Mixing and Upwelling Dynamics along the Continental Slope off Peru inferred from Tracer Release, Hydrographic and Microstructure Measurements

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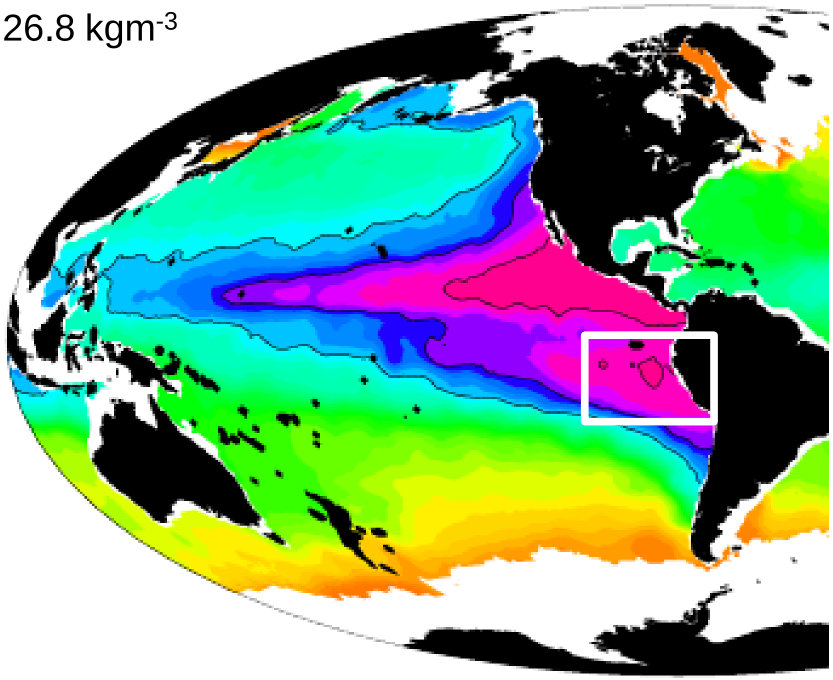
SFB754 Climate – Biogeochemistry Interactions in the Tropical Ocean

In the framework of the Peruvian Oxygen minimum zone System Tracer Release Experiment (POSTRE) a tracer was injected into the bottom boundary layer of the Peruvian shelf to investigate spreading pathways and fate of nutrients released from the sediments

Oxygen concentration on isopycnal 26.8 kgm^{-3}



Motivation of the tracer release experiment

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Artificial tracer (SF_5CF_3) represents nutrients from anoxic sediments

Nutrient flux from the sediments are potentially important for the development of oxygen minimum zone

Objective:

- Investigate spreading pathways and *fate of nutrients released from the sediments*
- **Study exchange between the continental margin and ocean interior**

Picture from Madeline Freund

Tracer release experiment at the continental slope off Peru 2015-2017

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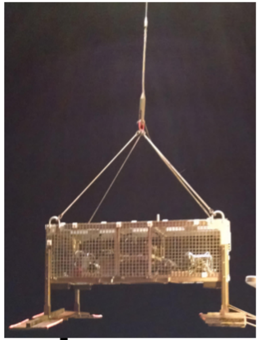

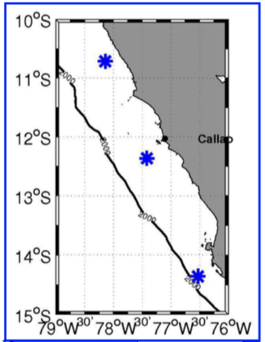

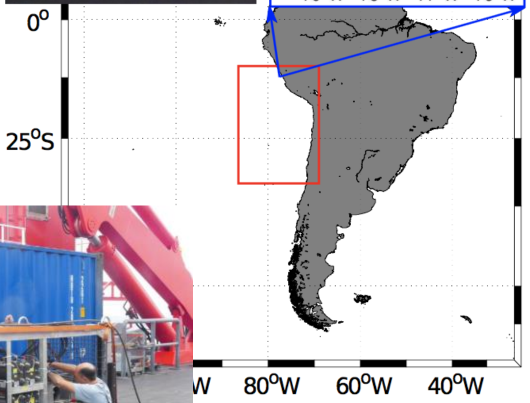

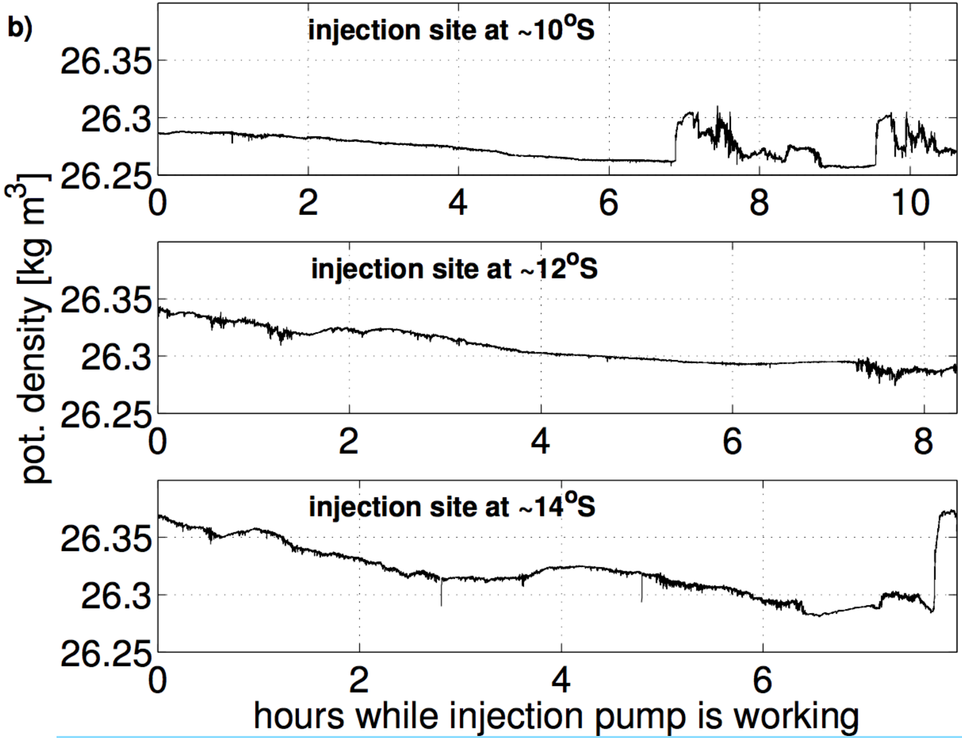

- ➢ Enhanced near-bottom density variability during injection due to (non-linear) baroclinic tides and internal waves cause by critical continental slopes

Tracer release experiment at the continental slope off Peru 2015-2017

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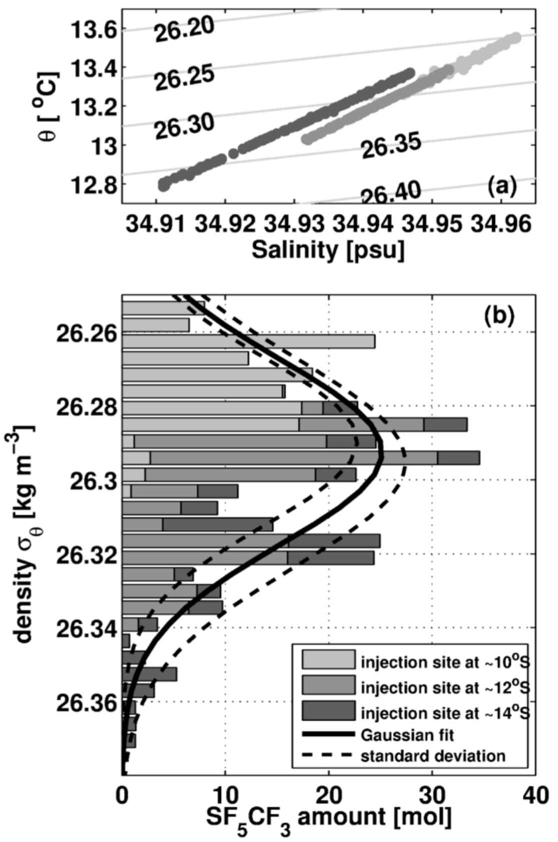
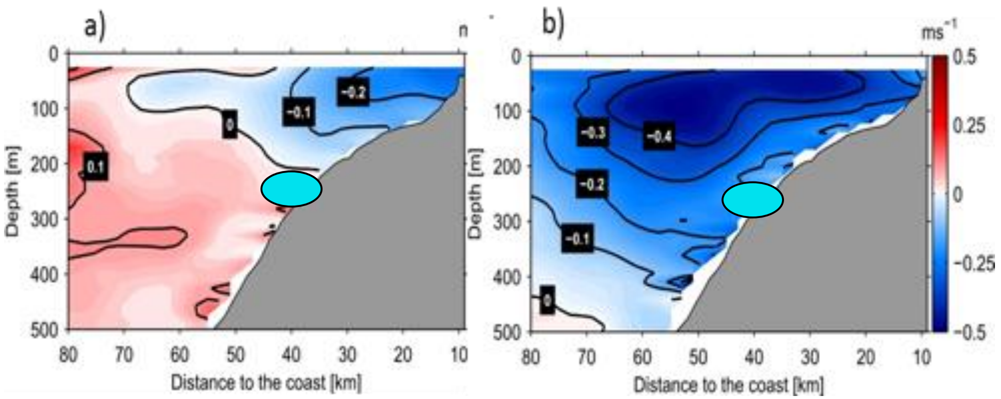


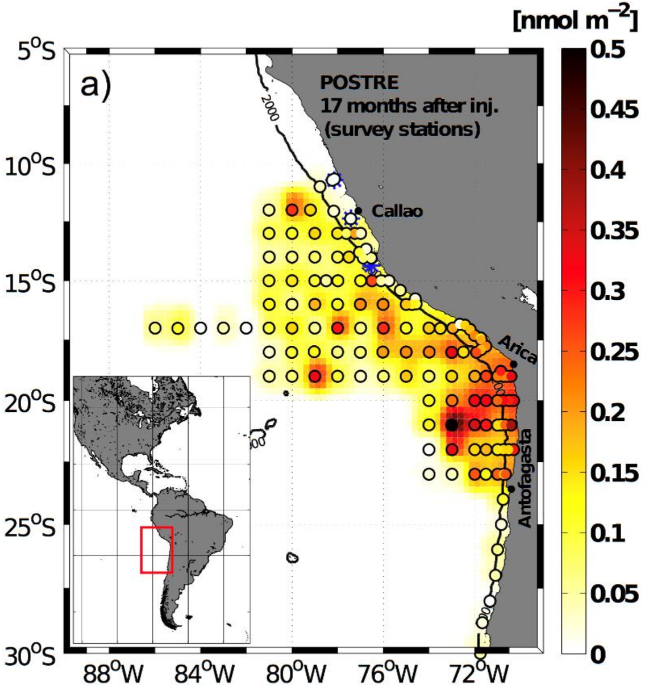


Alongshore velocity at 12°S in April, 2017 (a) and May, 2017 (b)

- About 70 kg of SF_5CF_3 were injected into the bottom boundary layer of the Peruvian continental slope in October 2015.
- Tracer was released at three sites at 250m depth and sampled 17 month later.

Temperature, salinity and density during injection of the tracer.

Tracer survey cruise on RV METEOR



Depth-integrated tracer concentrations from survey in March 2017

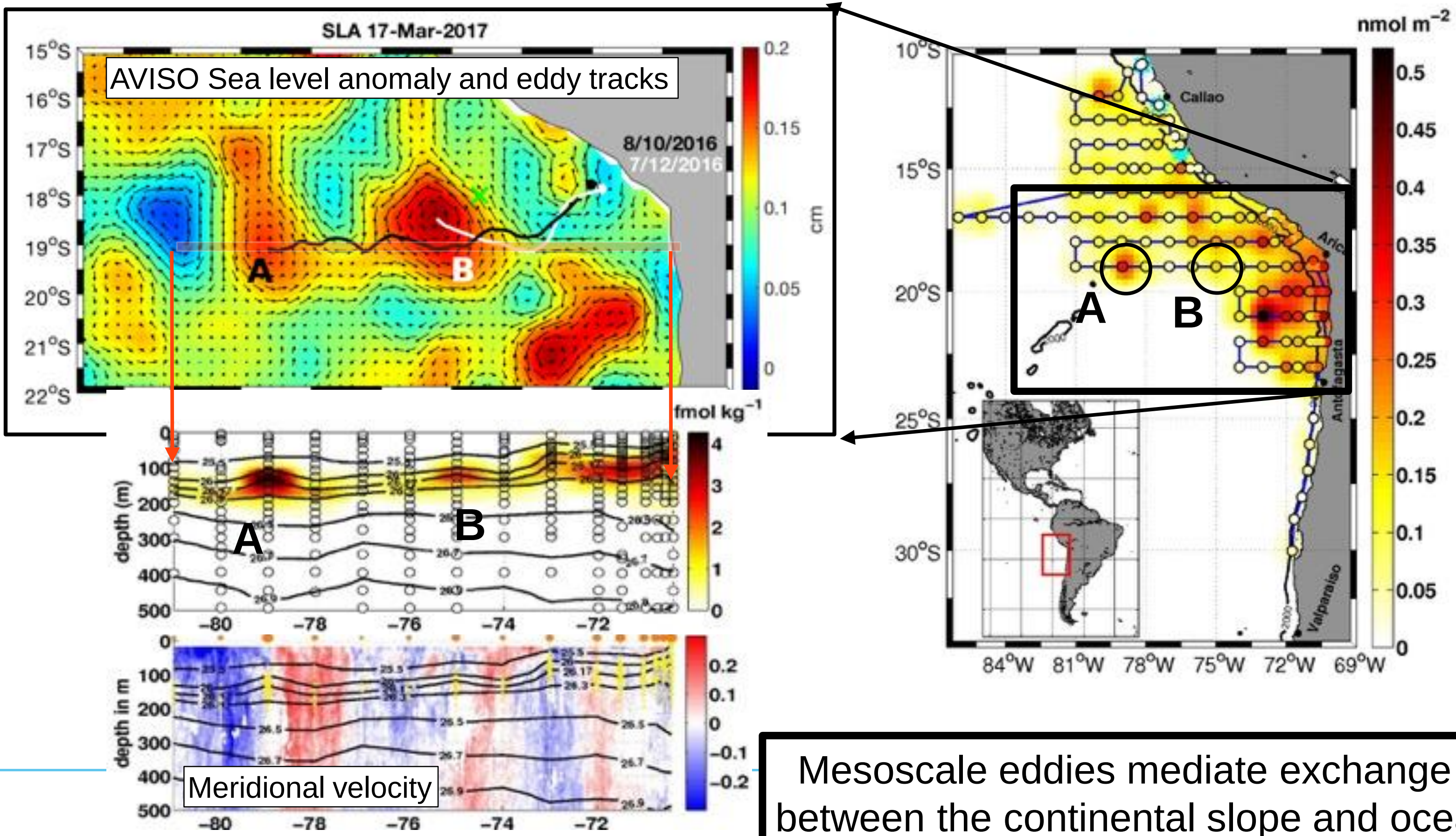
Tracer survey:

- March 2017, ~17 months after injection
- 132 stations (10-30°S, coast to 86°W)

Results:

- ~40±10% of tracer found
- 2000 km southward and 1400 km offshore of release site
- more than $2 \cdot 10^6$ km^2 covered

Exchange of tracer between the continental slope and ocean interior



Mesoscale eddies mediate exchange of tracer between the continental slope and ocean interior

Vertical distribution of the tracer

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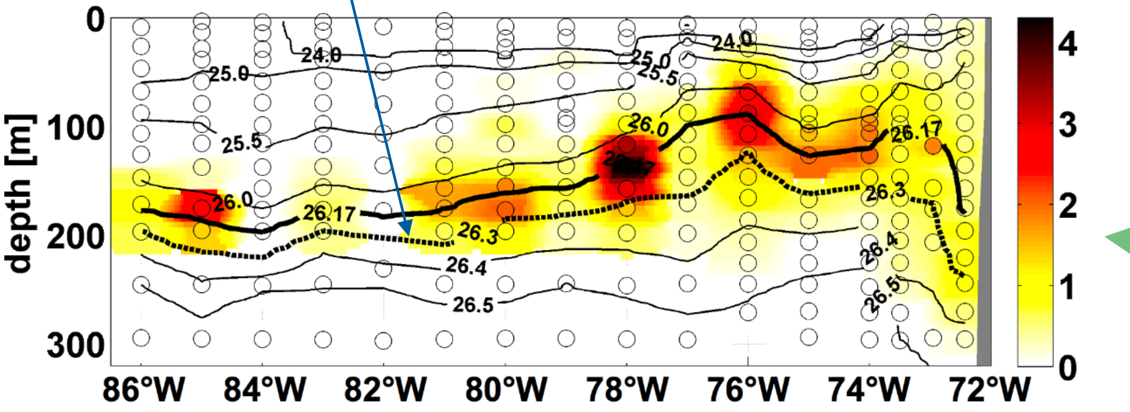
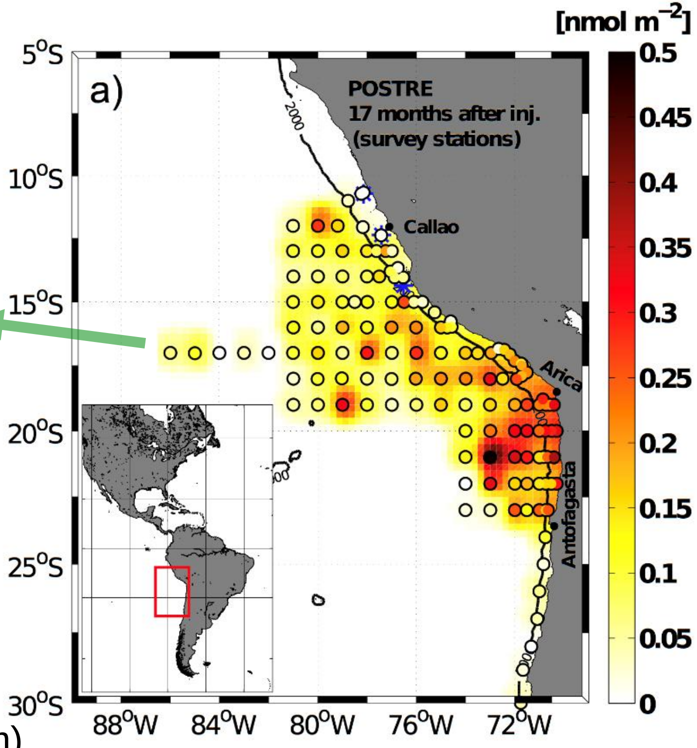
Density during injection 26.3 kgm^{-3}





- Center of mass is displaced:
- upward relative to release depth (Δζ = 150m)
- upward relative to mean depth of density surface (Δζ = 70m)

Density change / vertical displacement of the tracer's center of mass

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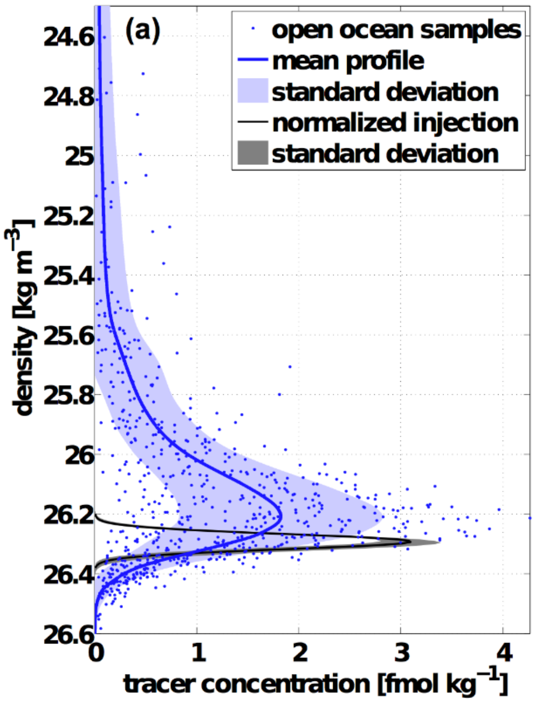
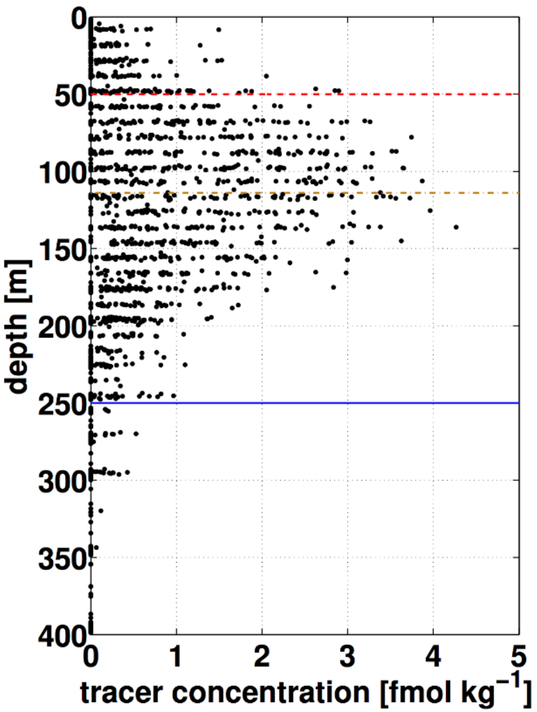
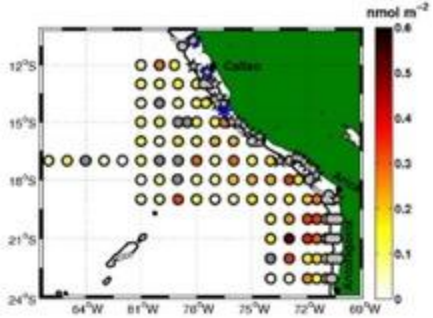
Concentration vs. density



Concentration vs. depth

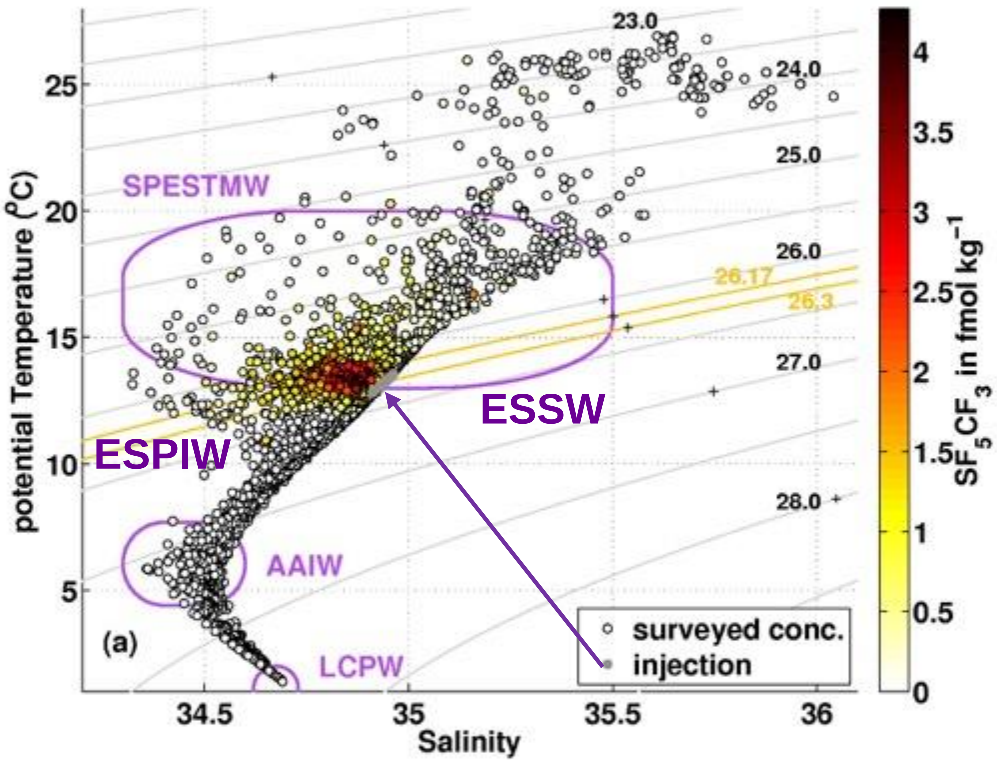




- Density of tracer's center of mass decreased by 0.13 kgm^{-3}.
- Corresponds to an upward displacement of about 70m
- Density change / vertical displacement is independent of region!

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Tracer distribution in Θ-S space and related water masses



ESSW - Equatorial Sub-Surface Water with linear Θ-S, transported by PCUC

ESPIW – Eastern South Pacific Intermediate Water, low salinity (~150m)

SEPSTMW - South Pacific Eastern Sub-Tropical Mode Water

AAIW - Antarctic Intermediate Water

Density of the tracer's center of mass density decrease (0.13 kg/m^3) due to

- warming by 0.28°C
- freshening by 0.10 psu

Diapycnal mixing processes at the Peruvian continental margin

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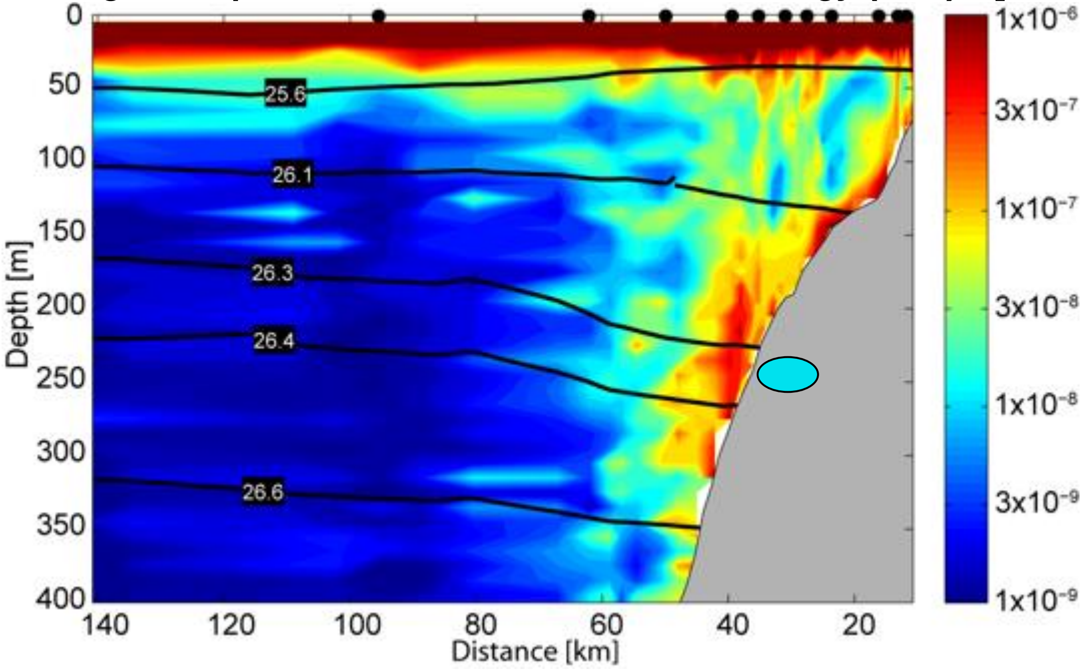
Average dissipation rate of turbulent kinetic energy (TKE) ε [m^2s^{-3}]



- TKE dissipation rates determined from **1300 loosely-tethered microstructure** profiles collected along the continental margin of Peru during 8 cruises (2013-2017)
- Near-bottom mixing is enhanced by an order of magnitude

Drivers for the displacement of the tracer's center of mass

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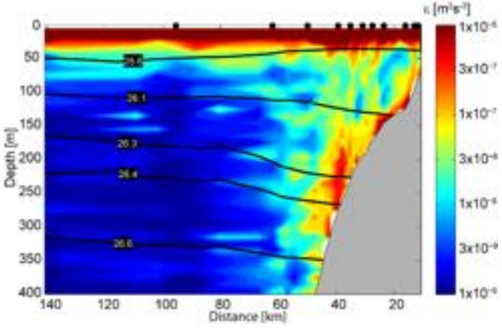
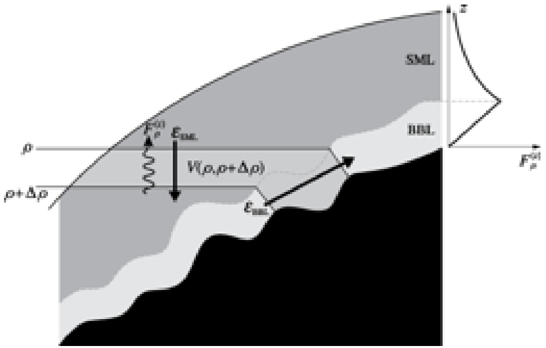
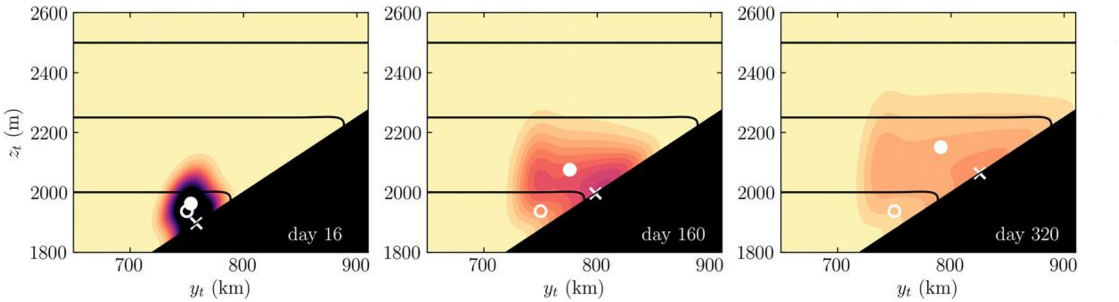




(Raf Ferrari et al., 2016)

- ➢ presence of the boundary displaces the center of mass to lower densities (by limiting its diffusion towards higher densities).
- ➢ upward along-slope diapycnal advective flow in the BBL displaces center of mass to lower densities.
- ➢ downward diapycnal velocities in the stratified mixing layer above the BBL displaces tracer's center of mass toward denser fluid.
- ➢ vertical diffusivity gradient above the BBL displaces the tracer's center of mass towards denser fluid.



(Ryan Holmes et al., 2019)

Evaluating upward along-slope diapycnal velocities

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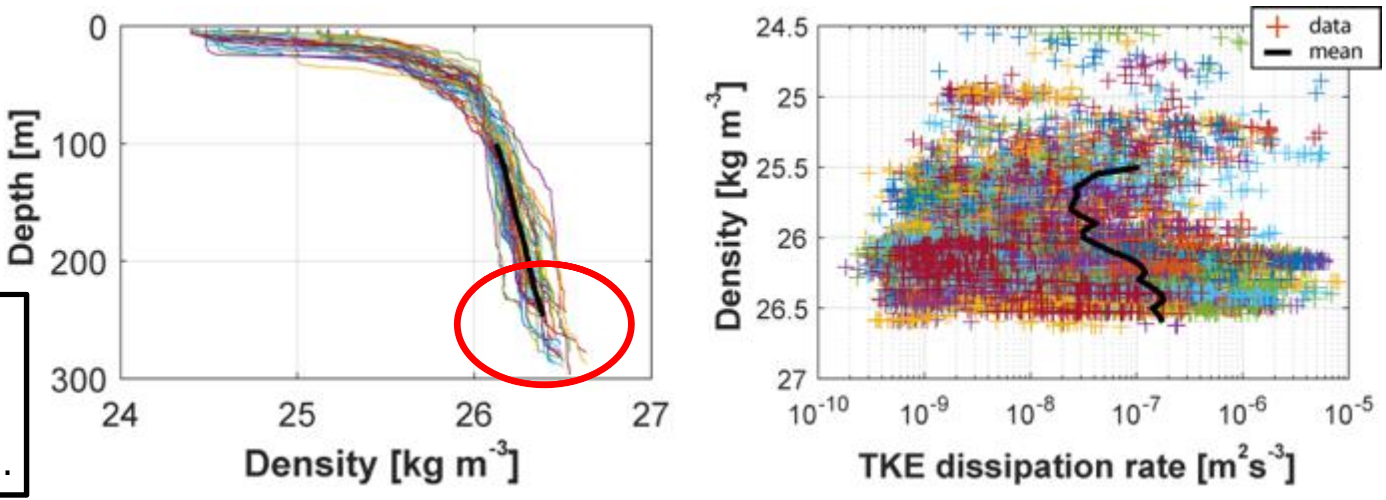
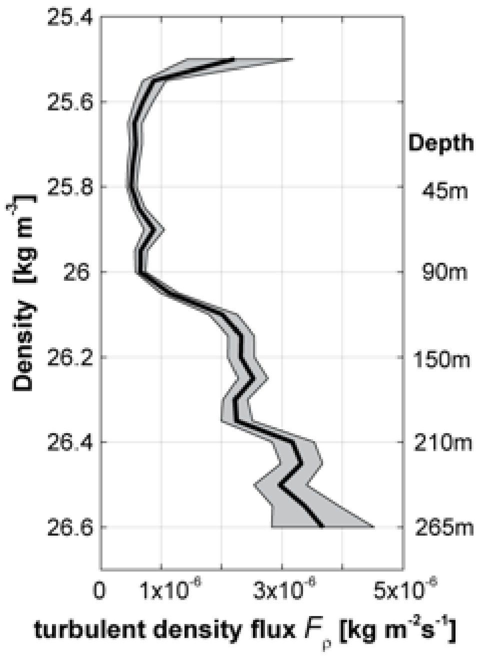
Bottom boundary layer is not pronounced.



- We assumed that diapycnal downwelling $\boldsymbol{\varepsilon_{SML}}$ in the stratified mixing layer induces diapycnal upwelling $\boldsymbol{\varepsilon_{BBL}}$ in the BBL
- Evaluating $\overrightarrow{\boldsymbol{\varepsilon_{SML}}} \cong -\rho_0 g^{-1}\Gamma \frac{\partial \epsilon}{\partial \rho} \overrightarrow{\boldsymbol{n_z}}$ from microstructure profiles collected between bottom depth of 200m and 280m yields: $\boldsymbol{\varepsilon_{SML}}$ ≈ **- 0.5 m day^{-1}.**

Residence time of the tracer at the eastern boundary

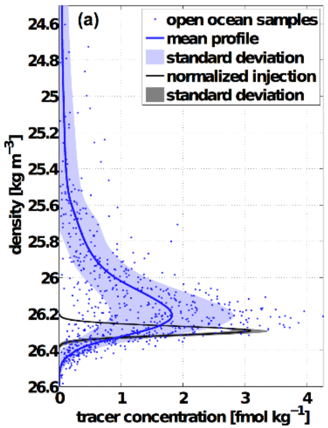
Density flux determined from all profiles measured at bottom depth between 200m and 280m.

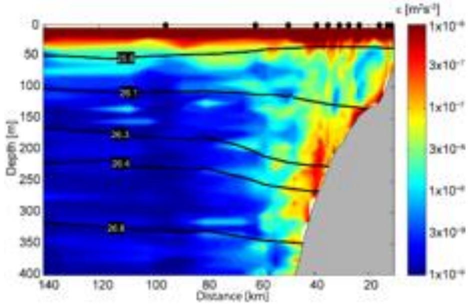


- Assuming $\boldsymbol{\varepsilon_{SML}} = -\boldsymbol{\varepsilon_{BBL}}$ yields diapycnal upwelling velocities of 0.5 m day^{-1} in the BBL.
- **A residence time in the BBL requires to be about 1.5 to 3 month** to explain the density change of the tracer's center of mass of 0.13 kg m^{-3}

Caveat:

- Vertical distribution of the density flux does not decrease near the bottom (vanishing flux at the bottom is required)
- A BBL is not obvious in the data!





Summary

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- During POSTRE about 70 kg SF_5CF_3 was injected into the bottom boundary layer at 3 sites of the upper Peruvian continental slope at 250m depth.
- After 17 month, the tracer had spread more than 2000 km southward and 1400 km offshore of release site by PUC and mesoscale eddies.
- Density of the tracer's center of mass decreased by 0.13 kgm^{-3}, corresponding to an upward displacement of 50-100m (relative to release density).
- At the Peruvian continental slope, turbulent mixing processes exhibit a near-bottom maximum that is estimated to drive a diapycnal downwelling of 0.5 m day^{-1} in the lower 50-100m of the water column.
- Diapycnal upwelling in the BBL can explain the density decrease of the tracer's center of mass, **requiring a BBL residence time of the tracer of 1.5 to 3 month.**
- The bulk diffusion estimate due to the tracer moments is only slightly above the canonical background values highlighting the fundamental importance of diapycnal advective fluxes in the and the stratified mixing layer above.