Biogeosciences Discuss., 3, S557–S560, 2006
www.biogeosciences-discuss.net/3/S557/2006/

Biogeosciences
Discussions

Interactive comment on "Co-evolution of phytoplankton C:N:P stoichiometry and the deep ocean N:P ratio" *by* T. M. Lenton and C. A. Klausmeier

T. M. Lenton and C. A. Klausmeier

Received and published: 2 October 2006

General comments

We thank the referee for their constructive remarks. Their comment that the paper is very hard to read has provoked us to revise it extensively, undertaking a complete analytical solution of the LW model and adding 5 figures to make the results easier to follow. More detail and explanation has been added to the results and discussion sections. It should now be possible to fully evaluate the validity of our conclusions because a complete analytical solution of one model is now available and further numerical solutions of the other model are presented.

There is some confusion about the different effects of changes in weathering and changes in the Redfield ratios. We now explain in more detail and show with figures that an increase in weathering and a corresponding rise in O_2 causes a large increase in NO_3 due to reduced denitrification, but only a small change in PO_4 because the increase in P input to the ocean is counteracted by *increased* P removal on Fe-oxides in a more oxygenated ocean. The result is that increased weathering increase deep ocean N:P, primarily via changes in NO_3. In contrast, decreasing the N:P and C:P Redfield ratios tends to increase PO_4 whilst not altering NO_3, thus decreasing the deep ocean N:P ratio.

We now estimate the combined effects of changes in weathering and Redfield ratios and suggest that both NO_3 and PO_4 were reduced in the past, consequently the deep ocean N:P ratio may have been fairly invariant. Furthermore, we note that the lower N:P ocean composition predicted under reduced weathering is at odds with the higher N:P of older phytoplankton groups. Hence the phytoplankton do not appear to have adapted to prevailing conditions when they originated, and both changes in their composition and changes in weathering could have altered ocean composition. The referee is right that organisms are not "doing it alone" but we think it is appropriate to talk of co-evolution of phytoplankton composition and ocean composition because it is clear from both models that changes in phytoplankton composition can drive changes in ocean composition.

Specific comments

1. The units of new production are carbon concentration in μmol kg^{-1}, produced in the surface ocean from the limiting nutrient.

2. The section introducing equation (2) for N-fixation has been rewritten and O_2 and C_0 are now introduced later, after the equation for the anoxic fraction.

3. Denitrification depends on the anoxic fraction, which in turn depends on O_2 and new production, C. This has been clarified by adding the equation for denitrification

BGD

3, S557–S560, 2006

Interactive Comment

explicitly.

4. The terms in the differential equations for NO_3 and PO_4 are now described more fully in the text.

5. A table with the key parameters varied in the study, from both models, has now been included.

6. A more complete analytical solution of the LW model has now been achieved, which includes a precise derivation of the conditions under which NO_3 is limiting and the threshold at which PO_4 becomes limiting.

7. The thought experiment has now been replaced with figures showing the analytical solutions for the dependence of nutrients and deep ocean N:P ratio on the N:P threshold for N-fixation, and the N:P ratio of the phytoplankton when fixing C:P or C:N.

8. $PO_4=(226/r_{C:P})+k_P$ i.e. the referee misplaced the bracket / we failed to make this totally clear. A complete derivation of this result is now given.

9. We have re-arranged the order of the argument here, first showing that the N:P ratio of non-fixers sets deep ocean N:P, and then noting that this contradicts Redfield's (1958) remark.

10. Results of the TT model are now included as a figure which shows that deep ocean N:P is insensitive to the N:P ratio of the N-fixers, and varies linearly with the N:P ratio of non-fixers.

11. It is now made clear which equations are used to calculate the NO_3 and PO_4 values in what is now Table 3.

12. The higher N:P ratio with increased weathering occurs due to a corresponding increase in atmospheric O_2. This reduces denitrification and increases NO_3 proportionally more than the increase in weathering increases PO_4. Indeed, when O_2 increases, a reduction in P recycling means that PO_4 changes relatively little. This is now de-

BGD

3, S557–S560, 2006

Interactive Comment

scribed, the equation here had an error which has been corrected, and a figure has been included showing the dependence of the nutrients and deep ocean N:P ratio on weathering.

13. The conclusion that the N:P uptake of other plankton determines the N:P threshold for N-fixation is based on model results (now included as a figure) and on a logical argument stated at the start of section 3.2: If the N:P supply ratio in the water is below the N:P requirement of non-fixers then they will use up all the N and leave some P remaining. N-fixers can utilise this P and in so doing add fixed N to the system. This will continue until the N:P supply ratio approaches the N:P requirement of the non-fixers, at which point the N-fixers become out-competed.

14. Weathering does not drive much change in PO_4 concentration, as now shown in a figure. Instead, the LW model analytical solution shows that changing the N:P Redfield ratio via changing the C:P ratio has a significant effect on PO_4.

15. The steady state analytical solution of the LW model shows that new production can only vary with changes in weathering (on timescales of millions of years). As is now noted, on shorter timescales, changing the Redfield ratios can drive a transient change in new production over a few thousand years, but the response decays away after approximately a hundred thousand years.

Interactive comment on Biogeosciences Discuss., 3, 1023, 2006.