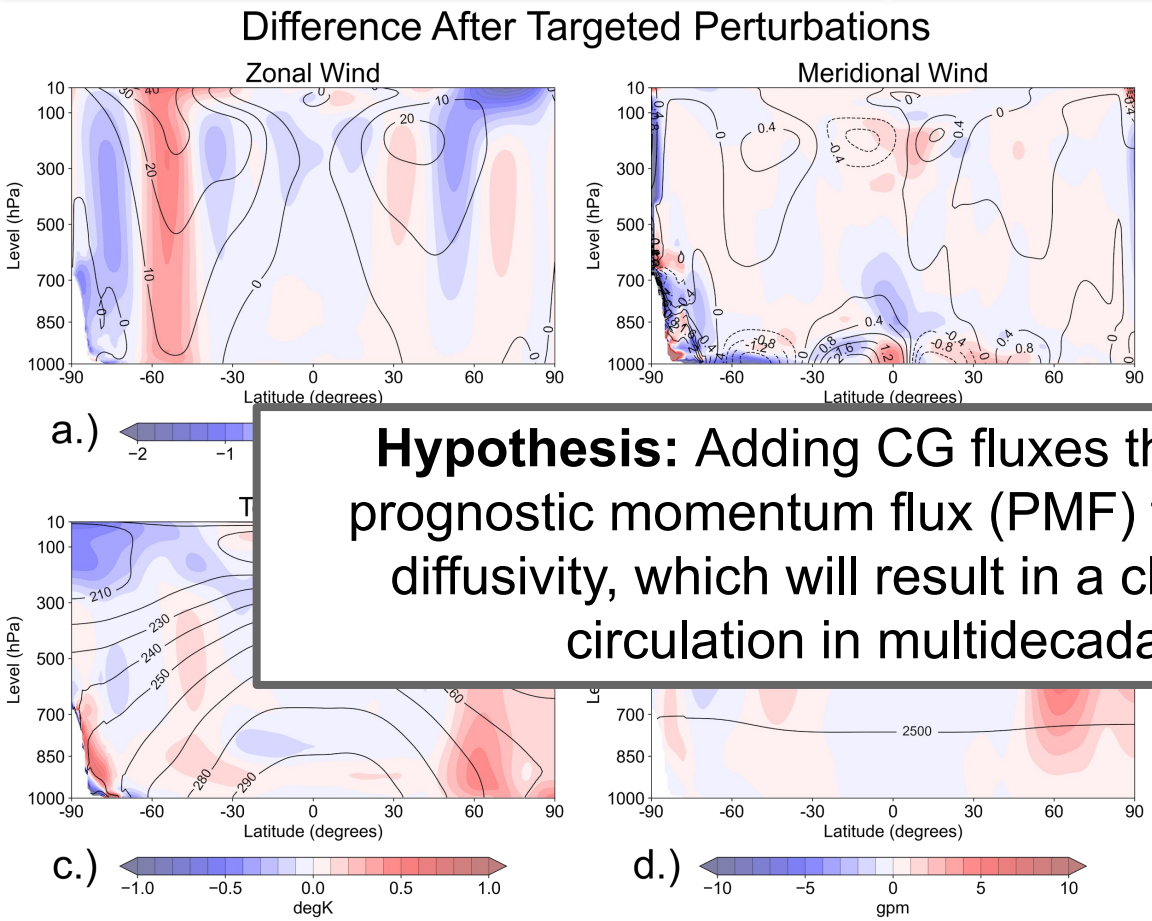
Why do we care about CG momentum fluxes with respect to the general circulation?



We perturbed a handful of impactful CLUBB input parameters that modulate vertical mixing in the PBL

Hypothesis: Adding CG fluxes through CLUBB's new prognostic momentum flux (PMF) formulation will impact diffusivity, which will result in a change in the general circulation in multidecadal simulations

Changes to the mean climate, in turn, influenced PBL processes and modulated CLUBB parameter sensitivities

A Method for Interpreting the Role of Parameterized Turbulence on Global Metrics in the Community Earth System Model

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How will we assess the role of CG fluxes and prognostic momentum flux on the general circulation?

- 30-year aquaplanet simulations w/ CAM6-CLUBB
- CAM6 development tag *cam6_3_124*
- Taus code turned off

Four Configurations:

1. **PMF:** configuration with full prognostic equation for momentum flux (includes countergradient/CG fluxes)
2. **PMF-noCG:** configuration resembling PMF but with sources of CG fluxes removed)
3. **high-diff:** diagnostic (DMF) formulation of momentum flux, tuned to produce relatively high vertical diffusivity
4. **low-diff:** DMF formulation tuned to produce relatively low vertical diffusivity compared to ”high-diff”

How are we calculating momentum flux in each of these configurations?

For the DMF configurations, we decrease the level of diffusivity by adjusting the value of the CK10 parameter (0.7 to 0.3)

$$\overline{u'w'} = -K_m \frac{\partial \overline{u}}{\partial z} \qquad K_m = C_{K10} K_h$$

$$\overline{v'w'} = -K_m \frac{\partial \overline{v}}{\partial z} \qquad K_h = C_k L \overline{e}^{\frac{1}{2}}$$

Using the PMF configuration, we can assess the impact of accounting for CG fluxes in our formulation of momentum flux

$$\frac{\partial \overline{u'w'}}{\partial t} = -\overline{w'^2}\frac{\partial \overline{u}}{\partial z} + \frac{g}{\theta_{vs}}\overline{u'\theta'_v} - C_7\frac{g}{\theta_{vs}}\overline{u'\theta'_v} - \frac{C_6}{\tau}\overline{u'w'} - \frac{1}{\rho}\frac{\partial \rho \overline{w'^2 u'}}{\partial z}$$

To fully understand the role of CG fluxes, we must also include a configuration that resembles PMF but has CG fluxes removed

How do we eliminate CG fluxes in CLUBB?

If we eliminate the CG flux terms, the result is a diagnostic for momentum flux that resembles the “downgradient diffusion” approximation, but formulated within the framework for the new prognostic momentum flux configuration

$$\overline{u'w'} = -\frac{\tau}{C_6}\overline{w'^2}\frac{\partial \overline{u}}{\partial z} + \frac{\tau}{C_6}(1 - C_7)\frac{g}{\theta_{vs}}\overline{u'\theta'_v} - \frac{\tau}{C_6}\frac{1}{\rho}\frac{\partial \rho \overline{w'^2 u'}}{\partial z}$$

$$\overline{u'w'} = -K_m\frac{\partial \overline{u}}{\partial z} \qquad K_m = \frac{\tau}{C_6}\overline{w'^2}$$

This is how we derive momentum flux in “PMF-noCG”!

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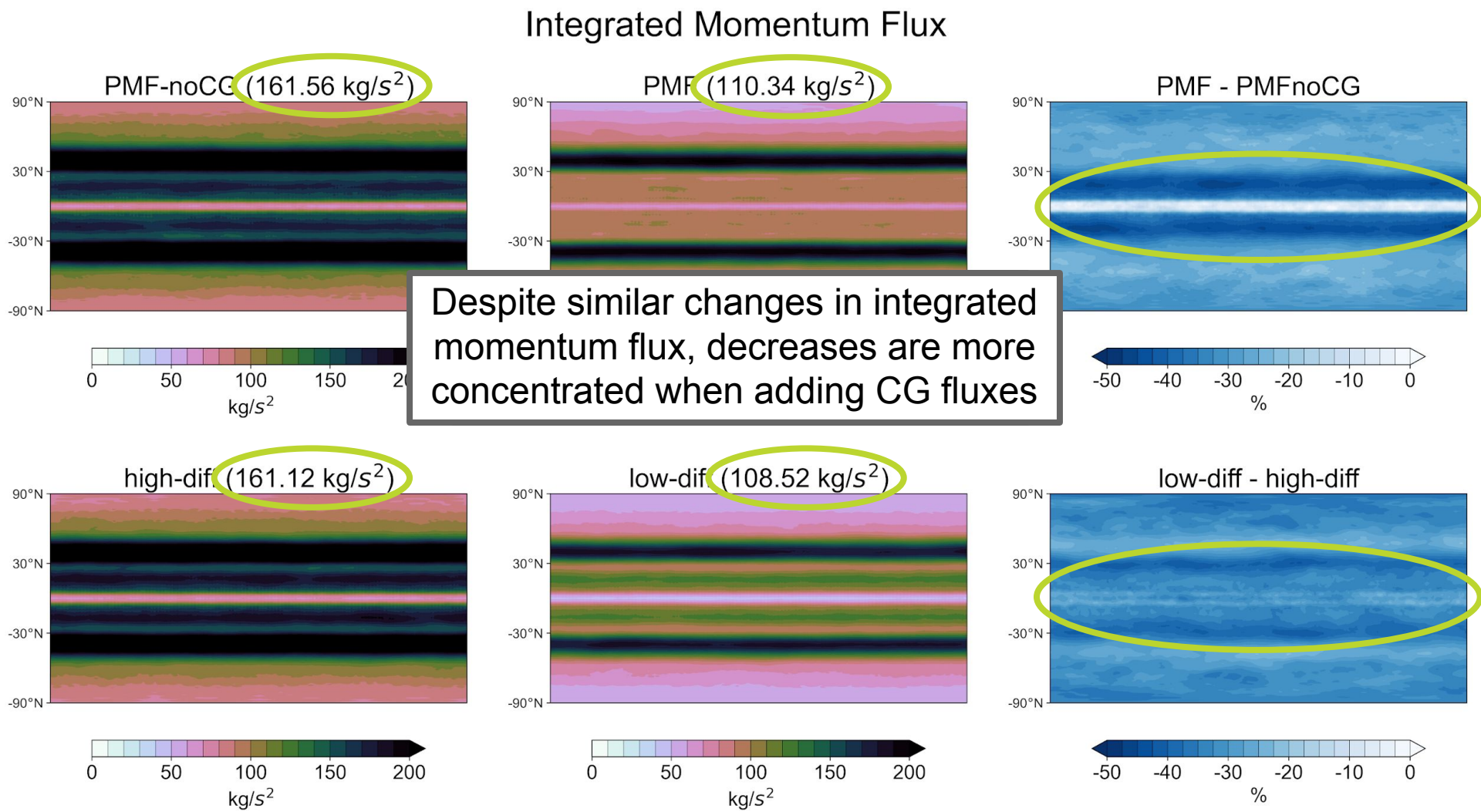
How does global momentum flux change by adding CG fluxes?



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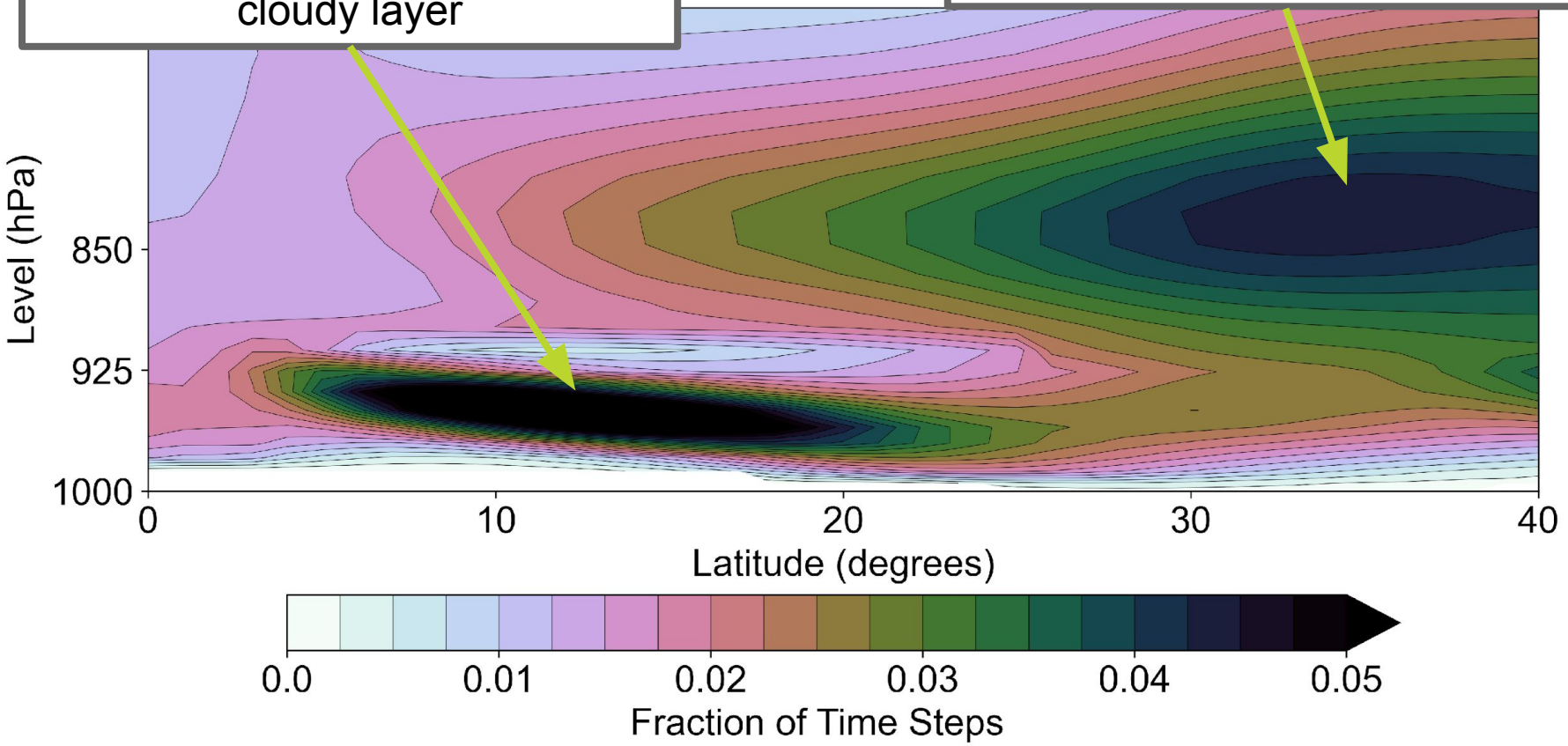
Where do we find CG fluxes?

CG fluxes frequently occur over the subtropics in the vicinity of a cloudy layer

They also often occur over the midlatitude storm track



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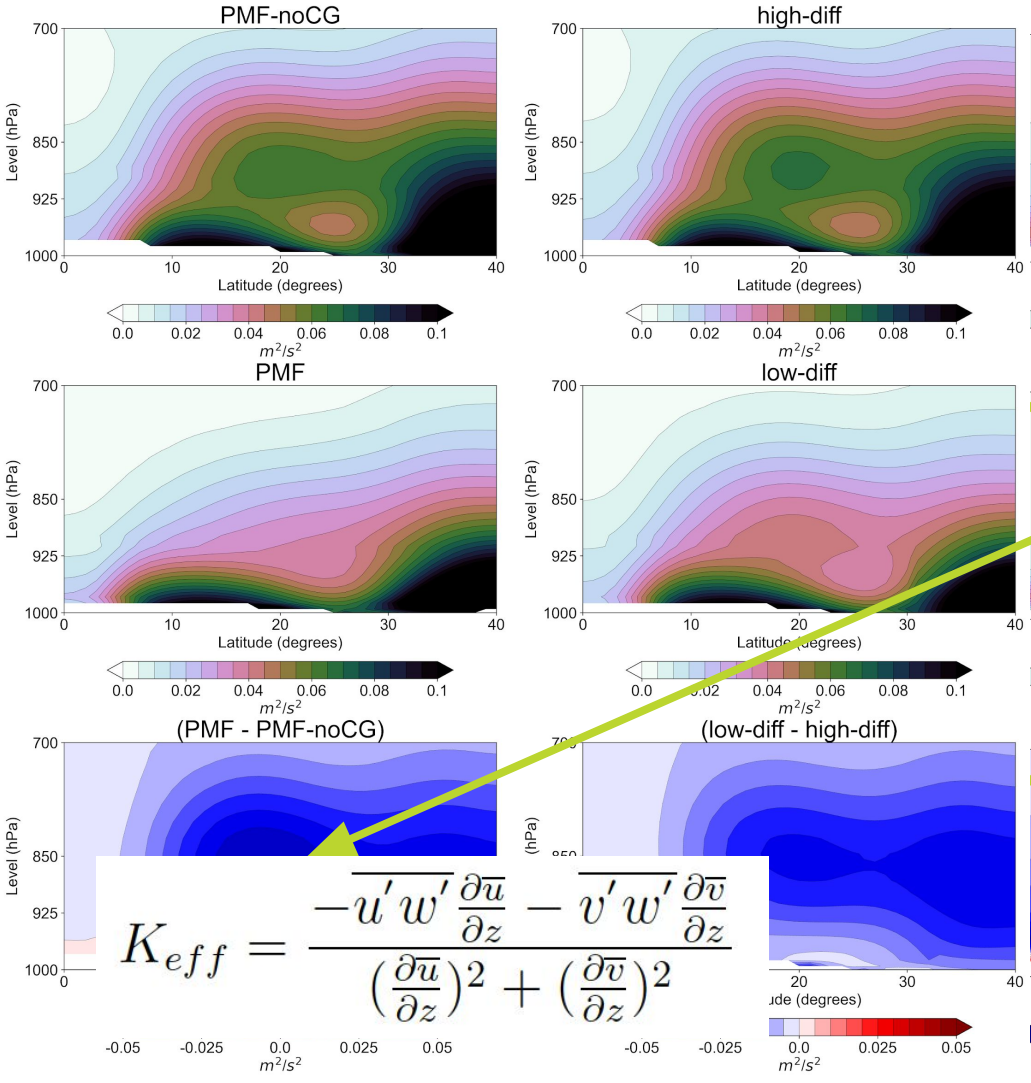
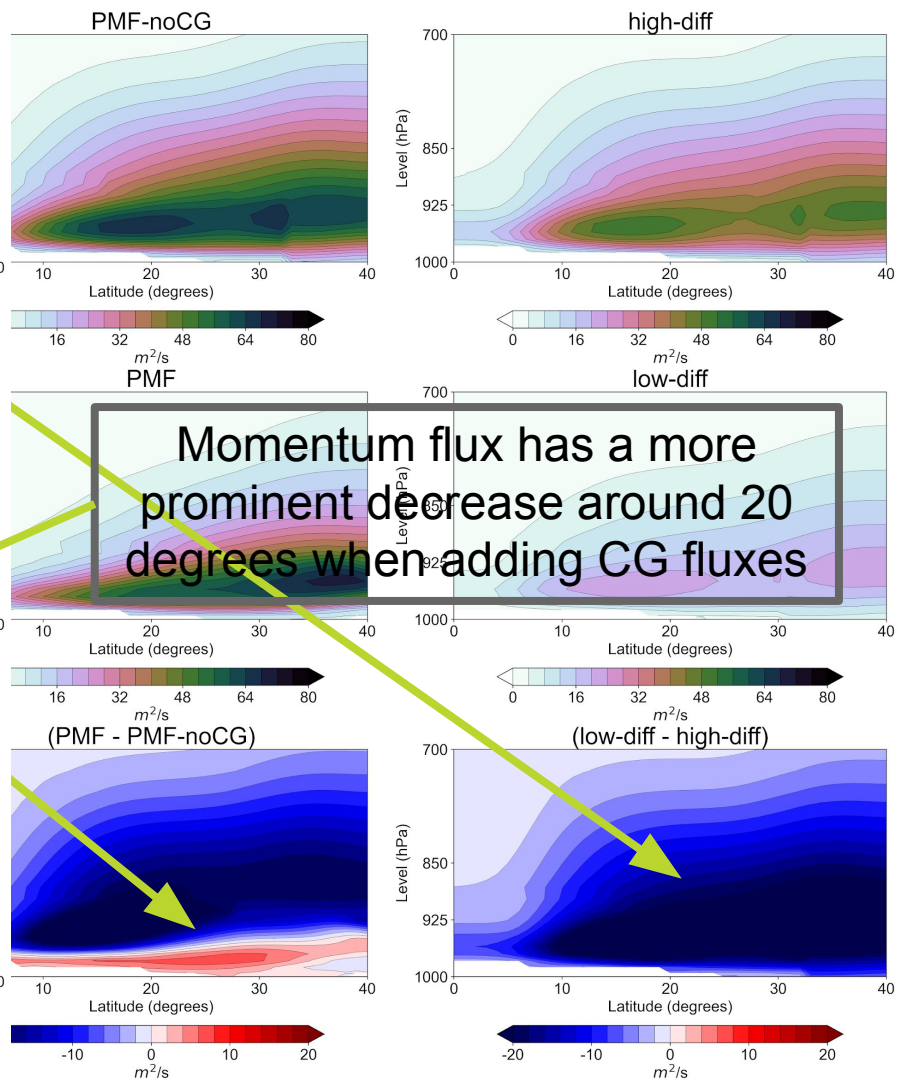
Does adding CG fluxes produce a different kind of change in diffusivity compared to decreasing CK10?

$\sqrt{\overline{u'w'}^2 + \overline{u'w'}^2}$ Momentum Flux Magnitude



Effective Eddy Diffusivity



Momentum flux has a more prominent decrease around 20 degrees when adding CG fluxes

$$K_{eff} = \frac{-\overline{u'w'}\frac{\partial \overline{u}}{\partial z} - \overline{v'w'}\frac{\partial \overline{v}}{\partial z}}{(\frac{\partial \overline{u}}{\partial z})^2 + (\frac{\partial \overline{v}}{\partial z})^2}$$

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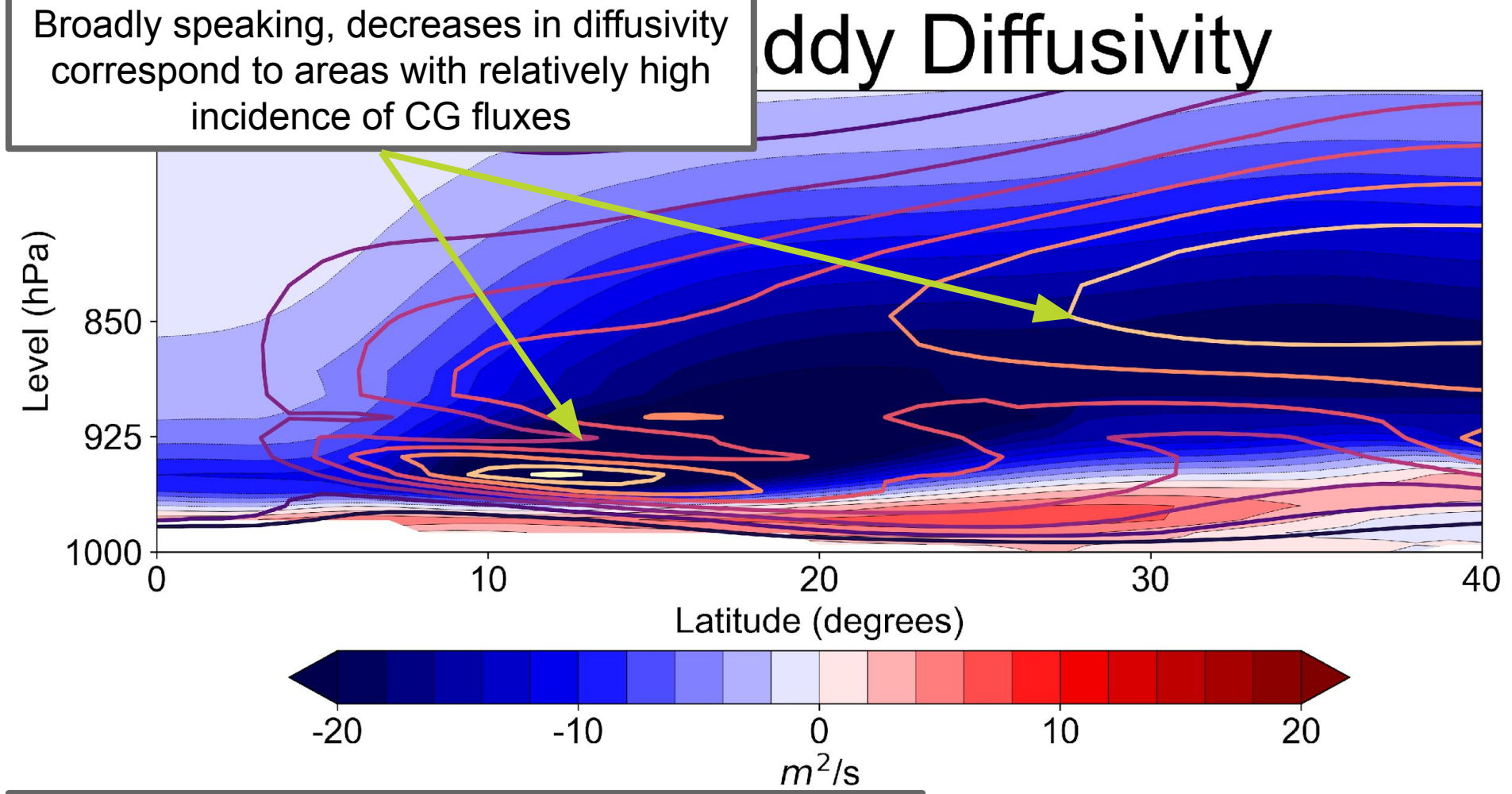
Where are CG fluxes relative to decreases in eddy diffusivity?

Broadly speaking, decreases in diffusivity correspond to areas with relatively high incidence of CG fluxes



Brighter contours imply greater frequency of CG fluxes (U + V direction combined)

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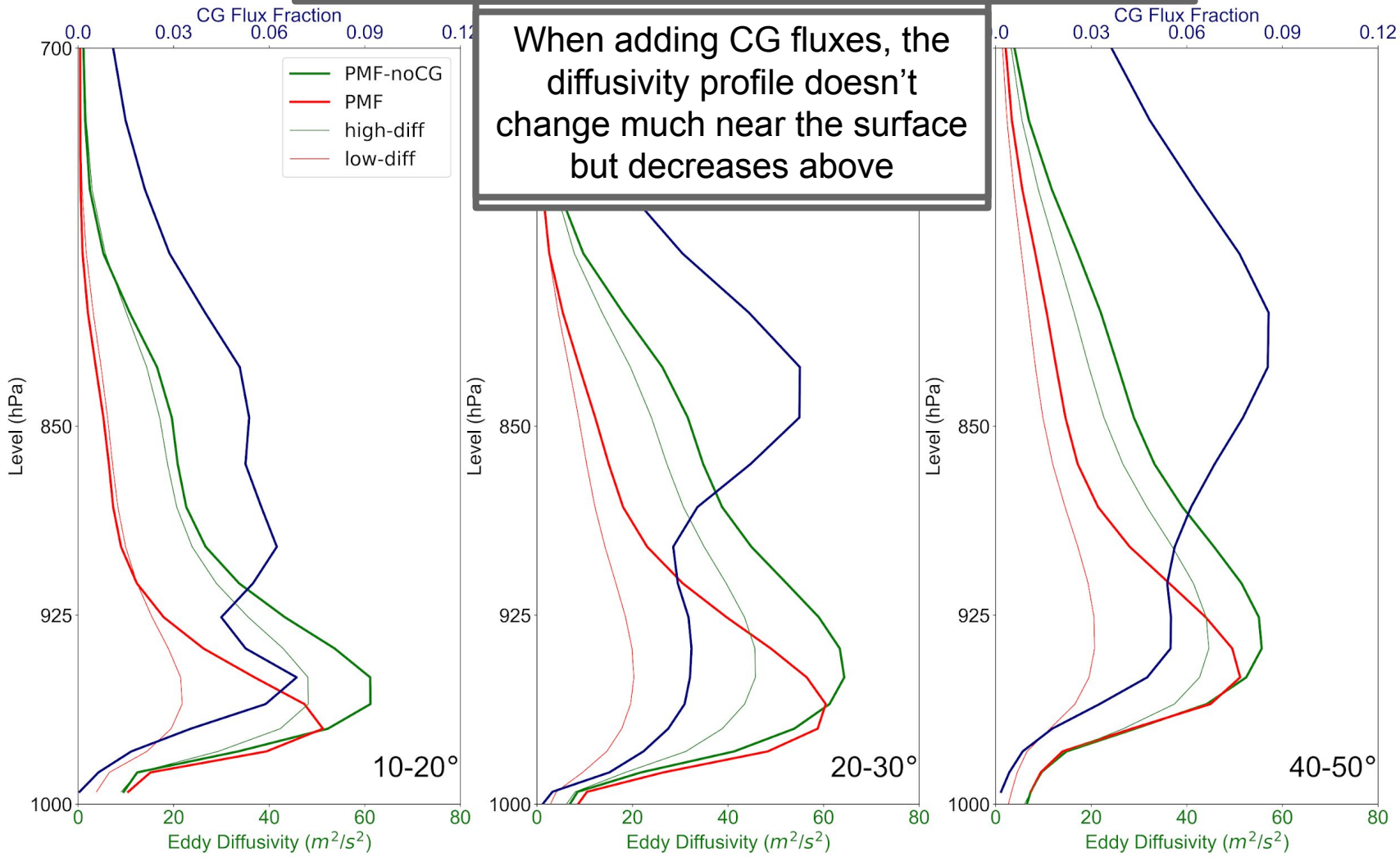
How does the change in diffusivity vary spatially?

Levels of decreased diffusivity in PMF correspond to where CG fluxes are relatively frequent

When adding CG fluxes, the diffusivity profile doesn't change much near the surface but decreases above



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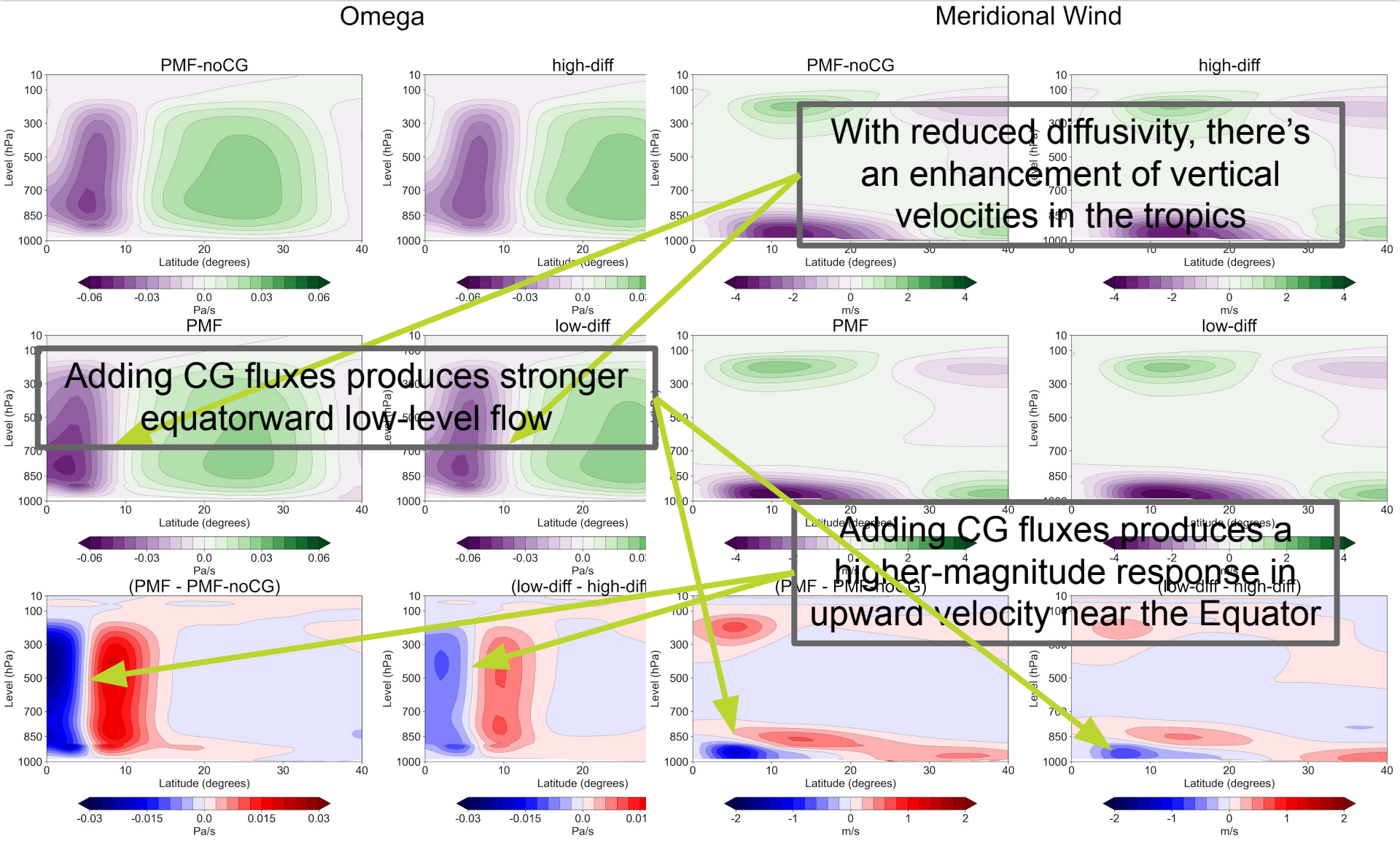
How does this affect the Hadley cell?



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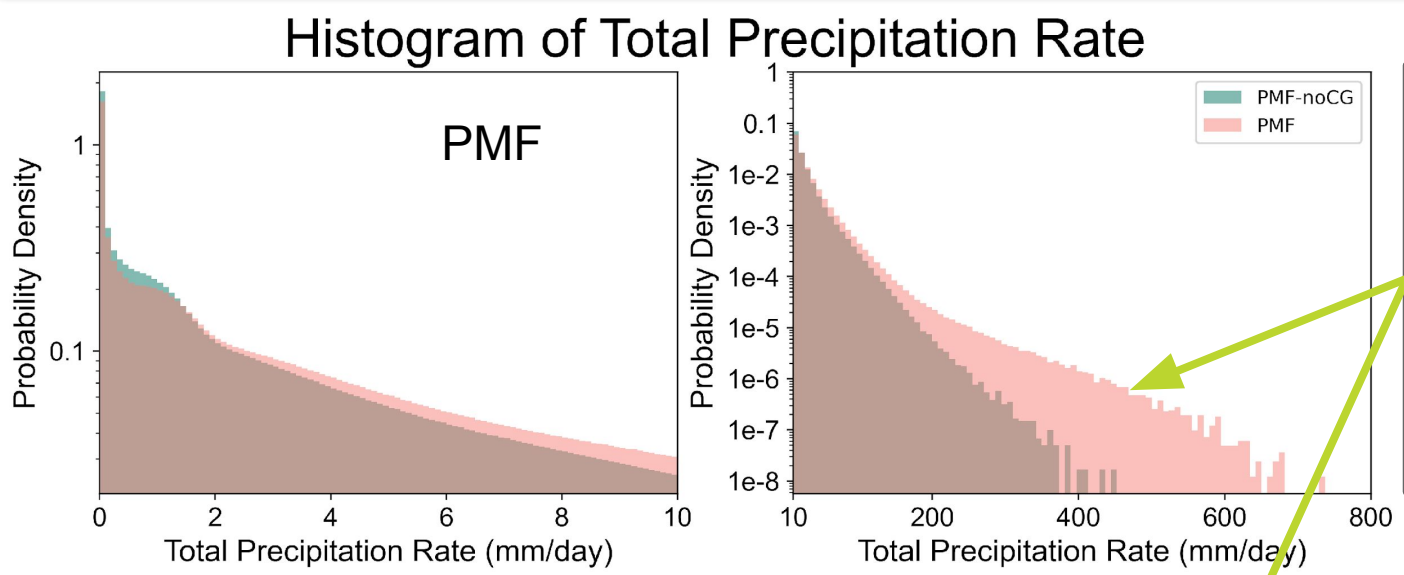
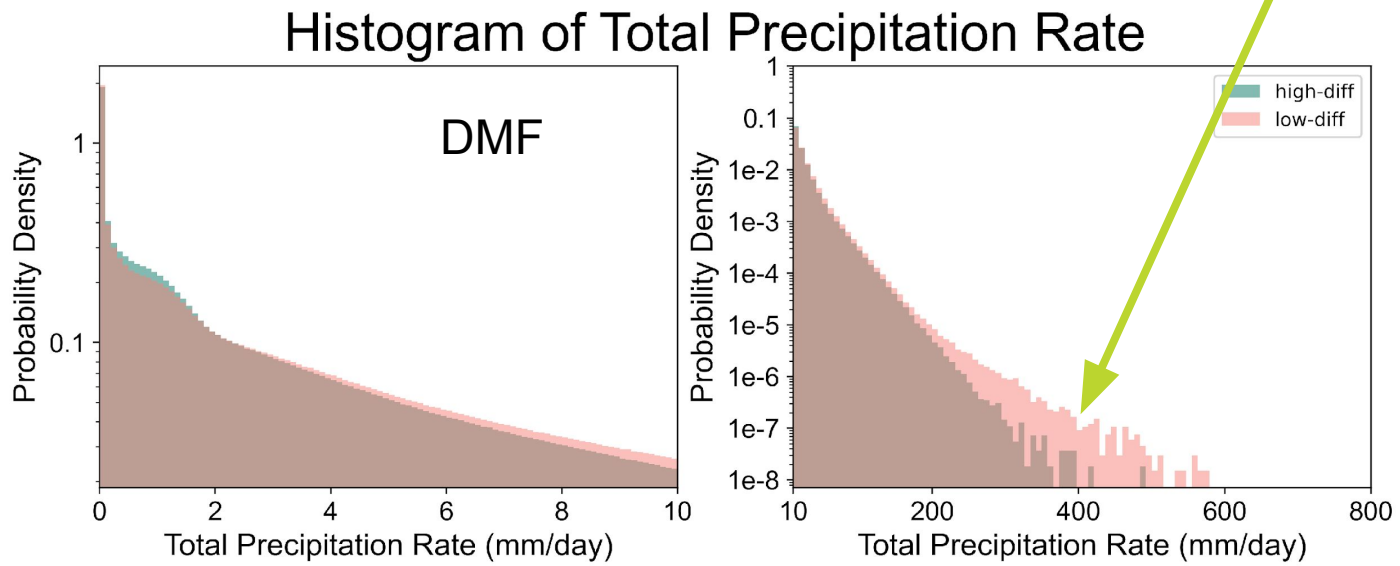
How does this affect precipitation?





In both sets of experiments, lower diffusivity produces enhancements in the frequency of extremely high precipitation totals

The shift toward favoring high precipitation totals is more prominent when adding CG fluxes

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Takeaways and Next Steps

- We can reduce the overall vertical diffusivity of CAM6-CLUBB by either 1) reducing the CK10 parameter or 2) adding CG fluxes through CLUBB's new PMF formulation
- However, adding CG fluxes produces a more spatially-dependent reduction in diffusivity
- Reducing diffusivity appears to increase the strength of the Hadley cell
- Changes are of higher magnitude when adding CG fluxes vs. reducing CK10

Next Steps:

1. **How do spatially-varying changes in diffusivity affect the general circulation?**
2. **Which CLUBB budget terms are most important?**

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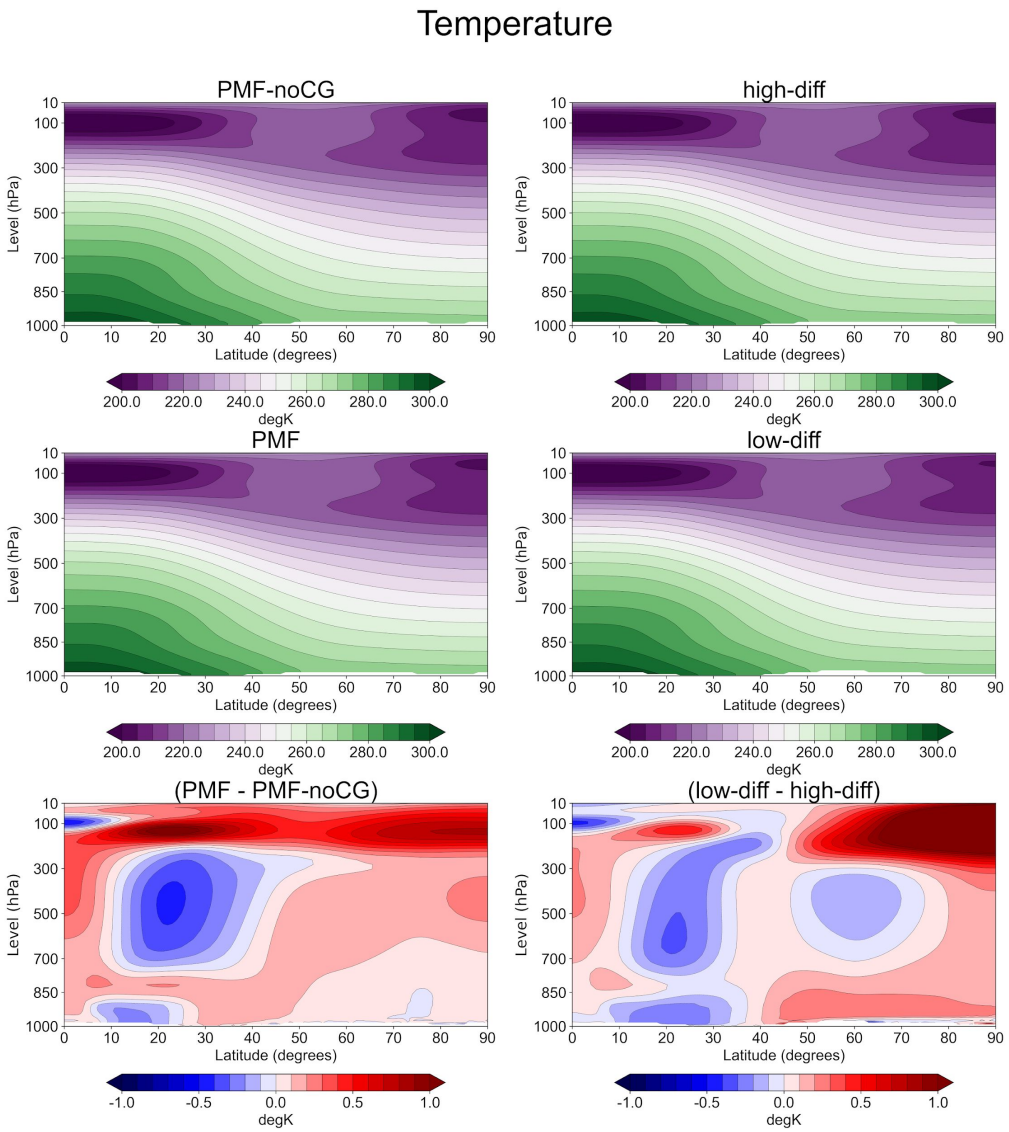
Extra Slides: Temperature gradient increases



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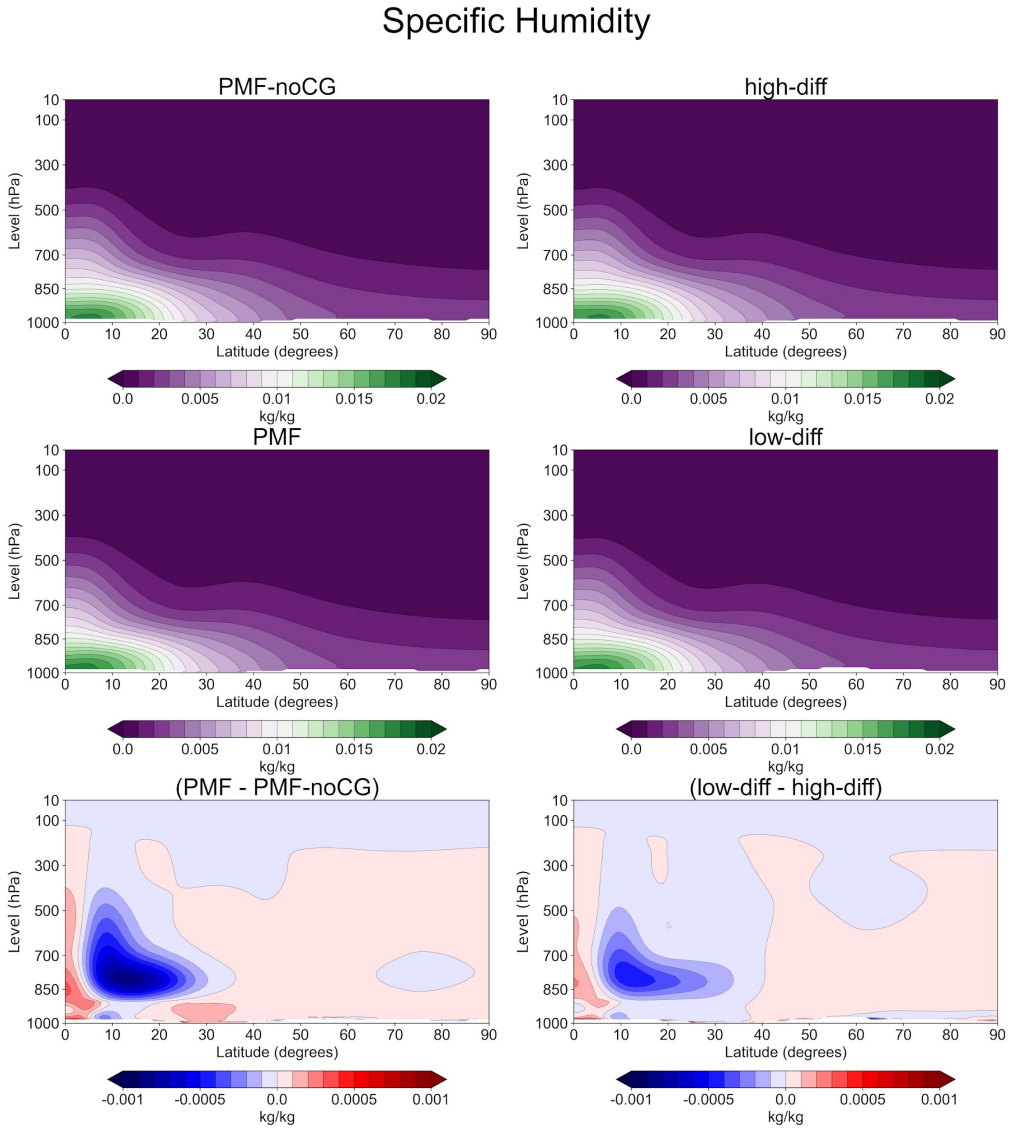
Extra Slides: Moisture gradient increases



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