

Reply to review of bg-2018-264 by Anonymous Referee #2

Reviewer's comment: It is a series of comments for the manuscript, entitled "Carbon and nitrogen turnover in the Arctic deep sea: in situ benthic community response to diatom and coccolithophorid phytodetritus" that has appeared on BG Discussion. I am pleased to read this article with a great interest. Because, this article tries to measure states of both carbon and nitrogen turnover at deep-sea floor through in situ feeding experiments. Even though numbers of experimental trials were a few, it gives an important data for benthic ecosystems research would like to make a couple of comments in terms of this worthy experiments.

Authors: We are very grateful for these constructive comments. Below, we answer to each comment in a point-by-point fashion. We underlined the new text that was added to the manuscript. The line numbers refer to the discussion paper (<https://www.biogeosciences-discuss.net/bg-2018-264/bg-2018-264.pdf>).

Reviewer's comment: Why did you select both *Thalassiosira* and *Emiliana* sp. for food materials? *Chaetoceros* and *Gephyrocapsa* spp. are also common species of primary production both at middle to high latitude seas. Please ask to add some additional explanation why you use *Emiliana* and *Thalassiosira* sp.

Reply: We selected *Thalassiosira* as it was one of the dominant diatom species in Fram Strait (Nöthig et al. 2015; Bauerfeind et al. 2009, Soltwedel et al. 2015). *Emiliana* was chosen as a possible 'future' food source, since it is a temperate species that can be transported into the Arctic Ocean along with warmer Atlantic currents (Bauerfeind et al., 2009). *Chaetoceros* is indeed another representative for Fram Strait (Nöthig et al. 2015; Bauerfeind et al. 2009, Soltwedel et al. 2015), but its contribution is limited in time and consists mainly of resting spores, not intact cells (Bauerfeind et al. 2009, Lalande et al. 2011). There are no records of dominance of *Gephyrocapsa* sp. The other occurring coccolithophore is *Coccolithus pelagicus*, but this species only occasionally contributed considerably to or dominated the sedimentation of coccolithophorids (Bauerfeind et al. 2009). This is stated in the introduction, lines 44-50, where we specified that *Thalassiosira* spp. dominates the diatom blooms and that *Emiliana huxleyi* has been observed during periods of enhanced Atlantic influence:

"This phenomenon also occurred in the eastern Fram Strait, where previously, phytoplankton communities were typically dominated by diatoms, mainly *Thalassiosira* spp. (Bauerfeind et al., 2009; Lalande et al., 2011). However, during recent warmer years, phytoplankton blooms became more mixed with *Phaeocystis pouchetti* (Nöthig et al., 2015; Soltwedel et al., 2015). Also *Emiliana huxleyi* (Prymnesiophyceae)-dominated coccolithophorid blooms have been observed between 2000-2005 – especially in 2004 – which has been attributed to northward transport of the species into Fram Strait by means of the North Atlantic Current and WSC. This 'Atlantification' with a combined change in water temperature and water mass origin has been suggested as one possible scenario for a community shift in phytoplankton communities in Fram Strait (Bauerfeind et al., 2009)."

Reviewer's comment: You have gotten subsamples with syringe tubes. You are better to evaluate statistically how subsamples represent sea floor states. Because, phytodetritus deposition is

heterogeneous at sea floor. This introduces patchy distribution of environments as discussed by Glud and others 2009. This may be the same in experimental chamber.

Reply: We actually sampled the entire sediment column recovered by the chamber layer-wise and homogenized the sediment before we took the subsamples. This means that we rule out the possible heterogeneity of the phytodetritus deposition. However, this comment brought our attention to an inconsistency in the discussion (lines 626-628) where we suggested inhomogeneous distribution as a possible explanation why C and N budgets are not closed: “(3) The added phytodetritus might not have been distributed evenly across each benthic chamber. This means that the location within the chamber from which samples for bacterial assimilation and tracer in the pore water were taken will have affected how much C and N was found in faunal and bacterial biomass.”. As we assume successful homogenization before sampling this is not a likely reason. Hence, we deleted this sentence from the manuscript.

Reviewer’s comment: You described that diatom frustules are easily decomposed by bacteria according to Bidle and Azam (1999) paper. I suppose that diatom frustules compose of the mixture of organic materials and amorphous silicate. Bacteria may be decomposed organic material. Then silicates dissolve in seawater. Seawater silicates may be undersaturated at Arctic. Do you have any silicate concentration data at the experimental site?

Reply: Thank you for this interesting comment. Seawater silicate is indeed undersaturated in deep Fram Strait waters (~10 μM actual bottom water concentration vs. saturation concentration of silicate ~1000 μM at 2500m water depth and 1.4°C; Sarmiento & Gruber 2013). Hence, silicate dissolution is indeed a pathway to be considered. We added this to the discussion, starting line 552: “Without this organic protection layer, the diatom frustule rapidly dissolves in undersaturated seawater (Ragueneau et al., 2006) ([SiO₂] at our study site ~10 μM vs. SiO₂ solubility ~ 1000 μM at 2500 m water depth and 1.4°C (Sarmiento and Gruber, 2013)).”

Reviewer’s comment: I understand that bacteria do not play a big role for dissolution of calcific tests. However, calcite concentration at Arctic is undersaturated in the Arctic deep-sea, coccolith may dissolve quickly at the site. Can you discuss about dissolution procedures of calcareous tests in laboratory condition? It is also required to discuss about Calcite Compensation Depth in Arctic. Normally, dissolution of calcareous tests at sea floor is much faster at polar seas than temperate oceans.

Reply: Thank you for pointing this out. We already discuss the dissolution procedures of calcareous tests in lines 552-555, but we now indicate that these results originate from laboratory experiments: “Similarly, the calcite matrix of the coccoliths can act as a physical barrier against bacterial degradation in laboratory experiments (Engel et al., 2009). However, comparable carbon-specific respiration rates were measured for aggregates of *Emiliana* and *Skeletonema* diatoms, suggesting similar degradability in laboratory experiments using surface waters (Iversen and Ploug, 2010).”.

To discuss the results in relation to the position of the lysocline, we added the following paragraph to the discussion (line 514 ff.): “It seems that *Emiliana* OM was initially (4 d and start of 14 d experiment) more respired than *Thalassiosira* (in 4 d experiment: 4 % of the added *Emiliana* OM, of

which 3.6 % by DIC release, as opposed to 2 % of the added *Thalassiosira* OM), but this could as well be ascribed to dissolution of the inorganic coccoliths. There was no NH_4^+ or NO_x^- release observed as it should co-occur with OM mineralization. This agree with a significant contribution of coccolithophorid dissolution to the observed DIC release. As the lysocline in the Arctic Ocean lies at ~4000m water depth (Jutterström and Anderson, 2005), it appears unlikely for the calcite from the coccoliths to quickly dissolve at our study site at 2500 m water depth. Nevertheless, Godoi et al. (2009) showed that the release of CO_2 during bacterial respiration can cause the decrease of the saturation state of sea water in the cell's microenvironment and may hence favour CaCO_3 dissolution."

Reviewer's comment: P17, lines 576~584. This paragraph mainly discuss about foraminiferal assimilation at sea floor. You described that Pyrgo may play a big role for assimilation of organic materials at Hausgarten site. In situ experiments at middle latitude show opportunistic species such as *Uvigerina* sp. *Fursenkoina fusiformis* or *Epistominella exigua* play more big role for assimilating organic materials at sediment water interface (for instance, Nomaki et al., 2005, 2008). These species are all size of meiofauna. Main players may not remain on your sieve. Please evaluate more details about roles of foraminifera at sediment-water interface. Series of Nomaki's in situ experimental works at Sagami Bay floor should be helpful to discuss about this topic.

Reply: The meiofaunal foraminifera contribution to carbon and nitrogen cycling is indeed an interesting topic to discuss, since we only considered the larger (>250 μm) foraminifera in our study. We highlight this now in the discussion, line 572-580: "Foraminifera still had a two orders of magnitude higher carbon-specific assimilation than bacteria, implying that larger organisms continued to dominate the competition for fresh OM. This confirms earlier studies showing that foraminifera can be key players in the early diagenesis of fresh OM at the deep-sea floor (Moodley et al., 2000, 2002; Nomaki et al., 2005; Woulds et al., 2007). However, these studies also included the meiofauna fraction of foraminifera (63-250 μm). Although macrofaunal (>250 μm) foraminifera can have a retarded response to phytodetritus inputs as compared to smaller (> 63 μm) foraminifera (Sweetman et al., 2009), the carbon assimilation rate by macrofaunal foraminifera in this study is similar to that of smaller foraminifera at Station M (Enge et al., 2011) and the central basin of Sagami bay (1449m) (Nomaki et al., 2005). Nevertheless, as smaller foraminifera were not analyzed here, it may be that the overall assimilation of this group was still underestimated."

We also highlight the importance of meiofaunal foraminifera in the discussion of the mass budget (line 610 ff.): "(c) We did not consider meiobenthos < 250 μm , since nematodes, the most abundant metazoan component of deep-sea meiobenthos, are usually responsible for only < 1 % of the total mineralization (Ingels et al., 2010). However, the meiofauna fraction of the foraminifera could have contributed to the mineralization (Moodley et al., 2002; Nomaki et al., 2005)"

Reviewer's comment: One of chamber experiments could only get top cm layer. This means that you are difficult to evaluate roles of infaunal species at sediment-water interface. It may be helpful to discuss how organisms from deep in sediments assimilate organic materials. You may evaluate thin layer chamber results. Please discuss more details about roles of infaunal species for both carbon and nitrogen turnover through your experimental work.

Reply: Indeed, we discuss this in line 608-610: "(a) We could not sample the sediment subsurface layers of the 4 d Emilia experiment as deeper layers were lost upon retrieval of samples from the chambers on board, and as such miss the subsurface processing pathway. However, in the other experiments, this part accounts for < 10 % of the sum of the total processed carbon and uncharacterized OM."

This means that most (>90%) of the carbon and nitrogen is turned over at the sediment surface (thin layer) and that the role for deeper infauna is limited (<<10%, because this 10% mainly includes the uncharacterized OM). However, biogenic mixing by infauna (bioturbation) is the process that must have brought the fresh detritus deeper down.

In accordance with the comments of the first reviewer, Jack Middelburg, we added the following paragraph that we believe also addresses the comments of Anonymous Reviewer #2 (line 572 ff.): "Alternatively, sediment reworking (bioturbation) by infauna also redistributes fresh organic matter deposited at the surface to the deeper sediment layers, where subsurface bacteria can also access it. Particle mixing in Arctic sediments is usually limited to the upper 3 cm of the sediment (Clough et al. 1997, Morata et al. 2015, Krauss 2016), which fits with our observations on the increase in subsurface algal-derived OM after 14 days (Figure 1A) and higher bacterial assimilation in the sediment subsurface (Figure 3)."