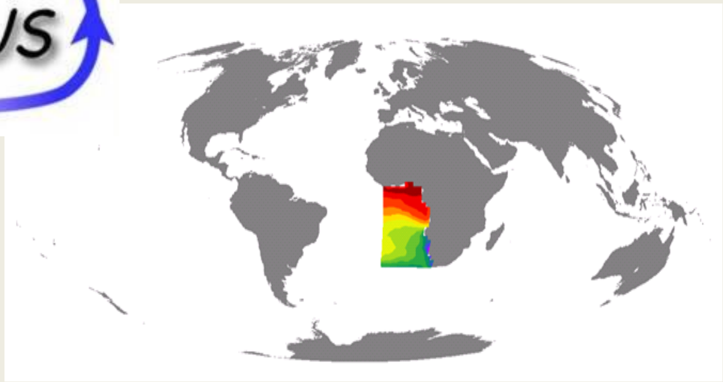
Dynamics of the oxygen minimum zone on the Namibian shelf: a model perspective



Geochemistry and Ecology of the Namibian Upwelling System

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Outline and scope

- Working hypothesis:
  - **The seasonal variability of low oxygen water on the continental shelf off Namibia is driven primarily by along-shore advection and local oxygen concentrations are only modified through biological consumption .**
- Tool:
  - Numerical simulation with a regional, 3D coupled hydrodynamic-biogeochemical ecosystem model: 1999-now
- This presentation:
  - Relevant processes (local biological and large-scale physical) controlling the oxygen budget on the Namibian shelf

Coupled hydrodynamic-biogeochemical model

3D Hydrodynamic Model (GFDL, USA)

Modular Ocean Model (MOM-5)

3D Biogeochemical Model (IOW, Germany)

Nutrient-Phytoplankton-Zooplankton-Detritus (NP_3Z_3D)-Model

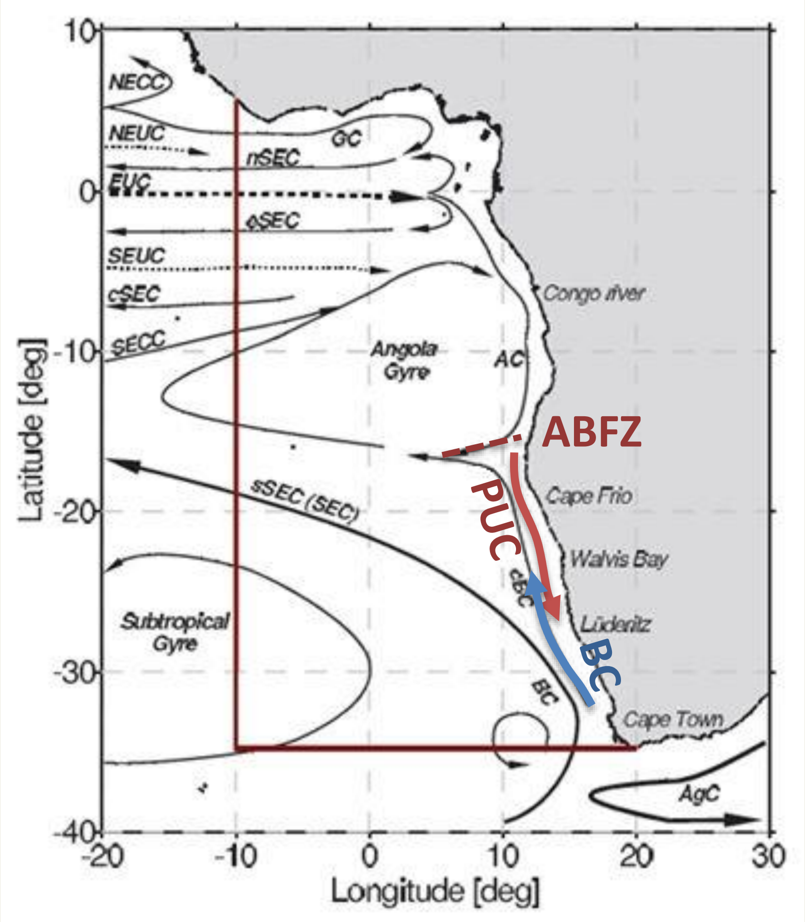
Sediment Model (IOW, Germany)

Mats of giant sulfur bacteria

Realistic atmospheric forcing

- Wind speed
- Wind direction
- Air pressure
- Air temperature
- Solar radiation
- Cloudiness
- Precipitation
- etc.

Large scale circulation



- South Atlantic Central Water (SACW) is transported with the poleward undercurrent (PUC) onto the Namibian shelf
- Eastern SACW (ESACW) spreads northward with the Benguela Current (BC) along the southwest African shelf edge

PUC: advection of nutrient rich but oxygen poor water masses

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

$$\left(\frac{\partial[O_2]}{\partial t}\right)_{dyn}$$

- Lateral advection
- Vertical advection

Biological sources and sinks

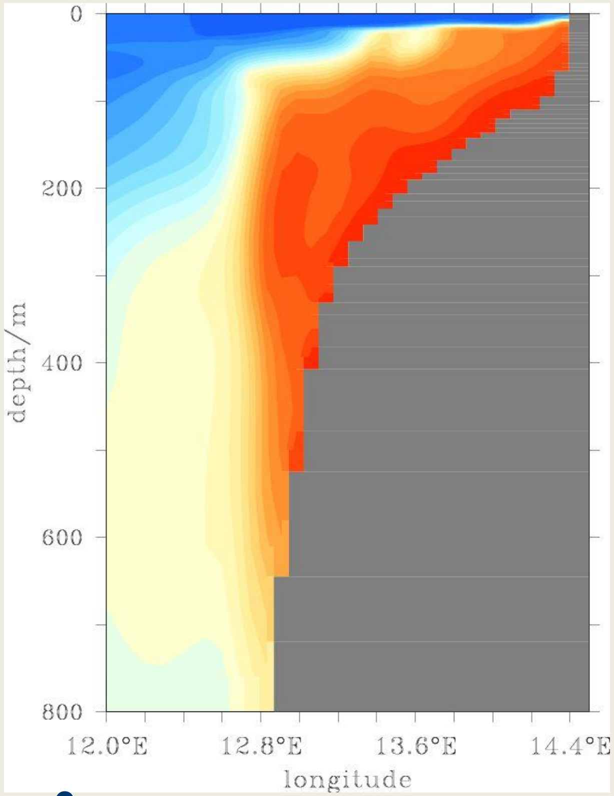
$$\left(\frac{\partial[O_2]}{\partial t}\right)_{bio}$$

+ New and regenerated primary production
- Aerobic remineralisation of sinking detritus
- Zooplankton respiration (reduced at hypoxic conditions)
- Nitrification

Biological and physical processes contribute to the variability in oxygen

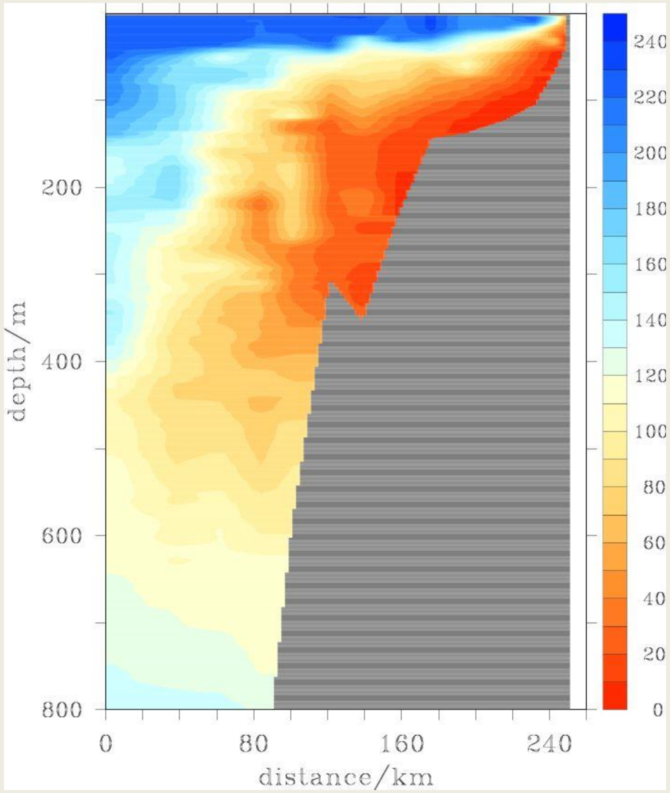
Extended Oxygen Minimum Zones

Model results



23° S in March 2003

CTD data: MSM 57-3



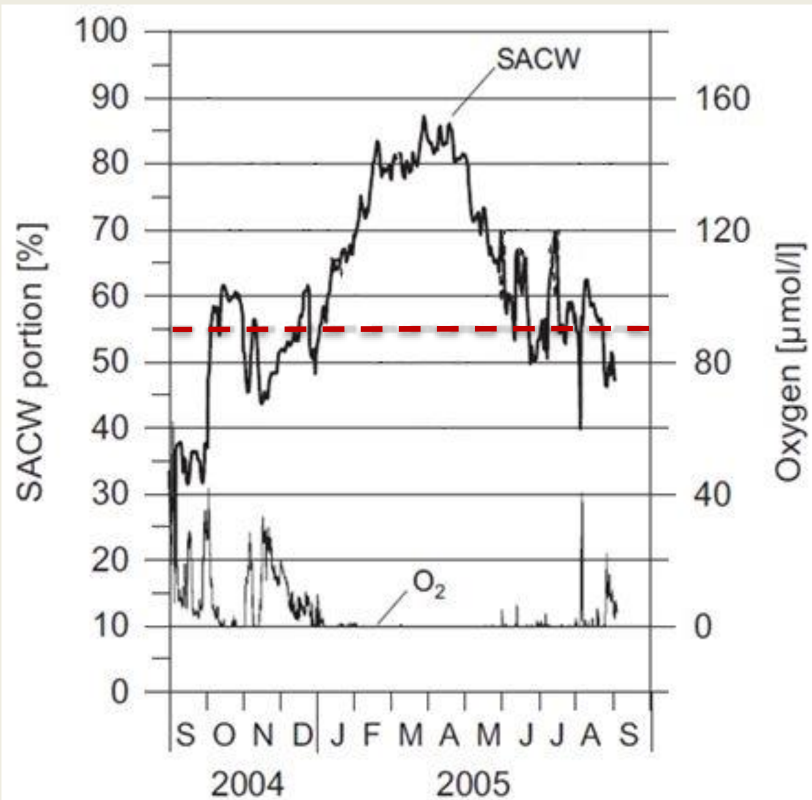
Oxygen concentration [μmol/kg]

- Hypoxic zone stretches in the near bottom water

Low ventilation of the near bottom water

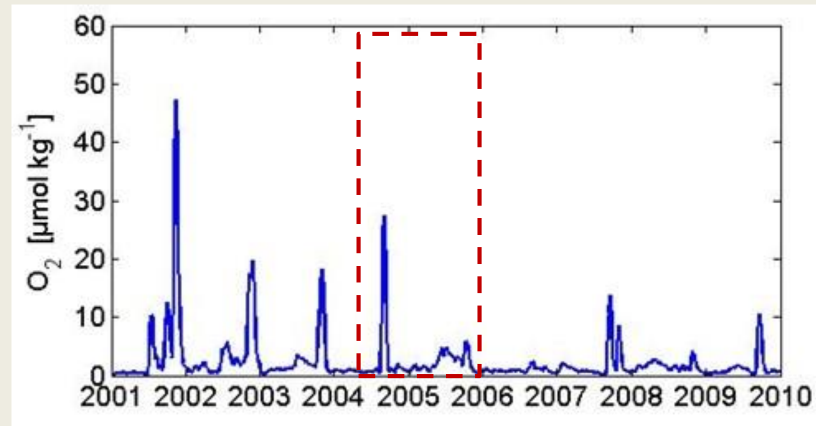
Oxygen time series from mooring off Walvis Bay

Field data, mooring: 120 m



Mohrholz, Bartholomae, van der Plas & Lass 2008

Model results: 120 m

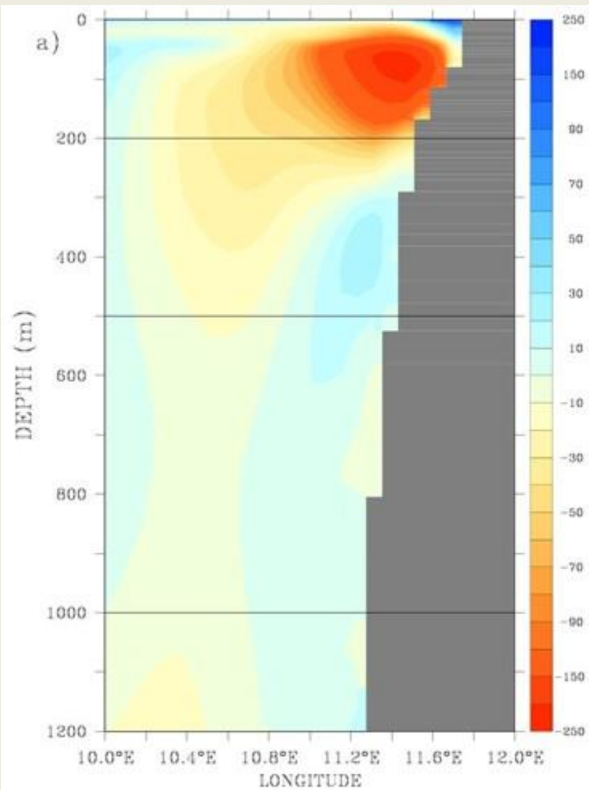


- Good simultion of hypoxic near bottom water (120 m) on the shelf
- Anoxic conditions correlate with an SACW fraction >55%

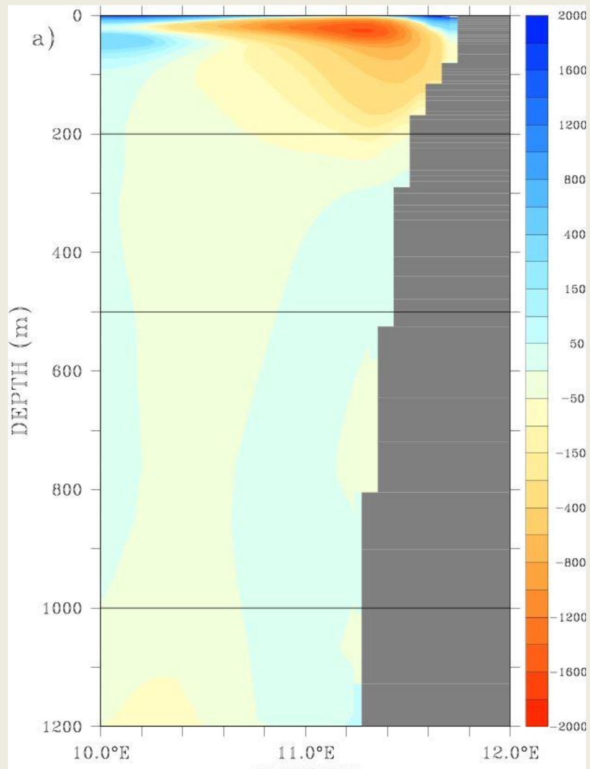
$[O_2]$ over the shelf depends to a high extent on the water mass composition

Fingerprint of the PUC

Nitrate transport



Oxygen transport



Transport

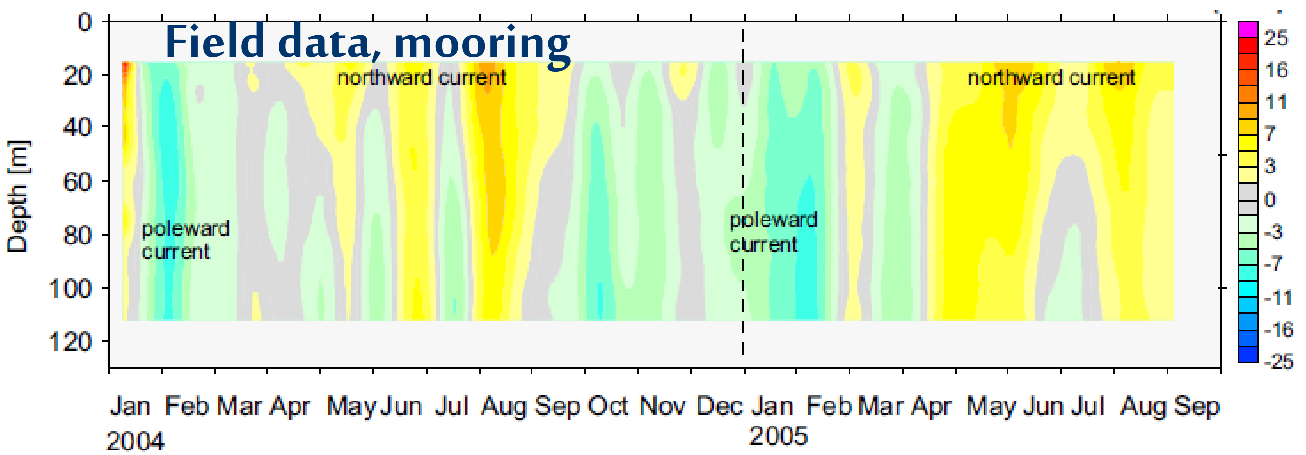
[mol/m2/d]

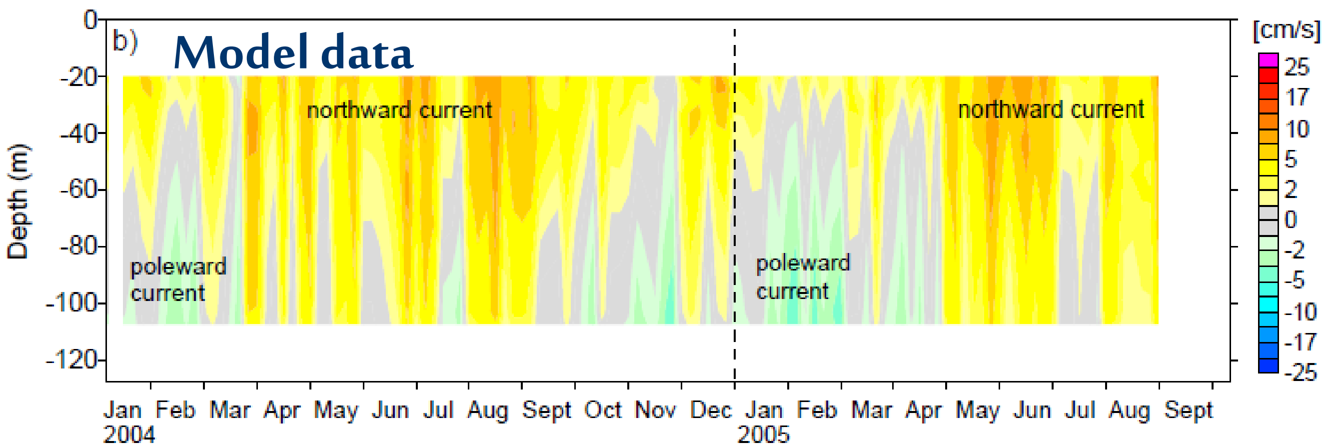
- PUC is a subsurface current (60-200 m)

18° S, average of 2004

Physical advection of nutrient-rich and oxygen-poor water

Meridional current data time-series



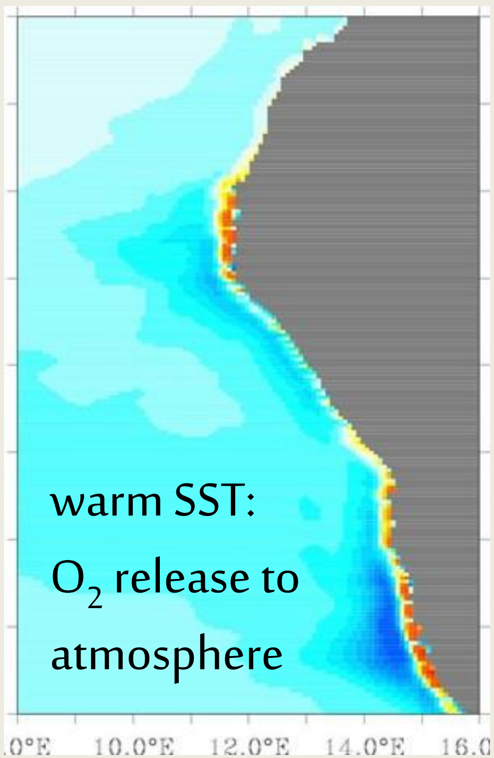


PhD thesis Muller 2012

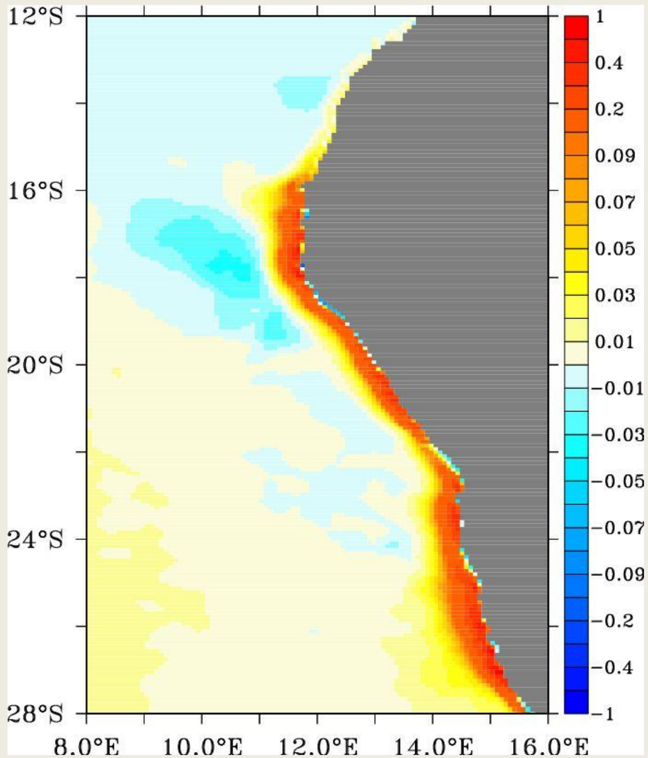
Strong seasonality of the PUC: high in summer

Air-sea oxygen flux

January$_{clim}$



August$_{clim}$



[mol/m2/d]

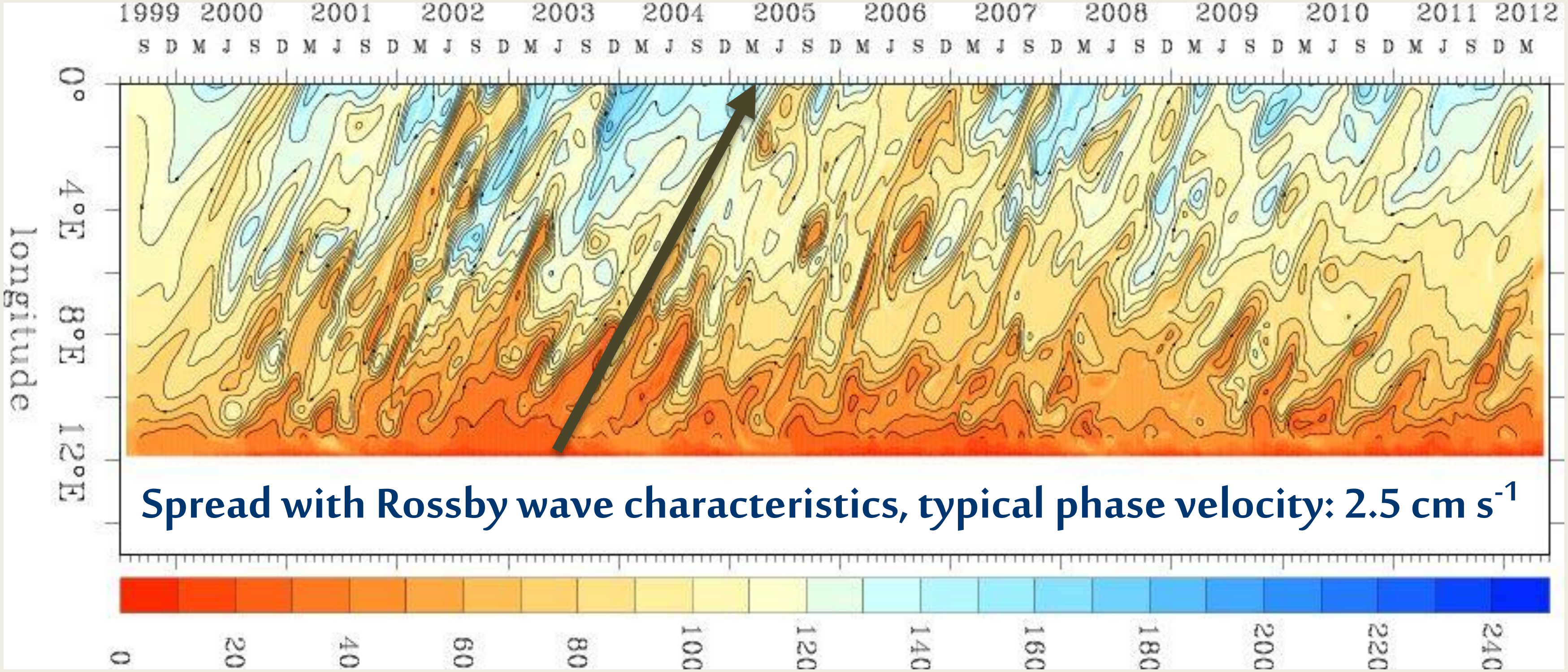
\+ flux towards ocean

- Offshore: seasonal differences driven by SST variation
- Shelf: upwelling of cold water with low oxygen

\- flux towards atmosphere

Shelf: upwelling of cold water with low oxygen

Offshore transport of low-oxygen water

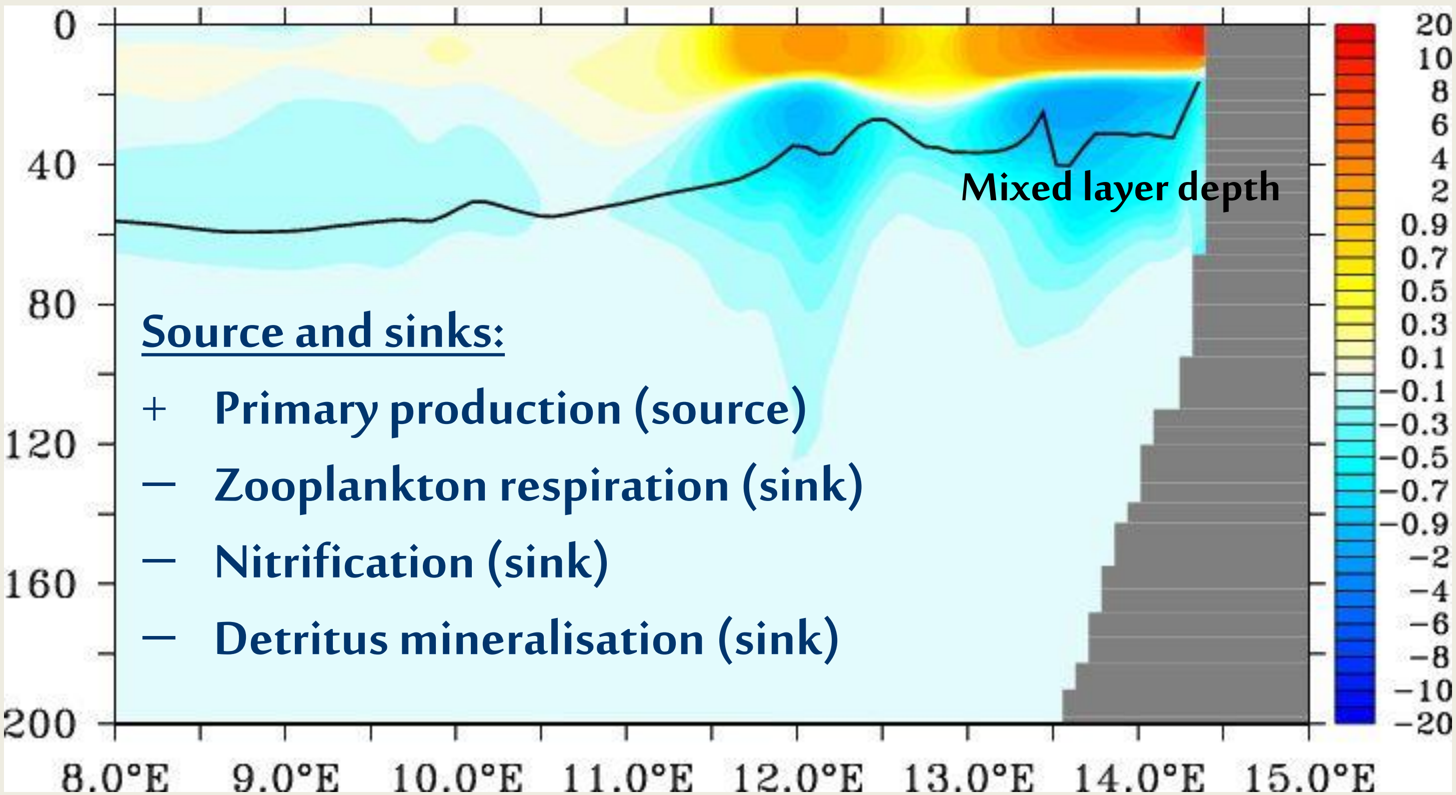


20° S, 400 m

Oxygen concentration [μmol/kg]

Offshore advection of hypoxic water in mesoscale filaments below the thermocline

The biological oxygen budget in the water column

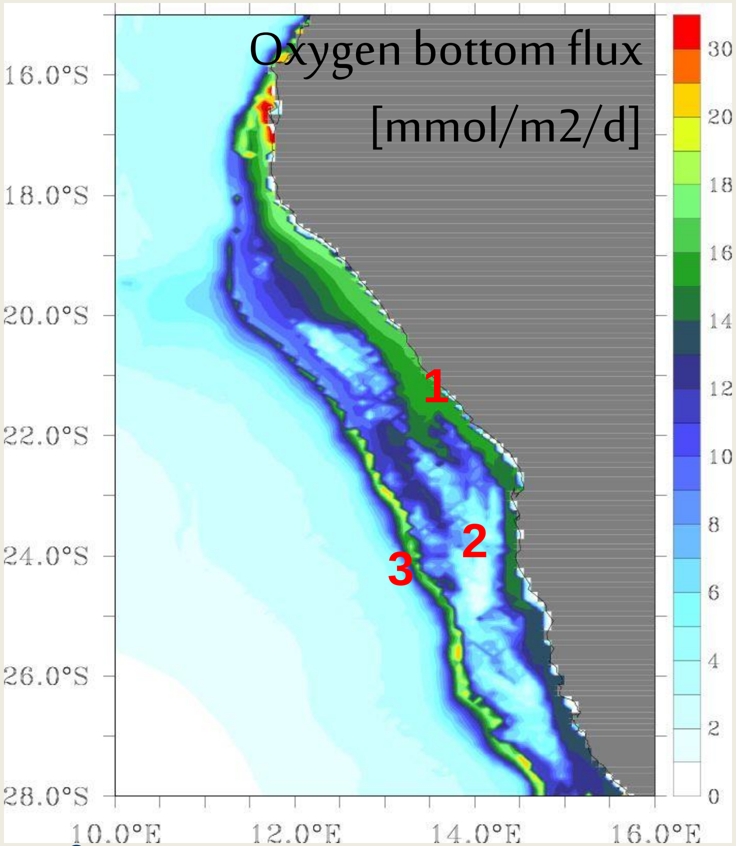


Oxygen net rates [mmol/m3/d]

23° S, July 2004

Biological oxygen consumption most intense below euphotic zone

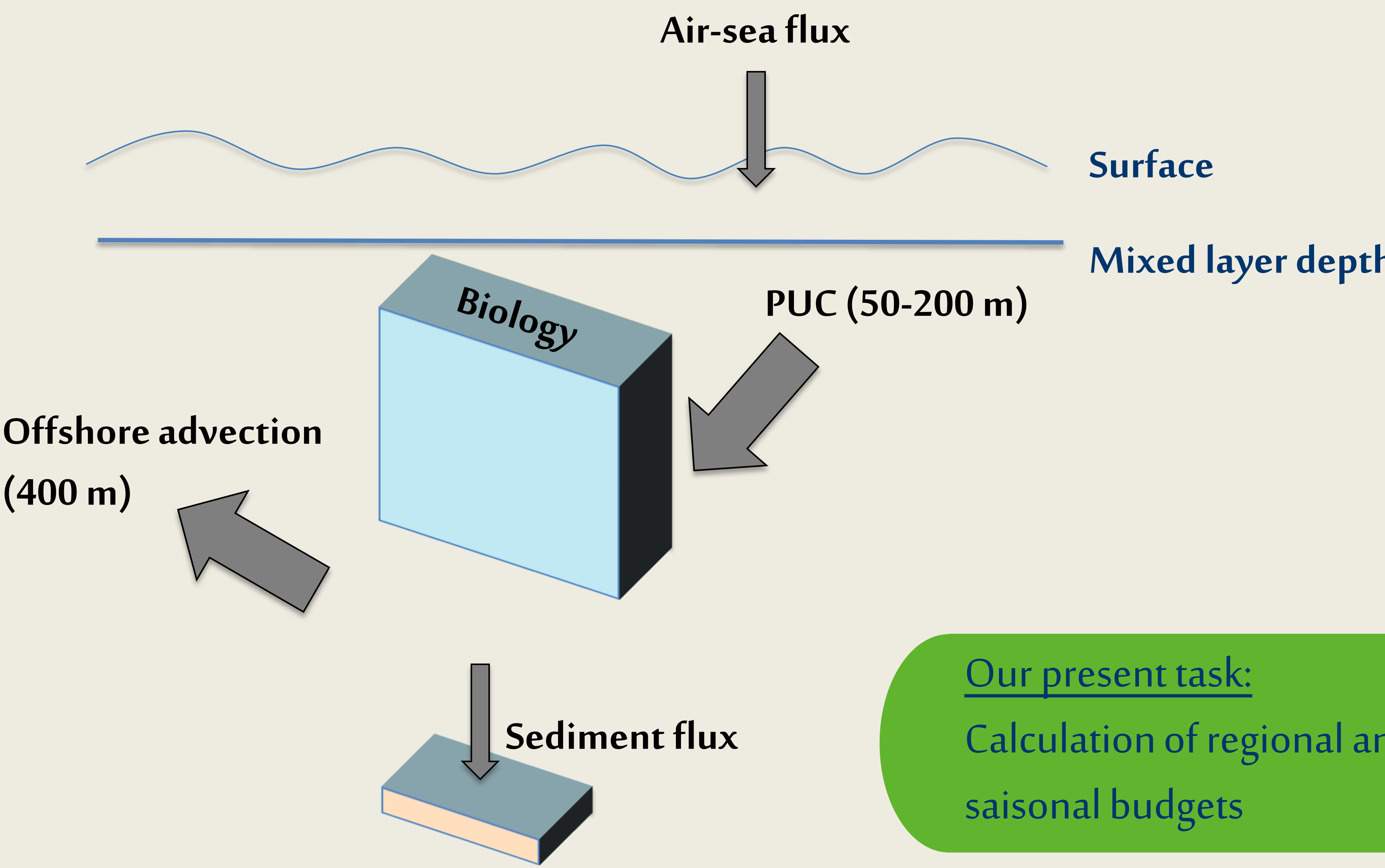
Oxygen bottom flux into the sediment



23° S, January 2004

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

Summary



<u>Our present task:</u>

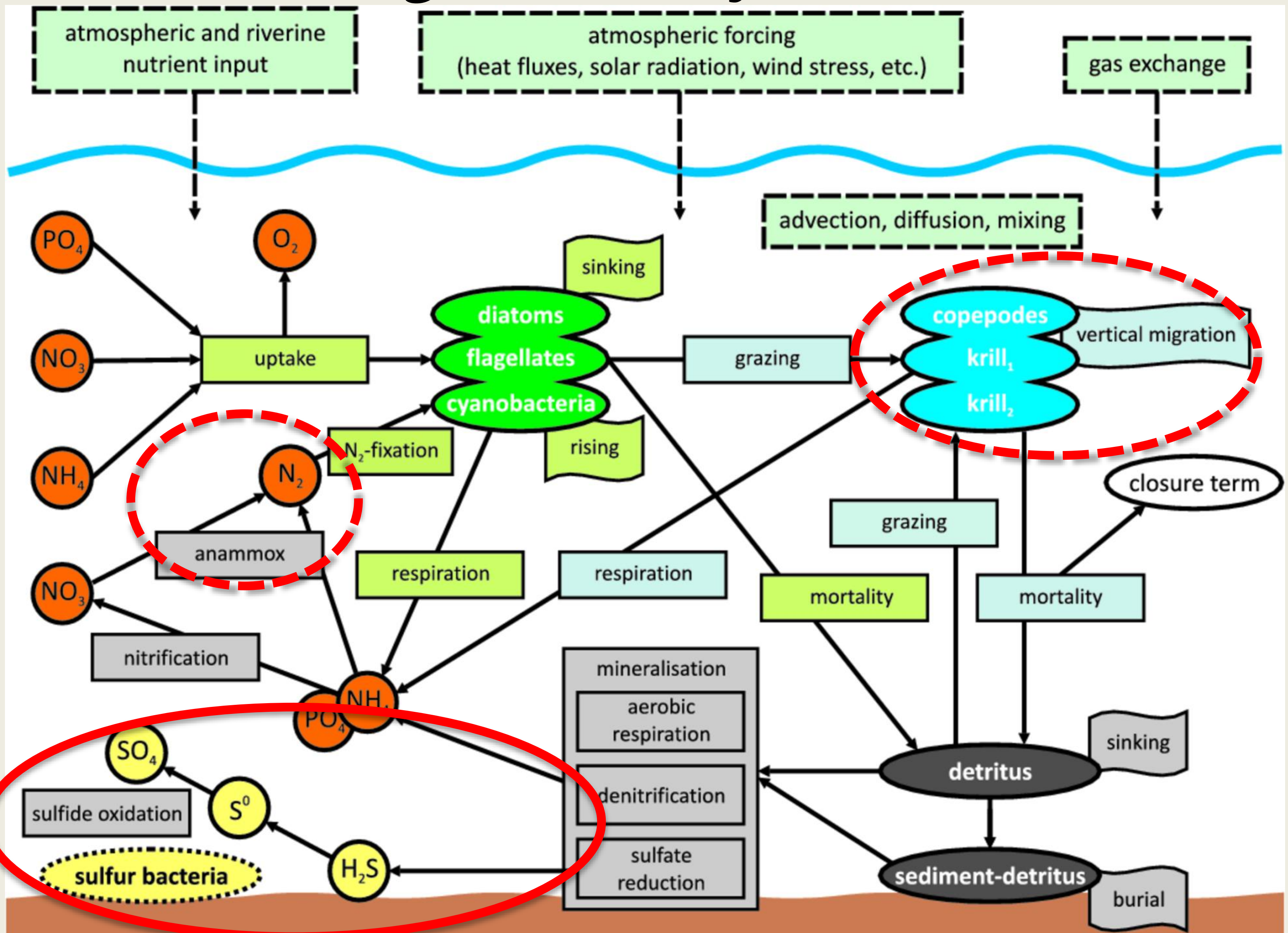
Calculation of regional and saisonal budgets

Our model of moderate complexity is able to simulate the oxygen conditions and its variability on the Namibian shelf.

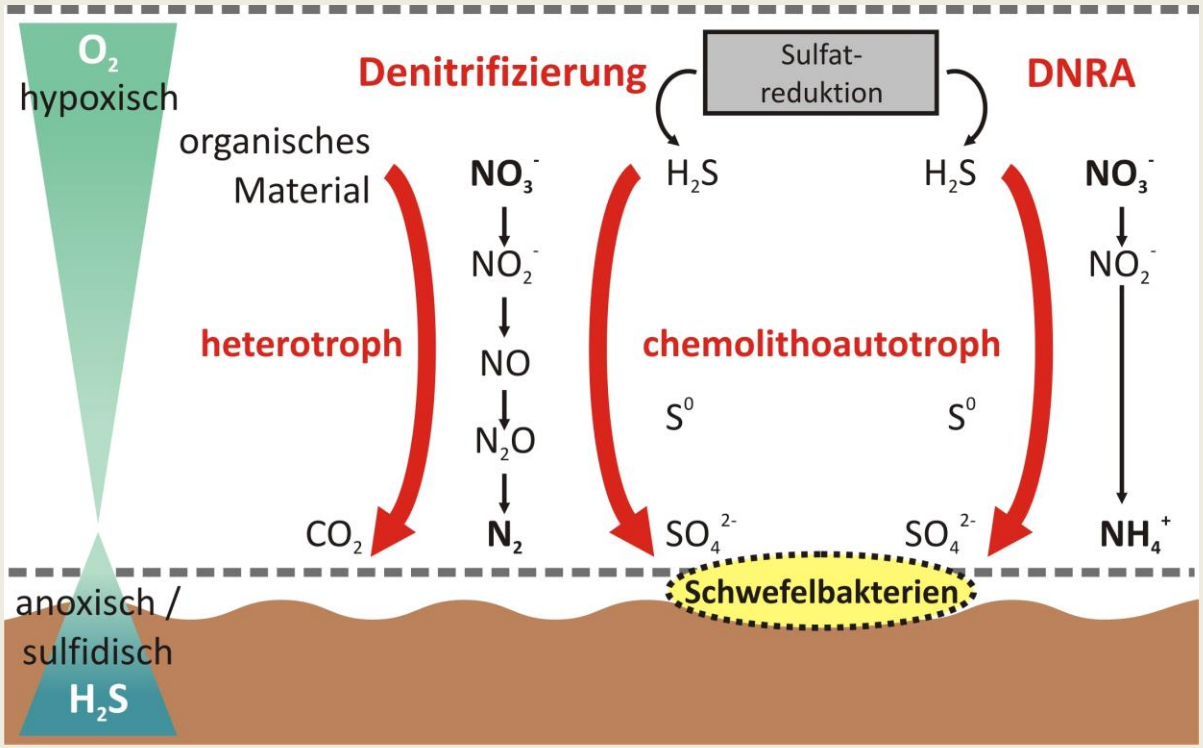
RV Mirabilis
23° S - Monitoring
May 2013

Thank you very much for your attention !

The Benguela ecosystem model



Modeled processes at the (sediment) redoxcline



DNRA-dissimilatory nitrate reduction to ammonium

- Chemolithoautotrophic oxidation of H_2S or S^0 with O_2 or NO_3^-
- NO_3^- reduced to
  - N_2 (denitrification)

  or

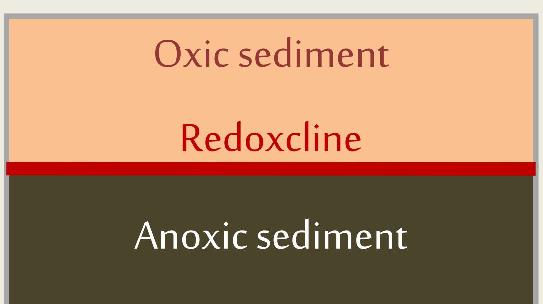
  - NH_4^+ (DNRA)
- NH_4^+ is biologically available, while N_2 is yy from the system !

Coupled sulfur- and nitrogen cycle

Coupled sediment model

‚thin' sediments

- Redoxcline within the sediment
- low H_2S –availability
- Mats of sulfur bacteria DO NOT develop



‚thick' sediments

- Redoxcline at the sediment surface or within the water column
- high H_2S-availability
- Mats of sulfur bacteria develop