Nitrite dynamics and associated feedback processes in the Benguela oxygen minimum zone

Modelling approach

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Introduction

NO_2^- is produced during NO_3^- assimilation, nitrification and denitrification. NO_2^- is the shortest lived among the N_2 species as it represents an intermediary species. The colorimetric method used to measure NO_2^- involves NO_3^- reduction. In some oceanic regions additional low level methods are required to measure NO_2^- concentrations as they occur below detection limits. In OMZs, NO_2^- is further reduced to N_2O, a greenhouse gas with a global warming potential of about 265–310 times higher than that of CO_2 [1]. This prevents NO_2^- accumulation and results in N_2 loss. In addition, NO_2^- in the Benguela OMZ is consumed during anammox. These mentioned factors combined with shortage of in–situ data make it difficult to understand nitrite dynamics. The Biogeochemical model for Eastern Boundary Upwelling Systems (BioEBUS) [2] is applied in the Benguela OMZ to understand NO_2^- dynamics and associated feedback processes.

Coupled physical–biogeochemical model

A coupled ROMS–BioEBUS nested configuration of the Southern African Experiment (SAfE) developed and validated by [4] and [5] is used in this study. Datasets used in the model:

- **Bathymetry:** 1′ gridded GEBCO (www.gebco.net).
- **Wind stress:** 1/2° QuickSCAT climatology (2000 to 2007).
- **Fluxes:** 1/2° COADS monthly heat and freshwater fluxes.
- **SST:** Pathfinder SST.
- **Initial and open boundary:** From 10th year of SAfE.
- **Biogeochemical:** O_2 and NO_3^- from CARS 2009.

The simulation was ran for 16 years and a stable output (from year 12–16) is used in this study. Comparisons between CARS and model data show that the model was able to capture the spatial variability of NO_3^- in the Benguela. NO_2^- concentrations were underestimated but within range as compared to previous studies and available data. Additionally, a 10 year diagnostics run was performed to obtain fluxes.

Results and discussion

Simulated NO_2^- concentrations in the ABF region and off Walvis Bay exhibit a two–peak profile (Fig. 1a–b). High concentrations occur in the euphotic zone (0–50 m – primary maxima) and at depth (below 100 m – secondary maxima).

- Primary NO_2^- maxima in both regions occur in well–oxygenated [> 60 mmol O_2 m^{-3}] waters.
- These maxima peak in association with the nitracline (increase in NO_3^- concentrations in the water column).
- Secondary NO_2^- maxima occur within the pronounced OMZ at 100–400 m in the ABF (Fig 1a).
- The secondary NO_2^- concentrations off Walvis Bay are depleted and located on the shelf slope (Fig 1b).

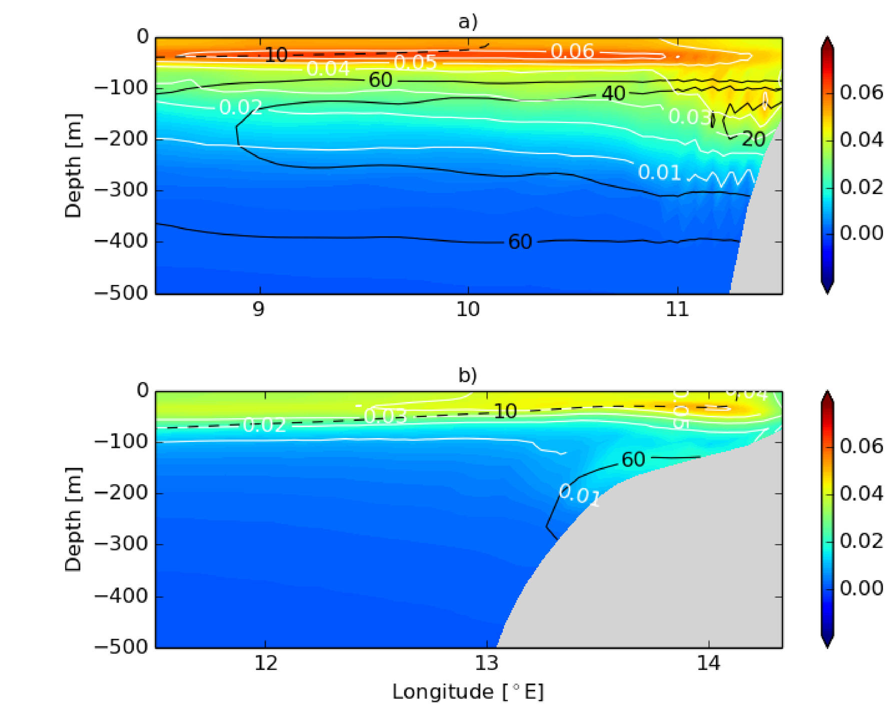

Figure 1: NO_2^- distribution in the (a) ABF and (b) Walvis Bay shelf waters. Black and white contours represent O_2 [mmol O_2 m^{-3}] and NO_2^- [mmol N m^{-3}], respectively. The dashed line represent the nitracline [mmol N m^{-3}]. Cross–shelf sections were averaged between 16–18°S and 22–24°S for the ABF and off Walvis Bay, respectively.

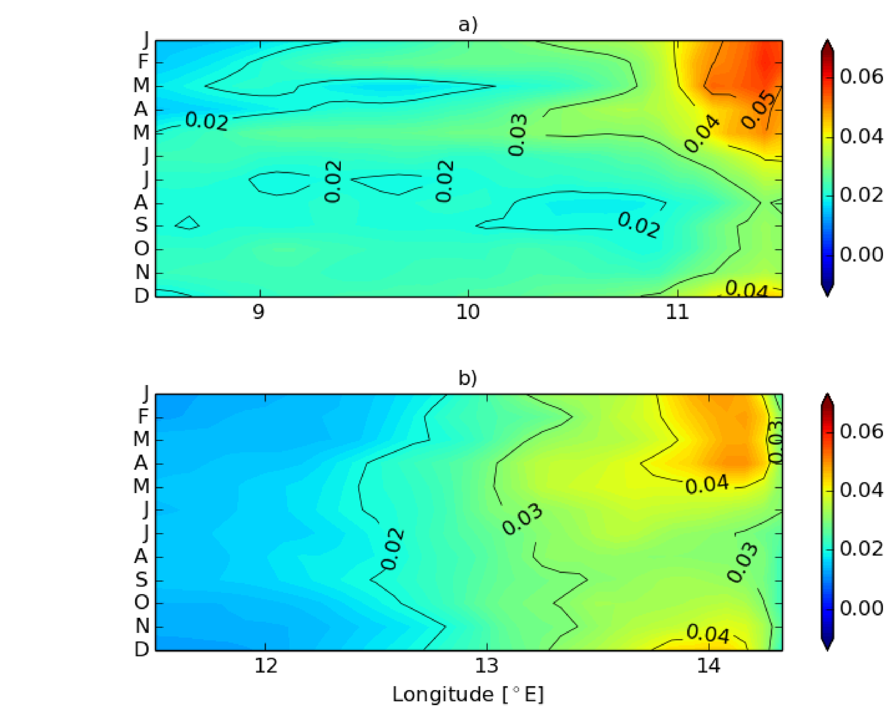

Figure 2: Hovmöller diagrams of depth–intergrated NO_2^- [mmol N m^{-2}] in the (a) ABF and (b) Walvis Bay. Sections were extracted and averaged between 16–18°S and 22–24°S for ABF and off Walvis Bay, respectively.

The primary maxima are attributed to nitrification and NO_3^- assimilation. Secondary NO_2^- maxima in both regions are attributed to denitrification. The depleted NO_2^- concentrations off Walvis bay are consumed by anammox.

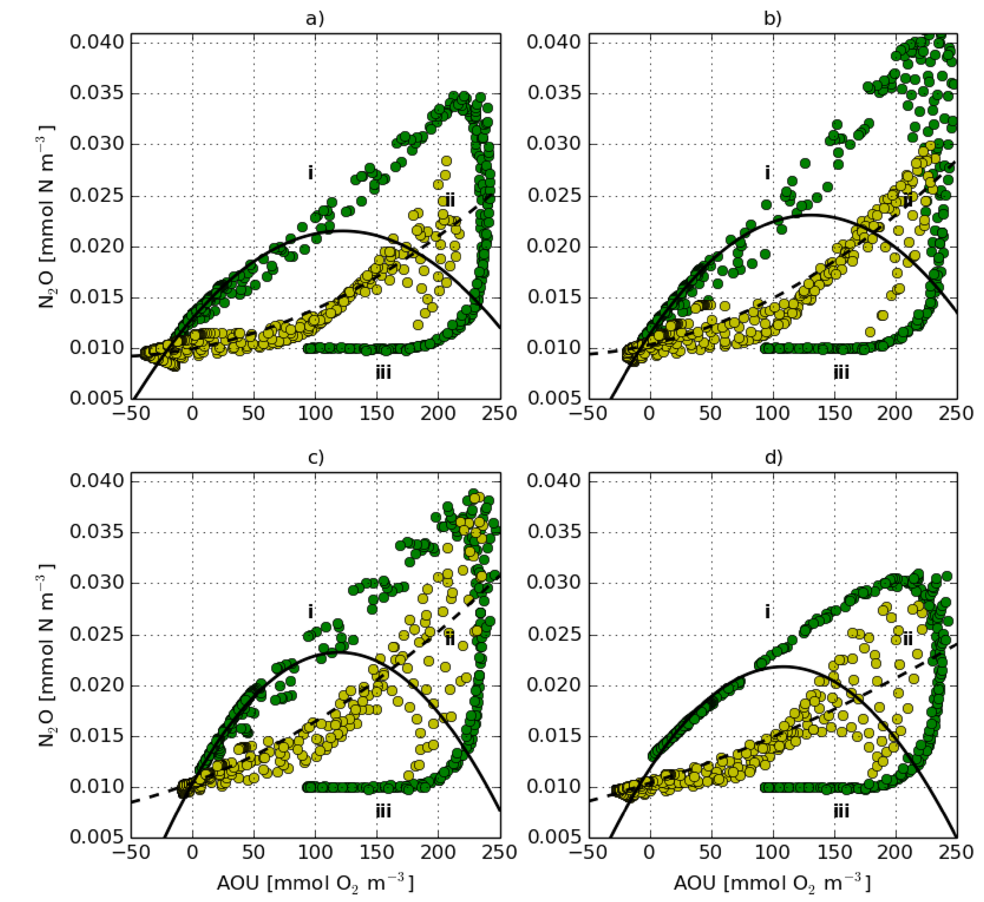

Figure 3: Scatter plots of AOU [mmol N m^{-3}] versus N_2O [mmol N m^{-3}] in the ABF (green) and off Walvis Bay (yellow) during (a) summer, (b) autumn, (c) winter and (d) spring. Solid and dashed lines represent polynomial fits of AOU in the ABF and off Walvis Bay, respectively. Water masses depths are denoted by (i) 0–100 m, (ii) 100–500 m and (iii) 500–1000 m.

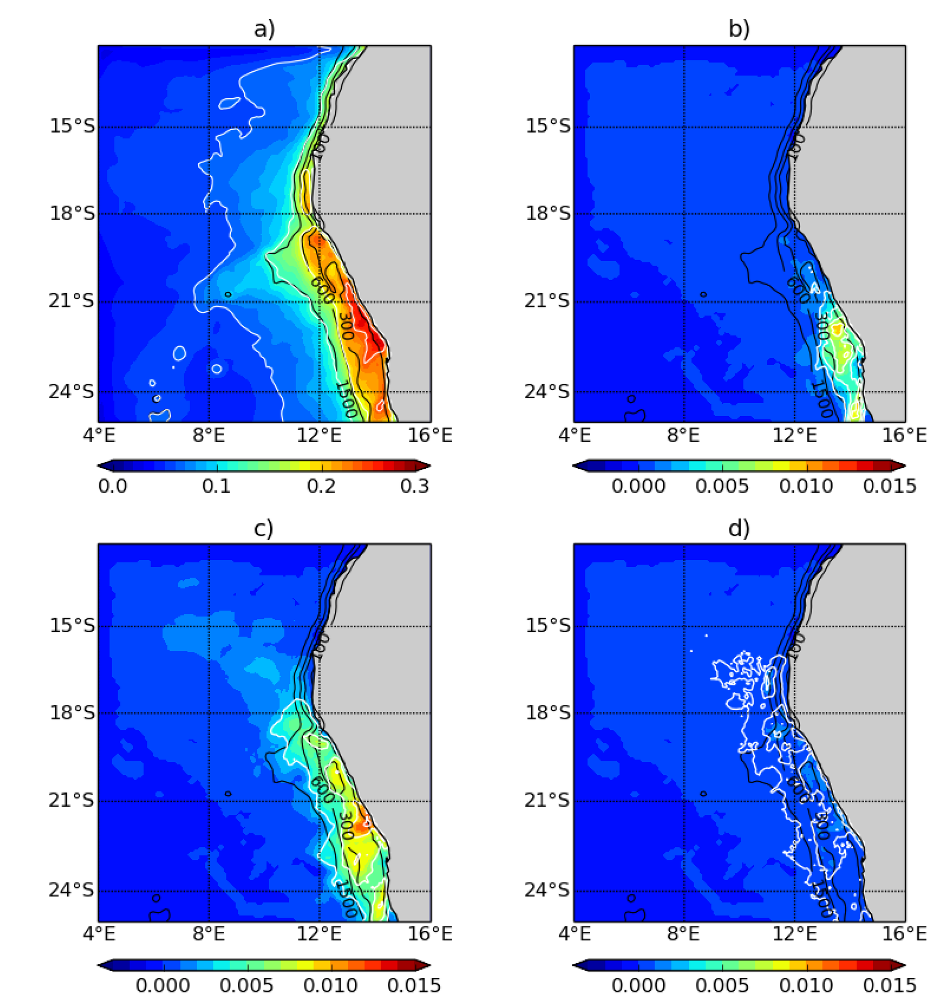

Figure 4: Depth–integrated N fluxes [mmol N m^{-2} d^{-1}] in the Benguela due to (a) nitrification (b) anammox (c) denitrification (detritus) and (d) denitrification (DON). Black contours represent water depths at 100, 300, 600 and 1500 m.

Evolution of simulated NO_2^- formed on the continental shelf is presented through Hovmöller diagrams (figure 2a–b).

1. Depth–integrated NO_2^- concentrations in the ABF and Walvis Bay occur throughout the annual cycle.
2. NO_2^- in the ABF is advected offshore throughout the annual cycle with the strongest advection observed during late autumn (May).
3. Off Walvis Bay, the NO_2^- maxima develop on and are restricted to the shelf.

Advection of NO_2^- in the ABF coincides with the increased wind stress conditions during autumn. Both NO_2^- peaks in these regions occur during summer when the poleward SACW dominate the Benguela. The stepwise reduction of NO_2^- in the Benguela lead to production of N_2O. Scatter plots of AOU versus N_2O reveal three distinct water masses associated with N_2O production in the ABF region (Fig 3.a–d). In contrast, two water masses are identified off Walvis Bay. N_2o production in both regions is predominantly through nitrification. Significant N_2O production through denitrification is observed in the OMZ core of the ABF region.

Conclusions

NO_2^- in the OMZ off Walvis Bay is consumed during anammox as reported in literature [3]. In the ABF region NO_2^- accumulate in the OMZ core. N_2O production in the Benguela is predominantly through nitrification with denitrification contributing significantly in the ABF. N_2 in the OMZ is predominantly lost through denitrification (Fig 4b–c).

Acknowledgements

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References

[1] EPA. Inventory of US greenhouse gas emissions and sinks: 1990-2013. Technical report, EPA 430-R-15-004, 2015.

[2] E Gutknecht, I Dadou, P Marchesiello, G Cambon, B Le Vu, J Sudre, V Garçon, E Machu, T Rixen, A Kock, et al. Nitrogen transfers off Walvis Bay: a 3-D coupled physical/biogeochemical modeling approach in the Namibian upwelling system. *Biogeosciences*, 10:4117–4135, 2013.

[3] M Kuypers, G Lavik, D Woebken, M Schmid, B Fuchs, R Amann, B Jørgensen, and M Jetten. Massive nitrogen loss from the Benguela upwelling system through anaerobic ammonium oxidation. *Proceedings of the National Academy of Sciences of the United States of America*, 102(18):6478–6483, 2005.

[4] P Penven, JRE Lutjeharms, and P Florenchie. Madagascar: A pacemaker for the Agulhas Current system? *Geophysical Research Letters*, 33(17), 2006.

[5] J Veitch, P Penven, and F Shillington. The Benguela: A laboratory for comparative modeling studies. *Progress in Oceanography*, 83(1):296–302, 2009.