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Underway acoustic survey of internal wave shear

and its use to estimate diapycnal mixing and transports in the interior ocean

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SOPRAN

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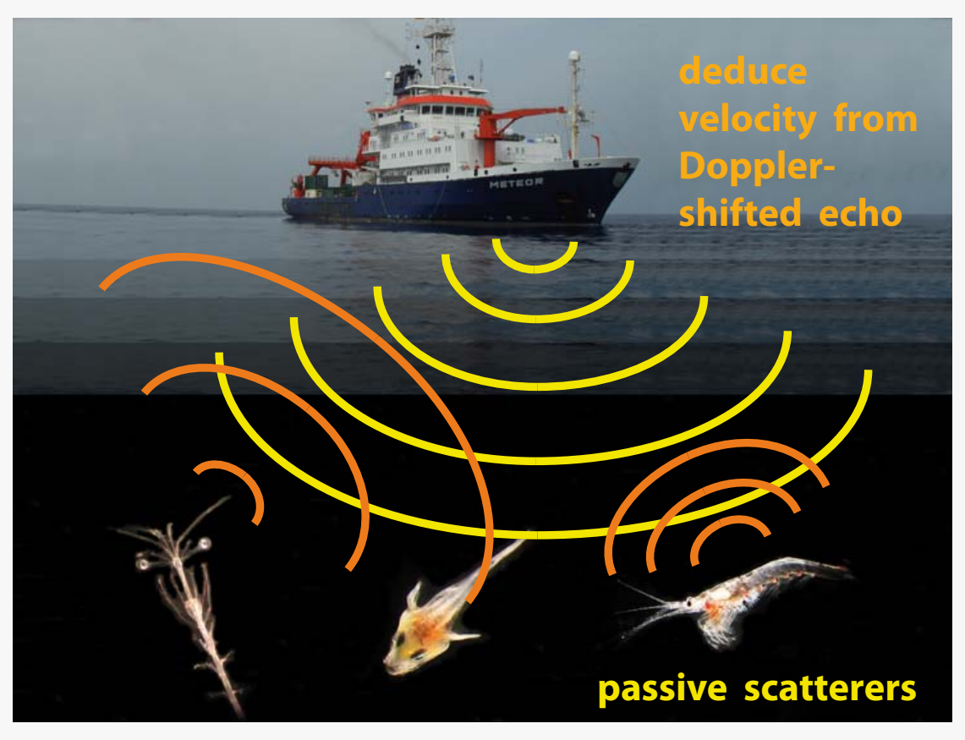
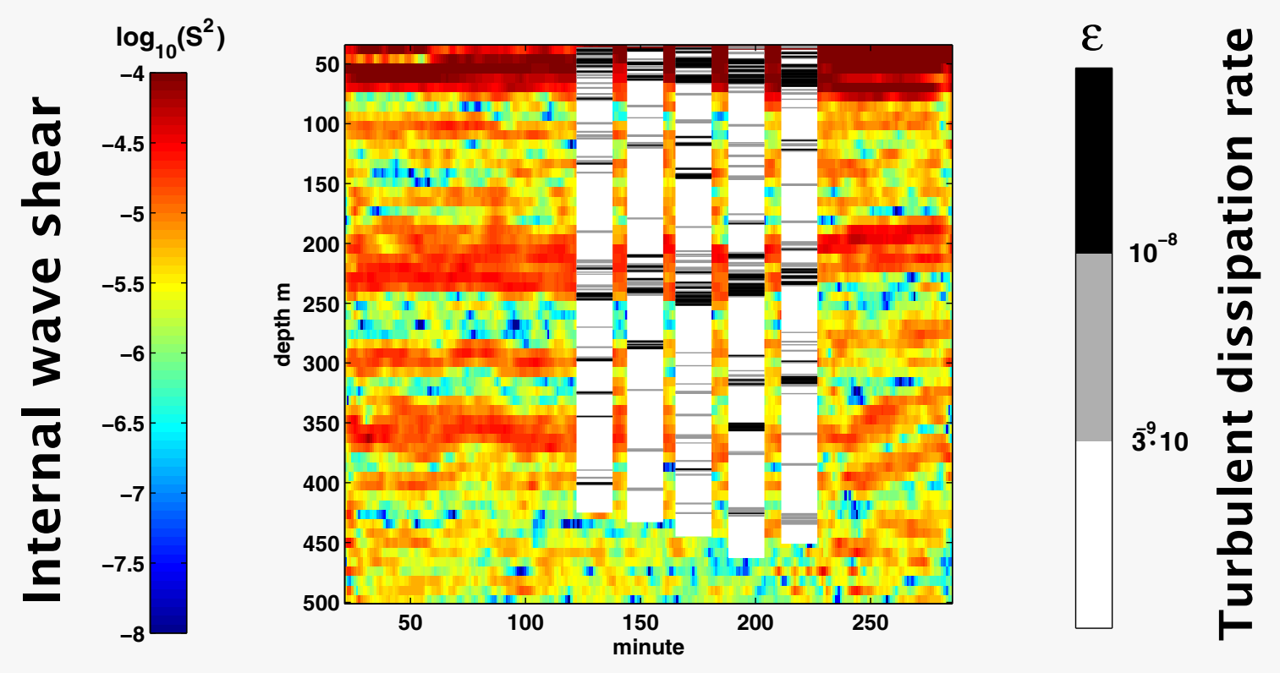
Acoustic imaging of internal wave shear — a proxy for turbulent mixing



Underway ADCP

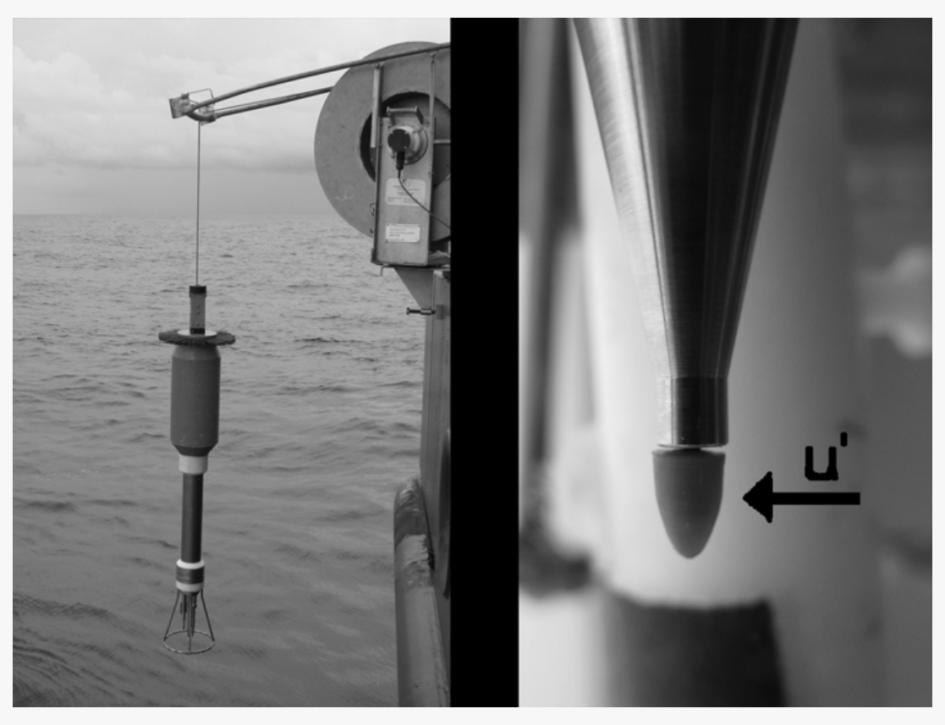
Acoustic Doppler Current Profilers (vessel mounted RDI Ocean Surveyor) allow recording of finescale velocity fluctuations associated with internal wave shear. We use a 75 kHz broadband configuration at maximum pingrate for optimum results. Nonetheless, neighbouring frequencies and/or narrowband mode do also work.

finescale shear and turbulence linked



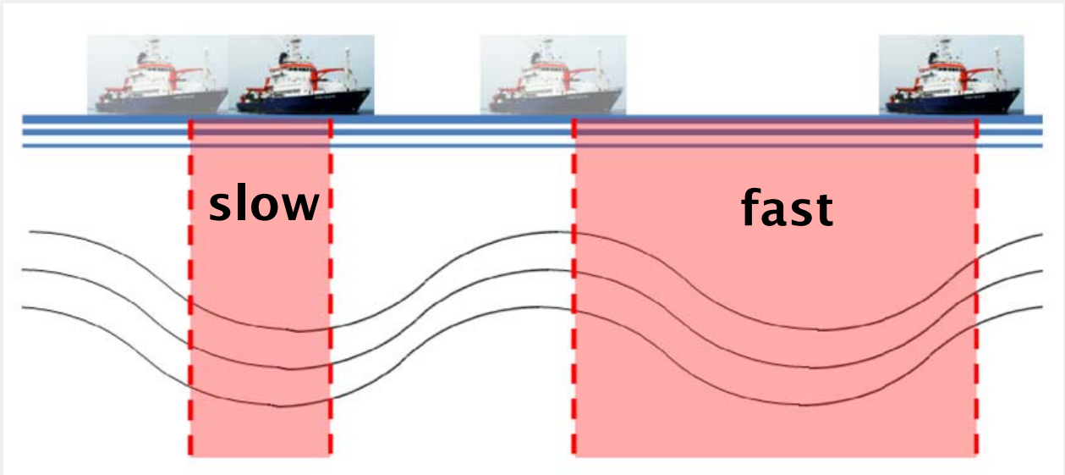
Microstructure profiles

serve as „ground-truthing“ for mixing estimates from internal wave shear. Airfoil shear sensors on a tethered profiling probe (Sea & Sun Technology) sense microstructure velocity fluctuations. These define ε, the dissipation rate of turbulent kinetic energy, as an indicator for mixing intensity. Instrument noise level is ε = 7e-10 for single bins and ε= 1e-10 for 300m-depth-range-averages.



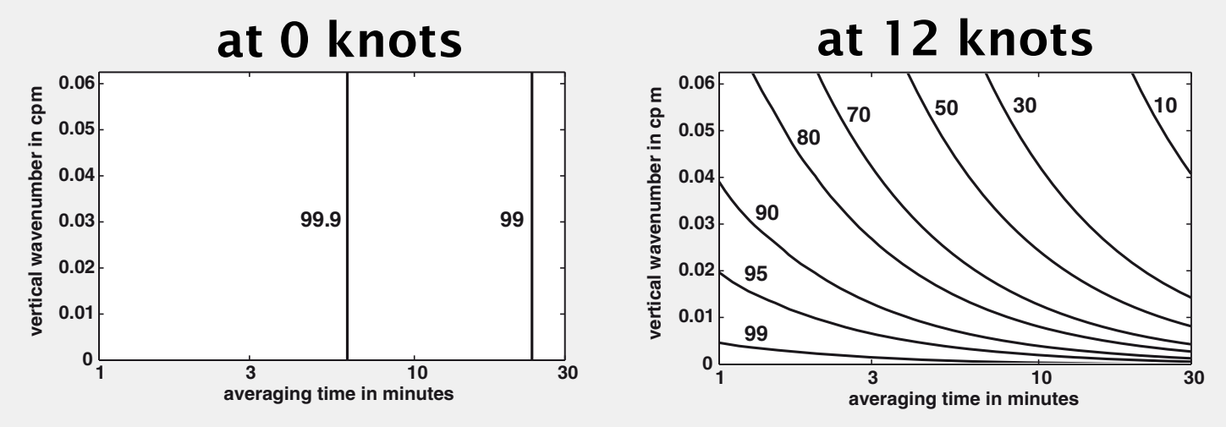
Shear quantification from a moving ship — 2 main issues

speed-dependent horizontal smoothing



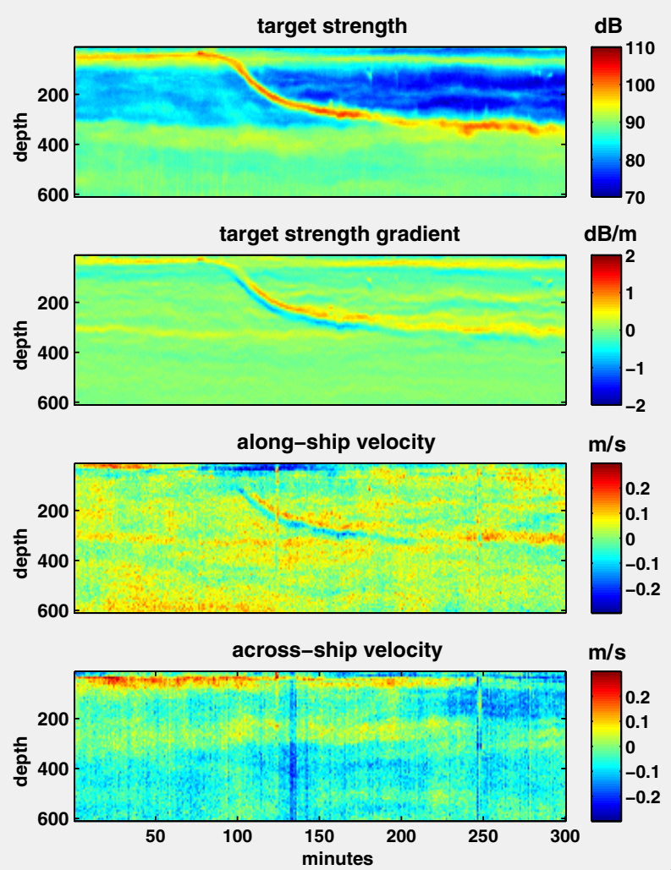
When moving, any observed periodic quantity will be reduced in variability by smoothing - as a function of shipspeed and distribution of involved horizontal wavelengths. Some degree of smoothing is unavoidable, because of needed noise reduction and because of the size of the acoustic footprint.

remaining shear variability in percent -
dependence on vertical wavelength and amount of averaging



Consequences:
- Reduce averaging time to 1 minute
- Obtain needed data precision by 2-D-filtering of velocity data. Filter adapted to IW spectral shape.
- Apply speed-dependent corrections to shear spectra

patchy distribution of acoustic scatterers



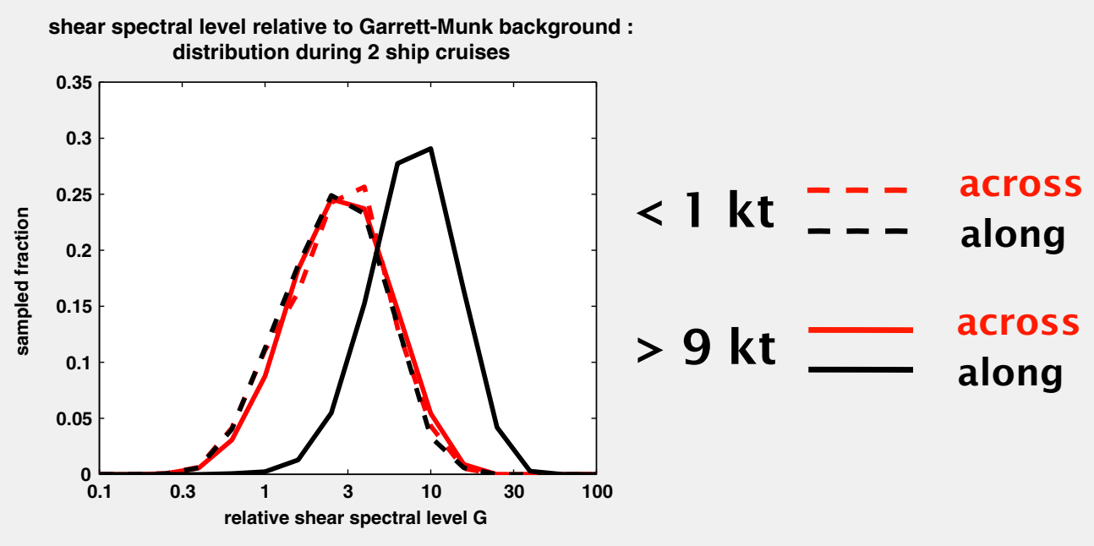
Acoustic scatterers like plankton distribute inhomogeneously.

Geometric acoustic beam spreading causes related spurious velocities.

This bias affects velocity component in direction of movement.

Across-ship velocity component is unaffected.

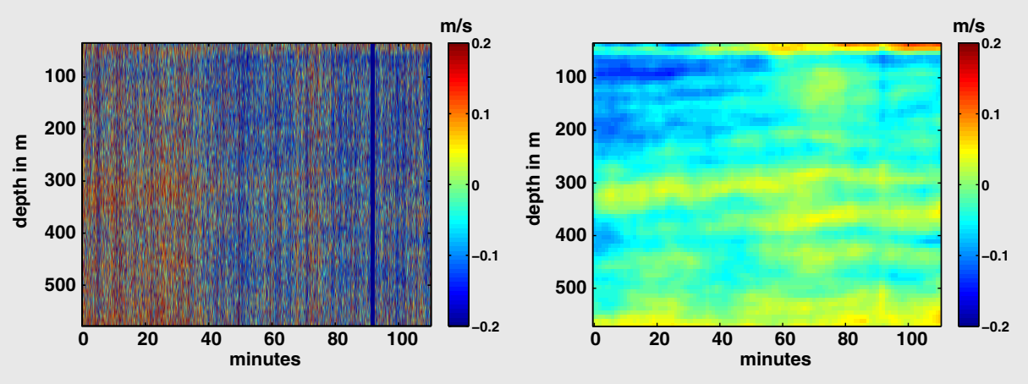
Spurious internal wave shear
in along-ship component when moving:



Consequence:
- Discard along-ship component unless on station

Processing: From acoustic pings to shear level to diapycnal diffusivity

average and filter ADCP velocities

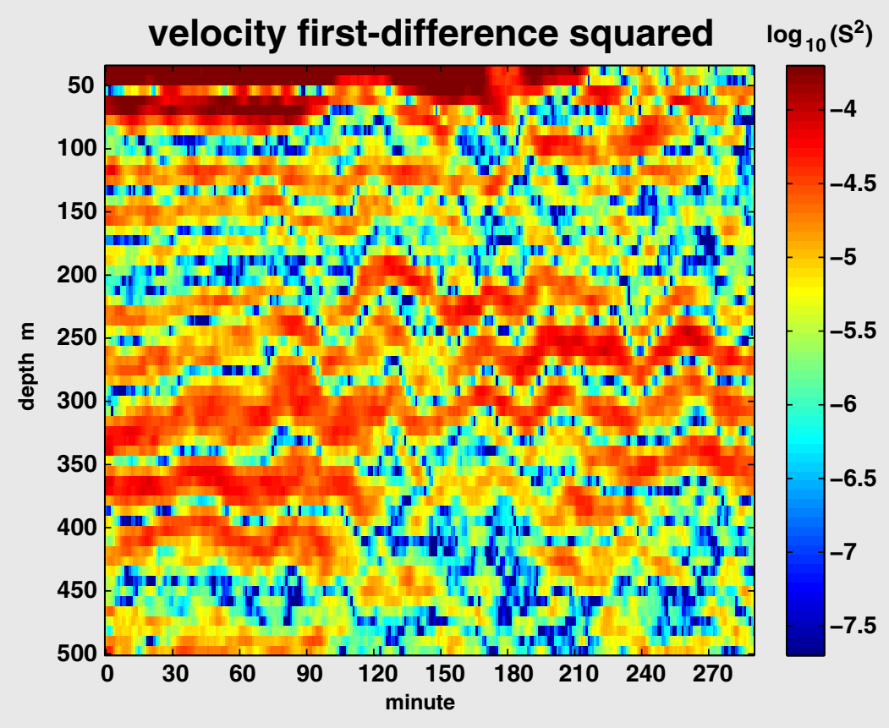


single ping across-ship velocity component

after 1-minute averaging and adapted 2-D filter:

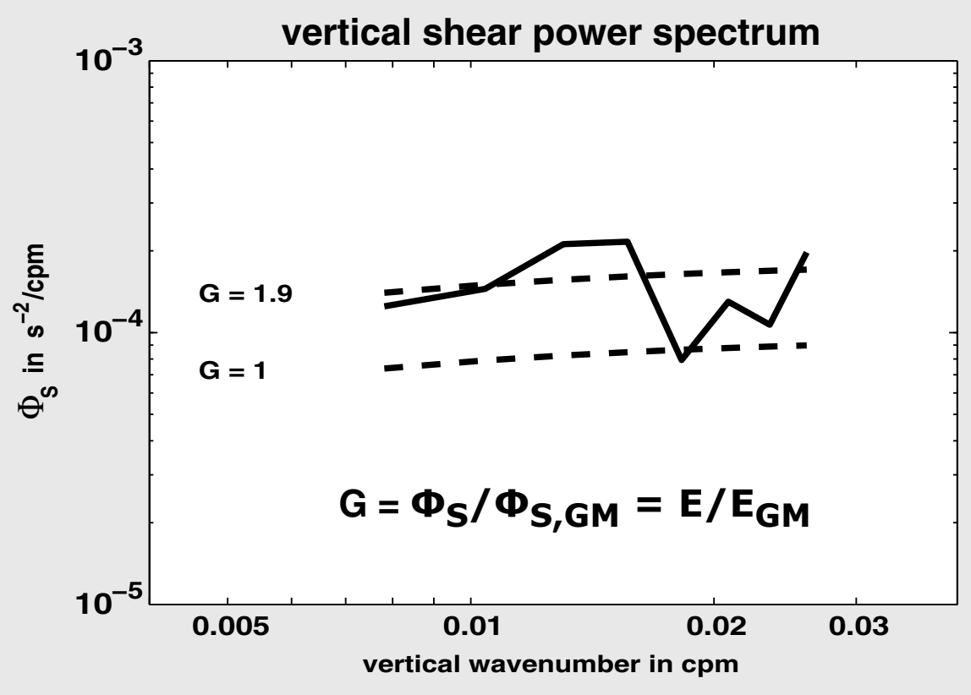
Δv = 0.5 cm/s

across-ship vertical shear (uncorrected)



across-ship corrected shear spectra:

determine shear spectral level G relative to Garrett-Munk background



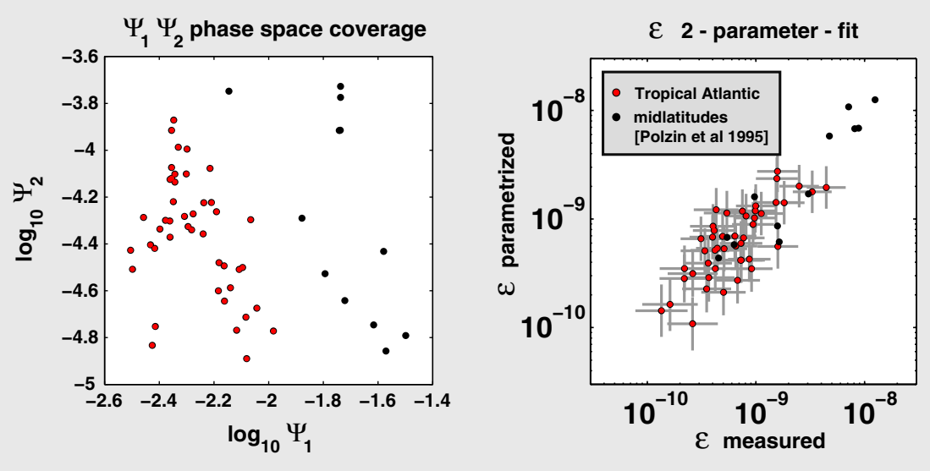
$$G = \Phi_S/\Phi_{S,GM} = E/E_{GM}$$

parametrize dissipation rate ε

from shear spectral level and internal wave slope

Ansatz $\varepsilon = c\,\Psi_1^{\,a}\,\Psi_2^{\,b}$

with $\Psi_1 = f/N$ prop. to wave slope
and $\Psi_2 = N^2G$ prop. to shear spectral level



ε estimates allow estimation of diapycnal diffusivity

$$\varepsilon = 1/24\ \Psi_1^{\,3/4}\ \Psi_2^{\,7/5}$$

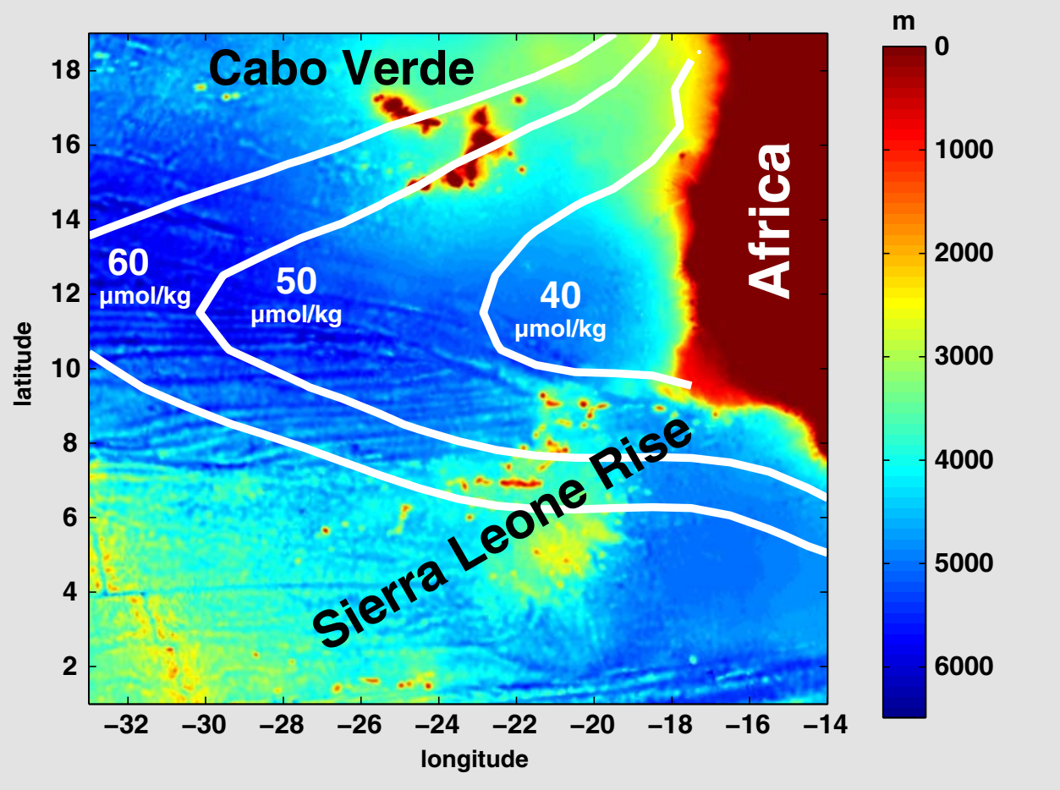
From ε calculate diapycnal diffusivity using Osborn‘s relation
$K = 0.2\ \varepsilon / N^2$

This parametrization for ε turns out to be a condensed version of the state-of-the-art parametrization [Polzin et al. 1995, Gregg et al. 2003] and is particularly appropriate for cruise work with short stations.

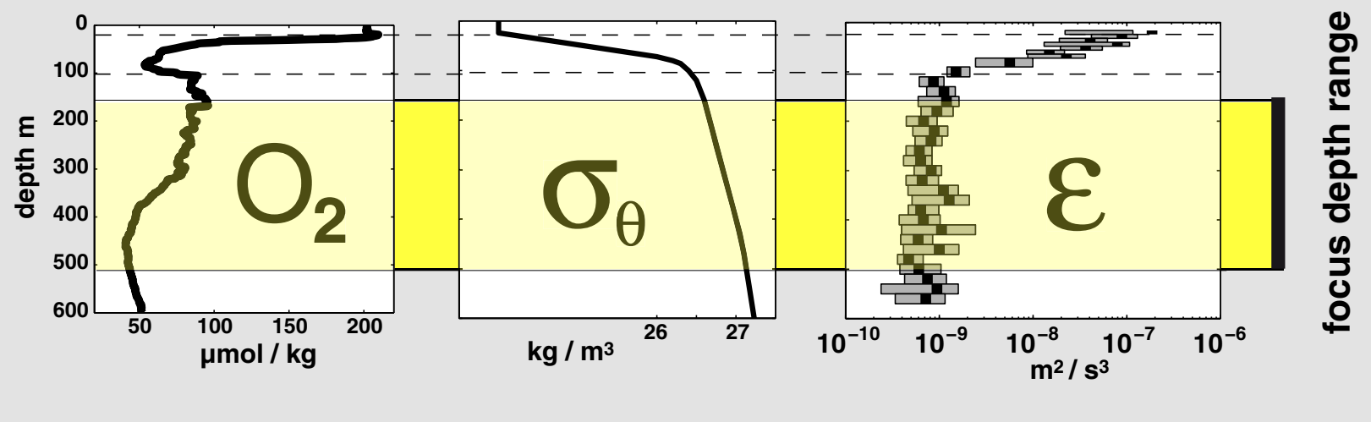
Application at Tropical North Atlantic Oxygen Minimum Zone : Inferring diapycnal mixing and diapycnal oxygen transport

Tropical Atlantic Oxygen Minimum Zone

bathymetry and oxygen minimum concentration

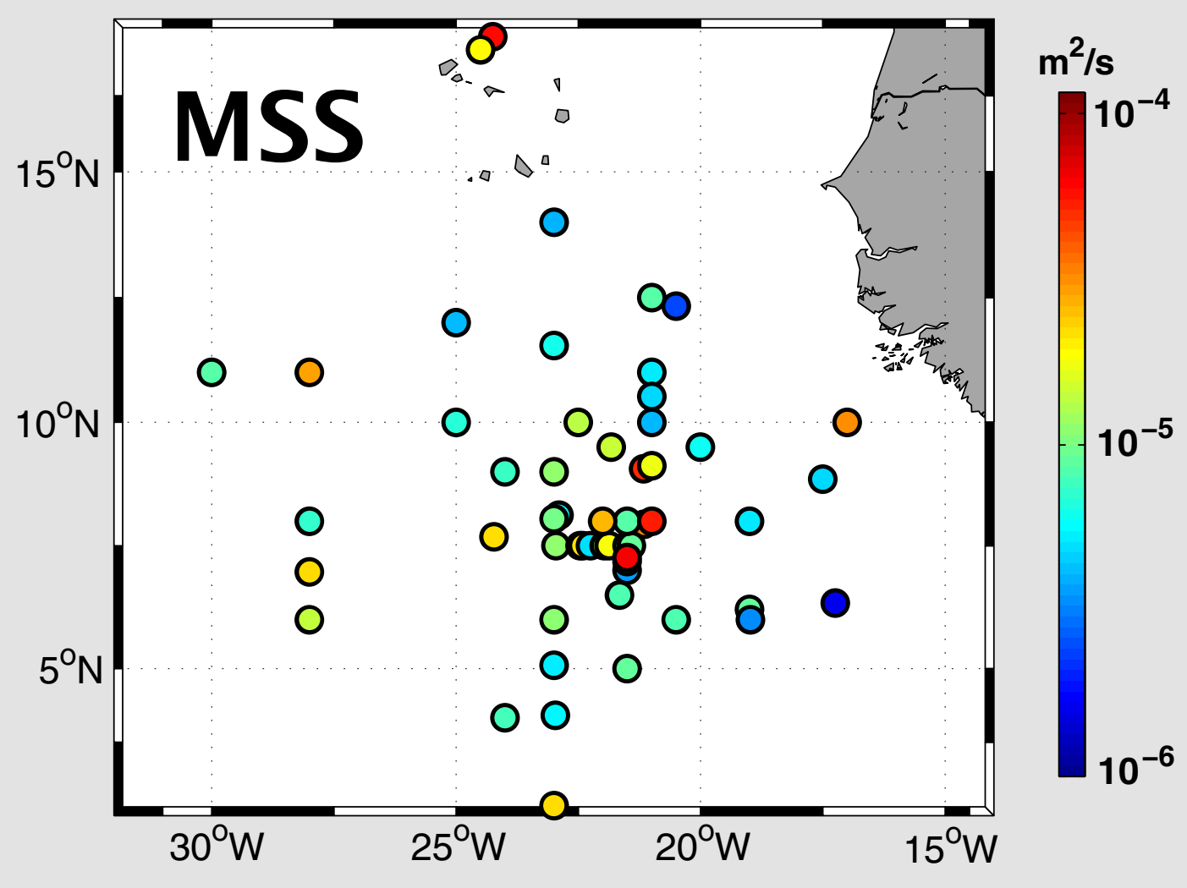


typical / average profiles of oxygen, density and dissipation rate



Diapycnal diffusivity K

estimated from microstructure measurements (during 3 cruises 2008-2010)

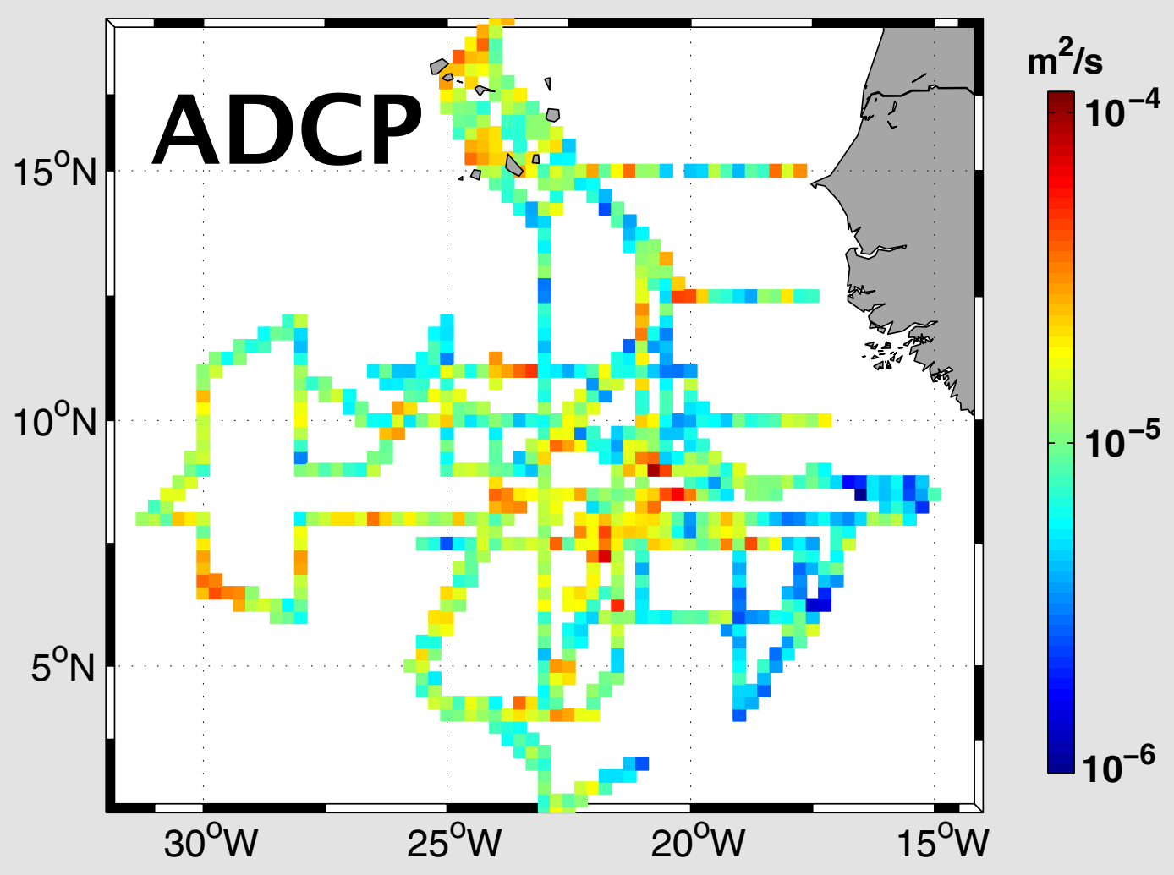


55 independent K values

time investment: 80 ship hours

Diapycnal diffusivity K

estimated from underway acoustics (during 3 cruises 2008-2010)



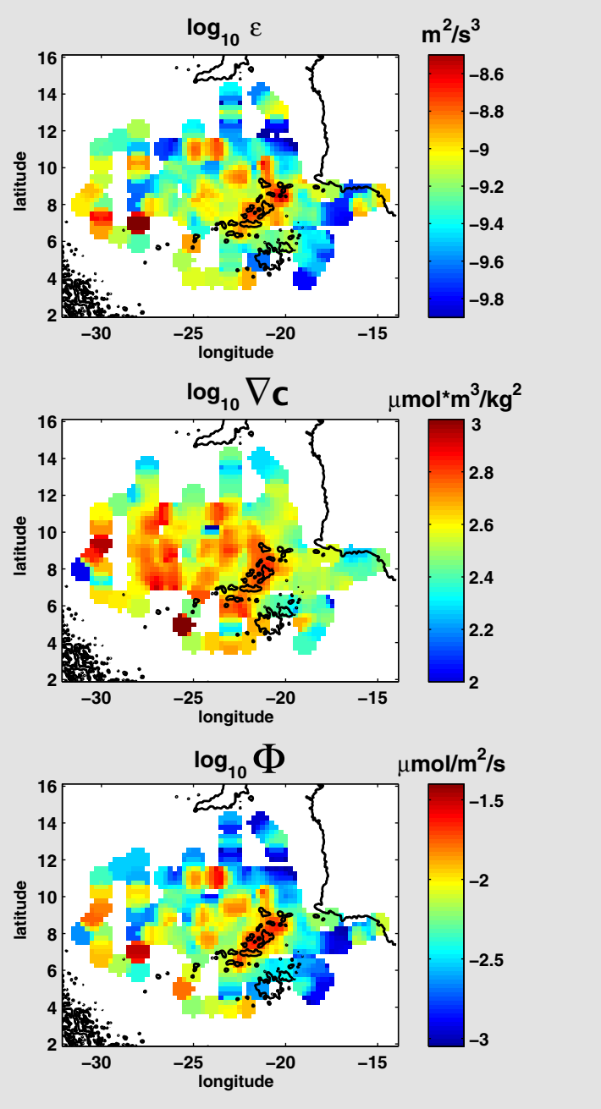
600 independent K values

no extra ship time needed

CTDs are helpful for N^2 input to the parametrization, but climatological N^2 data would be sufficiently precise.

Topographic patterns in diapycnal mixing and diapycnal oxygen downflux

Mixing, oxygen gradient and flux - all three peak at Sierra Leone Rise and become weak above the adjacent abyssal plains to the North and to the Southeast.



Dissipation rate ε at locations of oxygen profiles.
Mean $K = 1.2\cdot10^{-5}$ m²/s
In agreement with simultaneous Tracer Release Experiment [Banyte et al 2011]).

Oxygen gradient ∇c at upper boundary of deep oxygen minimum

Diapycnal oxygen downflux

$\Phi \propto \varepsilon\cdot\nabla c$

Mean Φ = 6 nmol/m²/s accounting for about 30 % of total supply.

References

Polzin, K., J. Toole, and R. Schmitt (1995) : *Finescale parameterizations of turbulent dissipation*, J. Phys. Oceanogr. 25, 306-328 ----- Gregg, M. C., T. B. Sanford, and D. P. Winkel (2003) : *Reduced mixing from the breaking of internal waves in equatorial waters*, Nature 422, 513-515 ----- Banyte, Tanhua, Visbeck, Wallace, Karstensen, Krahmann, Schneider, Stramma (2011) : *Diapycnal diffusivity at the upper boundary of the tropical North Atlantic oxygen minimum zone*, subm. to J. Geophys. Res. ----- Fischer, T. (2011) : *Diapycnal diffusivity and transport of matter in the open ocean estimated from underway acoustic profiling*, PhD thesis, University of Kiel

Acknowledgments

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