Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean

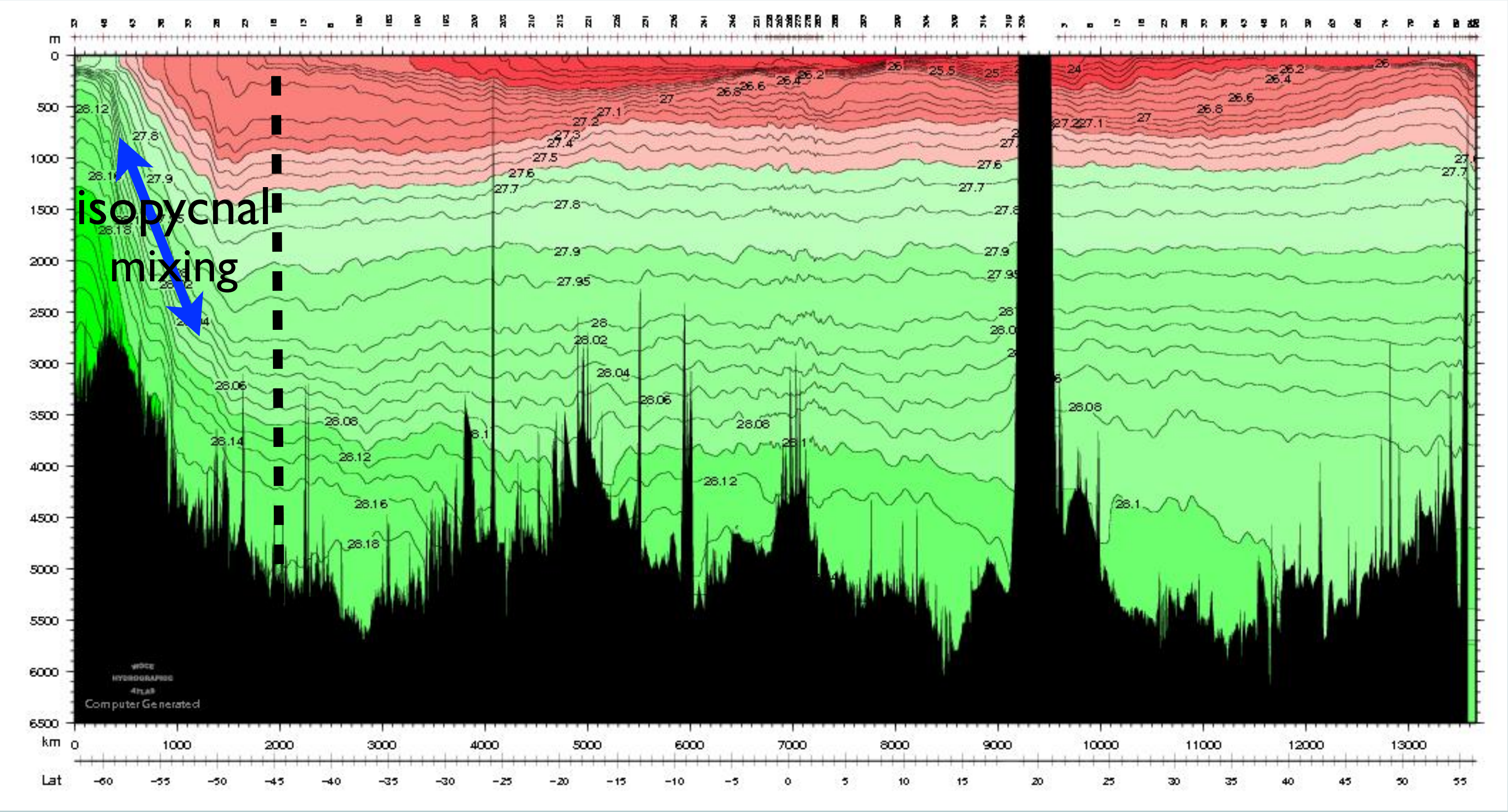
Raffaele Ferrari
Earth, Atmospheric and Planetary Sciences, MIT

in collaboration with the DIMES group

“Ocean’s Carbon and Heat Uptake Workshop”, San Francisco, December 12-14 2014

Southern Ocean and Climate

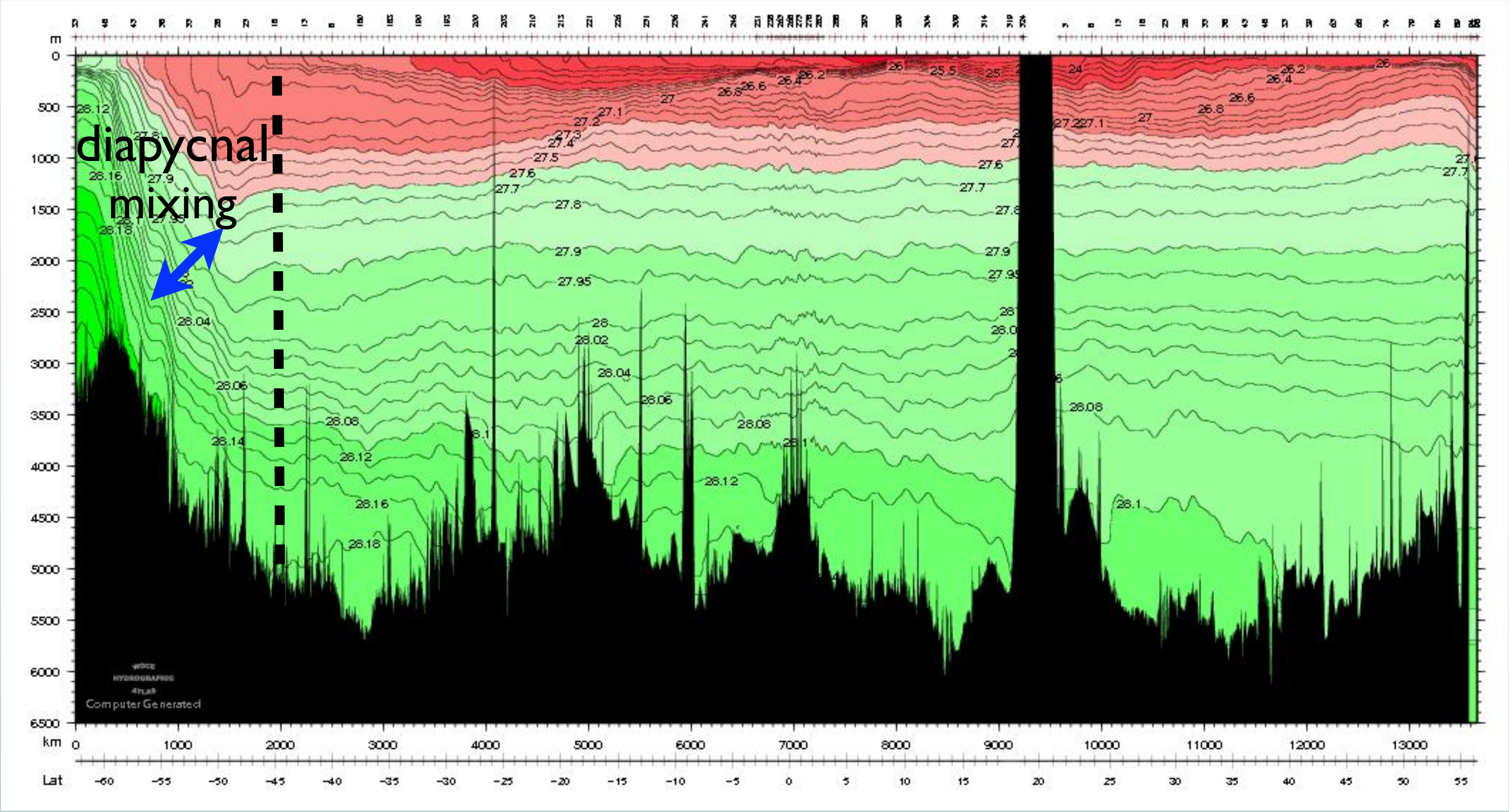
- Deep water masses come to the surface in the Southern Ocean and exchange heat/carbon with atmosphere
- Mixing plays a key role in transporting heat, carbon and nutrients in and out of the Southern Ocean along and across isopycnal



Neutral density (kg m³) section in the Pacific Ocean (WOCE, P16)

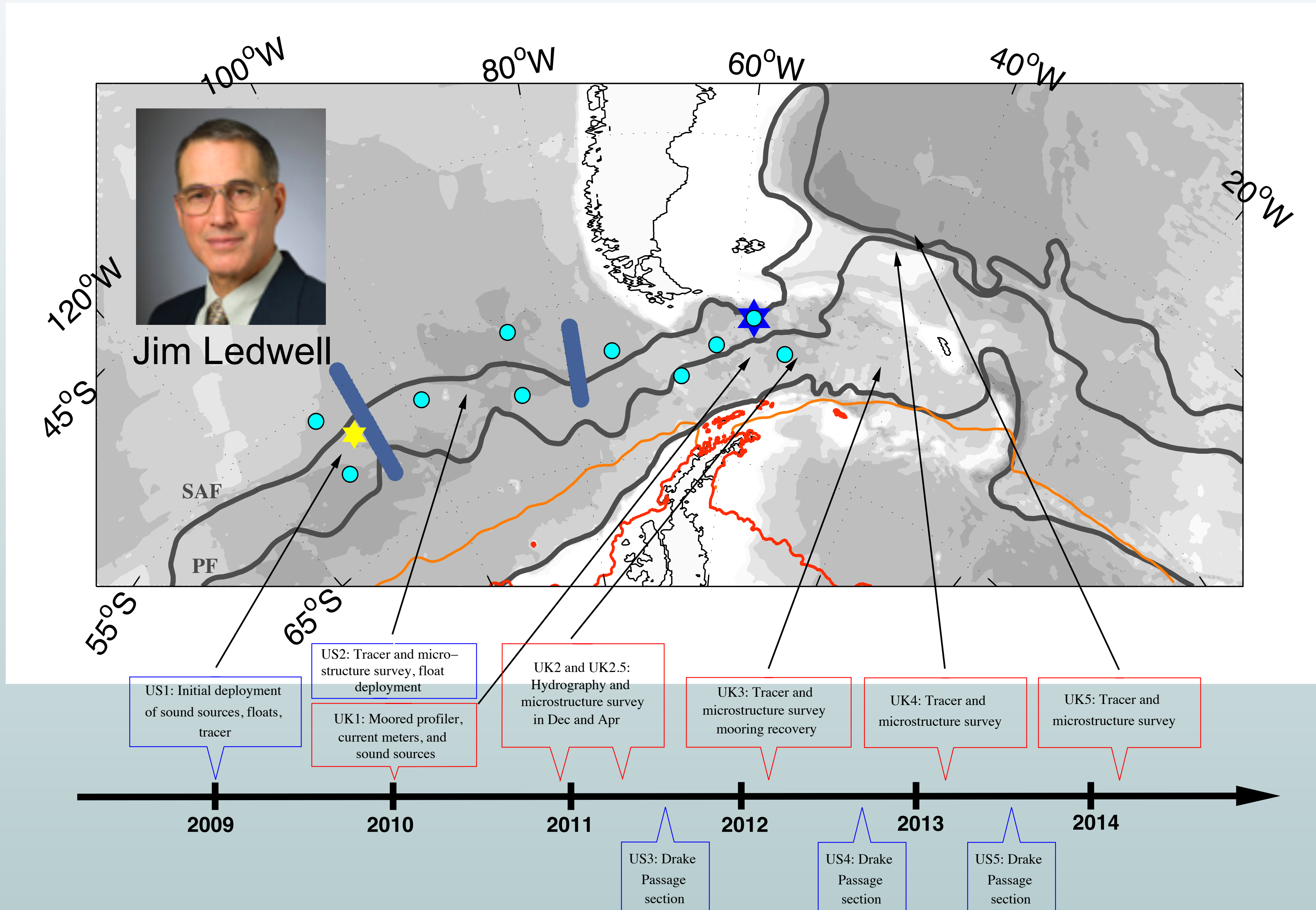
Southern Ocean and Climate

- Deep water masses come to the surface in the Southern Ocean and exchange heat/carbon with atmosphere
- Mixing plays a key role in transporting heat, carbon and nutrients in and out of the Southern Ocean along and across isopycnal



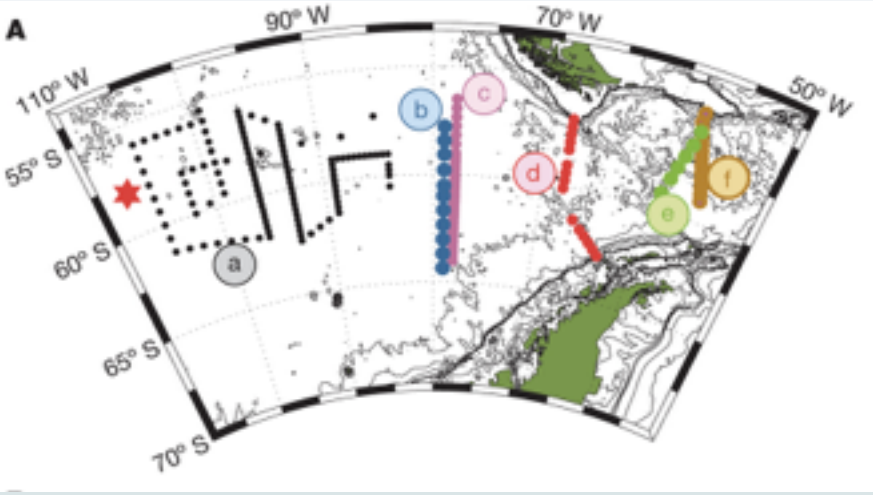
Neutral density (kg m3) section in the Pacific Ocean (WOCE, P16)

DIMES Experiment

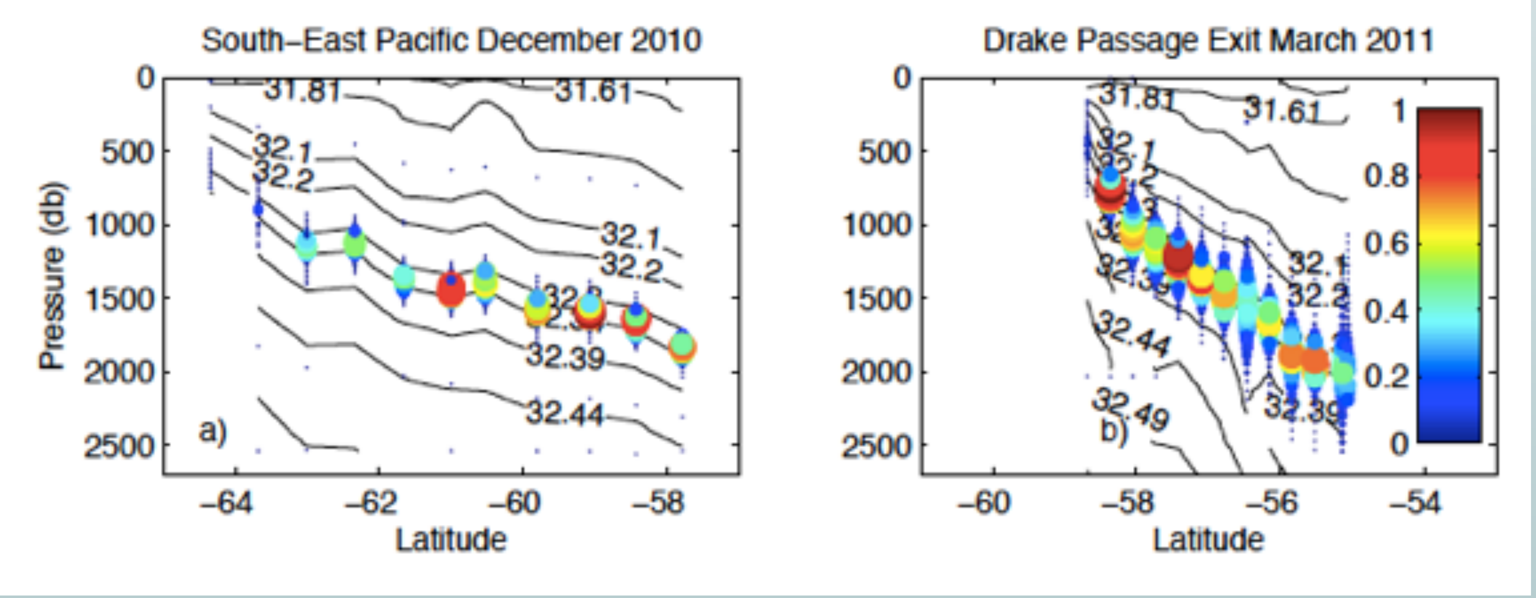


Tracer sampling

- Tracer released (107°W, 58°S) on ρ=27.9 kg/m^3 (1500m) in Feb 2009
- Tracer was sampled on a grid after 1 year and along a few transects after 2, 2.5 years and 3 years



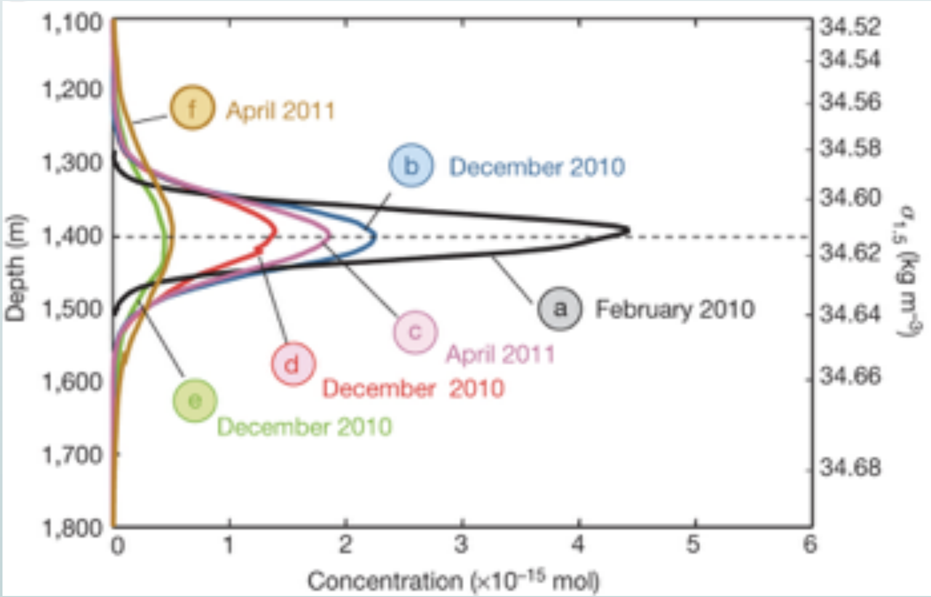
The tracer spread both along and across density surfaces

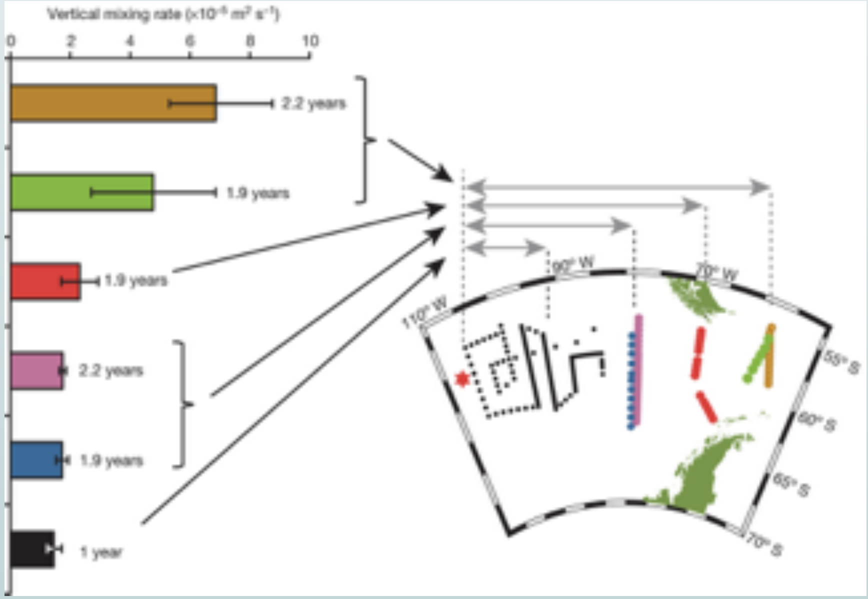


Diapycnal mixing

- The diapycnal diffusivity is the rate at which the tracer cloud spreads vertically

$$\kappa \equiv \frac{1}{2}\frac{d}{dt}\left(\frac{\langle (z-z_c)^2 c\rangle}{\langle c\rangle}\right) \approx \frac{1}{2T}\left[\frac{\langle (z-z_c)^2 c(T)\rangle}{\langle c(T)\rangle} - \frac{\langle (z-z_c)^2 c(0)\rangle}{\langle c(0)\rangle}\right]$$



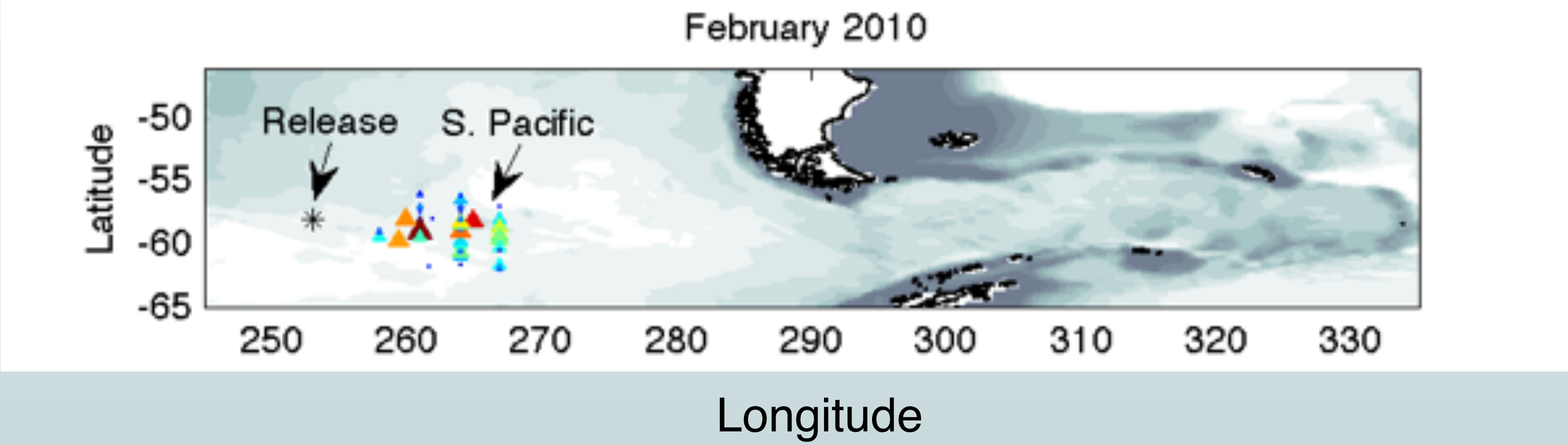


- The diapycnal diffusivity is small upstream of Drake Passage (1×10^{-5} m^2/s) *Ledwell et al. (JPO, 2011)*
- The diapycnal diffusivity is large downstream of Drake Passage(40×10^{-5} m^2/s) *Watson et al. (Nature, 2013)*

Isopycnal diffusivity

- The isopycnal diffusivity is the rate at which the tracer cloud spreads laterally

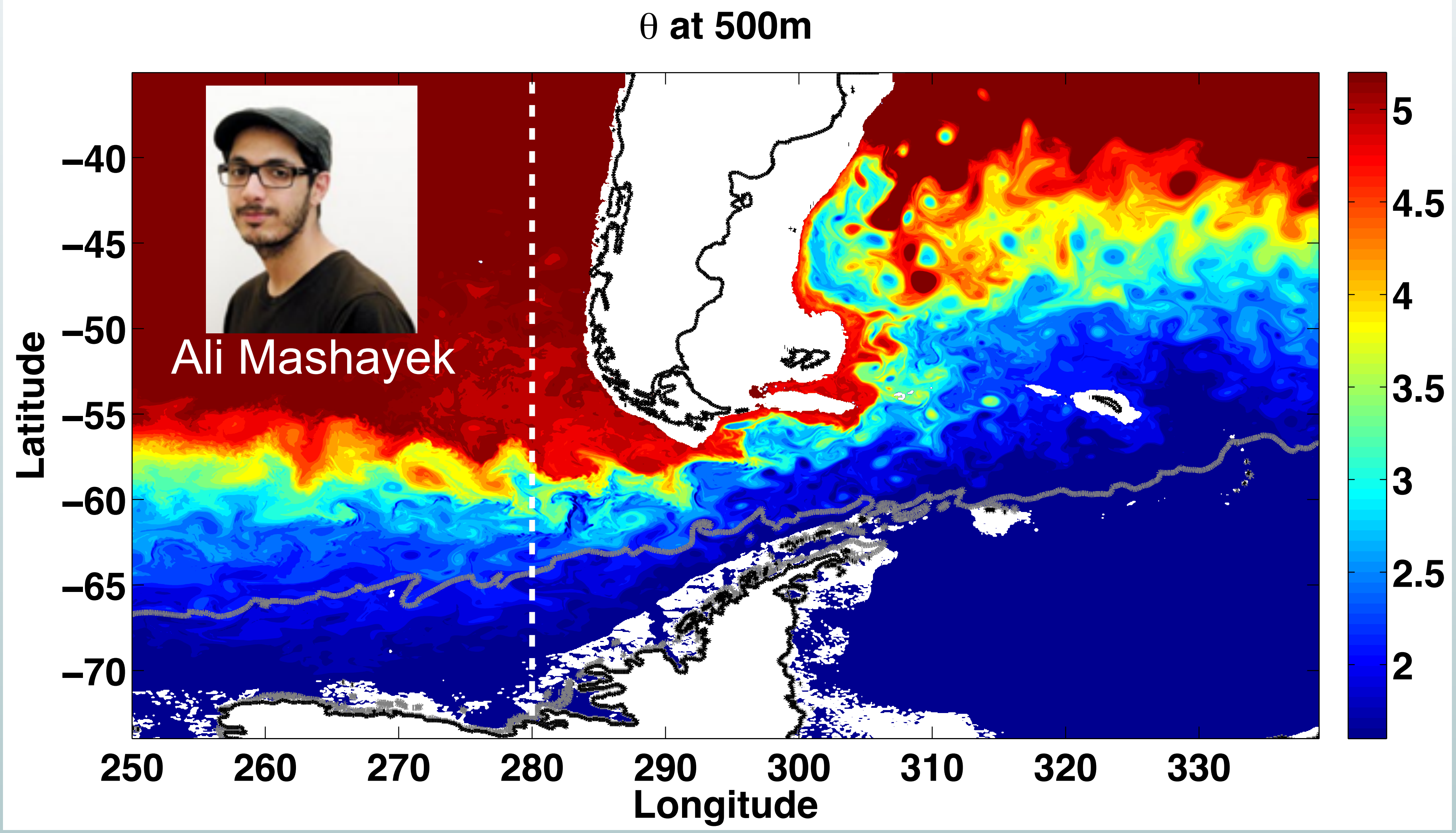
$$K \equiv \frac{1}{2}\frac{d}{dt}\left(\frac{\langle (y-y_c)^2 c\rangle}{\langle c\rangle}\right) \approx \frac{1}{2T}\left[\frac{\langle (y-y_c)^2 c(T)\rangle}{\langle c(T)\rangle} - \frac{\langle (y-y_c)^2 c(0)\rangle}{\langle c(0)\rangle}\right]$$



- The isopycnal diffusivity upstream of Drake Passage is 710±260 m^2/s
  Tulloch, Ferrari et al. (JPO, 2014)

Isopycnal diffusivty: model

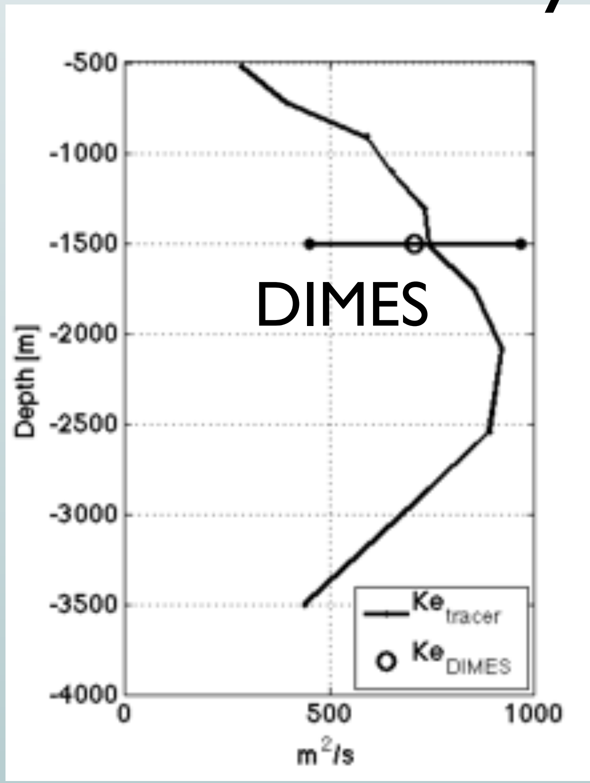
- MIT General Circulation Model, 3 km horizontal resolution, 100 vertical levels
- Forced with reanalysis surface fluxes and state estimate at lateral boundaries



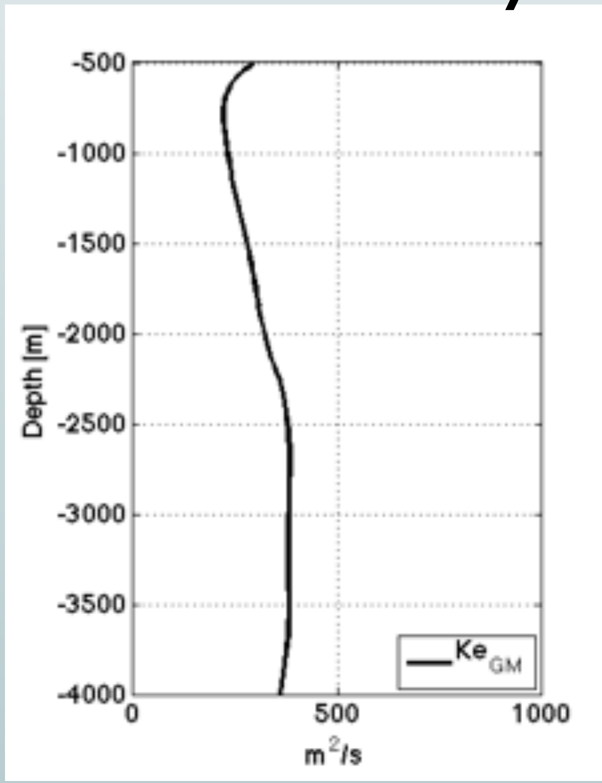
Isopycnal diffusivity

- The DIMES tracer indicate that at 1500m, K=710±260 m^2/s
- The model tracers indicate that K is less than 500 m^2/s in the upper kilometer and reaches 900 m^2/s at 2000 m
- The isopycnal diffusivity peaks at the critical level where the eddies drift at the mean flow speed

Tracer diffusivity



GM diffusivity

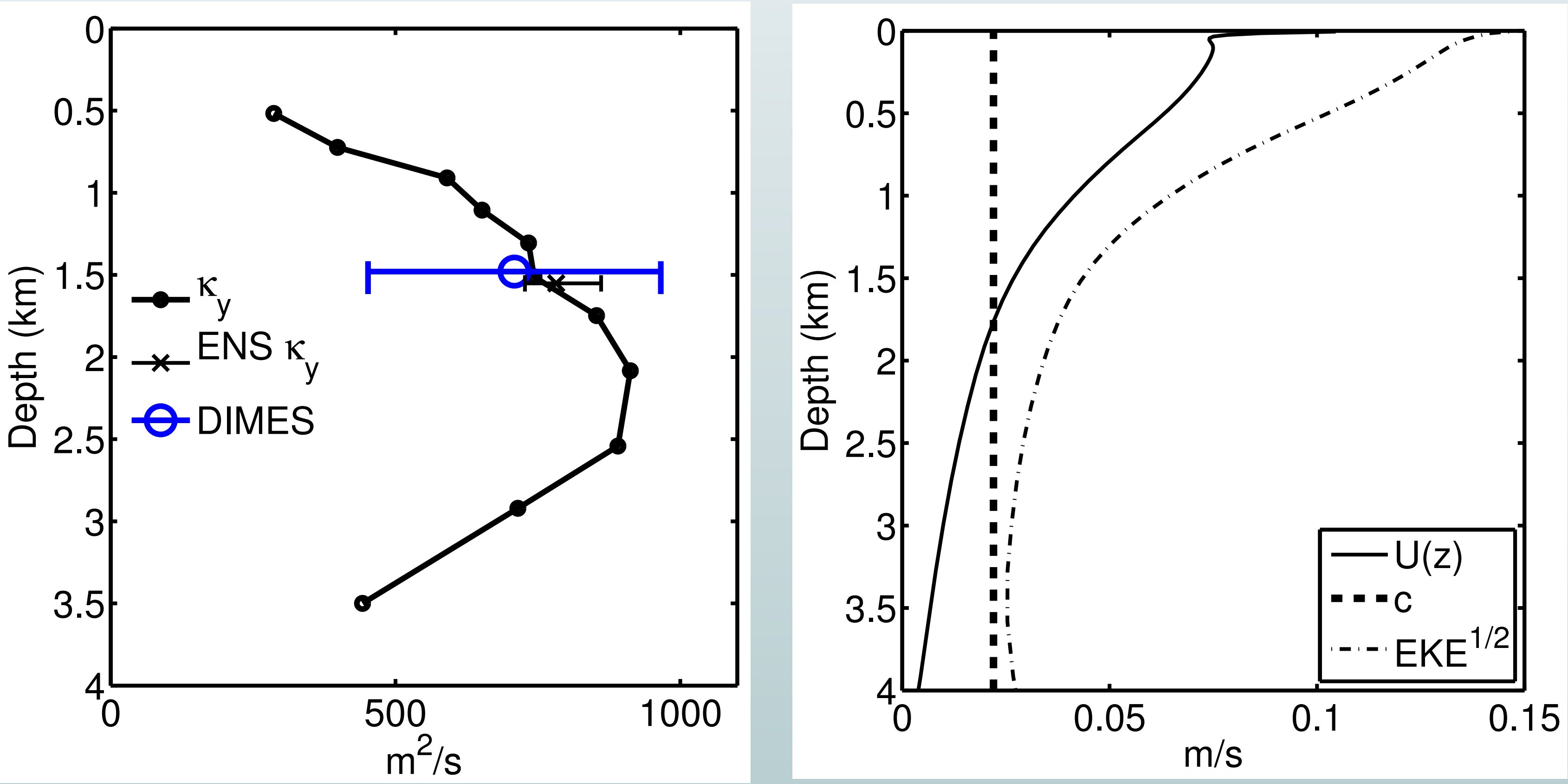


Conclusions

- The diapycnal diffusivity is enhanced close to topography in Drake Passage (*St. Laurent et al., 2012, Watson et al., 2013*)
- The isopycnal diffusivity peaks to 900 m^2/s at 2000m, the interface between upper and lower MOC cells (*Tulloch et al., 2014; LaCasce et al., 2014*)
- The GM diffusivity is uniform and close to 400 m^2/s *(Mashayek and Ferrari, to be submitted)*
- New eddy parameterizations are developed to capture variations of isopycnal diffusivity with depth (*Bates, Marshall, Ferrari, 2014*)

Vertical structure of K

- Eddy mixing is suppressed in the upper kilometer and enhanced at steering levels where $U=c$
- The vertical structure of K is well described by linear theory (Bretherton, 1966; Green, 1970; Ferrari and Nikurashin, 2010)



Tulloch, Ferrari et many al., submitted