Vertical Mixing in the Tropical North Atlantic Ocean; Results from a large scale Tracer Release Experiment

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The Oxygen Minimum Zone in the Tropical North Atlantic Ocean - The Guinea Dome.

Background:

The “SFB 754” Climate – Biogeochemistry Interactions in the Tropical Ocean

Guinea Upwelling Tracer Release Experiment (GUTRE)

How does subsurface dissolved oxygen in the tropical ocean respond to variability in ocean circulation and ventilation?
• Dissolved Oxygen can be supplied by:

1) Lateral Pathways by mean and variable currents along isopycnals

2) Vertical Pathways by mixing across isopycnals
Objective:

- Constrain estimates of diapycnal and isopycnal mixing in the ocean
- Observe advection of “labeled” water masses
- Study biogeochemical processes within the labeled water mass

Advantage:

- Integrated value of all processes over a certain time period over a larger area
- Estimates to high accuracy is possible

Challenges:

- Only limited process understanding
The Tracer Injection:

92 kg (470 mole) of CF$_3$SF$_5$ was injected on the density surface $\sigma_\Theta = 26.88$ kg m$^{-3}$ and $8^\circ$N, $23^\circ$W - in the upper oxygen gradient of the Tropical North Atlantic OMZ.

CF$_3$SF$_5$ is an inert gas that does not have any measurable background concentration in the ocean.

OTIS – Ocean Tracer Injection System
The Scene:

Topography

- Seamount chain in the SE
- Abyssal plain in the NW
- High stratification in SE
- Low stratification in NW

Stratification
Tracer Observations:

**Horizontal spreading**

- 7 months
- 20 months
- 30 months

**Vertical spreading**

- 7 months
- 20 months
- 30 months

**Diapycnal spreading**

- 7 months
- 20 months
- 30 months
Calculating the mixing:

Normalized vertical profiles closely resembles Gaussian distribution, so that the diffusivity can be calculated by the second moment of the Gaussian fit.

\[ K_z = S^2(t_2) - S^2(t_1) / 2(t_2 - t_1) \]

Assuming Gaussian distribution

We did these calculations in:

- **depth** \((D_z \text{ in } m^2 \text{ s}^{-1})\)
- **density** \((D_\rho \text{ in } (kg \text{ m}^{-3})^2 \text{ s}^{-1})\)
Results:

**Vertical velocity:**

\[ \omega_z = 0.6 \pm 1.3 \times 10^{-7} \text{ m s}^{-1} \]

\[ \omega_\rho = 1.3 \pm 2.0 \times 10^{-10} \text{ kg m}^{-3} \text{ s}^{-1} \]

**Vertical diffusivity:**

\[ D_z = 1.18 \pm 0.13 \times 10^{-5} \text{ m}^2 \text{ s}^{-1} \]

\[ D_\rho = 3.10 \pm 0.28 \times 10^{-11} \text{ (kg m}^{-3})^2 \text{ s}^{-1} \]

A significant upward velocity for the time between survey 1 and 2/3, 1.6 ± 0.6 \times 10^{-7} \text{ m s}^{-1} (i.e. ~5 \text{ m y}^{-1})

Insignificant vertical gradient in diffusion (\( \delta D/\delta z \))
Regional variability:

Stratification; $D_z$

Topography; $D_\rho$
Discussion:

The GUTRE experiment (Latitude 4° - 12° N) has somewhat higher diffusivity (dissipation rates) than predicted by Gregg et al., (2003) compared to the NATRE experiment (Latitude 10° - 26° N) (Ledwell et al., 1998).

Enhanced mixing over rough topography might be an explanation for this.

We have introduced the diapycnal diffusivity in density space ($D_\rho$) with the units of (kg m$^{-3}$)$^2$ s$^{-1}$. $D_\rho$ is a useful property; in our experiment we see higher mixing over rough Topography only in $D_\rho$ space, not in $D_z$ (where we see the opposite pattern).

\[
\langle w_\rho C_\rho' \rangle = -D_z \frac{d\rho}{dz} \frac{dO_2}{dz} = -D_\rho \frac{dO_2}{d\rho},
\]

$D_\rho$ thus defines the concentration changes over time for parameters like oxygen.
Conclusions:

A “tropical” TRE over the Oxygen Minimum Zone in the Atlantic Ocean

- We find diapycnal diffusivities that are slightly lower than for NATRE roughly 10° further north
  
  \[
  D_z = 1.18 \pm 0.13 \times 10^{-5} \text{ m}^2 \text{ s}^{-1} \\
  D_\rho = 3.10 \pm 0.28 \times 10^{-11} (\text{kg m}^{-3})^2 \text{ s}^{-1}
  \]

- We find significant regional differences in $D_\rho$ probably associated with topographic “roughness”