A benthic-pelagic nitrogen budget for the continental margin of the Peruvian oxygen minimum zone

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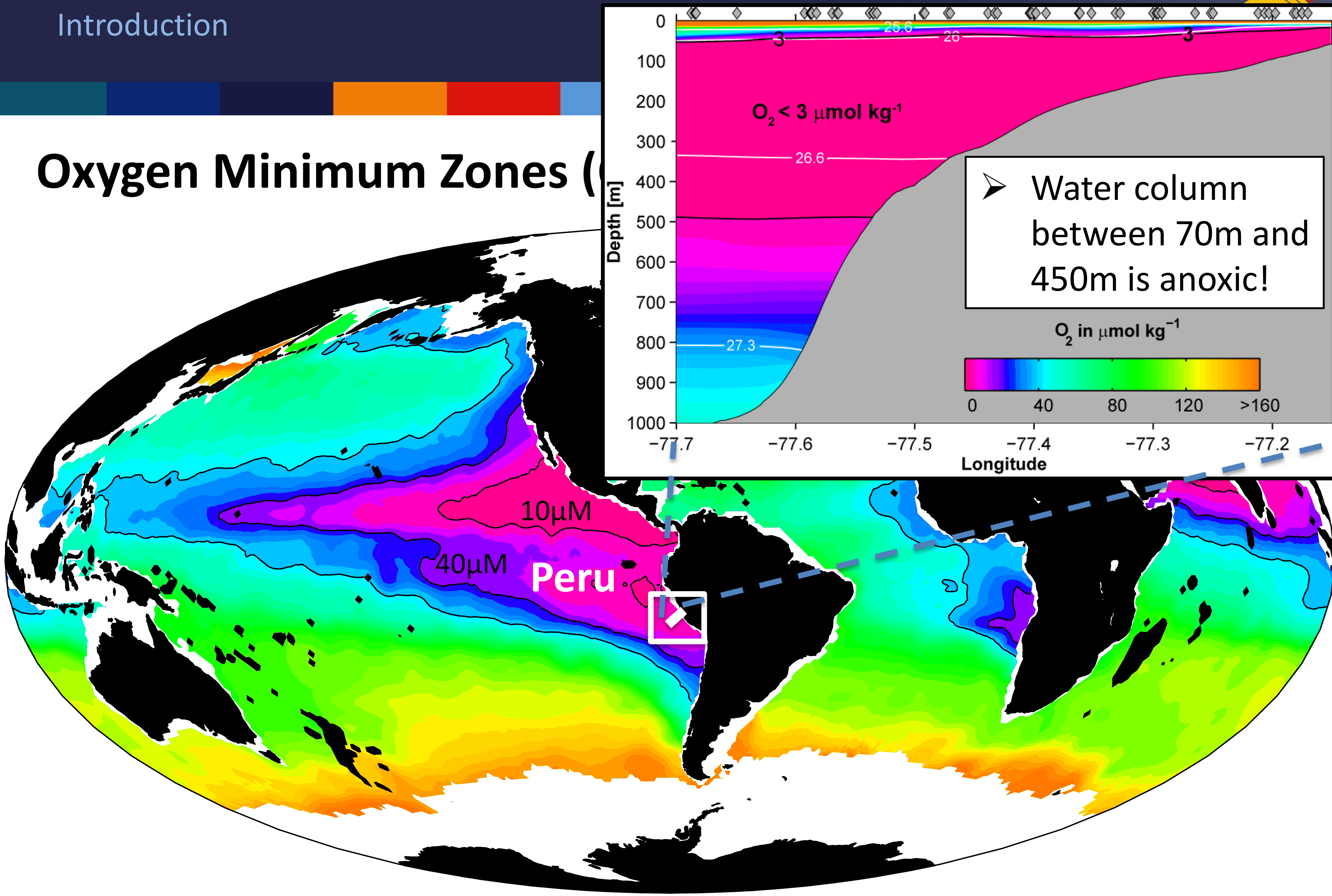
SFB 754

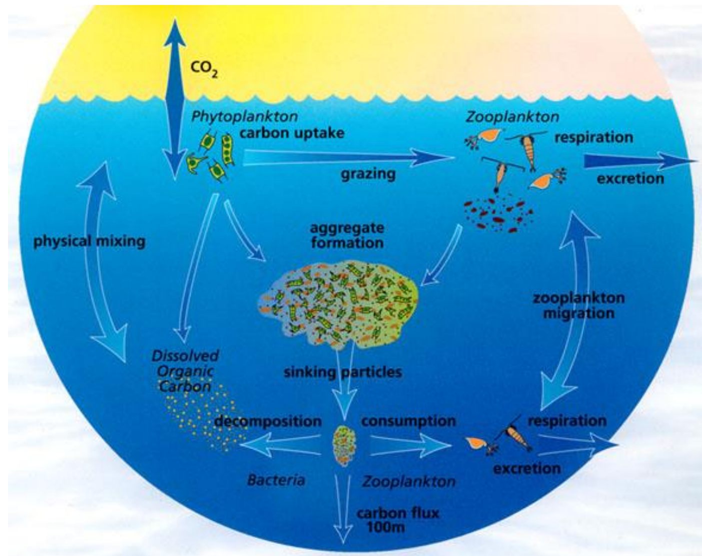
Oxygen Minimum Zones (



O_2 on σ_θ = 26.9 kg m^{-3} isopycnal (100-500m depth)

Biogeochemical feedback loops for OMZ maintenance

Primary production in surface layer



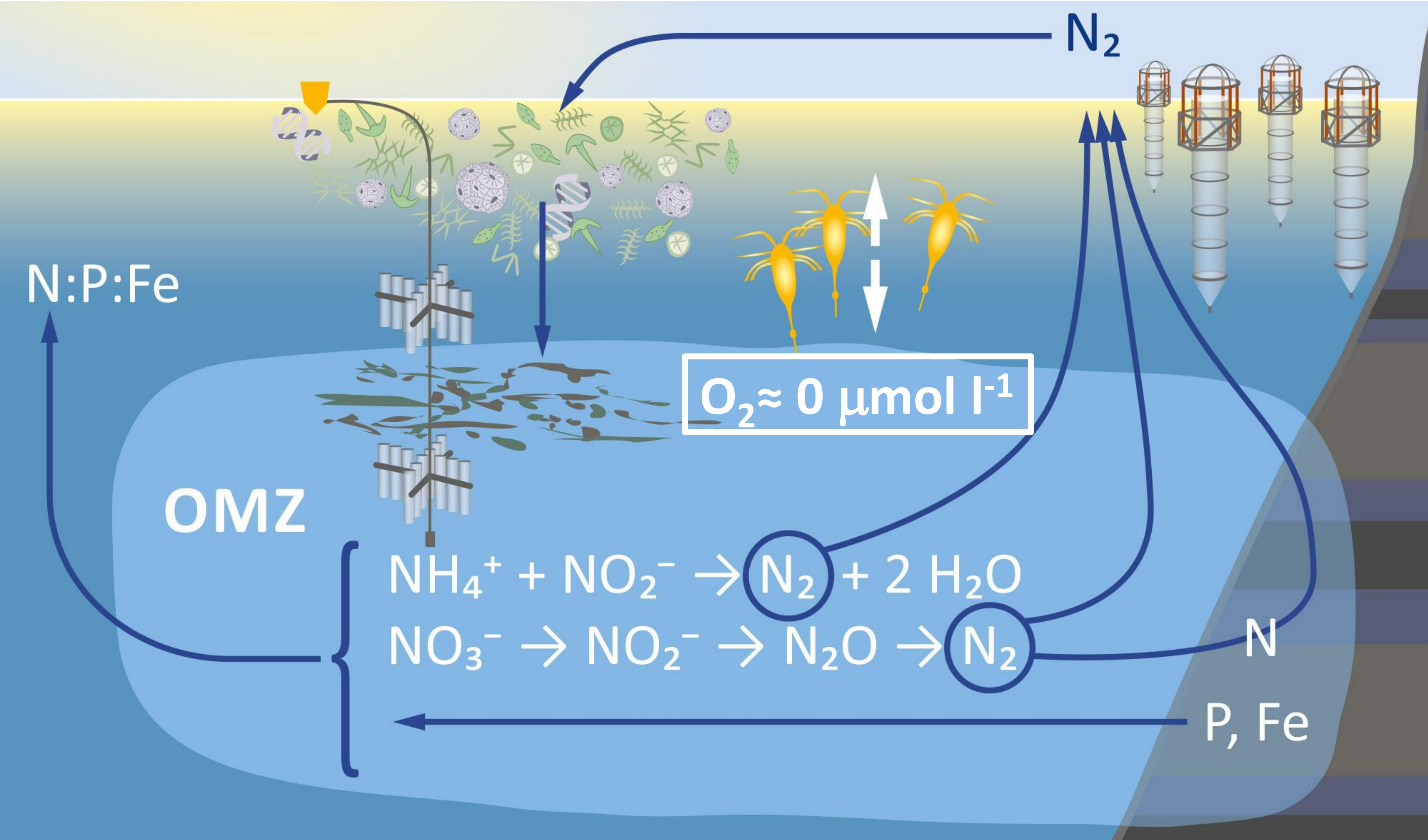
Primary production in surface layer use nutrients

- dead organisms (particles) sink
- Bacteria feed on organic material and release nutrients
- Use oxygen for breathing

Upwelling, vertical mixing

Sediments release nutrients (N, P, Fe, Si)

Sediments further degrade organic material



- Anaerobic respiration leads to a loss of N-nutrients in the ocean
- OMZs account for 20%-40% of the ocean nitrogen loss

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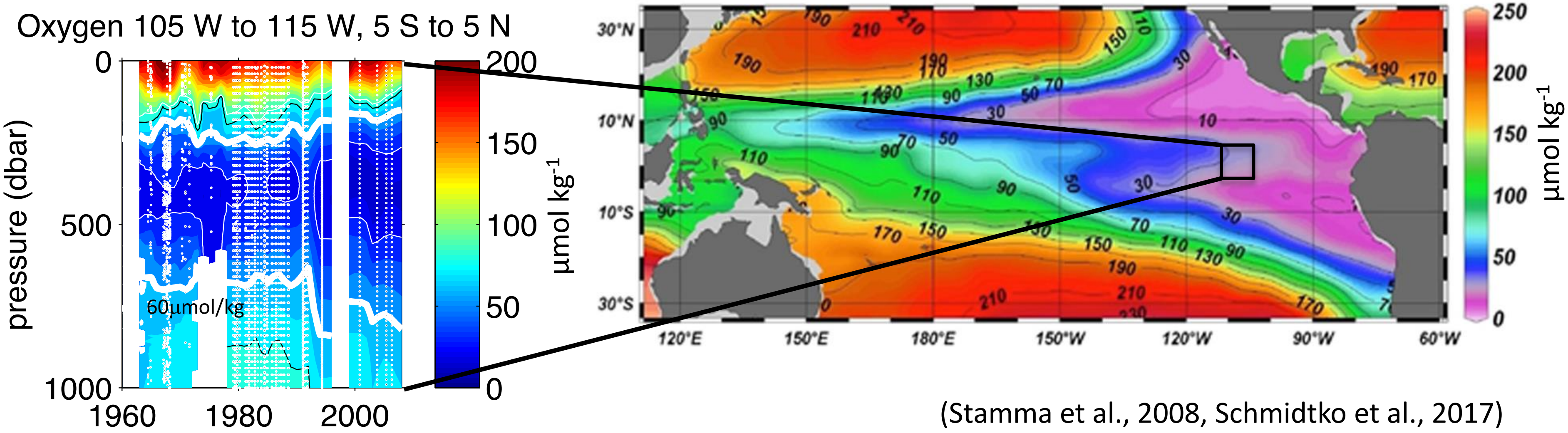
Evidence for ongoing ‘Ocean Deoxygenation’



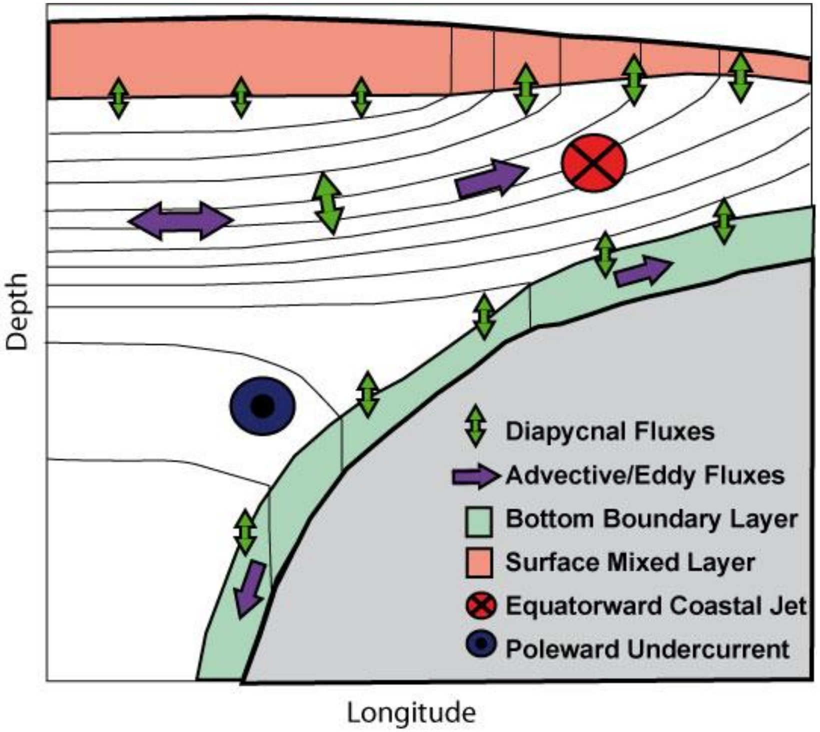
(Stamma et al., 2008, Schmidtko et al., 2017)

Overarching questions of SFB754 (excerpt):

- What are the sensitivities and feedbacks linking low or variable oxygen levels and key nutrient source & sink mechanisms?
- What are the magnitudes and time scales of past, present and likely future variations in oceanic oxygen and nutrient levels?

Objectives:

- Provide estimates of nutrient loss in an OMZ that can be used for model evaluation.
- Advance understanding of the physical processes controlling nutrient cycling and nutrient loss at the continental margin.



Approach:

- Conducted a process study allowing to estimate all terms of a transport budget for nutrients and dissolved N_2 at the continental margin.

$$\frac{\partial NO_3}{\partial t} + u \cdot \frac{\partial C_{NO_3}}{\partial x} + v \cdot \frac{\partial C_{NO_3}}{\partial y} + w \frac{\partial C_{NO_3}}{\partial z} =$$

$$\frac{\partial}{\partial x}\left(K_x \cdot \frac{\partial C_{NO_3}}{\partial z}\right) + \frac{\partial}{\partial y}\left(K_y \cdot \frac{\partial C_{NO_3}}{\partial z}\right) + \frac{\partial}{\partial z}\left(K_z \cdot \frac{\partial C_{NO_3}}{\partial z}\right) + \text{source}$$

Budget equation

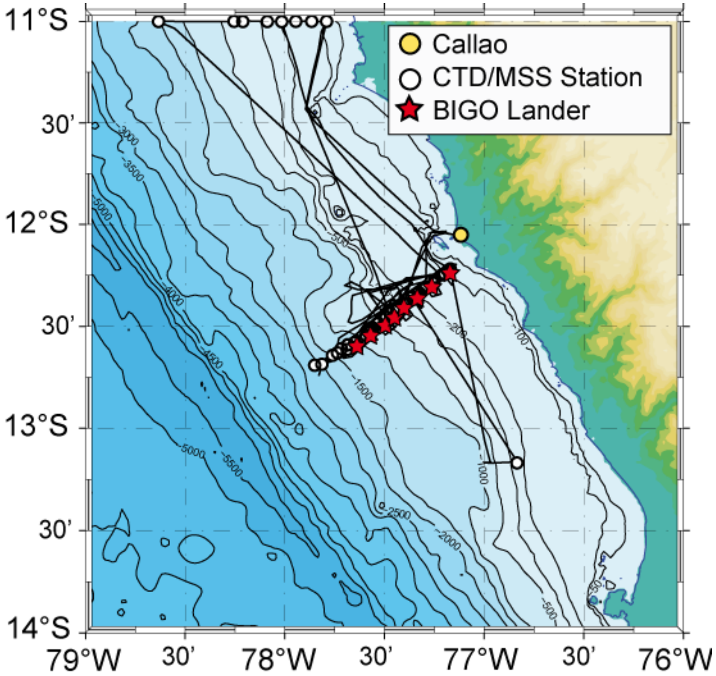
Measurement program of Peru at 12°S in austral summer 2013

Water column program

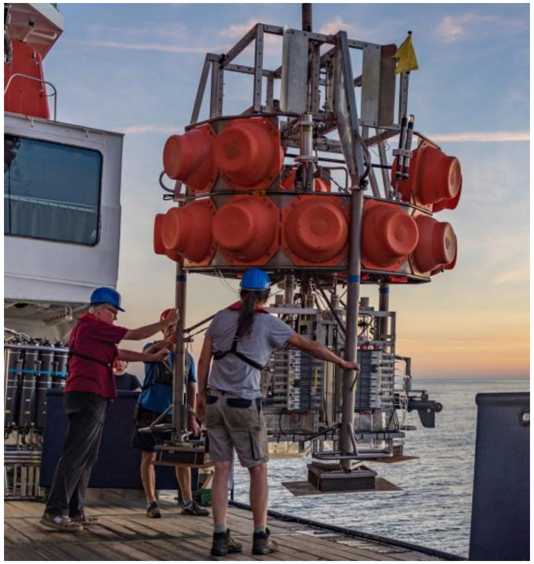
repeated CTD/O_2 stations
Including Nutrients, N_2

> 700 vessel-based microstructure profiles (MSS)

FS Meteor cruise M92
(Jan. 5 - Feb. 3, 2013)



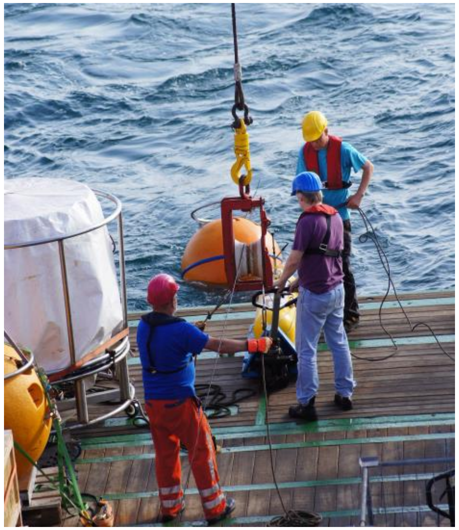
Benthic program



Biogeochemistry Observatory (BIGO) Lander deployments measuring benthic nutrient fluxes

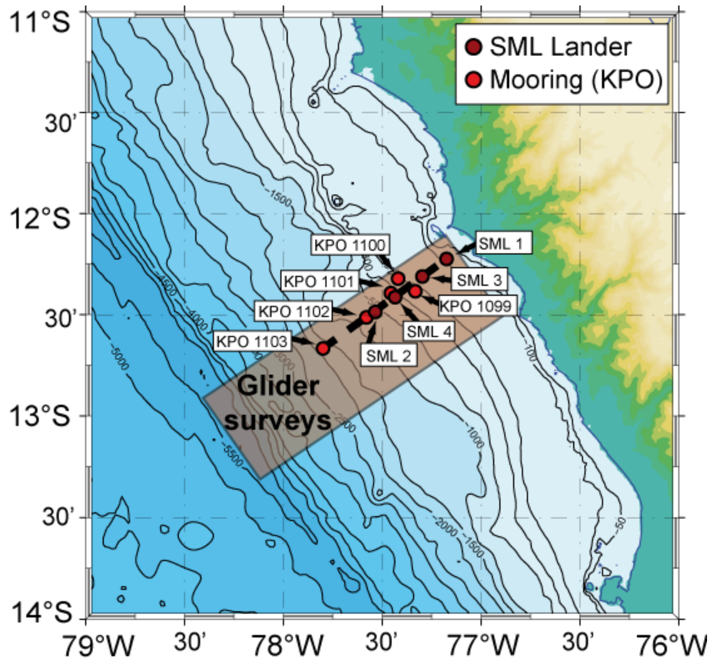
Measurement program of Peru at 12°S in austral summer 2013

mooring program



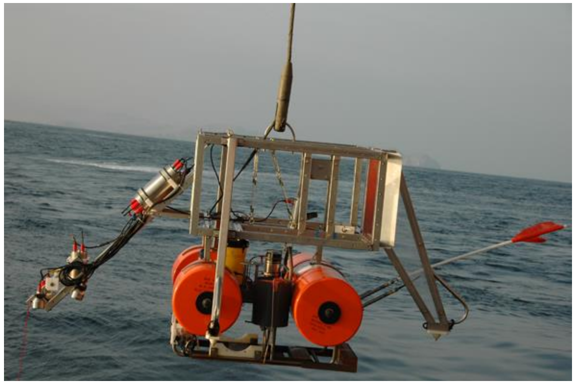
5 moorings with ADCP's and T, S, O_2 recorders

Mooring and lander positions



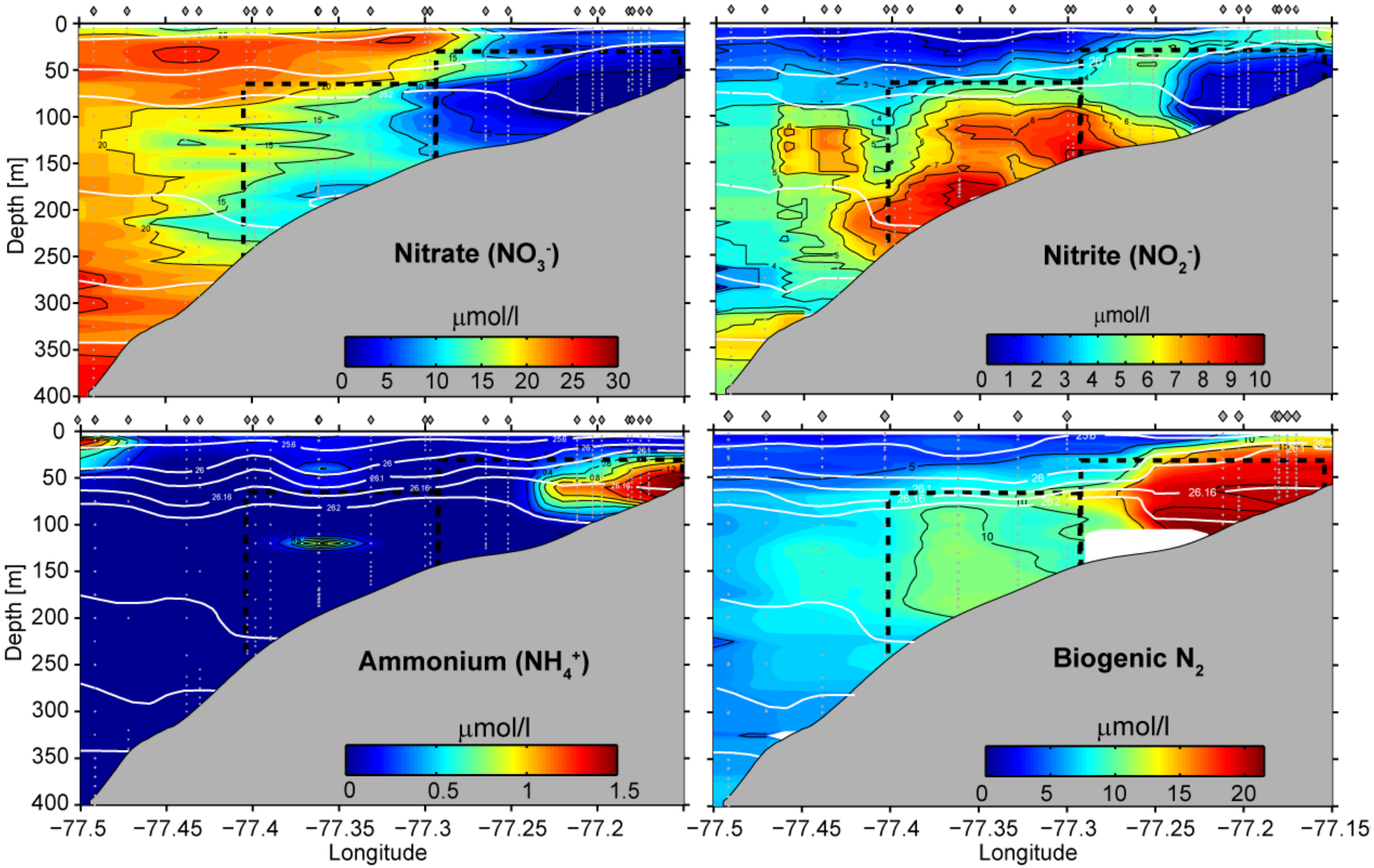
Gliders with microstructure to observe background conditions

lander program

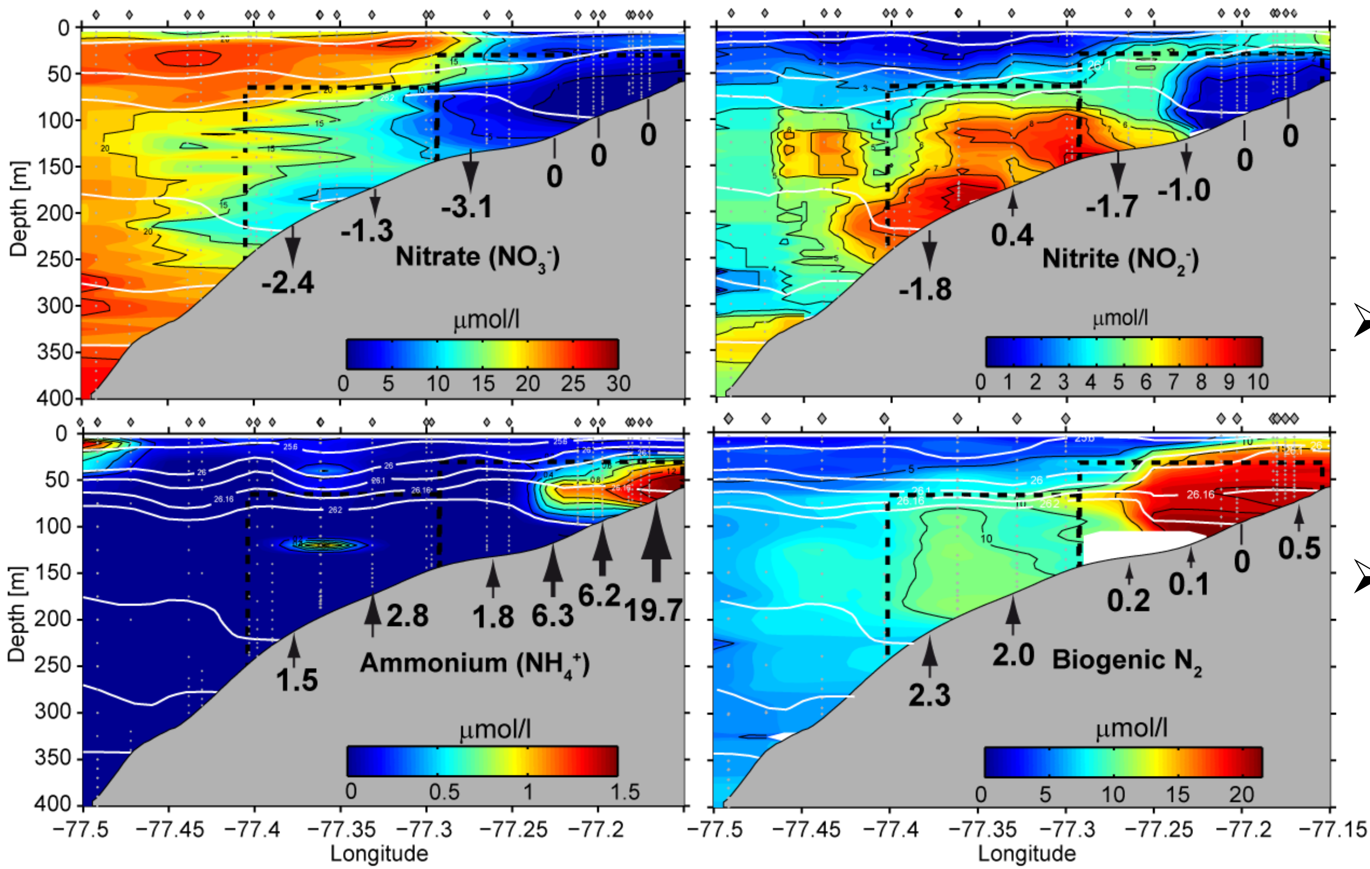


4 small-sized landers with ADCPs and T, S, O_2 recorders

Nitrogen nutrient and N_2 concentrations along 12°S



Benthic flux measurements



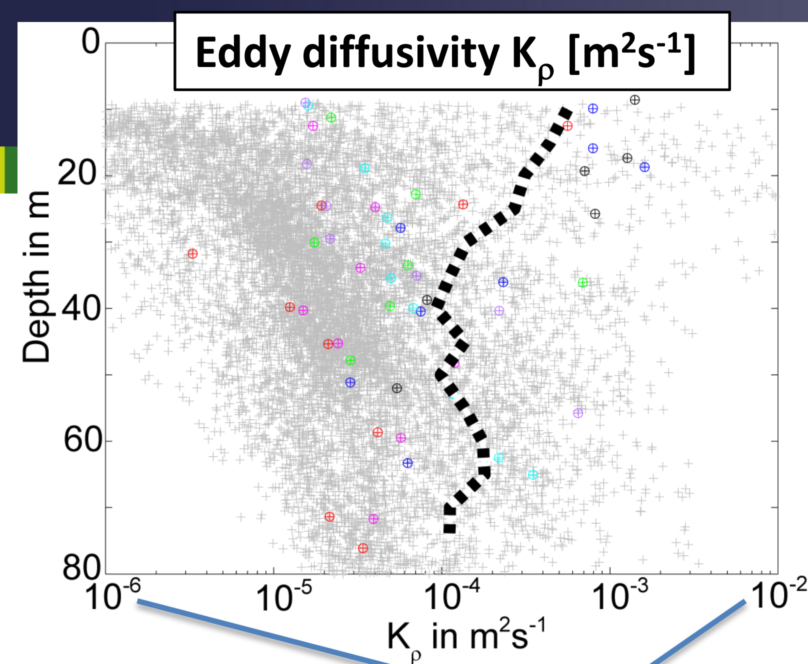
- Nitrate and nitrite are taken up by the sediments, ammonium is released
- Elevated benthic release of ammonium on the shelf (not in equilibrium)

Flux into water column in mmol m^{-2} d^{-1}

(Sommer et al., 2016)

Mixing processes at the continental slope

- Microstructure data show enhanced mixing at the continental slope, particularly near the bottom and near the surface.
- Eddy diffusivities on the slope and shelf are between $1x10^{-4}$ - $5x10^{-3}$ m^2s^{-1}.



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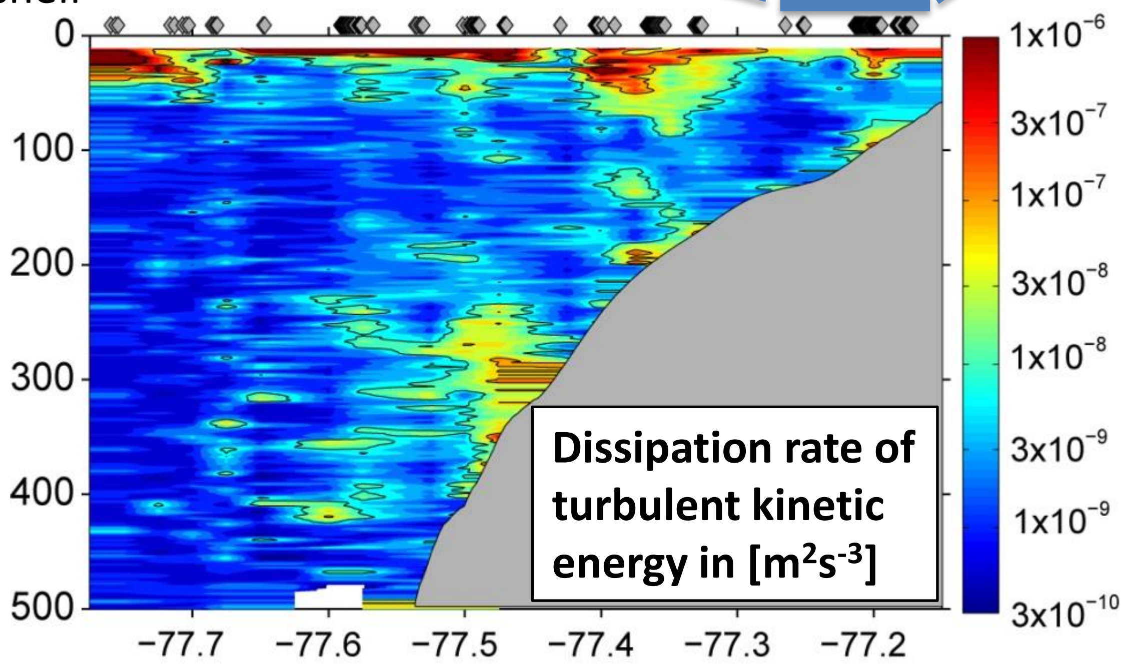
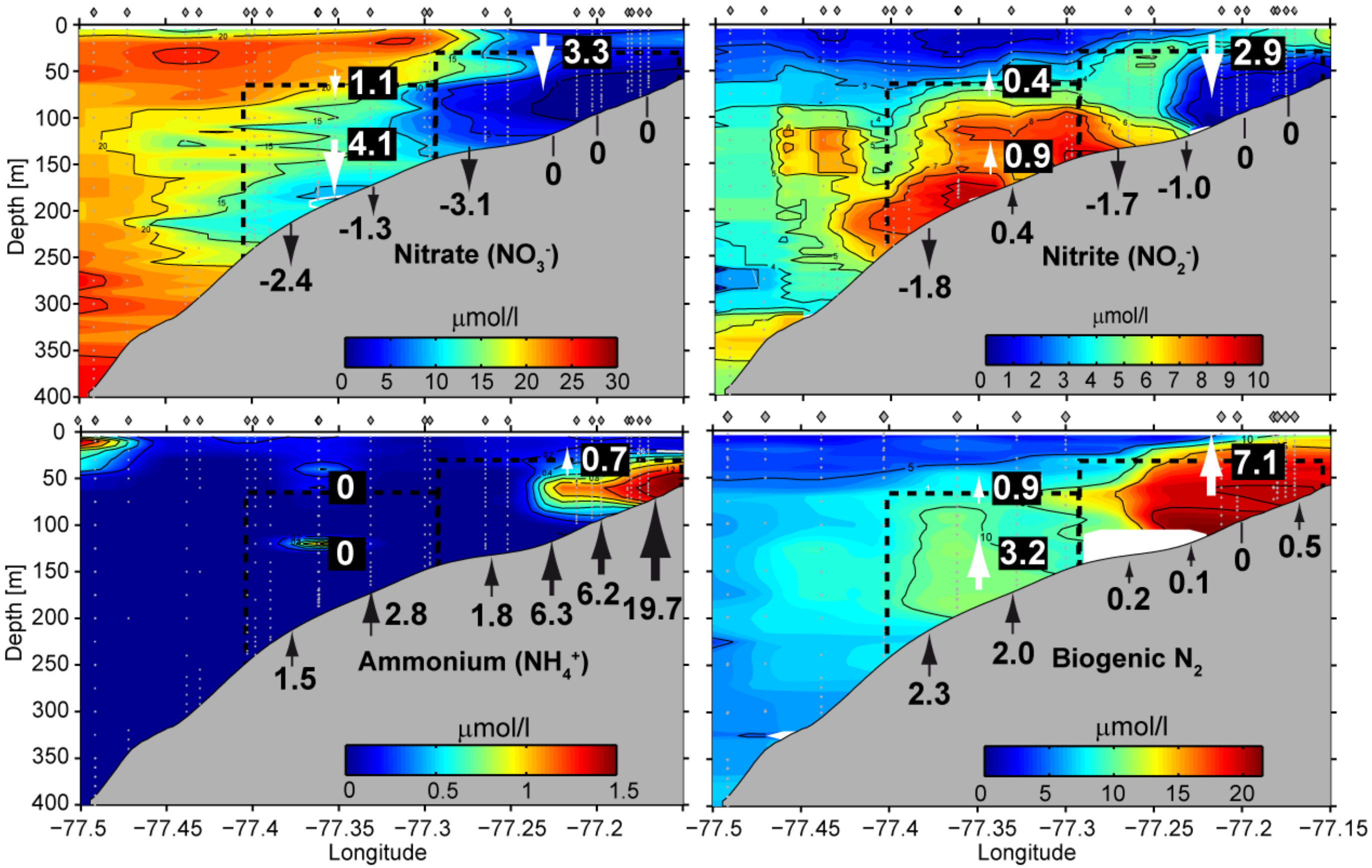


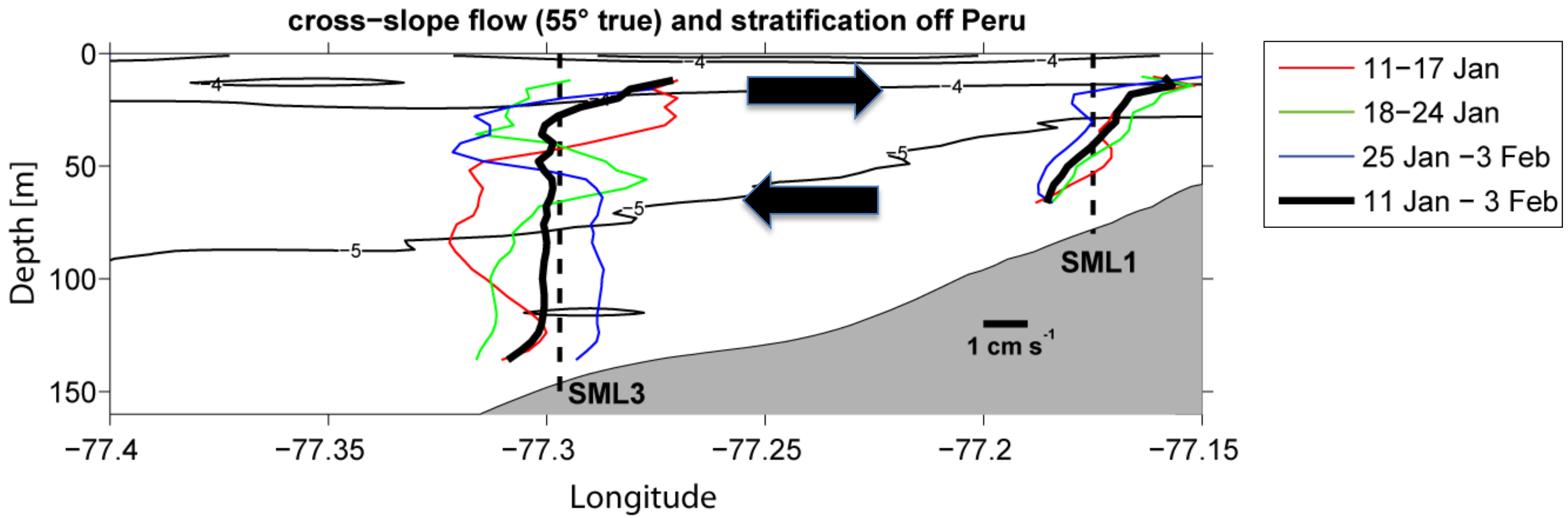
Diapycnal nutrient fluxes



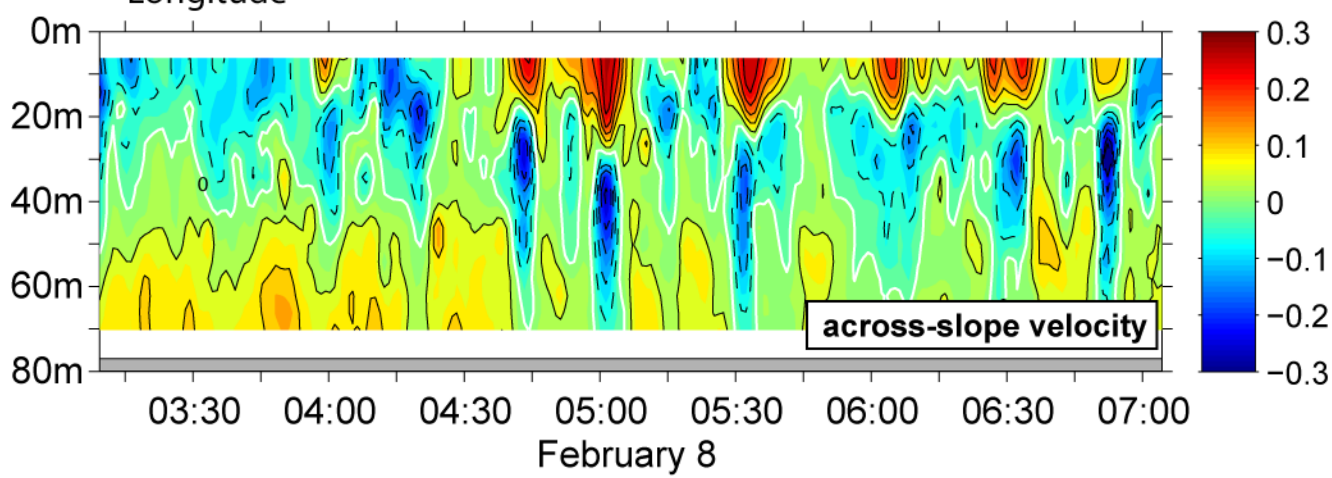
upward flux in mmol m^{-2} d^{-1}

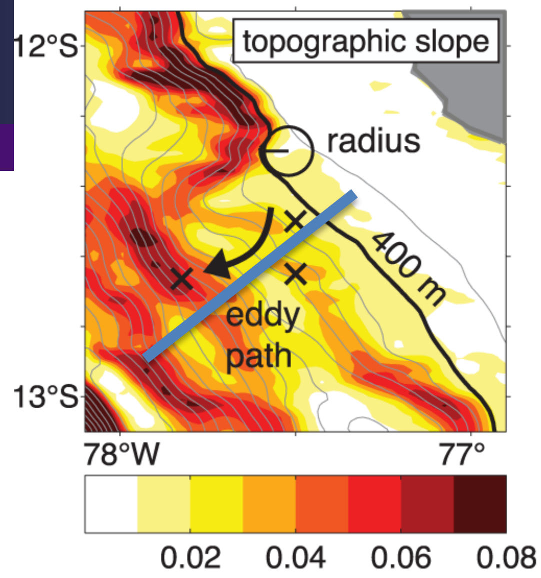
- Nitrate flux towards the sediments is larger than sediment uptake
- Nitrite is transported towards the surface in the deep box but towards the sediments in the shallow box
- Elevated flux of biogenic N_2 towards the surface in the shallow box

Cross-slope velocity on the shelf off Peru



- Nonlinear internal waves induced onshore surface flow exceeding offshore Ekman transport



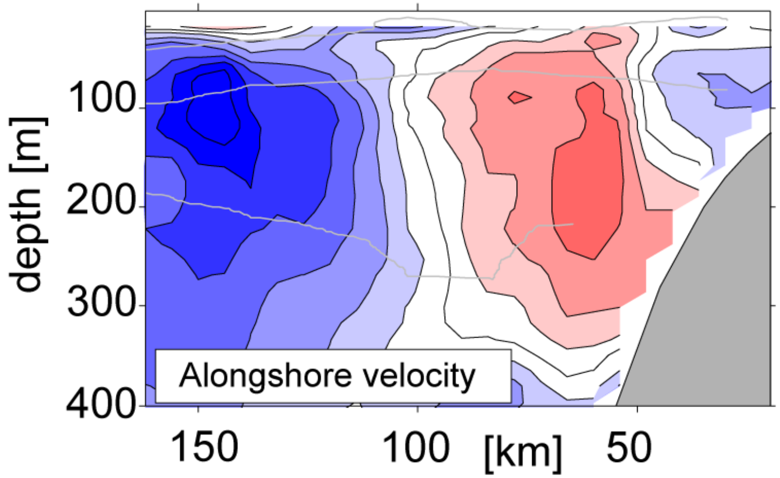


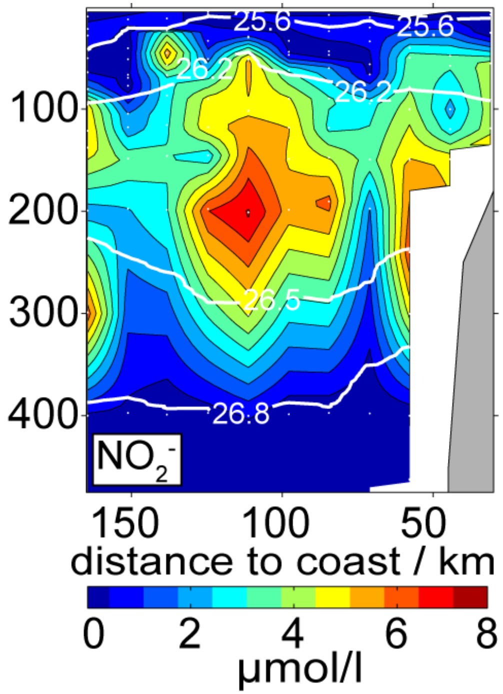
Topographic slope =

$$\left(\left(\partial H/_{\partial x}\right)^2 + \left(\partial H/_{\partial y}\right)^2\right)^{1/2}$$

Subsurface anticyclonic eddies

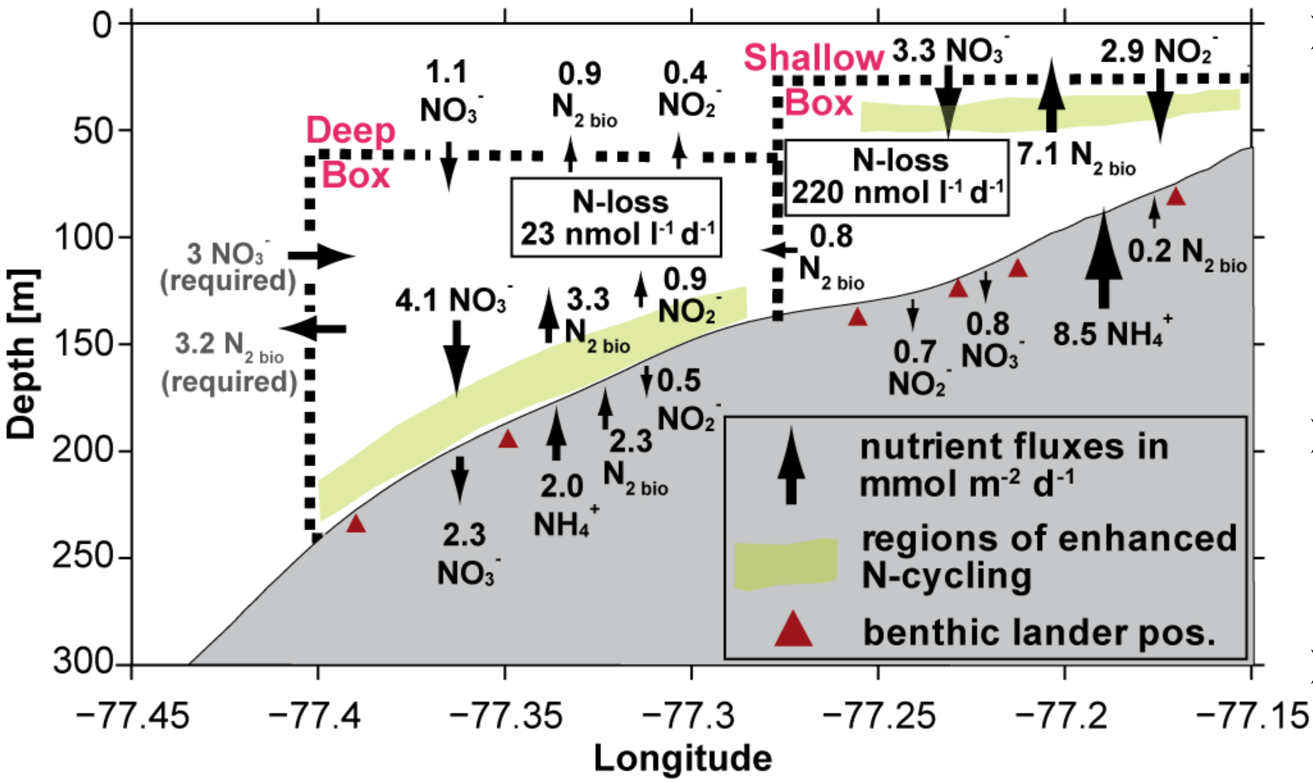
- Subsurface eddies are frequently generated near the 12°S section.
- Eddy induced cross-slope exchange include an onshore flux of nitrate and offshore flux of nitrate and $N_{2\ biogenic}$.





(Thomsen et al., 2016)

Coupled benthic-pelagic nutrient budget off Peru



N-loss: Shallow Box (112 < 220 < 368) nmol l^{-1} d^{-1}
Deep Box (12 < 23 < 41) nmol l^{-1} d^{-1}

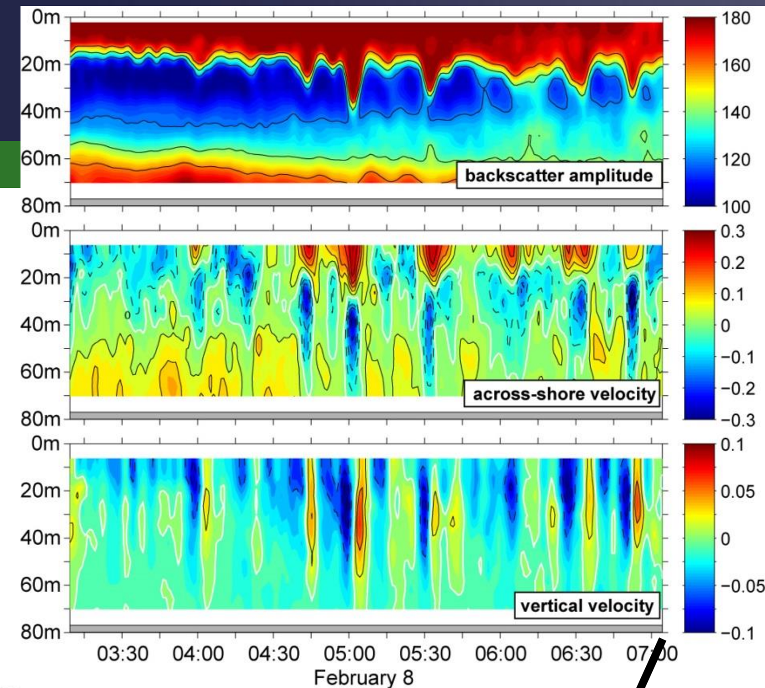
95% - confidence is large due to individual flux uncertainties!

- On the shelf, enhanced sediment release of ammonium (NH_4) and diapycnal flux convergences of nitrate and nitrite result in elevated N-loss.
- N-loss on the continental slope is lower by an order of magnitude.
- Nutrient budget estimates agree well with the flux divergence of biogenic N_2.

Conclusions:

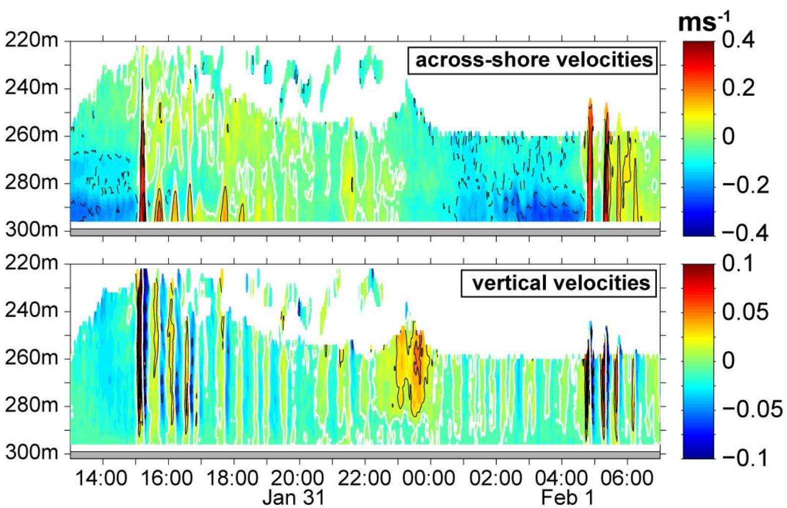
- Estimates of N-loss from the benthic-pelagic nutrient budget indicate lower N-loss than inferred previously.
- Study suggests that water-column NH_4 sources play only a minor role for N cycling processes along the continental margin of Peru.
- Results highlight diapycnal mixing and eddy induced cross-slope exchange as a key transport mechanism sustaining benthic and pelagic nutrient cycling.

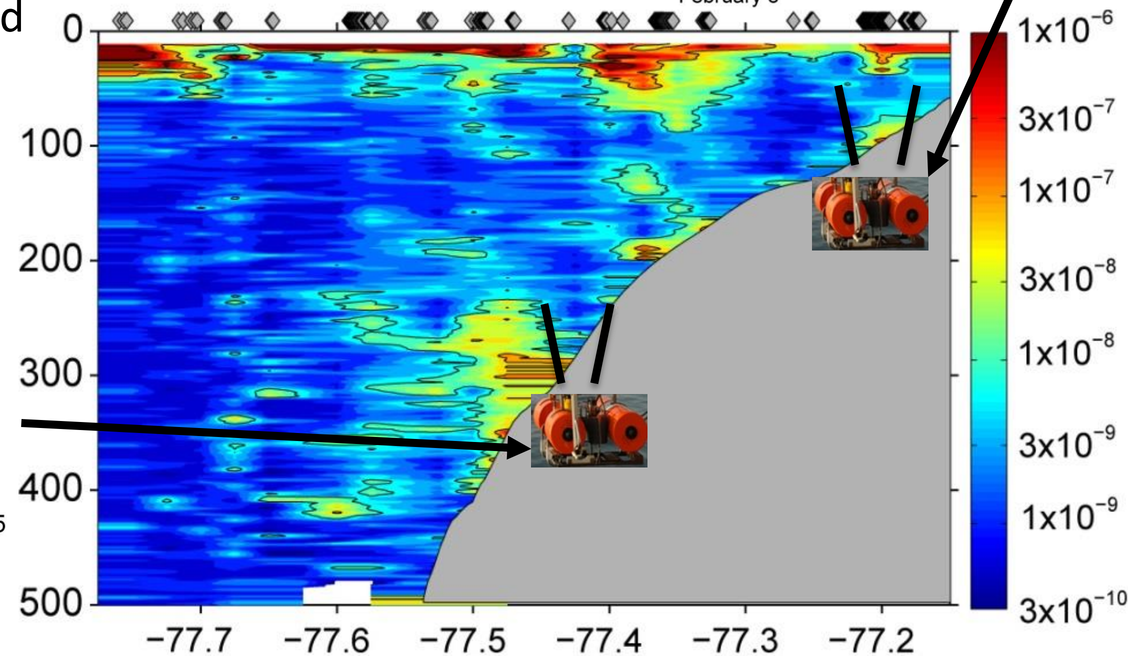
Thank you



Mixing processes at the continental slope

- ➢ Energetic nonlinear internal wave trains are regularly observed resulting from instability of baroclinic tides.
- ➢ Individual waves have frequencies near N and contribute elevated mixing and diapycnal nutrient fluxes.





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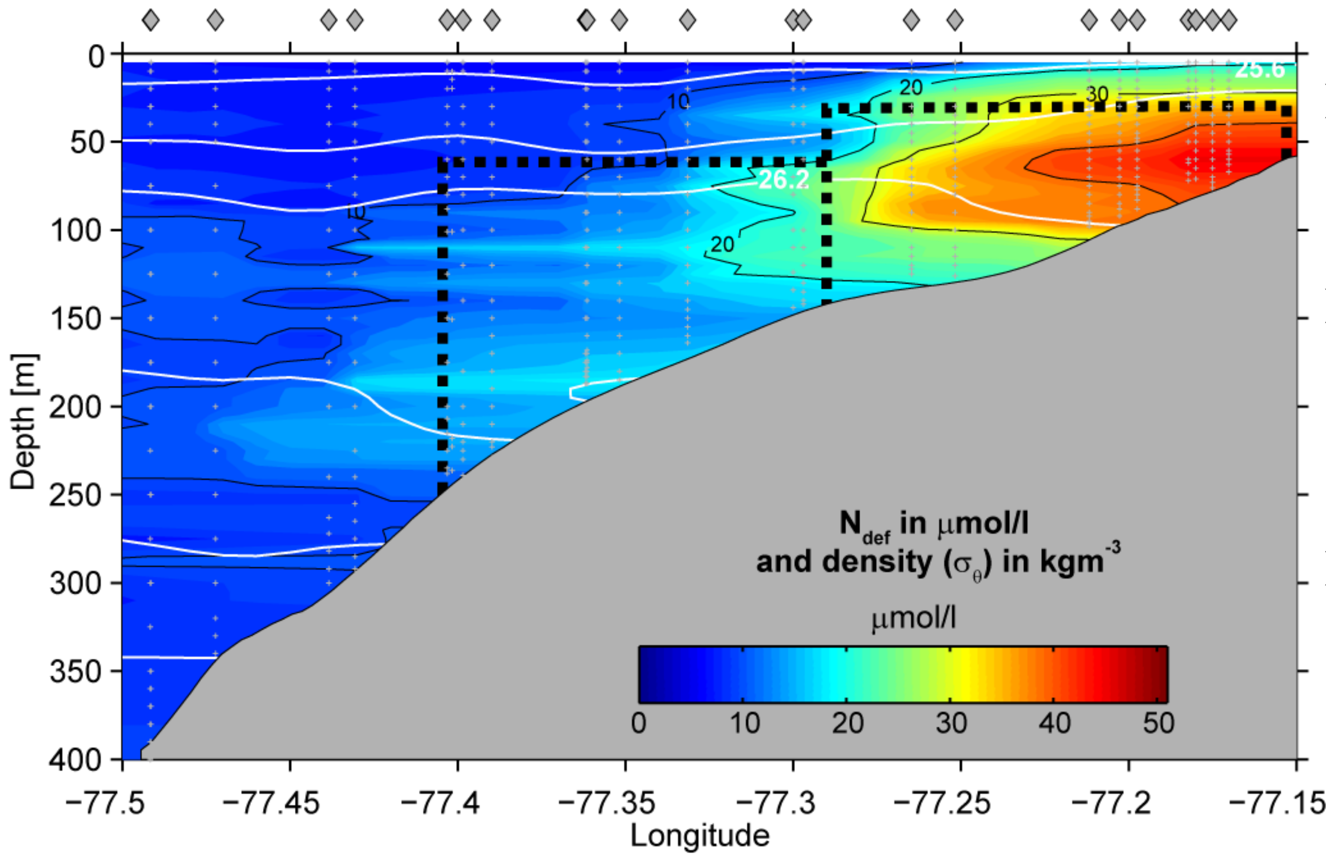
Deficit of nitrogen nutrient (N_{def}) along 11°S



- atomic ratio of nitrogen and phosphorus should be constant
- N_{def} indicates loss of nitrogen nutrients due to anaerobic bacterial respiration.
- Boxes define regions where nutrient budgets were performed

$N_{def} = 15.8\,(PO_4^{3-} - 0.3) - (NO_3^- + NO_2^- + NH_4^+)$ (Chang et al., 2010)