LA-UR-21-20975

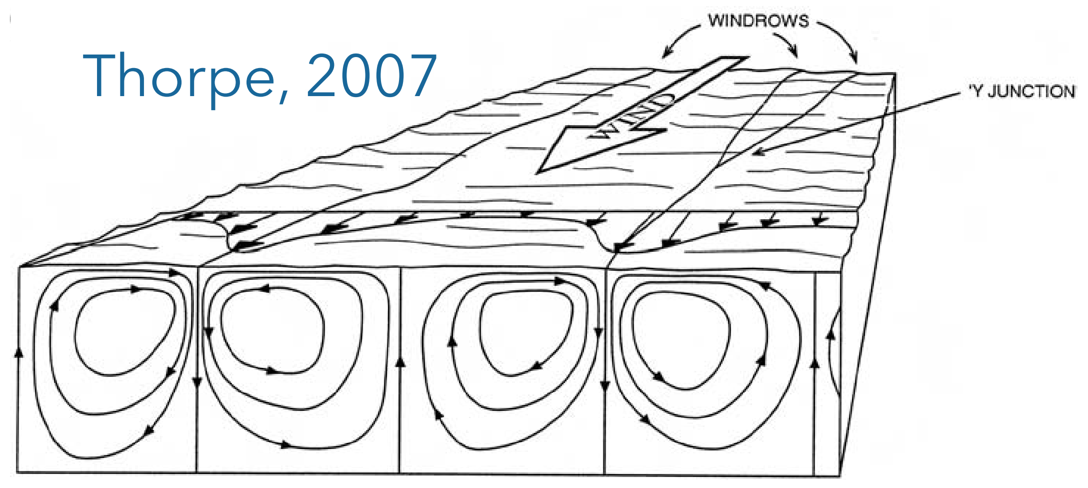
An Update on Langmuir Mixing Parameterizations in CESM2.2

& Discussions on Wave Coupling

Qing Li (Los Alamos National Laboratory)
with Alper Altuntas, Mike Levy, & many others in OMWG

Langmuir turbulence enhances vertical mixing

Thorpe, 2007

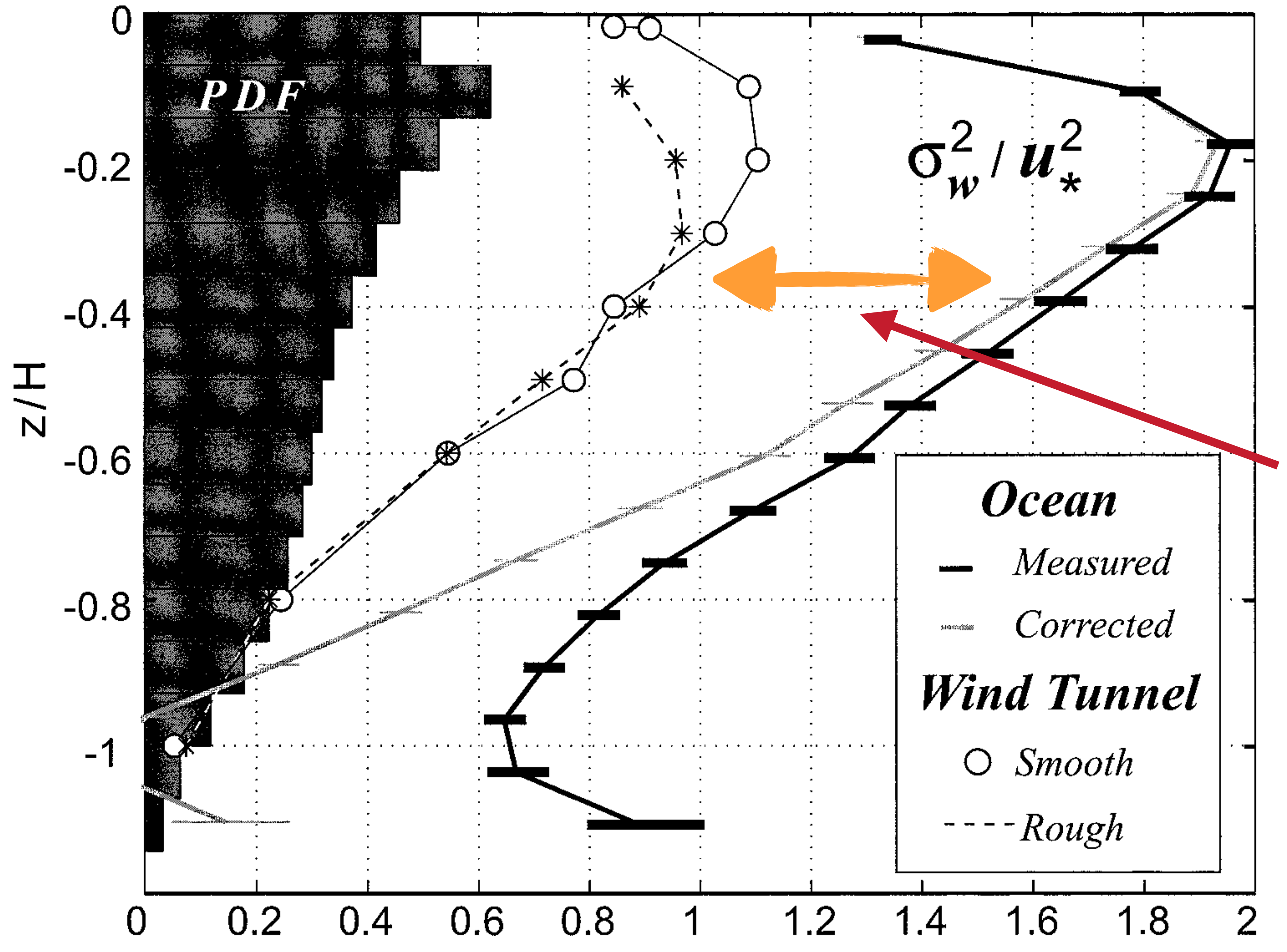


- Evidence from the observations

$$La^2 = \frac{\text{Surface friction velocity}}{\text{Stokes drift}}$$

D'Asaro, 2001

Depth



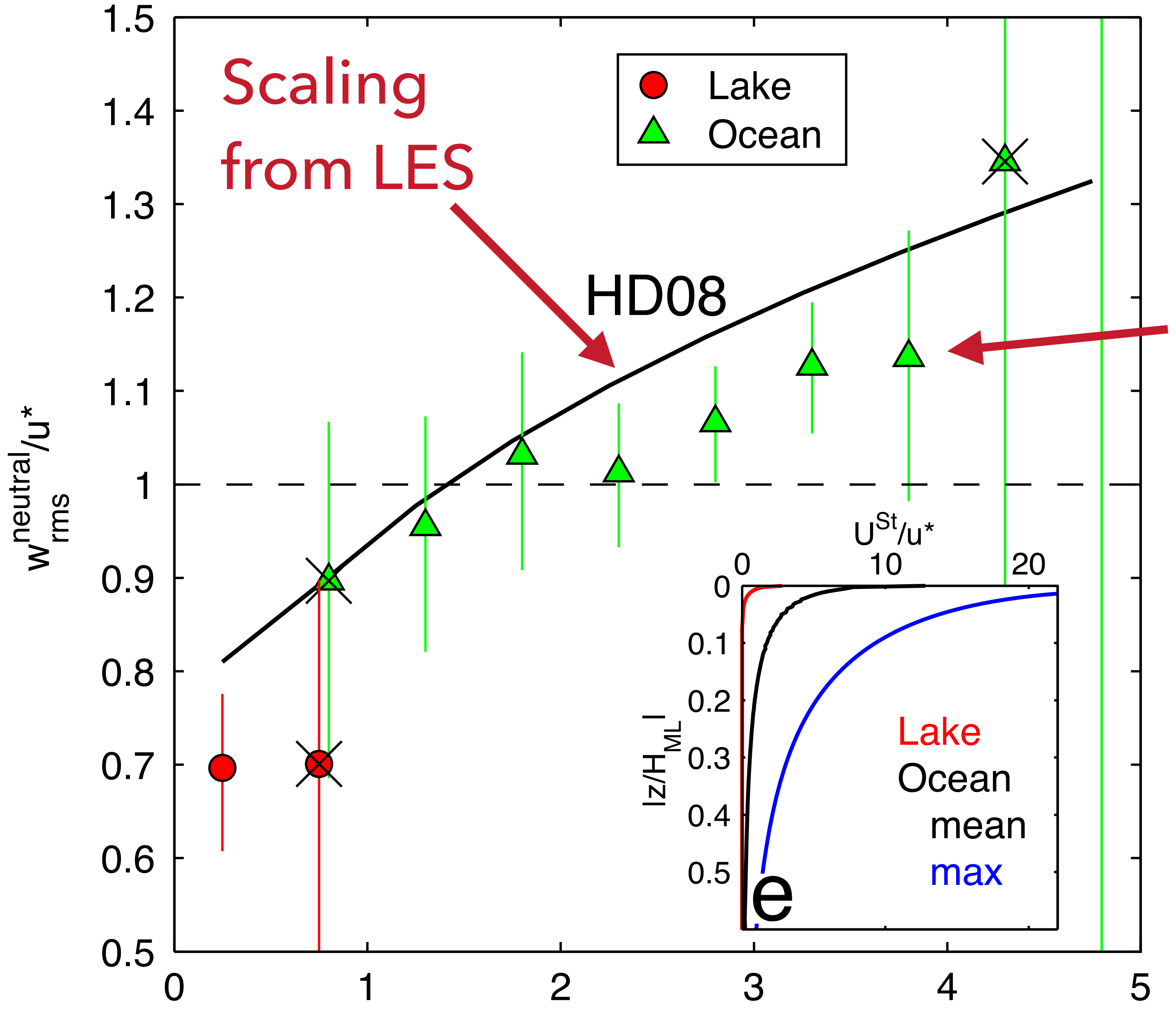
$$A(z) = \sigma_w^2/u^{*2}$$

Enhanced vertical velocity variance

Normalized vertical velocity variance

D'Asaro et al., 2014

Normalized vertical velocity variance



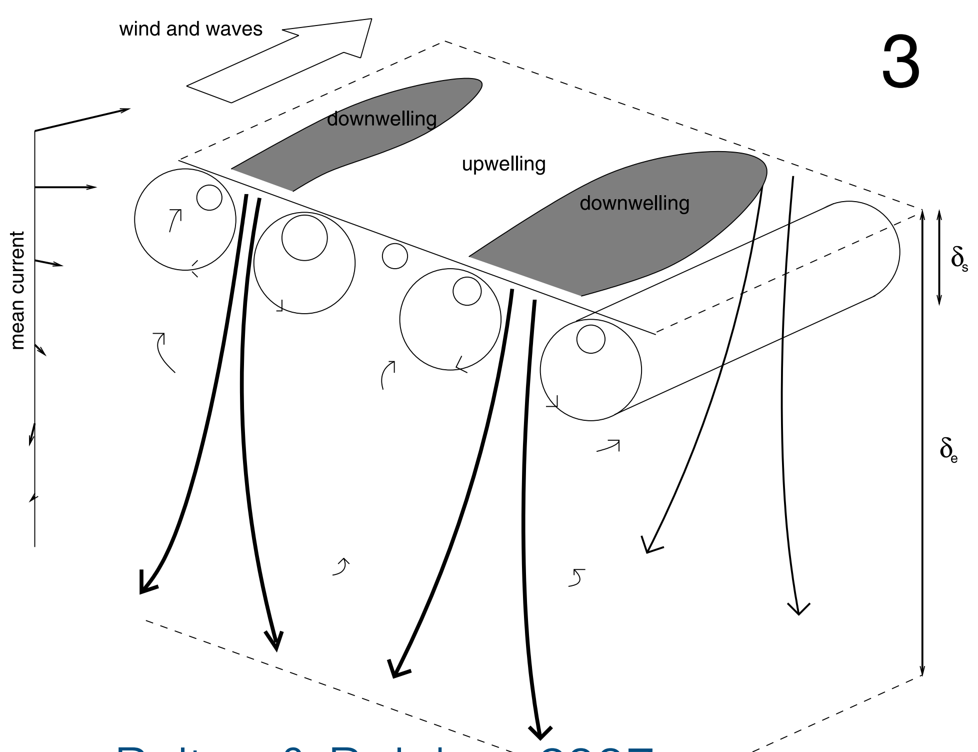
Scaling from LES

Observations

La_{SL}^{-2}

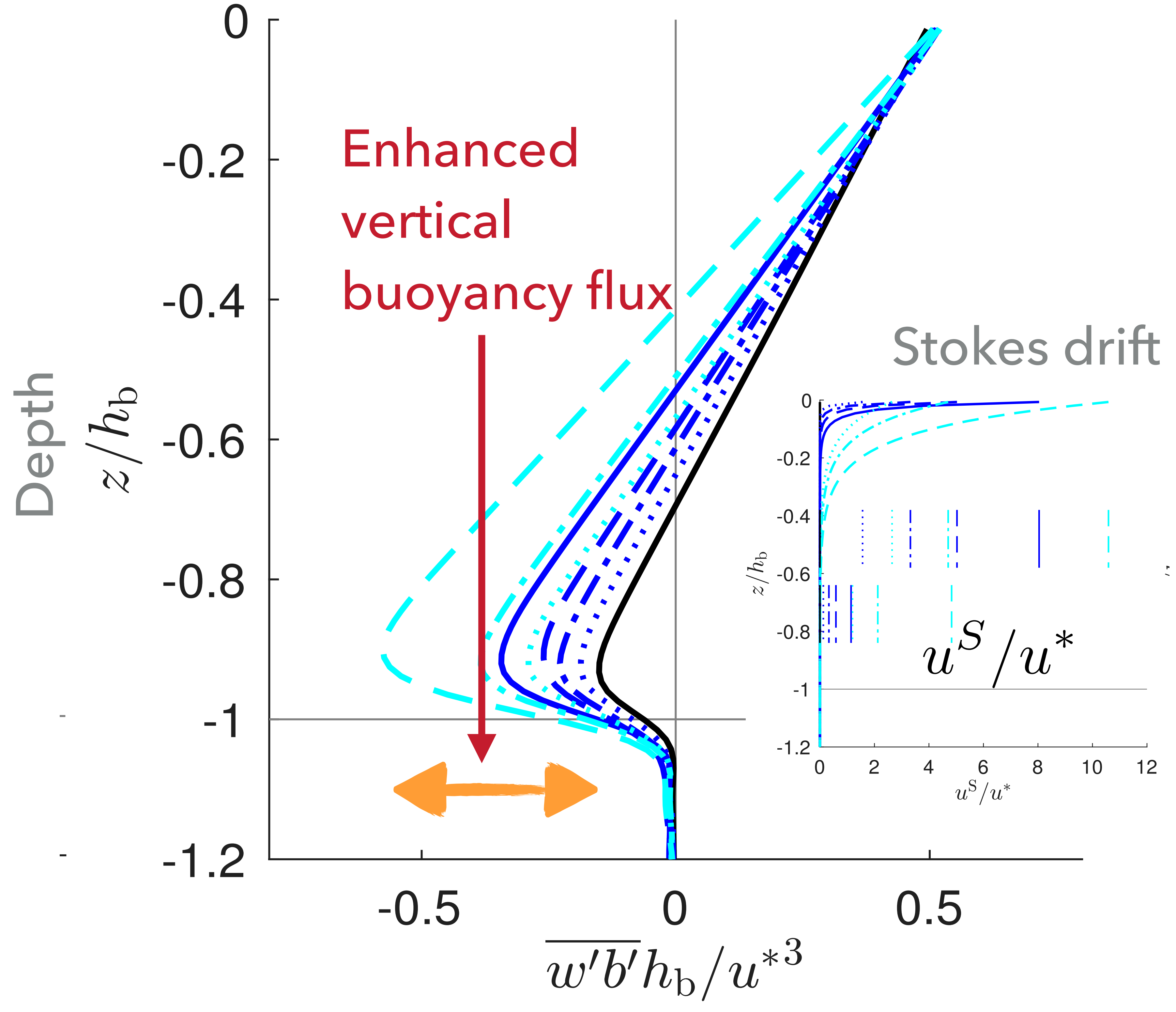
Stokes forcing

Langmuir turbulence enhances mixed layer entrainment

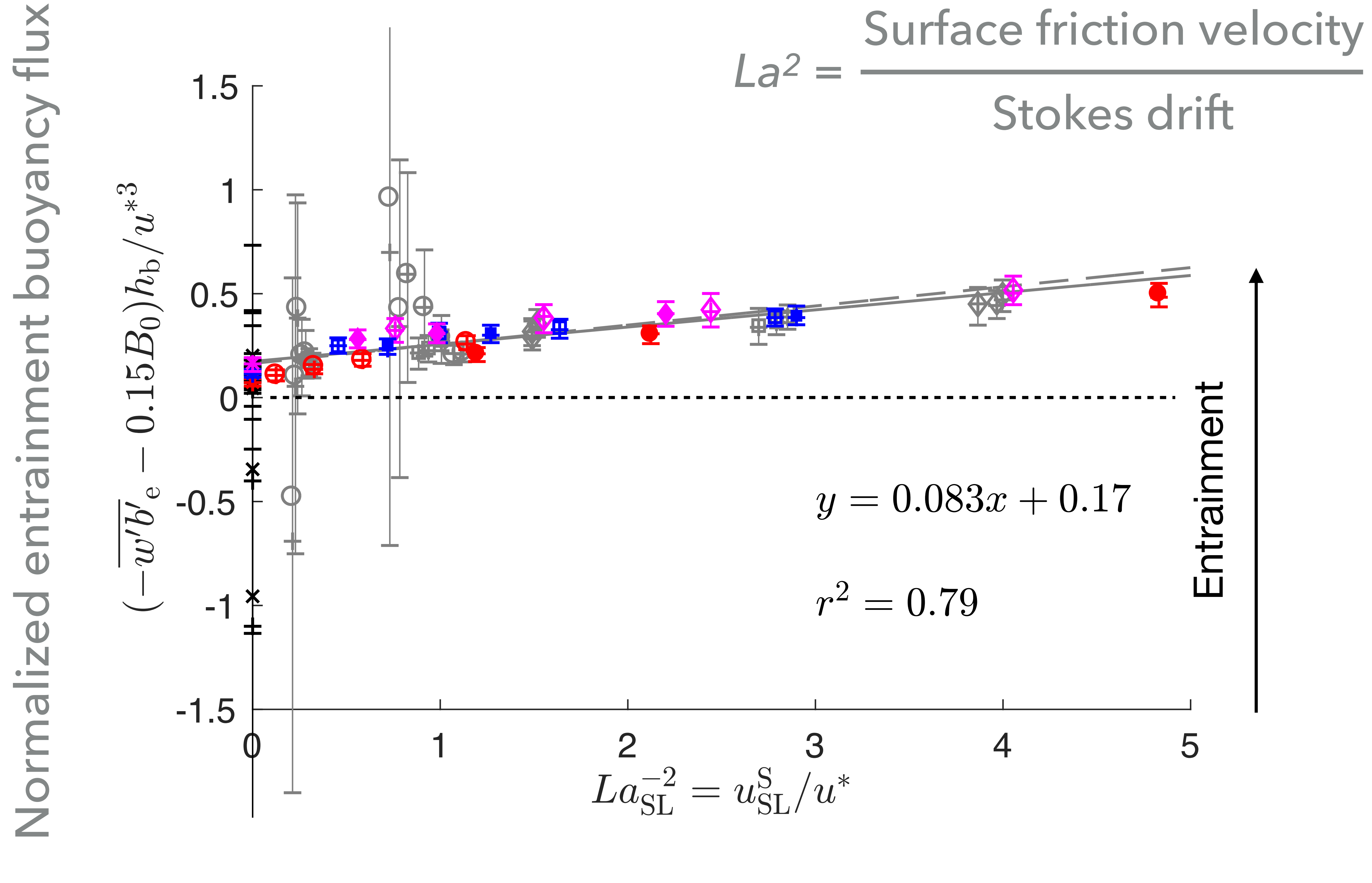


Polton & Belcher, 2007

- Scaling from Large Eddy Simulations



Normalized vertical buoyancy flux



Stokes forcing

Li & Fox-Kemper, 2017, JPO

See Li et al., 2019, JAMES for discussions on other effects of Langmuir turbulence

Parameterization of Langmuir turbulence in KPP

Vertical turbulent flux of a variable λ

Down-gradient component + 'Non-local' component

$$\overline{w'\lambda'} = -K_\lambda \partial_z \overline{\lambda} + \Gamma_\lambda$$

Eddy diffusivity

$$K_\lambda(\sigma) = h_b w_\lambda(\sigma) G(\sigma), \;\; \sigma = z/h_b$$

$\times \, \mathcal{E}$

Boundary layer depth × Turbulent velocity scale × Shape function

Boundary layer depth determined by

Buoyancy

$$\mathrm{Ri}_b = \frac{z[b_r - \overline{b}(z)]}{[\mathbf{u}_r - \overline{\mathbf{u}}(z)]^2 + U_t^2(z)}$$

Resolved shear + Unresolved shear

CESM2.1 ✔ **Enhanced vertical mixing**

- Enhancing the turbulent velocity scale by an enhancement factor
- Scaling derived from LES

$$\mathcal{E} = |\cos\theta_{\mathrm{wl}}| \left[1 + \left(3.1\,\mathrm{La}_{\mathrm{SLP}}\right)^{-2} + \left(5.4\,\mathrm{La}_{\mathrm{SLP}}\right)^{-4}\right]^{1/2},$$

CESM2.2 → **Enhanced mixed layer entrainment**

- Enhancing the entrainment at the base of the ocean surface boundary layer by enhancing the unresolved shear term
- Scaling derived from LES

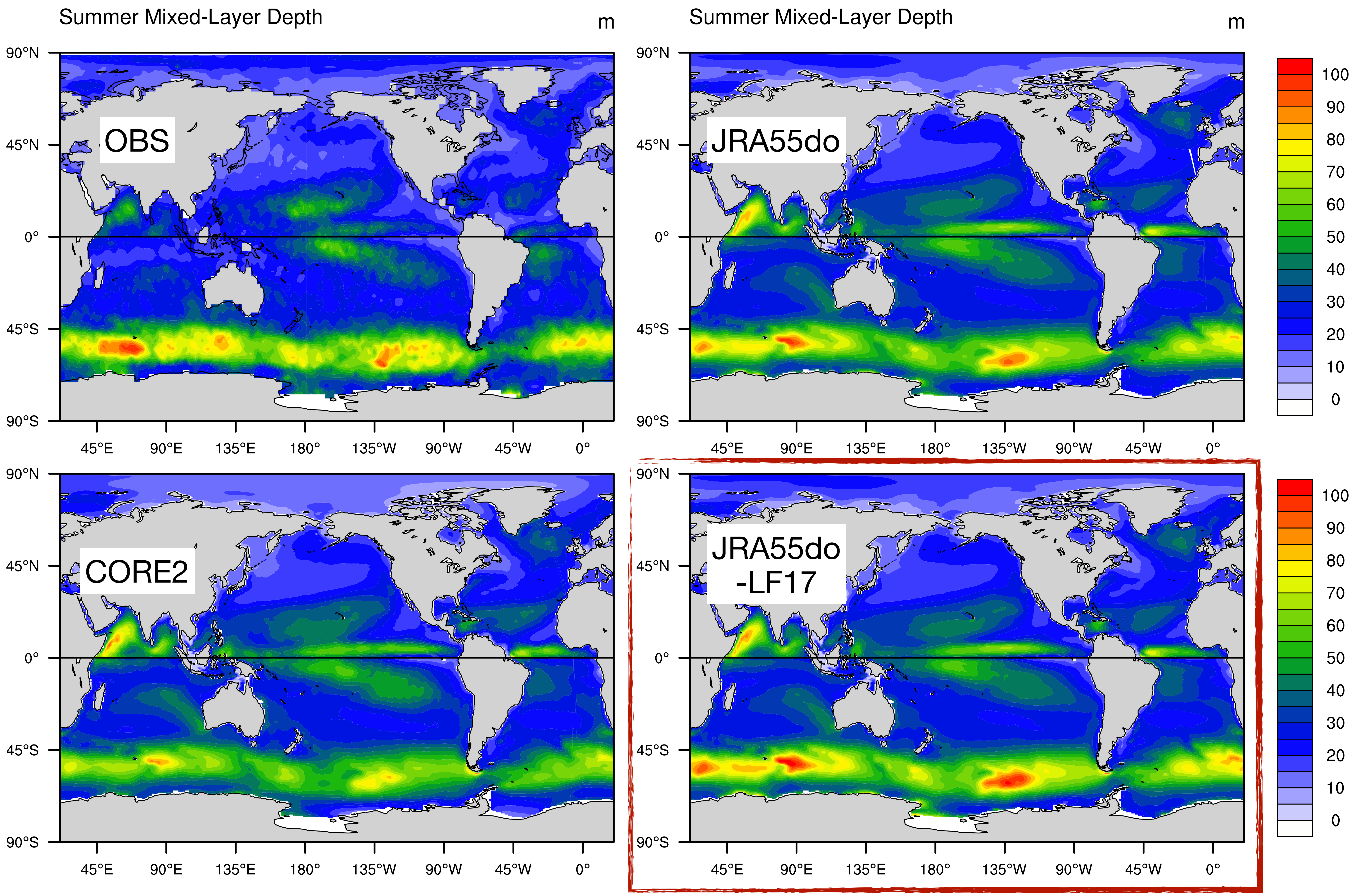
$$U_{tL}^2(z) = \frac{C_v N(z) w_\lambda(z) |z|}{\mathrm{Ri}_c} \left[\frac{0.15 w_*{}^3 + 0.17 u_*{}^3 (1 + 0.49\,\mathrm{La}_{\mathrm{SL}}^{-2})}{w_\lambda(z)^3}\right]^{1/2},$$

Li et al., 2016, OM; Li & Fox-Kemper, 2017, JPO

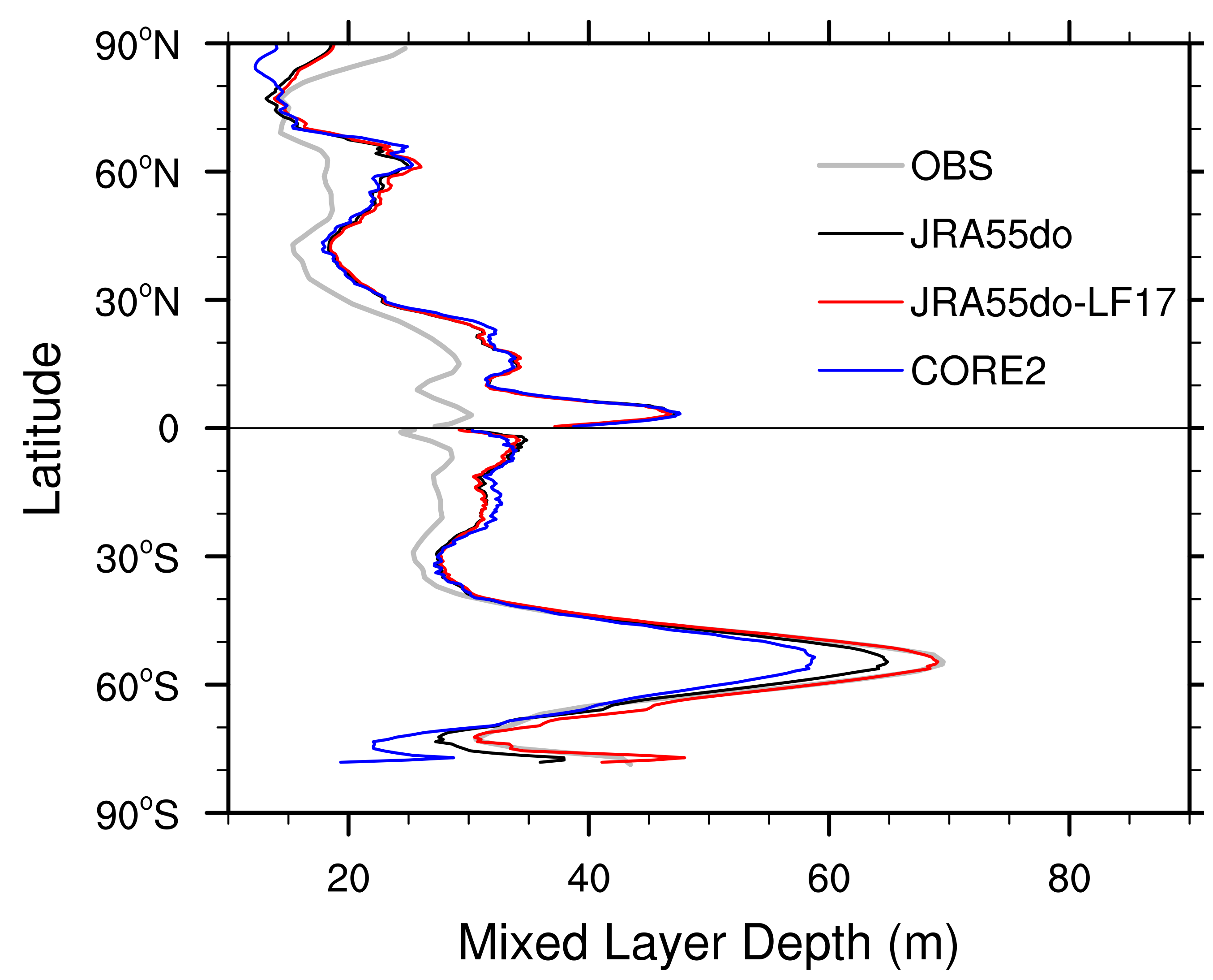
Summer MLD

1980-2009: years 23-52 for JRA55do & 33-62 for CORE2

OBS: de Boyer Montégut et al. (2004)
JRA55do: g.e21.GOMIPECOIAF_JRA.TL319_g17.CMIP6-omip2.001
CORE2: g.e21.GOMIPECOIAF.T62_g17.CMIP6-omip1.001
JRA55do-LF17: 20200517_LF17_GOMIPECOIAF_JRA-1p4-2018_TL319_g17



Zonal mean



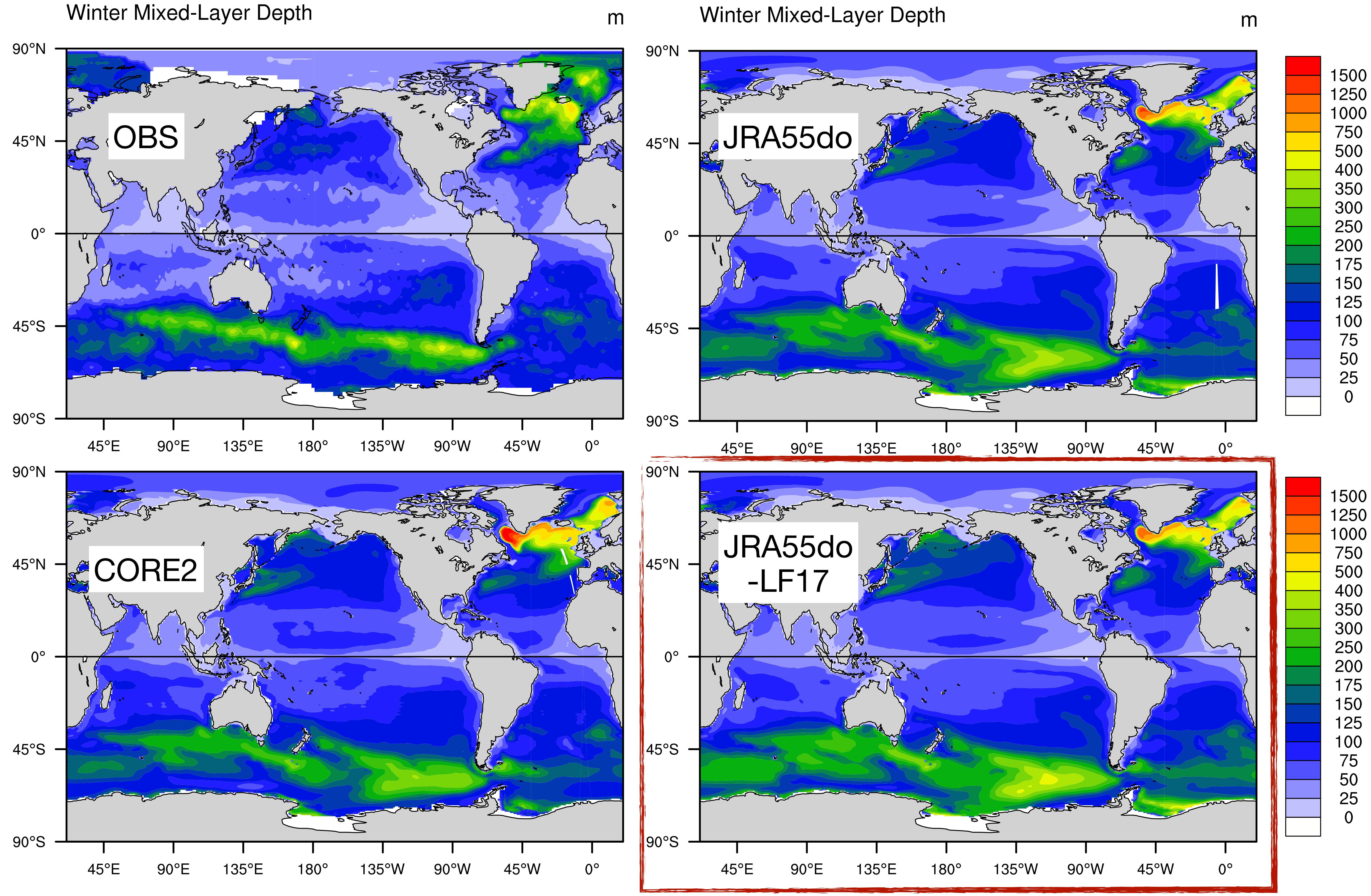
RMSE (m)

	Global	S of 30S	30S-30N
JRA55do	7.65	7.04	8.80
JRA55do-LF17	7.57	7.06	8.63
CORE2	8.54	9.09	9.16

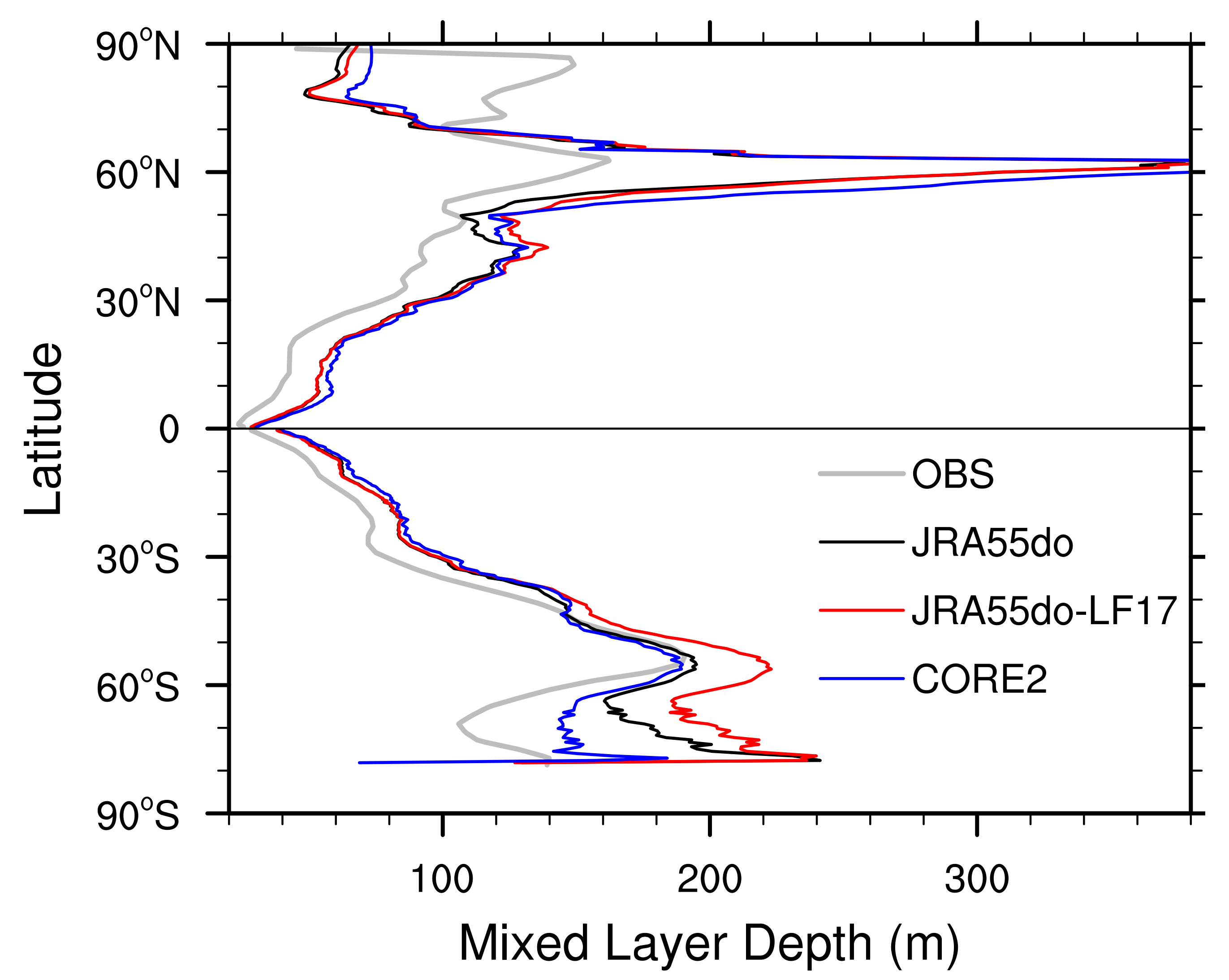
Winter MLD

1980-2009: years 23-52 for JRA55do & 33-62 for CORE2

OBS: de Boyer Montégut et al. (2004)
JRA55do: g.e21.GOMIPECOIAF_JRA.TL319_g17.CMIP6-omip2.001
CORE2: g.e21.GOMIPECOIAF.T62_g17.CMIP6-omip1.001
JRA55do-LF17: 20200517_LF17_GOMIPECOIAF_JRA-1p4-2018_TL319_g17



Zonal mean



RMSE (m)

	Global	S of 30S	30S-30N
JRA55do	47.40	47.16	16.89
JRA55do-LF17	50.67	57.81	16.89
CORE2	62.74	45.20	20.55

The "Theory Wave"

An empirical estimate of the Stokes drift

Surface layer averaged Stokes drift
-> Stokes drift profile

Empirical wave spectra
+
Directional spreading of wind waves

$$u^S_{SL} \approx u^S_0 \Big\{ 0.715 + \left(\frac{0.151}{k_p H_{SL}} - 0.840\right)[1 - T_1(k_p, H_{SL})] - \left(0.840 + \frac{0.0591}{k_p H_{SL}}\right) T_2(k_p, H_{SL}) + \left(\frac{0.0632}{k^*_p H_{SL}} + 0.125\right)[1 - T_1(k^*_p, H_{SL})] + \left(0.125 + \frac{0.0946}{k^*_p H_{SL}}\right) T_2(k^*_p, H_{SL}) \Big\},$$

$$u^S_0 \approx 0.016 U_{10},$$
$$V^S \approx 2.67 \times 10^{-5} g U^3_{10},$$
$$k_p \approx 0.176 \frac{u^S_0}{V^S},$$
$$k^*_p = 2.56 k_p,$$
$$H_{SL} = H_{BL}/5,$$
$$T_1(k, z) = e^{2kz},$$
$$T_2(k, z) = \sqrt{2\pi k|z|}\,\mathrm{erfc}\left(\sqrt{2k|z|}\right),$$

Empirical relations between wind & waves

Langmuir number
$$La_{SL} = \sqrt{\frac{u^*}{u^S_{SL}}},$$

Langmuir enhancement factor
$$\mathcal{E} = \sqrt{1 + (1.5 La_{SL})^{-2} + (5.4 La_{SL})^{-4}}.$$

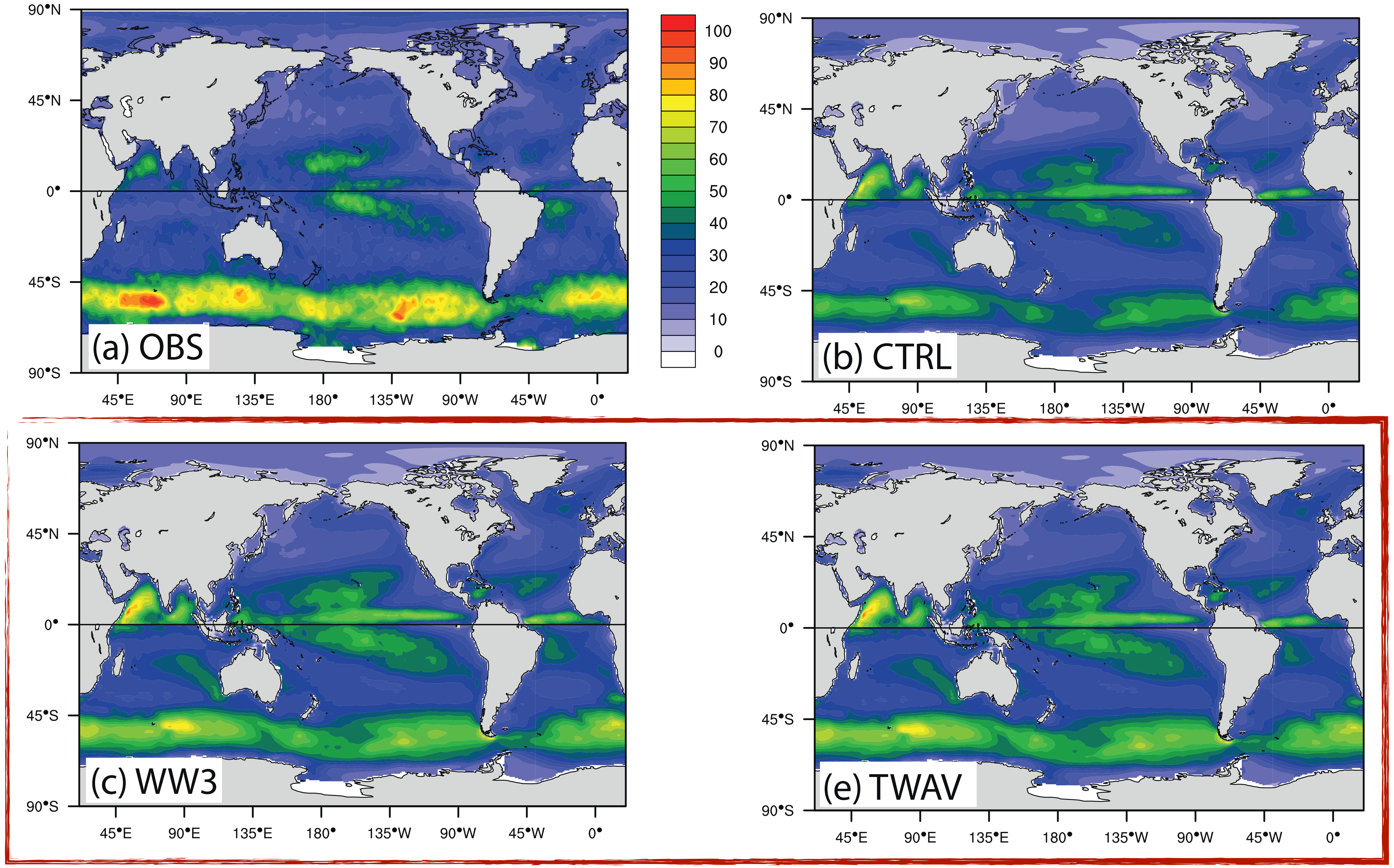
Li et al., 2017, OM

The “Theory Wave”

Tests in CESM1 forced by CORE-II

Observation

No Langmuir mixing



Langmuir mixing with WW3

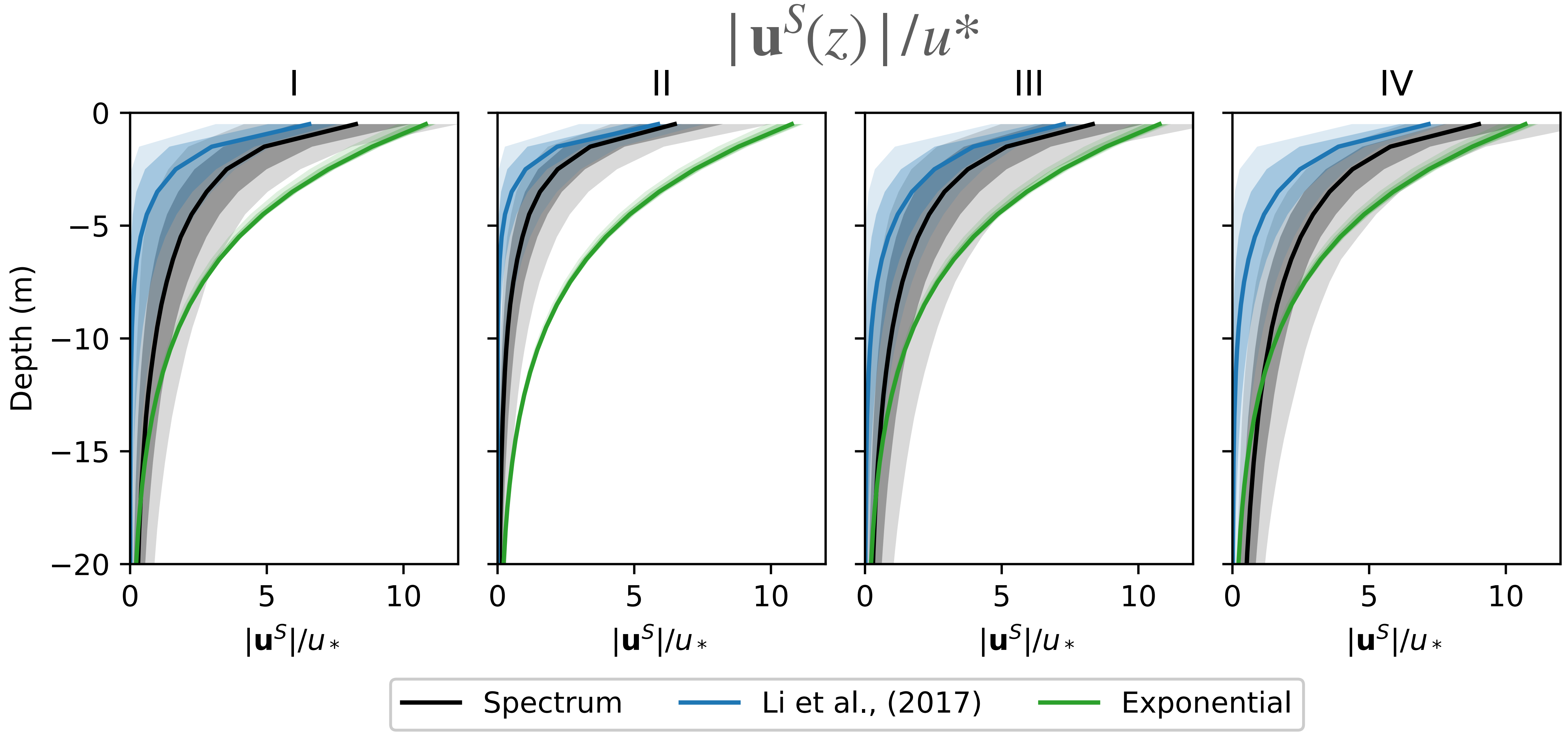
Langmuir mixing with “Theory Wave”

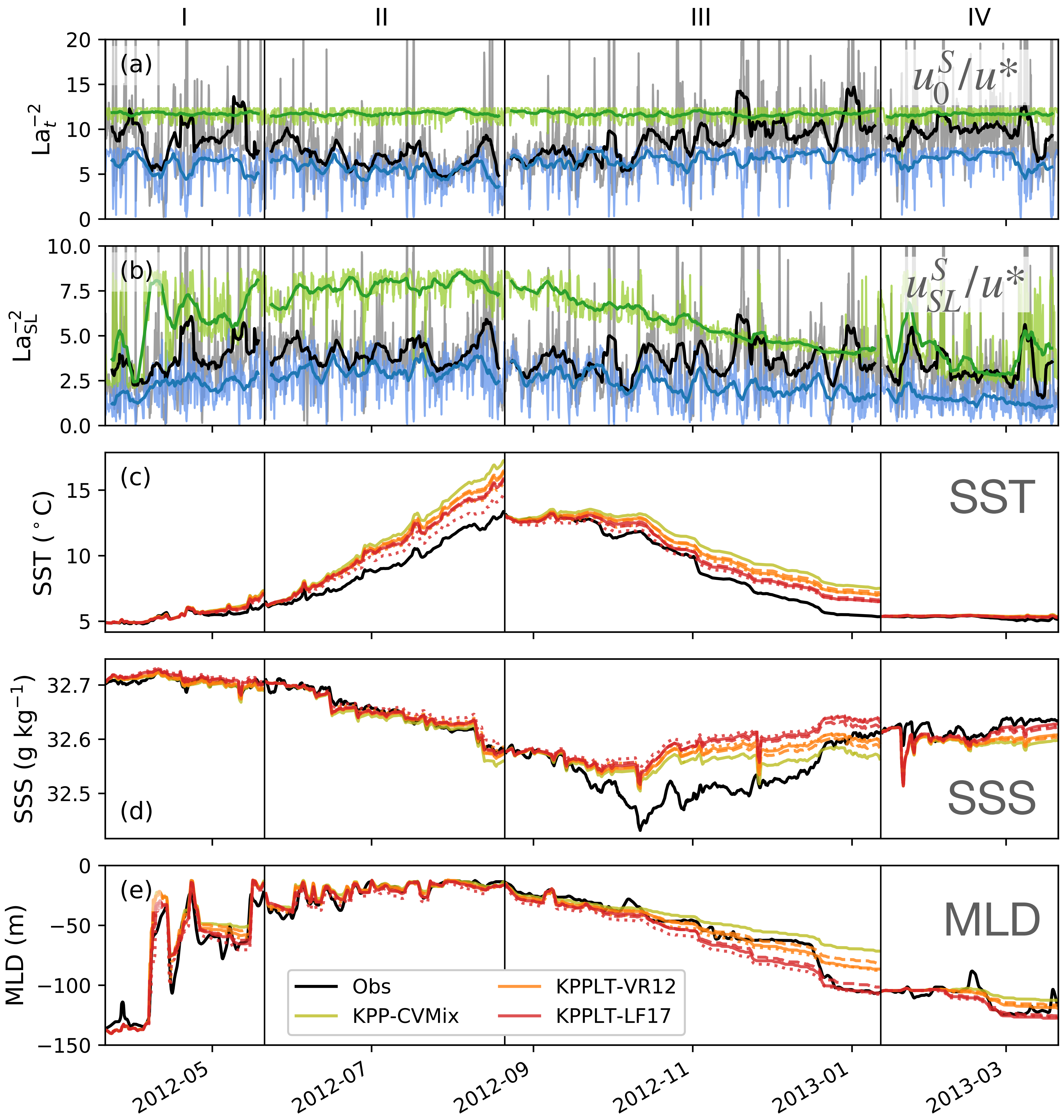
Summer mean mixed layer depth (m)

Li et al., 2017, OM

The "Theory Wave"

An example at Ocean Station Papa





25th - 75th percentiles

10th - 90th percentiles

Mean

Observed wave spectrum

"Theory Wave"

Exponential ($\mathrm{La}_t = 0.3$, $\delta^S = 5$ m), $\mathbf{u}^S(z) = \mathbf{u}_0^S \exp\left(\frac{z}{\delta^S}\right)$

An annual cycle at Ocean Station Papa

Li et al., submitted to GMD

Wave coupling

- Wave component in CESM
  - WW3
  - A “theory wave” option in the “data wave” mode (DWAV)
    - An estimate of the Stokes drift profile -> Langmuir number & Langmuir enhancement factor for Langmuir mixing parameterizations
    - Other wave parameters?
- Wave coupling interface
  - Wave statistics passed to the coupler

Wave statistics

- Stokes drift (e.g., surface Stokes drift partitions)
- Momentum fluxes, energy fluxes, breaking waves, etc
- COWCLIP wave statistics — (significant wave height, mean wave period, mean wave direction, swell wave height)
  - COWCLIP standard: diagnosed offline from 6-hourly output
  - mean, maximum, 10th, 50th, 90th, 95th, 99th percentiles (monthly, seasonal and annual)
- CESM standard output from the coupler, but keep the option to turn on the WW3 output in the native format

Moving forward

- Langmuir turbulence parameterization in MOM6 via CVMix
- The “theory wave” as an option in the “data wave” mode (DWAV)
- Update WW3 to the latest version, wave grid
- Wave coupling interface:
    - Wave variables for parameterizations (e.g., Langmuir turbulence, wave-ice interactions)
    - Wave statistics for wave climate analysis (e.g., COWCLIP)

Thank you!