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

Geochemistry and Ecology of the Namibian Upwelling System

Anja Eggert & Martin Schmidt

Leibniz Institute for Baltic Sea Research, Warnemünde (Germany)
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

Realistic atmospheric forcing

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

3D Hydrodynamic Model (GFDL, USA)

Modular Ocean Model (MOM-5)

3D Biogeochemical Model (IOW, Germany)

Nutrient-Phytoplankton-Zooplankton-Detritus
\((NP_2Z_2D)\)-Model

Sediment Model (IOW, Germany)

Mats of giant sulfur bacteria
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

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

Hydrodynamic transport

- Lateral advection
- Vertical advection

Biological sources and sinks

- 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

CTD data: MSM 57-3

Oxygen concentration [µmol/kg]

- Hypoxic zone stretches in the near bottom water

23° S in March 2003

Low ventilation of the near bottom water
Oxygen time series from mooring off Walvis Bay

Field data, mooring: 120 m

Model results: 120 m

- Good simulation 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

Mohrholz, Bartholomae, van der Plas & Lass 2008
Fingerprint of the PUC

In the diagram, the Nitrate transport and Oxygen transport are shown. The transport is measured as [mol/m²/d].

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

At 18° S, the average of 2004, there is physical advection of nutrient-rich and oxygen-poor water.
Meridional current data time-series

Strong seasonality of the PUC: high in summer

Field data, mooring

PhD thesis Muller 2012
Air-sea oxygen flux

**January\textsubscript{clim}**
- warm SST: O\textsubscript{2} release to atmosphere

**August\textsubscript{clim}**
- [mol/m\textsuperscript{2}/d]
  - flux towards ocean
  - Offshore: seasonal differences driven by SST variation
  - Shelf: upwelling of cold water with low oxygen

Shelf: upwelling of cold water with low oxygen
Offshore transport of low-oxygen water

Offshore advection of hypoxic water in mesoscale filaments below the thermocline

Spread with Rossby wave characteristics, typical phase velocity: 2.5 cm s\(^{-1}\)

20° S, 400 m

Oxygen concentration [µmol/kg]
The biological oxygen budget in the water column

Source and sinks:

+ Primary production (source)
- Zooplankton respiration (sink)
- Nitrification (sink)
- Detritus mineralisation (sink)

Oxygen net rates [mmol/m3/d]

Mixed layer depth

23° S, July 2004

Biological oxygen consumption most intense below euphotic zone
Oxygen bottom flux into the sediment

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

Spatial pattern of oxygen flux into the sediment
Summary

Our present task:
Calculation of regional and seasonal 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

- atmospheric and riverine nutrient input
- atmospheric forcing (heat fluxes, solar radiation, wind stress, etc.)
- gas exchange
- advection, diffusion, mixing
- copepodes
  - vertical migration
  - krill
    - grazing
    - mortality
  - krill
    - grazing
    - mortality
- closure term
- detritus
  - aerobic respiration
  - denitrification
  - sulfate reduction
- sediment-detritus
  - sinking
  - burial
- anammox
- nitrification
- respiration
- mineralisation
- sulfide oxidation
- sulfur bacteria
Modeled processes at the (sediment) redoxcline

- Chemolithoautotrophic oxidation of $H_2S$ or $S^0$ with $O_2$ or $NO_3^-$
- $NO_3^-$ reduced to
  - $N_2$ (denitrification)
  - $NH_4^+$ (DNRA)
- $NH_4^+$ is biologically available, while $N_2$ is yy from the system!
**Coupled sediment model**

**′thin′ sediments**
- Redoxcline within the sediment
- low $\text{H}_2\text{S}$ –availability
- Mats of sulfur bacteria DO NOT develop

**′thick′ sediments**
- Redoxcline at the sediment surface or within the water column
- high $\text{H}_2\text{S}$-availability
- Mats of sulfur bacteria develop

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**Ventilation of the bottom water**
- $\text{O}_2$, $\text{NO}_3$
- Redoxcline
- Sulfur bacteria

**No ventilation of the bottom water**
- $\text{Redoxcline}$
- $\text{H}_2\text{S}$
- Sulfur bacteria

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**Oxic sediment**
- Redoxcline

**Anoxic sediment**
- Sulfate reduction
- buried
Summary

Air-sea flux

1 mol/m<sup>2</sup>/d

Surface

Mixed layer depth

Offshore advection

(400 m)

50 mol/m<sup>2</sup>/d

Biology

-20 mol/m<sup>3</sup>/d

PUC (50-200 m)

1000 mol/m<sup>2</sup>/d

Sediment flux

5-20 mol/m<sup>2</sup>/d