

## **Response to Anonymous Referee #2**

We would like to thank anonymous reviewer #2 for his/her time and insightful thoughts on our manuscript. We would like to stress here again that the main focus of this manuscript is to describe the interannual variability of the total PF flux and discuss reasons for such variability. As mentioned in the response to the reviewer #1 comment, we cannot make detailed comments on the seasonal variability in PF species flux because our dataset does not represent all PF species but our PF species flux (11 species) will be combined with another long term overlapping time-series study [Prof. W. Prell] with a view to achieving this goal. Here we would like to address all comments and will revise the manuscript by incorporating other suggested changes. Reviewer's comments are in Arial font and italicised, responses are in Times font, and suggested additions if necessary are in bold, italic Times font within inverted commas:

1. *"In general the paper is concise, well written, clear and well-focused on the Bermuda. The latter, however is also a limitation as similar studies from elsewhere are not included in the discussion of results, which would increase the value of this study, e.g. with respect to both seasonality and eddy perturbation."*

We have not discussed species seasonality specifically in the discussion of the results because our manuscript is focusing on interannual variability (also see response to reviewer #1 comments).

We are happy to add some more discussion within this context in section 5.1.1 and section 5.2 taking into consideration other global studies on total PF flux variability, as below:

**(Interannual variability) Section 5.1.1, Page 12232, line 17 (changes in bold italic):**

"Here, we also observed a simultaneous seasonal peak in chlorophyll a and maximum depth of the MLD *as seen by previous studies at BATS (Cianca et al. 2012)*, the timing and amplitude of which coincides with the maximum PF flux (Fig. 2c and d). *This observation is consistent with previous findings in other oceans*

*where seasonal changes in mixed layer depth are closely associated with changes in foraminifera production (Thunell and Reynolds, 1984, Sautter and Thunell, 1989, Pujol and Vergnaud Grazzini 1995, Schmucker and Sciebel 2002) and chlorophyll a concentrations (King and Howard, 2003, 2005). Siegel et al. 2002 proposed that south of 40°N, the initiation and extent of the spring bloom is limited by nutrients rather than light, and this is supported by the simultaneous increase in phytoplankton concentrations with mixing depth at BATS (Treusch et al. 2012).*

Vertical mixing in late winter and spring distribute nutrients into the euphotic zone to support the spring phytoplankton bloom *which fuels foraminifera production*, as indicated by the seasonal peak in export fluxes of organic carbon (Fig. 1d)”

**(Eddy perturbation) Section 5.2, page 12234, line 12:**

“The negative sea level anomalies in spring 2009 and 2010 indicate that the large (and in 2010 prolonged) PF fluxes in these years are clearly associated with the passage of cyclonic eddies (Fig 2b). *Eddy pumping of nitrate into the euphotic zone has been extensively studied at BATS and shown to significantly increase new production (Oschlies and Garçon, 1998) although estimates of eddy nitrate contribution range from ~30-70% in the Sargasso Sea. The upwelling/downwelling of nutrients by cyclonic/anticyclonic eddies have been shown to either promote or suppress* phytoplankton blooms (Eden et al., 2009; Goldthwait and Steinberg, 2008; McGillicuddy et al., 1998, 1999, 2007; Sweeney et al., 2003; McGillicuddy and Robinson, 1997, *Lomas et al. 2013, Cianca et al. 2012) and therefore affect the food source of planktonic foraminifera (Schmucker and Schiebel, 2002). Previous studies have found higher fluxes of certain PF species such as Globigerinita glutinata associated with cyclonic eddy structures in the Caribbean Sea (Schmucker and Schiebel, 2002), North Atlantic (Beckman et al. 1987), in conjunction with upwelling frontal regions in the Mexican Pacific (Machain-Castillo et al. 2008) and deep mixed layers during winter in the Mediterranean (Pujol and Vergnaud Grazzini, 1995). We see a similar response in our record in spring 2009, which was the largest PF flux observed over the entire record, even though the maximum MLD was modest, and the average rates of mixed layer deepening and shoaling were similar to lower flux years (Table 2).”*

**(Eddy perturbation) Section 5.2, page 12235, line 4**

“...during the seasonal flux of deeper dwellers (Fig. 6). *This observation is in agreement with findings from the eastern Basin of the Mediterranean where greater numbers of grazing species such as G. truncatulinoides and G. inflata are found in association with numerous eddy structures and deep mixed layers (Pujol and Vergnaud Grazzini, 1995). These findings suggest that cyclonic eddies enhance the abundance of deeper dwelling species through aiding their annual reproductive migration through mixing of the water column in addition to driving large carbon export flux.*”

2. *“Having said that, the manuscript is well within the scope of BG, presents novel data and discusses these data in a broader oceanographic perspective. The manuscript would benefit from the addition of a map showing the location of the site with major surface currents, as well as with a full data table (supplementary).”*

We will add a map without surface currents, as there are not significant boundary currents or fronts present at this site. We will include all data in Pangea.de (also see our response to reviewer #1).

3. *“Materials and Methods, 3.2, line 15-16: The authors state that the fast settling rates for individual tests of larger species would not cause a temporal offset between the hydrography and their arrival at 1500m depth (3 days for G. inflata and 7 days for G. ruber). However, this time period is taken from the moment the export of shells starts, not the time of life before that, which may be anywhere from two weeks to a full year. How does a living foram population respond to perturbances like eddies, or do they only generate a pulse of settling shells?”*

The two cyclonic eddies focused on in this study both remained over the sediment trap site from between 1 month (January-February 2009) up to 3 months (April-June 2010). Both of these eddies span a typical PF lifecycle (2-weeks to a month) and would have lasted long enough for the next generation of PF to respond. In this study, the 2009 eddy coincided with this narrow reproductive window of the deeper-

dwellers (*globorotaliid* species e.g. *G. truncatulinoides*) and boosted their numbers, through increasing their food availability in addition to aiding their vertical migration through destabilisation of the water column. The large flux of *globorotaliid* species, in particular *G. truncatulinoides*, associated with a cyclonic eddy e.g. in 2009 (this study) and 2007 (unpublished results) suggests that the physical disruption of the water column benefits the reproduction of this particular species. A pulse of settling shells would be less species-specific and presumably represent increased numbers of all PF species abundant at that time rather than just this one.

We suggest that eddies enhance the existing seasonal cycle which is dominantly constrained by MLD and food availability, rather than sparking spontaneous production of foraminifera.

4. *“Fig. 3a. From the graph it seems that the relationship of PF flux to Chl a concentration is curvilinear rather than rectilinear, i.e. while Chl a increases, PF fluxes level off. If so, linear correlation is not warranted.”*

We could amend the trendline in Figure 3a from linear to curvilinear but this produces a smaller  $r^2$  suggesting that the dominant relationship is actually linear. In addition, we have no reason to believe that there should be less sensitivity of PF flux at higher Chl *a* concentrations.

5. *“Given the title of the paper (“.. strength of the carbonate pump..”), what is the contribution of planktonic foraminifera to the carbonate mass flux?”*

~40 % of total carbonate flux during winter as stated in the submitted manuscript:

- Abstract, page 12224, line 11
- Section 4.2, page 12231, line 27-28
- Section 6, page 12236, line 29
- Section 7, page 12237, line 18

6. *“Conclusions, 7, line 16-19: The authors argue that the heavy tests of particularly the winter globorotaliids “...may serve as ballasting mechanisms for carbonate...”. It is unclear, however, what is meant here as the large heavy tests concerned have settling velocities that exceed those of organic matter aggregates and would settle as individual particles rather than ballasting these aggregates as e.g. coccoliths do. Please clarify and include the reasoning in the discussion of results rather than in the conclusions.”*

The use of term ‘ballasting’ was used to describe the *Globorotaliid* tests as ballasts for their own carbonate as they are three times denser than surface dwelling species. These tests do not aggregate with other particles but settle out of water column quickly due to their high settling velocities. We are happy to change this as below.

Adding a sentence to Section 5.1.1, Page 12234, line 5. Changes are shown in bold italic:

“We thus conclude that the depth of the mixed layer plays an important role in regulating PF flux by controlling the abundance and timing of their food availability. ***This in turn controls the flux of the denser tests of Globorotaliids (up to three times denser than surface species). These tests accelerate the transfer of carbonate from surface to deep ocean, thereby strengthening the carbonate pump.***

And changing Conclusion, 7, page 12238, line 17 to:

“We suggest that these dense carbonate tests (***up to three times denser than surface dwellers***) may ***strengthen the carbonate pump by accelerating the transfer of carbonate from surface to deep ocean*** and contribute up to 40% of the contemporaneous peak in total carbonate export fluxes”

7. *“There are various repetitive typos with respect to taxonomy that need correction: Globorotalia rather than Globorotalia; crassaformis rather than crassiformis; Globigeri- noides rather than Globigenerioides”*

Corrected.

## New References

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