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Interactive comment on “On the treatment of particulate organic matter sinking in large-scale models of marine biogeochemical cycles” by I. Kriest and A. Oschlies

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We would like to thank referee #1 for the review and the very helpful comments.

We would like to follow the referee’s suggestions as follows:

1. In fact, in this work we did not mean to “validate” or fit the models, but rather compare the simulated and observed variability of sedimentation with each other, and propose one possible explanation for the observed regional variability of the remineralisation length scales. Fitting the models to observations at different sites would not only require a model of remineralisation length scales, but also a model that, e.g., for the gamma function approach, predicts the size distribution and/or composition of particles

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on seasonal to annual time scales. We intend to do this later with a different model, that not only deals with the biogeochemistry and sinking parameterisations, but also contains detailed physics, and a detailed model-data comparison with respect to fluxes and biogeochemical tracers. Thus, we would prefer not to fit the individual functions to observed profile at this stage.

To increase the “readability” of the Figure 3, and because there are some methodological differences between the observations presented in this figure we would prefer to split the Figure 3 into three parts: (A) model results plotted with observations from the NABE study site, because these were collected during biweekly intervals, and can be interpreted as some sort of temporal development of the sinking flux; (B) model results plus observations made at/during HOT, BATS, OSP and AS-C, because these represent long-term (at least annual) moorings. OSP differs slightly with respect to the biogeochemical province, which may nicely reflect the regional variability of flux collected with this method; (C) finally, we would then compare the models to the data set by Buesseler et al., which was collected with neutrally buoyant sediment traps; this also reflects the regional variability of observed profiles.

2. It might be necessary to distinguish between different particle types, namely aggregates (formed via collision) and biogenic particles such as individual phytoplankton cells, fecal pellets, and other detrital material. Stemmann et al. (2004a,b) have extensively reviewed and investigated the different processes that might lead to changes in the particle size spectra and properties, especially with respect to aggregates. To name but a few, settling, coagulation and physical fragmentation might lead to changes in the particle size spectra. While coagulation and fragmentation might play a smaller role in the mesopelagic realm, where shear rates are low, zooplankton feeding and microbial degradation might play a larger role (see Stemmann et al., 2004a,b).

Zooplankton feeding can affect the size spectra in two directions: breakup during feeding will reduce the average particle size, while the ingestion of small cells, and the

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production of large fecal pellets would shift the main mode towards the upper end of the size spectrum. Both processes will depend on the size structure of the zooplankton community, the animals' preference for certain food size, and the animals feeding mode. E.g. flux feeders will focus on the large, fast settling particles, whereas the filter feeders ingestion will depend on the size and geometry of their feeding apparatus. Stemann et al. (2004) found that especially flux feeding (and the associated production of fecal pellets) could be as important for variations in the mass of large particles as settling; however, they did not consider a size spectrum of zooplankton and/or size-dependent grazing.

Microbial degradation of biogenic particles can be an important process in the deep ocean, depending on the way the particles are remineralised. If the decay rate is constant with size, and particles assumed to shrink during degradation, it will change the size spectra towards smaller particles (see Stemann et al., 2004b). Zuur and Nyffeler (1992) in their model also assumed that particle size decreases during remineralisation. A change in mass:volume relationships of decaying phytoplankton (indicating a decrease of the mass of individual particles) has been observed by Verity et al. (2000).

The effect of remineralisation on size may depend, however, on the time scales considered, and on the definition of "sinking particle". Because our model formulation is linked strongly to the way we consider POM and its decay, it seems worthwhile to take a closer look at the succession in the "detritosphere", as described by Biddanda and Pomeroy (1988):

Biddanda and Pomeroy (1988) showed that particle decay happens in different stages: first, bacteria start to grow in the vicinity of the particle (day 0-4). Afterwards, the bacteria will colonize the particle (\approx day 1-6) and convert its POC first to DOC by means of exoenzymes. Only a small fraction of the organic carbon will be incorporated into bacterial biomass, the rest will be respired (Biddanda, 1988). (Assuming fixed C:N ratios for bacteria, we might assume that an equivalent amount of organic nitrogen available to bacteria will then remain/be released as DON and/or ammonia.) The production

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of sticky extracellular mucopolysaccharides leads to aggregation of detritus particles and/or bacteria. At the same time there is an increase in protozoa which feed on the bacteria. The combined effects of microbial and protozoan activity finally lead to the disintegration of the detrital aggregates, which have largely disappeared by day 16.

Summarizing, the mass contained in detrital organic matter will first be converted to organic and inorganic forms, with some amount of this mass being in bacteria that are attached to the POC. I.e., in terms of mass there will be a shrinkage of the particle itself; the mass decrease will be less if we consider bacteria as a part of this particle. Considering the entire detritosphere, and neglecting diffusion out of the detritosphere, there will be a transformation of mass, but not a loss. Considering the diameter of the particle (more exactly: the detrital particle plus bacteria), the associated aggregation will lead to an increase in particle size. In the end (\approx day 16), the disaggregation and consumption by protozoa will lead to the decrease in both numbers and mass of the detritus. Thus, on a roughly biweekly timescale there will be shifts in the size spectrum due to “leakage” of organic substances out of the detritus particle and subsequent remineralization, colonization by bacteria (if we consider these to be part of the particle), aggregation and disaggregation. In the end, a particle with mass m will have vanished entirely; this process, under the assumption of size-independent decay rate (Ploug and Grossart, 2000), and over a long enough time scale, will leave no imprint on the size spectrum.

Finally, the presence of calcifiers or diatoms (in contrast to phytoplankton without shells) will not only affect the density of the particles (and thus increase their sinking rate), but might also protect the organic tissue of the cells from degradation. Both an increase in particle density as well as a decrease in its remineralisation rate will have an effect flux profiles, and increase the flux of organic matter to the deep ocean. For more details on this process we would rather direct the reader to Armstrong et al. (2002) and Klaas and Archer (2002).

We suggest to slightly extend the discussion on the different processes as presented

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above; however, especially the works by Stemmann et al. (2004a,b) provide very comprehensive overviews on these processes, and we would like to direct the reader to these for more information.

3. Yes, we fully agree: this would be the most comprehensive and thorough test of the models. As this requires the simulation of three-dimensional models towards equilibrium, this will take some time, and will be subject of future work.

4. We try to highlight the most important findings more clearly in a revised version. (See point 1 in our response to referee #2.)

We have inserted all specific comments into a revised version of this paper, unless noted below.

Specific comments:

3007,26 We have inserted 0.2-1000 instead 0.45 - 1000, because 0.2 is often used as lower limit for picophytoplankton (Nucleopore filter size).

3022,2 Yes, but “The newly formed POC quantities are released instantaneously in depth z according a penetration flux $(100m/z)^{0.8}$ for $z > 100m$ (...)” (p. 654), and then POC decays with a temperature dependent time scale of 0.002/month/degree centigrade (except in the bottom layer, where it degrades faster).

3012,9 We would prefer to keep the current notation (dM_i/dt) , but insert “for simplification, we note that $M_i = M_i(t, z)$ ”.

BGD

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3022,8 We agree that this might not be valid in these regions, and would modify the sentence in a revised version accordingly.

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