Diagnostics to Assess the Impact of CLUBB Parameters on Global and Regional Metrics in CAM6

Kyle Nardi
Colin Zarzycki
Vince Larson

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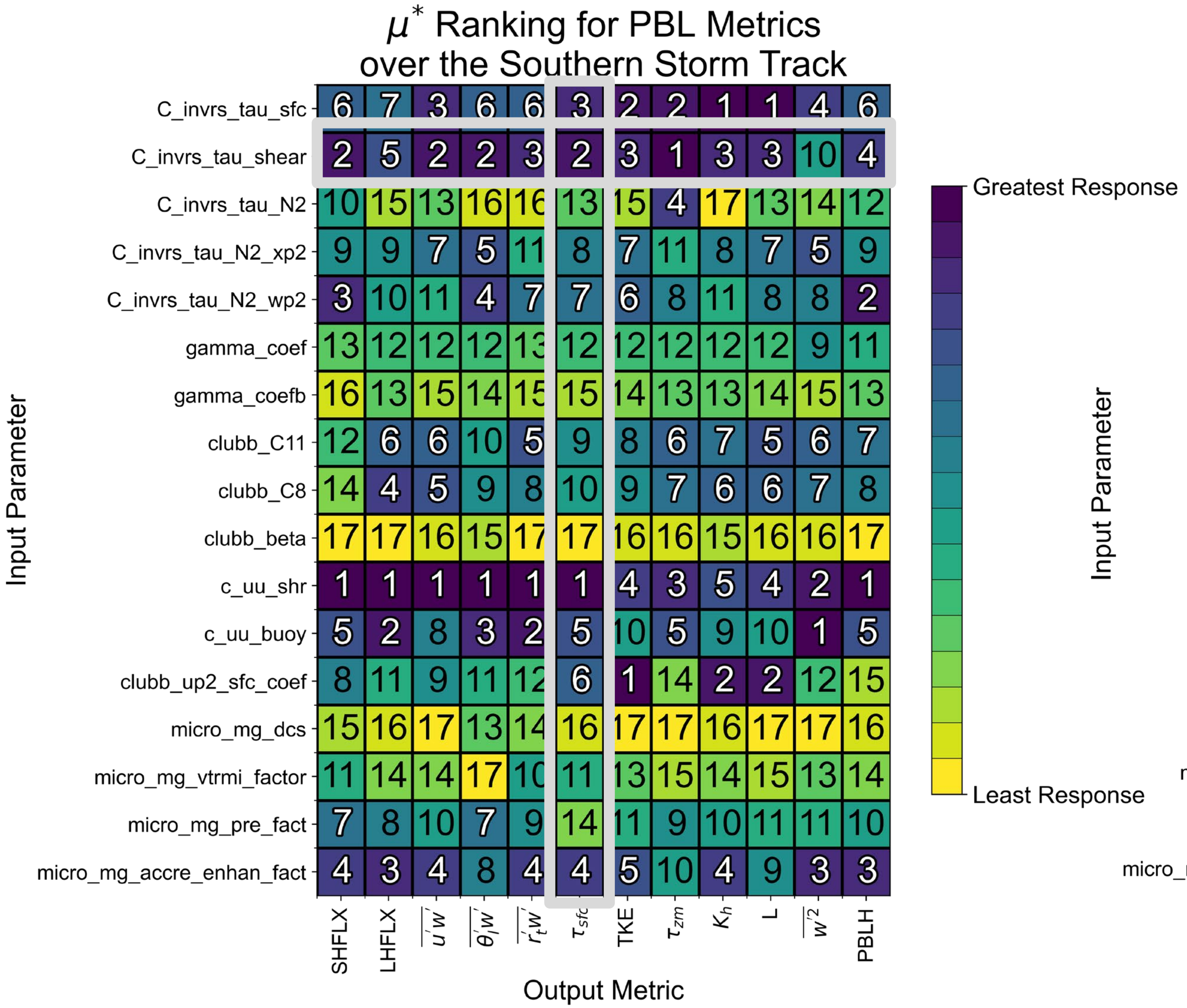
The main goal of my work is to better understand *how* and *why* CLUBB parameters influence various aspects of the climate system

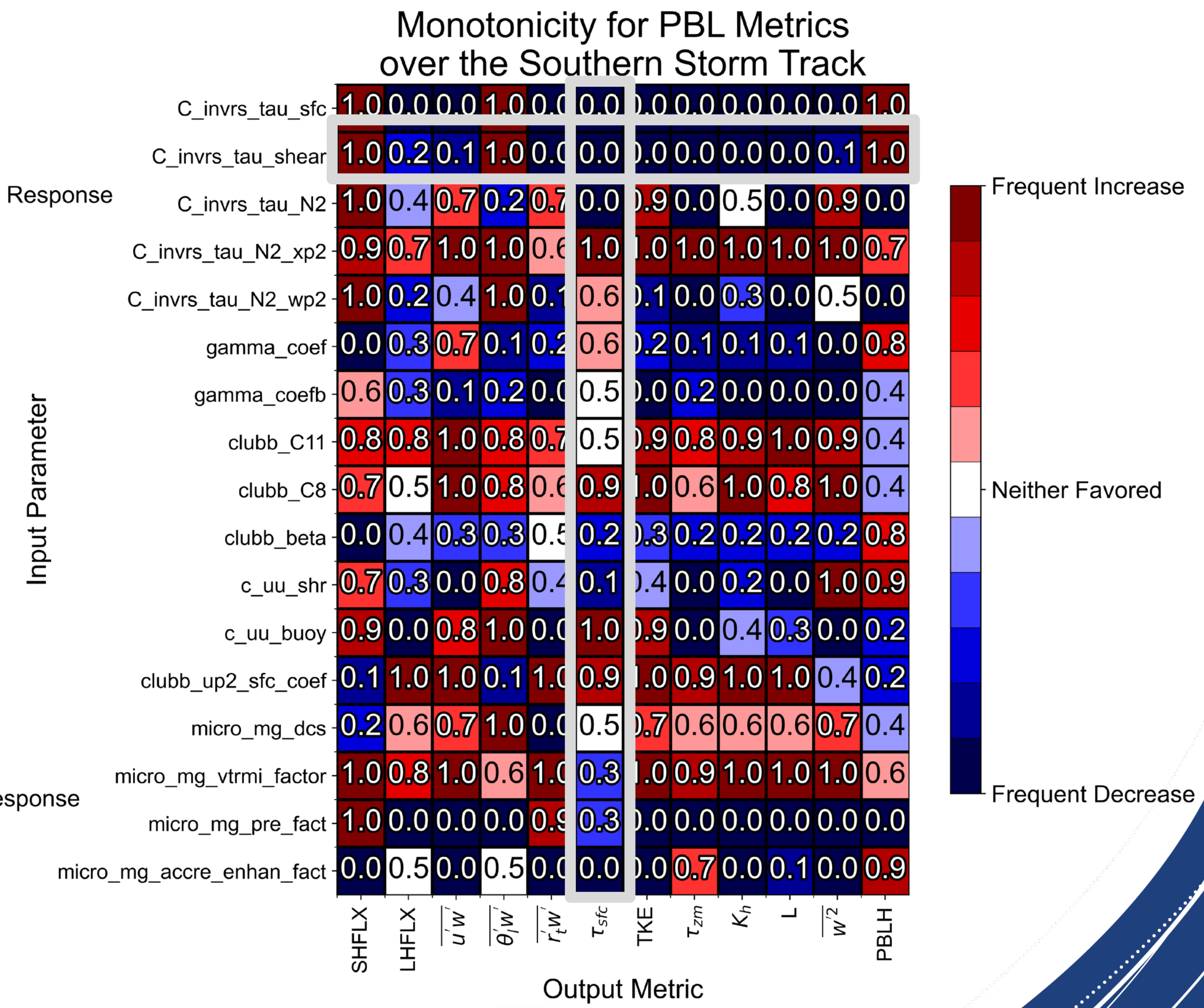
- Running CLUBB with prognostic momentum and "taus code" turned on (I refer to this as CLUBBX)
- A prior study showed that certain "taus code" parameters were influential in depicting the structure of extreme weather phenomena (e.g., tropical cyclones)
- ***How do these same parameters influence the modeled climate over longer time scales?***
- We use a simple parameter sensitivity analysis (Morris) to better understand how the climate is impacted by CLUBBX parameters
- Seeking better understanding of the physical mechanisms at play

A sensitivity analysis applied to many short-term, initialized hindcasts with CAM6-CLUBBX

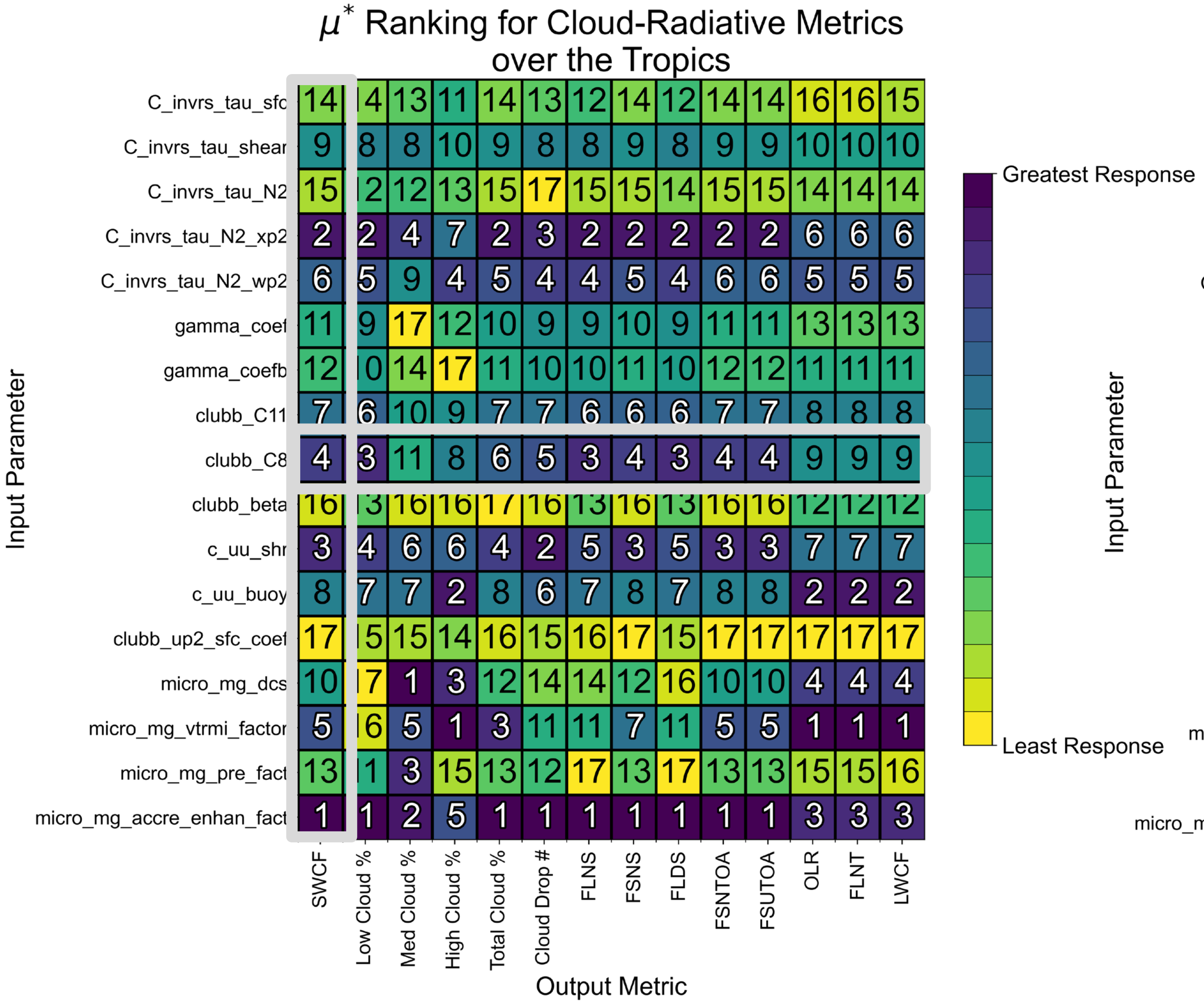
- CAM6 w/ CLUBBX run over 3 days (Qian et al. 2018)
  - "Betacast" mode with the atmosphere initialized using ERA5
  - SST and sea ice initialized using NOAA data
  - land conditions spun up for 12 months prior to initialization
  - during spinup land model runs with prescribed atmosphere
- 17 parameters perturbed over 10 different paths (baseline states)
  - 180 unique combinations of CLUBBX parameter values
  - set of combinations run for 24 different initial conditions
  - for each month, 2 years randomly selected from 2010-2020
  - model initialized at 00Z on the first of that month
  - 4320 total model simulations ***(why we only do 3-day runs)***

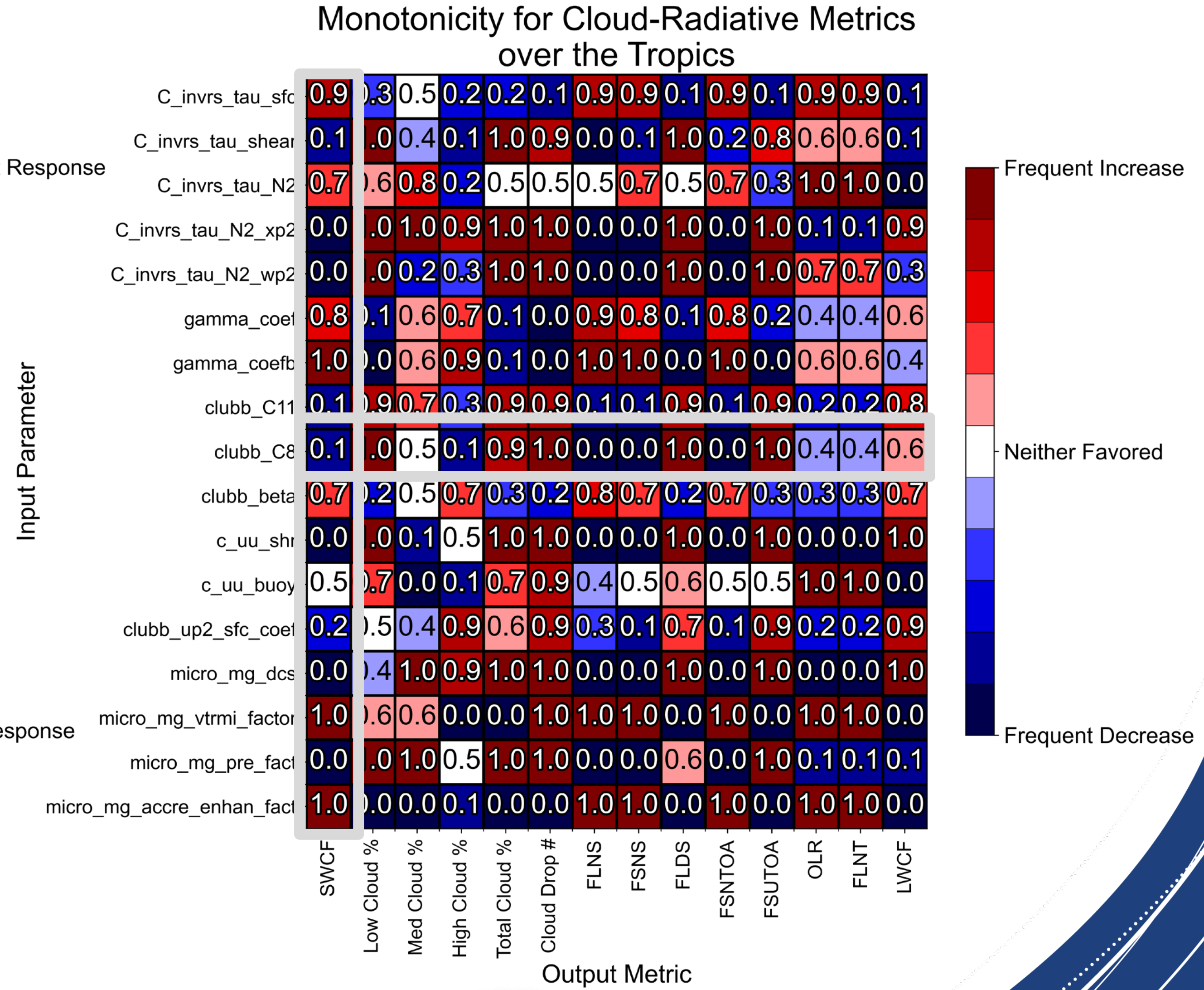
We can assess the a) average magnitude and b) direction of the response of PBL metrics





We can similarly assess the response of cloud-radiative metrics (over the Tropics this time)





Kyle M. Nardi
kmn182@psu.edu
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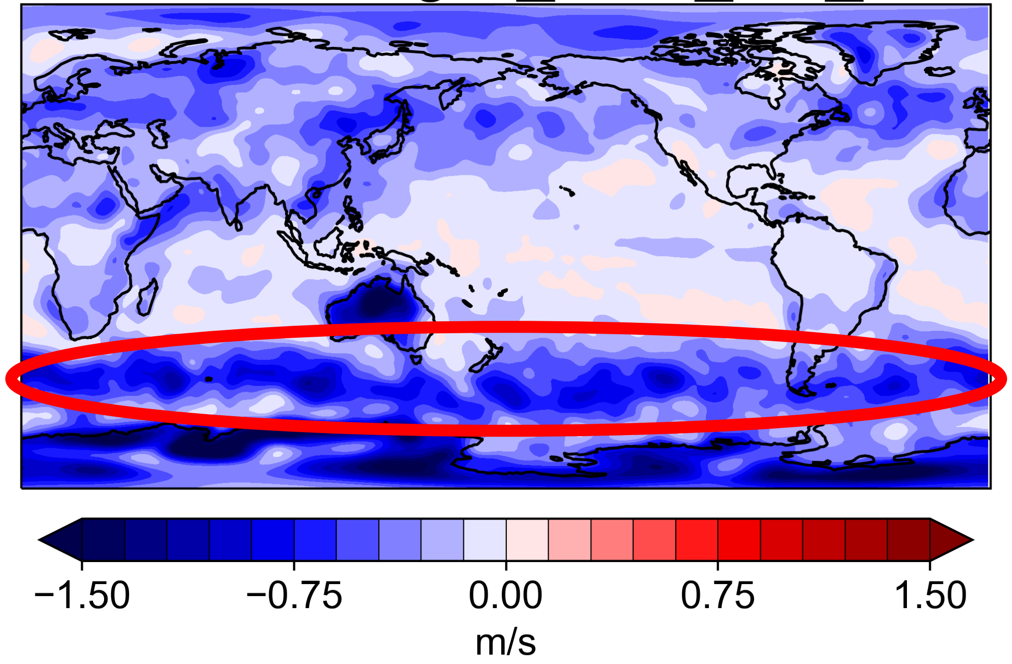
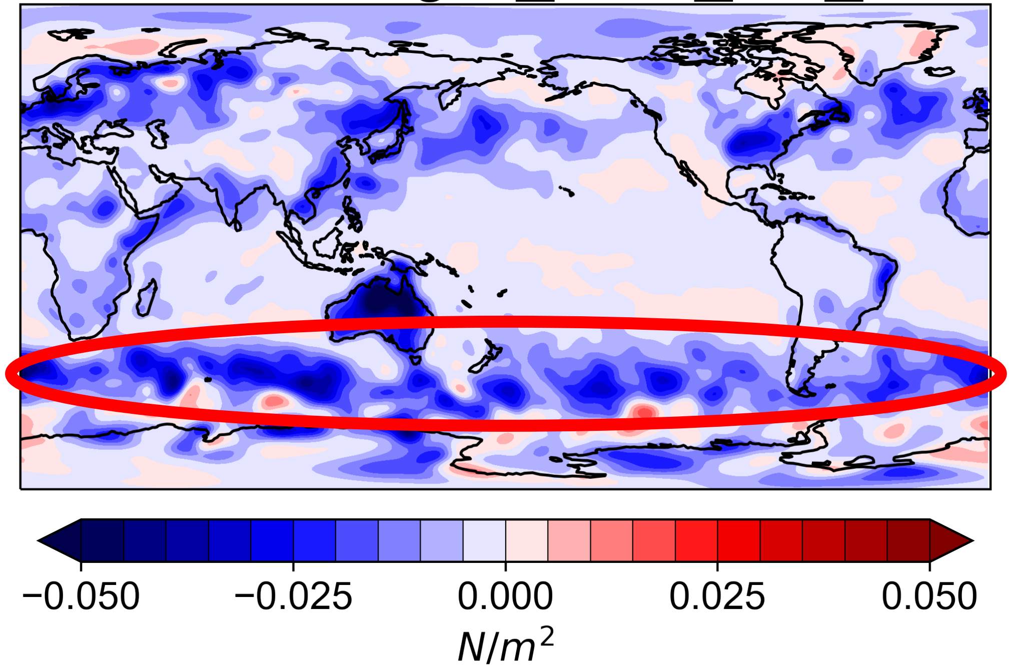
Increasing *C_invrs_tau_shear* produces a decrease in wind speed at the lowest model level over the Southern Storm Track

Difference in u_{bot}
After Increasing C_invrs_tau_shear



After Avg. = 5.909 Before Avg. = 6.203 Diff = -0.293

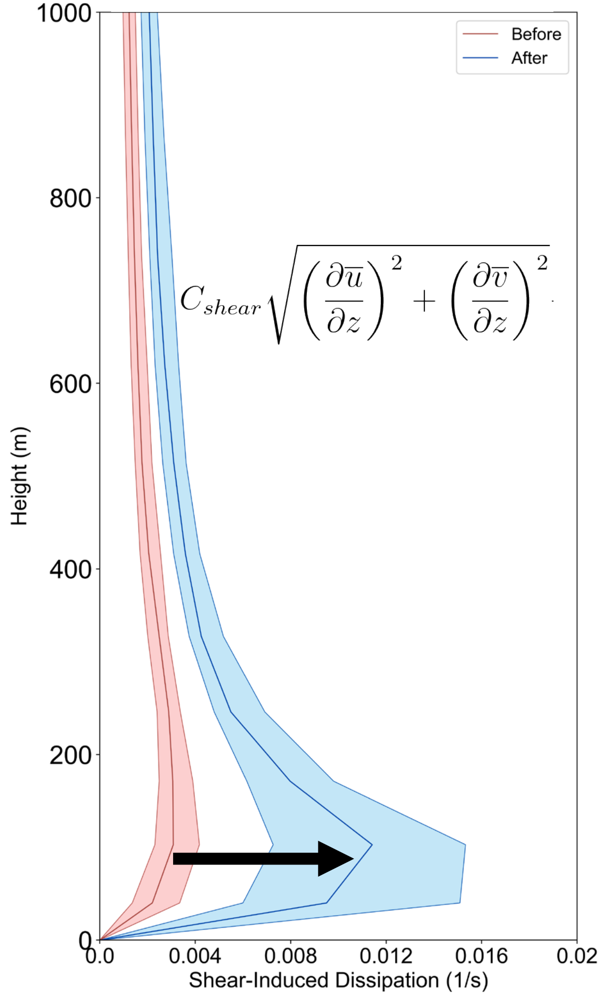
Difference in τ_{sfc}
After Increasing C_invrs_tau_shear



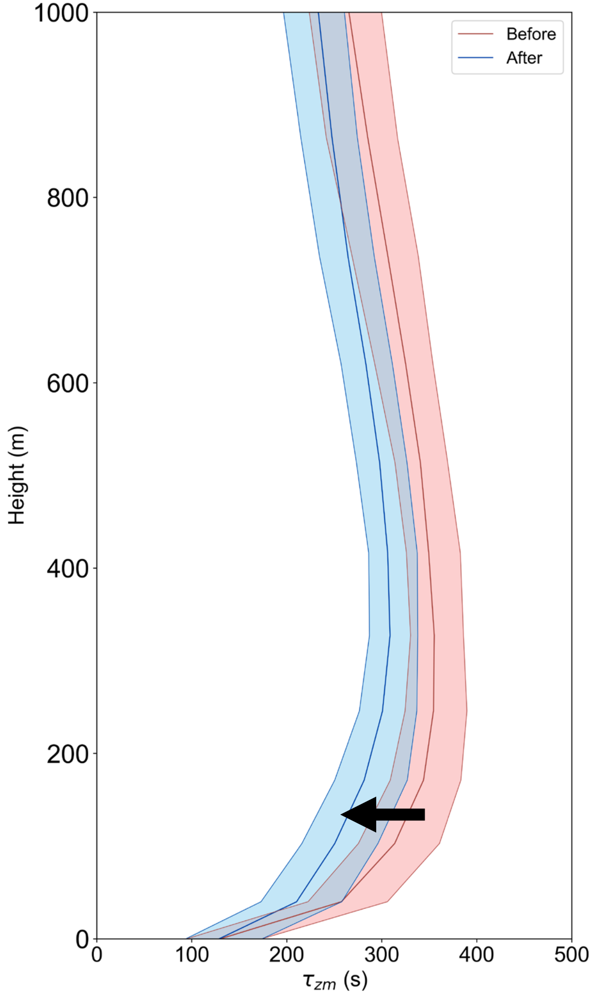
After Avg. = 0.11 Before Avg. = 0.117 Diff = -0.007

Increasing *C_invrs_tau_shear* decreases eddy turnover time scale and damps momentum flux

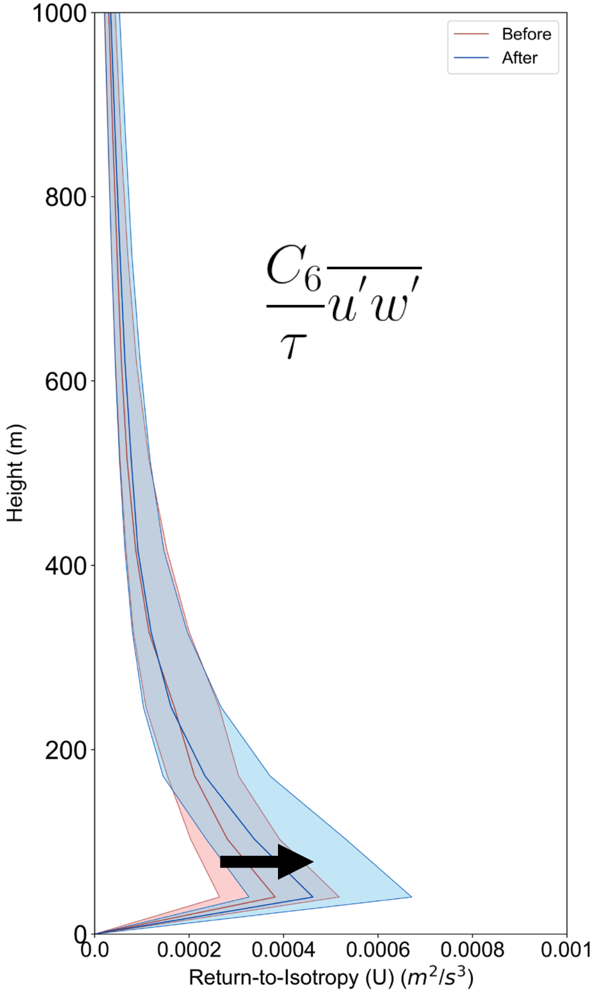
Shear Dissipation



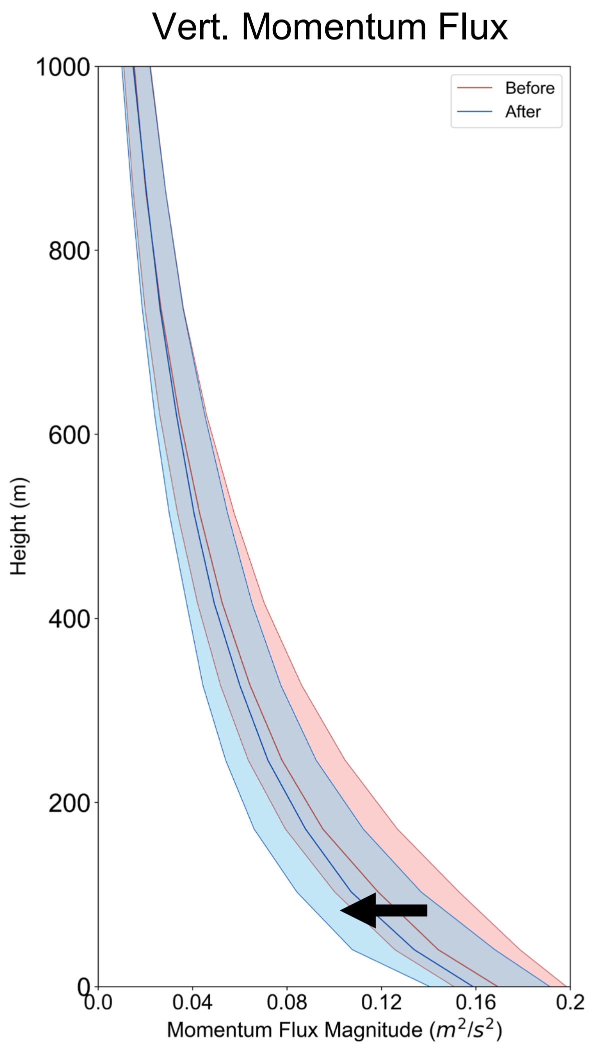
Eddy Time Scale (“tau”)

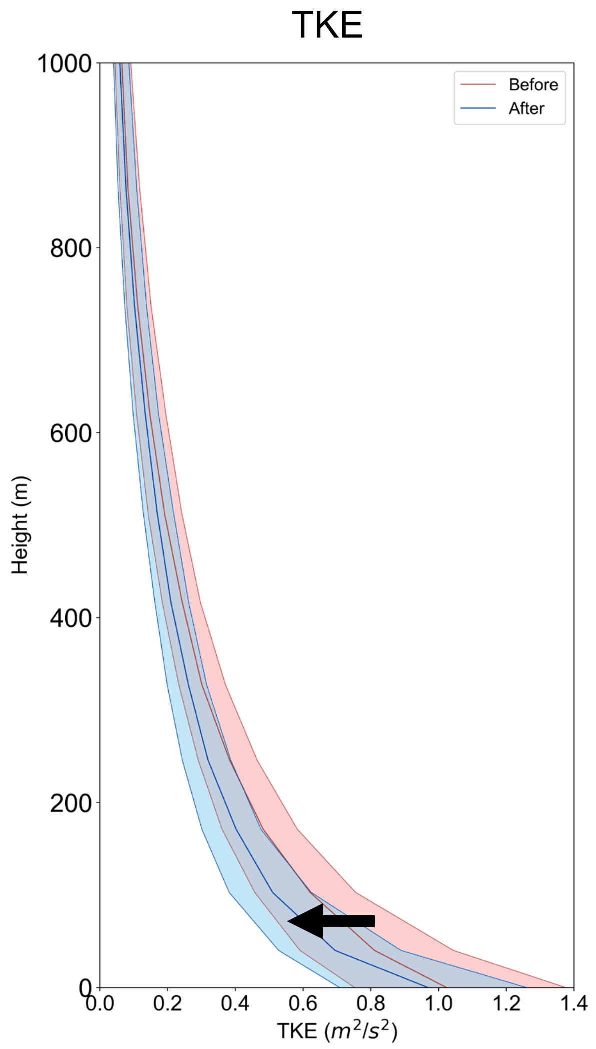


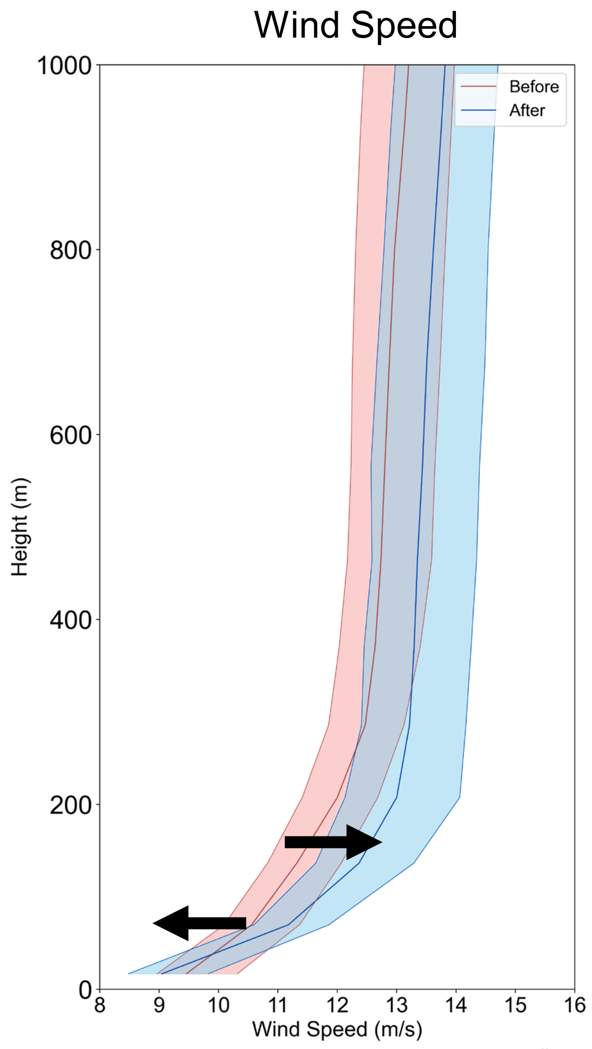
Pressure Damping



Increasing *C_invrs_tau_shear* reduces momentum flux and TKE, resulting in increased wind shear







We next test how well the sensitivity results for 3-day simulations apply to longer simulations

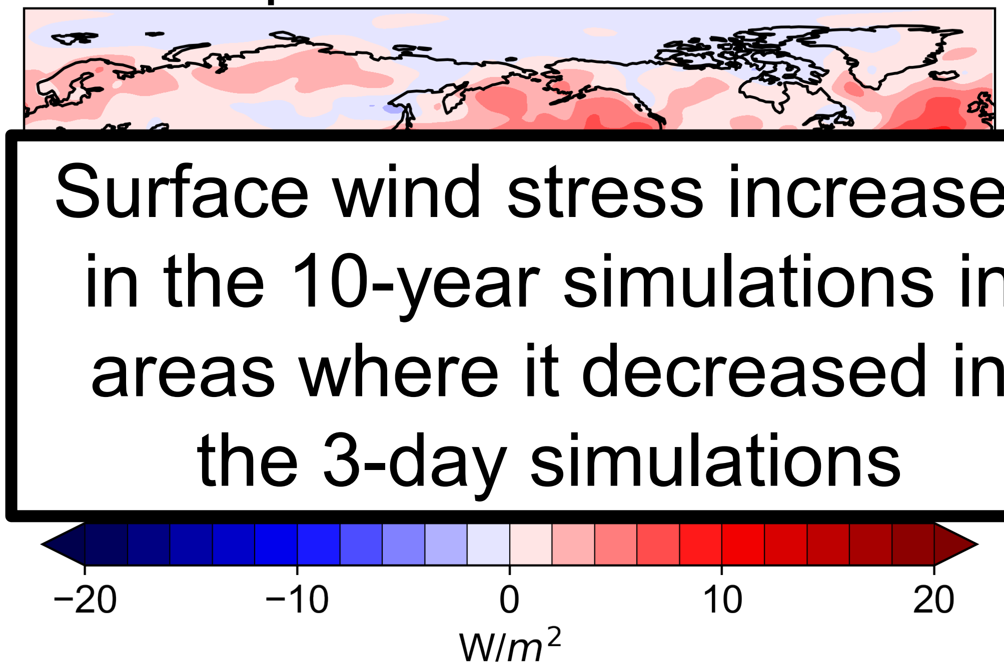
- Suppose we want to **1) decrease surface wind stress over the Southern Storm Track** and **2) increase SWCF (dim clouds) over the Tropics** (Just an illustrative example…)
- The Morris Method highlights several pathways towards achieving this for 3-day simulations:

1. **Increasing** *C_invrs_tau_shear* decreases stress
2. **Decreasing** *C8* increases SWCF (decreases cloud fraction)

- Each parameter has a large effect on one output but less of an effect on the other
- We run two 10-year, F-compset simulations, one baseline and the other with the two experimental parameter perturbations

10-year perturbed simulation produces the expected response in SWCF, but an unexpected response in surface wind stress

Difference in SWCF
After Experimental Perturbations

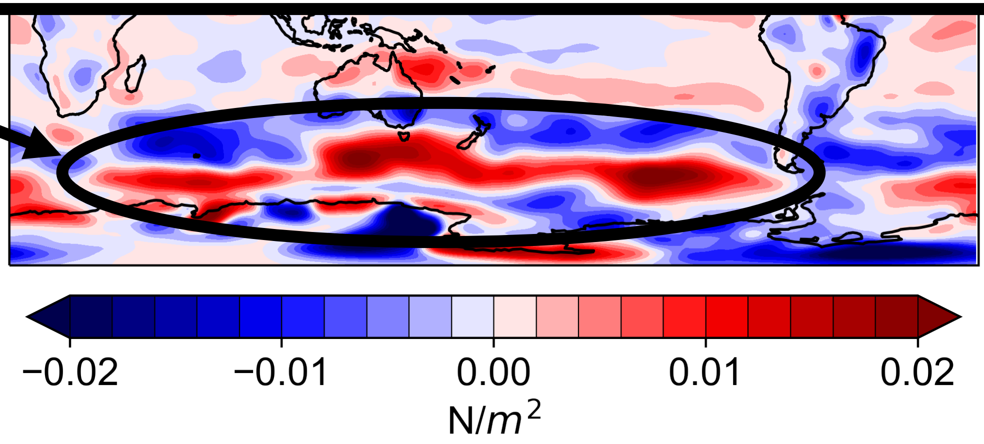


Surface wind stress increases in the 10-year simulations in areas where it decreased in the 3-day simulations

Pert Avg. = -35.646 Baseline Avg. = -39.077 Diff = 3.431

Difference in τ_{sfc}

SWCF increases over the tropical band analyzed with the sensitivity analysis

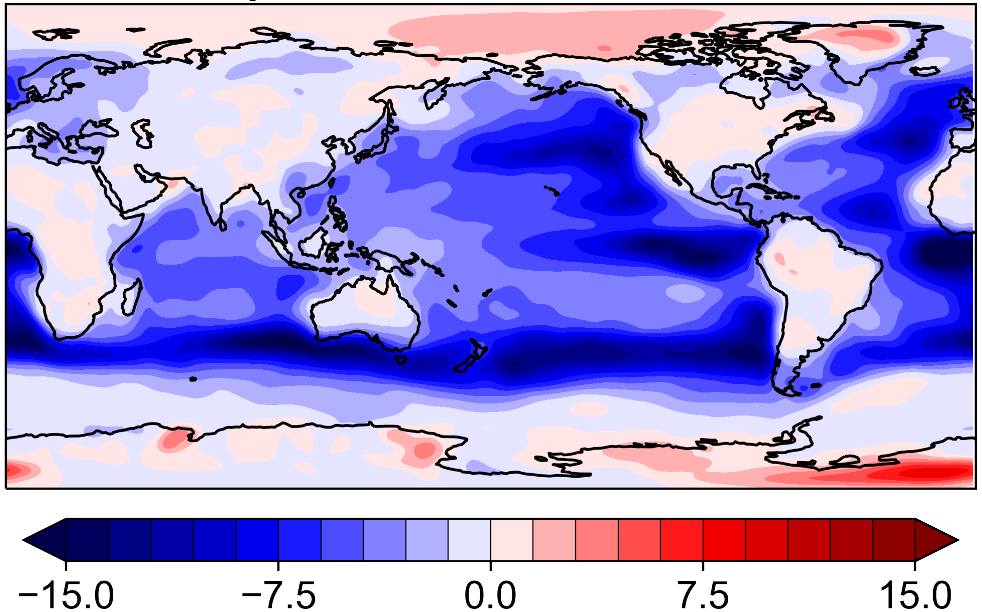


Pert Avg. = 0.085 Baseline Avg. = 0.086 Diff = -0.001

Kyle M. Nardi AMWG Meeting 2024 kmn182@psu.edu PennState

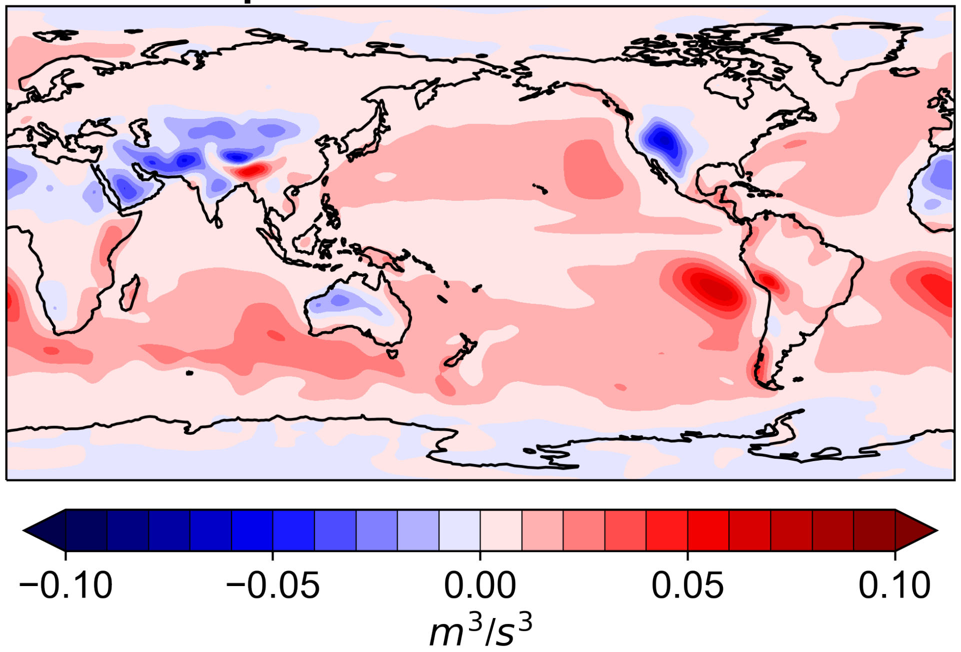
SWCF increases due to a decrease in cloud cover as the regime transitions to more cumulus

Difference in Low Cloud %
After Experimental Perturbations



Pert Avg. = 36.954 Baseline Avg. = 40.76 Diff = -3.806

Difference in 850-hPa $\overline{w'^3}$
After Experimental Perturbations



Pert Avg. = 0.023 Baseline Avg. = 0.015 Diff = 0.008

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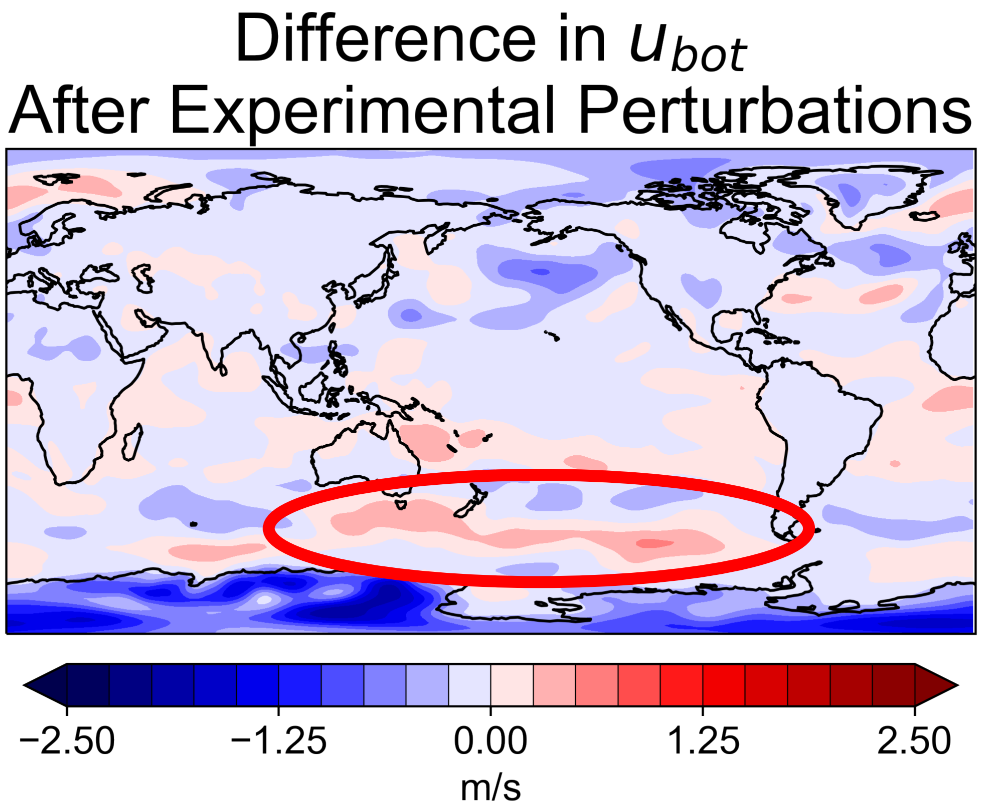
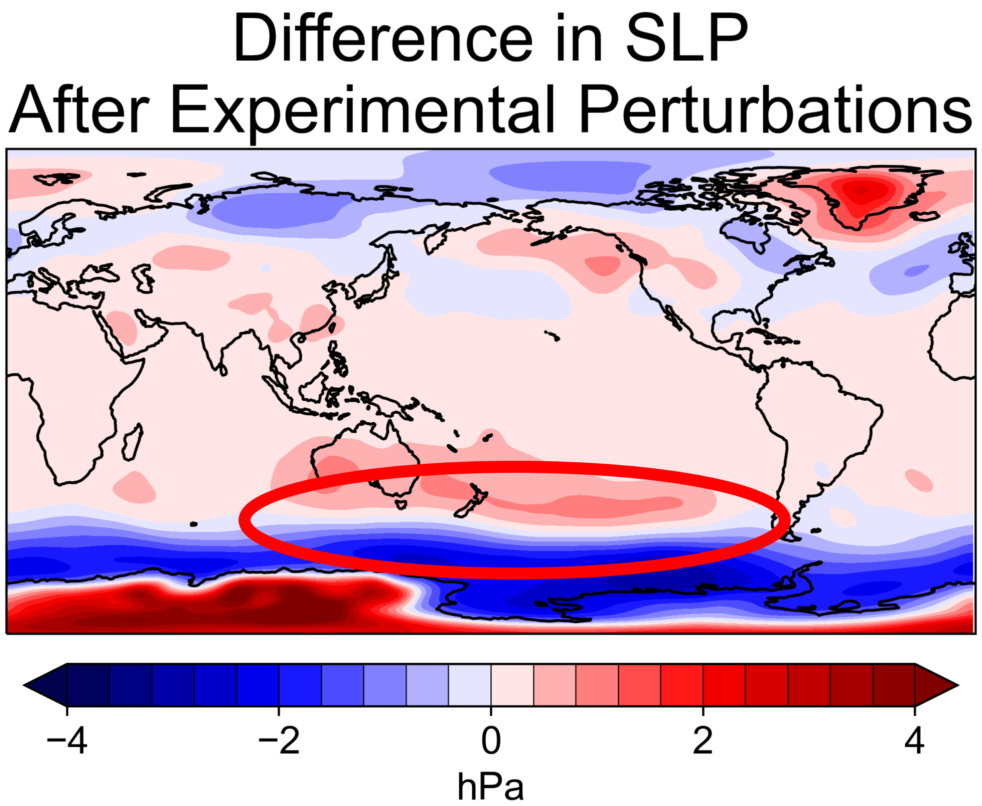
In the 10-year simulations, low-level wind speeds increase in response to a stronger pressure gradient



Pert Avg. = 4.276 Baseline Avg. = 4.357 Diff = -0.081



Pert Avg. = 1011.383 Baseline Avg. = 1011.339 Diff = 0.044

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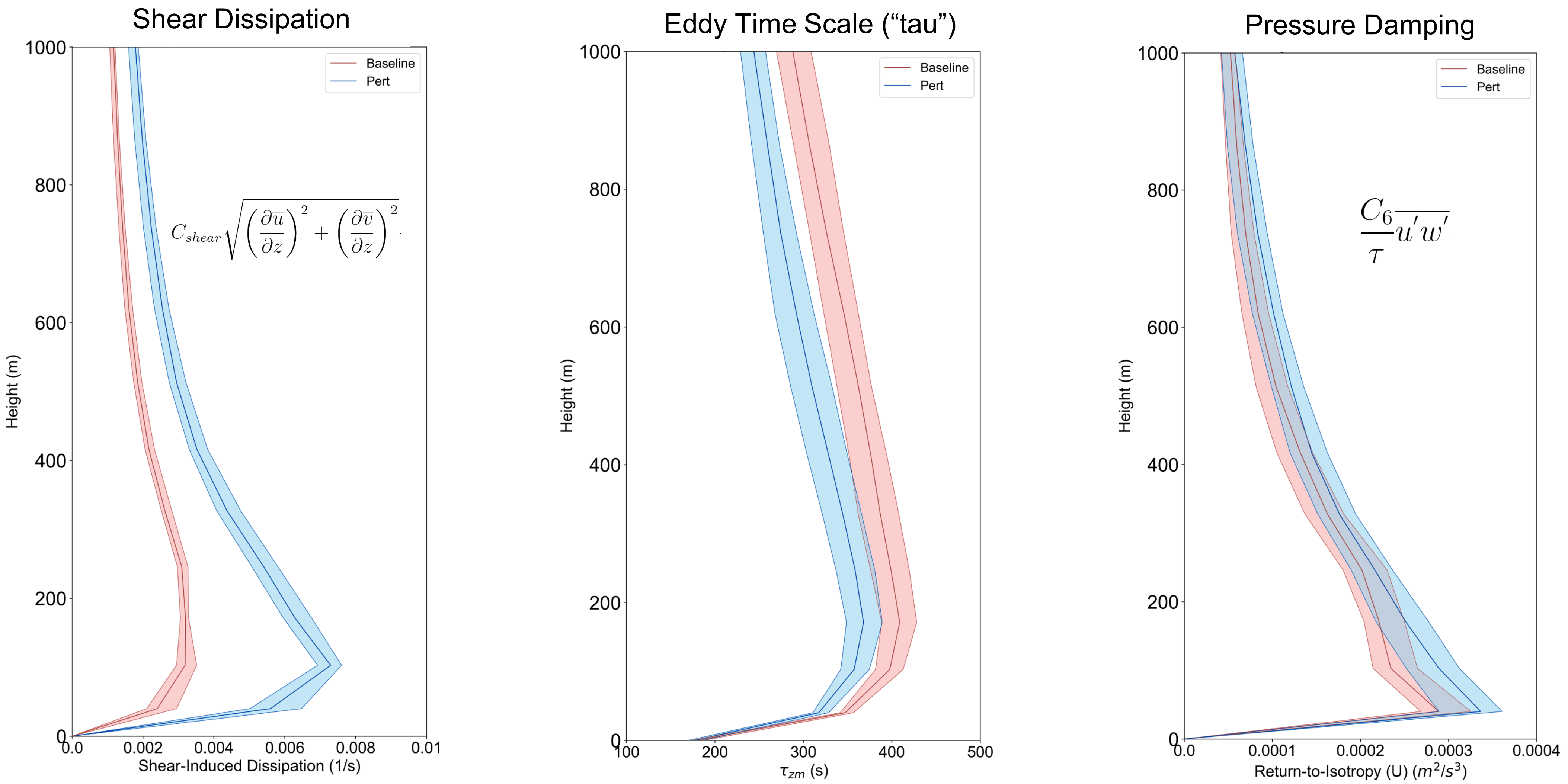
The experimental perturbations produced expected responses in eddy dissipation in the 10-year run



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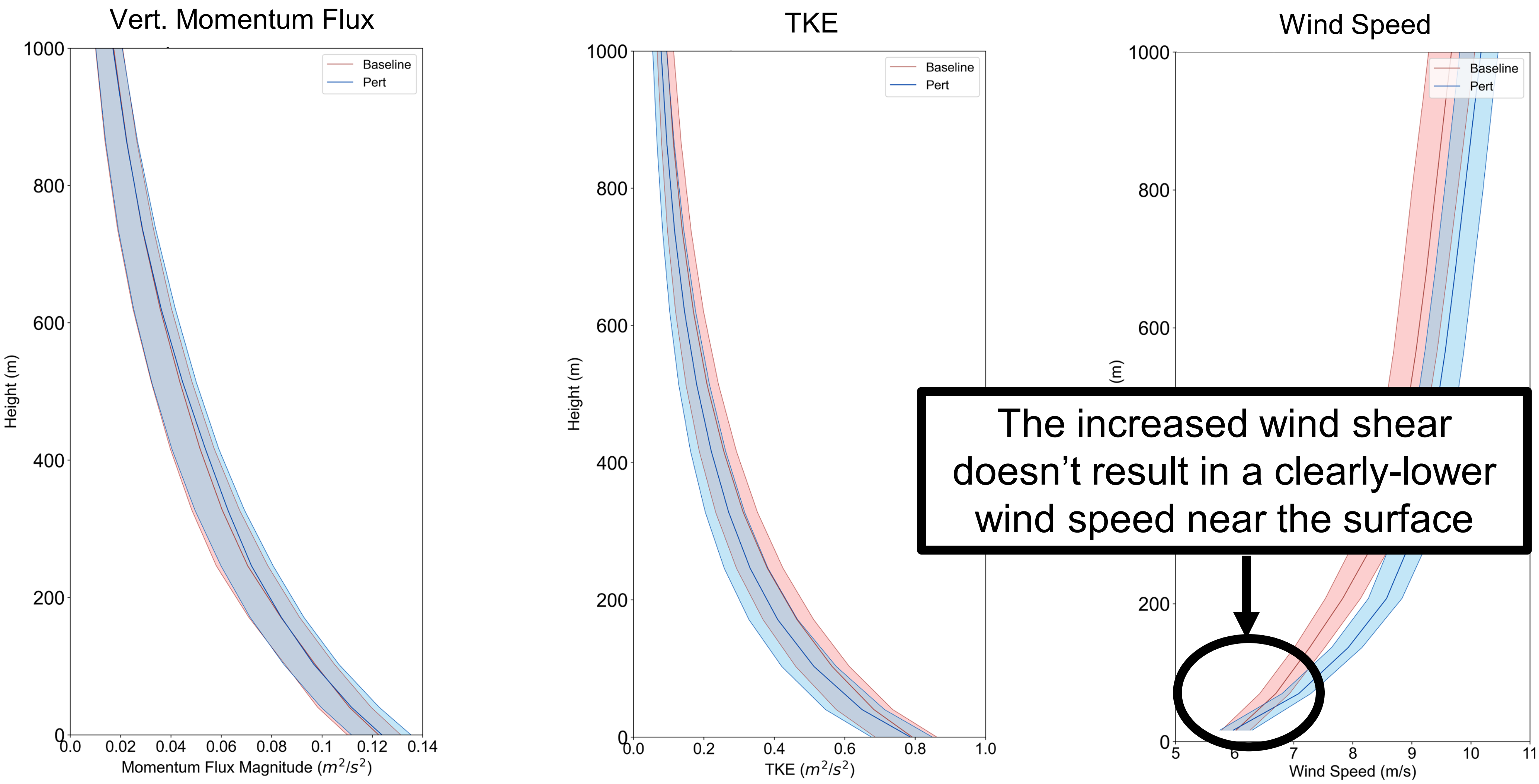
As with the 3-day hindcasts, wind shear increases with reduced vertical mixing



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Main Takeaways

- Morris Method using 3-day hindcasts can provide useful information about physical mechanisms driving parameter sensitivities
- 3-day hindcasts can be used to predict long-term responses of some variables (e.g., cloud fraction, SWCF, etc.)
- But for other fields (e.g., low level wind profiles, surface stress, etc.) 3-day hindcasts may not capture nonlinear interactions that govern long-term responses
- **Future Work:** Better understand physical mechanisms driving responses in sea-level pressure (looking at changes in wind turning, cross-isobaric mass flux, and general circulation)

CLUBBX Diagnostics Page:

https://colinzarzycki.com/cpt/kyle/webpage.html

kmn182@psu.edu
PennState

Extra Slides

Two influential input parameters appear in the experimental CLUBBX equations governing vertical momentum flux

$$\frac{\partial \overline{u'w'}}{\partial t} = -\overline{w}\frac{\partial \overline{u'w'}}{\partial z} - \frac{1}{\rho}\frac{\partial \rho\overline{w'^2u'}}{\partial z} - (1 - C_{uu\_shr})\overline{w'^2}\frac{\partial \overline{u}}{\partial z} -$$

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

$$\frac{1}{\tau} = C_{bkgnd}\frac{1}{\alpha} + C_{sfc}\frac{u^*}{\kappa}\frac{1}{(z - z_{sfc} + d)} + C_{shear}\sqrt{\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2} + C_{N2}\sqrt{N^2}$$

CLUBB's prognostic momentum flux formulation includes several tunable parameters

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

Advection of momentum flux
by the mean vertical wind

Turbulent production

- Allows for upgradient fluxes
- C_6, C_7, and C_{uu_shr} are all tunable parameters in CLUBB
- **The τ term in the return-to-isotropy adjustment can also be tuned using the new regime-specific formulation**

Kyle M. Nardi AMWG Meeting 2024 kmn182@psu.edu PennState

The formulation of inverse eddy turnover time scale depends on environmental conditions

$$L = \tau \overline{e}^{\frac{1}{2}}$$

← Vertical turbulent length scale is the product of the eddy turnover time scale and the square root of TKE

Where the eddy time scale is the sum of dissipating processes…

$$\frac{1}{\tau} = C_{bkgnd}\frac{1}{\alpha} + C_{sfc}\frac{u^*}{\kappa}\frac{1}{(z - z_{sfc} + d)} + C_{shear}\sqrt{\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2} + C_{N2}\sqrt{N^2}$$

Backgro…

- The coefficients attached to each term on the RHS are tunable within CLUBB
- This allows the dissipation of turbulent eddies to be tailored to a specific atmospheric regime (e.g., stable boundary layer)

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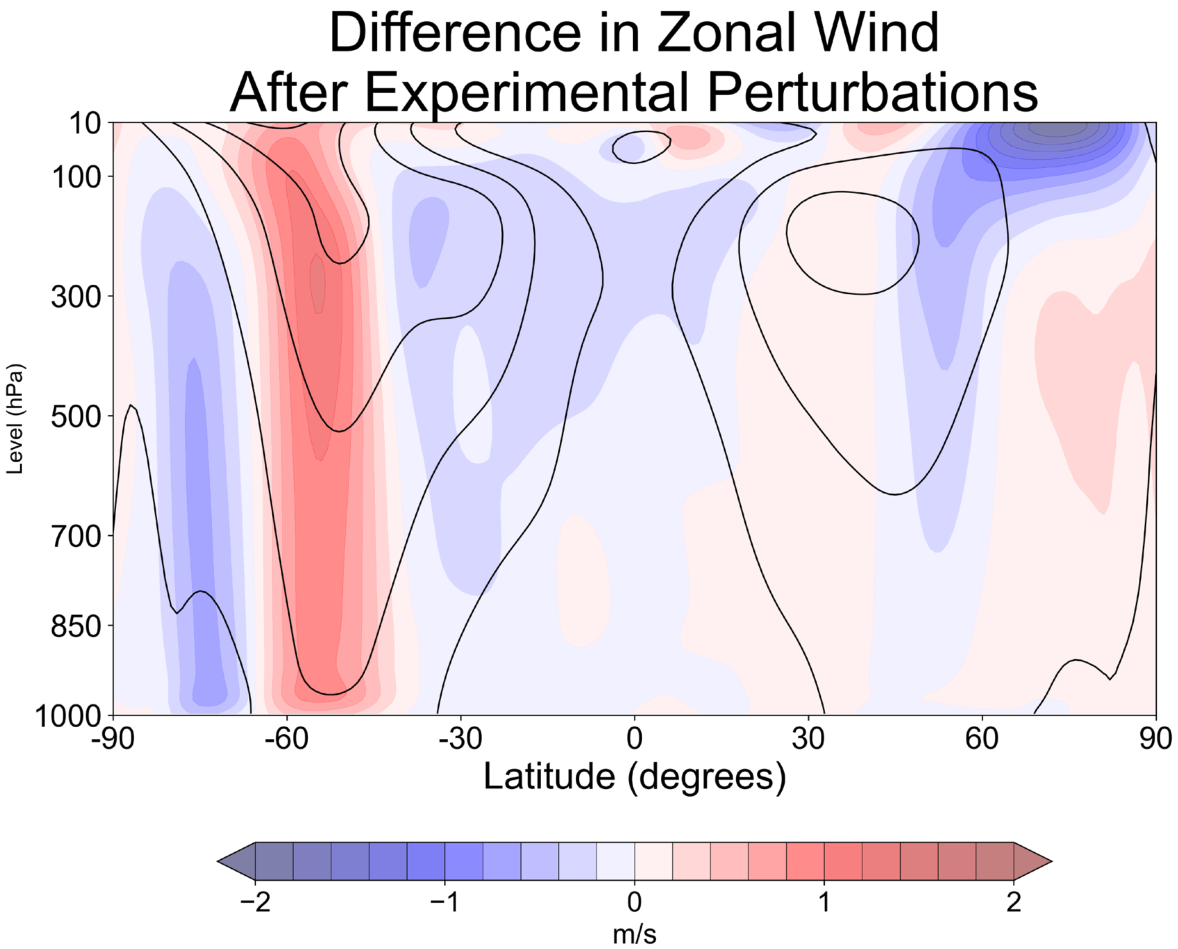
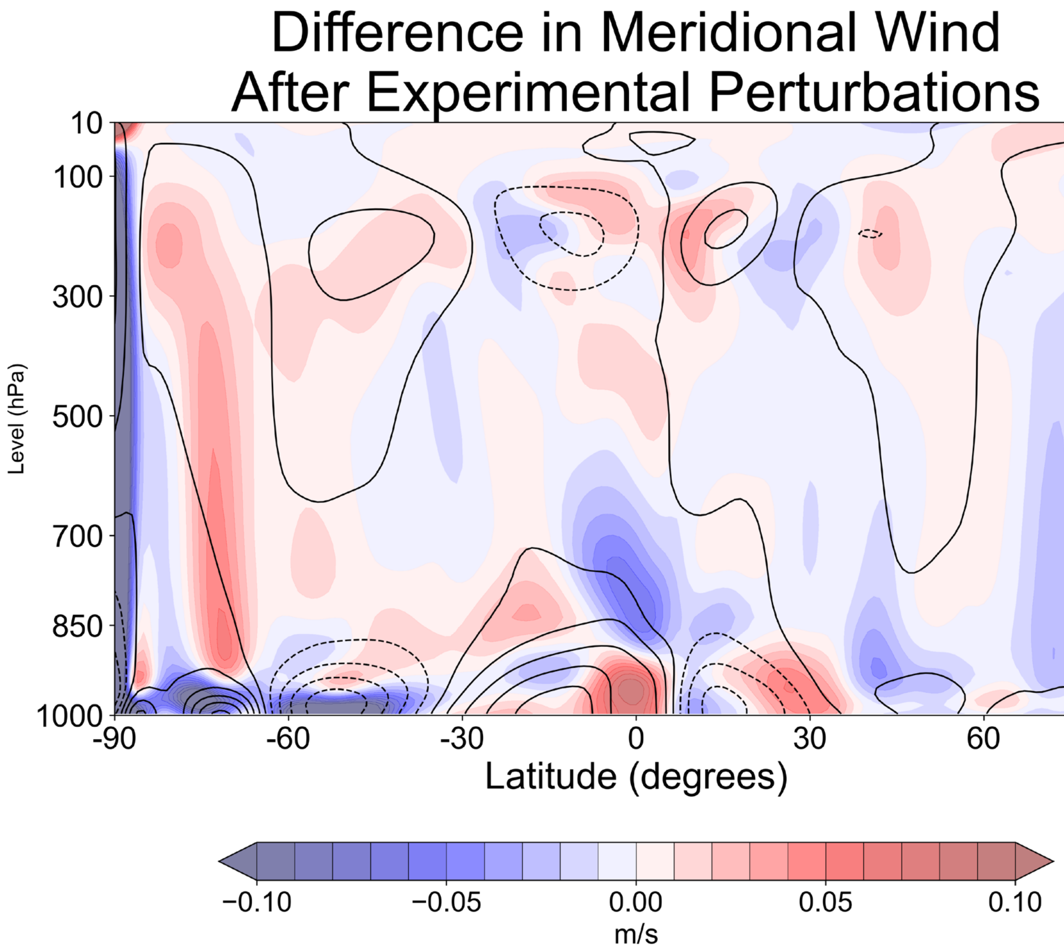
The experimental perturbations appear to change aspects of the general circulation





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