BROWN

Assessing the Influence of Surface Wind Waves to the Global Climate by Incorporating WAVEWATCH III in CESM

Phase I: Langmuir Mixing in KPP

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Image: NPR.org, Deep Water Horizon Spill

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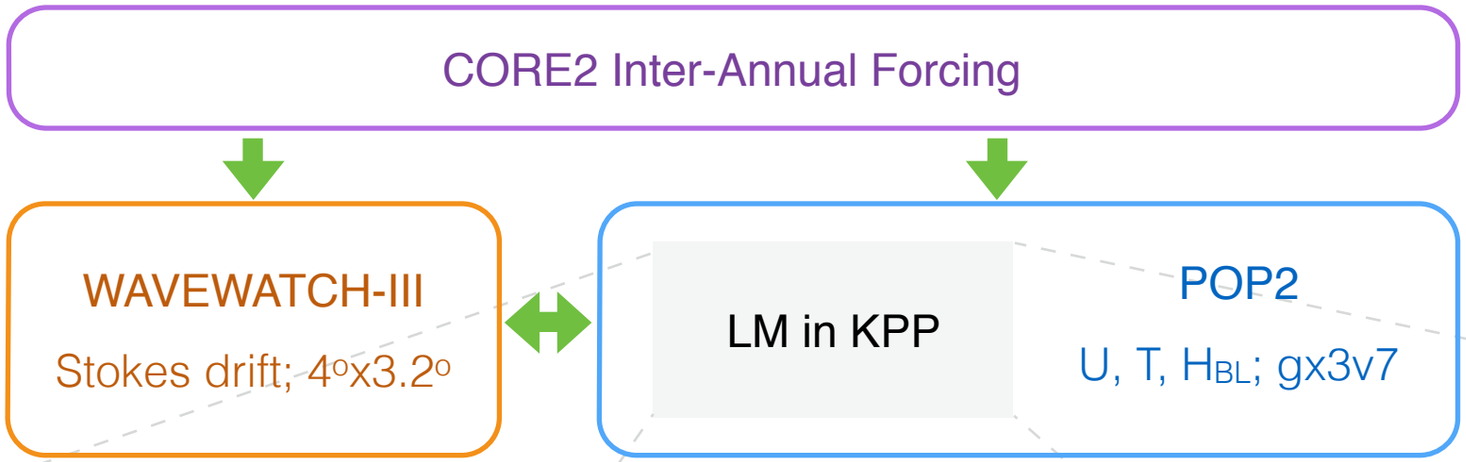
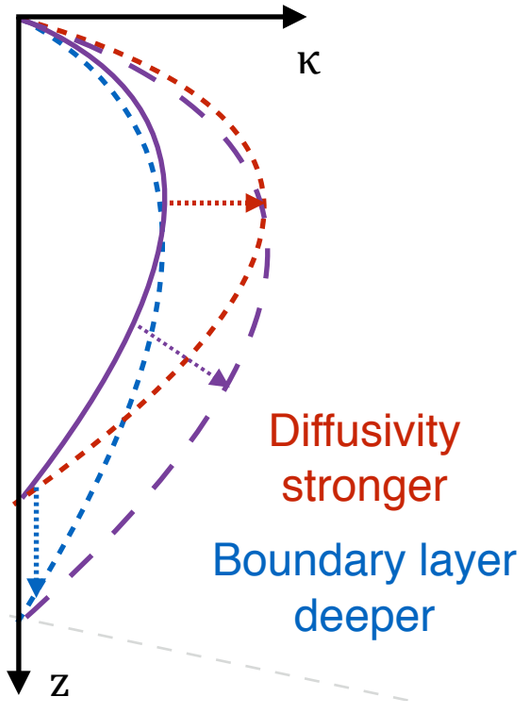
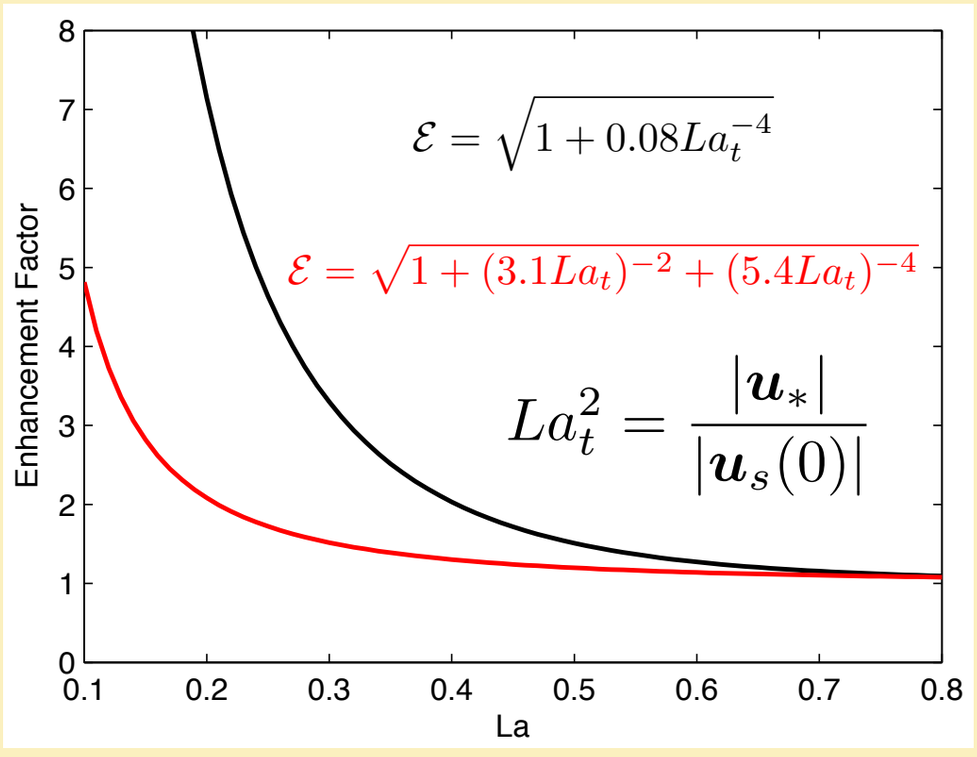
Langmuir Mixing in KPP Choosing a better parameterization





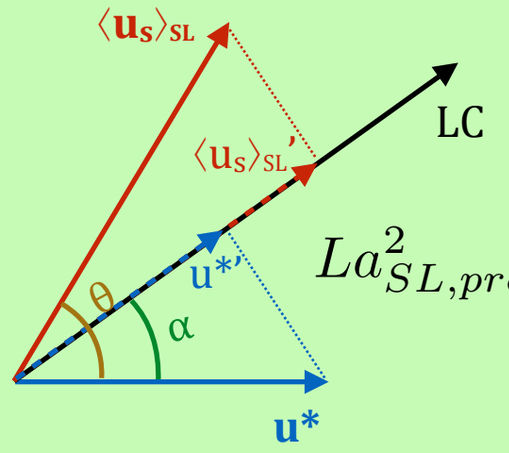
Enhancement factor to vertical velocity scale W
Aligned wind and waves



MS2K

VR12a

Misaligned wind and waves **VR12g**



$$La^2_{SL,proj} = \frac{|\boldsymbol{u}_*|cos(\alpha)}{|\langle \boldsymbol{u}_s \rangle_{SL}|cos(\theta - \alpha)}$$

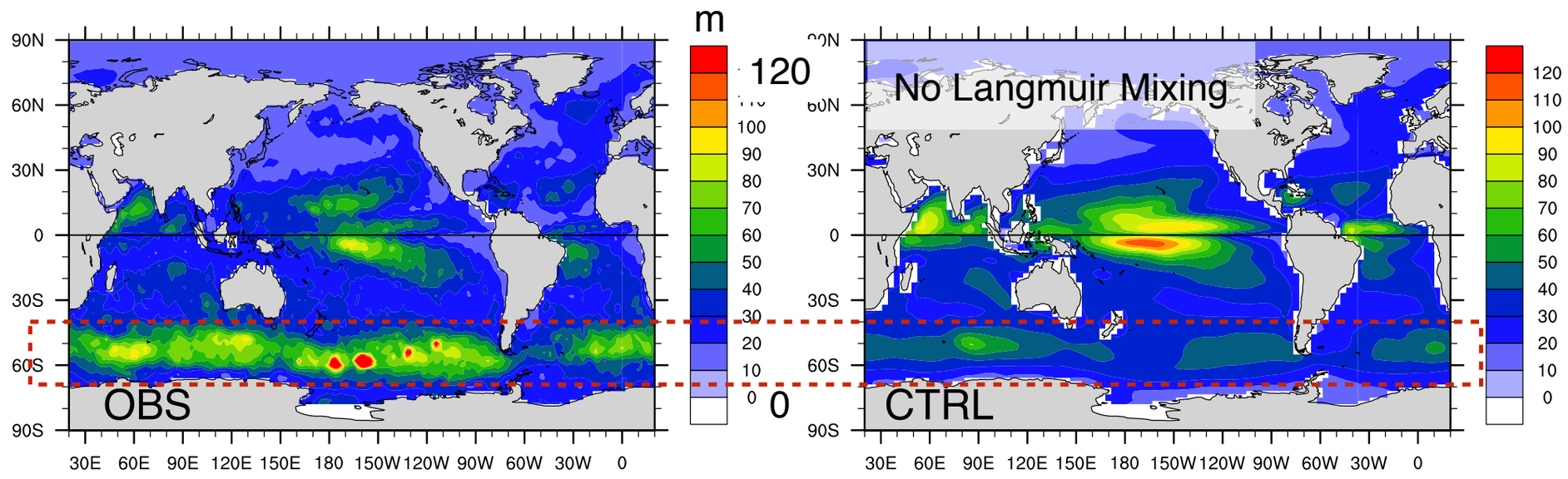
Including Stokes shear
Making the boundary layer even deeper **VR12h**

$$Ri_b = \frac{d\,[b_r - b(d)]}{|\langle \boldsymbol{u}_r \rangle - \langle \boldsymbol{u}(d) \rangle|^2 + U_t^2 + |\boldsymbol{u}_s(0)|^2}$$

McWilliams and Sullivan, 2000; Van Roekel et al., 2012

Summer Mixed Layer Depth (JAS for NH & JFM for SH)

RMSE (m)	
Global	15.63
20S-20N	17.89
South of 30S	**19.50**



Shallow bias in the Southern Ocean

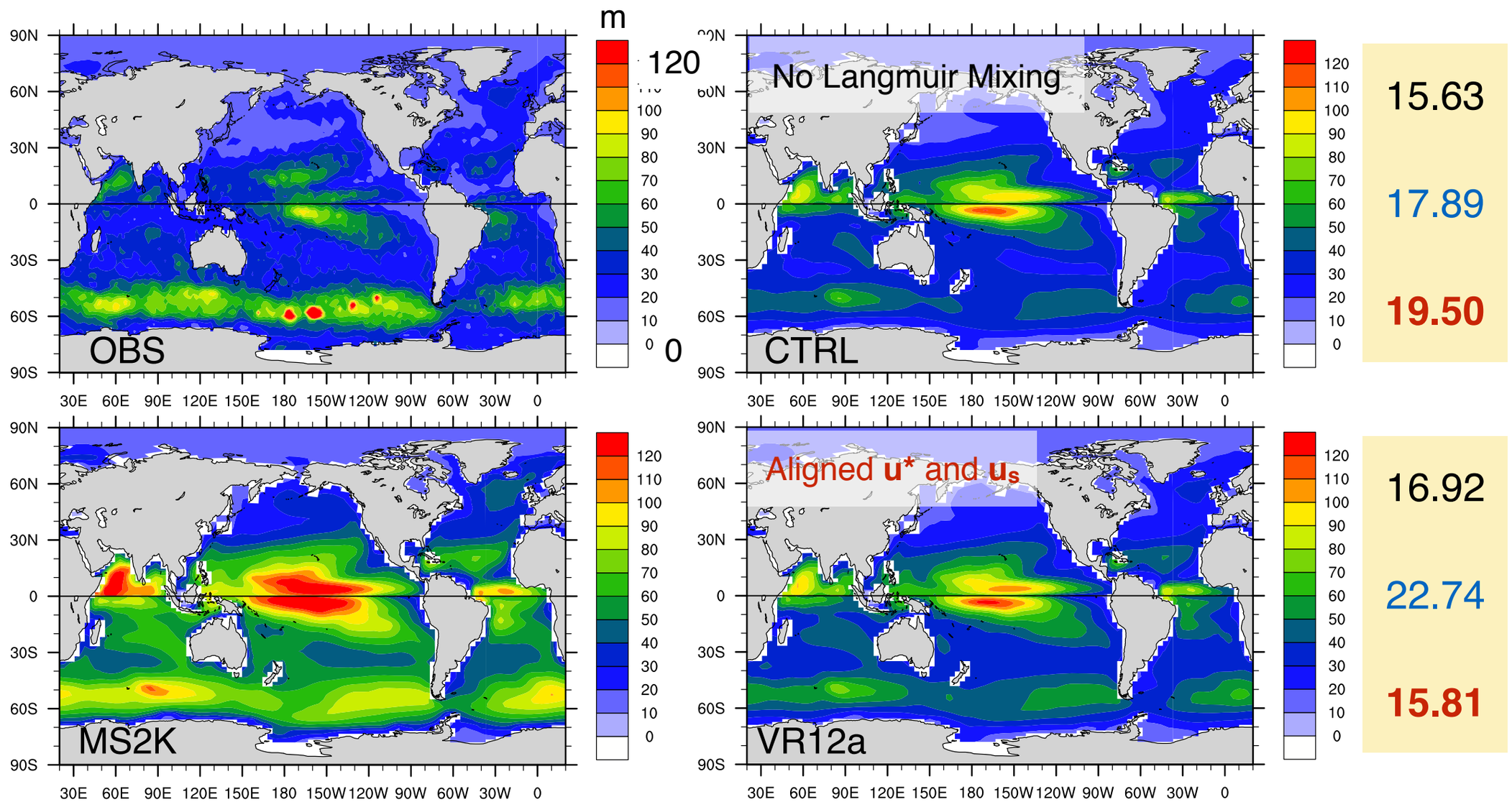
Setup

- WAVEWATCH-III (Stokes drift; 4^ox3.2^o) <-> POP2 (U, T, H_{BL}; gx3v7)
- CORE2 interannual forcing (Large and Yeager,2009)
- 4 IAF cycles; average over last 50 years for climatology
- Same forcing but different Langmuir Mixing parameterizations

OBS: de Boyer Montégut et al. 2004

Summer Mixed Layer Depth (JAS for NH & JFM for SH)

RMSE (m)	OBS	CTRL	MS2K	VR12a
Global		15.63	30.62	16.92
20S-20N		17.89	43.56	22.74
South of 30S		**19.50**	**20.13**	**15.81**

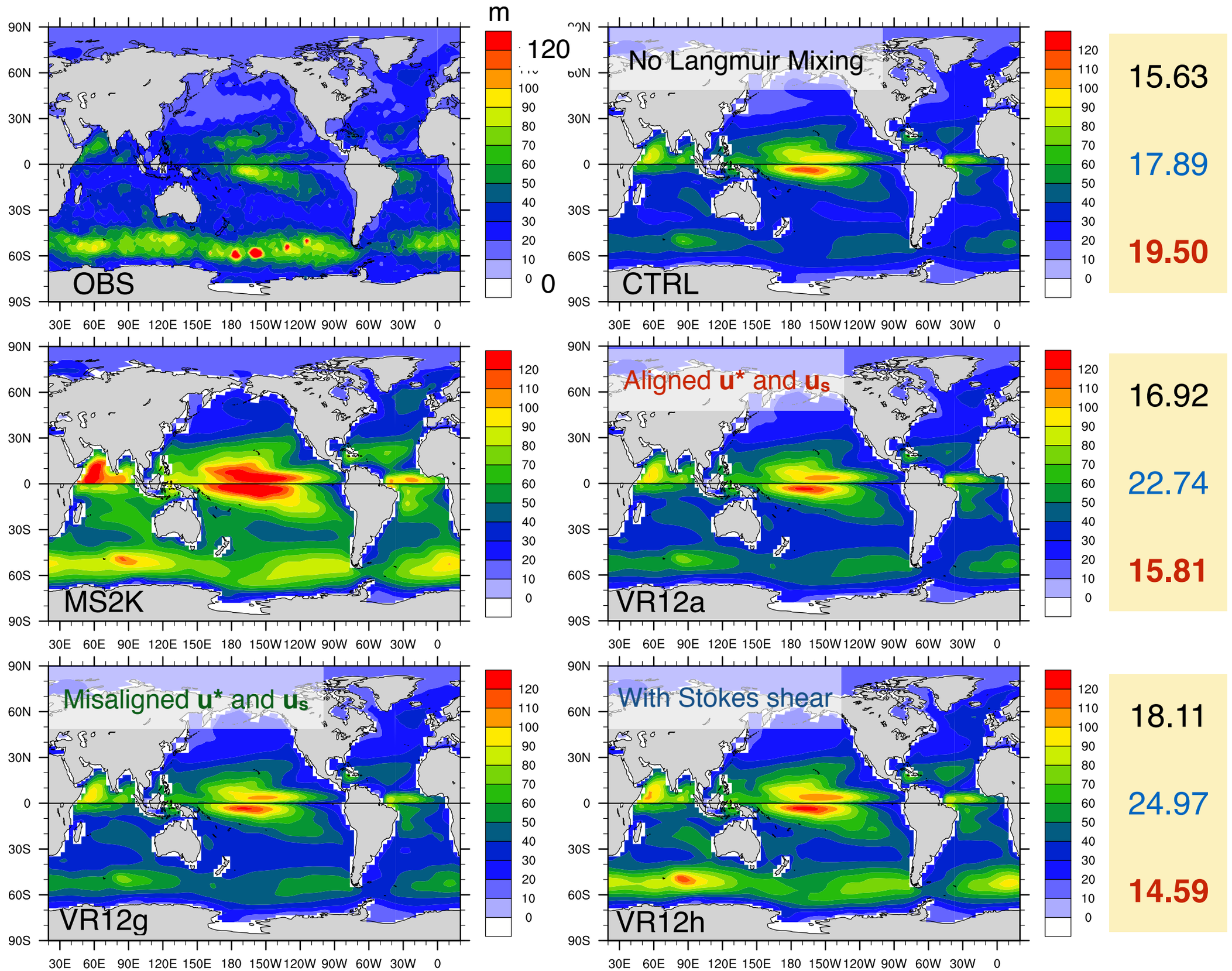


Enhanced mixing, but too much in MS2K

OBS: de Boyer Montégut et al. 2004

Summer Mixed Layer Depth (JAS for NH & JFM for SH)

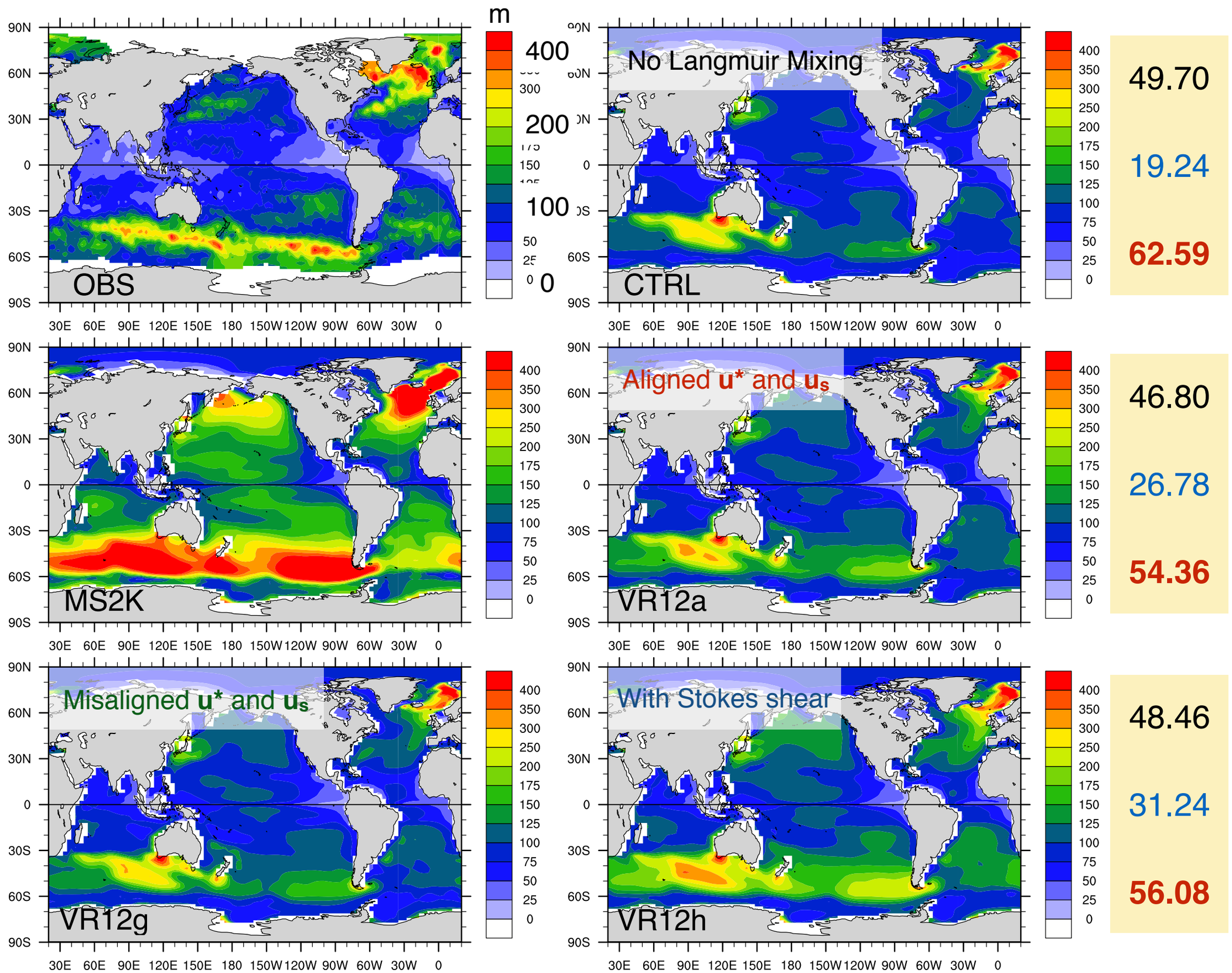
RMSE (m)	OBS	No Langmuir Mixing	Aligned **u*** and $\mathbf{u_s}$	With Stokes shear
Global		15.63	16.92	18.11
20S-20N		17.89	22.74	24.97
South of 30S		**19.50**	**15.81**	**14.59**
	30.62	43.56	20.13	
	16.36	21.36	15.85	



OBS: de Boyer Montégut et al. 2004

Winter Mixed Layer Depth (JFM for NH & JAS for SH)

RMSE (m)	OBS	No Langmuir Mixing	Aligned **u*** and $\mathbf{u_s}$	With Stokes shear
Global		49.70	46.80	48.46
20S-20N		19.24	26.78	31.24
South of 30S		**62.59**	**54.36**	**56.08**
129.20	64.57	**183.18**		
47.69	24.79	**56.99**		

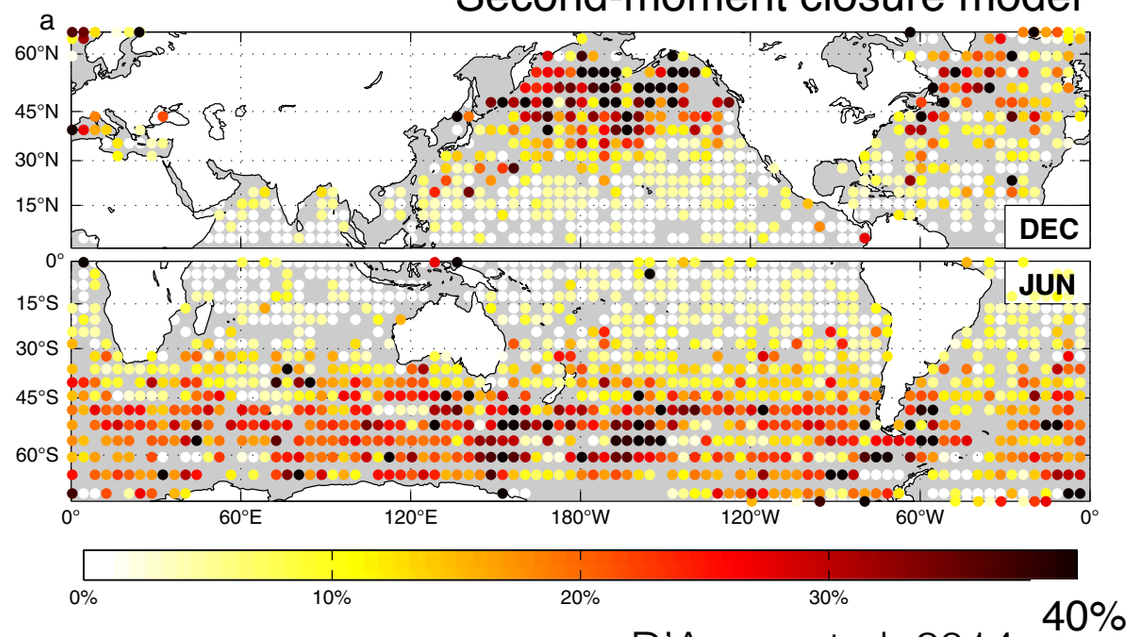


OBS: de Boyer Montégut et al. 2004

Percentage change in MLD by Langmuir Mixing

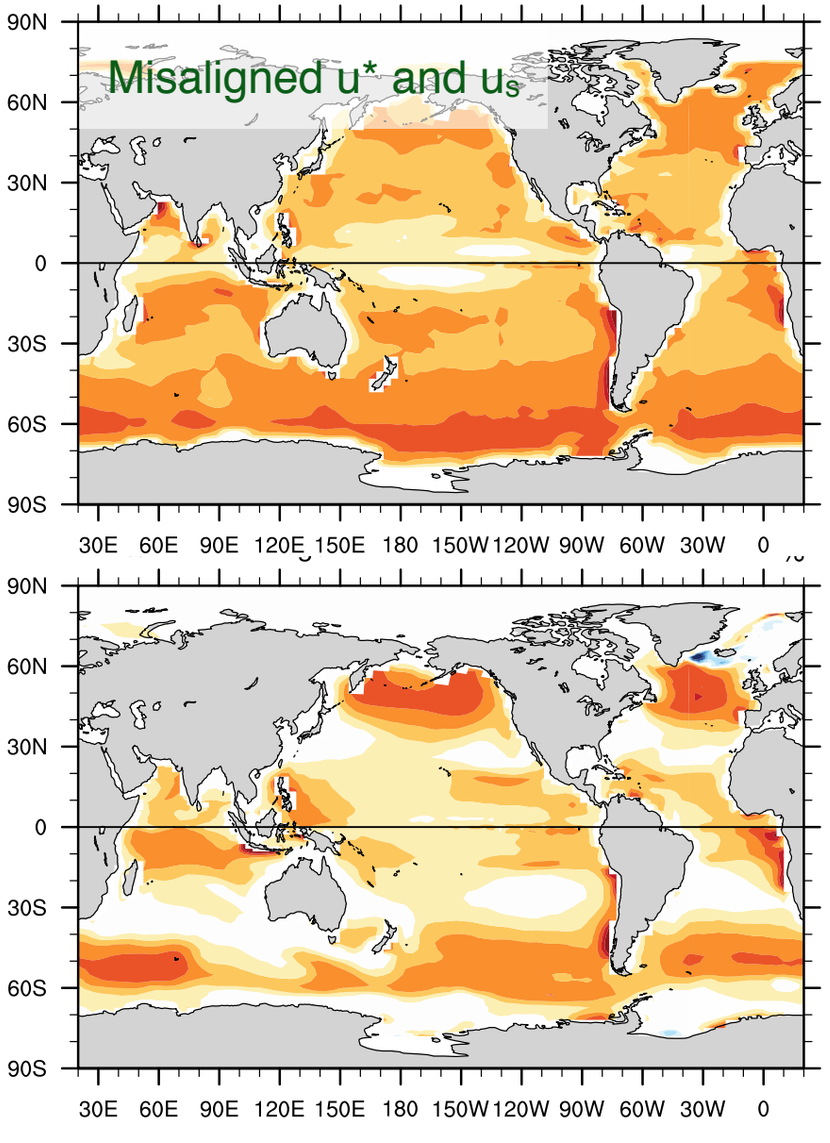
The surface wind waves increase the mixed layer depth at high latitude by 20% ~ 60%

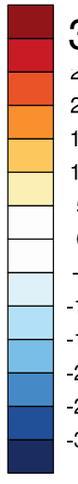
Second-moment closure model



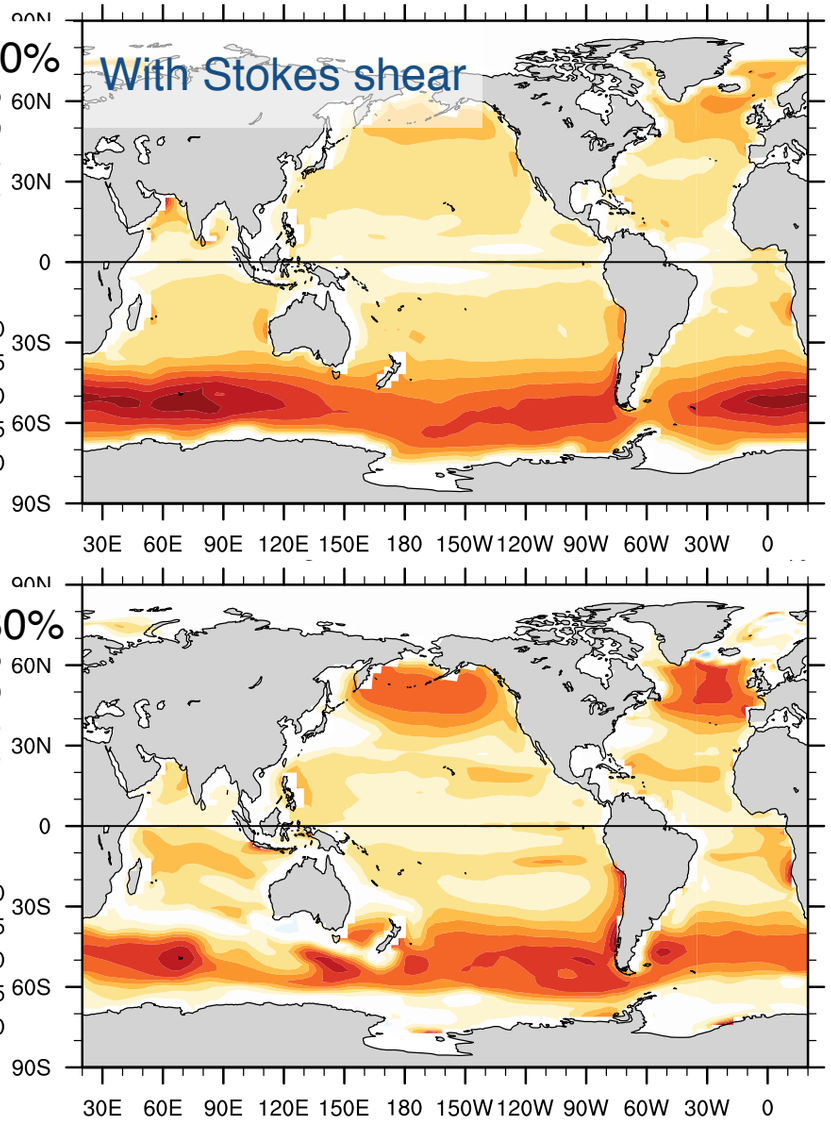
D'Asaro et al. 2014

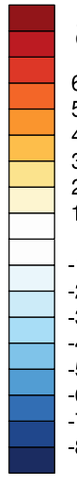
VR12g - CTRL



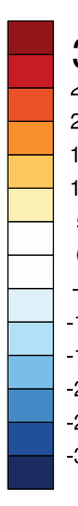


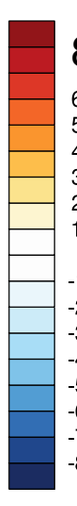
VR12h - CTRL





Summer (JAS for NH & JFM for SH)





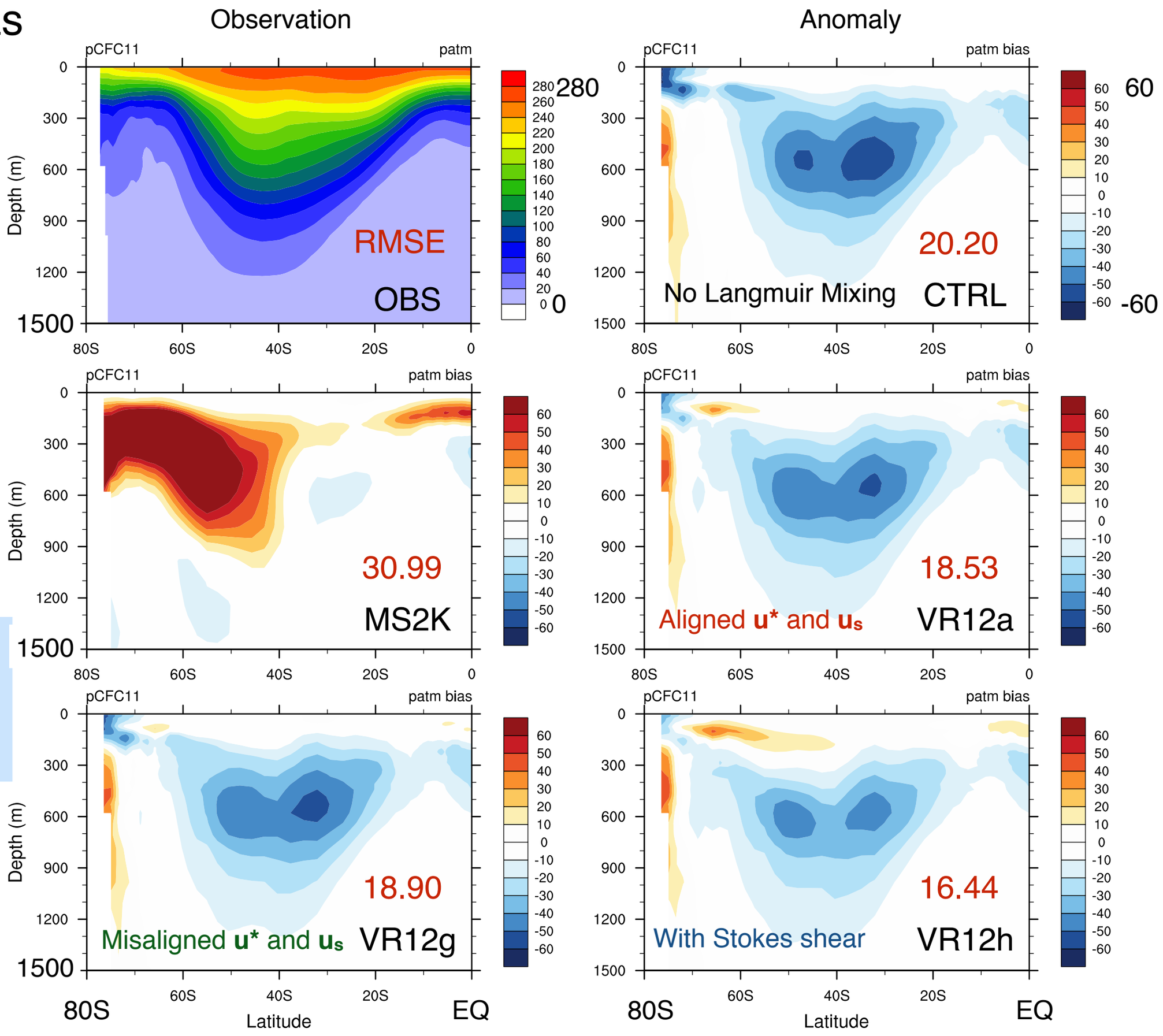
Winter (JFM for NH & JAS for SH)

pCFC11 Bias

Southern Hemisphere

Langmuir Mixing enhance ventilation and reduce low pCFC11 biases

RMSEs are reduced by **6% ~ 18%**



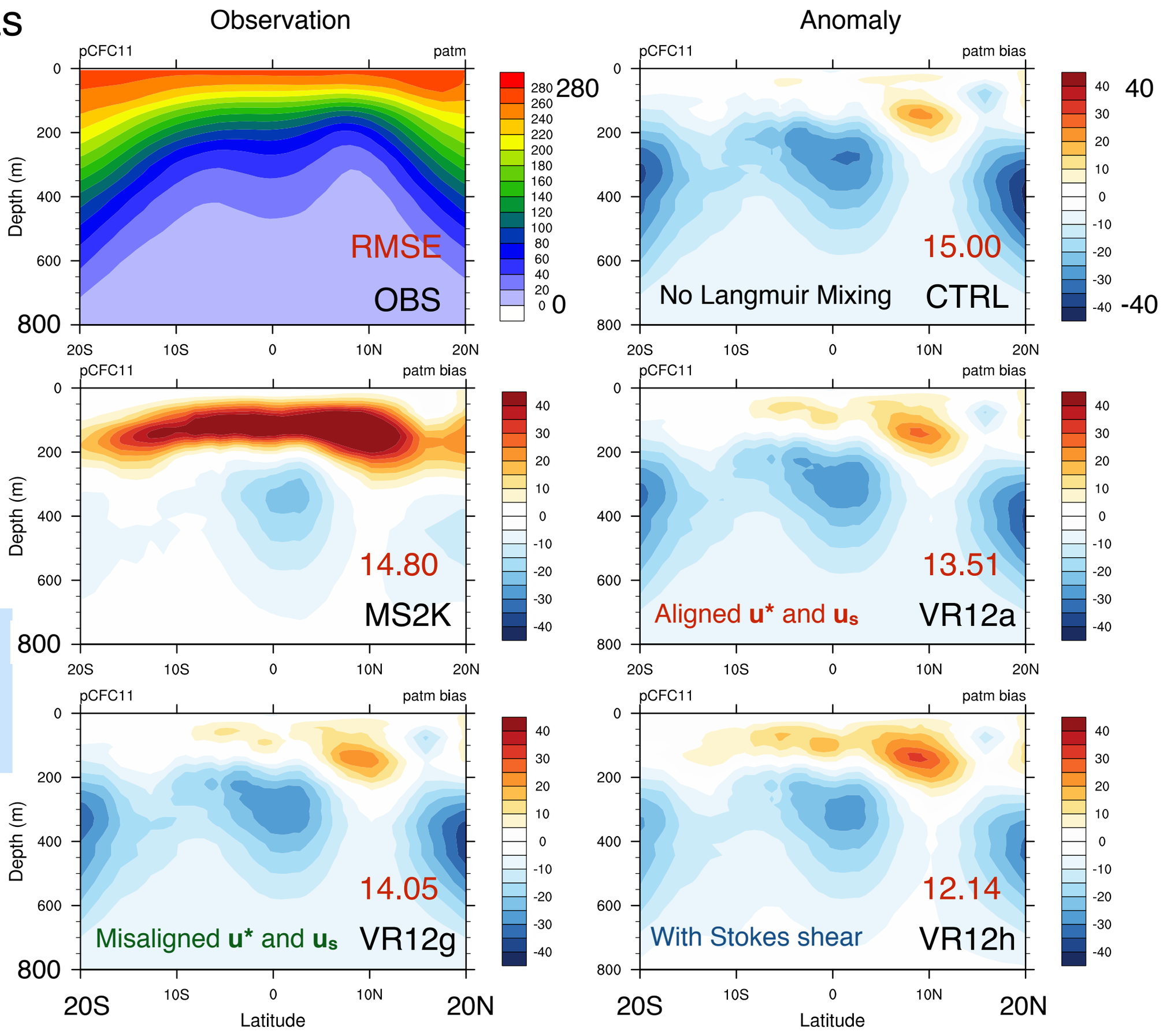
OBS: Key et al. 2004 (GLODAP)

pCFC11 Bias

Equatorial Region

Langmuir Mixing enhance ventilation and reduce low pCFC11 biases

RMSEs are reduced by **6% ~ 19%**



OBS: Key et al. 2004 (GLODAP)

Summary and Future Work (by Jan, 2015)

- WAVEWATCH III as a component of CESM and coupled with POP
- Langmuir mixing
  - Reduces the shallow bias of mixed layer depth in the Southern Ocean (RMSE reduction: summer 20%; winter 10%).
  - Reduces low biases in zonal mean pCFC11 both in the Southern Ocean and Equatorial region (RMSE reduction: ~18%).
- Equatorial region, depend on the MLD definition.
  - LM enhances ventilation; Mean MLD might not be a good indicator there.

- More tests:
  - Fully coupling with active atmosphere and sea ice model.
  - Considerations in the Equatorial region.
  - CVMix.
- An efficient but accurate data wave model.

Model Setup

- WAVEWATCH III v3.14
  - 3rd generation wave model
  - Solves the spectral action density balance equation
  - Res: WW3a (4^{o}x3.2^{o})
- CESM1.2; Ocean-Wave only
  - Compset: CIAF_WAV Res: gx3v7
  - CORE2 Interannual forcing; 4 IAF cycles (62 years); average over the last 50 years for climatology
  - CFC active starting near the end of the 3rd cycle (model year 170, corresponding to data year1931) and through the 4th cycle
  - CFC11 comparison: annual mean of model year 233 (corresponding to data year 1994)
- Mixed layer depth definition
  - OBS: MLD in density with a variable threshold criterion (equivalent to a 0.2°C decrease)
  - CESM: Shallowest depth where the local, interpolated buoyancy gradient matches the maximum buoyancy gradient between the surface and any discrete depth within that water column

Stokes Drift

- At the surface

$$\boldsymbol{u}_s(0) = 2\int_0^{2\pi}\int_0^{\infty}(cos\theta, sin\theta, 0)\frac{\omega^3}{g}S(\omega,\theta)d\omega d\theta$$

- Surface layer mean

$$\langle \boldsymbol{u}_s \rangle_{SL} = \frac{1}{H_{SL}}\int_0^{2\pi}\int_0^{\infty}(cos\theta, sin\theta, 0)(1-e^{-\frac{2\omega^2 H_{SL}}{g}})\omega S(\omega,\theta)d\omega d\theta$$

Langmuir Mixing in KPP Aligned Wind and Waves

- Turbulent Langmuir Number

$$La_t^2 = \frac{|\boldsymbol{u}_*|}{|\boldsymbol{u}_s(0)|}$$

- Vertical velocity scale

$$W = \frac{kU_*}{\phi}\mathcal{E}$$

- Enhancement factor (**MS2K**)

$$\mathcal{E} = \sqrt{1 + 0.08La_t^{-4}}$$

- Diffusivity

$$\kappa_v = WH_{BL}G(\sigma)$$

- Shape function

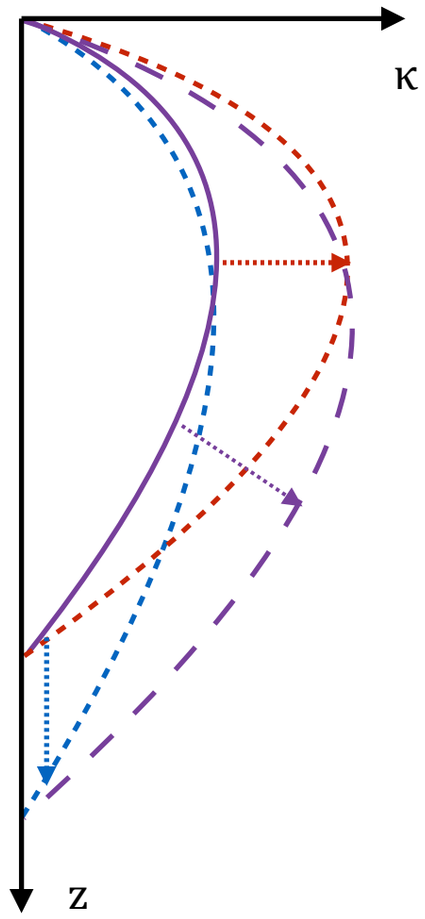
$$G(\sigma) = \sigma(1-\sigma)^2 \qquad \sigma = \frac{d}{H_{BL}}$$

- The boundary layer depth is determined from

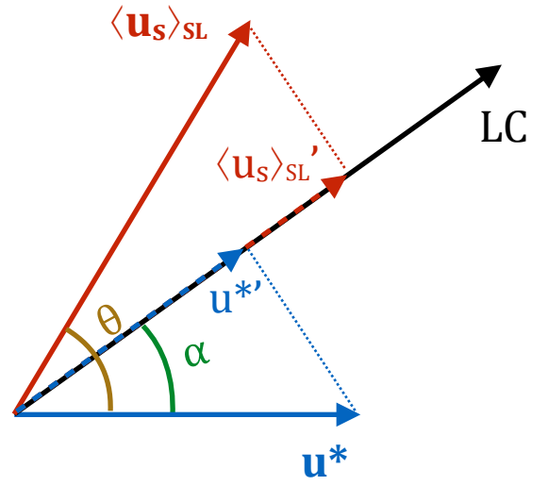
$$Ri_b = \frac{H_{BL}\left[b_r - b(H_{BL})\right]}{|\langle \boldsymbol{u}_r \rangle - \langle \boldsymbol{u}(H_{BL}) \rangle|^2 + U_t^2} \approx 0.3$$

- Enhancement factor (**VR12a**)

$$\mathcal{E} = \sqrt{1 + (3.1La_t)^{-2} + (5.4La_t)^{-4}}$$



Langmuir Mixing in KPP Misaligned Wind and Waves



- Surface layer averaged, projected Langmuir Number

$$La^2_{SL,proj} = \frac{|\boldsymbol{u}_*|cos(\alpha)}{|\langle \boldsymbol{u}_s \rangle_{SL}|cos(\theta - \alpha)}$$

- Angle between Langmuir cell and wind

$$\alpha \approx \tan^{-1}\left[\frac{\sin(\theta)}{\frac{u_*}{u_s(0)\kappa}\ln(|H_{BL}/z_1|) + \cos(\theta)}\right]$$

- Enhancement factor (**VR12g**, **VR12h**)

$$\mathcal{E} = |cos\alpha|\sqrt{1 + (1.5La_{SL,proj})^{-2} + (5.4La_{SL,proj})^{-4}}$$

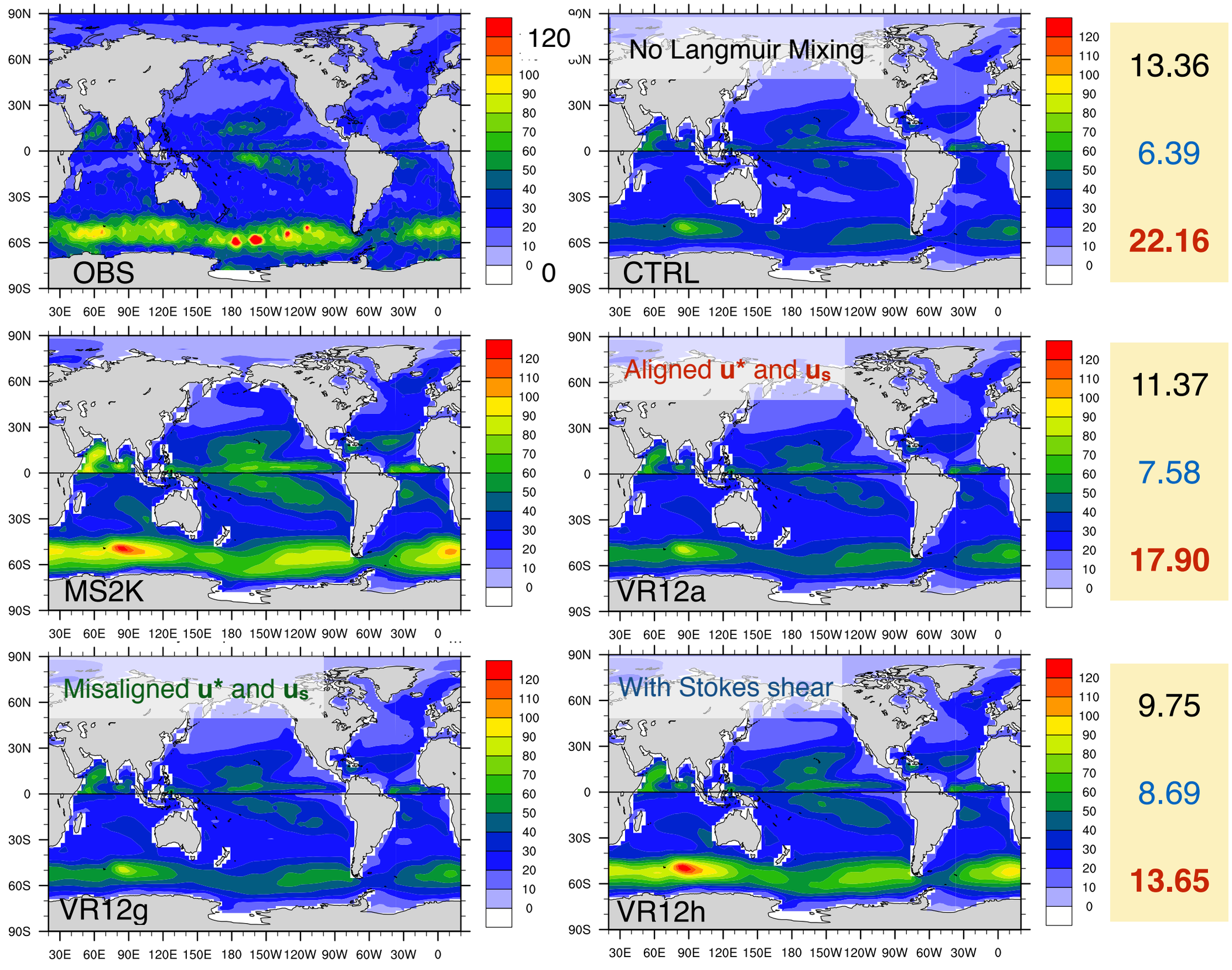
- The boundary layer depth (**VR12h**) is determined from

$$Ri_b = \frac{H_{BL}\left[b_r - b(H_{BL})\right]}{|\langle \boldsymbol{u}_r \rangle - \langle \boldsymbol{u}(H_{BL}) \rangle|^2 + U_t^2 + |\boldsymbol{u}_s(0)|^2} \approx 0.3$$

Summer Mixed Layer Depth (JAS for NH & JFM for SH)

0.03 kg/m^3 density criterion

RMSE (m)		
Global	OBS	
20S-20N		
South of 30S		
13.57	MS2K	13.36
16.22		6.39
14.64		**22.16**
11.38	VR12g	11.37
7.11		7.58
18.71		**17.90**
	VR12h	9.75
		8.69
		13.65



OBS: de Boyer Montégut et al. 2004