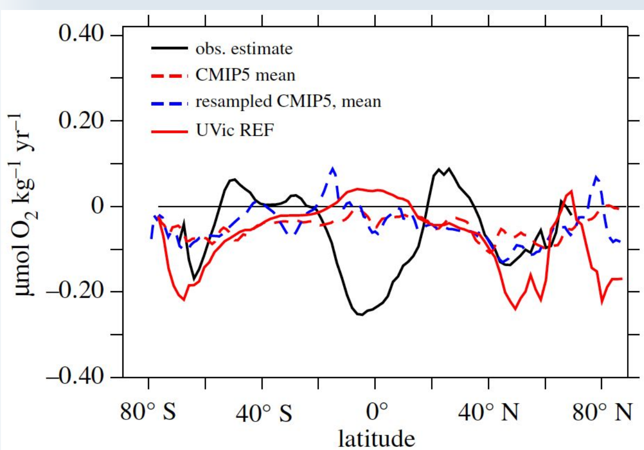
Decadal variability of circulation and oxygen in the upper tropical Atlantic

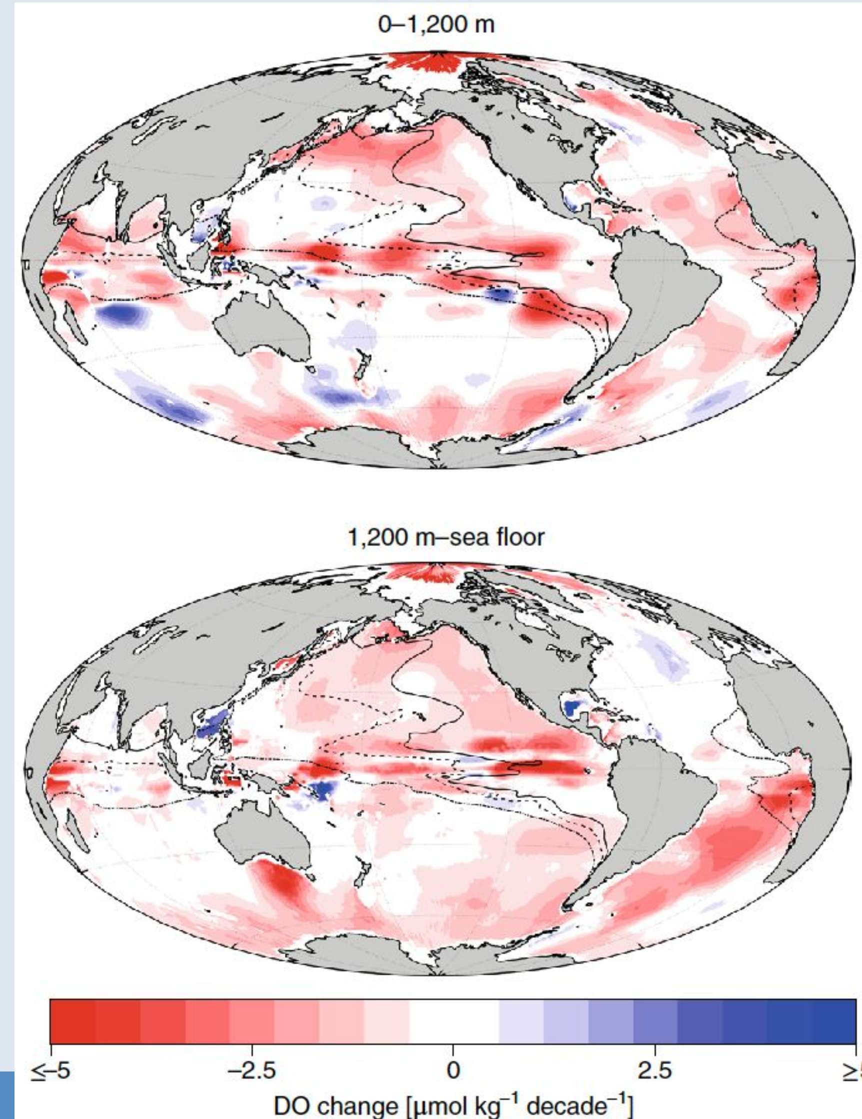
Peter Brandt[1,2], Johannes Hahn[1], Sunke Schmidtko[1], Franz Philip Tuchen[1], Robert Kopte[2], Rainer Kiko[1,3], Bernard Bourlès[4], Rena Czeschel[1], Marcus Dengler[1]

[1]GEOMAR, [2]CAU, Kiel, Germany, [3]LOV, Villefranche-sur-Mer, [4]IRD, Plouzané, France

Oxygen Changes in the Ocean (1960-2010)

- Global deoxygenation with 2% reduction since 1960s
- Different pattern in upper and deep ocean
- Models have still difficulties to reproduce observed pattern

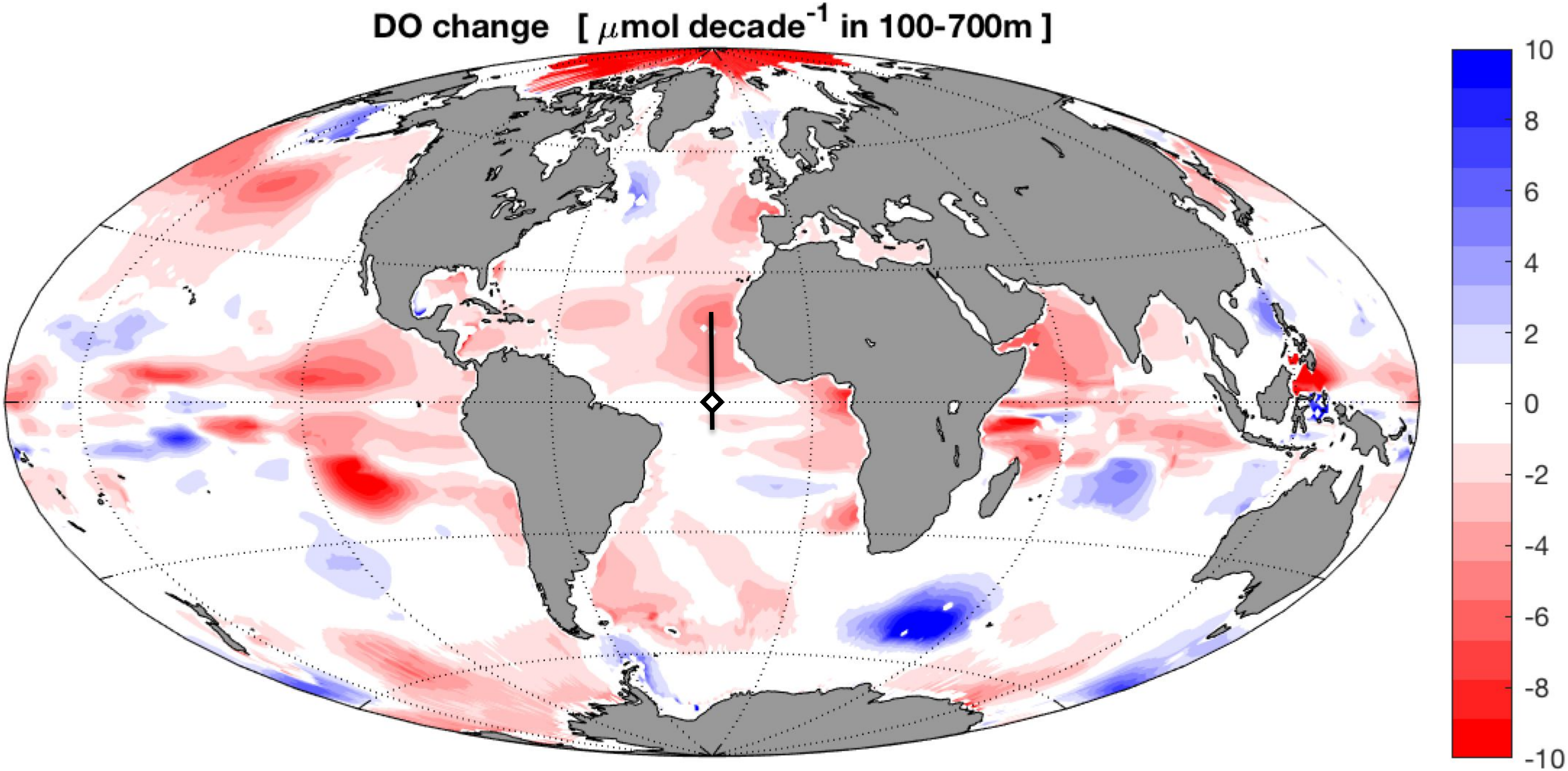




Schmidtko et al. 2017; Oschlies et al. 2018

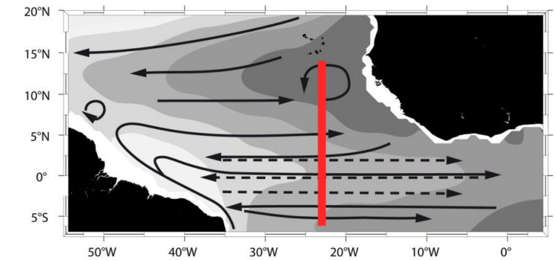
Oxygen Change in the Ocean (1960-2010)

- Deoxygenation particularly in tropical oxygen minimum

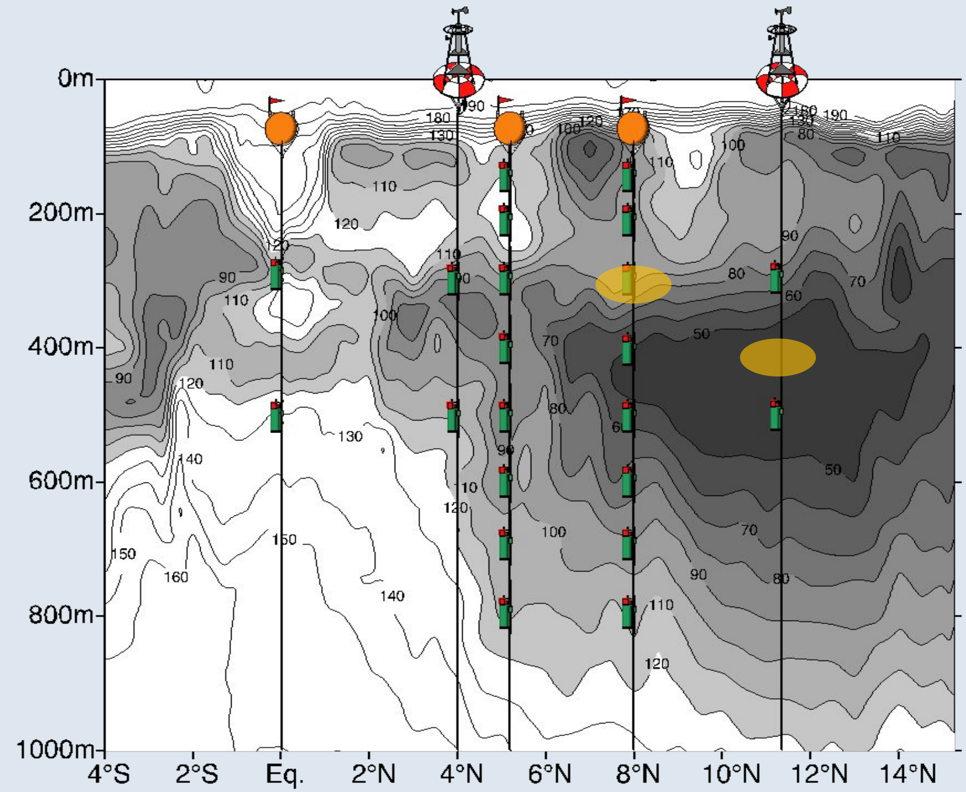


- Since 2006 focus on 23°W section

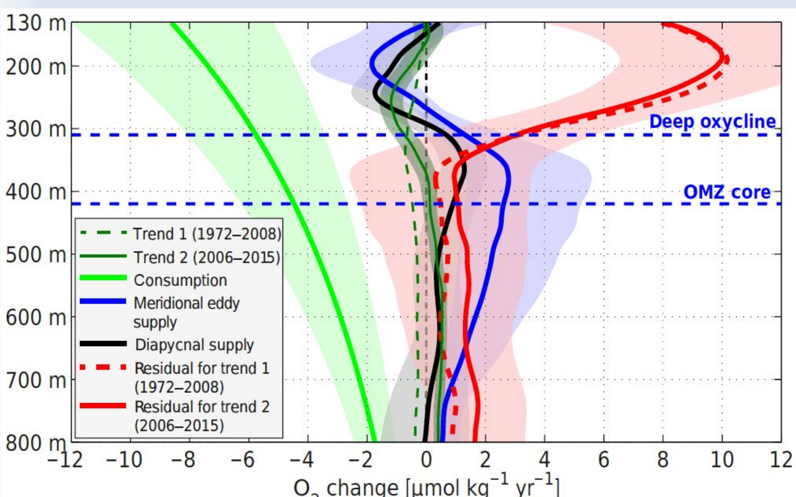
23°W Observations



- SFB754: Climate-Biogeochemistry Interaction program (2008-2019)
  - Shipboard, moored, glider observations; two tracer release experiments
  - Ventilation processes and oxygen budget (6°N-14°N)

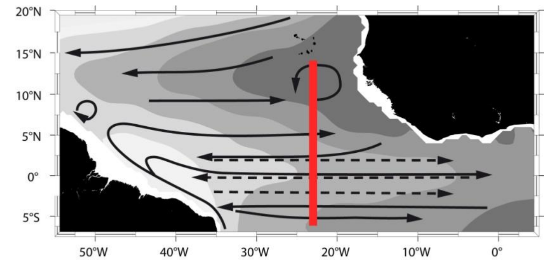


- Meridional eddy supply is the dominant term in the OMZ core; contribution from diapycnal mixing
- Residuum mostly zonal advection
- Upper 300m dominated by advection



Hahn et al. 2017

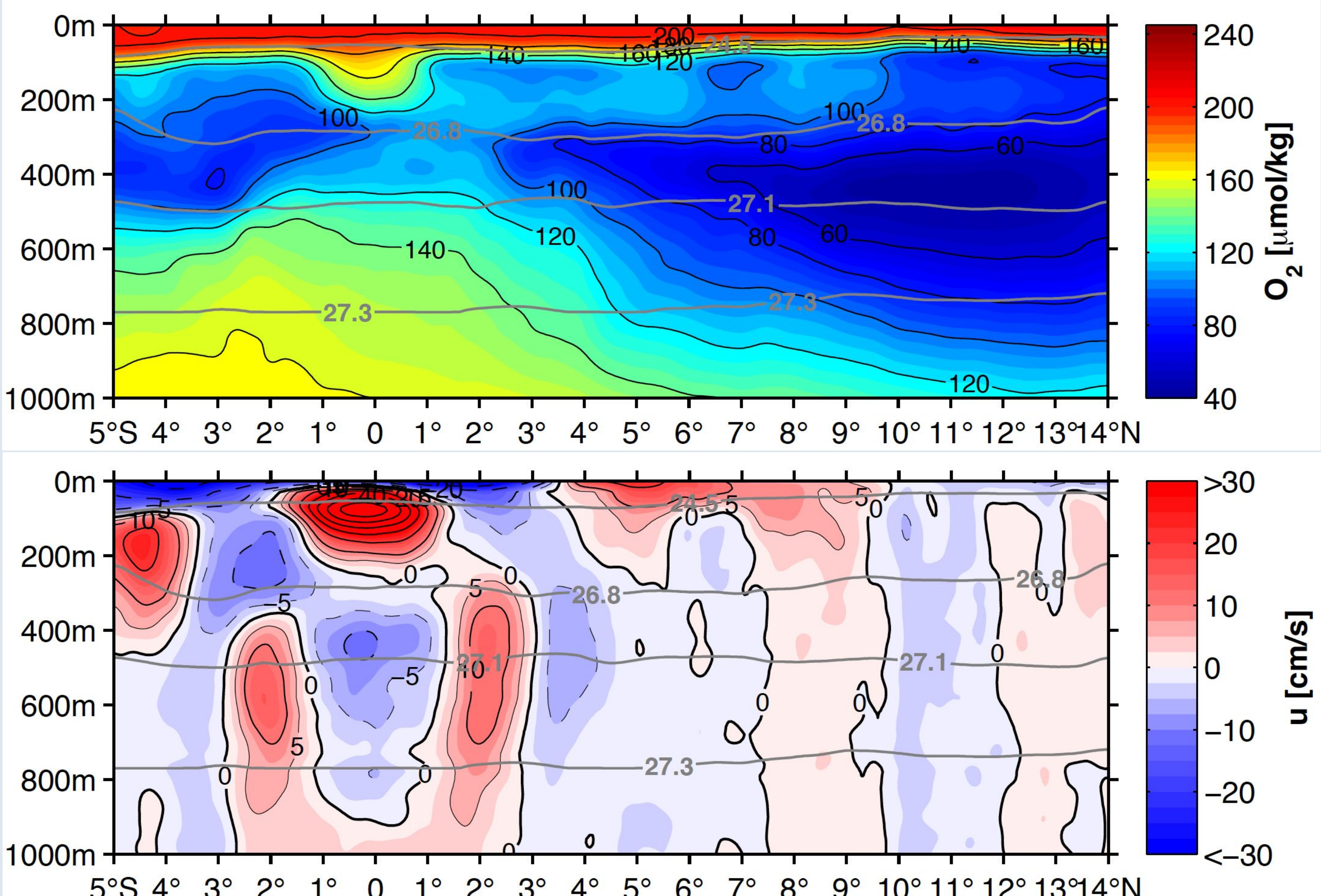
Mean 23°W Section



Equatorial oxygen maximum

OMZ Core at 400m, 11°N

Upper ocean eastward currents associated with enhanced oxygen



Brandt et al. 2015

Oxygen Change along 23°W (2006-2018)

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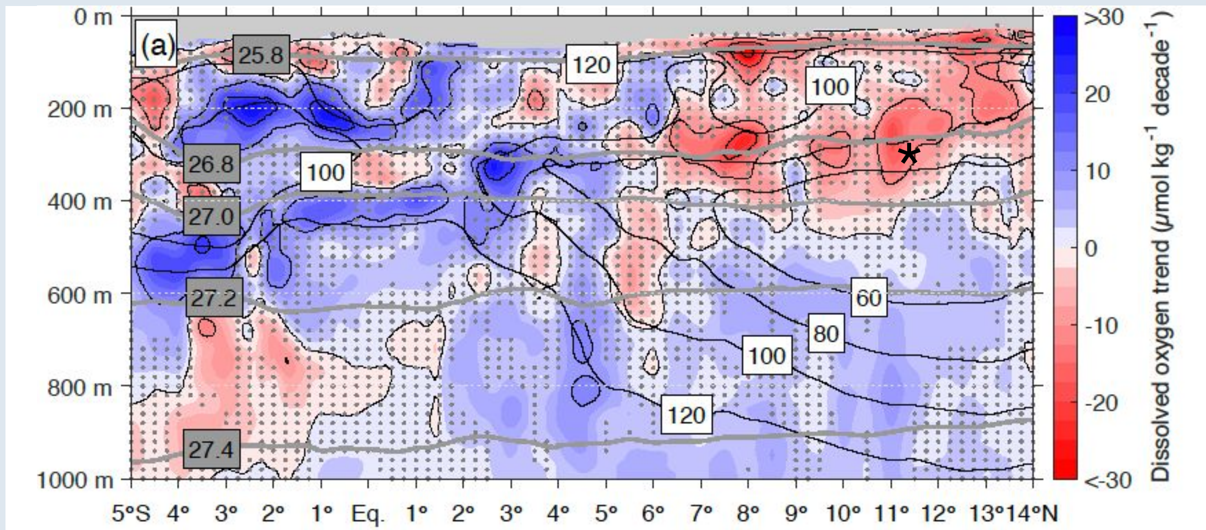
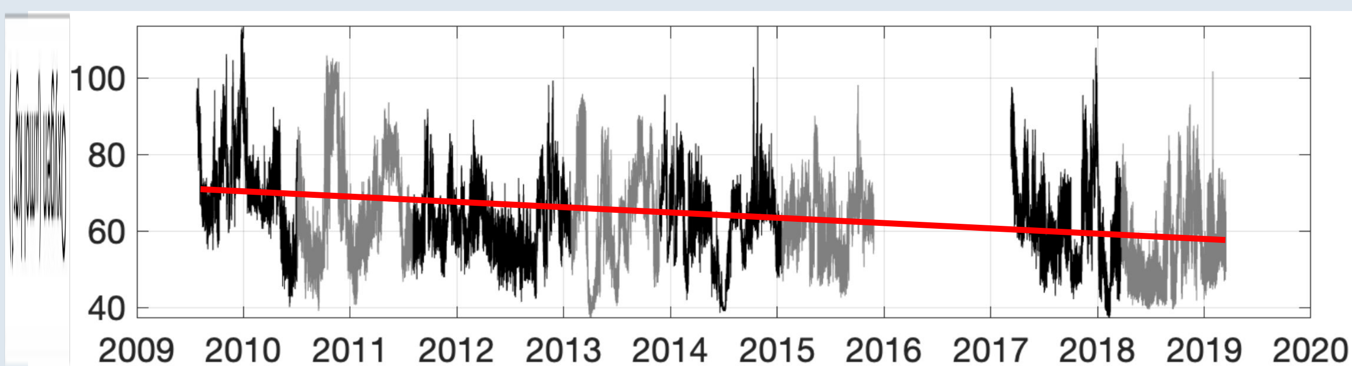
4 Dipole pattern in upper 400m: oxygen increase/decrease south/north of 5°N likely associated with wind-driven circulation changes

4 Oxygen changes most likely associated with circulation changes



2006-2018 trend from 15 oxygen sections

PIRATA oxygen timeseries: 11.5°N, 23°W



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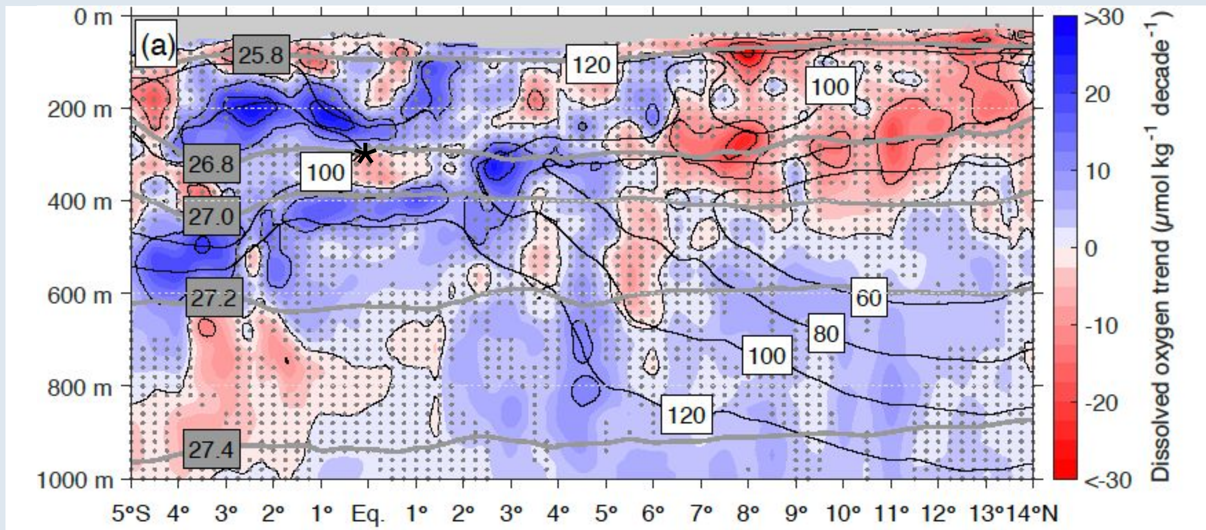
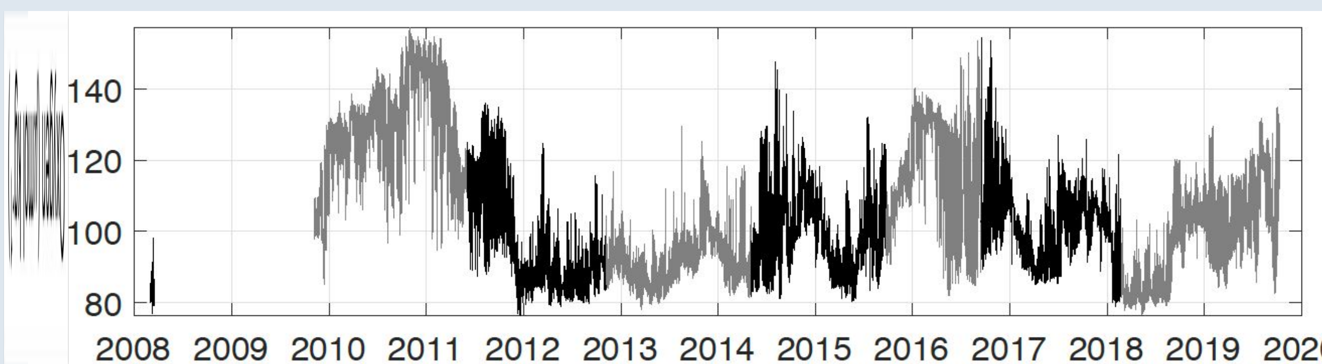


2006-2018 trend from 15 oxygen sections

PIRATA oxygen timeseries: 0°N, 23°W



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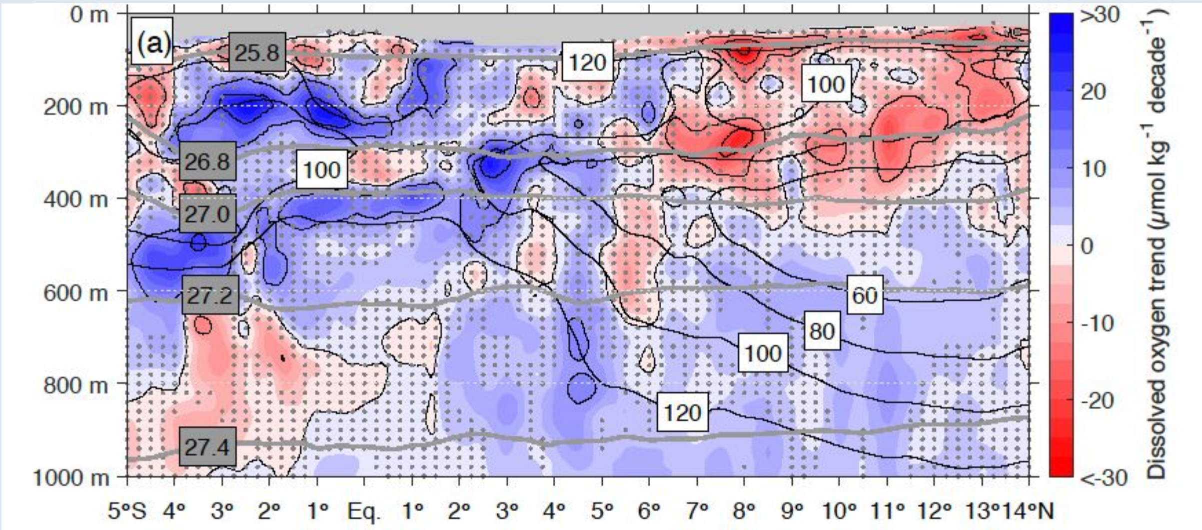

2006-2018 trend from
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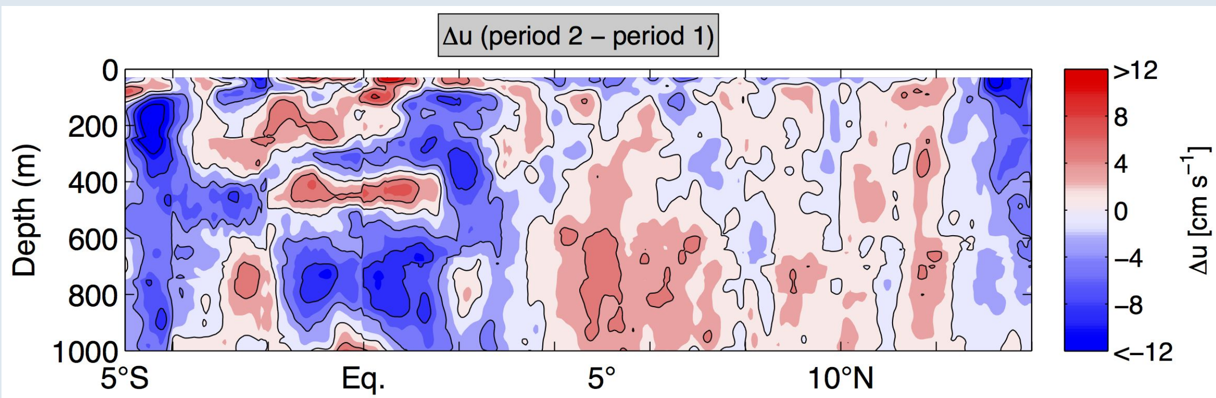

Period 1 (2006-2010)
10 velocity sections
Period 2 (2011-2018)
8 velocity sections

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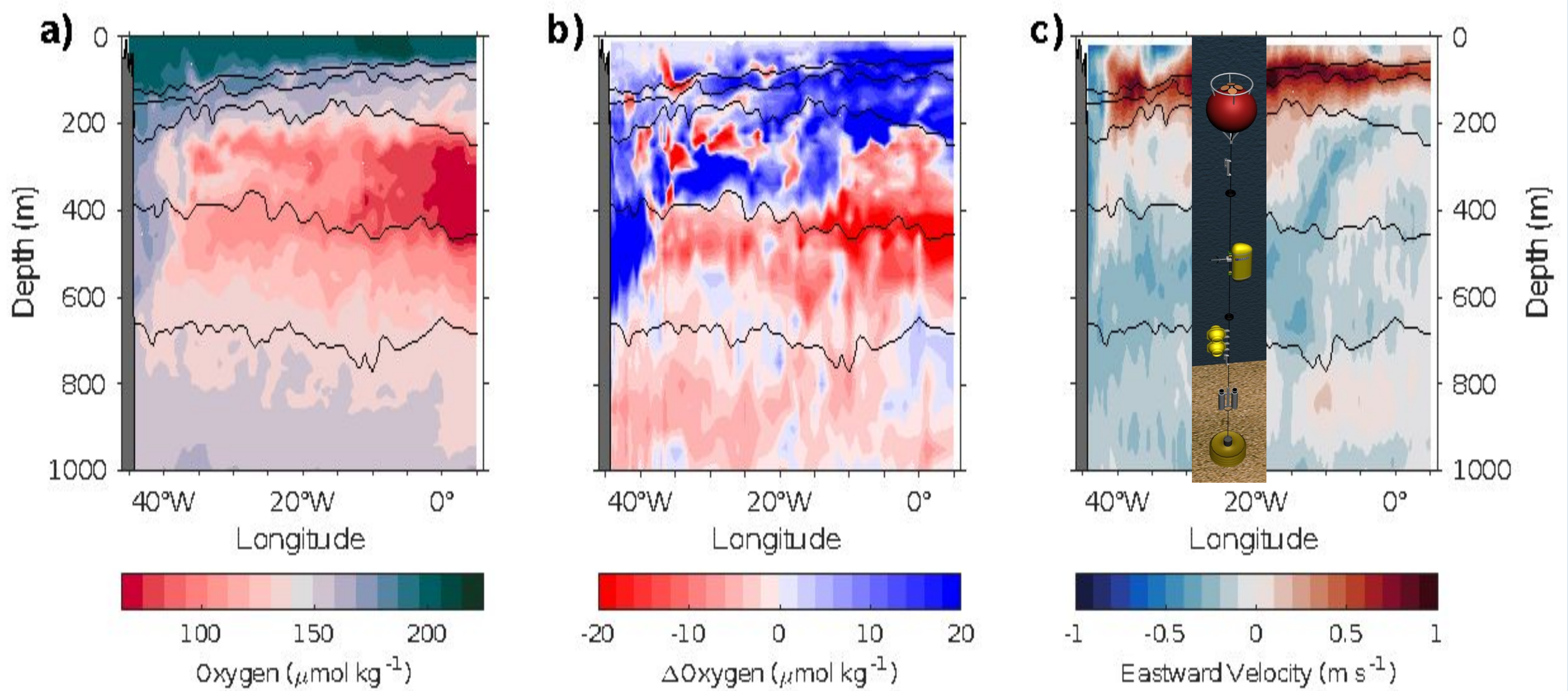
Trans-Atlantic Equatorial Cruise 1 (Sep./Oct. 2019)

- Oxygen (a) and velocity (c) along the equator
  - Enhanced oxygen levels in 2019 relative to 2000 climatology (b)
  - Current meter mooring service at 23°W



Brandt et al. 2021

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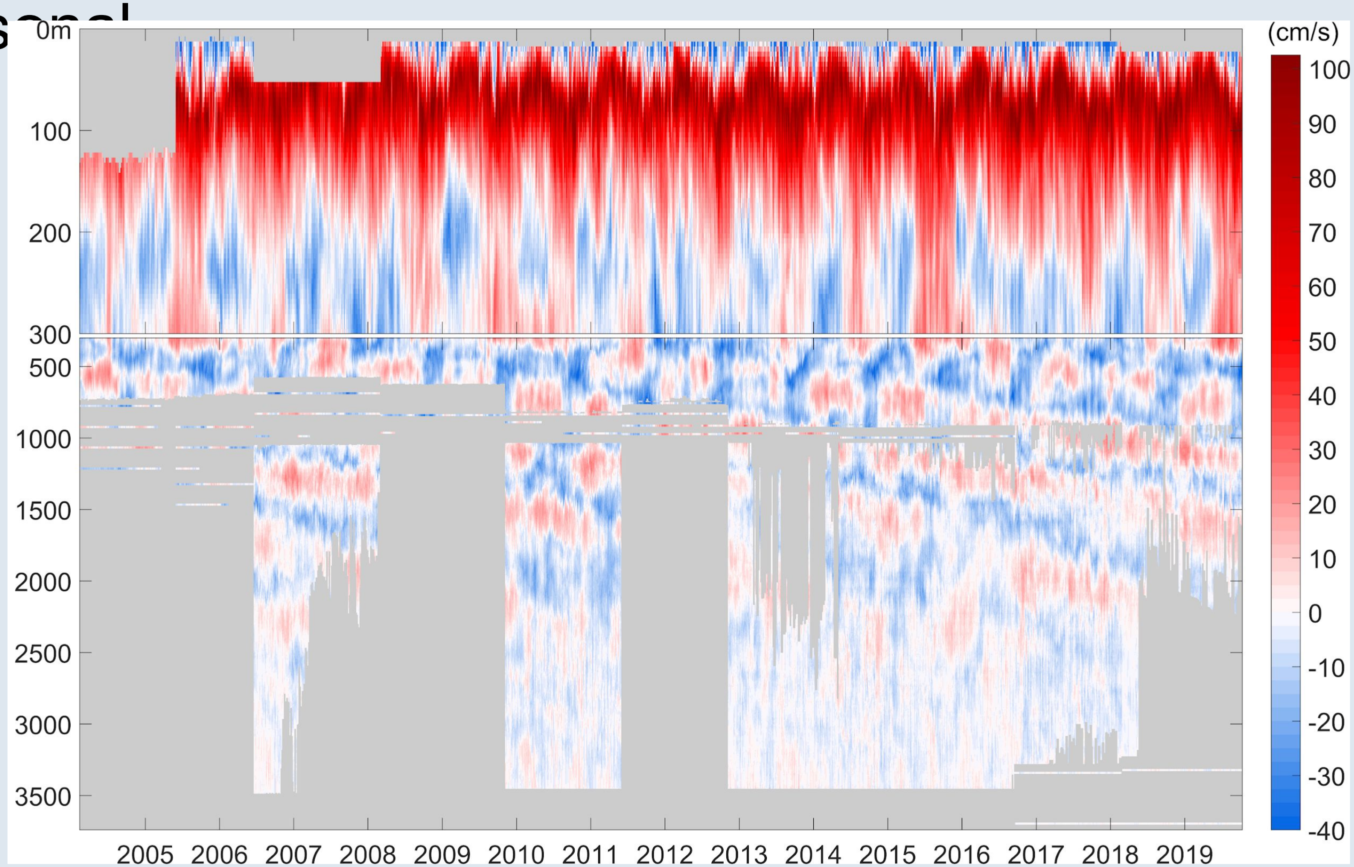
Equator, 23°W Mooring

4 Long-term current-meter mooring since 2001 in cooperation with PIRATA-France

4 Equatorial Undercurrent, Equatorial Deep Jets, intra-seasonal waves, TIWs, seasonal cycle



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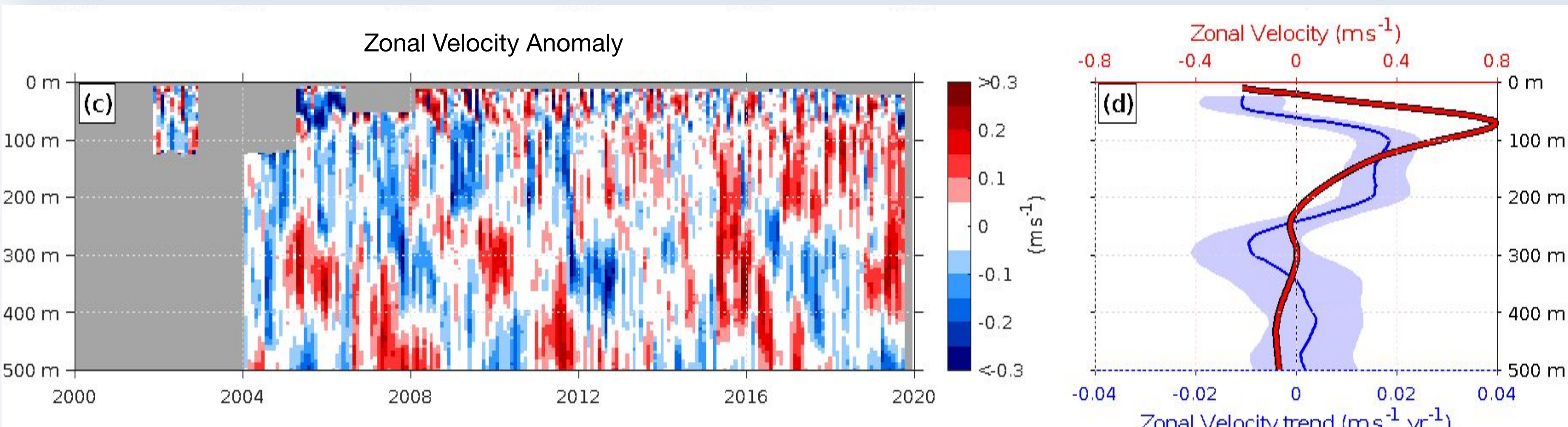
Observations of EUC and Ekman Divergence

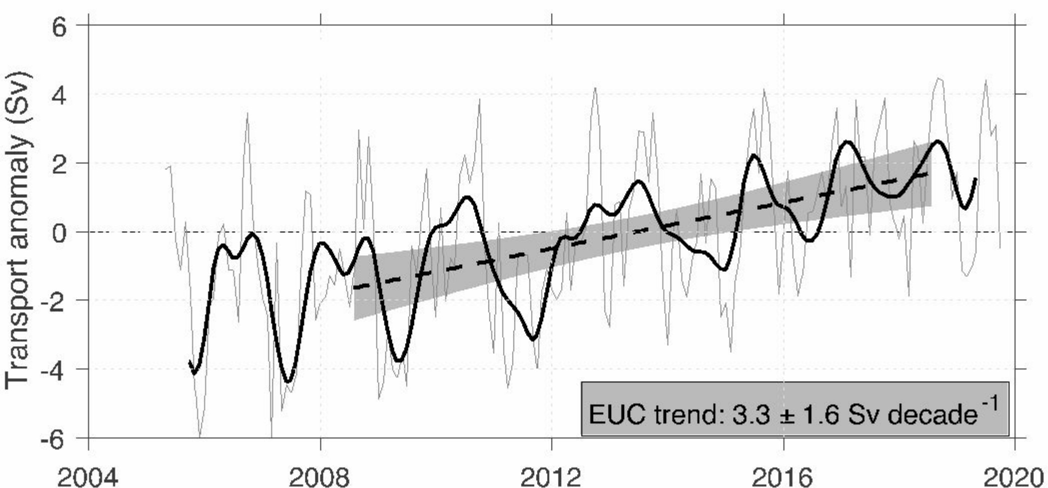
- 10-year strengthening (2008-2018) of equatorial zonal velocity in the depth range from 100-200 m

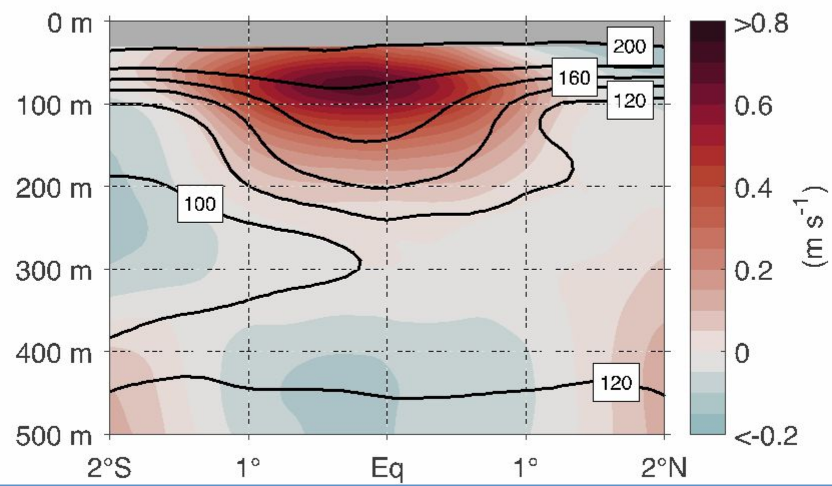


Brandt et al. 2021

EUC Transport and Ekman Divergence

- 10-year strengthening (2008-2018) of equatorial zonal velocity in the depth range from 100-200 m
- Transport of the Equatorial Undercurrent (calculated following Brandt et al. 2014) increases by more than 20%

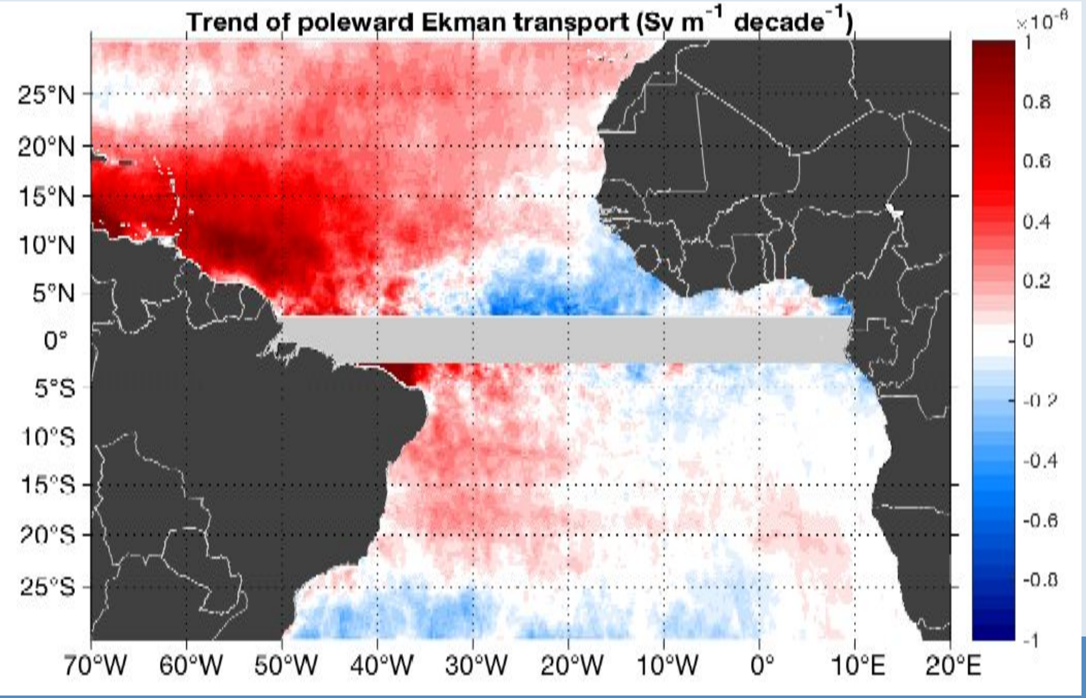




Brandt et al. 2021

EUC Transport and Ekman Divergence

- 10-year strengthening (2008-2018) of equatorial zonal velocity in the depth range from 100-200 m
- Transport of the Equatorial Undercurrent (calculated following Brandt et al. 2014) increases by more than 20%
- Mainly driven by an intensification of the trade winds in the tropical North Atlantic



Brandt et al. 2021

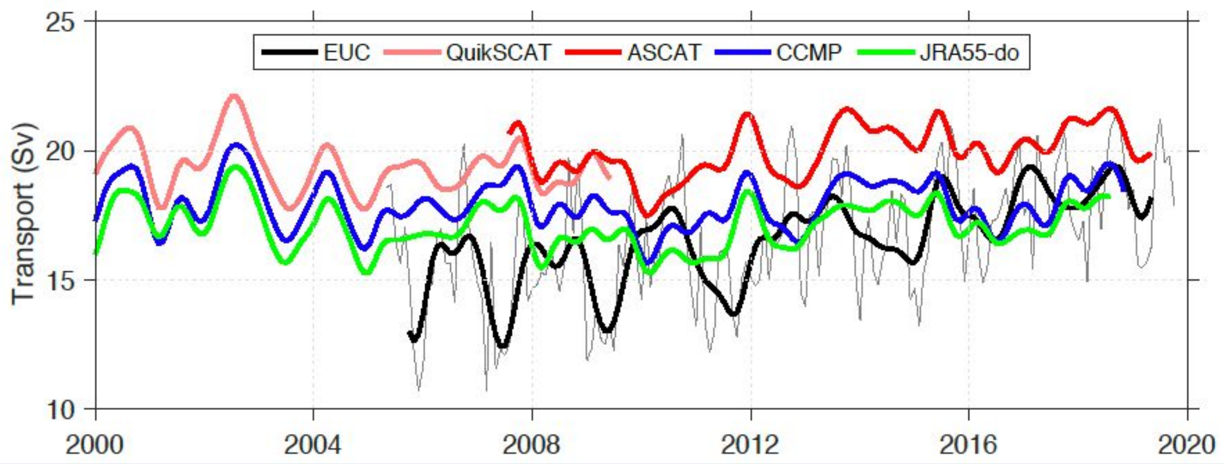
EUC Transport and Ekman Divergence

- Different wind products show trend in Ekman divergence
- Large variability between different products: trends are uncertain
- Observations of wind-driven circulation might help constraining wind-forced ocean simulation

Table 1 | Ten-year trend in Ekman divergence and transport for different wind products

Wind product	Ekman divergence (10° N–10° S) (Sv dec^{-1})	Northward Ekman transport at 10° N (Sv dec^{-1})	Southward Ekman transport at 10° S (Sv dec^{-1})
ASCAT	2.0 ± 1.2	1.5 ± 1.2	0.4 ± 0.6
CCMP	1.1 ± 1.2	1.0 ± 1.1	0.1 ± 0.6
JRA55-do	1.5 ± 1.0	1.3 ± 1.0	0.2 ± 0.7

Ranges are the 95% confidence intervals. JRA55-do refers to Japanese 55-year atmospheric reanalysis.



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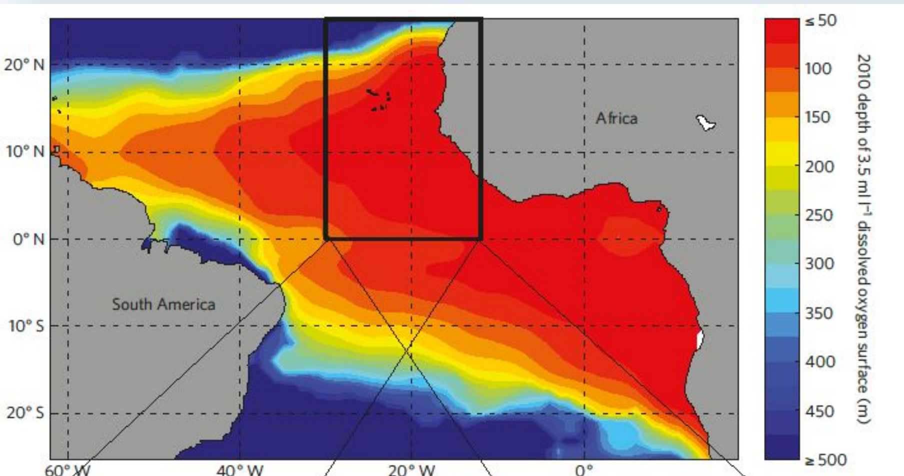
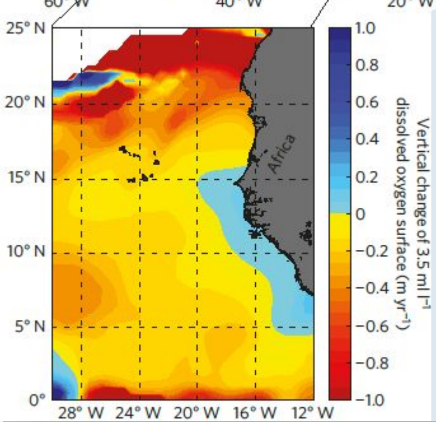
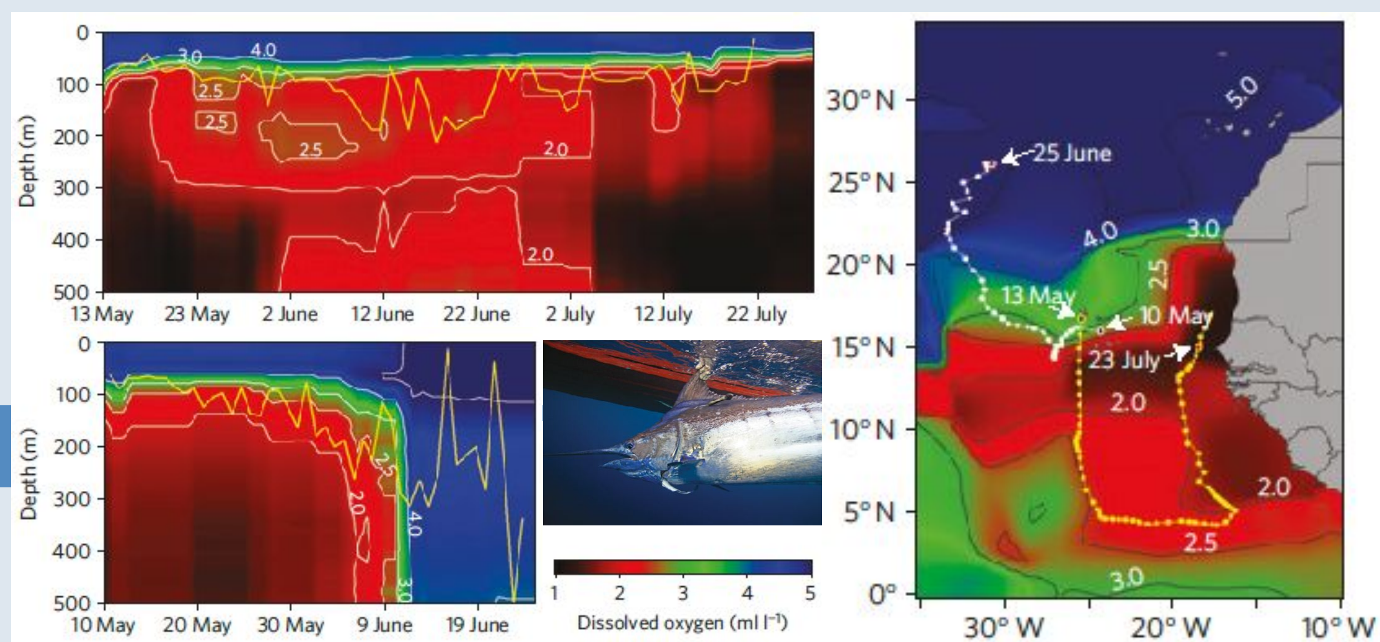
Habitat of Tropical Pelagic Fish

- Electronic tagging data reveal habitat of blue marlin
- Habitat defined by surface oxygenated layer decrease (1960-2009) due to expansion of low-oxygen regions particularly at the equator





Stramma et al. 2012



Multi-decadal Variability of Surface Oxygenated Layer Thickness

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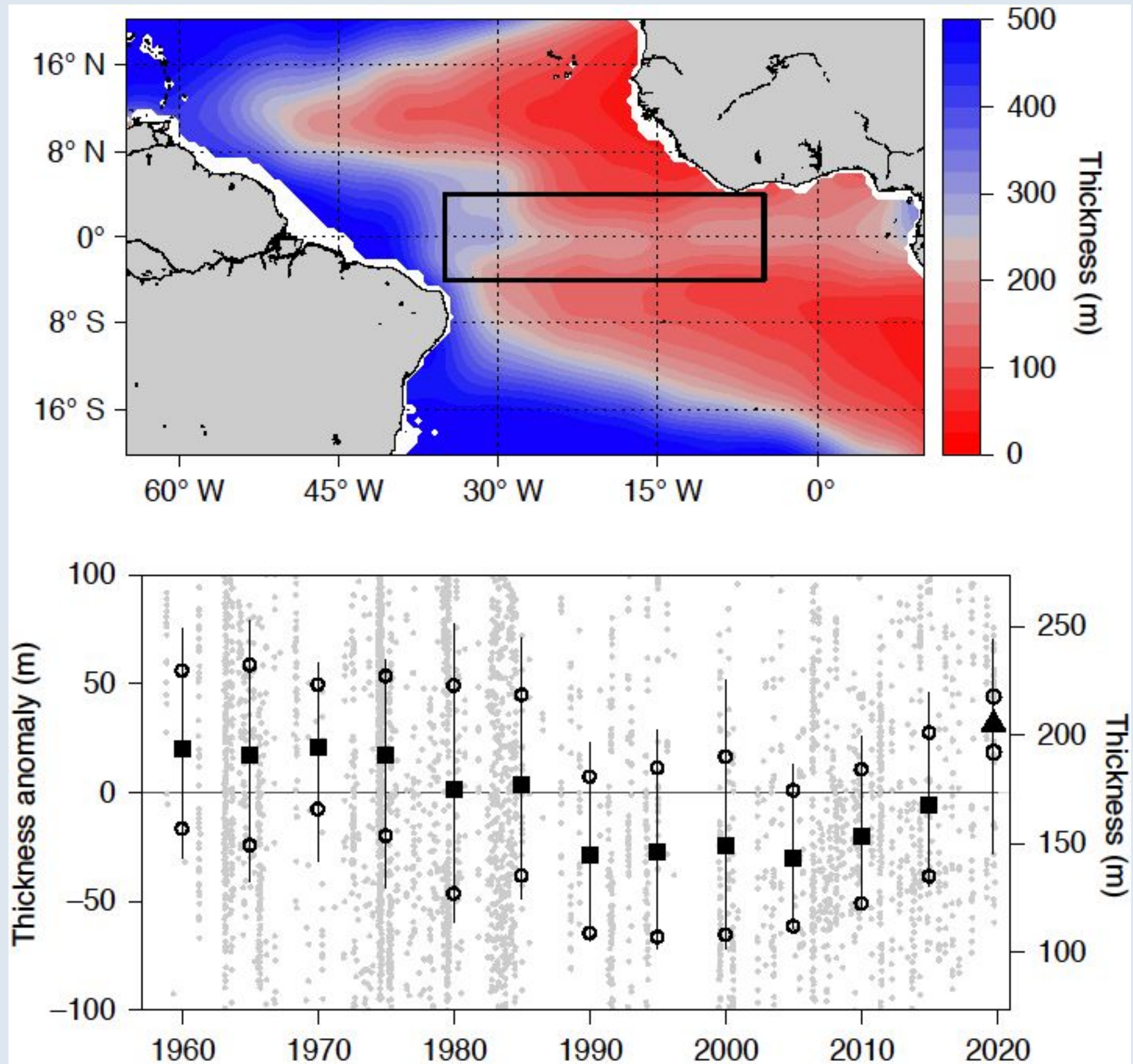
- Oxygenated layer (120µmol kg^{-1}) thin over oxygen minimum zones and deeper at the western boundary and equator
- Layer thickness large in the 1960s and 1970s and small in the 1990s and 2000s: variability could be linked to Atlantic multidecadal oscillation
- Layer thickening during last ~15 years



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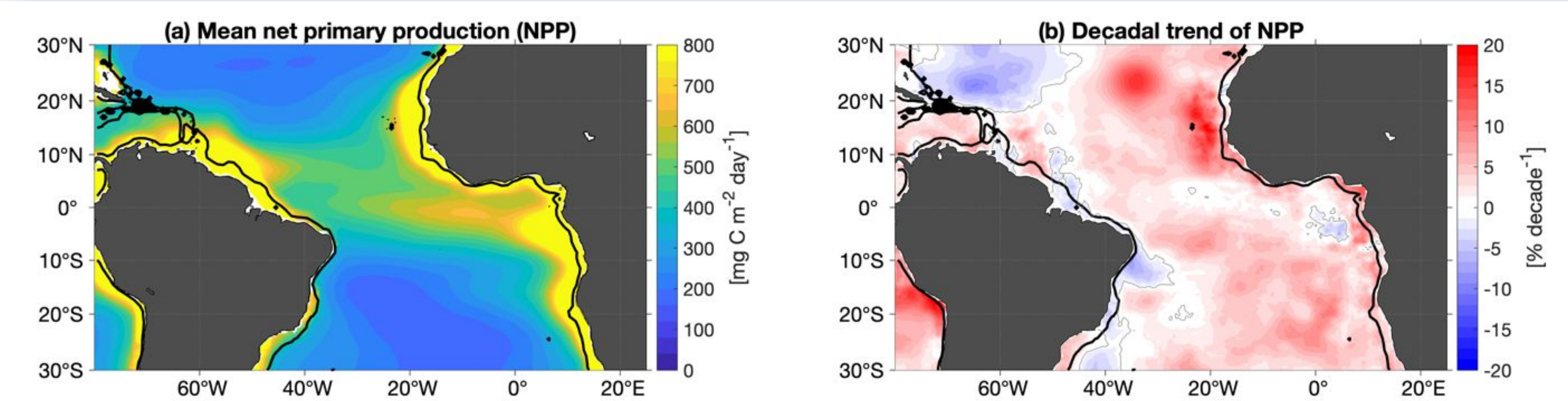
Summary/Discussion

- Realism of equatorial circulation is critical for mean oxygen but also for long-term variability (Duteil et al., 2014a; Busecke et al., 2019)
- AMV likely play an important role via northern hemisphere forcing (e.g. Frajka-Williams et al., 2017); southern hemisphere forcing important during other periods (Tuchen et al., 2020)
- Large uncertainties of wind forcing on interannual to decadal timescales (Ramon et al. 2019); circulation variability could help to evaluate wind products used in forced ocean model simulations
- Duteil et al. (2014b): STC variability, role of enhanced productivity
- Roch et al. (2021, in preparation) decadal trend of primary productivity

Net Primary Productivity 2006-2019



Roch et al. 2021, in preparation

Mean and trend of net primary production (NPP) deduced from satellite observations from Ocean Productivity site for the time period of 2006-2019.

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- Mislan et al. (2017) Tuna habitat development under climate warming (also Hollowed et al., 2013); altered predator-prey relationships, assessment of overfishing, changing fishing effort
- Upwelling regions crucial for air-sea oxygen flux (Eddebar et al., 2017) due to anomalous ocean oxygen outgassing under increased subsurface oxygen levels (Oschlies et al. 2018)

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Acknowledgements

- Study in the frame of the Tropical and South Atlantic climate-based marine ecosystem prediction for sustainable management (EU TRIATLAS) project
- Based on the observational program of SFB 754 “Climate – Biogeochemical Interactions in the Tropical Ocean”
- Mooring work in cooperation with PIRATA, BMBF NORDATLANTIK and RACE, CLIVAR TACE
- We thank the captains, crews, scientists and technical groups involved in the different national and international research cruises to the tropical Atlantic that contributed to collecting shipboard and mooring data and making them freely available.

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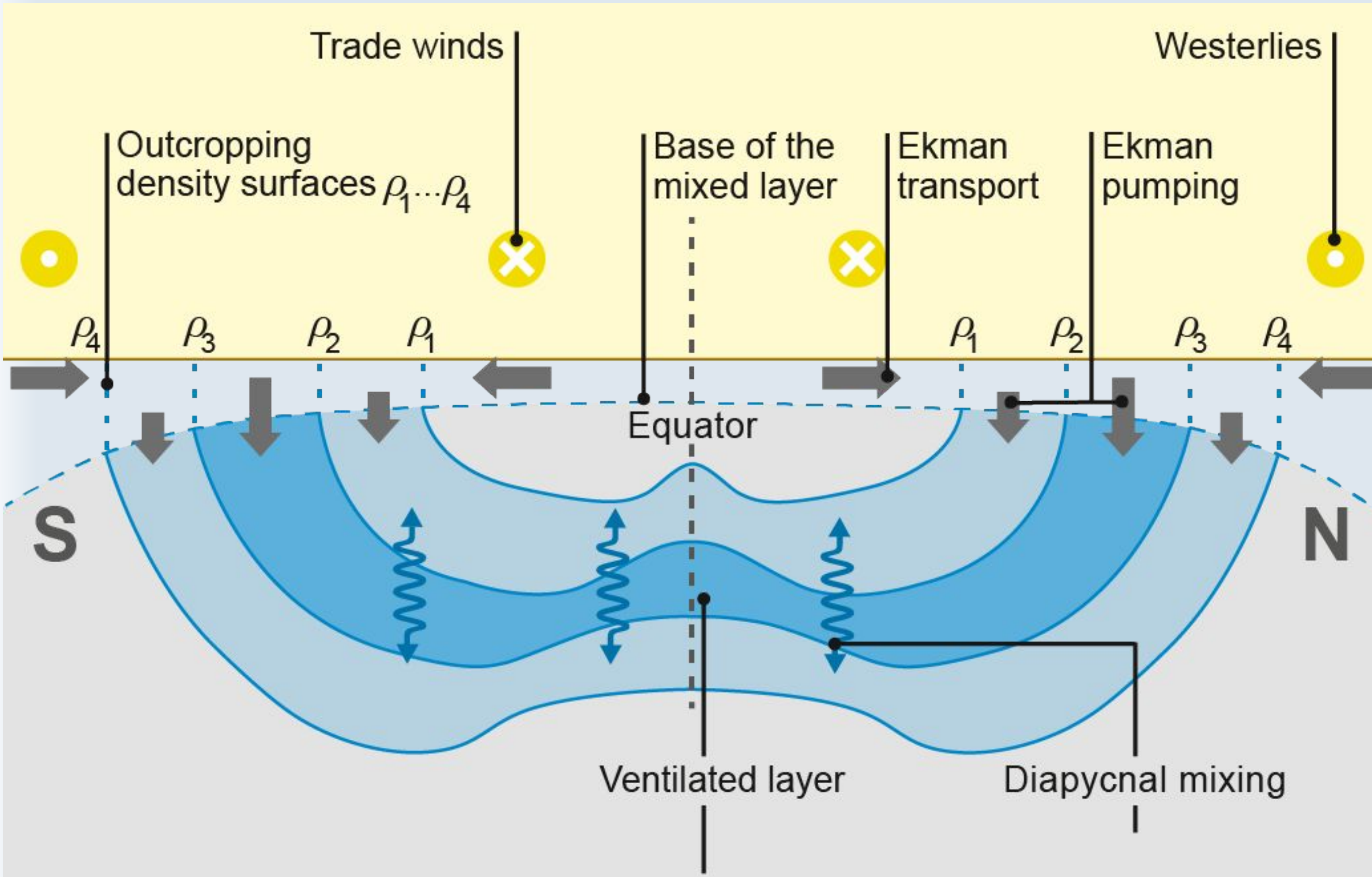
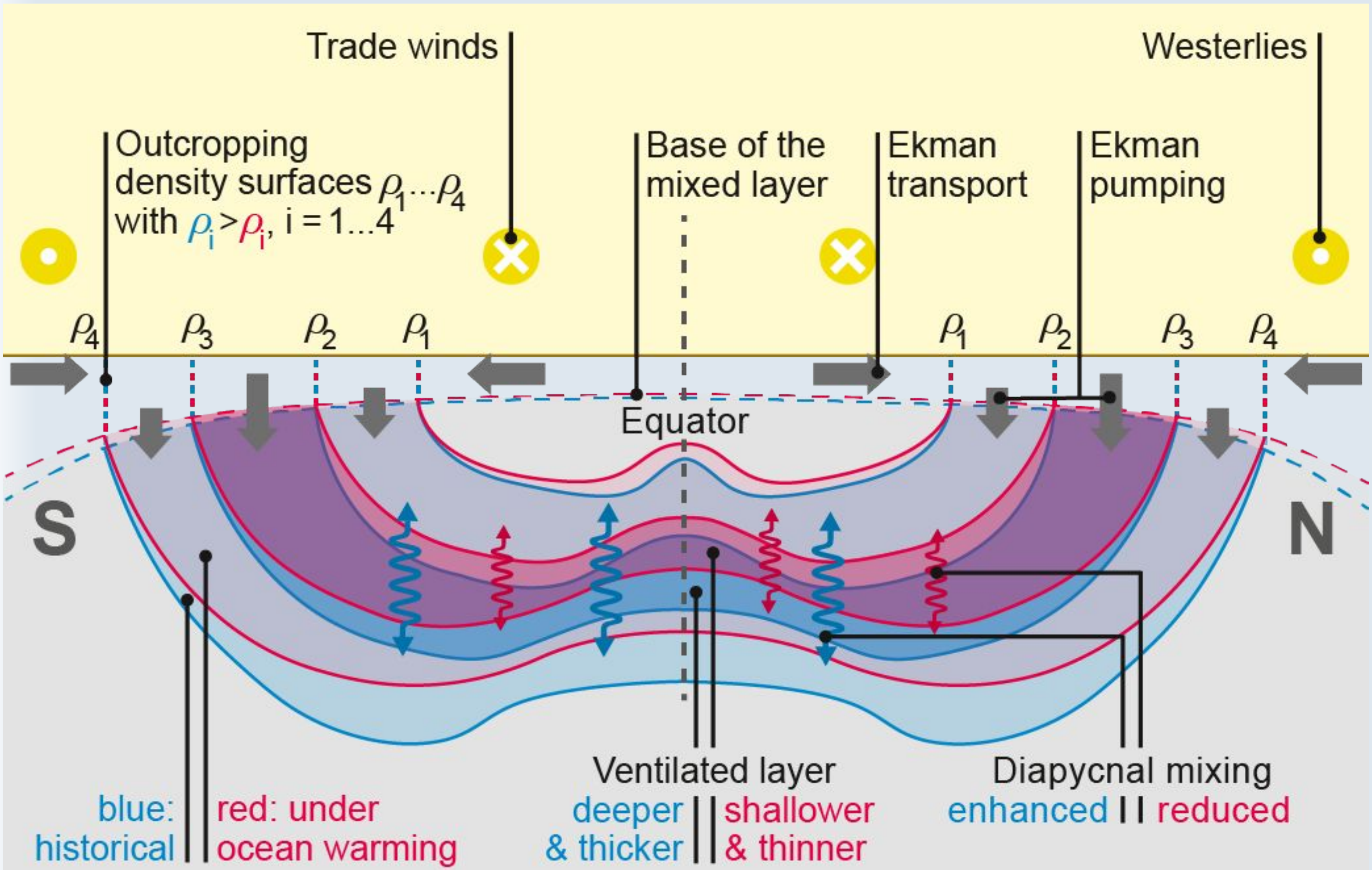
Thank you for your

Mechanisms of Thermocline Oxygen Changes



Oschlies et al. 2018

Mechanisms of Thermocline Oxygen Changes



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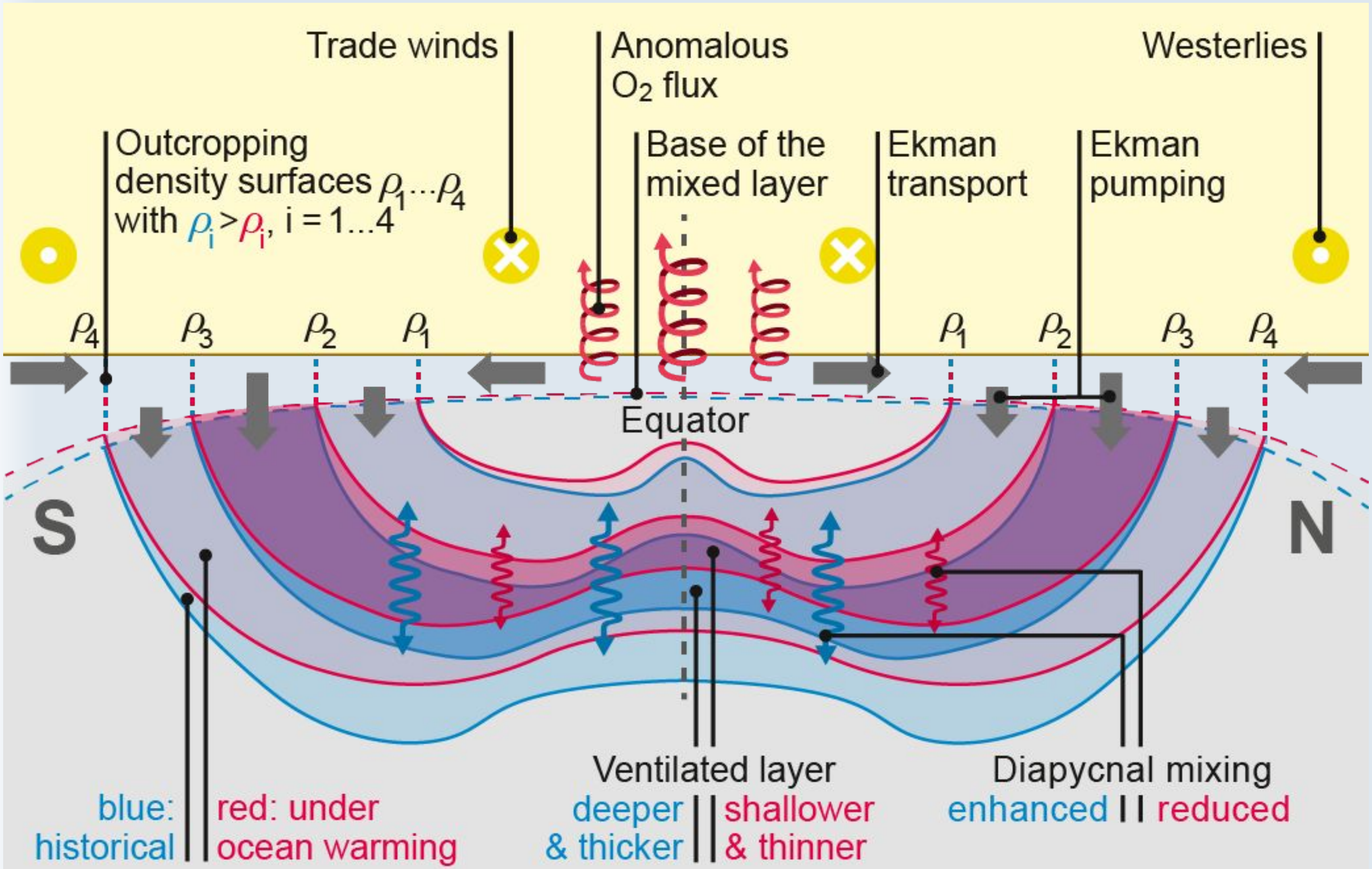

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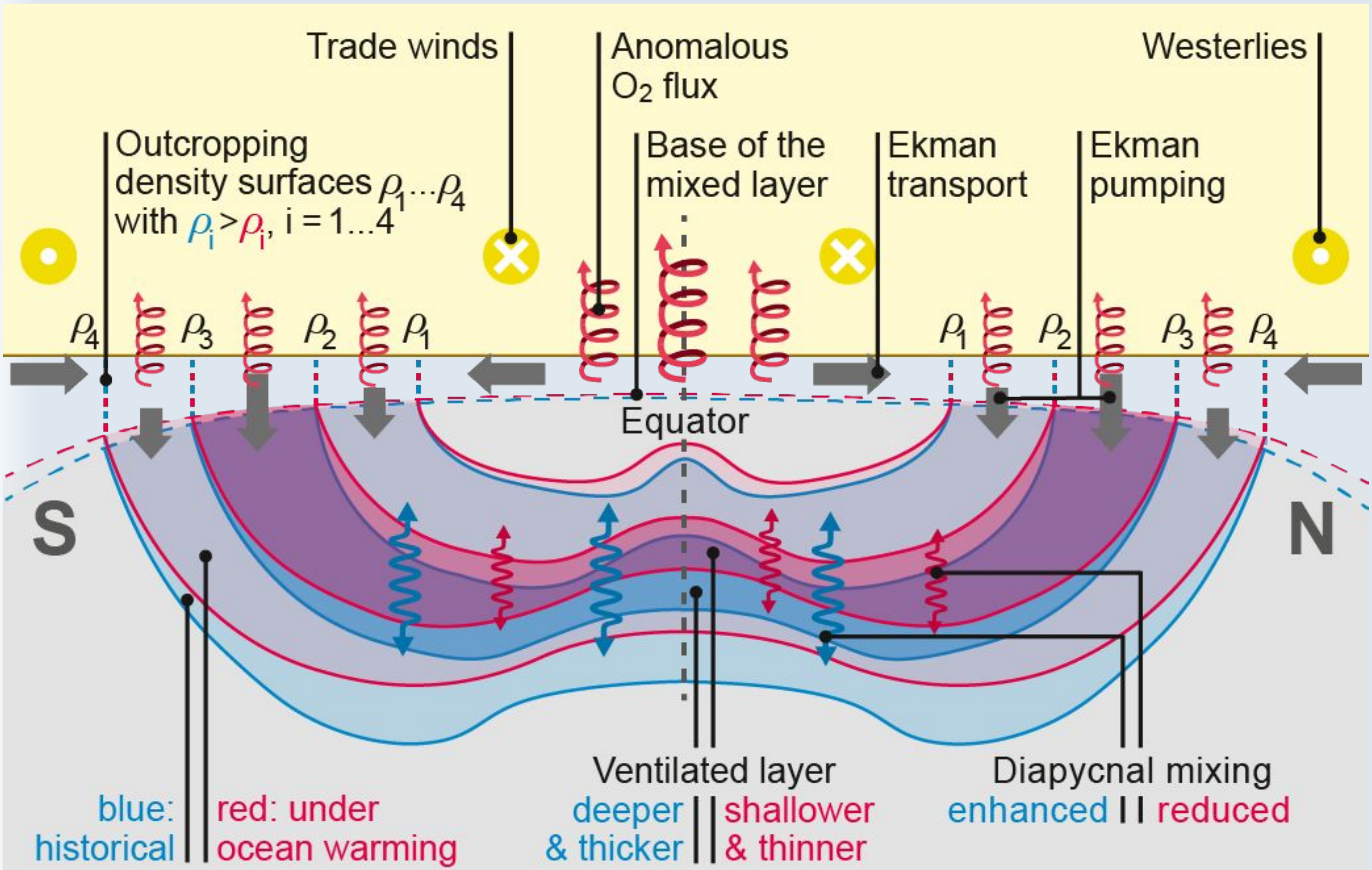

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