Biogeosciences Discussions, 2, S163–S169, 2005
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European Geosciences Union

Biogeosciences Discussions

Interactive comment on "Diatoms and their influence on the biologically mediated uptake of atmospheric CO_2 in the Arabian Sea upwelling system" *by* T. Rixen et al.

T. Rixen et al.

Received and published: 22 April 2005

Please find below a point-by-point response to the issues raised by the referee #2.

S35/36

1.) At the onset of our research in Indian Ocean in 1986 we believed low SSTs in the western Arabian Sea are caused by vertical mixing, then it was advection of coastally upwelled water from Somalia and Oman than only advection of upwelled water from the Oman coast and open ocean upwelling. The latest JGOFS's results imply that advection of coastally upwelled water is the main feature in the western Arabian Sea during the upwelling season (Smith, 2001; Fischer et al., 2002). This would justify the application of a two-end-member mixing analysis. 2.) Our two-end-member mixing analysis leads to realistic Redfield and rain ratios and to new production rates which are in line with published data on primary and export production rates measured at the same time. These acceptable results support the conclusion drawn from the JGOFS data as mentioned above. Within the revise version of the manuscript we have changed the first paragraph of chapter 3 to discuss this issue in more detail.

3.) The results obtained by the mixing analysis have been linked to sediment trap data, plankton counts and nutrient concentrations in order to see to which extend surface ocean processes are reflected in records derived from the deep sea. Our main conclusions based on the consistent picture which we tried to draw form all these data and not only from one data set. We tried to introduce this general concept of the paper in a better way by modifying the last paragraph of chapter 1 and by restructuring the discussion in the revised version of the manuscript.

S36 p2

1. Diatoms and rain ratios: -by definition, diatoms will enhance rain ratios, so there is no need to draw this conclusion- As far as we know there is no direct method to measure rain ratios in the ocean and all information we have on rain ratios is driven from indirect approaches. Furthermore, the hypothesis that diatoms and rain ratios are linked based on the relationship between diatoms and coccolithophorids. But Schiebel (Schiebel, 2002) pointed out that forams are the main carbonate producers in the ocean and this appears to be true also in the Arabian Sea where the peak export of diatoms and forams occurs simultaneously and coccolithophorids contribute only˜ 15% to the PIC export (Zeltner, 2000). This implies that the relationship between diatoms and rain ratios is more complicated than one would assume and as mentioned by (Sarmiento et al., 2002) data based estimates of rain ratios are scarce (see also chapter 1).

2. Silicate seems to limit the diatom growth in the North Atlantic and iron is assumed to limit the diatom growth in parts of the Southern Ocean and the Pacific Ocean. In the Arabian Sea silicate in contrast to inorganic nitrogen hardly approaches concentrations close to zero. Plankton counts during the cruises M32/5 and ttn50 show that the num-

BGD

2, S163–S169, 2005

Interactive Comment

ber of diatoms and the contribution of diatoms to the plankton community, respectively, decrease although silicate is not depleted in the surface water. This shows that in the Arabian Sea the relationship between silicate and diatom is not straightforward as one would assume. Results obtained from the Norwegian mesocosms reveal that diatoms lose their ecological advantage over other organisms when the silicate concentration falls below 2 μmol/l. This implies that in addition to nutrient concentration ecological aspects also have to be considered in order to explain declining diatom blooms in the Arabian Sea and that is what we tried to do better this time in the revised version of our manuscript.

3. The C/P, N/P and C/N ratio derived from the mixing analysis vary between ˜ 80 and 150, between 7 and 24 and between 5 and 15 (see figure 5, and chapter 3). To our opinion these are large and significant changes but the large variability seen in C/N ratio is are not reflected in the C/N ratios derived from sediment trap data. As discussed in the chapter 4 (last section) we think that is caused by the decomposition of POM in the water column reducing the magnitude of short-term and small scale changes of upper ocean parameters. This is of course not a new idea but as far as we know it is the first time that data indicating this process are presented from the Arabian Sea.

4. Si/N uptake ratios - Our approach provided an idea about the Si/N uptake ratios in a natural environment and the results are within the range of Si/N uptake ratios reported from other environments. The trend seen in our Si/N uptake ratios fits into our overall concept as pointed out in the old version of the manuscript. Nevertheless, the approach is problematic and for that reason we have not used it to support our conclusions in the revised version of the manuscript.

S36 p3 To us it seems to be problematic to include approximations and assumptions leading to unrealistic results into the error estimate because the error range obviously increases as the assumptions become more unrealistic. Please see also response number S35/36.

S37 p1 ‘Si-limitation’ and ‘Redfield ratio’: Please see response number S36 p2. C/N ratios derived from sediment trap data reveal a 7% decrease at the transition from the upwelling to the more oligotrophic sites. This might be not much and it is lower than the variation seen in the Redfield ratios which have been derived from the mixing analysis (see also S36 p2). To our opinion this shows that decomposition of POM in the water reduces or even eliminates short term and small scale variations seen in the mixed layer. We think that it is important to trace signals produced in the surface ocean because its penetration-depth into the deep sea indicates its quantitative importance in the carbon cycle. For that reason we think it interesting to see to which extend the generally larger variability of surface ocean processes is reflected in sediment trap data. We hope this important aspect is more convincingly introduced in chapter 4 of the revised version of the manuscript.

S37 p2 Within the revised version of the manuscript new (published) data on the abundance of diatom have been included as well as new references in order to show that iron could play an important for the development of large diatom blooms in the Arabian Sea. Please see chapter 4 , ‘Diatom blooms’ and ‘The role of iron for the development of diatom blooms’ in the revised version of the manuscript.

S37 p 3 Our results (see conclusion) support the opinion of the referee.

S37 p 4 One of the aims of the two-end-member mixing analyses was to see whether the computed rain ratios agree with those derived from the sediment data. This has been pointed out more clearly at the end of the introduction of the revised version of the manuscript. In chapter 3 ‘Rain ratios’ we showed that rain ratios derived from the mixing analysis and the sediment trap data reveal a consistent picture.

S37 p5 S38 p1 The high phosphate concentration is associated with a low temperature and a low salinity and this indicates a high proportion of upwelled water. For that reason the sampling point shifted to the right in Fig 3b. Please see also our response number S35/36 regarding the application of a two-end-member mixing analysis.

S38 p2/3/4 As mentioned above (S36 p2) our approach provided an idea about the Si/N uptake ratios in a natural environment. The results are within the range of Si/N uptake ratios reported from other environments and fits into our overall concept. But due to the problematic mentioned by the referee we are not using the Si/N ratio to support our conclusion in the revised version of the manuscript.

S38 p4/ S39 p1 During the cruise ttn49, at 93 km offshore the iron concentration was ˜ 2.5 nmol /l. At the other upwelling influenced sites iron concentrations are $>$ 1 nmol /l. During the cruise ttn50 the iron concentrations varied between 0.6 and ˜ 0.9 nmol /l. Data obtained form the coastal upwelling regime off California (Hutchins and Bruland, 1998) show that Fe concentrations increasing from $<$ 0.5 to 2.5 nmol/l halves the Si/N uptake ratio. This suggests that changes in the iron concentration between 0.6 and 2.5 nmol/l could have large impacts on the diatom growth. Within the revised version of the manuscript data obtained from Schiebel et al (2004) on the abundance of diatom have been included as well as new references in order to show that iron could play an important for the development of large diatom blooms in the Arabian Sea. Please see chapter 4, 'Diatom blooms' and 'The role of iron for the development of diatom blooms' of the revised version of the manuscript.

S30 p2 Haake et al. (1993b) andHaake et al. (1993a) reported results obtained from sediment traps deployed more than 500 km offshore and a nutrient profile. Plankton data and information on the composition of settling particles in the upwelling region (distance to the coast $<$ 500 km) were not available at that time. But what we found and what is an annual repeating feature is that there are no large diatom blooms during the onset of the upwelling season as indicated by enhanced carbonate/biogenic opal ratios determined at our long-term sediment trap site in the western Arabian Sea (Rixen et al., 2000; Rixen et al., 2002). Data collected during JGOFS allow us for the first time to link our deep sea record to plankton counts, nutrient concentration and other sediment trap data measured along the transect from the upwelling centres towards the open Arabian Sea via our long-term sediment trap site as discussed in our

BGD

2, S163–S169, 2005

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Discussion Paper

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manuscript. We present in the revised version of the manuscript published data on the abundance of diatoms and coccolithophirds during the onset of the upwelling season but to our knowledge there are no information about the abundance of other organisms during this time. Due to the lack of this information it is difficult to estimate the contribution of diatoms to the planktonic community. Therefore we rely on indicators. The calculated silicon consumption is an indicator as pointed out in the revised version of the manuscript. How significant the observed changes in the silicon consumption are we do not know but we could show that the increasing silicon consumption is associated with increasing rain ratios in the upwelling area. This implies that the increasing rain ratios are accompanied by an increasing relevance of diatoms in the surface water. This in turn indicates that with an increasing dominance of diatoms the PIC export is relative to POC export reduced. Please see also our response S36 p2.

S39 p4 Only POC/PIC ratios measured in sediment traps have been converted into rain ratios. The C/N ratios have been obtained from the deepest sediment traps deployed at each of the mooring sites (see figure 1) and averaged for the SW monsoon period. Within the revised version of the manuscript the C/N ratios have been averaged only for time during which the cruise ttn49 took place (considering a delay of 14 days between surface and the deep ocean processes) because we compared it with data obtained from the mixing analysis which is based on data measured during the cruise ttn49.

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Interactive comment on Biogeosciences Discussions, 2, 103, 2005.