The Sensitivity of the Global Mean Climate to Parameterized Momentum Flux in an Experimental Version of CAM6-CLUBB(X)

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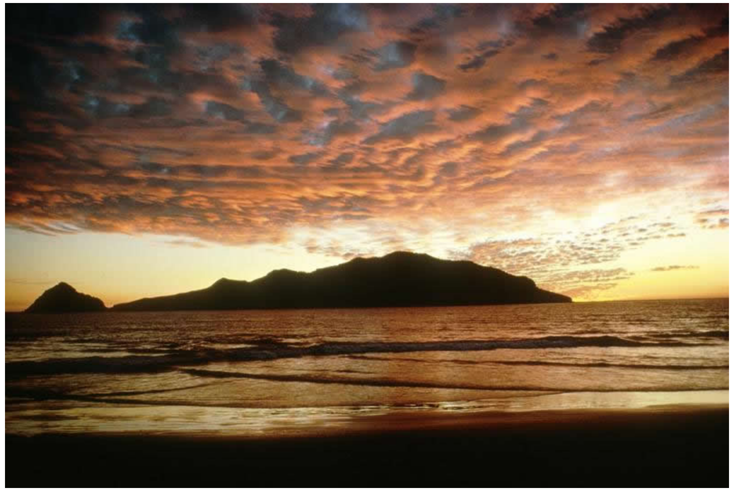
CESM Workshop
Tuesday 13 June 2023



CLUBBX’s prognostic momentum flux formulation includes several tunable parameters

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

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

Advection of momentum flux
by the mean vertical wind

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Turbulent advection of momentum flux

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Turbulent production
from updrafts and downdrafts

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Turbulent production
by existing momentum flux

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Buoyant production of momentum flux

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Return-to-isotropy adjustment term

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Term representing other dissipating processes

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- Allows for upgradient fluxes

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- 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**

We target several notable mean state biases in CAM6-CLUBBX

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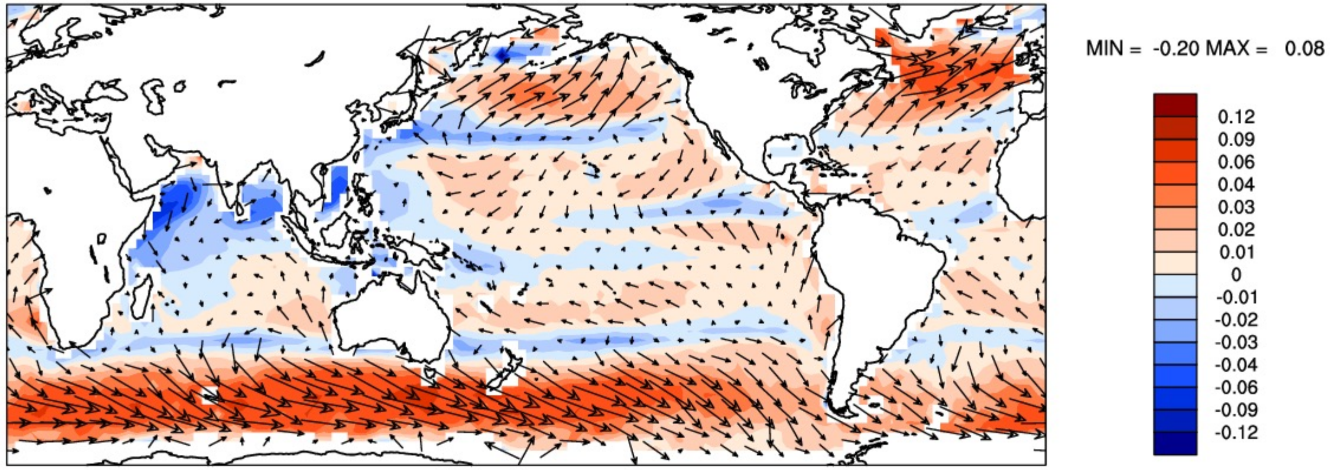
Baseline Annual Surface Stress Bias



10-year simulations with baseline CLUBBX parameter settings

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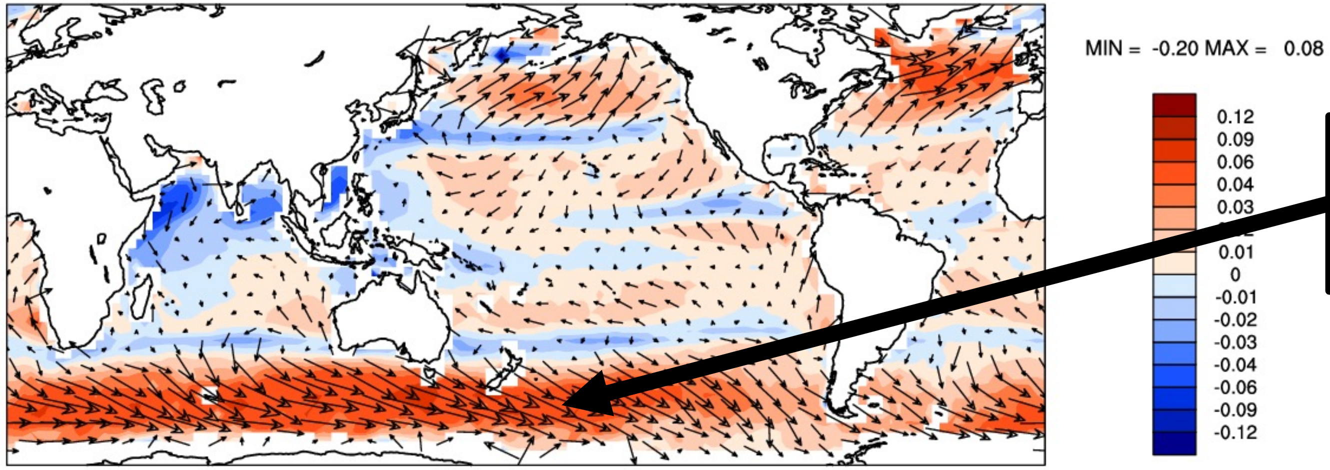

Baseline surface stress is too high over the Southern Ocean

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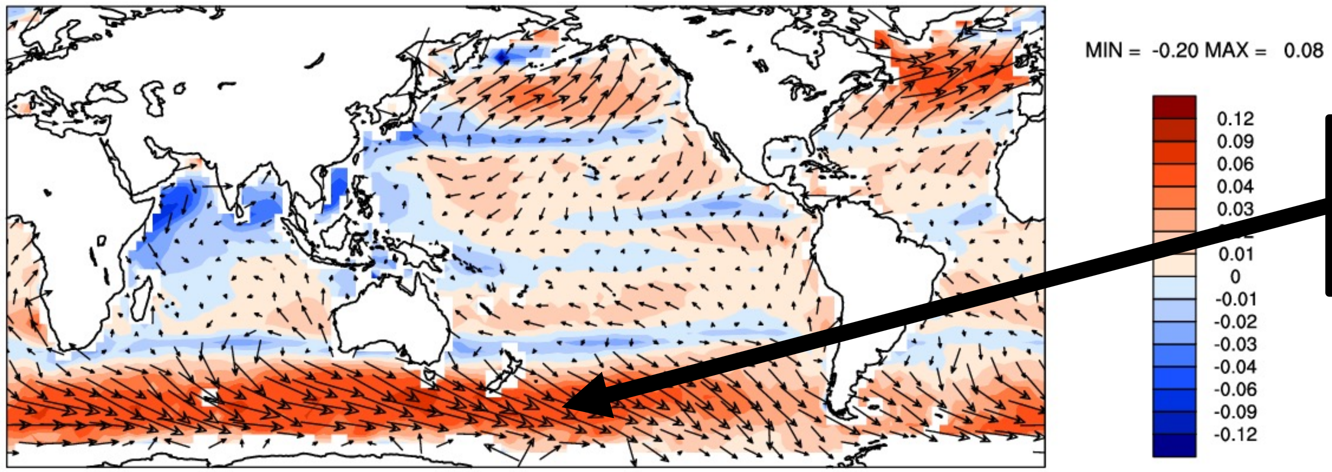

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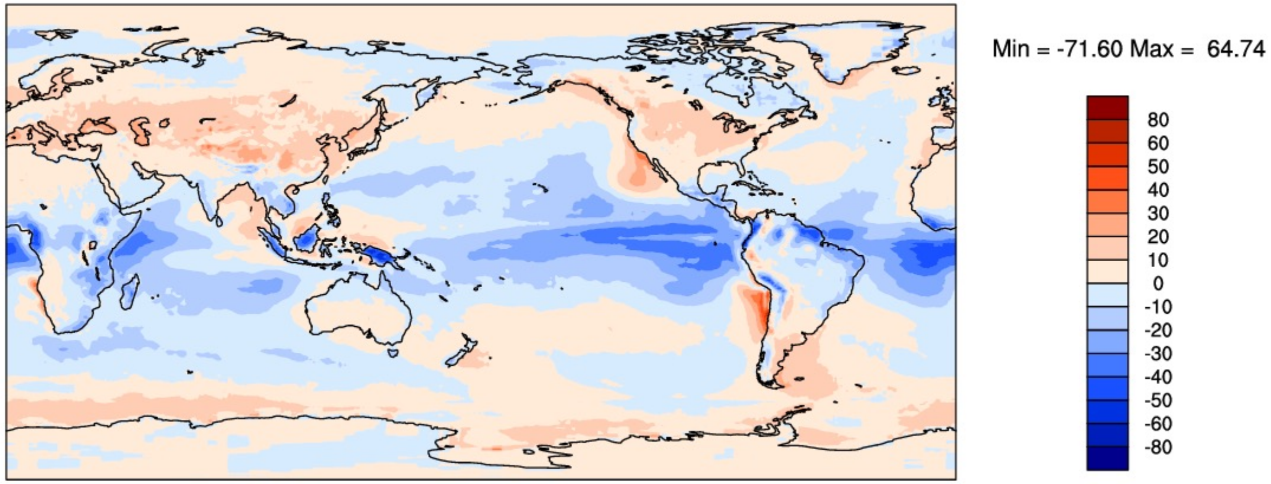
Baseline Annual SWCF Bias



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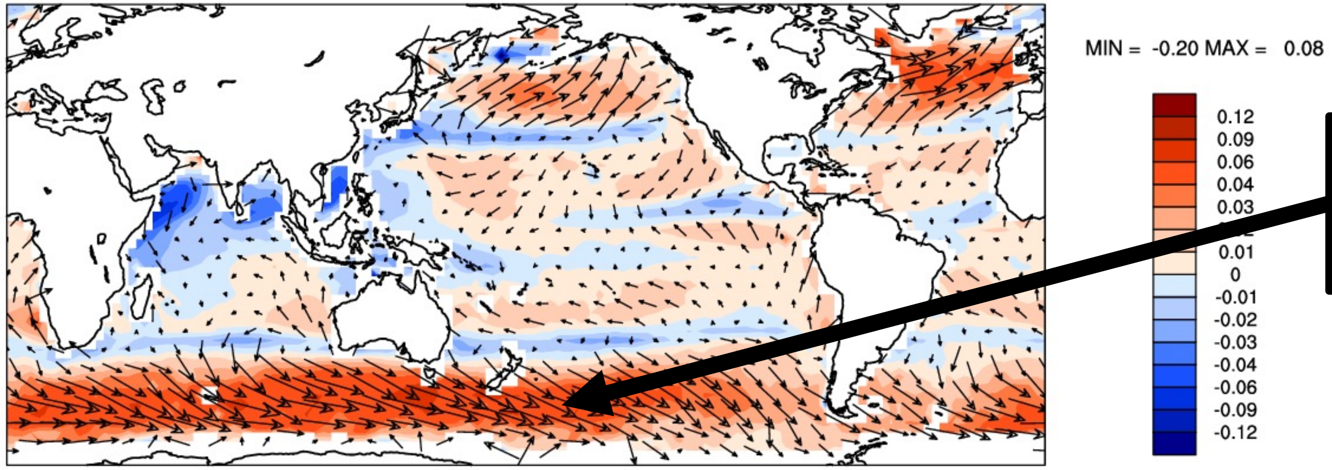

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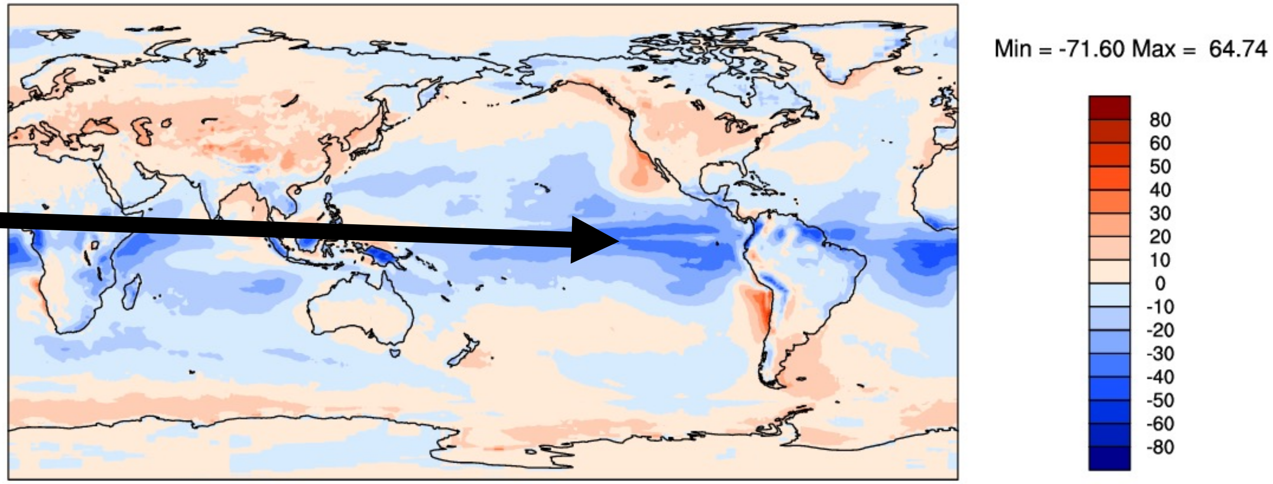

Negative baseline SWCF bias due to high bias in low cloud fraction

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- 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 **10** different initial combinations of input parameter values

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- Sensitivities calculated at t=72 hours (Qian et al. 2018, JGR-A)

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MOAT identifies several input parameters in the momentum flux budget that influence surface stress

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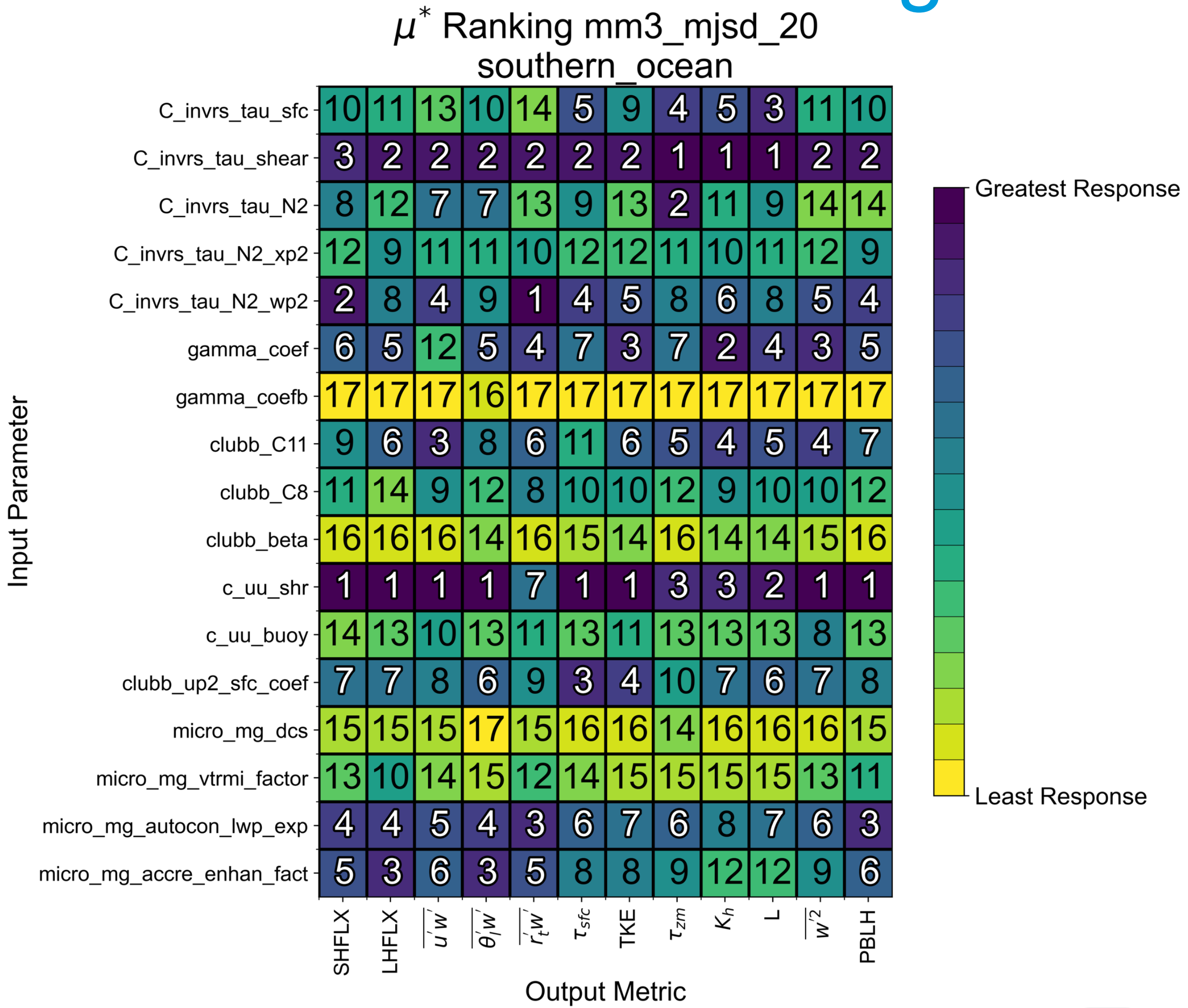

μ^* Ranking mm3_mjsd_20
southern_ocean

	SHFLX	LHFLX	$\overline{u'w'}$	$\overline{\theta_l'w'}$	$\overline{r_t'w'}$	τ_{sfc}	TKE	τ_{zm}	K_h	L	$\overline{w'^2}$	PBLH
C_invrs_tau_sfc	10	11	13	10	14	5	9	4	5	3	11	10
C_invrs_tau_shear	3	2	2	2	2	2	2	1	1	1	2	2
C_invrs_tau_N2	8	12	7	7	13	9	13	2	11	9	14	14
C_invrs_tau_N2_xp2	12	9	11	11	10	12	12	11	10	11	12	9
C_invrs_tau_N2_wp2	2	8	4	9	1	4	5	8	6	8	5	4
gamma_coef	6	5	12	5	4	7	3	7	2	4	3	5
gamma_coefb	17	17	17	16	17	17	17	17	17	17	17	17
clubb_C11	9	6	3	8	6	11	6	5	4	5	4	7
clubb_C8	11	14	9	12	8	10	10	12	9	10	10	12
clubb_beta	16	16	16	14	16	15	14	16	14	14	15	16
c_uu_shr	1	1	1	1	7	1	1	3	3	2	1	1
c_uu_buoy	14	13	10	13	11	13	11	13	13	13	8	13
clubb_up2_sfc_coef	7	7	8	6	9	3	4	10	7	6	7	8
micro_mg_dcs	15	15	15	17	15	16	16	14	16	16	16	15
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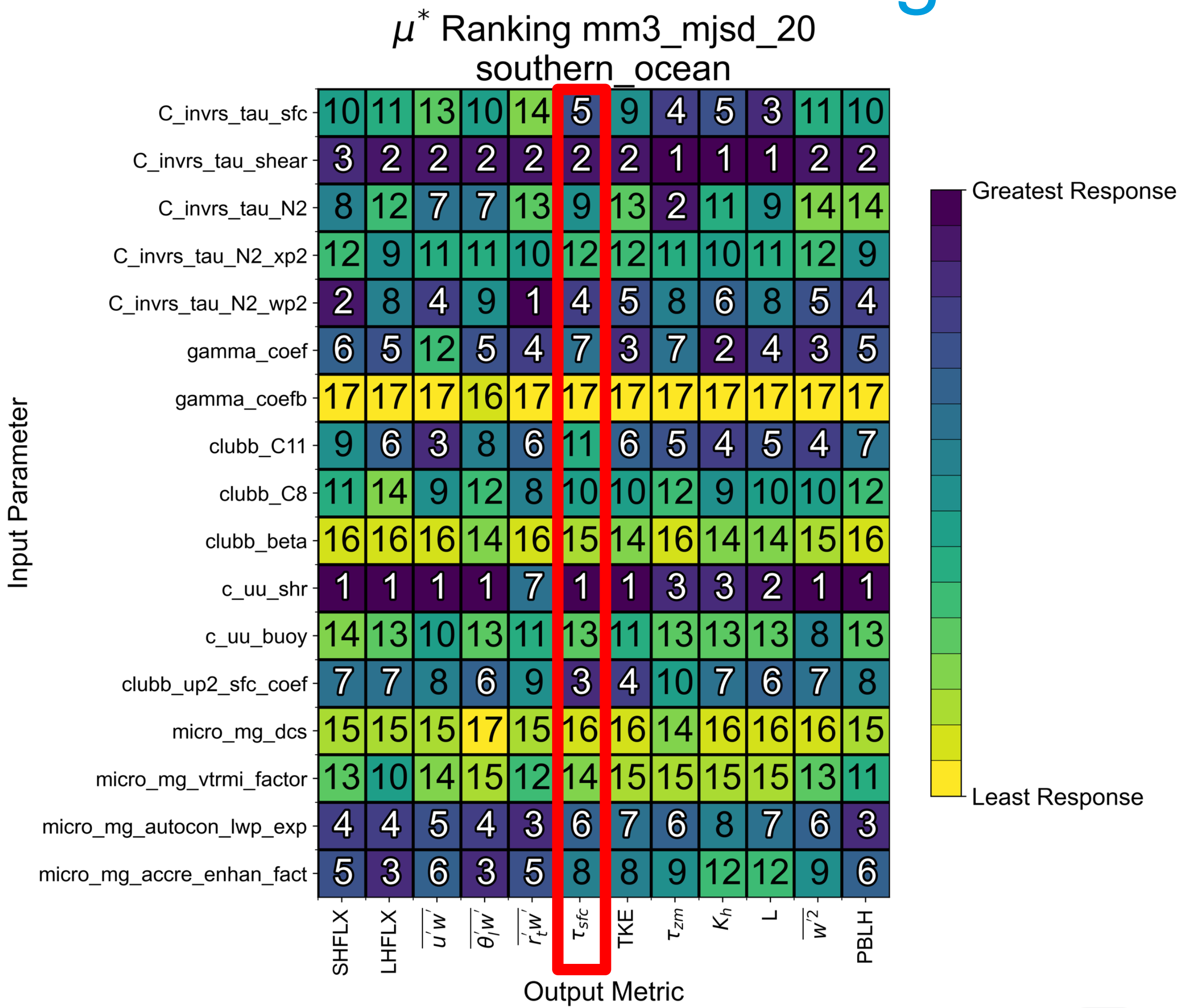

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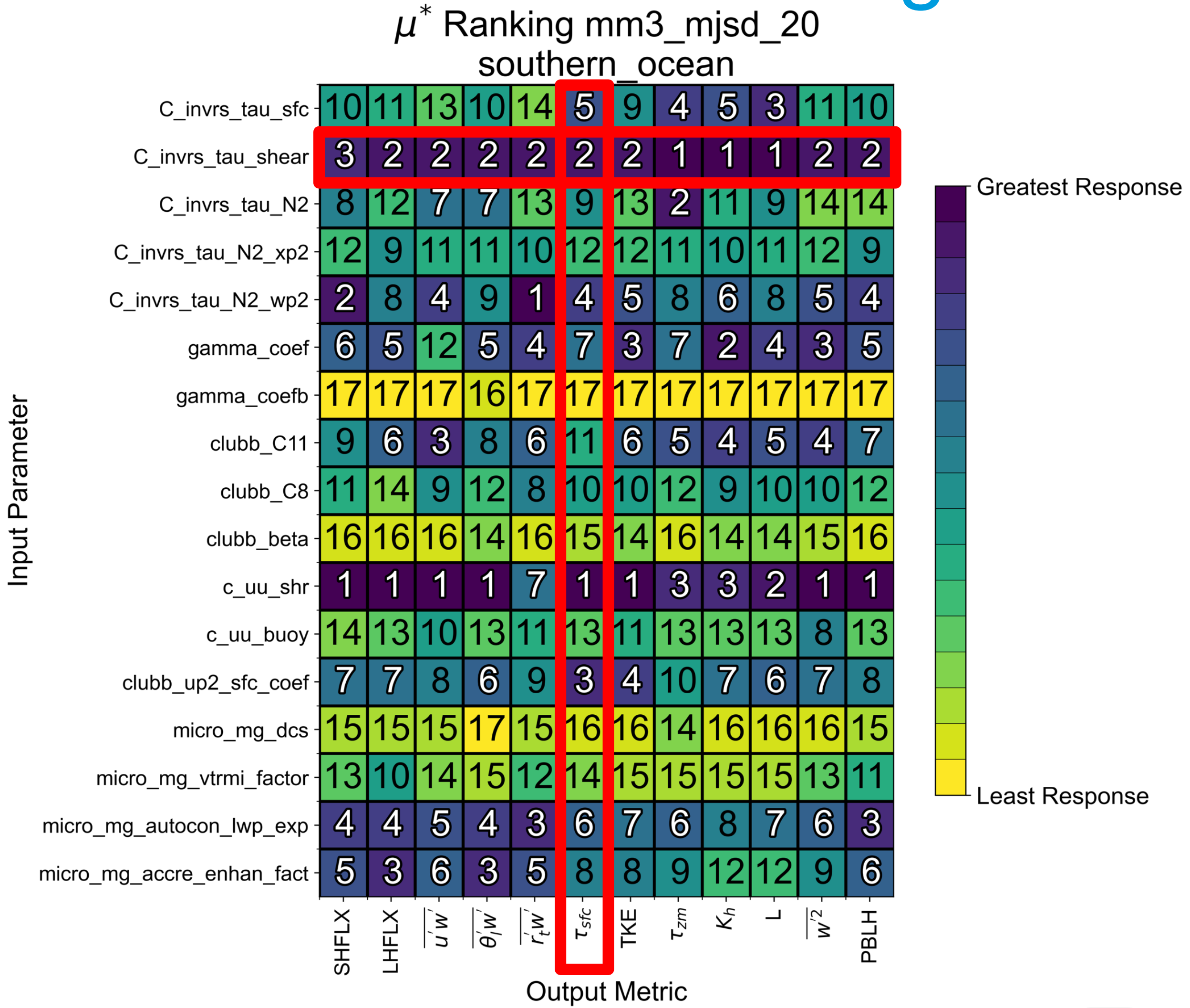

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$$\frac{C_6}{\tau}\overline{u'w'}$$

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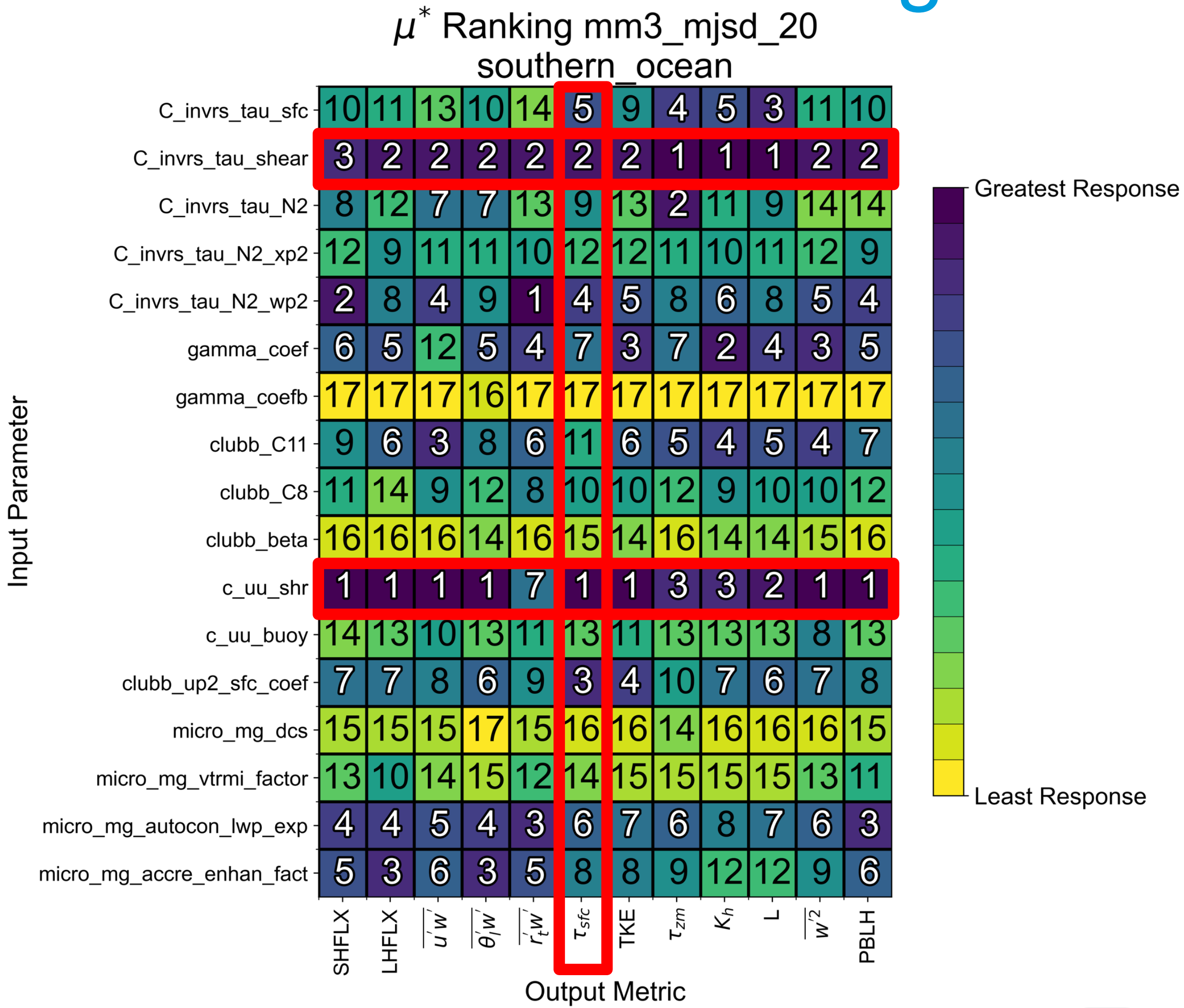

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$$\frac{C_6}{\tau}\overline{u'w'}$$

$$(1-C_{uu\_shr})\overline{w'^2}\frac{\partial\overline{u}}{\partial z}$$

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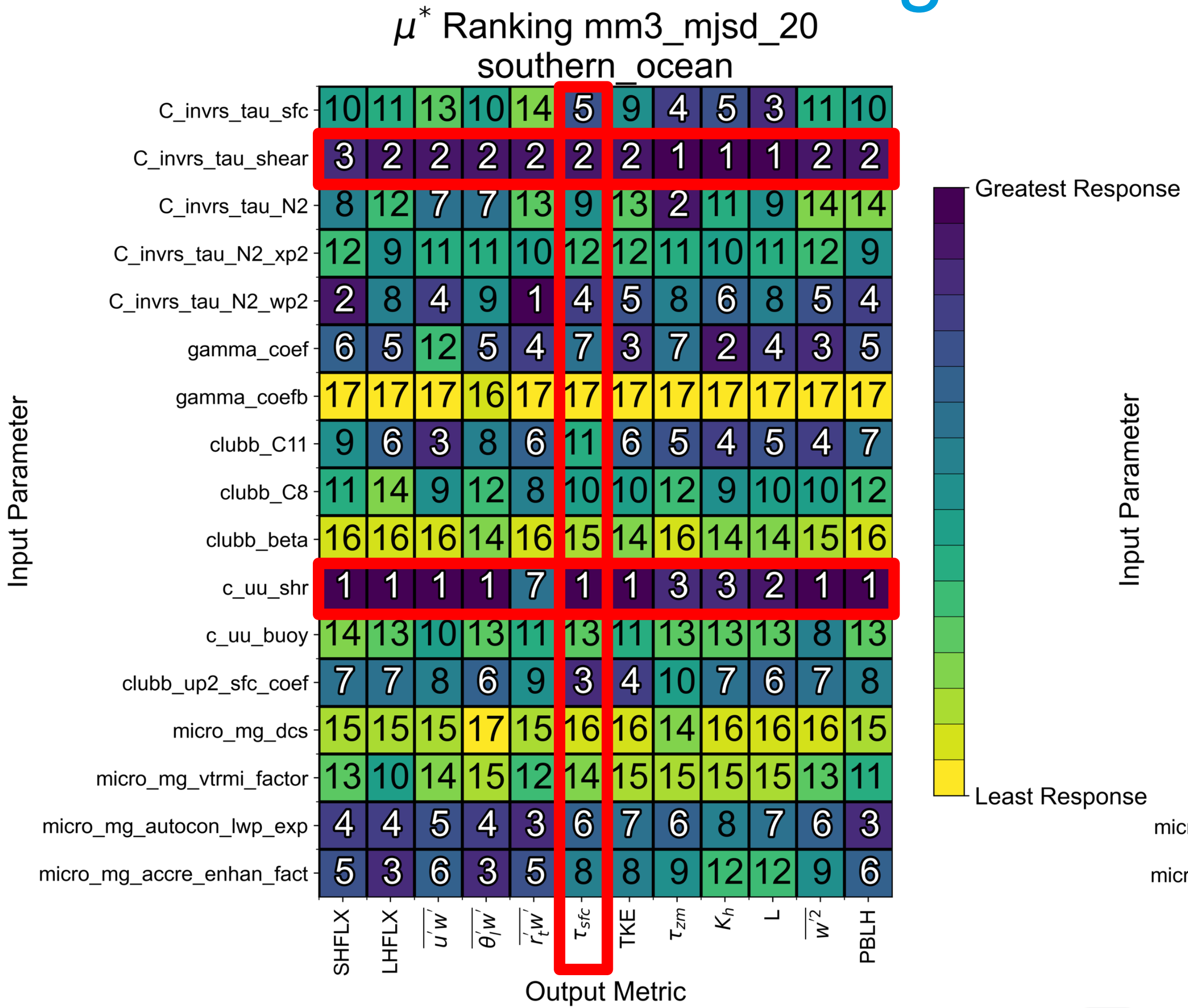
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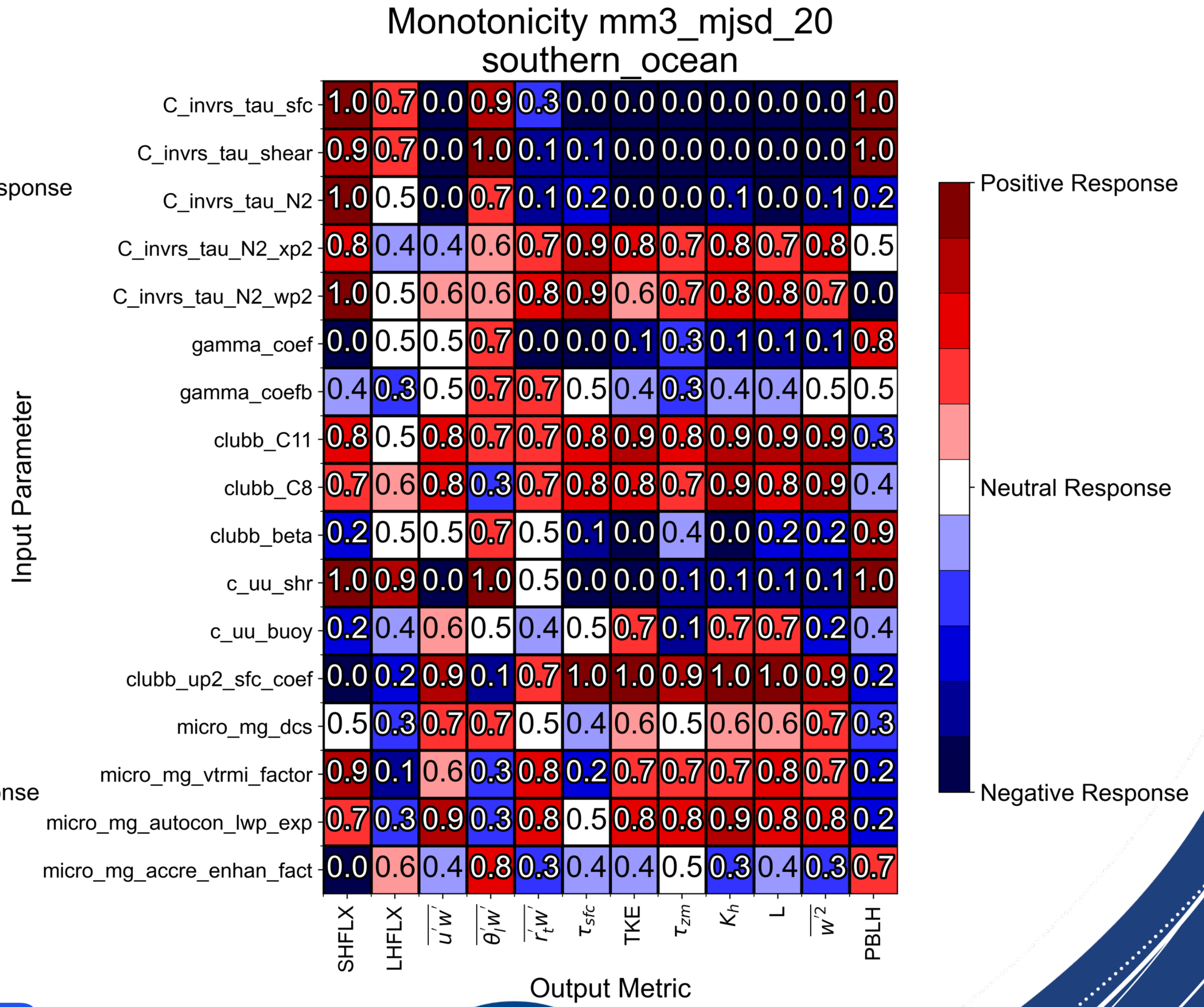
Input Parameter	SHFLX	LHFLX	$\overline{u'w'}$	$\overline{\theta_l'w'}$	$\overline{r_t'w'}$	τ_{sfc}	TKE	τ_{zm}	K_h	L	$\overline{w'^2}$	PBLH
C_invrs_tau_sfc	10	11	13	10	14	5	9	4	5	3	11	10
C_invrs_tau_shear	3	2	2	2	2	2	2	1	1	1	2	2
C_invrs_tau_N2	8	12	7	7	13	9	13	2	11	9	14	14
C_invrs_tau_N2_xp2	12	9	11	11	10	12	12	11	10	11	12	9
C_invrs_tau_N2_wp2	2	8	4	9	1	4	5	8	6	8	5	4
gamma_coef	6	5	12	5	4	7	3	7	2	4	3	5
gamma_coefb	17	17	17	16	17	17	17	17	17	17	17	17
clubb_C11	9	6	3	8	6	11	6	5	4	5	4	7
clubb_C8	11	14	9	12	8	10	10	12	9	10	10	12
clubb_beta	16	16	16	14	16	15	14	16	14	14	15	16
c_uu_shr	1	1	1	1	7	1	1	3	3	2	1	1
c_uu_buoy	14	13	10	13	11	13	11	13	13	13	8	13
clubb_up2_sfc_coef	7	7	8	6	9	3	4	10	7	6	7	8
micro_mg_dcs	15	15	15	17	15	16	16	14	16	16	16	15
micro_mg_vtrmi_factor	13	10	14	15	12	14	15	15	15	15	13	11
micro_mg_autocon_lwp_exp	4	4	5	4	3	6	7	6	8	7	6	3
micro_mg_accre_enhan_fact	5	3	6	3	5	8	8	9	12	12	9	6


Monotonicity mm3_mjsd_20
southern_ocean

Input Parameter	SHFLX	LHFLX	$\overline{u'w'}$	$\overline{\theta_l'w'}$	$\overline{r_t'w'}$	τ_{sfc}	TKE	τ_{zm}	K_h	L	$\overline{w'^2}$	PBLH
C_invrs_tau_sfc	1.0	0.7	0.0	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0
C_invrs_tau_shear	0.9	0.7	0.0	1.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	1.0
C_invrs_tau_N2	1.0	0.5	0.0	0.7	0.1	0.2	0.0	0.0	0.1	0.0	0.1	0.2
C_invrs_tau_N2_xp2	0.8	0.4	0.4	0.6	0.7	0.9	0.8	0.7	0.8	0.7	0.8	0.5
C_invrs_tau_N2_wp2	1.0	0.5	0.6	0.6	0.8	0.9	0.6	0.7	0.8	0.8	0.7	0.0
gamma_coef	0.0	0.5	0.5	0.7	0.0	0.0	0.1	0.3	0.1	0.1	0.1	0.8
gamma_coefb	0.4	0.3	0.5	0.7	0.7	0.5	0.4	0.3	0.4	0.4	0.5	0.5
clubb_C11	0.8	0.5	0.8	0.7	0.7	0.8	0.9	0.8	0.9	0.9	0.9	0.3
clubb_C8	0.7	0.6	0.8	0.3	0.7	0.8	0.8	0.7	0.9	0.8	0.9	0.4
clubb_beta	0.2	0.5	0.5	0.7	0.5	0.1	0.0	0.4	0.0	0.2	0.2	0.9
c_uu_shr	1.0	0.9	0.0	1.0	0.5	0.0	0.0	0.1	0.1	0.1	0.1	1.0
c_uu_buoy	0.2	0.4	0.6	0.5	0.4	0.5	0.7	0.1	0.7	0.7	0.2	0.4
clubb_up2_sfc_coef	0.0	0.2	0.9	0.1	0.7	1.0	1.0	0.9	1.0	1.0	0.9	0.2
micro_mg_dcs	0.5	0.3	0.7	0.7	0.5	0.4	0.6	0.5	0.6	0.6	0.7	0.3
micro_mg_vtrmi_factor	0.9	0.1	0.6	0.3	0.8	0.2	0.7	0.7	0.7	0.8	0.7	0.2
micro_mg_autocon_lwp_exp	0.7	0.3	0.9	0.3	0.8	0.5	0.8	0.8	0.9	0.8	0.8	0.2
micro_mg_accre_enhan_fact	0.0	0.6	0.4	0.8	0.3	0.4	0.4	0.5	0.3	0.4	0.3	0.7

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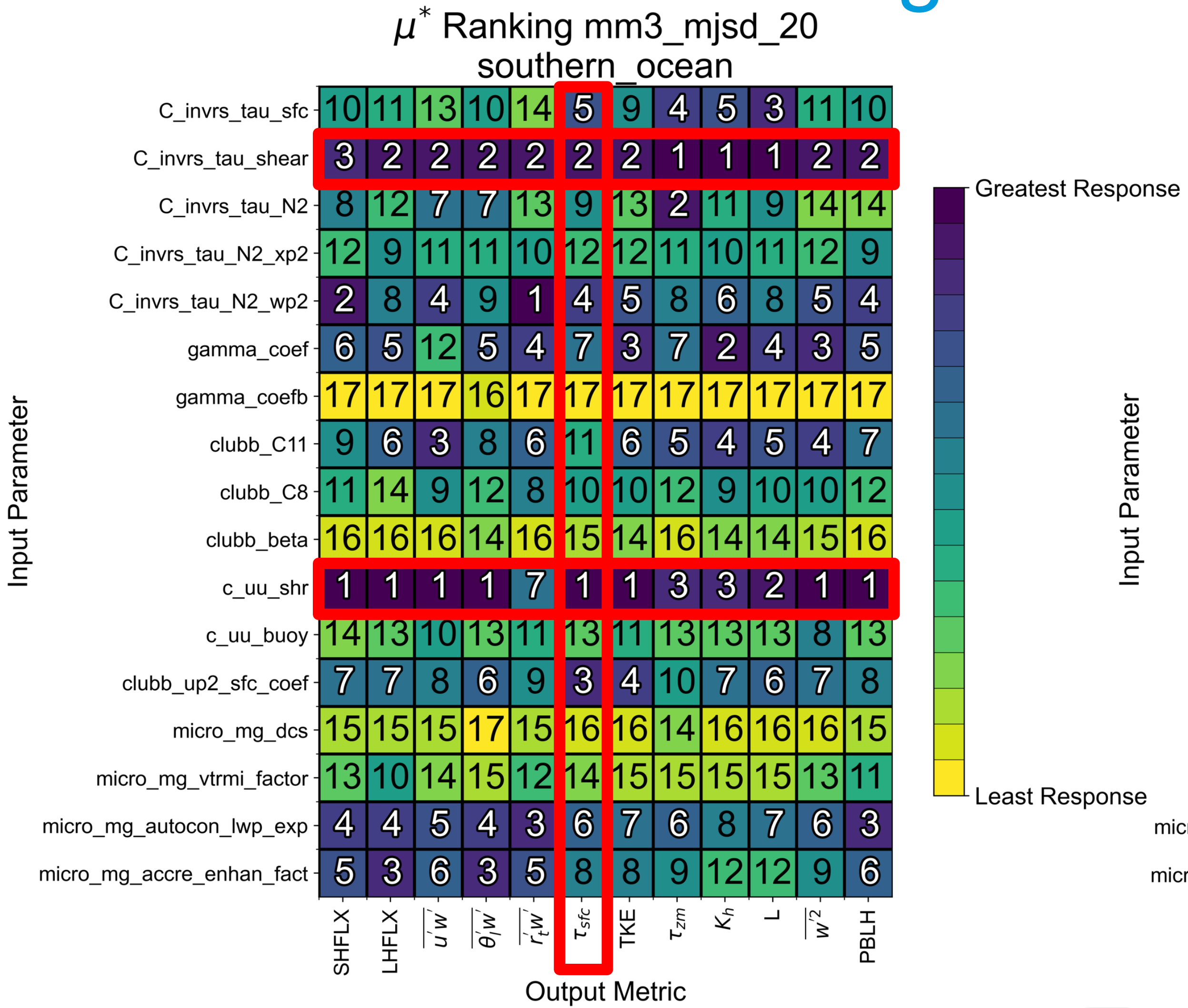
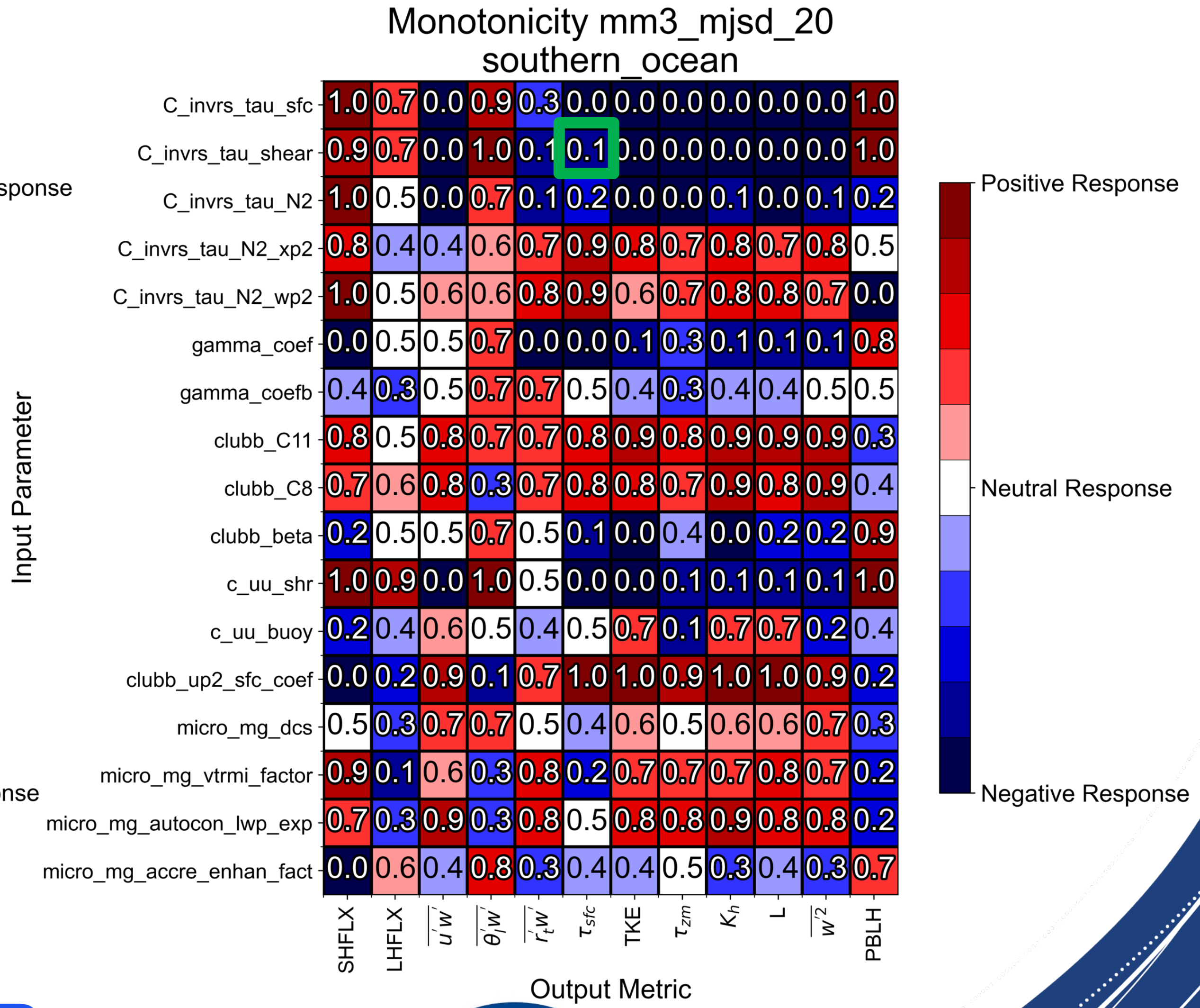
MOAT identifies several input parameters in the momentum flux budget that influence surface stress


μ^* Ranking mm3_mjsd_20
southern_ocean

	SHFLX	LHFLX	$\overline{u'w'}$	$\overline{\theta_l'w'}$	$\overline{r_t'w'}$	τ_{sfc}	TKE	τ_{zm}	K_h	L	$\overline{w'^2}$	PBLH
C_invrs_tau_sfc	10	11	13	10	14	5	9	4	5	3	11	10
C_invrs_tau_shear	3	2	2	2	2	2	2	1	1	1	2	2
C_invrs_tau_N2	8	12	7	7	13	9	13	2	11	9	14	14
C_invrs_tau_N2_xp2	12	9	11	11	10	12	12	11	10	11	12	9
C_invrs_tau_N2_wp2	2	8	4	9	1	4	5	8	6	8	5	4
gamma_coef	6	5	12	5	4	7	3	7	2	4	3	5
gamma_coefb	17	17	17	16	17	17	17	17	17	17	17	17
clubb_C11	9	6	3	8	6	11	6	5	4	5	4	7
clubb_C8	11	14	9	12	8	10	10	12	9	10	10	12
clubb_beta	16	16	16	14	16	15	14	16	14	14	15	16
c_uu_shr	1	1	1	1	7	1	1	3	3	2	1	1
c_uu_buoy	14	13	10	13	11	13	11	13	13	13	8	13
clubb_up2_sfc_coef	7	7	8	6	9	3	4	10	7	6	7	8
micro_mg_dcs	15	15	15	17	15	16	16	14	16	16	16	15
micro_mg_vtrmi_factor	13	10	14	15	12	14	15	15	15	15	13	11
micro_mg_autocon_lwp_exp	4	4	5	4	3	6	7	6	8	7	6	3
micro_mg_accre_enhan_fact	5	3	6	3	5	8	8	9	12	12	9	6


Monotonicity mm3_mjsd_20
southern_ocean

	SHFLX	LHFLX	$\overline{u'w'}$	$\overline{\theta_l'w'}$	$\overline{r_t'w'}$	τ_{sfc}	TKE	τ_{zm}	K_h	L	$\overline{w'^2}$	PBLH
C_invrs_tau_sfc	1.0	0.7	0.0	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0
C_invrs_tau_shear	0.9	0.7	0.0	1.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	1.0
C_invrs_tau_N2	1.0	0.5	0.0	0.7	0.1	0.2	0.0	0.0	0.1	0.0	0.1	0.2
C_invrs_tau_N2_xp2	0.8	0.4	0.4	0.6	0.7	0.9	0.8	0.7	0.8	0.7	0.8	0.5
C_invrs_tau_N2_wp2	1.0	0.5	0.6	0.6	0.8	0.9	0.6	0.7	0.8	0.8	0.7	0.0
gamma_coef	0.0	0.5	0.5	0.7	0.0	0.0	0.1	0.3	0.1	0.1	0.1	0.8
gamma_coefb	0.4	0.3	0.5	0.7	0.7	0.5	0.4	0.3	0.4	0.4	0.5	0.5
clubb_C11	0.8	0.5	0.8	0.7	0.7	0.8	0.9	0.8	0.9	0.9	0.9	0.3
clubb_C8	0.7	0.6	0.8	0.3	0.7	0.8	0.8	0.7	0.9	0.8	0.9	0.4
clubb_beta	0.2	0.5	0.5	0.7	0.5	0.1	0.0	0.4	0.0	0.2	0.2	0.9
c_uu_shr	1.0	0.9	0.0	1.0	0.5	0.0	0.0	0.1	0.1	0.1	0.1	1.0
c_uu_buoy	0.2	0.4	0.6	0.5	0.4	0.5	0.7	0.1	0.7	0.7	0.2	0.4
clubb_up2_sfc_coef	0.0	0.2	0.9	0.1	0.7	1.0	1.0	0.9	1.0	1.0	0.9	0.2
micro_mg_dcs	0.5	0.3	0.7	0.7	0.5	0.4	0.6	0.5	0.6	0.6	0.7	0.3
micro_mg_vtrmi_factor	0.9	0.1	0.6	0.3	0.8	0.2	0.7	0.7	0.7	0.8	0.7	0.2
micro_mg_autocon_lwp_exp	0.7	0.3	0.9	0.3	0.8	0.5	0.8	0.8	0.9	0.8	0.8	0.2
micro_mg_accre_enhan_fact	0.0	0.6	0.4	0.8	0.3	0.4	0.4	0.5	0.3	0.4	0.3	0.7

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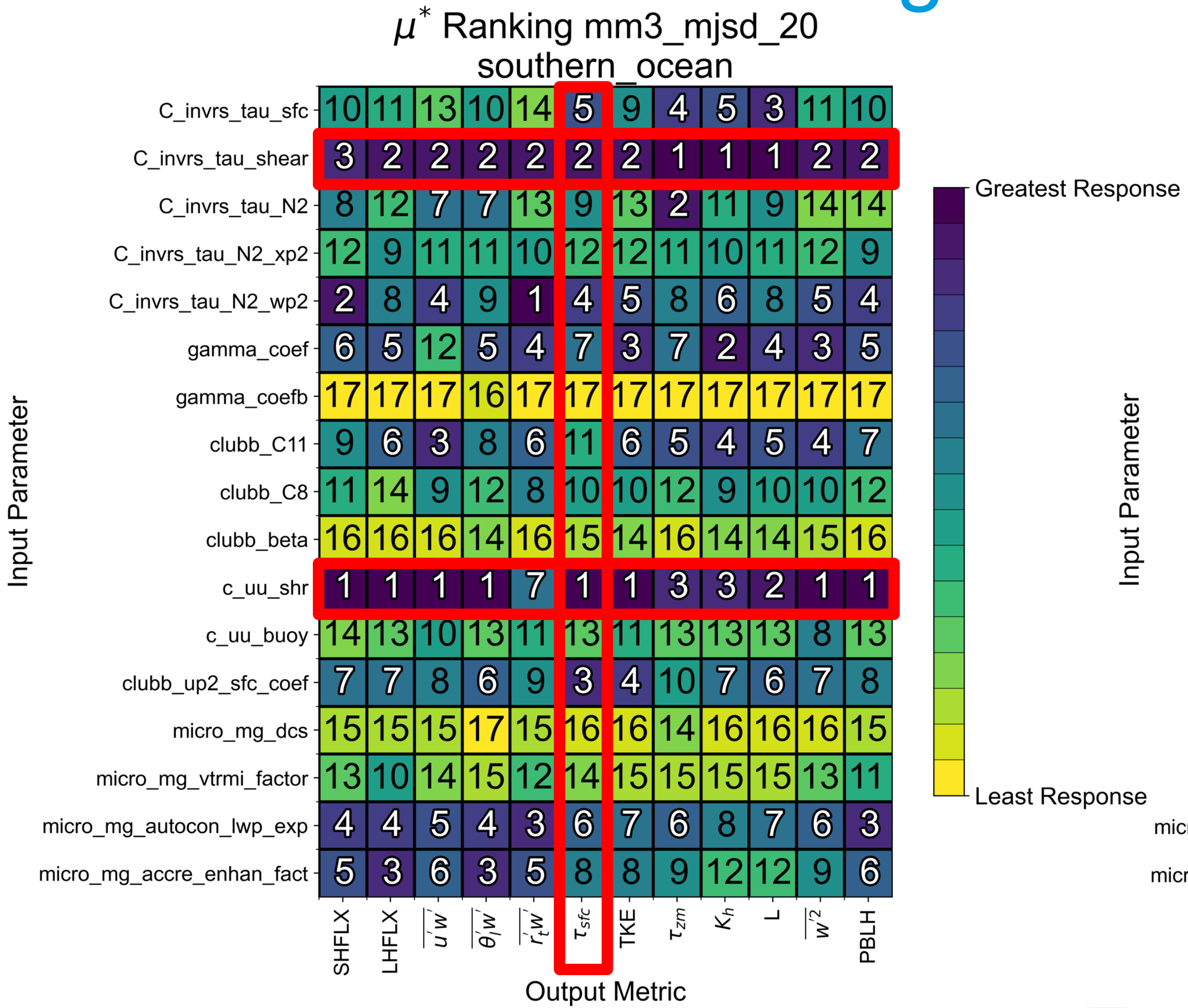
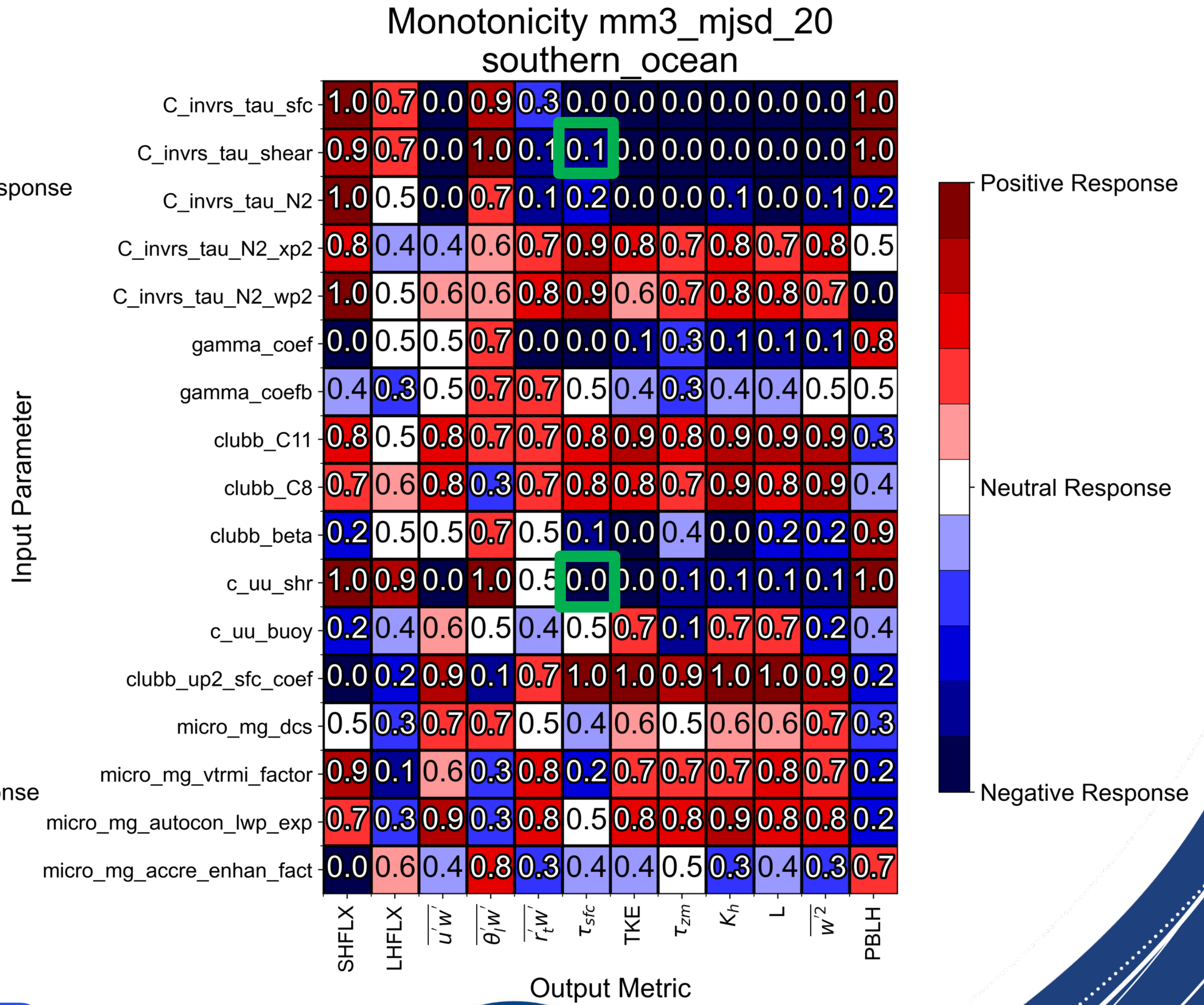
MOAT identifies several input parameters in the momentum flux budget that influence surface stress



μ^* Ranking mm3_mjsd_20 southern_ocean

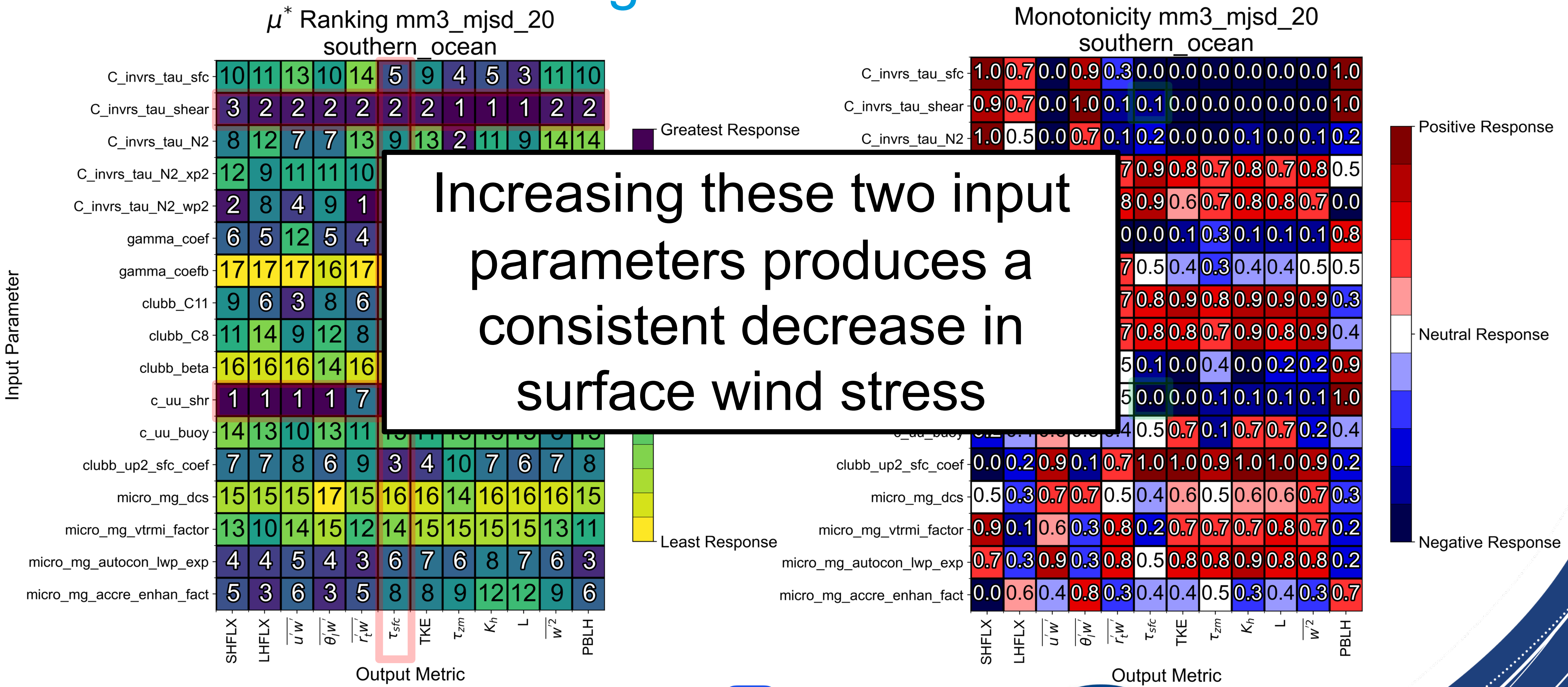
Input Parameter	SHFLX	LHFLX	$\overline{u'w'}$	$\overline{\theta_l'w'}$	$\overline{r_t'w'}$	τ_{sfc}	TKE	τ_{zm}	K_h	L	$\overline{w'^2}$	PBLH
C_invrs_tau_sfc	10	11	13	10	14	5	9	4	5	3	11	10
C_invrs_tau_shear	3	2	2	2	2	2	2	1	1	1	2	2
C_invrs_tau_N2	8	12	7	7	13	9	13	2	11	9	14	14
C_invrs_tau_N2_xp2	12	9	11	11	10	12	12	11	10	11	12	9
C_invrs_tau_N2_wp2	2	8	4	9	1	4	5	8	6	8	5	4
gamma_coef	6	5	12	5	4	7	3	7	2	4	3	5
gamma_coefb	17	17	17	16	17	17	17	17	17	17	17	17
clubb_C11	9	6	3	8	6	11	6	5	4	5	4	7
clubb_C8	11	14	9	12	8	10	10	12	9	10	10	12
clubb_beta	16	16	16	14	16	15	14	16	14	14	15	16
c_uu_shr	1	1	1	1	7	1	1	3	3	2	1	1
c_uu_buoy	14	13	10	13	11	13	11	13	13	13	8	13
clubb_up2_sfc_coef	7	7	8	6	9	3	4	10	7	6	7	8
micro_mg_dcs	15	15	15	17	15	16	16	14	16	16	16	15
micro_mg_vtrmi_factor	13	10	14	15	12	14	15	15	15	15	13	11
micro_mg_autocon_lwp_exp	4	4	5	4	3	6	7	6	8	7	6	3
micro_mg_accre_enhan_fact	5	3	6	3	5	8	8	9	12	12	9	6



Monotonicity mm3_mjsd_20 southern_ocean

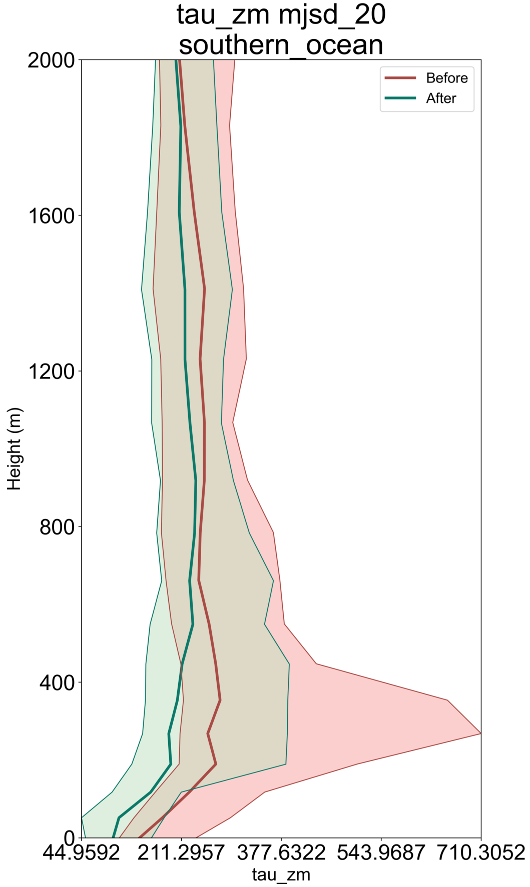
Input Parameter	SHFLX	LHFLX	$\overline{u'w'}$	$\overline{\theta_l'w'}$	$\overline{r_t'w'}$	τ_{sfc}	TKE	τ_{zm}	K_h	L	$\overline{w'^2}$	PBLH
C_invrs_tau_sfc	1.0	0.7	0.0	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0
C_invrs_tau_shear	0.9	0.7	0.0	1.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	1.0
C_invrs_tau_N2	1.0	0.5	0.0	0.7	0.1	0.2	0.0	0.0	0.1	0.0	0.1	0.2
C_invrs_tau_N2_xp2	0.8	0.4	0.4	0.6	0.7	0.9	0.8	0.7	0.8	0.7	0.8	0.5
C_invrs_tau_N2_wp2	1.0	0.5	0.6	0.6	0.8	0.9	0.6	0.7	0.8	0.8	0.7	0.0
gamma_coef	0.0	0.5	0.5	0.7	0.0	0.0	0.1	0.3	0.1	0.1	0.1	0.8
gamma_coefb	0.4	0.3	0.5	0.7	0.7	0.5	0.4	0.3	0.4	0.4	0.5	0.5
clubb_C11	0.8	0.5	0.8	0.7	0.7	0.8	0.9	0.8	0.9	0.9	0.9	0.3
clubb_C8	0.7	0.6	0.8	0.3	0.7	0.8	0.8	0.7	0.9	0.8	0.9	0.4
clubb_beta	0.2	0.5	0.5	0.7	0.5	0.1	0.0	0.4	0.0	0.2	0.2	0.9
c_uu_shr	1.0	0.9	0.0	1.0	0.5	0.0	0.0	0.1	0.1	0.1	0.1	1.0
c_uu_buoy	0.2	0.4	0.6	0.5	0.4	0.5	0.7	0.1	0.7	0.7	0.2	0.4
clubb_up2_sfc_coef	0.0	0.2	0.9	0.1	0.7	1.0	1.0	0.9	1.0	1.0	0.9	0.2
micro_mg_dcs	0.5	0.3	0.7	0.7	0.5	0.4	0.6	0.5	0.6	0.6	0.7	0.3
micro_mg_vtrmi_factor	0.9	0.1	0.6	0.3	0.8	0.2	0.7	0.7	0.7	0.8	0.7	0.2
micro_mg_autocon_lwp_exp	0.7	0.3	0.9	0.3	0.8	0.5	0.8	0.8	0.9	0.8	0.8	0.2
micro_mg_accre_enhan_fact	0.0	0.6	0.4	0.8	0.3	0.4	0.4	0.5	0.3	0.4	0.3	0.7

MOAT identifies several input parameters in the momentum flux budget that influence surface stress



Increasing these two input parameters produces a consistent decrease in surface wind stress

We can track the impact of increasing one of these terms ($C_{invrs\_tau,shear}$) through the CLUBBX equations



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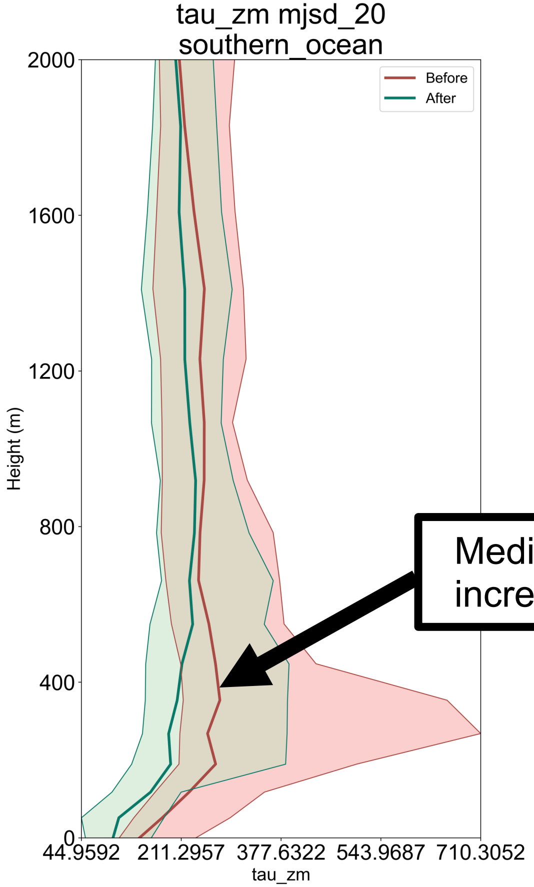
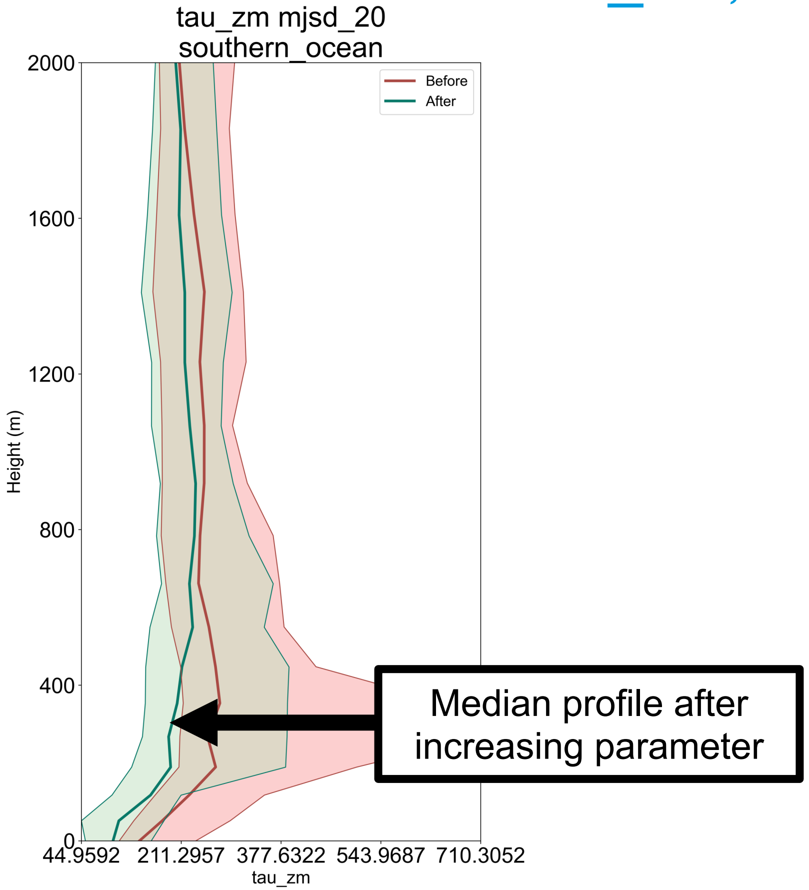
We can track the impact of increasing one of these terms ($C_{invrs\_tau,shear}$) through the CLUBBX equations



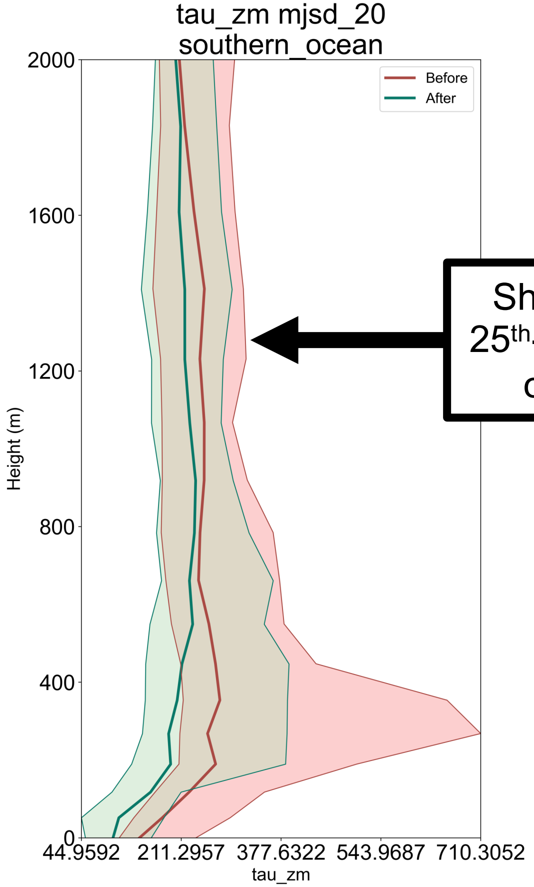
Median profile before increasing parameter

We can track the impact of increasing one of these terms ($C_{invrs\_tau,shear}$) through the CLUBBX equations



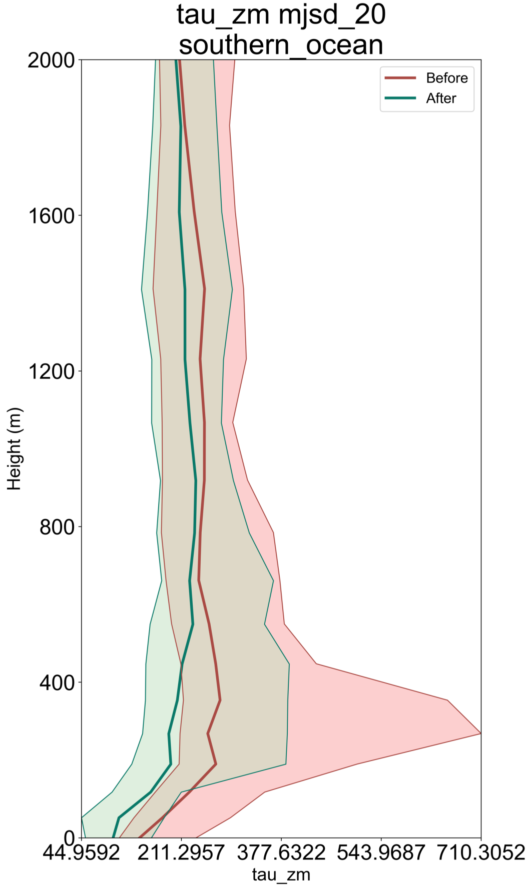
Median profile after increasing parameter

We can track the impact of increasing one of these terms ($C_{invrs\_tau,shear}$) through the CLUBBX equations



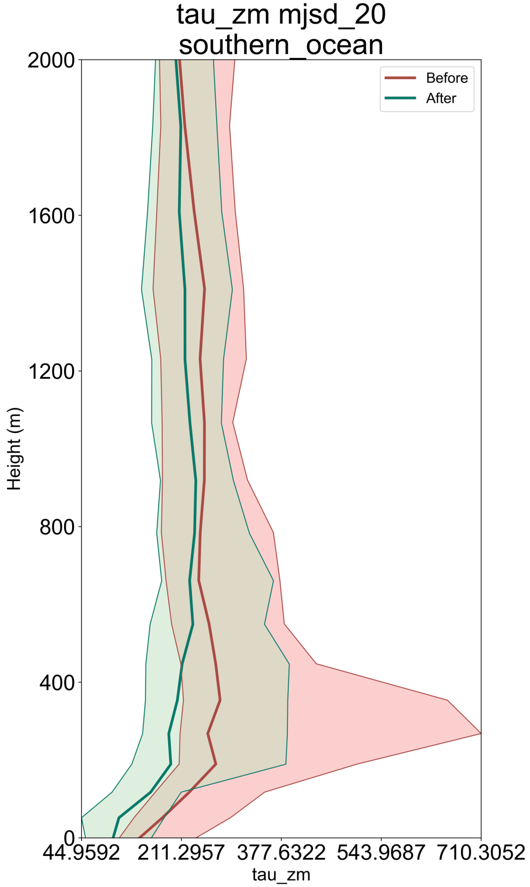
Shading represents the 25^{th}-75^{th} percentiles of the output at each level

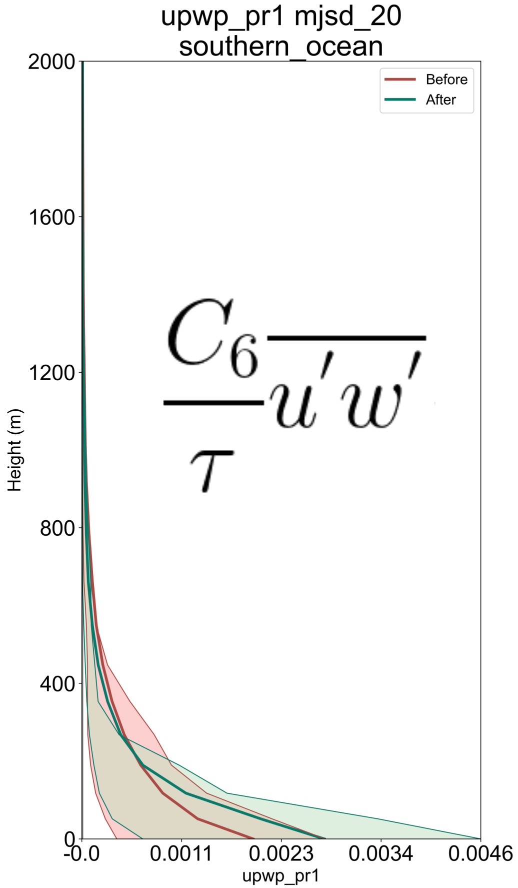
We can track the impact of increasing one of these terms ($C_{invrs\_tau,shear}$) through the CLUBBX equations



Increasing parameter increases eddy dissipation and reduces the eddy turnover timescale/turbulent length scale

We can track the impact of increasing one of these terms ($C_{invrs\_tau,shear}$) through the CLUBBX equations


tau_zm mjsd_20
southern_ocean


upwp_pr1 mjsd_20
southern_ocean

$$\frac{C_6}{\tau}\overline{u'w'}$$

Increasing parameter increases eddy dissipation and reduces the eddy turnover timescale/turbulent length scale

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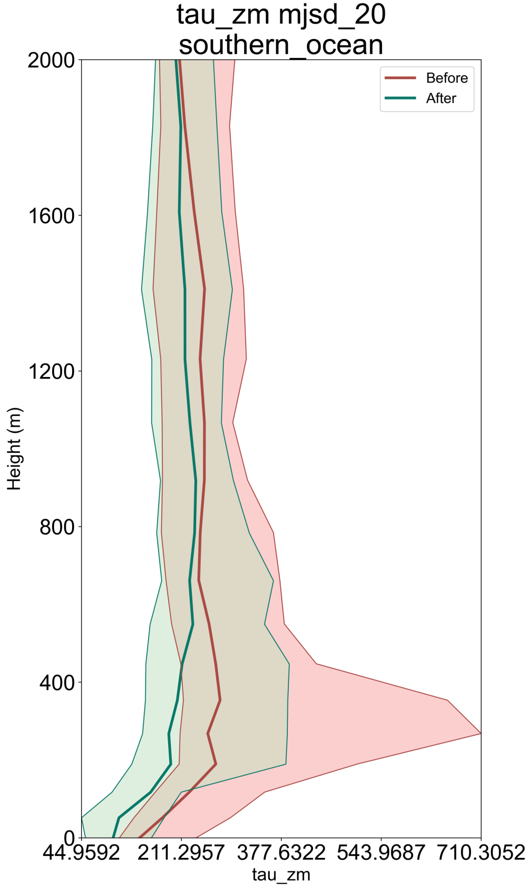
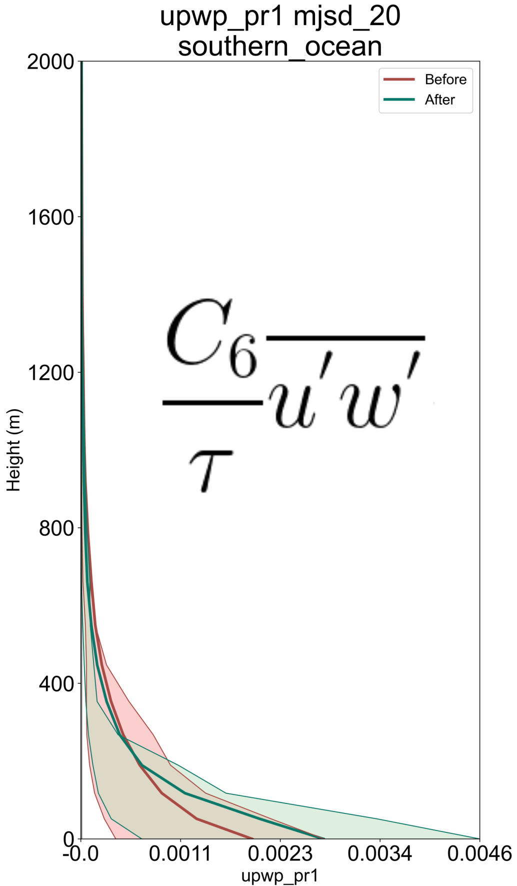
We can track the impact of increasing one of these terms ($C_{invrs\_tau,shear}$) through the CLUBBX equations


tau_zm mjsd_20
southern_ocean

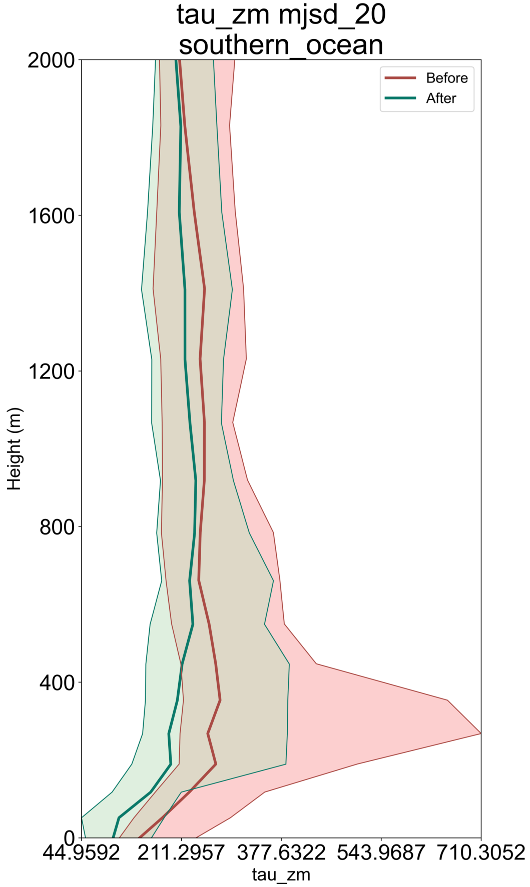

upwp_pr1 mjsd_20
southern_ocean

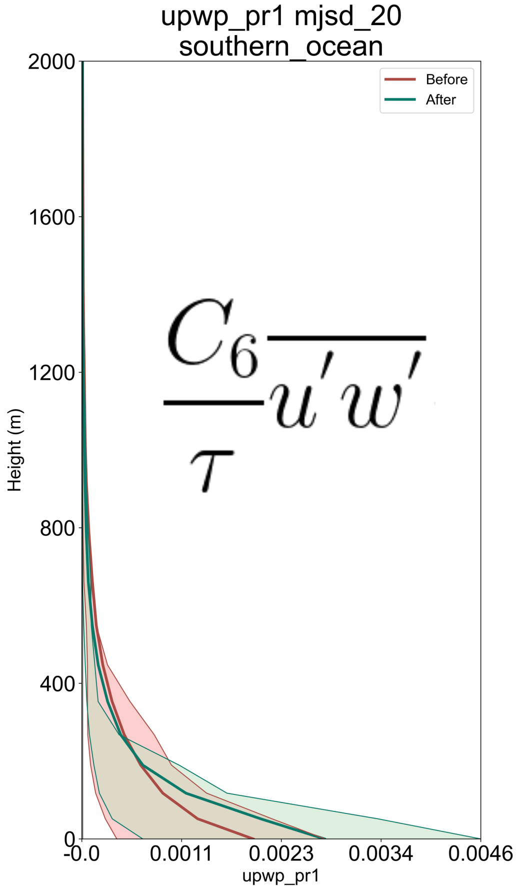
$$\frac{C_6}{\tau}\overline{u'w'}$$

Increasing parameter increases eddy dissipation and reduces the eddy turnover timescale/turbulent length scale

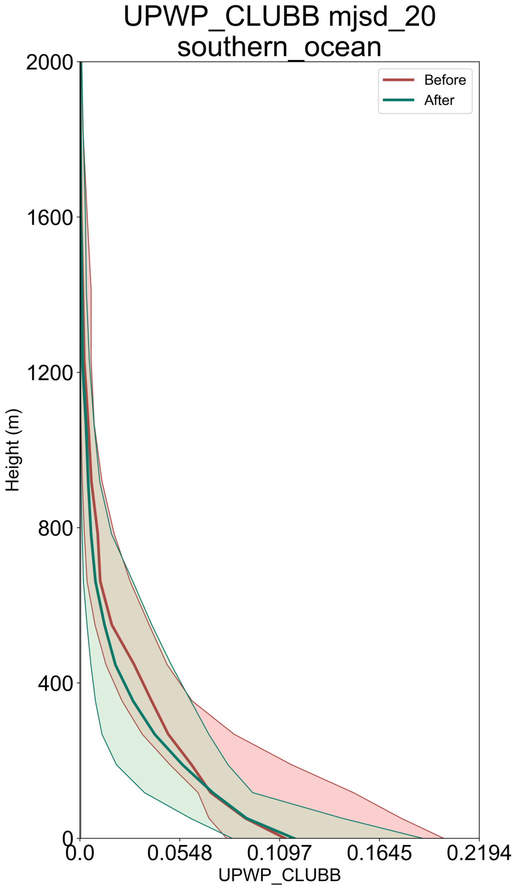
Increasing parameter increases the inverse of the eddy timescale, thus increasing the return-to-isotropy term

We can track the impact of increasing one of these terms ($C_{invrs\_tau,shear}$) through the CLUBBX equations





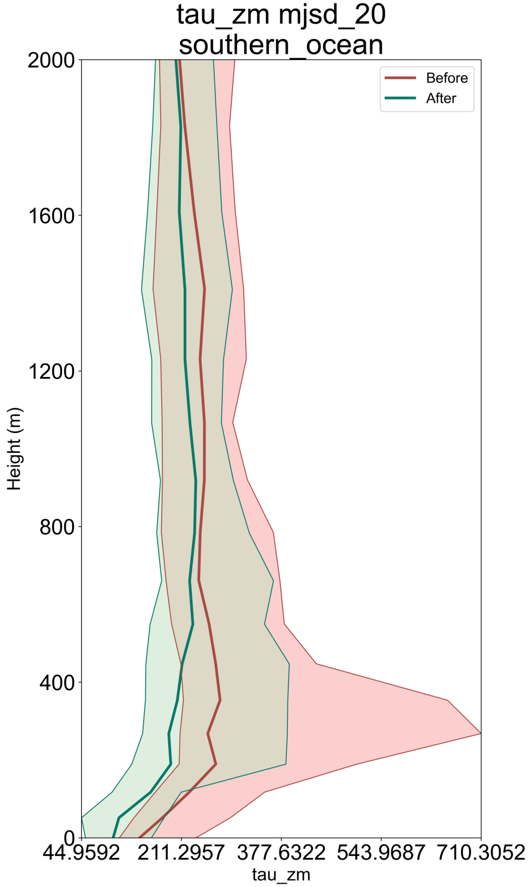
$$\frac{C_6}{\tau}\overline{u'w'}$$



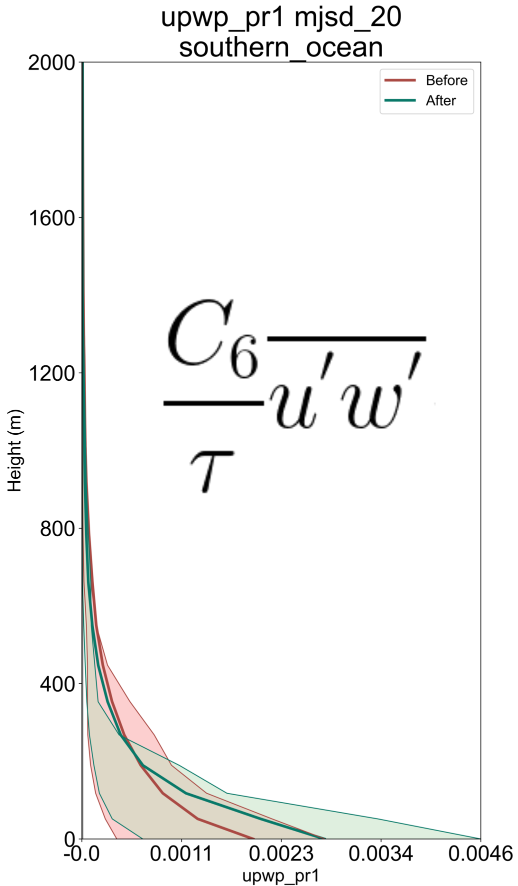
Increasing parameter increases eddy dissipation and reduces the eddy turnover timescale/turbulent length scale

Increasing parameter increases the inverse of the eddy timescale, thus increasing the return-to-isotropy term

We can track the impact of increasing one of these terms ($C_{invrs\_tau,shear}$) through the CLUBBX equations

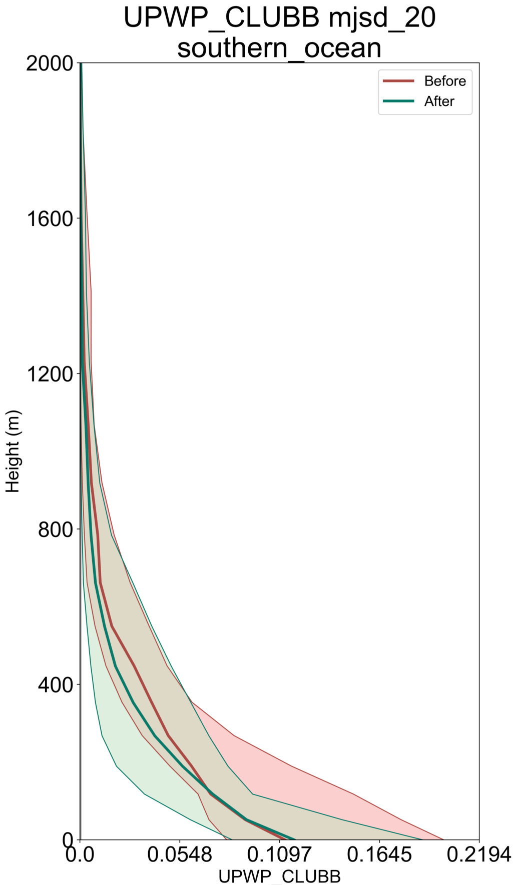


Increasing parameter increases eddy dissipation and reduces the eddy turnover timescale/turbulent length scale



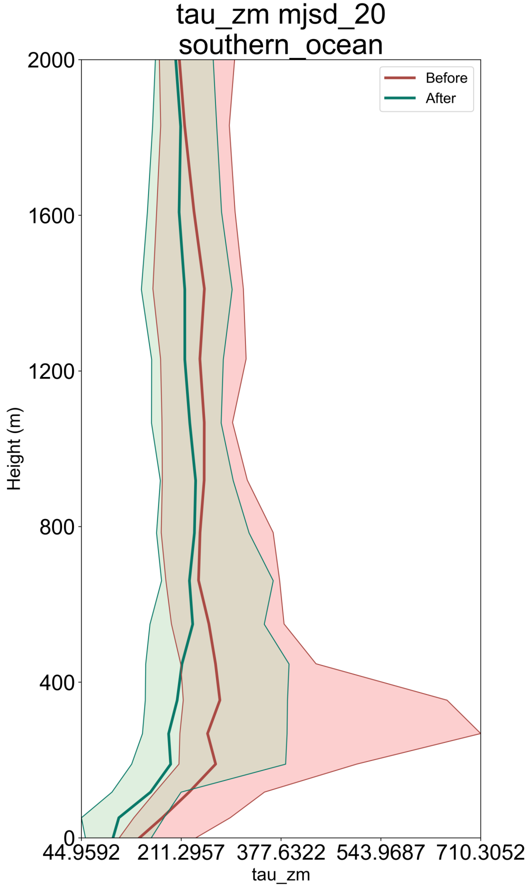
$$\frac{C_6}{\tau}\overline{u'w'}$$

Increasing parameter increases the inverse of the eddy timescale, thus increasing the return-to-isotropy term

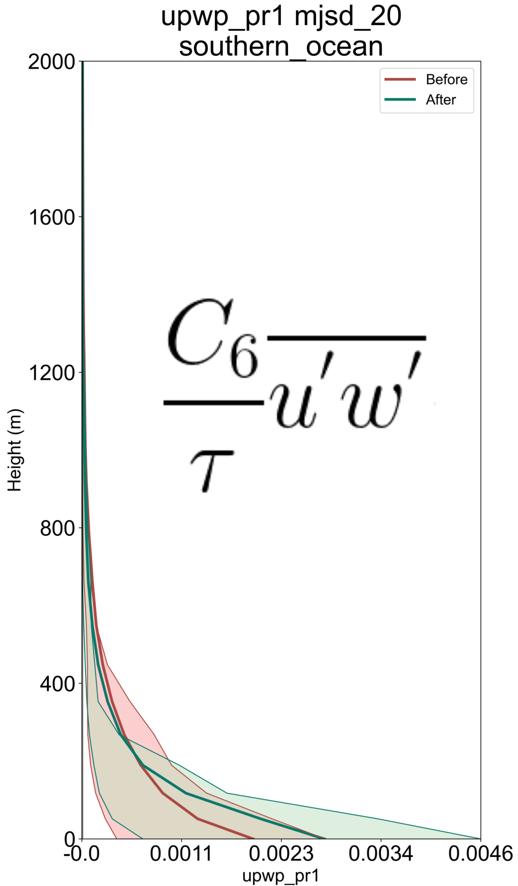


Increasing the magnitude of the return-to-isotropy term reduces the time tendency of vertical momentum flux

We can track the impact of increasing one of these terms ($C_{invrs\_tau,shear}$) through the CLUBBX equations



Increasing parameter increases eddy dissipation and reduces the eddy turnover timescale/turbulent length scale



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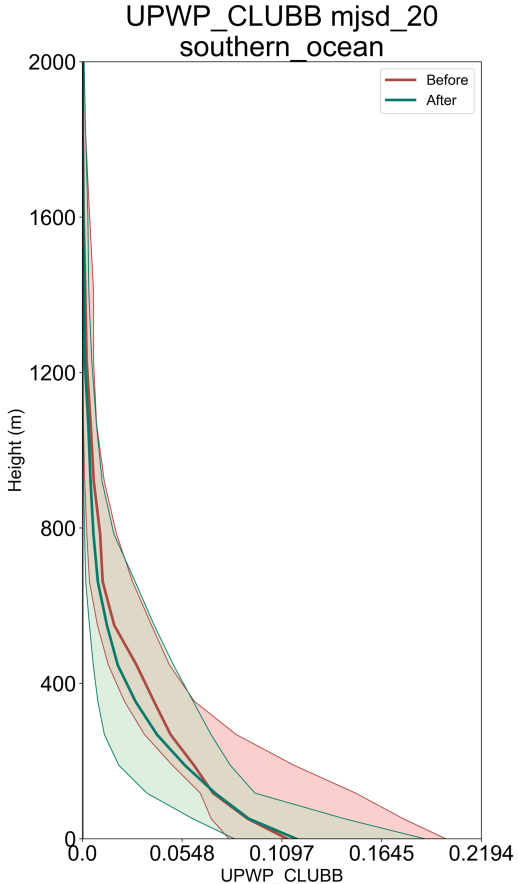

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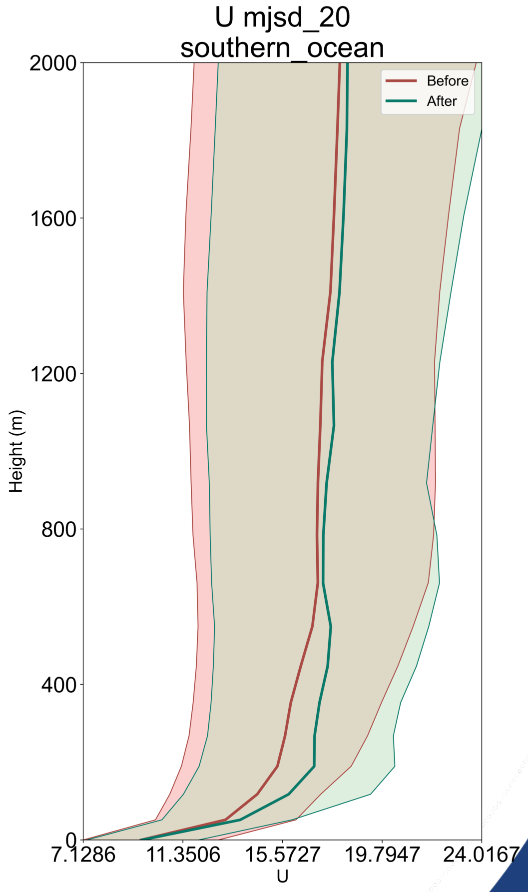

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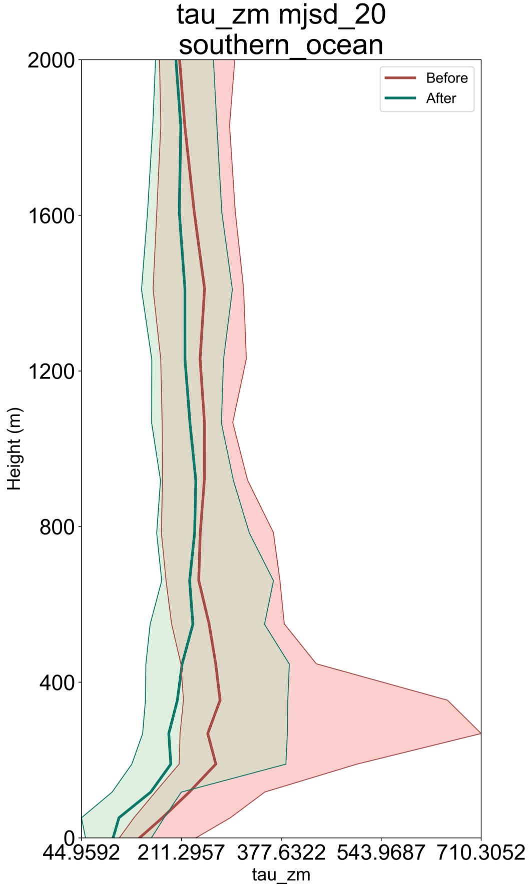
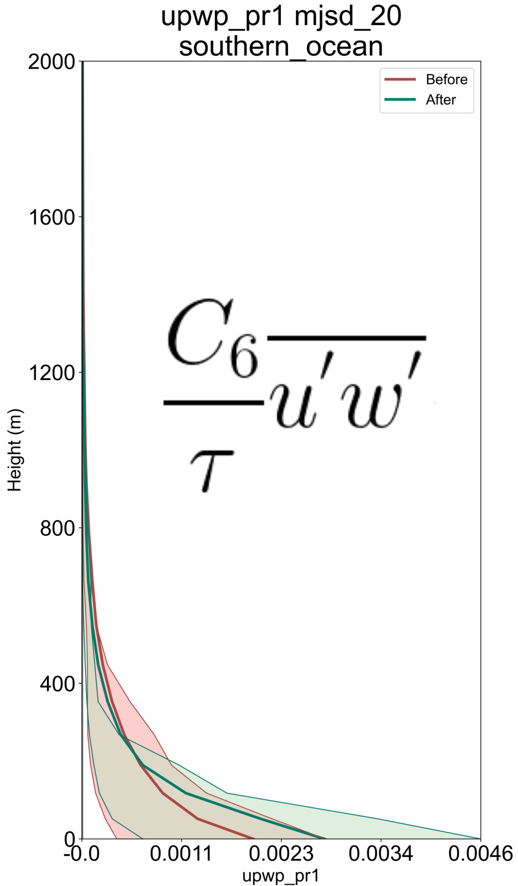
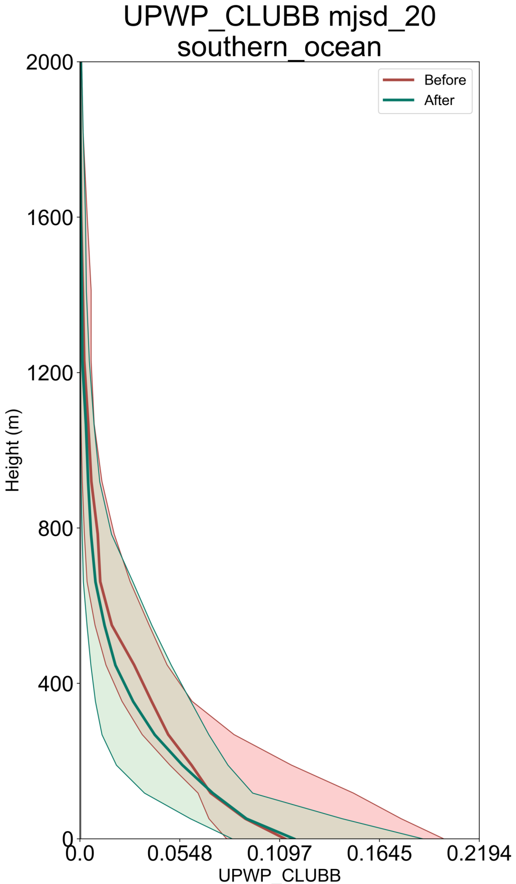

tau_zm mjsd_20
southern_ocean

Increasing parameter increases eddy dissipation and reduces the eddy turnover timescale/turbulent length scale

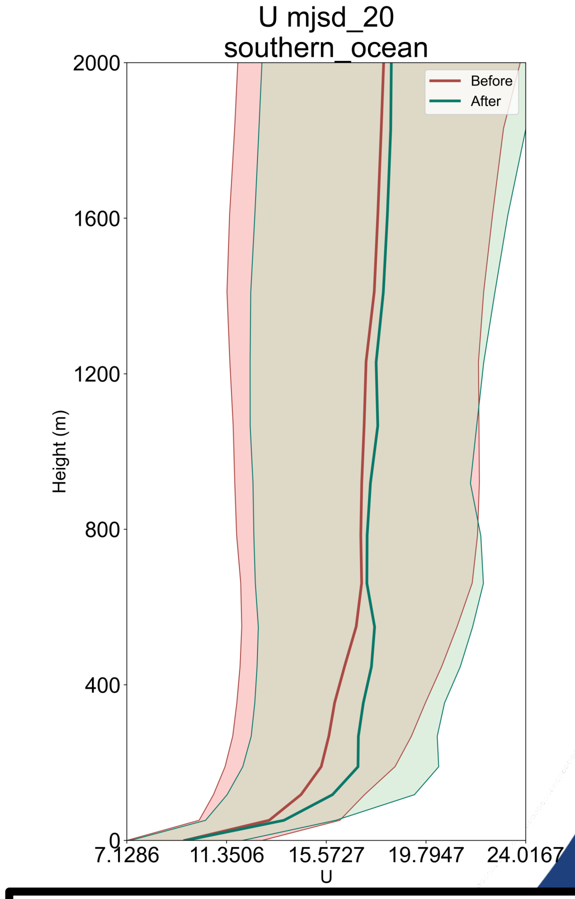

upwp_pr1 mjsd_20
southern_ocean

$$\frac{C_6}{\tau}\overline{u'w'}$$

Increasing parameter increases the inverse of the eddy timescale, thus increasing the return-to-isotropy term


UPWP_CLUBB mjsd_20
southern_ocean

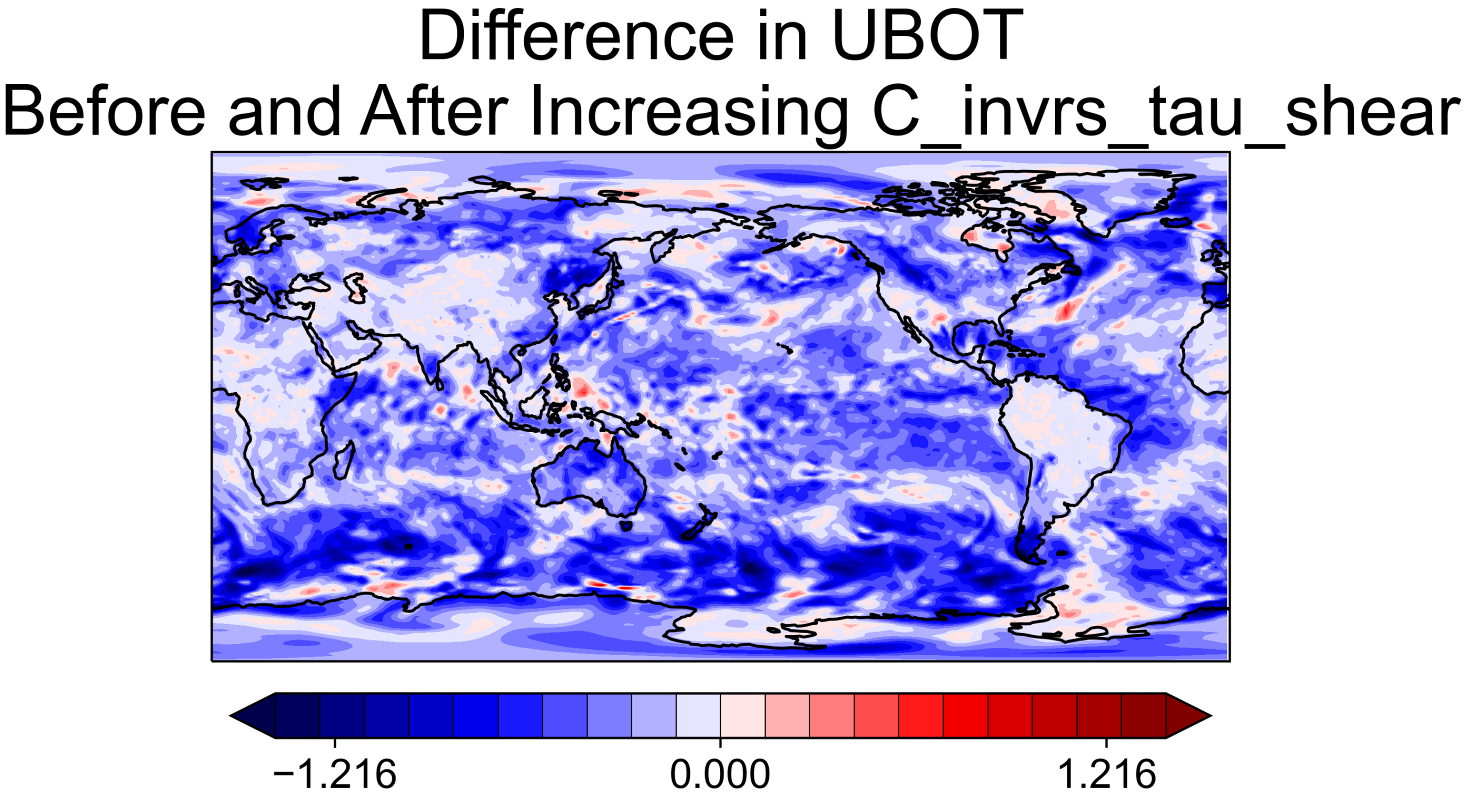
Increasing the magnitude of the return-to-isotropy term reduces the time tendency of vertical momentum flux


U mjsd_20
southern_ocean

Reducing the magnitude of vertical momentum flux reduces the mixing of stronger winds down to the surface

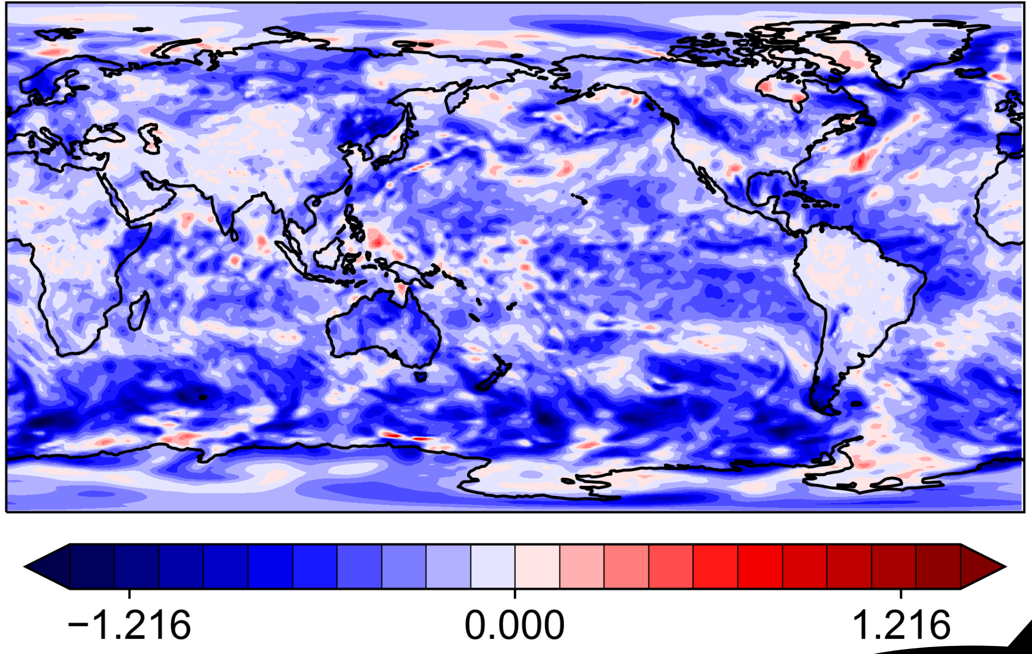
With reduced near-surface wind speeds, surface wind stress is reduced

With reduced near-surface wind speeds, surface wind stress is reduced



After Avg. = 5.68563   Before Avg. = 5.99972   Diff = -0.31409

With reduced near-surface wind speeds, surface wind stress is reduced

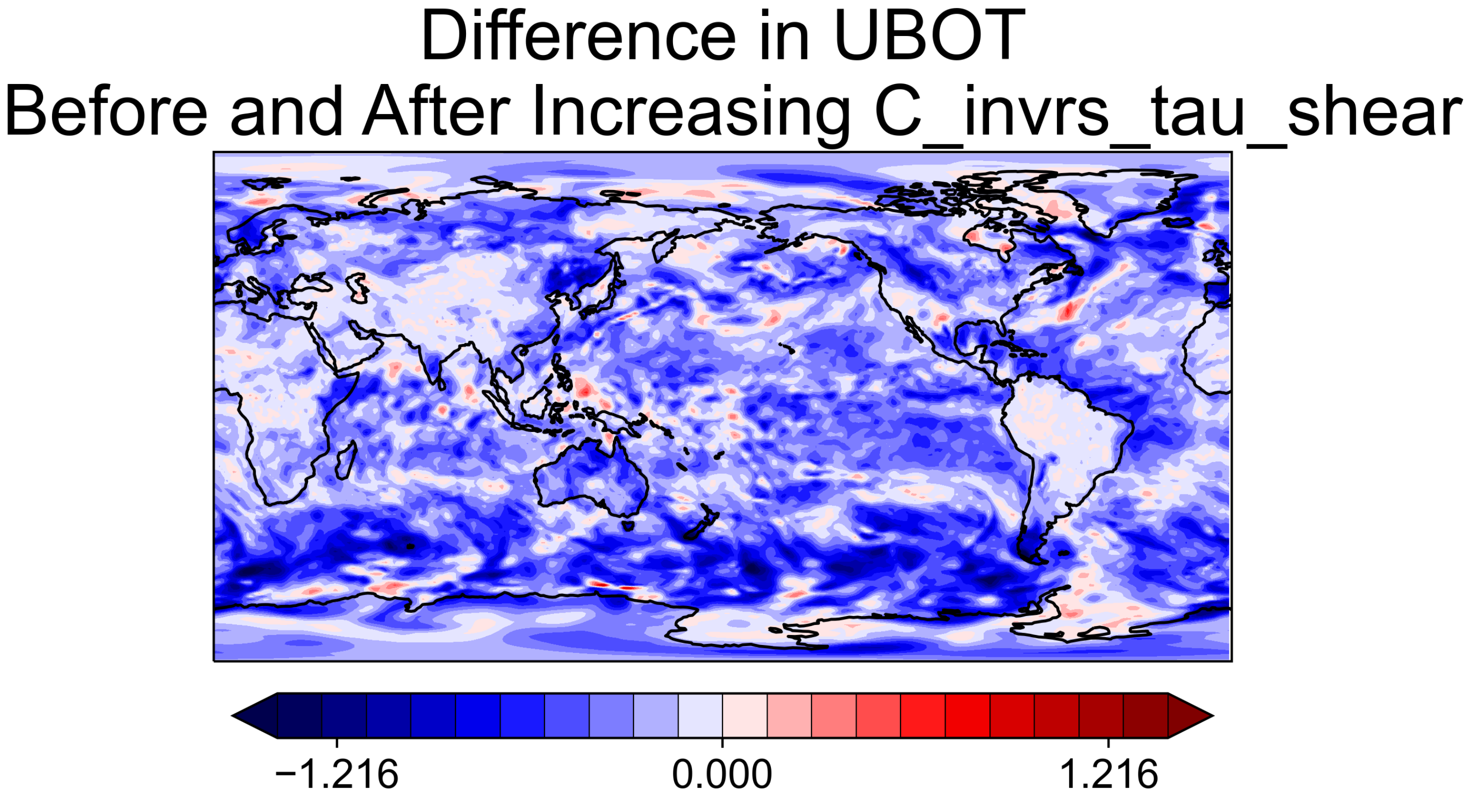


Difference in UBOT
Before and After Increasing C_invrs_tau_shear

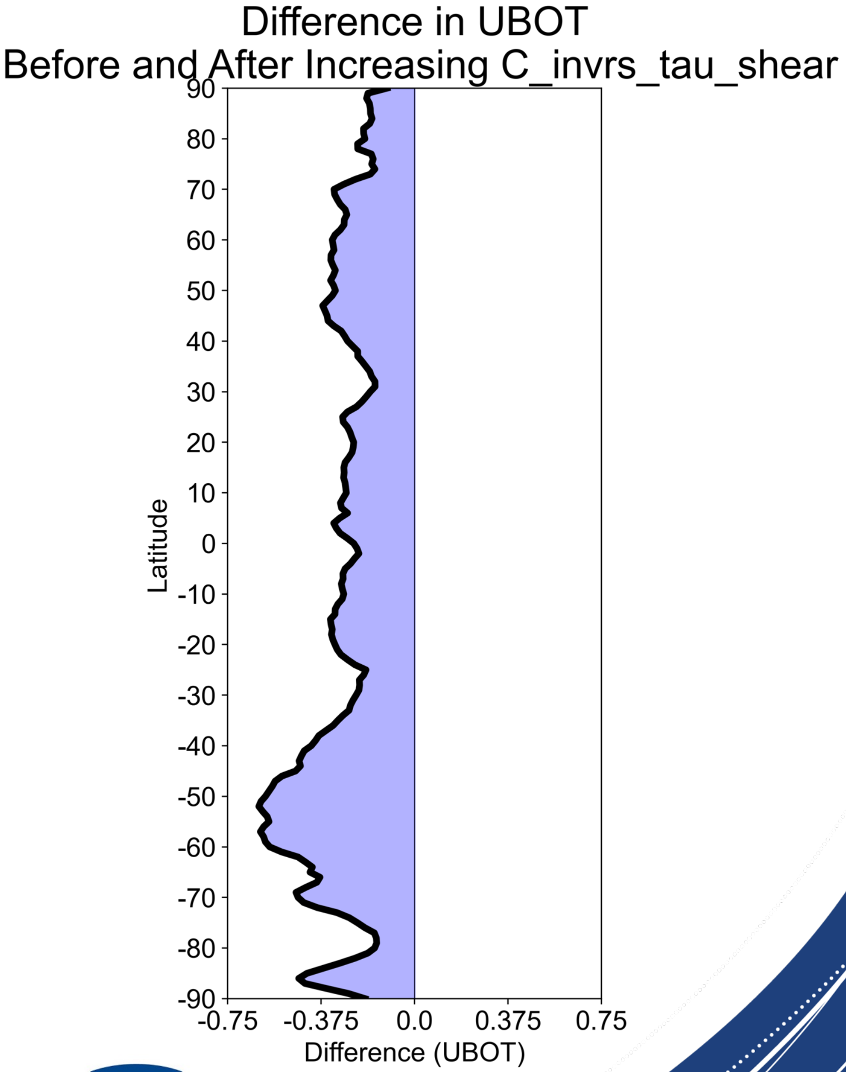
After Avg. = 5.68563 Before Avg. = 5.99972 Diff = -0.31409

Difference in globally-averaged near-surface wind between “before” and “after” configs

With reduced near-surface wind speeds, surface wind stress is reduced

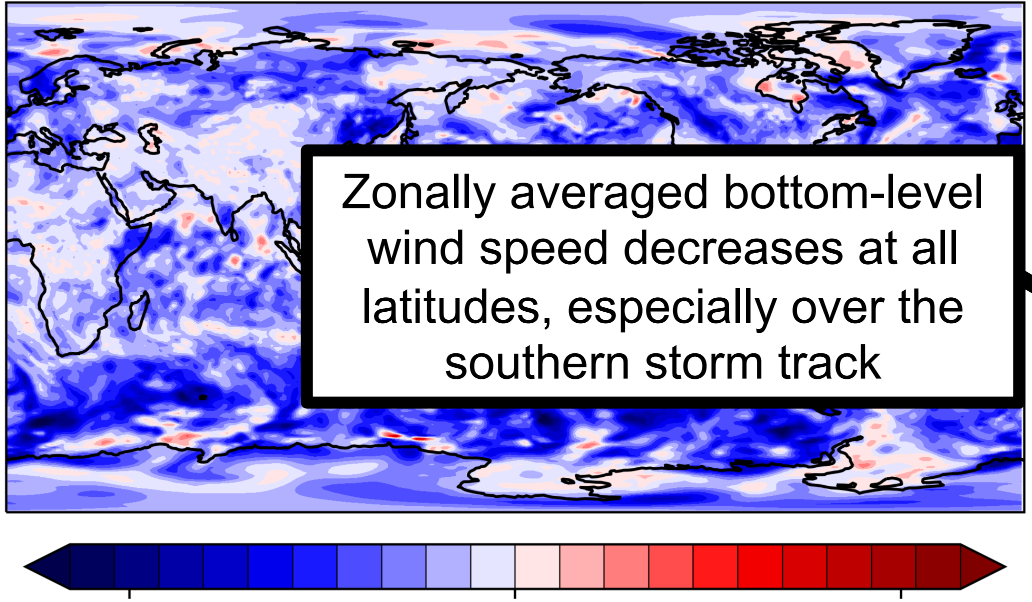


After Avg. = 5.68563 Before Avg. = 5.99972 Diff = -0.31409



With reduced near-surface wind speeds, surface wind stress is reduced

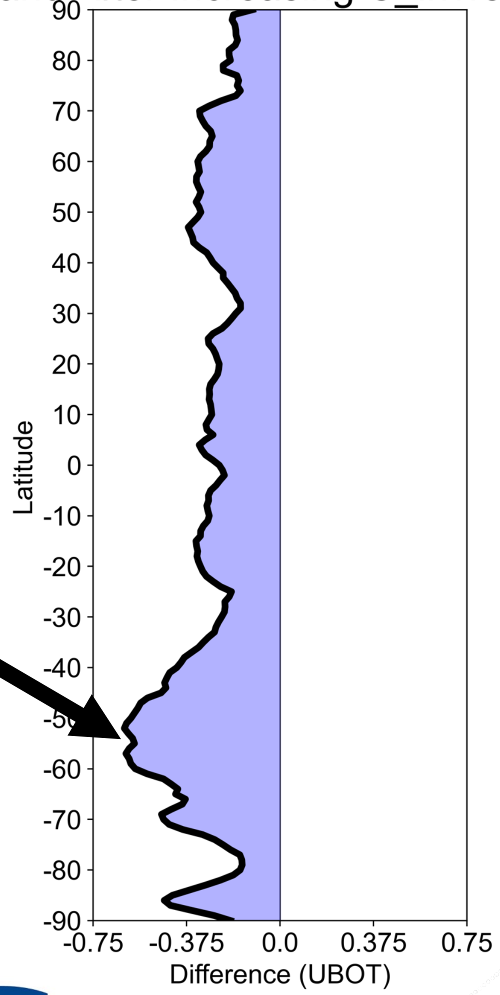
Difference in UBOT
Before and After Increasing C_invrs_tau_shear



Zonally averaged bottom-level wind speed decreases at all latitudes, especially over the southern storm track

After Avg. = 5.68563   Before Avg. = 5.99972   Diff = -0.31409

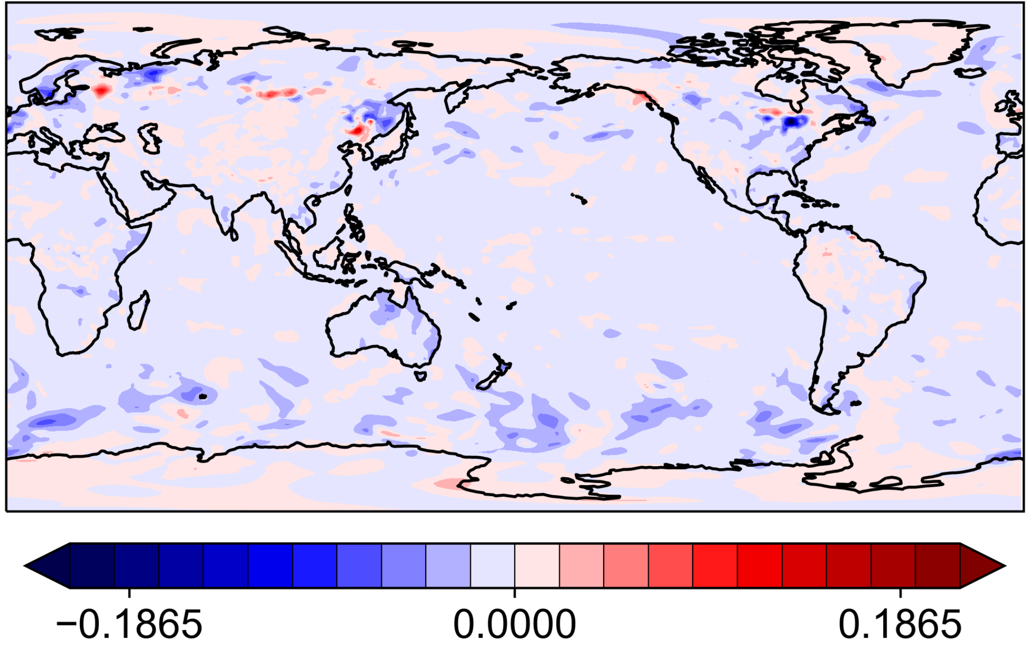
Difference in UBOT
Before and After Increasing C_invrs_tau_shear



With reduced near-surface wind speeds, surface wind stress is reduced

With reduced near-surface wind speeds, surface wind stress is reduced

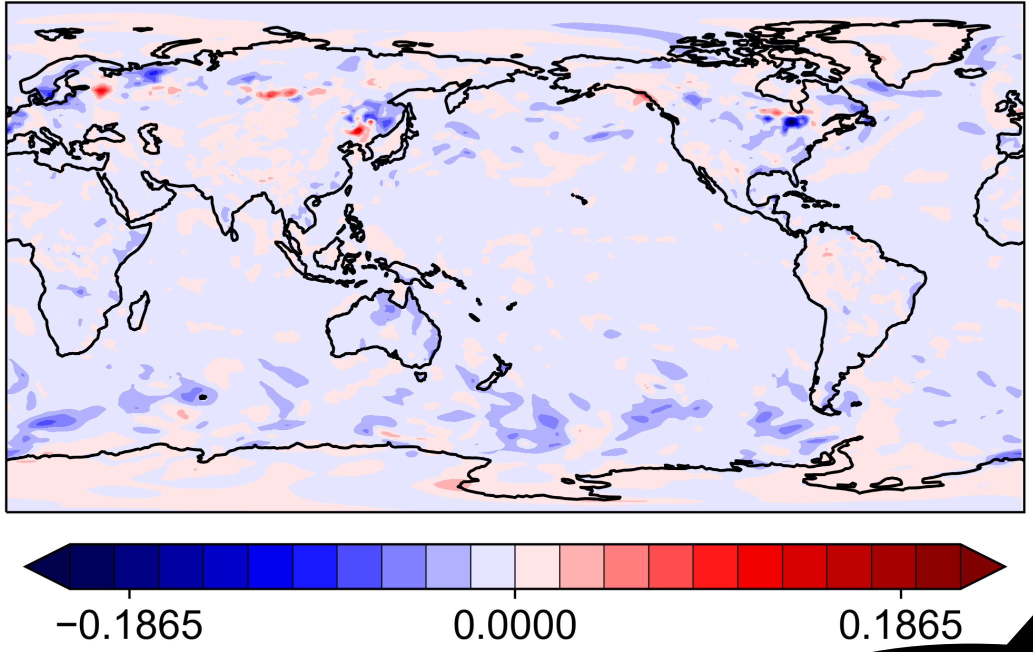
Difference in TAU
Before and After Increasing C_invrs_tau_shear



After Avg. = 0.10154 Before Avg. = 0.10774 Diff = -0.0062

Kyle M. Nardi CESM Workshop-June 2023 kmn182@psu.edu PennState

With reduced near-surface wind speeds, surface wind stress is reduced

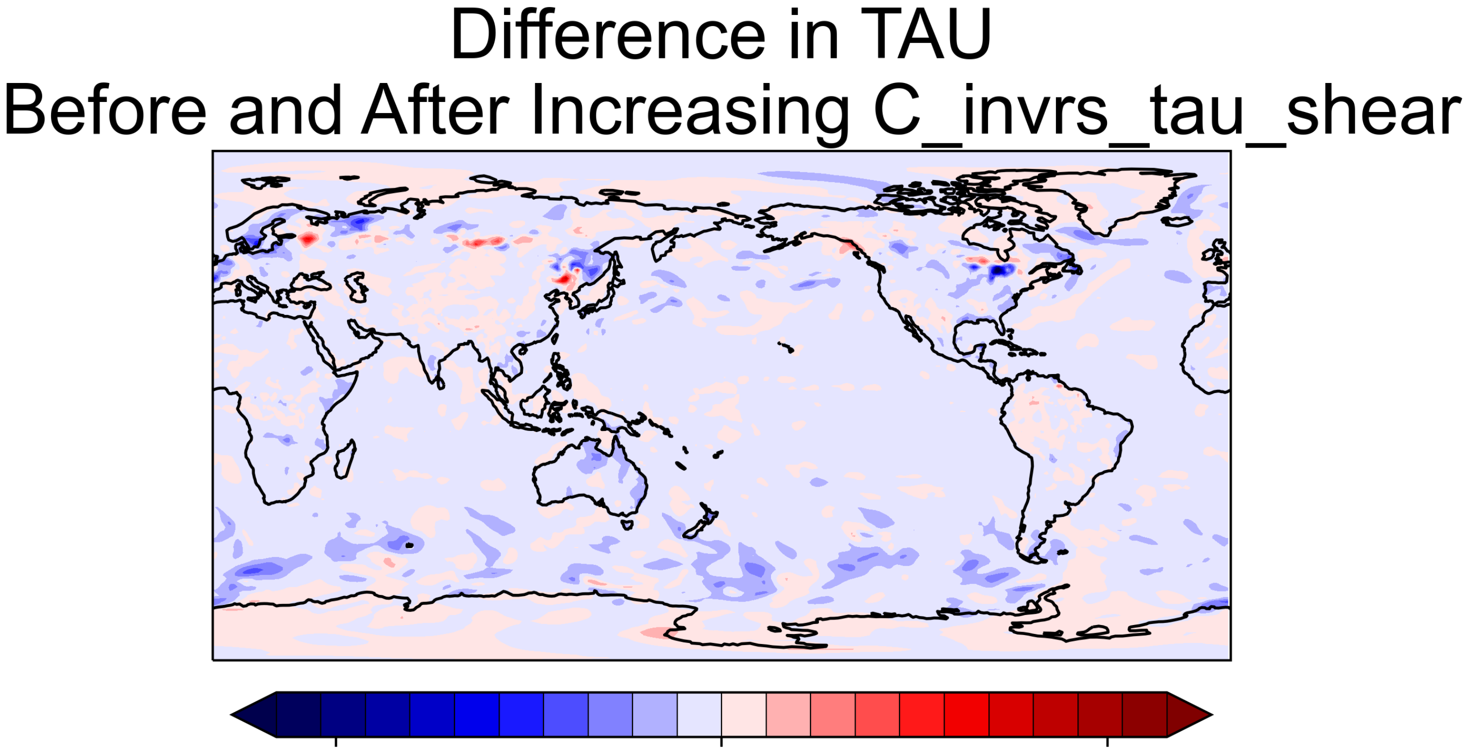


Difference in TAU
Before and After Increasing C_invrs_tau_shear

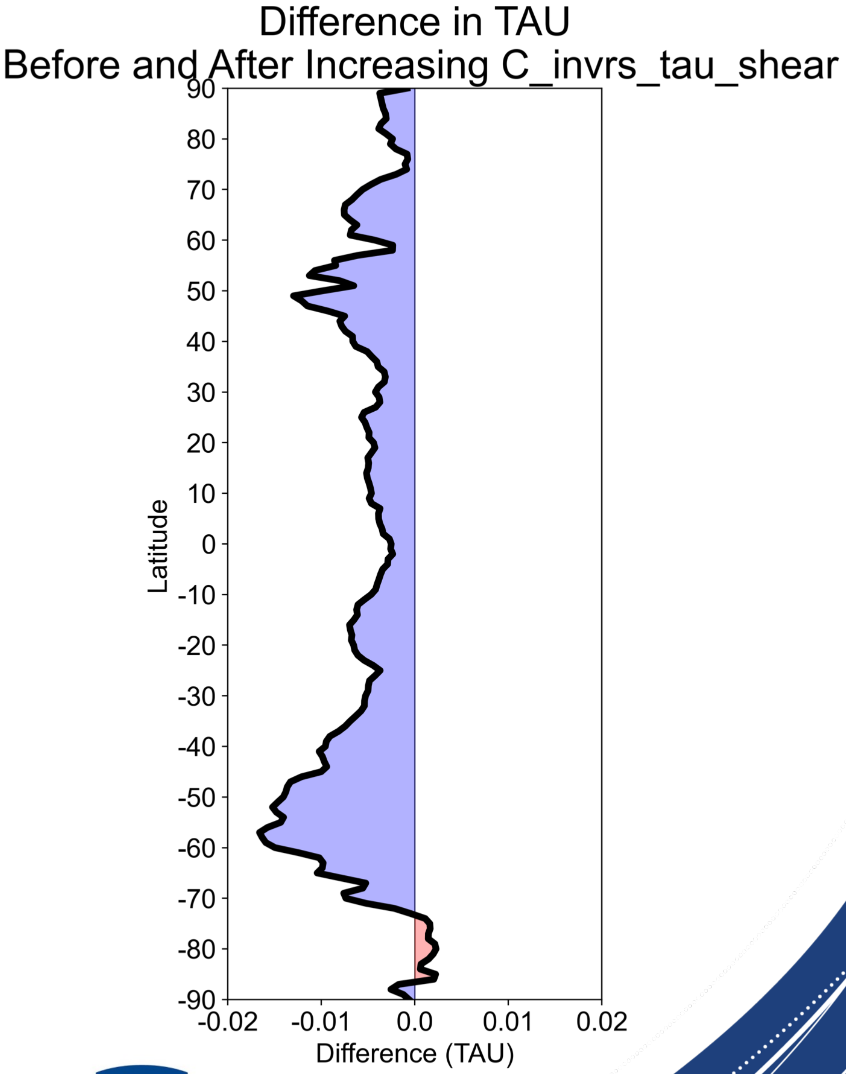
After Avg. = 0.10154   Before Avg. = 0.10774   Diff = -0.0062

Difference in globally-averaged surface stress between “before” and “after” configs

With reduced near-surface wind speeds, surface wind stress is reduced

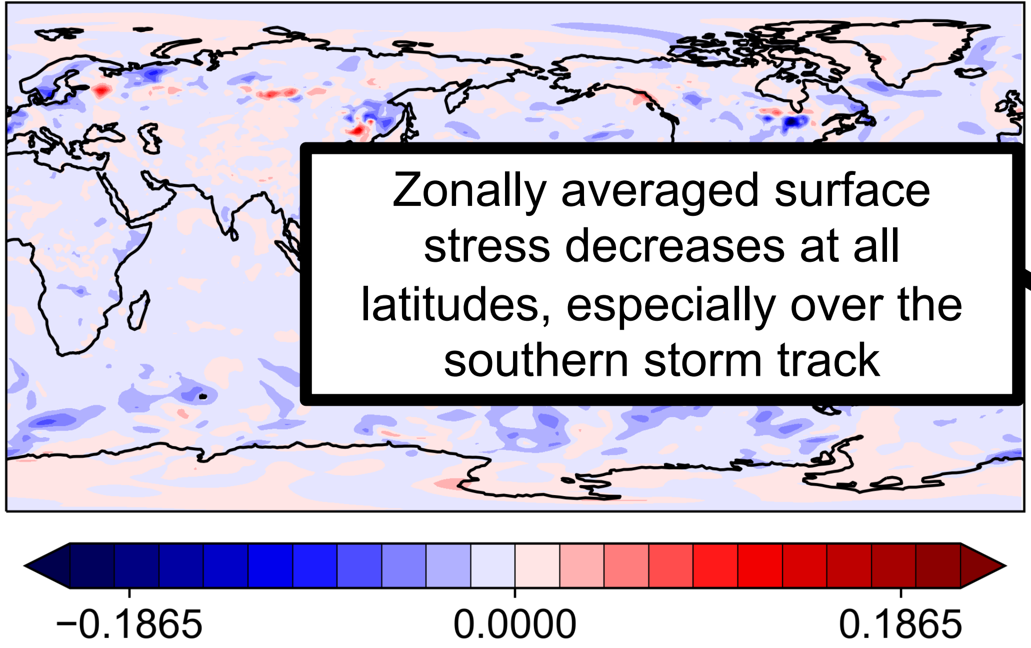


After Avg. = 0.10154 Before Avg. = 0.10774 Diff = -0.0062



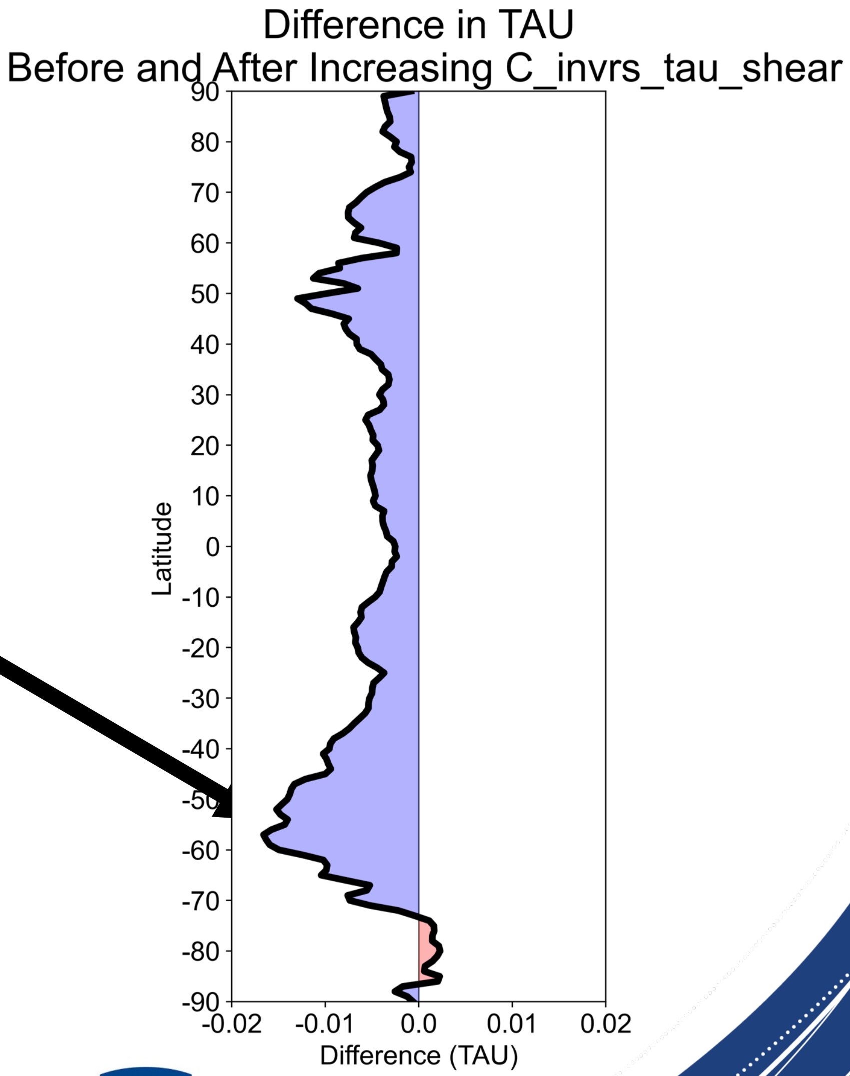
With reduced near-surface wind speeds, surface wind stress is reduced

Difference in TAU
Before and After Increasing C_invrs_tau_shear



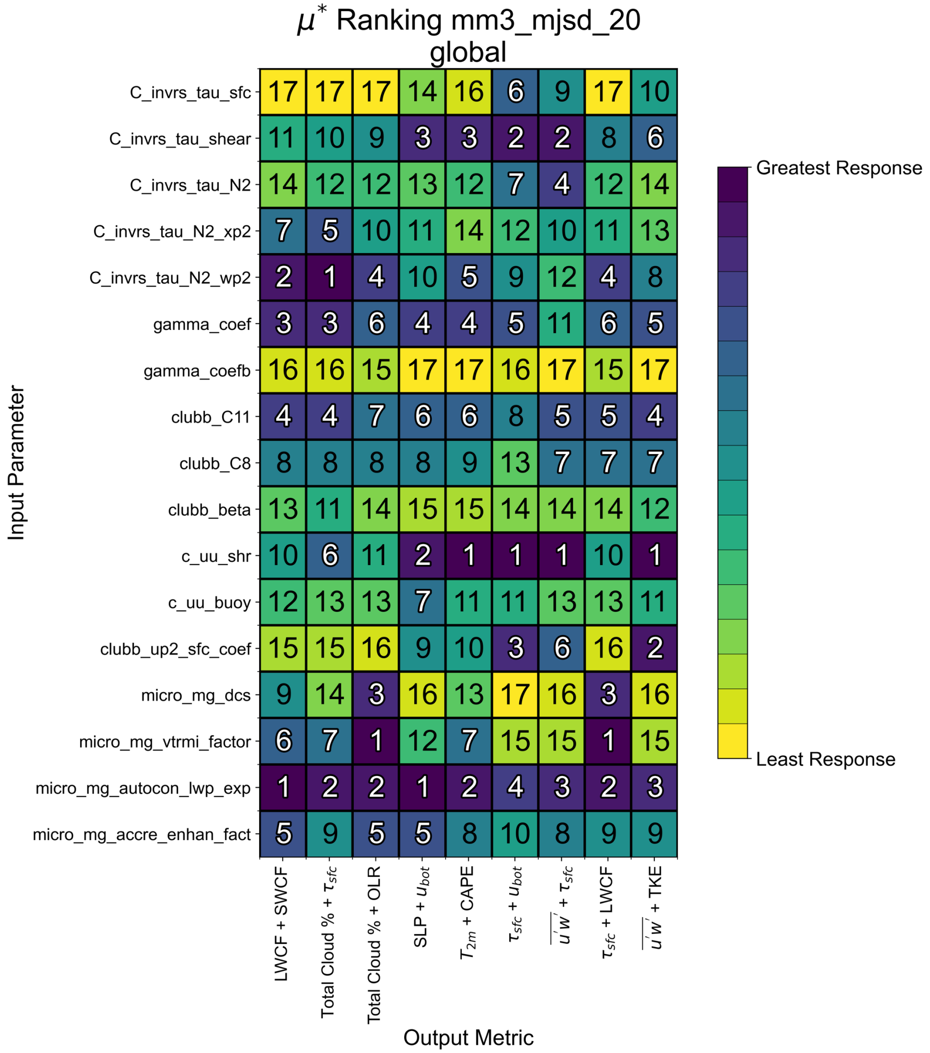
Zonally averaged surface stress decreases at all latitudes, especially over the southern storm track

After Avg. = 0.10154 Before Avg. = 0.10774 Diff = -0.0062



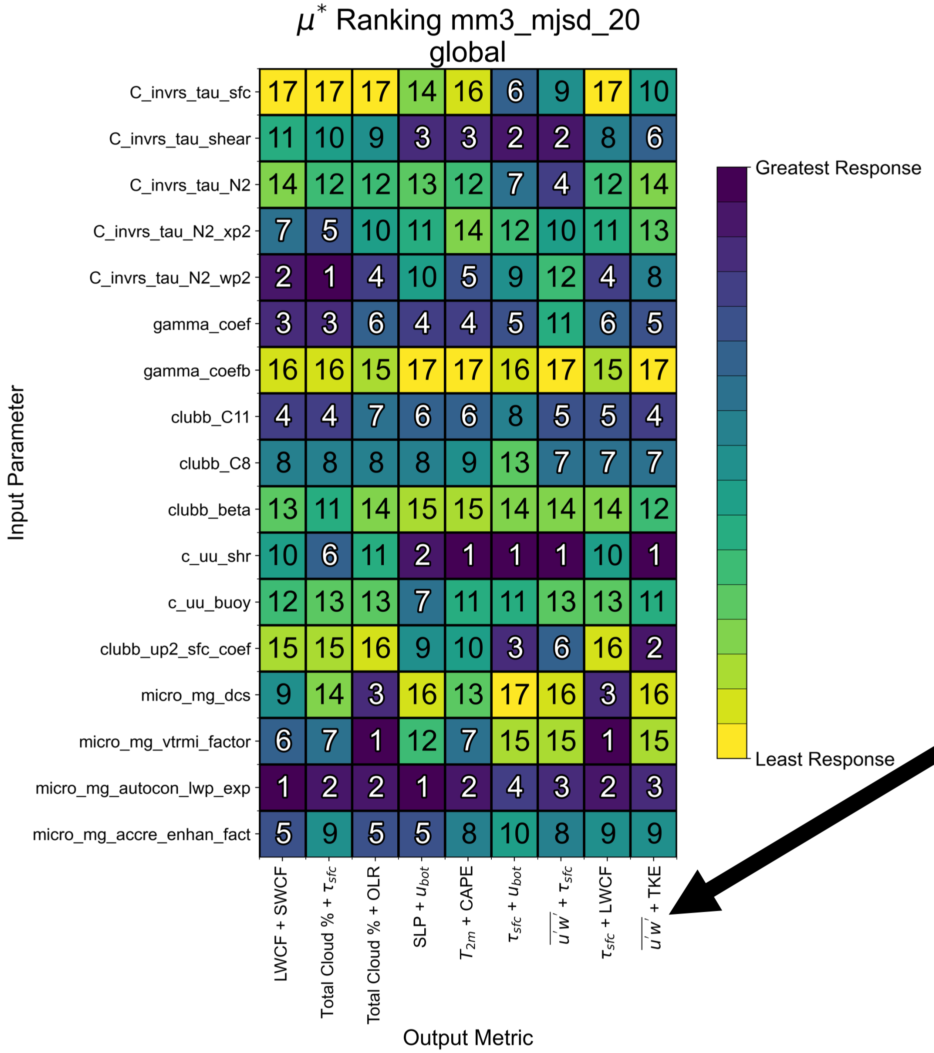
Kyle M. Nardi CESM Workshop-June 2023 kmn182@psu.edu PennState

Ongoing Work: we can repeat the sensitivity analysis for combined globally-averaged metrics



Input Parameter	LWCF + SWCF	Total Cloud % + τ_{sfc}	Total Cloud % + OLR	SLP + u_{bot}	T_{2m} + CAPE	τ_{sfc} + u_{bot}	$\overline{u^{'}w^{'}}$ + τ_{sfc}	τ_{sfc} + LWCF	$\overline{u^{'}w^{'}}$ + TKE
C_invrs_tau_sfc	17	17	17	14	16	6	9	17	10
C_invrs_tau_shear	11	10	9	3	3	2	2	8	6
C_invrs_tau_N2	14	12	12	13	12	7	4	12	14
C_invrs_tau_N2_xp2	7	5	10	11	14	12	10	11	13
C_invrs_tau_N2_wp2	2	1	4	10	5	9	12	4	8
gamma_coef	3	3	6	4	4	5	11	6	5
gamma_coefb	16	16	15	17	17	16	17	15	17
clubb_C11	4	4	7	6	6	8	5	5	4
clubb_C8	8	8	8	8	9	13	7	7	7
clubb_beta	13	11	14	15	15	14	14	14	12
c_uu_shr	10	6	11	2	1	1	1	10	1
c_uu_buoy	12	13	13	7	11	11	13	13	11
clubb_up2_sfc_coef	15	15	16	9	10	3	6	16	2
micro_mg_dcs	9	14	3	16	13	17	16	3	16
micro_mg_vtrmi_factor	6	7	1	12	7	15	15	1	15
micro_mg_autocon_lwp_exp	1	2	2	1	2	4	3	2	3
micro_mg_accre_enhan_fact	5	9	5	5	8	10	8	9	9

Ongoing Work: we can repeat the sensitivity analysis for combined globally-averaged metrics



μ^* Ranking mm3_mjsd_20 global

Input Parameter	LWCF + SWCF	Total Cloud % + τ_{sfc}	Total Cloud % + OLR	SLP + u_{bot}	T_{2m} + CAPE	τ_{sfc} + u_{bot}	$\overline{u^{'}w^{'}}$ + τ_{sfc}	τ_{sfc} + LWCF	$\overline{u^{'}w^{'}}$ + TKE
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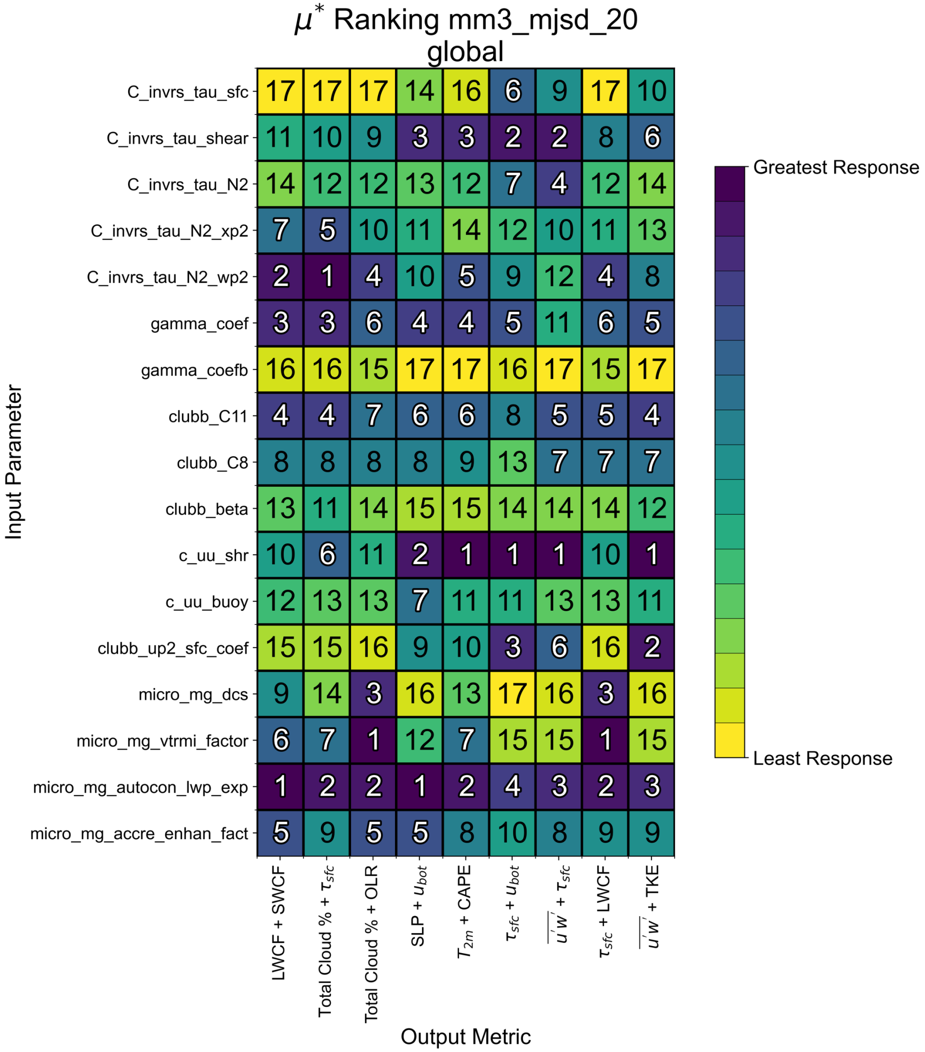
gamma_coef	3	3	6	4	4	5	11	6	5
gamma_coefb	16	16	15	17	17	16	17	15	17
clubb_C11	4	4	7	6	6	8	5	5	4
clubb_C8	8	8	8	8	9	13	7	7	7
clubb_beta	13	11	14	15	15	14	14	14	12
c_uu_shr	10	6	11	2	1	1	1	10	1
c_uu_buoy	12	13	13	7	11	11	13	13	11
clubb_up2_sfc_coef	15	15	16	9	10	3	6	16	2
micro_mg_dcs	9	14	3	16	13	17	16	3	16
micro_mg_vtrmi_factor	6	7	1	12	7	15	15	1	15
micro_mg_autocon_lwp_exp	1	2	2	1	2	4	3	2	3
micro_mg_accre_enhan_fact	5	9	5	5	8	10	8	9	9

Output Metric

Linear combinations of two globally-averaged output metrics

Ongoing Work: we can repeat the sensitivity analysis for combined globally-averaged metrics



μ^* Ranking mm3_mjsd_20 global

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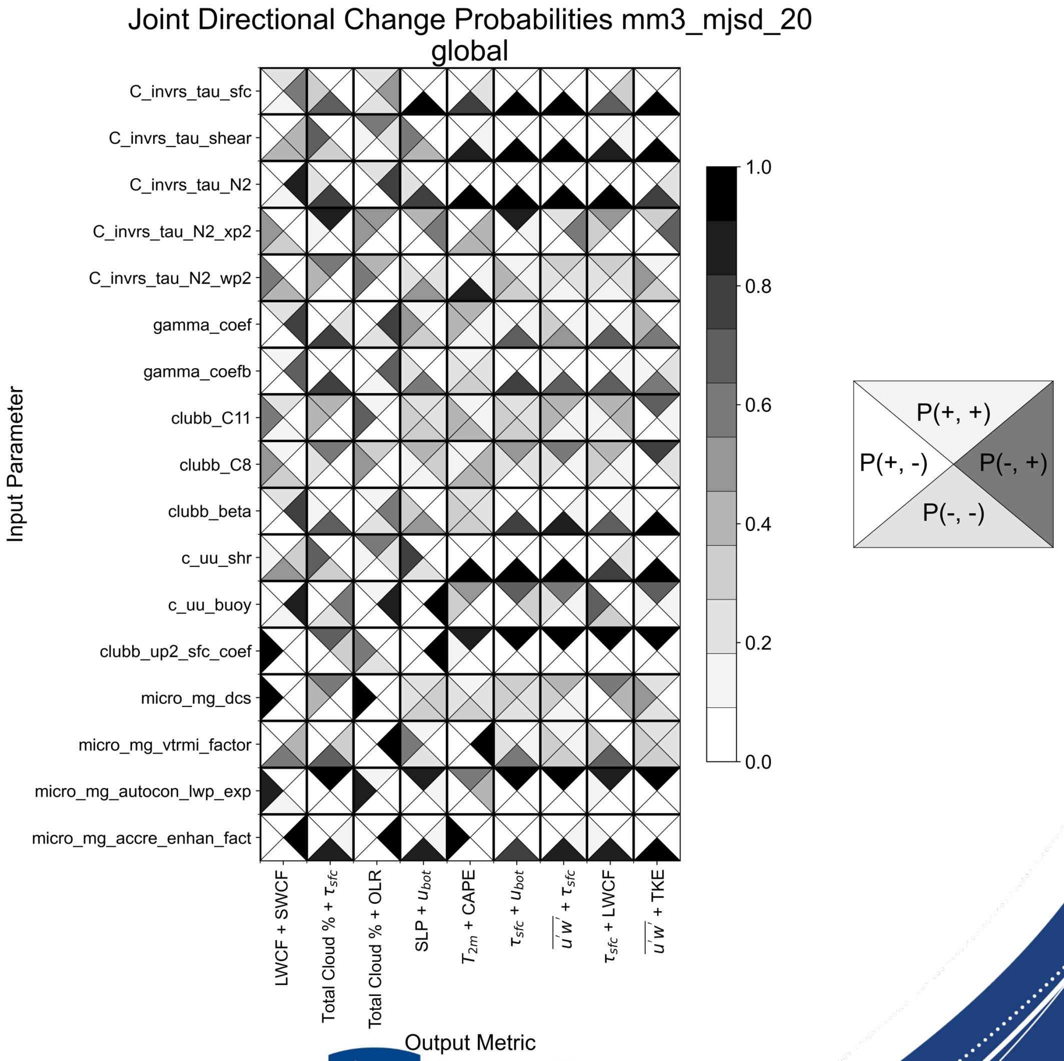
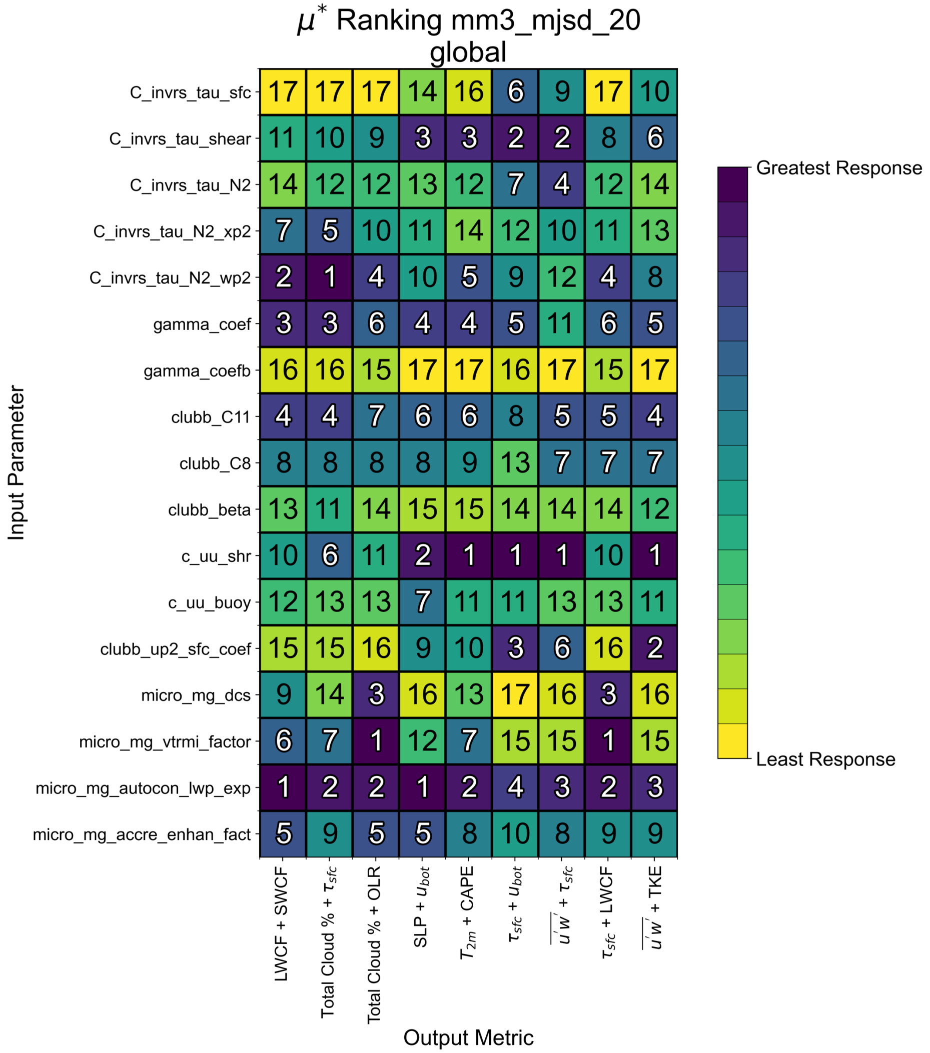
micro_mg_vtrmi_factor	6	7	1	12	7	15	15	1	15
micro_mg_autocon_lwp_exp	1	2	2	1	2	4	3	2	3
micro_mg_accre_enhan_fact	5	9	5	5	8	10	8	9	9



Joint Directional Change Probabilities mm3_mjsd_20 global

Ongoing Work: we can repeat the sensitivity analysis for combined globally-averaged metrics


μ^* Ranking mm3_mjsd_20
global

	LWCF + SWCF	Total Cloud % + τ_{sfc}	Total Cloud % + OLR	SLP + u_{bot}	T_{2m} + CAPE	τ_{sfc} + u_{bot}	$\overline{u'w'}$ + τ_{sfc}	τ_{sfc} + LWCF	$\overline{u'w'}$ + TKE
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clubb_C11	4	4	7	6	6	8	5	5	4
clubb_C8	8	8	8	8	9	13	7	7	7
clubb_beta	13	11	14	15	15	14	14	14	12
c_uu_shr	10	6	11	2	1	1	1	10	1
c_uu_buoy	12	13	13	7	11	11	13	13	11
clubb_up2_sfc_coef	15	15	16	9	10	3	6	16	2
micro_mg_dcs	9	14	3	16	13	17	16	3	16
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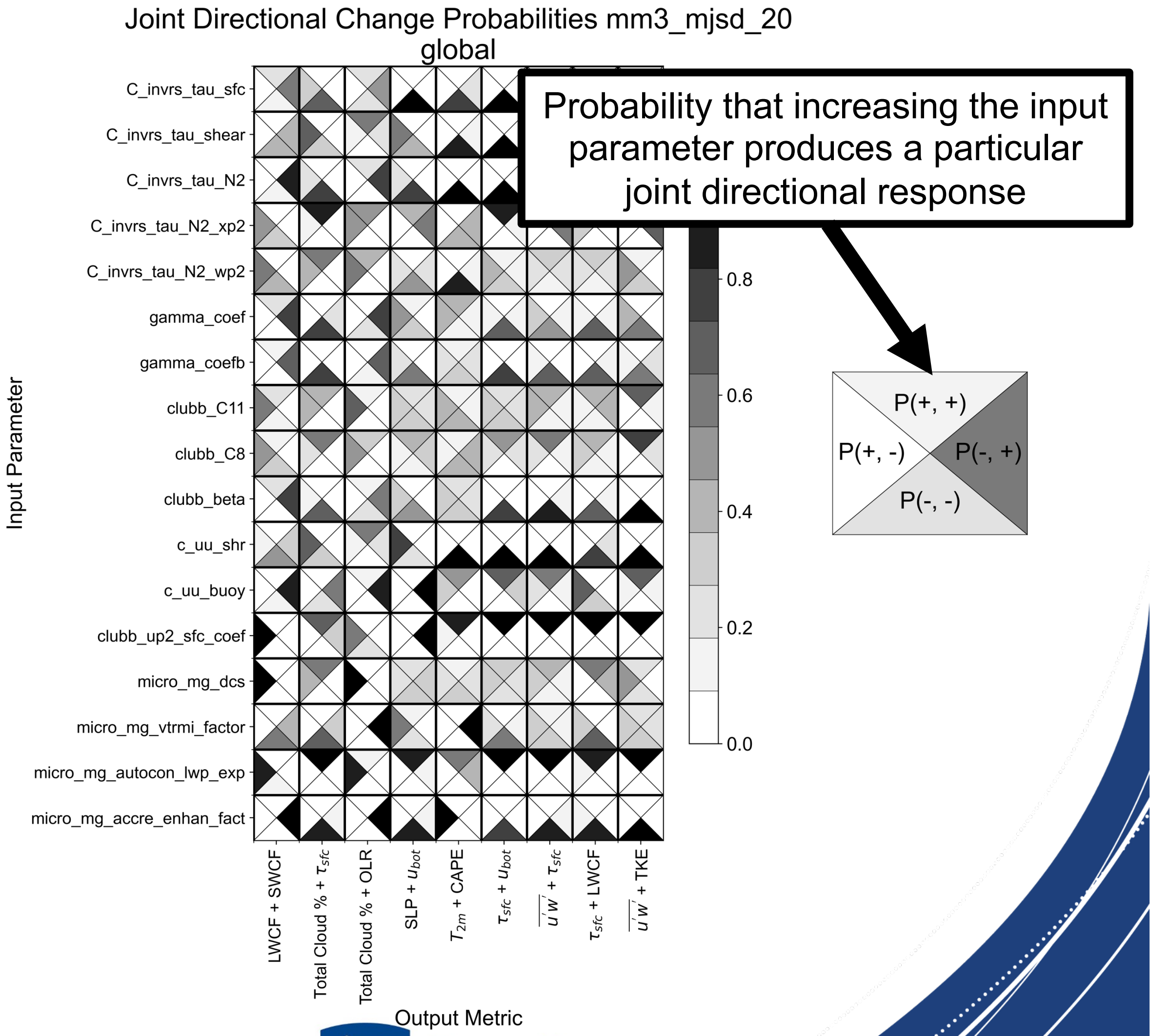
micro_mg_autocon_lwp_exp	1	2	2	1	2	4	3	2	3
micro_mg_accre_enhan_fact	5	9	5	5	8	10	8	9	9


Probability that increasing the input parameter produces a particular joint directional response

Main Takeaways

Additional Questions?
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Main Takeaways

- We can use a sensitivity analysis to highlight input parameters in CLUBB that influence regional biases in fields like SWCF (Tropical Pacific) and surface wind stress (Southern Ocean)

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- The impacts of perturbing these input parameters are related changes in budgets of turbulent fluxes like heat/moisture flux and momentum flux

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- **Future work: Apply the results of the sensitivity analysis for short-term hindcasts to longer-term simulations**

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- **Can we perturb a handful of input parameters in a 10-year, free-running simulation and reduce certain regional biases?**

We thank our partners in this work

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For more details about this 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.

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Main Takeaways

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Extra Slides

CLUBBX's formulation of inverse eddy turnover time scale depends on environmental conditions

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

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

CLUBBX's 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…

CLUBBX's formulation of inverse eddy turnover time scale depends on environmental conditions

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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…

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

CLUBBX's formulation of inverse eddy turnover time scale depends on environmental conditions

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← 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…

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

Background eddy dissipation
at all levels

CLUBBX's formulation of inverse eddy turnover time scale depends on environmental conditions

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

←

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…

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

↑

Eddy dissipation due to **surface effects**

kmn182@psu.edu

CLUBBX's 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…

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

↑

Eddy dissipation in
sheared flow

CLUBBX's formulation of inverse eddy turnover time scale depends on environmental conditions

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

←

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Eddy dissipation in **stable environment**

CLUBBX's formulation of inverse eddy turnover time scale depends on environmental conditions

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

We can track the impact of increasing one of these terms ($C_{N2,wp2}$) through the CLUBBX equations

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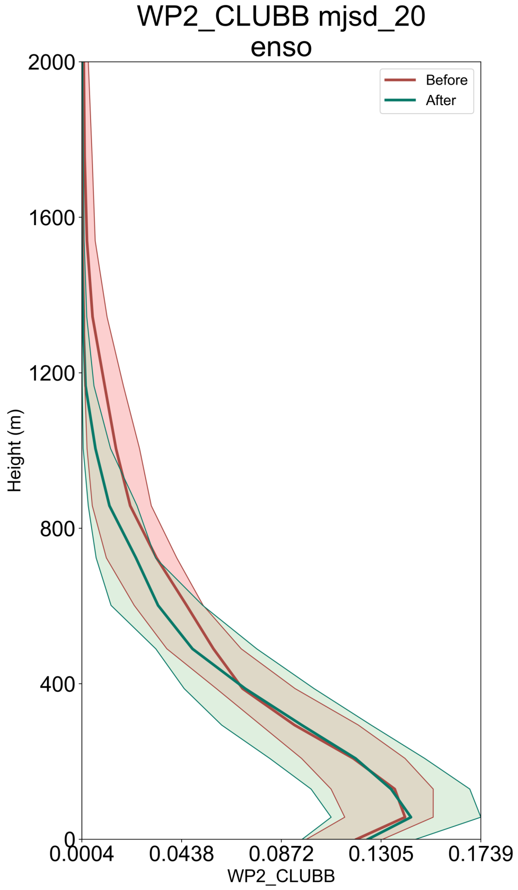

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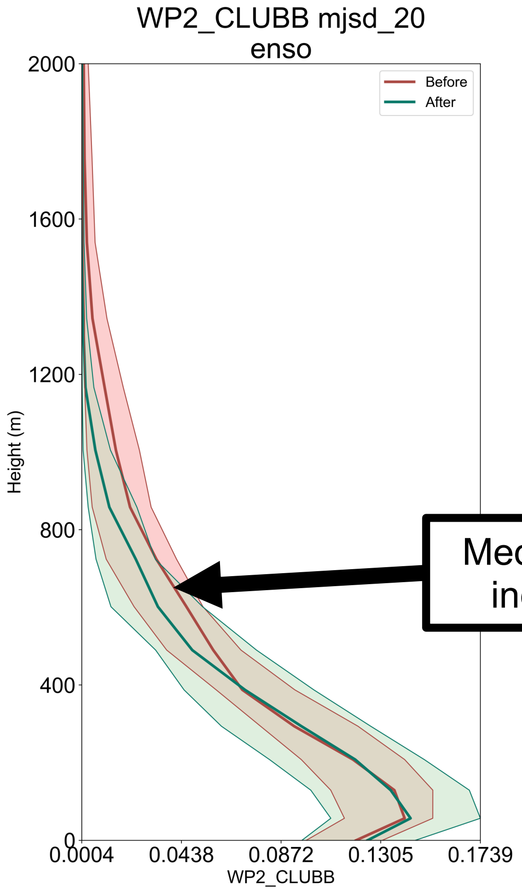

Median profile before increasing $C_{N2,wp2}$

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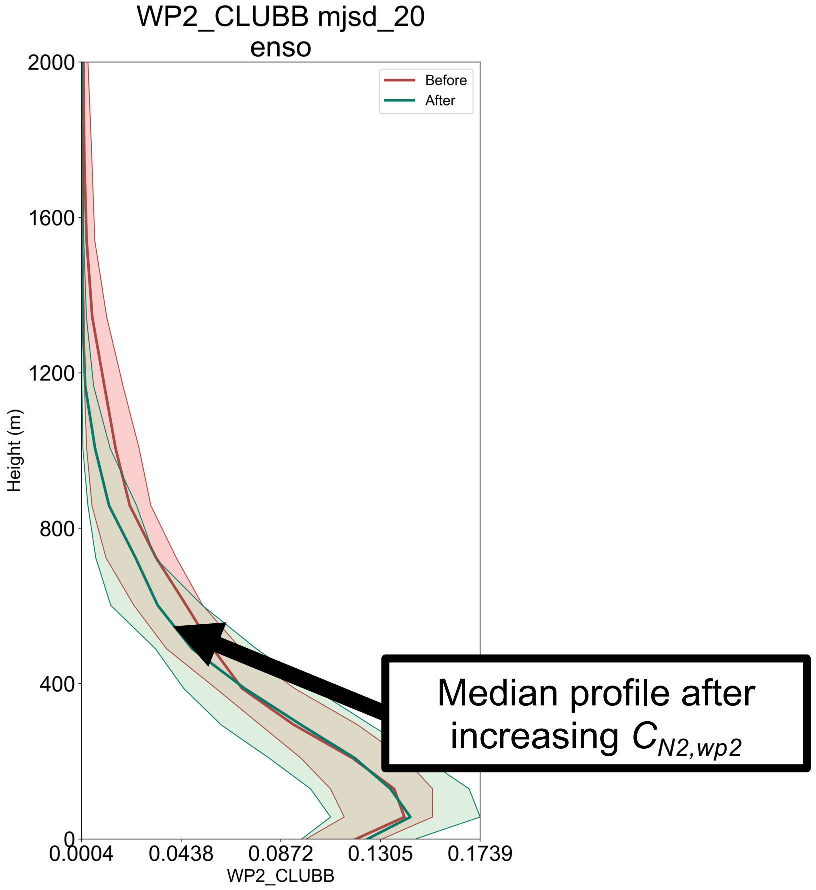

Median profile after increasing $C_{N2,wp2}$

Kyle M. Nardi

kmn182@psu.edu
PennState

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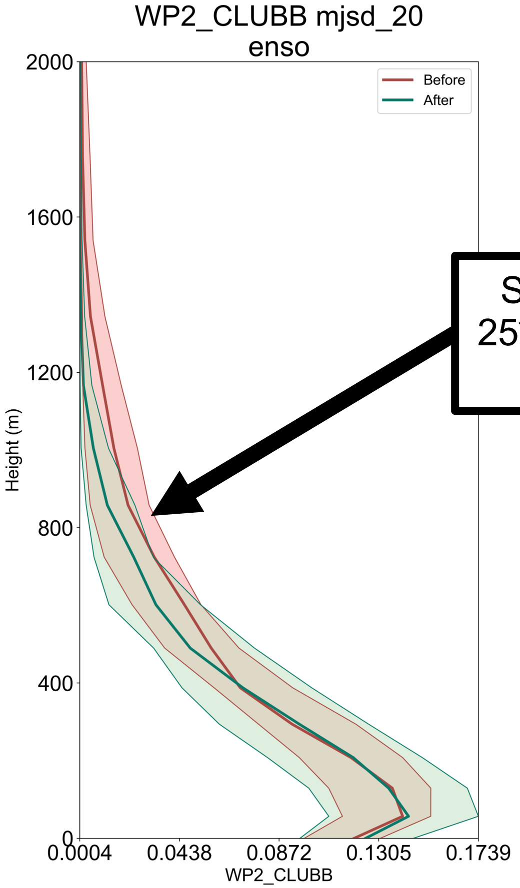

Shading represents the 25th-75th percentiles of the output at each level

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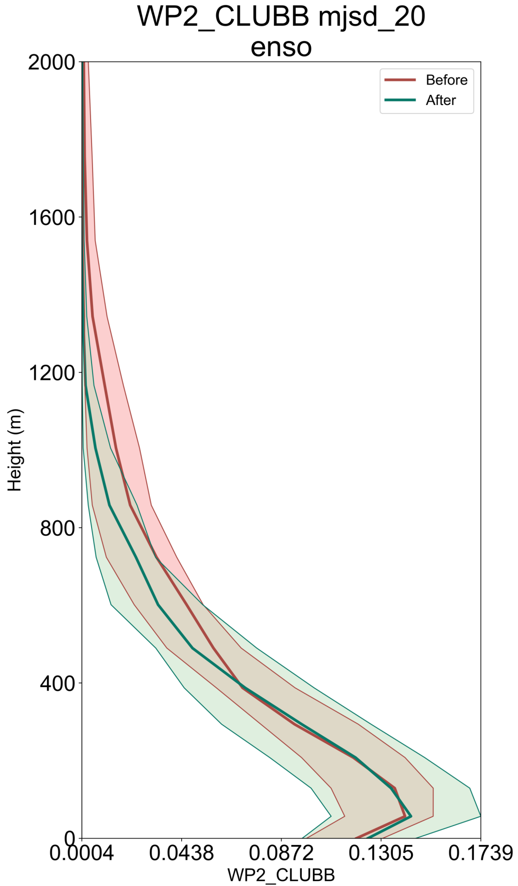

Increasing $C_{N2,wp2}$ dampens the vertical velocity variance where stable stratification exists, thus reducing wp2

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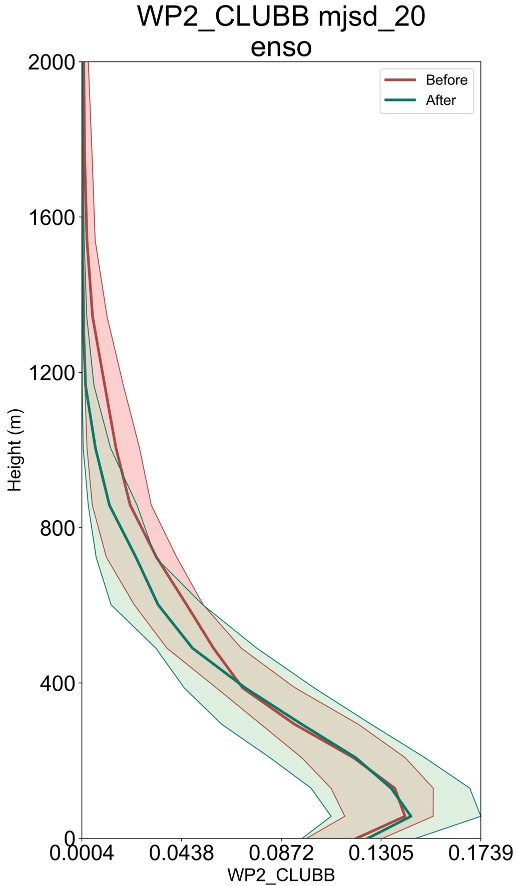

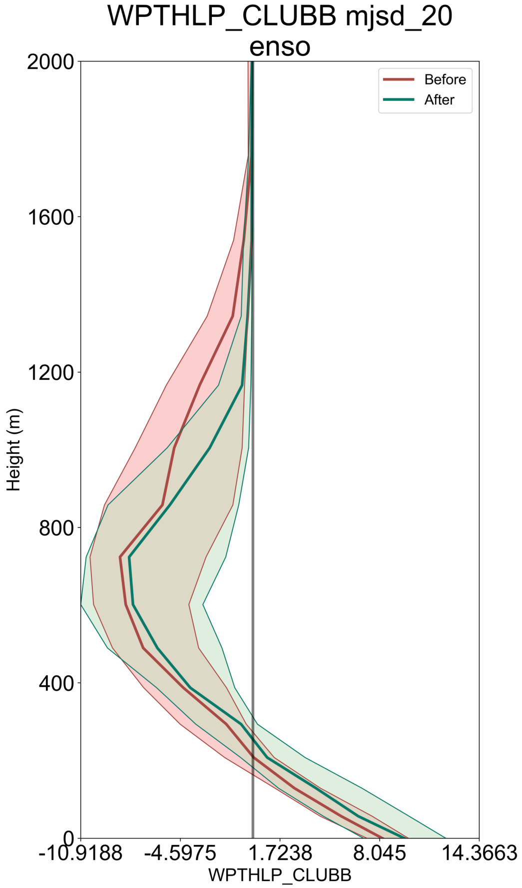

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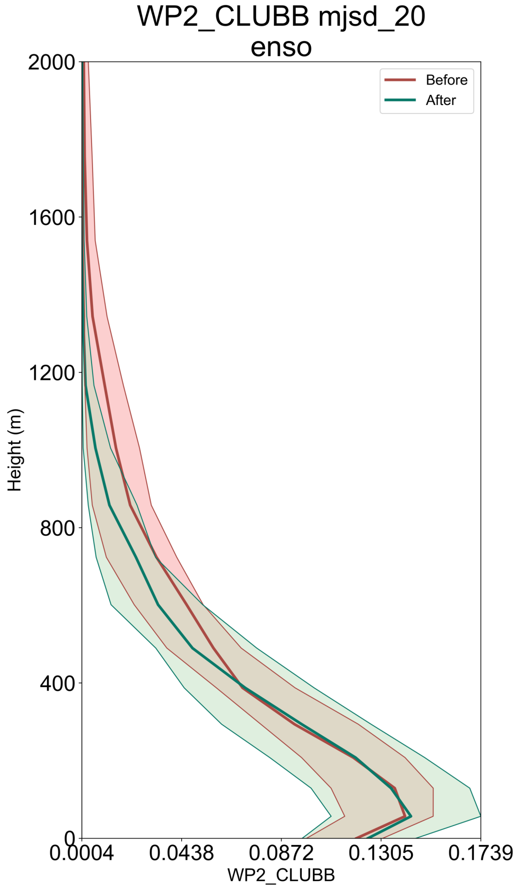

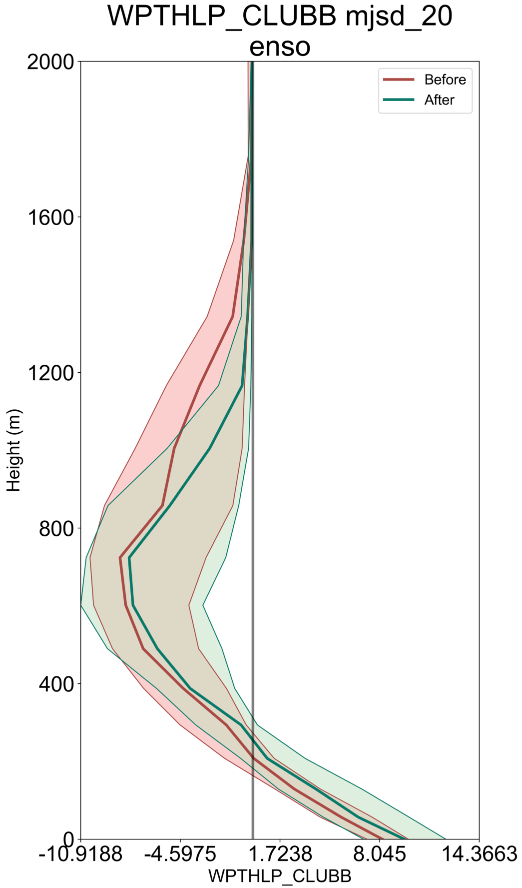

Increasing $C_{N2,wp2}$ dampens the vertical velocity variance where stable stratification exists, thus reducing wp2

Increasing $C_{N2,wp2}$ decreases the downward transport of higher θ_v air from above (increased stability)

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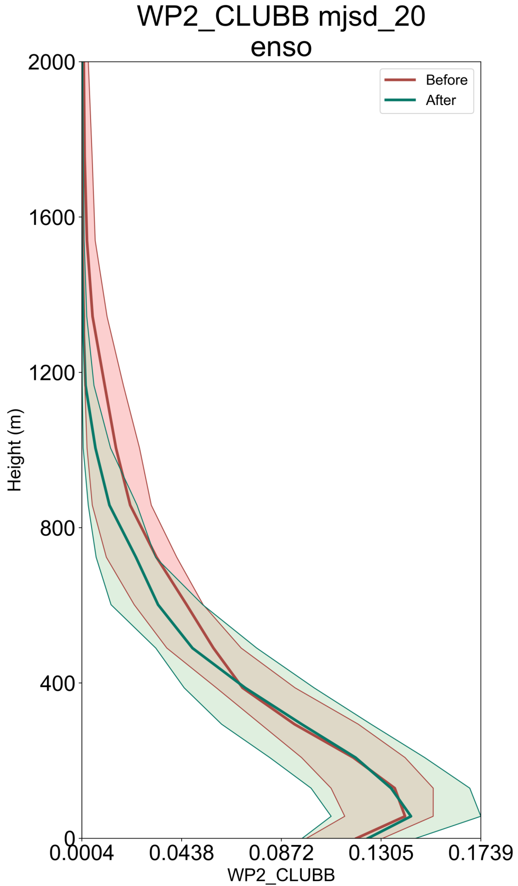

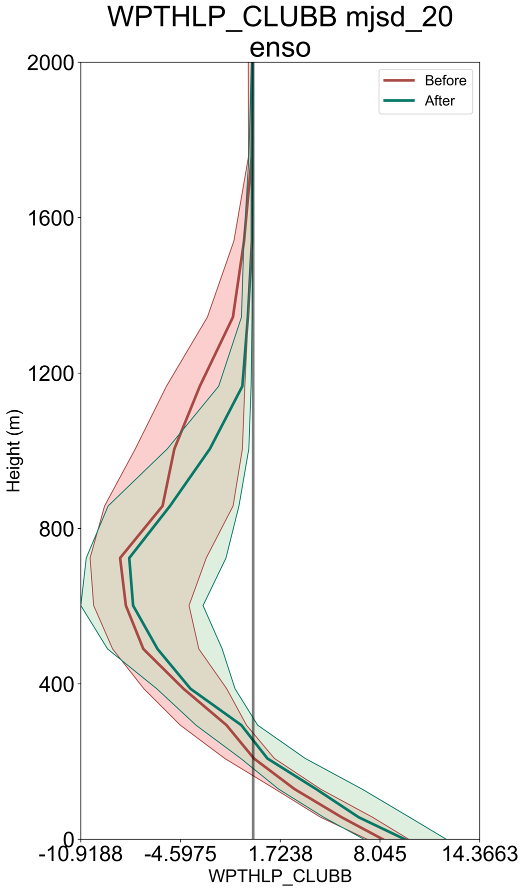

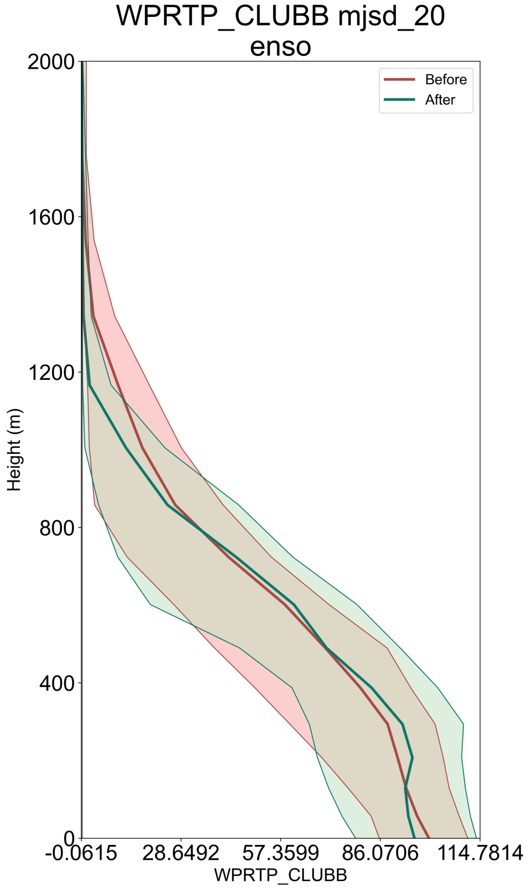

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Kyle M. Nardi CESM Workshop-June 2023 kmn182@psu.edu PennState

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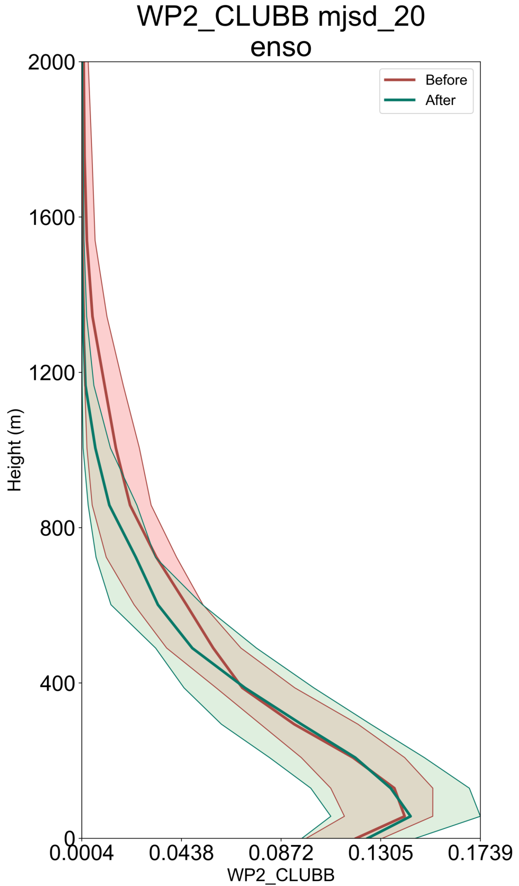
WP2_CLUBB mjsd_20 enso

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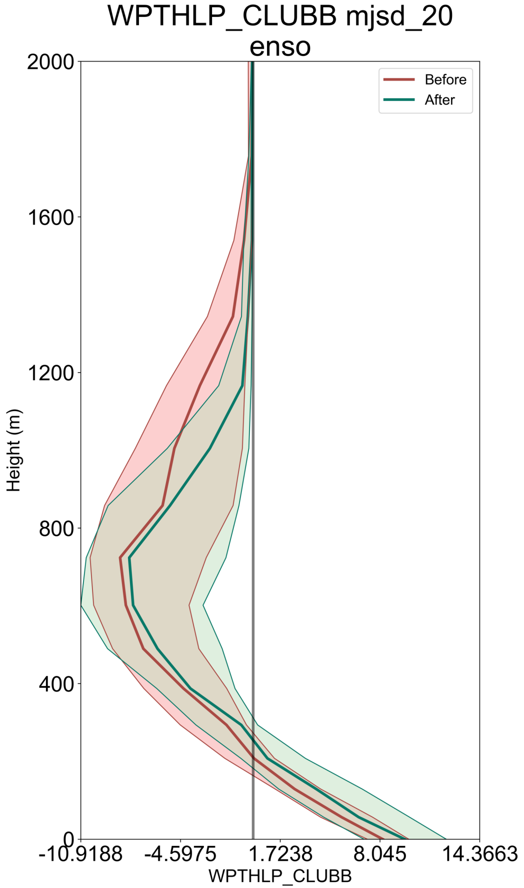
WPTHLP_CLUBB mjsd_20 enso

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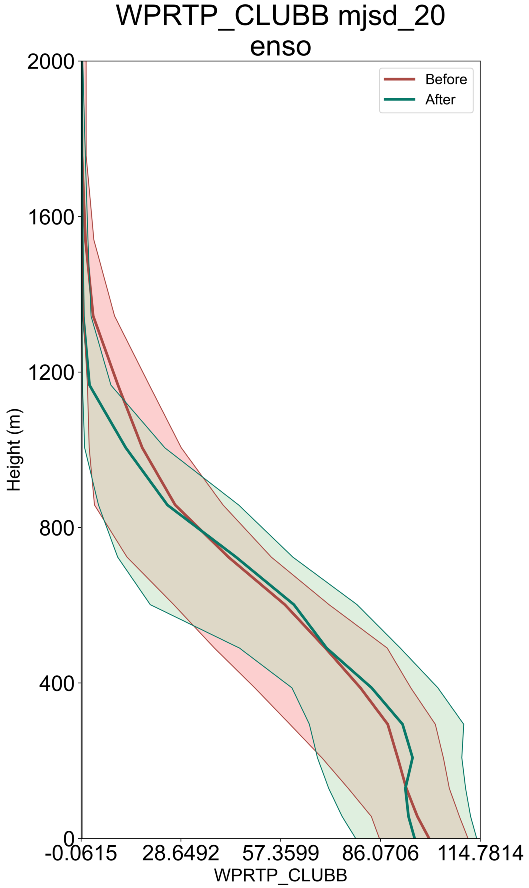
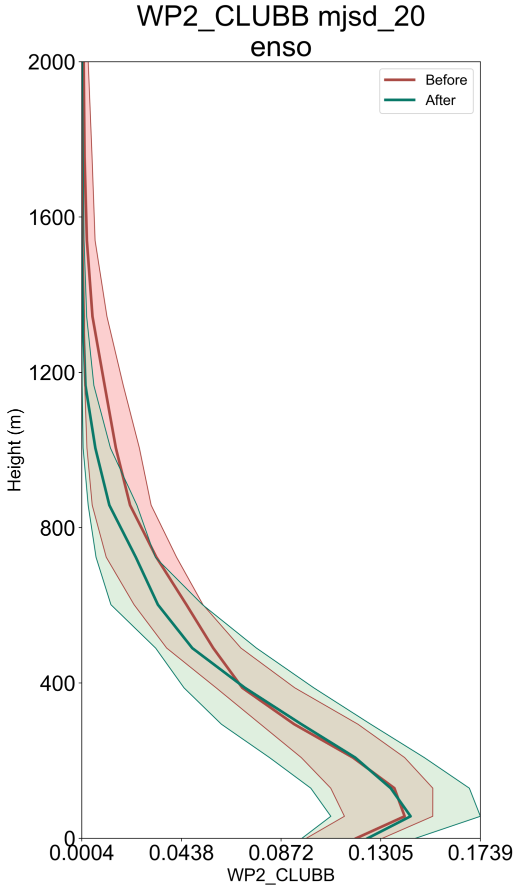

WPRTP_CLUBB mjsd_20 enso

Above about 800 m, there's a decrease in the magnitude of downward transport of drier air from above

We can track the impact of increasing one of these terms ($C_{N2,wp2}$) through the CLUBBX equations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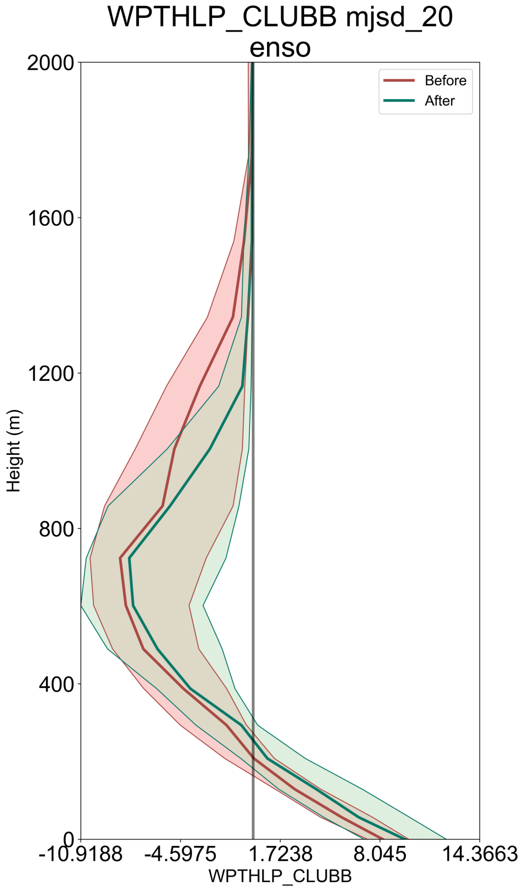
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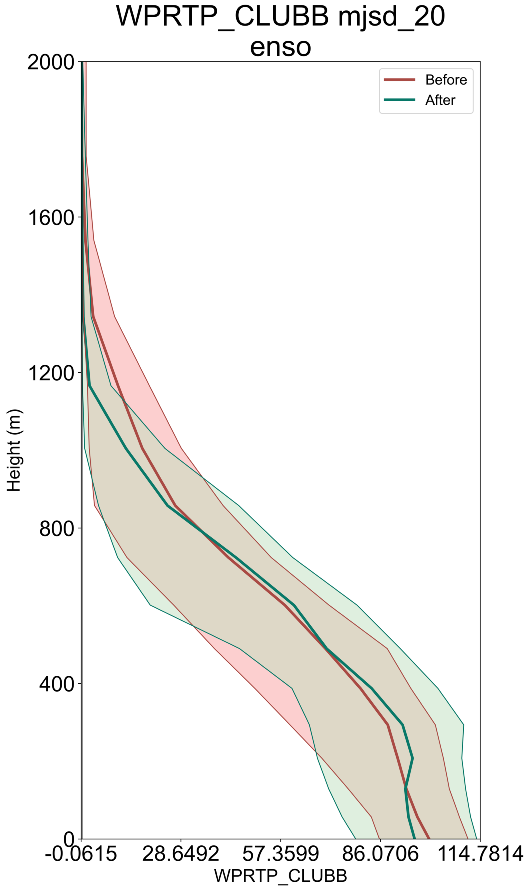
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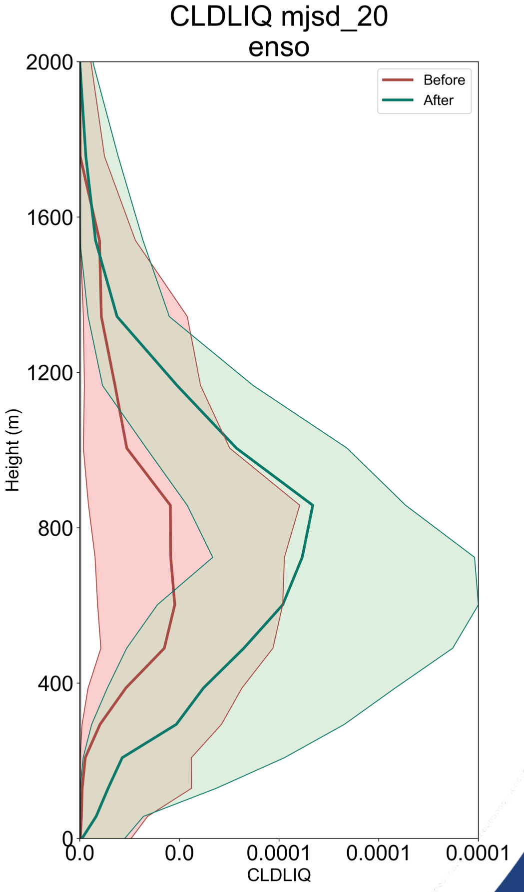
CLDLIQ mjsd_20 enso

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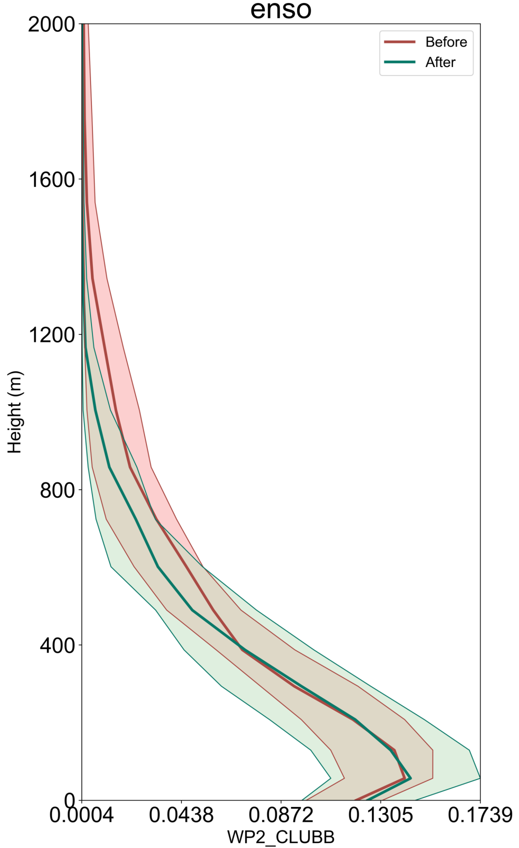
WP2_CLUBB mjsd_20 enso



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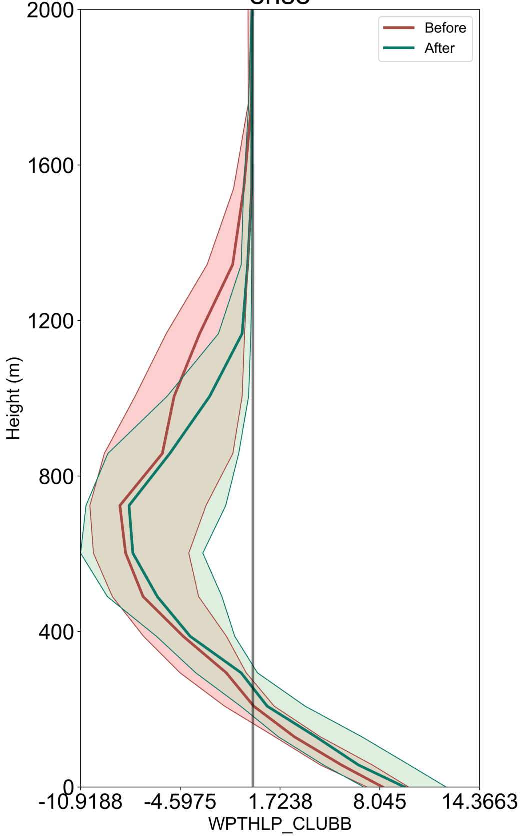

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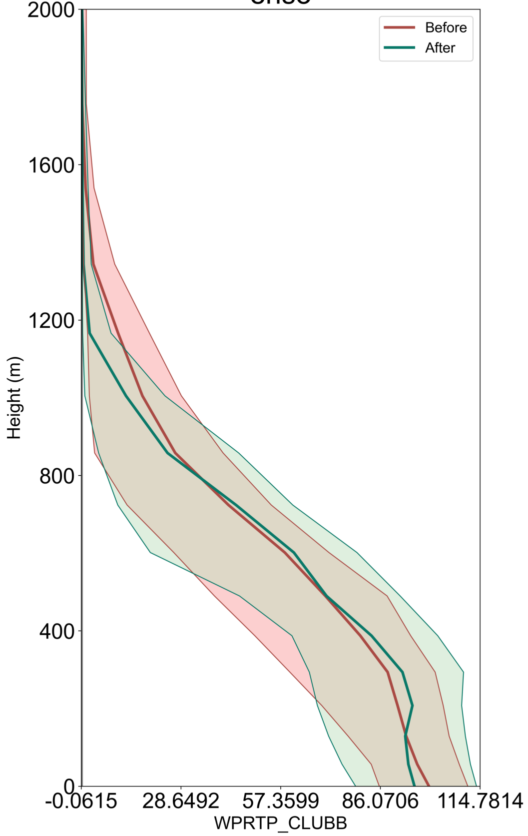

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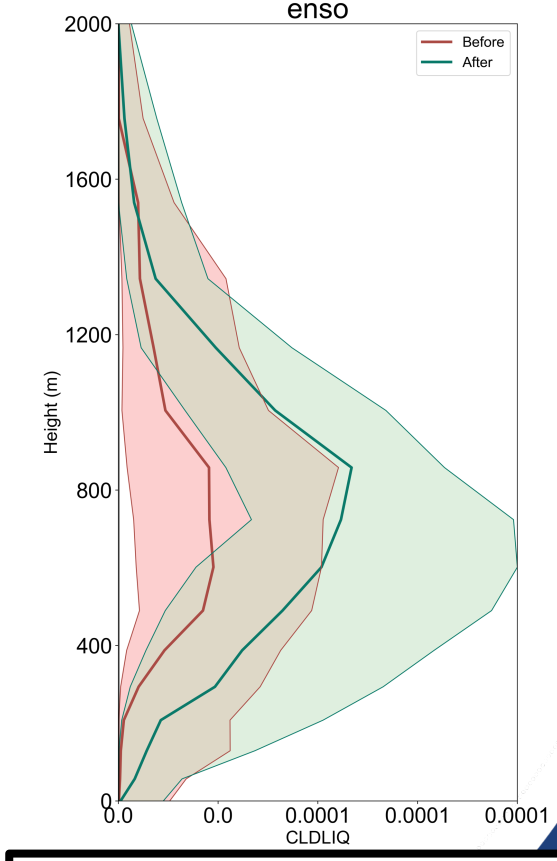

With reduced downward transport of drier air and increased stability, cloud liquid water content increases

With an increase in cloud liquid water content in the PBL, there's an appreciable increase in low cloud fraction

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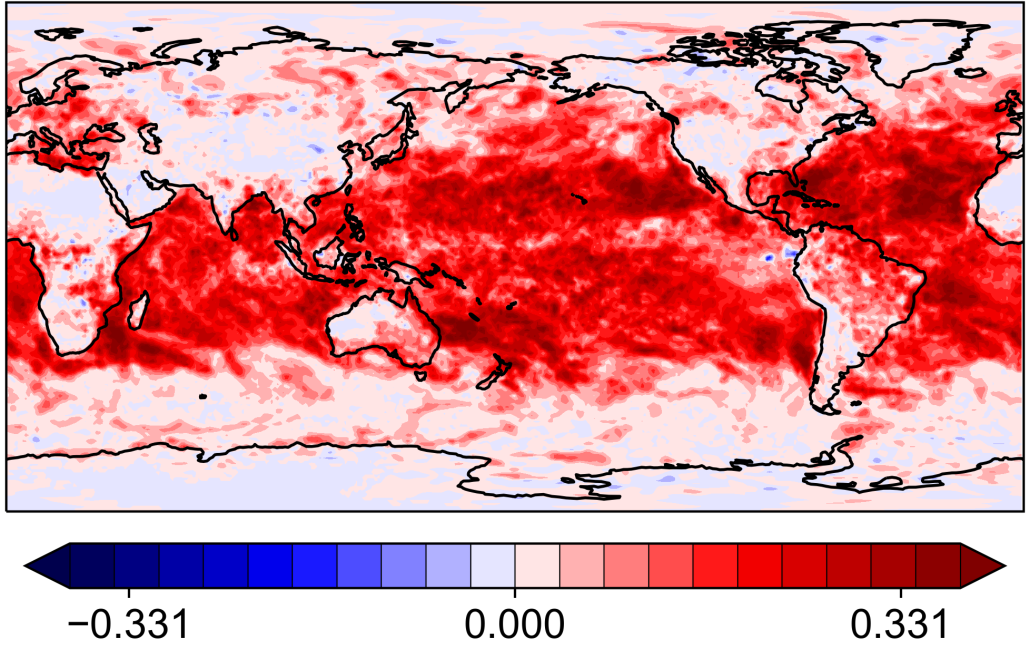
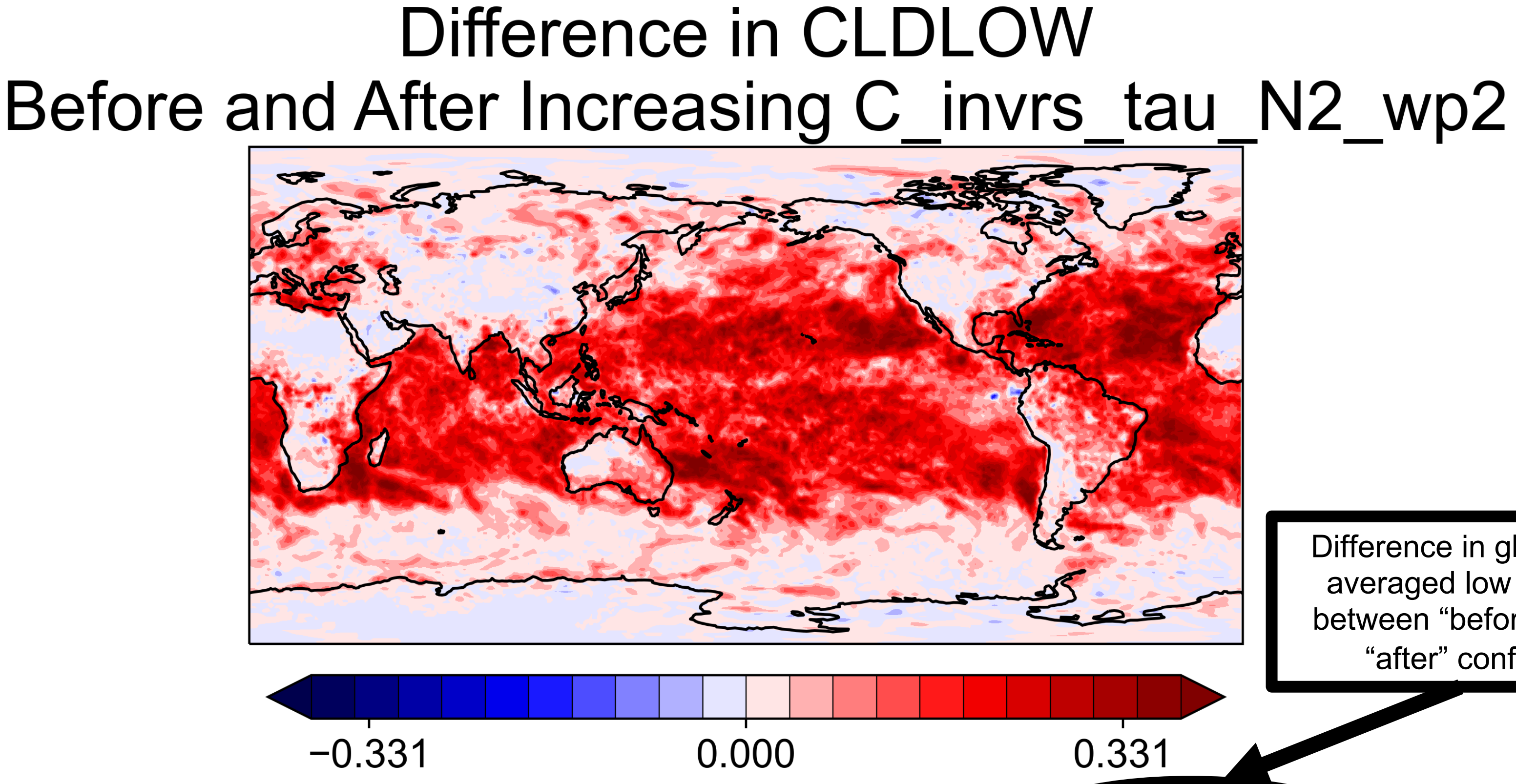


Difference in CLDLOW
Before and After Increasing C_invrs_tau_N2_wp2

After Avg. = 0.6922 Before Avg. = 0.57557 Diff = 0.11663

With an increase in cloud liquid water content in the PBL, there's an appreciable increase in low cloud fraction



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Difference in globally-averaged low cloud between "before" and "after" configs

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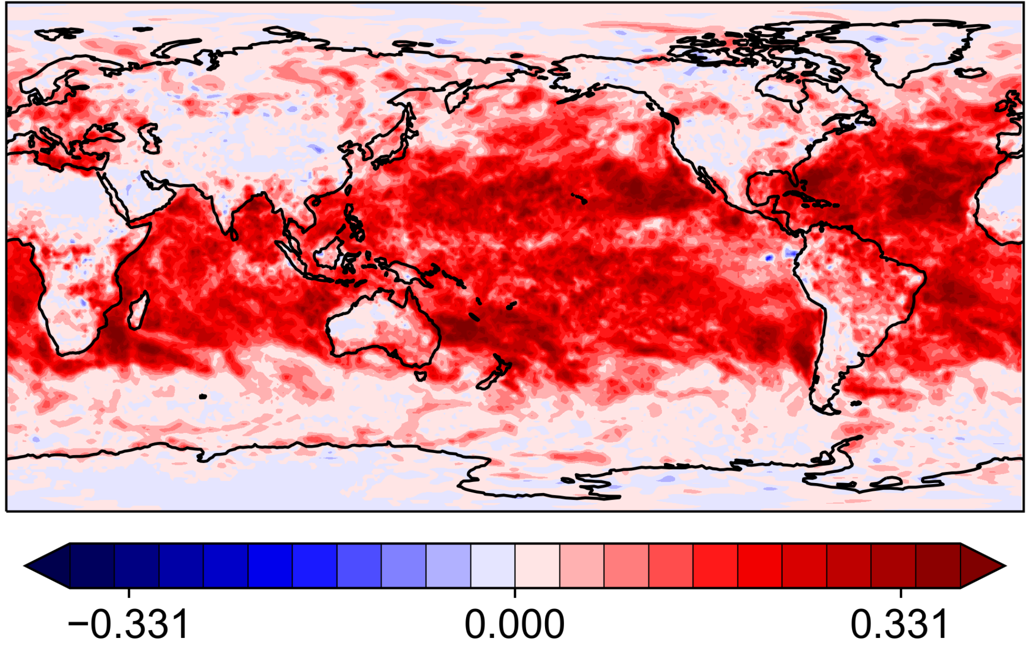

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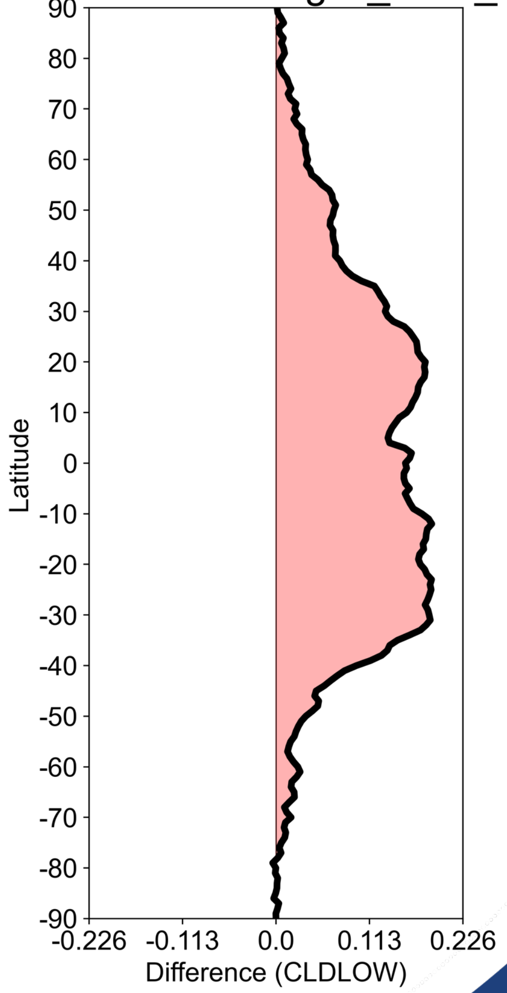

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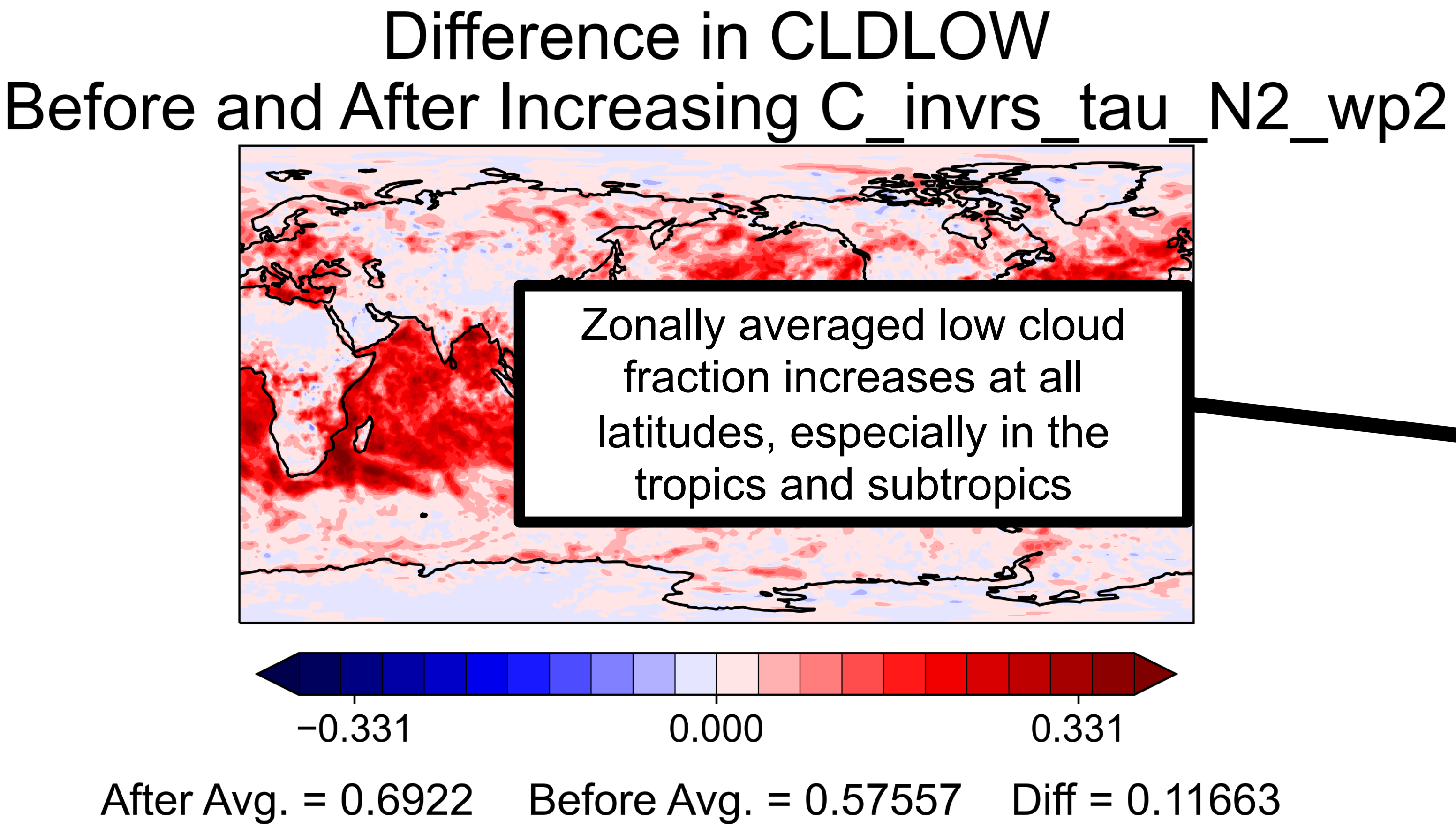

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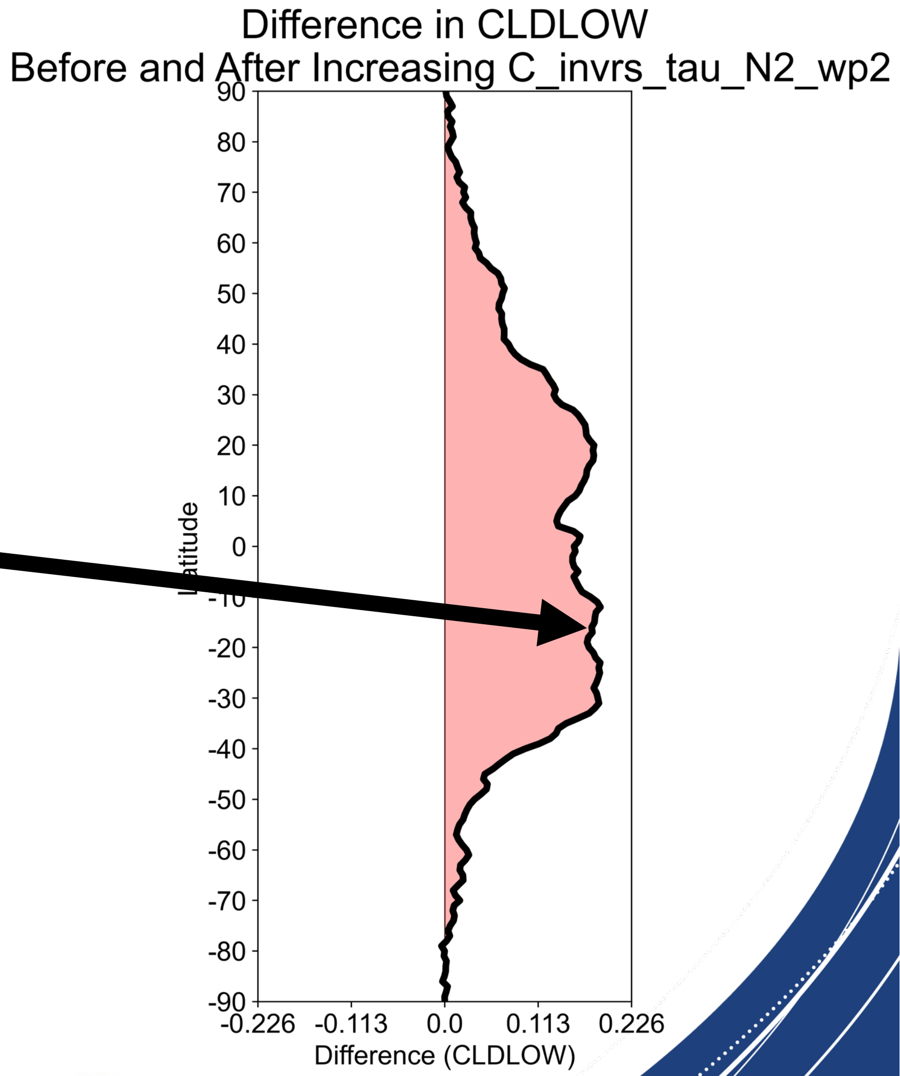
Zonally averaged low cloud fraction increases at all latitudes, especially in the tropics and subtropics



With an increase in low cloud fraction, there's a considerable decrease in SWCF (increased magnitude)

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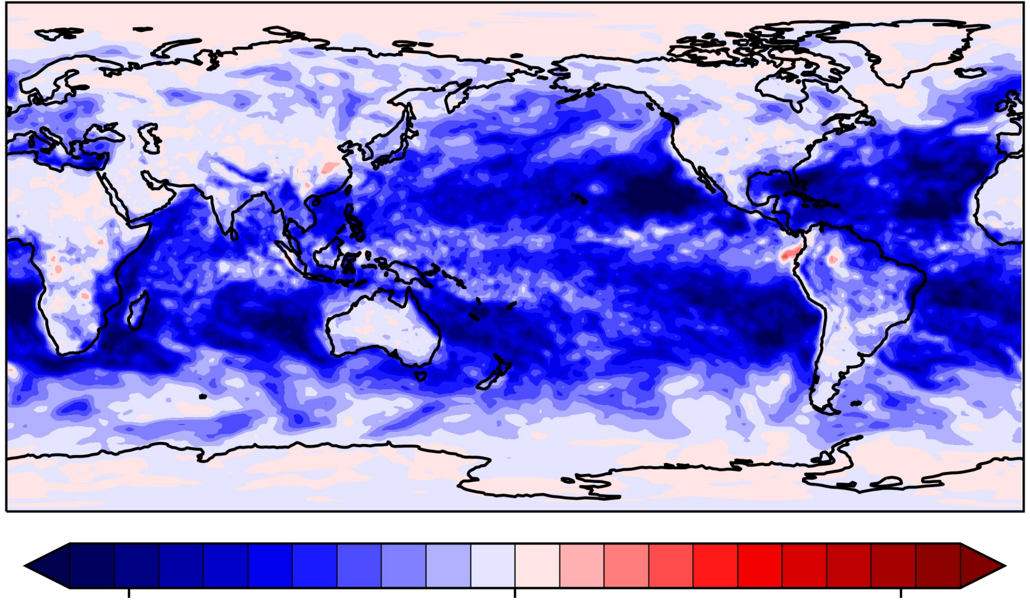

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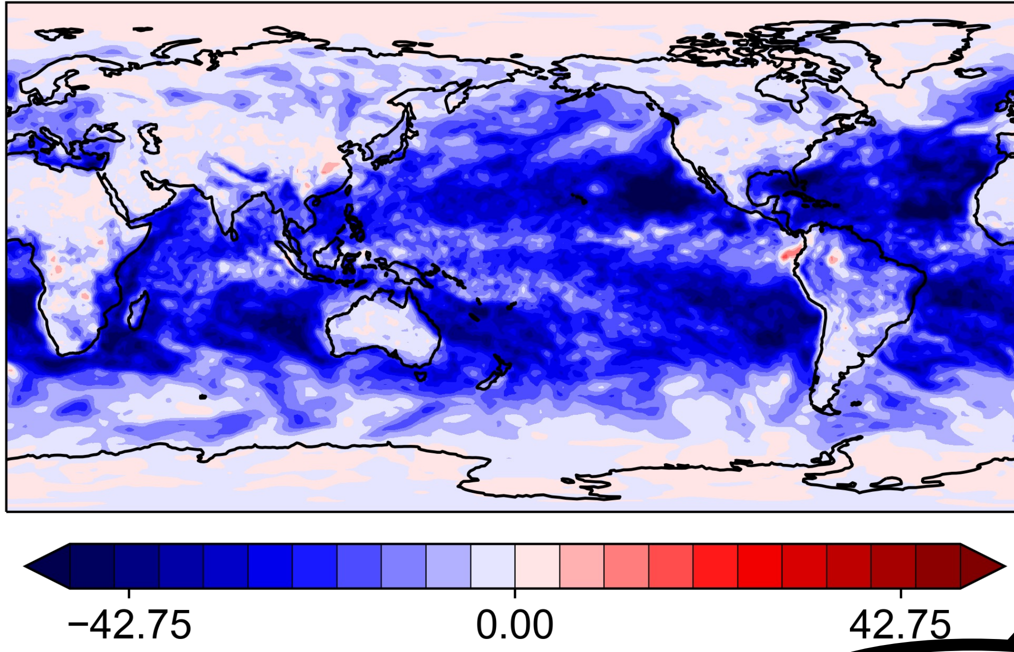

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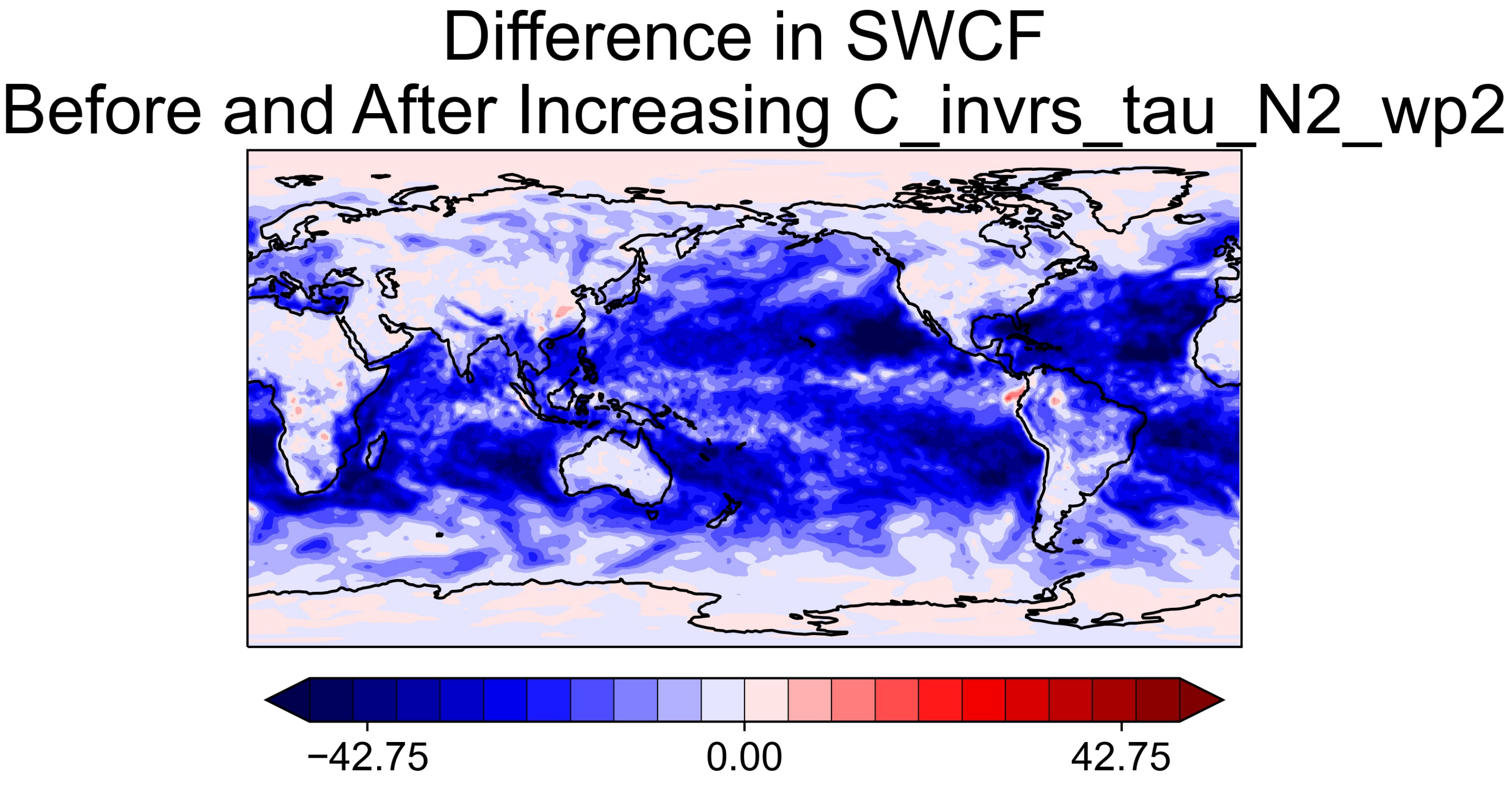

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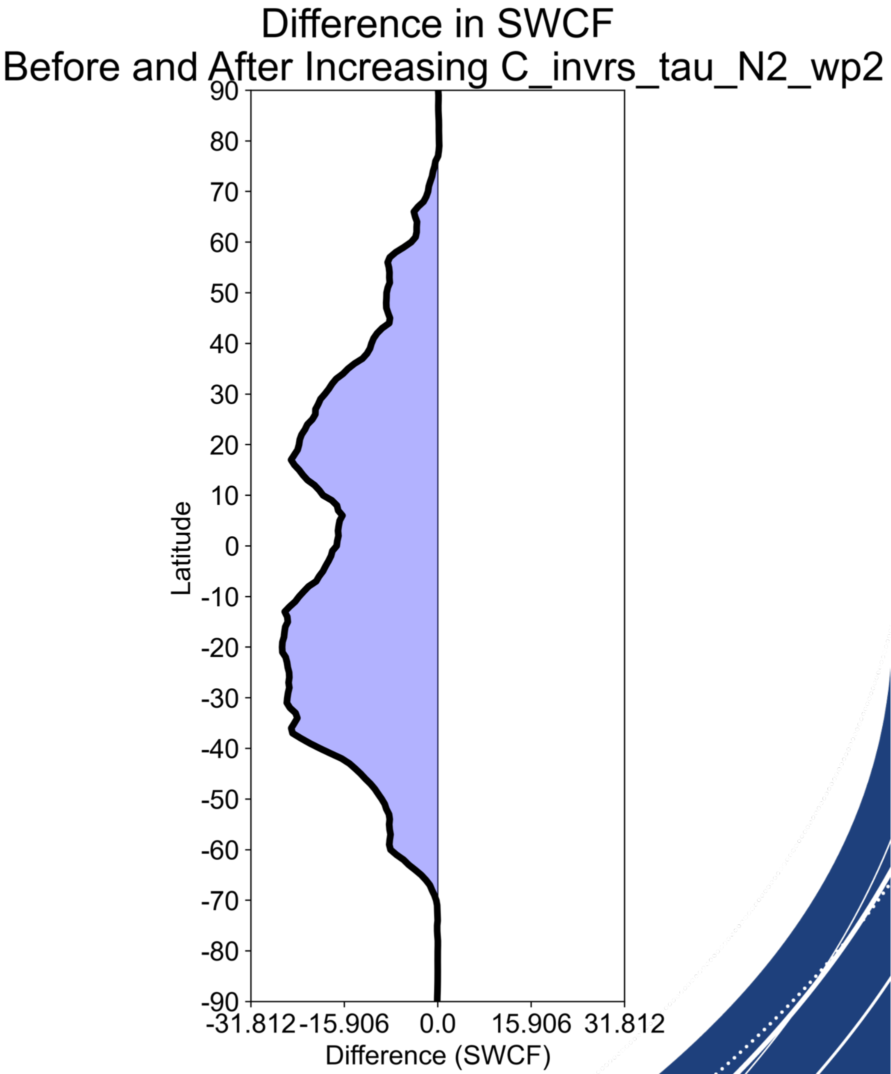

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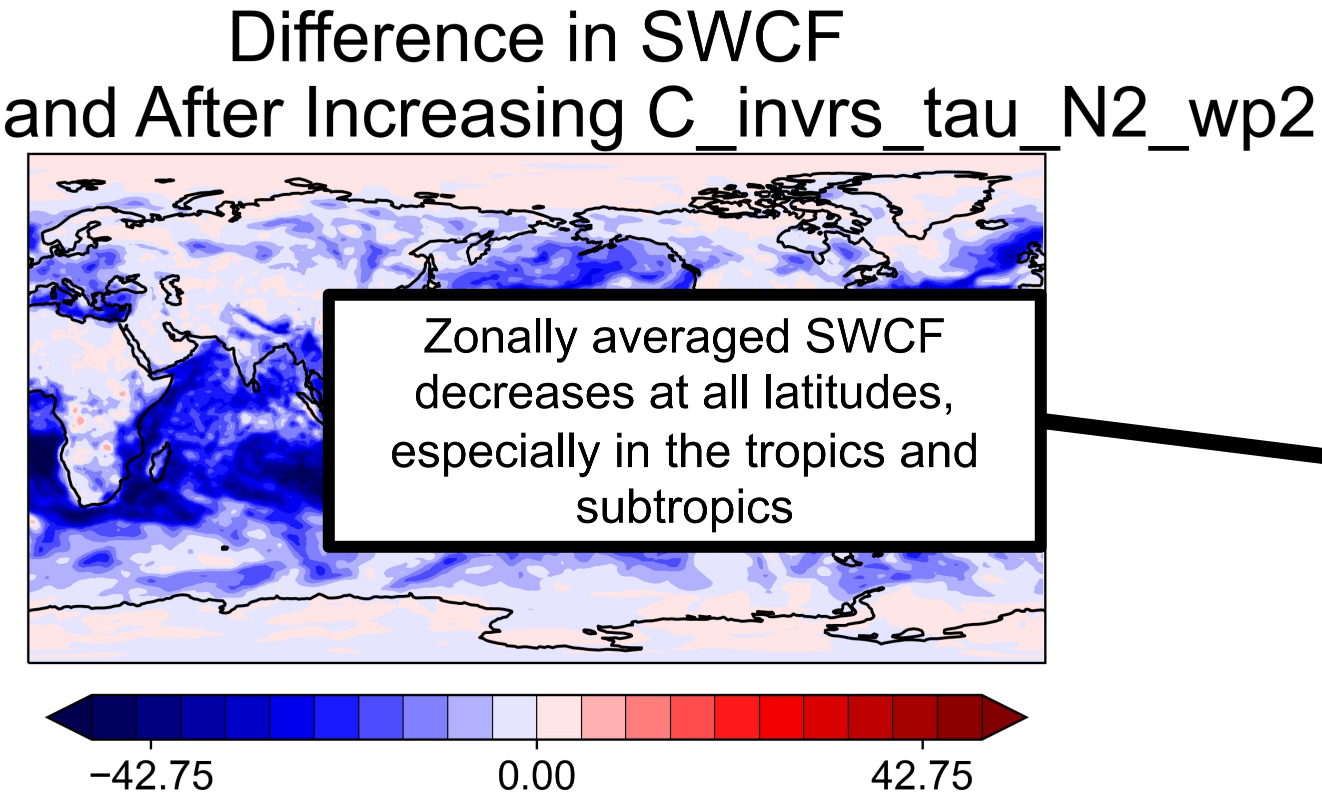
Difference in SWCF
Before and After Increasing C_invrs_tau_N2_wp2

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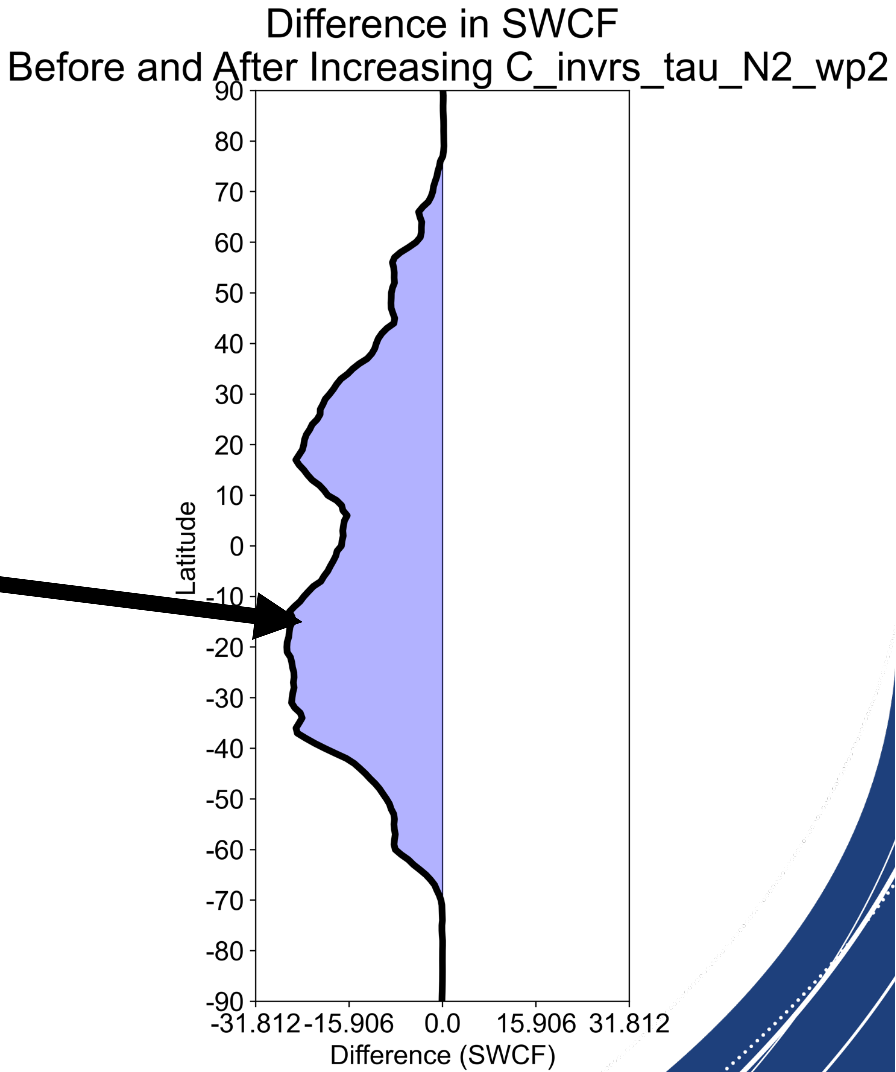
Zonally averaged SWCF decreases at all latitudes, especially in the tropics and subtropics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Several input parameters stand out as broadly influential for TC structure

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C_{uu_shr}: term that offsets the turbulent production of $\overline{u'w'}$ by updrafts

Increasing this term is expected to reduce the magnitude of $\overline{u'w'}$

$$(1-C_{uu\_shr})\overline{w'^2}\frac{\partial\overline{u}}{\partial z}$$

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***C*$_{sfc}$**: weighting term for turbulent eddy dissipation near surface

Increasing this term reduces the vertical turbulent length scale *L*

$$C_{sfc}\frac{u^*}{\kappa}\frac{1}{(z - z_{sfc} + d)}$$

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$$C_{sfc}\frac{u^*}{\kappa}\frac{1}{(z - z_{sfc} + d)}$$

C_{shear}: weighting term for eddy dissipation from wind shear
Increasing this term also reduces the vertical turbulent length scale *L*

$$C_{shear}\sqrt{\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2}$$