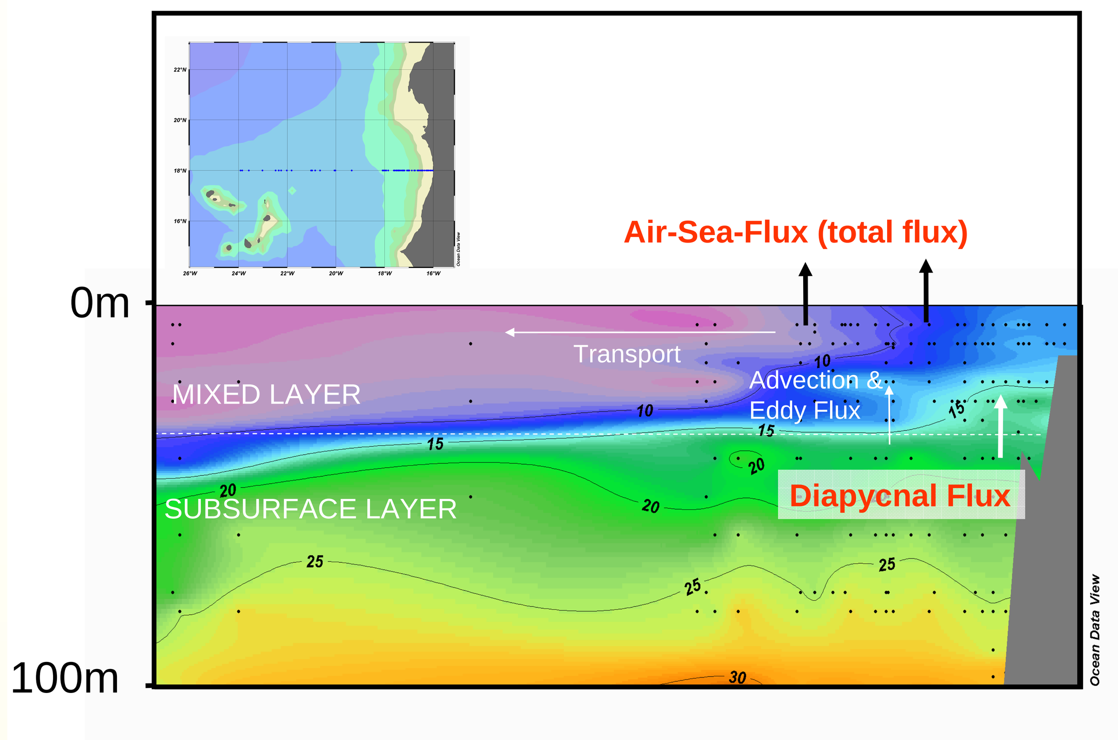
The contribution of turbulent mixing to N_2O flux into the mixed layer of the Mauritanian upwelling system

• Kock (akock@ifm-geomar.de), J. Schafstall (jschafstall@ifm-geomar.de),
H. W. Bange, P. Brandt, M. Dengler

IFM-GEOMAR

MOTIVATION

- **Turbulent mixing is supposed to play a significant role for transport of material through stratified horizons [1].**
- **The role of turbulent mixing for material flux in upwelling systems was investigated by comparison of diapycnal and air-sea flux of nitrous oxide (N_2O).**
- **The integrated air-sea flux gives a measure for the total flux while diapycnal flux only accounts for the part that is induced by mixing.**

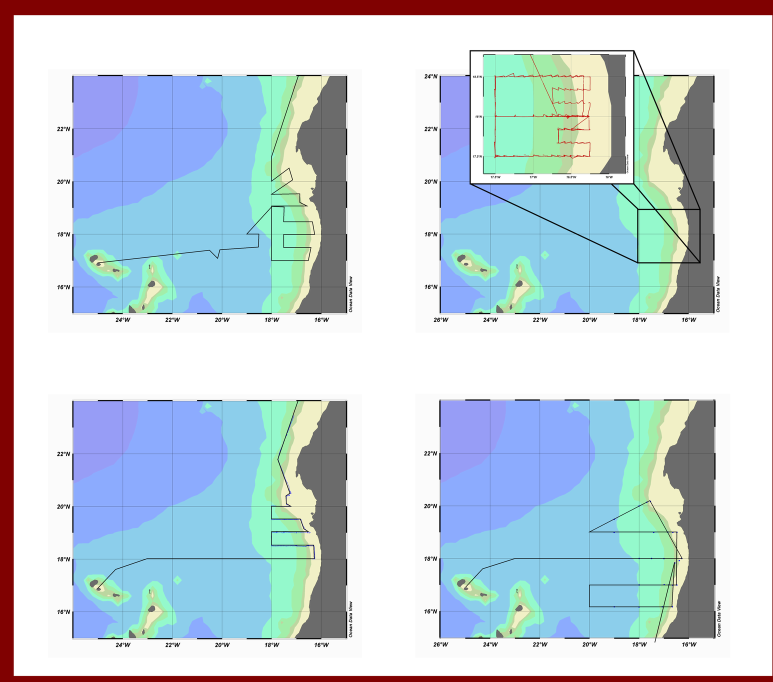


Composed zonal section of N_2O along 18°N between the Mauritanian coast and the Cape Verde islands. Stations north and south of 18°N were projected on the transect according to their bottom depth. Superimposed is a scheme of important physical processes that affect the N_2O concentration in the mixed layer. The investigated processes are shown in red.

STUDY SITE AND DATA SET

The Mauritanian upwelling area is part of the Canary Current upwelling system and one of the most productive areas in the world ocean. Nutrient fluxes from subsurface waters into the mixed layer fuel biological production during upwelling. Upwelling shows a strong seasonality, with strong upwelling between December and May[2].

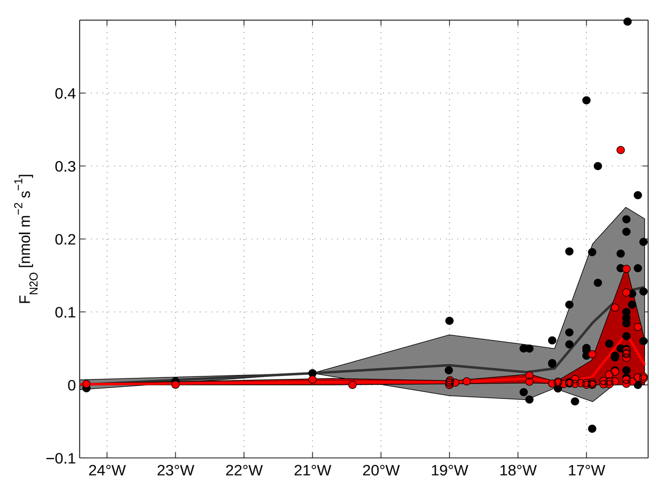
N_2O and microstructure profiles were obtained during five cruises between 2005 and 2008. Four cruises took place between January and May (upwelling season), one cruise took place in July / August (non-upwelling) (not shown). The poster presents only data from the upwelling season.



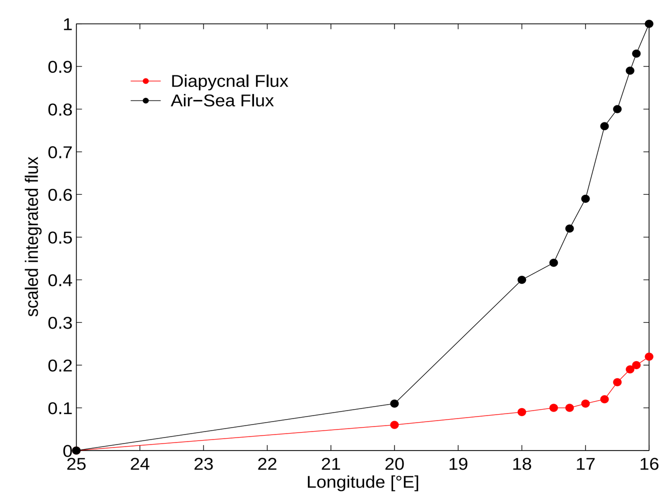
SUMMARY

- **Enhanced diapycnal flux was found in a narrow band above the shelf break (between 100 and 400 m). Averaged fluxes were 15 times higher on the slope than offshore.**
- **Elevated air-sea fluxes extended farther offshore (~19°W) with exponential decay.**
- **Significant, but not dominant role of turbulent mixing: About 20% of the transport of N_2O can be assigned to diapycnal flux -> Advection / Eddy fluxes responsible for the difference.**
- **A seasonally weighed, regionally averaged emission estimate (15-20°N, 16-20°W, $20*10^4$ km²) from air-sea flux yields 5.3 Gg N/yr (≈ 3 % of global coastal upwelling emissions[3])**

Air-sea fluxes higher than diapycnal fluxes:



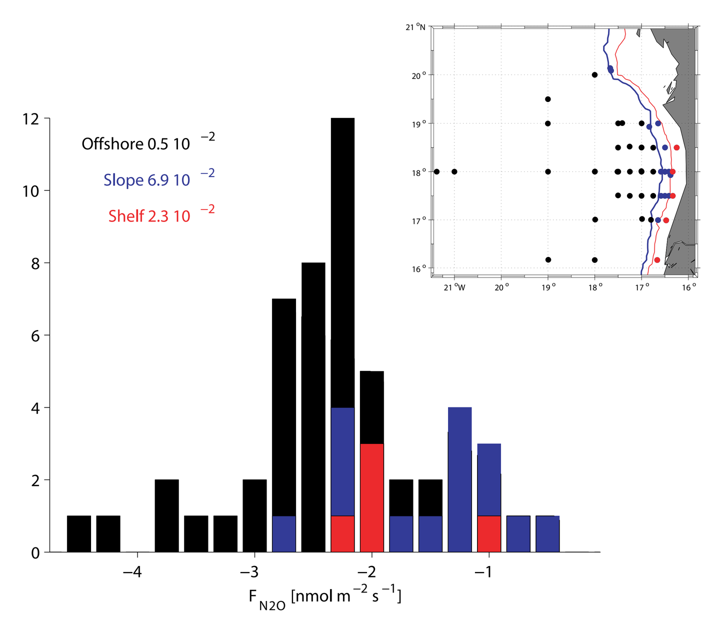
Composed section along 18°N of diapycnal (red dots) and air-sea fluxes (black dots). Red and grey lines denote zonally averaged mean values. Shaded areas are the standard deviations for the averaged values.



Zonally averaged, integrated fluxes. Data were binned into packages of 5-10 data points and averaged. Values were weighted according to their longitudinal extent and scaled to the integrated air-sea flux. Averaged fluxes were: $6.59*10^{-3}$ (diapycnal) and $2.97*10^{-2}$ (air-sea).

Zonally averaged fluxes were used to calculate a seasonally weighted emission estimate for the whole region (15-20°N, 16-20°W, $20*10^4$ km²). The average length of the upwelling season was set to 6 months. For the non-upwelling season, the open ocean value was extrapolated to the whole region. The resulting annual emissions were 5.8 Gg N yr⁻¹.

Different regional distribution



Elevated diapycnal flux is confined to a narrow band along the shelf break (blue dots on the map), with fluxes 15 times higher than offshore.

Air-sea flux is dispersed farther offshore due to Ekman transport of the surface water masses. Assuming a constant gas exchange coefficient k_w of $3.0*10^{-5}$ ms⁻¹ and an mean mixed layer depth of 20 m, gas exchange can be treated as a first order rate law with $t_{1/2}$ = 115 h. An offshore velocity of 0.2 ms⁻¹ would lead to a transport of about 100 km.

WHY N_2O ?

- N_2O is naturally produced below the mixed layer (ML) during Nitrification [4].
- No production/consumption pathway is known for the mixed layer - thus, the concentrations in the mixed layer are only determined by physical processes.
- Assuming steady-state conditions for horizontal transport, air-sea exchange is the only known loss process for N_2O from the ML – Air-sea flux gives an upper estimate for the total transport of materia into the mixed layer. The contribution of other transport processes can be scaled according to this number.

AIR-SEA FLUX

Air-sea flux was calculated according to:

$$F_{N_2O} = k_w \cdot \Delta N_2O$$

where k_w is the gas exchange coefficient, calculated using the k_w/wind speed relationship of Nightingale (2000)[5]. It is:

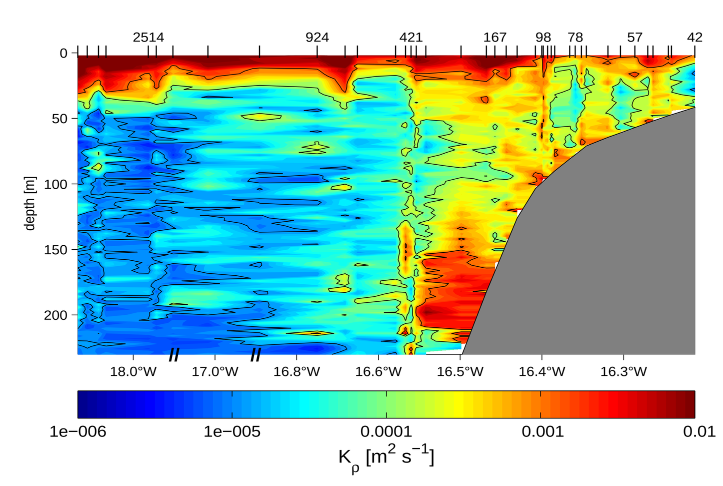
$$k_w \propto u_{wind}^2$$

ΔN_2O is the difference between the measured N_2O concentration in the mixed layer and the equilibrium concentration, calculated with a mixing ratio of 320 ppb. Wind speeds were taken from the ship's underway data record and adjusted to 10 m.

DIAPYCNAL FLUX

Diapycnal Flux was calculated according to: $F_{N_2O} = K_\rho \cdot \frac{\partial C_{N_2O}}{\partial z}$,

where K_ρ is the diapycnal diffusion coefficient at the base of the mixed layer, obtained from microstructure profiles, and $\partial N_2O / \partial z$ is the N_2O gradient at the same depth. As N_2O profiles were obtained from discrete sampling, the gradient was determined using the deepest sample within the mixed layer and the next deeper sample.



Diapycnal diffusion coefficient along 18°N (Composed section from microstructure profiles). Soaring turbulence is found at the continental slope, induced by breaking of internal waves along the shelf break.

References: [1] Hales et al. (2005), *J. Geophys. Res.*, *110*, C10S11, doi:10.1029/2004JC002685; [2] Minas et al. (1982), Rapp. P.-V. Réun. Cons. Int. Explor. Mer *180*: 148-182, [3] Nevison et al. (2004), *Global Biogeochem. Cycles 18*, GB1018, doi:10.1029/2003GB002110;[4] Bange, H. W. (2008), in: Nitrogen in the Marine Environment, D. G. CAPONE, D. A. BRONK, M. R. MULHOLLAND and E. J. CARPENTER, Academic Press/Elsevier, 51-94; [5] Nightingale et al. (2000), *Global Biogeochem. Cycles 14*(1), 373-387.

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