GO$_2$NE
Global Ocean Oxygen NEtwork

Institut de Recherche pour le Développement
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Climate variability and ocean deoxygenation over continental margins associated to the Peru-Chile and other upwelling systems: insights from proxy records

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PICES
NORTH PACIFIC MARINE SCIENCE ORGANIZATION

Contents

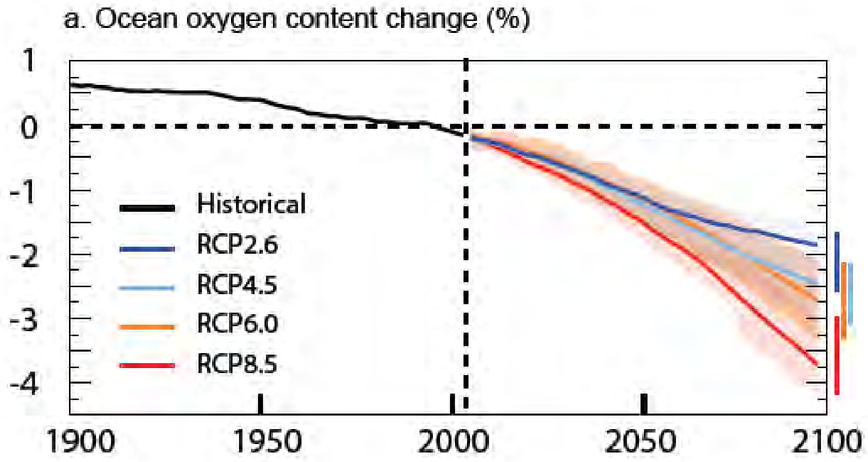
- Background - ocean deoxygenation
- Current distribution of OMZs and over continental margins
- Last Glacial Maximum to Holocene oxygenation changes of main OMZs
- From last millenium to Anthropocene records in the ETSP
- Conclusions

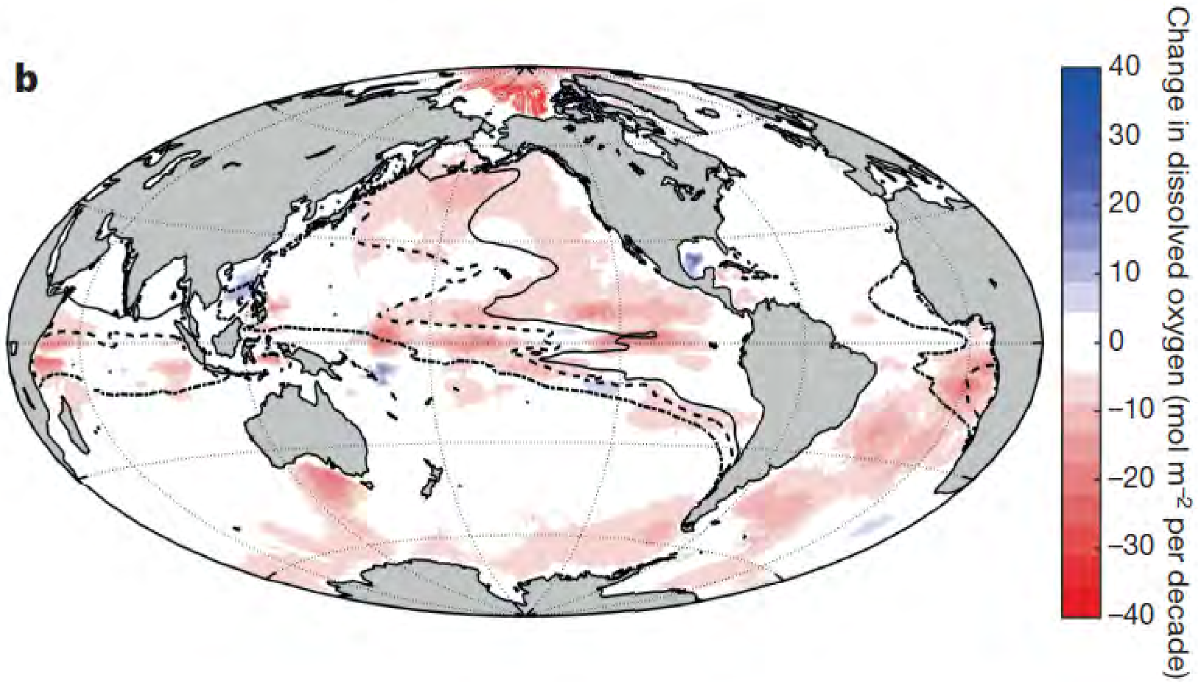
Deoxygenation in the open ocean: global projection and trends

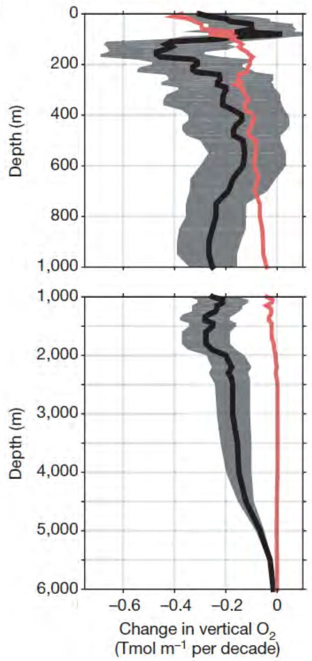
IPCC, 2013

Global warming causes oxygen loss, due to:

- Solubility decrease (explains 15% of global trend since 1960)
- Lower ventilation due to increased stratification / circulation changes
- Stronger respiration and biological oxygen consumption







Trends since 1960 (Schmidtko et al., 2017)

S4

Observations and models

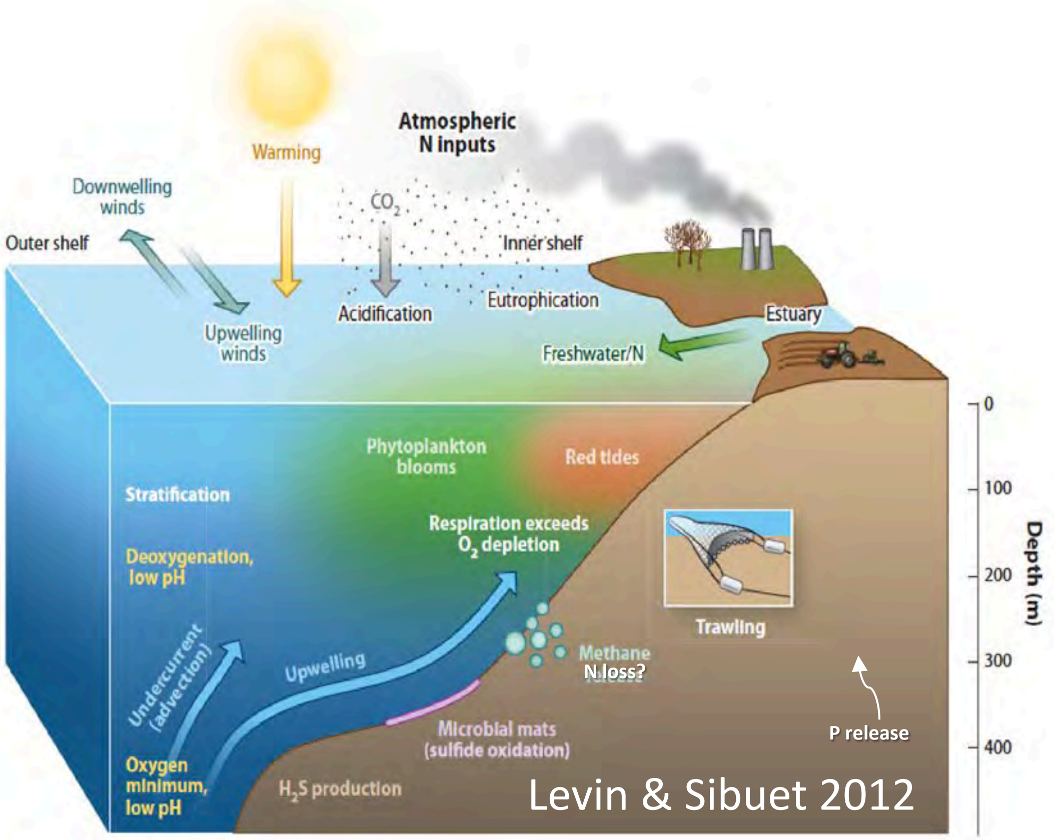
Stramma, Chavez

Alin, Barth, Wang, Duteil, Devasena, Oschlies, García, Galbraith

Impacts

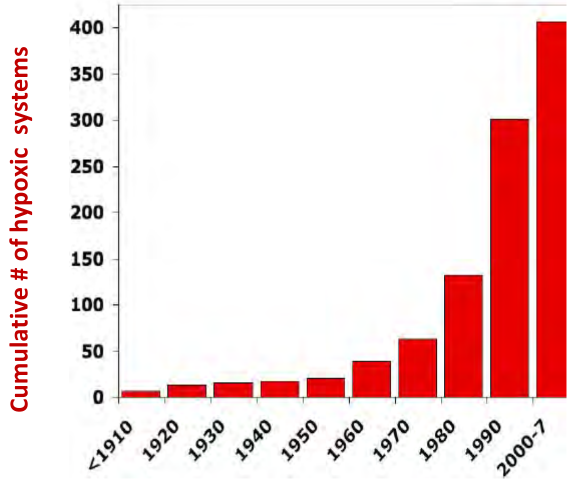
Rosa, Gallo, Rosa

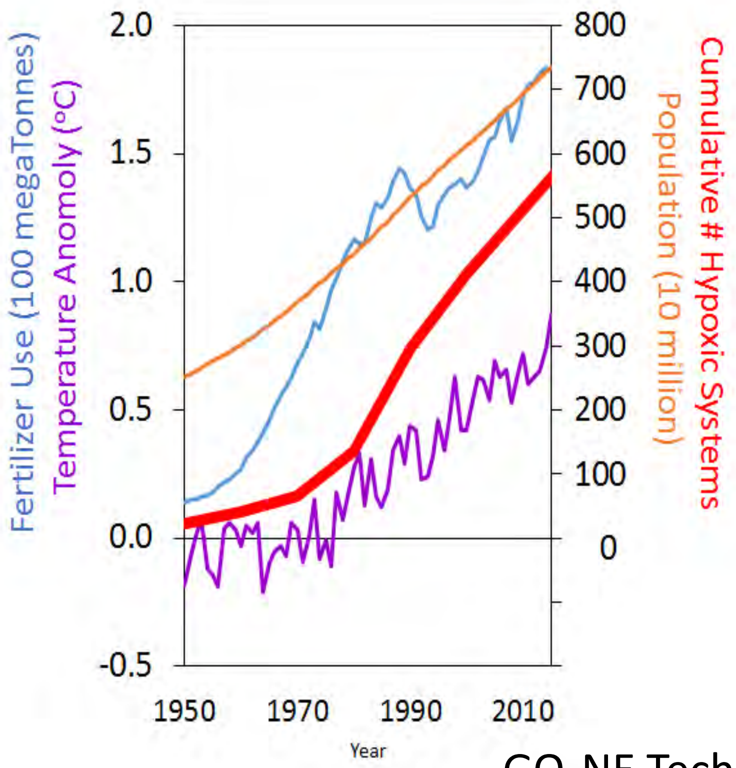
Warming, eutrophication and coastal hypoxia



Levin & Sibuet 2012

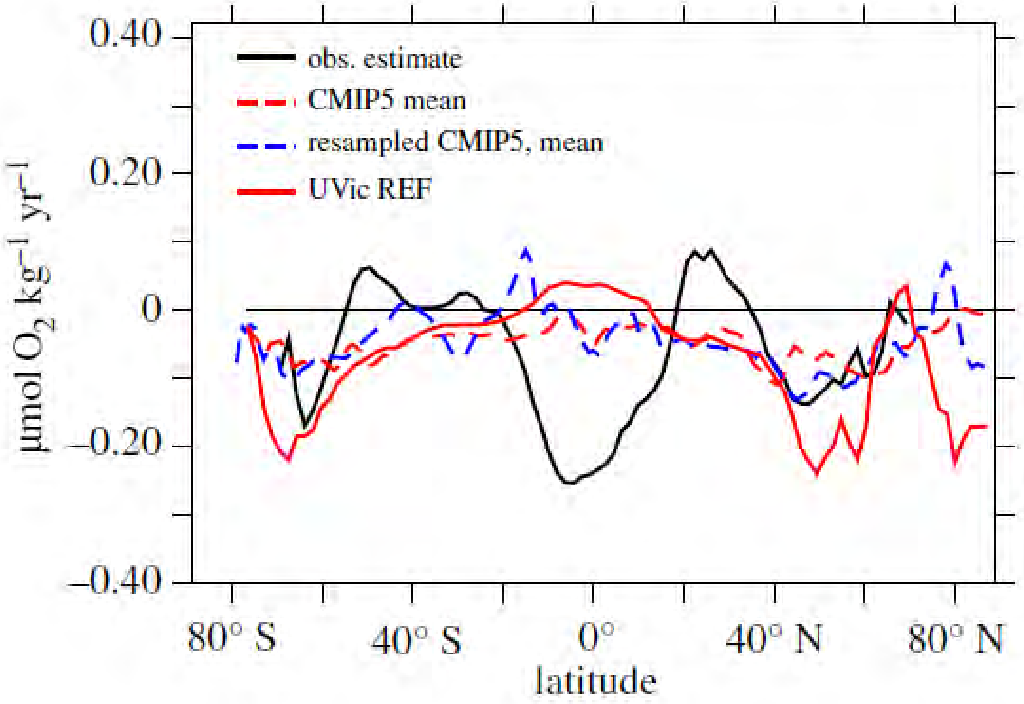
Increase of coastal hypoxia is linked to anthropogenic eutrophication and possibly aggravated by global warming



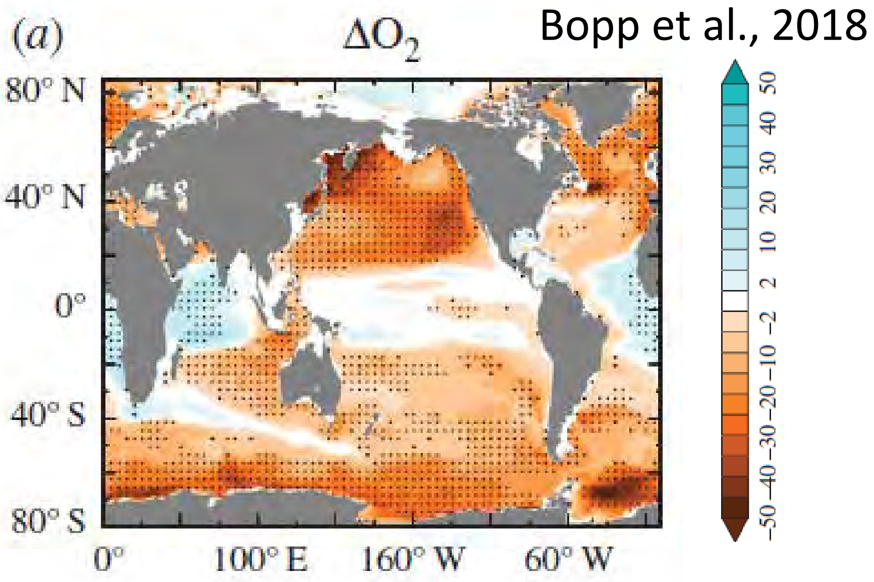


GO$_2$NE Technical Brief, in prep.

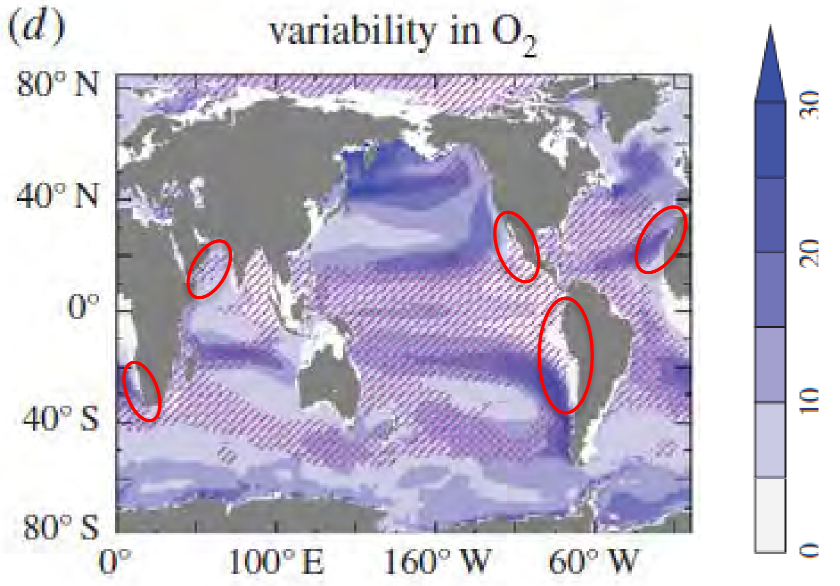
S4
Swarzenski, Costa Jr. , Irby



Observed vs modelled oxygen trends (Oschlies et al., 2018)



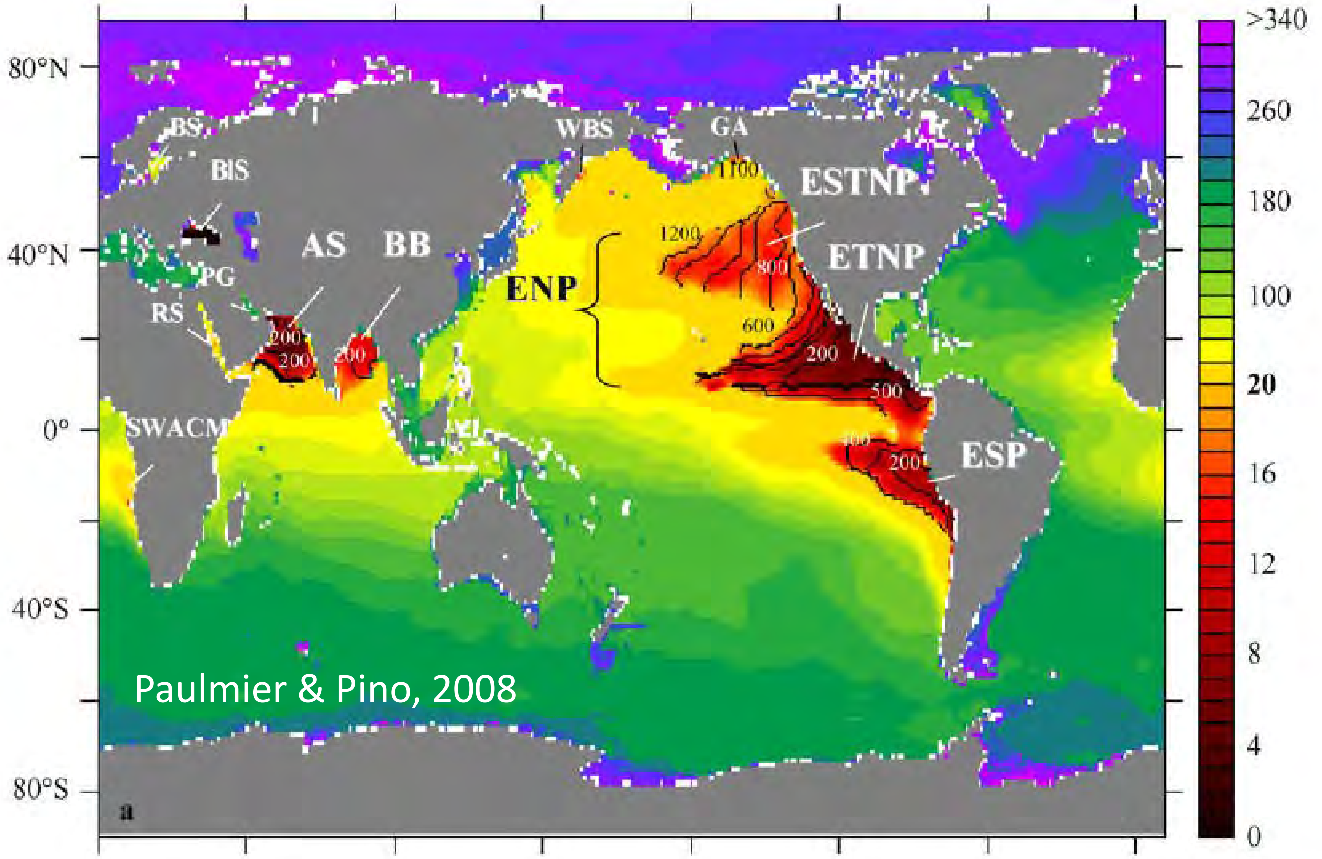
(RCP 8.5, 200–600 m, 2090s–1990s, mmol m^{-3})

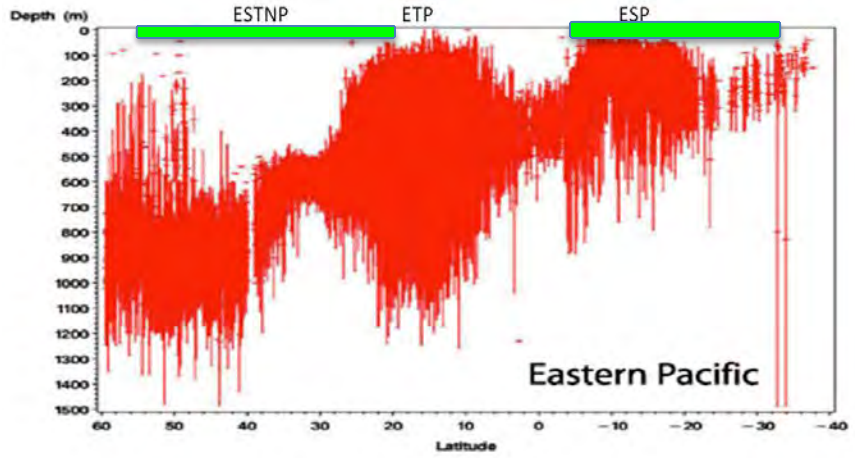


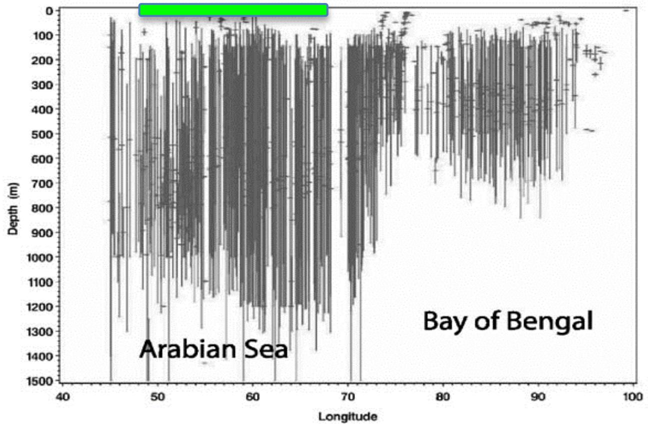
(PI Control, 200–600 m, 2-sigma, mr $^{-3}$)

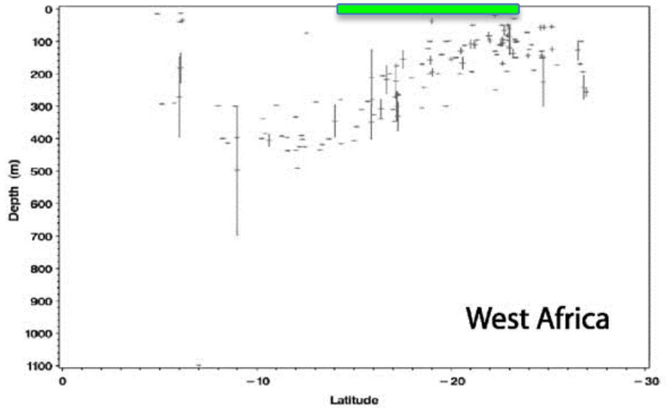
- Models exhibit limitations to reproduce historical trends
- High uncertainty of future trends among models, particularly in tropical and several upwelling regions

Global distribution of Oxygen Minimum Zones and over continental margins





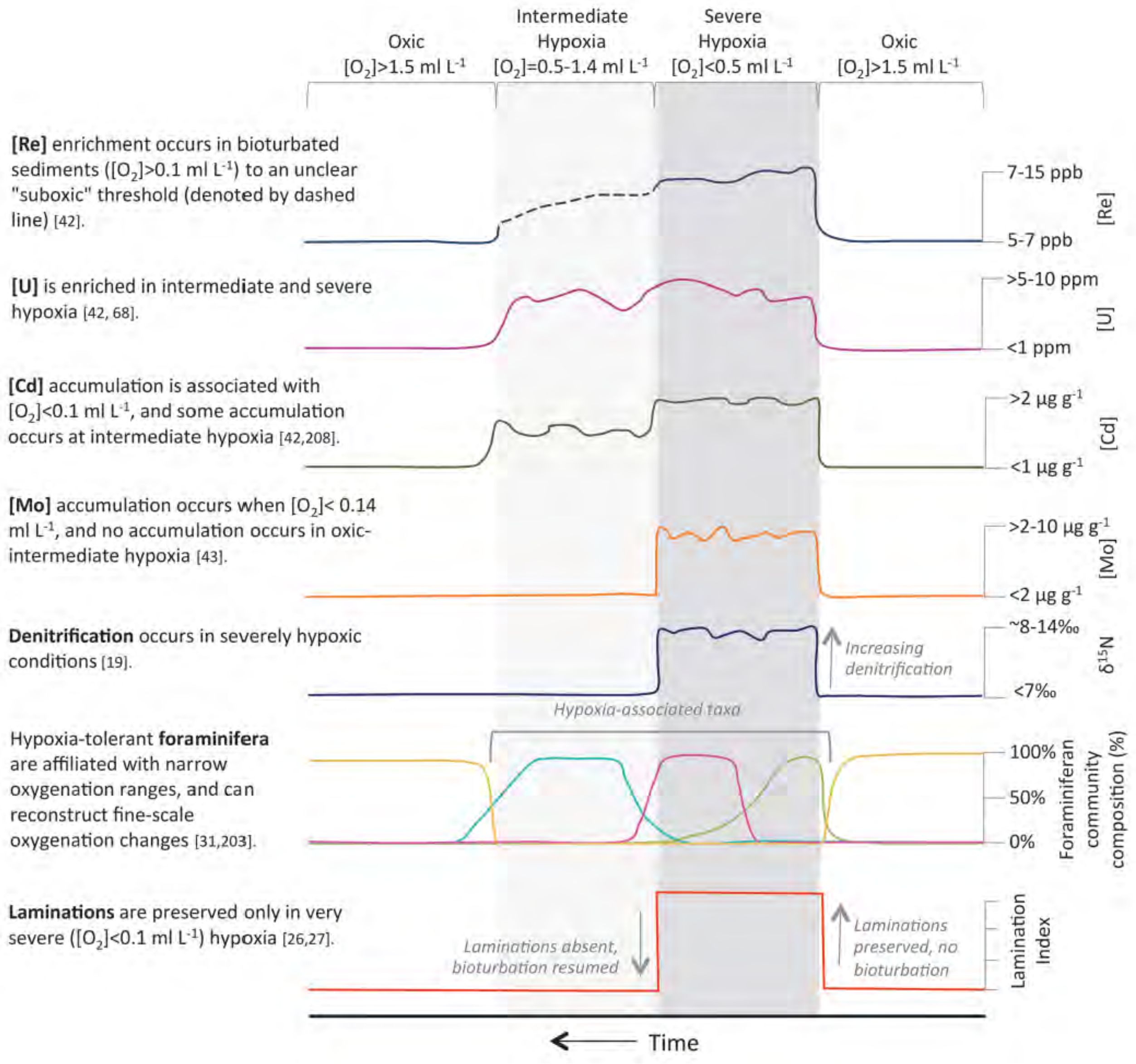




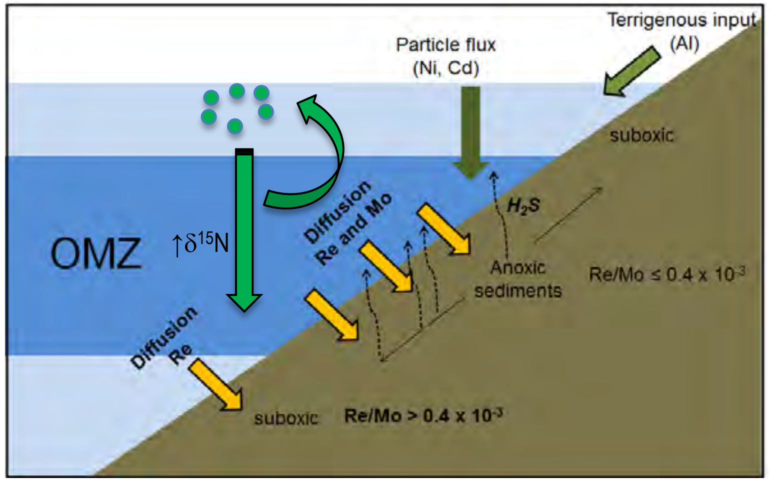
Vertical range of DO<20μM over continental margins (Helly & Levin, 2004).

Coastal upwelling regions:

Paleo-oxygenation proxies



Moffitt et al., 2015

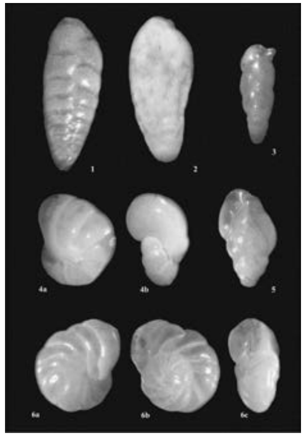


SOM $\delta^{15}N$

redox-sensitive metals

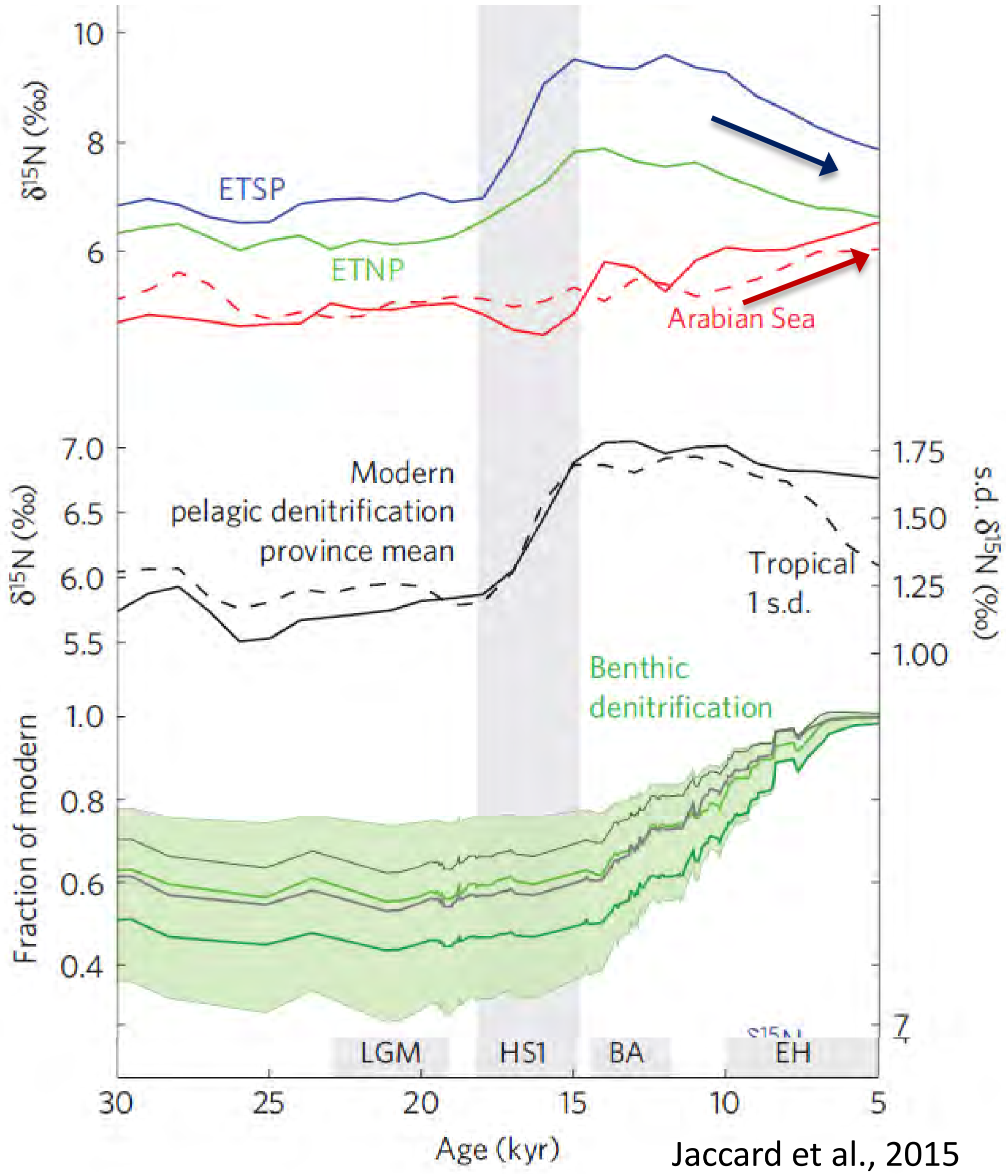
laminations

benthic foraminiferal assemblages

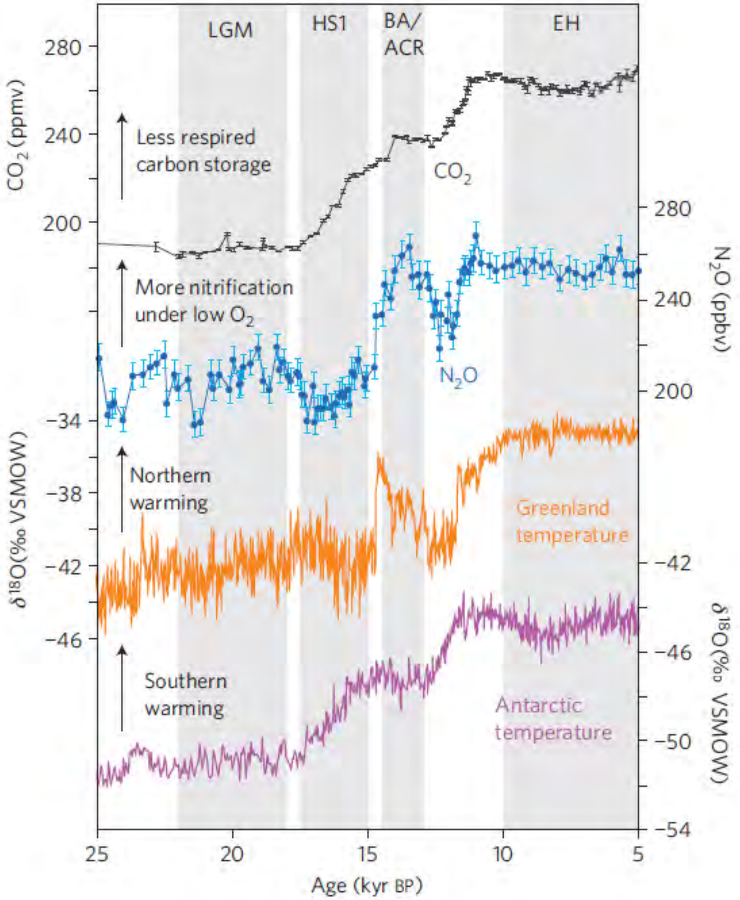


Paleo-oxygenation changes since the LGM

- Deglacial warming favor higher respiration and deoxygenation in mid- and subsurface waters (while better oxygenation in the deep ocean; Jaccard & Galbraith, 2012)
- Differences in timing of WC oxygenation (as inferred from denitrification) among the main oxygen-deficient regions.
- ETSP follows the SH deglacial warming signature. AS follows the NH signal.
- Arabian Sea denitrification mostly increase during the Holocene, while Pacific denitrification decrease towards the mid-Holocene



Jaccard et al., 2015

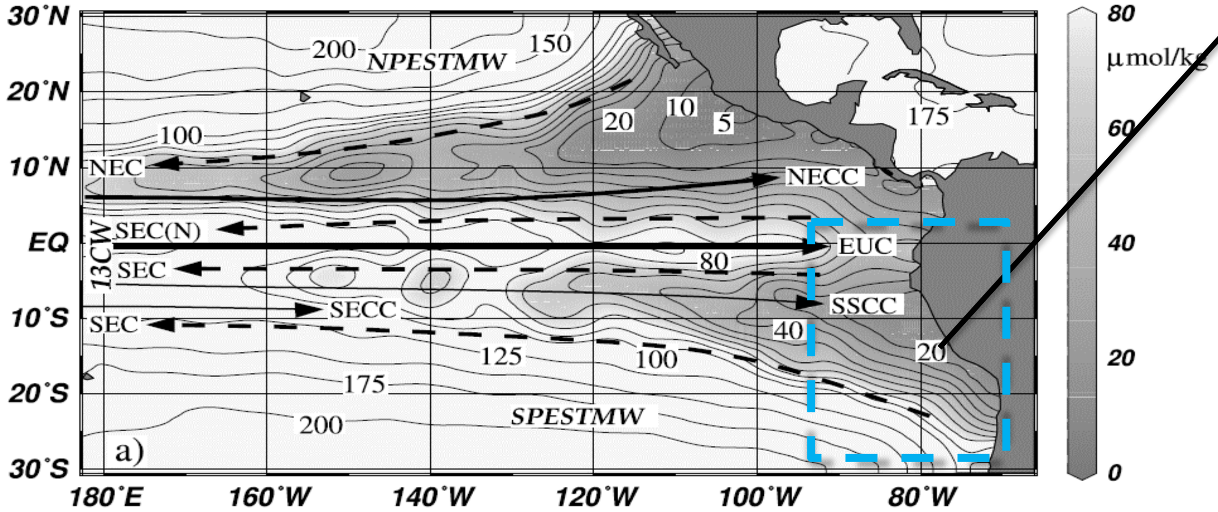


Jaccard & Galbraith, 2012

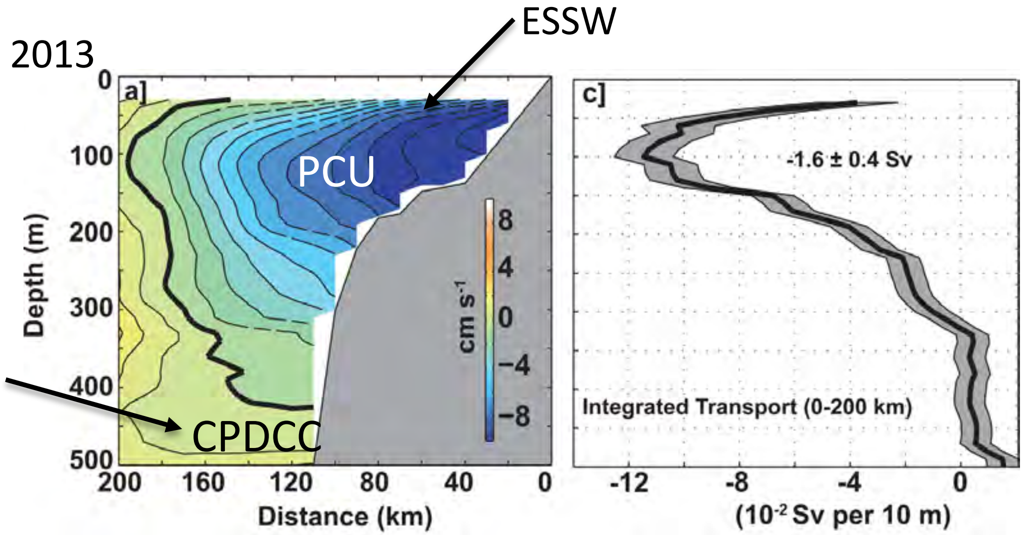
Circulation and OMZ in the South Eastern Tropical Pacific

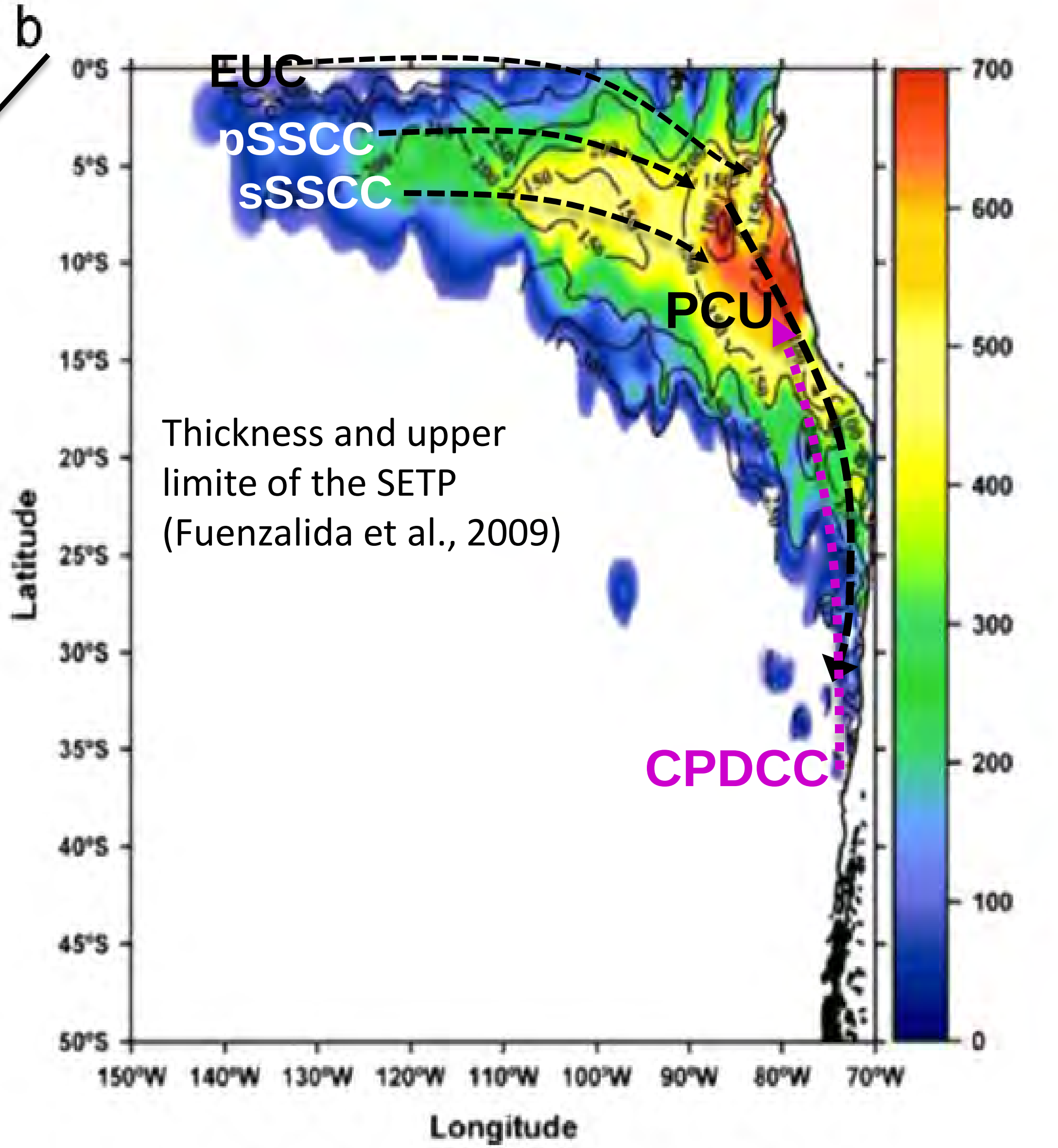
Equatorial Current System (EUC and associated jets) acts to ventilate the Eastern Pacific boundary regions and module the cycles of oxygen

(Stramma et al., 2010)



Chaigneau et al., 2013

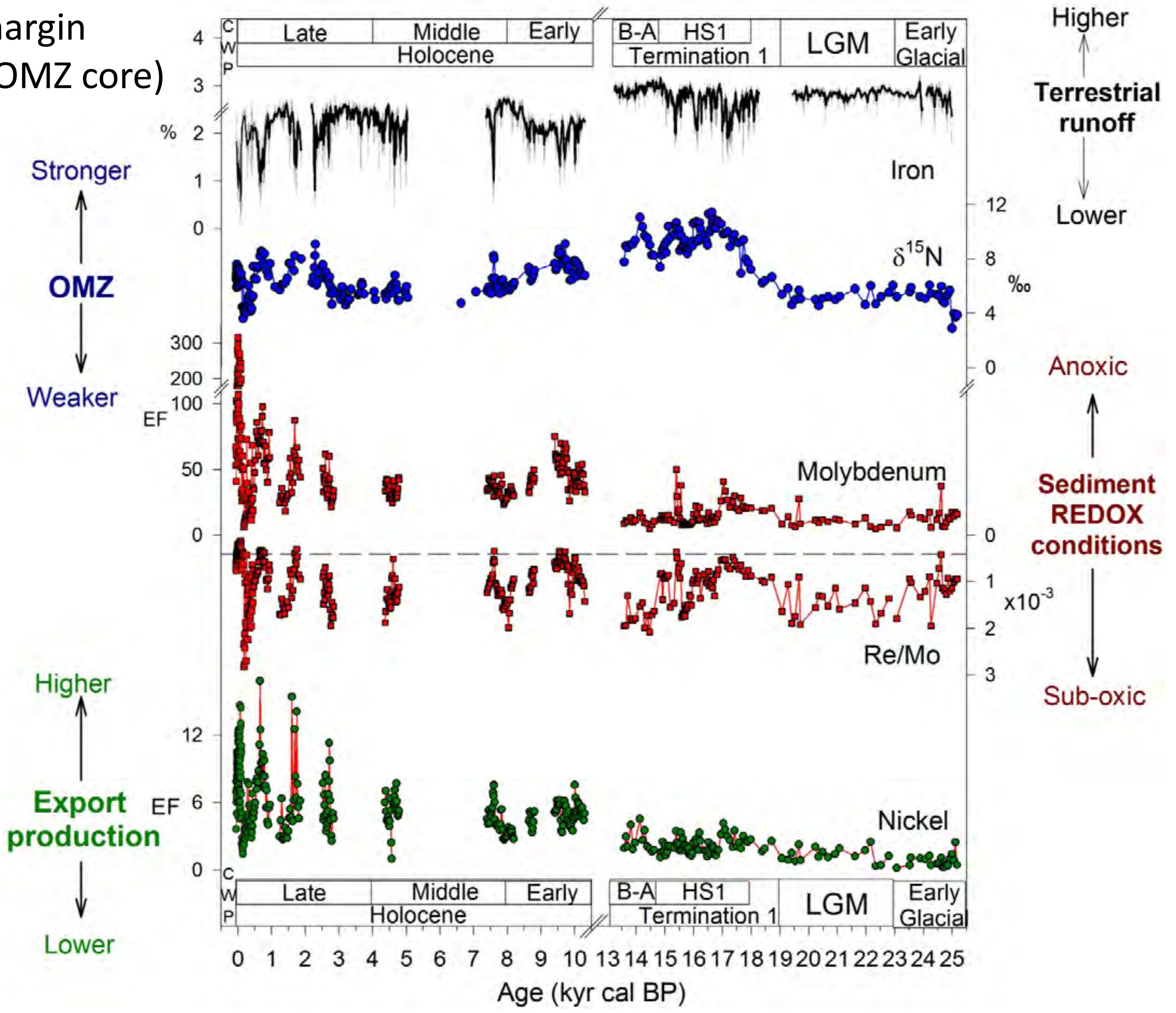




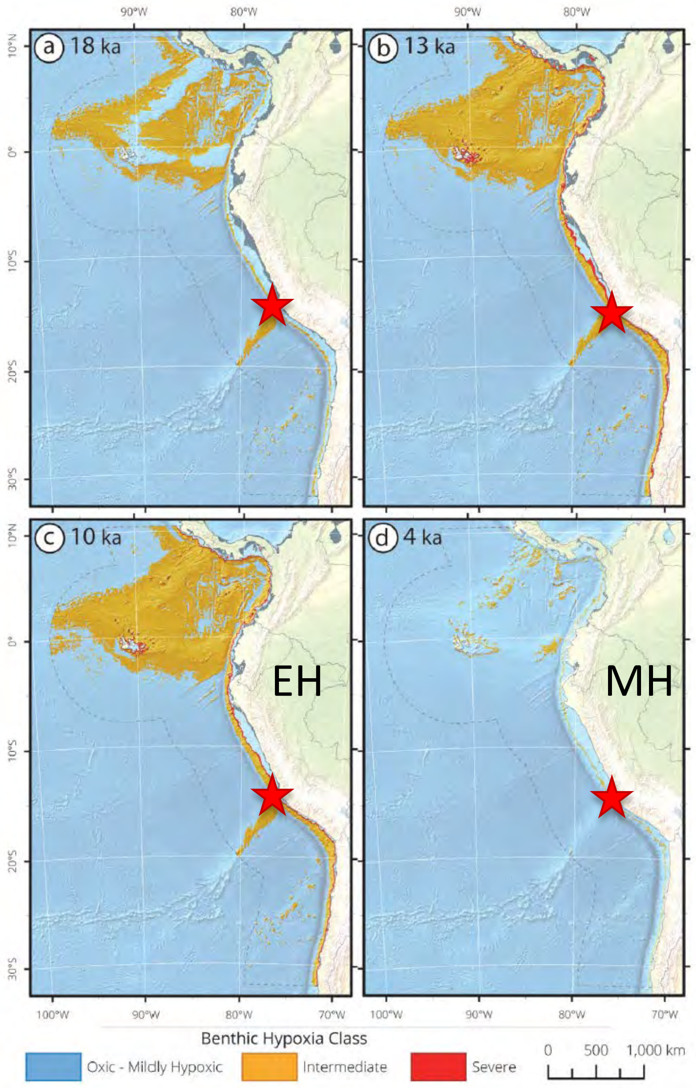
Thickness and upper limite of the SETP (Fuenzalida et al., 2009)

ETSP records (LGM to Holocene)

Peru margin
(14°S, OMZ core)



Salvatteci et al., 2016

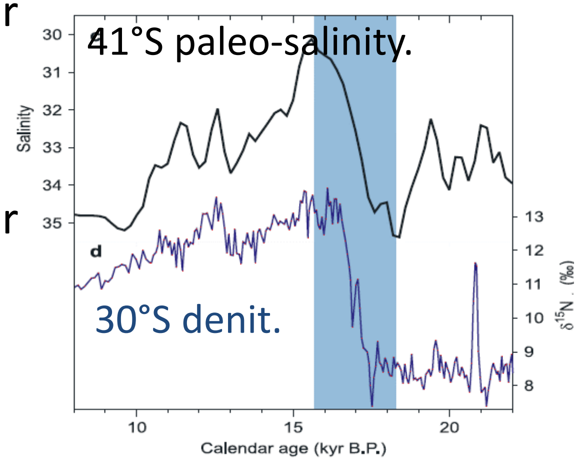


Regional benthic oxygenation
(Moffitt et al., 2015)

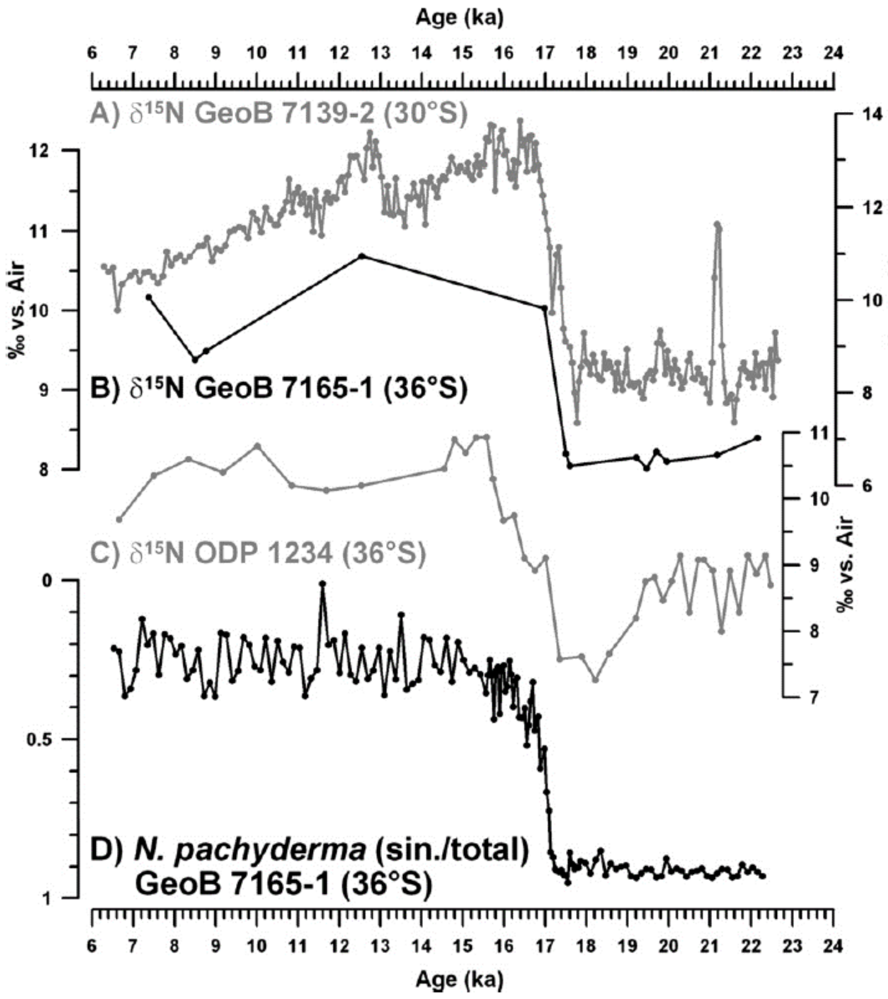
Central Chile records (LGM to Holocene)

fresher

saltier



De Pol-Holz et al., 2006

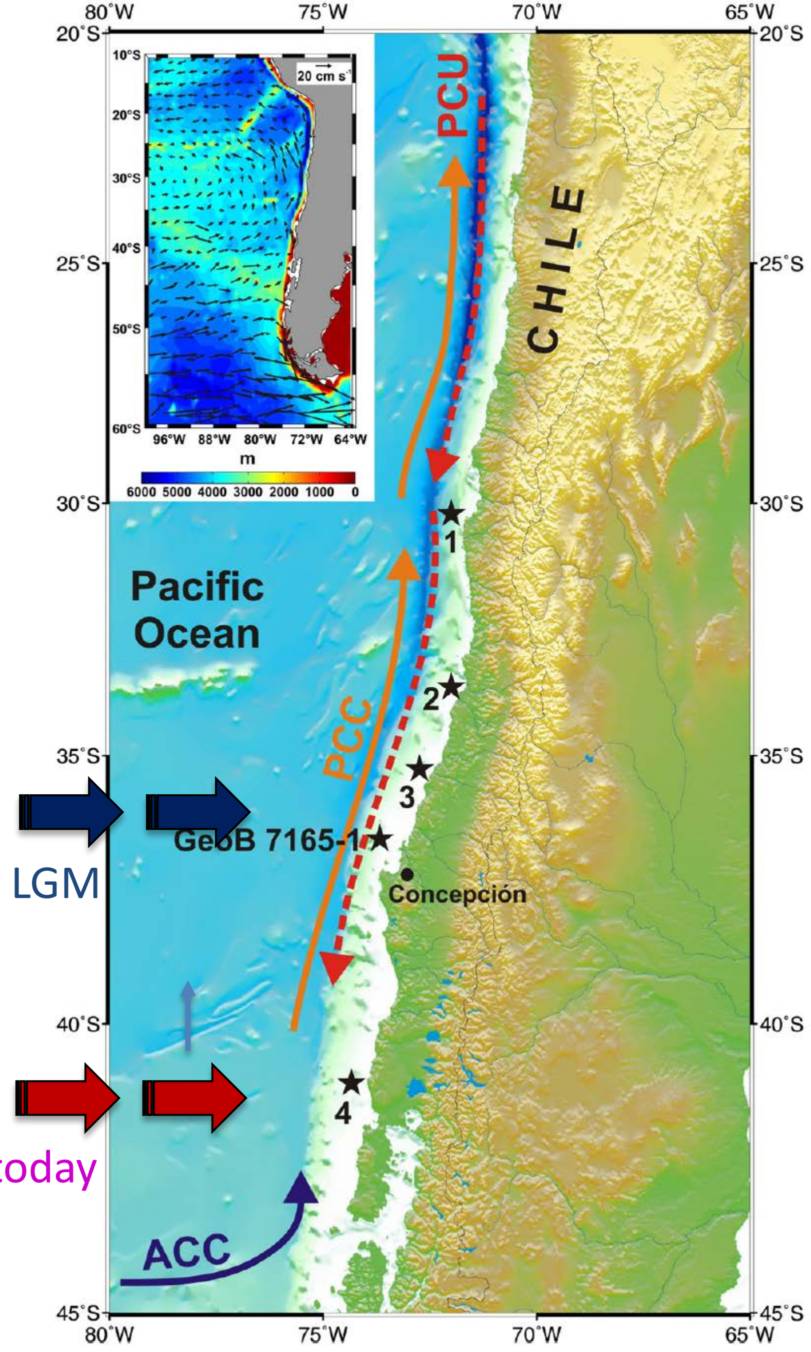


Mohtadi et al., 2008

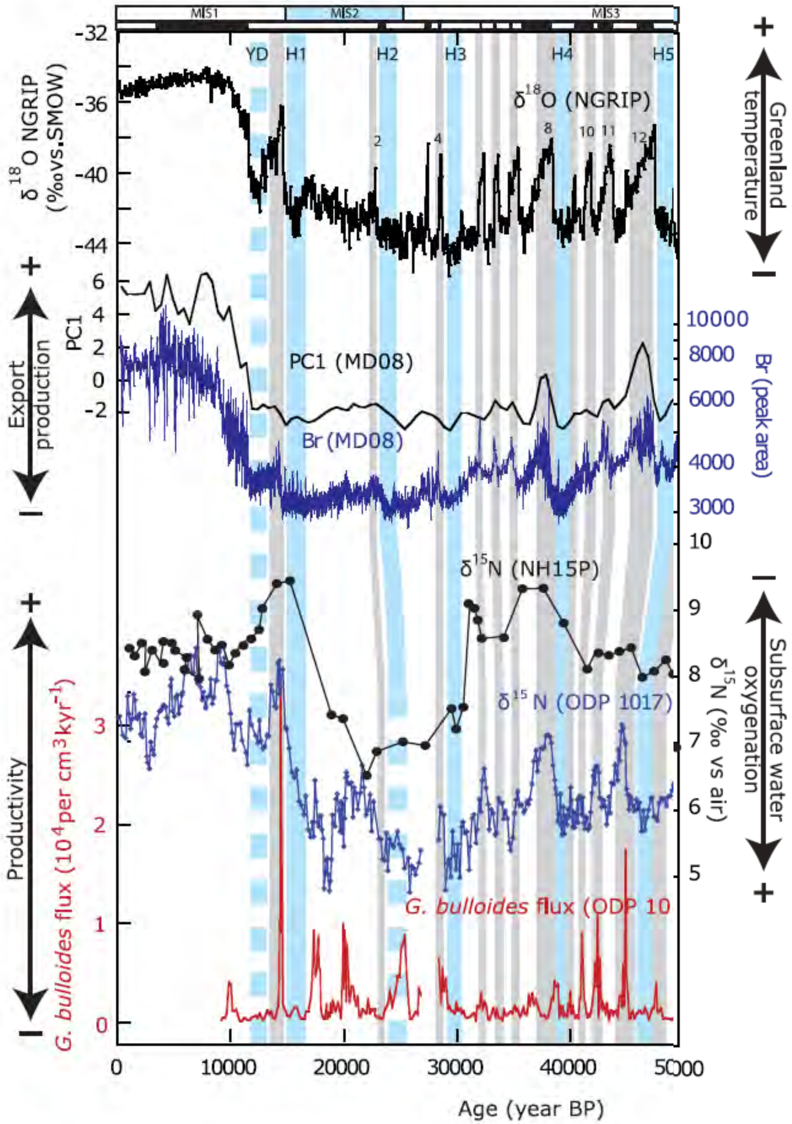
WC denitrification and oxygen loss followed SH signature. SWW shift affected the subsurface ventilation of the OMZ and paleoproductivity changes.

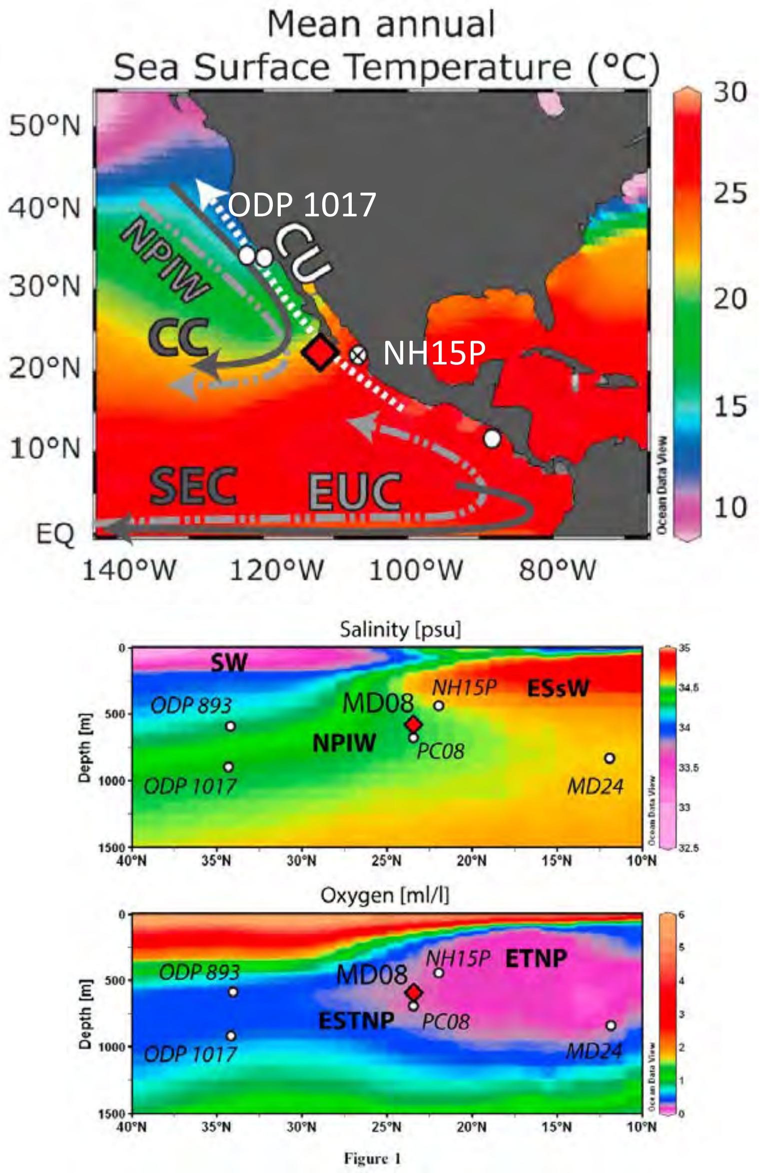
SWW LGM

SWW today

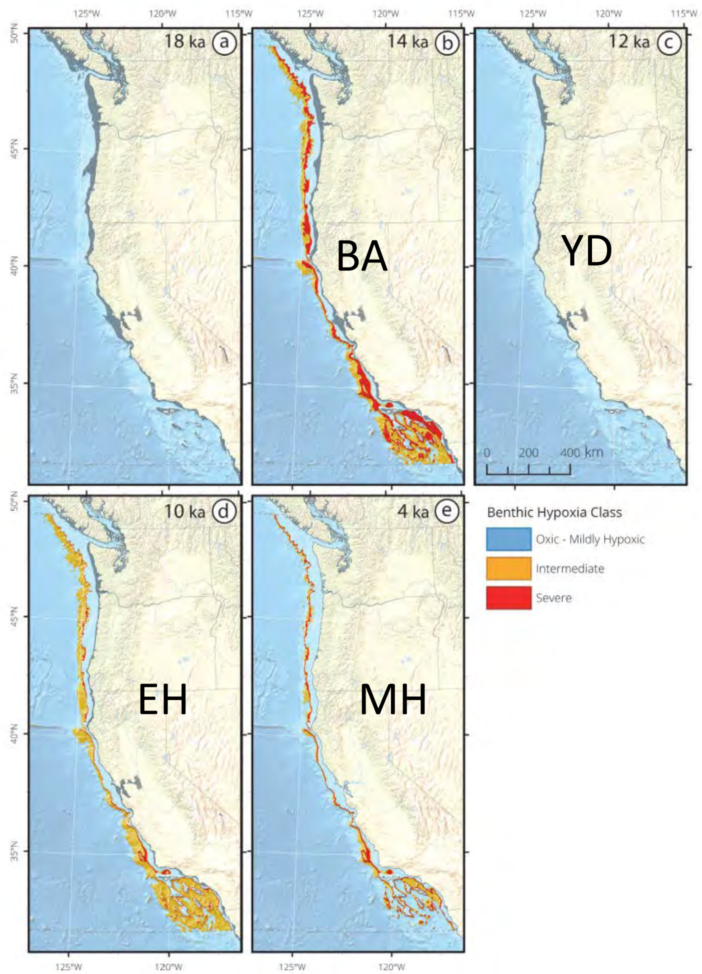


California Current



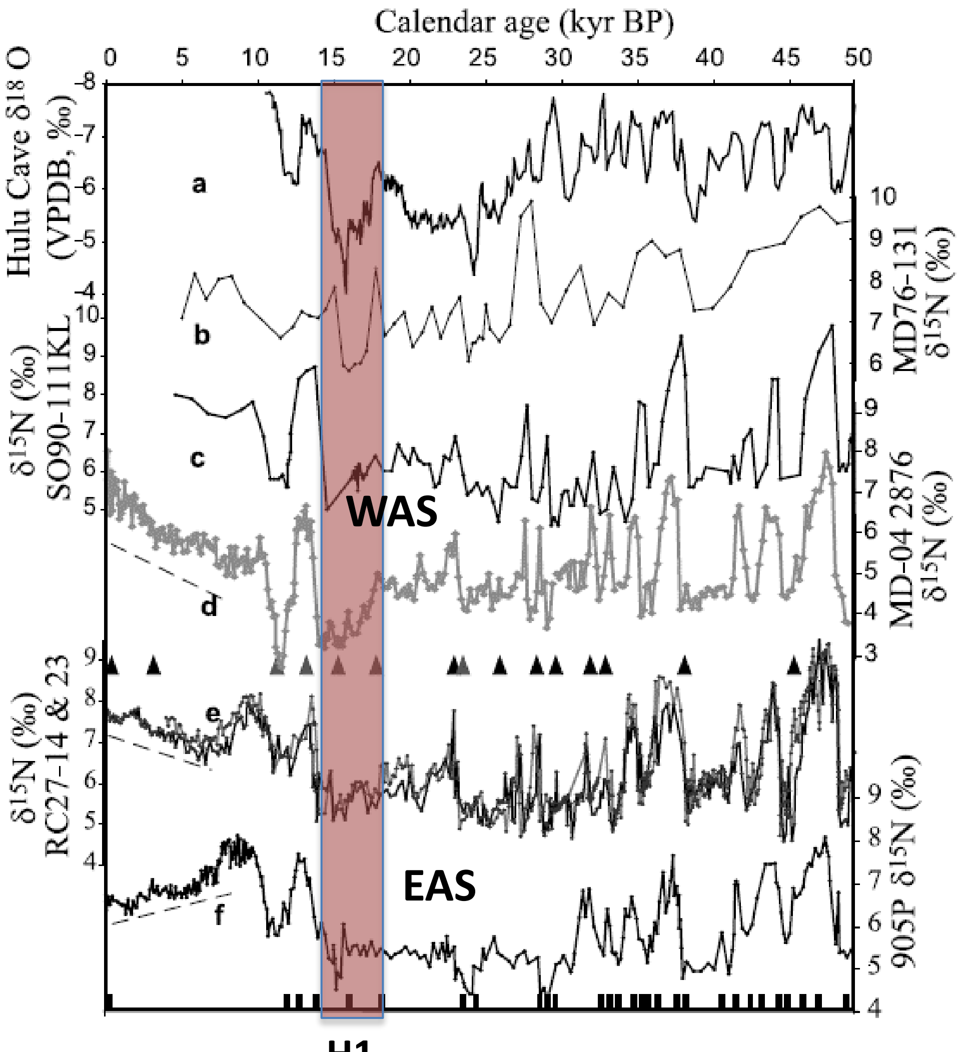


Cartapanis et al., 2011

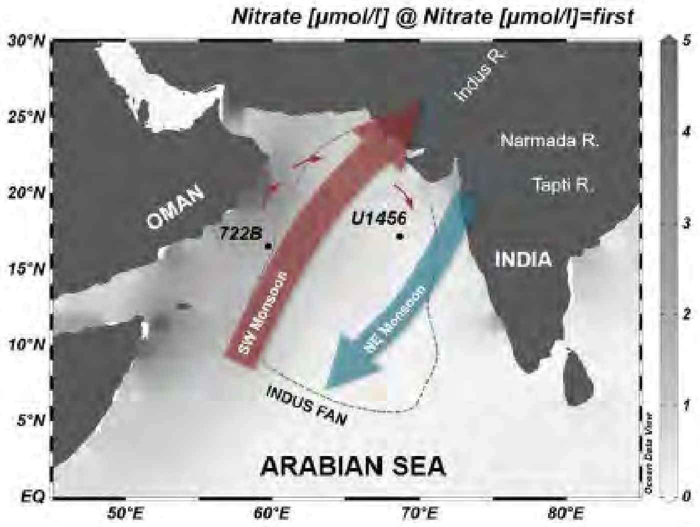


Moffitt et al. 2015

Arabian Sea



Pichevin et al., 2007

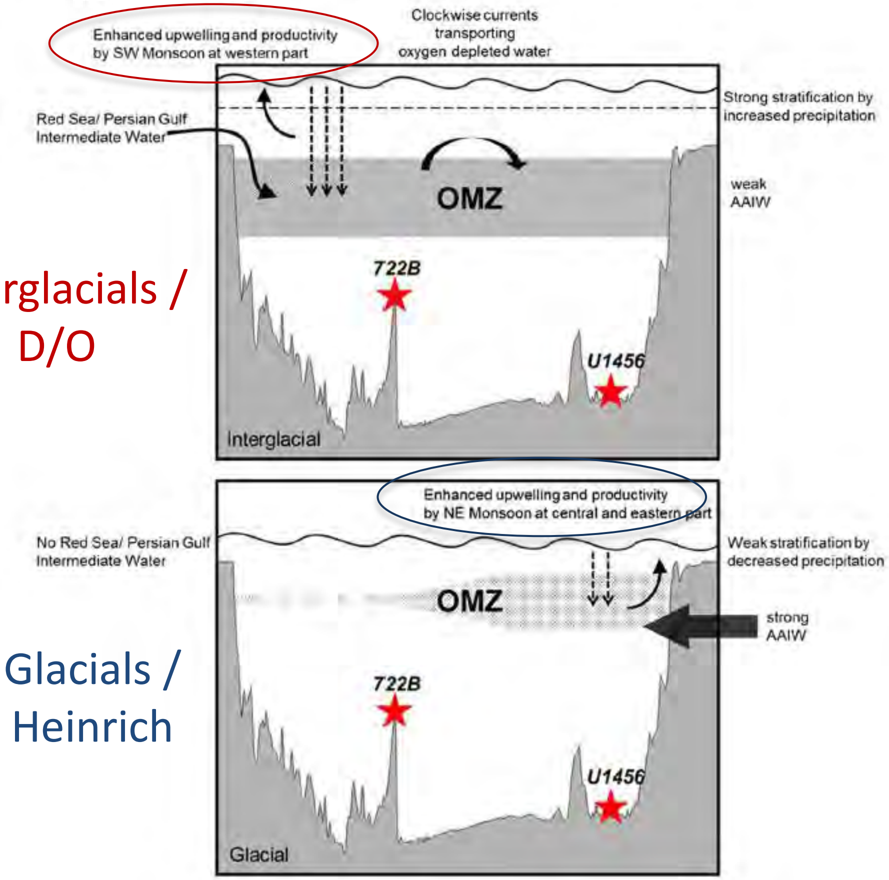


Kim et al., 2018

Stronger summer monsoon (with northward shifts of ITCZ) during warmer interglacial and D/O periods enhance coastal upwelling and OMZ development in the Eastern Arabian Sea. Denitrification/WCO since the LGM follows NH signature

Interglacials / D/O

Glacials / Heinrich



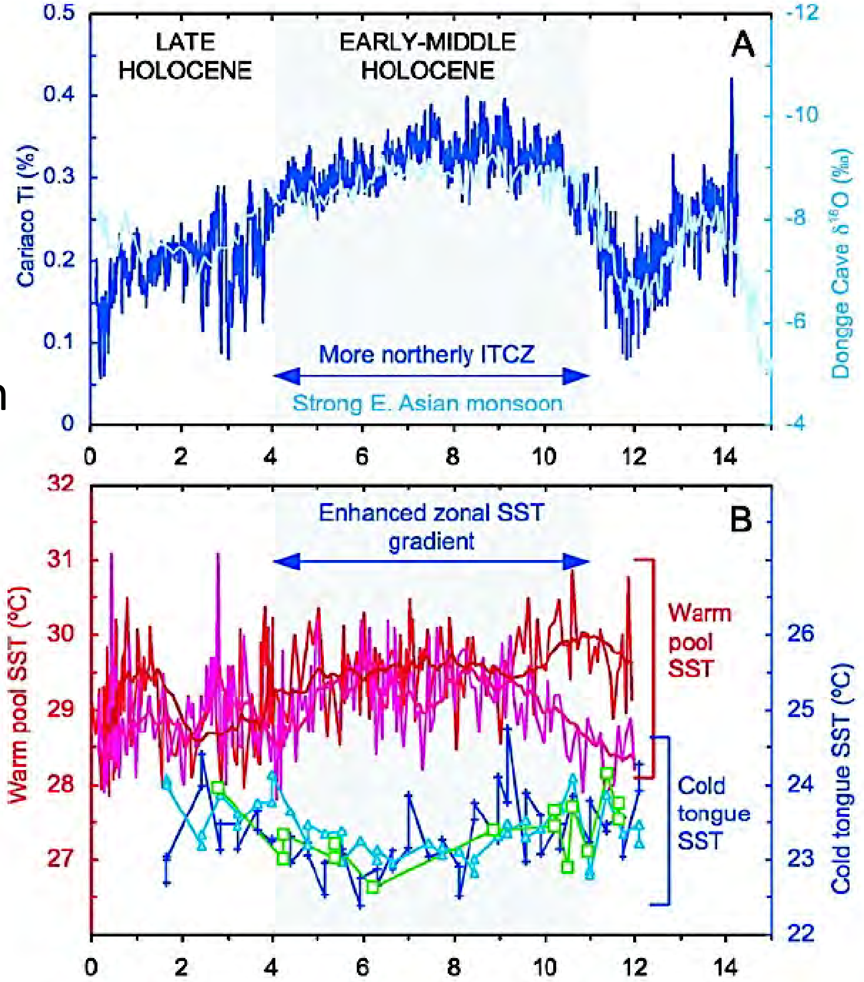
Weakening of the Eastern Pacific OMZ during the mid-Holocene

Koutavas et al., 2006

north

ITCZ

south



PI

MH-PI

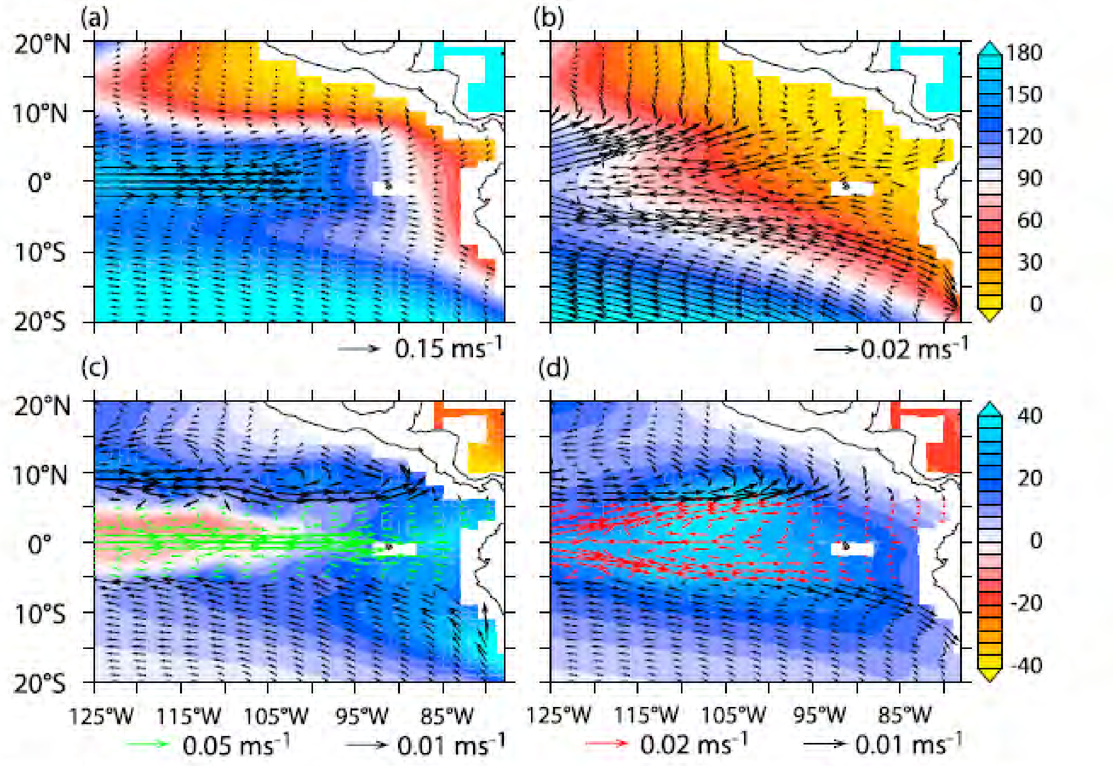


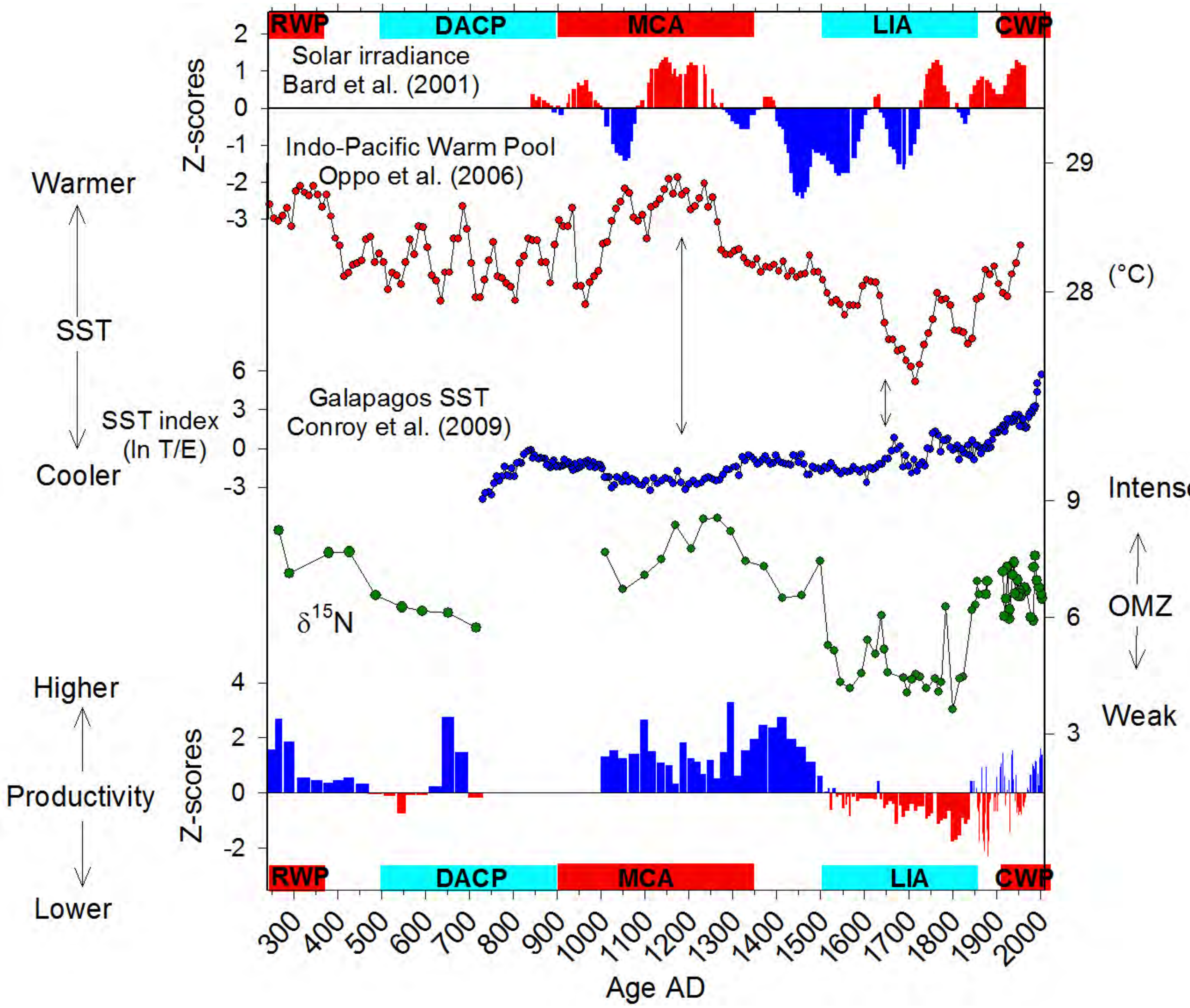
Figure 2. Model results for simulated present day O_2 concentration (shading, µmol L^{-1}) and velocity field (arrows, m s^{-1}) at (a) $\sigma_\theta = 26.0$ kg m^{-3} and (b) $\sigma_\theta = 26.5$ kg m^{-3} and mid-Holocene change in O_2 concentration (shading) and change in velocity field (arrows, note different scaling vectors) for (c) $\sigma_\theta = 26.0$ kg m^{-3} and (d) $\sigma_\theta = 26.5$ kg m^{-3}.

The MH was an extended ‘La Niña-like’ climate state in the EEP, due to orbitally-driven changes in the ITCZ position and Walker circulation intensity

Xu et al., 2015: there is a local shift of trade winds and **intensification of the ocean equatorial currents** that provide oxygen to the EEP

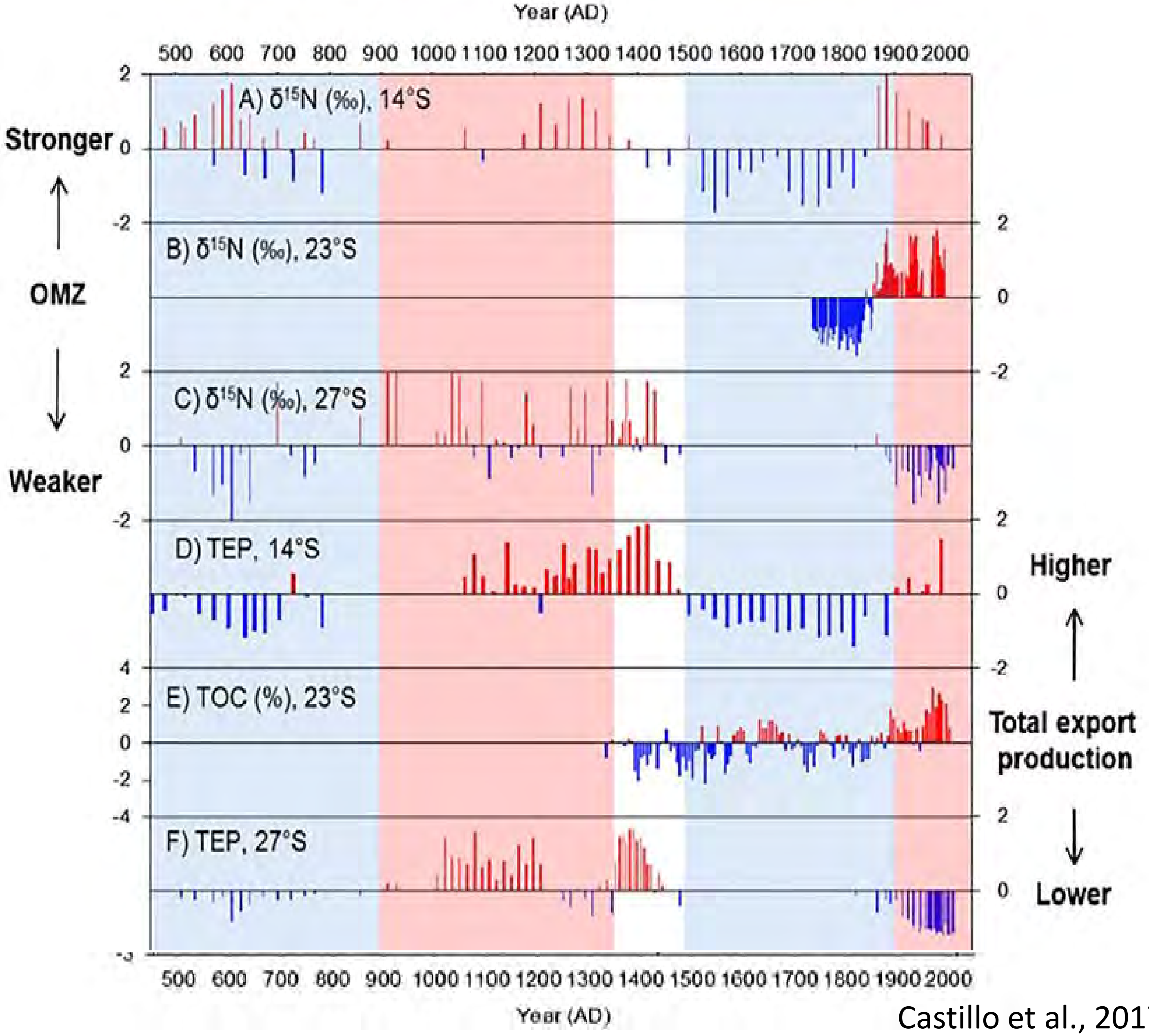
Centennial fluctuations of OMZ in the ETSP in the last millenia

- Weaker OMZ and export production under centennial global cold periods (e.g. LIA), with reduced zonal SST gradient in the Pacific.
- Stronger OMZ and export production under centennial global warm periods (e.g. late MCA, CWP), with increased zonal SST gradient in the Pacific



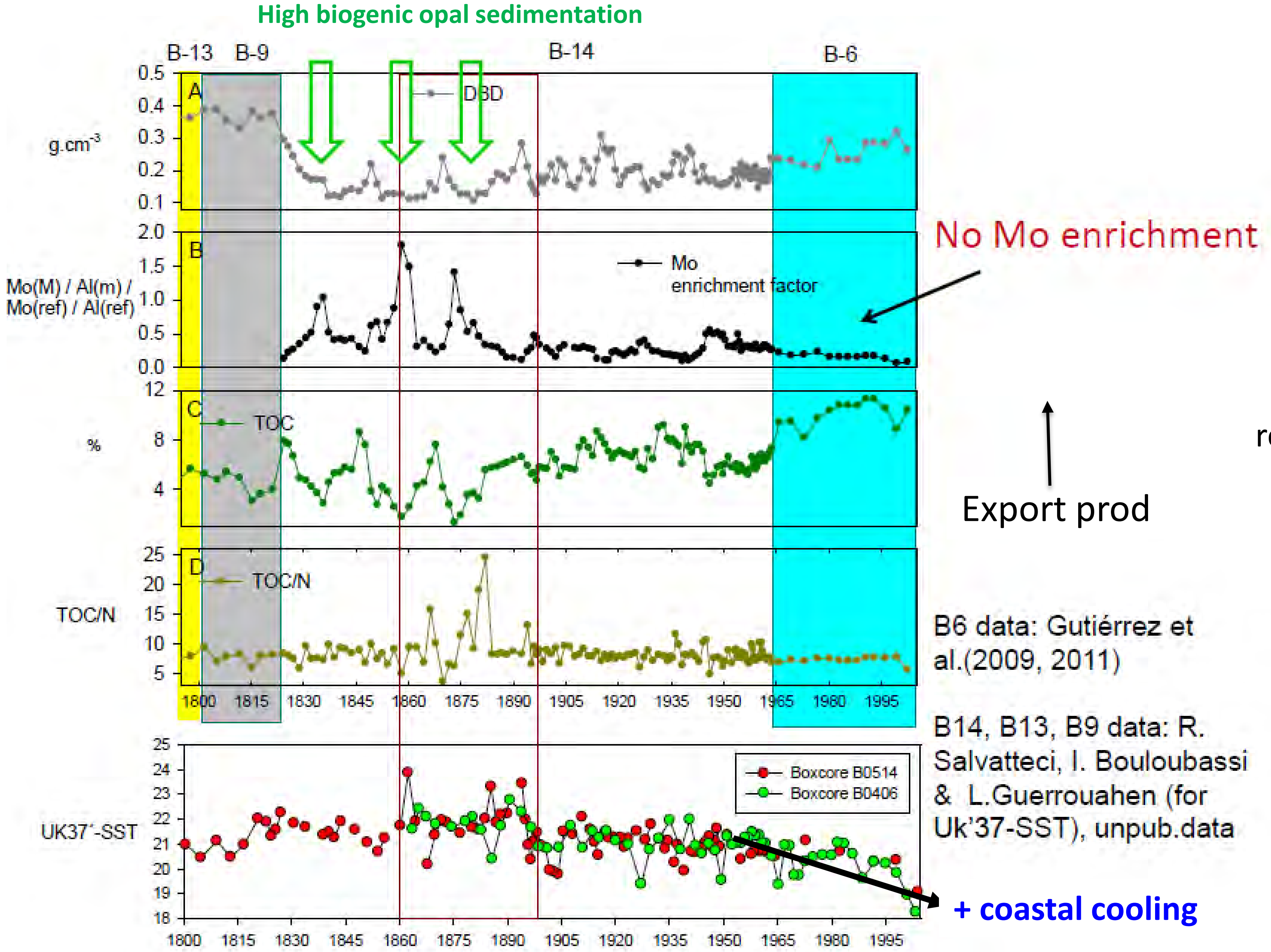
Centennial fluctuations of OMZ in the ETSP in the last millennia (2)

- Good synchronicity of oxygenation changes along the ETSP during most of the period
- At 27°S, there is a negative trend in export production and an oxygenation trend for the XXth century



Castillo et al., 2017

Multidecadal variability of the Peru upwelling during the Anthropocene



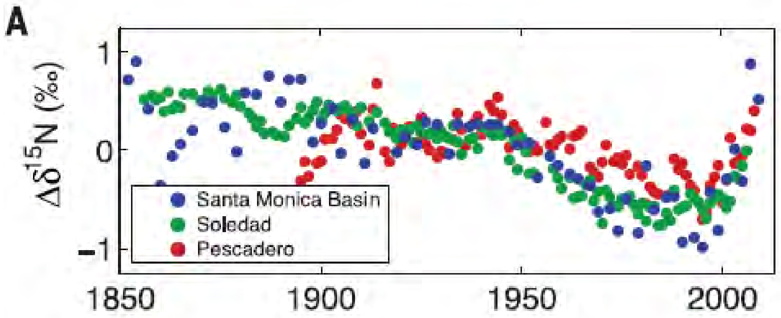
Export production is increasing, while coastal SST is cooling, but less reducing conditions in the sediments

B6 data: Gutiérrez et al.(2009, 2011)

B14, B13, B9 data: R. Salvatteci, I. Bouloubassi & L.Guerrouahen (for Uk'37-SST), unpub.data

Anthropocene records of oxygenation in the Eastern Pacific

- Oxygenation trend during the XXth century.
- Mechanisms?
  - Shoaling of Equatorial thermocline in the EEP
  - Enhanced eastward circulation (EUC)
  - Subtropical ventilation in the OMZ



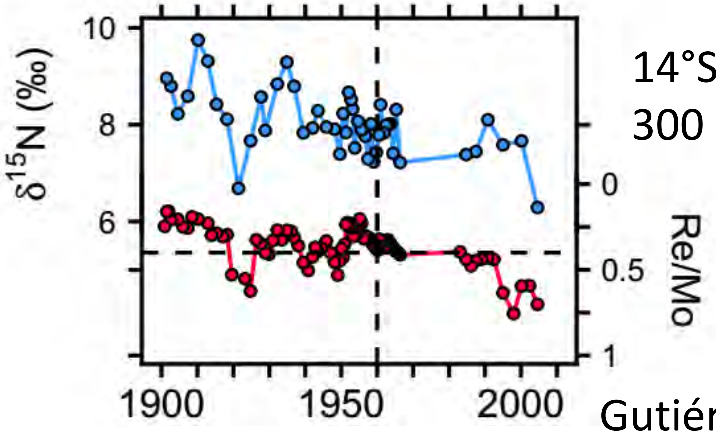
30°N, ETNP
>1000 m

Deutsch et al. 2014

strong

OMZ

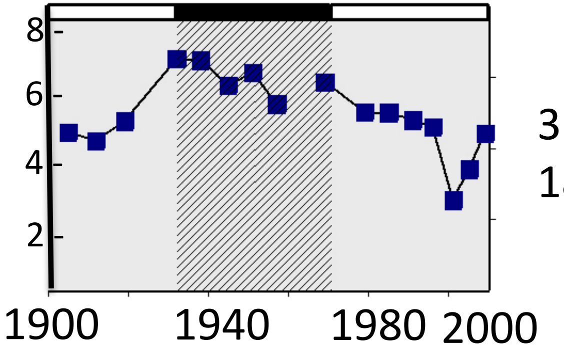
weak



14°S, ETSP
300 m

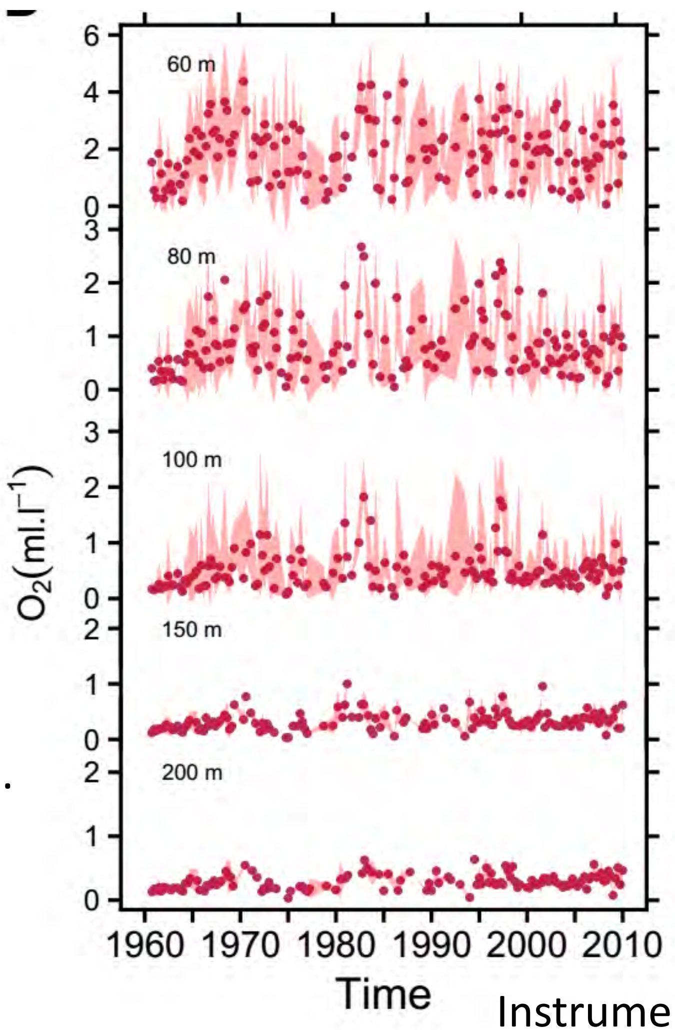
Gutiérrez et al. In prep.

Moxs (ppm)



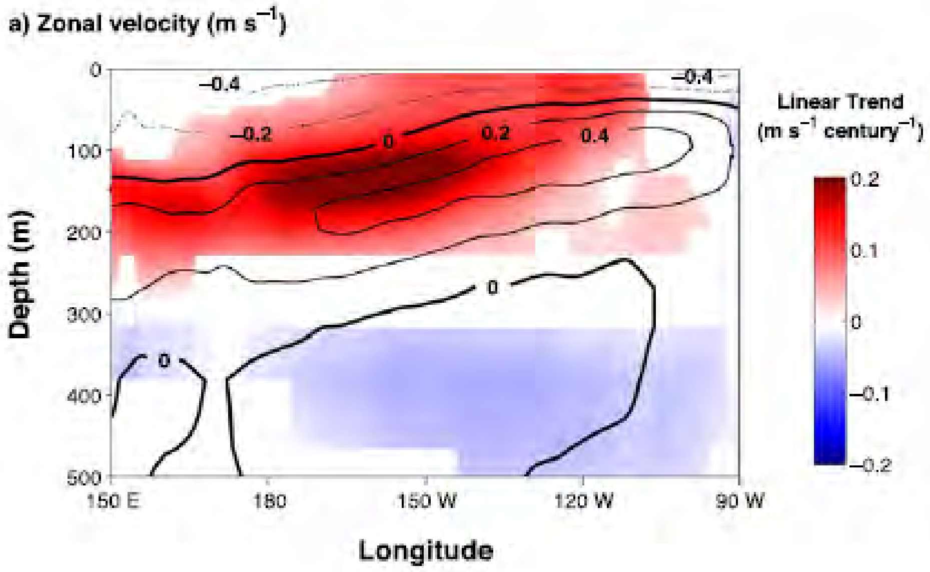
36°S, Central Chile
180 m

Srain et al. 2015.



Instrumental data (IMARPE)

In search of the mechanisms



Strengthening of the Pacific Equatorial Undercurrent in the SODA Reanalysis: Mechanisms, Ocean Dynamics, and Implications

2014

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Centennial changes in North Pacific anoxia linked to tropical trade winds

Curtis Deutsch,* William Berelson, Robert Thunell, Tom Weber, Caitlin Tems, James McManus, John Crusius, Taka Ito, Timothy Baumgartner, Vicente Ferreira, Jacob Mey, Alexander van Geen

Variability in subtropical-tropical cells drives oxygen levels in the tropical Pacific Ocean

Olaf Duteil[1], Claus W. Böning[1], and Andreas Oschlies[1]

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Changes in source waters to the Southern California Bight

Steven J. Bograd [a,*], Mercedes Pozo Buil [b], Emanuele Di Lorenzo [b], Carmen G. Castro [c], Isaac D. Schroeder [a], Ralf Goericke [d], Clarissa R. Anderson [e], Claudia Benitez-Nelson [f], Frank A. Whitney [g]

Final remarks

- Sedimentary paleorecords evidence the influence of climate variability on the expansion/contraction of the OMZs associated to continental margins at multiple time-scales. Paleoclimate models are valuable tools to investigate the multiple processes and factors involved in the natural climate-driven oxygen changes.

- Off Peru and Northern Chile, Walker circulation is the principal factor that modulate the OMZ intensity and the upwelling productivity; while the subduction of oxygen-rich waters and their meridional transport exerts an influence on the subsurface ventilation, mainly at higher latitudes.

- WCO over the California margin also appears to be modulated by the equatorial forcing, through changes of the thermocline depth, surface productivity & respiration, and the advection of oxygen-poor water by the California undercurrent or from the North Pacific.

- In the Arabian Sea WCO is coupled with surface productivity driven by the monsoon upwelling, which in turn is influenced by meridional displacements of the ITCZ.

- An oxygenation trend for the XXth century is observed from sedimentary paleorecords of the California Current and the Peru and Chile margins, but the TSEP keep this trend, while there is a reversal in the CC. More observations and research are needed to confirm these patterns and elucidate the mechanisms.

Acknowledgments

Renato Salvatteci, Jorge Cardich, Alexis Castillo, Abdel Sifeddine, Francisco Chavez

IRD-LOCEAN (Paleotraces & Discoh)

The Global Ocean Oxygenation Network – GO2NE

PICES-ECCWO