Last Gasps of POPping Langmuir

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OMWG Telecon

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How We Got Here

CESM2 code lock for POP: 2016

CESM3 adoption of MOM6: 2016

Li et al KPP-LT: 2016, 2017a, 2017b , 2019, 2020

"theory waves" "entrainment"

CESM2 Has

- Langmuir-induced within-BL mixing driven by WaveWatch or Climatology (“Data Waves”)
  - Van Roekel et al. (2012), Li et al. (2016)
- WaveWatch as a component, all wave variables accessible
  - Li et al. (2016)
- KPP (without Langmuir updates since 2012)

CVMix Has

- KPP-Langmuir Turbulence (Li et al., 2016, 2017a, 2017b, 2019, 2020)
- EPBL-Langmuir Turbulence (Reichl & Li, 2019)
- CM, CESM, E3SM, GOTM-capability (Li et al. 2019)

CESM Doesn't Have

- Passing of La_{SL} (from WaveWatch, only E) or other wave variables (e.g., u_stokes)
- CIME create_newcase allowing swapping of "Theory Waves" for WaveWatch or "Data Waves"
  - "Theory Waves" without CVMix, for roughness or Stokes drift, high-resolution, etc.

CVMix Has

- Langmuir-induced Entrainment (req'd: E and La_{SL})
- KPP or EPBL "Theory Waves" (triggered via software alteration within CVMix using flags)
- Capability of being run in MOM, POP, MPAS-O, GOTM

Theory Waves:
Cheaper than WaveWatch & Better than Data Waves

Table 1
A summary of computational cost[a] for simulations without Langmuir mixing parameterization (CTRL), coupled with WAVEWATCH III (WW3), with the Data Wave (DWAV) and the Theory Wave (TWAV).

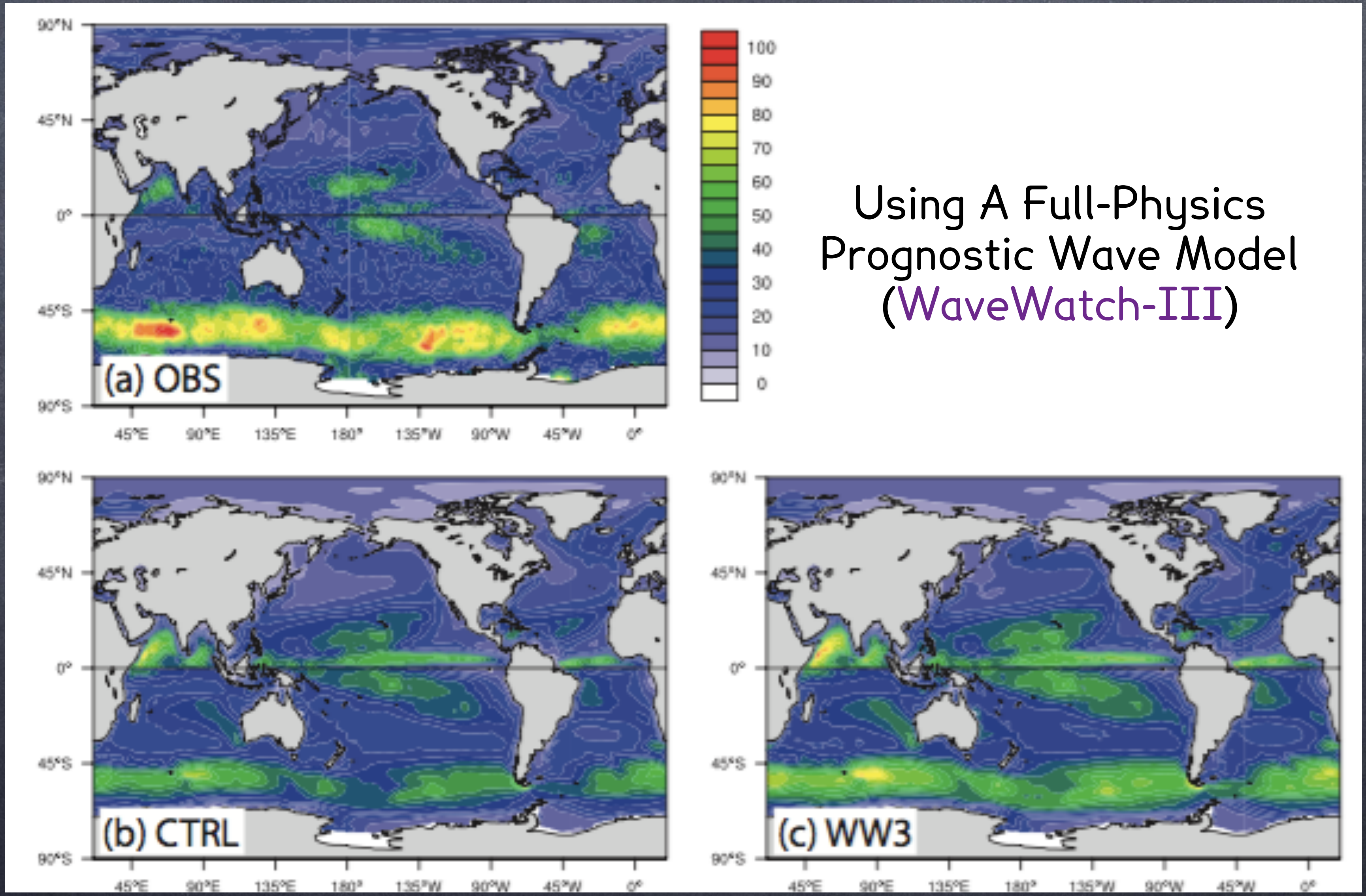
Case name	CTRL	WW3	DWAV	TWAV	NP[b]	NS[c]	Description
CORE-II	100 ± 0.7	103.2 ± 1.4	100.7 ± 1.2	99.7 ± 0.4	64	7	CORE-II forced ocean-wave
PI	100 ± 0.6	110.1 ± 0.9	100.3 ± 0.4	100.6 ± 0.5	128	16	Preindustrial fully coupled; CAM4
20C	100 ± 1.1	105.4 ± 1.2	–	–	128	38	20th century fully coupled; CAM5

[a] Measured in processor element-hours per simulated-year as mean ± standard deviation, normalized by the mean cost of CTRL for each case and then multiplied by 100 to show the percentage. All simulations were performed on the NCAR supercomputer Yellowstone, with a nominal 1° resolution for the ocean model and 1.9° × 2.5° for the atmosphere model when applicable.
[b] Number of processors. Fully sequential component layout is used.
[c] Number of timing samples represented in the statistics.

WaveWatch on coarse WW3a grid increases g-cases by 3%, increases b-cases by 5-10%
Theory waves & data wave costs are undetectable

How accurate do we need the waves to be?

Langmuir Turbulence Parameterizations are robust to large approximations in wave modeling, e.g., replacing wave models with climatology, theoretical scalings



Q. Li, B. Fox-Kemper, O. Breivik, and A. Webb. Statistical modeling of global Langmuir mixing. Ocean Modelling, 113:95-114, May 2017.

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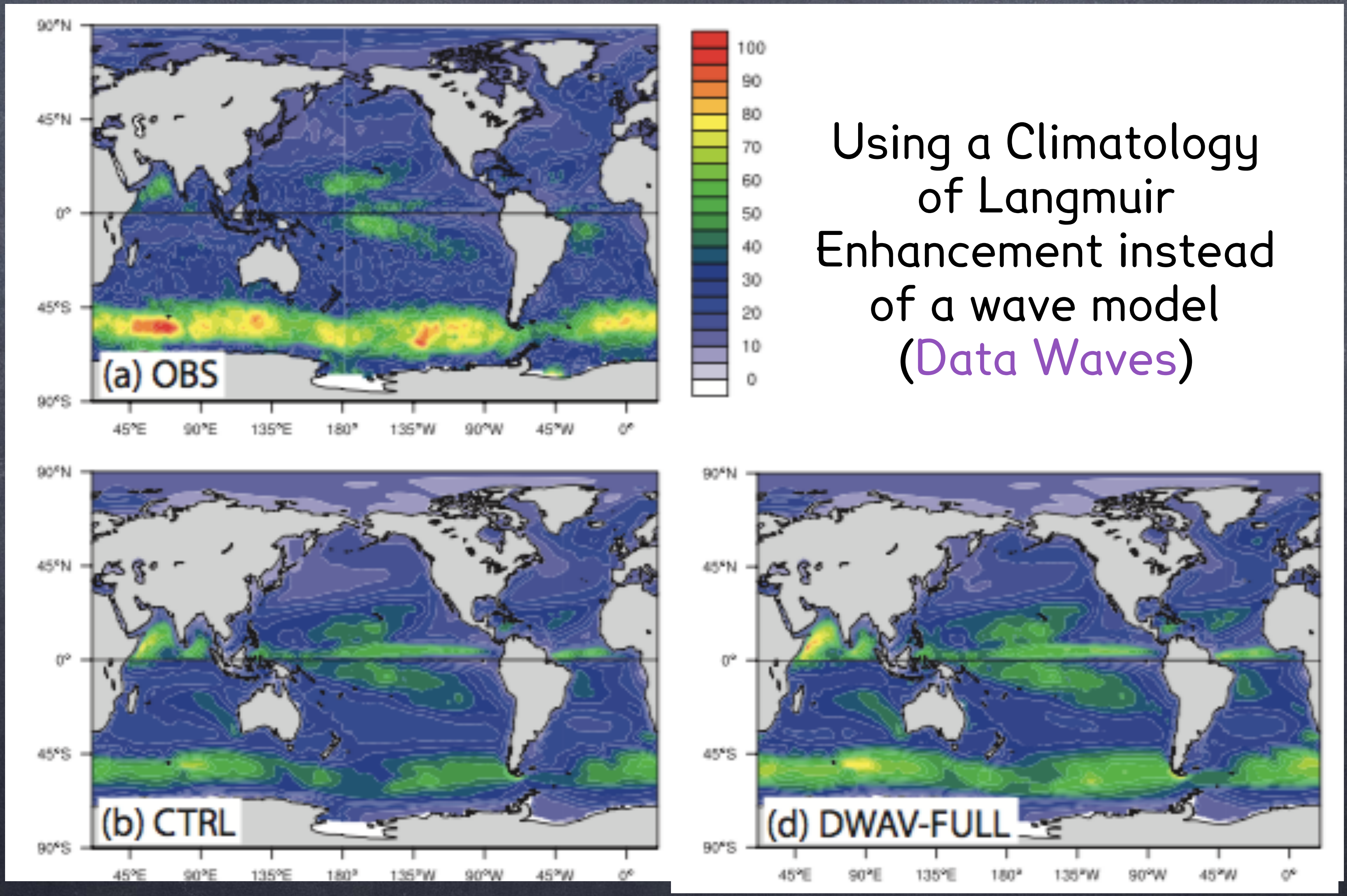

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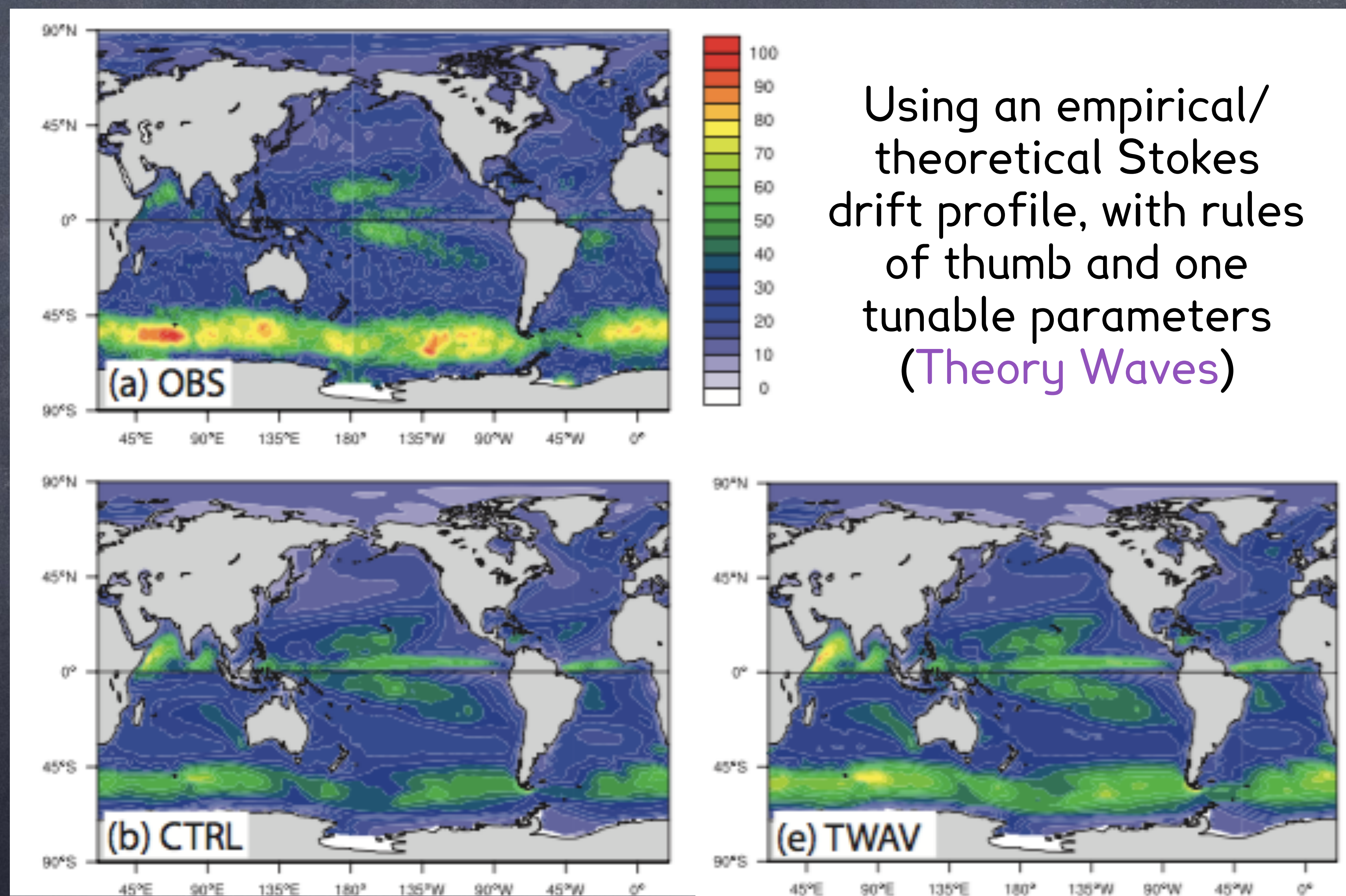

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Robust Formulation

- Mixing by Langmuir Turbulence

For quick reference and easy implementation, all the essential equations required in the Theory Wave model, (24), are summarized below.

$$
\begin{aligned}
u_0^S &\approx 0.016 U_{10}, \\
V^S &\approx 2.67 \times 10^{-5} g U_{10}^3, \\
k_p &\approx 0.176 \frac{u_0^S}{V^S}, \\
k_p^* &= 2.56 k_p, \\
H_{SL} &= H_{BL}/5, \\
T_1(k, z) &= e^{2kz}, \\
T_2(k, z) &= \sqrt{2\pi k|z|}\,\mathrm{erfc}\left(\sqrt{2k|z|}\right), \\
u_{SL}^S &\approx u_0^S \Big\{ 0.715 \\
&\quad + \left(\frac{0.151}{k_p H_{SL}} - 0.840\right)\left[1 - T_1(k_p, H_{SL})\right] \\
&\quad - \left(0.840 + \frac{0.0591}{k_p H_{SL}}\right) T_2(k_p, H_{SL}) \\
&\quad + \left(\frac{0.0632}{k_p^* H_{SL}} + 0.125\right)\left[1 - T_1(k_p^*, H_{SL})\right] \\
&\quad + \left(0.125 + \frac{0.0946}{k_p^* H_{SL}}\right) T_2(k_p^*, H_{SL}) \Big\}, \\
La_{SL} &= \sqrt{\frac{u^*}{u_{SL}^S}}, \\
\mathcal{E} &= \sqrt{1 + (1.5 La_{SL})^{-2} + (5.4 La_{SL})^{-4}}. \qquad (25)
\end{aligned}
$$

Enhancement following McWilliams & Sullivan

Parameterized Waves Following Phillips—no wave model needed!

Q. Li, B. Fox-Kemper, O. Breivik, and A. Webb. Statistical models of global Langmuir mixing. Ocean Modelling, 113:95-114, May 2017.

Langmuir Entrainment:
Free with WaveWatch or Theory Waves & Better than Langmuir mixing Only

Control

2 versions of Li et al 2016

Li et al. 2017

	Summer			Winter		
Case	Global	South of 30°S	30°S-30°N	Global	South of 30°S	30°S-30°N
CTRL	10.28 ± 0.29	16.00 ± 0.48	6.57 ± 0.23	50.24 ± 1.42	52.52 ± 0.54	15.89 ± 0.33
VR12-MA	9.31 ± 0.28	10.64 ± 0.49	9.60 ± 0.33	47.65 ± 1.15	48.47 ± 0.49	22.98 ± 0.42
VR12-EN	11.65 ± 0.29	11.91 ± 0.83	12.79 ± 0.39	56.85 ± 0.93	61.30 ± 1.21	33.60 ± 0.55
LF17	8.48 ± 0.24	8.92 ± 0.39	9.15 ± 0.30	47.78 ± 1.08	49.98 ± 0.77	22.43 ± 0.43

Q. Li and B. Fox-Kemper. Assessing the effects of Langmuir turbulence on the entrainment buoyancy flux in the ocean surface boundary layer. Journal of Physical Oceanography, 47:2863-2886, December 2017.

Q. Li and B. Fox-Kemper. Anisotropy of Langmuir turbulence and the Langmuir-enhanced mixed layer entrainment. Physical Review Fluids, 5:013803, January 2020.

Next Few:

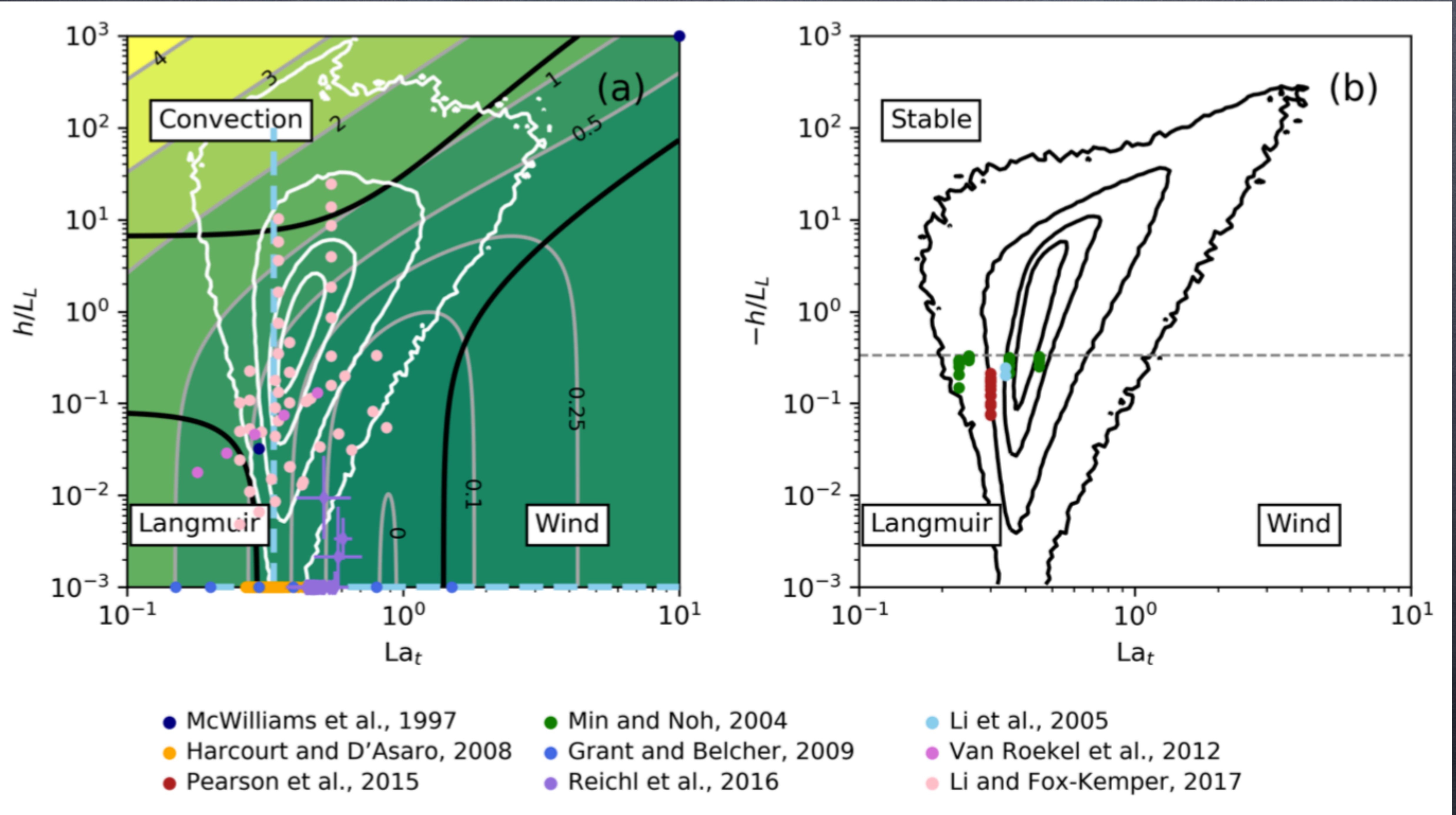
Q. Li, B. G. Reichl, B. Fox-Kemper, A. J. Adcroft, S. Belcher, G. Danabasoglu, A. Grant, S. M. Griffies, R. W. Hallberg, T. Hara, R. Harcourt, T. Kukulka, W. G. Large, J. C. McWilliams, B. Pearson, P. Sullivan, L. V. Roekel, P. Wang, and Z. Zheng. Comparing ocean boundary vertical mixing schemes including Langmuir turbulence. Journal of Advances in Modeling Earth Systems (JAMES), 11(11):3545-3592, November 2019.

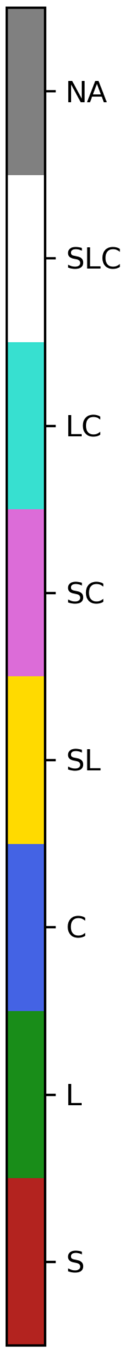
Global JRA55 initial profiles from Argo

Following Regime diagnostic approches from Belcher et al. (2012)

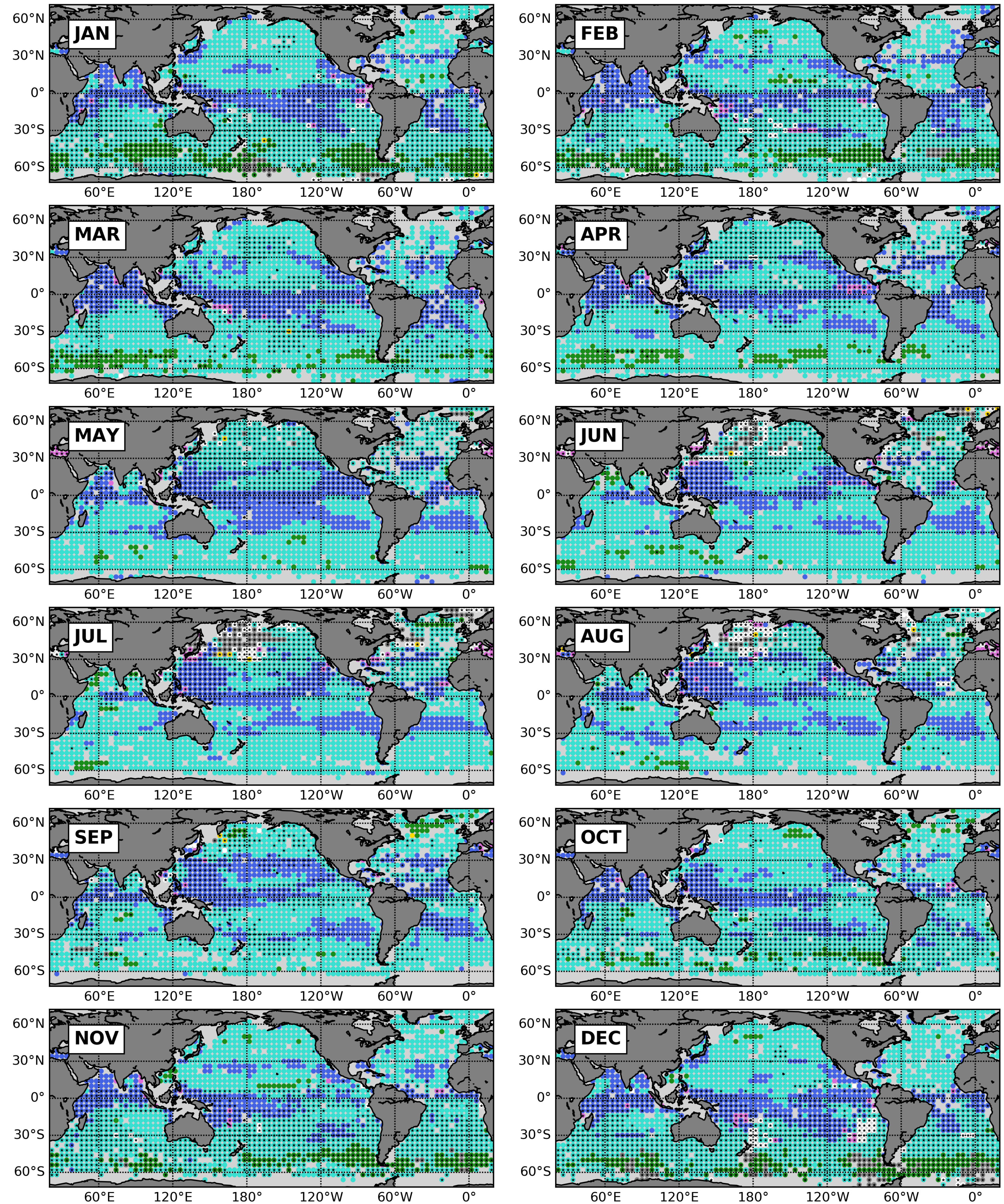
No TRUTH in obs!

Limited LES as truth!





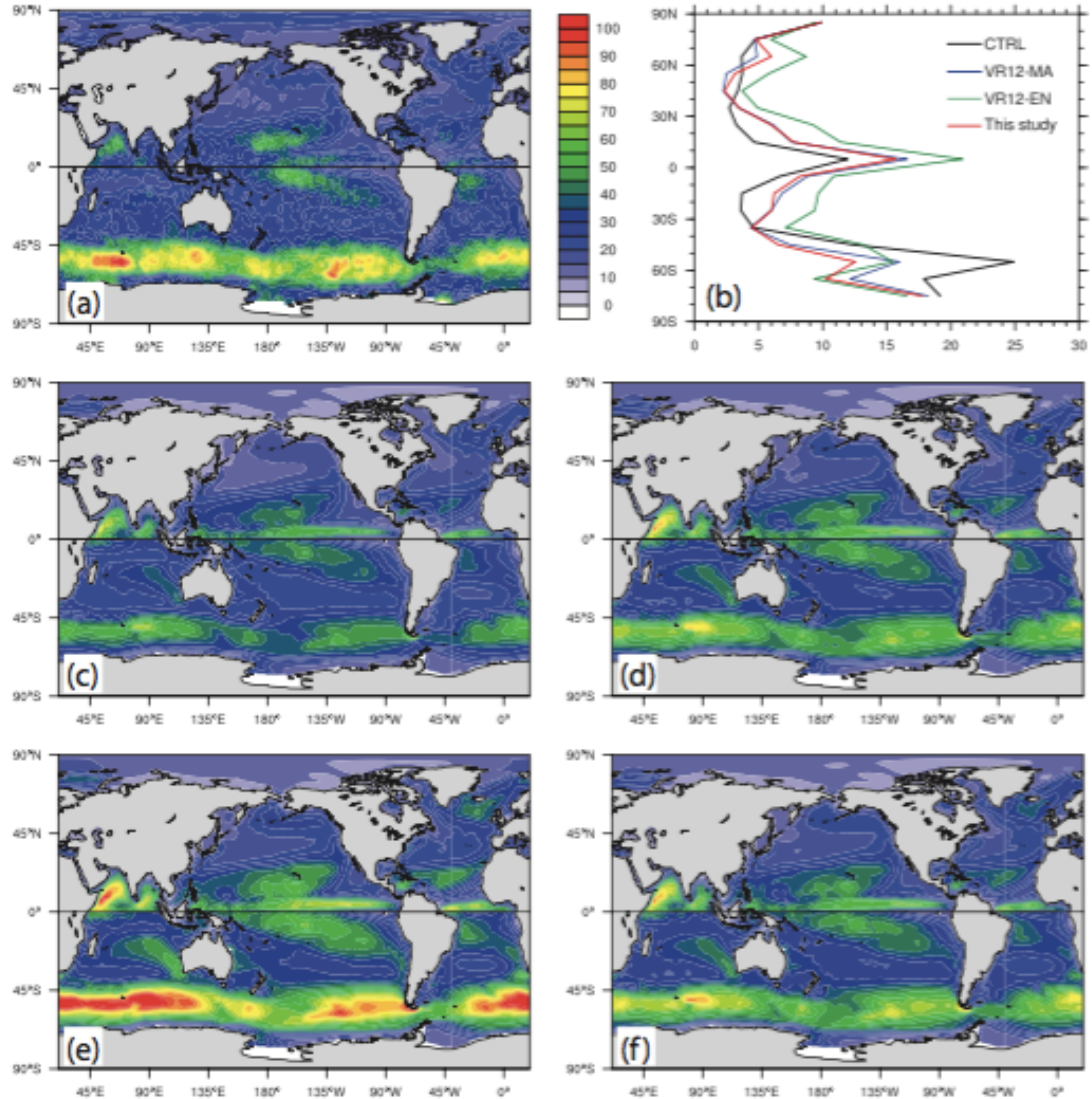
Langmuir, Convection, and their combination are the dominant regimes



Obs.

Control
No
Lang.
(~CESM1)

Early
Entrain
Guess.
Li et al.
2016
Not
Used

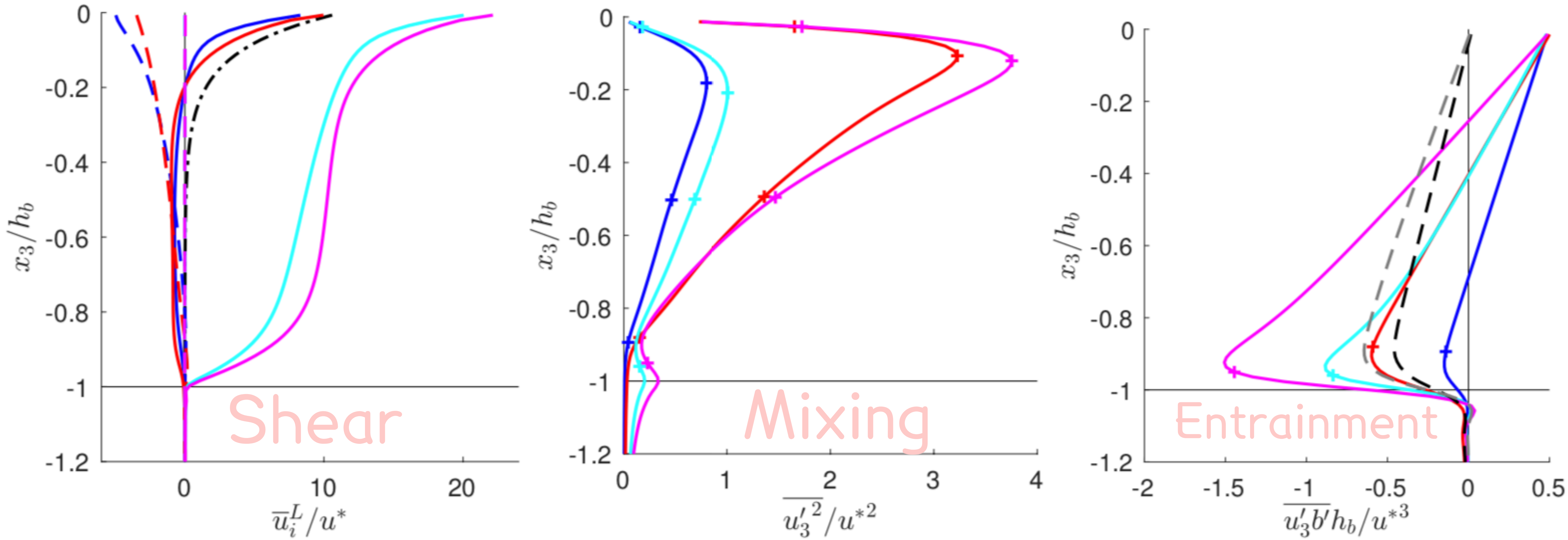


Q. Li and BFK. Assessing the effects of Langmuir turbulence on the entrainment buoyancy flux in the ocean surface boundary layer. Journal of Physical Oceanography, 47:2863-2886, December 2017.

Mixing
w/o
Entrain
Li et al.
2016
(CESM2)

Mixing
&
Refined
Entrain.
Li et al
2017
(CESM2.2)

Why is entrainment hard? (Li & F-K 20)



Hor. Velocity RMS W ‹wb›

LES shows: depends a lot on shear profile—resolved & unresolved.

Li & F-K (2017) adjust unresolved shear to arrive at LES-consistent entrainment rates without overadjusting mixing rate

Q. Li and BFK. Assessing the effects of Langmuir turbulence on the entrainment buoyancy flux in the ocean surface boundary layer. Journal of Physical Oceanography, 47:2863-2886, December 2017.

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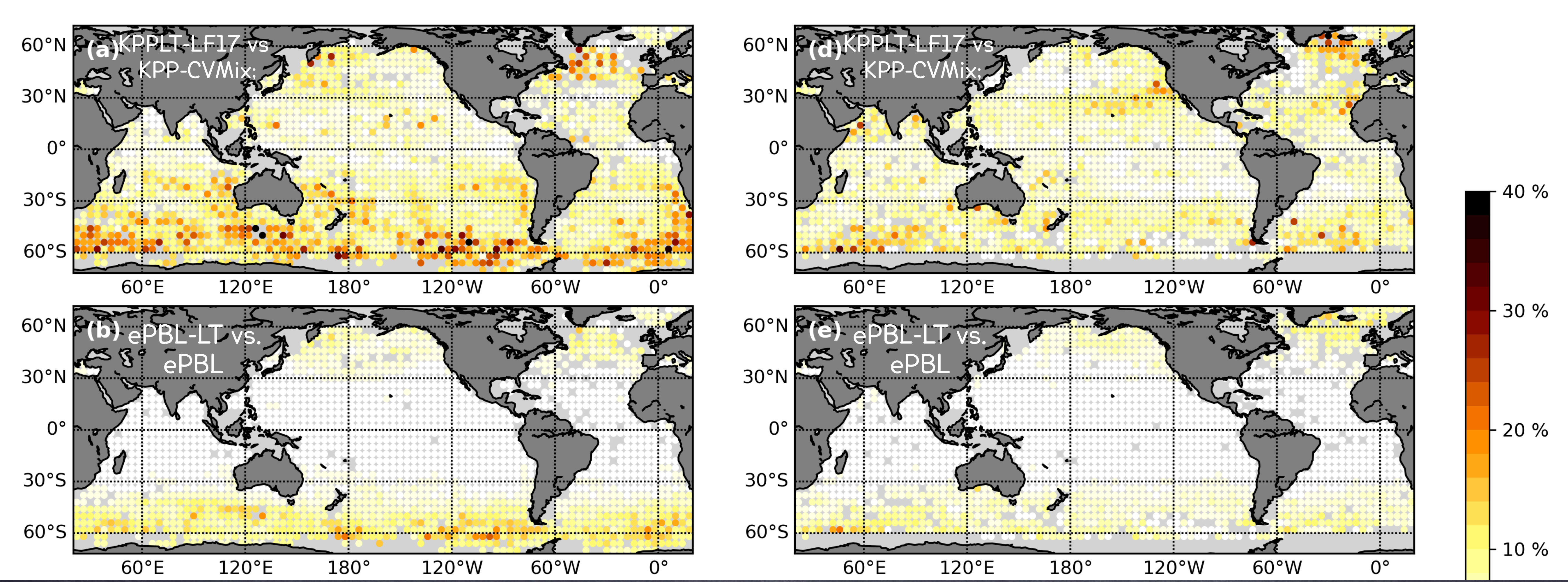
Percentage change from non-Langmuir to Langmuir Partner in CVMix LT Schemes

January | July



Versus LES both best skilled

Comparable vs. OSMOSIS observations

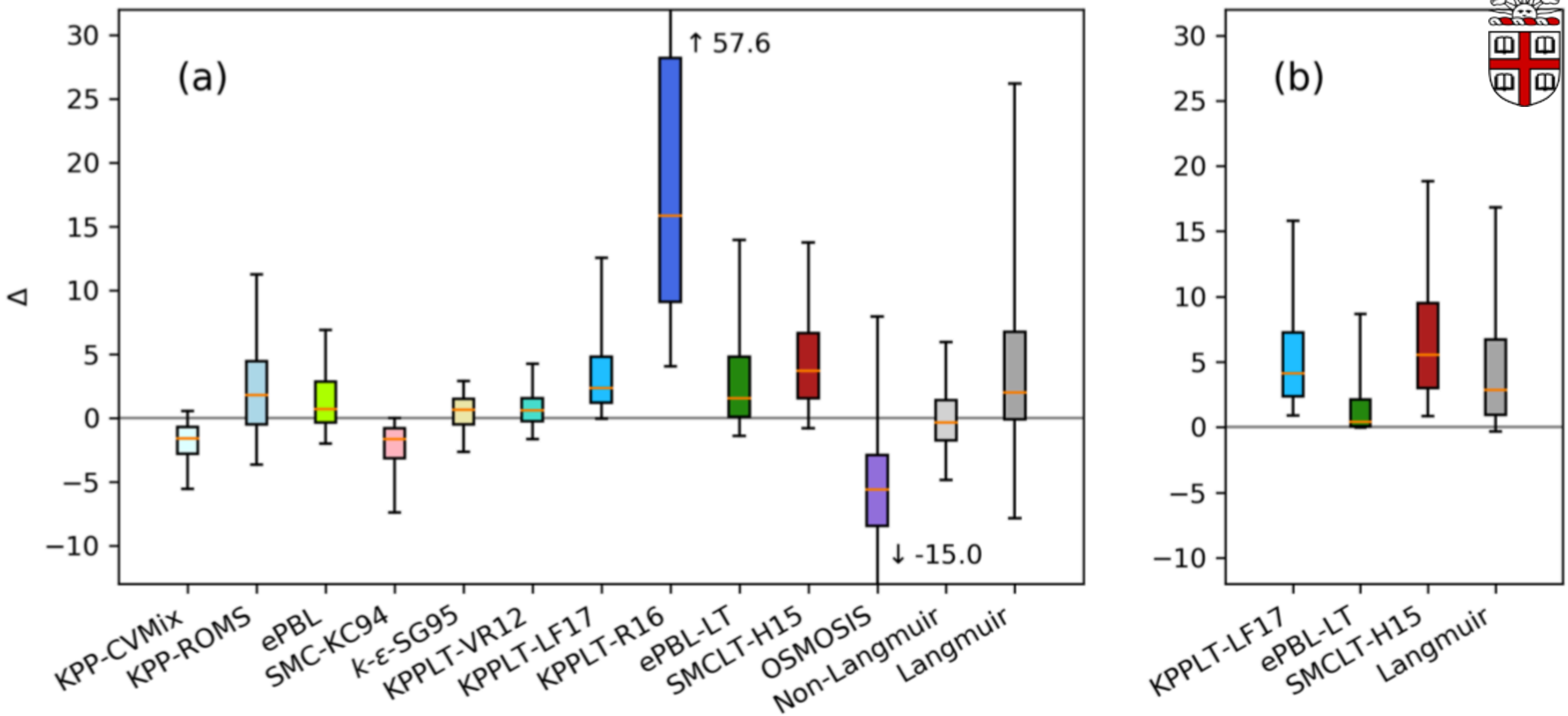
Under Realistic, Global Forcing

EPBL-LT and KPP-LT are not the same

Model Diversity suggests keeping both for CESM3

Conclusions

- 1) Theory Waves (in CVMix, needs CIME implement):
  - Cheaper than WaveWatch
  - Better than Data Waves
  - Useful for high-res, future & paleo scenarios where data waves not appropriate, etc.
- 2) Langmuir-Induced Entrainment (in CVMix, default for CESM2.2?)
  - Free with WaveWatch or Theory Waves
  - Better than Langmuir Mixing in BL alone
    - Reduces Bias (not true of older guess)
    - Matches LES & Obs. (in 3 different process studies)
  - Different from EPBL-LT under realistic, global forcing
    - In CESM3, could use KPP-LT instead of CM's EPBL-LT

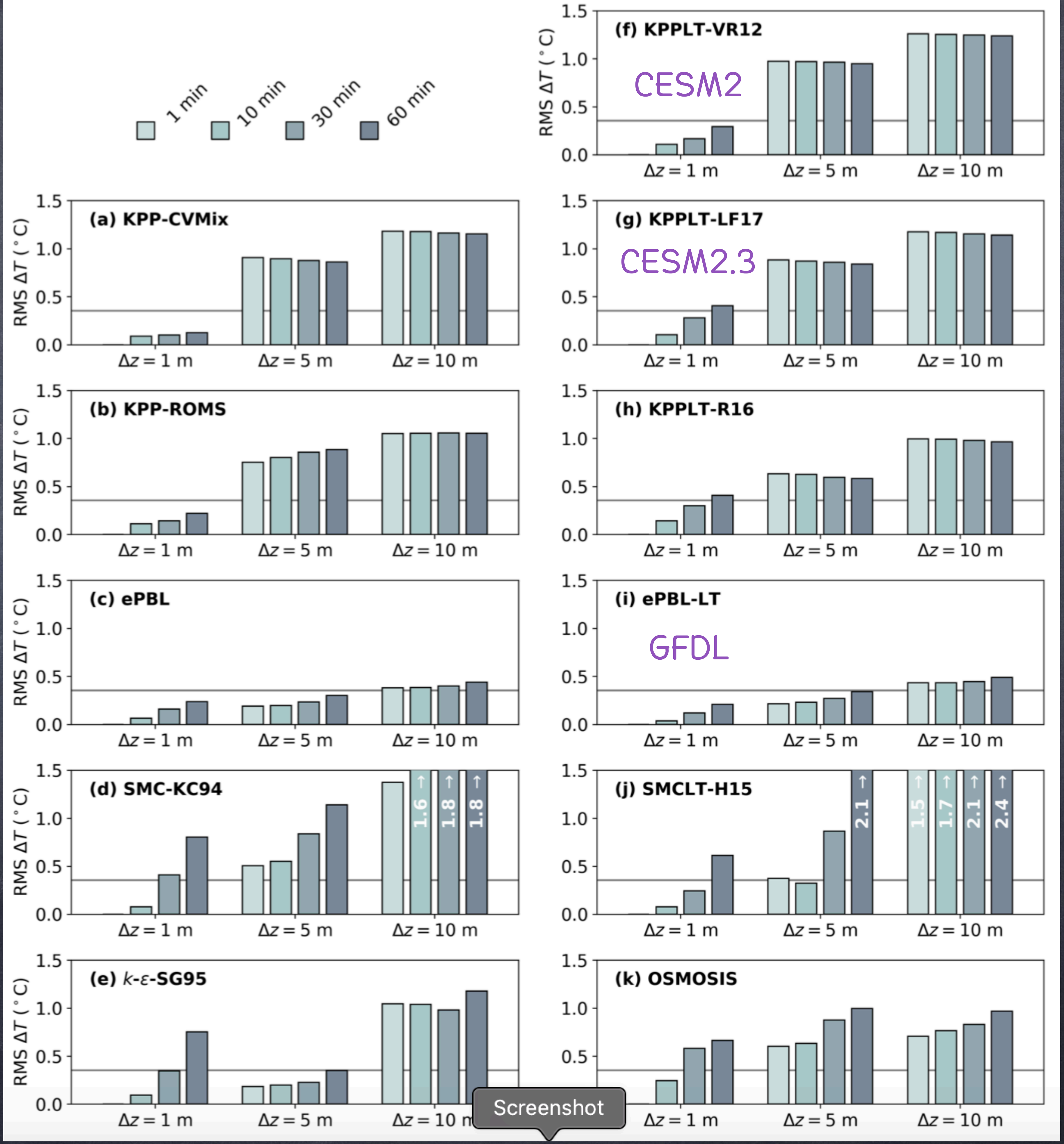


Change of MLD vs. non-Langmuir multi-scheme avg.

Change of MLD vs. non-Langmuir partner avg.

Q. Li, B. G. Reichl, B. Fox-Kemper, A. J. Adcroft, S. Belcher, G. Danabasoglu, A. Grant, S. M. Griffies, R. W. Hallberg, T. Hara, R. Harcourt, T. Kukulka, W. G. Large, J. C. McWilliams, B. Pearson, P. Sulli- van, L. V. Roekel, P. Wang, and Z. Zheng. Comparing ocean boundary vertical mixing schemes including Langmuir turbulence. Journal of Advances in Modeling Earth Systems (JAMES), 2019. In preparation.

Time-step and vertical resolution sensitivity

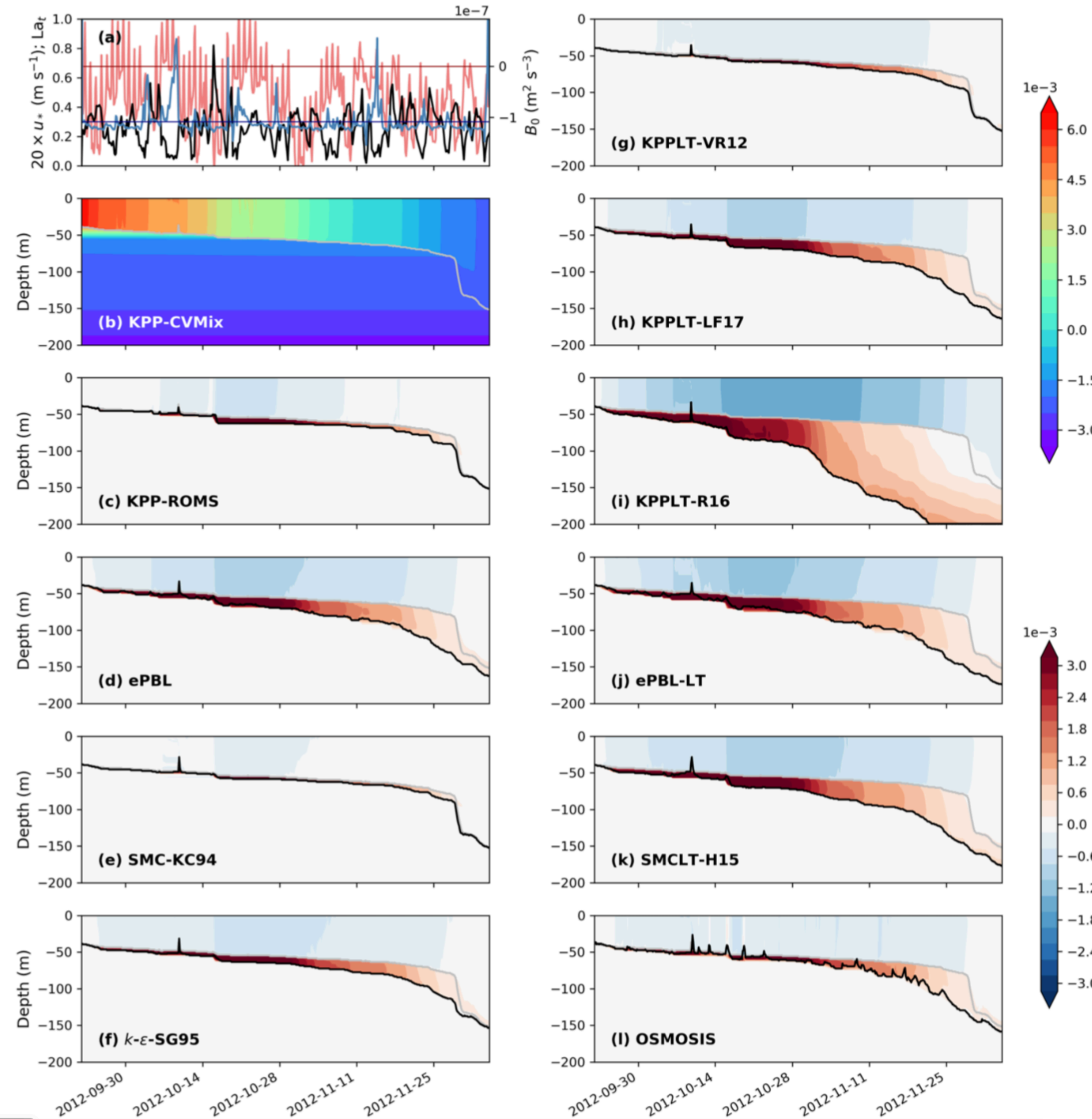


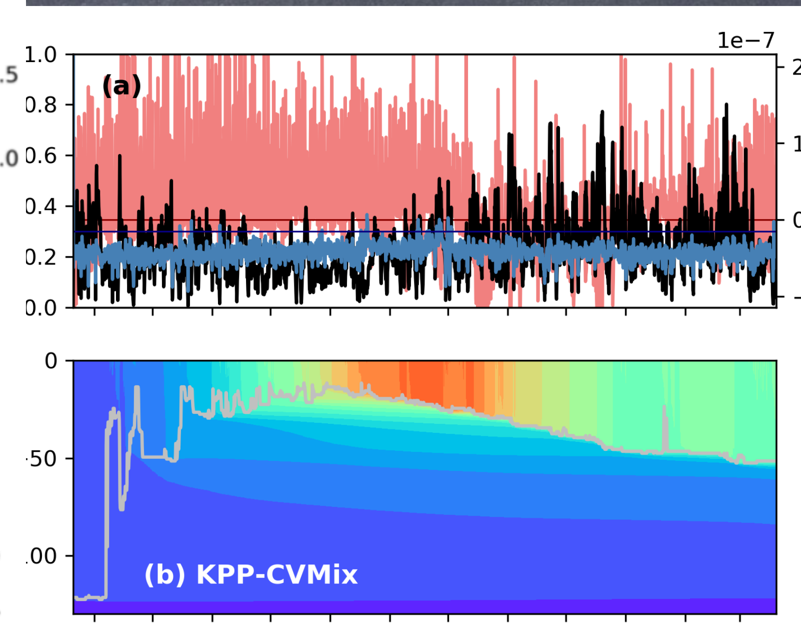
Building on recent diagnostic approches from Van Roekel et al. (2018) and Reichl & Halberg (2018)

, but

d...

x as control

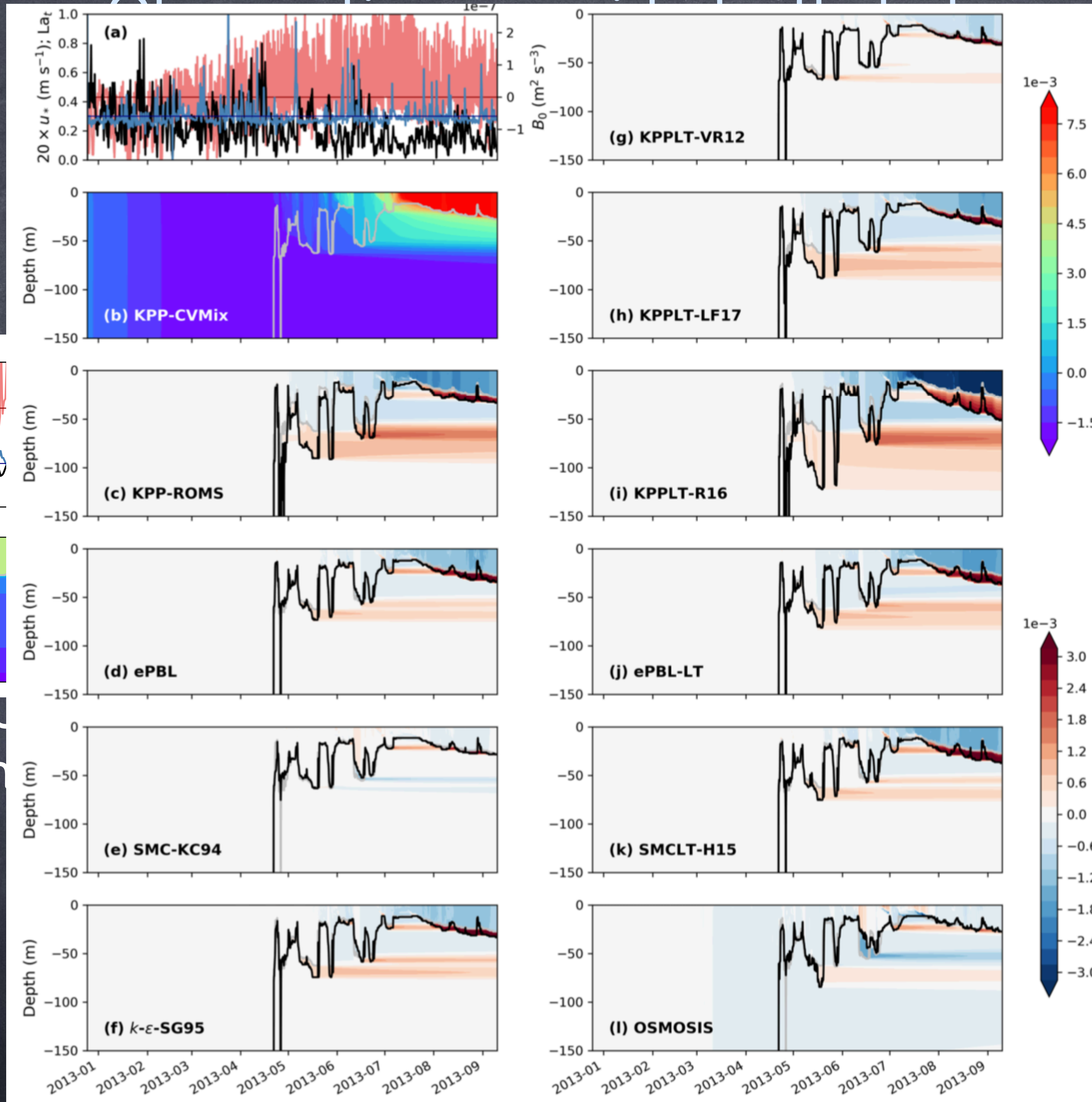


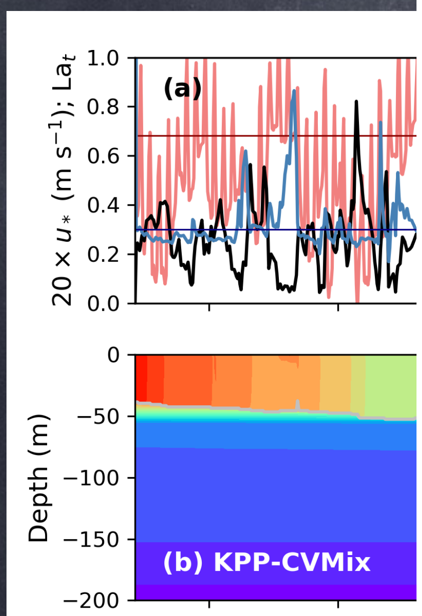


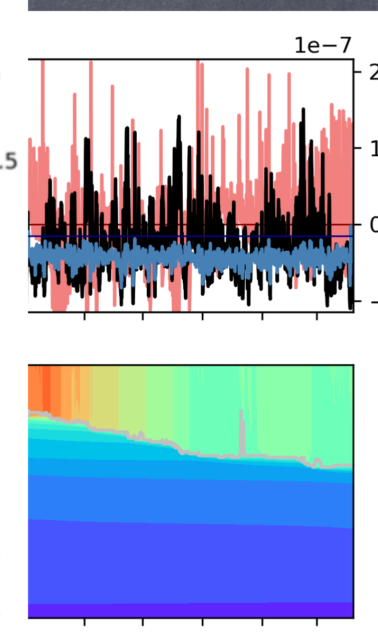
OCS-Papa

Q. Li, B. G. Reichl, B. Fox-Kemper, A. J. Adcroft, S. Belcher, G. Danabasoglu, A. Grant, S. M. Griffies, R. W. Hallberg, T. Hara, R. Harcourt, T. Kukulka, W. G. Large, J. C. McWilliams, B. Pearson, P. Sulli- van, L. V. Roekel, P. Wang, and Z. Zheng. Comparing ocean boundary vertical mixing schemes including Langmuir turbulence. Journal of Advances in Modeling Earth Systems (JAMES), 2019. In preparation.

So … rol





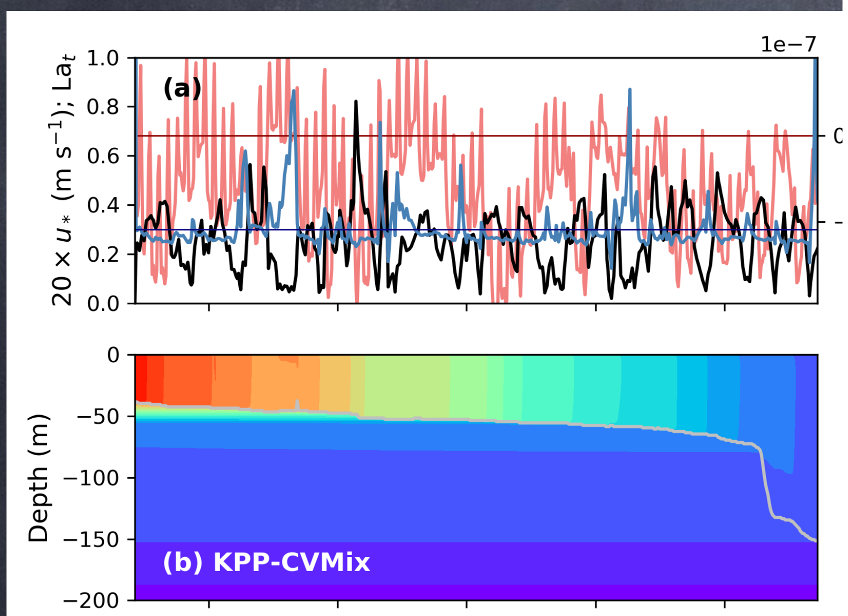


OSMO…

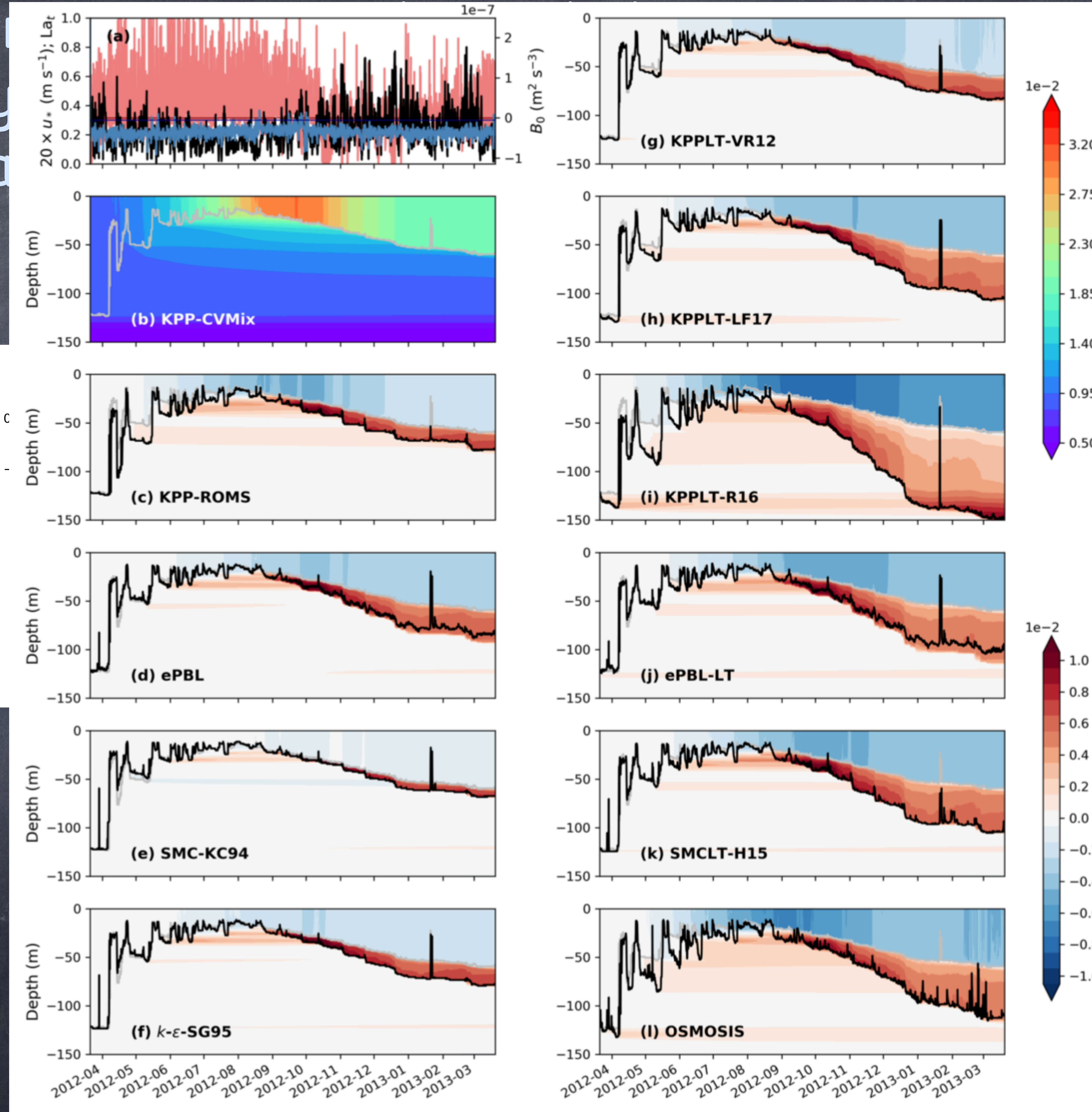
Win… Papa

…Kemper, A. J. …anabasoglu, A. Grant, …erg, T. Hara, R. …G. Large, J. C. …P. Sulli- van, L. V. …Zheng. Comparing …mixing schemes including Langmuir turbulence. Journal of Advances in Modeling Earth Systems (JAMES), 2019. In preparation.

Obse
only
So use devia



OSMOSIS-
Winter



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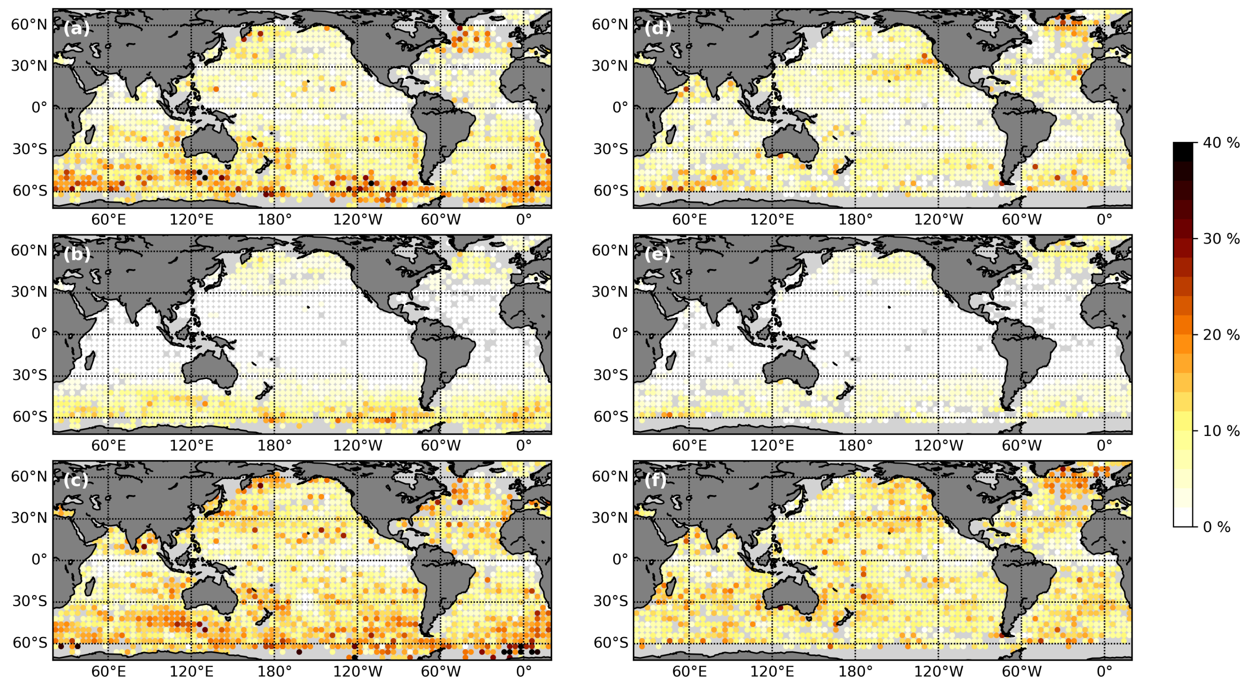
The relative deepening due to Langmuir, and relative differences among schemes is fairly robust whichever dataset is used.

JRA55-do



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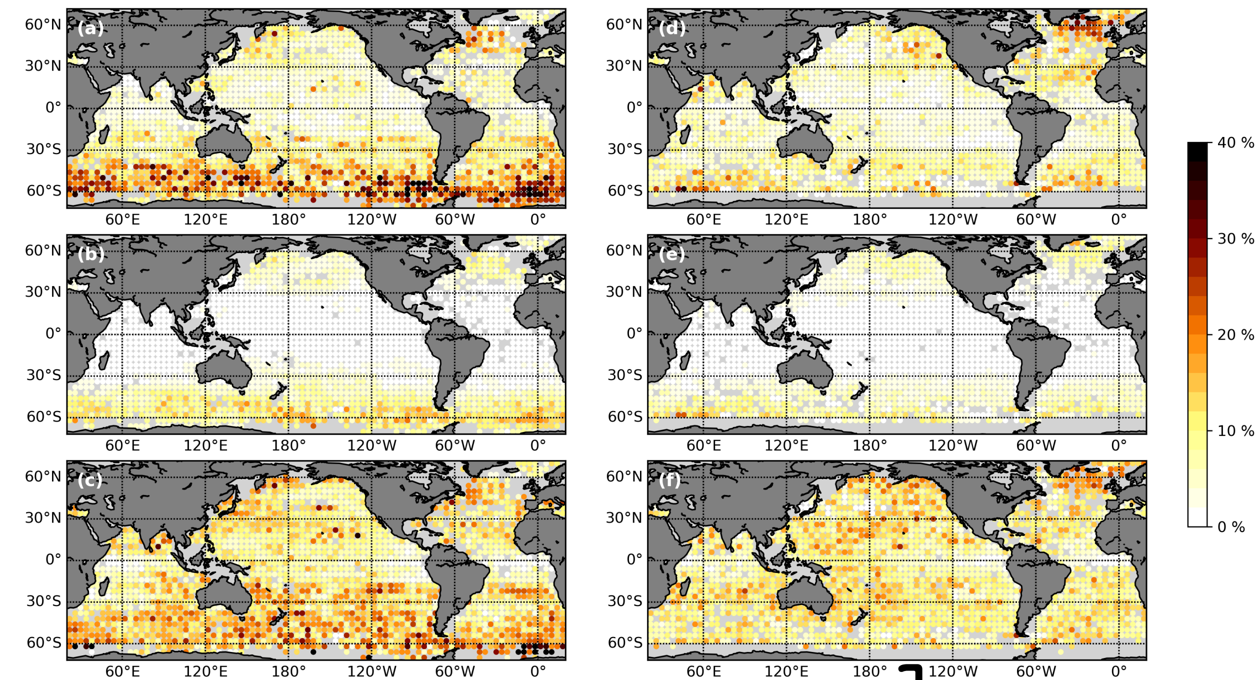
CORE-II



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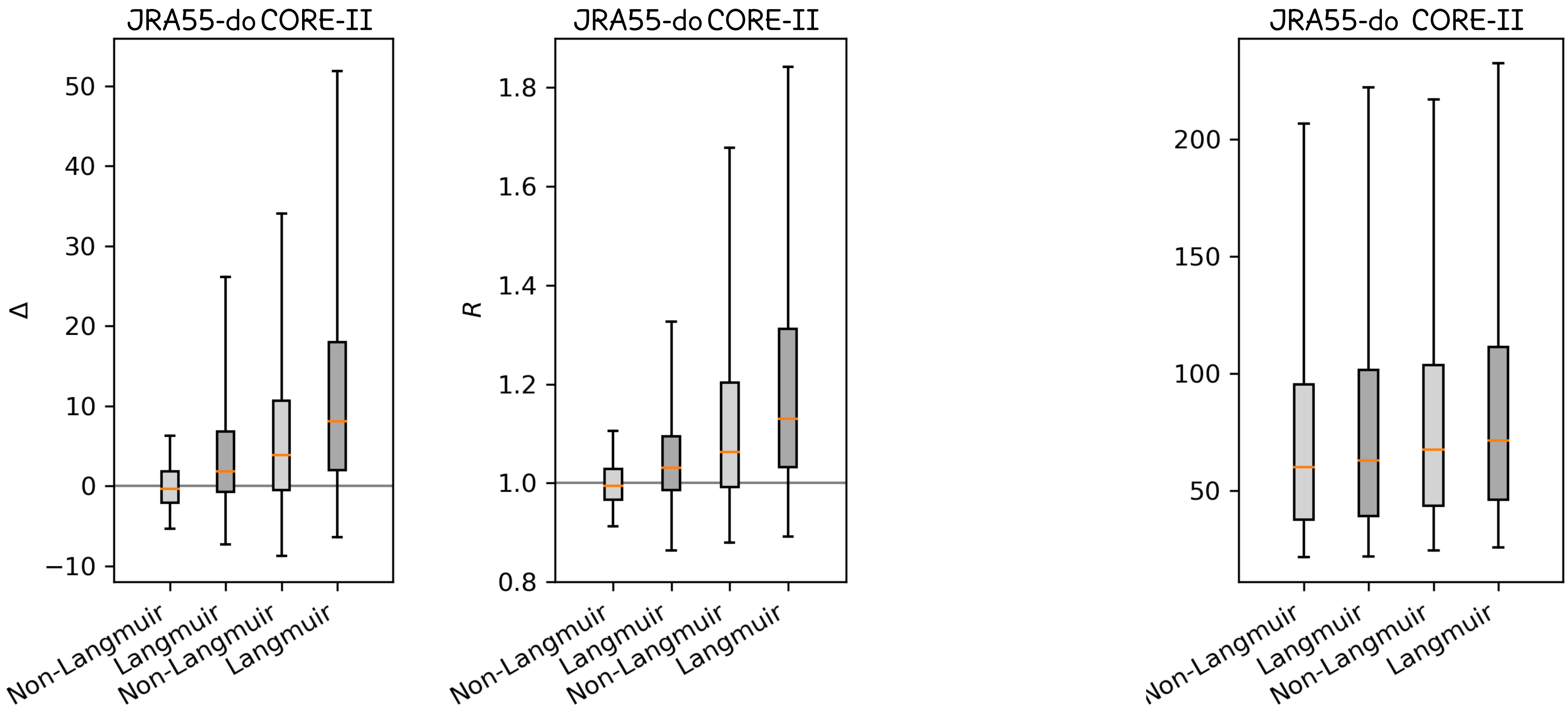
However, the differences in mean MLD between JRA55-do and CORE-II exceed the inter-scheme differences



Distribution of absolute MLD