The Role of Parameterized Momentum Flux on Mean State Biases in CAM6-CLUBB

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AMWG Meeting
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We’ve previously found that certain CLUBB input parameters are influential for idealized TC structure

<u>CAM6-CLUBB w/ Two Modifications (CLUBBX):</u>

1. Prognostic r
   replaces dia
   formulation
2. Regime-spe
   eddy turnov

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Assessing the Sensitivi
Parameterization of Momentum Flux in the Community Earth System Model

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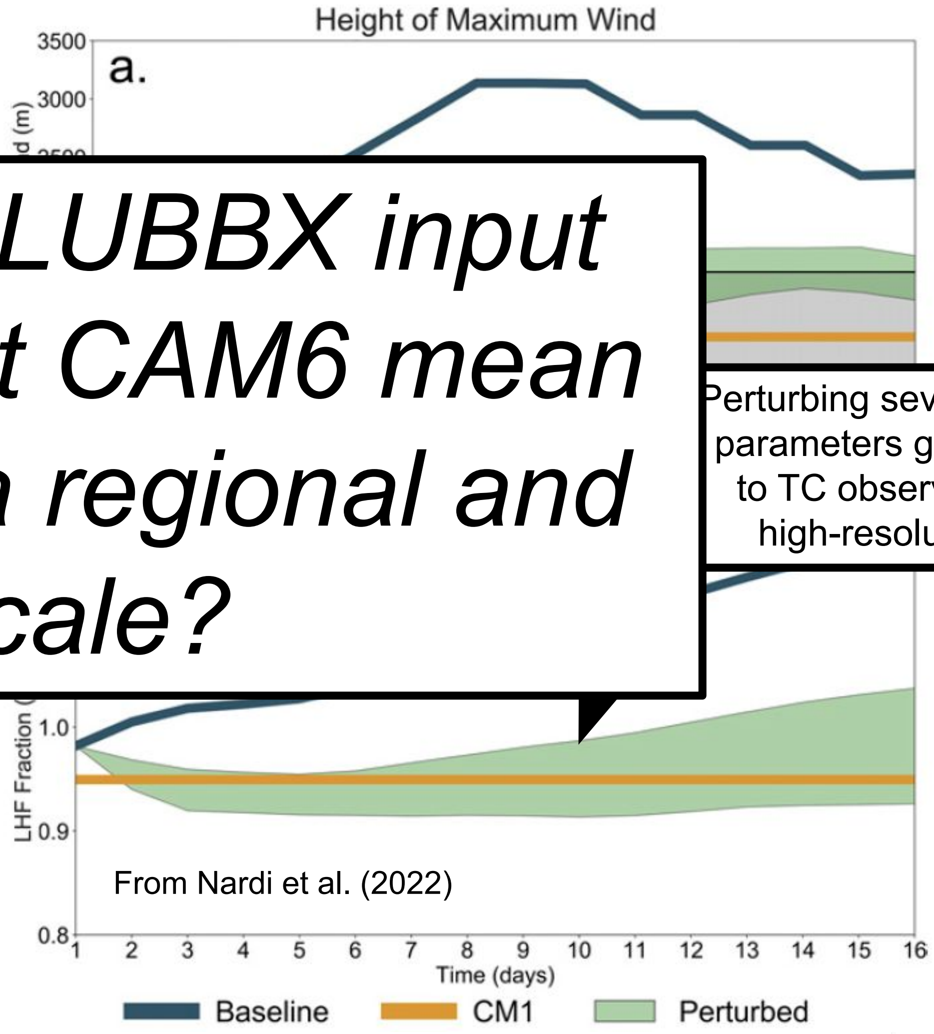
How do these CLUBBX input parameters affect CAM6 mean state biases on a regional and global scale?



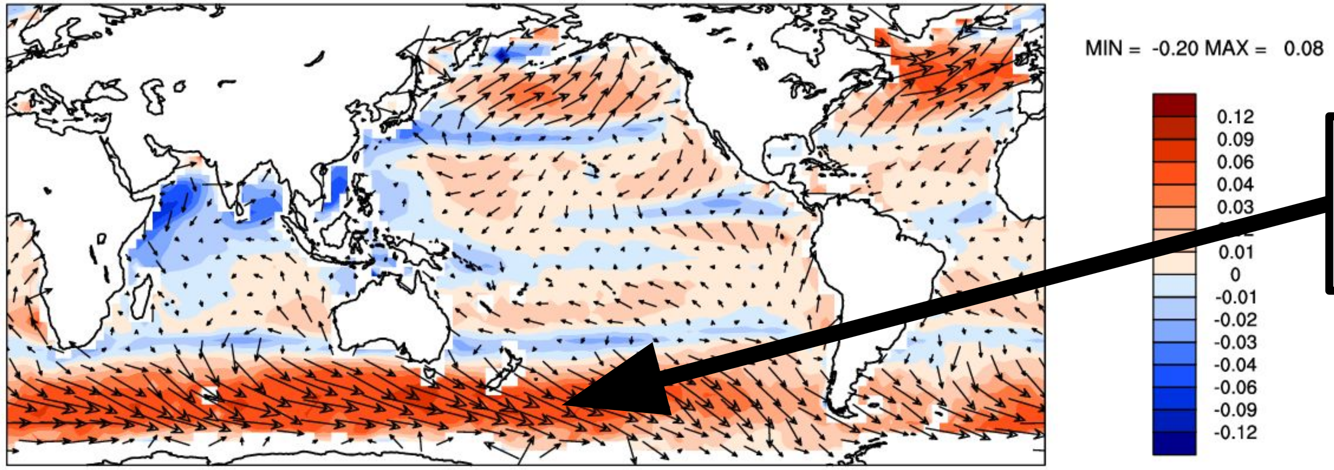
From Nardi et al. (2022)

Perturbing several CLUBBX parameters gets us closer to TC observations and high-resolution NWP

We target several notable mean state biases in CAM6-CLUBBX

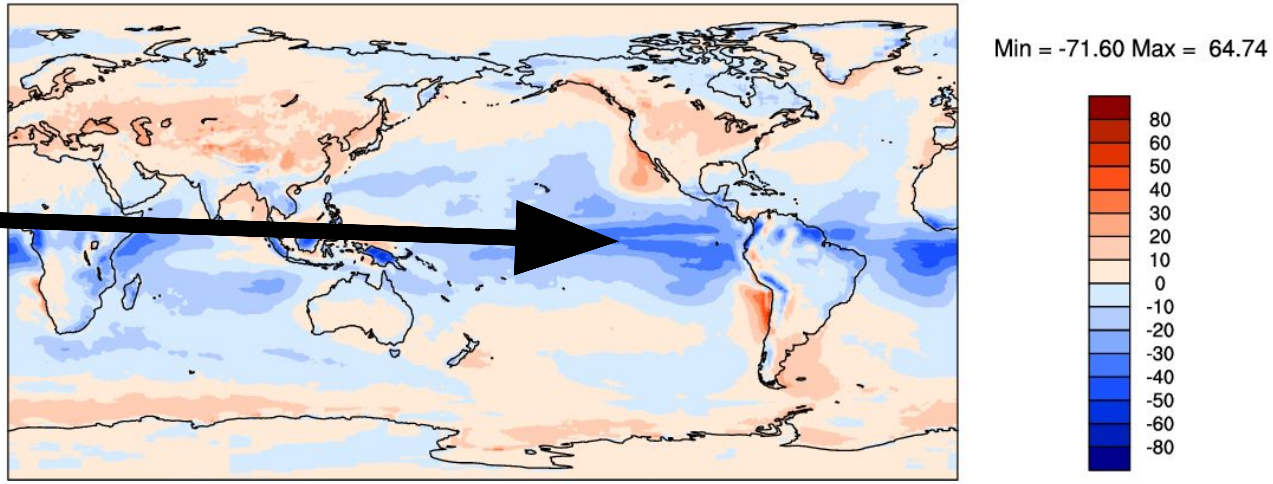
10-year simulations with baseline CLUBBX parameter settings

Baseline Annual Surface Stress Bias



Baseline surface stress is too high over the Southern Ocean

Baseline Annual SWCF Bias



Negative baseline SWCF bias due to high bias in low cloud fraction

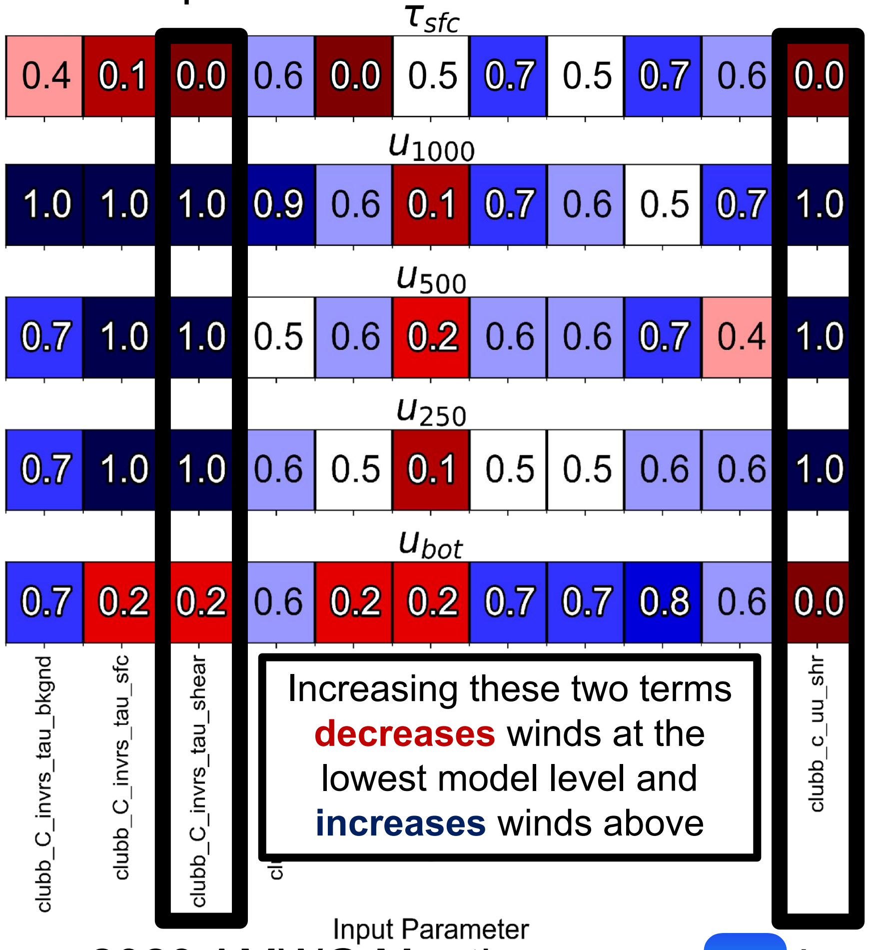
A sensitivity analysis helps us identify several CLUBBX input parameters that impact these biases

Values closer to 1: Increasing input parameter frequently increases output

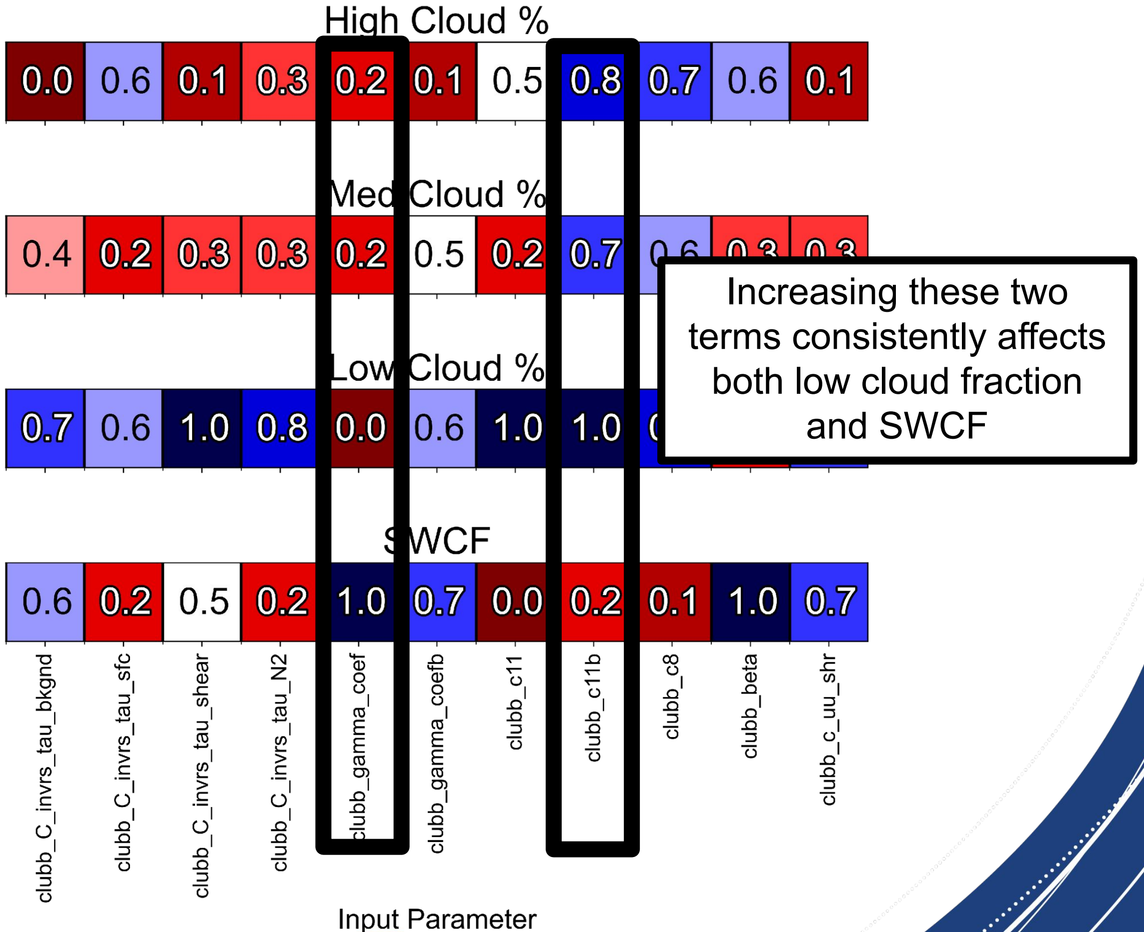
Values closer to 0: Increasing input parameter frequently decreases output

These parameters were also influential for TC structure!

Frequency of Positive Change in Output When Input Increased in Southern Ocean



% Change in Output Per Unit Change in Input in ENSO Region



Targeted perturbations to these parameters result in a reduction in mean state regional biases

10-year simulations with and without perturbations to four CLUBBX parameters

Difference in Annual Surface Stress

Difference in Annual SWCF

Two Follow-Up Questions (among others…)

1. *How to address effects seen in other regions?* ***(good question…this is future work)***
2. *What physical mechanisms are driving these sensitivities? (**we'll start to address this here)***

N/m^2

W/m^2

CLUBBX's prognostic momentum flux formulation includes several tunable parameters we perturb here

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

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

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

$$+\left.\frac{\partial \overline{u_h'w'}}{\partial t}\right|_{\mathrm{cl}} + \left.\frac{\partial \overline{u_h'w'}}{\partial t}\right|_{\mathrm{mfl}}$$

Directly affecting these terms

But indirectly affecting others!

Larson et al. (2020)

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 CLUBBX
- ***C_{shear} is one of the four input parameters we choose to perturb, thus directly affecting inverse tau***

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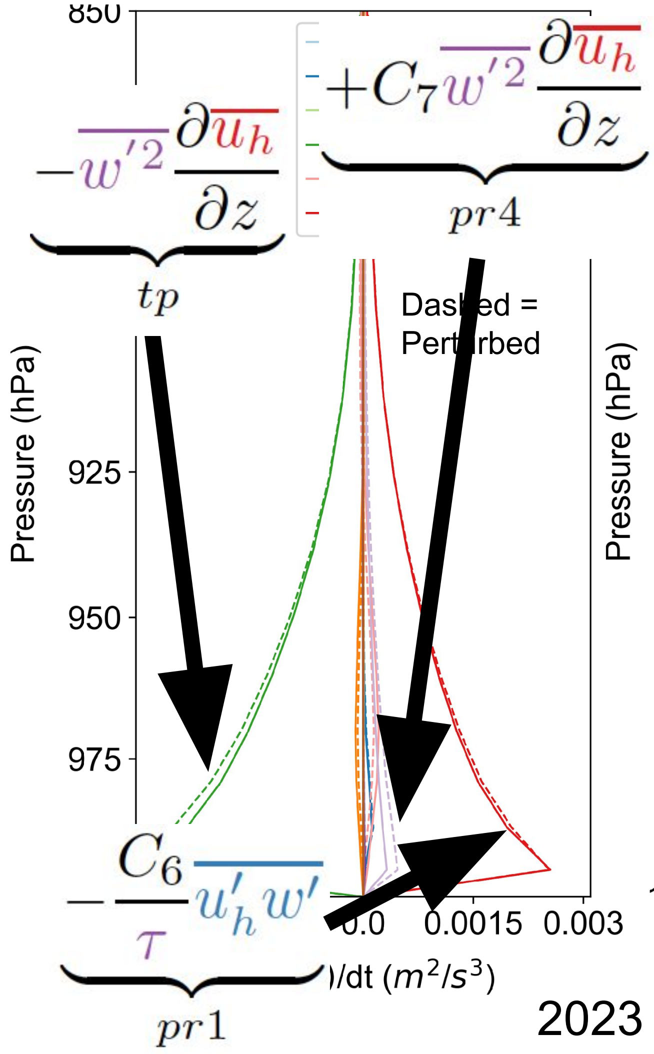
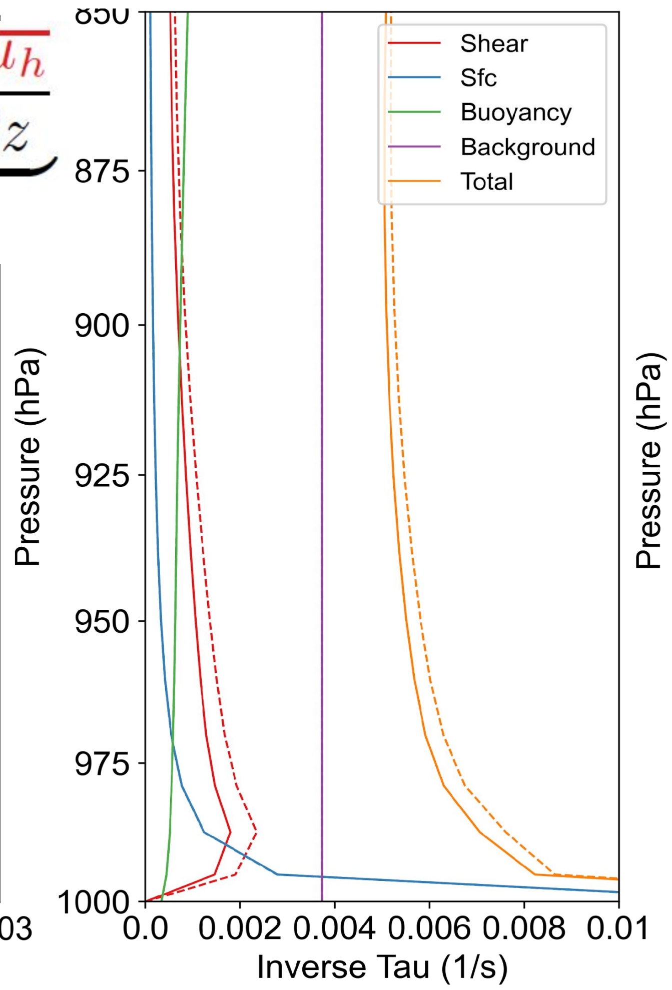
Simultaneously changing the four CLUBBX input parameters modifies the momentum flux budget

Southern Ocean

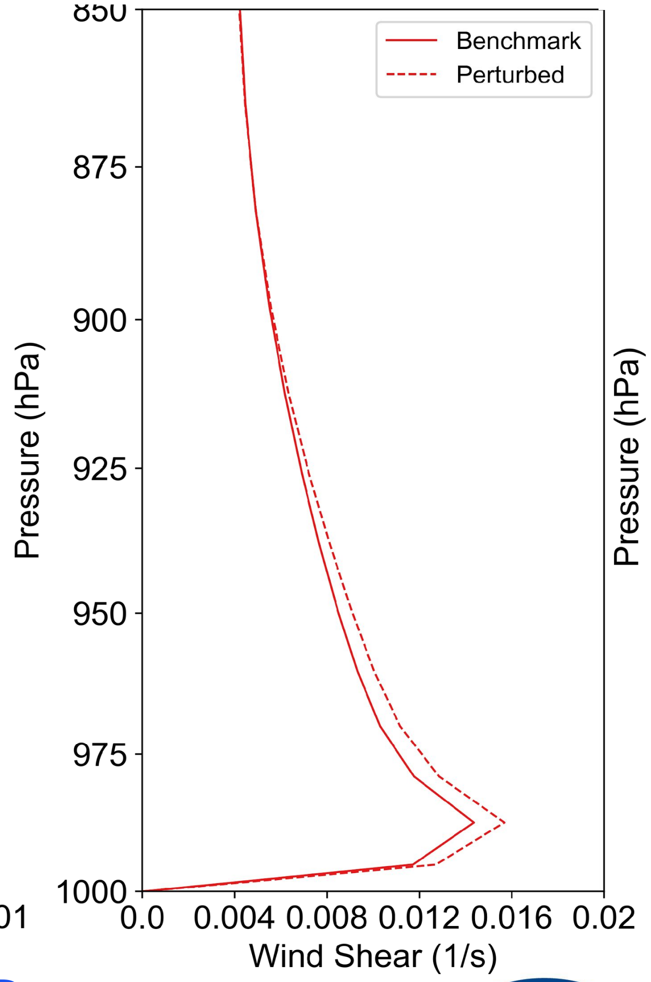
Momentum Flux Budget



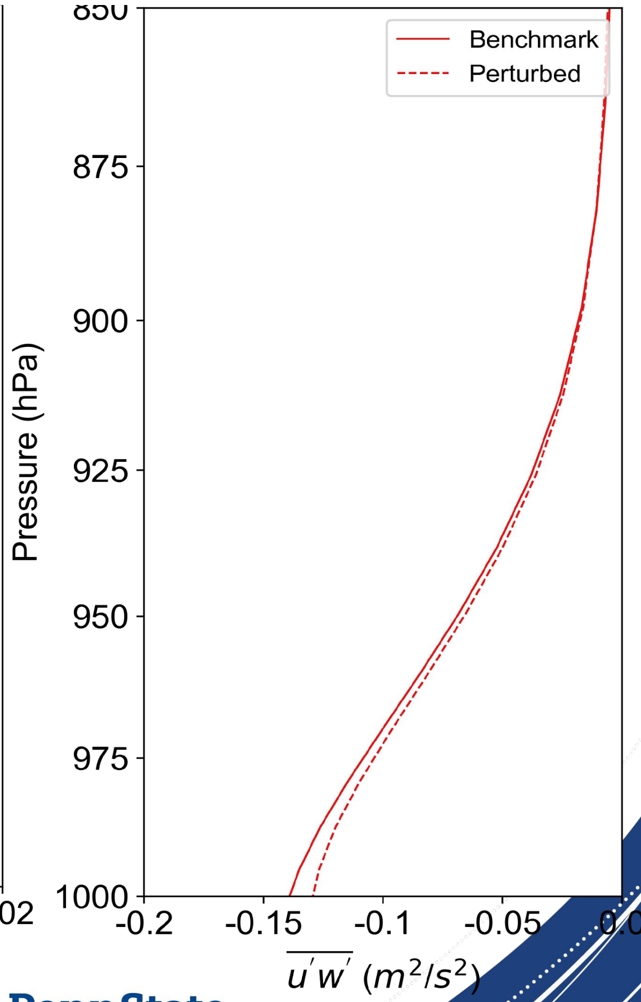
Eddy Dissipation Terms



Vertical Wind Shear



Momentum Flux



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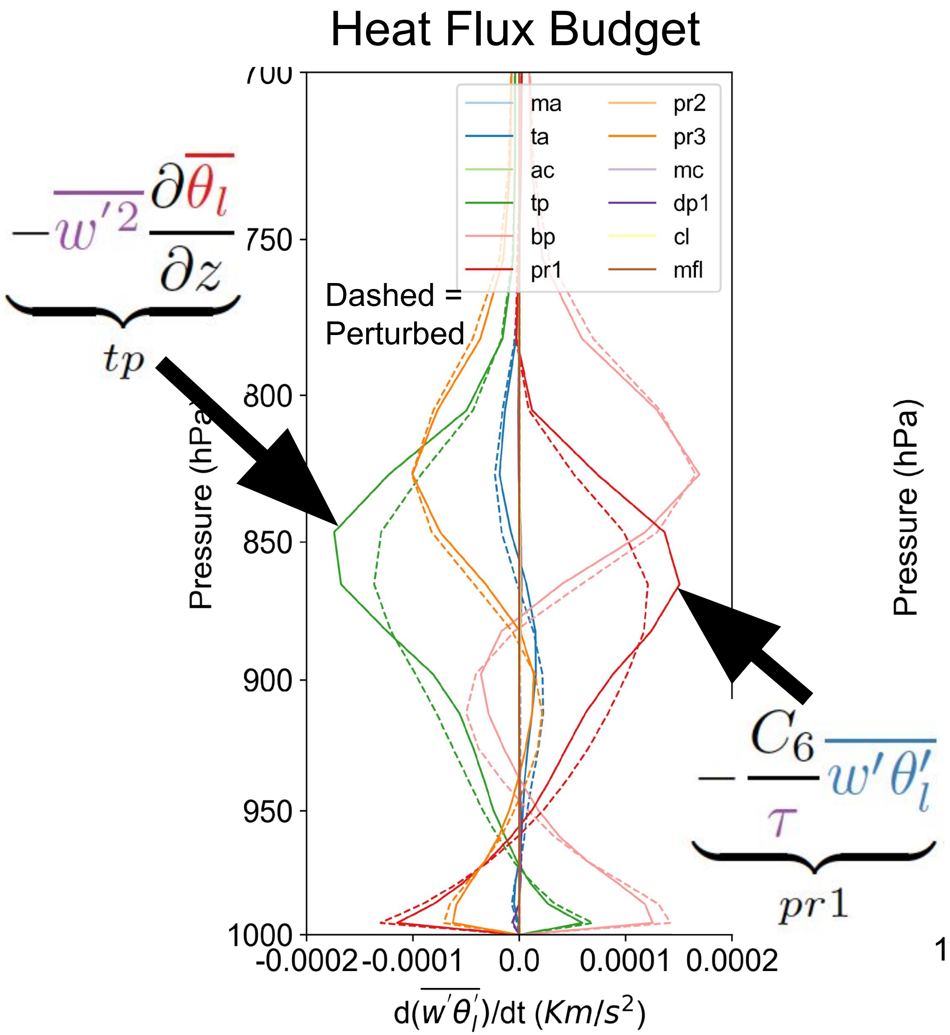
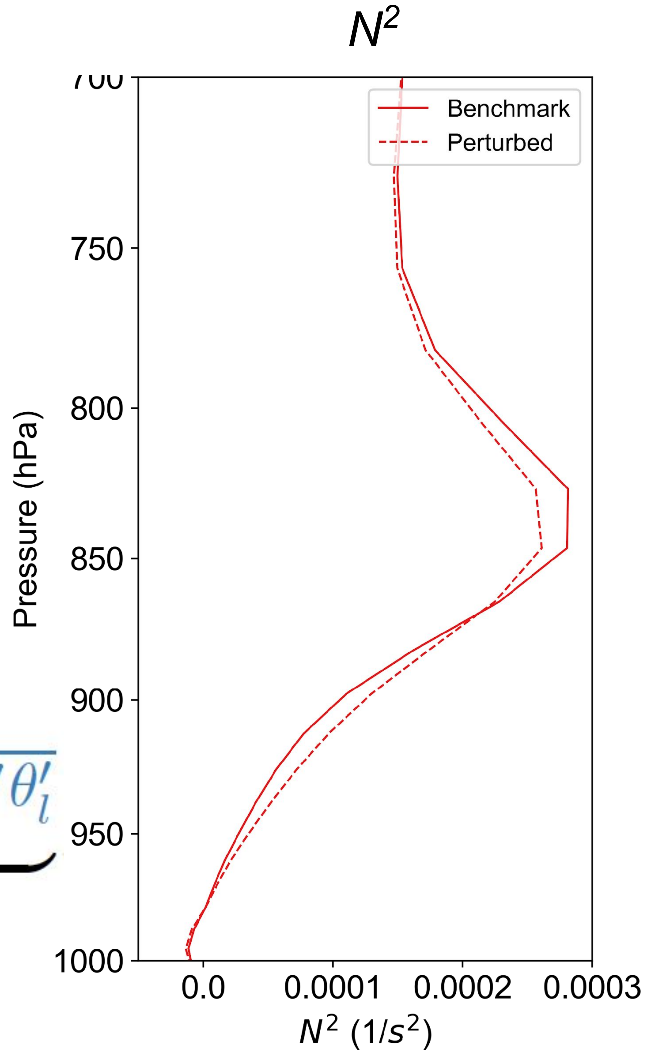
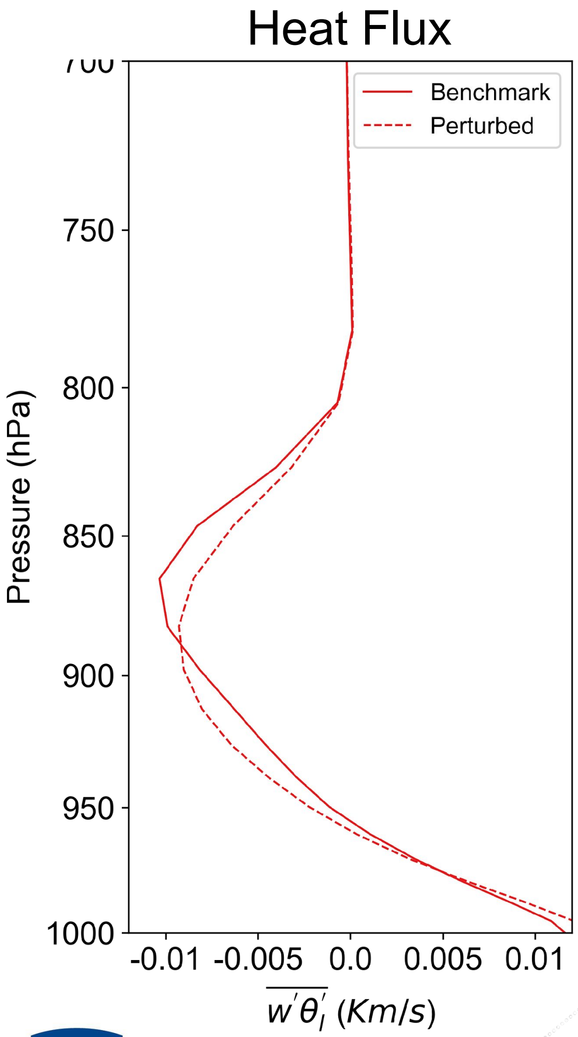
Simultaneously changing the four CLUBBX input parameters also modifies the heat flux budget

Eastern Tropical Pacific







Main Takeaways

Additional Questions?
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- CLUBBX input parameters that were influential for TC structure are also broadly influential for other aspects of the mean climate
- Sensitivity analysis identifies parameters to be targeted to reduce regional biases in mean state surface stress and SWCF
- Perturbing these input parameters affects the budgets of momentum and heat fluxes in the PBL
- **Future Work:** leverage a high-resolution model like CM1 to compare CLUBBX turbulence profiles to what should be expected in the real world
- **Other Future Work:** evaluate ways to “contain” the effects of perturbations to specific regions of interest

We thank our partners in this work

For more details about prior TC work…

Nardi, K., C. Zarzycki, V. Larson, and G. Bryan, 2022: Assessing the sensitivity in depicting the tropical cyclone boundary layer to changes in the parameterization of momentum flux in the Community Earth System Model, *Mon. Wea. Rev.*, doi: 10.1175/MWR-D-21-0186.1.

Link to MWR paper:

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Main Takeaways

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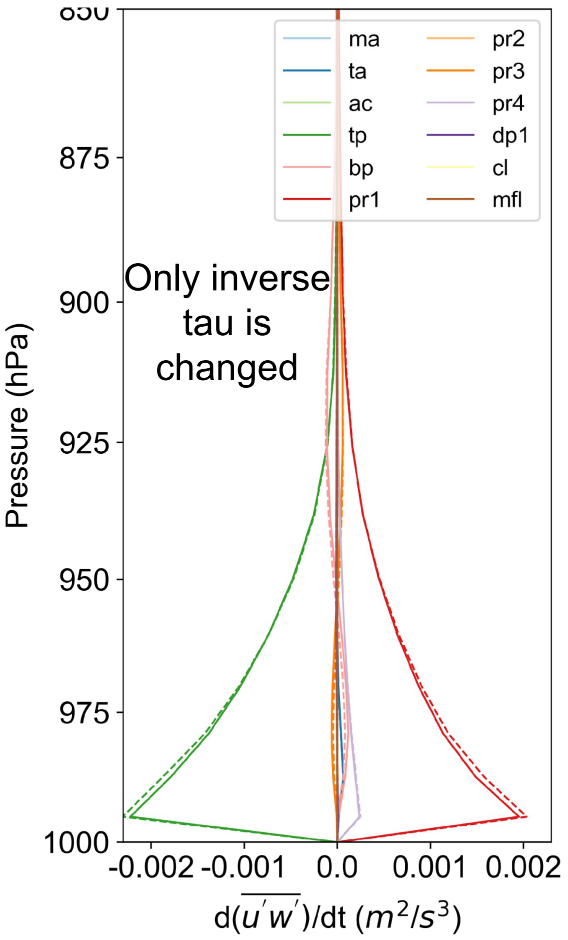
Extra Slides

We can also see how changing each of the four parameters individually affects the budget

Southern Ocean

Momentum Flux Budget



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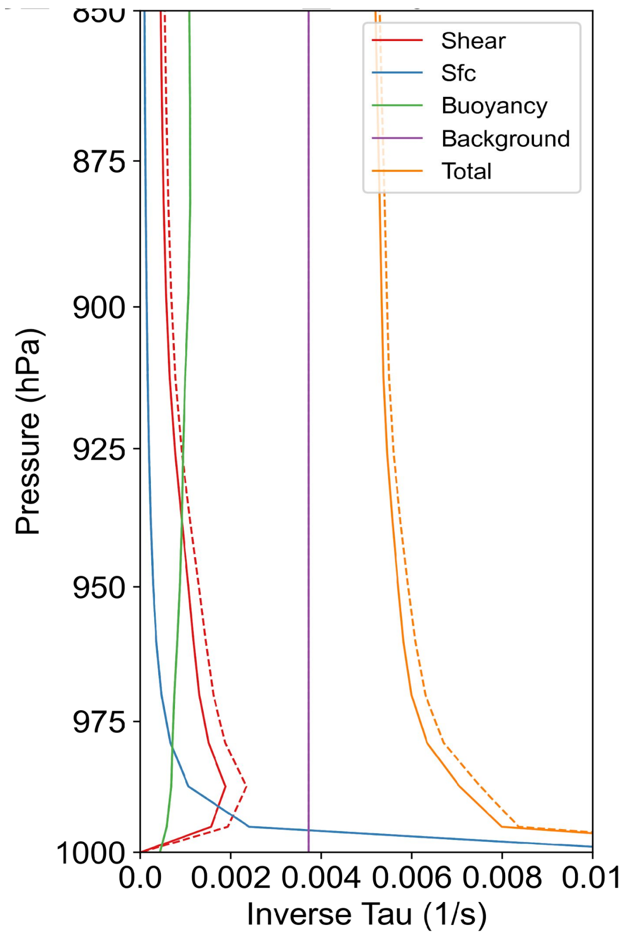
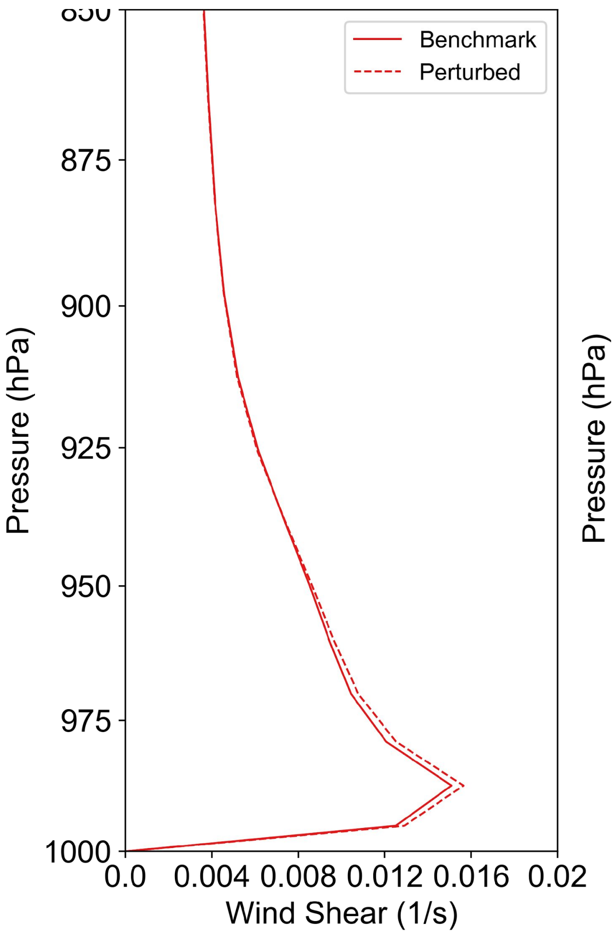
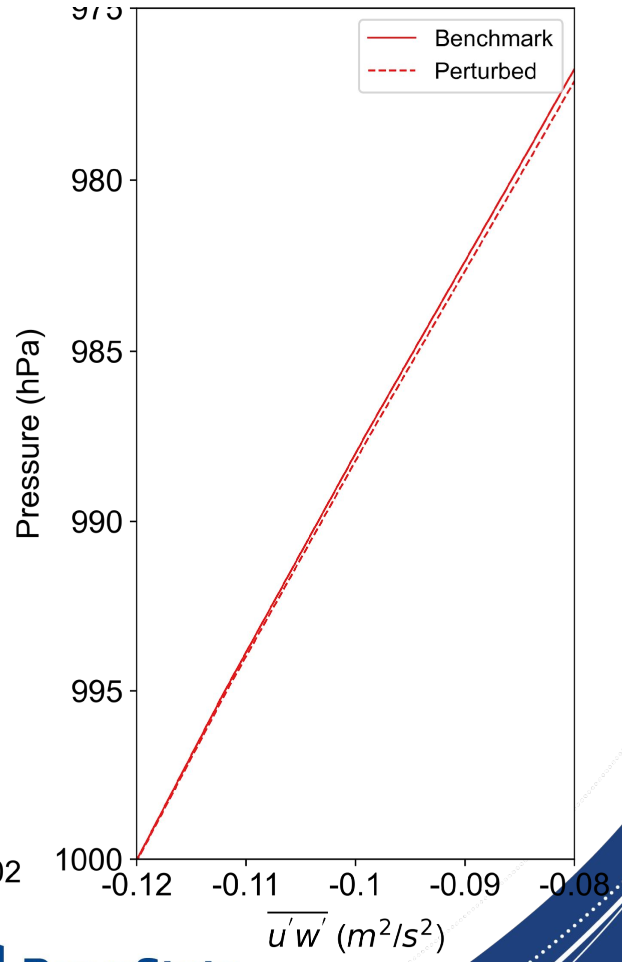


Vertical Wind Shear



Momentum Flux



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How can CLUBB be adjusted to remove some of these biases in TC structure?

Problem: *CLUBB contains many tunable parameters that could be adjusted*

Question: *How can we efficiently screen a large number of input parameters to identify those that merit additional analysis?*

Solution: ***The Morris One at a Time (MOAT) method***

- *Start with a set of tunable input parameters*
- *Run model multiple times with unique combinations of parameter values*
- *From one run to the next, change the value of only one input parameter*
- *Analyze the difference in model output between runs*
- *Repeat for **15** different initial combinations of input parameter values*