Modifying the Mixed Layer Eddies Parameterization:

Frontal Width Determined by Boundary Layer Turbulence

Abigail Bodner

OMWG Winter Meeting

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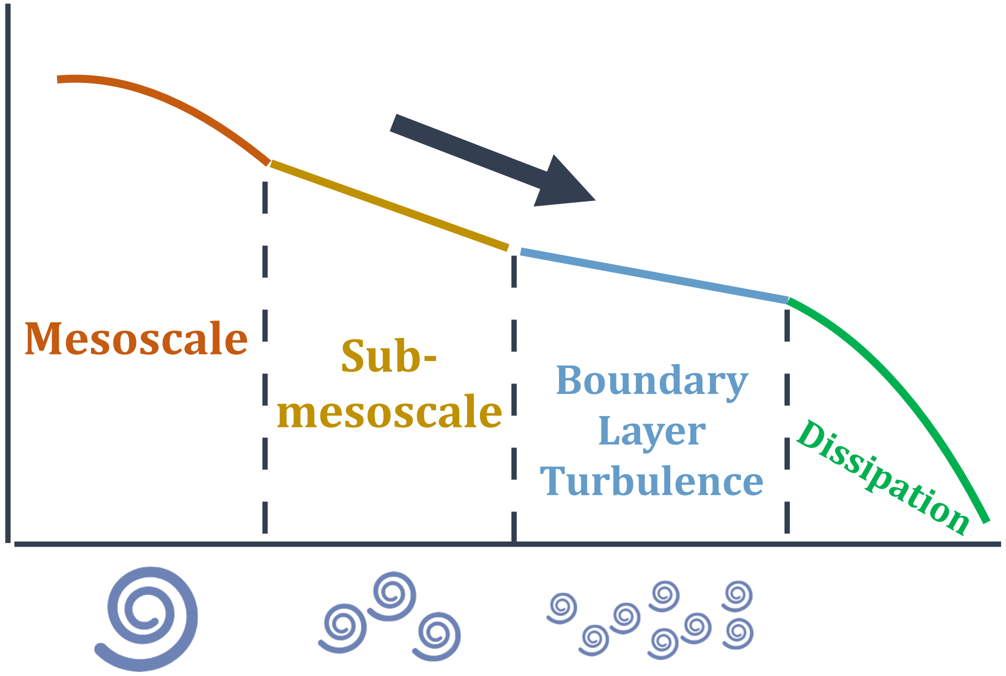

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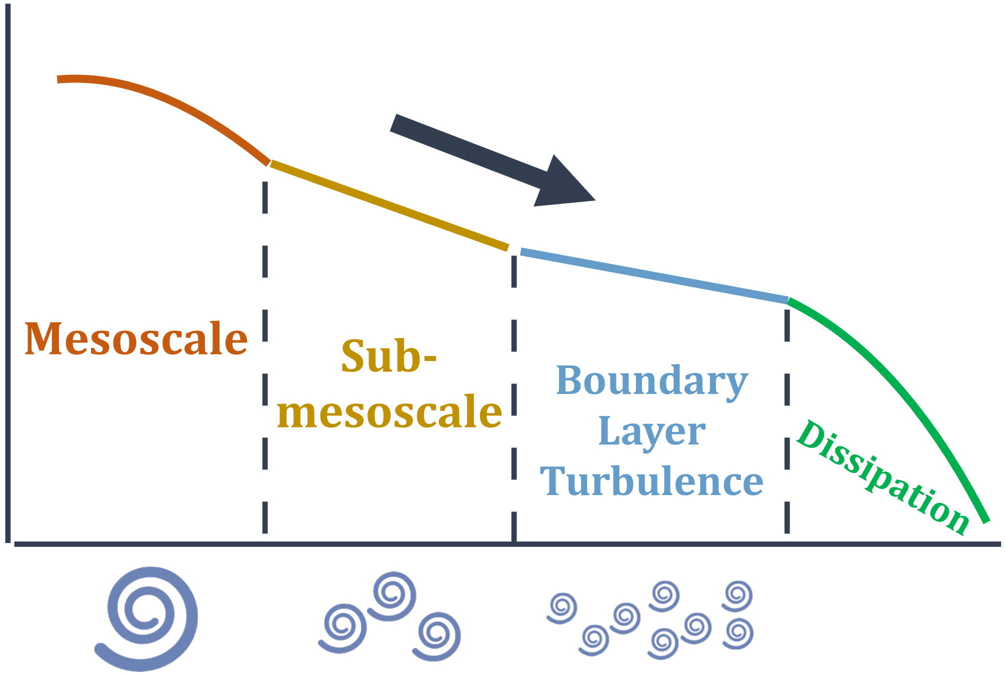
BROWN

Modifying the Mixed Layer Eddies Parameterization:

Frontal Width Determined by Boundary Layer Turbulence

- Horizontal fluxes dominated by mesoscales
- Vertical fluxes dominated by submesoscales and boundary layer turbulence
- Boundary layer turbulence mix and deepen the mixed layer
- Mixed layer (submesoscale) eddies restratify and shoal the mixed layer

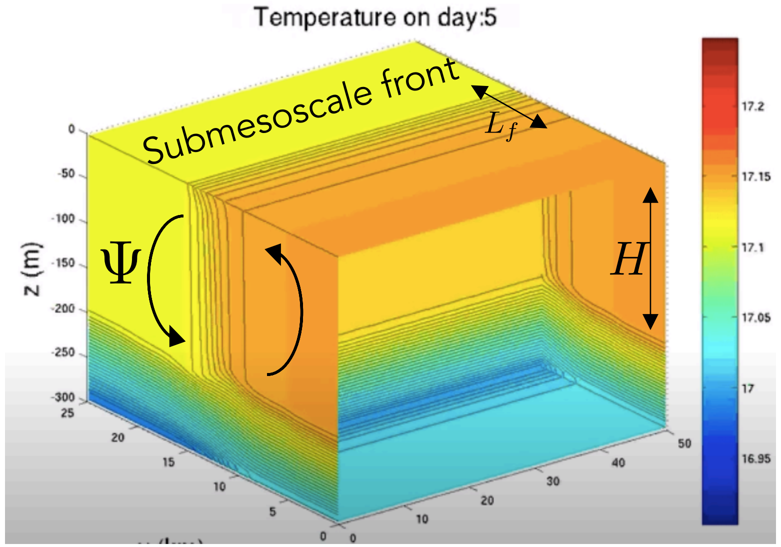


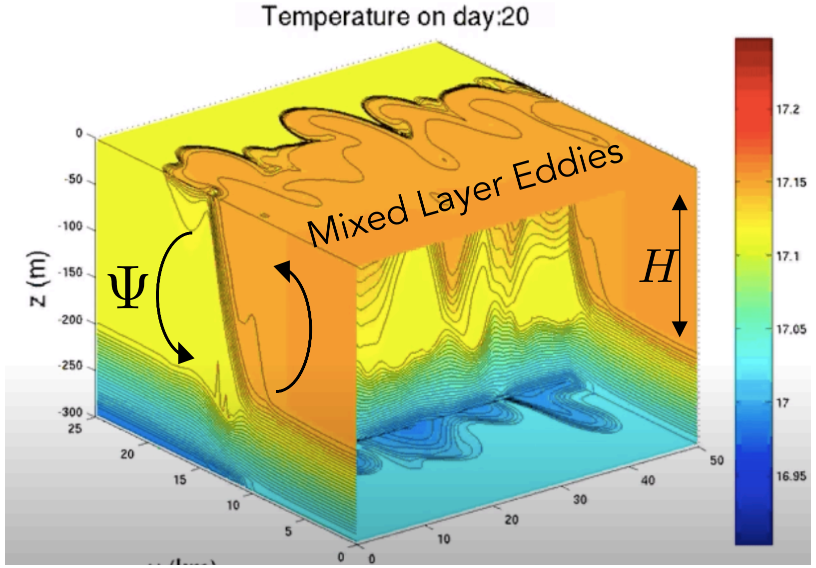
The Mixed Layer (Submesoscale) Eddies parameterization

- Overturning streamfunction within the mixed layer, acting to slump isopycnals (submesoscale fronts)

$$\Psi = C_e \frac{\Delta s}{\boxed{L_f}} \frac{H^2 \nabla \bar{b}^z \times \hat{\mathbf{z}}}{\sqrt{f^2 + \tau^{-2}}} \mu(z)$$

- Strength depends on **frontal width** L_f
- Currently set as deformation radius $L_f = \frac{NH}{f}$
- Determined by boundary layer turbulence ?





Fox-Kemper et. al. 2008

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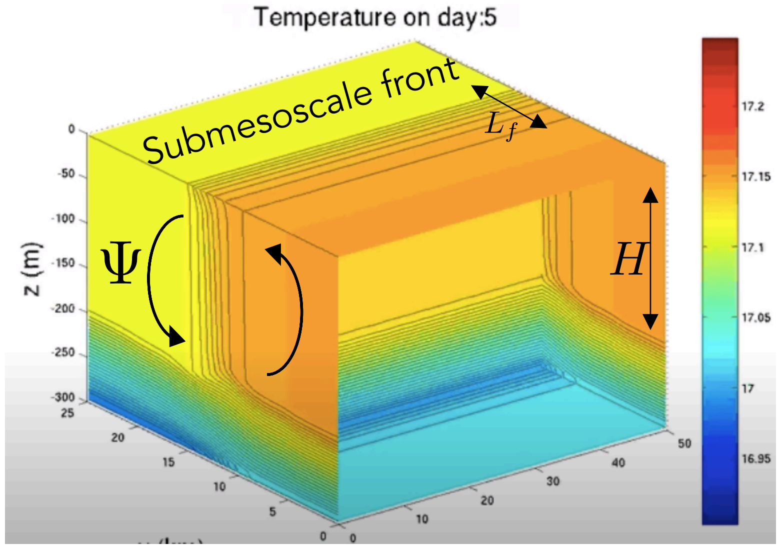
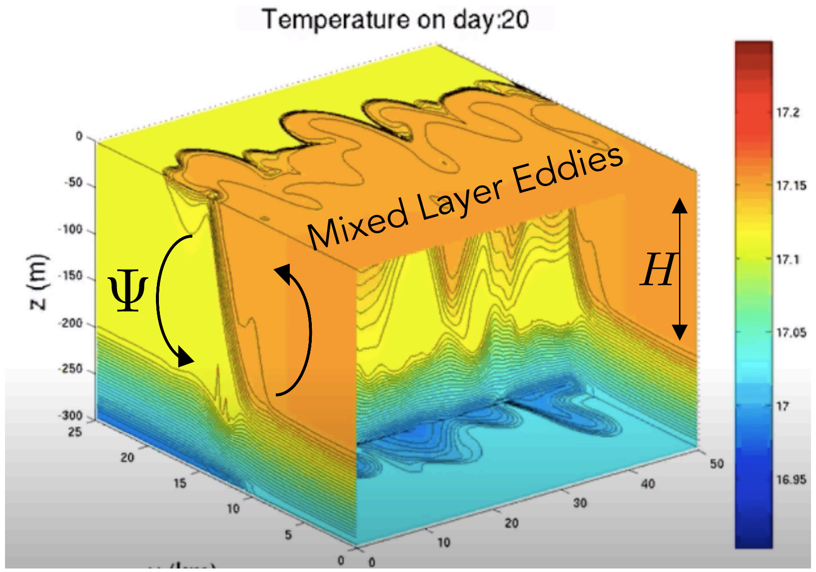
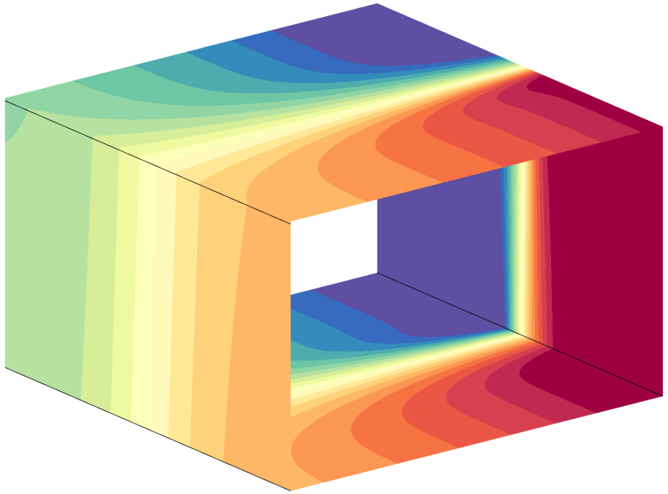


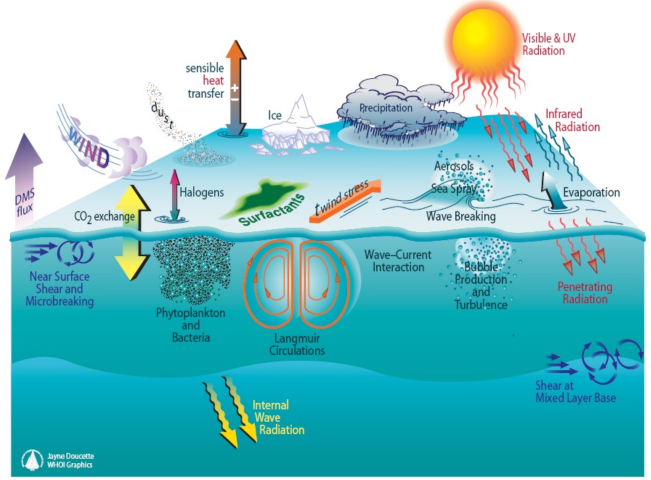


Fox-Kemper et. al. 2008

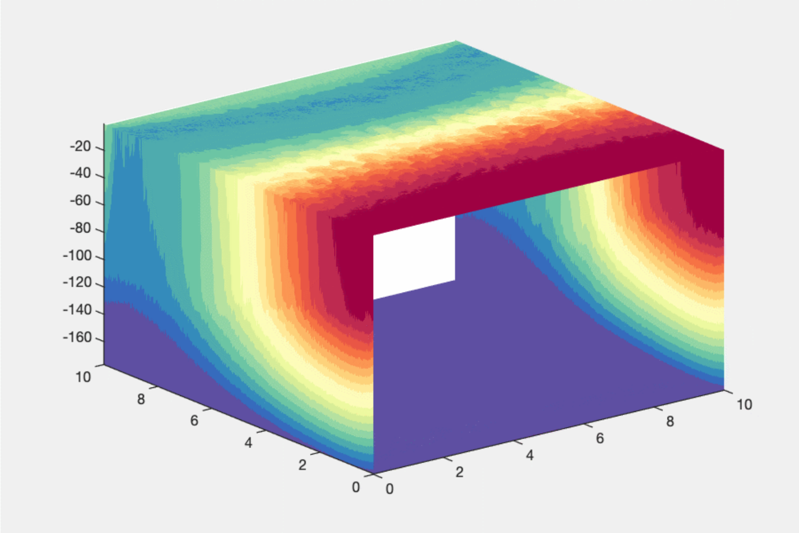
Submesoscales and Boundary Layer Turbulence

Theoretical submesoscale front
Simplified, weak turbulence





Simulated submesoscale front
Strong turbulence driven by instabilities, wind, waves and surface cooling



Bodner, A. S., Fox-Kemper, B., Van Roekel, L. P., McWilliams, J. C. & Sullivan, P. P. (2019).

Bodner, A. S. & Fox-Kemper, B. (2020).
Sullivan, P.P & McWilliams (2018)

Frontogenesis by vertical turbulent fluxes
Frontal arrest by horizontal turbulent fluxes

Frontal width given by Turbulent Thermal Wind

New frontal width scaling given by the Turbulent Thermal Wind Balance

$$\nabla_H b = -f\hat{\mathbf{z}} \times \mathbf{s} + \frac{\partial^2(\nu \mathbf{s})}{\partial z^2}$$

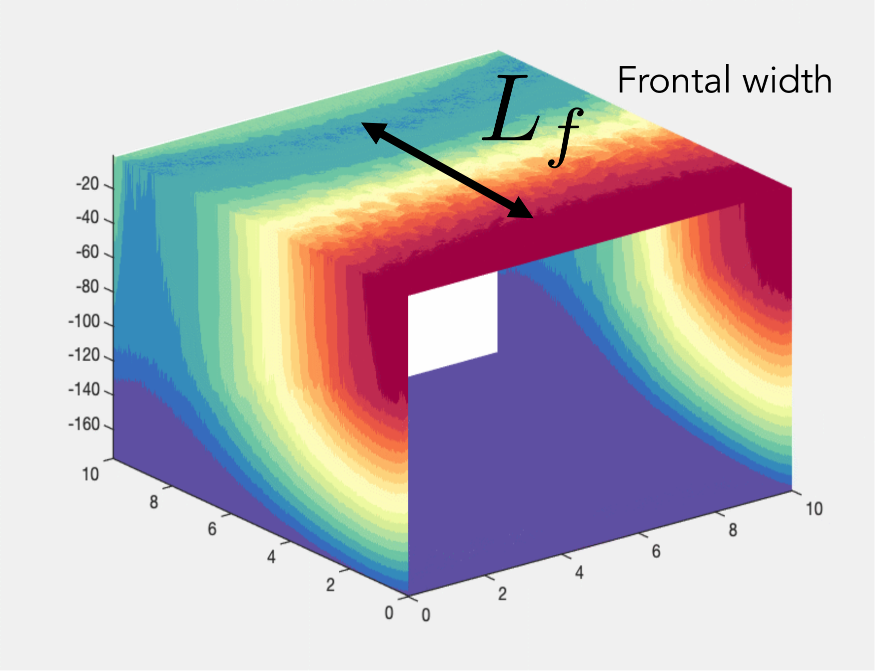
Buoyancy gradient

Vertical shear

Vertical eddy viscosity

Vertical shear $\mathbf{s} = \dfrac{\partial \mathbf{u}}{\partial z}$

McWilliams (2015)



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McWilliams (2015)

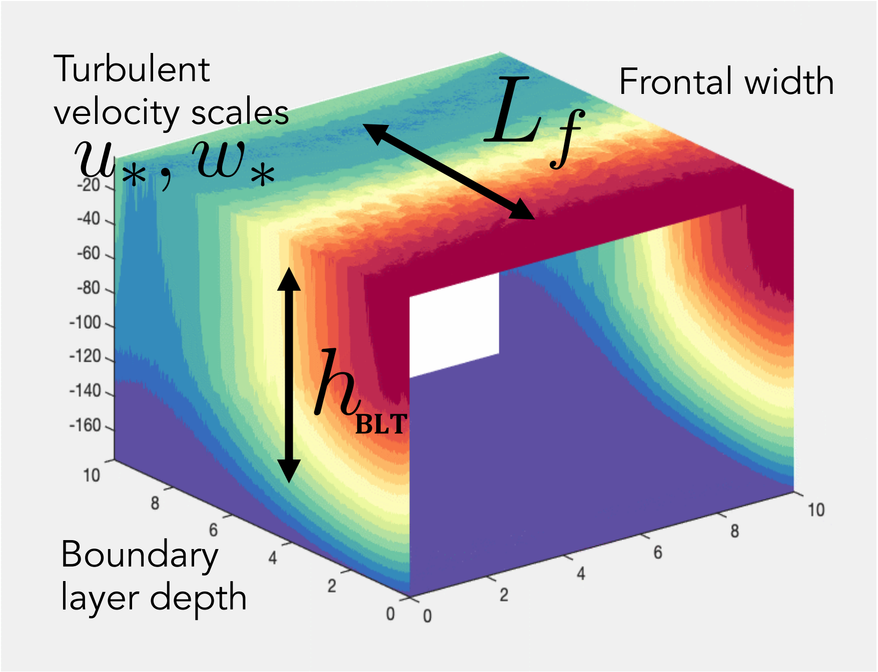
Turbulent friction velocity

$$u_* = \sqrt{\frac{|\tau|}{\rho_0}}$$

Turbulent convective velocity

$$w_* = (B_0 h)^{\frac{1}{3}}$$

$$L_f = C_f \cdot \frac{(m_* u_*^3 + n_* w_*^3)^{\frac{2}{3}}}{f^2} \cdot \frac{1}{h_{\mathrm{BLT}}}$$

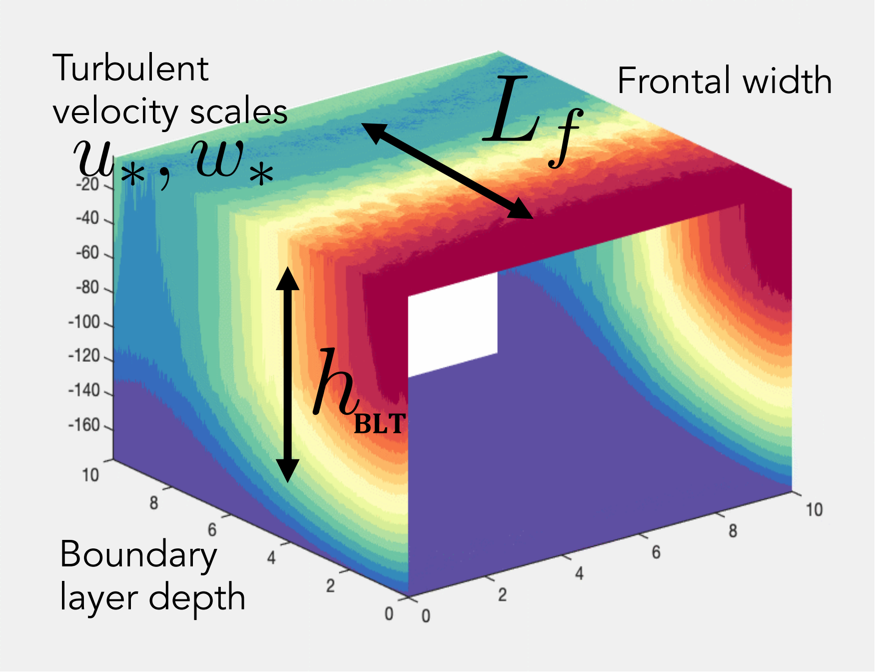


Frontal width given by Turbulent Thermal Wind

$$\Psi = C_e \frac{\Delta s}{L_f} \frac{H^2 \nabla \overline{b}^z \times \hat{\mathbf{z}}}{\sqrt{f^2 + \cancel{\tau^{-2}}}} \mu(z) \longrightarrow \boxed{\Psi = \frac{C_e}{C_f} \frac{\Delta s |f| h H^2 \nabla \overline{b}^z \times \hat{\mathbf{z}}}{(m_* u_*^3 + n_* w_*^3)^{\frac{2}{3}}} \mu(z)}$$

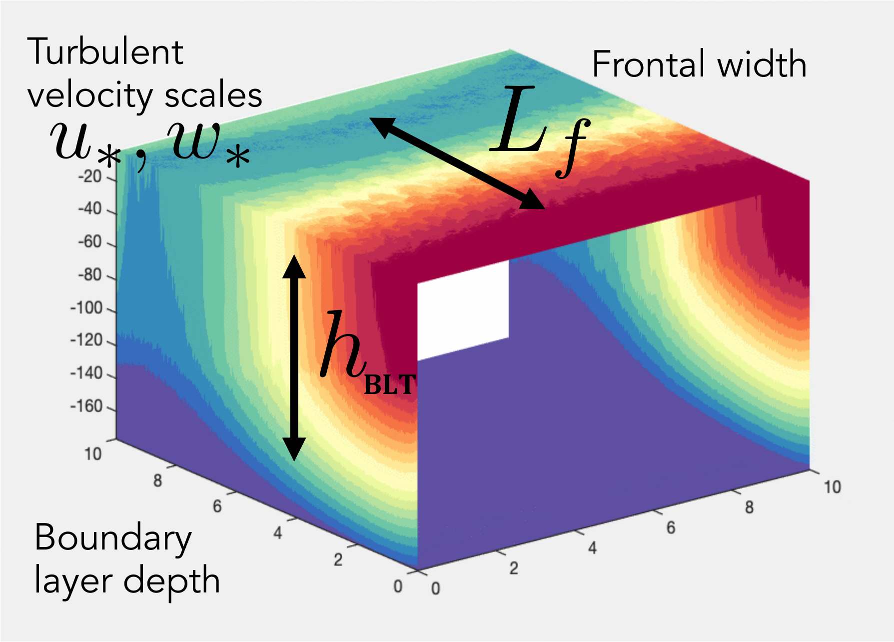
$$L_f = C_f \cdot \frac{(m_* u_*^3 + n_* w_*^3)^{\frac{2}{3}}}{f^2} \cdot \frac{1}{h_{\text{BLT}}}$$

From boundary layer turbulence schemes (KPP, ePBL)

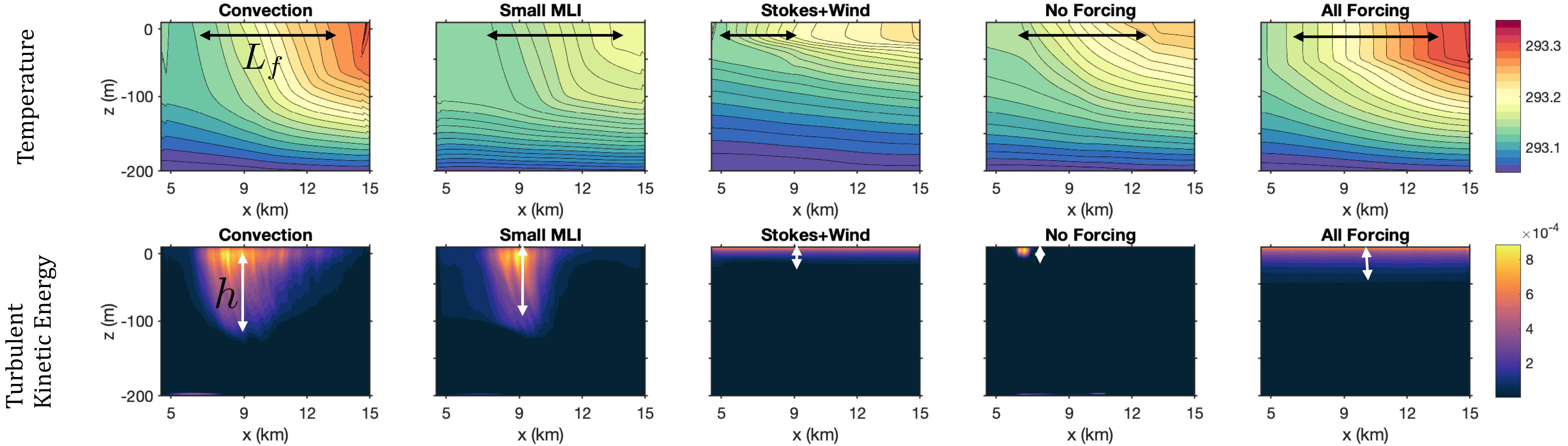


Frontal width given by Turbulent Thermal Wind

$$L_f = \overset{?}{C_f} \cdot \frac{(m_* u_*^3 + n_* w_*^3)^{\frac{2}{3}}}{f^2} \cdot \frac{1}{h_{\mathrm{BLT}}}$$



LES with varying turbulent properties u_*, w_*

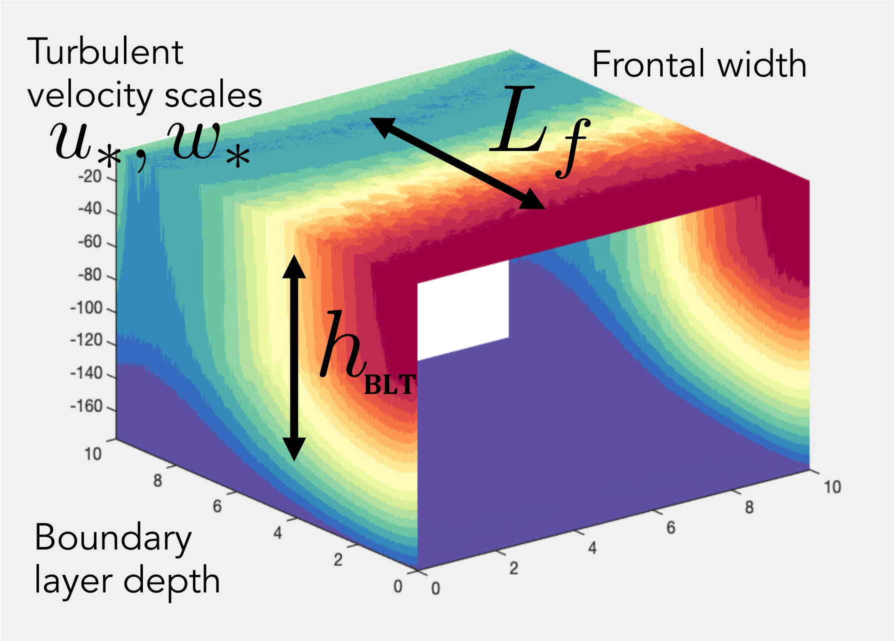


Frontal width given by Turbulent Thermal Wind

$$L_f = C_f \cdot \frac{(m_* u_*^3 + n_* w_*^3)^{\frac{2}{3}}}{f^2} \cdot \frac{1}{h_{\mathrm{BLT}}}$$

$Ri_T \approx 0.25$

Horizontal shear instability



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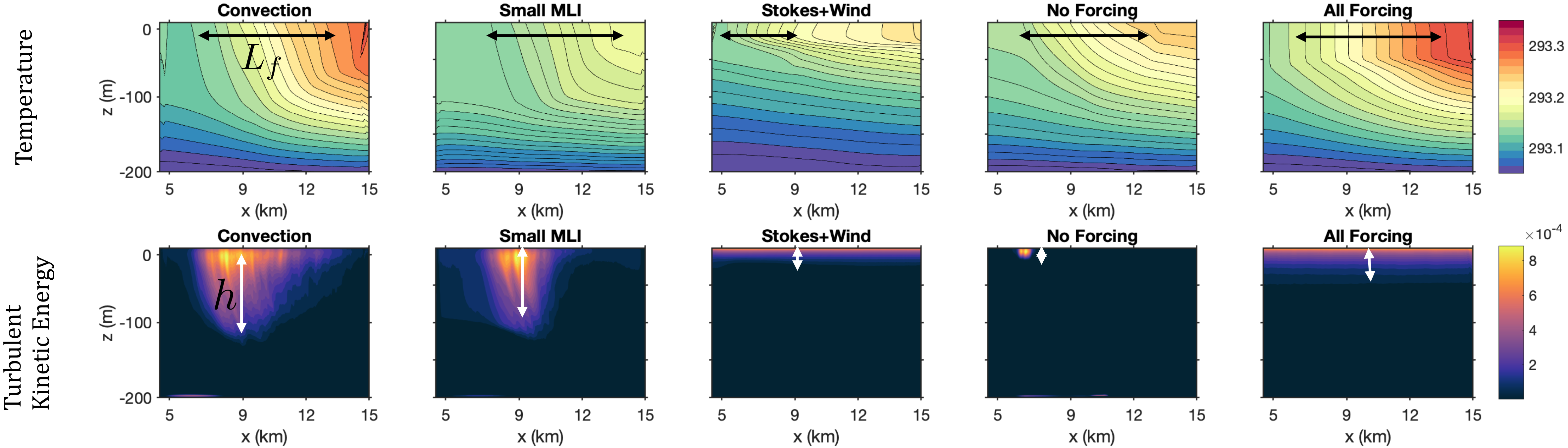


Frontal width given by Turbulent Thermal Wind

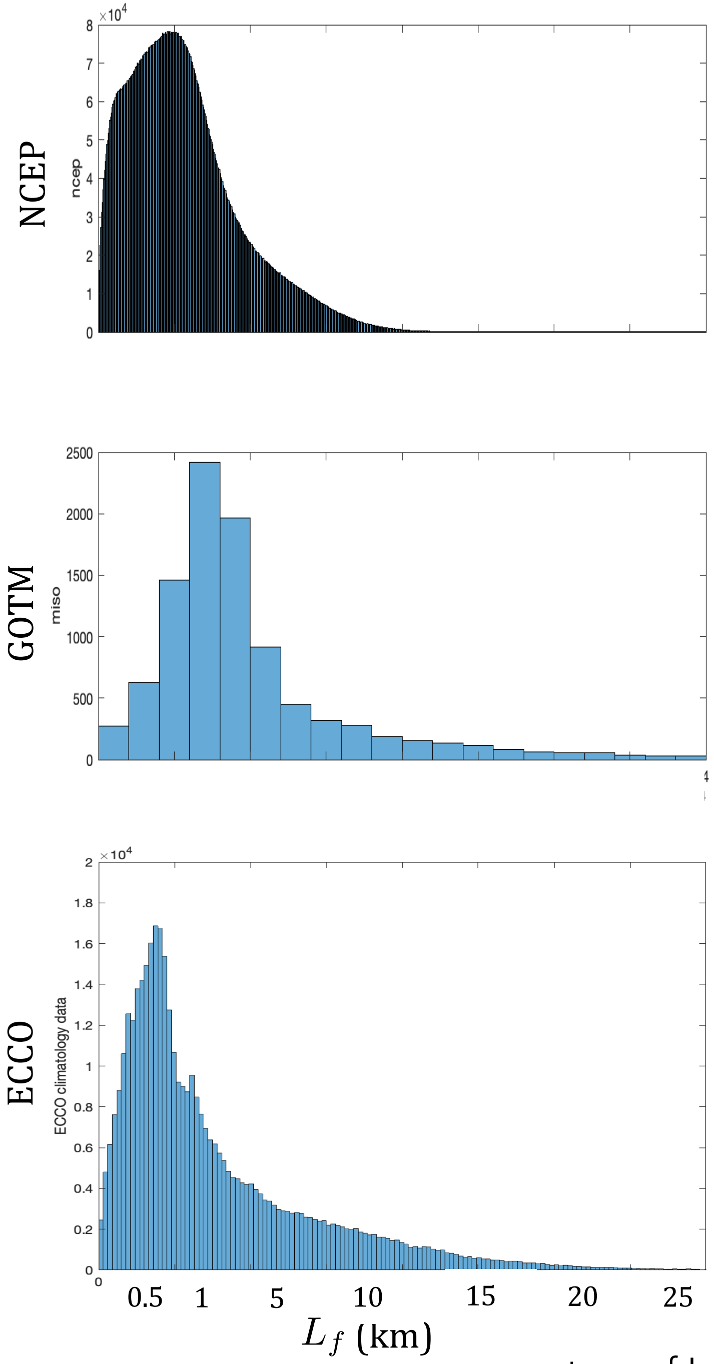
$$L_f = \underset{\uparrow}{C_f} \cdot \frac{(m_* u_*^3 + n_* w_*^3)^{\frac{2}{3}}}{f^2} \cdot \frac{1}{h_{\mathbf{BLT}}}$$

$Ri_T \approx 0.25$

Horizontal shear instability

- “Sanity check”
- New scaling gives realistic distributions of L_f

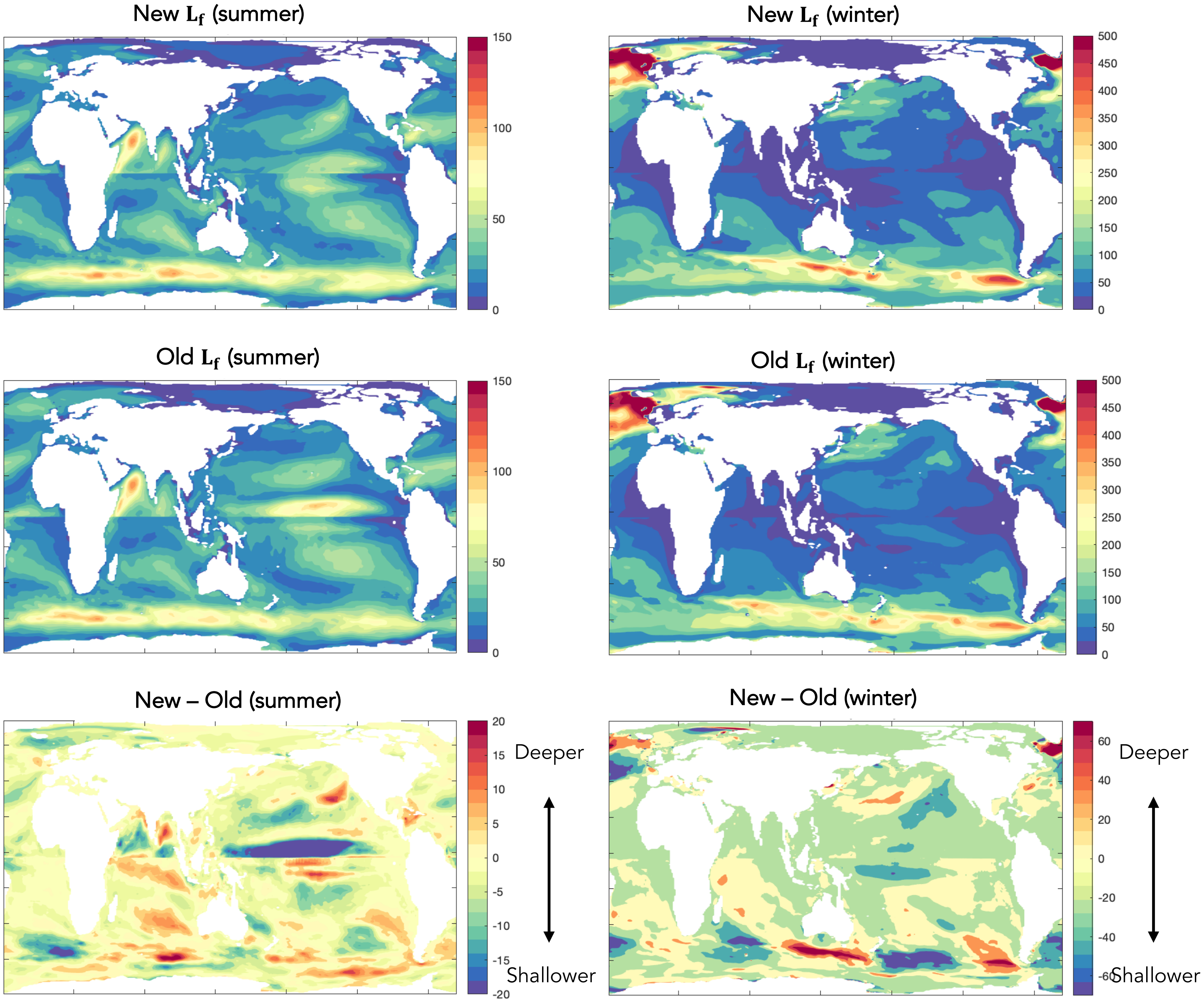
- NCEP: observed winds but uses MLD climatology (not h_{BLT})
- GOTM in the Bay of Bengal: observed surface fluxes combined with cvmix turbulence scheme
- ECCO: MITgcm constrained by observations, also uses MLD climatology (not h_{BLT})



courtesy of Leah Johnson

Testing in CESM – mixed layer depth

- Some climatologically important regions are modified by this scale factor.
- e.g. Equatorial Pacific, Southern Ocean, Arctic
- The full impact of this is a work in progress
- So far tested in POP, will be testing in MOM6 soon
- Looking also at forced JRA simulations



New L_f (summer)

New L_f (winter)

Old L_f (summer)

Old L_f (winter)

New – Old (summer)

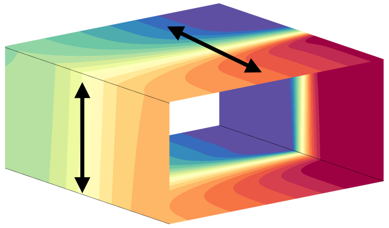
New – Old (winter)

Summary

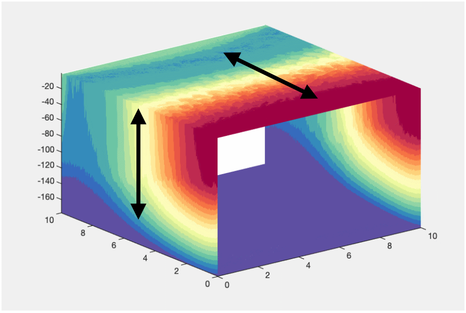
- The Mixed Layer Eddies (submesoscale) parameterization represents the restratification process of adjusting submesoscale fronts
- The parameterization depends on frontal width, but the current form has been shown to be too simplistic
- A new scaling law relates frontal width with boundary layer turbulence by building on the Turbulent Thermal Wind balance
- The modified parameterization utilizes variables from the boundary layer turbulence scheme: u_*, w_*, h_{BLT}

<u>In progress:</u>

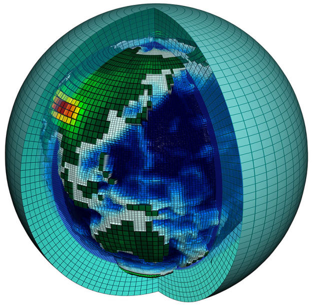
- Validating with LES of submesoscales and boundary layer turbulence
- Testing in CESM and estimating climate sensitivity and impact



TTW Theory



Validation in LES



Testing in CESM

Extra slides

MLI parameterization

$$\boldsymbol{\Psi} = C_e \frac{\Delta s}{L_f} \frac{H^2 \nabla \bar{b}^z \times \hat{\mathbf{z}}}{\sqrt{f^2 + \tau^{-2}}} \mu(z)$$

C_e is found to be 0.06–0.08

$$\mu(z) = \max\left\{0, \left[1 - \left(\frac{2z}{H} + 1\right)^2\right]\left[1 + \frac{5}{21}\left(\frac{2z}{H} + 1\right)^2\right]\right\},$$

timescale τ is roughly the time needed to mix momentum across the mixed layer (≈1–10 days, see Section 2.3).

Hosegood et al. (2006) suggest L_f is close to the mixed layer deformation radius NH/f, where N is the buoyancy frequency based on the mixed layer stratification.