Modeling biogechemistry response off the Northern Humboldt Current System (NHCS) during ENSO events

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1 Abstract

The response of the biogeochemistry, to intense ENSO events in the Northern Humboldt Current System is assessed with eddy-resolving numerical simulation of a coupled physical-biogeochemical model. El Niño (EN) 1997-1998 and La Niña (LN) 1999-2000 are well reproduced, leading to larger changes on the spatial distribution and intensity of the biogeochemical tracers at three different important upwelling coastal centers along Peruvian coast (Chimbote 9.4°S, Callao 12.1°S, and Pisco 14°S). The contribution of anaerobic ammonium oxidation (anammox) against denitrification on the removal of nitrogen and the outgassing of nitrous oxide during ENSO events. It was found that all of these processes are modulated by the oxygen distribution in the environment due to the spatiotemporal variability of the Oxygen Minimum Zone (OMZ) through El Niño (ventilation phase) and the opposite La Niña phase.

2 Introduction

Eastern Boundary Upwelling Systems (EBUS) are the most productive regions of the world's oceans. The Humboldt EBUS is located at the Eastern Tropical Pacific (ETP) along the coast of Peru and Chile being responsible for more than 20% of the worldwide marine fish catch. High biological activity along the Peruvian coast results from yearlong coastal upwelling due to the Trade Winds. This upwelling−favorable wind is intensified during austral winter, sustaining high levels of biological productivity, inducing high rates of aerobic remineralization (consumption of oxygen by decomposition of organic matter) permiting the development and maintenance of one of the major Oxygen Minimum Zones (OMZ), which in the last 50 years, has been expanding and intensifying, affecting the biodiversity and their distribution.

Important biogeochemical processes such as denitrification and anammox, associated with the microbial loop, take place within the OMZ (concentrations lower than 0.5 ml O_2 l^{-1}). These processes lead to an increasing loss of fixed oceanic nitrogen from the ocean, emitting nitrous oxide gas (N_2O) to the atmosphere, which is a well known greenhouse gas with a warming potential 300 times larger than CO_2. The global ocean contributes with 40% from the global emissions of N_2O with almost a half of this oceanic contribution is attributed to coastal upwellings regions.

3 Objectives

Assess how physical and biogeochemical processes are affected by large scale changes in the physical environment in coastal areas in the Northern Humboldt Current System (NHCS) at extreme ENSO events.

- Modelling the Peruvian Current System (PCS) with their Equatorial connections to reproduce extreme ENSO events: El Niño 1997-98 and La Niña 1999-2000.
- Analyze and quantify the spatial-temporal variability of nutrients and oxygen contents, as well as the main oxygen-dependent processes during ENSO events.

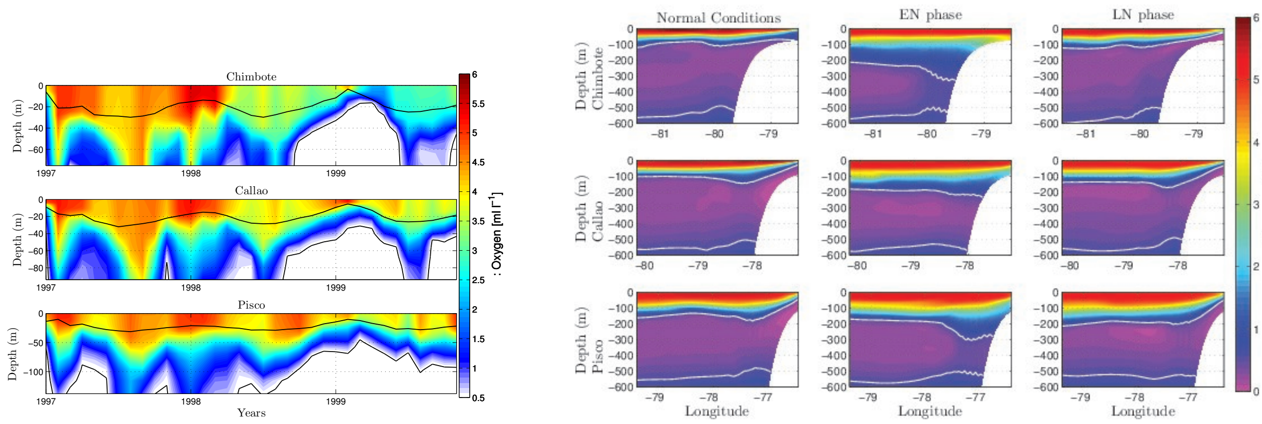
4 Methodology

We used the Regional Oceanic Modeling System (ROMS-AGRIF) (Shchepetkin and McWilliams, 2005) coupled with the nitrogen-based biogeochemical model especially developed for EBUS, called BioEBUS (Gutknecht et al., 2013). Biological model parameters are similar to the ones used in Montes et al. (2014) who fit the modeled oxygen and nitrate fields to the observations.The remaining values are kept as in the original version used in previous studies in other EBUS (Benguela).

The domain used in all numerical experiments in this study spans the region between 70°W to 90°W and from 5°N to 20°S with a horizontal resolution of 11 km. A neutral-ENSO simulation was ran for 10 years as a control simulation. Interannual simulations from 1995 thru 2000 were forced with NCEP-CFSR realistic winds and with SODA reanalysis product as the lateral forcings. We do not have a realistic interannual variability in our boundary conditions related with biological tracers, however by proceeding so, we might reproduce the physical impact on climatological biogeochemistry (forced with CARS 2009 database), and reproducing the biological response during ENSO events.

5 Results and Discussion

The OMZ experiences a sinking (on average 200m deeper than neutral phase) and a strong offshore displacement (on average 80 km offshore than neutral phase) during EN phase due to the intrusion of equatorial surface and subsurface ventilated waters. The nearshore part of the OMZ in the NHCS, is shallower shoreward and southward under neutral conditions, meanwhile during LN phase, the OMZ spans over the continental shelf deventilating the nearshore coastal band. Chimbote exhibits larger changes during ENSO events, due to the nearness of equatorial variability and due to the wider continental shelf, presenting high levels of oxygen concentrations during EN and in contrast, during LN, an outcropping of the top edge of the OMZ at the coast leads to depleted oxygen waters due to high rates of biological activity and enhanced upwelling process.



(a) Time-Depth diagram

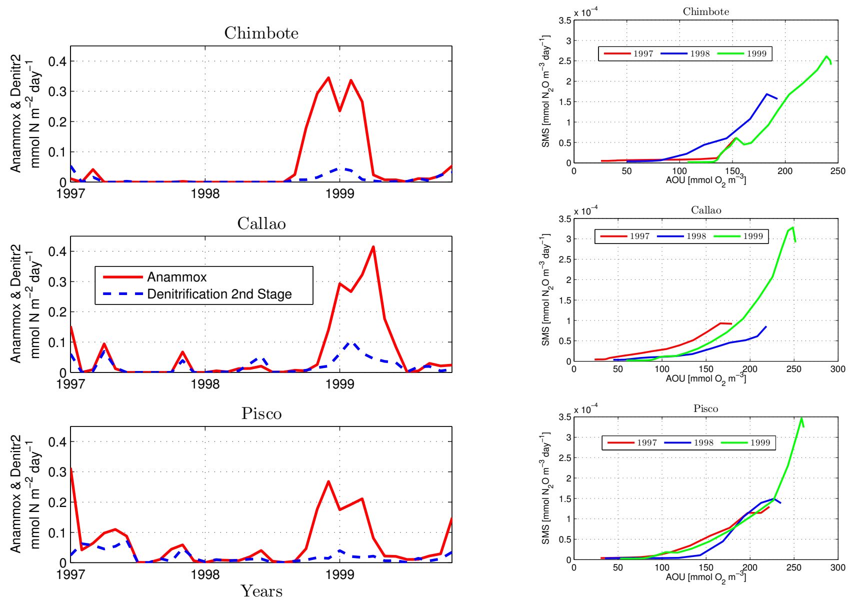
(b) Vertical sections (OMZ)

Figure 1: *spatiotemporal variability of oxygen contents.*

Within the OMZ, important suboxic processes, such anammox and denitrification, occur (See Figure 2). During neutral conditions, anammox is imposed on denitrification at Pisco contributing with about 70% of nitrogen removal, with also an important 30% at Callao, meanwhile at Chimbote denitrification is dominating the removal of nitrogen. During EN phase, anammox is suppressed, in contrast to LN phase, where Chimbote reachs 53%, Callao 50%, Pisco 47% of the percentual contribution of nitrogen removal against denitrification; implying that the cool ENSO phase enhanced anammox rates from Chimbote to Pisco decreasing southward. The nitrous oxide gas interchange flux at the sea−air interface was estimated and we concluded that EN phase leads to a constrainment of the greenhouse N_2O gas emission, which during LN phase becomes an intensified source with a horizontal expansion of the emmitting area, spanning over the equatorial band.

6 Conclusions

We could assess the main changes on biogeochemical processes in the NHCS and describe general responses for a better understanding of climatic variability and ENSO cycles. NHCS goes across a ventilation phase during EN, leading to a supression of suboxic processes.



(a) (b)

Figure 2: *(a) Anammox Vs Denitrification rates, (b) Source minus Sink terms of N_2O Vs AOU*

Denitrification activity takes place at the top edge of the OMZ in our simulations, decreasing in intensity southward where anammox appears to gain importance. These two processes are the two main pathways of nitrogen removal and are mostly controlled by the oxygen contents in the NHCS. We might also propose use the outgassing N_2O as a proxy of the nearness of OMZ at the peruvian coast and also as a new long term ENSO biogeochemical indicator, where strong decay of emissions might be related with the warm ENSO phase.

References

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