Nitrogen dynamics during the Cenomanian-Turonian oceanic Anoxic Event 2: A model study for the proto-North Atlantic

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1. Introduction

Evidence from sediment core records and model studies suggest that increased nutrient supply played a key role in the initiation of the Cenomanian-Turonian oceanic anoxic event 2 (OAE2; 94 Ma). However, the relative roles of nitrogen (N) and phosphorus (P) availability in controlling primary productivity during the event are not fully understood. Low nitrogen-isotope ratios of OAE2 sediments in the proto-North Atlantic suggest an important role for both N_2-fixation [1] and recycling of ammonium (NH_4^+) [2] in supplying N for primary producers.

2. Aim

1) Assess the effect of changes in ocean oxygen, P availability and circulation on N dynamics in the proto-North Atlantic during OAE2
2) Identify the spatial trends in denitrification and N_2-fixation
3) Compare the role of upwelling of NH_4^+ to N_2-fixation

3. Model

We expand an existing multi-box model of the coupled cycles of water (fig. 1) , P, carbon and oxygen in the proto-North Atlantic [3] with the marine N cycle. The model includes both the coastal and open ocean. All initial rates are defined for pre-OAE2 conditions. Key processes for N are:

1) N uptake for phytoplankton growth
2) Degradation of particulate organic N (PON)
3) Conversion of NH_4^+ to nitrate (nitrification)
4) Export and burial of PON
5) Denitrification (sediment and water column)
6) N_2-fixation

4. Numerical experiments

STANDARD (for OAE2):
- Enhanced P supply by weathering (0.03 Tmol y^{-1})
- P (1.4 Tmol y^{-1}) and oxygen input ([O_2]=10 µmol L^{-1}) from the Pacific Ocean
- Meridional ocean overturning of 12 Sv (70% the original)

Experiment 1: STANDARD + change in P input of Pacific bottom waters (from 0.6 to 1.9 Tmol y^{-1}).

Experiment 2: STANDARD + change in oxygen concentrations of Pacific bottom waters (from 0 to 200 µmol L^{-1}).

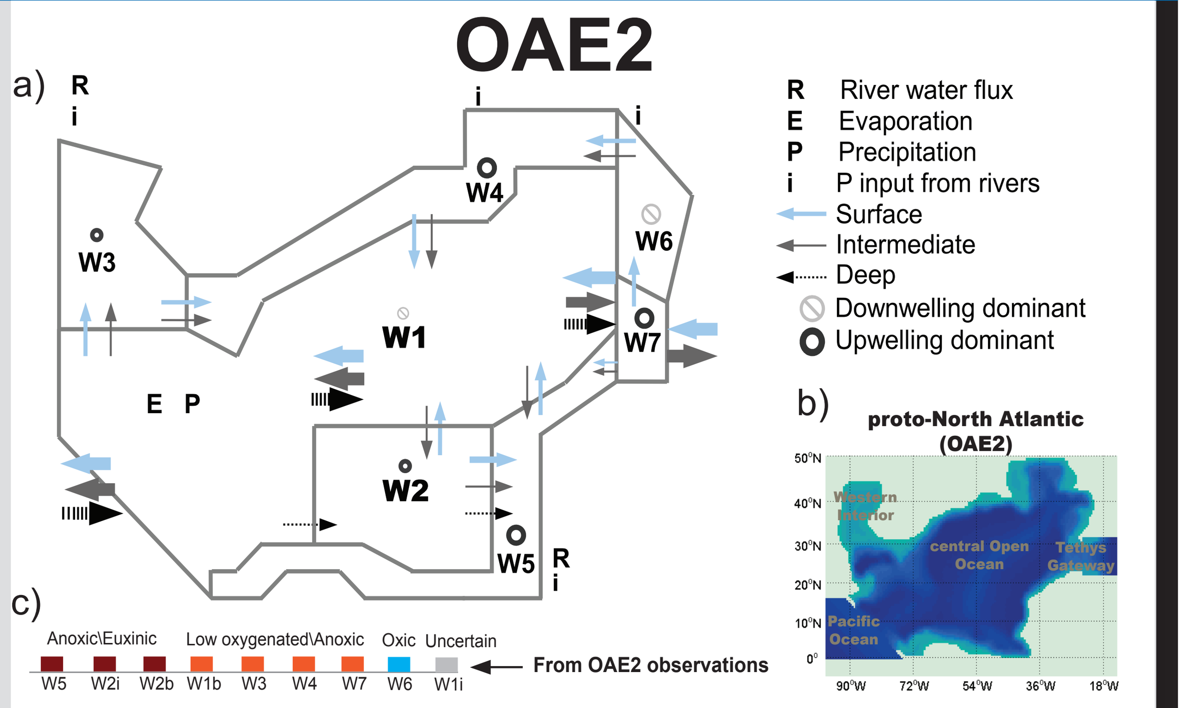
Experiment 3: STANDARD + change in ocean circulation (from 100 to 30% of the original model)

Fig. 1: Model configuration

a) Model water cycle during OAE2: The proto-North Atlantic is divided into 7 boxes based on the locations of upwelling/downwelling regions and bathymetric features [4].

b) Bathymetry of the proto-North Atlantic during OAE2 [4].

c) Simplified trend in oxygen as deduced from geological records and as captured by the original box-model (boxe index: i=intermediate, b=bottom).



5. Results and Discussion

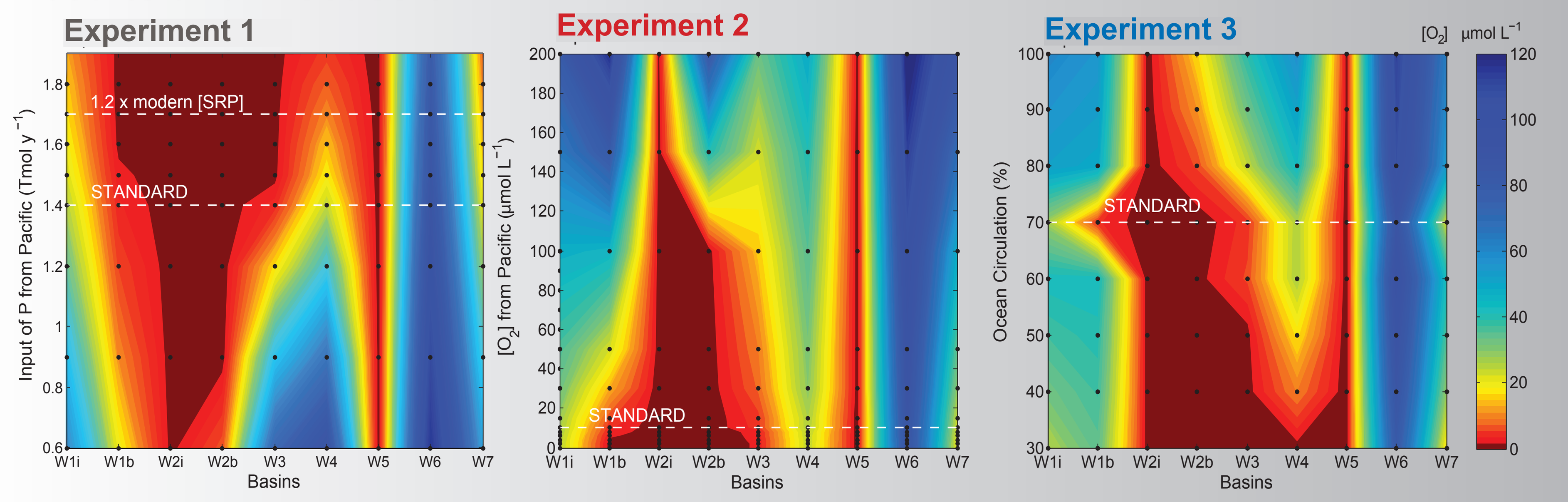


Fig. 2: Oxygen distribution

Oxygen concentrations in the proto-North Atlantic are higly sensitive to input of oxygen and P from the Pacific Ocean and to ocean circulation. **Anoxia in the central open bottom waters (W1b), as expected from observations, can be obtained only by further increasing the P supply (or reducing the oxygen concentrations) from the Pacific Ocean relative to the *STANDARD* run.**

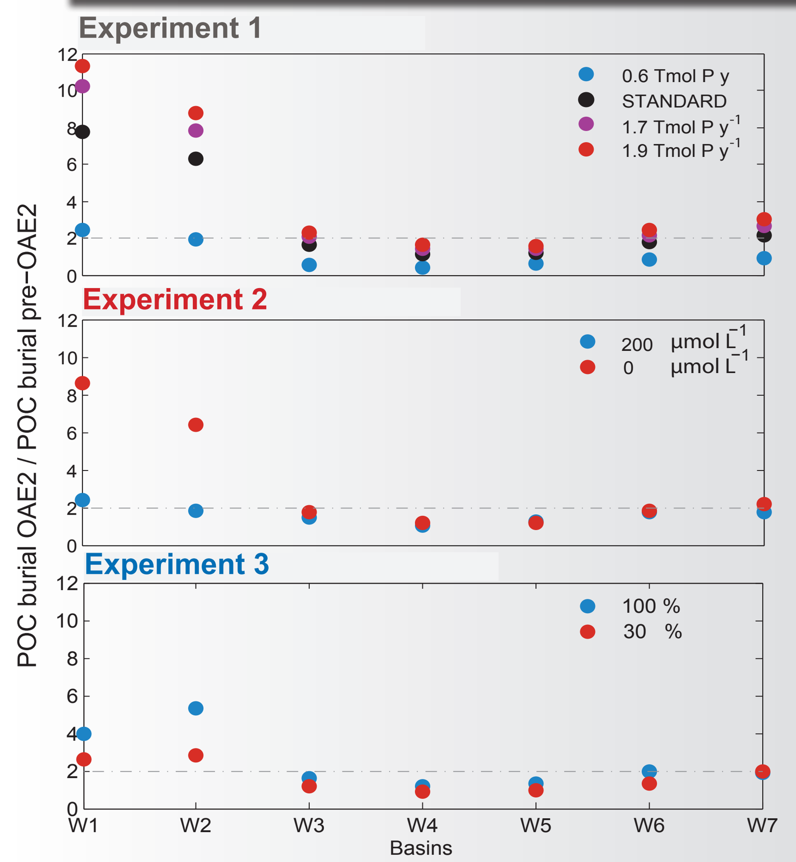


Fig. 3: Relative increase in burial of POC

The geological record suggests at least a doubling of particulate organic carbon (POC) burial from pre OAE2 to OAE2 conditions (dashed grey line) in the proto-North Atlantic. This can be somewhat reproduced in the *STANDARD* run. However, burial of POC is particularly sensitive to increases in P supply from the Pacific Ocean. An input of at least 1.7 Tmol P y^{-1} leads to a doubling of POC burial in all coastal basins. **This suggests that P supply was a major forcing for anoxia in the proto-North Atlantic during OAE2.** In our model, high burial of POC is possible because of high N_2-fixation rates which compensate for N-losses due to denitrification.

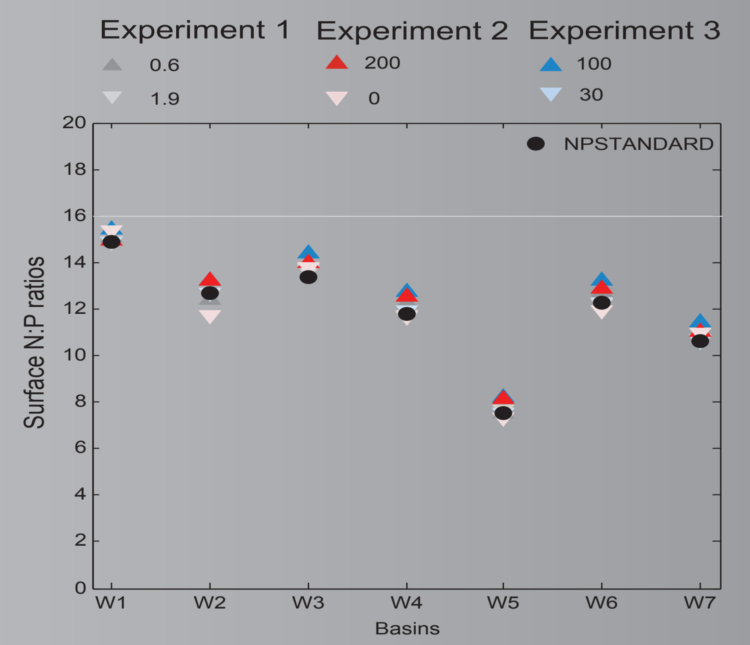


Fig. 4: N:P ratios in surface waters

While in pre-OAE2 conditions, all N:P ratios are close to Redfield (N:P=16:1; horizontal white line), in all experiments for OAE2, N:P ratios are lower than Redfield. **This makes N the limiting nutrient for primary productivity.** During OAE2, the ratios show a strong spatial variability due to local differences in transport, sources and sinks of nutrients. The lowest ratios are found in the southern coast (W5) where euxinia develops. Highest ratios are observed in the central open ocean (W1).

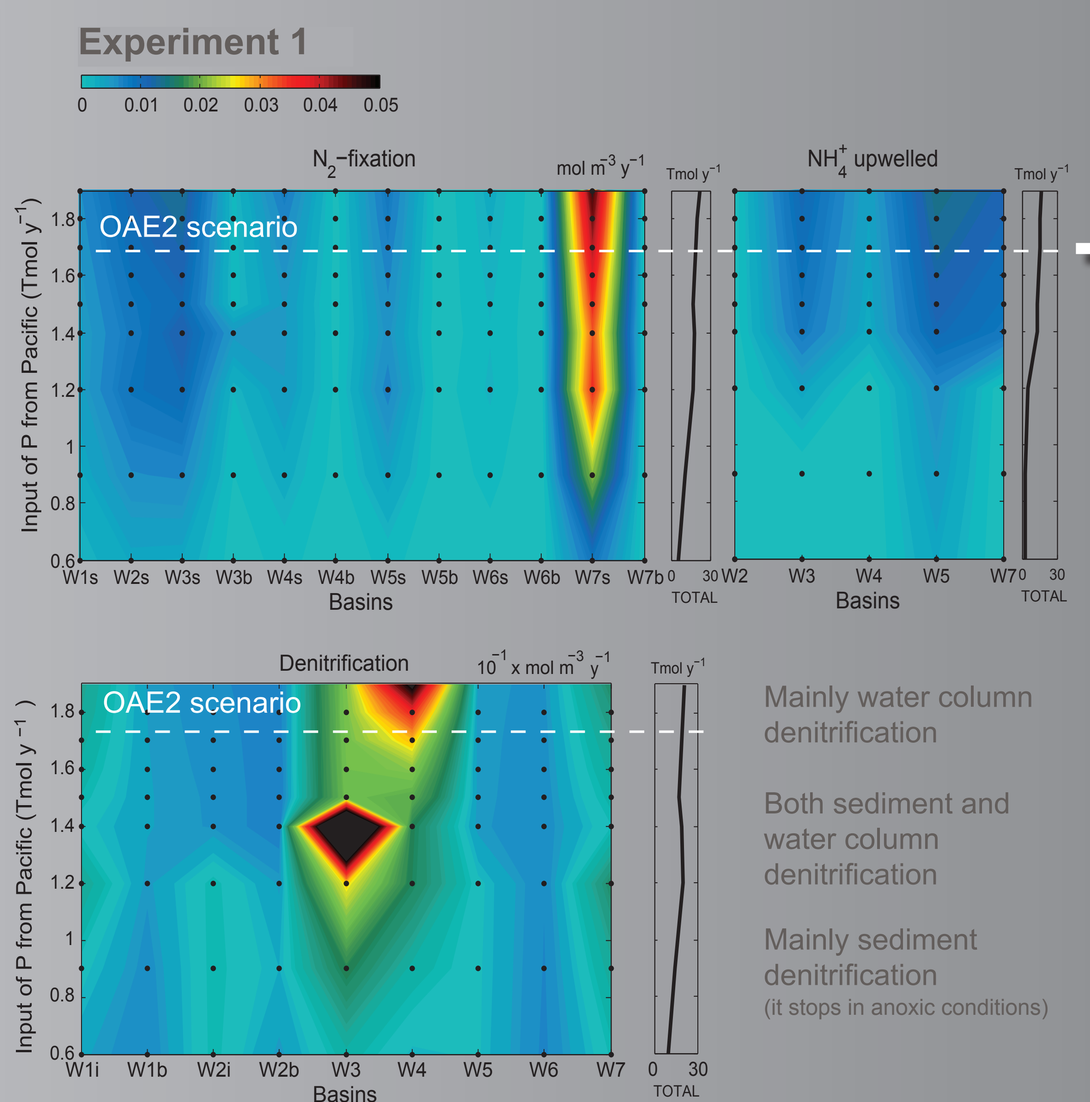


Fig. 5: N dynamics

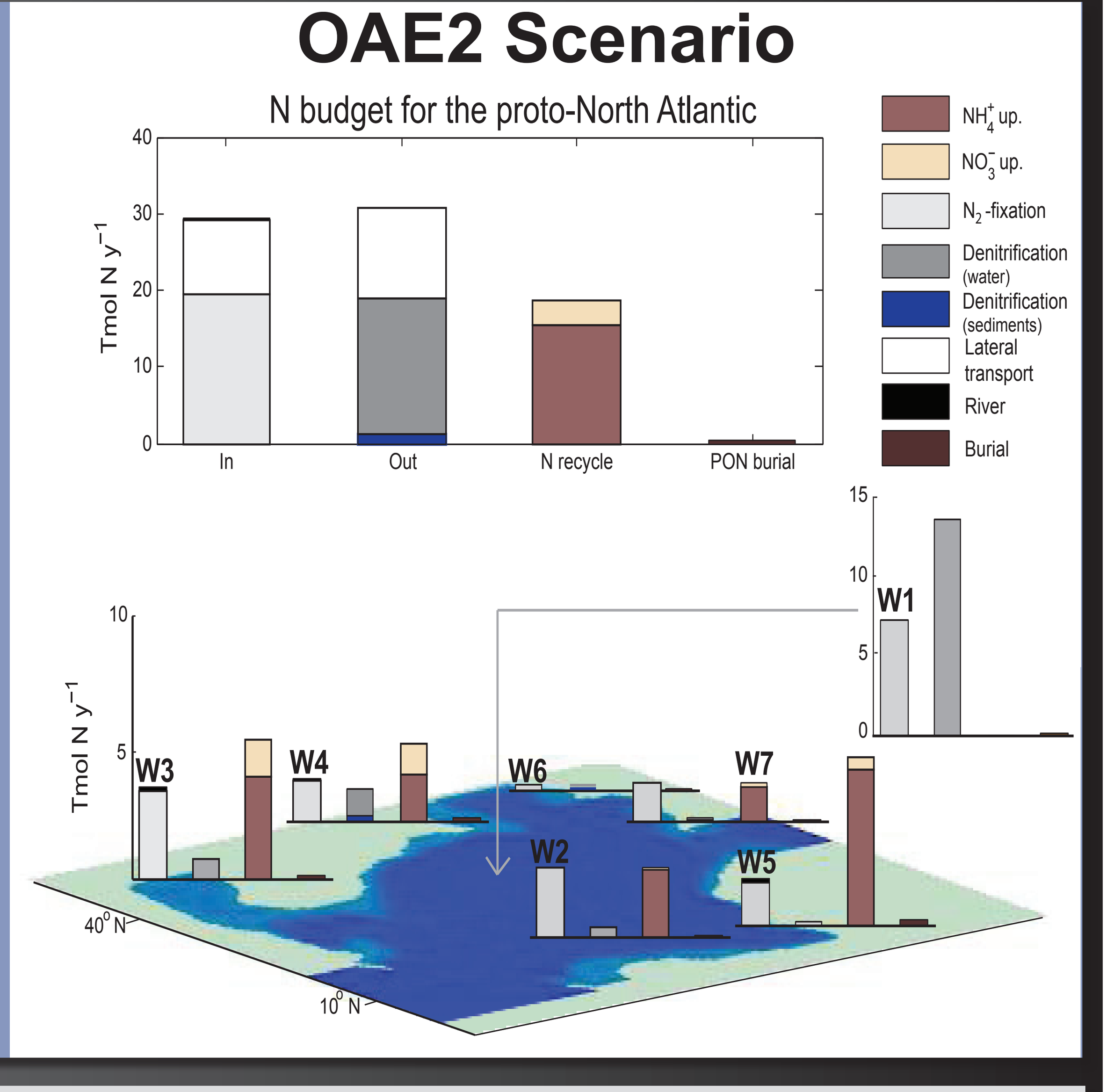
N dynamics are significantly affected by inputs of P and oxygen from the Pacific Ocean and by ocean circulation. The increase in P supply during OAE2 leads to a N-deficit that favours N_2-fixation (especially in W7s).

There is a strong relationship between anoxia, N_2-fixation, denitrification and upwelling of NH_4^+. **The strong regional variability in nutrient availability and oxygen concentrations in the proto-North Atlantic leads to large spatial differences in N dynamics.**

Fig. 6: OAE Scenario

During OAE2, **large P inputs enhanced** not only primary productivity, but also **N_2-fixation**. Total N_2-fixation in the proto-North Atlantic could have been as high as modern global rates (10-24 Tmol y^{-1}). **The N sources and sinks are similar in magnitude to upwelled NH_4^+. There is a strong spatial variability in N fluxes.**

While high N_2-fixation rates are widespread, denitrification rates are most important in the central open ocean (W1), the Western Interior (W3) and the northern coast (W4). NH_4^+ contributes to primary productivity mainly in upwelling regions and is highest in the southern proto-North Atlantic, where euxinia develops.



6. Conclusions

Our model confirms that upwelling of NH_4^+ is important in supplying N to surface waters during OAE2 with rates that are of the same order of magnitude as N_2-fixation. N dynamics in the proto-Atlantic are highly sensitive to changes in the strength of the circulation and changes in oxygen and P supply from the Pacific Ocean.

References:

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