PICES

Large-scale ocean oxygen changes

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SFB 754

6 June 2018

GEOMAR

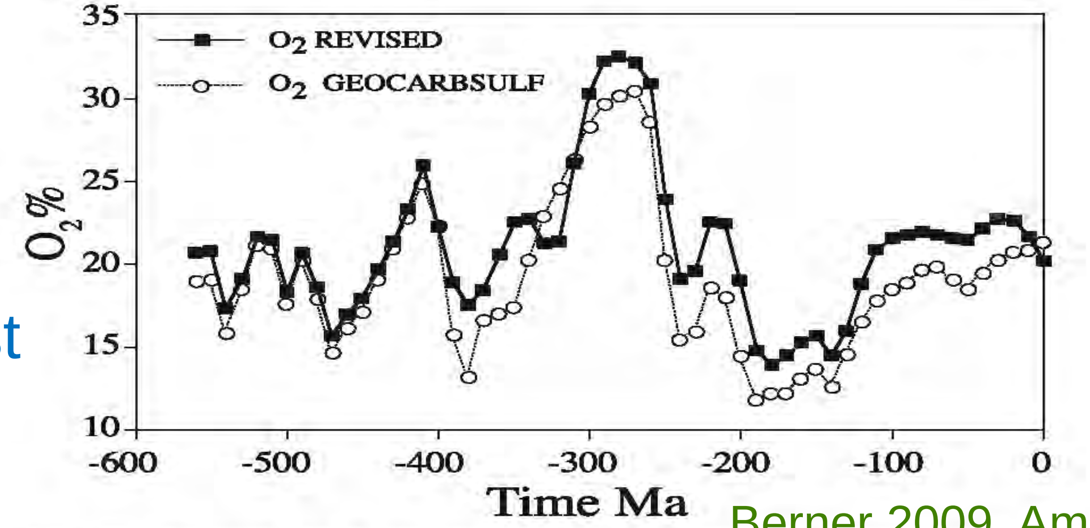
Session 4: Deoxygenation in
global ocean and coastal waters in relation to climate change

Oxygen: Are there changes in oxygen?

Present day atmosphere 20.9% oxygen

humans >7%

Atmospheric oxygen in geological past

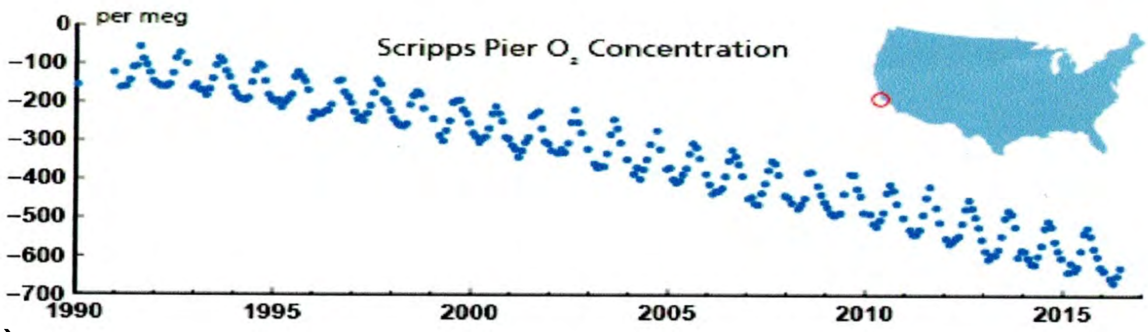


Berner 2009, Am. J. of Science

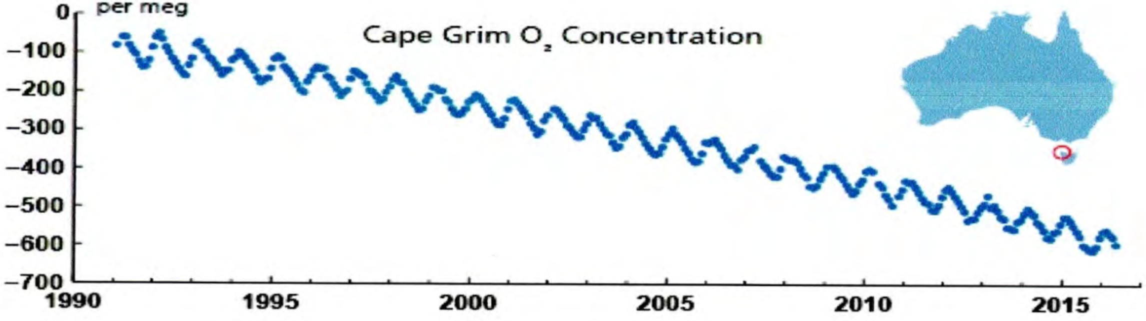
Fig. 2. Results for atmospheric O_2 over time based on the calculations of the present paper (REVISED) compared to those for the original GEOCARBSULF paper (Berner, 2006a).

Ocean hypoxic 60-120 µmol/kg, 85 µmol/kg~2ml/l=0.2%

Atmosphere
(recent years)



(per meg =0.0001 per cent)



Atmosphere loses 0.0019% oxygen per year

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99% of atmosphere/ocean oxygen in the atmosphere

Geological past (ocean)

Most dramatic oxygen decrease at the end of Permian (251 Myr ago) associated with elevated atmospheric CO_2 and massive extinctions on land as well as in the ocean (ocean reduced oxygen, land large continents, temperature increase)

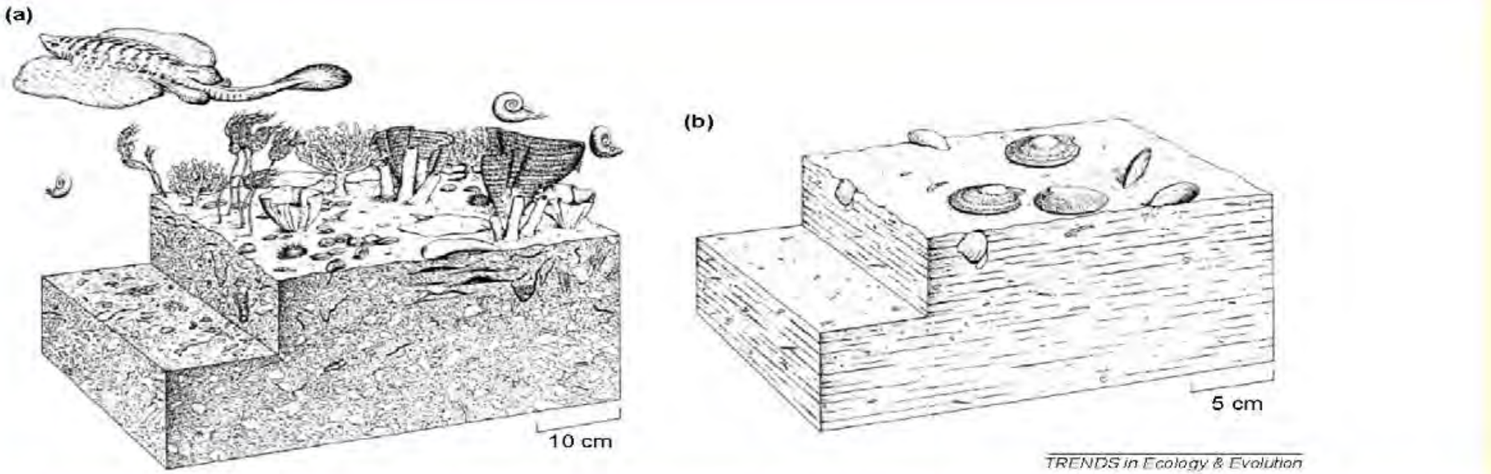


Fig. I. Block-diagram reconstructions of the ancient seabed in southern China immediately before (a) and after (b) the Permo–Triassic mass extinction. Note the richness of reef life and the burrowing infauna before the crisis, and the absence of such species after. A marine fauna of 100 or more species is reduced to four or five. Original artwork by John Sibbick.

Loss of as much as 95% of all species on earth

Benton and Twitchett 2003, Trends in Ecol. And Evol.

Present time long term trends from measurements

Global ocean loss in oxygen of ~2% over the last 50 years (global oceanic oxygen content of 227.4+/- 1.1 Pmol decreased by more than 2% (4.8+/-2.1 Pmol) since 1960)

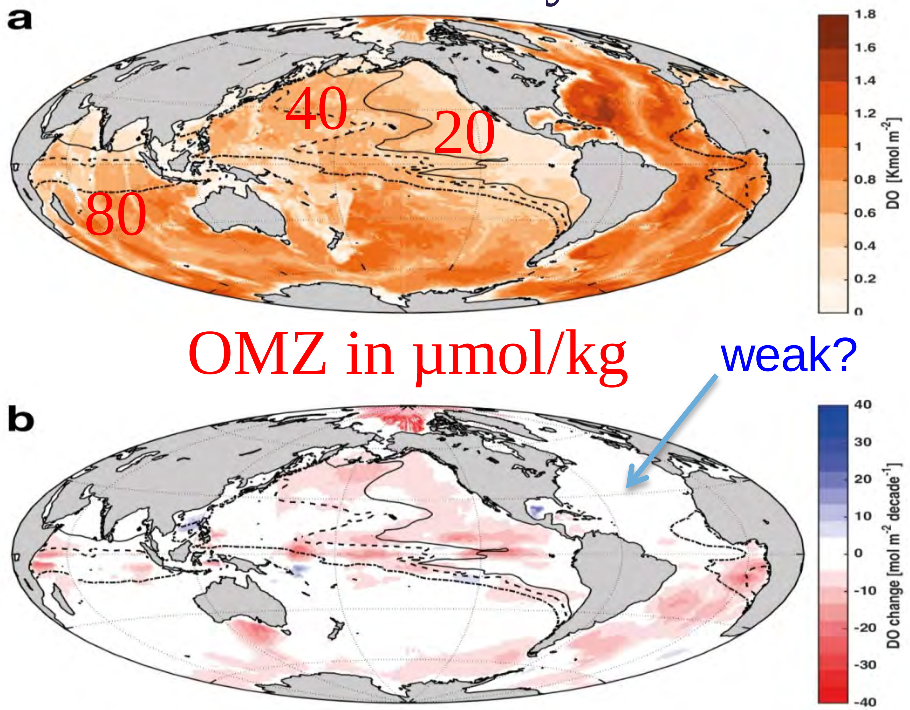
Upper ocean: warming induced decrease solubility + comsumption

Deep Ocean: overturning slowdown

(Pmol =10^{15} mol)

Schmidtko, Stramma, Visbeck 2017, Nature

O2-inventory



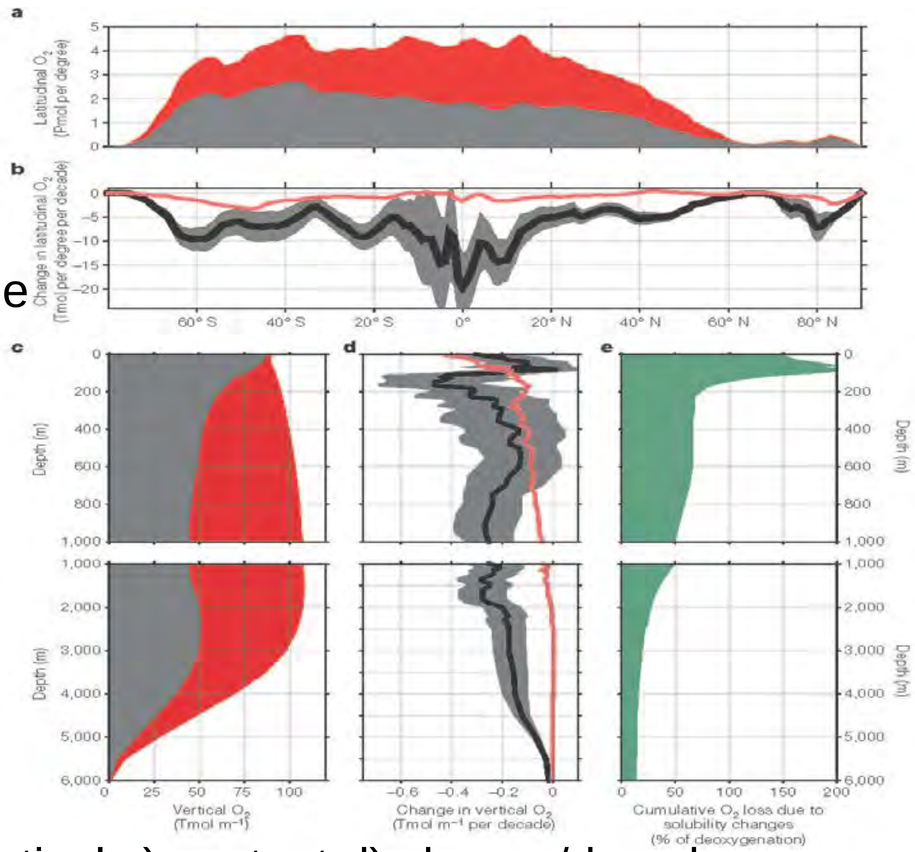
Change of O2 in mol per square meter per decade

Global oxygen change per decade, 50 year period (1960-2010)

a) latitudinal O_2 content

and

b) change/decade



Vertical c) content d) change/decade

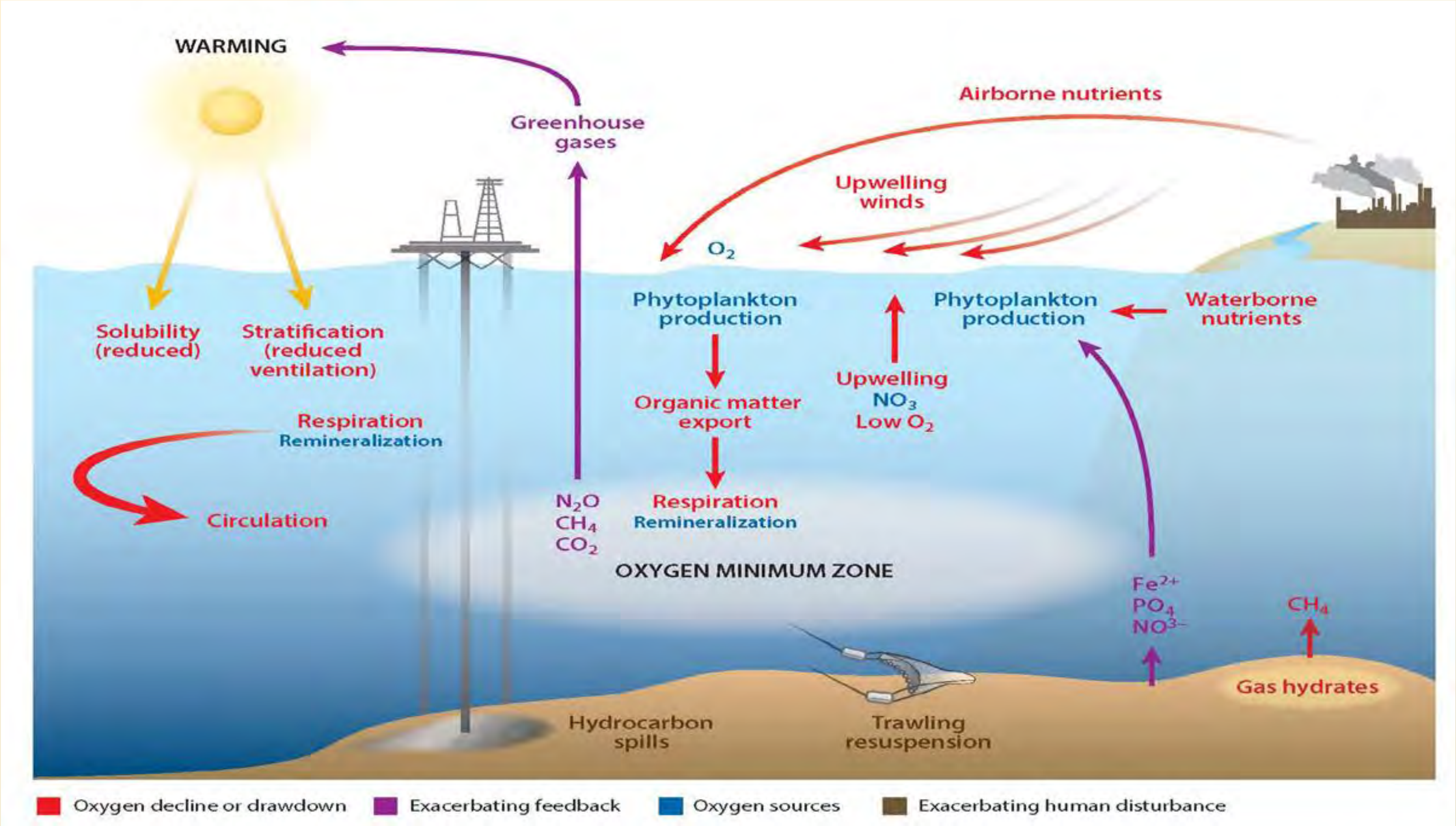
a) c) grey integrated O_2 and red area: AOU for 100% saturation

b) d) red line: O_2 loss expected from solubility changes

e) Cumulative oxygen loss due to solubility change as % of observed deoxygenation

Schmidtko, Stramma, Visbeck 2017

Drivers and processes affecting open ocean deoxygenation



Levin 2018

Ongoing work

Long term trends upper/lower ocean 1960-2010

Potential primary drivers:
(e.g. Schmidtko et al. 2017: Levin 2018)

Solubility and stratification

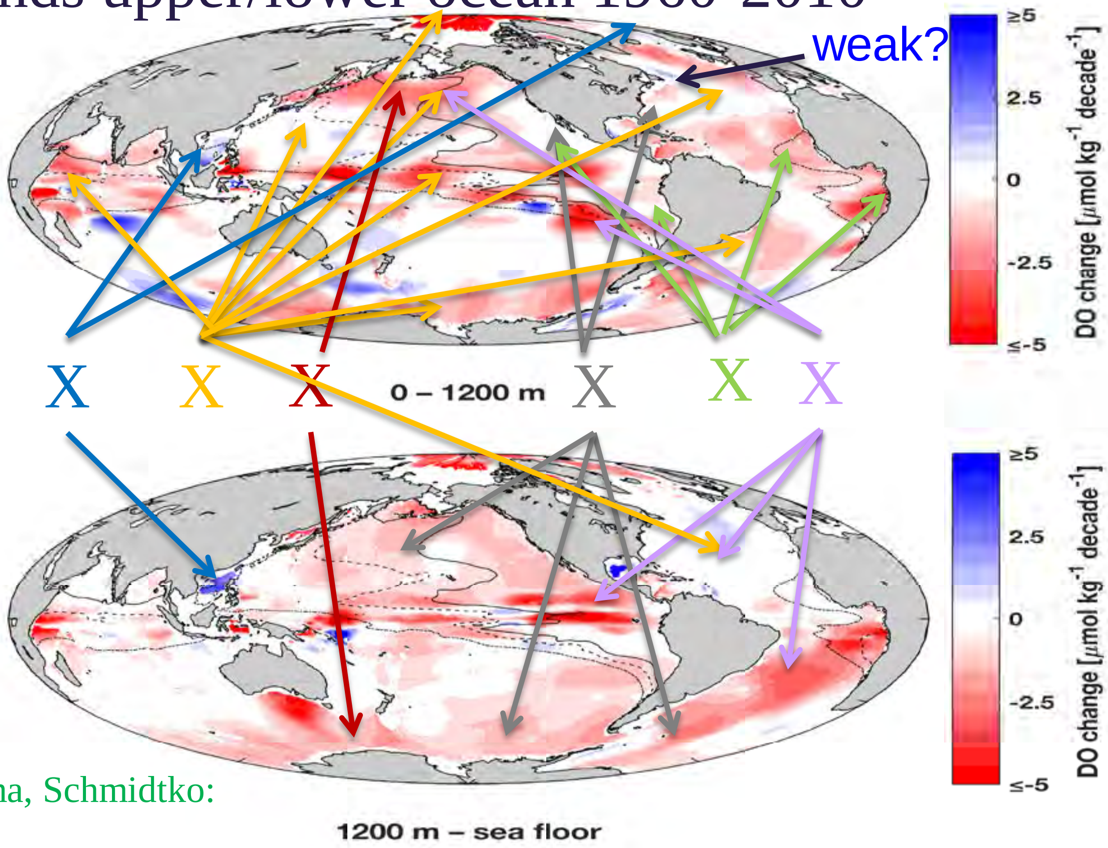
Decline in source waters

Increase in source water

(Overturning) circulation driven

Nutrient stimulation via upwelling

Multidecadal variability



Modified figure: Oschlies, Brandt, Stramma, Schmidtko: Nat. Geo. accepted 2018

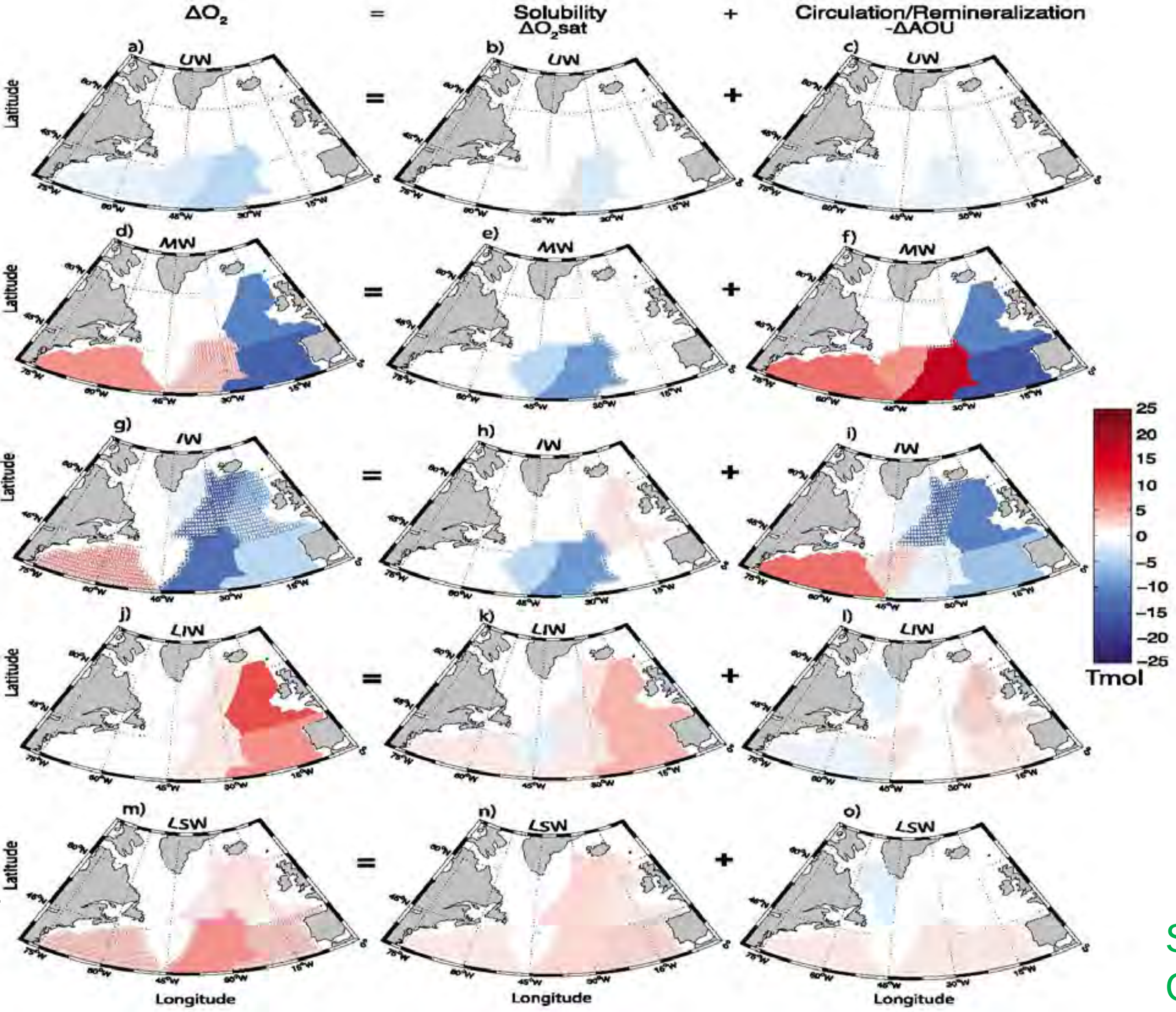
Upper Water

Mode Water

Intermediate Water

Lower Intermediate Water

Labrador Sea Water



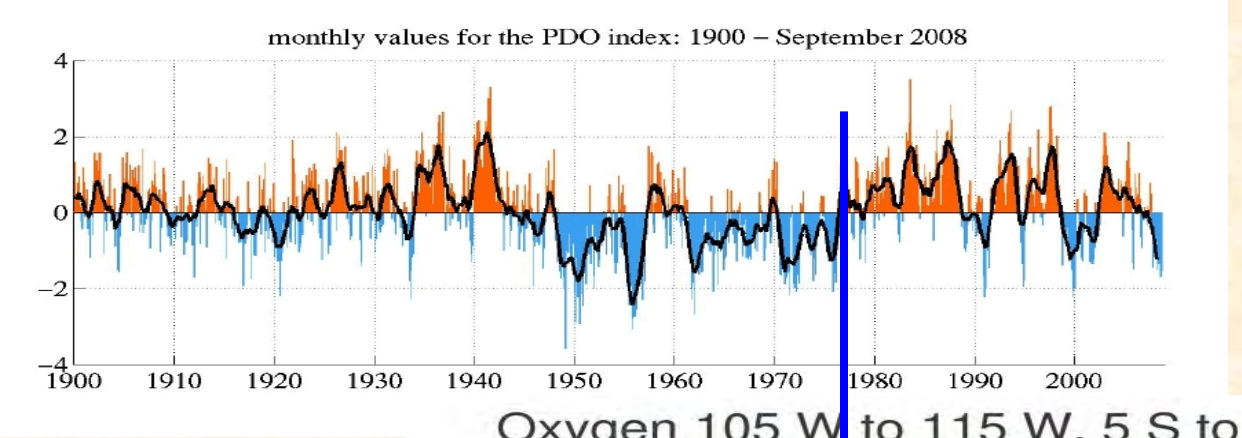
UW, MW, IW loss of 57 Tmol;

LIW, LSW gain of 46 Tmol

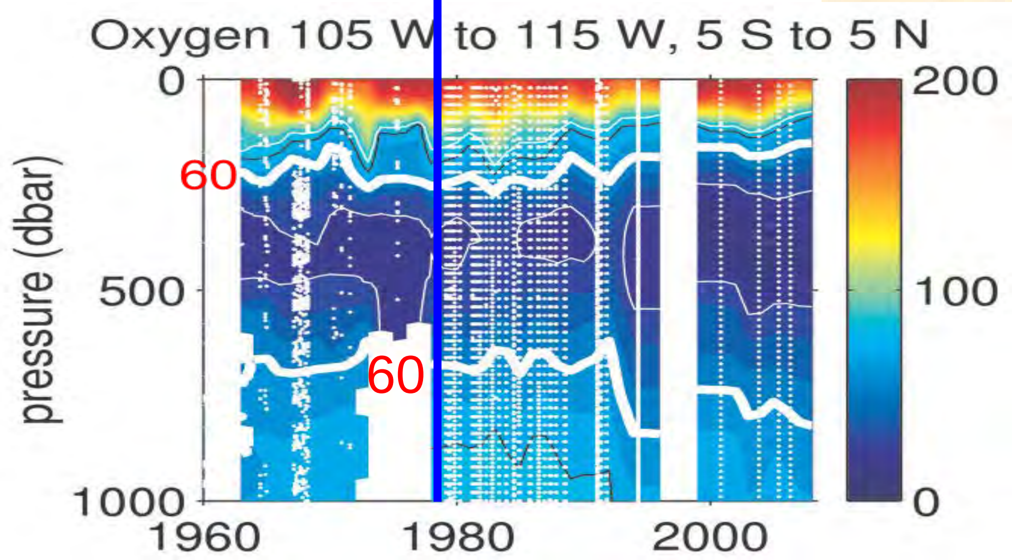
Drivers: MW, IW circulation ventilation; UW, LIW, LSW solubility NAO

Stendardo and Gruber 2012

Climate modes e.g. Pacific PDO



e.g.Deser et al. 2010, Annu. Rev. Mar. Sci.



5°S-5°N 105°W-115°W
200-600 m:
-0.23 μmol/kg/yr 1960-2008
cold/warm PDO
-0.64 μmol/kg/yr 1979-2008
warm PDO

Model PDO-changes Duteil 3 pm

Stramma et al. 2008, Science

ongoing work

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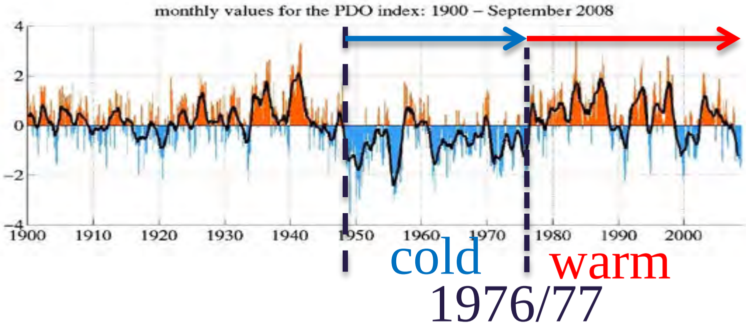
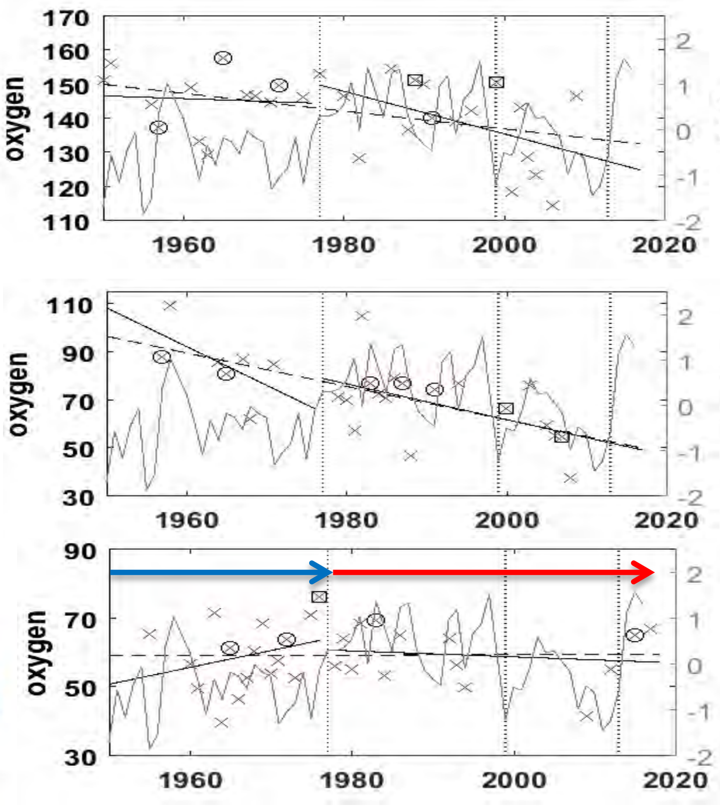
Long term trends

Equatorial Pacific
PDO periods
negative 1950-1976
„positive“ 1977-present
Long term oxygen decrease,
eastern Pacific PDO influence





50-300 m,
(in µmol/kg)

5°S-5°N,
165-175°W

5°S-5°N,
105-115°W

5°S-5°N,
84-88°W

Strong El Niño – circle, strong La Niña - square

ongoing work

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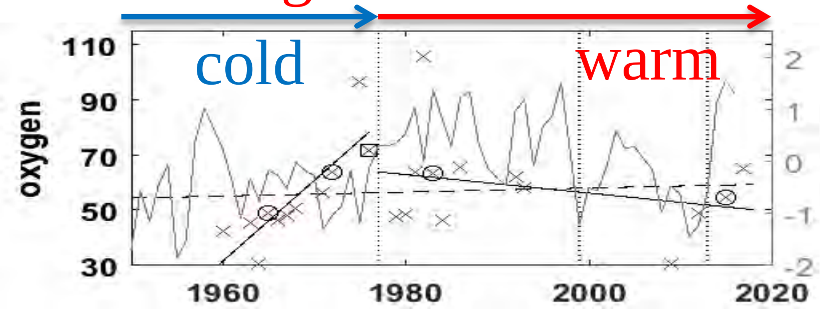
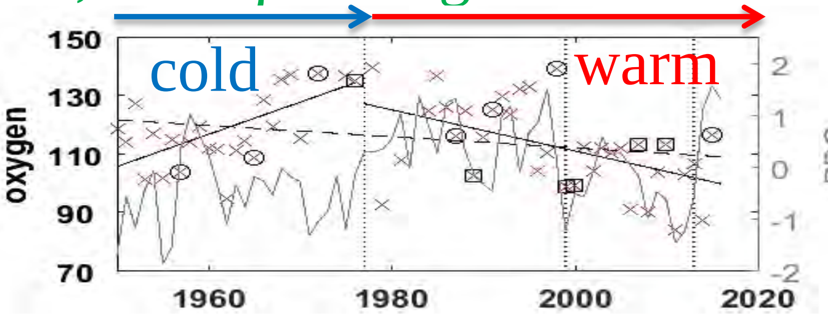
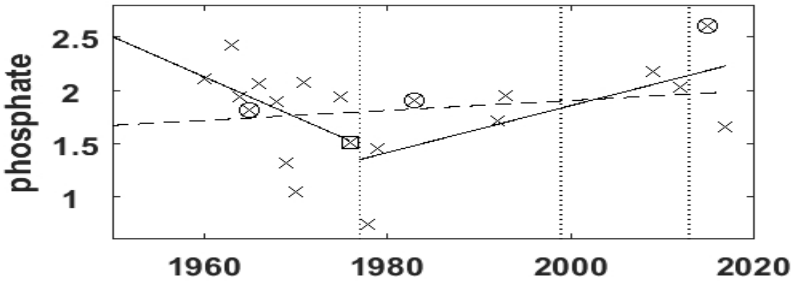
Long term trends: 50-300 m, all in µmol/kg

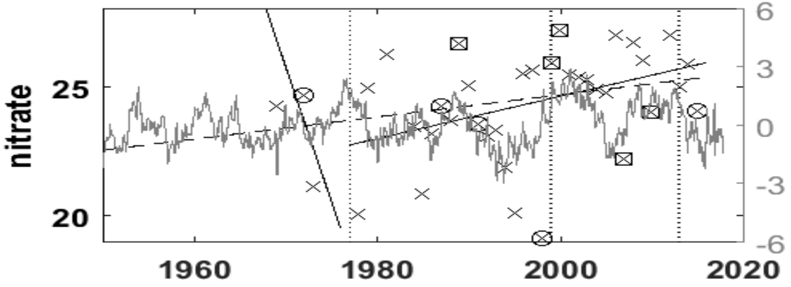




5°S-2°S, 84-87°W

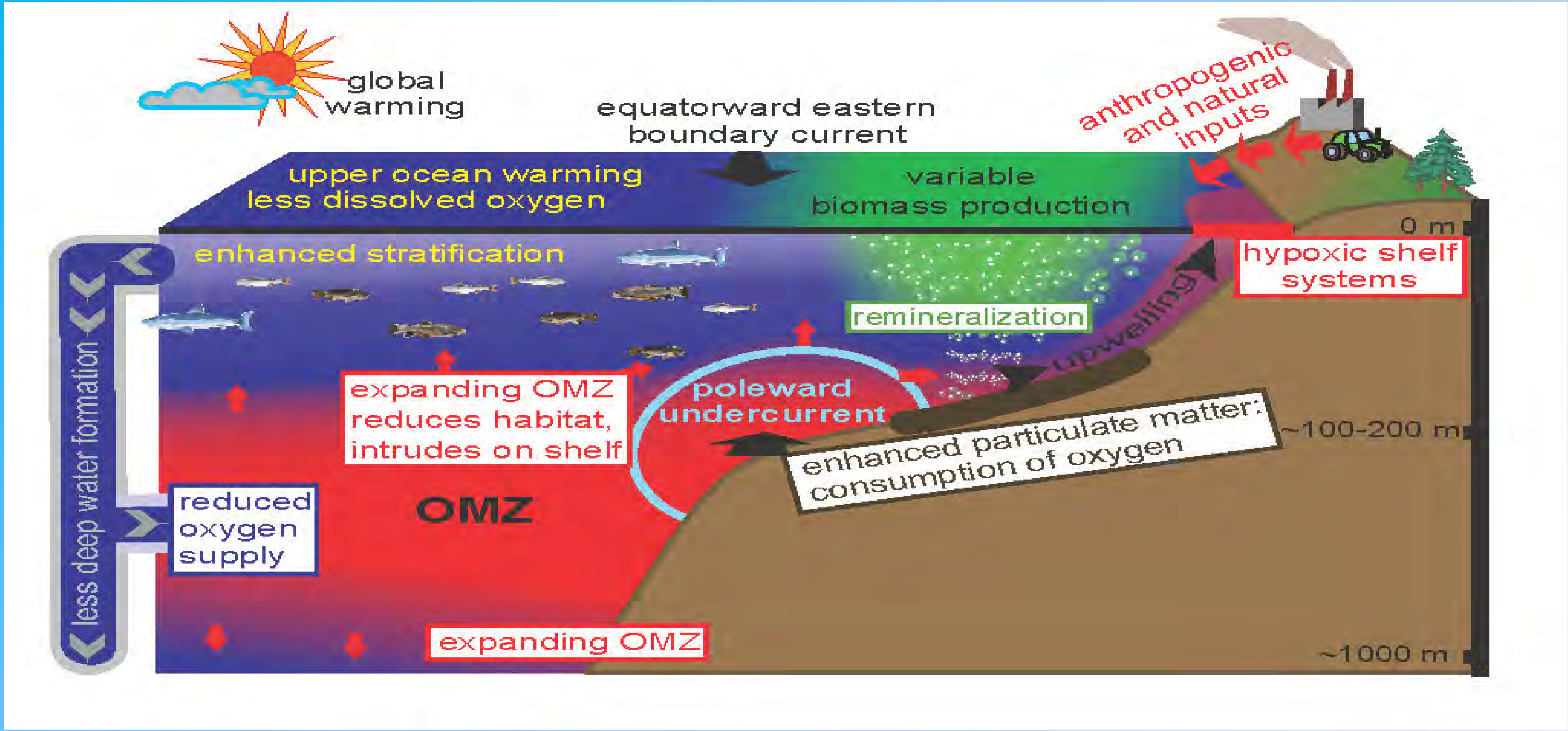
34°-35°N,121-122°W, CALCOFI





Strong El Niño – circle, strong La Niña - square

Open ocean – shelf interaction



Schematic interaction of oxygen minimum zones with hypoxic shelf system on continental shelves of eastern ocean boundaries

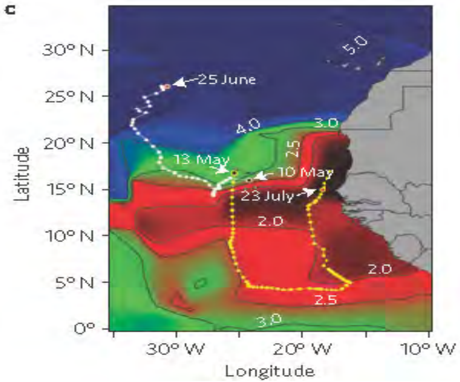
(Stramma, Schmidtko, Levin, Johnson 2010, DSR-I)

Open ocean:

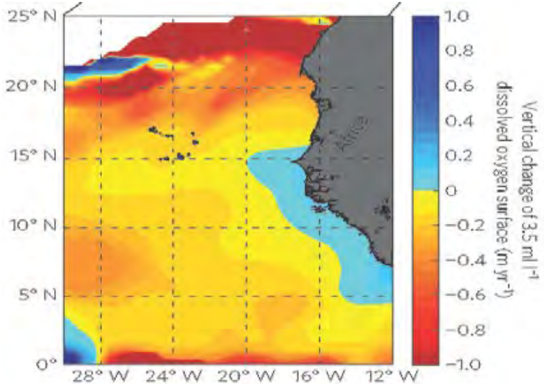
tag

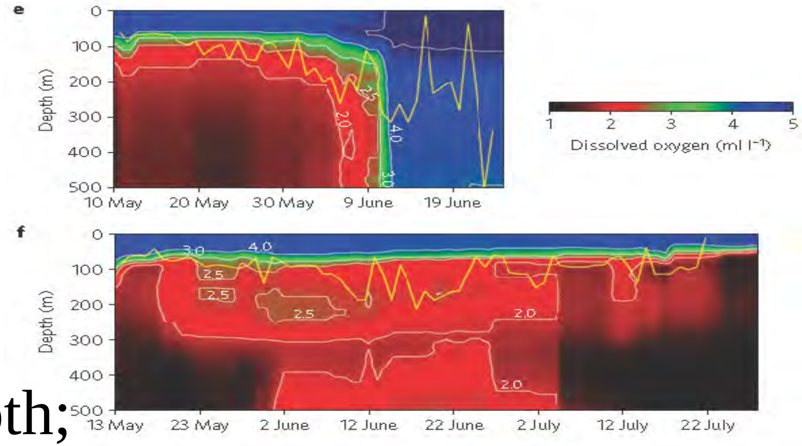
Long-term trends:

Blue marlin with tag



Blue marlin tracks 2004





Maximum daily dive depth; DO in ml/l

Vertical change of 3.5 ml/l depth; 1960-2010 15% habitat loss

(Stramma, Prince, Schmidtko et al. 2012, Nature Climate Change)

Shelf hypoxia (dead zones)

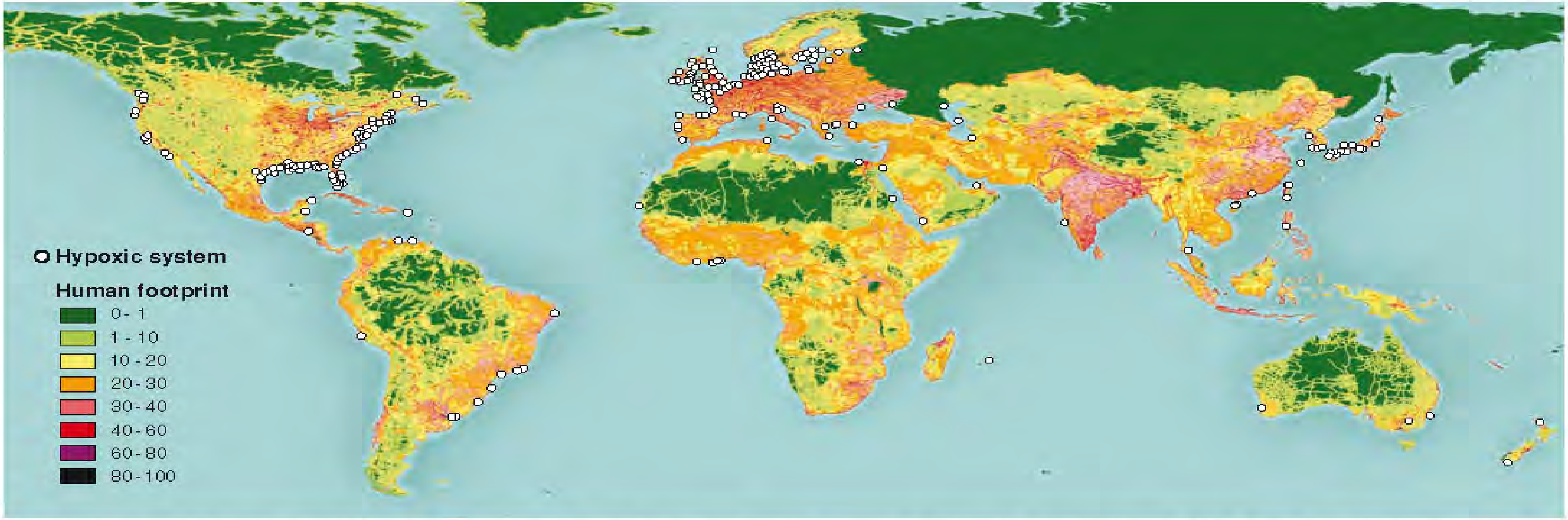


Fig. 1. Global distribution of 400-plus systems that have scientifically reported accounts of being eutrophication-associated dead zones. Their distribution matches the global human footprint [the normalized human influence is expressed as a percent (*41*)] in the Northern Hemisphere. For the Southern Hemisphere, the occurrence of dead zones is only recently being reported. Details on each system are in tables S1 and S2.

Diaz and Rosenberg 2008, Science

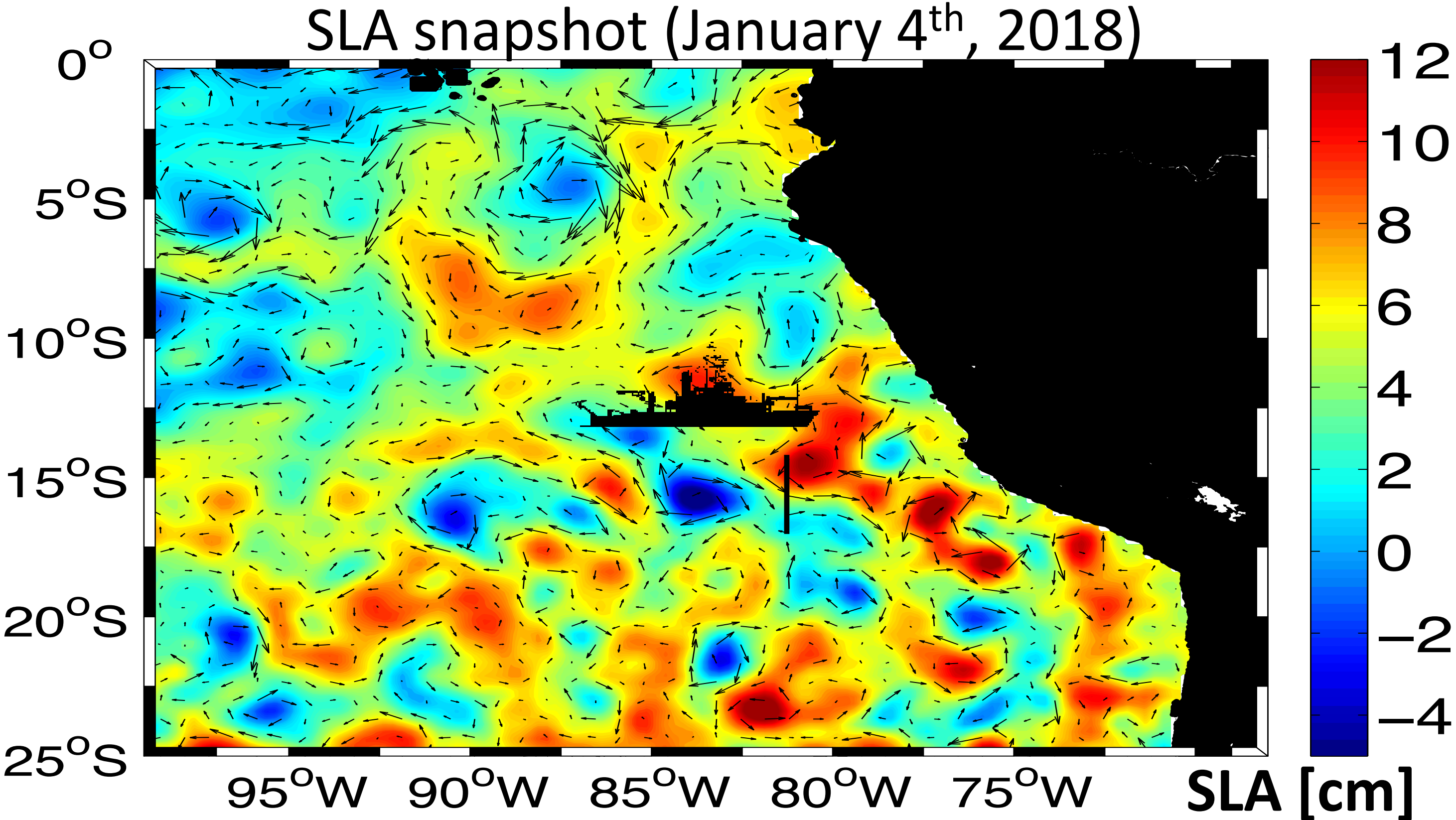
Shelf region (Gulf of Mexico):

Mobile Bay Jubilee:
Each summer since 1860 crabs and fish are near the shore.
100 years later recognized as ecological desaster. Front of oxygen poor water pushed to shore by wind. (anthropogenic input farming and cities).

27 August 2012 from LSU Forum

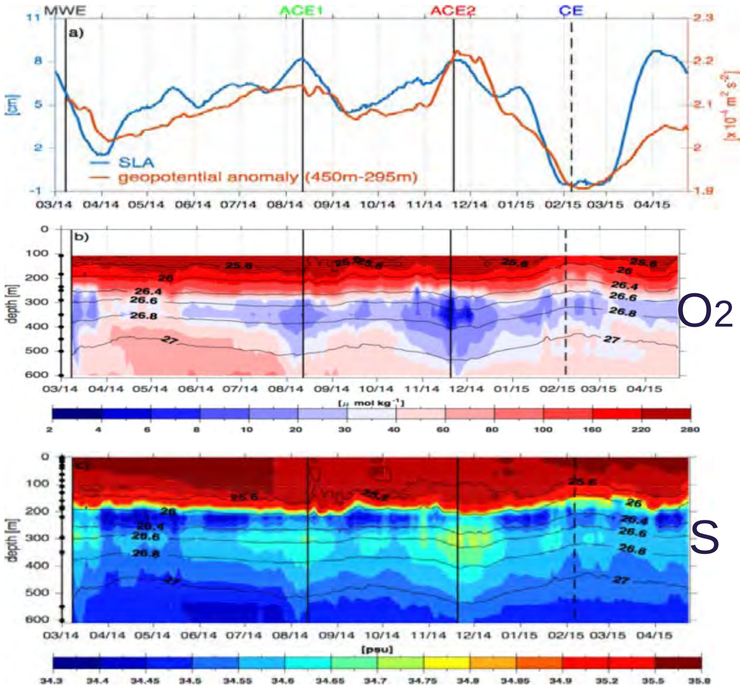
Encyclopedia of Alabama

Mesoscale eddies field



anticyclonic, cyclonic eddies

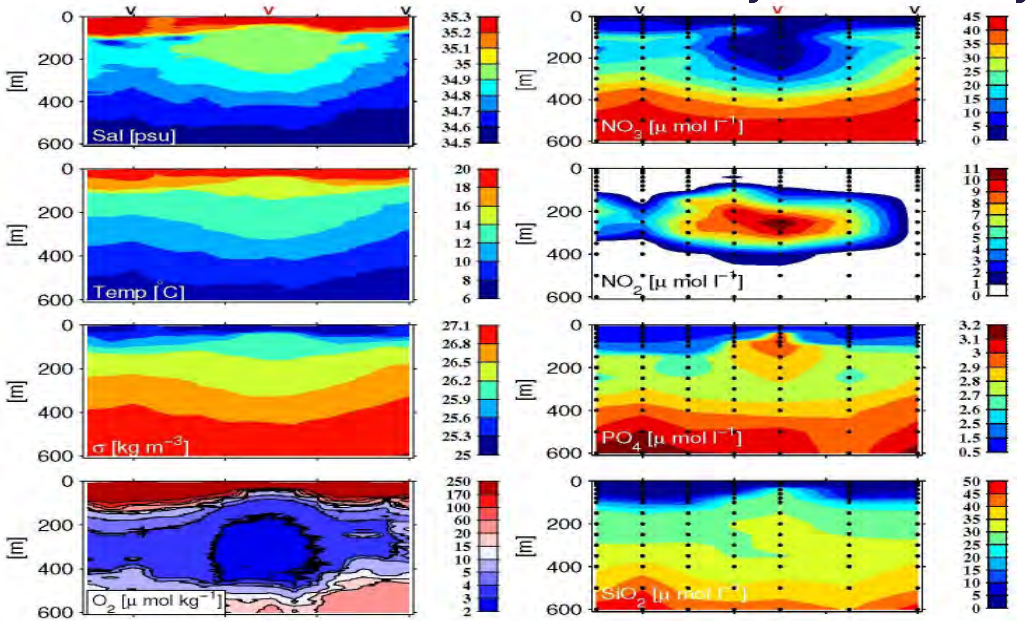
Mesoscale eddy anomalies



STRATUS mooring 19°37‘S, 84°57‘W

Czeschel et al. submitted 2018

Parameter distribution in an anticyclonic eddy



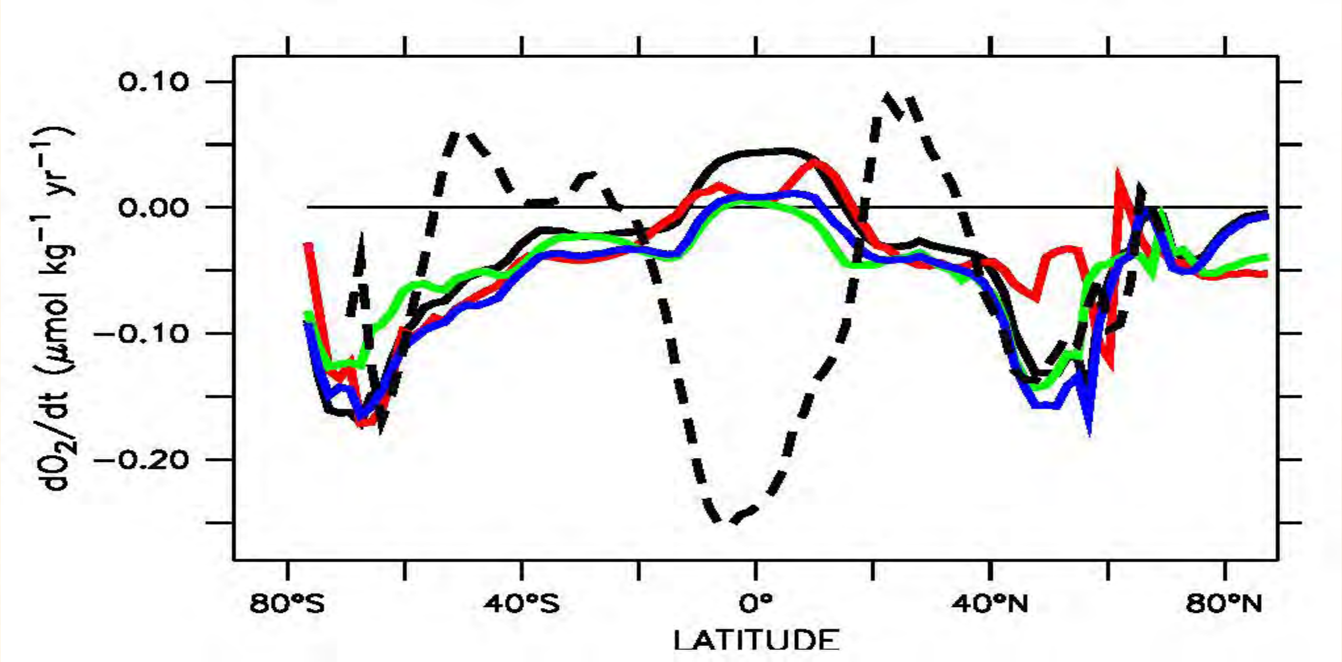
15°10‘S
76°42‘W

17°30‘S
76°W

near Peruvian shelf

Stramma et al. 2013

Observation-model discrepancies last 50 years



Zonally averaged changes at 300 dbar, black dashed: observations, solid curves model runs (color: different background diffusivities)

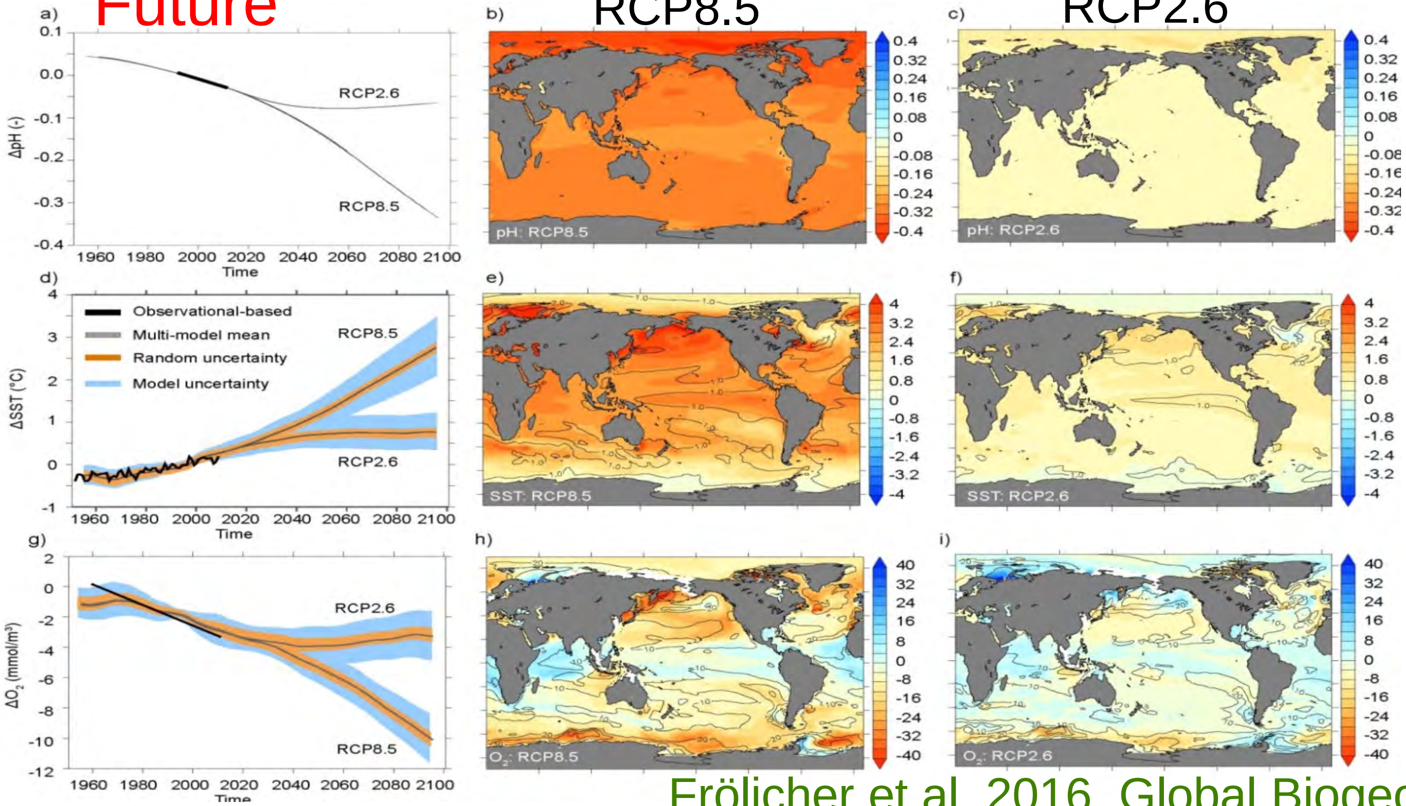
Global mean 50°N-50°S 300 m 1960-2010 obs -0.066 μmol/kg/yr

Model -0.027 to -0.047 μmol/kg/yr (monthly climatological wind forcing); improvement with interannually varying reanalysis wind forcing

Stramma, Oschlies, Schmidtko 2012, Biogeosciences

Future

RCP8.5 | RCP2.6



Surface pH
acidification

SST
warming

100-600 m
deoxygenation

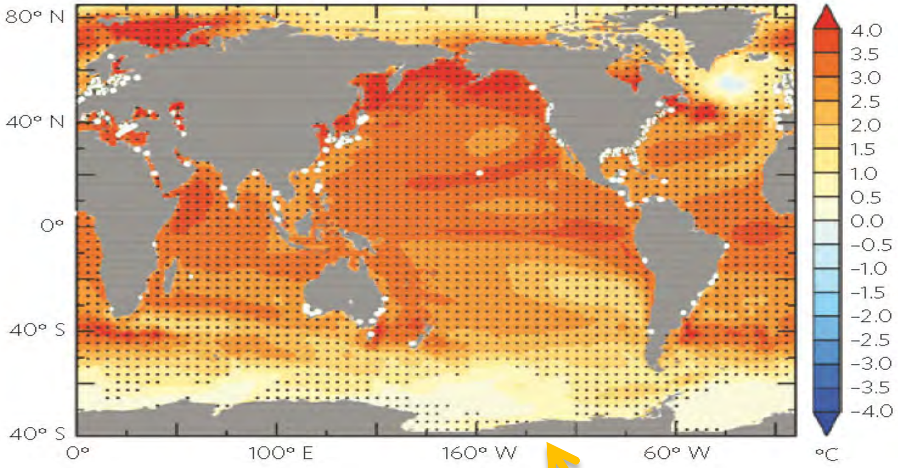
Frölicher et al. 2016, Global Biogeochem. Cycl.

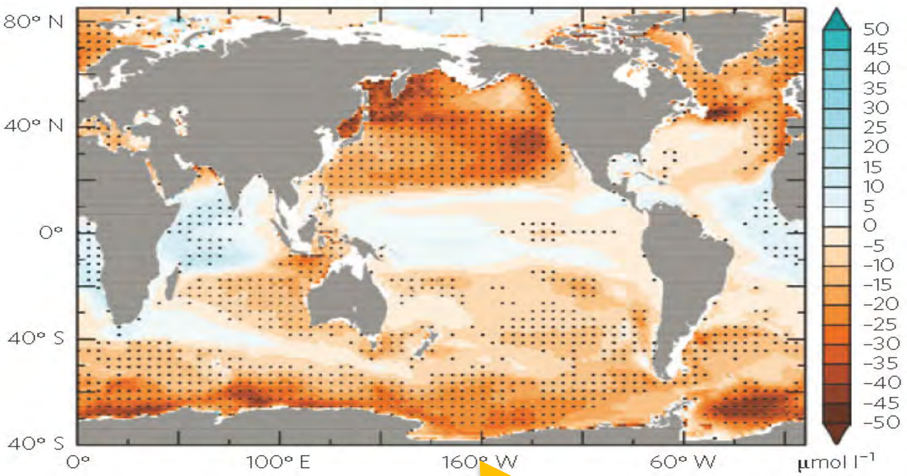
changes from several Earth System Models (2076-2095) – (1985-2004)

RCP8.5: business as usual (+4.8°C by year 2100); RCP2.6 (+1.0°C by year 2100)

Representative Concentration Pathways; radiative forcing of +8.5 W/m^2 year 2100 compared to preindustrial due to greenhouse gas emissions

Present coastal hypoxia white dots





Changes in sea surface temperature and oxygen concentration 200-600 m 2090-2099 relative to 1990-1999, RCP8.5: ‚business as usual' scenario from 10 earth system models;

SST:+2.73°C

global oxygen content -3.45%

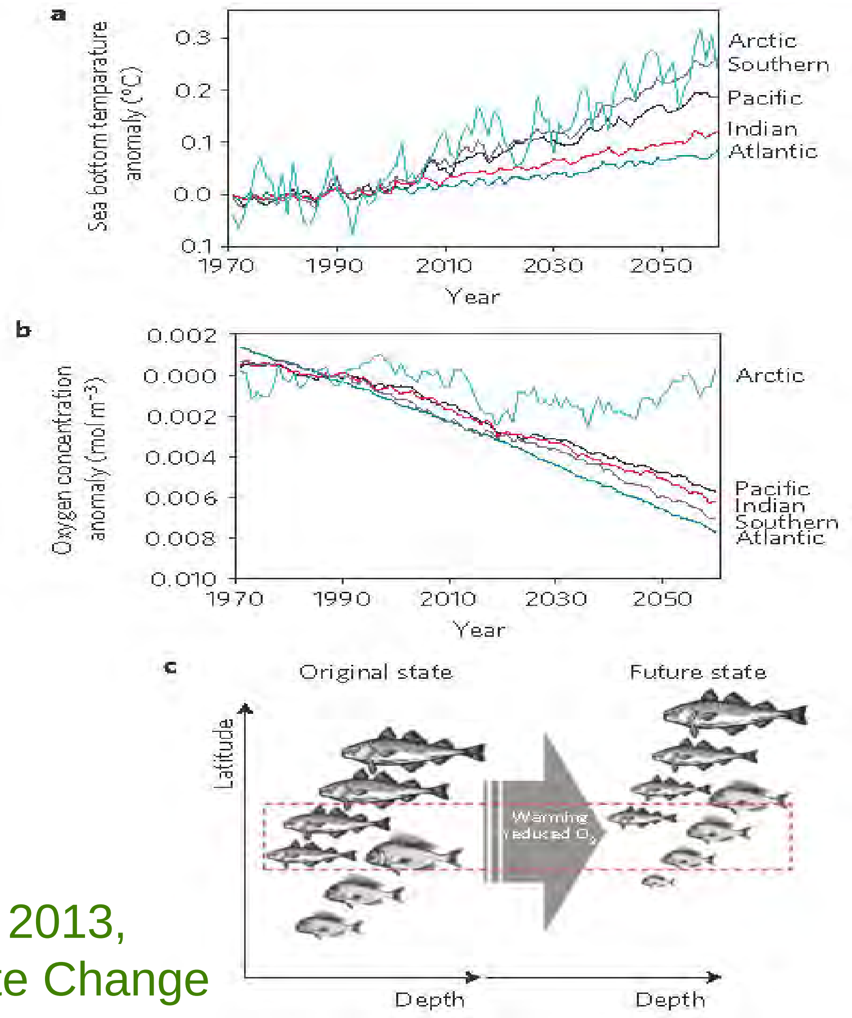
Schmidtko et al. 2017 -2% in 50 years, here -3.45% in 100 years, but in the model less than 1% for the period 1960 to 2010

Figures from Levin and Breitburg 2015, Nature Clim. Change, model by Bopp et al. 2013, Biogeosciences

Future

Biological response of over 600 species, body weight is expected to shrink by14-24% globally from 2000 to 2050

(GFDL model SRES a2 scenario ~ RCP8.5)



Cheung et al. 2013, Nature Climate Change

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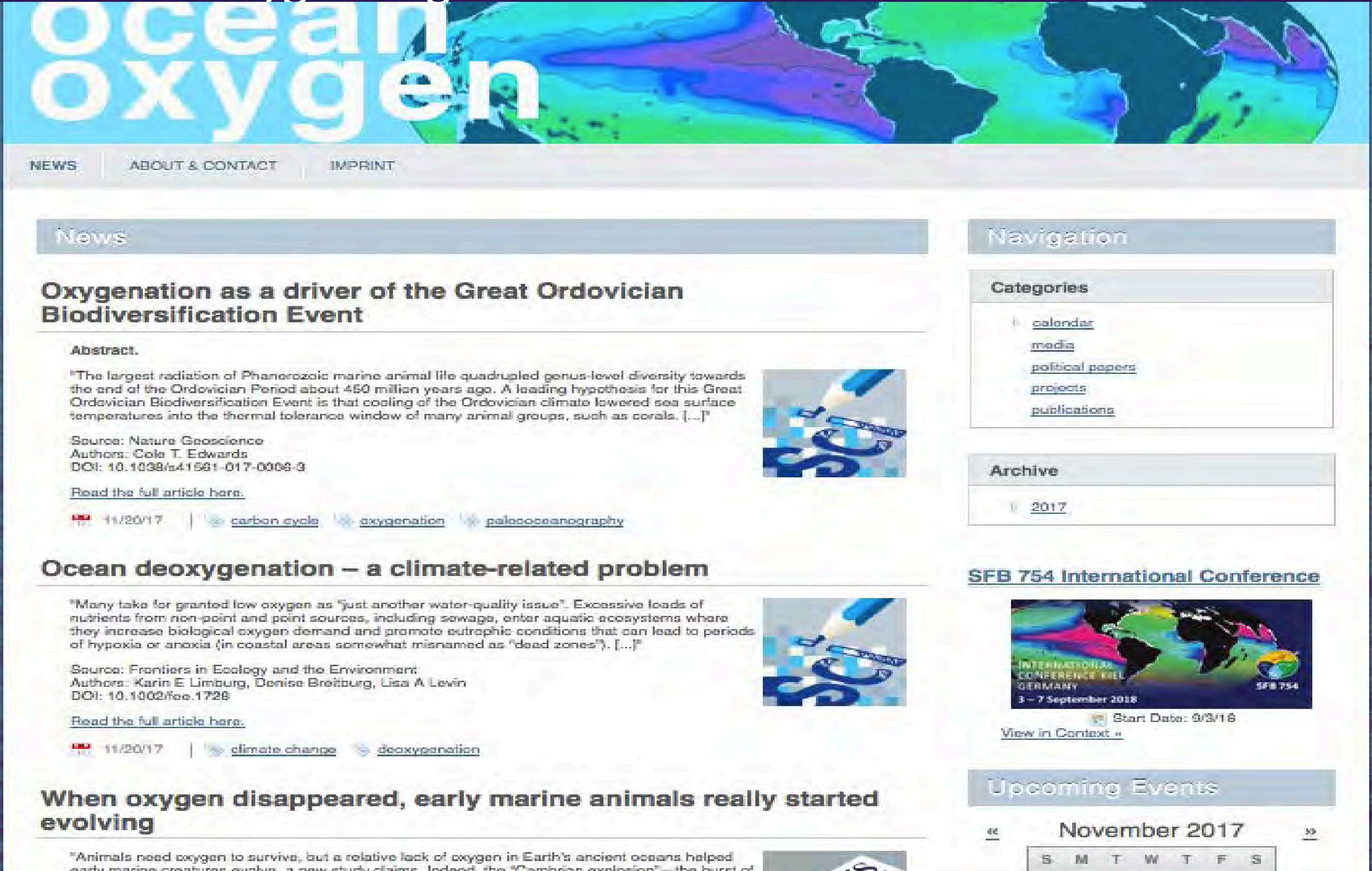
www. ocean-oxygen.org



ocean oxygen

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News

Oxygenation as a driver of the Great Ordovician Biodiversification Event

Abstract.

"The largest radiation of Phanerozoic marine animal life quadrupled genus-level diversity towards the end of the Ordovician Period about 450 million years ago. A leading hypothesis for this Great Ordovician Biodiversification Event is that cooling of the Ordovician climate lowered sea surface temperatures into the thermal tolerance window of many animal groups, such as corals. [...]"

Source: Nature Geoscience
Authors: Cole T. Edwards
DOI: 10.1038/s41561-017-0006-3

Read the full article here.

11/20/17 | carbon cycle, oxygenation, paleooceanography

Ocean deoxygenation – a climate-related problem

"Many take for granted low oxygen as "just another water-quality issue". Excessive loads of nutrients from non-point and point sources, including sewage, enter aquatic ecosystems where they increase biological oxygen demand and promote eutrophic conditions that can lead to periods of hypoxia or anoxia (in coastal areas somewhat misnamed as "dead zones"). [...]"

Source: Frontiers in Ecology and the Environment
Authors: Karin E Limburg, Denise Breitburg, Lisa A Levin
DOI: 10.1002/fee.1728

Read the full article here.

11/20/17 | climate change, deoxygenation

When oxygen disappeared, early marine animals really started evolving

"Animals need oxygen to survive, but a relative lack of oxygen in Earth's ancient oceans helped early marine creatures evolve, a new study claims. Indeed, the "Cambrian explosion"—the burst of

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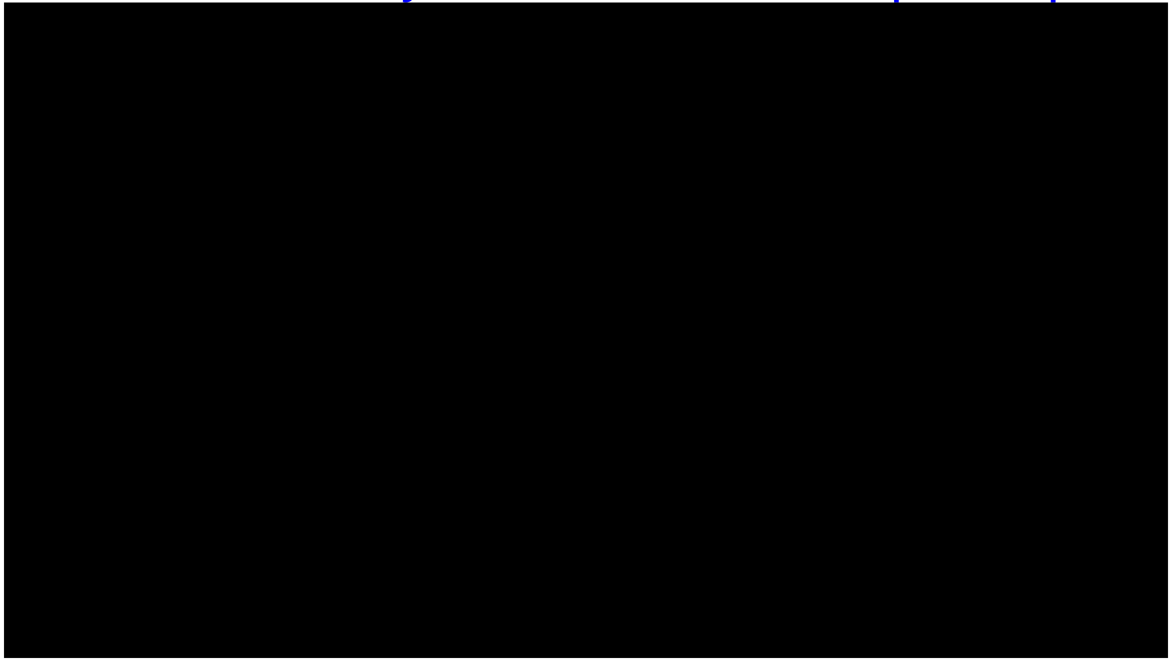
« November 2017 »

Influence on ecosystem:

ROV-based video of 50 m rocky reef habitats off Cape Perpetua, Oregon, USA



Aug. 26, 2000 pre anoxia (A) black rockfish
Aug. 8, 2006 anoxia (G) moribund or decomposing carcasses of Dungeness crabs
and sunflower stars
Aug. 21, 2006 (H) moribund unidentified sipunculid worms and sea cucumbers

(from Chan, Barth, Lubchenko, Kirincich, Weeks, Peterson, Menge 2008, Science, Suppl.)