How lateral mixing affects the amplitude of El Nino

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1. Motivation

Lateral mixing coefficient in ocean is very uncertain

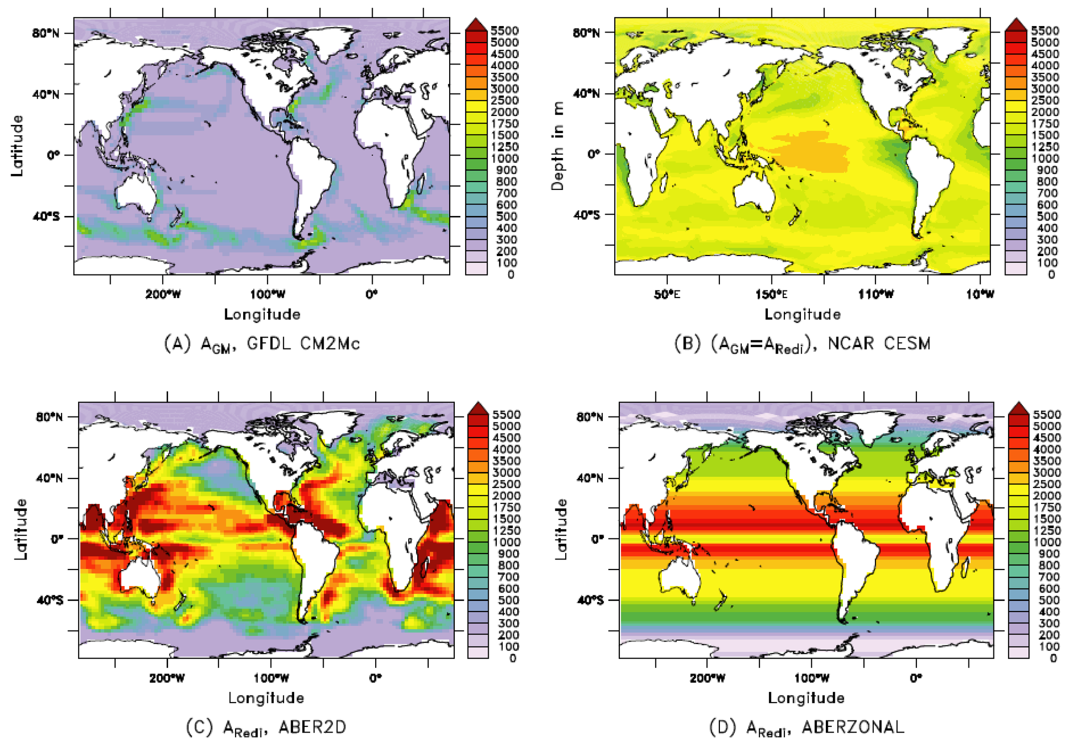

Figure 1

Some theories relate coefficient strongly to baroclinicity (Figure Aa) based on theories developed for vertical E-P flux- low values on equator.

NCAR CESM has higher value on equator in surface layer (Fig. 1B) though values at 700m look very similar to Fig. 1A.

Recent estimates based on satellite altimetry (Fig 1C) show very different distribution. (Abernathey and Marshall, J. Geophys. Res-Oceans., 2013)

Zonal average of this distribution (Fig. 1d) has very high values in mid-latitudes.

What are the implications of this uncertainty for simulating El Nino?

2. Approach

Take GFDL CM2Mc model.

Do 4 runs with spatially constant coefficient (400, 800, 1200 and 2400 m^2/s denoted by AREDI400, AREDI800, AREDI1200 and AREDI2400)

2D-coefficient from Fig. 1C above (ABER2D)

Zonally averaged version from Fig. 1D above (ABERZONAL).

Perform term balance regression following von Oldenborgh et al. (Ocean Sciences, 2005) in which

$$\frac{\partial T'}{\partial t} = \alpha z'_{20} + \beta \tau'_x - \gamma T'$$

Where T', z_{20}' and τ'_x are the anomalous temperatures, pycnocline depth and wind stress respectively.

Increases in α, β and $1/\gamma$ mean that the ocean is more responsive to the atmosphere.

Regression can be done using total tendencies or just using tendencies due to particular processes.

$$\frac{\partial T'}{\partial t} = \left(\frac{\partial T'}{\partial t}\right)_{advection} + \left(\frac{\partial T'}{\partial t}\right)_{vertdiff} + \left(\frac{\partial T'}{\partial t}\right)_{eddy}$$

2. Results

Mean state

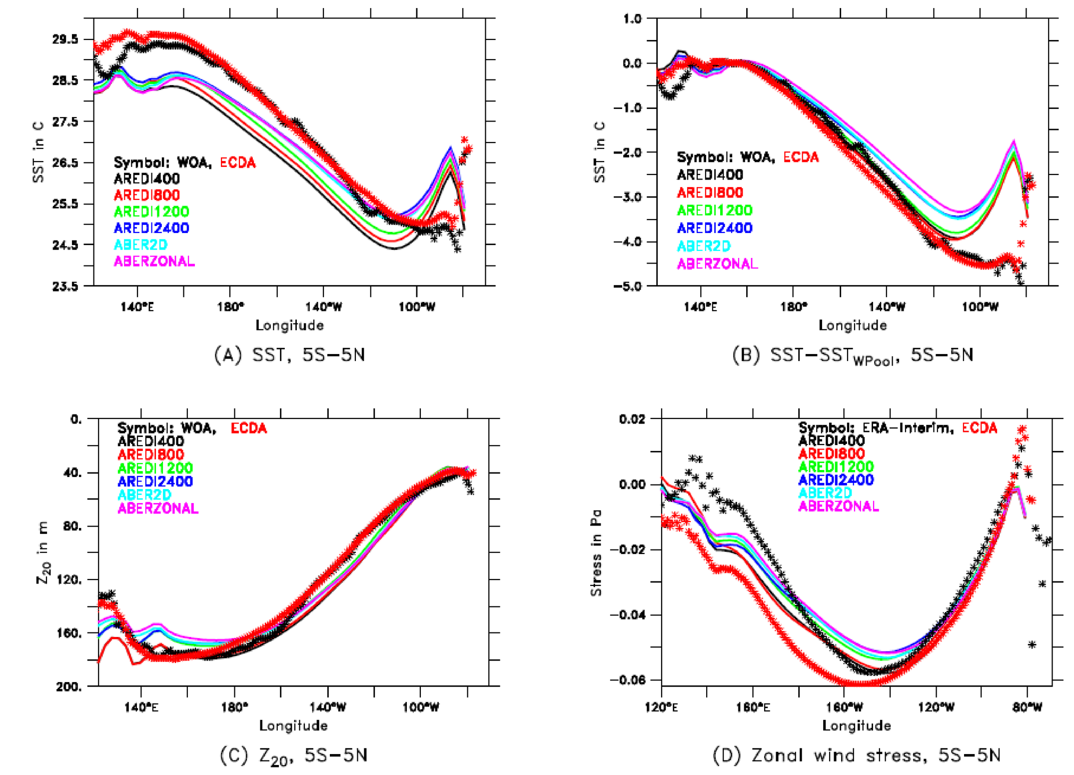

Figure 2

Good overall agreement.

Increasing mixing warms SSTs (Fig. 2A), reduces cross Pacific temperature contrast (Fig. 2B) shallow pycnocline slightly (Fig. 2C and weakens zonal stress slightly (Fig. 2D)

Drivers of mean change

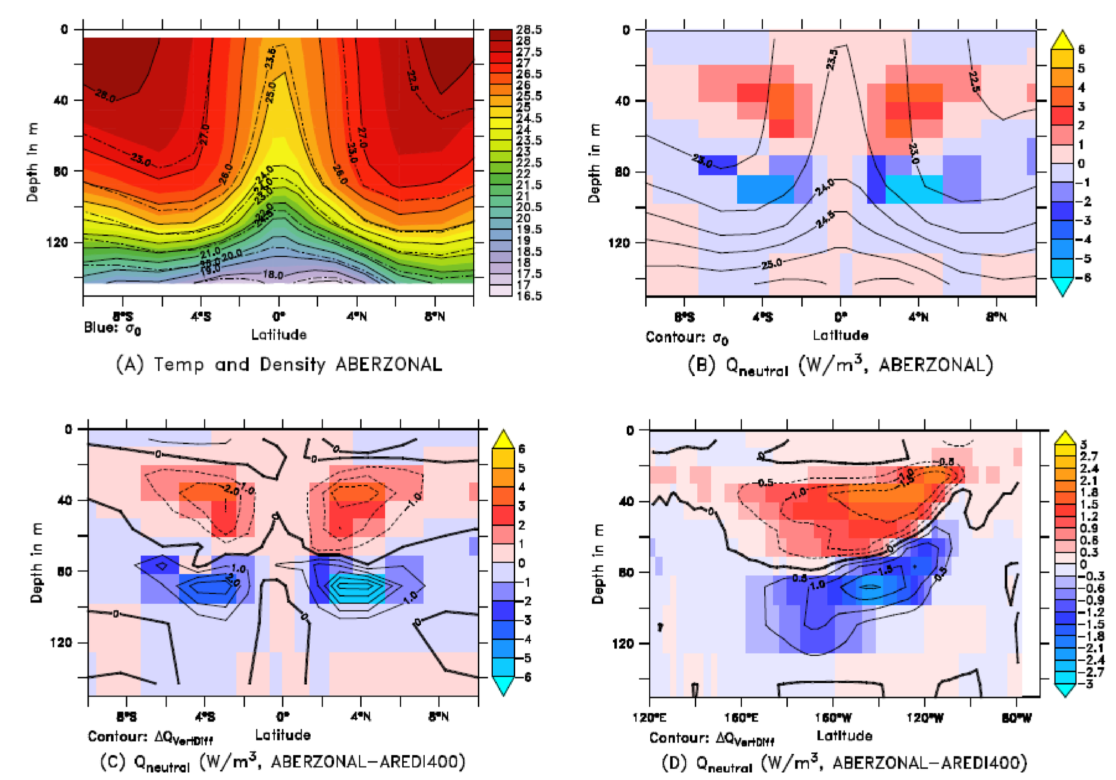

Figure 3

Isopycnals (Fig. 3A, contours) cross isotherms (Fig. 3A, colors) near equator.

Isopycnal mixing moves heat up in water column (Fig. 3B).

Changing isopycnal mixing (ABERZONAL-AREDI400) moves more heat up in water column (colors Fig. 3C) but this is compensated by vertical mixing (contours Fig. 3C)

Same compensation is seen in section along the equator (Fig. 3D).

Increase in vertical mixing is due to higher mixing increasing stratification (mixing coefficients actually drop).

Variability

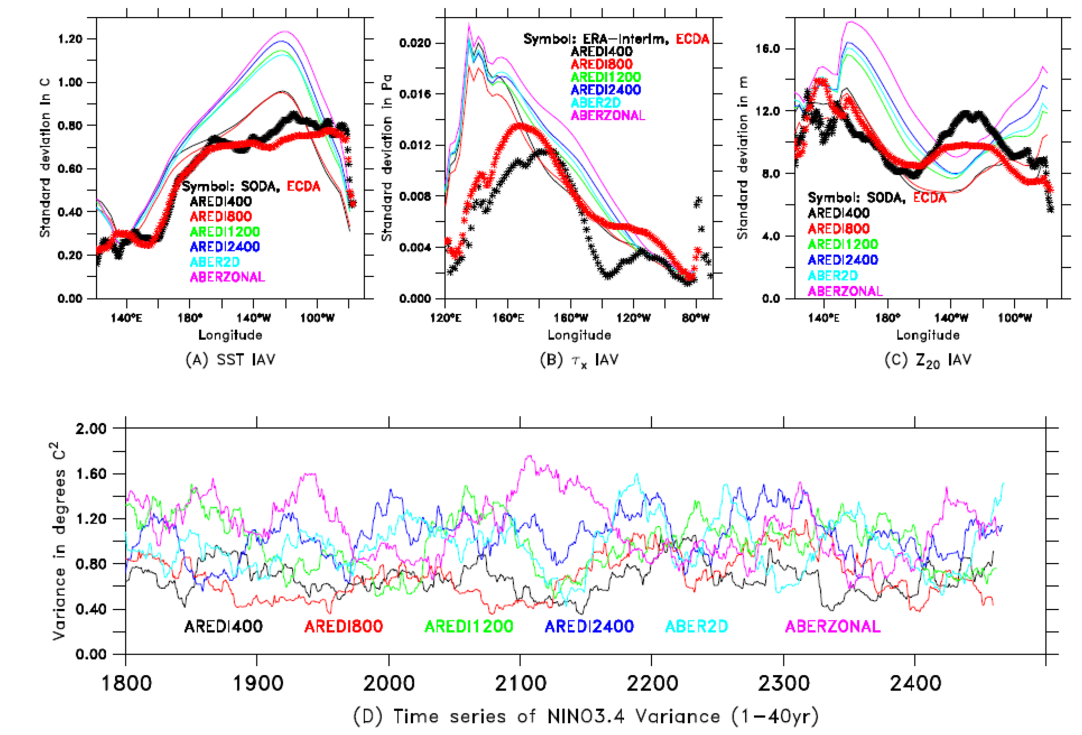

Figure 4

Increasing mixing

1.increases interannual SST variability (Fig. 4A)
2.Increases interannual wind stress variability (Fig. 4B)
3.Increases interannual z_{20} variability.

Shapes of patterns fairly similar.

Feedback Analysis 1

Regression of temperature tendency terms over top 100m vs. SST

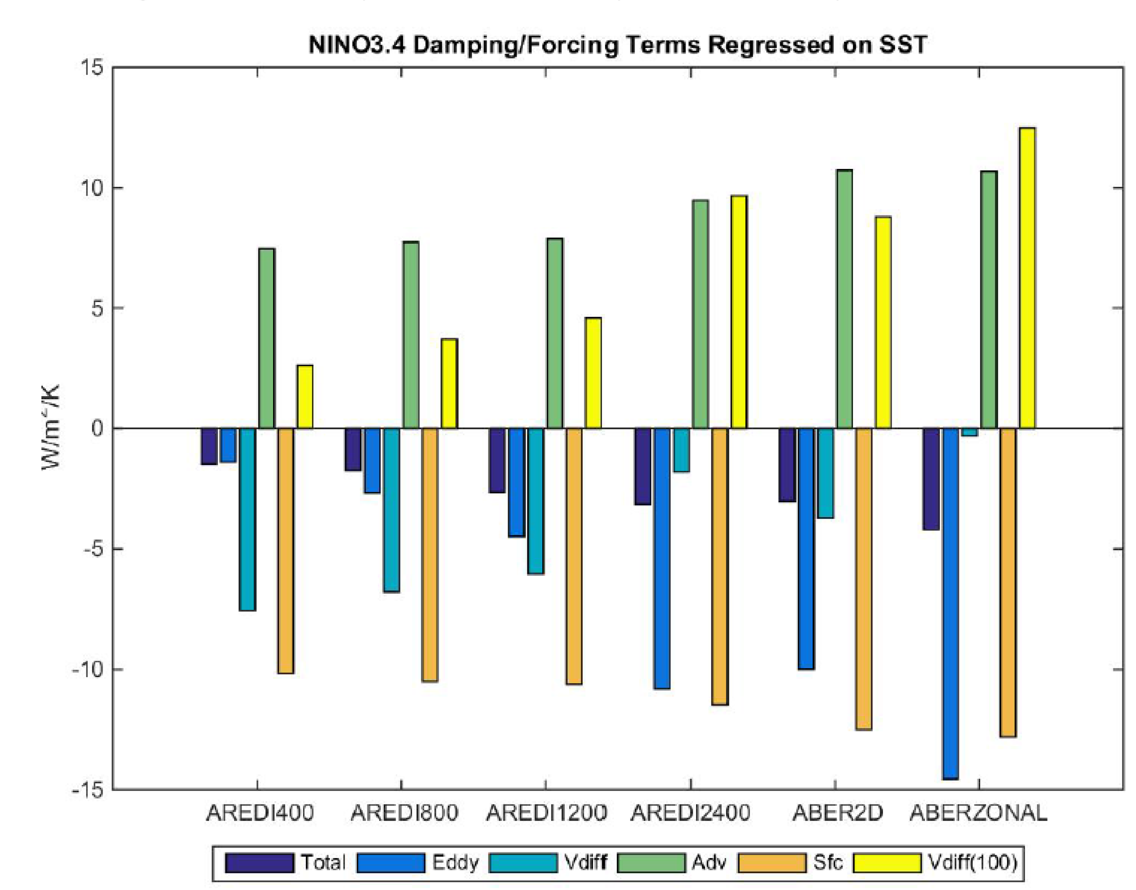

Figure 5

Moving from left to right, as mixing increases

Ocean heat balance terms give stronger damping.
Eddy mixing exerts stronger damping
Total vertical heat transport exerts weaker damping
Advection becomes a stronger driver.
Surface heating damping provides slightly stronger damping.
Vertical diffusion of heat from below (interruption of mixing of cold water as surface warms) becomes stronger driver.

Zonally resolved feedback analysis

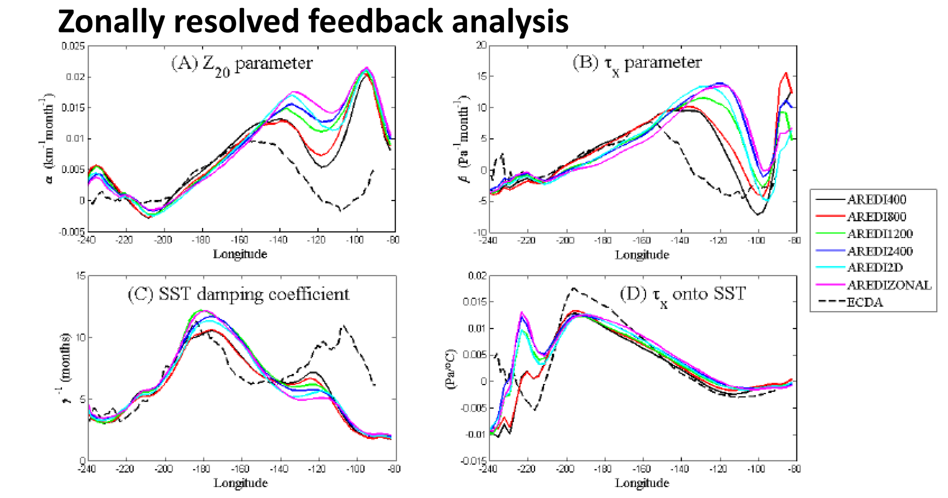

Figure 6

Increasing mixing

1.Increases responsiveness of SST to changes in thermocline (Fig. 6A)
2. Increases respsonsiveness of ocean to wind stress in eastern Pacific (Fig. 6B)
3. Shifts region of high damping time to west. (Fig 6C).
4. Increases responsiveness of atmosphere to ocean (Fig. 6D).

Breaking down ocean feedbacks by term.

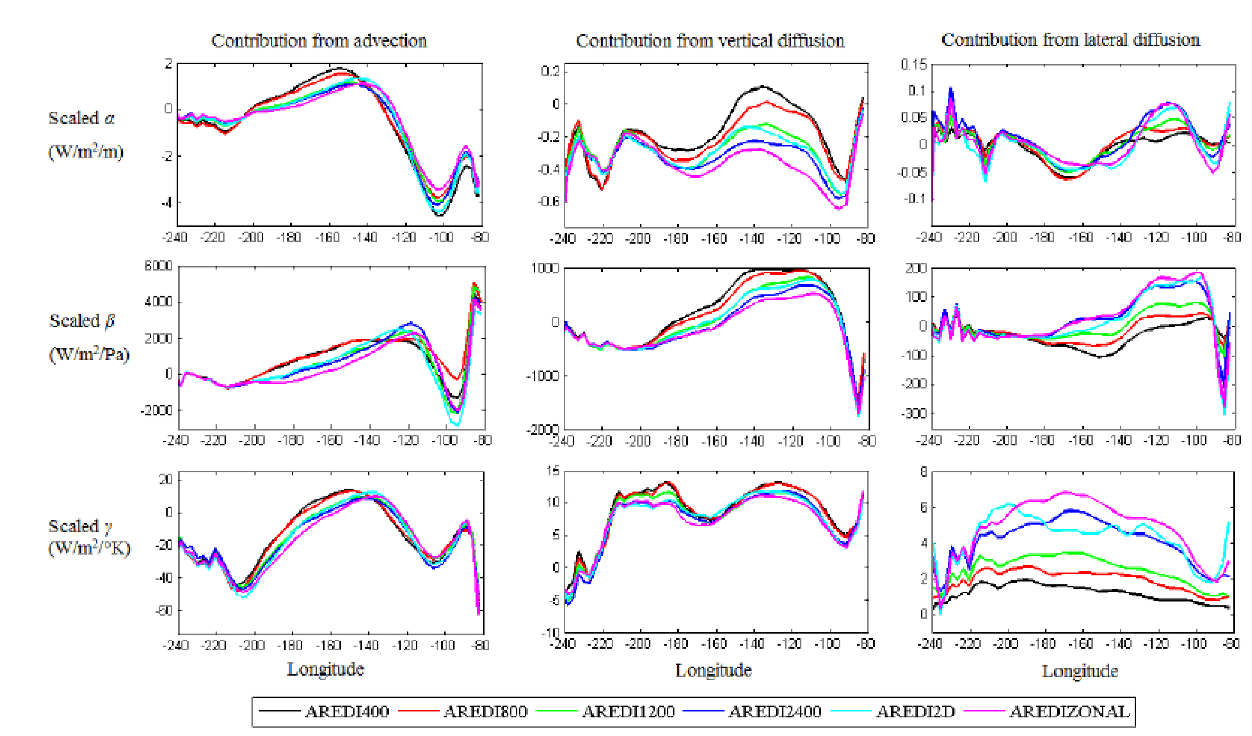

Fig. 7

Eddy diffusion does effect γ term across basin (lower right).

But changes are balanced by opposite change in vertical diffusion (lower center).

Increase in responsiveness of ocean to thermocline (top center) associated with vertical diffusion.

Increase in responsiveness of ocean to wind stress (center) also associated with vertical diffusion.

3. Conclusions

Increasing isopycnal mixing does damp anomalies all else being equal… but all else is not equal.

Warming east Pacific makes atmosphere more sensitive to SST perturbations (as in previous work by Anderson, Gnanadesikan and Wittenberg, Ocean Sciences, 2009; Russell and Gnanadesikan, J. Clim. 2014).

Increasing stratification produces compensating changes in vertical diffusion.

Careful attention must be paid to interaction between vertical and lateral diffusion.