# Southern Ocean Hydrography and Circulation: Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES): Diapycnal Mixing Results


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**Aim.** The aim of DIMES is to measure and to better understand diapycnal mixing and along-isopycnal eddy transport in the Antarctic Circumpolar Current (ACC) so that the Meridional Overturnig Circulation (MOC) of the ocean may be better understood and more accurately modeled. This poster focuses on results for diapycnal mixing. Please see the accompanying poster by Gille et al. for results on isopycnal processes.

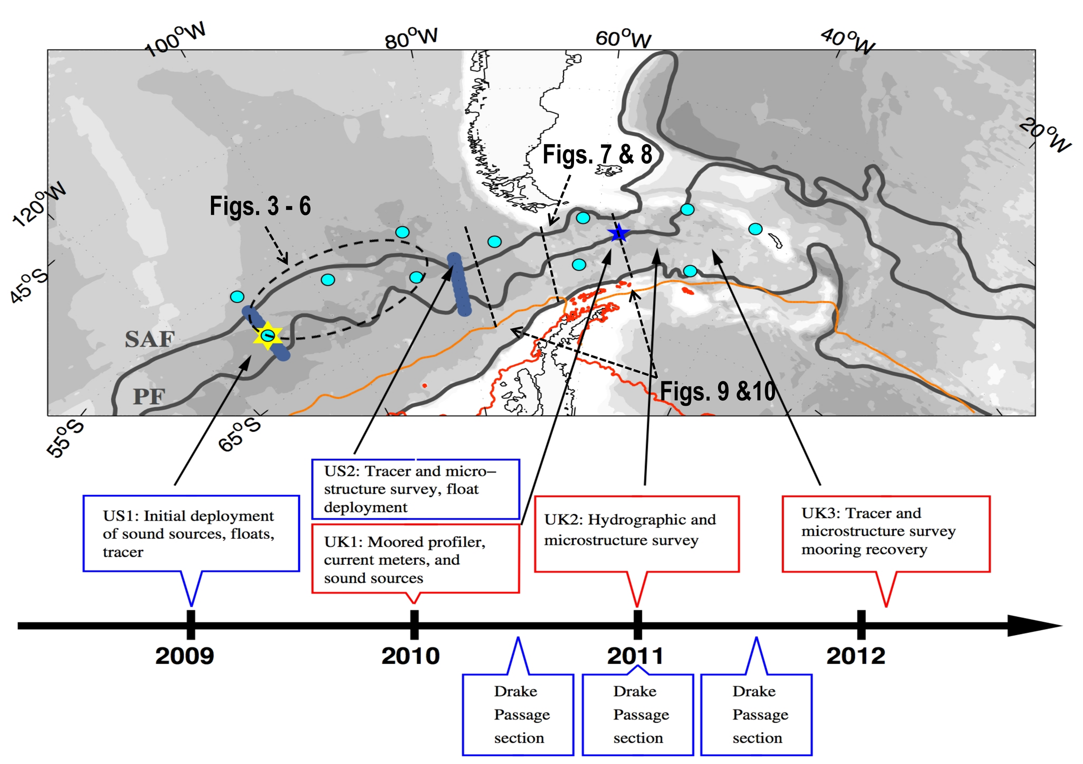

**Fig. 1.** The experiment began in early 2009 with the release of 76 kg of trifluoromethyl sulfur pentafluoride, $CF_3SF_5$, in the ACC near 105°W (yellow star) between the Subantarctic Front (SAF) and Polar Front (PF). Seventy-five RAFOS floats, equipped with passive devices to make them approximately isopycnal, were also released near 105°W (blue dots – the 2010 floats were also released along 105°W rather than the location shown), with sources deployed in the region to track them (cyan dots). A mooring array was deployed late in 2009 east of Drake Passage to study energy transfer from the mesoscale through the internal wave field to mixing (blue star). The experiment was planned so that the tracer and floats would first pass through the region of relatively smooth topography and low eddy energy of the eastern Pacific, and then through the region of relatively rough topography and high eddy energy in Drake Passage. Locations for some of the later figures are indicated with dashed lines.

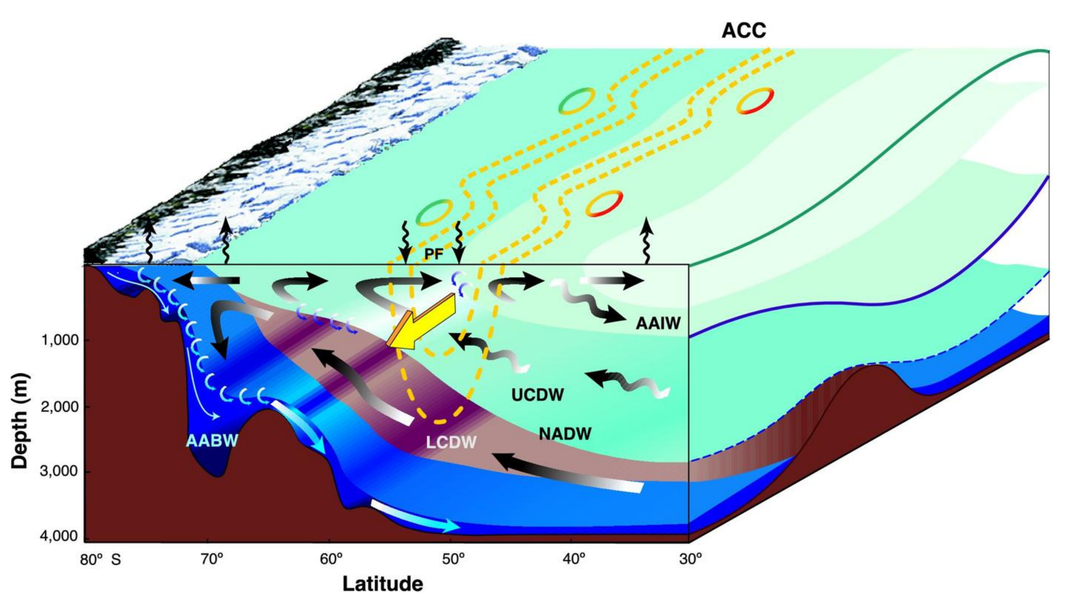

**Fig. 2.** The tracer was released approximately 1500 m deep on the $\gamma_n$ = 27.9 kg m$^{-3}$ neutral density surface between the Polar Front (PF) and the Subantarctic Front, near the transition between Lower Circumpolar Deep Water (LCDW) and Upper Circumpolar Deep Water (UCDW). These waters rise to the south to feed Antarctic Bottom Water (AABW) that descends and spreads over the abyss in the "Lower Limb" of the MOC, and Antarctic Intermediate Water (AAIW) that is driven north near the surface by the winds in the "Upper Limb". Eddy fluxes play a dominant role in cross-ACC transport of mass and properties in the waters above topography, i.e. above ~1500 m. Diapycnal mixing is needed to transform abyssal water to deep water, closing the "Lower Limb". The degree to which diapycnal mixing modifies density in the upper waters, and thereby short-circuits the "Upper Limb" is an outstanding question. Diapycnal mixing throughout the water column, over both rough and smooth topography underlying the ACC, is one of the main objects of DIMES.

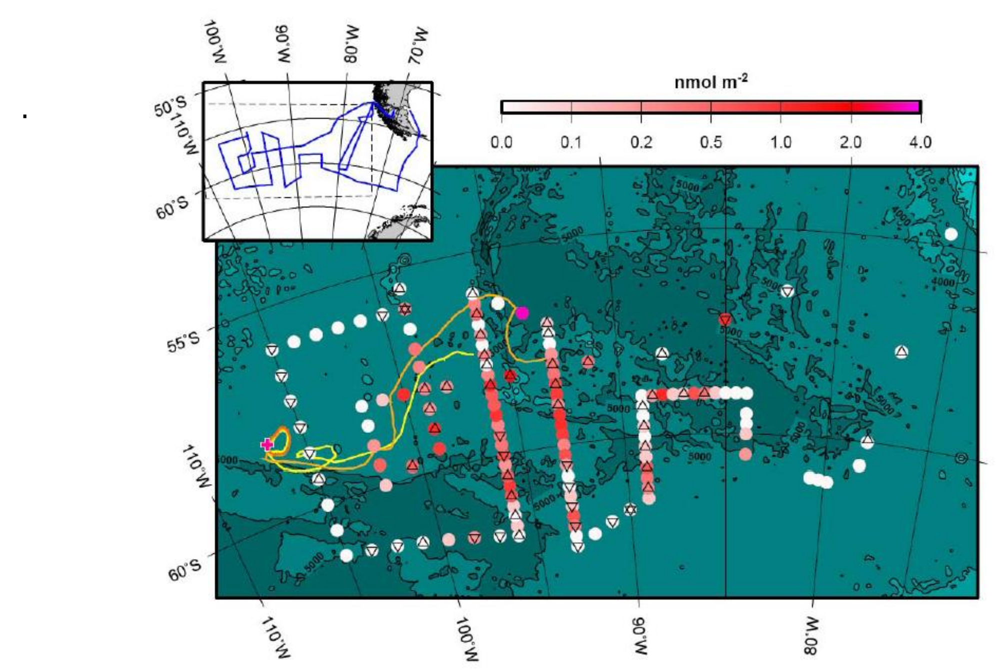

**Fig. 3.** Stations occupied 12 months after the tracer release (dots – colored according to how much tracer was found). Fine- and microstructure were measured with free-falling profilers at the stations marked with triangles. The yellow and brown lines show the trajectories of three EM-APEX floats (see Fig. 6) from February to October 2009.

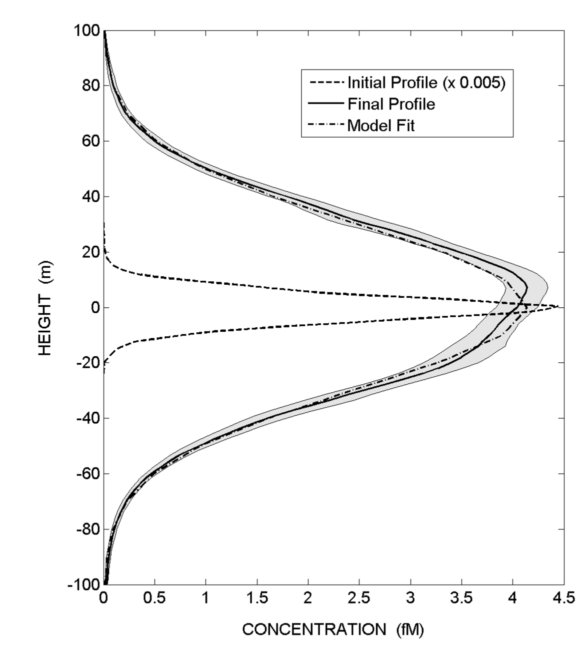

**Fig. 4.** Average vertical tracer profiles obtained within 2 weeks of the release (dashed line) and from the 12-month survey (solid line)[6]. Height on the y-axis is relative to the $\gamma_n$ = 27.9 kg m$^{-3}$ surface, using the mean density-depth relation from the 12-month survey. The initial profile was multiplied by 0.005 to keep it on scale. The dot-dash line is the best Gaussian fit to the 12-month profile. The grey region is an estimate of the uncertainty envelope for the 12-month profile. The change from the initial to the 12-month profile, modeled with the 1-D diffusion equation, gives a tracer diapycnal diffusivity for the relatively smooth-bottom eastern Pacific sector of the ACC of (1.3 $\pm$ 0.2) x 10$^{-5}$ m$^2$ s$^{-1}$ for the first year of the experiment, in the stratification observed at 12 months.

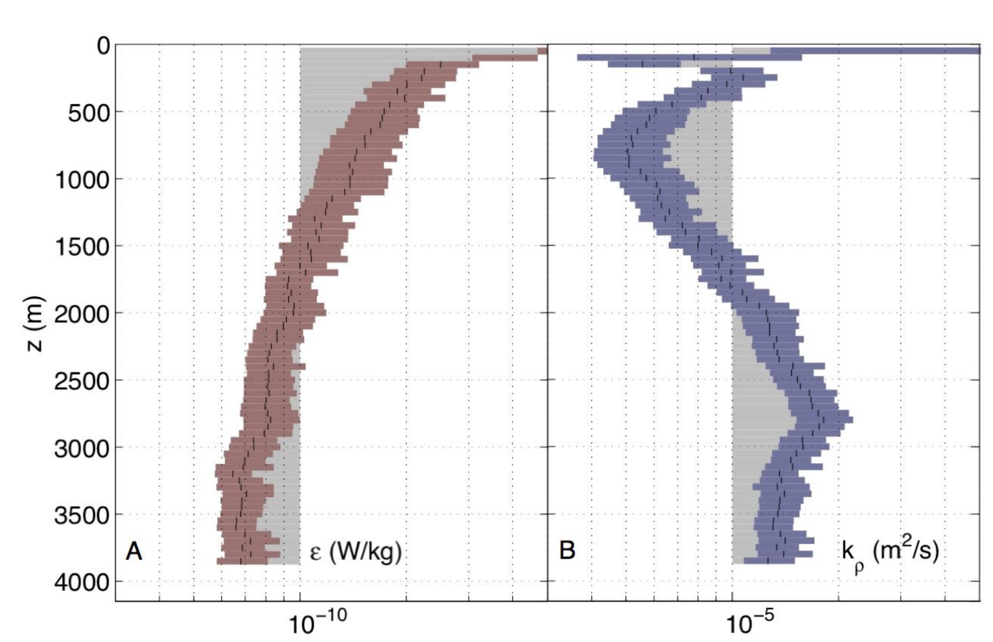

**Fig. 5.** (A) Mean turbulent kinetic energy dissipation, and (B) diapycnal diffusivity for density $K_\rho$, estimated from the microstructure profiles obtained in the eastern Pacific during the 12-month survey (Fig. 3)[6]. The diffusivity estimated at 1500 m, the approximate tracer depth, is (0.7 to 1.0) x 10$^{-5}$ m$^2$ s$^{-1}$.

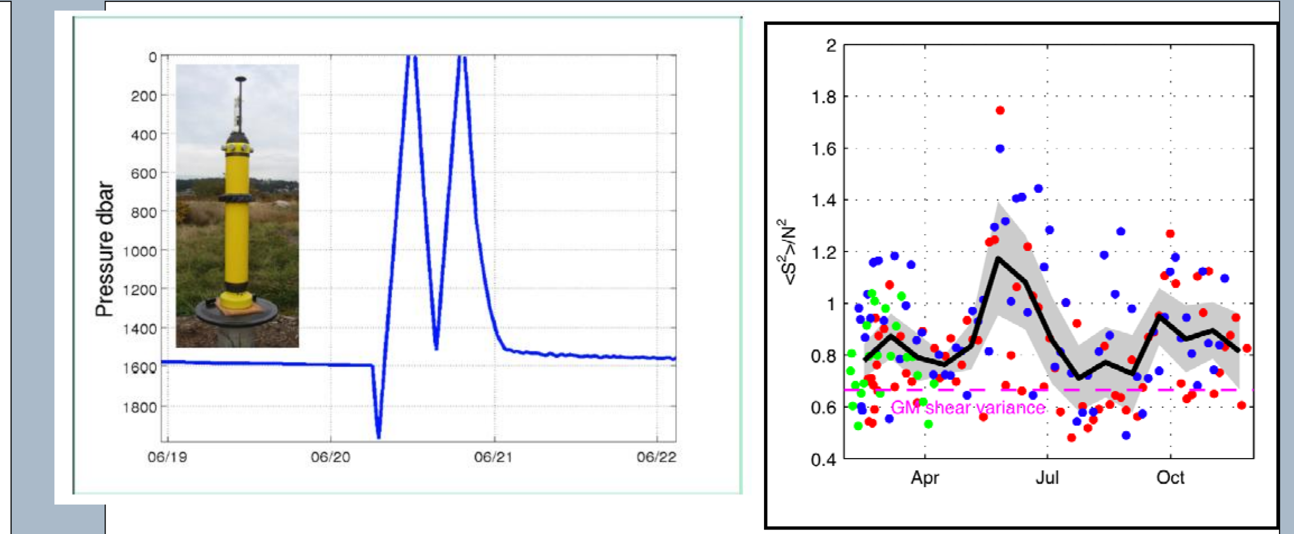

**Fig. 6.** Left panel: excursions made by an EM-APEX float during one cycle. Two excursions to the surface, separated by half an inertial period, are made every 2 days. Right panel: Ratio of shear variance to $N^2$ during 2009 (tracks shown in Fig. 3)[6]. The green, red and blue dots are for the three floats launched with the tracer. The dotted magenta line is the shear variance expected for the Garrett and Munk model spectrum for background internal waves in the ocean. There is a peak in shear variance in June which may explain the modest difference between the tracer diffusivity, which integrates over a year of mixing, and $K_\rho$ estimated from energy dissipation rates, which were measured in February/March 2010.

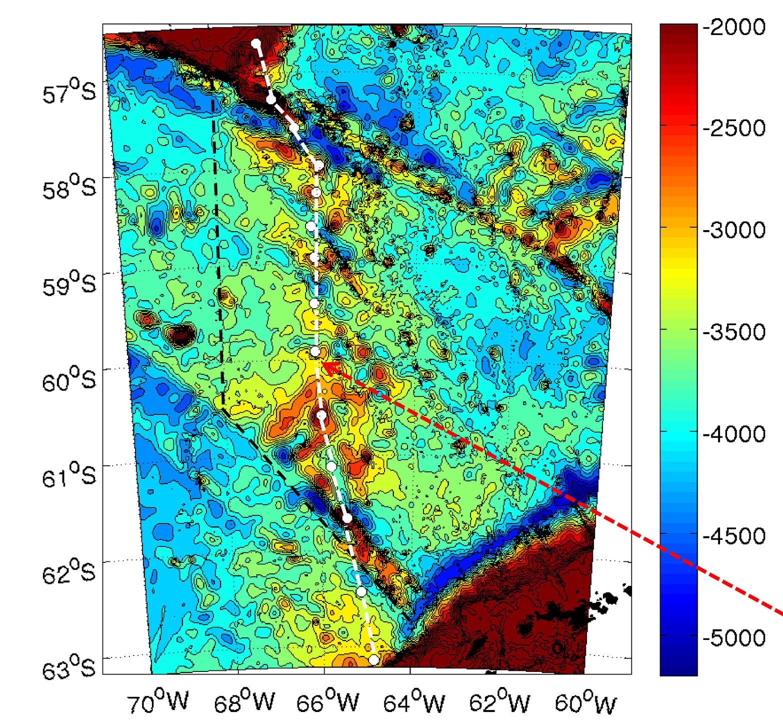

**Fig. 7.** Microstructure stations along Phoenix Ridge in Drake Passage in February 2010 (white dots along white dashed line). Microstructure was also measured along the dashed line in December 2010 The color shows the bottom depth.

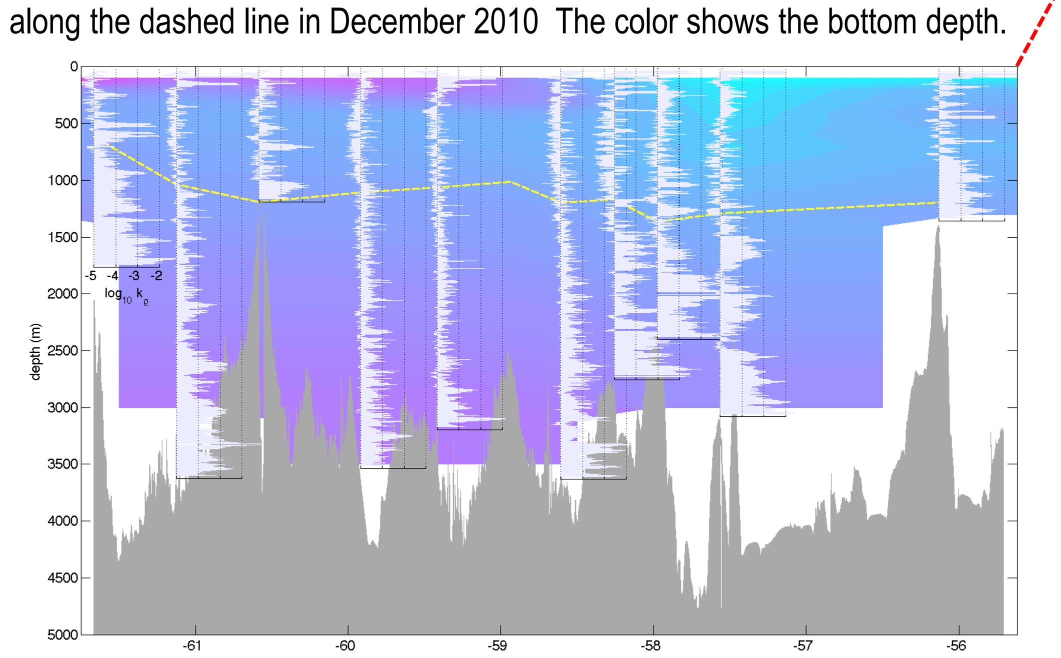

**Fig. 8.** $\log_{10}(K_\rho)$, in m$^2$ s$^{-1}$, estimated from the dissipation of kinetic energy measured by shear probes on microstructure profilers at the stations shown in Fig. 7. The $\log_{10}$ scale goes from -5 to -2, as shown in the inset. The grey bottom is from the PDR along the ship's track. The yellow dashed line shows the depth of the $\gamma_n$ = 27.9 kg m$^{-3}$ surface at the stations, along which the mean $K_\rho$ is more than an order of magnitude greater than that found from dissipation rates in the eastern Pacific. Diffusivities of order 10$^{-3}$ m$^2$ s$^{-1}$ are typically seen within 1000 m of the bottom. Microstructure stations were also occupied to the west of Phoenix Ridge in December 2010 over smoother topography (dashed line in Fig. 7), and the mean value of $K_\rho$ there at $\gamma_n$ = 27.9 was about 3 times greater than in the eastern Pacific. The background color shows the pattern of potential temperature.

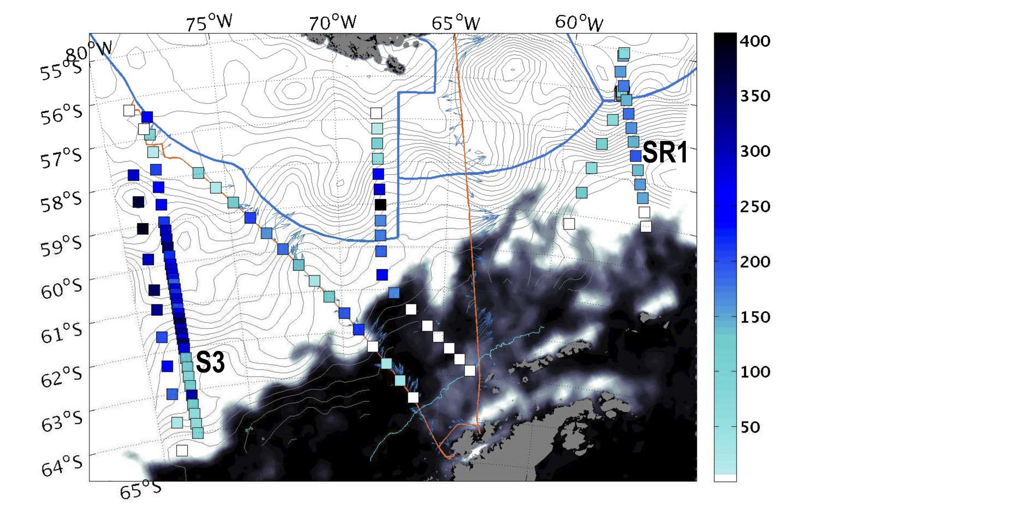

**Fig. 9.** Stations were occupied both east and west of Drake Passage in late 2010, and again in April 2011, with the striking result that the diapycnal spread of the tracer was much greater to the east of Drake Passage than to the west. The next figure shows mean diapycnal tracer profiles from the lines marked S3 and SR1, both occupied in April 2010.

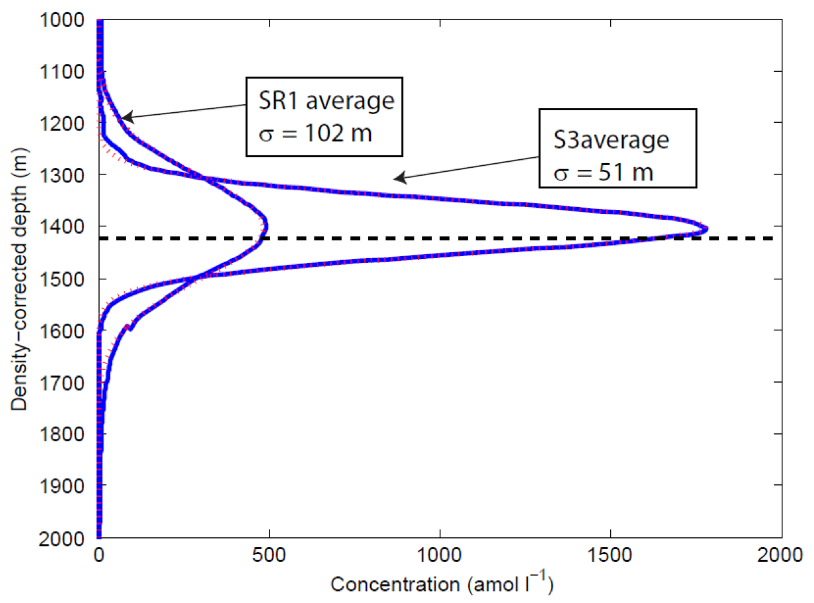

**Fig. 10.** Mean vertical profiles of tracer (blues lines) from west of Drake Passage (S3) and east of Drake Passage (SR1), with Gaussian fits to the Curves (red dotted lines). Both profiles were obtained in April 2011, 26 months after Tracer release. The depth is from the mean depth/density relation for April 2011. The dashed line is at the density of the tracer release, subject to calibration errors. The difference in the width gives a diapycnal diffusivity for the tracer of ~6 x 10$^{-4}$ m$^2$ s$^{-1}$, based on a preliminary estimate of the mean velocity of the tracer between the sections. With account taken of the weaker stratification in the east than in the west, the diffusivity is around 30 times larger in Drake Passage than in the eastern Pacific (Fig. 4).

**Conclusion.** We have found low diffusivities in the eastern Pacific, and elevated diffusivities in Drake Passage. Efforts to understand the mechanisms driving the mixing, to tentatively extrapolate the results to the whole ACC and to assess implications for the overturning circulation are underway. The measurement program will continue into 2014.


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**Reference**:
[6]Ledwell, J. R., L. C. St. Laurent, J. B. Girton, and J. M. Toole, Diapycnal mixing in the Antarctic Circumpolar Current, *J. Phys. Oceanogr.*, **41**, 241-246, 2011.



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