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Biogeosciences Discussions

Interactive comment on "Sinking rates of particles in biogenic silica- and carbonate-dominated production systems of the Atlantic Ocean: implications for the organic carbon fluxes to the deep ocean" *by* G. Fischer and G. Karakas

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Interactive comment on review of referee #3:

The starting point for our ms was the paper of Francois et al. (2002, GBC) showing a statistically valid relationship between the transfer efficiency of organic carbon to depth and carbonate fluxes derived from deep ocean sediment traps ('ballast theory', e.g. Armstrong et al. 2002). Francois et al. finally speculated that higher particle settling rates in carbonate production systems where sedimentation is mostly determined by densely packed fecal pellets might be responsible for this observation (more details at page 2550/2551 line 24..). In contrast, Armstrong et al. hypothesized that a better

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protection of organic matter in carbonate systems could explain this relationship. We have now argued from our entire data set that there is indication that particle settling rates might indeed be a key factor controlling remineralisation and carbon flux in the water column. Therefore, our conclusion is not exclusively based on the data shown in Figures 3c and 4d. The referee is absolutely right in saying that there is no statistical evidence for our conclusions from these two figures. We said this explicitly at page 2551 (starting with line 22 : 'However, a close relationship between particle settling rates and carbonate content was not found'. We also explained what the reason for this statement might be (starting with line 24).

Our conclusions are supported by own seasonal (Fig. 6) and regional data (e.g. Pacific vs Arabian Sea, Berelson, 2002, page 2550, lines 16-19) (Eq. Atlantic, page 2552, lines 14-20). Also alkenone and flux studies from the Cape Blanc region (Mauritania) point to high carbon transfer combined with high particle sinking rates, when coccolithophorids dominated mass flux (page 2554, lines 11-22). Very densely packed appendicularian fecal pellets preserved in sediment trap samples off Cape Blanc had settling rates (measured with a vertical flow system) of 732 m d-1 (Ploug et al., 2008b, L&O 53, 5) Furthermore, experimental/laboratory studies highlight our field observations. M. Iversen and H. Ploug from the MPI in Bremen found higher sinking rates in experimental aggregates containing coccolithophorids compared to those with diatoms. In addition, they could show that sinking rates directly influence particle degradation and that protection by minerals is not the key factor (see also Ploug et al. 2008a, L&O 53, 2). We aim to include these findings and arguments in our new version. We will formulate our conclusions more carefully and emphasize that they are based on multiple evidence not only from the regional data shown in the figures 3 and 4. We will also put error bars into figures 3c and 4d. We feel that albeit not statistically proven, the tendency to higher sinking rates in carbonate (coccolithophorid) production systems is of great interest for the study of aggregate remineralisation processes and carbon flux (see comment of reviewer at page S1665, top and middle sections) and will stimulate further research in this important field which is also of relevance for global change scenarios.

Referee #3 is right in saying that we gave little concern to the second major characteristic of aggregates (shape) and that our focus was on mainly on mass properties. As organic-rich marine snow aggregates are not preserved as original particles in sediment trap samples, this does not make sense. Only non-destructive methods will be able to provide more insight into this matter. For these purposes, we have have installed various high-resolution cameras on moored technical platforms.

Specific comments: Page 2543 line 10: The reviewer is correct, we will reformulate to 'the detritus of small zooplankton and phytoplankton';

Page 2543 line 20: We will replace 'particle characteristics' by 'density and porosity'

Page 2546 line 10-11: Concerning the size of aggregates. Stemmann et al. (2004) showed that very large aggregates ($>$ 1.5 mm) but also very small ones are not so important for mass flux. We used a nylon mesh size to remove larger zooplankton swimmers ($>$ 1 mm) from our samples. As larger, organic-rich and porous aggregates rapidly disintegrate in the sampling cups they are in fact not removed from the sample by this separation method.

Page 2549 line 1: Small detritus remineralises 3 times faster than the large detritus in the original model (Gruber et al., 2006) and we kept this ratio as it is in our setup as well. Besides remineralisation of large aggregates are different than that of small particles. As the referee #1 indicates, such a relationship has also been found in silica dissolution rates by Moriceau et al. (2007) between aggregated and freely suspended diatoms. Increasing the settling velocity of particles to the observed values requires increasing particle remineralisation rates in the biogeochemical model to keep the carbon balance and also to have similar particle remineralisation length scales as in the original model. Since particle settling was rised from 10 m d-1 to 75 m d-1, particle remineralisation has also been elevated with a similar ratio and the values that we used (i.e. 0.18 and 0.06 d-1) appear to be realistic. Ploug and Grossart (2000) and Ploug et al. (2008)

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report very similar remineralisation rates for marine snow as we used in our study. In the revised manuscript we will justify the choice of values and provide a more clear explanation with references.

Page 2549 line 20: Settling velocities, which the referee refers to in Table 1, are those which are calculated from sediment traps at two different water depths. The upper trap is located at 1228 m depth. However, the value that is used in the model corresponds to a mean sinking velocity for the entire water column. Because the sinking velocity increases with depth, the velocity for the entire water column must be less than the one measured in deeper layers between upper and lower traps. In the model, therefore, we must refer to a settling velocity which takes into account the entire water column. Helmke et al. (2005) give such an estimate by looking into the delay between chlorophyll maxima at the surface and the corresponding sedimentation peaks in the traps. In fact their value also compares well to the sinking rates of alkenone associated particles shown in Table 2, that are calculated based on the time shift between maxima/minima of measured SST and alkenone-derived temperatures obtained from trap samples. The original biogeochemical model consists of 2 compartments of particulate organic matter; small detritus with a mean size of 10 μm and large one with a size of 100 μm or larger. Sinking velocities of small and large detritus were 1 and 10 m d-1 respectively (Gruber et al., 2006). Because small detritus pool represent particles with minimum diameter in the system, in our configuration the settling velocity of this class remained the same as in the original model. As the referee points out this particle pool remineralises in the surface due to its slow settling velocity and does not contribute to the calculated carbon fluxes in the depth. The estimated carbon flux is therefore solely due to aggregates. We will clarify the ambiguity surrounding settling velocities in the revised manuscript.

Page 2550 lines 12-15: concerning statistical test see comments above. We will put error bars into these figures.

Page 2550, line 19: will be changed accordingly

Page 2555, line 10: will be rewritten

Table 1: standard deviations for the mean values will be given

Fig. 1: abbreviations will be explained

Fig. 3 and 4: error bars will be included

Fig, 6: No, labels have not been inverted, we will make a new figure to show the data more clearly

We thank referee #3 for his review and the clear and valuable comments and suggestions.

Interactive comment on Biogeosciences Discuss., 5, 2541, 2008.