Modeling ocean biogeochemistry in the Cretaceous: what triggers ocean anoxia?

Itzel Ruvalcaba-Baroni, Caroline P. Slomp, Henk Brinkhuis

Introduction

In the late Cretaceous, sea surface temperatures and sea level were higher than at present and severe oxygen depletion occurred in oceanic bottom waters. During these so called Oceanic Anoxic Events (OAEs) thermohaline circulation may have been slower than present day, and a moderate increase in nutrient delivery could have resulted in a cascade effect causing complete oxygen depletion in the deep sea waters (Tsandev and Slomp, 2009). As yet, the relative roles of nitrogen (N) and phosphorus (P) availability in controlling primary productivity during this time are not fully understood.

Aim of this study

Here, we expand an existing box model of the global oceanic carbon, oxygen and phosphorus cycles with the nitrogen (N) cycle to test whether enhanced availability of P can fuel N-fixation and organic C burial and trigger oceanic anoxia.

Model description

The original model (Slomp and Van Cappellen, 2007) is expanded with the N-cycle as shown in Figure 1, where SRN is the soluble reactive nitrogen and PON is particulate organic nitrogen. The model distinguishes between nearshore coastal environments (proximal coastal zone), continental shelves (distal zone) and the surface and deep ocean. The relevant processes related to the N-cycle that are included are:

- Denitrification
- N-fixation
- Formation of PON
- Remineralization of PON
- Burial of PON
- Export of PON and SRN

Burial of P in the sediment is assumed to be redox-dependent and is enhanced under anoxia.

Model application

First, we assess the sensitivity of the model to reduced oceanic circulation. We focus on the steady state model response as a function of water column mixing (vmix) and vary the extent of recycling of P from sediments in the coastal zone (+/- redox dependent P burial)

Second, we assess the transient response of the model to a 50% increase in river input of SRN and SRP and reduced oceanic mixing (50% of present-day circulation) in an ocean with 2x larger shelves than today.

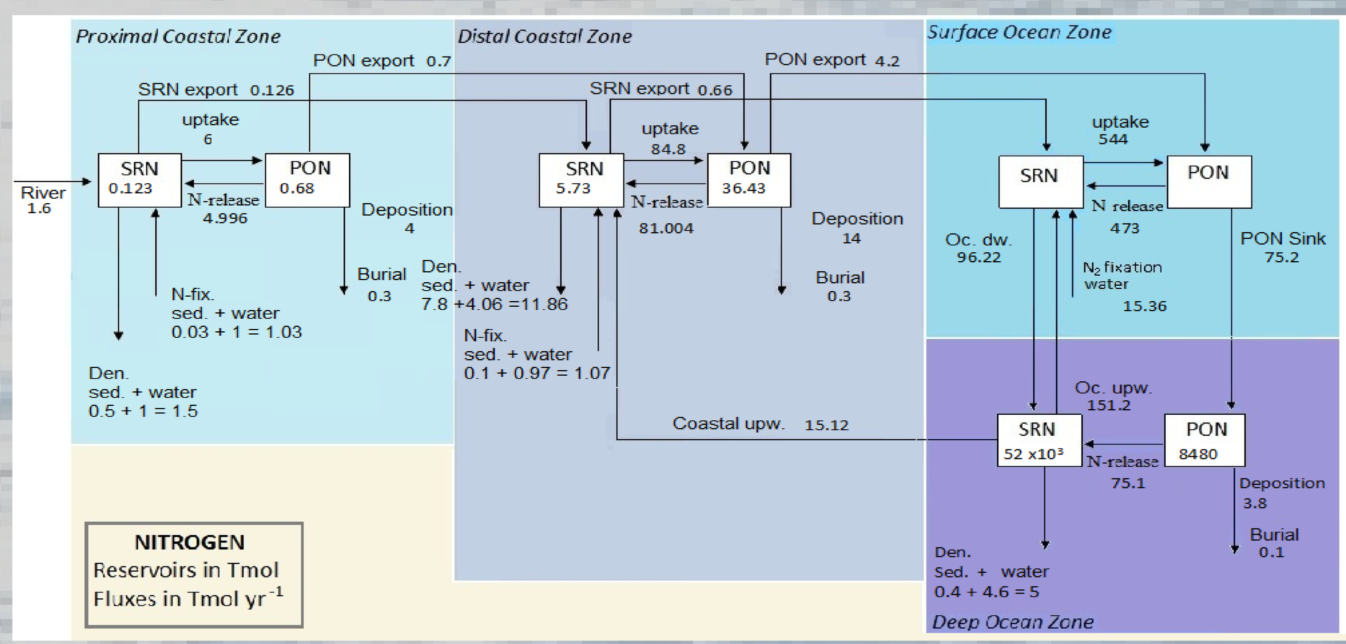

Figure 1. Modern steady-state oceanic N cycle as added to the model of Slomp and Van Cappellen (2007). SRN: soluble reactive N; PON: particulate organic N.

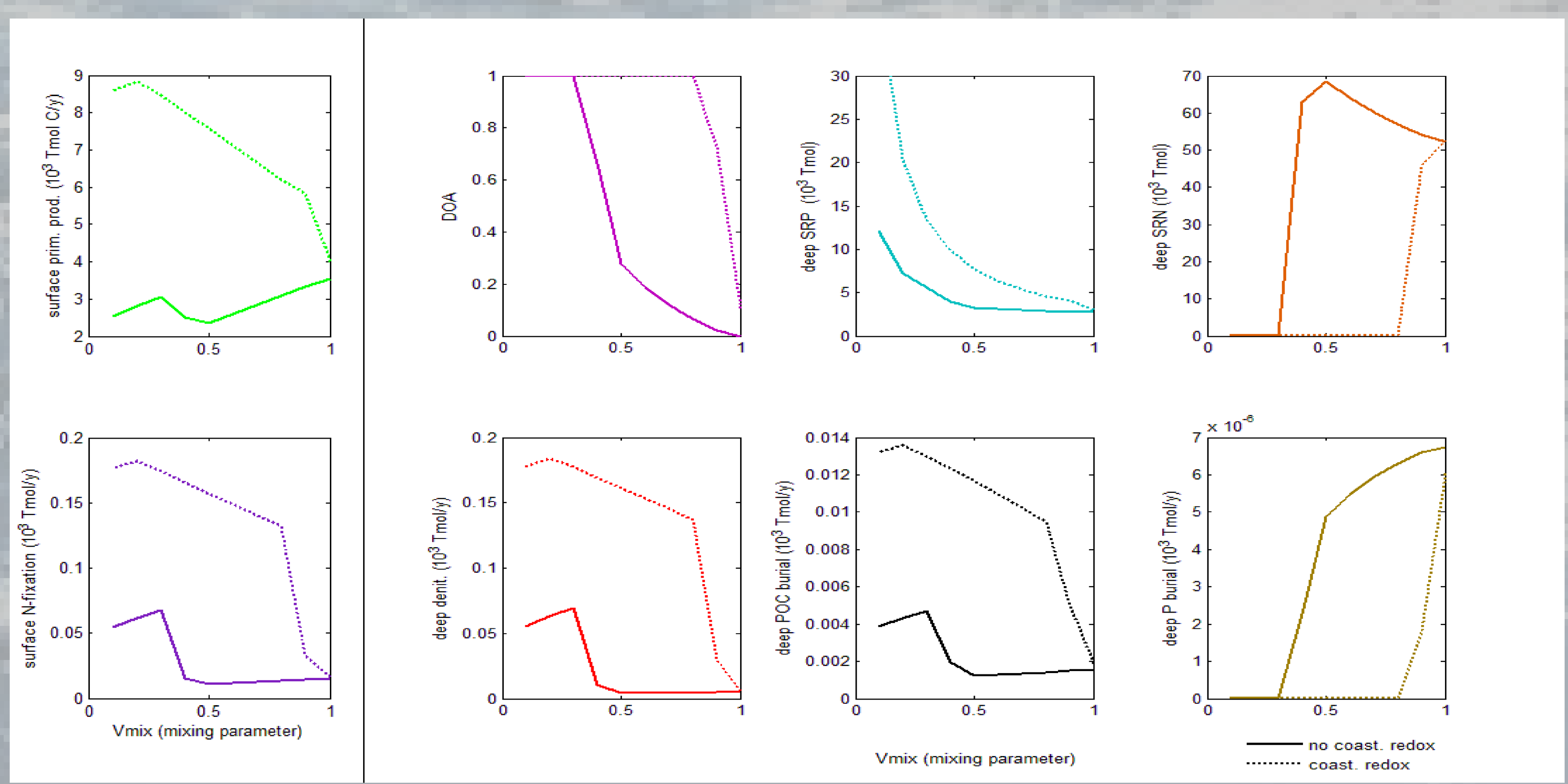

Figure 2. Steady state response of surface primary productivity and N-fixation, the degree of anoxia in the ocean (DOA), deep SRP (soluble reactive P) and SRN, denitrification, POC burial and total reactive P burial to reduced oceanic circulation (vmix) for +/- redox dependent P burial in the coastal zone.

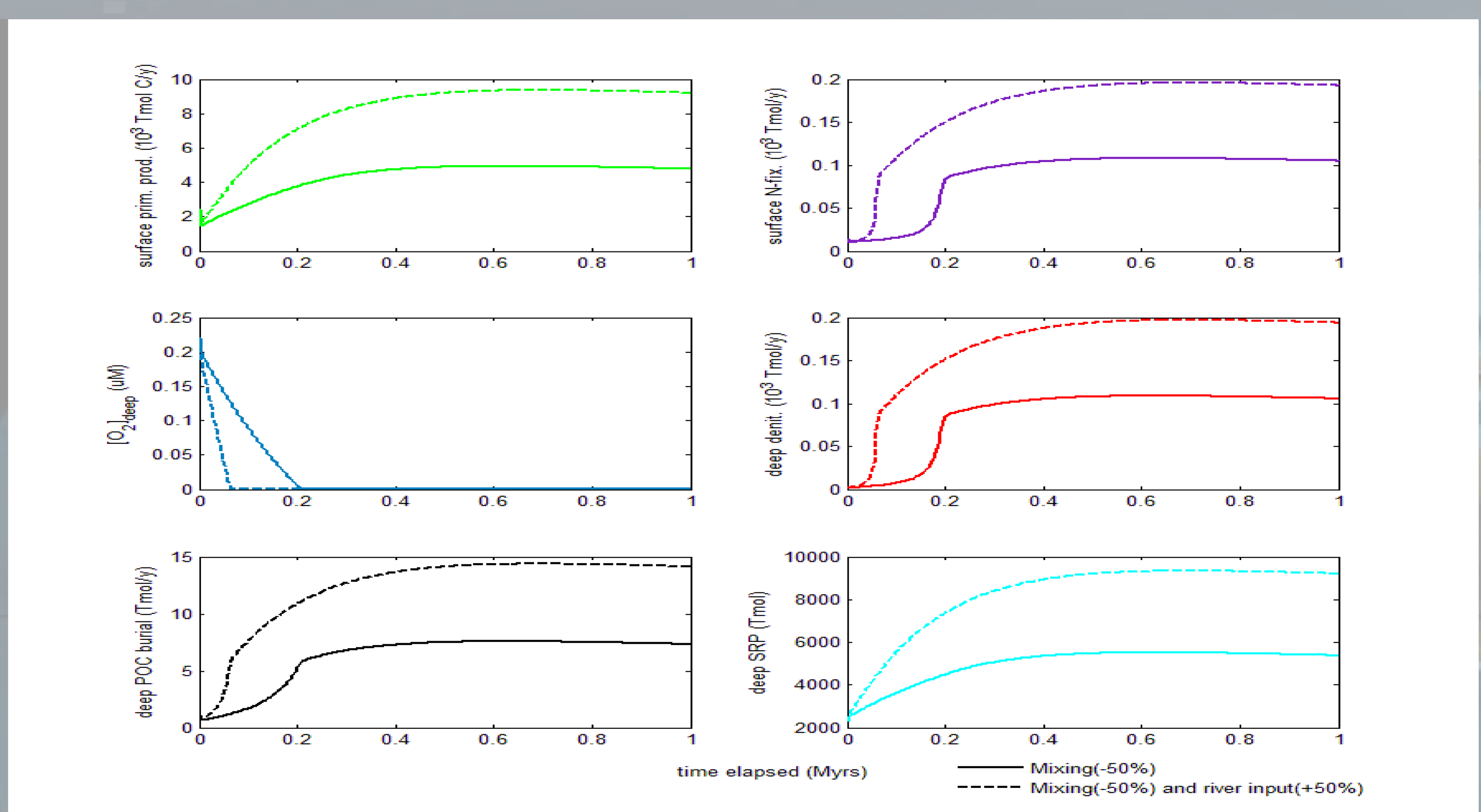

Figure 3. Transient simulation for 2x larger shelves for a 50% reduction in mixing and a 50% increase in river input of SRN for scenarios with and without redox-dependent p burial in the coastal zone.

Results and discussion

Steady state response. Reduced oceanic mixing (a smaller value of vmix) leads to increased deep water anoxia, a greater availability of SRP and reduced deep water SRN. Both N-fixation and denitrification are enhanced. Including redox dependent P burial in the coastal zone leads to more oceanic SRP. The availability of SRP ultimately controls primary productivity and organic carbon burial.

Transient response. Reduced oceanic circulation leads to depletion of oxygen in the deep ocean within 0.2 Myrs. Under these conditions, SRP availability is enhanced and N-fixation compensates for N-loss through denitrification. This allows an elevated primary productivity and increased burial of particulate organic carbon (POC). A further increased availability of SRP due to increased river input leads to more rapid oxygen depletion and an even further increased POC burial.

Conclusion and outlook

• Model results suggest that increased availability of SRP in the ocean can fuel N-fixation. This can compensate for N-loss through denitrification, thus allowing a high productivity to be maintained that may help trigger and sustain ocean anoxia.

• Further work will focus on
  - The inclusion of anammox in the model
  - A detailed assessment of the role of the coastal zone versus the open ocean
  - The implementation of more realistic scenarios for the Cretaceous

References

Slomp, C.P. Van Cappellen, P., 2007. The global marine phosphorus cycle: sensitivity to oceanic circulation. Biogeosciences, 4, 155–171

Tsandev, I., Slomp, C.P., 2009. Modeling phosphorus cycling and carbon burial during Cretaceous Oceanic Anoxic Events, Earth Planet. Sci. Lett., doi:10.1016/j.epsl.2009.06.016