Investigating Southern Ocean Mixed Layer Biases

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Bill Large, Gokhan Danabasoglu, Ned Patton, Peter Sullivan, Mike Levy

OMWG meeting – Feb. 28, 2017

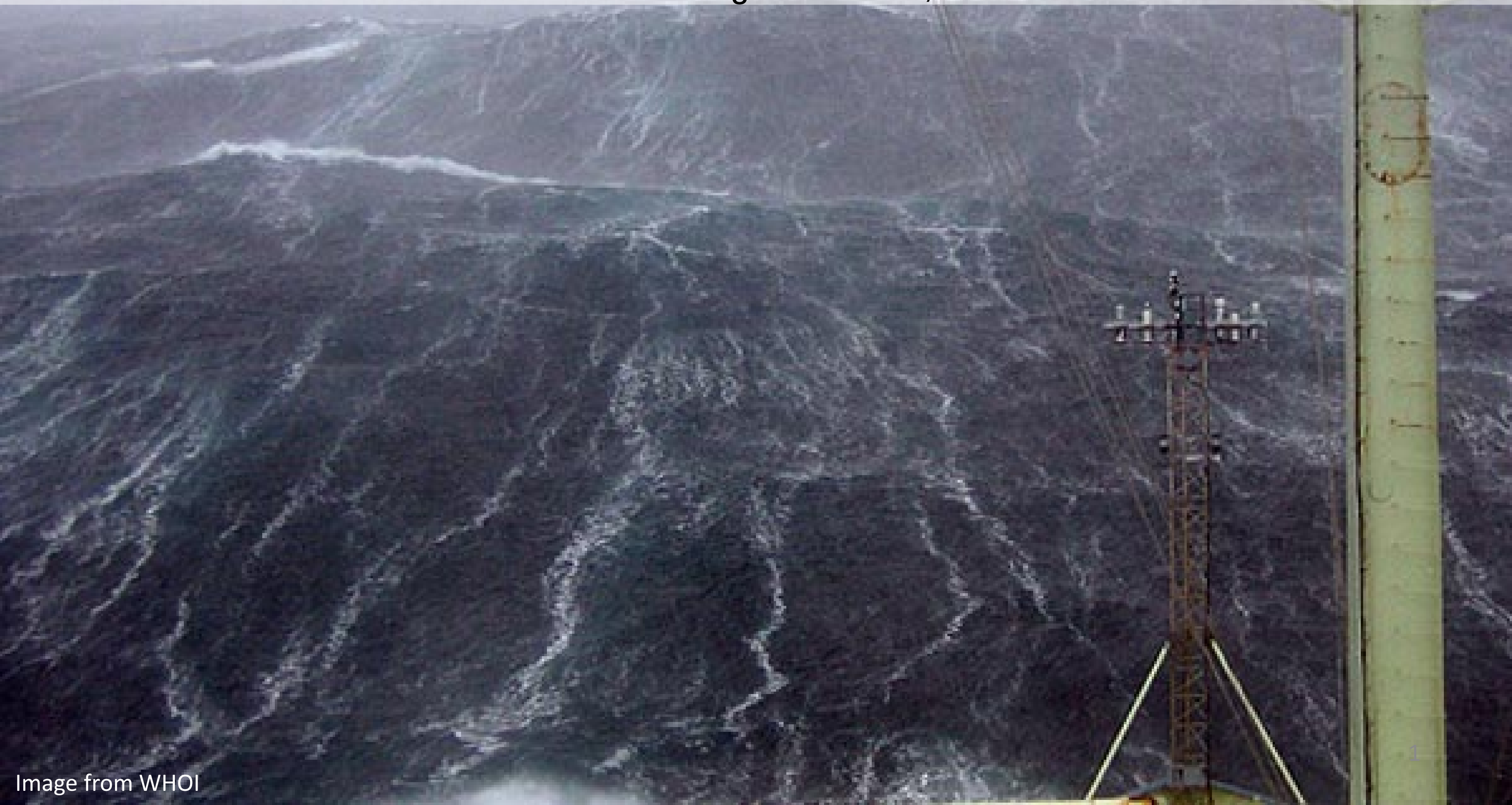


Image from WHOI

CCSM has shallow mixed layer bias over the Southern Ocean in winter months (JAS).

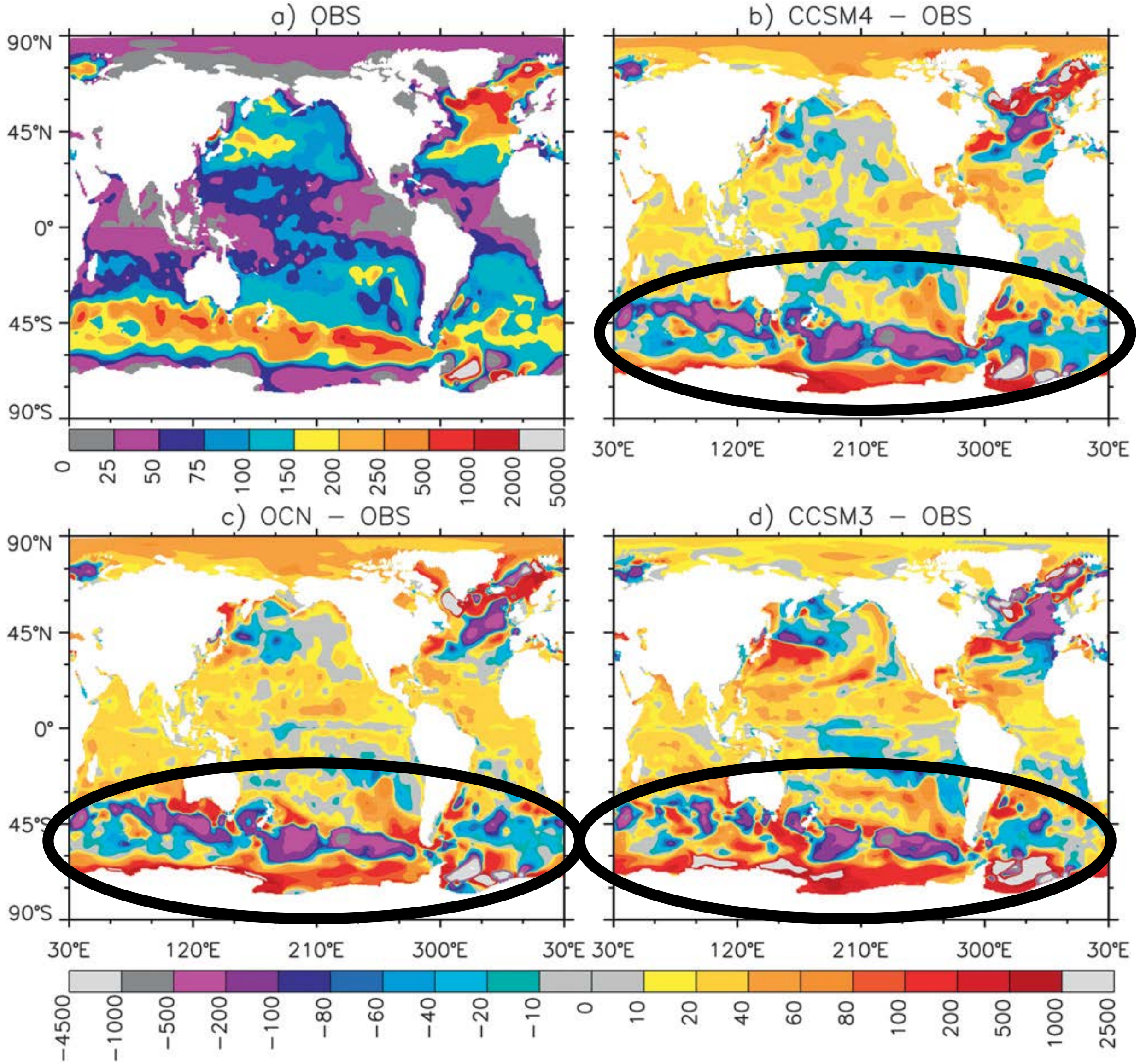


Figure from Danabasoglu et al.

How does ocean model resolution impact the mixed layer bias and for what reasons?

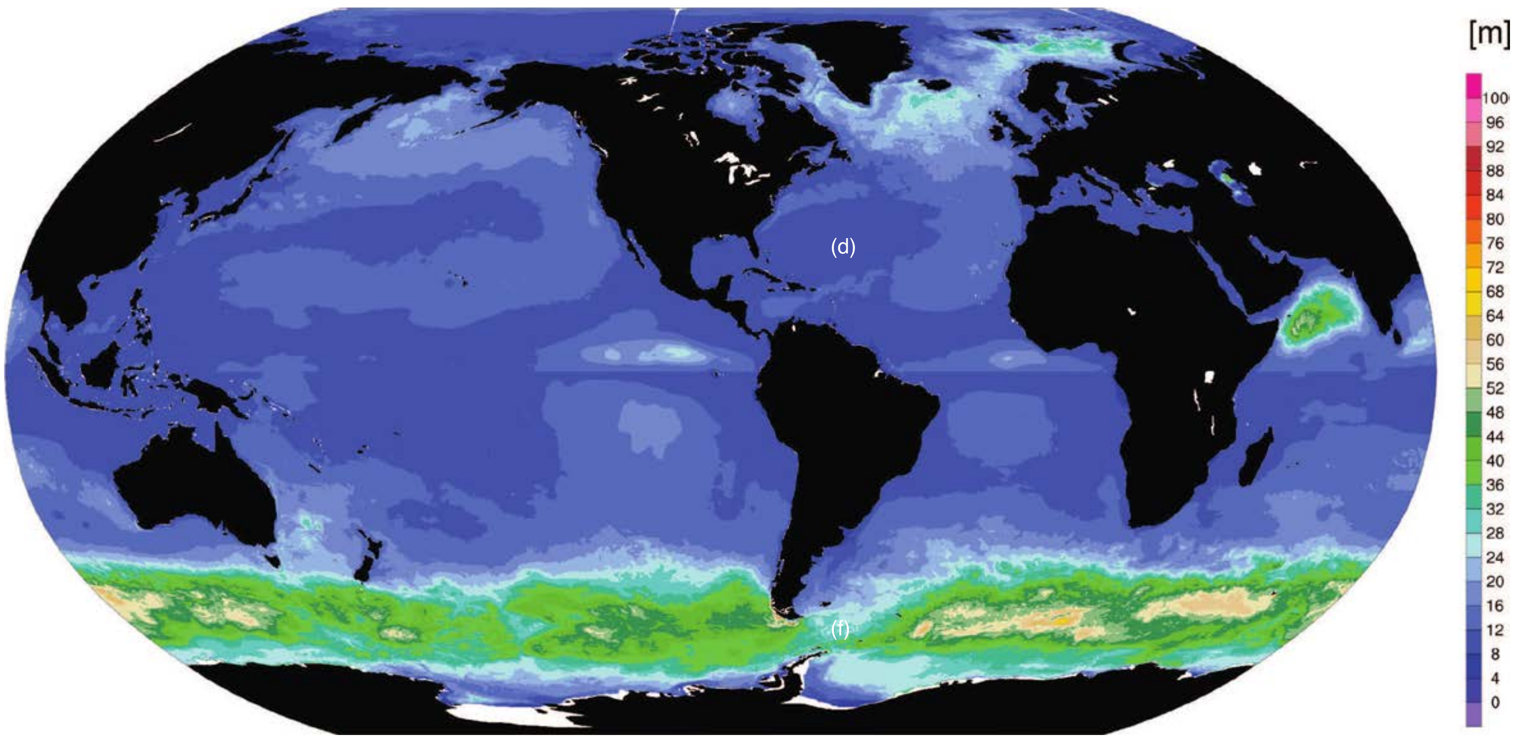
Winter

Summer

Observations

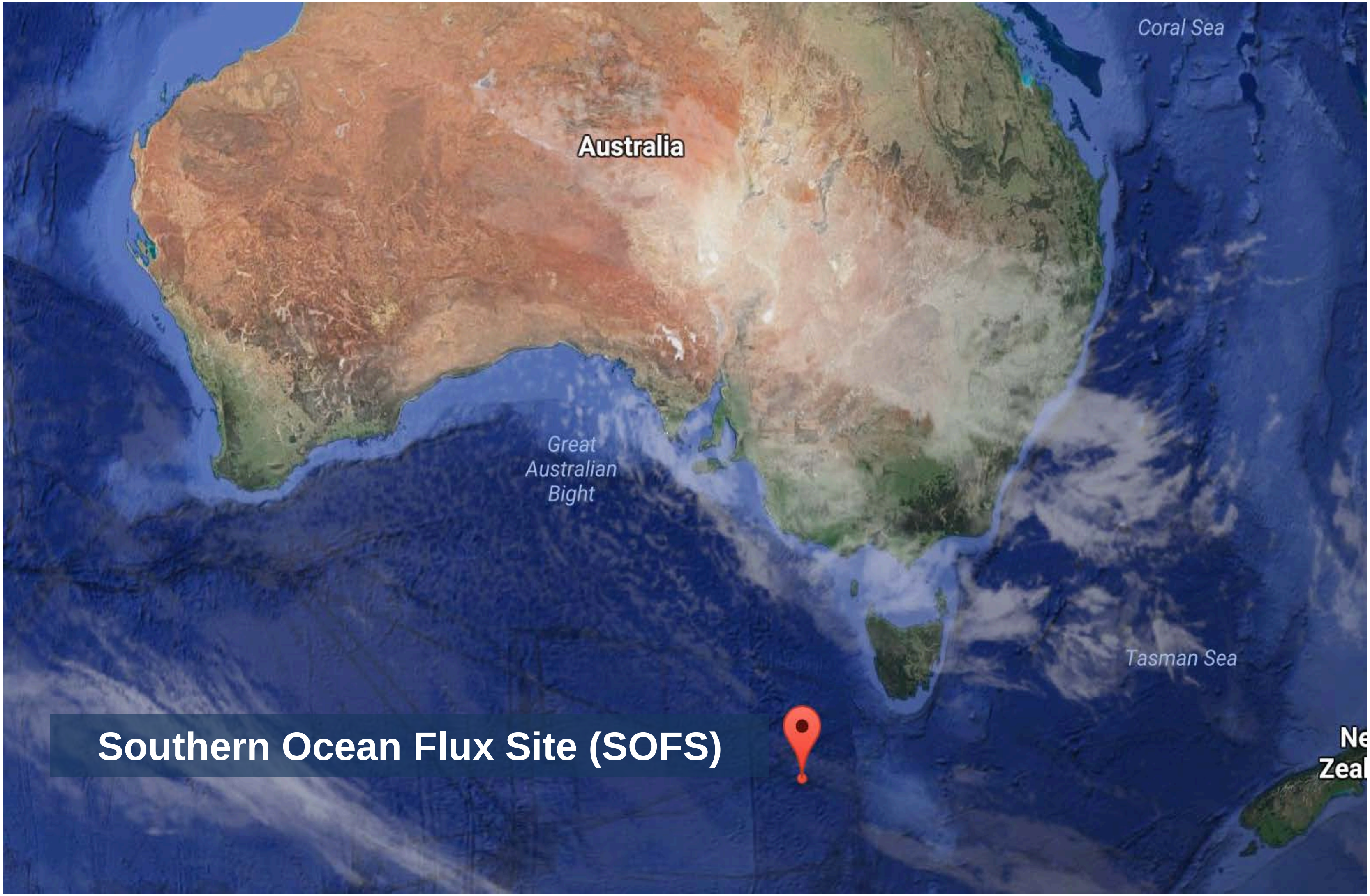
0.1° Model

1° Model



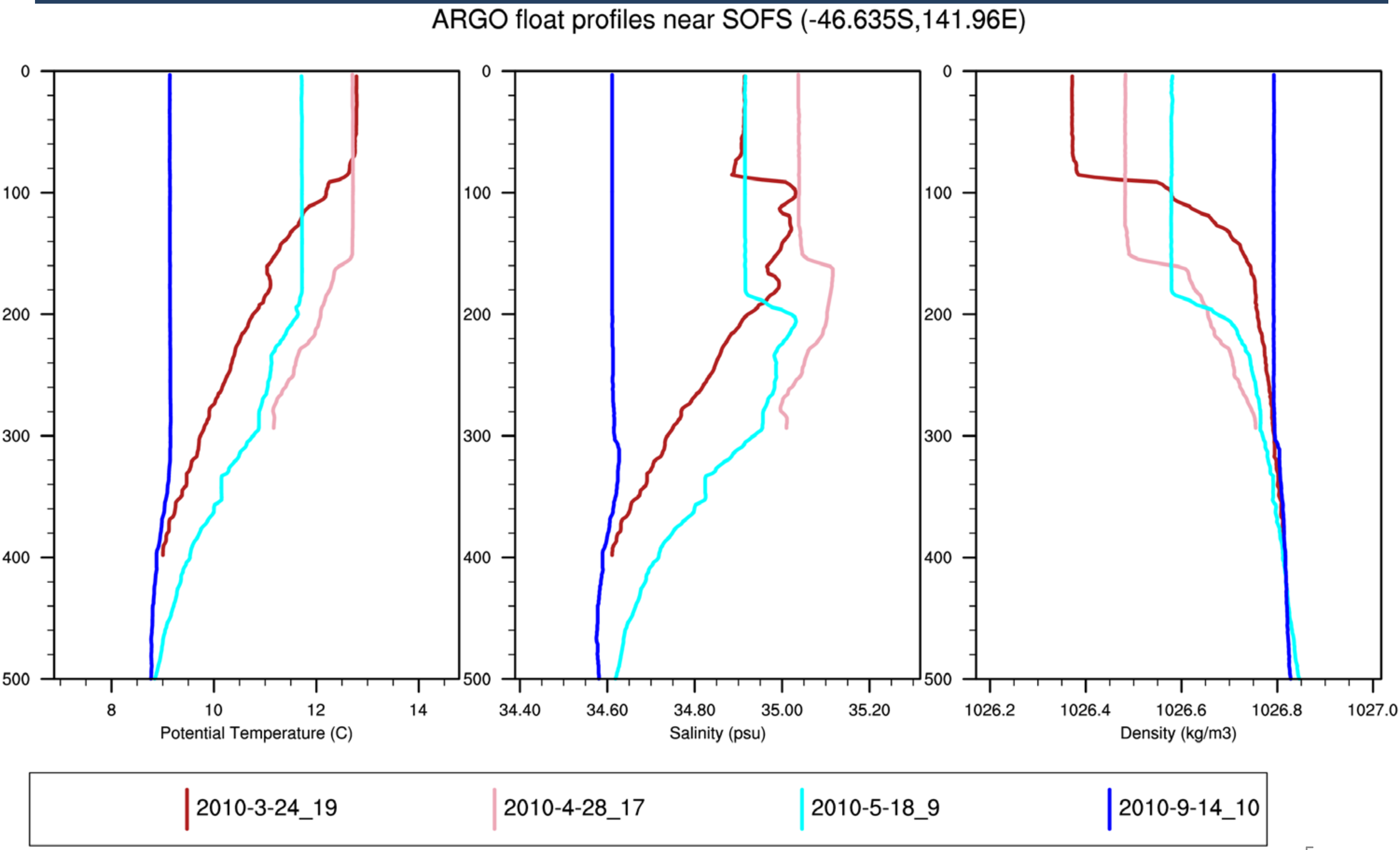
- Figure courtesy of Matt Long. Simulations use CORE standard year.

First Southern Ocean measurements of annual cycle air-sea fluxes available at SOFS in 2010.

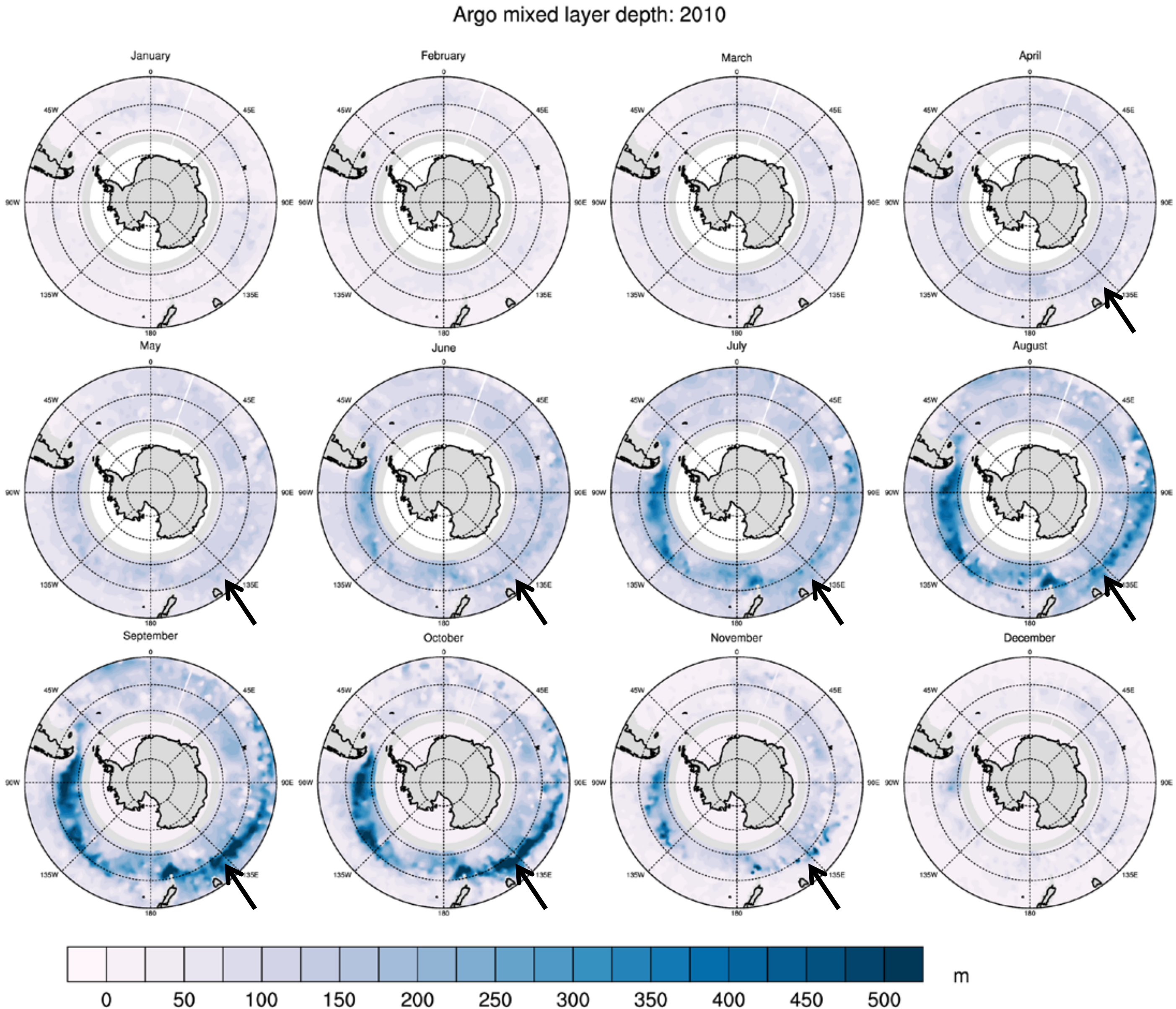


* Schultz et al. 2012, First air-sea flux mooring measurements in the Southern Ocean, GRL

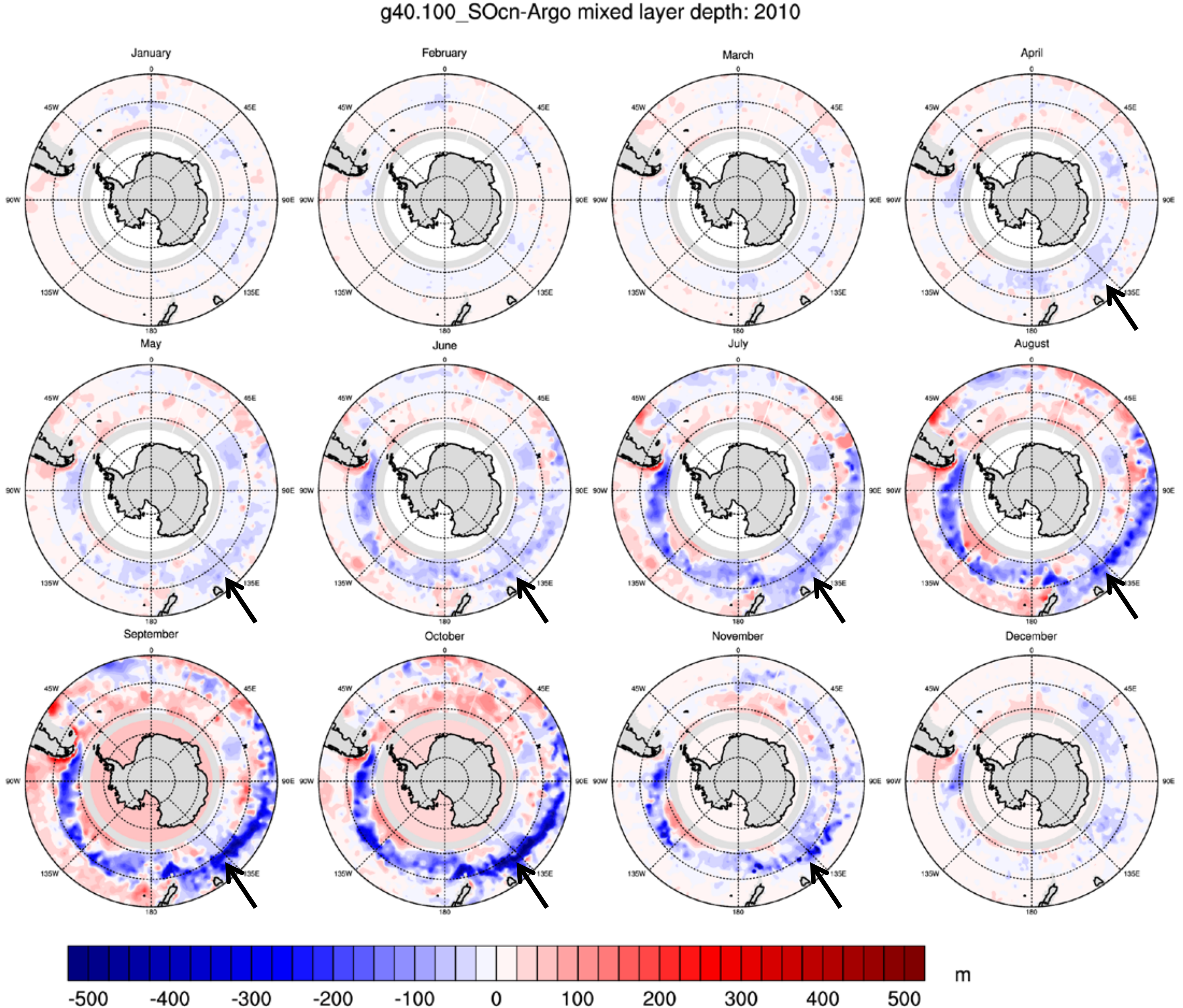
Argo floats reveal seasonal deepening of ocean mixed layer.



Gridded Argo observations show deepest winter mixed layers in Pacific in Indian sectors.



1° model shows (expected) shallow MLD bias in 2010.



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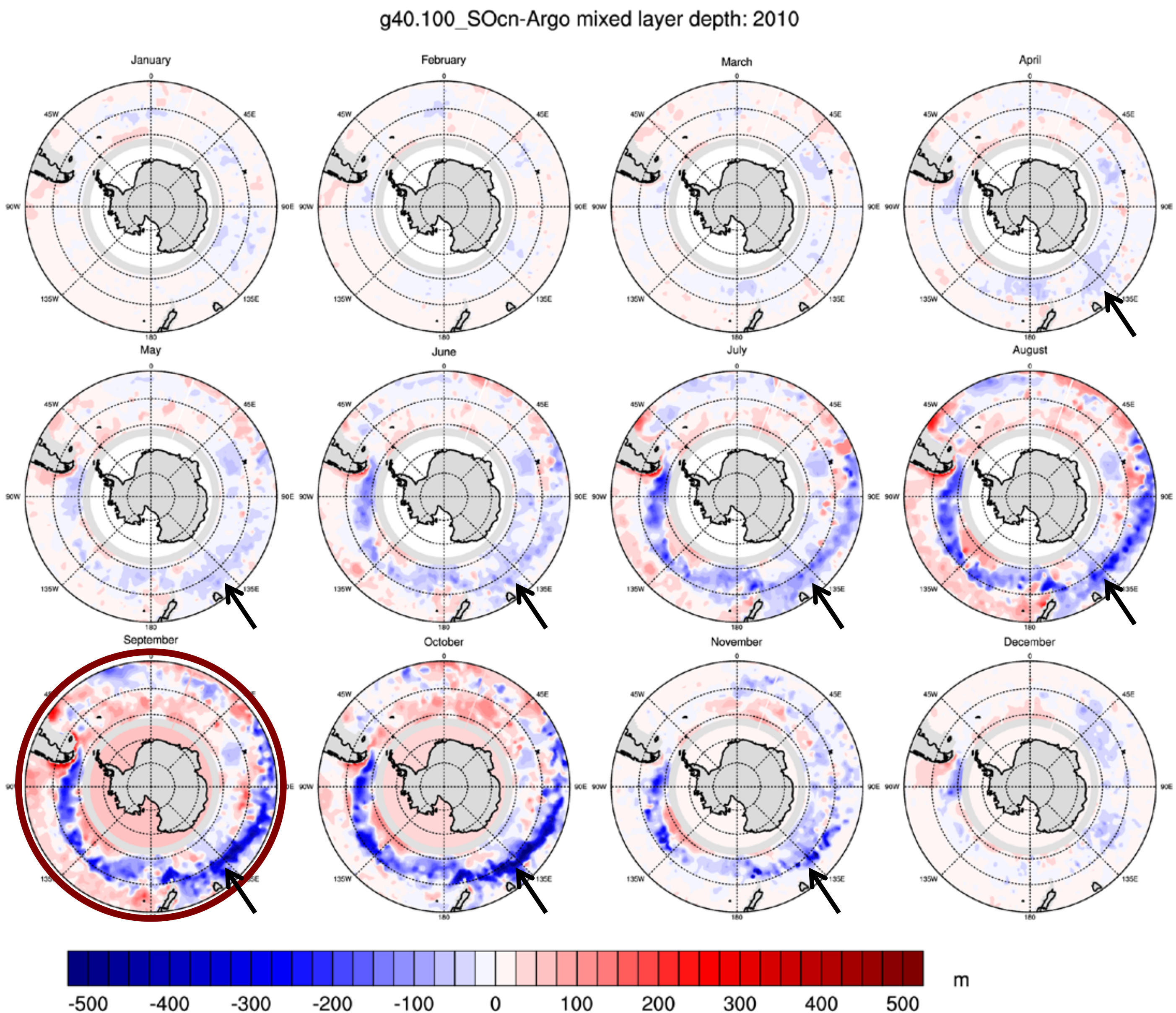
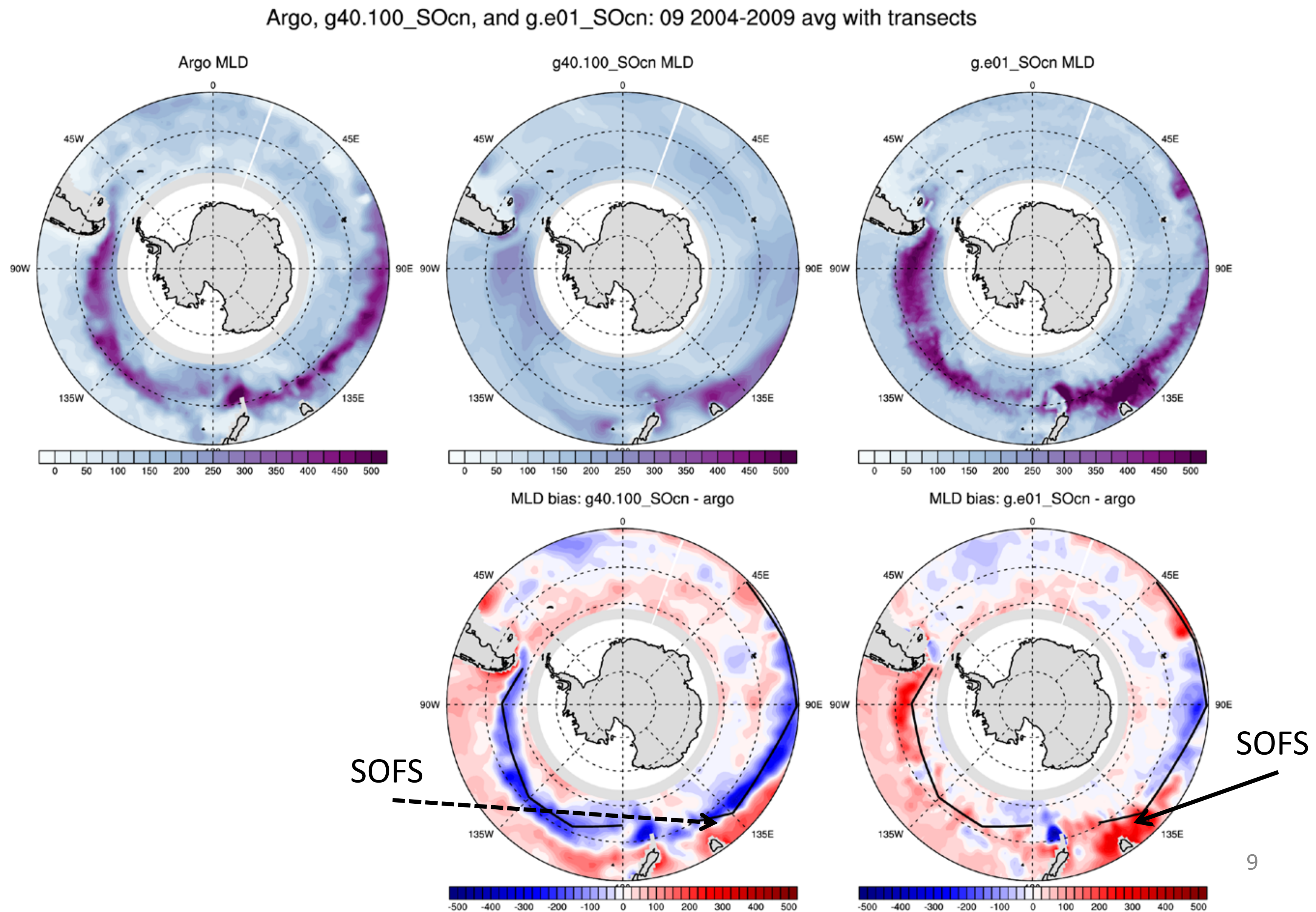
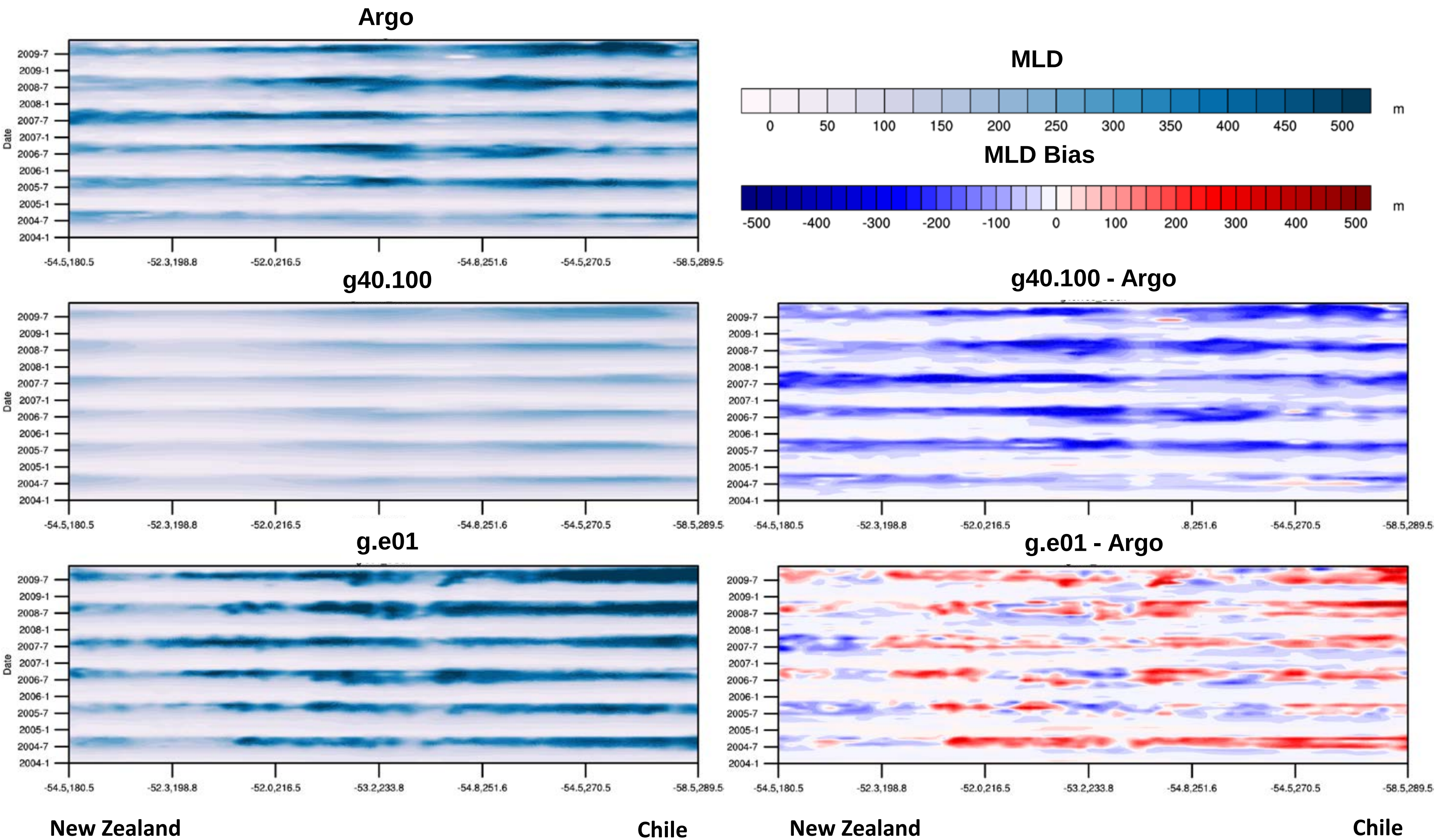


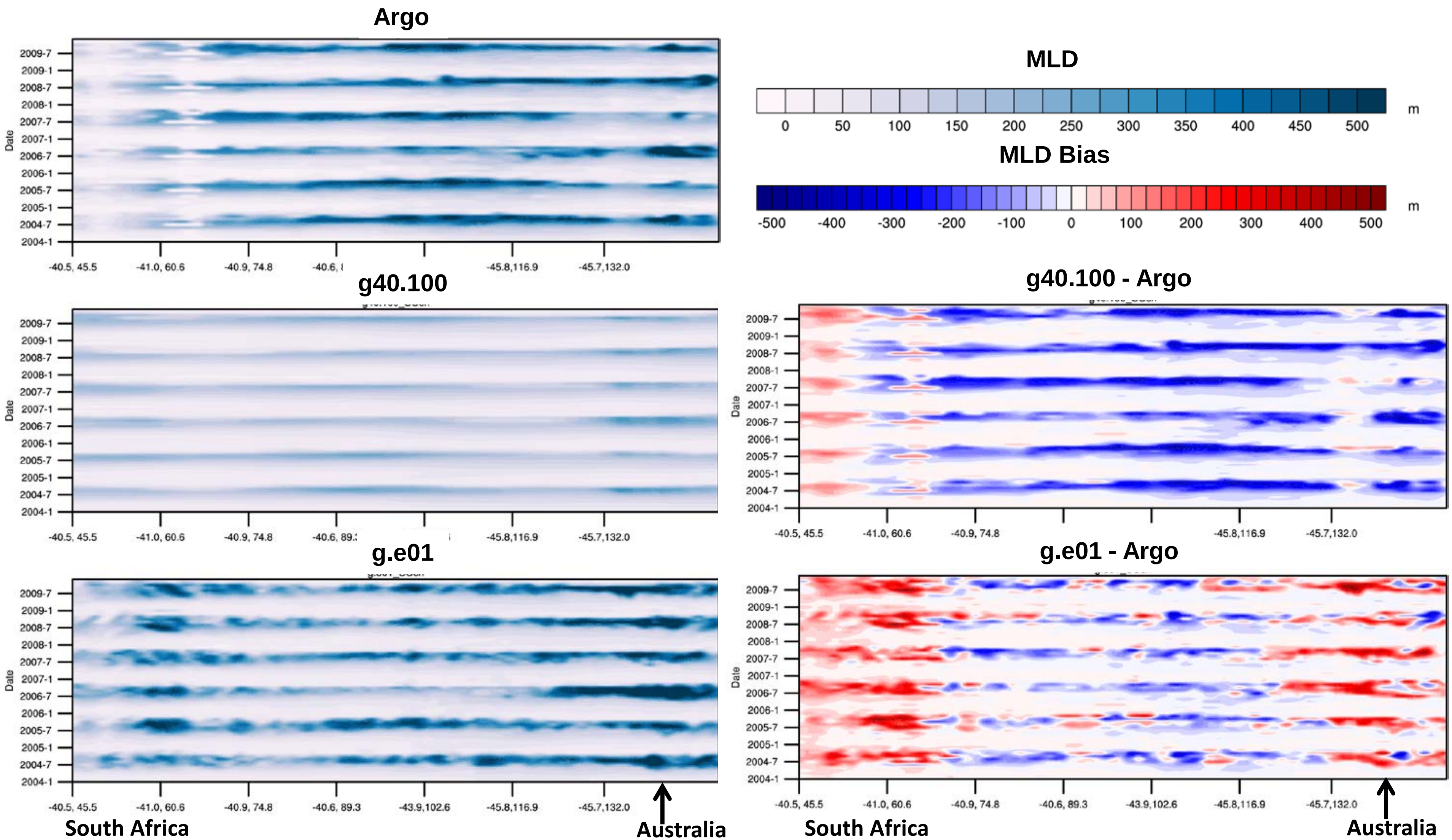
In September, 1° and 0.1° models have opposite biases.



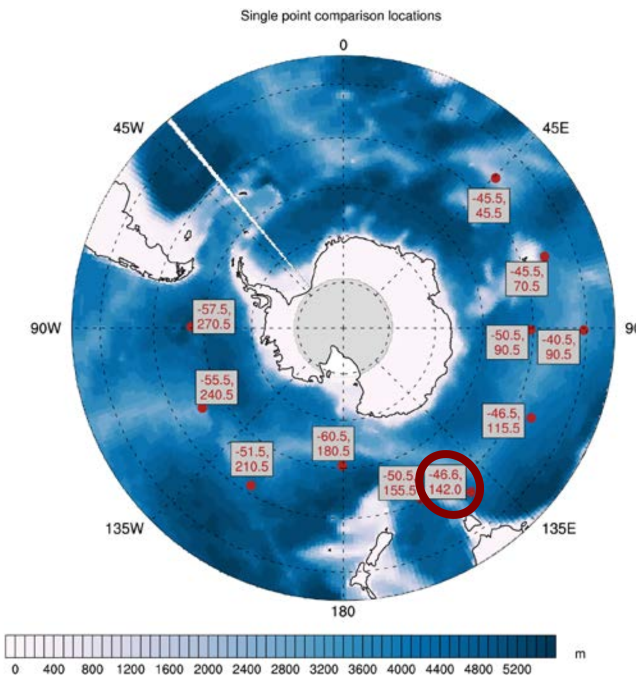
In Pacific sector, the signs and locations of the bias are consistent in time for 1° and 0.1° models.

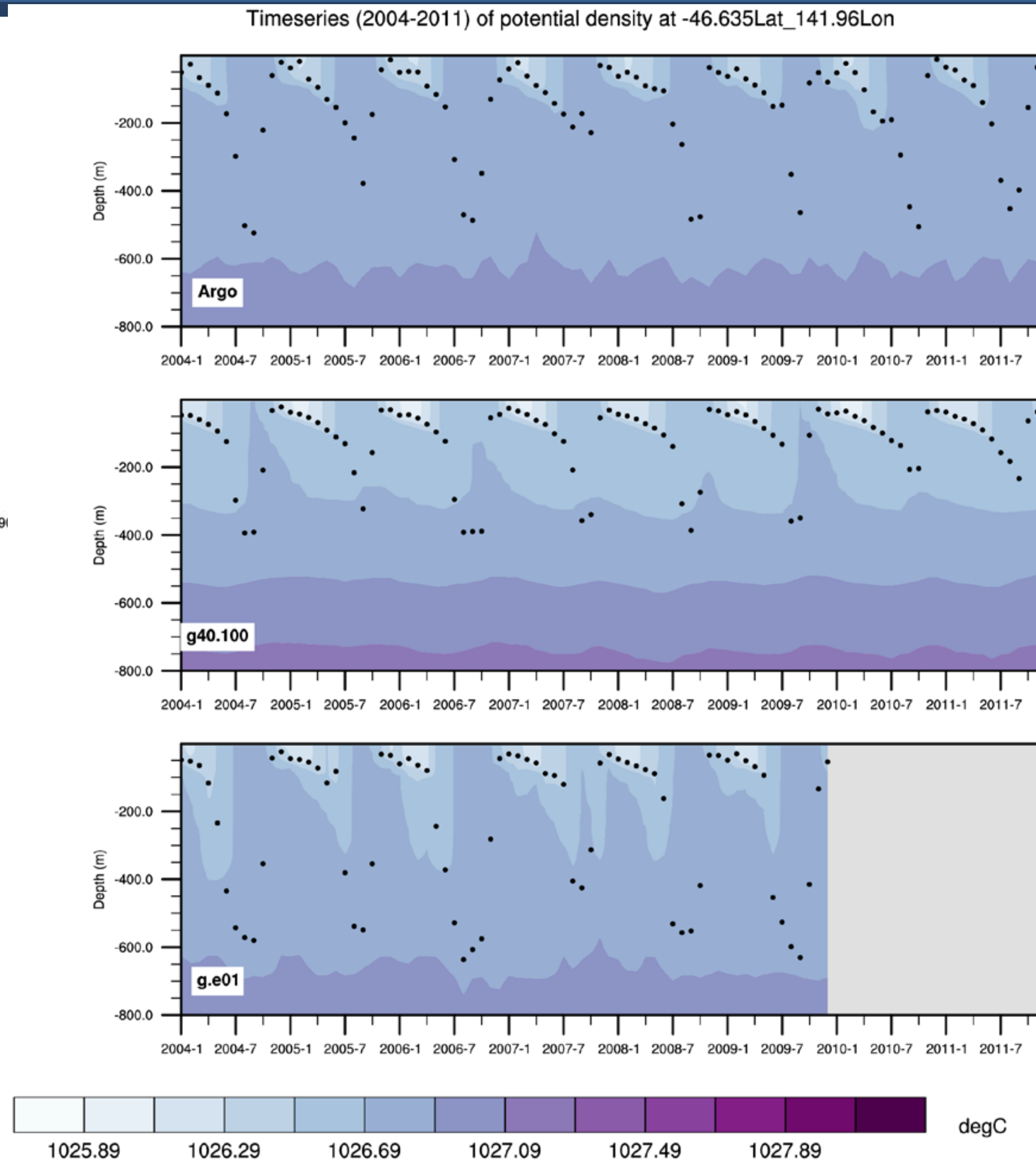


In Indian sector, the signs and locations of the bias are consistent in time for 1° and 0.1° models.



At SOFS, MLD biases consistent over time though near surface density gradients are similar.





Tracking down the MLD bias origin

1. Missing ocean physics (waves)
2. Initial ocean state and transport
3. Atmospheric Forcing
4. Combination of factors

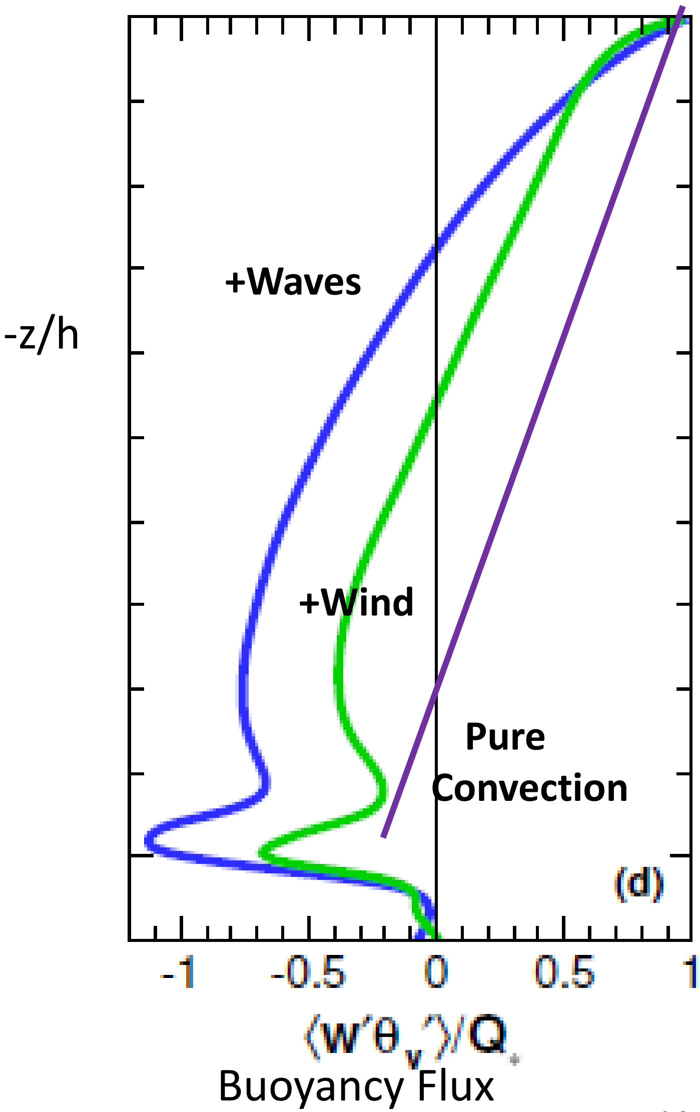
Image from the wilds of the internet

Tracking down the MLD bias origin

1. Missing ocean physics (waves)
2. Initial ocean state and transport
3. Atmospheric Forcing
4. Combination of factors

Use 4 LES simulations:
-April and June SOFS forcing over variety of surface buoyancy fluxes
-With and without waves (stokes)

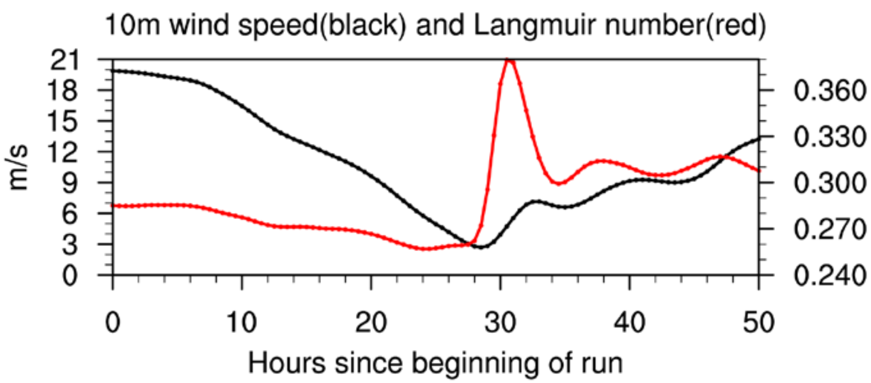
→ These simulations provide guidance to how to incorporate missing wave physics into KPP mixing.

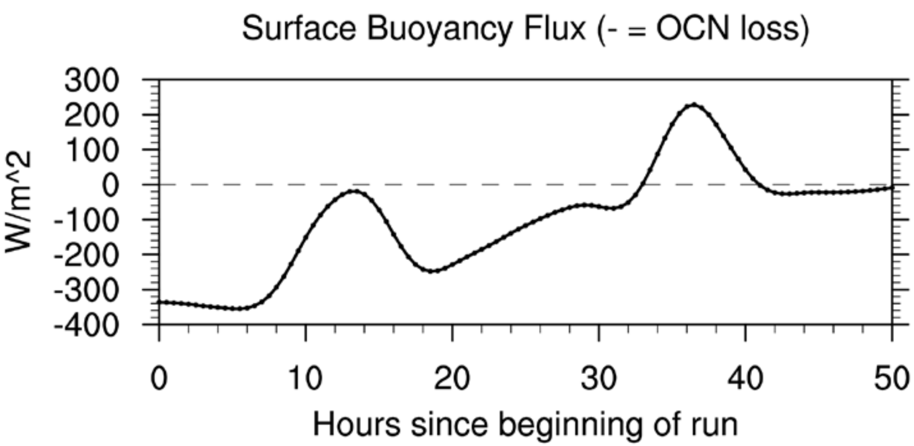


From: Sullivan, Patton, Romero, McWilliams

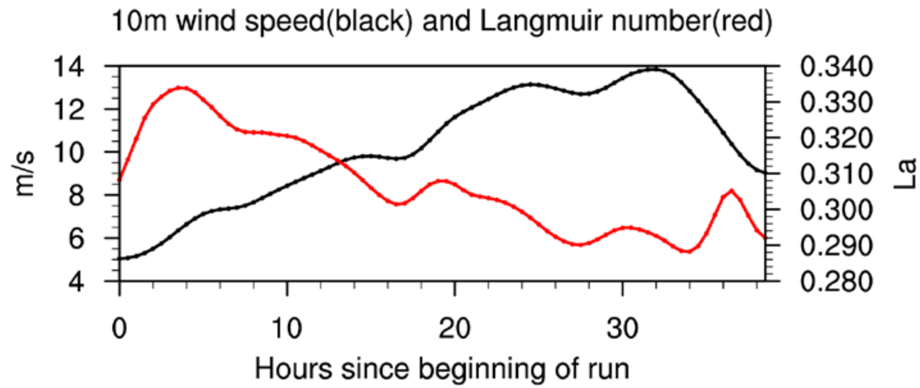
Surface forcing for LES cases.

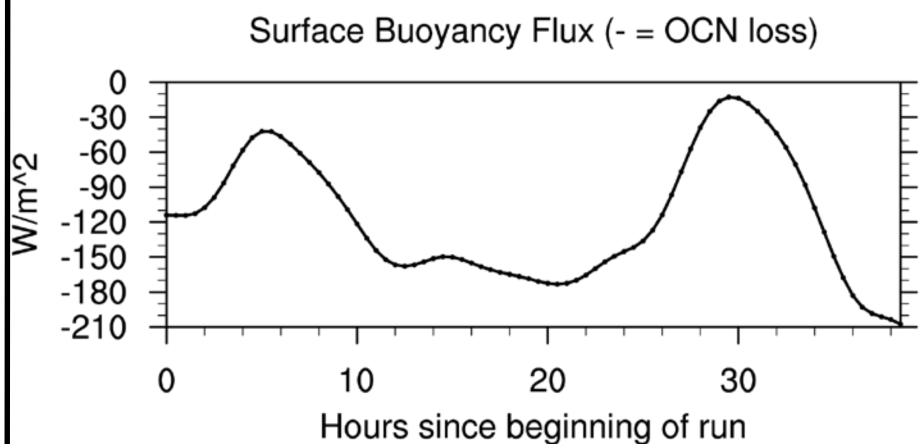
April





June

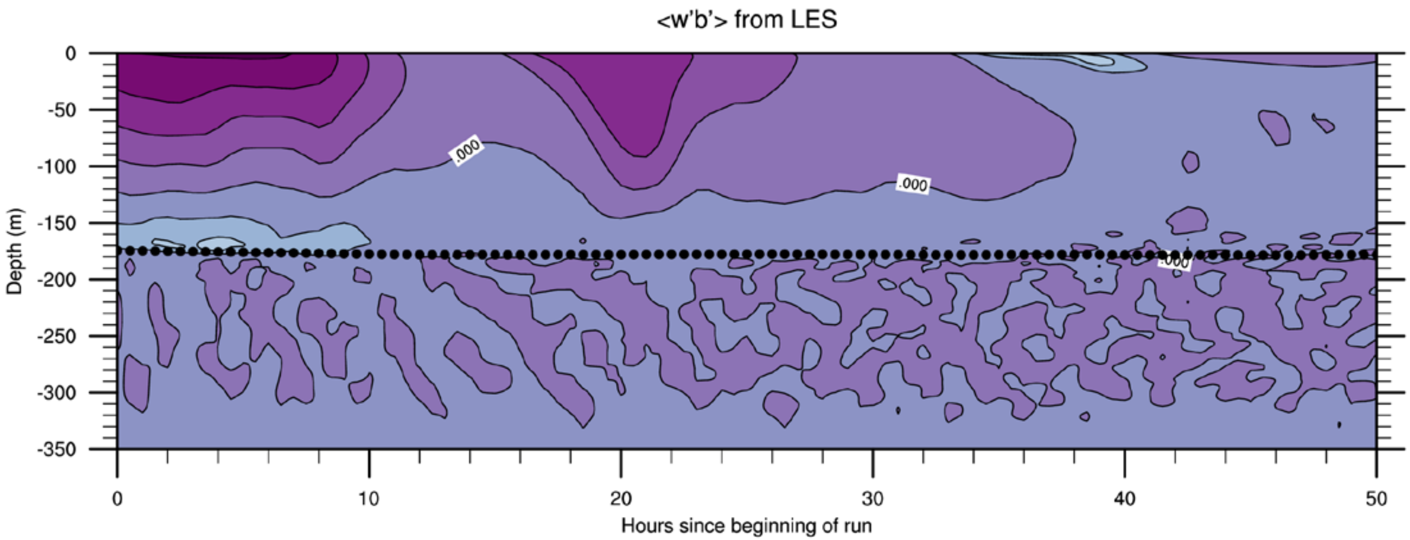


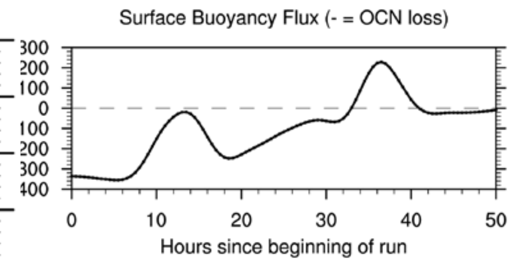


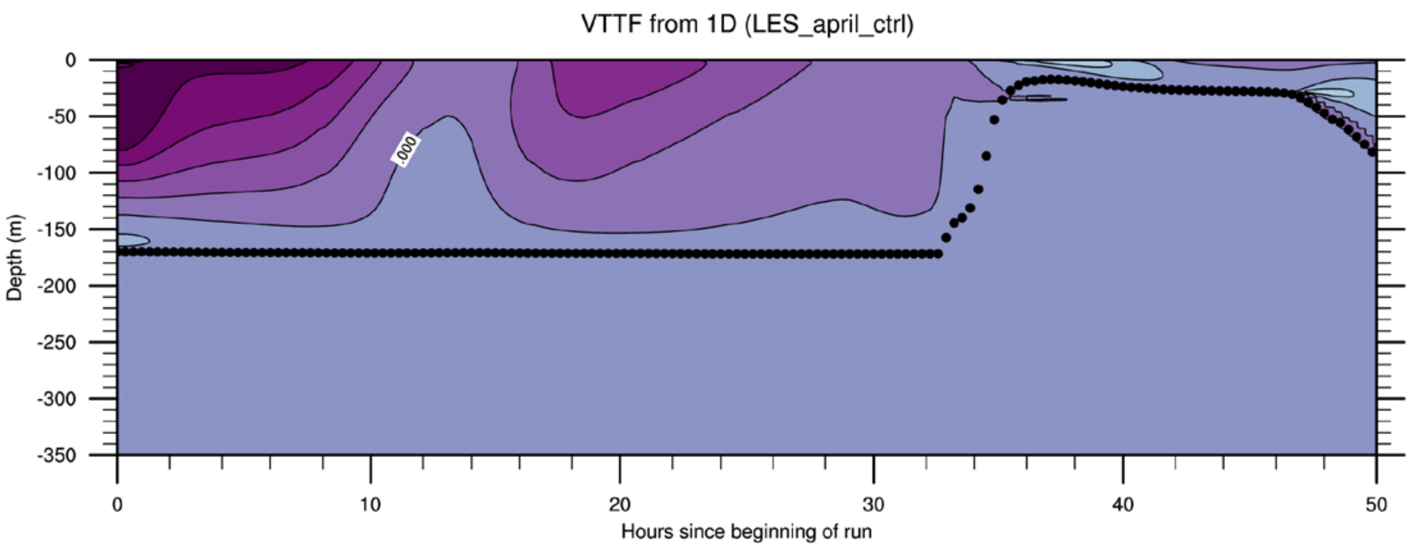
$$La^2 = \frac{u^*}{u_{stokes}}$$

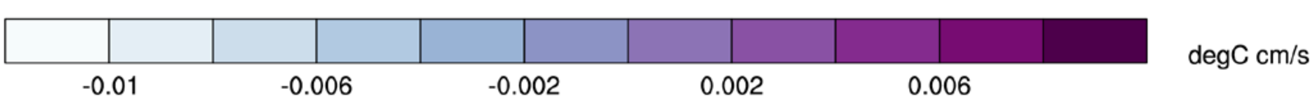
Small La ➔ Big waves

April: turbulent **buoyancy** flux without stokes effects.



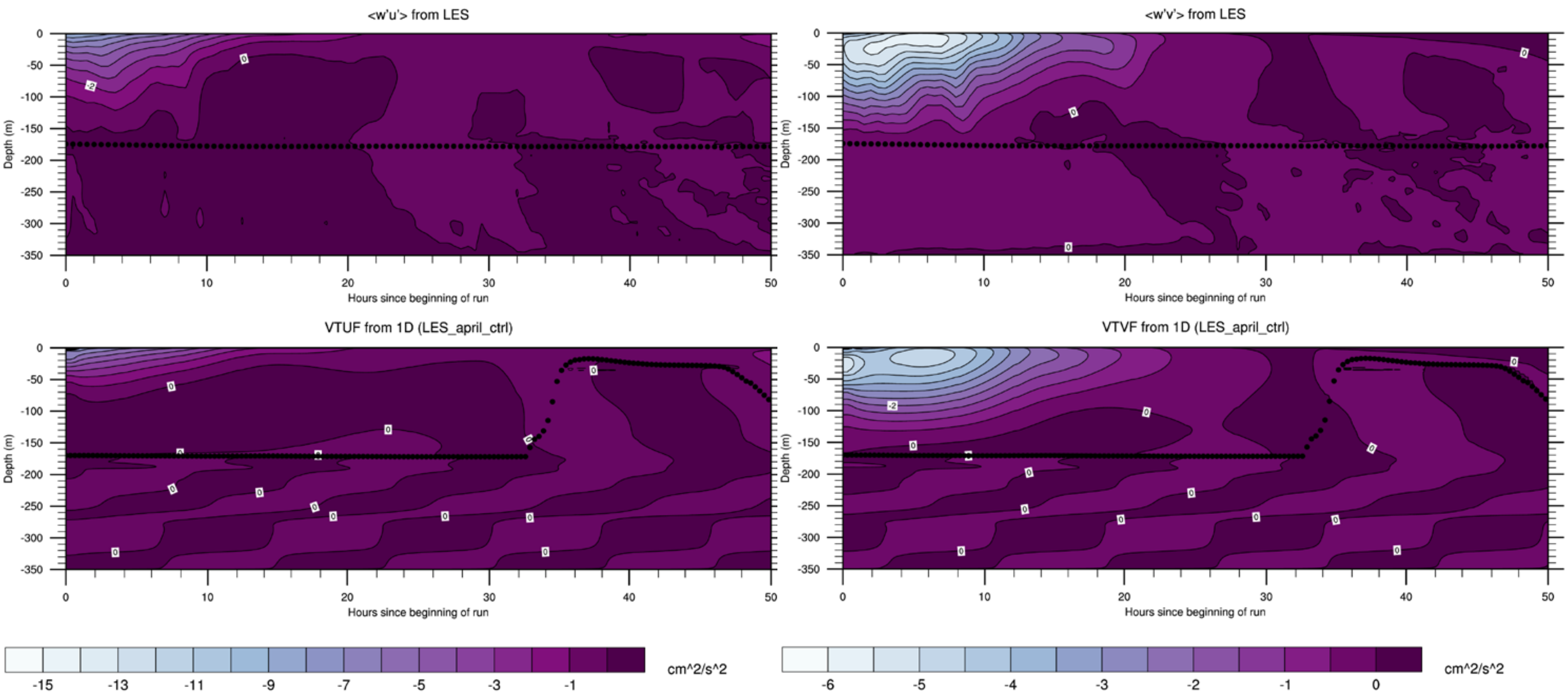






*Note: 1D model uses current KPP implementation (no waves or non-local momentum terms)

April: turbulent **momentum** fluxes without stokes effects.



*No waves or non-local momentum term

KPP: Path forward

Local (down-gradient) Nonlocal (counter-gradient)

$$\langle w'x' \rangle = \underbrace{-K_X \partial_z X}_{\text{Local (down-gradient)}} + \underbrace{K'_X \gamma_{CON} \hat{e}_{CON} + K''_X \gamma_{STK} \hat{e}_{STK}}_{\text{Nonlocal (counter-gradient)}}$$

$$K_X = w_x \, h G(\sigma)$$

$$K_X \stackrel{?}{=} K'_X \stackrel{?}{=} K''_X$$

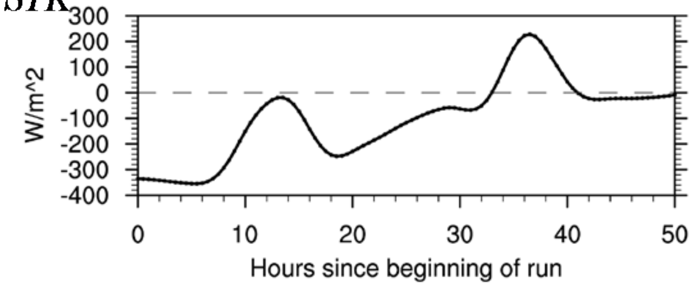
$$For\ scalars:\ \hat{e} = 1$$

$$For\ momentum:\ \gamma_{CON} \neq 0;\ \gamma_{STK} \neq 0;\ \hat{e}_{CON} \neq \hat{e}_{STK}$$

KPP: range of cases allows us to attack each term.

Local (down-gradient) Nonlocal (counter-gradient)

$$\langle w'x' \rangle = -K_X \partial_z X + K'_X \gamma_{CON} \hat{e}_{CON} + K''_X \gamma_{STK} \hat{e}_{STK}$$



April	April	April	April	June	June
no stokes	stokes	no stokes	stokes	no stokes	stokes
Sfc. Buoy. forcing: stable	Sfc. Buoy. forcing: stable	Sfc. Buoy. forcing: unstable	All forcing	All forcing	All forcing
K_X	$K''_X \gamma_{STK} \hat{e}_{STK}$	$K'_X \gamma_{CON} \hat{e}_{CON}$	$K'_X \gamma_{CON} \hat{e}_{CON} +$ $K''_X \gamma_{STK} \hat{e}_{STK}$	Verify	Verify

KPP: range of cases allows us to attack each term.

Local (down-gradient) Nonlocal (counter-gradient)

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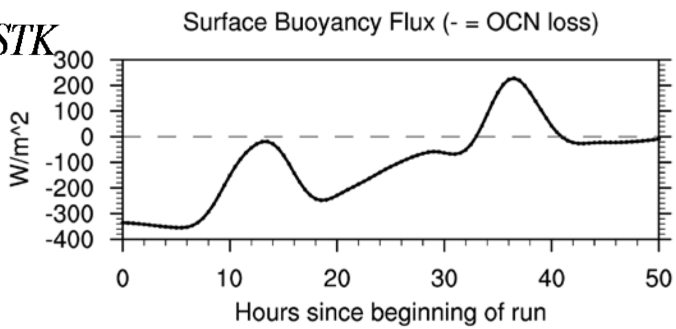
April

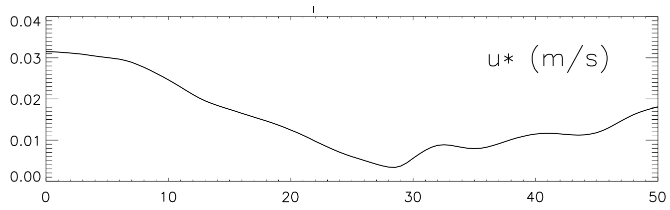


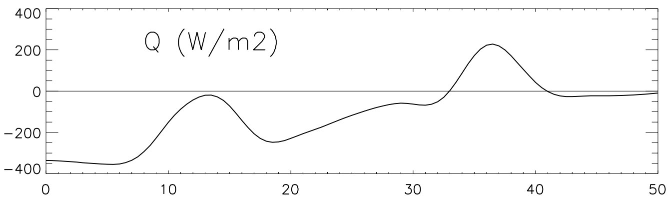
April	April	April	April	June	June
no stokes	stokes	no stokes	stokes	no stokes	stokes
Sfc. Buoy. forcing: stable	Sfc. Buoy. forcing: stable	Sfc. Buoy. forcing: unstable	All forcing	All forcing	All forcing
K_X	$K''_X \gamma_{STK} \hat{e}_{STK}$	$K'_X \gamma_{CON} \hat{e}_{CON}$	$K'_X \gamma_{CON} \hat{e}_{CON} +$ $K''_X \gamma_{STK} \hat{e}_{STK}$	Verify	Verify

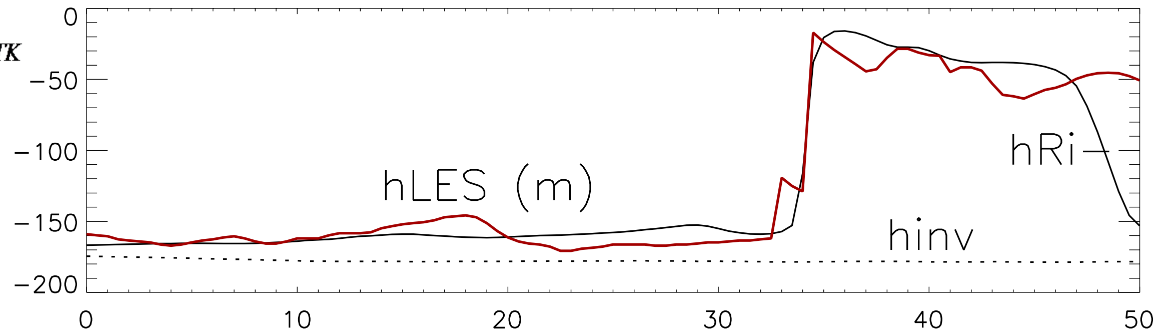
First order of business: Use April LES to guide treatment of reference depth(h) and turbulent velocity (w_x) scale.

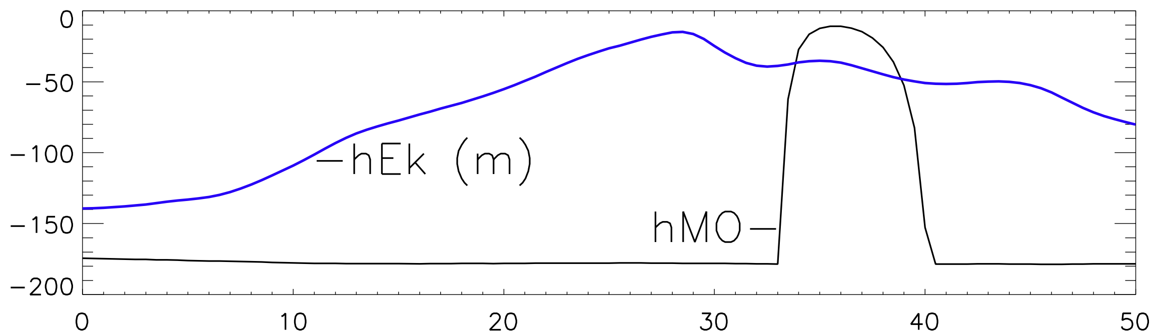
$$\langle w'x' \rangle = -K_X \partial_z X + K'_X \gamma_{CON} \hat{e}_{CON} + K''_X \gamma_{STK} \hat{e}_{STK}$$

$$K_X = w_x h G(\sigma)$$









hinv : LES inversion depth [max d_zB]

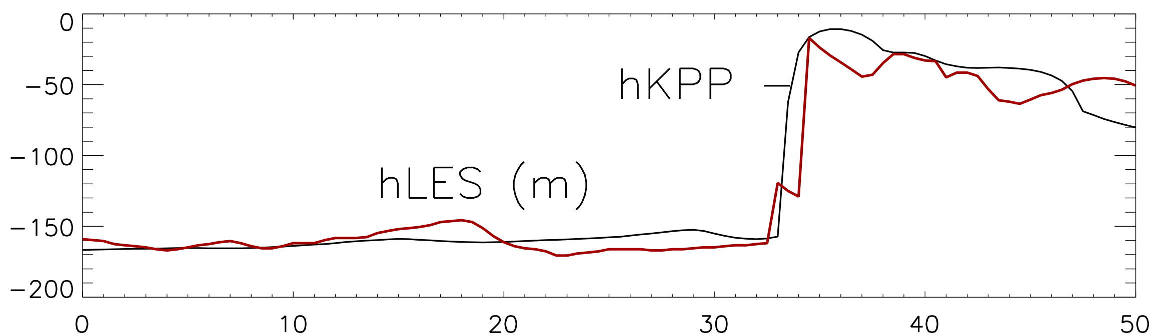
hLES : LES turbulence depth [$<w'^2>$]

hRi : Critical Richardson # depth [Ri>0.3]

hMO : Monin-Obukhov length [$u^{*3}/(K^*B_{sfc})$]

hEk : Ekman depth [0.5u*/f]

hKPP : Combo of Ri,MO,Ek methods



Thank you, Questions?

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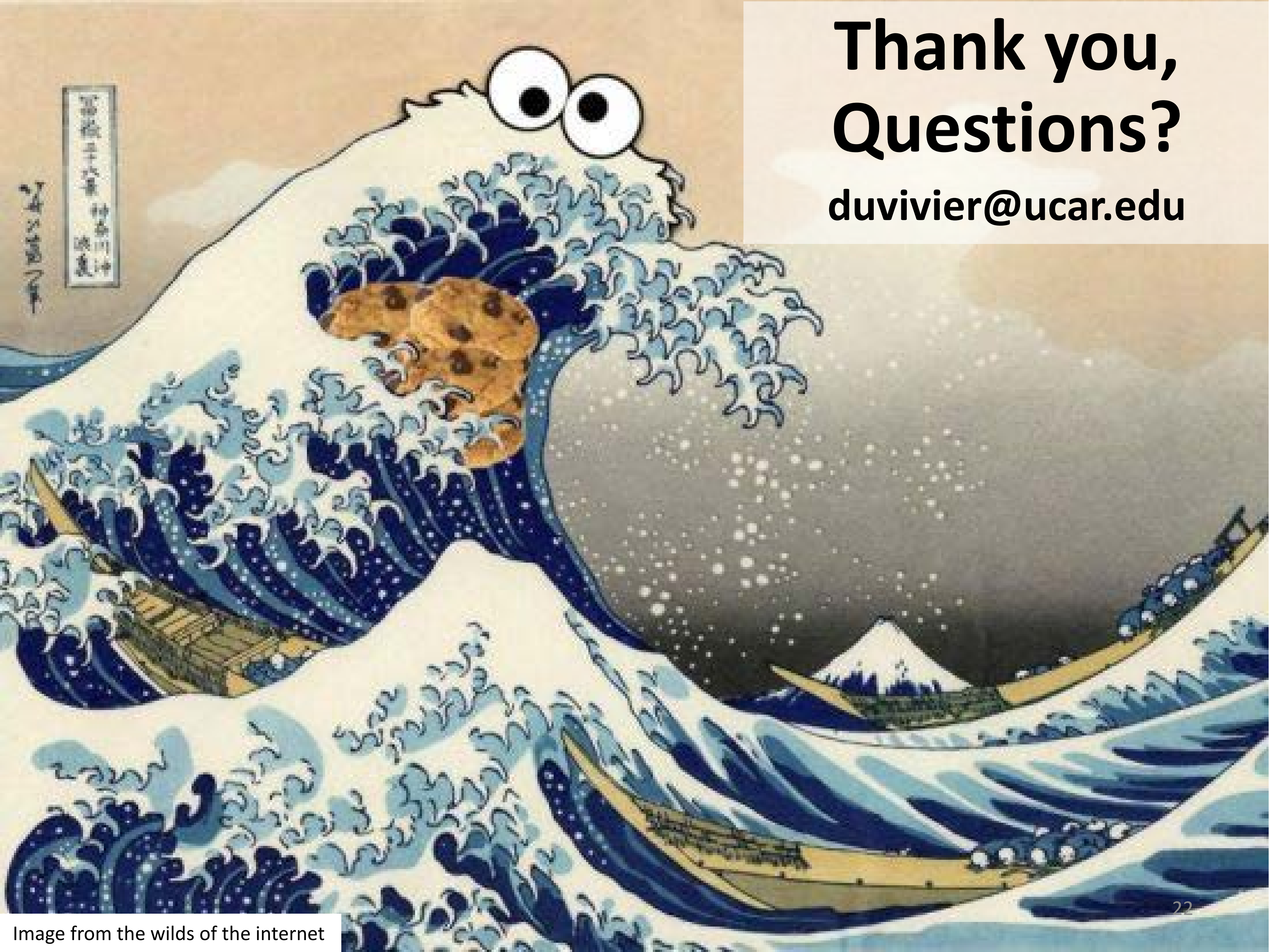
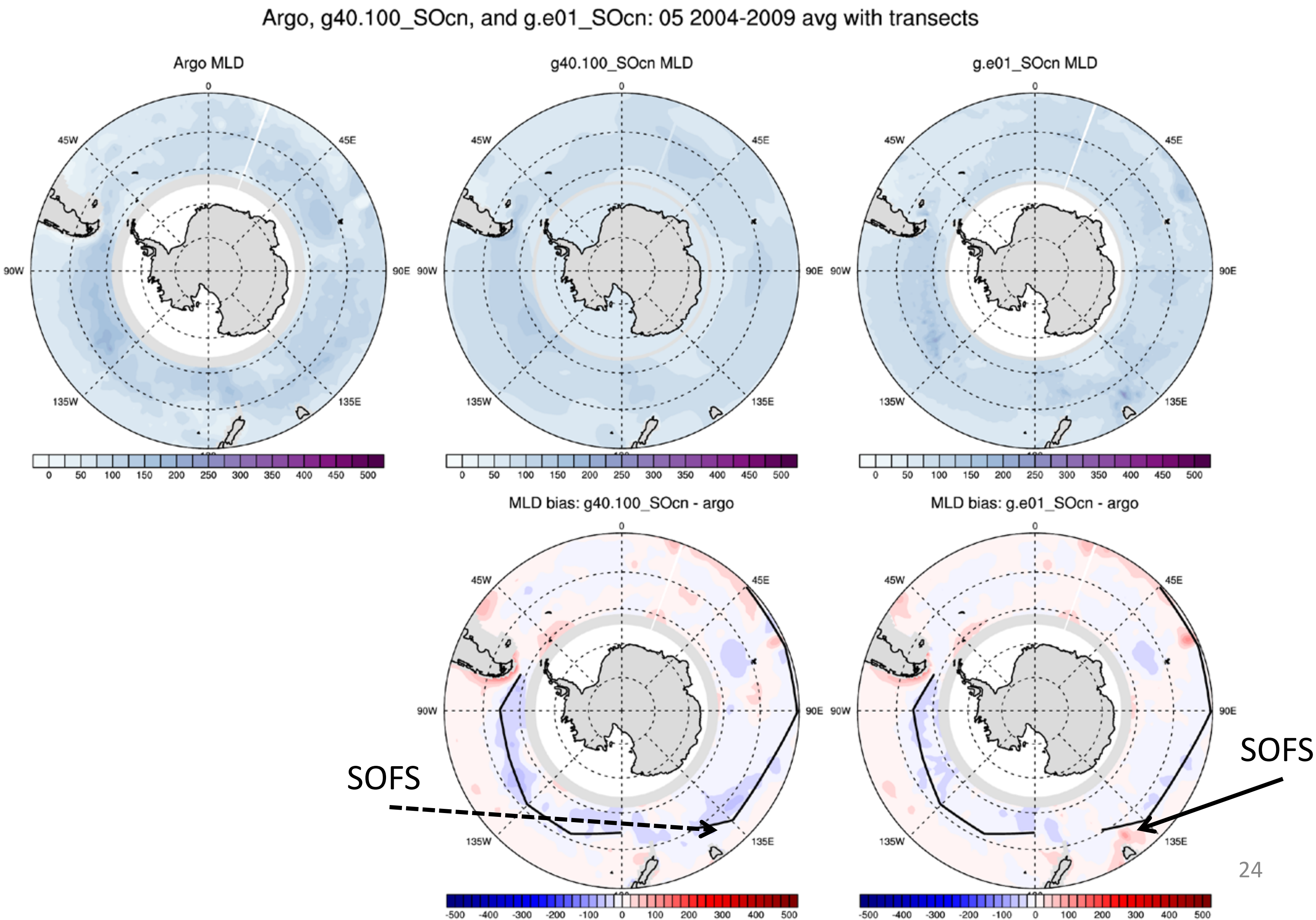


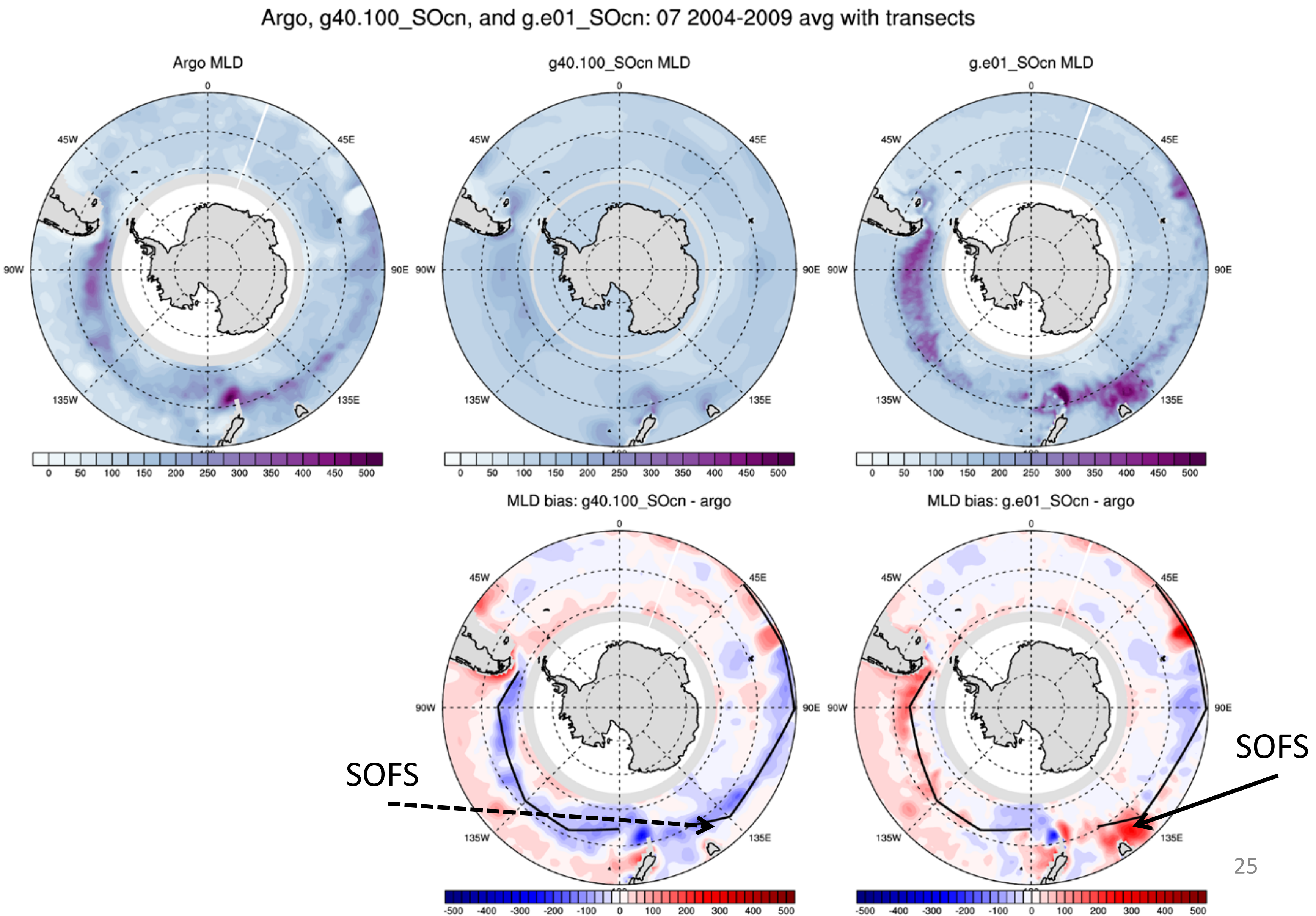
Image from the wilds of the internet

Southern Ocean Mixed Layers

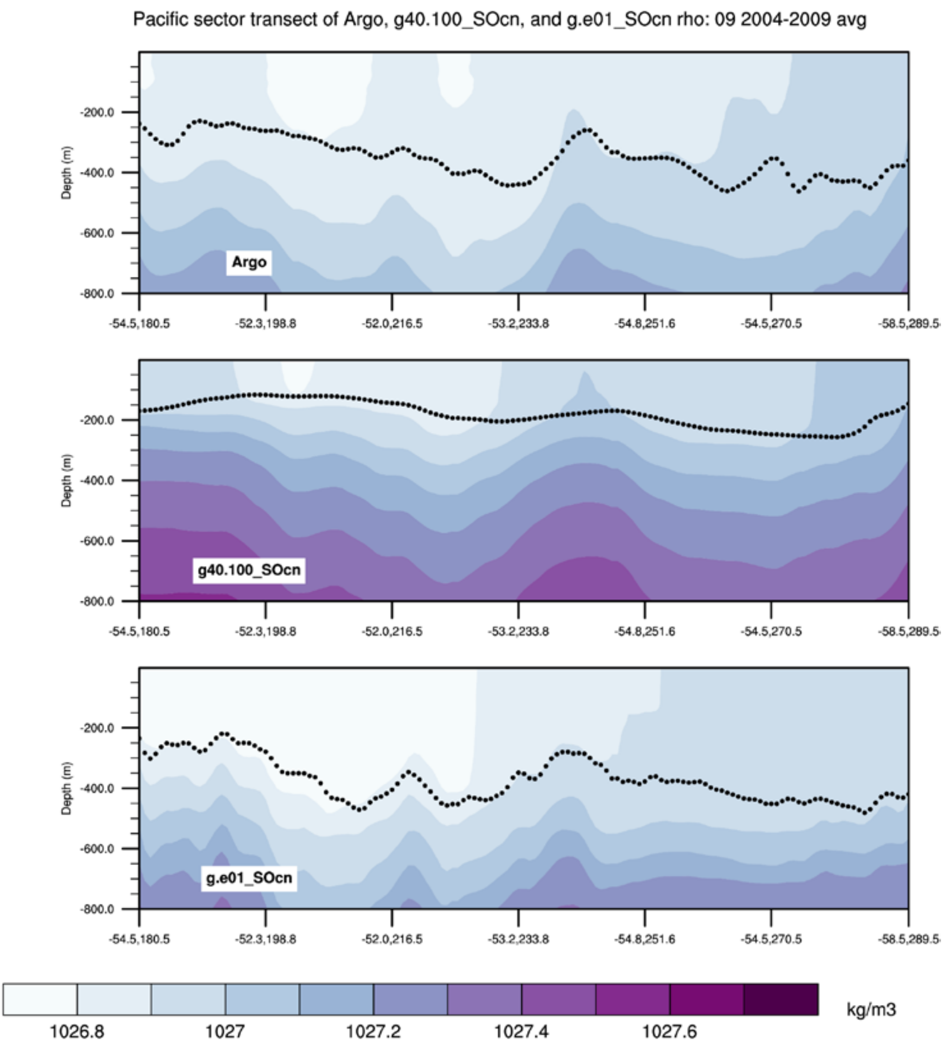
1° and 0.1° models have similar biases at start (May) of SH winter.

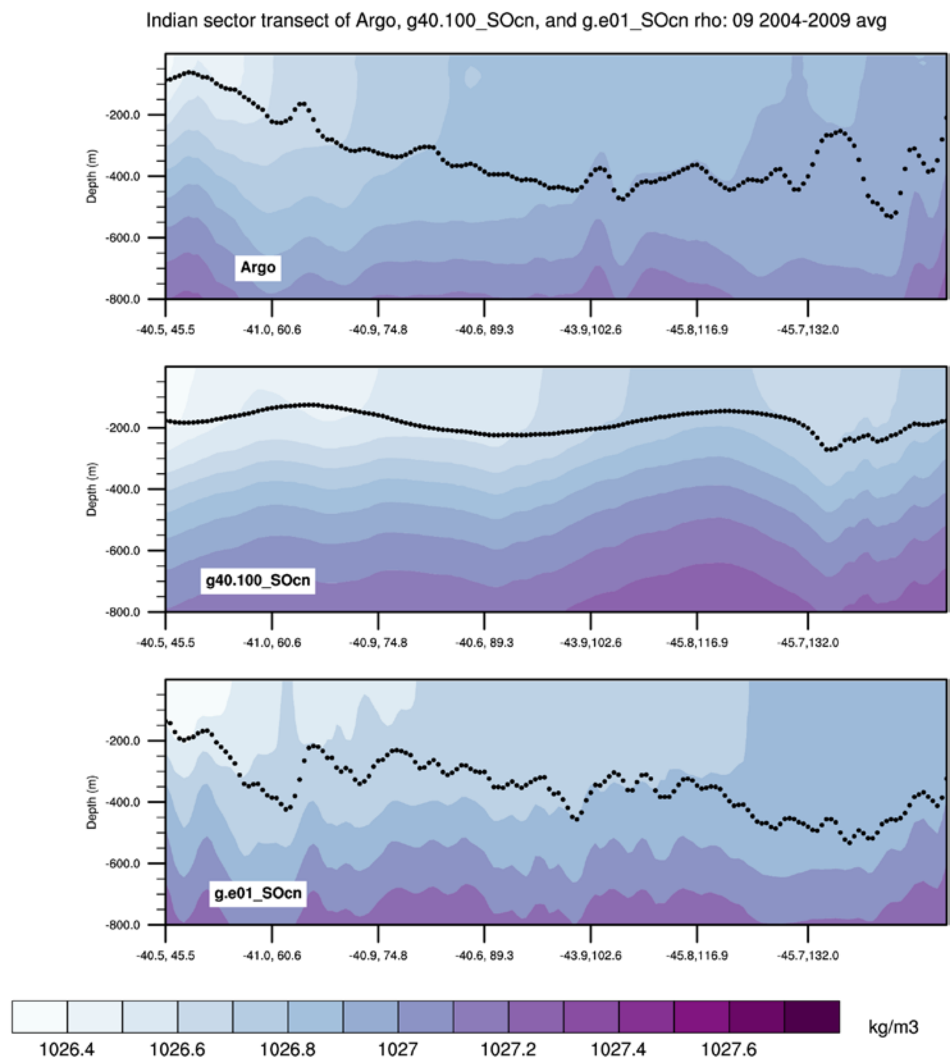


By July, 1° and 0.1° models have opposite biases.

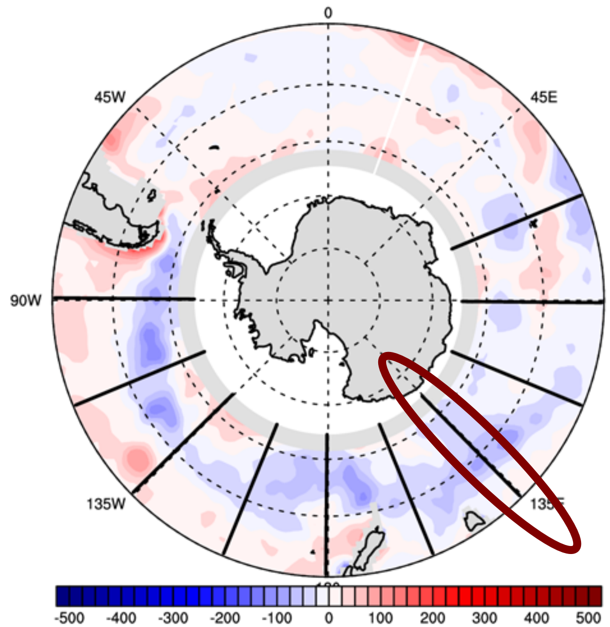


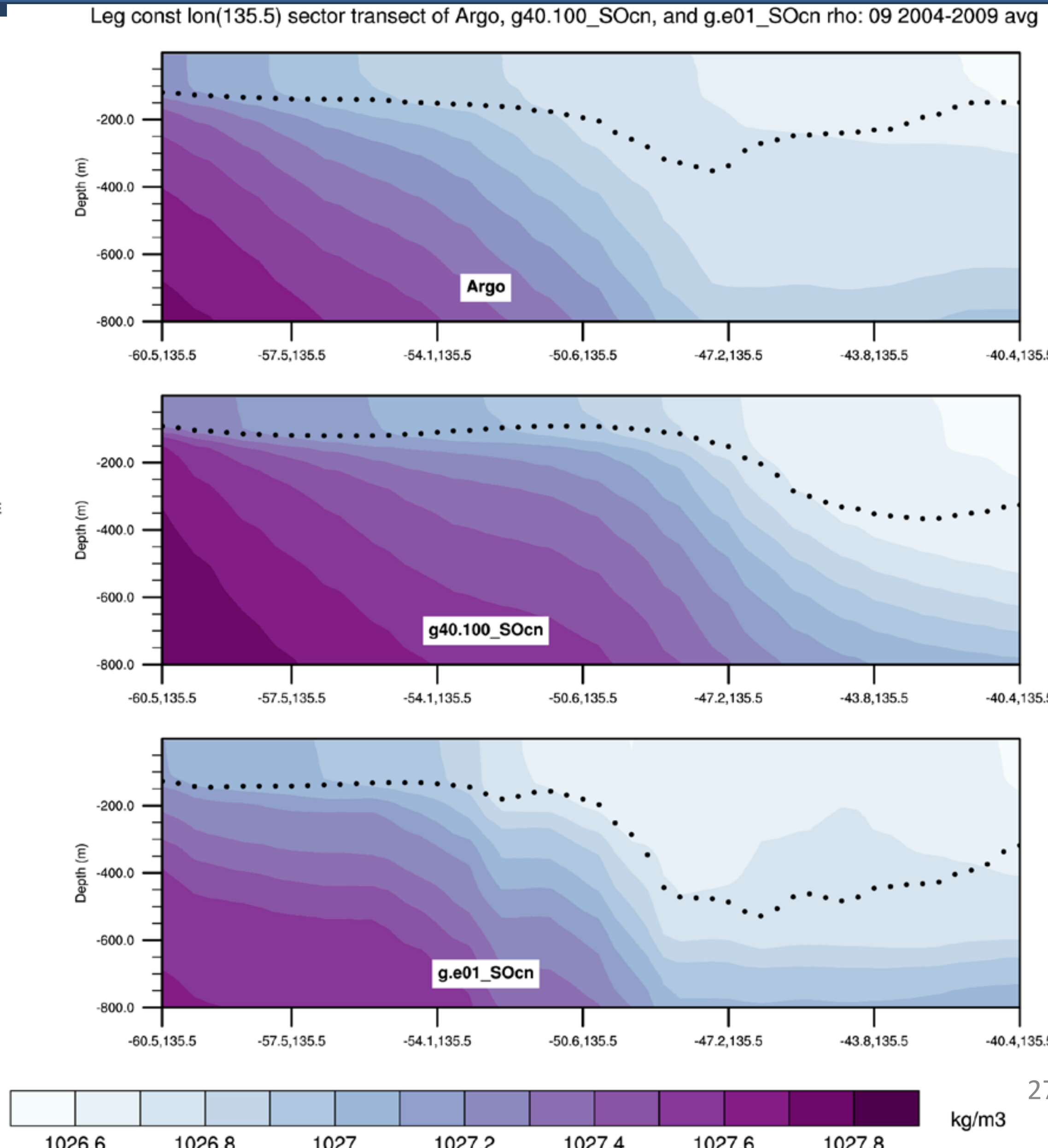
In Pacific and Indian sectors, near surface stability differs for 1° and 0.1° models.



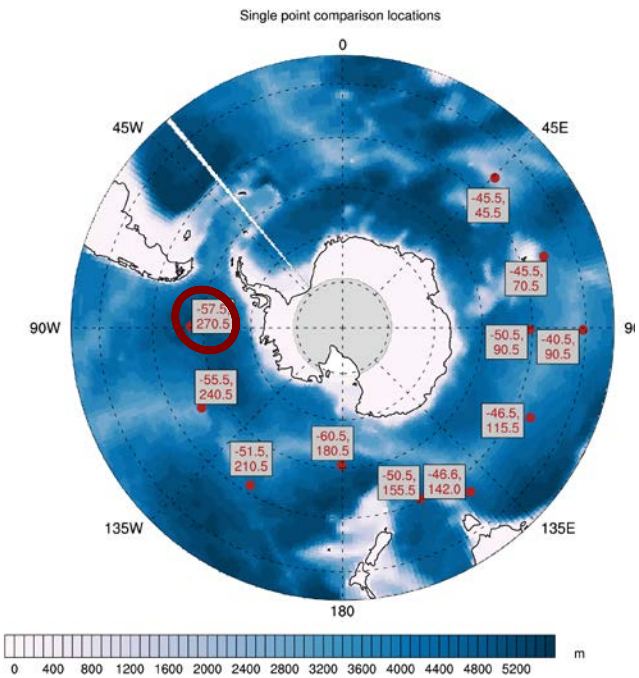


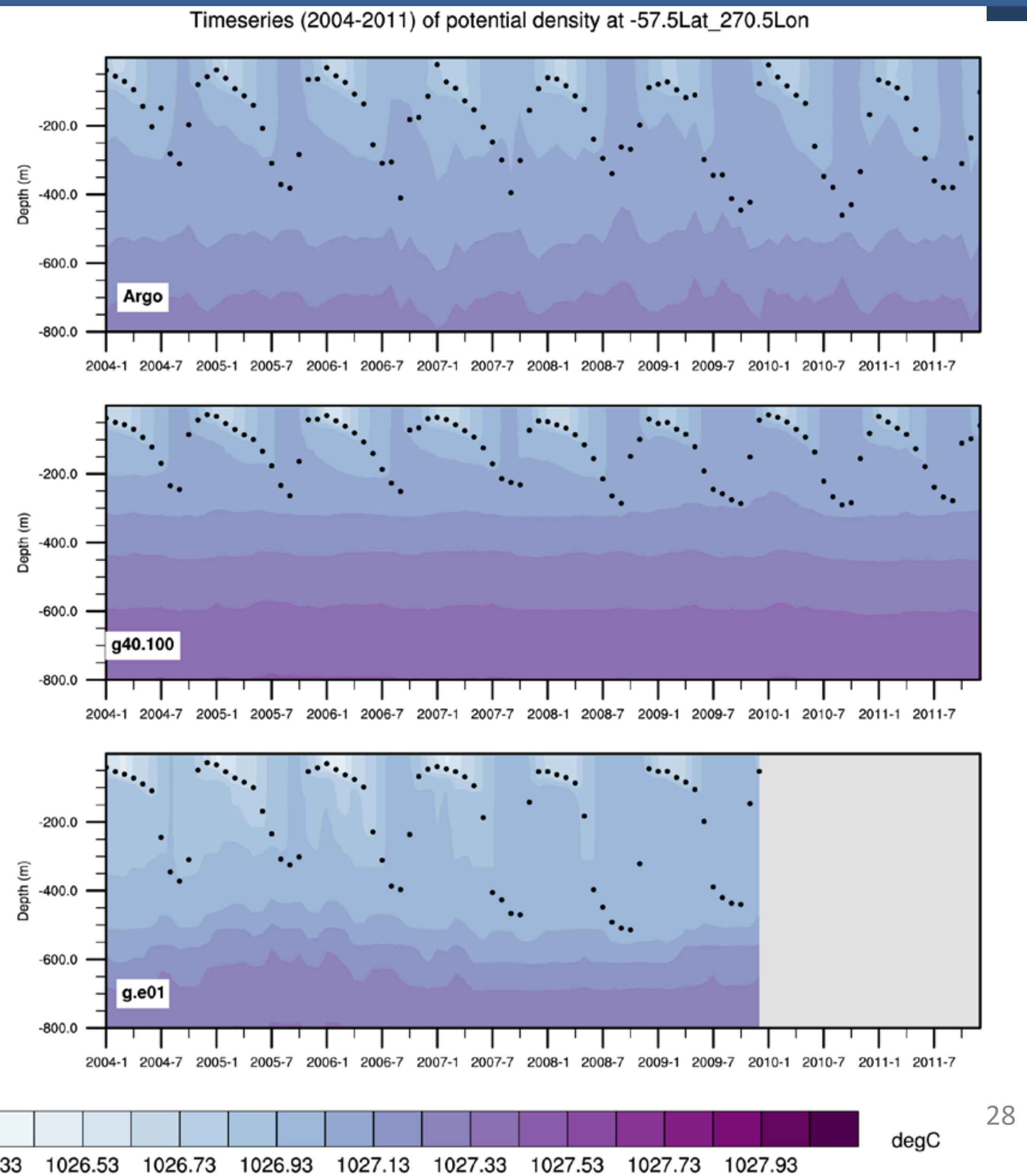
Upper ocean stability differs for 1° and 0.1° models.



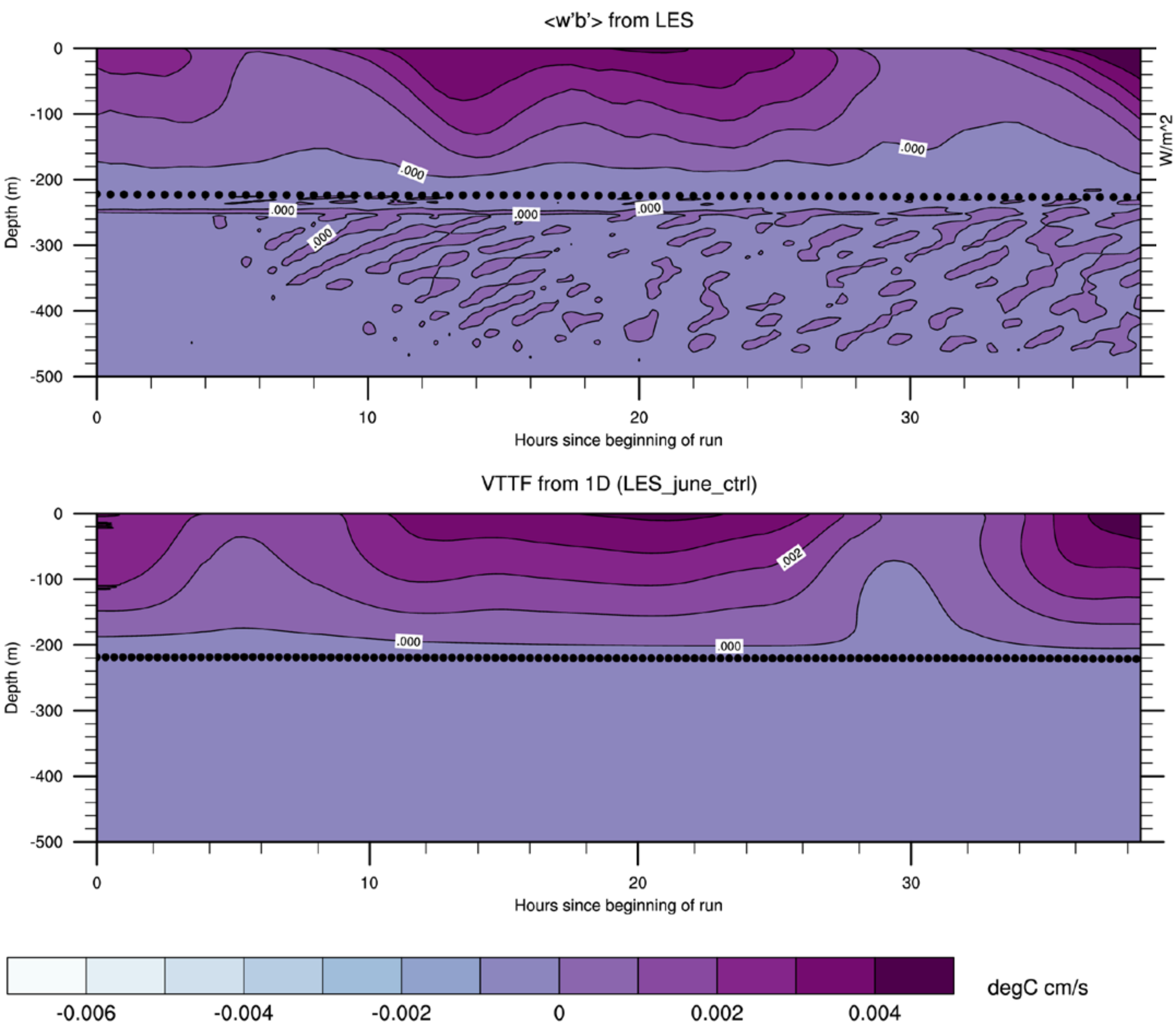


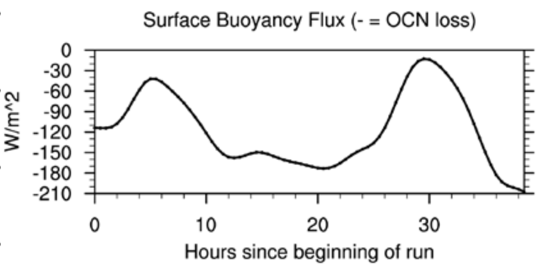
Southern Ocean Mixed Layers





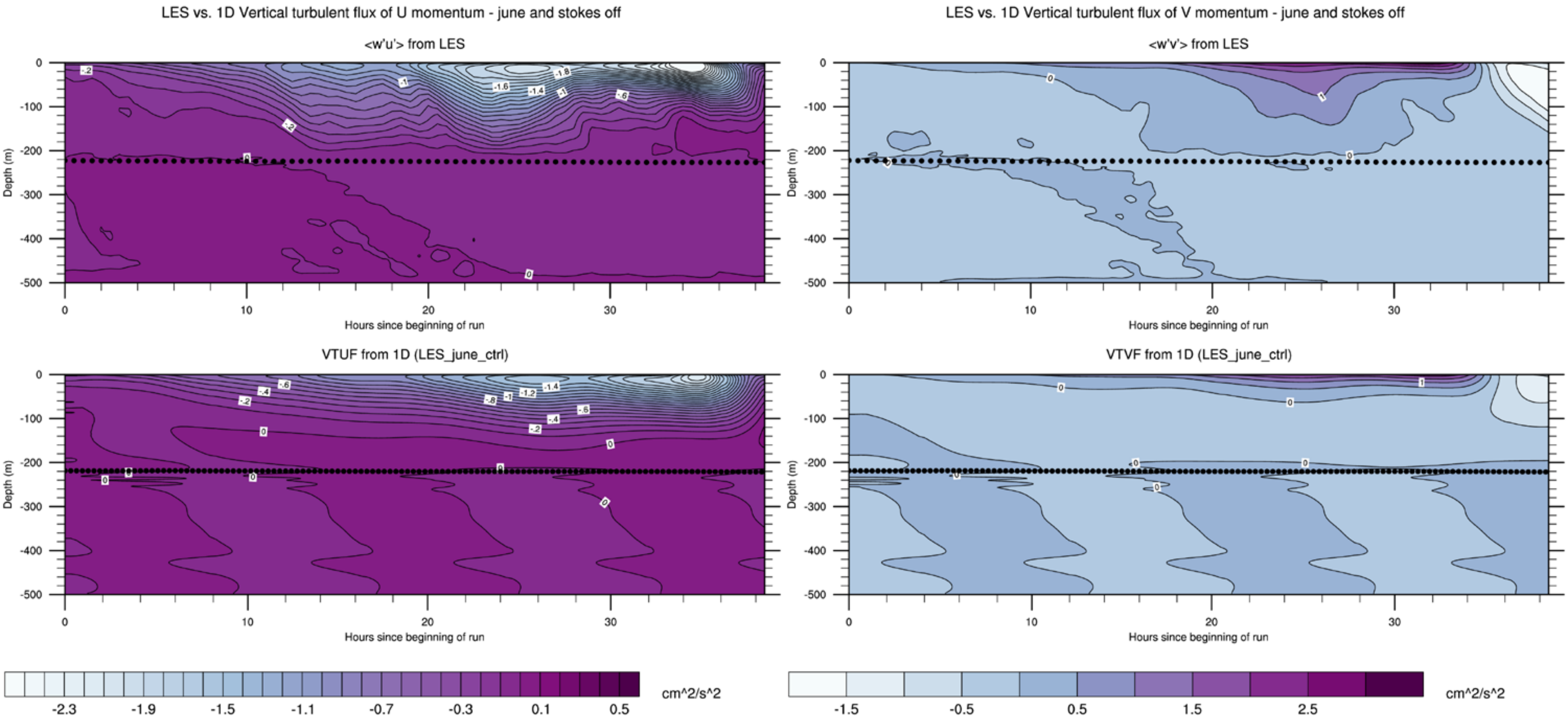
June: turbulent **buoyancy** fluxes without stokes effects.





*Note: 1D model uses current KPP implementation (no waves or non-local momentum terms)

June: turbulent **momentum** fluxes without stokes effects.



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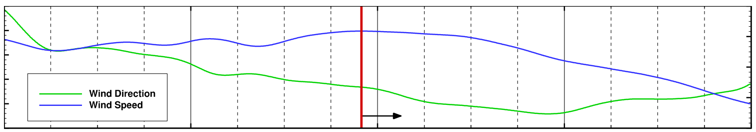
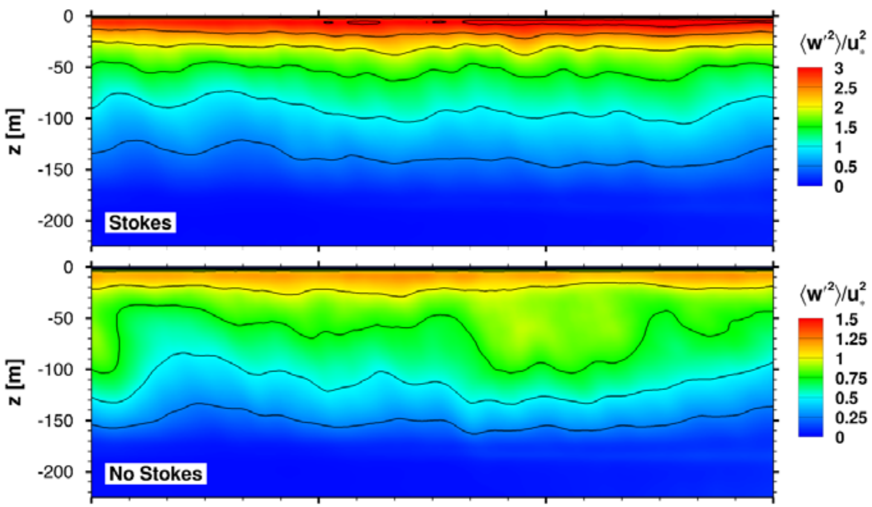
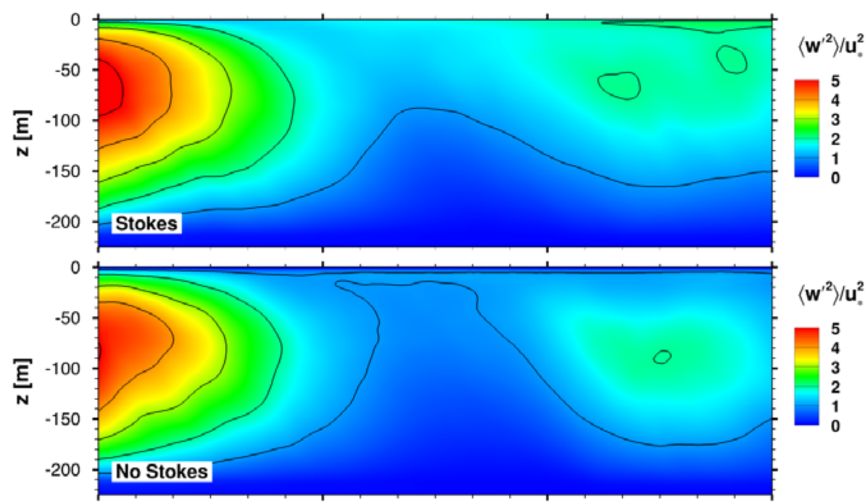
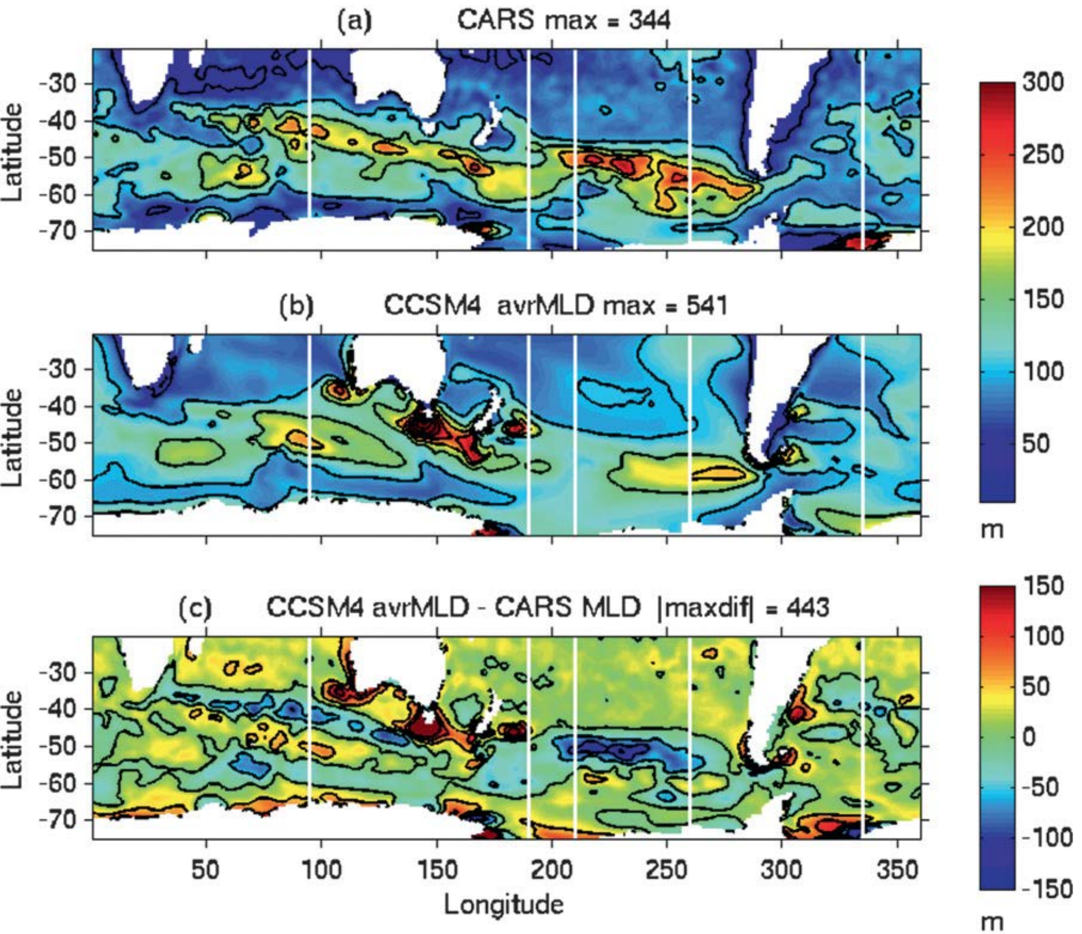
Southern Ocean Mixed Layers







Southern Ocean Mixed Layers



Weijer et al. 2012 - Figure 8.
Southern Ocean Climate in CCSM4

OUTLINE: Southern Ocean Mixed Layers

- Profiles from Argo floats showing progression in 2010. No “MLD” feature obvious.
    - Discuss briefly the depth metrics: MLD, BLD, etc. and how these work
- Compare Argo gridded and g40 and g.e01. Discuss biases, seasonal progression, resolution. Show spatial plots, cross sections, and timeseries at a point.
- 1D modeling: March/Sept (??) Point is to show bias in MLD and importance of initial conditions on the result. (Have sims w/ g40, g.e01, etc. as initial condition, but start with comparison of model result initialized with argo float)
- LES vs. 1D:
    - Location, not biased in space or time based on argo/model comparisons
    - Timeseries of forcing (wind, waves, buoyancy) for april and june
    - Compare w and w/o stokes??
    - ** Bill has figure of buoyancy, buoyancy+wind, buoyancy+wind+waves**
    - Initial turbulent flux comparisons w/o stokes: VTTF, VTUF, VTVF
    - Talk about the path forward with KPP (generally)
        - Scaling with stokes (including alignment of wind and waves)
        - Nonlocal terms: momentum and scalars, wind and waves

Don’t talk about Salinity feature and future work on this…