Nitrogen loss in Oxygen Deficient Zone Mesoscale Eddies

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1 WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

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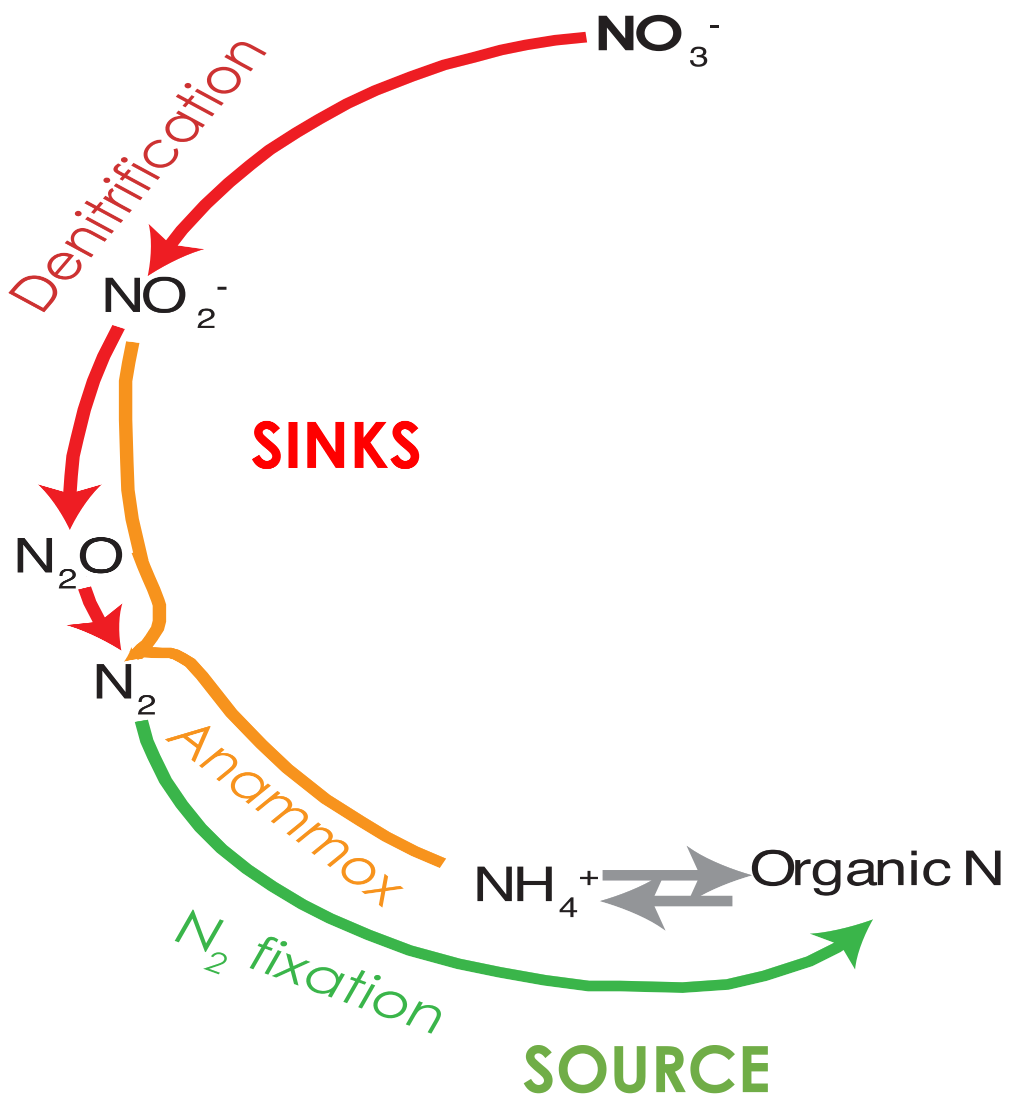
Marine nitrogen cycling

Balance between N_2 fixation and fixed N-loss: implications for primary productivity, CO_2 sequestration and climate change.

Oxygen Deficient Zones: 0.1% of oceanic volume, 30 to 50% of global fixed N-loss.



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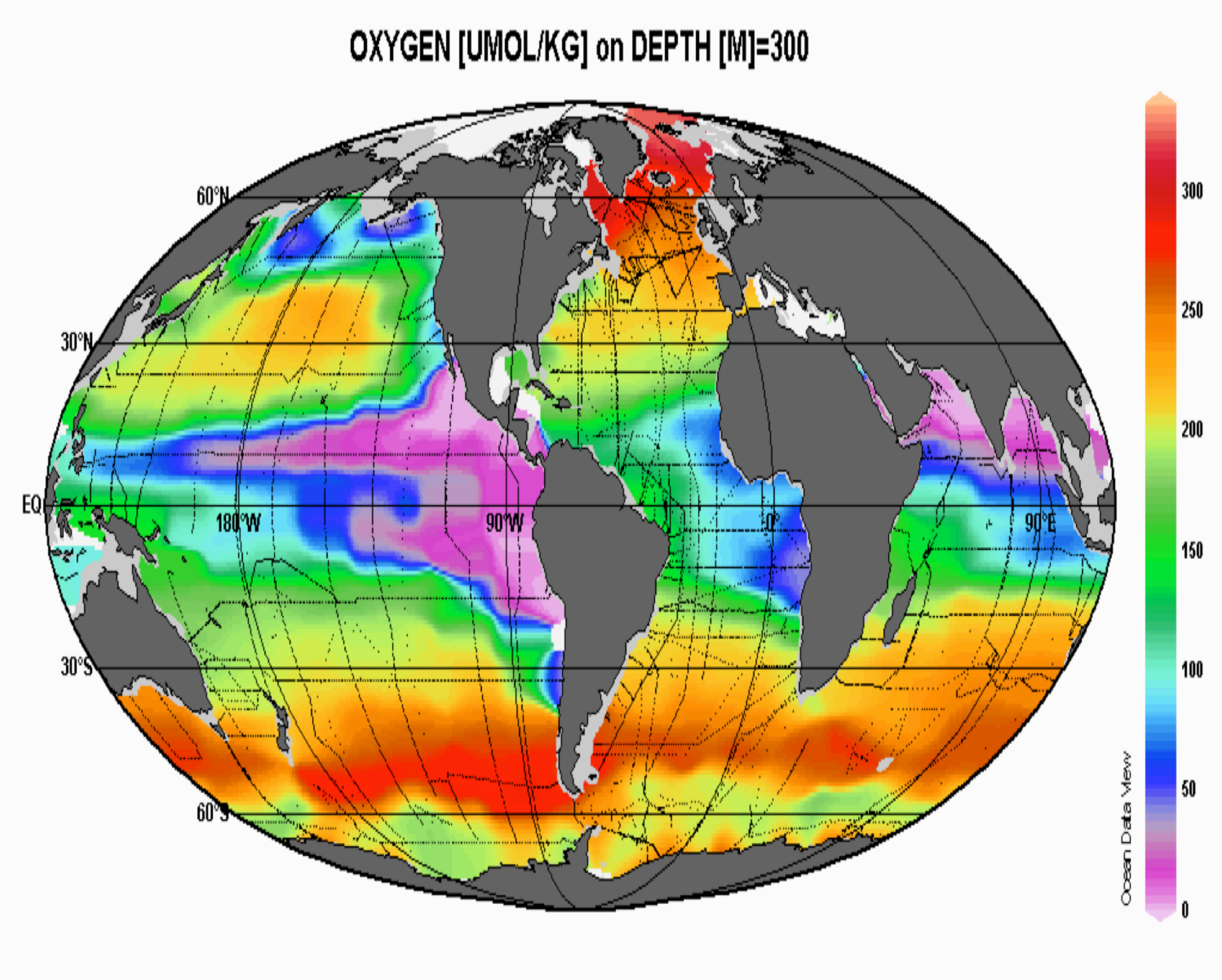


Global marine N budget

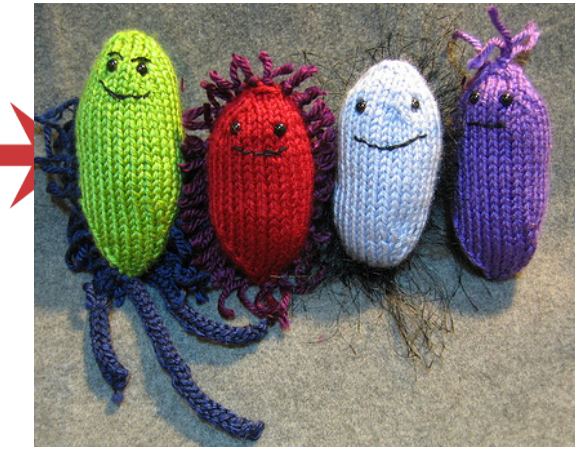
Process (in Tg (10^{12} g) /year)	Codispoti (2001; 2007)	Gruber (2004; 2008)	Eugster and Gruber (2012)
N_2 fixation	>>>135	135 ± 50	94 to 175
Water column N-loss	>>150	65 ± 20	39 to 66
Benthic N-loss	>300	180 ± 50	68 to 122
(%) Benthic N-loss/ Total N-loss	~65	~75	~65
Total (all sources and sinks)	-230	-10 ± 110	-40 to 40

Stable isotopes as tracer of N-cycle processes

Kinetic isotope fractionation: e.g., denitrifiers preferentially assimilate lighter isotopes, leaving substrate (NO_3^-) enriched in ^{15}N

^{14}N (99.6%), ^{16}O (99.8%)

^{15}N (0.4%), ^{18}O (0.2%)



δ notation in ‰:

$(R_{sample}/R_{standard} - 1) \times 1000$

R : isotopic ratio (ex: $^{15}N/^{14}N$)

Standards: AIR for nitrogen and V-SMOW for oxygen.

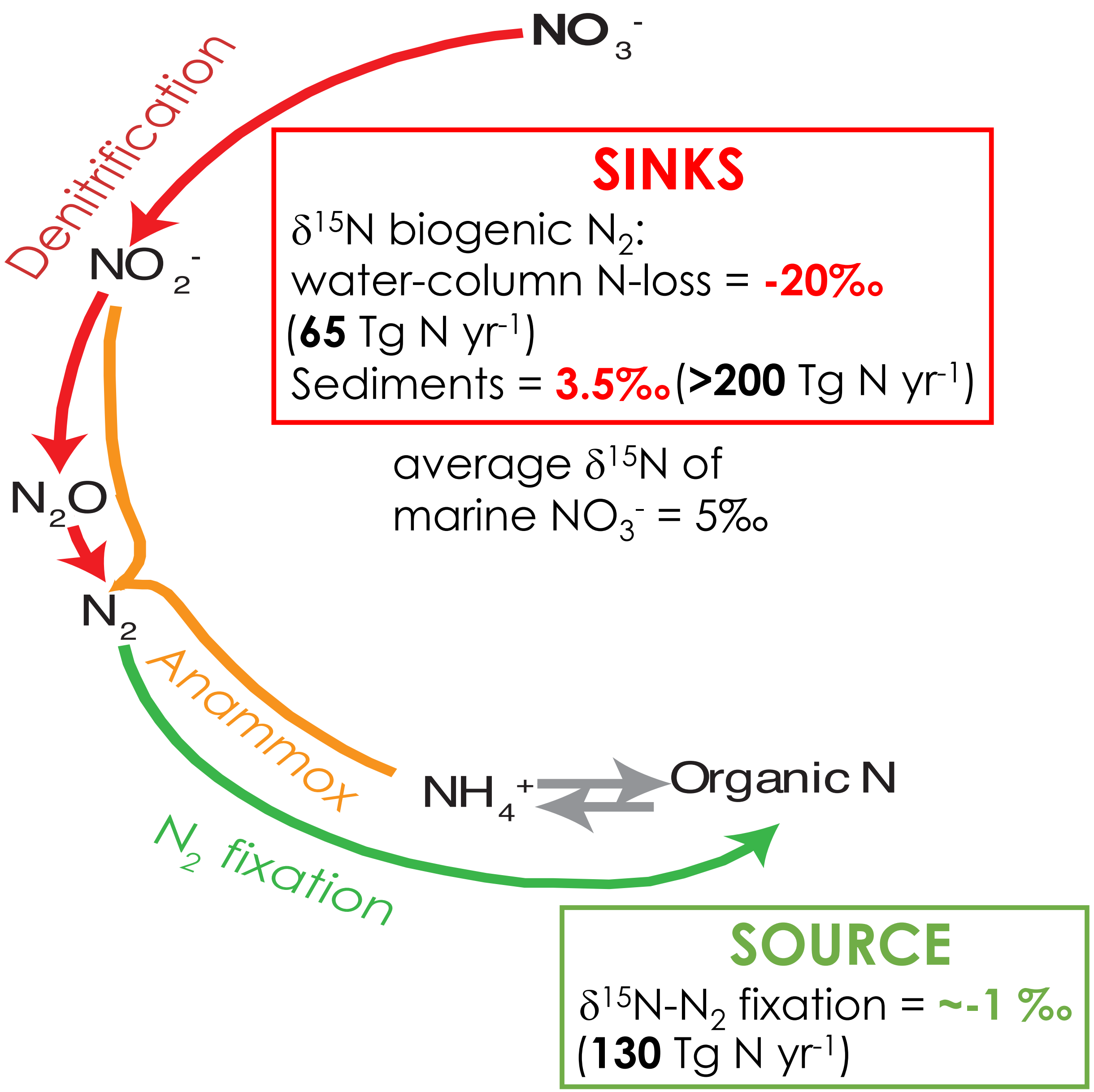
Isotope mass balance

Sedimentary N-loss is determined by isotope mass balance

$\varepsilon = \delta^{15}N_{substrate} - \delta^{15}N_{product}$
$\delta^{15}N_{product} = \delta^{15}N_{substrate} - \varepsilon$

N-loss:
water-column: high ε of 25‰
sediments: suppressed ε of ~1.5‰

Sedimentary N-loss ≈ 75% of total N loss.



Role of mesoscale processes for N-loss in ODZs

Biogeosciences, 9, 4897–4908, 2012
www.biogeosciences.net/9/4897/2012/
doi:10.5194/bg-9-4897-2012

Biogeosciences

An eddy-stimulated hotspot for fixed nitrogen-loss from the Peru oxygen minimum zone

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[4]Max Planck Institute for M

Correspondence to: M. A. A

Received: 30 May 2012 – P
Revised: 25 October 2012 –

Abstract. Fixed nitrogen (N
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Biogeosciences, 10, 7293–7306, 2013
www.biogeosciences.net/10/7293/2013/
doi:10.5194/bg-10-7293-2013

Biogeosciences Open Access

On the role of mesoscale eddies for the biological productivity and biogeochemistry in the eastern tropical Pacific Ocean off Peru

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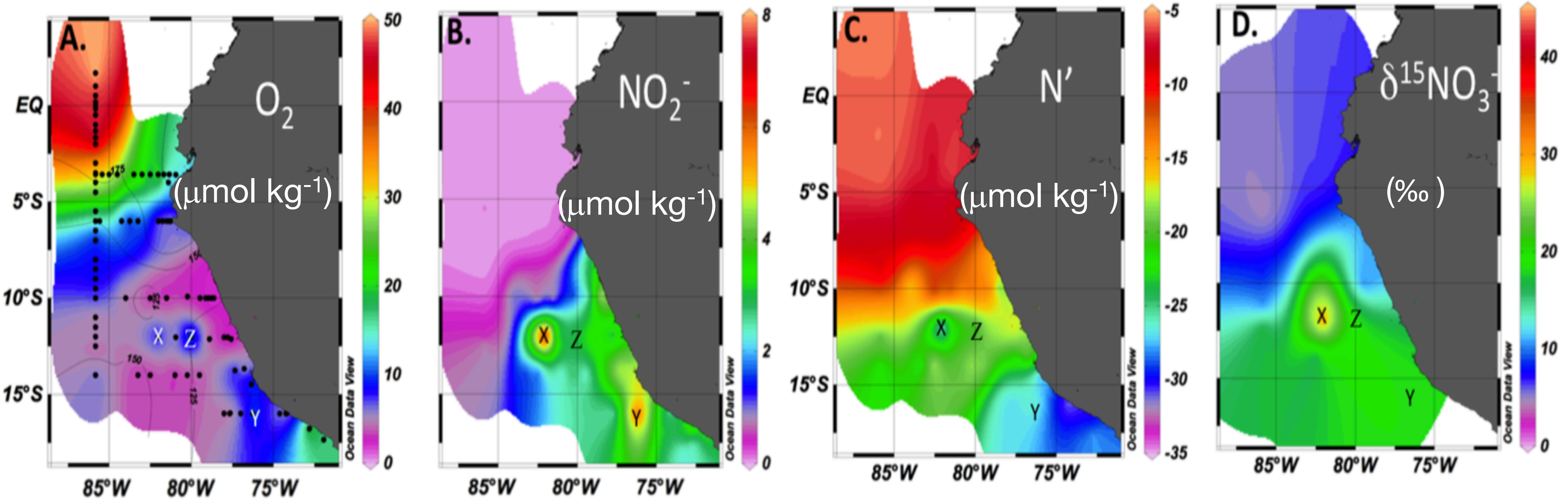
Revised: 11 October 2013 – Accepted: 13 October 2013 – Published: 14 November 2013

Abstract. Mesoscale eddies seem to play an important role for both the hydrography and biogeochemistry of the eastern tropical Pacific Ocean (ETSP) off Peru. However, detailed surveys of these eddies are not available, which has ferences between the young and old mode water eddies. The coastal mode water eddy was found to be a site of nitrogen (N) loss in the OMZ with a maximum ΔNO_3^- anomaly (i.e. N loss) of about $-25\,\mu mol\,L^{-1}$ in 250 m water depth, whereas,

Mesoscale eddies as N-loss hotspots

($\sigma_\theta = 26.3$, depth = 100 to 170 m)



stn X at the edge of an anticyclonic eddy.

Are eddies N-loss hotspots?

DIN deficit (N')= $DIN_{expected} - DIN_{observed}$, $DIN_{expected} = 16 \times [PO_4^{3-}]$

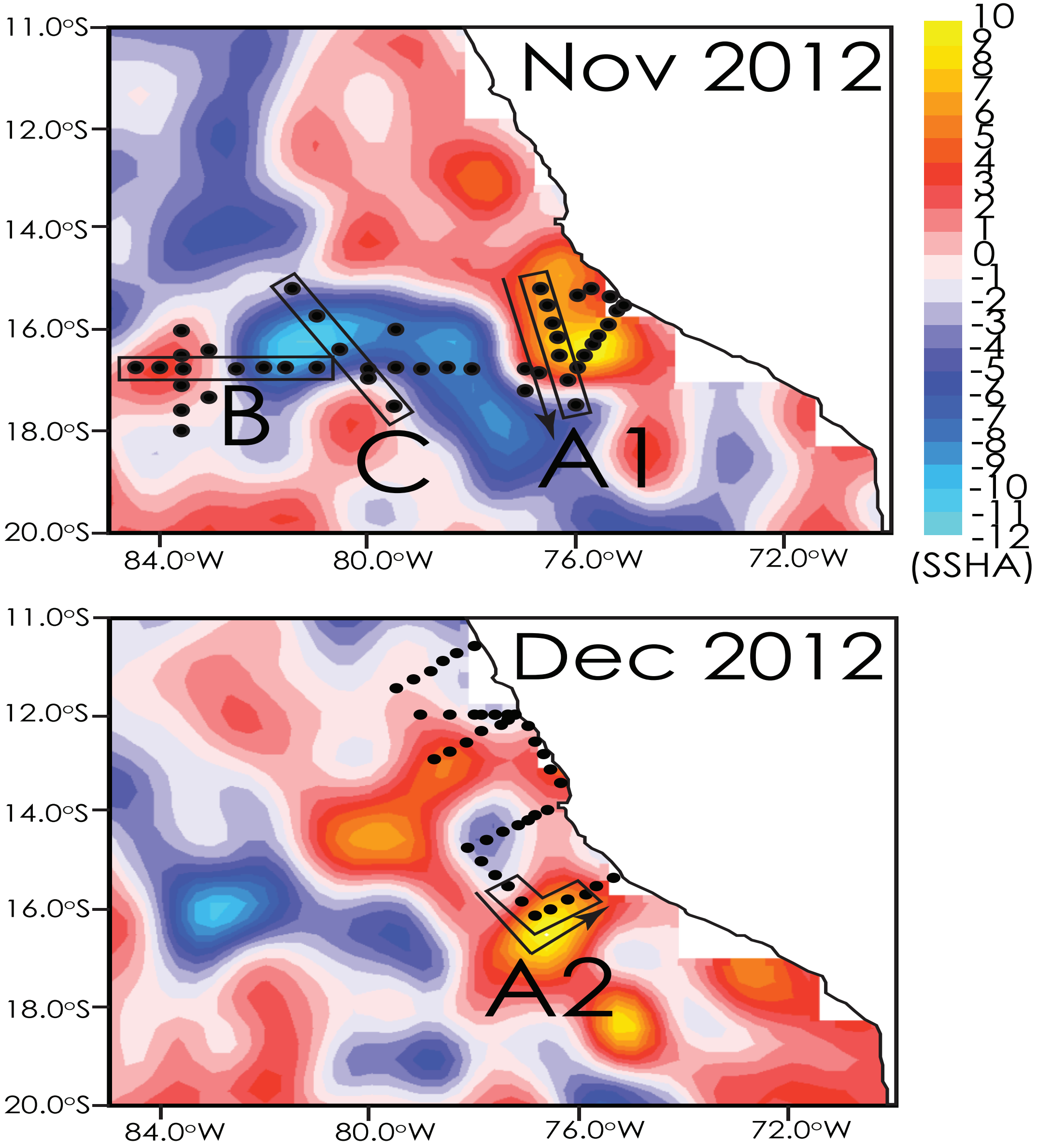
Altabet *et al*., *Biogeosciences*, 2012

Mesoscale eddies as N-loss hotspots

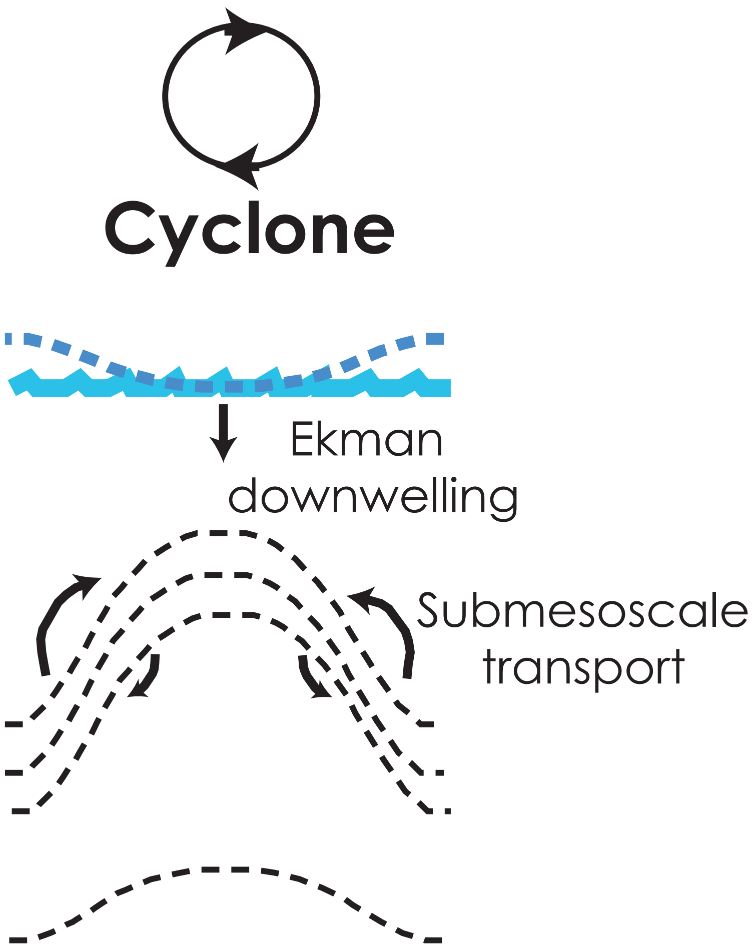
Eddies off Peru sampled in November and December 2012.

SFB (Sonderforschungsbereich) 754: Climate – Biogeochemistry interactions in the Tropical Ocean

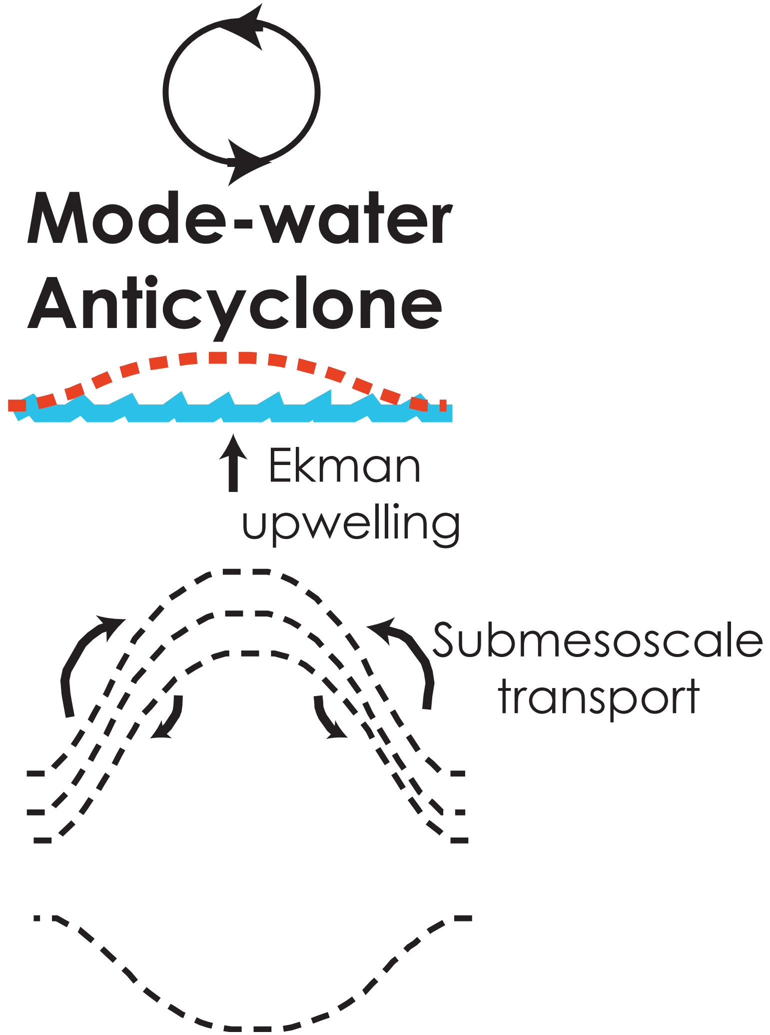
SFB 754



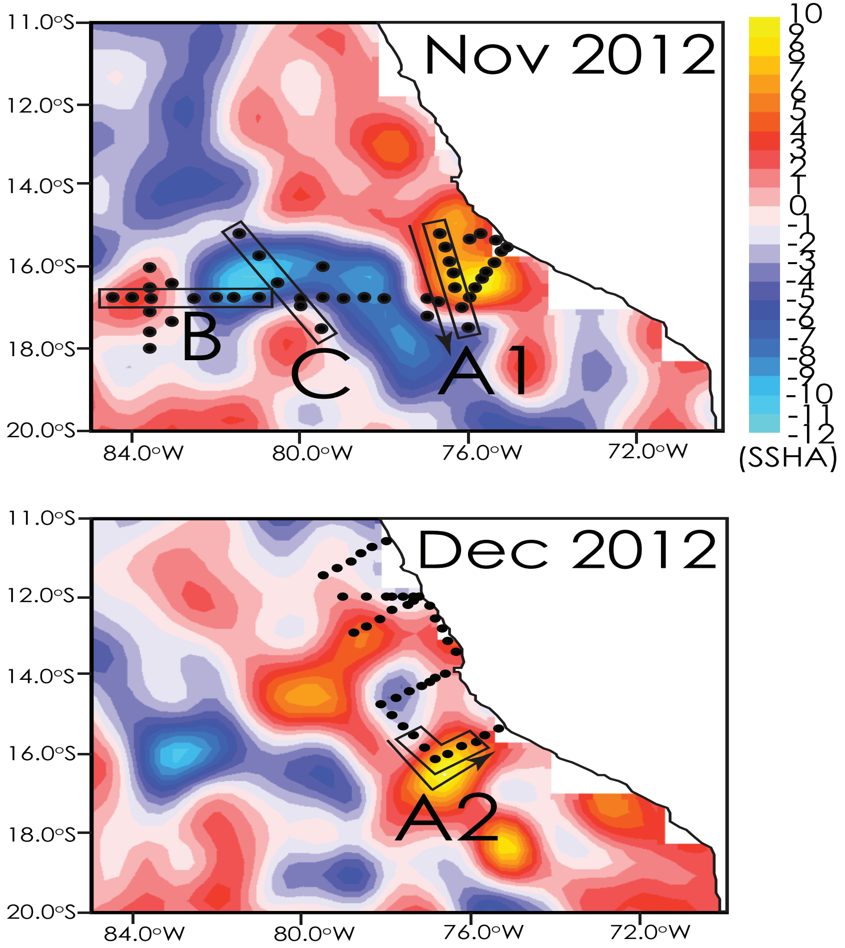
Eddy types



Eddies **C**

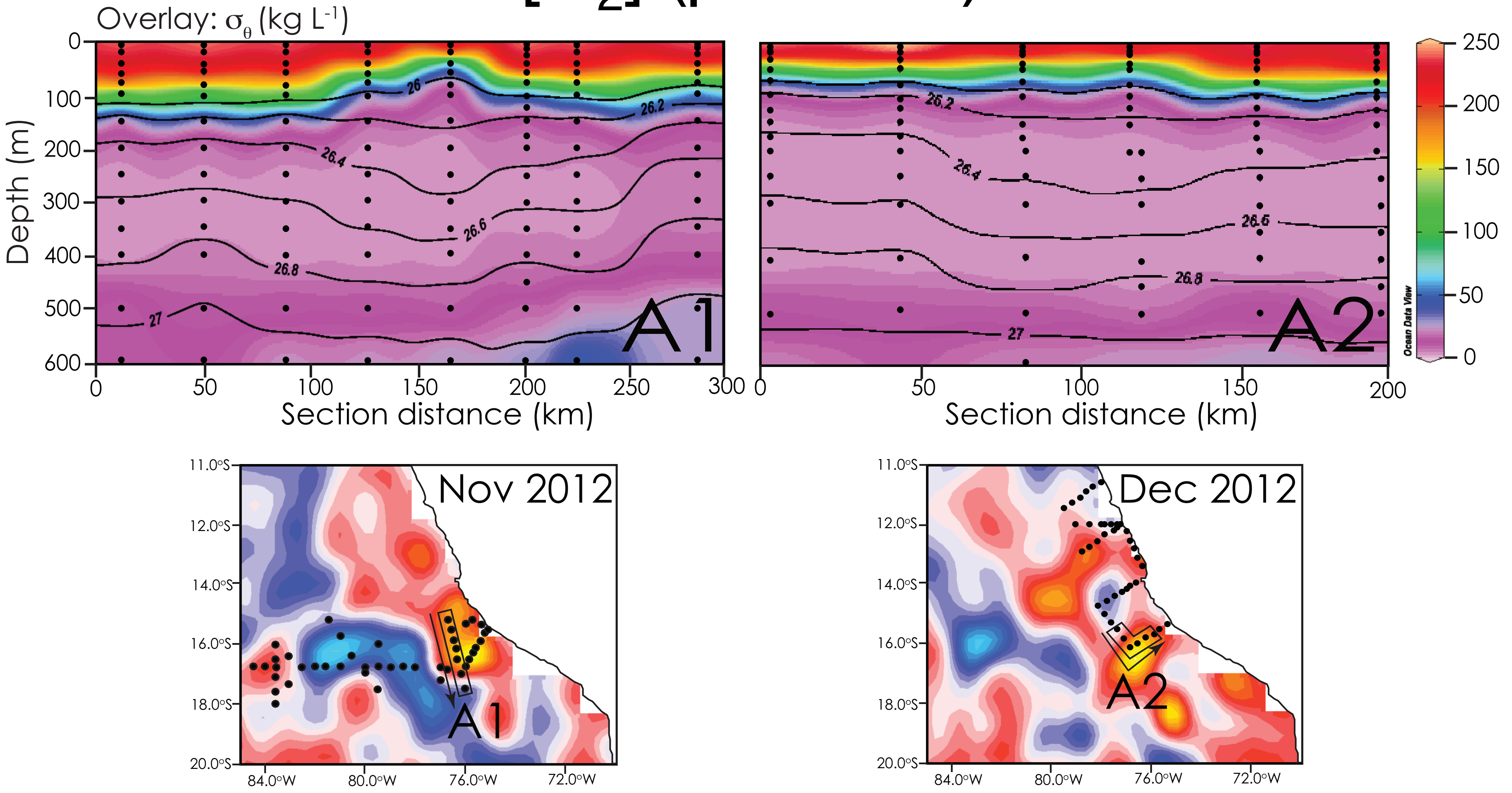


Eddies **A1** (2-3 months old), **B** (5 months old)



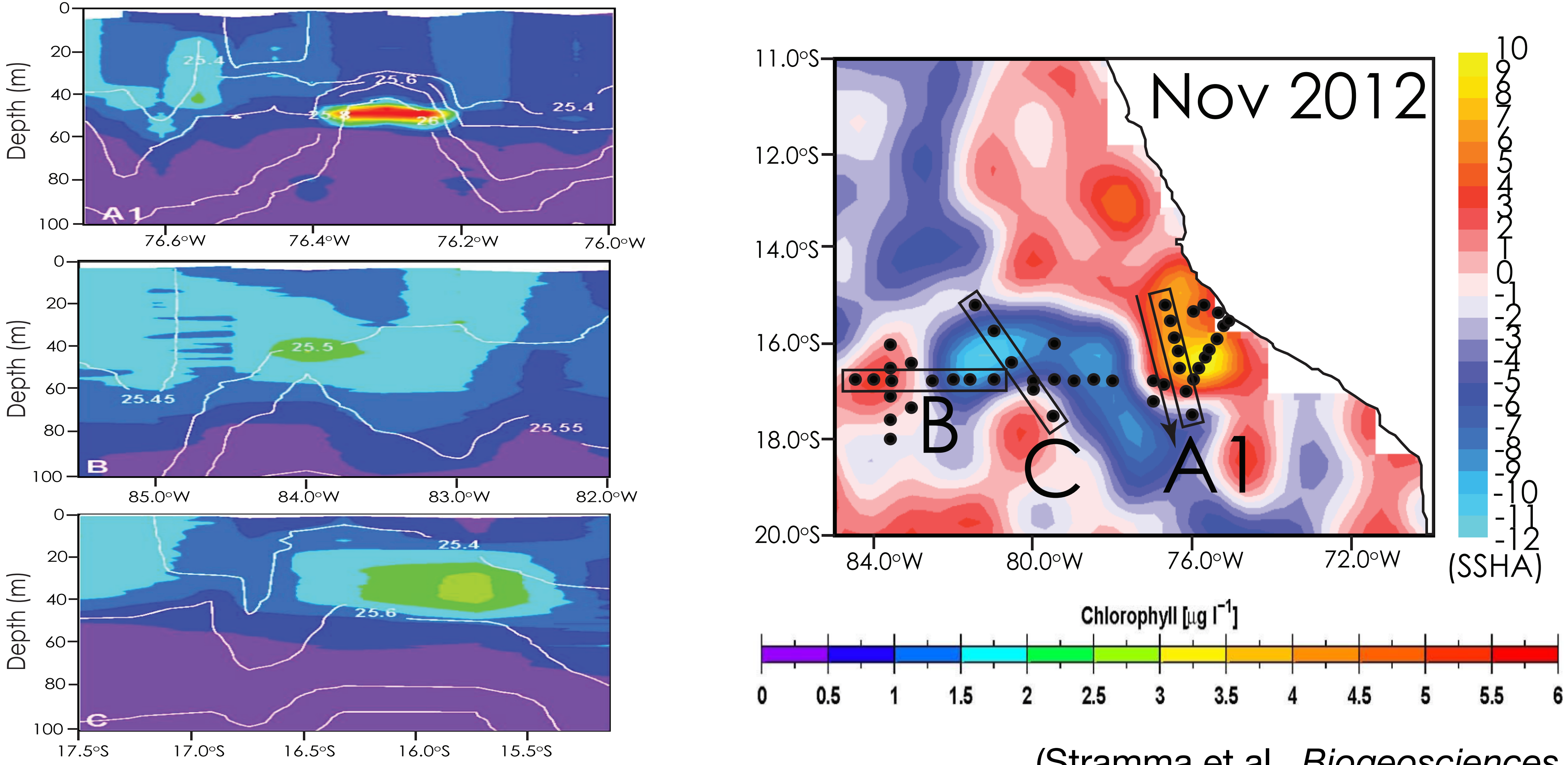
Eddies as N-loss hotspots

$[O_2]$ (µmol L^{-1})



(Stramma et al., *Biogeosciences*, 2013)

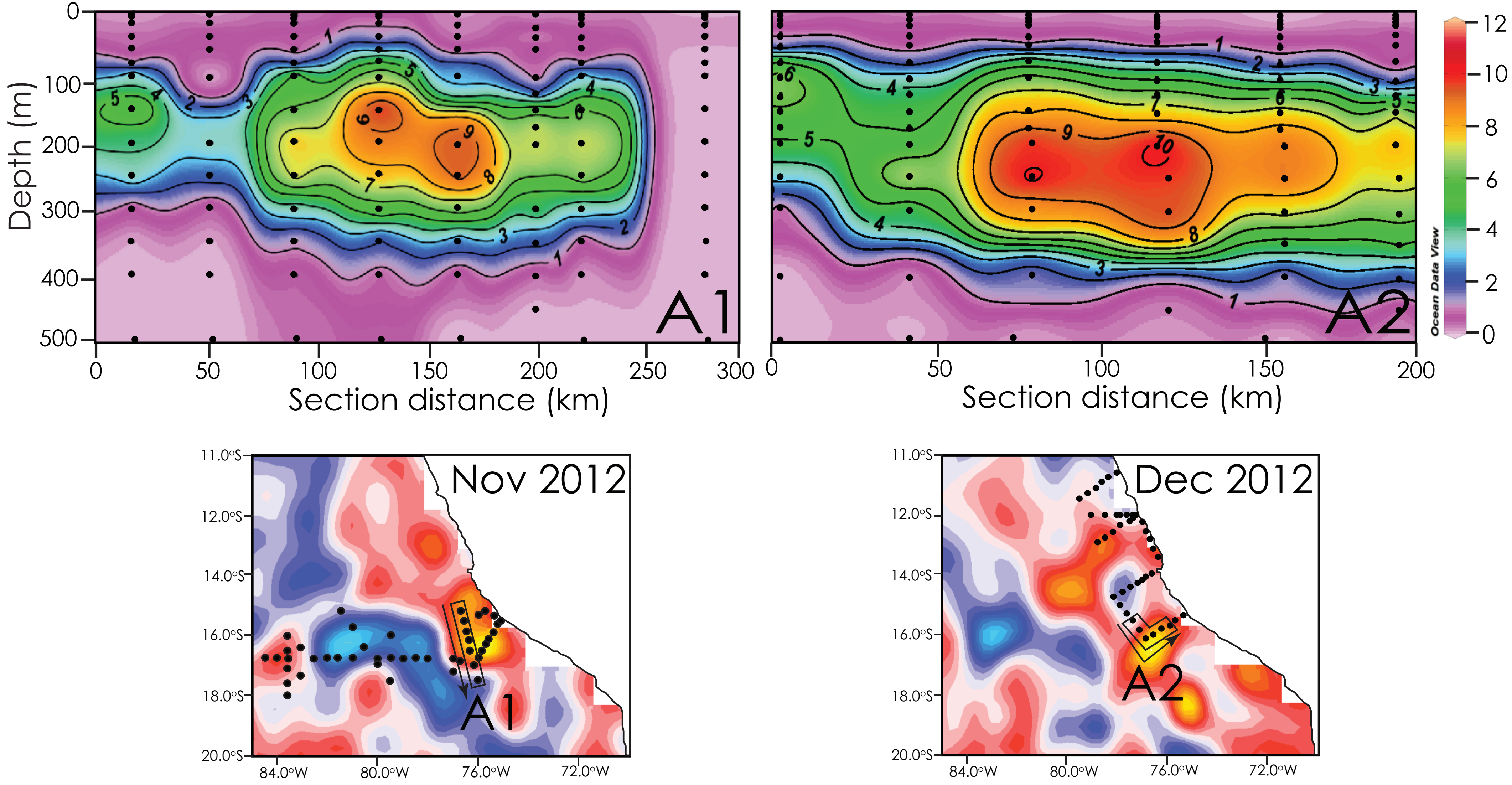
Eddies as N-loss hotspots
Chlorophyll



(Stramma et al., *Biogeosciences*, 2013)

Eddies as N-loss hotspots

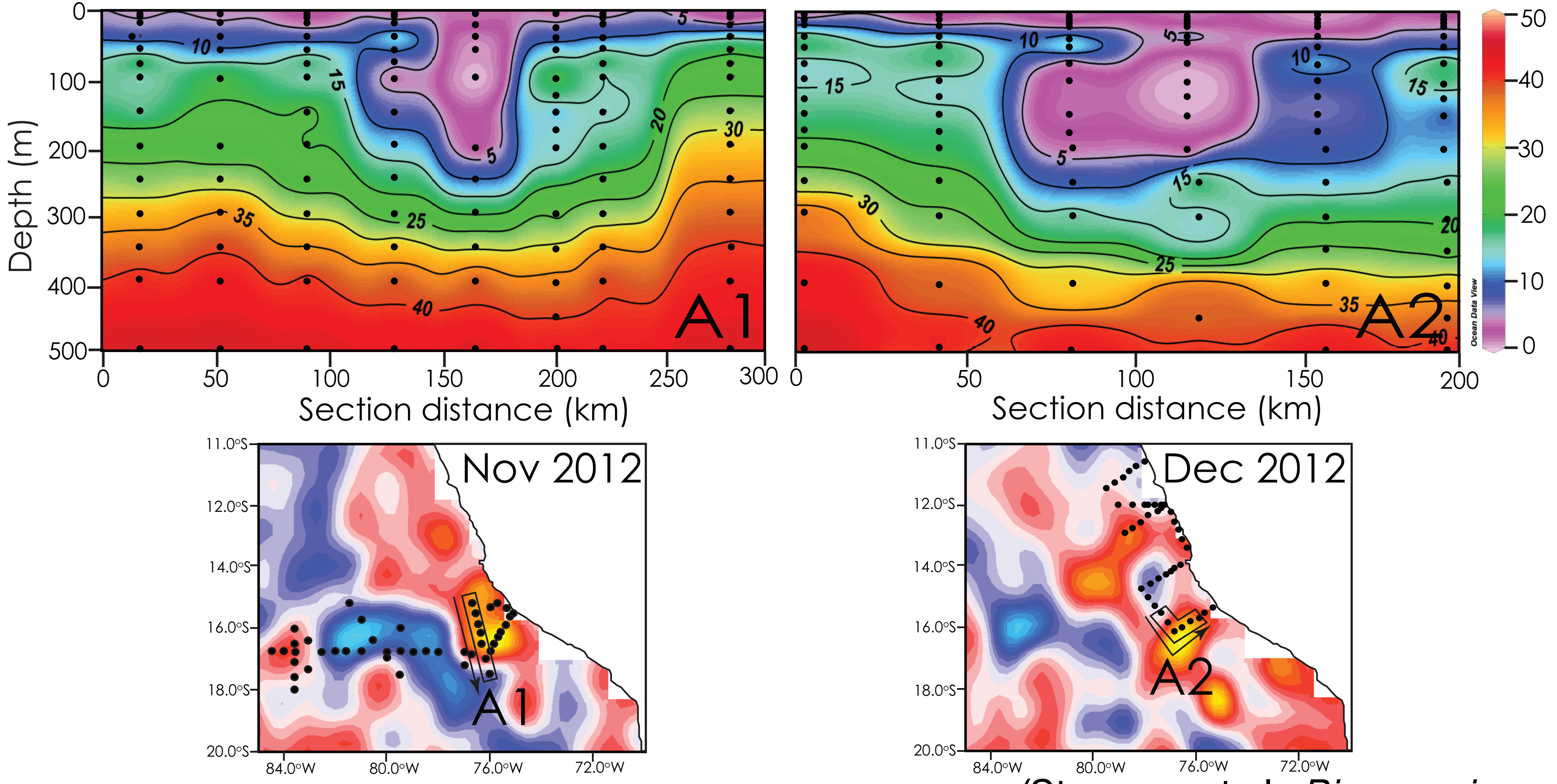
[NO_2^-] up to 12 µmol L^{-1}



(Stramma et al., *Biogeosciences*, 2013)

Eddies as N-loss hotspots

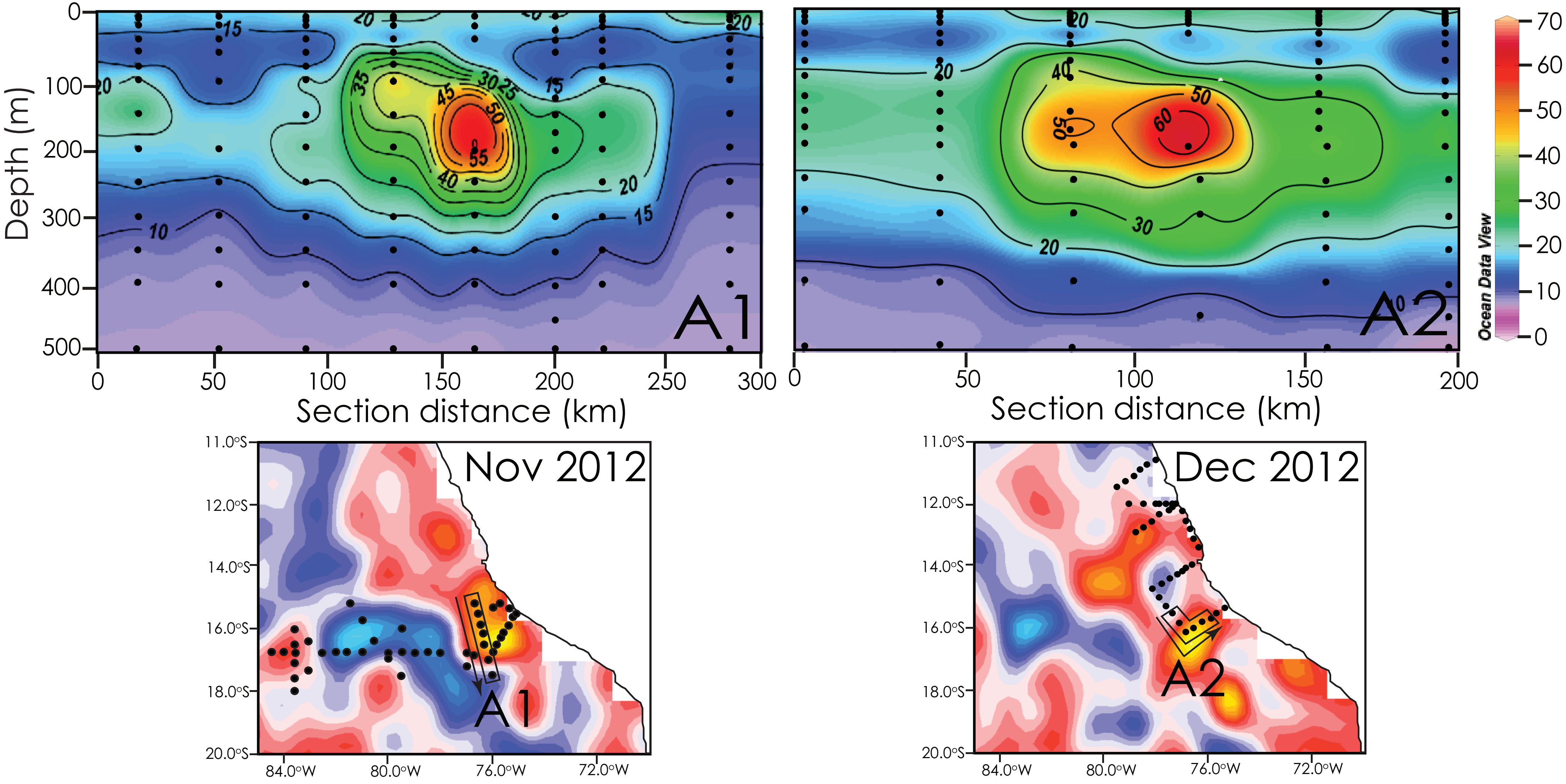
$[NO_3^-]$ (μmol L^{-1})



(Stramma et al., *Biogeosciences*, 2013)

Eddies as N-loss hotspots

$\delta^{15}N-NO_3^-$ up to 70 ‰

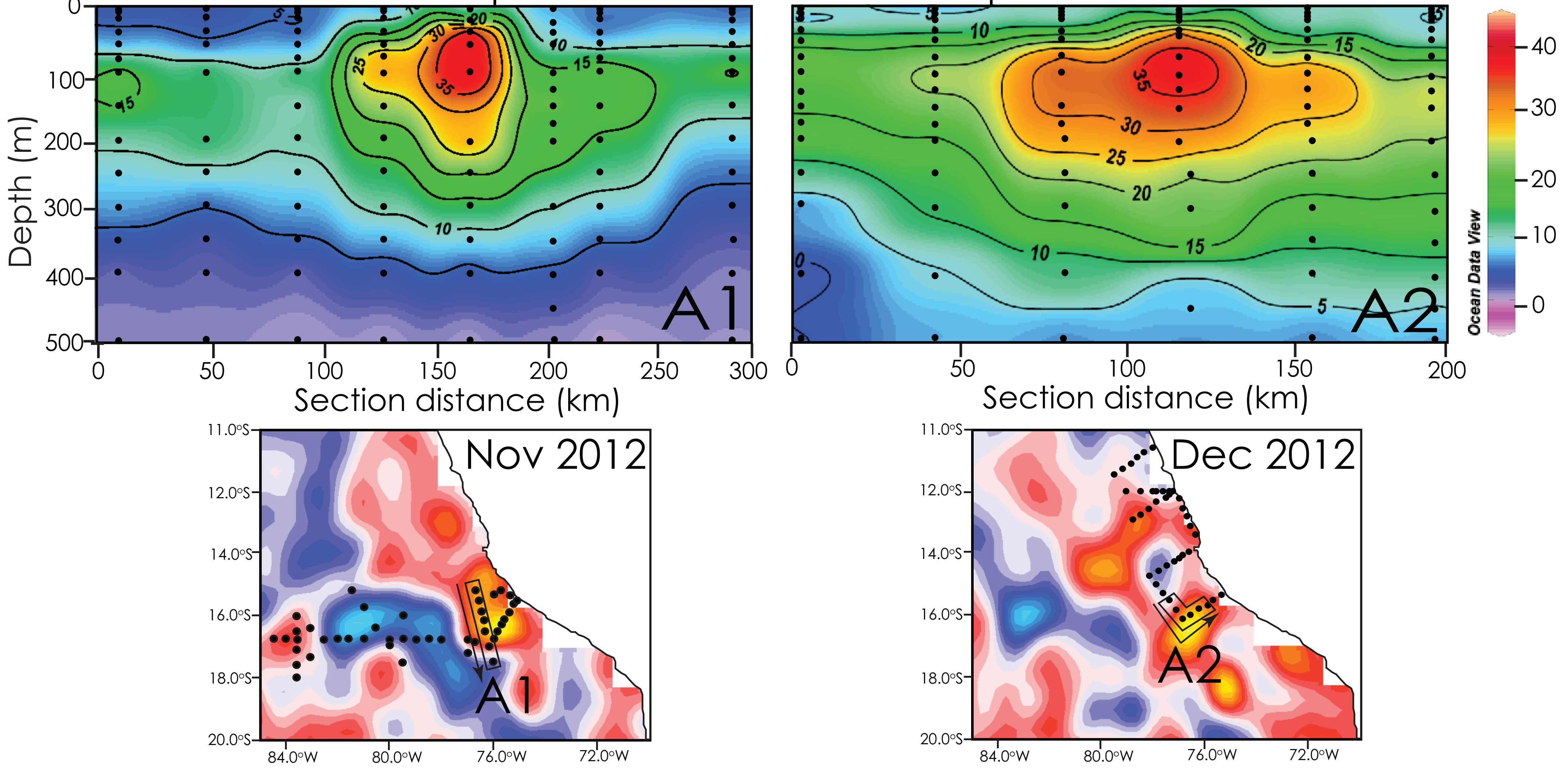


(Bourbonnais et al., GBC, 2015)

Eddies as N-loss hotspots

DIN ($NO_3^- + NO_2^-$) deficit: up to 40 μmol N L^{-1}

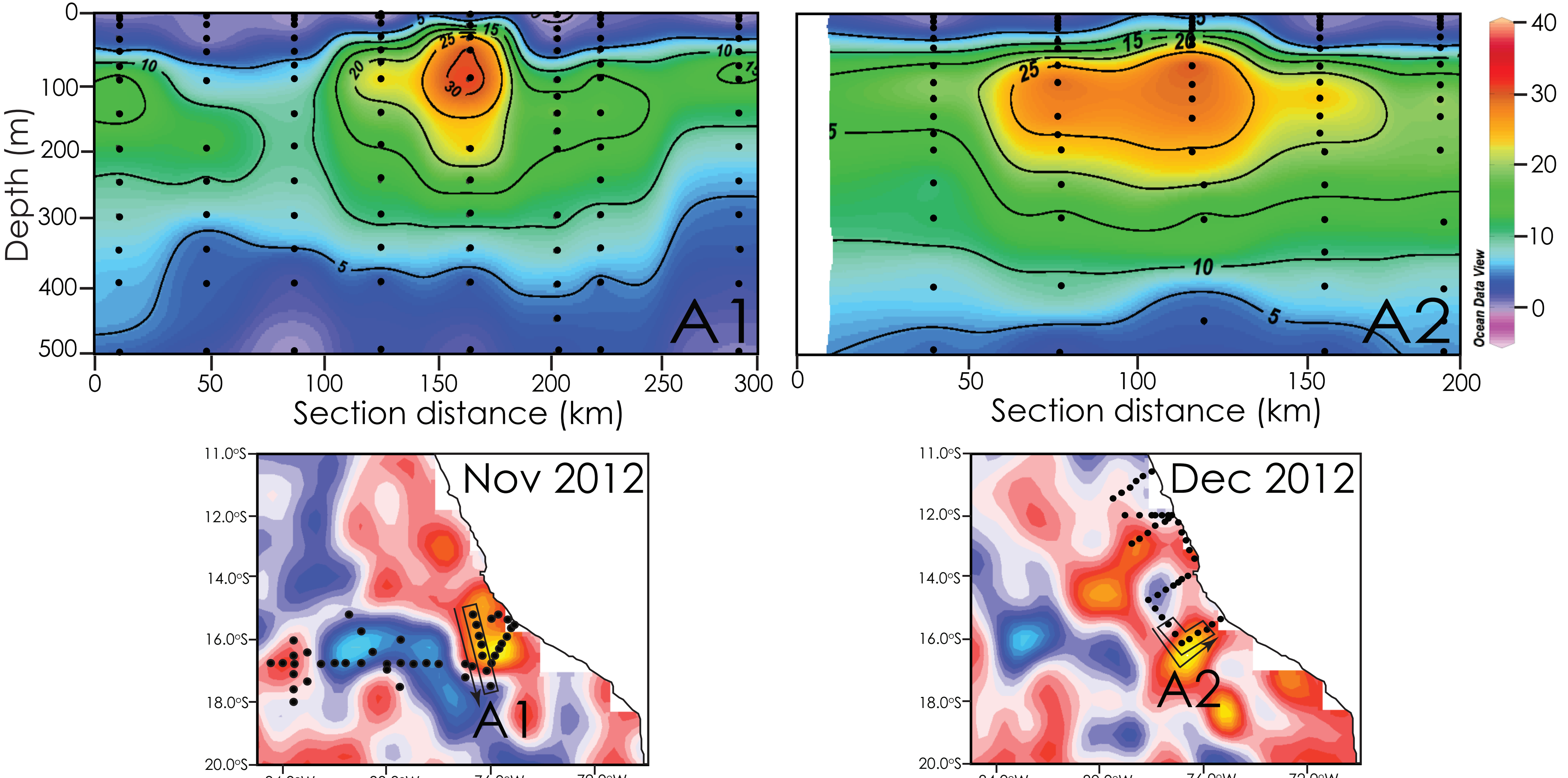
N deficit = $N_{expected} - N_{observed}$ $N_{expected} = 16 \times [PO_4^{3-}]$



(Bourbonnais et al., GBC, 2015)

Eddies as N-loss hotspots

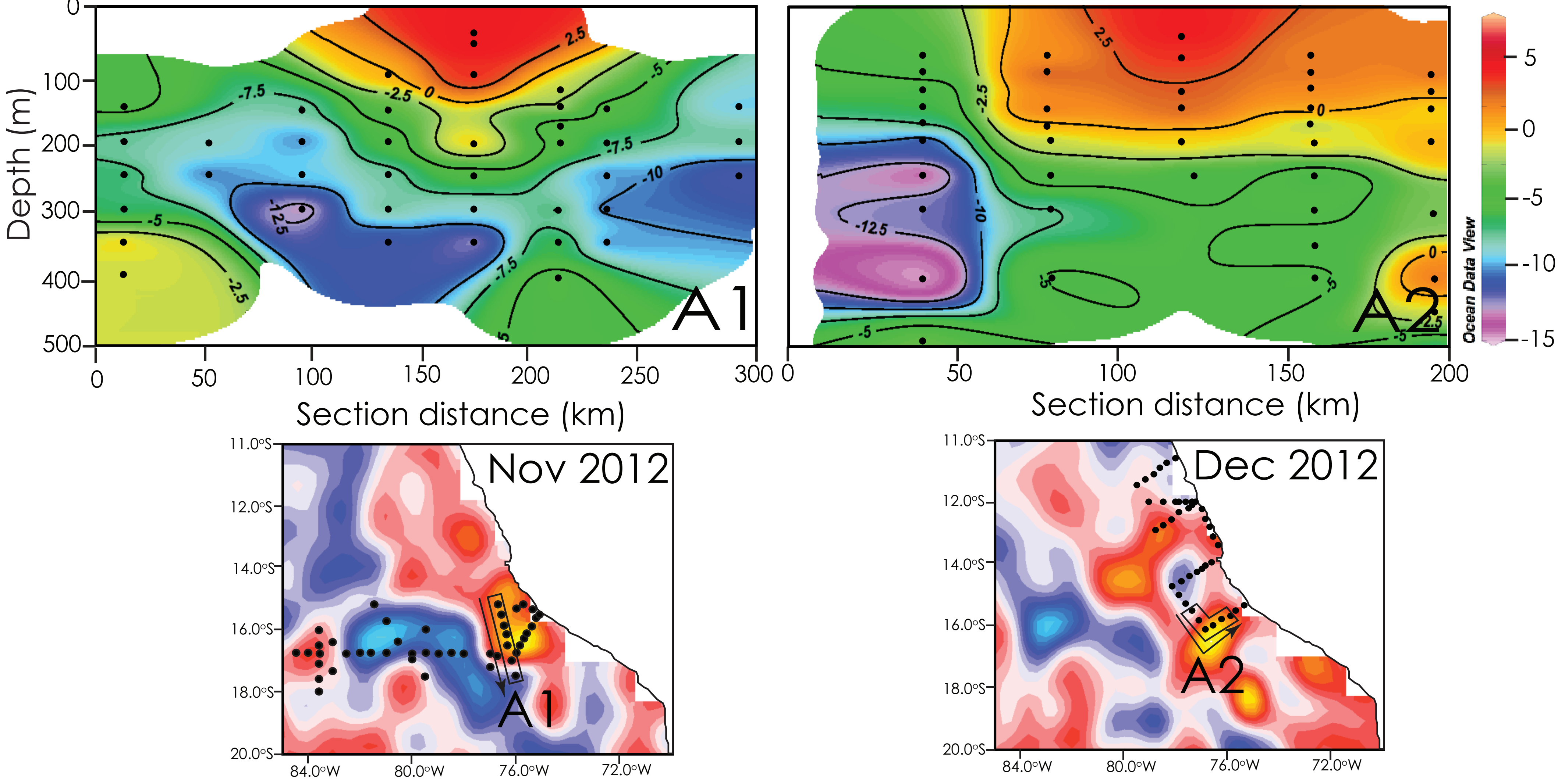
Biogenic N_2: up to 40 µmol N L^{-1}



(Bourbonnais et al., GBC, 2015)

Eddies as N-loss hotspots

$\delta^{15}N$-biogenic N_2

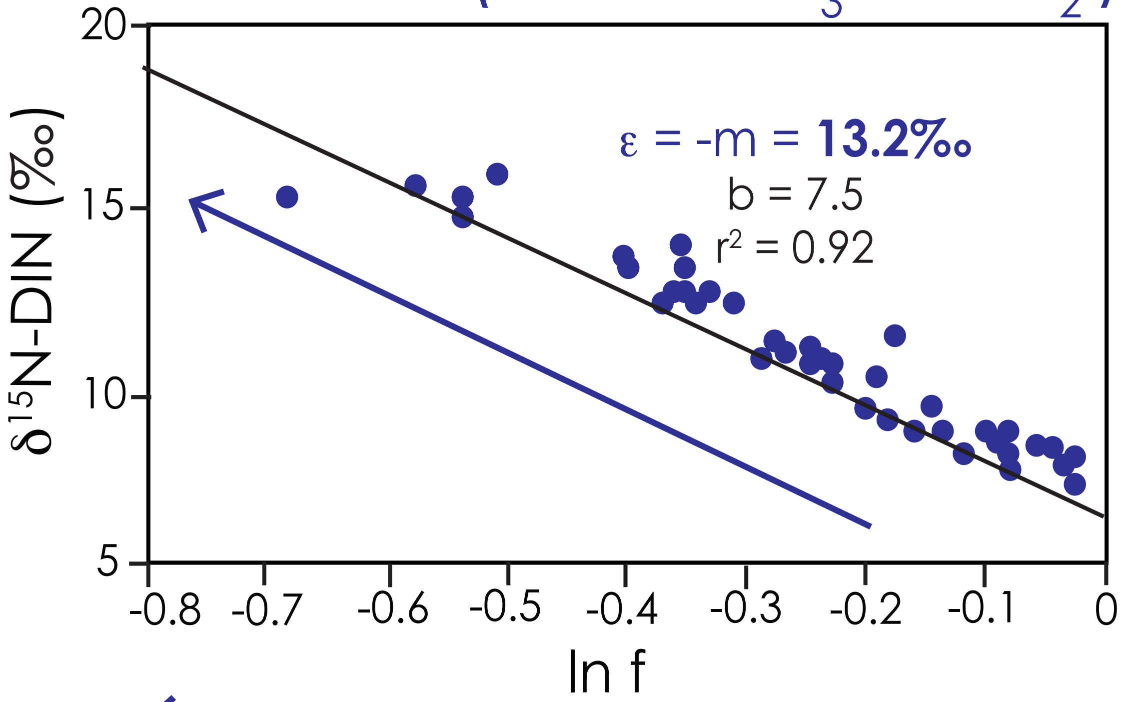


(Bourbonnais et al., GBC, 2015)

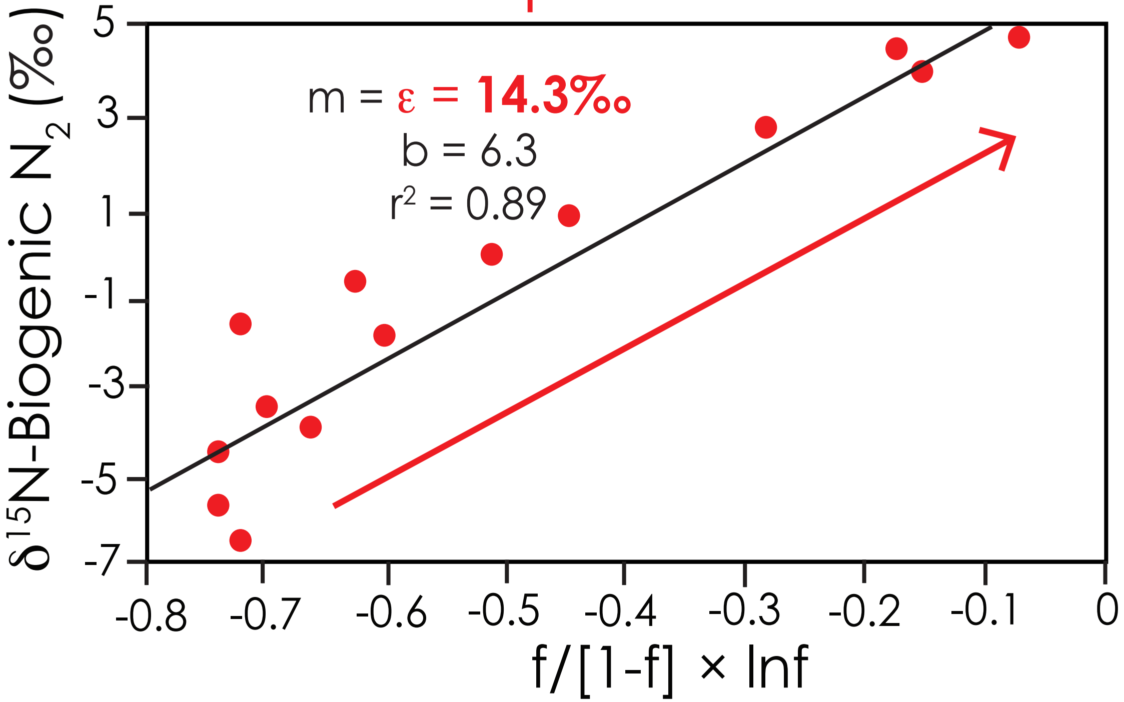
Eddies as natural laboratories

Rayleigh kinetic isotope fractionation: e.g. N-loss in the ETSP

substrate (DIN = NO_3^- + NO_2^-)



product



substrate consumption

biogenic N_2 production

Ryabenko *et al.*, *Biogeosciences*, (2012): ε for NO_3^- reduction of 16‰

ε N-loss is higher in other ODZs: 20-30‰

Bourbonnais *et al.*, *GBC*, 2015)

Implications for the global N budget

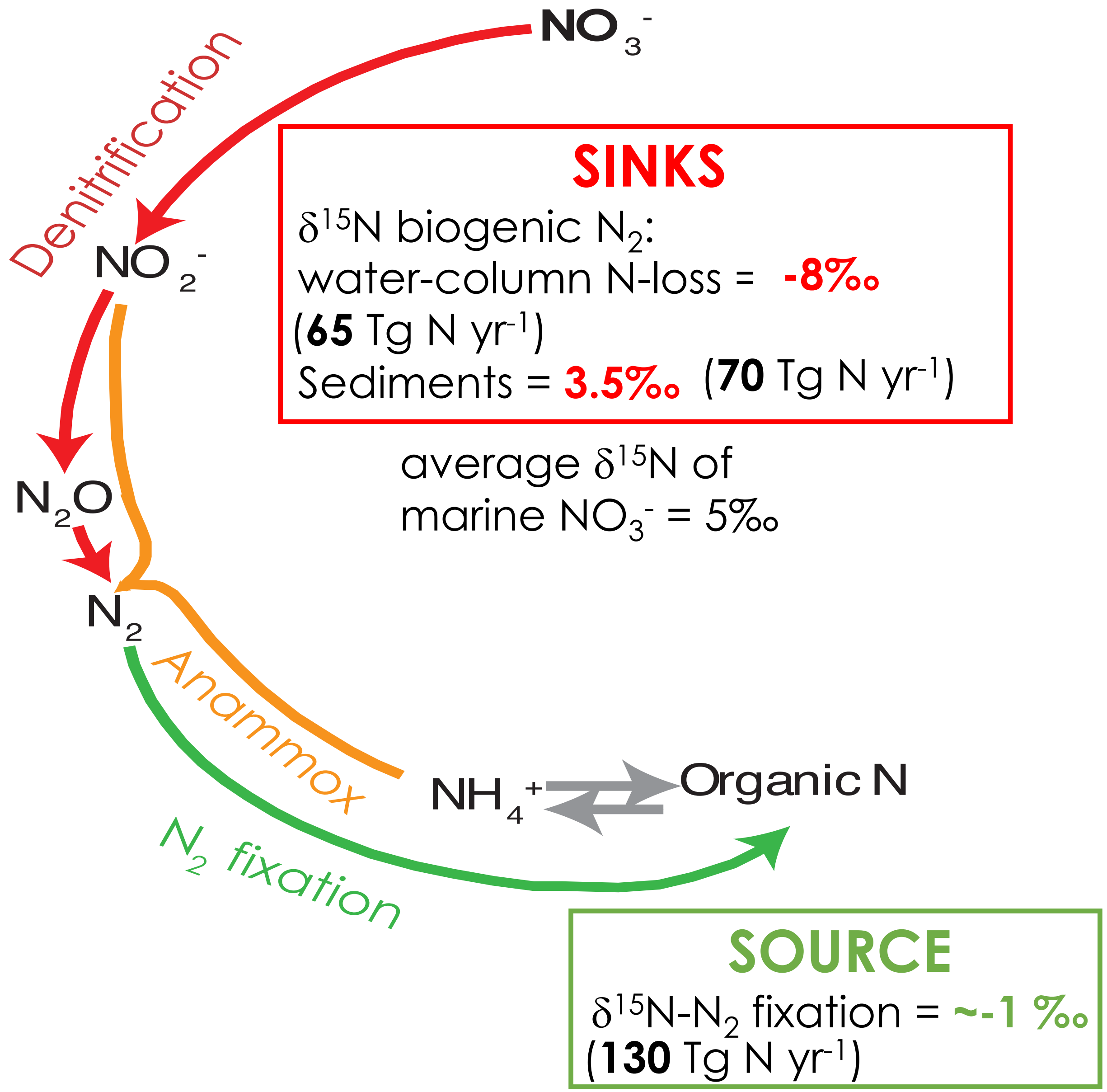
Current budgets: sedimentary denitrification: 65 to 75% of total N-loss

$$\delta^{15}N_{product} = \delta^{15}N_{substrate} - \varepsilon$$

ε N-loss water-column: assumed to be 25‰

ETSP: lower ε N-loss (13‰)

Sedimentary N-loss ≈ 50% of total N-loss = more balanced N-budget



Possible mechanisms for enhanced N-loss in eddies

1) High N-loss signal originates from the productive coast.

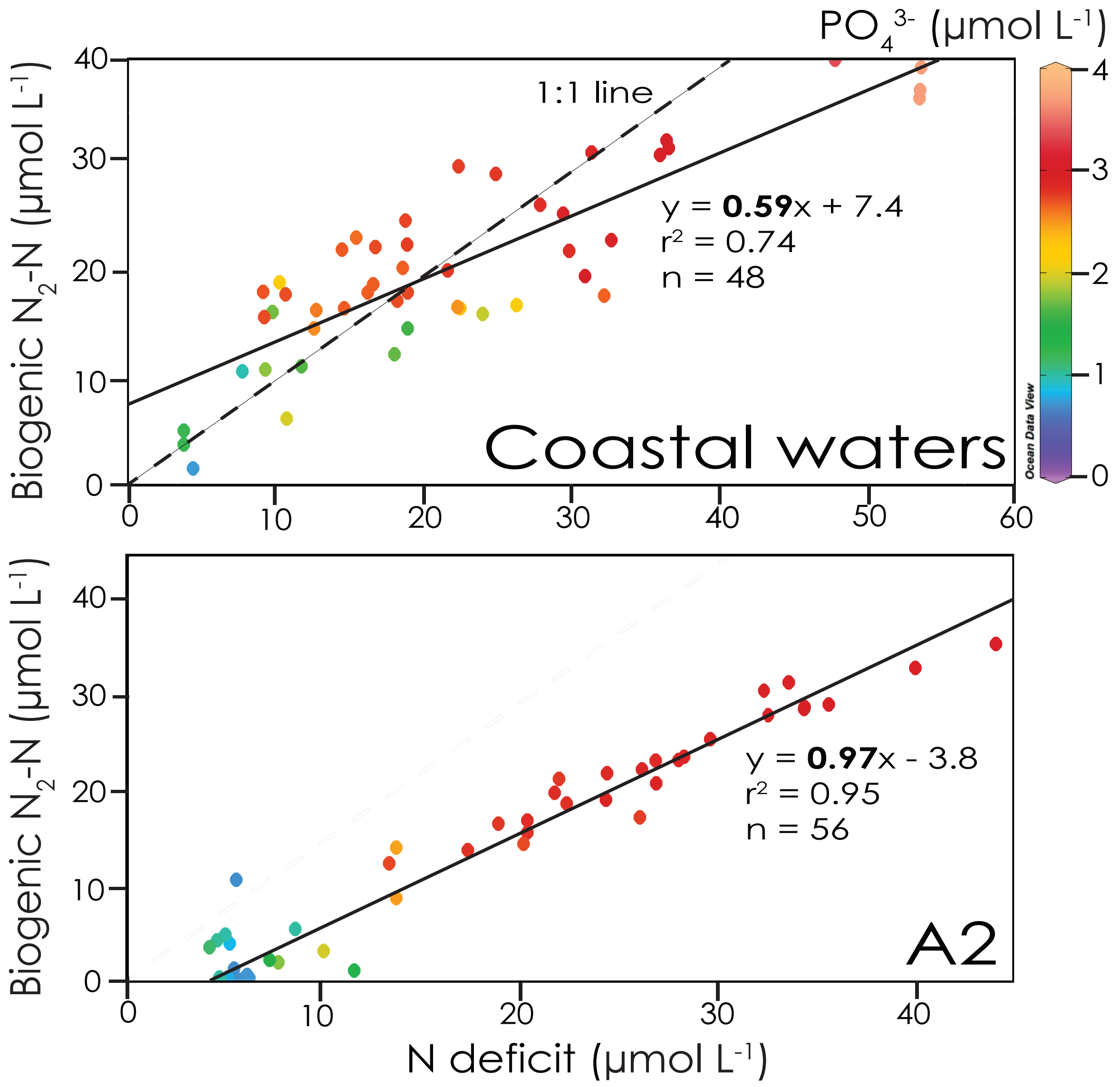
2) Organic material (chlorophyll) is trapped during eddy formation near the coast, supporting N-loss offshore.

3) Increased primary productivity and N-loss from mesoscale and submesoscale processes.

1) Water transport from shelf

1) Shallow shelf waters: PO_4^{3-} and SiO_4^- anomalies from sedimentary fluxes. No such anomalies in Eddy A.
N deficit = $N_{expected} - N_{observed}$
$N_{expected} = 16 \times [PO_4^{3-}]$

2) Shelf waters: suppressed N-loss isotope effect due to sediment N-cycling (7‰ , Hu et al., *Biogeosciences*, 2016). Isotope effect in Eddy A (14‰) is similar to the rest of the offshore Peru ODZ.



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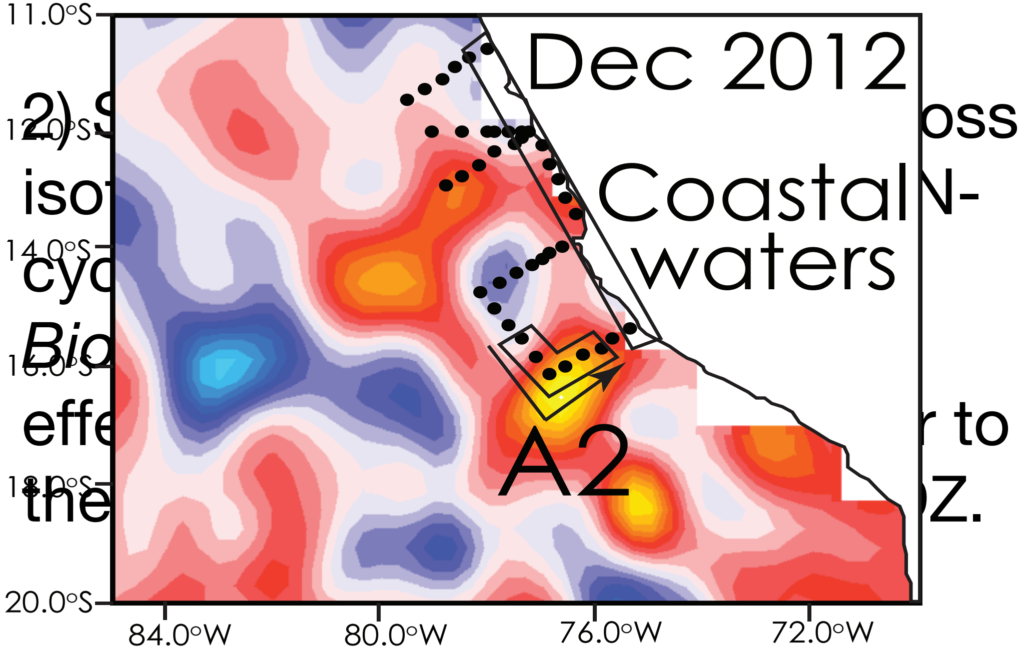
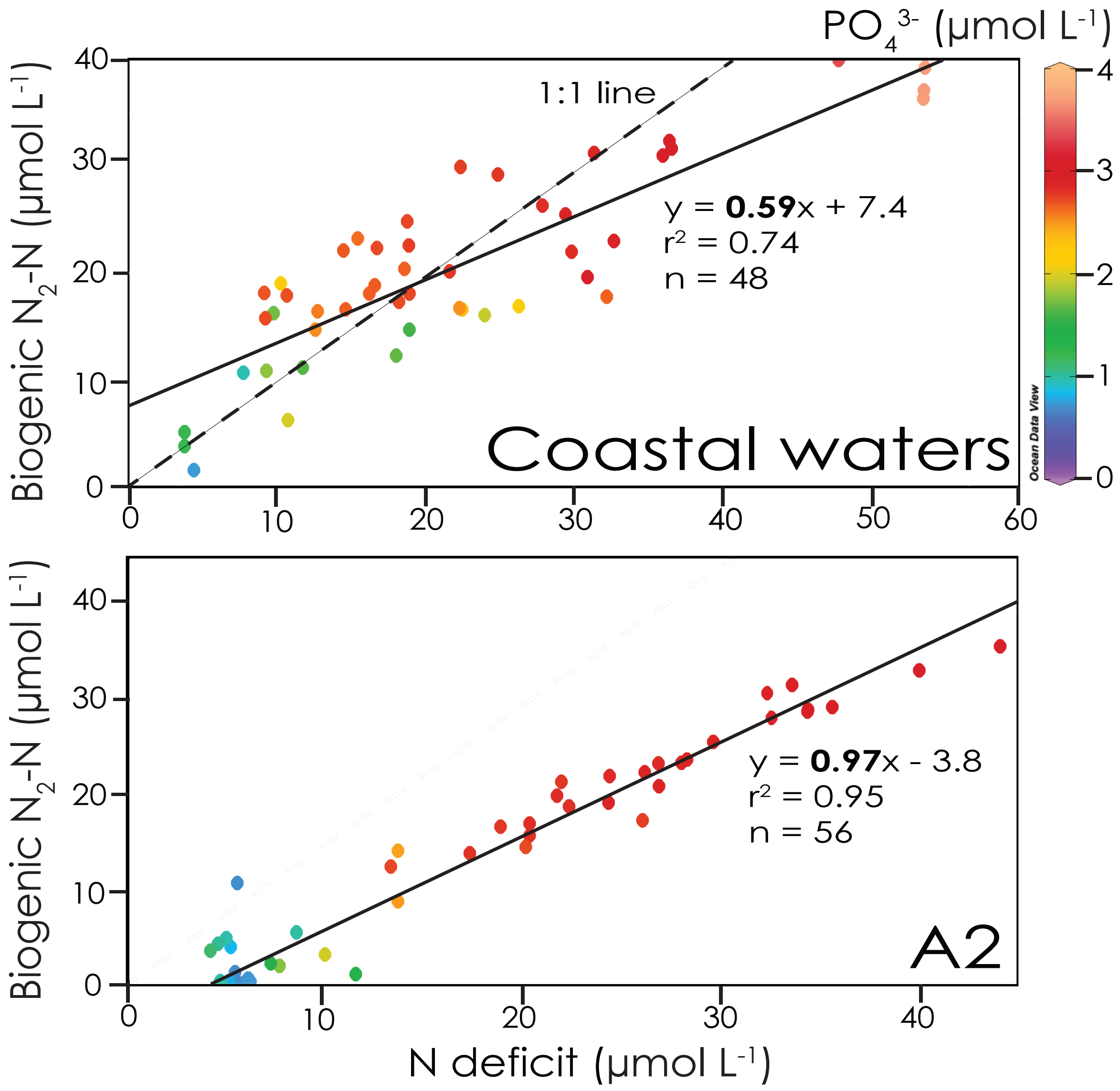
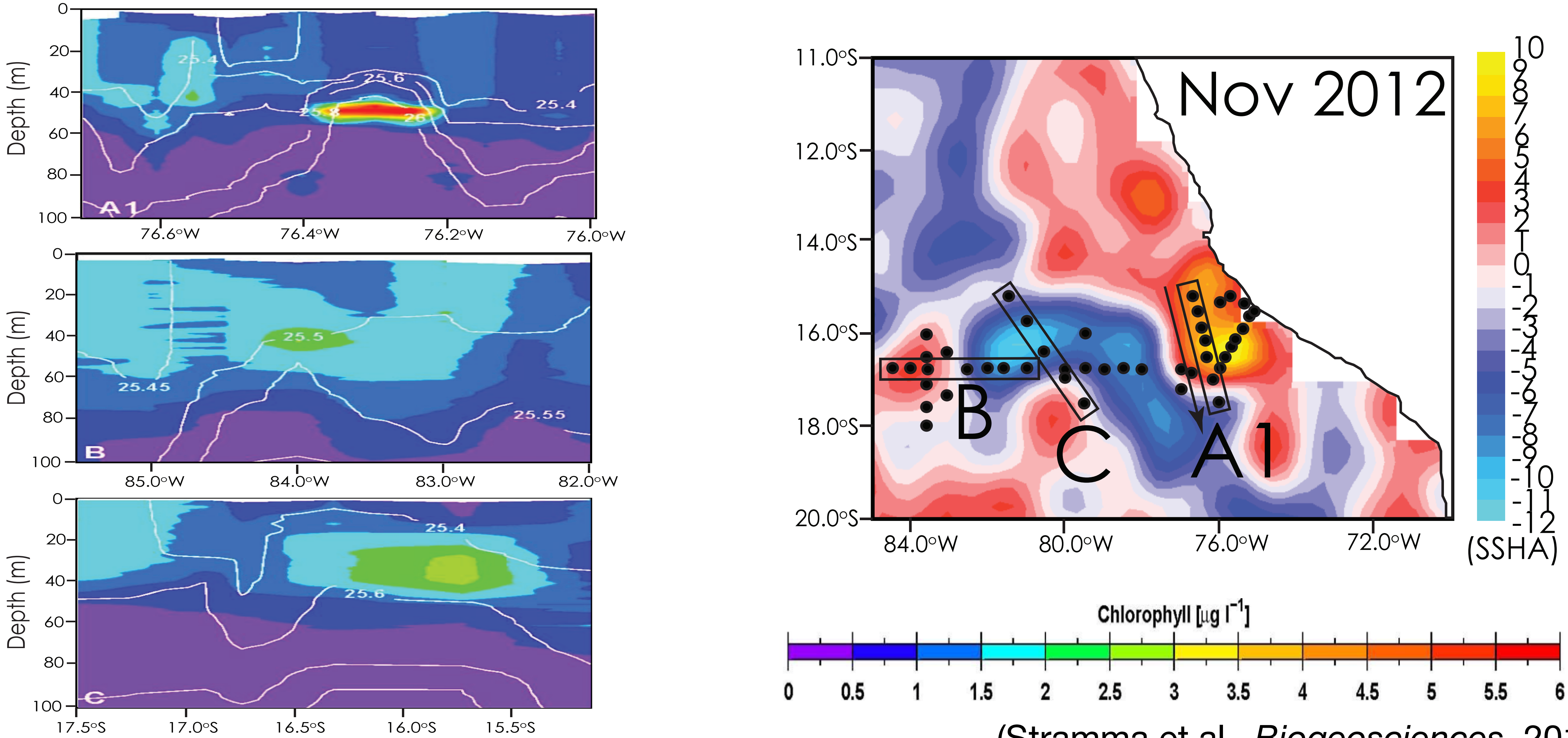




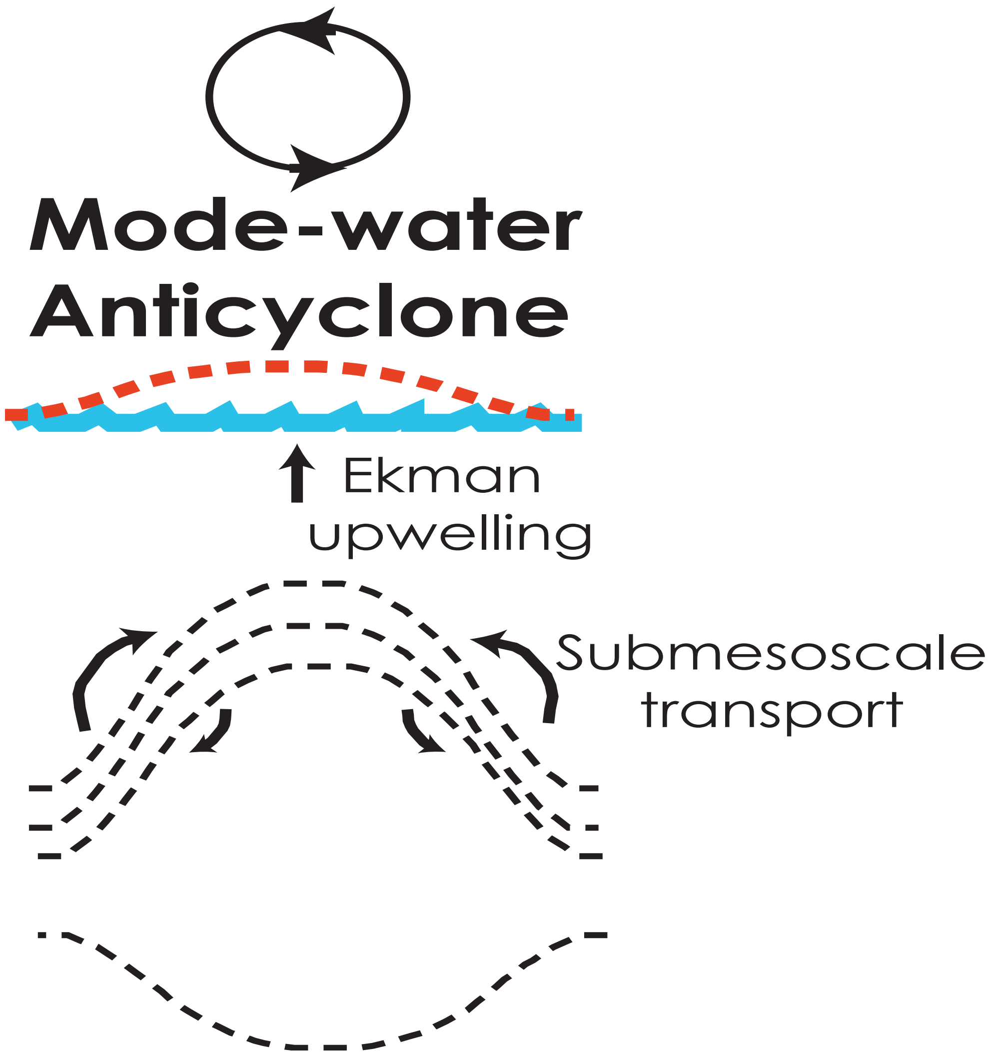
2) Organic material transported offshore



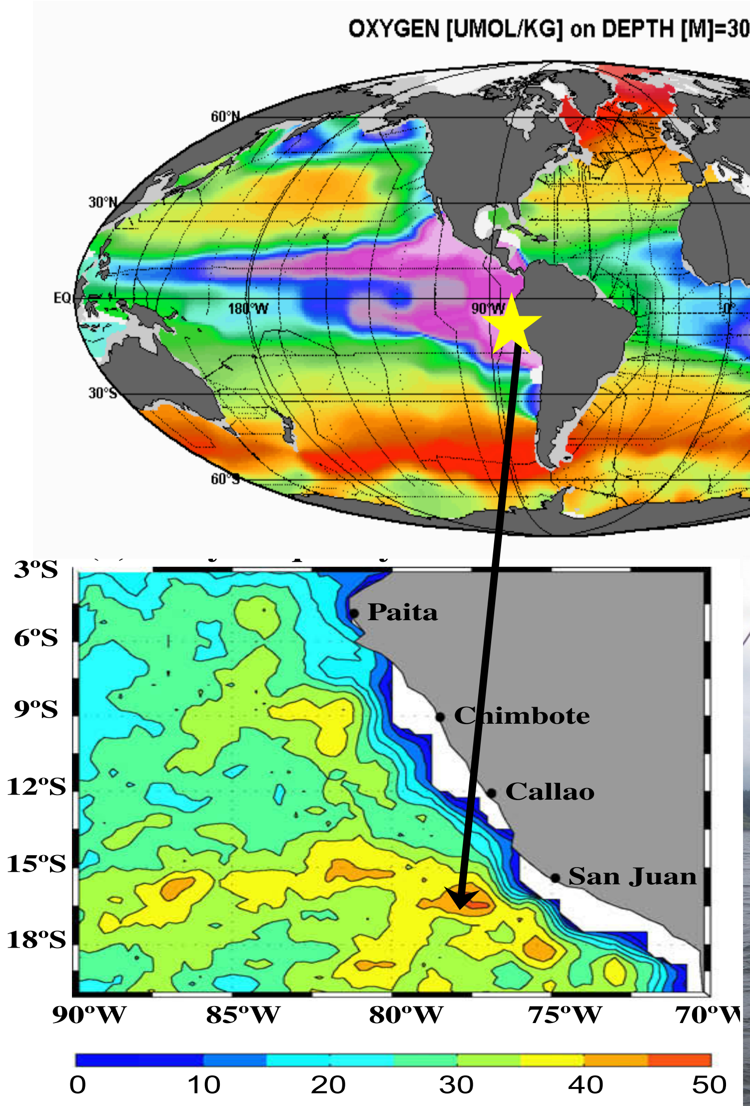
(Stramma et al., *Biogeosciences*, 2013)

3) Mesoscale and submesoscale processes

Calbeck *et al*., PLOS ONE, 2017:
Highest N-loss rates (anammox, up to 8 mmol N m^{-2} d^{-1}) at the periphery of Eddy A attributed to "*enhanced vertical nutrient transport caused by an eddy-driven submesoscale mechanism operating at the eddy periphery*".



Future projects



(Chaigneau et al., *Progress in Oceanography*, 2013)

Lagrangian floats to study N-loss in ODZ eddies off Peru

Collaborators:
Eric D’Asaro,
Craig McNeil,
Curtis Deutsch,
University of Washington

Float deployment during GO-SHIP, P18 line, leg 1

19th Nov -23rd Dec 2016, deployment at 16°N off Mexico

Argo Float with new gas tension (P_T) device (GTD) with response time of minutes

Collaborators:
Eric D'Asaro, Craig McNeil, University of Washington

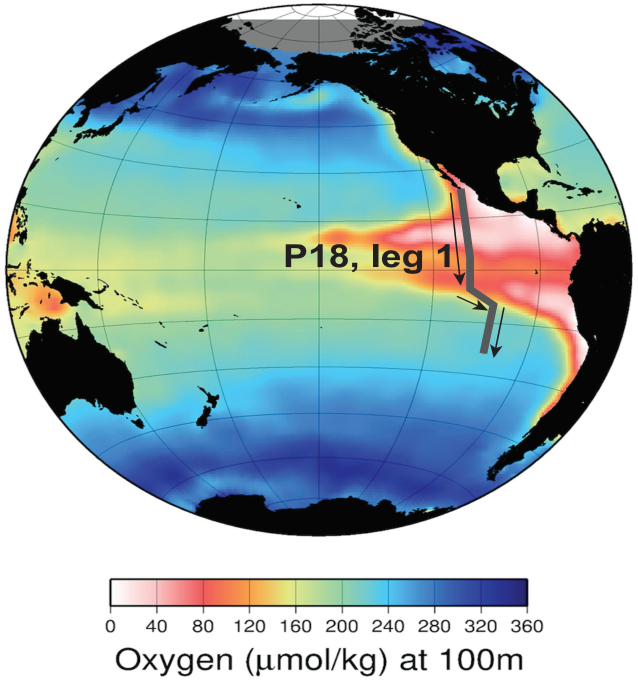


Figure: William J. Jenkins, WHOI

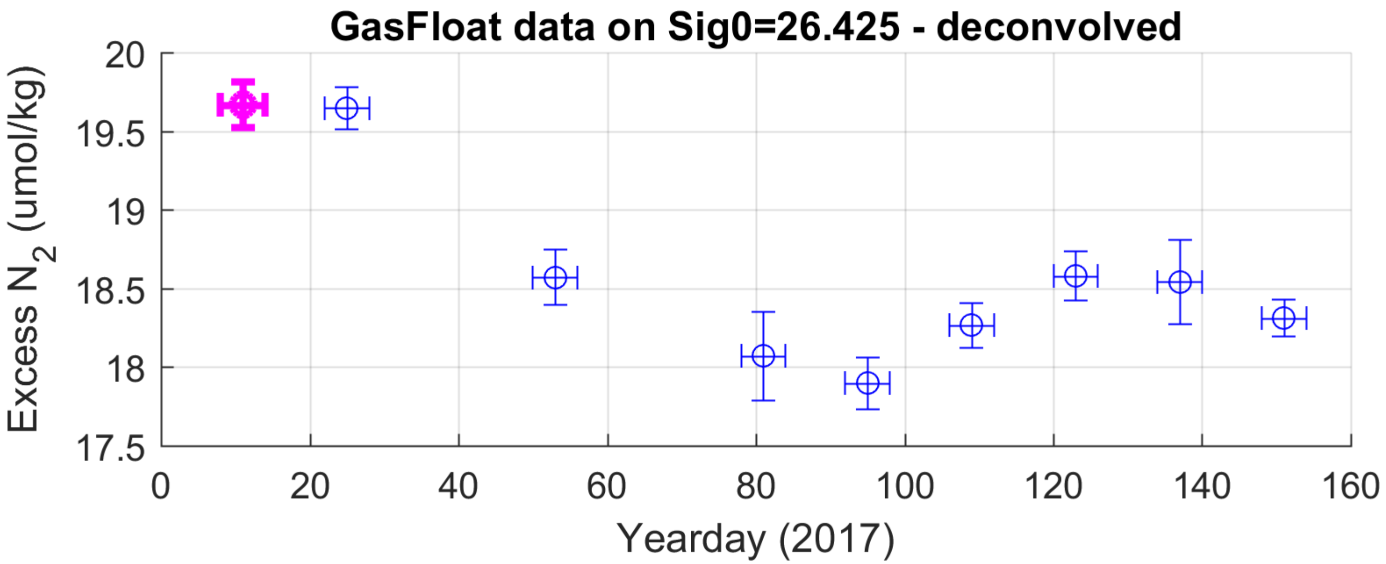
Lagrangian floats to study eddies

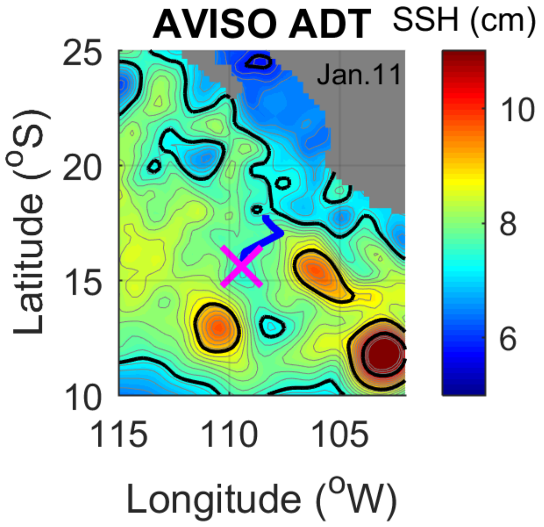
Gas float ($N_{2\ excess\text{-}GTD}$) data on deeper isopycnal at 26.425 (or 190-220 dbar)

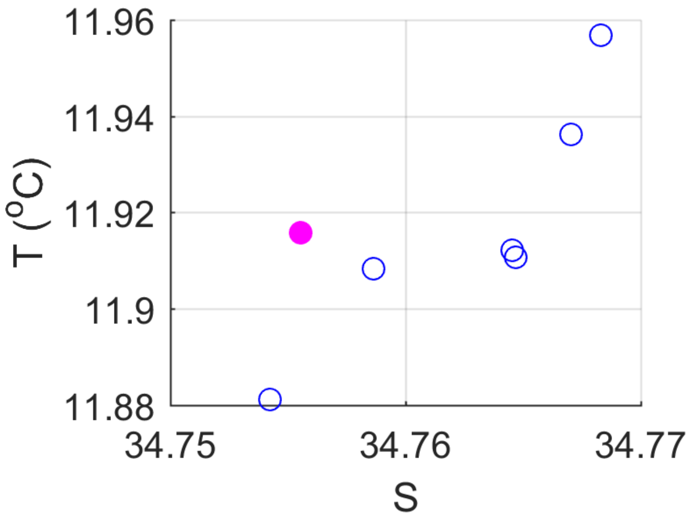
$$pN_2 = P_T - pO_2 - pH_2O - pTrace$$

$$N_{2\ excess\text{-}GTD} = [S_H^{N2} \times pN_2] - [S_H^{N2}(P{=}0) \times pN_{2\ eq}]$$

S_H^{N2} = Henry's Law solubility coefficient, function of temperature, salinity, and hydrostatic pressure (P)







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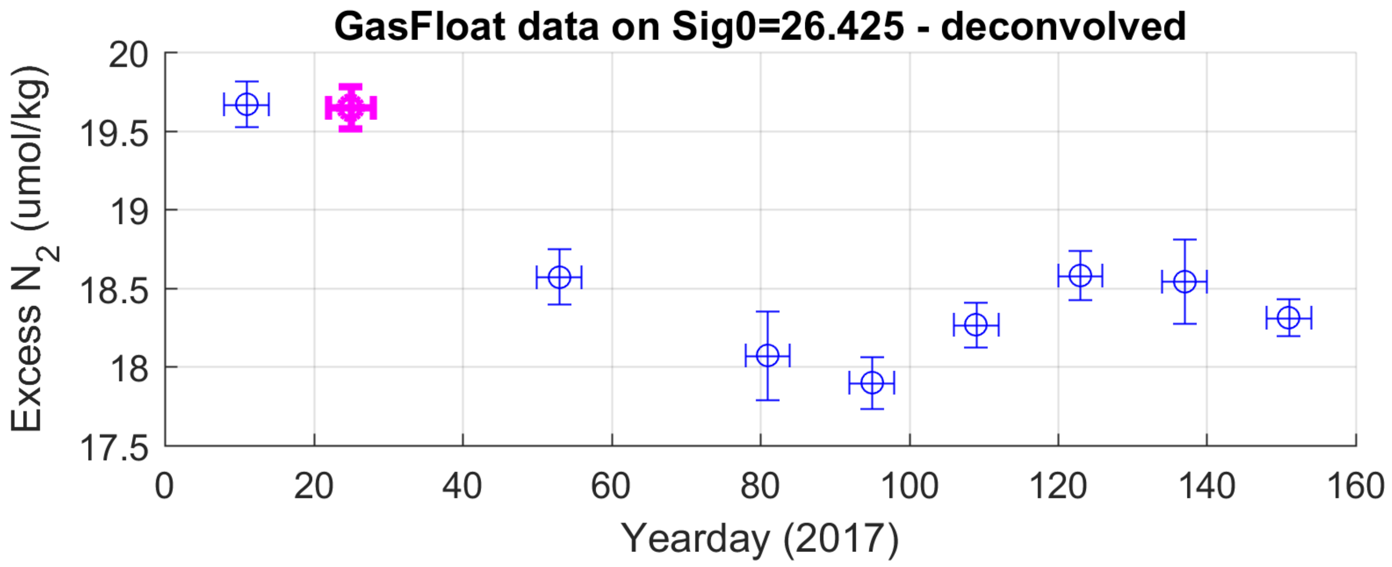

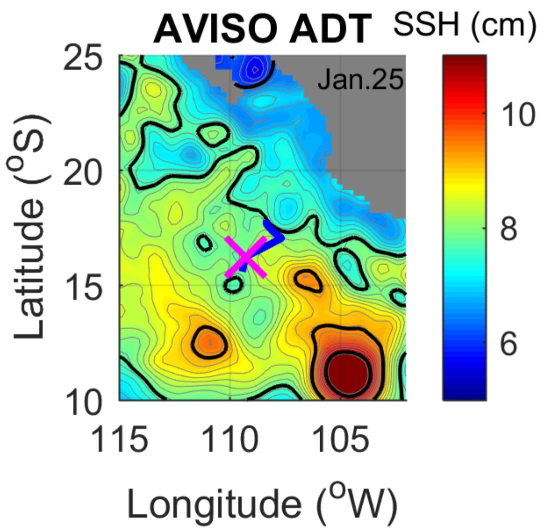

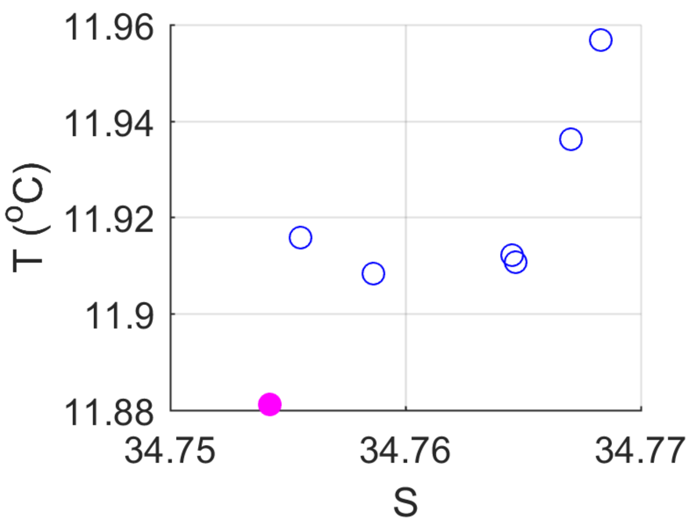

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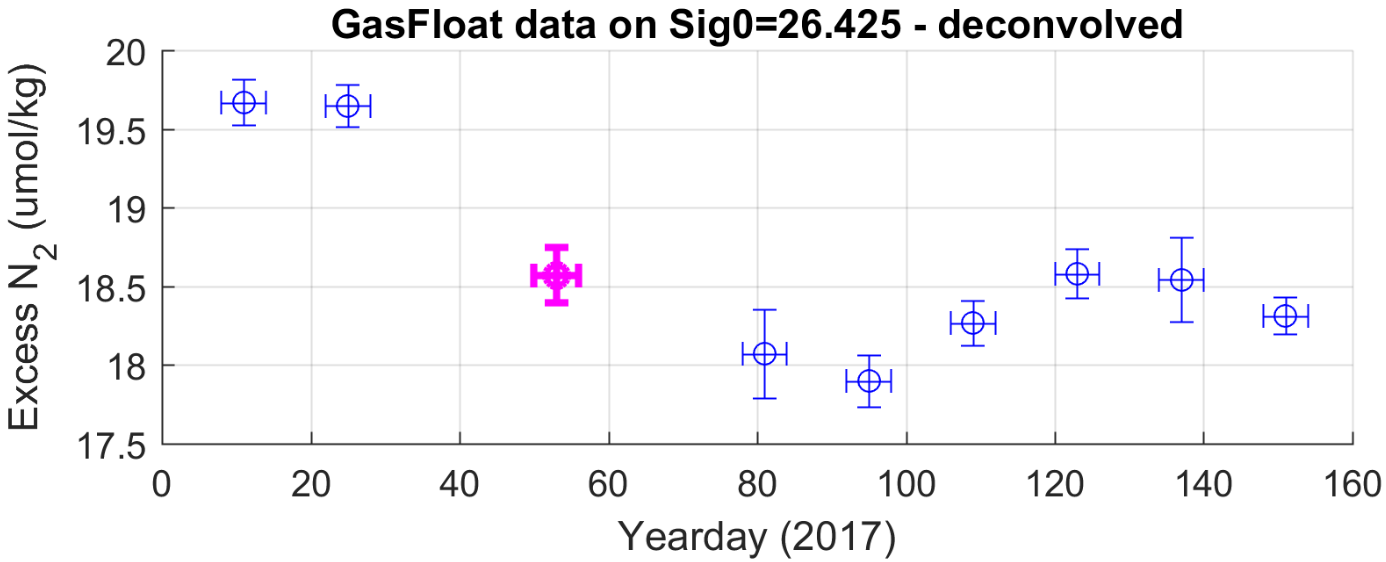

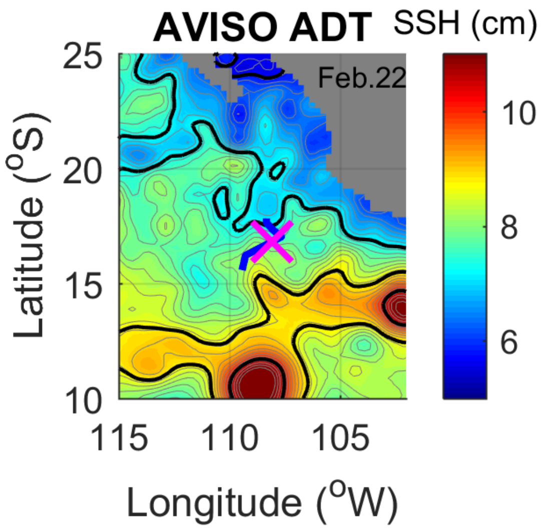

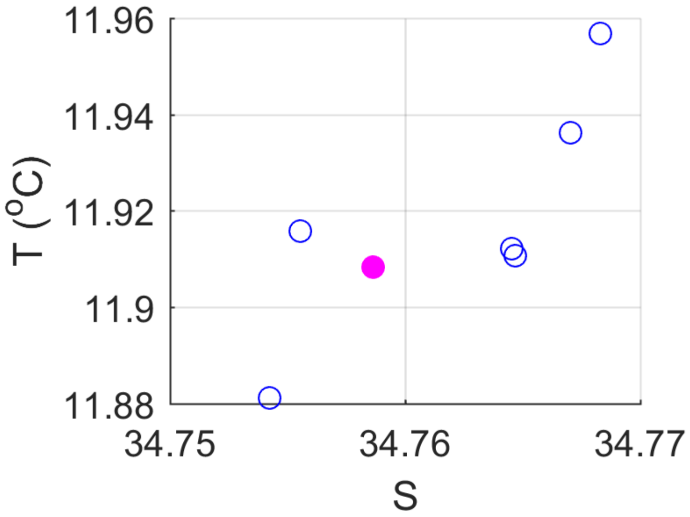

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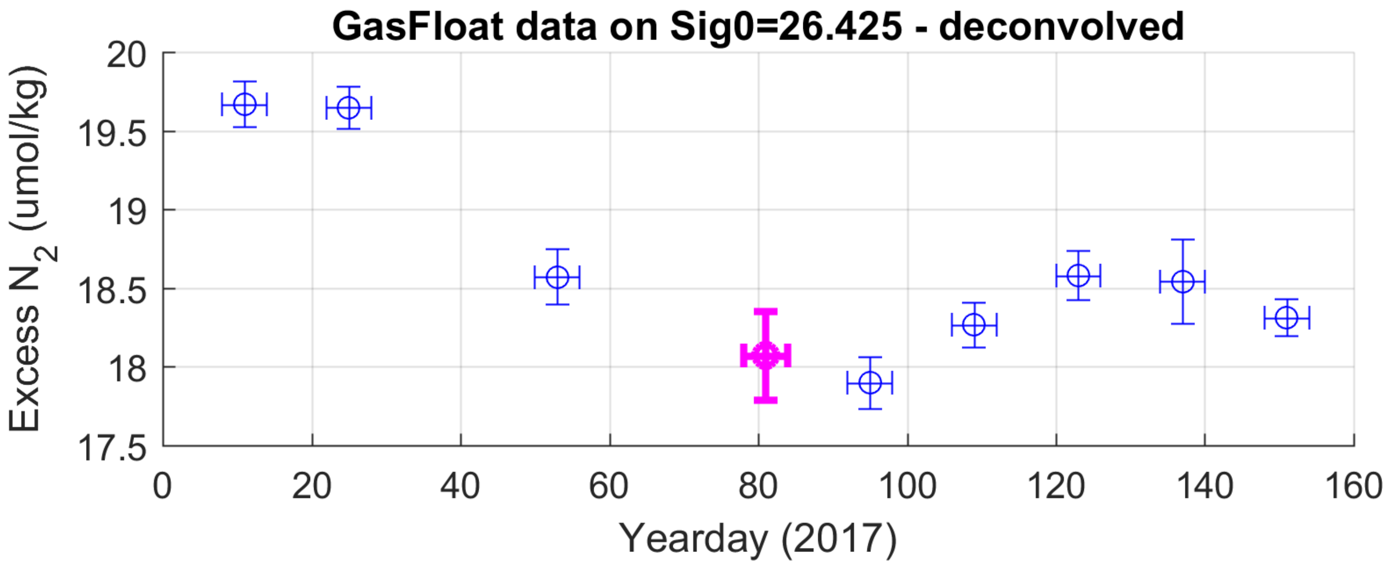

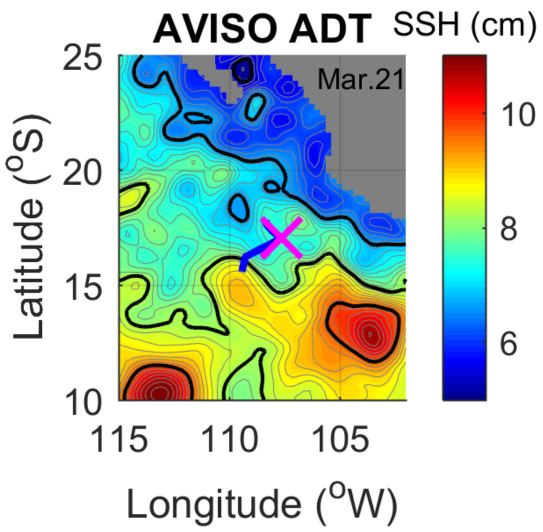

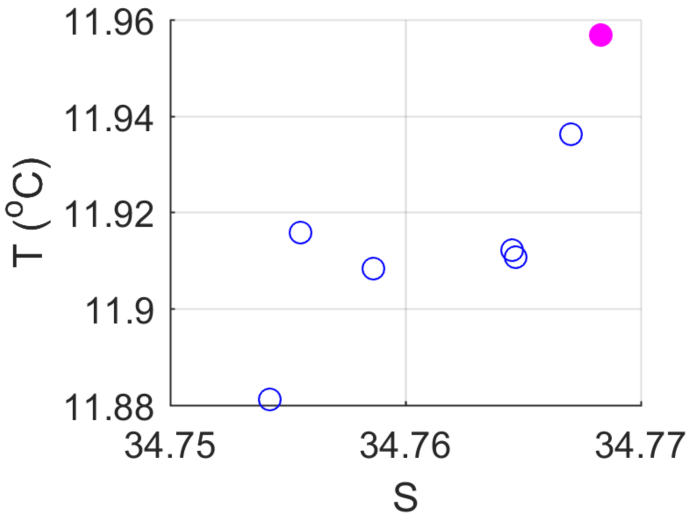

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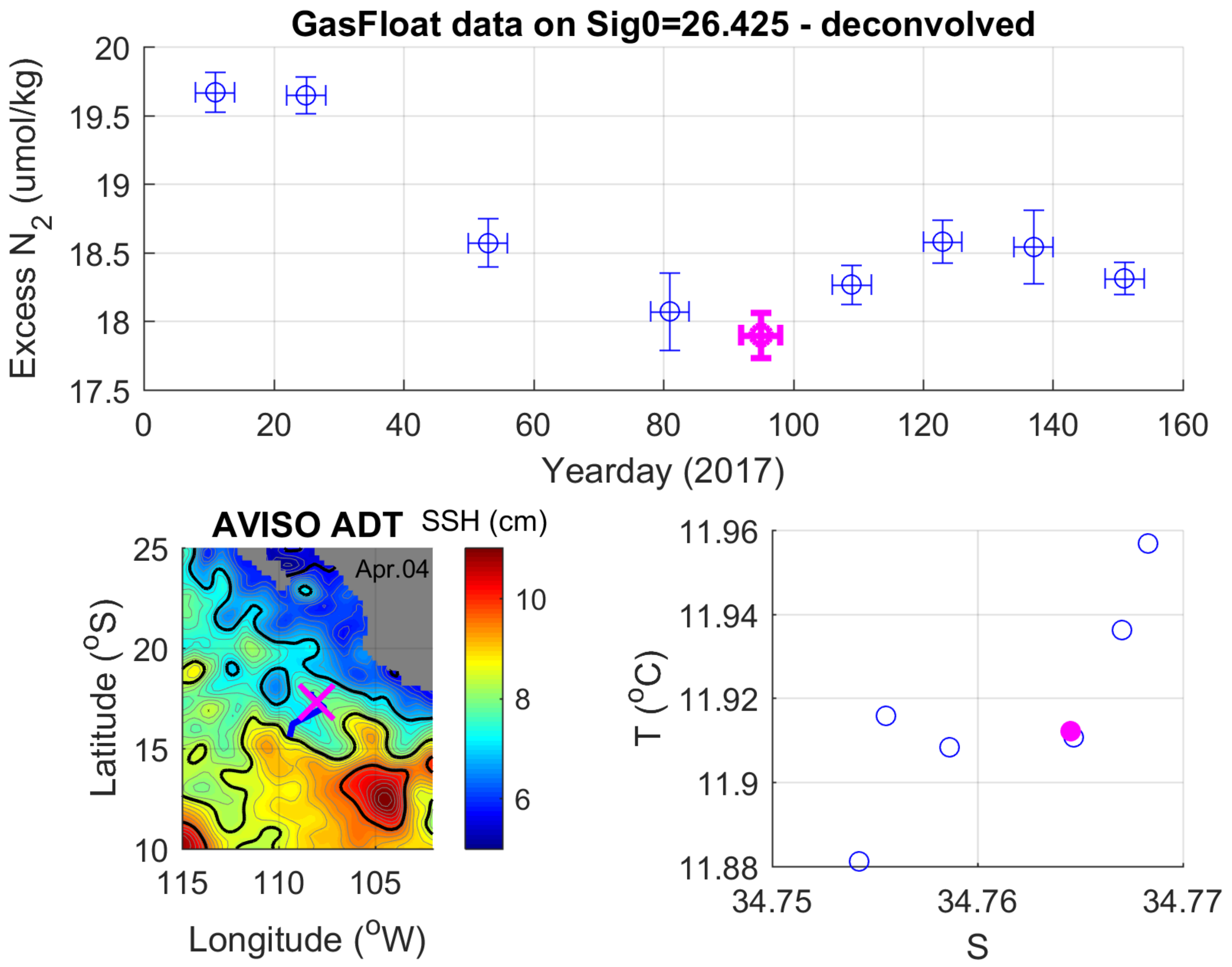

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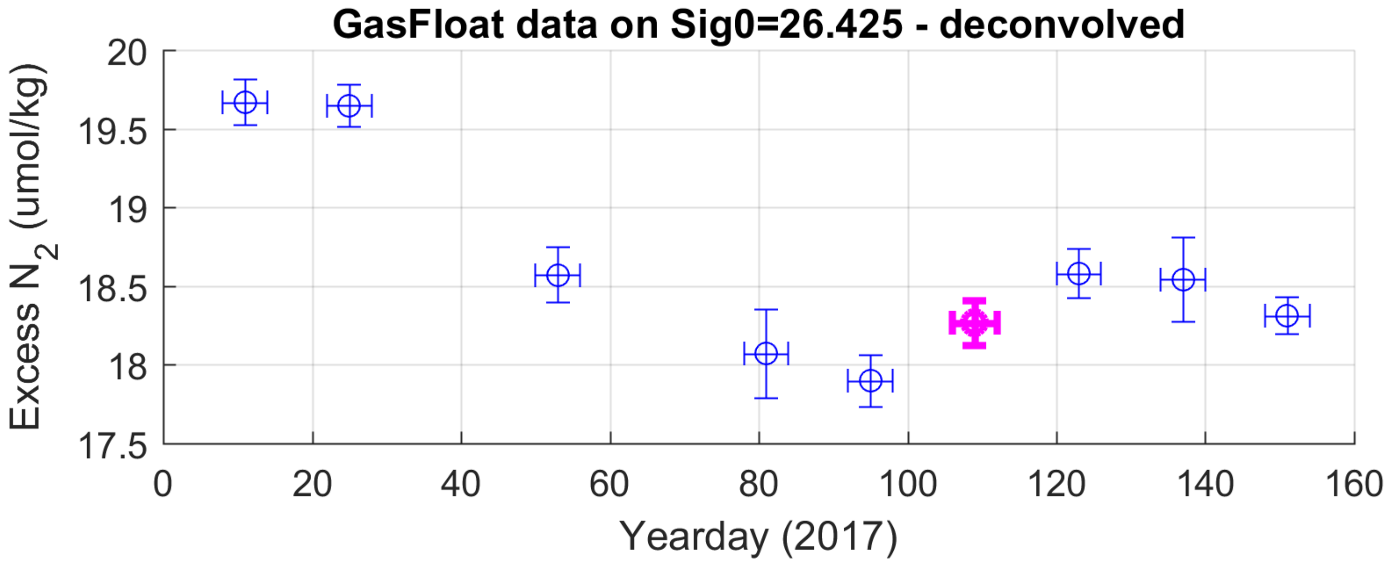
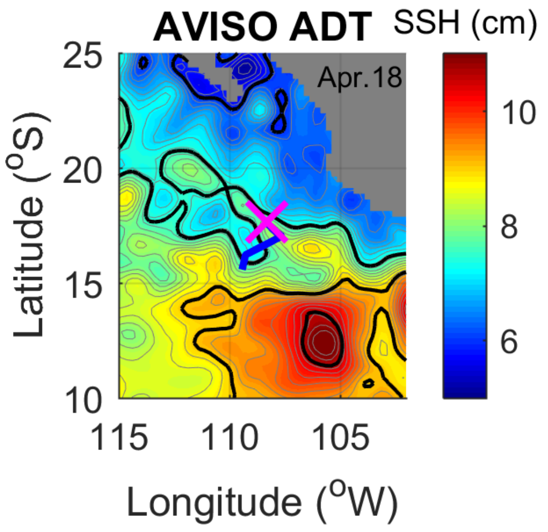
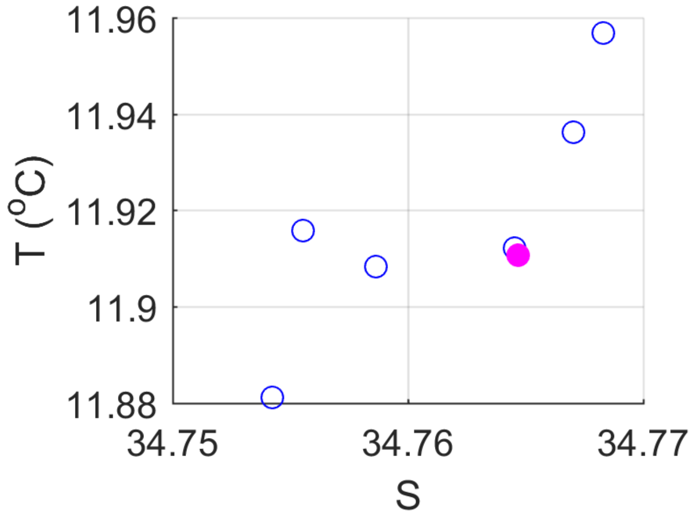






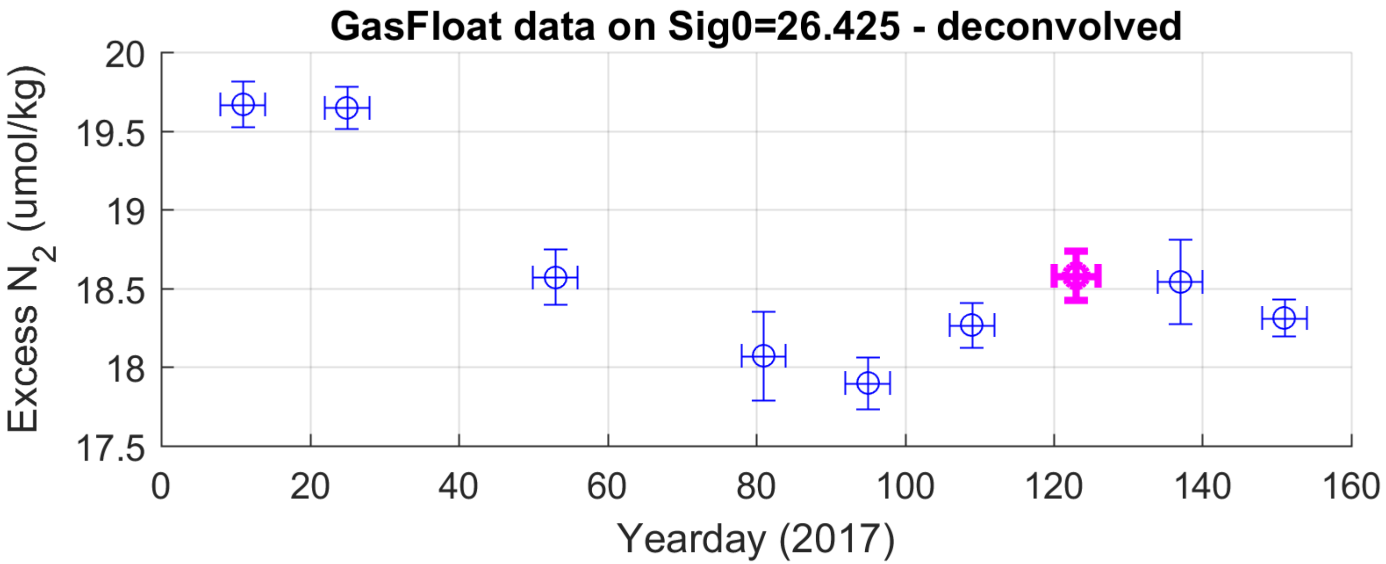
Lagrangian floats to study eddies

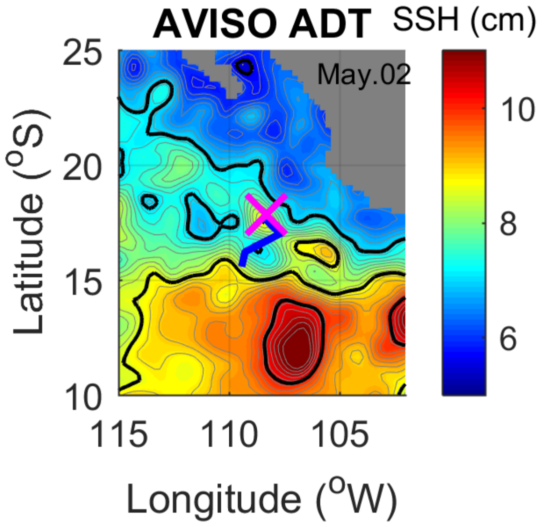
Gas float ($N_{2\ excess\text{-}GTD}$) data on deeper isopycnal at 26.425 (or 190-220 dbar)

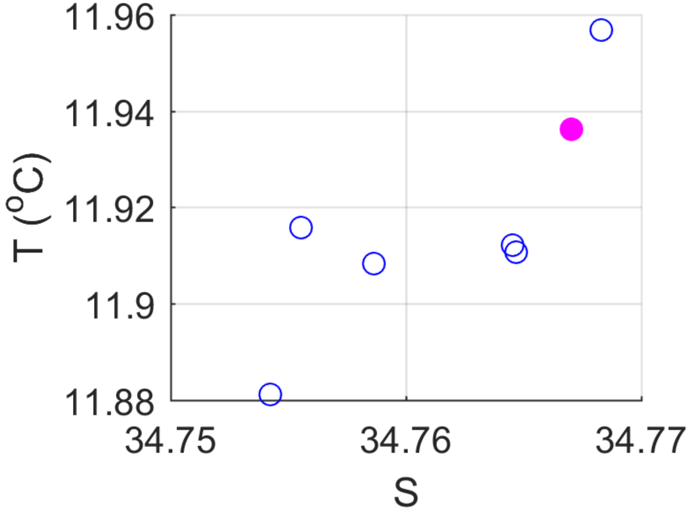
$$pN_2 = P_T - pO_2 - pH_2O - pTrace$$

$$N_{2\ excess\text{-}GTD} = [S_H^{N2} \times pN_2] - [S_H^{N2}(P{=}0) \times pN_{2\ eq}]$$

S_H^{N2} = Henry's Law solubility coefficient, function of temperature, salinity, and hydrostatic pressure (P)







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