

Interactive comment on “Export fluxes in a naturally fertilized area of the Southern Ocean, the Kerguelen Plateau: ecological vectors of carbon and biogenic silica to depth (Part 2)” by Rembauville et al.

Response to the reviewer #3.

We thank the anonymous reviewer #3 for the careful reading of our manuscript and the constructive comments that helped improving the manuscript. All the modifications appear on the new version of the paper attached as a supplement to this answer.

R3-Cx: Reviewer’s comment, **R3-Rx:** authors response.

General comments

***R3-C1.** This paper combines chemical analysis of flux coupled to a species based approach to identifying the main phytoplankton agents of flux. This is an important and commendable approach and one that is essential if our mechanistic understanding of the workings of the marine biological carbon pump are to be improved. As such this approach is also a prerequisite to marine carbon cycle model parameterization. The distinction between full and empty diatom cells is also especially relevant in addressing the issues of potential coupling and decoupling of the carbon and silica cycle, and the reconstruction of a seasonal flux succession of species related to Si/C is especially innovative and impressive. There is also a useful appraisal of the relative importance of the different types of faecal pellets for POC flux. The paper is, on the whole, well written and should be published with minor to moderate revisions.*

However, the paper is linked to a “Part 1” (also a Discussion paper in this issue of Biogeosciences) which documents the biogeochemical fluxes but also makes the case for strong flux attenuation. This case is not well made and the “part 1” will require substantial revision if it is to be reconsidered. Consequently the present paper should be made to stand alone on its own merits and some revision in references to the “Part 1” and some “decoupling” will be required.

R3-R1. We thank the reviewer #3 for the interest he showed in our this manuscript. Given the need for major revisions, we have fully rewritten the discussion of the “Part 1” that now acknowledges and details possible bias in the sediment trap collection efficiency. We took into account these details and incorporated them into our revised “Part 2” manuscript, notably by deleting the reference to “Part 1” in the introduction that suggested strong flux attenuation between 200 m and 300 m. Moreover, we added a sentence about the trapping efficiency in the materials and methods section 2.

MS change section 2, Materials and methods introduction: “Comparison with thorium-based estimates of carbon export suggests a trapping efficiency of 15-30 % relative to the proxy, although strong particle flux attenuation between 200 m and the trap depth (289 m) might also contribute to the low fluxes. We therefore interpret our results to accurately reflect the relationships between the biological and geochemical signals of the material caught by the sediment trap, which we acknowledge does not necessarily represent the entire particle export at 289 m.”

Specific comments

R3-C2. *P 17093 The Section “As reported in the companion paper . . .” in lines 2 – 12. This needs re-written since the case for flux attenuation in the “part 1” companion paper is not well made (see reviews of Part 1).*

R3-R2. We have reformulated this paragraph in the introduction to include the possible hydrodynamic and biological biases that may have affected the collection efficiency of the moored sediment trap. Moreover we specify that the low POC fluxes also originate from the intense heterotrophic microbial activity and zooplankton grazing pressure in the mixed layer.

MS change in the introduction, paragraph 4: “The central Kerguelen Plateau is a good environment to study the ecological vectors of export with sediment traps due to the naturally fertilized recurrent bloom (Blain et al., 2007) and shallow bathymetry that breaks the strong Antarctic Circumpolar Current flow (Park et al., 2008, 2014). As reported in the companion paper (Rembauville et al., 2014), annual POC export measured by the sediment trap deployment at 289 m beneath the southeastern iron-fertilized Kerguelen bloom is 98 ± 4 mmol $\text{m}^{-2} \text{y}^{-1}$. This downward flux of carbon may account for as little as ~ 1.5 % of seasonal net community carbon production (6.6 ± 2.2 mol m^{-2} , Jouandet et al., 2008) and < 2 % of seasonally integrated POC export estimated at 200 m from a dissolved inorganic carbon budget (5.1 molC m^{-2} ; Blain et al., 2007). Although hydrodynamical and biological biases relative to the shallow moored sediment trap deployment might be responsible for a part of the low POC fluxes we report, other measurements of low deep POC fluxes at the same station are consistent with the hypothesis of an intense flux attenuation below the winter mixed layer (Ebersbach and Trull, 2008; Jouandet et al., 2014; Rembauville et al., 2014). These observations lead to a ‘High Biomass, Low Export’ (HBLE, Lam and Bishop, 2007) status characterizing the productive Kerguelen Plateau. HBLE status appears to be a common feature of other productive sites of the Southern Ocean (Lam and Bishop, 2007; Ebersbach et al., 2011; Lam et al., 2011; Maiti et al., 2013; Cavan et al., 2015). Describing the temporal succession of POC and BSi flux vectors from the Kerguelen Plateau is of interest to increase our understanding of the ecological processes characterizing HBLE environments. In particular, phytoplankton community composition and faecal pellet fluxes may be a significant component of particles exported from the Kerguelen Plateau.

R3-C3. *Section 2 (introduction to Materials and Methods) and 2.1 (Sediment trap sample processing) may need expanded to stand more on their own, pending the fate of “part 1”.*

R3-R3. A short description of sediment trap deployment settings (trap type, deployment depth, seafloor depth, location) is necessary in this paper dedicated to the ecological components of the flux. Reviewer #1 suggested that POC and PON analyses belong to the “Part 1” and should not be described here. We thus deleted the section 2.1. and only describe biogenic and lithogenic silicon analyses. We reformulated the material and methods introduction as follows :

MS change section 2: “As part of the multidisciplinary research program KEOPS2 a moored sediment trap (Technicap PPS3) was deployed at 289 m (seafloor depth: 527 m) at the representative bloom station A3 ($50^{\circ}38.3' \text{ S} - 72^{\circ}02.6' \text{ E}$) for a period of 321 days (21 October 2011 to 7 September 2012). The sediment trap mooring was located within an iron-fertilized bloom site on the southern part of the Kerguelen Plateau (Blain et al., 2007). The cup rotation dates of the sediment trap are listed in Table 1. Details of sediment trap design, hydrological conditions, samples processing, POC and PON analyses and surface chlorophyll *a* data extraction are described in the companion paper (Rembauville et al., 2014). Comparison with thorium-based estimates of carbon export suggests a trapping efficiency of 15-30 % relative to the proxy, although strong particle flux attenuation between 200 m and

the trap depth (289 m) might also contribute to the low fluxes. We therefore interpret our results to accurately reflect the relationships between the biological and geochemical signals of the material caught by the sediment trap, which we acknowledge does not necessarily represent the entirety particle export at 289 m”

R3-C4. At the beginning of the discussion section (p17109 lines 7-8) the authors state: “Although there was generally a strong attenuation of flux between the base of the winter mixed layer (WML) and 300 m on the Kerguelen Plateau (Rembeauville et al., 2014). . .”. As stated above, the case for strong flux attenuation is not well made so that this statement should be withdrawn from the present manuscript.

R3-R4. In the companion paper “Part 1”, we have previously compared our sediment trap record (289 m) with other independent flux estimates at 200 m. As pointed out by reviewers of “Part 1”, the diversity of the methods have prevented robust calculations of attenuation coefficients. We have rephrased this statement that is now based on two independent measurements at 200 m and ~350 m in spring (Jouandet et al., 2014) and summer (Ebersbach and Trull, 2008). These results allows us to provide b-values of 3.3 and 4, that are in the range reported for the Southern Ocean (0.9 - 3.9, Lam and Bishop, 2007; Henson et al., 2012; Cavan et al., 2015).

MS change section 4.1: “In a companion paper we present multiple lines of evidence that converge on a scenario of strong flux attenuation between the base of the winter mixed layer (WML at ~220 m) and 300 m on the Kerguelen Plateau. Most notably large attenuation coefficients (3.3 – 4) were calculated from independent measurements in spring and summer.(Ebersbach and Trull, 2008; Jouandet et al., 2014; Rembauville et al., 2014). The flux attenuation, together with under trapping due to hydrodynamics and swimmers, explain the low fluxes at annual scale. Generally POC fluxes...”

R3-C5. In the discussion, the section listing studies that have documented the importance of Chaetoceros resting spores for flux (p 17110 lines 3-22) may be misleading since important specifics are missed out and in fact many of these occurrences are coastal. For example, the study of Kato et al. (2003) is referred to in the text as being of the “East China Sea” – but is in fact on “Omura Bay”. Similarly, Treppke et al (1996) referred to as “Eastern Equatorial Atlantic” ascribe the presence of Chaetoceros resting spores to lateral advection from the coastal upwelling cell. The discussion would be improved if it clarified which of these studies documented truly oceanic or “deep sea” occurrences as opposed to coastal or shelf-related. This is an important distinction since there appear to be three situations where resting spores are important for flux: 1) the well-known coastal/ shelf occurrences generally associated with upwelling or spring bloom; 2) the near-ocean island occurrences (e.g. Crozet & this study) ad 3) the genuinely oceanic occurrences – of which the North Atlantic example documented by Rynearson et al (2013) may be the only documented occurrence. The manuscript would be improved by a more thorough treatment of this point.

R3-R5. This point was also mentioned by Reviewer #1 (see R1-C25 and the response R1-R25). On the first version on the manuscript, it was not clear enough that resting spores contribution to carbon fluxes were essentially restricted to the neritic ocean, with the exception of the (Rynearson et al., 2013) study. We rephrased this paragraph to clearly state that resting spore contribution to carbon flux is a feature occurring in coastal environments or upwelling-influenced areas. The exception in the (Rynearson et al., 2013) might be due to the advection of the coastal populations into the open ocean.

MS change section 4.1.: “Numerous sediment trap studies have reported a strong contribution, if not dominance, of CRS to diatom fluxes at depth in various oceanographic regions: firstly, in coastal influenced regions (e.g. Antarctic Peninsula (Leventer, 1991),

Bransfield Strait (Abelmann and Gersonde, 1991), Gulf of California (Sancetta, 1995), the Omura Bay (Kato et al., 2003), North Pacific Ocean (Chang et al., 2013) and the Arctic (Onodera et al., 2014)), secondly in upwelling-influenced regions (e.g. Santa Barbara basin (Lange, 1997), Eastern Equatorial Atlantic (Treppke et al., 1996)) and finally in the open ocean probably through the advection of coastal populations in the subarctic Atlantic (Rynearson et al., 2013). Similar to sediment trap observations, CRS are reported as dominant in surface sediments of coastal regions (peri-Antarctic shelf and Antarctic sea ice (Crosta et al., 1997; Zielinski and Gersonde, 1997; Armand et al., 2005), the North Scotia Sea (Allen et al., 2005) and east of Kerguelen Island (Armand et al., 2008b)), but also in upwelling-influenced regions (the northeastern Pacific (Grimm et al., 1996), the northeast Pacific (Lopes et al., 2006)) and finally in the open ocean (the North Atlantic, Bao et al., 2000). Moreover, the annual POC export from the A3 station sediment trap at 289 m ($98.2 \pm 4.4 \text{ mmol m}^{-2} \text{ y}^{-1}$) falls near annual estimates from deep sediment traps (>2000 m) located in the naturally fertilized area downstream of the Crozet Islands (37-60 and 40-42 $\text{mmol m}^{-2} \text{ y}^{-1}$, Salter et al., 2012) where fluxes were considered as mainly driven by resting spores of *Eucampia antarctica* var. *antarctica*. Diatom resting spores are frequently observed in blooms heavily influenced by the proximity of the coast. Major resting spores contribution to carbon fluxes was observed in one study in the open North Atlantic Ocean (Rynearson et al., 2013), but they are generally absent or very rare in open ocean sediment trap studies (Fischer et al., 2002; Grigorov et al., 2014; Rigual-Hernández et al., 2015). The frequent occurrence and widespread distribution of diatoms resting spores in the neritic or coastal-influenced ocean suggest their pivotal role in the efficient transfer of carbon to depth in these areas.”

Technical corrections

R3-C6. In the representation of the fluxes in the figures, the diatom and biogeochemical fluxes are represented by month whereas the faecal pellet fluxes are represented by cup number. It would help if the latter also included months so that more ready comparisons could be made.

R3-R6. We originally chose to represent the cup number for the boxplots of faecal pellet size as centered on the x-axis. We have now updated the figure following the Reviewer’s suggestion (see the new Figure 5 at the end of this answer and in the new version of the manuscript).

R3-C7. Abstract: line 9 – should be “cells”; and “of the biological pump”.

R3-R7. Change implemented.

R3-C8. p 17091 line 3 “mode” waters not “modal”;

R3-R8. Change implemented.

R3-C9. p 17091 line 20 “micronutrient” not “micronutrients”

R3-R9. Change implemented.

R3-C10. p 17101 line 10 replace “comprised in” with “within”

R3-R10. Change implemented.

R3-C11. p 17103 line 15 “The flux of. . .” delete flux

R3-R11. Change implemented.

R3-C12. p 17109 line 23 “the remaining of the..” needs re-written

R3-R12. We rephrased this sentence and added another possible explanation for the observation of empty vegetative stages of *C. Hyalochaete* following Reviewer #1’s suggestions (see R1-C24 and the response R1-R24).

MS change section 4.1.: “These empty frustules may be the remnants of vegetative stages following the spore formation. Alternatively, dissolution of the lightly silicified valves or girdle bands of the vegetative cell could result in the rapid consumption of the cellular organic material in the upper water column and this may also explain the absence of full vegetative cells in the sediment trap record.”

R3-C13. p 17111 lines 14-15 should be “life cycles” also delete “the” in line 15.

R3-R13. Change implemented.

R3-C14. p 17115 lines 8 – 12: this sentence needs a rewrite

R3-R14. We simplified the section of text by deleting the end of the sentence.

MS change section 4.3.: “Nevertheless, the increasing full cell flux of *Eucampia antarctica* var. *antarctica* from spring to summer in the sediment trap time series is consistent with the observations of an increasing abundance in the mixed layer at the station A3 in summer (Armand et al., 2008). ~~and therefore the role this species plays as an efficient vector for carbon export.~~”

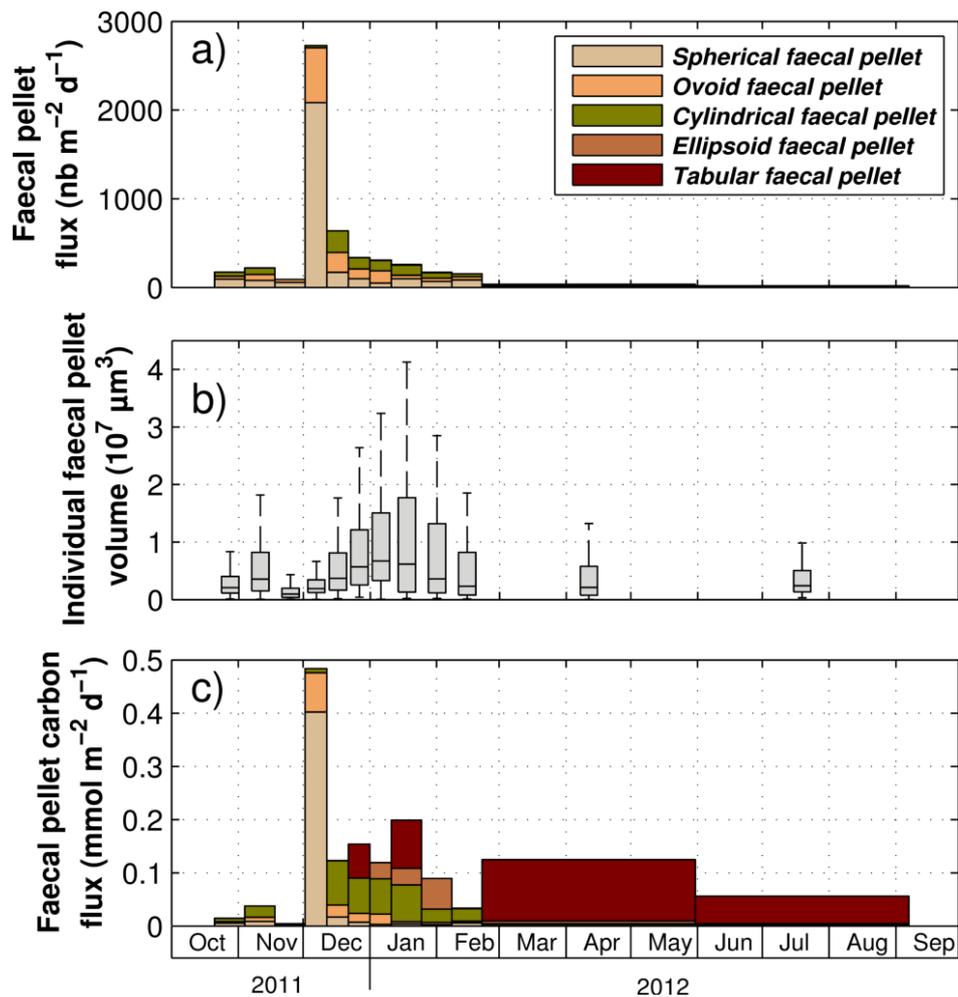
R3-C15. p 17119 line 18 – spore not “sport”

R3-R15. Change implemented.

R3-C16. p17124 line 12 “Quguiner” spelling

R3-R16. Change implemented..

New Figure 5 following reviewer #3 suggestions:



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