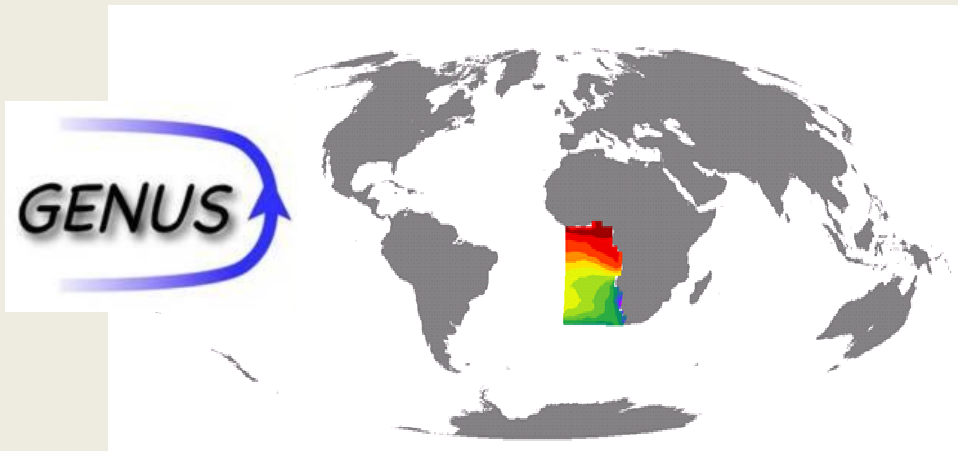
Physical-biological controlling of the oxygen budget on the Namibian shelf



Geochemistry and Ecology of the Namibian Upwelling System

The GENUS project is funded by the German Federal Ministry of Education and Research and is an endorsed IMBER project.

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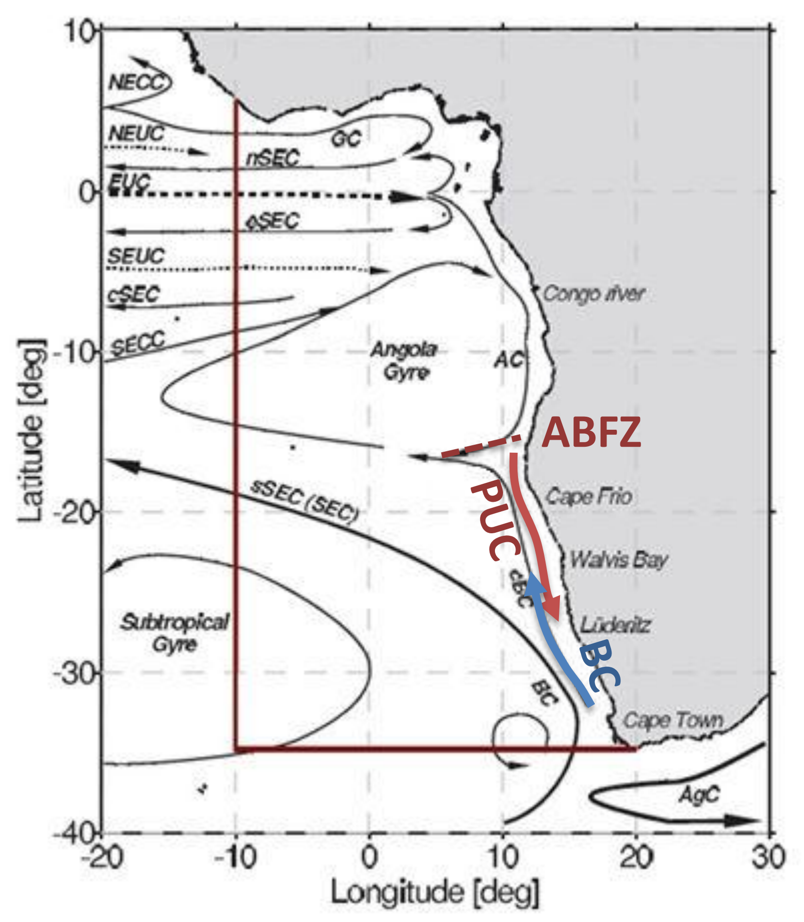
Anja Eggert

Large scale circulation

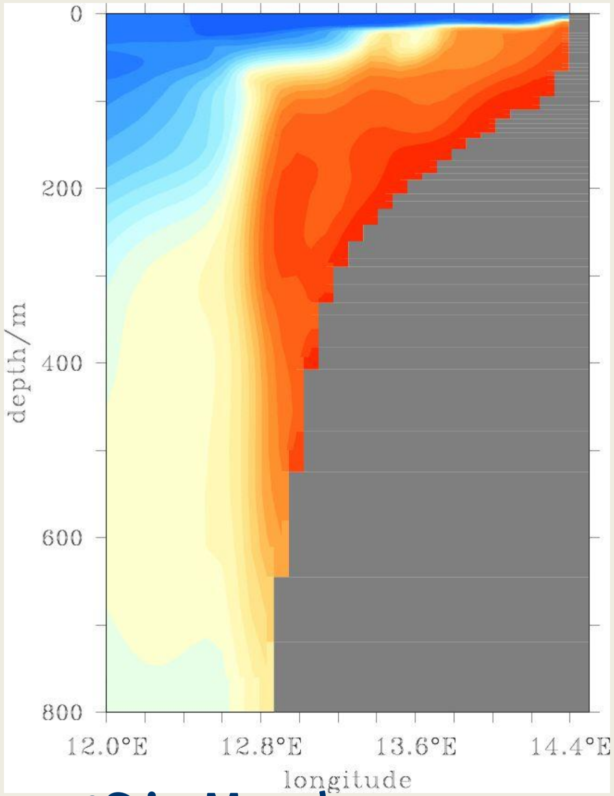


- **South Atlantic Central Water (SACW)** is transported with the **poleward undercurrent (PUC)** onto the Namibian shelf
  - specific salinity and temperature signature
  - high nutrients and a low dissolved oxygen content
- **Eastern SACW (ESACW)** spreads northward with the **Benguela Current (BC)** along the southwest African shelf edge, by cross-shelf circulation onto the Namibian shelf
  - less saline and less nutrients and more oxygen than the PUC

Large spatial and temporal variability of hydrographic conditions and currents: combination of locally and remotely forced processes

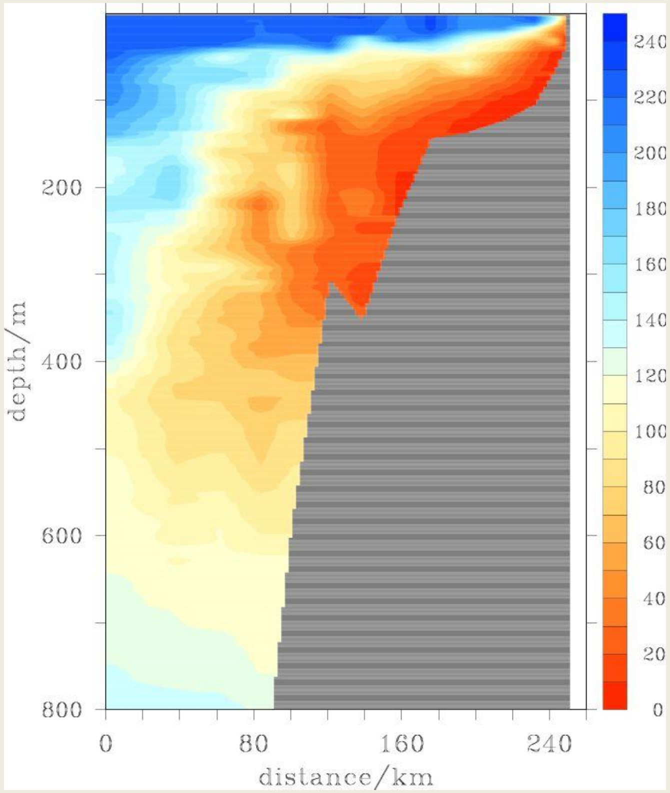
Extended Oxygen Minimum Zone

Model results



23ºS in March 2003

Field data: M57/3



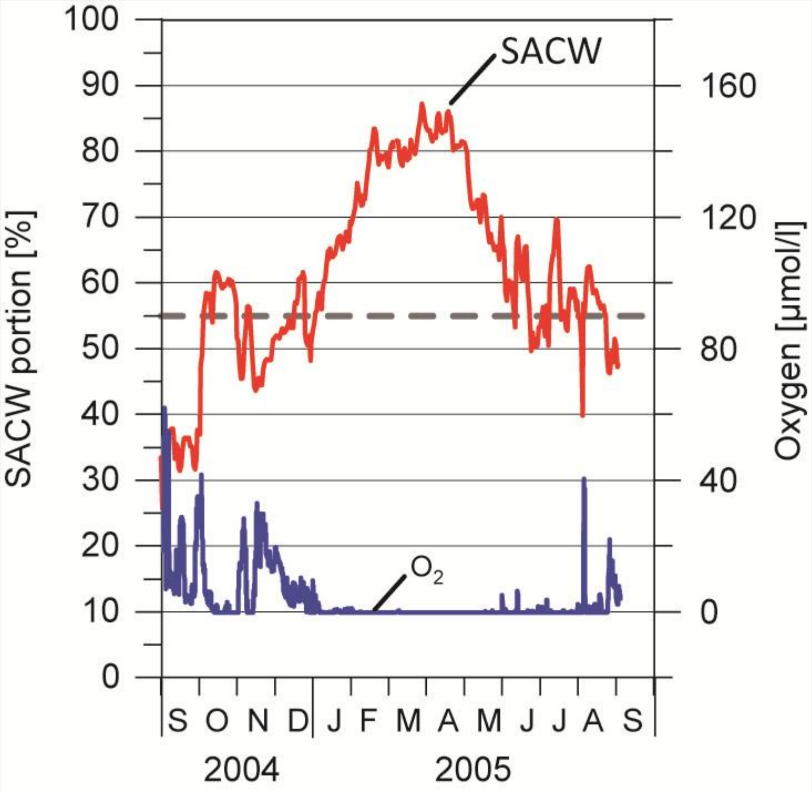
Oxygen concentration [µmol/kg]

- The shape of the OMZ on the shelf is well reproduced
- BUT model overestimates extension of OMZ and field data show more variability

Oxygen-deficient shelf water

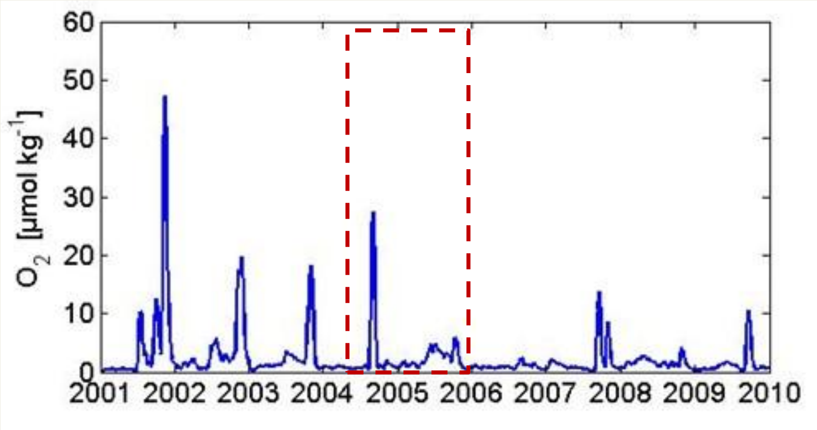
Oxygen in the near bottom water

Field data: mooring off Walvis Bay (120 m)



Mohrholz et al. 2008

Model results



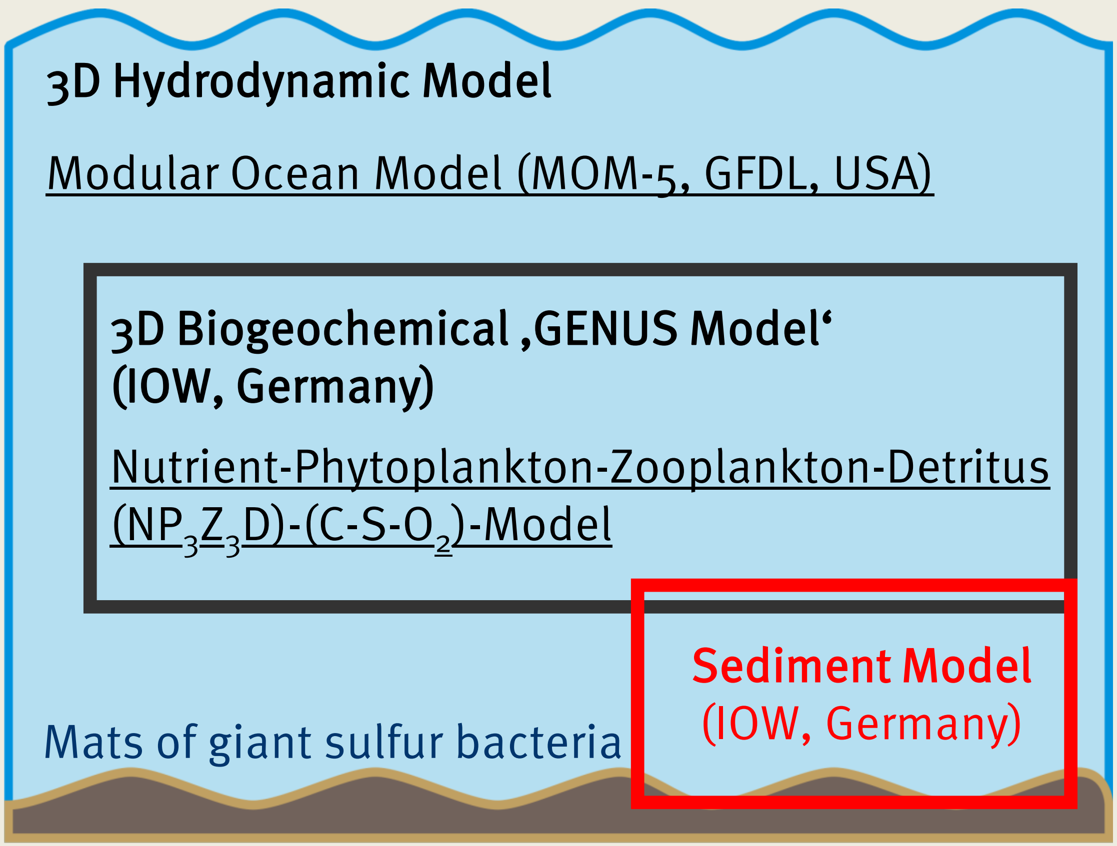
- Good simulation of hypoxic near bottom water on the shelf
- Anoxic conditions correlate with an SACW fraction >55%

High dependence on composition of water masses ESACW and SACW

Outline

- Working hypothesis:
  - **The low oxygen water on the continental shelf off Namibia is primarily driven by physical advection and is only modified through local biogeochemical oxygen consumption.**
- Tool:
  - Numerical simulation with a regional, 3D coupled hydrodynamic-biogeochemical ecosystem model: 1999-2013
- This presentation:
  - Relevant physical and biogeochemical processes controlling the oxygen budget on the Namibian shelf
  - Calculation of residence times to compare the relative importance of the physical and biogeochemical processes on the local oxygen concentration

Coupled hydrodynamic-biogeochemical ecosystem model



- **Model currency:** nitrogen, coupled carbon, oxygen and sulfur cycles
- **Feedback OMZ and zooplankton:** reduced respiration at hypoxic conditions, zooplankton diel vertical migration regulates low O_2 water in the OMZ
- **Nutrient cycling in the bottom sediment:** thin oxic and thick anoxic sediments with mats of large sulfur bacteria

Relevant processes

air-sea flux

$$\frac{\partial[O_2]}{\partial t} = \left(\frac{\partial[O_2]}{\partial t}\right)_{dyn} + \left(\frac{\partial[O_2]}{\partial t}\right)_{bio} + J_{flux}$$

Hydrodynamic transport

- Meridional and zonal lateral advection
- Vertical advection

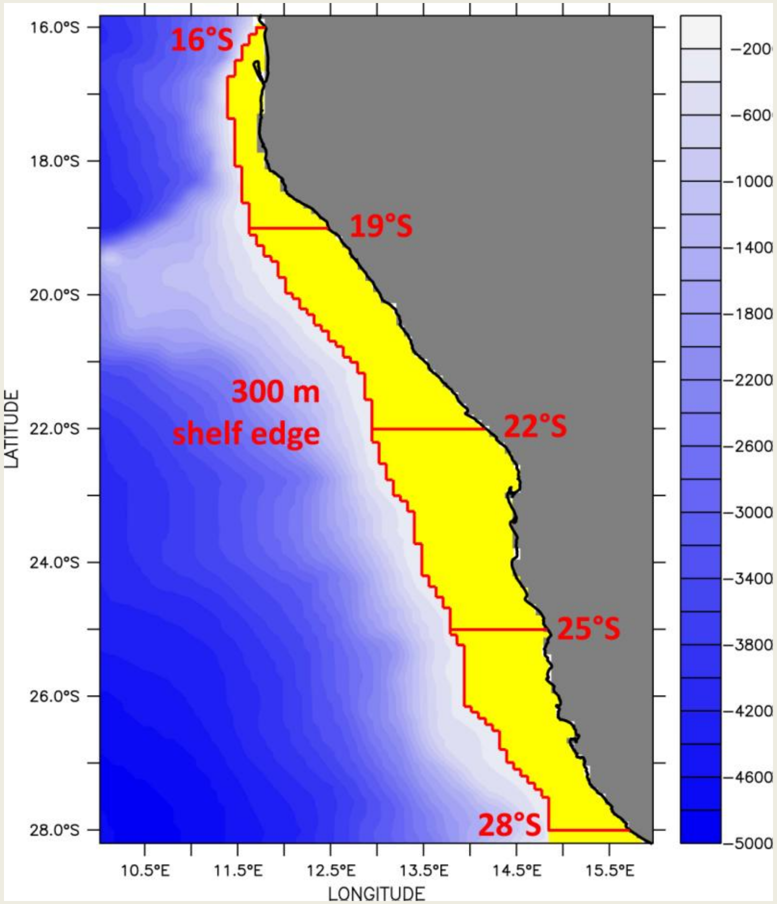
Biogeochemical source and sinks

+ Primary production
- Aerobic mineralisation of sinking detritus in the water column
- Zooplankton respiration
- Nitrification
- Aerobic mineralisation at the sediment-water boundary

Contribution of physical and biogeochemical processes

Residence times on the Namibian shelf

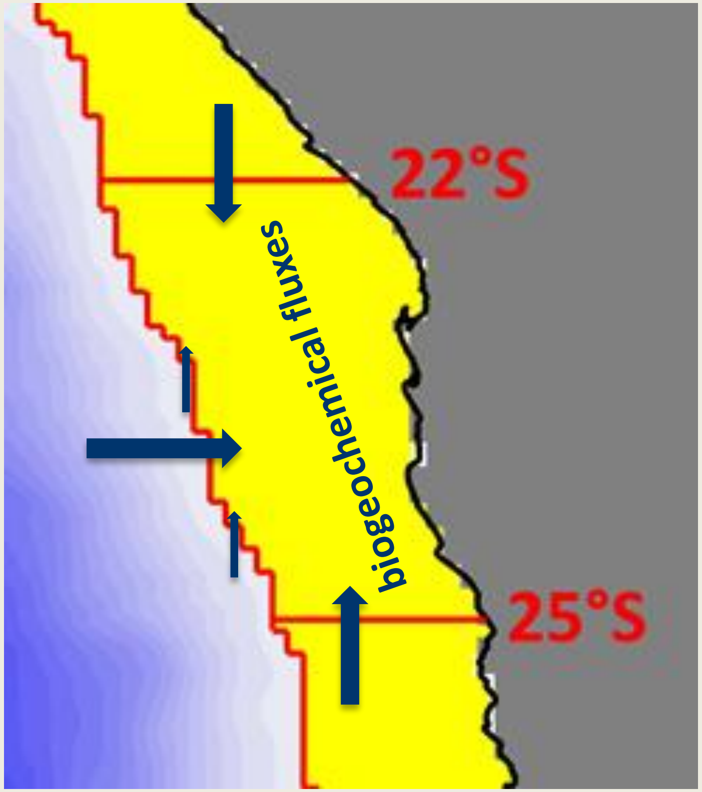
- Latitudinal division of the Namibian shelf:
  - 16-28°S (Cape Frio/Kunene)
  - 19-22°S (Central Namibia)
  - 22-25°S (Walvis Bay)
  - 25-28°S (Lüderitz)



Relative importance of physical and biogeochemical processes along the shelf

Residence times on the Namibian shelf

- Division of the Namibian shelf (300 m shelf edge)
  - 16-28°S (Cape Frio/Kunene)
  - 19-22°S (Central Namibia)
  - 22-25°S (Walvis Bay)
  - 25-28°S (Lüderitz)

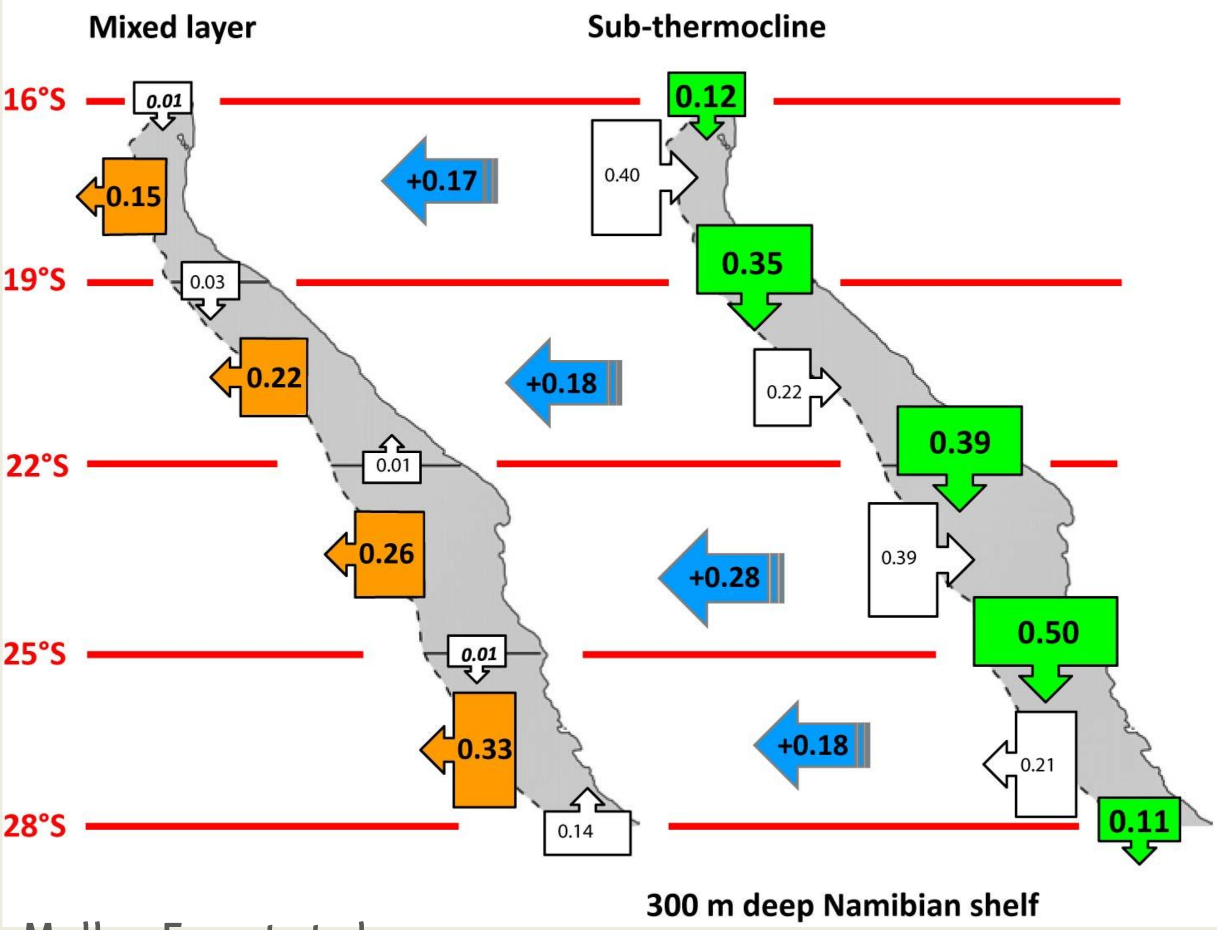


$$\tau_{dyn} = \frac{O_2 \text{ inventory}}{\sum \text{oxygen transport fluxes into box}}$$

$$\tau_{bio} = \frac{O_2 \text{ inventory}}{\sum \text{biogeochemical fluxes within box}}$$

Relative importance of physical and biogeochemical processes in the 22-25°S box

Local current patterns



Muller, Eggert et al. 2014

Volume transport flux budget [Sv]
austral summer (DJF)

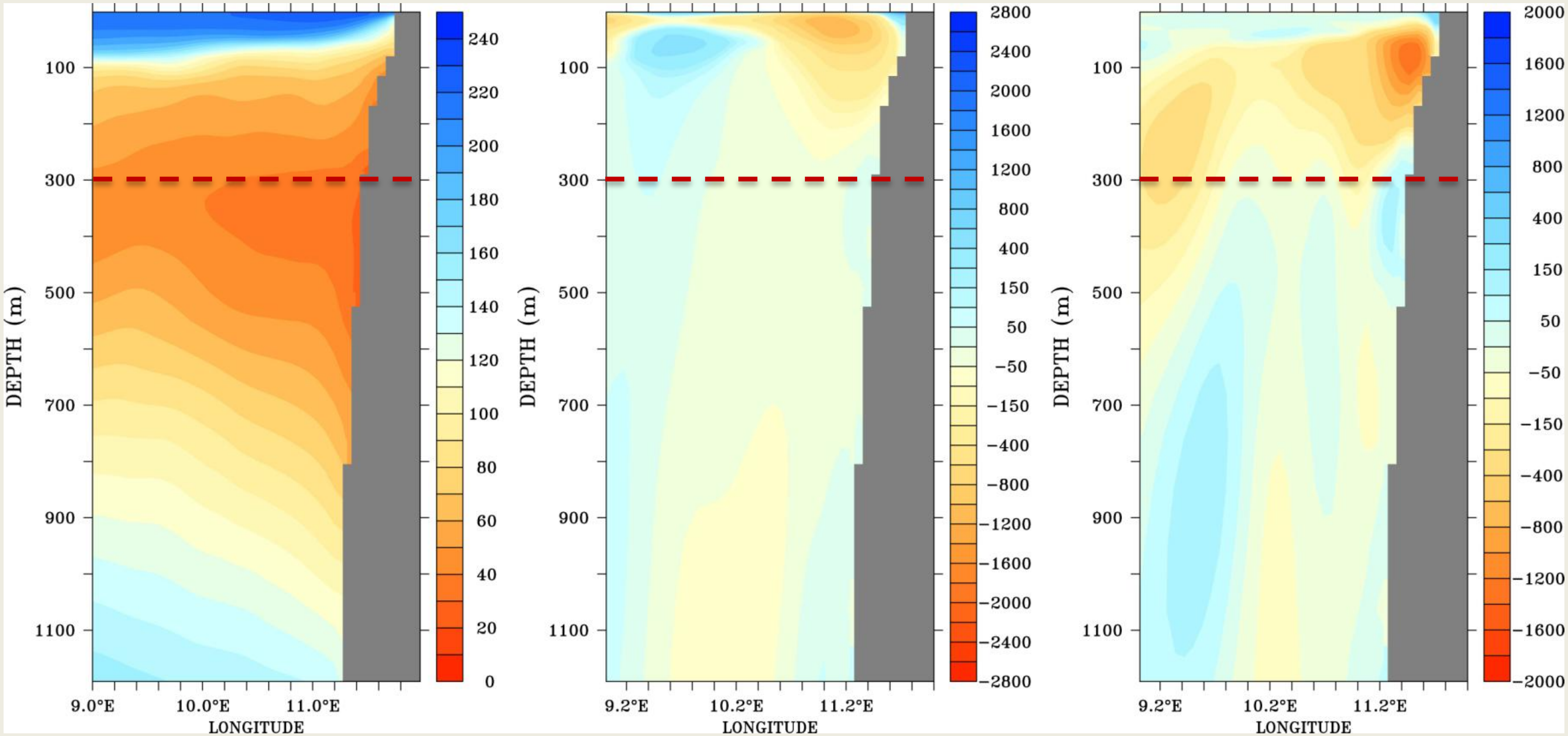
- **Off shelf** Ekman transport through the mixed layer
- **Poleward undercurrent** in sub-thermocline
- **Upwelling,** i.e. upward flux into mixed layer

PUC dominates transport fluxes in the sub-thermocline, seasonal maximum in DJF

Anja Eggert

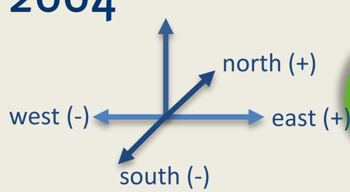
Fingerprint of the PUC

Oxygen concentration | Oxygen transport | AOU transport



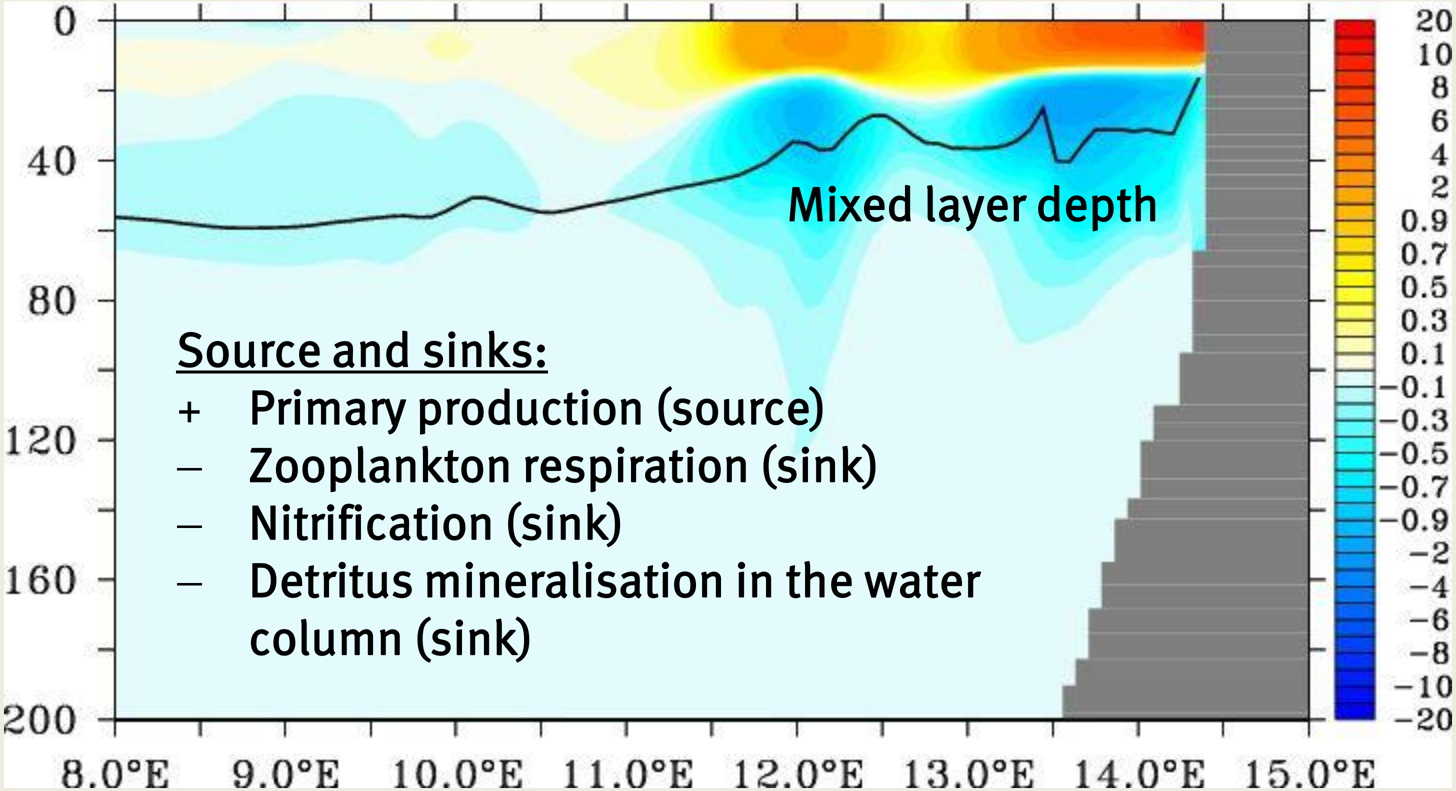
18°S, average of 2004

Transport [mol/m²/d]



Physical advection of oxygen-poor water

The biological oxygen budget in the water column



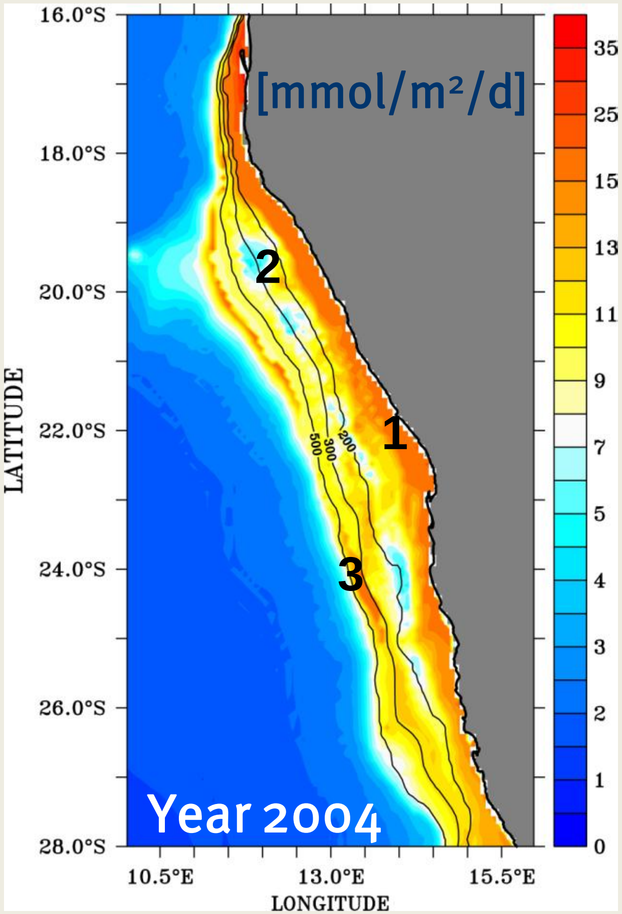
Net oxygen rates [mmol/m³/d]

23°S, July 2004

Biological oxygen consumption most intense at mixed layer depth

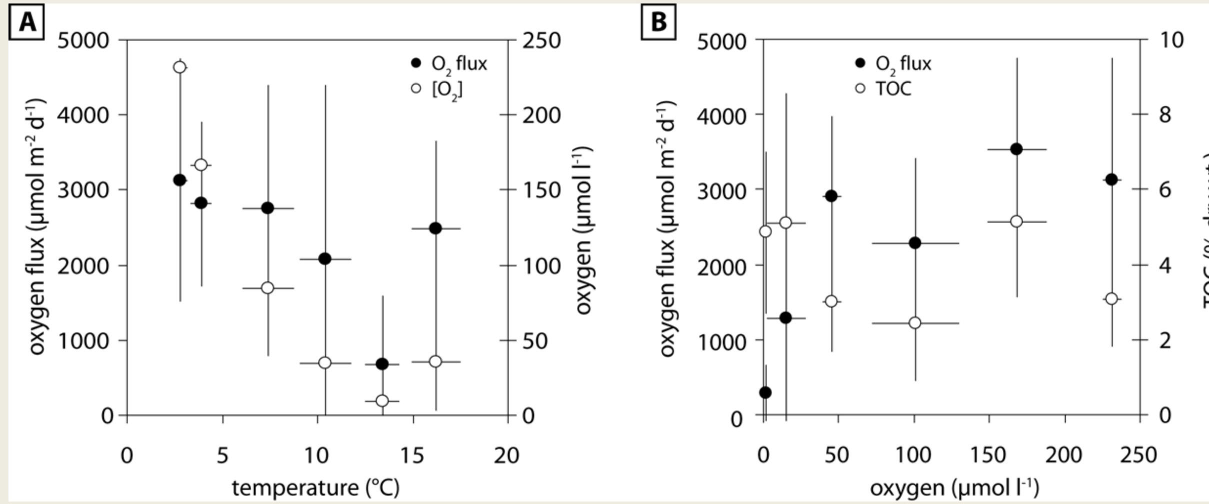
Relevant oxygen fluxes at the sediment

Model results



Field data

Andreas Neumann, yet unpubl. results



1. **High oxygen flux in shallow areas:** O_2 flux consumed by sulfur bacteria, i.e. no diffusion of O_2 into the sediment !
2. **Lower O_2 flux at intermediate depths:** due to hypoxic or anoxic bottom water
3. **High O_2 flux at the shelf edge:** no mats of sulfur bacteria, aerobic mineralisation of sediment detritus

Spatial pattern of fluxes into the sediment, 25% of water column consumption

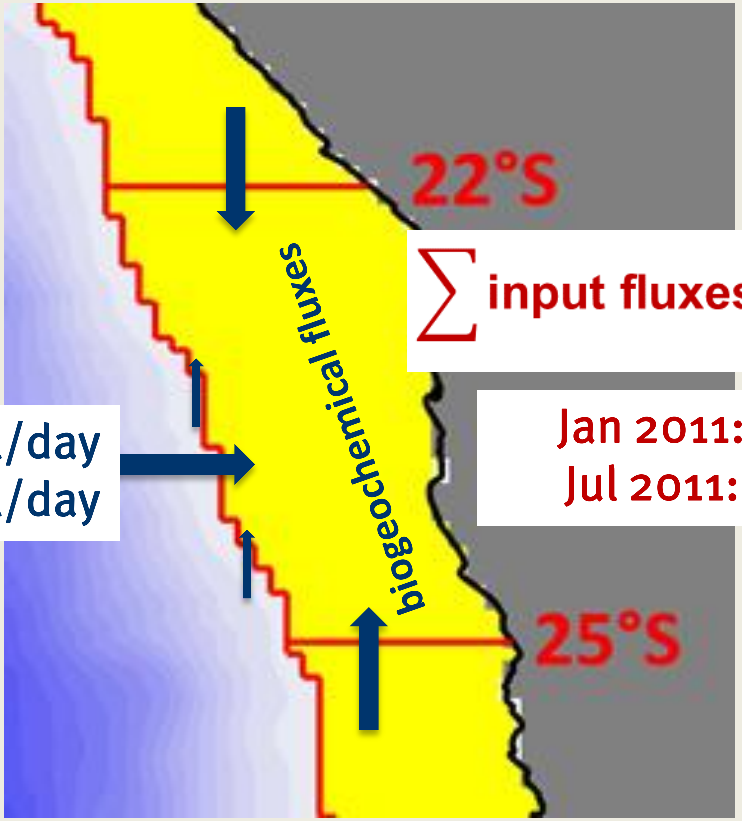
Physical advection of oxygen

meridional (*v*)
transport from the **North**

Jan 2011: -2.8 Gmol/day
Jul 2011: -1.0 Gmol/day

zonal (*u*)
transport from
the **West**

Jan 2011: +5.4 Gmol/day
Jul 2011: +3.2 Gmol/day



$\sum$ input fluxes

Jan 2011: 10.1 Gmol/day
Jul 2011: 14.6 Gmol/day

Jan 2011: +2.0 Gmol/day
Jul 2011: +10.4 Gmol/day

meridional (*v*)
transport from the **South**

Seasonality in poleward undercurrent (PUC) and Bengula Current (BC)

Physical and biogeochemical residence times

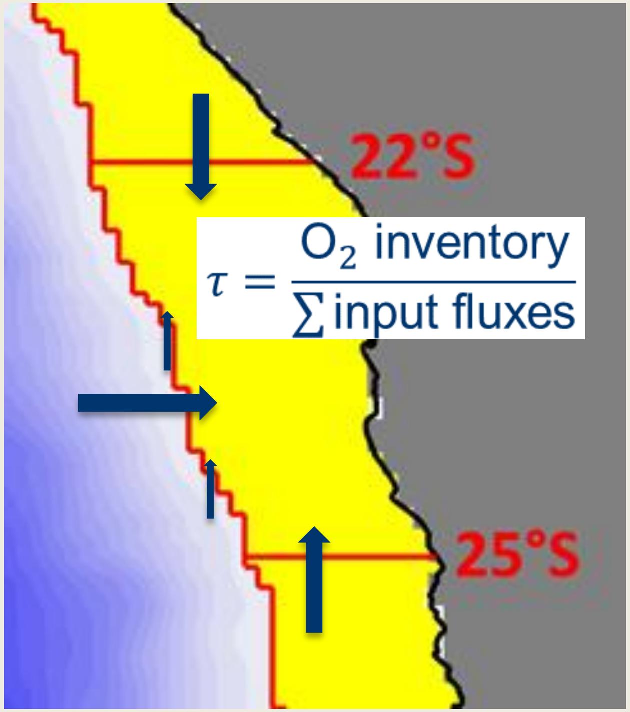
Physical advection of oxygen

- January 2011

$$\tau_{dyn} = \frac{462\text{Gmol}}{10.1\ \frac{\text{Gmol}}{\text{day}}} = \mathbf{46\ days}$$

- July 2011

$$\tau_{dyn} = \frac{699\text{ Gmol}}{14.6\ \frac{\text{Gmol}}{\text{day}}} = \mathbf{48\ days}$$



$$\tau = \frac{O_2 \text{ inventory}}{\sum \text{input fluxes}}$$

Biogeochemical oxygen consumption

- January 2011

$$\tau_{bio} = \frac{462\text{ Gmol}}{2.3\ \frac{\text{Gmol}}{\text{day}}} = \mathbf{206\ days}$$

- July 2011

$$\tau_{bio} = \frac{699\text{ Gmol}}{3.5\ \frac{\text{Gmol}}{\text{day}}} = \mathbf{199\ days}$$

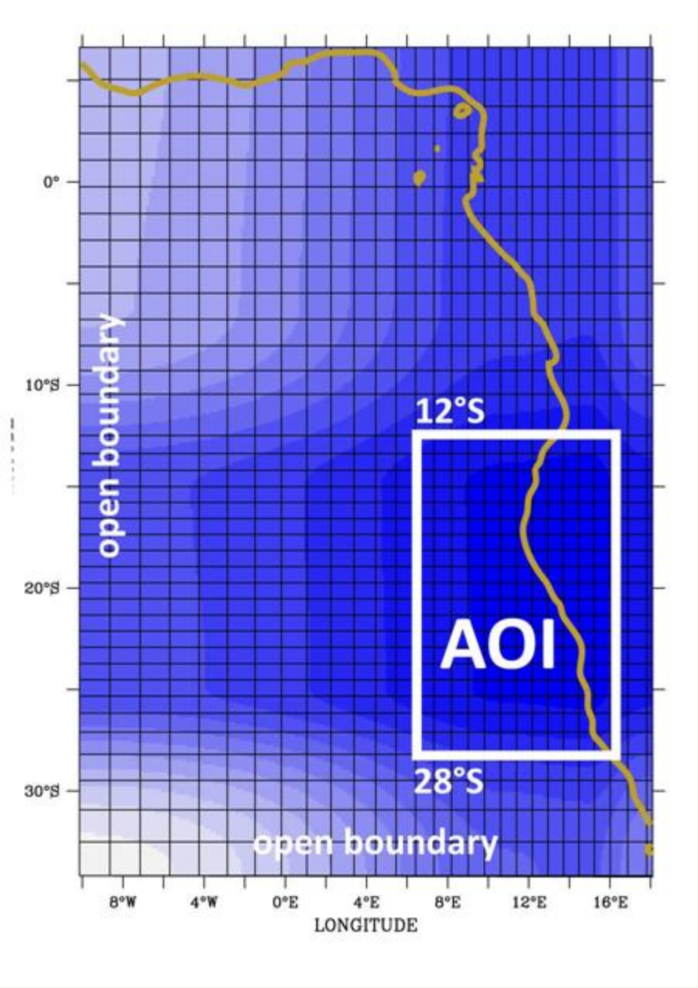
Dominance of physical advection over biogeochemical consumption (4 x)

The low oxygen water on the continental shelf off Namibia is primarily driven by physical advection and is only modified through local biogeochemical oxygen consumption.

RV Mirabilis
23°S - Monitoring
May 2013

Thank you very much for your attention !

SE Atlantic regional ecosystem model



Hydrodynamic model: MOM-5 (GFDL) with min ~8 km, max ~18 km resolution

Vertical grid resolution: 0-200 m depth 1.5-3 m, then increase to 300 m

Model bathymetry: ETOPO-5 and 30 arc-seconds version of the GEBCO data set

Open boundaries/ Initialisation : ECCO global circulation model (sea level, currents, temperature and salinity); World Ocean Atlas (nutrients, oxygen)

Realistic atmospheric forcings: NCEP or ERA-interim reanalysis data, modulated scatterometer wind fields (QuikScat, ASCAT)