Supplement. Answer to reviewer #1

R1-Cx : Referee comment, **R1-Rx:** authors response.

R1-C1: **General comments**

Rigual-Hernandez and co-workers studied the seasonal and interannual variability of particle and diatoms fluxes trapped at two locations in front areas between Tasmania and Antarctica. Station 47_S was deployed in the central SAZ (two-year record), while Station 54_S (six-year record) was located in the PFZ. They compare and discuss their data with results previously gained at both stations and at 51_S and 61_S. Fluxes are highly seasonal, with two maxima registered during the austral summer and minima during winter. Biogenic silica (opal) is the dominant component at 54_S, less important at 47_S. The strong correlation between opal and organic carbon suggests that a significant fraction of the organic matter exported to the deep sea is delivered by diatom productivity events. Seasonal diatom fluxes appear driven principally by changes in the flux of *Fragilariopsis kerguelensis*, the main contributor to the diatom/opal flux during the bloom season. In addition, a diverse diatom assemblage delivers information on species dynamics, which can be useful for understanding the signal preserved in late Quaternary sediments from the Southern Ocean.

The manuscript is well written and well organized and can be published in Biogeosciences after some revision. The Introduction and the Discussion would greatly benefit from some shortening. Below I list a few remarks and make some comments, which I hope the authors find helpful.

R1-R1: General comments

We thank Dr. Oscar Romero (reviewer #1) for the careful reading of our manuscript and the constructive comments that helped improving the manuscript. Overall, the introduction and the discussion have been shortened significantly following referee #1's recommendations. The description of the PCA analysis in the results section has been rephrased and shortened. Moreover, a new graph showing the temporal variability and the interannual average of the molar ratio BSi:PIC has been included in the new version of the manuscript (supplementary figure 1). Additionally, the issues raised by reviewer #1 regarding the formation of aggregates have been clarified in the manuscript by re-phrasing and shortening the discussion and rephrasing the conclusions. Finally, all the above mentioned changes, together with a throughout revision of the manuscript have reduced significantly the number of references presented in the reference list.

R1-C2: **Specific comments**

The Introduction addresses several subjects. Although these subjects are discussed afterward, I suggest some shortening and/or a re-arrangements of issues addressed. The first paragraphs mainly deals with the significance of the Southern Ocean in the marine realm. Part of the issues addressed here are also mentioned in "2. Oceanographic and biological setting". Paragraphs 3 (Diatoms in water and sediments) and 4 (Temporal variability of diatom productivity) can be shortened and combine into one paragraph. The research using sediment traps has been running for some decades in the meanwhile. I don't think it is necessary to extend much on this issue in the Intro. Issues related with diatoms and/or biological pump can be combined into Paragraphs 2 and 3-4. Objectives 1. and 2. are very similar. Rephrase (or combine?).

R1-R2: Corrected according to Reviewer #1´s suggestion. The introduction has been re-structured and re-written in the following manner:

- The text has been shortened to ~two-thirds of its original length (from 1415 to 1032 words).

- Paragraphs 3 (Diatoms in the Southern Ocean waters and sediments) and 4 (gaps in the knowledge) have been shortened significantly following reviewer #1's advice. However, since each paragraph deals with a different topic, they remain separated into two different paragraphs in the new version of the manuscript.

- Paragraph 5, which was dedicated to review the application of sediment traps, has been reduced to approximately half of its original size. Now the literature review skips the general applications of sediment traps and focuses on the major findings on diatom ecology in the Southern Ocean using sediment traps.

- The formation of intermediate and mode waters in the SAZ and PFZ plays a key role in the global distribution of nutrients and CO_2 and therefore this is a critical point that should be stressed in our study. Although the formation of these water masses is mentioned in both the introduction and section "2. Oceanographic and biological setting", this topic is addressed from a different perspective in each section. In the introduction the role of the Southern Ocean in the global conveyor belt is presented while in Section 2 the oceanographic circulation is addressed from a regional perspective (i.e. Australian Sector) providing the names of the intermediate and mode waters formed. Taking into account that the text dedicated to this explanation only occupied 6 lines (line 26, page 8621 and 1 to 5, page 8622; original version of the manuscript) in section "2. Oceanographic and biological setting" we believe that this part of the manuscript shouldn't be modified in the new version of the manuscript.

- The changes applied to the introduction have also reduced significantly the number of references of this section (see R1-C26).

- Finally Objectives 1 and 2 have been combined together following reviewer one's recommendations.

R1-C3: *p. 8621, l. 17-18: provide a recent reference for SST. Rintoul and Trull, 2001, hardly cover the studied period presented in the manuscript.*

R1-R3: Corrected according to reviewer's suggestion. The summer range of SST provided by Rintoul and Trull (2001) has been replaced by a new range obtained from the SST data presented in Figure 2. Please note that the SST data in figure 2 was obtained from the IGOSS NMC database (the Integrated Global Ocean Services System Products Bulletin, National Meteorological Center;

Reynolds et al., 2002). The source of these data is provided in section “3.7 Environmental variables”.

R1-C4: *p. 8621, l. 22-24: sort of similar to what is said above in l. 16-18. Revise.*

R1-R4: Corrected according to reviewer’s suggestion. The average summer SSTs for the study period has been estimated from the SST data presented in figure 3. The new SST range has been included and Figure 3 cited.

R1-C5: *p. 8622, l. 6: which zones? Clarify.*

R1-R5: Corrected according to reviewer’s suggestion. The words “both zones” have been replaced by “the PFZ and SAZ” (198, manuscript with tracked changes).

R1-C6: *p. 8622, l. 8: chemical elements sometimes fully written, sometimes abbreviated. Please revise and unify.*

R1-R6: Corrected according to reviewer’s suggestion. The whole manuscript has been revised and the chemical elements are now fully written in the manuscript. The only exception is Biogenic silica which has been replaced by BSi in order to reduce the number of words in the manuscript.

R1-C7: *P. 8623, l. 14: it is not quite right to state that results are presented for a six-year record between 1997 and 2007. Please detail which years have been sampled. The info about the trapping intervals should be in the Abstract and in the Intro as well.*

R1-R7: Corrected according to reviewer’s suggestion. The years that have been sampled are now detailed in the abstract, section “3.1 Field experiment” (line 237, manuscript with tracked changes), section “4. Results” (lines 388-390, manuscript with tracked changes) and listed in Table 2. However, the dates have not been included in the Introduction to avoid excessive repetition.

R1-C8: *P.8624, l. 12: any suggestion of the “degree of undertrapping” being seasonally dependent? Or remained the same all-year round?*

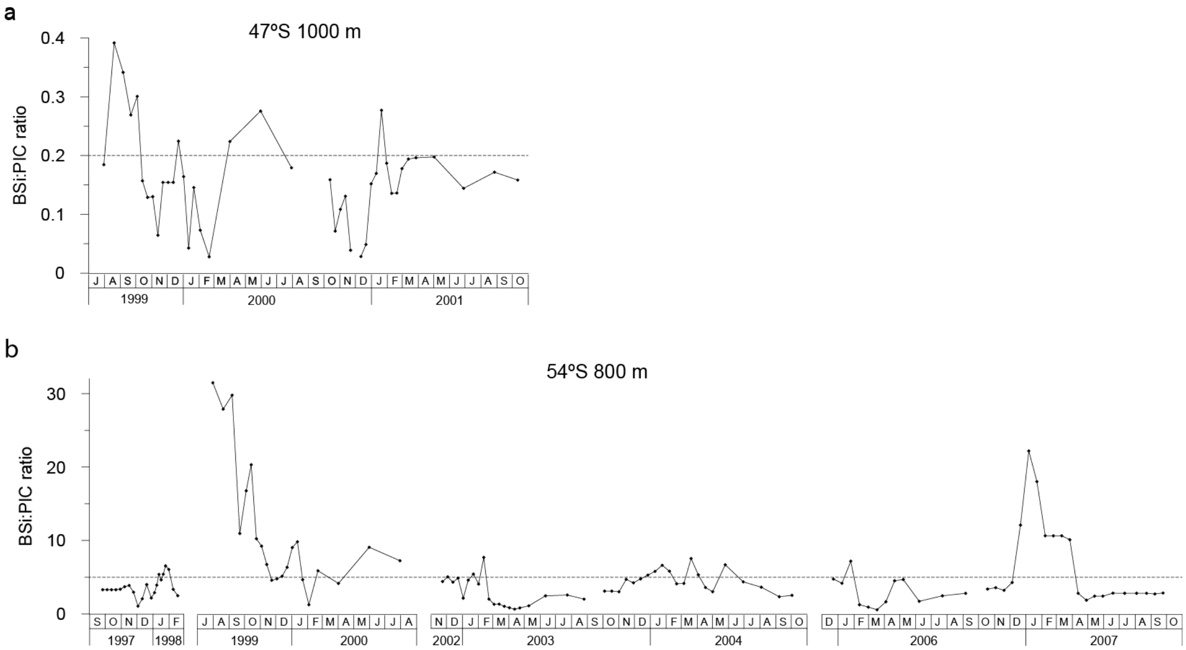
R1-R8: Current meter data at trap depths showed little seasonal variability, and therefore the seasonally of collection is likely to be small. The first half of section “3.2 Quality check of downward particles” has been re-written in order to clarify this point (lines 217-224, manuscript with tracked changes).

R1-C9: *P. 8628, l. 17-19: start describing new results, move this sentence to the end of the first Results paragraph.*

R1-R9: Corrected according to reviewer’s suggestion. In the new version of the manuscript we first introduce the new data that is presented in our study and then we mentioned the study by Trull et al. (2001) that covered the first year deployment.

R1-C10: *P. 8629, l. 17-19: plot the temporal pattern of BSi:PIC mole.*

R1-R10: The temporal patterns of BSi:PIC mole of both the 47°S and 54°S sites together with its inter-annual average have been plotted in Supplementary figure 1 (pasted below). This figure is cited in the new version of the manuscript (lines lines 417-418, manuscript with tracked changes).



Supplementary figure 1: Temporal pattern of BSi:PIC ratio at the 47°S (a) and 54°S (b) mooring sites. Dashed lines represent the average inter-annual BSi:PIC ratio.

R1-C11: *P. 8631, l. 16-17: are these diversity index values annual averages? Or averages for the entire trap experiments?*

R1-R11: The *H’* diversity indexes for the 61°S, 54°S and 47°S sites were estimated from the relative contribution of the diatom species for the entire sampling period at each site. This point has been clarified in the new version of the manuscript following reviewer #1’s suggestion (line 470, manuscript with tracked changes).

R1-C12: *Same question for the statement in l. 19: 43% for F kerguelensis refers to which interval?*

R1-R12: Corrected according reviewer one’s suggestion. In the new version of the manuscript it is clarified that the relative contribution of *F. kerguelensis* was obtained from the integrated diatom assemblage for the entire sampling period (lines 473-474, manuscript with tracked changes).

R1-C12: *The same for the listed spp. in the following lines.*

R1-R13: This point has already been clarified for *F. kerguelensis* in the previous sentence and therefore the reader can infer that the subordinate contributions of the rest of the species were estimated in the same manner as for *F. kerguelensis*. We believe that explaining again how these values were obtained would be somewhat redundant.

R1-C14: *P. 8632: "4.3. Principal component analysis" OF WHAT?*

R1-R14: The title of this section has been clarified following reviewer one' request. The new title is: "4.3 Principal component analysis of diatom assemblages"

R1-C15: *In general, the description of the PCA is wordy and tedious to read. Rephrase and shorten!*

R1-R15: The description of the PCA has been rephrased and shortened following reviewer #1's recommendation. The references to *Nitzschia bicapitata* and *Thalassiosira* sp. 1 in the 47°S PCA and *Thalassiosira lentiginosa* in the 54°S PCA have been deleted in order to shorten the description of the results of the analysis.

R1-C16: P. 8632, l. 6-7: the use of only two axes for site 47_S explain less than 40% of the variance. Whether this information is ecologically significant is a quite different issue.

R1-R16: We acknowledge the point our reviewer is trying to make- that the information provided by the two first PCA (40% of the variance) is probably not enough to explain the variability of the diatom assemblages at site 47°S. The first four axes (64% of the variance) were initially considered when analysing the PCA of the 47°S site (Table 5a). However, as mentioned in the first version of the manuscript the last two components are monospecific and had no clear ecological significance, that's why they are not discussed in the text.
The main purpose of the PCA performed at the 47°S is to serve as a comparison with the results of station 54°S with the objective to show the contrasting role that the diatom species play in the controls of particle export in the SAZ and PFZ. Whilst at the 54°S site the diatom species are clearly grouped into clusters that exhibit a strong relationship with the major components of the flux, the distribution of diatom species in the 47°S PCA is scattered with none of the factors showing a clear relationship with the components of the flux. Finally, it is worth noting that although the groups suggested by the 47°S PCA are mentioned in section 5.3 (lines 704-708, manuscript with tracked changes) we are brief and cautious with our interpretations and their seasonal variability is not interpreted as a clear response to external forcing or environmental variability.

R1-C17: P. 8636, "5.2. Latitudinal diatom species distribution" and "5.3.Seasonal variability of diatom assemblages": this two Discussion sections can be shortened and combined. The seasonal variability in the composition of the diatom community follows the same pattern of discussion: first the community at 47_S, then at 54_S, then the comparison with previous near-by studies. I suggest also constraining the discussion to the ecologically most significant species (based on PCA?). Section 5.3. is extremely detailed and wordy. For the audience less familiar with diatoms, it is difficult to follow and try to pick up the main message/s. Some space can be saved by abbreviating the genera name (no need to fully write them once they have been mentioned).

R1-R17: Both sections have been shortened and re-arranged following reviewer one's suggestion:

- Section "5.2. Latitudinal diatom species distribution" has been reduced ~30% of its original length (from 954 to 692 words) and the discussion has been constrained to the ecologically most significant species as suggested by reviewer #1. The main two changes made to this section are:
    1. Elimination of the paragraph dedicated to the *Chaetoceros* resting spores (RS) and their possible advection from the Tasman coast (lines 604-617, manuscript with tracked changes). The presence of *Chaetoceros* RS was interpreted as an indicator of coastal waters advected from the Tasman coast towards the 47°S site. However, according to reviewer #2´s (comment **R2-C8**), the production of *Chaetoceros* RS could have also occurred *in situ*. Therefore, in order to avoid speculations and shorten the length of section 5.2 this paragraph has been left out in the new version of the manuscript.
    2. Elimination of the references to sea-ice affiliated species at the end of the section (lines 24-28 P. 8637). The fluxes of sea-ice affiliated species were low at site 61°S (Rigual-Hernández et al. 2015) and negligible at the 54°S and therefore this information can be cut out in the manuscript.

- Section "5.3.Seasonal variability of diatom assemblages" has also been shortened to about two thirds of its original length (from 1455 to 1043 words) and re-arranged in the following manner:
    1. The first part of this section (lines 661 to 668, manuscript with tracked changes) has been deleted. The direct relationship between primary production and export fluxes is a common phenomenon in open ocean environments and thus it doesn't have to be necessary mentioned in the manuscript.
    2. The last speculations about the possible explanations for the bimodal distribution of the diatom bloom, i.e. other ecological factors and statistical funnel issues (lines 724-730, manuscript with tracked changes) have been deleted.
    3. Moreover, this section has been re-arranged following reviewer #1's recommendation and now the seasonal succession at the 47°S site is presented before the one of the 54°S site.
    4. The paragraph dedicated to *Pseudo-nitzschia heimii*, *Thalassiothrix antarctica* and *Proboscia* (lines 766-774, manuscript with tracked changes) has been deleted in order to shorten this section. However, the relationship between the sedimentation of these species with the POC fluxes is now addressed in a new paragraph included at the end of section 5.4 (lines 854-867, manuscript with tracked changes) following reviewer #2's recommendations (see Answer to referee #2 comments).
    5. In the first version of the manuscript diatom names were written in full the first time they appeared in each section. In the new version of the manuscript diatom species names are now only written in full the first time they are mentioned in the manuscript or at the beginning of a sentence. However, some exceptions were made, in particular

with *Thalassiothrix antarctica*, the abbreviated name of this species can be confused with *Thalassiosira antarctica* and therefore, we have decided to leave the name in full in the text to avoid confusion.

Since both sections deal with quite different topics, i.e. geographical vs. temporal species distribution, the new version of the manuscript still maintain the two sections separated.
Moreover, the last paragraph of section "5.4 Ecological flux vectors in the PFZ" (lines 867-877, manuscript with tracked changes) dedicated to the particulate export during the autumn and winter months has been deleted in order to reduce the length of the discussion.

R1-C18: P. 8637, l.17: abundance of F kerguelensis: relative or absolute?

R1-R18: Relative abundance. This point has been clarified in the text following reviewer #1's suggestion (line 464, manuscript with tracked changes).

R1-C19: P. 8638, l. 7-17: this has been already discussed above.

R1-R19: Despite the fact that the composition of the particle fluxes at the 54°S and 47°S sites has already been discussed in section 5.1, this is the first and only time in the manuscript where the correlation coefficients between mass and diatom valve fluxes are discussed. These correlation coefficients are a key argument to point out the different role of diatoms in the control or particle export in the SAZ and in the PFZ (as highlighted in the last sentence of the paragraph), and therefore we believe that this piece of text should remain in the final version of the manuscript.

R1-C20: P. 8643: as long as the authors do not provide own observations on the occurrence of aggregates in their trap samples, this part of the Discussion remains speculative.

R1-R20: Due to the postcollection changes of the particles stored in the sediment trap cups, the analysis of the size spectrum of the particles that originally settled into the traps was discarded for our study. However, there are three solid arguments that strongly support the idea that the formation of aggregates recurrently occurs during the productive season (summer) in our 54°S study site. Firstly, the study by Ebersbach et al. (2011) conducted at the 54°S site in summer 2007 with cylindrical traps filled with polyacrylamide gels showed that more than 90% of the particle flux occurred in the form of aggregates. We referred to this study in the original version of the manuscript (lines 5-6 page 8643 and from line 26 page 8645 to line 4 page 8646; original version of the manuscript). Moreover, a previous sediment trap study along the AESOPS transect (170°W) in the Pacific sector reached a similar conclusion (Grigorov et al. 2014) (line 6 page 8643, original version of the manuscript). Finally, based on the time lag between samples with similar silicon isotopic signature in the shallow and deeper traps in our mooring line at 54°S site, Closset et al. (2015) (this paper has just been accepted in Global Biogeochemical Cycles and the citation updated in the new version of the manuscript; lines 805-810, manuscript with tracked changes) estimated the sinking rates of the settling particles. These sinking rates were at least 35 m d^{-1}, a value that falls within the range of marine snow and faecal pellets (Turner et al. 2002), indicating that that most of the particles at this site sink in the form of aggregates during summer. These latter studies together

with the fact that all the components of the flux were highly correlated in our samples strongly suggest that the different particles co-sedimented in the form of aggregates (as suggested at the end of section 5.4).
However, in order to be more cautious with our interpretations some changes have been included in section 5.4. The factors affecting/defining the formation of aggregates (lines 814-819, manuscript with tracked changes) have been deleted. Also the sentence in line 819 (manuscript with tracked changes) "We suggest that the massive development of "High-export group" diatoms during the growth season facilitates the formation of aggregates in the upper water column" has been replaced by "We speculate that…". Moreover, in line 816 (manuscript with tracked changes), the second sentence has been rephrased, now it reads: "Although speculative, it is possible that that the formation of aggregates during the diatom bloom also facilitated the scavenging...".

R1-C21: In l. 10-27 factors affecting/defining the formation of aggregates is discussed: is this necessary?

R1-R21: As mentioned in the answer to the previous comment, the introduction to the factors affecting/defining the formation of aggregates has been deleted in the new version of the manuscript.

R1-C22: In P. 8644, l. 8-14, the possible effect of aggregate formation is again raised.

R1-R22: This point has already been clarified in **R1-R20**.

R1-C23: The "aggregate" issue appears also in "6. Conclusions" (P. 8647, 14-16).

R1-R23: The text referred by reviewer one has been rephrased in order to be more cautious with our statements regarding the formation of aggregates. In the new version of the manuscript it reads: "Our results suggest that the development of a group of bloom-forming diatom species during the growth season **probably led** to the formation of algal and/or faecal aggregates." (line 951, manuscript with tracked changes).

R1-C24: P. 8644, l. 2.5: this is somehow confusing. Please revise.

R1-R24: The sentence referred by reviewer #1 has been rephrased in order to make it easier to understand. Now it reads: "In contrast, the thick-shelled *F. kerguelensis* is a more compelling candidate to be responsible for the bulk of the BSi export, because despite the fact that its relative abundance exhibited the lowest values of the record during summer, its valve fluxes always were highest during this season." (lines 836-839).

R1-C25: **Figures:**
Fig C3174 2: what do the authors mean with "Others"? Lithogenics? (see also Fig 3)

R1-R25: Figure captions 2 and 3 have been rephrased and clarified (lines 996-1020). Moreover, the term "Others" has been replaced in Figure 2 and 3 by "Other".

R1-C26: **References:**

I leave this up to the Editor: for a research article, the Reference list is quite long.

R1-R26: Corrected according to reviewer two' suggestion. Due to the shortening of the text and the removal of unnecessary references along the text, the reference list of the new version of the manuscript is 50 references shorter.

R1-C27: **Technical corrections**

P. 8639, l. 23: delete the dot before Kopczynska.

R1-R27: Corrected according to reviewer 1´ suggestion.

R1-C28: P. 8644, l. 2: delete w after to.

R1-R28: Corrected according to reviewer 1´ suggestion.

Additional technical corrections

Line 18 P. 8633. The value 60% corresponded to the relative abundance of the High export group, not to the relative abundance of *Pseudo-nitzchia lineola* cf. *lineola* and small *Fragilariopsis* together. In the new version of the manuscript this value has been replaced by the correct one (50%).

As mentioned in **R1-R25** the term "Others" has been replaced by "Other" in Figures 2b and 3b. Moreover, the axes of the 3b were displaced in the first version of the manuscript. This error has been fixed in the new version of the manuscript. Figures will be provided to the editorial board in the next stage of the publication process.

Table 3c. There was an error in the BSi:PIC flux of year 2002-03 (the value 5.9 should be 3.4 instead). The corrected value has been included and the annual average and SD corrected (i.e. the value 5.4 ± 2.1 has been replaced by 5.0 ± 2.2). This value has also been updated in the text (line 417, manuscript with tracked changes).

Supplement. Answer to reviewer #2

R2-Cx : Referee comment, **R2-Rx:** authors response.

R2-C1: *This is an important contribution that takes a species-based approach to the attribution of carbon flux and potential CO2 draw down. Sediment traps that tap export from the surface layer in key locations in the Pacific sector of the Southern Ocean offer an important insight into the operation of the biological carbon pump. The paper is, on the whole, well written, with just a few lapses in phrasing (see detailed comments below).*
While the role of key species and species groups is generally well considered, there are some potentially miss-leading and contradictory over-generalisations regarding some taxa, notably Thalassiothrix – see detailed comments below.

R2-R1: We appreciated the constructive criticism of reviewer #2 and have carefully considered all their comments, addressing each of their concerns as outlined below. Overall, in the new version of the manuscript the issues addressed by reviewer #2 in regard to the formation the Subsurface Chlorophyll Maximum in the PFZ have been clarified. Moreover, a new paragraph dedicated to the role in the carbon export to the ocean interior of *Thalassiothrix antarctica* and other shade flora species at the 54°S site has been included in section "5.4. Ecological flux vectors in the PFZ" (lines 854-867, manuscript with tracked changes). Finally, *Thalassiothrix antarctica* has been deleted from the list of diatoms that preferentially sink silicon versus carbon mentioned in section "5.5 Relative importance of the SAZ and PFZ to carbon export" in order to avoid over-generalizations.

***R2-C2*: Specific comments:**
Last sentence of abstract is muddled – needs rephrased to e.g. "F. kerguelensis plays a major role in the decoupling: : :.".

R2-R2: Corrected according to reviewer #2´s suggestion. The sentence "... *F. kerguelensis* is a major aspect of the decoupling of the carbon and silicon cycles in the high-nutrient low-chlorophyll waters of the Southern Ocean" has been replaced by "... *F. kerguelensis* plays a major role in the decoupling of the carbon and silicon cycles in the high-nutrient low-chlorophyll waters of the Southern Ocean" (lines 44-46, manuscript with tracked changes).

R2-C3: P 8619 – line 7 replace "to determine" with "the determination of".

R2-R3: Corrected according to reviewer #2´s suggestion (line 109, manuscript with tracked changes).

R2-C3: P 8621 – line 12 "biological distributions" - meaning uncertain – do you mean "biological characteristics"?

R2-R3: Corrected according to reviewer #2's suggestion. "biological distributions" has been replaced by "biological characteristics" (line 178, manuscript with tracked changes).

R2-C4:P. 8622 lines 23-27. It is not clear how a subsurface chlorophyll maximum (SCM) can be formed as a response to iron and silicate colimitation. Surely the SCM is formed either by settling of cells to depth or by growth at depth – this needs clarification.

R2-R4: Corrected according to reviewer #2's suggestion. The explanation of the possible causes of the formation of the SCM in the PFZ south of Tasmania has been extended and clarified in the new version of the manuscript. Now it reads as: "Finally, it is worthy to note a feature present in the PFZ but not in the SAZ: a subsurface chlorophyll maximum (SCM) dominated by large diatom species (Kopczynska et al., 2001) has been consistently reported during summer in the PFZ within or beneath the seasonal pycnocline. The formation and maintenance of this SCM is most likely due to the settling of phytoplankton cells as a response to iron and silicate colimitation in the mixed layer during summer (Popp et al., 1999; Parslow et al., 2001)." (lines 215-221, manuscript with tracked changes)

R2-C5: P. 8626 line 19 – replace "at" with "to".

R2-R5: Corrected according to reviewer #2's suggestion (line 332, manuscript with tracked changes).

R2-C6: P. 8633 – line 17 – insert "the" before "relative".

R2-R6: Corrected according to reviewer #2's suggestion (line 531, manuscript with tracked changes).

R2-C7: P. 8633 – line 25 replace "distributions" with "characteristics".

R2-R7: Corrected according to reviewer #2's suggestion. The word "distributions" has been replaced by "characteristics" (line 541, manuscript with tracked changes).

R2-C8:**Discussion:**
p. 8636 – line 5; the authors state that Chaetoceros resting spores are indicators of coastal environments. – Yes – but not exclusively – see for example the recent account of massive flux of Chaetoceros resting spores in the oceanic North Atlantic (Rynearson, T.A. 2013 "Major contribution of diatom resting spores to vertical flux in the sub-polar North Atlantic" Deep-Sea Research I, 82, 60-71). This study should be referred to here, and the possibility of oceanic resting spore formation acknowledged.

R2-R8: In order to fulfil reviewer #1's recommendations (see **R1-R17**), section "5.2. Latitudinal diatom species distribution" has been reduced to the ecologically most significant species. The paragraph dedicated to the possible origin of *Chaetoceros* resting spores was quite long and not essential in the discussion. Therefore, this part of the discussion has been deleted in the new version of the manuscript. Nonetheless, we acknowledge reviewer #2's comment on the possible origin of *Chaetoceros* resting spores and the reference of Rynearson et al. (2013) will be cited in a future paper that will compare the diatom assemblages captured by the sediment traps (shallow and deep traps) and the ones registered in the surface sediments.

R2-C9:P. 8641 – line 11: replace "any" with "one".

R2-R9: Corrected according to reviewer #2' suggestion (line 697, manuscript with tracked changes).

R2-C10: P. 8646 - lines 13-17 – here the authors lump a number of species together including Thalassiothrix antarctica with Fragilariopsis kerguelensis – following the quoted Assmy et al (2013) study. But, in fact, both the present discussion paper and the Assmy study are selective here. Both studies make the ecological association of T. antarctica with other subsurface chlorophyll maximum taxa such as the relatively more lightly silicified Proboscia – then both papers place T. antarctica together with F. kerguelensis. The main difference here is that T. antarctica with its fall dump sedimentation (along with Proboscia) is probably much more critical as a carbon sinker than F. kerguelensis. The manuscript would benefit from a fuller discussion of these issues.

R2-R10: Corrected according to reviewer #2's suggestion. *Thalassiothrix antarctica* has been deleted from the list of diatoms that preferentially sequester silicon relative to carbon in the last section of the discussion (line 924, manuscript with tracked changes). Moreover, a paragraph dedicated to the subsurface chlorophyll maximum taxa (i.e. *Thalassiothrix* and *Proboscia*) and their role driving carbon export at the 54°S site has been included in the new version of the manuscript (lines 853-866, manuscript with tracked changes).

Latitudinal and temporal distributions of diatom populations in the pelagic waters of the Subantarctic and Polar Frontal Zones of the Southern Ocean and their role in the biological pump

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Código de campo cambiado

Abstract

The Subantarctic and Polar Frontal zones (SAZ and PFZ) represent a large portion of the total area of the Southern Ocean and serve as a strong sink for atmospheric CO_2. These regions are central to hypotheses linking particle fluxes and climate change, yet multi-year records of modern flux and the organisms that control it are, for obvious reasons, rare. In this study, we examine two sediment trap records of the flux of diatoms and bulk components collected by two bottom-tethered sediment traps deployed at mesopelagic depths (~1 km) in the SAZ (two-year record; July 1999 - October 2001) and in the PFZ (six-year record; September 1997 - February 1998, July 1999 - August 2000, November 2002 - October 2004 and December 2005 - October 2007) along the 140°E meridian. These traps provide a direct measure of transfer below winter mixed layer depths, i.e. at depths where effective sequestration from the atmosphere occurs, in contrast to study of processes in the surface ocean. Total mass fluxes were about two-fold higher in the PFZ (24 ± 13 g m^{-2} yr^{-1}) than in the SAZ (14 ± 2 g m^{-2} yr^{-1}). Bulk chemical composition of the particle fluxes mirrored the composition of the distinct plankton communities of the surface layer, being dominated by carbonate in the SAZ and by biogenic silica in the PFZ. POC export was similar for the annual average at both sites (1.0 ± 0.1 and 0.8 ± 0.4 g m^{-2} yr^{-1}, for the PFZ and SAZ, respectively), indicating that the particles in the SAZ were relatively POC rich. Seasonality in the particle export was more pronounced in the PFZ. Peak fluxes occurred during summer in the PFZ and during spring in the SAZ. The strong summer pulses in the PFZ are responsible for a large fraction of the variability in carbon sequestration from the atmosphere in this region. The latitudinal variation of the total diatom flux was found to be in line with the biogenic silica export with an annual flux of 31 ± 5.5 x 10^8 valves m^{-2} yr^{-1} at the PFZ compared to 0.5 ± 0.4 x 10^8 m^{-2} yr^{-1} of the SAZ. *Fragilariopsis kerguelensis* dominated the annual diatom export at both sites (43% at the SAZ and 59% in the PFZ). POC fluxes displayed a strong positive correlation with the relative contribution of a group of weakly-silicified and bloom-forming species in the PFZ. Several lines of evidence suggest that the development of these species during the growth season facilitates the formation of aggregates and carbon export. Our results confirm previous work suggesting that *F. kerguelensis* plays ~~is~~ a major role in the ~~aspect of the~~ decoupling of the carbon and silicon cycles in the high-nutrient low-chlorophyll waters of the Southern Ocean.

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1. Introduction

The Southern Ocean is a critical component of the Earth's ocean-climate system and plays a pivotal role in the global biogeochemical cycles of nutrients and carbon. Due to its unique meridional overturning circulation, deep waters are upwelled south of the Polar Front supplying the surface waters with nutrients and allowing the ventilation of carbon dioxide accumulated during centuries of deep-sea respiration (Anderson et al., 2002; Pollard et al., 2006). Strong interactions with the atmosphere transform the upwelled deep waters into bottom, intermediate, and mode waters, which spread to lower latitudes renewing the intermediate and abyssal depths of the world ocean (Sarmiento et al., 2004; Sigman et al., 2010). Dissolution of carbon dioxide in these newly formed waters (i.e. the solubility pump) and the transport of photosynthetically fixed carbon to depth in settling particles (i.e. the biological pump) modulate the extent to which the carbon dioxide is transferred to the atmosphere. The balance between these processes determines the role of the Southern Ocean either as a source or sink of atmospheric CO_2 over glacial-interglacial climate cycles (Kohfeld et al., 2005; Anderson et al., 2009; Sigman et al., 2010).

At present, the Southern Ocean biological pump is not operating at its full capacity (De La Rocha, 2010). ~~High concentrations of macronutrients coupled with only modest rates of primary production characterize its surface waters (Arrigo et al., 1998; Falkowski et al., 1998; Moore and Abbott, 2000; Arrigo et al., 2008).~~ Low sun angles, deep wind-mixed surface waters and lack of the micronutrient iron restrict phytoplankton growth (~~Johnson et al., 1997; Fitzwater et al., 2000;~~ Boyd et al., 2007; Venables and Moore, 2010) making the Southern Ocean the largest high nutrient low-chlorophyll (HNLC) region in the world ocean (Martin, 1990). However, there are exceptions to this situation with areas of higher phytoplankton abundance occurring along oceanographic fronts (Laubscher et al., 1993; Moore and Abbott, 2000), downstream of some islands (Blain et al., 2001; Park et al., 2010), in the wake of the retreating seasonal sea ice (Smith et al., 1988; Brzezinski et al., 2001), in coastal polynyas (Arrigo and van Dijken, 2003) and in coastal systems of Antarctica (Sedwick et al., 2000; Brzezinski et al., 2001). In these areas iron fertilizes the surface layer triggering phytoplankton blooms in spring and summer.

Diatoms ~~are a group of eukaryotic unicellular algae characterized by opaline silica tests (frustules) that can be preserved in the sedimentary record. They~~ are one of the most abundant primary producers in the Southern Ocean and make the major contribution to the biogenic silica (BSi) content of deep-sea sediments. ~~Satellite and in situ observations reveal that e~~Extensive diatom blooms occasionally develop in the Antarctic Circumpolar current (ACC) (e.g. Kopczynska et al., 2001; Green and Sambrotto, 2006; Alvain et al., 2008; ~~de Salas et al., 2011;~~ Grigorov et al., 2014) which results in the formation of a band of siliceous ooze that encircles Antarctica (DeMaster, 1981; Buesseler et al., 2001; DeMaster, 2002). This “Diatom Ooze Belt” ~~defined by Burckle and Cirilli (1987)~~ constitutes the world's largest sedimentary sink for ~~biogenic silica~~BSi ~~and~~ accounting~~s~~ for about one third of the global ~~biogenic silica~~BSi accumulation (Tréguer and De La Rocha, 2013; Tréguer, 2014). Therefore, the production and export of diatoms in the Southern Ocean are critical components of the global cycling of silica, and potentially the biological carbon pump. Indeed there is evidence from silicon isotopes and other paleo-proxies that silica export in the Southern Ocean has varied, in concert with other biogeochemical changes and atmospheric CO_2 variations, over a range of timescales (Brzezinski et al., 2002; Matsumoto et al., 2002; Sarmiento et al., 2004).

~~Despite improvements during the last two decades, our understanding of temporal and spatial variability of diatom production in the Southern Ocean is still severely limited by undersampling. Owing to its remoteness and harsh conditions, in situ observations of the structure and composition of Southern Ocean ecosystems have been traditionally performed from research vessels. These studies are limited to short observational periods and therefore are insufficient to characterize the seasonal and inter-annual variability of diatom populations and their contribution to primary production and export.~~ Most of our current knowledge about the temporal and spatial dynamics of phytoplankton in the Southern Ocean waters derives from satellite observations and biogeochemical models (e.g. Moore et al., 1999; Moore and Abbott, 2000; Arrigo et al., 2008; Gregg and Rousseaux, 2014). Recently, advances in the interpretation of optical signals have allowed the determination of~~to determine~~ the specific contribution of major phytoplankton groups (e.g., coccolithophores, phaeocystis-like, diatoms, etc.) to phytoplankton abundance on a global and regional scale (e.g. Alvain et al., 2005; Raitsos et al., 2008; Rousseaux and Gregg, 2012; Alvain et al., 2013). However, as a more complete picture of the structure of the planktonic communities emerges, it becomes evident that in order to determine the role of phytoplankton in the biological pump and biogeochemical cycles, it is of critical importance to distinguish not just among major taxonomic groups but also within them. In particular, recent studies have shown how variations in the composition of diatom communities, which exhibit a wide range of competitive strategies, contribute to the regulation of the stoichiometric relationship between elements such as carbon and silicon in the global ocean (Boyd et al., 2010; Assmy et al., 2013; Boyd, 2013; Quéguiner, 2013).

~~Bottom-tethered sediment traps have contributed significantly to our understanding of seasonality o algo así the particle transfer in open ocean ecosystems (e.g. Lampitt and Antia, 1997; Honjo et al., 2008; Romero and Armand, 2010~~)~~. Materials collected by sediment traps enable the characterization of the seasonal and inter-annual variability of biogeochemical and micro-organism fluxes. They can be used to determine the timing and magnitude of phytoplankton blooms (e.g. Ziveri et al., 2000b; Romero et al., 2009a; Grigorov et al., 2014), calibrate the ecological preferences of planktonic species (e.g. Romero et al., 1999; Rigual-Hernández et al., 2010; Howard et al., 2011) and assess the potential of specific taxa for palaeoceanographic reconstructions in a particular study region (e.g. Leventer, 1991; Leventer and Dunbar,~~

~~1996; Gersonde and Zielinski, 2000; Romero et al., 2002; King and Howard, 2003, 2005; Romero et al., 2009b; Rigual-Hernández et al., 2012). Additionally, they provide details of the vectors responsible for sedimentation and their influence on the oceanic chemical budgets (e.g. Boyd and Newton, 1999; Ziveri et al., 2000a; Lampitt et al., 2009). For example, sediment trap studies in the Southern Ocean have~~

Bottom-tethered sediment traps have contributed significantly to the characterization of the spatial and temporal variability of biochemical and microorganism fluxes in the Southern Ocean (Romero and Armand, 2010). For example, sediment trap experiments have revealed that the particle export in this region is highly seasonal and that maximum fluxes of particulate matter occur in areas under the influence of seasonal sea ice where diatoms are most abundant ~~(e.g. Honjo et al., 2000;~~ ~~Suzuki et al., 2001;~~ Fischer et al., 2002; Pilskaln et al., 2004; Grigorov et al., 2014). Other studies have revealed the crucial role of particular diatom species in driving the biological pump in naturally iron-fertilized waters, such as *Chaetoceros* and *Thalassiosira* resting spores around the Kerguelen Plateau (Rembauville et al., 2014) or the resting stages of *Eucampia antarctica* ~~var. *antarctica*~~ in the Crozet Island system (Salter et al., 2012). Most of these ~~sediment trap experiments~~ studies have been carried out in areas of relatively high primary production such as coastal systems and areas under the influence of seasonal sea ice. However very few sediment trap experiments have been conducted in the pelagic province which, despite its relatively low phytoplankton abundance, is responsible for approximately 90% of the annual primary production in the Southern Ocean due to its large size (Arrigo et al., 2008).

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In this work we document the seasonal and inter-annual variability of the chemical (total mass, ~~biogenic silica~~BSi, carbonate and particulate organic carbon) and biological (diatom assemblages) composition of the material captured at two mooring sites along the 140°E, representative of a large proportion of the ~~Subantarctic and Polar Frontal Zones of the Southern Ocean~~SAZ and PFZ. The main objectives of this study are:

(1) to document the latitudinal and seasonal variations in the composition of the particle fluxes and diatom communities across sites.

(2) to assess the role of the seasonal variability of diatom communities on the biological pump and cycling of silica.

(3) to provide annual estimates of biogenic silica, carbonate, particulate organic carbon and diatom valve fluxes to the deep ocean for ~~two major pelagic hydrological regions of the Southern Ocean~~the SAZ and PFZ.

2. Oceanographic and biological setting

The Southern Ocean is divided into concentric zones surrounding Antarctica by a series of frontal systems (Fig. 1), which are characterized by large geostrophic surface velocities (Orsi et al., 1995) and are linked to contours of sea surface height (SSH) (Sokolov and Rintoul, 2002, 2009b, a). Between these fronts lie zones of weak flow that tend to have relatively uniform water mass properties (Zentara and Kamykowski, 1981; Rintoul and Bullister, 1999) and biological characteristics ~~distributions~~ (Boyd, 2002; Thomalla et al., 2011). The Subantarctic Zone extends from the Subtropical front (STF) to the Subantarctic Front (SAF) and represents a transition zone between the subtropical gyres to the north and the Antarctic Circumpolar Current (AAC) to the south (Rintoul and Bullister, 1999). SAZ surface waters along ~140°E have summer SST's ranging between ~~8-12~~11-12°C (Fig. 2) whilst the mixed layer depth during winter can exceed 600 m (Rintoul and Trull, 2001). The SAF is characterised by a marked latitudinal surface gradient in temperature and salinity and, in the Australian sector, is split into two branches or filaments at mean latitudes of 50.5°S and 52°S (Sokolov and Rintoul, 2002). The Polar Frontal Zone (PFZ) lies just south of the SAZ and represents the northernmost extent of the Antarctic waters. PFZ surface waters have summer SST's typically between ~~4-7~~5-6°C in summer (Fig. 3), but the winter mixed layer is shallower (less than 200 m) than at the SAZ (Rintoul and Trull, 2001).

Together the SAZ and PFZ make up the Sub-Antarctic region (Fig. 1), which is the site of the formation of the Subantarctic Mode and Antarctic Intermediate Waters (SAMW and AIW, respectively) (McCartney, 1977). Both SAMW and AAIW are subducted northward beneath the subtropical gyres ventilating their lower thermocline (Sallée et al., 2006; Downes et al., 2009) and eventually supplying with nutrients the surface waters across the oceans of the southern hemisphere and North Atlantic (Sarmiento et al., 2004).

In terms of biogeochemical distributions, ~~both zones~~ the SAZ and PFZ can be defined as high nutrient-low chlorophyll (HNLC) regimes but with a remarkable difference between them. While PFZ surface waters are replete with phosphate, nitrate and silicate until at least mid-summer, in the SAZ silicate remains at low levels throughout the year (Rintoul and Trull, 2001; Wang et al., 2001). Dissolved iron concentrations in the mixed layer along the 140°E longitude transect are low and exhibit a decreasing trend with increasing latitude, with 0.27 ± 0.04 nmol/l in the SAZ and 0.22 ± 0.02 nmol/l in the PFZ (Lannuzel et al., 2011). Primary production is thought to be co-limited by ~~Fe~~ iron supply and light in the PFZ and by ~~Fe~~ iron supply and low silicic acid concentration in the case of the SAZ (Boyd et al., 1999; Boyd et al., 2001; Lannuzel et al., 2011).

As a consequence of these different physical and biochemical properties, the SAZ and PFZ exhibit two distinct phytoplankton communities. SAZ surface waters are dominated by coccolithophores, other flagellates and cyanobacteria with lower abundances of diatoms. PFZ waters are also rich in coccolithophores and flagellates, but contain few cyanobacteria whereas diatoms are more abundant and of larger size (~~Deacon, 1982; Wright et al., 1996;~~ Popp et al., 1999; Kopczynska et al., 2001; de Salas et al., 2011). Finally, it is worthy to note a feature present in the PFZ but not in the SAZ: a subsurface chlorophyll maximum (SCM) dominated by large diatom species (Kopczynska et al., 2001) has been consistently reported during summer in the PFZ within or beneath the seasonal pycnocline~~,~~. ~~probably formed~~ The formation and maintenance of this SCM is most likely due to the settling of phytoplankton cells as a response to iron and silicate colimitation in the mixed layer~~-~~during summer (Popp et al., 1999; Parslow et al., 2001).

3. Material and methods

3.1 Field experiment

A series of deep-moored sediment trap deployments was instigated in 1997 by the Australian SAZ program (Trull et al., 2001b) and now continues as a component of the Australian Integrated Marine Observing System Southern Ocean Time Series (Trull et al., 2010; Shadwick et al., 2015). Two sites representative of a large proportion of the SAZ and PFZ were occupied quasi-continuously for the decade 1997-2007. Both sites were located along the 140°E longitude: station 47°S was set on the abyssal plain of the central SAZ whereas station 54°S was placed on a bathymetric high of the Southeast Indian Ridge in the PFZ (Fig. 1; Table 1). Additionally, two other sites were instrumented over a one-year period, beneath the SAF (site 51°S, 1997-98) and within the southern Antarctic Zone (site 61°S, 2001-02). Here, we present data from the 47°S 1000 m trap between 1999-2001 (two-year record) and from the 54°S 800 m trap between ~~1997-2007~~1997-98, 1999-2000, 2002-04 and 2005-07 (six-year record). Biogenic particle flux data of sites 47°S, 51°S and 54°S for the first year deployment (1997-98) and of site 61°S for the year 2001-02 have already been published in Trull et al. (2001a) and Rigual-Hernández et al. (2015), respectively.

All traps were MacLane Parflux sediment traps: conical in shape with a 0.5 m^2 opening area and equipped with a carrousel of 13 or 21 sampling cups. Cup rotation intervals were established based on anticipated mass fluxes. Shortest intervals corresponded with the austral summer and autumn ranging typically between 4.25 and 10 days, whereas the longest intervals were 60 days, corresponding with winter (Table 2). Each trap was paired with an Aanderaa current meter and temperature sensor. The 250 ml collection cups were filled with a buffered solution of sodium tetraborate (1 g L^{-1}), sodium chloride (5 g L^{-1}) and mercury chloride (3 g L^{-1}) in unfiltered deep seawater from the region (collected at 1200 m depth, 49°17´ S, 153°58´ E). Full details of the mooring designs can be found in Bray et al. (2000) and Trull et al. (2001a).

3.2 Quality check of downward particle fluxes

Current speeds largely influence the efficiency with which sediment traps collect the particles sinking in the water column (Baker et al., 1988; ~~Gust et al., 1992;~~ Yu et al., 2001). The threshold of current velocity above which sinking particles are no longer quantitatively sampled is not well known, but has been suggested ~~generally considered~~ to be around 12 cm s^{-1} (Baker et al., 1988). Average current speeds for the whole sampling interval at the trap levels were lower than 11 cm s^{-1} for both sites and showed little seasonal variability (Bray, unpublished results, available on-line at imos.org.au)~~, and~~. Therefore, these mild conditions ~~therefore they~~ seem to be ~~non~~sub-critical for any strong concerns over collection efficiencies. Additionally, radioisotope analyses of material from the first year deployment by Trull et al. (2001) provide some extra insights to assess the collection efficiency of the traps. The ^{230}Th flux/production ratios for the 1997-98 deployment were 0.6 ± 0.1 and 0.7 ± 0.1 for the 47°S and 54°S traps, respectively. These values suggest that some degree of undertrapping is likely to have occurred at both sites. However, as these values are almost identical for both traps, it can be assumed that the trapping efficiency did not account for the observed latitudinal variations in the magnitude of the particle export between sites. Taking into consideration all the above and the fact that the assessment of trapping efficiency from ^{230}Th alone is fraught with uncertainties (Trull et al., 2001a; Buesseler et al., 2007), trap fluxes were not corrected for possible undertrapping in the present study.

3.3 Determination of major constituents of the flux

A detailed description of the methodology used for the determination of the flux intensity and composition of settling particles for the first mooring deployments in 1997-1998 can be found in Bray et al. (2000) and Trull et al. (2001a). After recovery, sediment trap cups were allowed to settle before supernatant was drawn off with a syringe for salinity, nutrients and pH measurements. The remaining sample slurries were sieved through a 1-mm sieve and then split into 10 fractions using a rotary splitter (McLane, Inc.). Three of these splits were filtered onto Nucleopore filteres (0.45 pore size), removed from the filter as a wet cake of material, oven-dried at 60°C and ground in a mortar. This material was used to determine the dry mass flux and the major components of the flux (particulate inorganic carbon, particulate organic carbon and biogenic silica). Particulate inorganic carbon (PIC) was determined by closed system acidification with phosphoric acid and coulometry. Particulate total carbon (PC) was determined by unacidified combustion using a CHN analyzer. Particulate organic carbon (POC) was calculated from PC by substraction of PIC. Total silicon and aluminium contents were estimated by HF/HNO_3 microwave digestion and inductively coupled plasma emissions spectrometry following the methodology described by Bray et al. (2000). Biogenic silica was determined from total silica by substracting lithogenic silica estimated by assuming a lithogenic Al/Si mass ratio of 3.42 (Taylor, 1964). These methods for PIC and POC/PON were used for all subsequent years, with very slight modifications: i) the wet cake method was replaced by drying prior to removing the material from the filter, ii) in some years sieving and filtering was done at sea and the samples were frozen on the filters until dried on return to land. The silica methods varied more strongly over time: i) for deployments beginning in 1998, 1999, and 2000, the use of HF in the digestion was replaced by high temperature combustion with lithium borate in a graphite crucible and HNO_3 digestion to determine total ~~Si~~ Silicon and Aluminium, ii) biogenic silica for these years (and retroactively for 1997) was calculated using the updated estimate for the lithogenic Al/Si mass ratio of 3.83 (Taylor and McLennan, 1985), iii) from 2001 onwards, total silica was not measured, instead hot alkaline digestion and colorimetry was used to estimate biogenic silica directly (following the method of Quéguiner, 2001).

3.4 Siliceous microplankton sample preparation

A total of 138 samples were processed for siliceous microplankton analysis. Each split was refilled with distilled water to 40 ml, from which 10 ml were subsampled and buffered with a solution of sodium carbonate and sodium hydrogen carbonate (pH 8) and stored at 4°C in the dark for future calcareous nannoplankton analysis. The remaining 30 ml were treated with potassium permanganate, hydrogen peroxide, and concentrated hydrochloric acid following the methodology used by (Romero et al., 1999). Three slides per sample were prepared and mounted using the standard decantation method outlined by Bárcena and Abrantes (1998). This method produces random settling of the diatom valves for quantitative microscopic purposes. Siliceous microplankton analysis was carried out on permanent slides (Norland optical adhesive 61 mounting medium; refractive index: 1.56) of acid-cleaned material. Qualitative and quantitative analysis were done at x1000 and x400 magnifications using an Olympus BH-2 compound light optical microscope with phase-contrast illumination. In order to properly characterize the diatom assemblages, a target of 400 diatom valves was counted per sample. Owing to the strong seasonality in diatom production, some cups collected very low numbers of diatom valves. For these samples a compromise between number to be counted and time spent had to be reached but the number of valves counted was never less than 100 with the exception of Cup 6 of year 2000-01, and cup 14 of year 1999-2000 at the 47°S site which were not considered for relative abundance calculations due to their negligible diatom content. The resulting counts yielded estimates of specimens m^{-2} d^{-1} according to Sancetta and Calvert (1988) and Romero et al. (2009b), as well as relative abundances of diatom taxa.

3.5 Taxonomic identifications

All diatom and silicoflagellate specimens were identified to the lowest taxonomic level possible. Radiolarians were only identified ~~at~~ to group level. Scanning Electron Microscope imagery was used on selected samples to verify taxonomic identifications made with the light microscope. Taxonomy followed modern concepts in Hasle and Syvertsen (1997). The resting spores of members of the subgenus

Hyalochaete of the genus *Chaetoceros* were identified only at group level due to a lack of morphological criteria. The differentiation between *Pseudo-nitzschia lineola* and *Pseudo-nitzschia turgiduloides* was often difficult due to their state of preservation in the samples, therefore, they were grouped under the category *Pseudo-nitzschia* cf. *lineola* in this study. A species or group of species of the genus *Thalassiosira* larger than 20 µm, highly dissolved and with radial to fasciculated areolation were grouped together under the name *Thalassiosira* sp. 1. Several small *Thalassiosira* species with similar morphological features were assembled together under *Thalassiosira trifulta* group following Shiono and Koizumi (2000). Due to the gradational nature of the morphology between *Thalassiosira gracilis* var. *gracilis* and *T. gracilis* var. *expecta*, both varieties were grouped together under the name *T. gracilis* group following the recommendations of Crosta et al. (2005).

3.6 Statistical analysis

In order to enable comparison with other sites, annual flux estimates are provided in Table 3. These were obtained by assuming that total mass flux outside of the sampling period was constant and by linearly interpolating values for the small gaps (i.e. 8.5 to 17 days intervals) during the productive season. No attempt was made to annualize the relative contribution of the diatom taxa, and therefore average values of the integrated diatom assemblage for whole sampling interval are provided in Table 3.

In order to investigate the covariability between the main diatom taxa along our sediment trap records, we conducted separate principal component analyses (PCA) for each site using of Statistica 7.0® software. PCA analysis is a statistical technique that reduces the information brought by a high number of independent variables into smaller set of dimensions (factors) with a minimum loss of information. Only species and taxonomic groups with relative contributions > 1% for the entire sampling period were considered in the analysis, i.e. thirteen taxa from site 47°S and nine taxa from site 54°S. The relative contribution of these groups of species was recalculated for each sample and then a log-transformation (log x+1) was applied in order to normalize the distribution of the data. Diatom groups were then determined using a Q-mode factor analysis of the samples with a maximized variance (VARIMAX) rotation.

The Shannon's diversity index (Shannon, 1949) was used to document latitudinal diversity trends across sites (Table 4).

3.7 Environmental variables

Weekly Sea-surface temperatures (SST) for the decade 1997-2007 were derived from the IGOSS NMC (the Integrated Global Ocean Services System Products Bulletin, National Meteorological Center; Reynolds et al., 2002) database, each value is a weekly composite of data collected within the area 48.5-45.5°S x 130-150°E for the 47°S site and 55.5-52.5°S x 130-150°E for the 54°S site (Fig. 2a and 3a). Sea-WIFS satellite-derived chlorophyll-*a* and photo-synthetically active radiation (PAR) estimates were obtained from NASA's Giovanni online data system (Acker and Leptoukh, 2007) for the same area used for the SST estimates (Fig. 2a and 3a).

Primary productivity values (mg C m^{-2} d^{-1}) for all the sites were obtained from the Ocean Productivity site (www.science.oregonstate.edu/ocean.productivity/index.php), which provides estimates of net primary productivity derived from SeaWIFS satellite data by the standard vertically generalized production model (VGPM; Behrenfeld and Falkowski, 1997) and the carbon-based production model (CbPM; Behrenfeld et al., 2005).

4. Results

Here, we present the chemical (total mass, biogenic silica, carbonate and POC) and biological (diatom species) compositions of the particle fluxes registered at ~1000 m at the 47°S site during two years (July 1999 - October 2001) and at 54°S site during six years (September 1997 - February 1998, July 1999 - August 2000, November 2002 - October 2004 and December 2005 - October 2007; Table 2). A description of the total particle flux and its chemical signature at stations 47°S and 54°S for the first year deployment of the sediment traps (1997-98) can be found in Trull et al. (2001). ~~Here, we present the chemical (total mass, biogenic silica, carbonate and POC) and biological (diatom species) compositions of the particle fluxes registered at ~1000 m at the 47°S site during two years (July 1999 - October 2001) and at 54°S site during six years (September 1997 - February 1998, July 1999 - August 2000, November 2002 - October 2004 and December 2005 - October 2007; Table 2).~~

4.1 Biogeochemical fluxes

The total mass and bulk component (biogenic silica, carbonate and POC) fluxes for both traps are shown in Figures 2b and 3b and listed in Table 2. Annual total mass flux at ~1 km depth was lowest at station 47°S (14 ± 2 g m^{-2} yr^{-1}; two-year average ±

standard deviation) and highest at station 54°S (24 ± 13 g m^{-2} yr^{-1}; six-year average ± standard deviation) (Table 3). ~~Biogenic silica (~~BSi~~)~~ flux followed a similar latitudinal trend with lower fluxes at 47°S (1 ± 0 g m^{-2} yr^{-1}) compared to 54°S (12 ± 9 g m^{-2} yr^{-1}). Carbonate export exhibited less variability between sites, with values somewhat higher at 47°S (10 ± 3 g m^{-2} yr^{-1}) than those measured at 54°S (7 ± 3 g m^{-2} yr^{-1}, respectively). Interestingly, despite the strong latitudinal differences in the magnitude of the mass fluxes, POC export was very similar at both stations (1.0 ± 0.1 and 0.8 ± 0.4 g m^{-2} yr^{-1}, for 47°S and 54°S, respectively).

In terms of relative abundance, the biogenic silica fraction represented 57% of the mass flux at the 54°S site whereas its contribution dramatically dropped to 7% at the 47°S station. Calcium carbonate and POC accounted for 70% and 7.3% at the 47°S site, respectively and 21% and 3% at the 54°S station (Table 3). These differences were primarily driven by the northward decrease in the biogenic silica fluxes. The BSi:PIC mole ratios decreased northward mirroring the latitudinal variations of the particle composition, from 5.~~4~~0 at station 54°S to 0.2 at station 47°S (Table 3, Supplementary figure 1). The POC:BSi followed an opposite pattern with 0.3 at 54°S and 4.9 at 47°S.

The seasonality of the total mass flux at station 47°S during the two-year record showed a period of enhanced particle export in spring and secondary peaks in summer and autumn (Fig. 2b). The highest fluxes were registered in November-December 2000 (92-176 mg m^{-2} d^{-1}), March 2001 (105 mg m^{-2} d^{-1}) and October 1999 (90 mg m^{-2} d^{-1}). Total mass flux at the 54°S site was strongly seasonal with maximum values occurring during the late spring-summer and very low export prevailing through the autumn and winter months. The late spring-summer export maxima were as short as three months and often showed a bimodal distribution (e.g. 1997-98, 1999-2000, 2002-03; Fig. 3b). The highest total mass fluxes at this site were collected during December-January 1999 (511-724 mg m^{-2} d^{-1}), January 2006 (418 mg m^{-2} d^{-1}), February 2003 (397 mg m^{-2} d^{-1}) and January 1998 (396 mg m^{-2} d^{-1}).

4.2 Diatom fluxes

The biogenic silica flux at the 47°S and 54°S site was composed of diatoms, silicoflagellates, radiolarians, and a handful of skeletons of the dinoflagellate *Actiniscus pentasterias*. Diatom fluxes were one order of magnitude higher than those of silicoflagellates and radiolarians at the 47°S site, and one and three orders of magnitude higher, respectively, at the 54°S site. Consistent with the biogenic silica flux, diatoms were most numerous in the 54°S site with an annual flux of 31 ± 5.5 10^{8} valves m^{-2} yr^{-1} (six-year average ± standard deviation) compared to 0.5 ± 0.4 10^{8} valves m^{-2} yr^{-1} (two-year average ± standard deviation) of the 47°S site.

Total diatom valve flux at the 47°S site (Fig. 4a) showed a less pronounced seasonality than that observed at 54°S (Fig. 5a) and exhibited a weak correlation with the total mass ($r = 0.37$, $n = 30$) and BSi ($r = 0.42$, $n = 29$) fluxes. Diatoms occurred in greatest numbers during November 2000 (1.6 x 10^{6} valves m^{-2} d^{-1}), February-March 2001 (0.4-0.8 x 10^{6} valves m^{-2} d^{-1}) and October 1999 (0.4 x 10^{6} valves m^{-2} d^{-1}).

At station 54°S, total diatom valve flux was highly seasonal and followed a similar pattern to that of the total mass ($r = 0.66$, $n = 108$) and BSi fluxes ($r = 0.68$, $n = 108$). These correlations are high despite the biases associated to our diatom valve counting technique which does not allow quantification of small valve fragments. In particular the high diatom-valve fragmentation observed during the productive period of 1999-2000 reduced the correlations between diatom valve flux and total mass and ~~biogenic silica~~BSi fluxes. In fact, the latter correlations increased significantly after excluding the 1999-2000 data ($r = 0.85$, $n = 88$ and $r = 0.87$, $n = 88$, respectively).

The spring-summer diatom bloom often exhibited two peaks of enhanced export separated by a period of lower flux (e.g. 1997-98, 1999-00, 2002-03; Fig. 5a and Fig. 7). During the productive period of 2006-07, the diatom bloom exhibited one single peak during which the largest diatom fluxes of the record were registered (up to 100 x 10^{6} valves m^{-2} d^{-1} in January 2007) (Fig. 5a). Secondary diatom flux maxima were registered in January 1998 (71 x 10^{6} valves m^{-2} d^{-1}), December 2002 (65 x 10^{6} valves m^{-2} d^{-1}) and December 1999 (52 x 10^{6} valves m^{-2} d^{-1}). We noticed that during the 1999-2000 summer bloom the high BSi fluxes were not coupled with a proportional increase of the diatom valves (Fig. 5a). The higher degree of fragmentation observed on these samples could be attributed to either a more intense grazing pressure by the zooplankton community that year or by a higher fragmentation of the valves during the sample preparation due to the presence of abundant numbers of weakly silicified diatoms (e.g. species of the genus *Pseudo-nitzschia*) which are more prone to break during the sample processing (Rembauville et al., 2014).

In terms of diatom assemblage composition, the occurrence and fractional contributions of all the diatom taxa found at the 47° and 54°S study sites, as well as at 61°S (Rigual-Hernández et al., 2015) are provided in Table 4. The diatom sinking assemblage at station 47°S was more diversified (*H´* for the entire sampling period ~~*H´*~~ =

2.48) than those found south the SAF (*H´* = 1.86 at the 54°S; *H´* = 1.04 at the 61°S) consisting of 79 species or groups of species. The most abundant species was *Fragilariopsis kerguelensis*, which represented 43% of the integrated assemblage for the entire sampling period (Fig. 4). Subordinate contributions to the diatom assemblage were made by *Azpeitia tabularis* (10%), *Thalassiosira* sp. 1 (4%), *Nitzschia bicapitata* (4%), resting spores of *Chaetoceros* spp. (subgenus *Hyalochaetae*) (3%), *Thalassiosira oestrupii* var. *oestrupii* (3%), *Hemidiscus cuneiformis* (3%) and *Roperia tesselata* (3%) (Fig. 4). A total of 77 taxa were identified at the 54°S site (Table 4). *F. kerguelensis* was also the dominant species, contributing up to 59% of the diatom assemblage for the whole sampling period (Fig. 5). Secondary contributors correspond to *Pseudo-nitzschia* cf. *lineola* (8%), *Pseudo-nitzschia heimii* (5%), *Thalassiosira gracilis* group (4%), *Fragilariopsis pseudonana* (3%), *Fragilariopsis rhombica* (2%) and *Thalassiosira lentiginosa* (2%) (Fig. 5).

4.3 Principal component analysis of diatom assemblages

The PCA for the 47°S site identified 4 components containing 64% of the total variance whereas that of the 54°S site required three components to describe 79% of the information of diatom data (Table 5). ~~Components 3 and 4 for 47°S and component 3 for 54°S explained only 13-14% of the variance, were mostly monospecific and had no clear ecological significance. Therefore, we used only the first and second axes of the PCA that explain 38% and 65% of the variance for the 47°S and 54°S sites, respectively~~. Figure 6 shows the position of the species on the first two PCA axes for the 47°S and 54°S sites. Together with the species, we plotted total and major components mass fluxes.

The first component of the PCA for the 47°S site accounted for ~~(~~19% of the variance. ~~) was dominated by the open ocean species *N. bicapitata* (Table 5). This species had a negative loading on factor 1 and showed its highest annual relative contribution during the autumn and winter months.~~ The centric species ~~*Azpeitia*~~ *A. tabularis* and ~~*Hemidiscus*~~ *H. cuneiformis* (Fig. 6) had a positive loading on factor 1 and exhibited ~~showed~~ their highest relative abundance during spring and summer (Fig. 4). Factor 2 explained 19% of the variance and was dominated by *F. kerguelensis*, *T. oestrupii* var. *oestrupii* and *Thalassiosira* sp. 1. ~~*Fragilariopsis*~~ *F. kerguelensis* maintained a relatively constant contribution to the diatom assemblages during the whole sampling interval with a tendency to peak in late-summer and autumn together with *T. oestrupii* var. *oestrupii*. ~~*Thalassiosira* sp. 1 had a positive contribution to factor 2 and its maximum relative contribution occurred in late winter and spring.~~ None of the factors of the PCA of the 47°S site were significantly correlated with the biogenic particle fluxes (Fig. 6a and Table 6a).

At the 54°S site, the first component (48% of the total variance) was highly correlated with the bulk components of the flux (Fig. 6b and Table 6b) and individualizes two groups of diatom species~~ which are defined by high absolute values of factor loadings~~. High-positive factor loadings characterize the bloom-forming *Pseudo-nitzschia* cf. *lineola*, *F. rhombica*, *F. pseudonana* and *N. directa* and the cool-open-ocean diatom *T. gracilis* group. The relative contribution of these species peaked during the productive season (Fig. 5) and showed a strong positive correlation with all the components of the flux (Fig. 6b and Table 6b). Therefore, diatom species characterized by a high-positive first factor loading can be defined as the “High-export group”. In contrast, a high-negative factor loading on the first PCA axis was attributed to *F. kerguelensis* which ~~. The relative contribution of *F. kerguelensis*~~ peaked during winter and autumn, coinciding with very low particle fluxes. *Pseudo-nitzschia heimii* was the only species with a high positive factor loading on the second PCA axis (Fig. 6b and Table 5) and its relative abundance peaked mainly from mid-summer to autumn. ~~*Thalassiosira lentiginosa* had a high-negative factor loading in factor 2 and its maximum relative abundances occurred mainly during spring and autumn.~~

With the exception of year 2002-03, a consistent diatom species succession was consistently observed over the growth season at the 54°S site (Fig. 5b and 7). During those years with a double-peak diatom sedimentation bloom, the first maximum (November to early-December) was always dominated by *F. kerguelensis* and by other large and heavily silicified diatoms, such as *T. lentiginosa*. During the second peak (in late-December to early-February), the relative contribution of *Pseudo-nitzchia* cf. *lineola* and small *Fragilariopsis* species increased sharply, representing together up to 50% ~~60%~~ of the diatom assemblage in January 2000 (Fig. 5b and 7). Even during year 2006-07, when the diatom sedimentation bloom exhibited a single maximum, a similar succession can be discerned within the peak.

5. Discussion

5.1. Latitudinal trend of biogenic particle fluxes to the ocean interior

The contrasting latitudinal variations in the composition and magnitude of the particle fluxes along the 140°E transect reflect the physicochemical and biological ~~distributions~~ characteristics of the different zonal systems sampled by the traps. Relatively low BSi and diatom export measured in the mesopelagic waters of the SAZ (Fig. 8a and Table 3) are consistent with the low-to-moderate diatom biomass accumulation in the surface layer of this region (Kopczynska et al., 2001; de Salas et al., 2011). Low silicic acid (~~Smith Jr et al., 2000;~~ ~~Trull et al., 2001a; Wang et al., 2001;~~ Bowie et al., 2011a) and iron levels (~~Sedwick et al., 1997;~~ Sedwick et al., 2008; Bowie et al., 2009; Mongin et al., 2011), together with light limitation, as a result of cloudiness (Bishop and Rossow, 1991) and deep summer mixed layers (70-100 m, Rintoul and Trull, 2001), are considered the main factors responsible for the reduced diatom production in the SAZ. Moreover, the low BSi:PIC mole ratios measured by the traps (<<1; Table 3) illustrate the relatively low contribution of diatoms to the particle flux export to the ocean interior. Low diatom export fluxes and BSi:PIC mole ratios are characteristic of carbonate-dominated and low-productivity regimes (Honjo et al., 2008) and typical of much of the circumpolar SAZ (Honjo et al., 2000; Trull et al., 2001a).

The higher diatom valve fluxes and BSi export at the 54°S site (Table 3; Fig. 8a) agrees well with previous studies of the PFZ surface waters south of Tasmania, which reported relatively large and heavily silicified diatoms as major contributors to the phytoplankton biomass (Kopczynska et al., 2001; de Salas et al., 2011). Higher levels of silicic acid (Smith Jr et al., 2000), colder summer surface waters and shallower mixed winter layers than those of the SAZ (Rintoul and Trull, 2001) are most likely the main factors responsible for the greater prevalence of diatoms in this region. As a result of the enhanced diatom production and the drop in the abundance of calcifying phytoplankton (~~Nishida, 1986;~~ Findlay and Giraudeau, 2000; Honjo et al., 2000), BSi:PIC mole ratios of the settling material at this site shift to > 1 (Table 3).

Further south, at station 61°S in the southern AZ, Rigual-Hernández et al. (2015) documented an annual diatom flux one order of magnitude greater than that measured at the 54°S site (243 x 10^8 valves m^{-2} d^{-1} at 2000 m; Table 3 and Fig. 8a). The corresponding BSi export was as large as 65 g m^{-2} y^{-1}, a value very similar to that reported in the AZ south New Zealand by Honjo et al. (2000) (57 g m^{-2}, station MS-4; Fig. 1). These very high BSi fluxes are arguably the largest BSi exports ever measured in the world's ocean (Honjo et al., 2008). Due to the upwelling of Circumpolar Deep

Waters (CDW) at the Antarctic Divergence, the surface waters of the southern AZ exhibit very high silicate concentrations (up to 70 mmol Si m^{-3}; Pollard et al., 2006) which enhance diatom growth at the expense of other phytoplankton groups (Mengelt et al., 2001; Selph et al., 2001). These high diatom export values are consistent with the large accumulation of diatom remains in the surface sediments between the PF and the winter sea-ice edge that encircles Antarctica, the so-called Diatom Ooze Belt (Burckle and Cirilli, 1987). This Diatom Ooze Belt constitutes the single most important sink for silica in the world ocean (DeMaster, 1981; Ledford-Hoffman et al., 1986; Tréguer et al., 1995; Tréguer, 2014).

5.2 Latitudinal diatom species distribution

The species occurrence observed along the 140°E ~~sediment trap~~ transect is consistent with previous reports on diatom assemblage composition in the surface waters (~~Kozlova, 1966;~~ Kopczynska et al., 1986; Kopczynska et al., 2001; de Salas et al., 2011) and sediments (Armand et al., 2005; Crosta et al., 2005; Romero et al., 2005) of the Australian sector of the Southern Ocean and provide evidence, once again, that the frontal systems represent natural physical boundaries for phytoplankton species distribution (Boyd, 2002).

Overall, the diatom assemblage registered at the 47°S site is typical of the SAZ and differs significantly from those found in the PFZ and AZ (Table 4). The SAZ represents a "buffer zone" between the subtropical gyres to the north and the polar waters to the south which results in a highly diverse diatom community as highlighted by the highest *H´* (2.48; Table 4) of the study transect. The occurrence of the warm water taxa ~~*Hemidiscus*~~ *H. cuneiformis*, *Fragilariopsis doliolus*, *Nitzschia kolaczeckii* and ~~*Thalassiosira*~~ *T. lineata* (~~Romero et al., 2002;~~ Romero et al., 2005; Venrick et al., 2008) is restricted to this station, and therefore, these species appear as good indicators for the southward migration of the warmer, saltier and nutrient-poorer water masses of the SAZ into the ACC. Moreover, the stark increase in the abundance of the open-ocean diatoms ~~*Azpeitia*~~ *A. tabularis*, *N.*~~*itzschia*~~ *bicapitata*, ~~*Nitzschia braarudii, Rhizosolenia bergonii, Roperia*~~ *R. tesselata*, ~~*Thalassiosira eccentrica*,~~ and *Thalassiosira oestrupii* ~~and *Thalassiosira symmetrica*~~ north of the SAF suggest the preference of these species for warmer waters (Hasle and Syvertsen, 1997; Romero et al., 2005)~~as already~~

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~~suggested by Hasle and Syvertsen (1997) and Romero et al. (2005). Since *Chaetoceros* resting spores are generally regarded as indicators of coastal environments (Abrantes, 1988; Treppke et al., 1996; Crosta et al., 1997; Takahashi et al., 2002; Rigual-Hernández et al., 2013), their presence at the 47°S site suggests that they could have been advected from a coastal region rather than having autochthonous origin. This concept is further supported by the significant correlation (r = 0.7, n = 31) between the fluxes of the coastal species group (*Cocconeis* spp. *Diploneis bombus* and *Paralia* spp.) and those of *Chaetoceros* RS. Some influence of coastal and subtropical waters over the study area is possible, as eddies from the East Australia Current and intermediate waters from the Tasman Outflow (a remnant of the East Australian Current) have been reported to extend as far south as the SAZ (Ridgway and Dunn, 2007; Herraiz-Borreguero and Rintoul, 2010; Herraiz-Borreguero and Rintoul, 2011). Thus, we interpret the occurrence of *Chaetoceros* RS and coastal taxa in the 47°S site as the advection of hemipelagic and/or neritic water masses from the Tasmanian shelf.~~

The sinking diatom assemblage registered at the 54°S site is characteristic of the ~~cold and iron-limited waters of the~~ ACC waters and largely defined by the dominance of ~~*Fragilariopsis*~~ *F. kerguelensis*. The relative abundance of *F. kerguelensis* at the PFZ (59%) represents a transitional value between that of the AZ (80%) and that of the SAZ (43%). This strong latitudinal gradient mirrors its distribution in the surface sediments, which has been previously tied to summer SST (Crosta et al., 2005; Esper et al., 2010). However, other potentially important influences such as mixed layer depth, seasonality, and iron and silicate abundance also exhibit latitudinal gradients and therefore may also influence the distribution of this species. Peak abundances of *Pseudo-nitzschia* species ~~(*P-n. heimii* and *Pseudo-nitzschia* cf. *lineola*)~~ along the 140°~~-~~E transect are observed in the PFZ (Table 4) and are consistent with previous studies that described this genus as a major contributor to the bulk phytoplankton biomass in the ACC waters (e.g. Kopczynska et al., 2001; Smetacek et al., 2002; de Salas et al., 2011). Moreover, it is worth noting that *P-n. heimii*, together with other large diatoms (e.g. *Thalassiothrix* ~~antarctica,~~and *Proboscia* ~~*alata*~~), have been reported to be major contributors of a ~~Subsurface Chlorophyll Maximum (~~SCM~~)~~ consistently observed between 53° and 58° S along 140°E (Kopczynska et al., 2001; Parslow et al., 2001). –*Navicula directa* also showed maximum abundances at the PFZ site with values ~5%. This species has been traditionally described as a benthic-dwelling species (Scott and Marchant, 2005 and

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references therein) with affinity for sea-ice conditions (Armand, 1997). However, its persistent presence throughout the six-year record and similar seasonal flux pattern to that of other well-known open-ocean species of the ACC, such as *Thalassiosira gracilis* group (r = 0.8, n = 108; Fig. 5b) point to a pelagic distribution of this species. This concept agrees well with Kopczynska et al. (1986) and Waite and Nodder (2001) who documented *Navicula* populations of considerable abundance in areas remote from coastal and sea-ice influence in the Australian sector.

Although in many aspects the composition of the diatom assemblage at the 61°S site was similar to that of station 54°S, there were some qualitative and quantitative differences. As a result of the southward increase in the relative abundance of *F. kerguelensis*, the diversity (*H´*) and the relative contribution of most of the secondary constituents of the diatom assemblage at 61°S exhibited lower values than at 54°S (Table 4). For example, *Pseudo-nitzchia* species that represented cumulatively 13% of the integrated assemblage, dropped to < 1% at the 61°S site. *Navicula directa* followed a similar pattern with maximum abundances at 54°S (5%) and negligible fluxes at 61°S. It is possible however, that other factors, such as selective grazing or ecological constraints may also account for the lower contribution of these species in the AZ. ~~Moreover, the sea-ice affiliated species *Fragilariopsis curta* and *Fragilariopsis cylindrus*, that contributed significantly to total diatom fluxes at station 61 S during limited intervals (up to 4 and 3 % during summer; Rigual-Hernández et al., 2015), exhibited negligible fluxes at the 54°S site, which reflects the absence of sea-ice influence in the PFZ south of Tasmania.~~

5.3. Seasonal variability of diatom assemblages

~~Variations in the magnitude of particulate fluxes at the 47°S and 54°S sites are primarily driven by the seasonal cycle of primary production. Low chlorophyll-*a* concentrations and particle fluxes over winter are consistent with light limited production in response to reduced incident radiation and mixed layer deepening. The duration of biomass accumulation extends from November to March in the SAZ and has a short weak maximum from November to January in the PFZ (Figs. 2a and 3a; Bowie et al., 2011a). The period of enhanced particle export was broadly in line with the chlorophyll-*a* estimates at both sites.~~ Taking into account that diatoms are, by far, the main contributors to the ~~biogenic silica~~BSi production at the 54°S site, and that the

~~biogenic silica~~BSi fraction, in turn, dominated the total mass flux, the strong correlation between diatom valve and mass fluxes (r = 0.85; n = 88) suggests that the particle export at the PFZ is mainly mediated by diatoms. In contrast, at the 47°S site, the silica-poor content of the particles and the low correlation between diatom valve and mass fluxes (r = 0.37; n = 30) indicates a minor role for diatoms in regulating the export in the SAZ. These results underscore the contrasting role that diatoms play in the controls on the flux north and south the SAF (Trull et al., 2001a; Ebersbach et al., 2011).

The less defined seasonal pattern and lower amplitude of the diatom fluxes observed at the 47°S site (Fig. 4) are a reflection of the different algal community north of the SAF, dominated by non-siliceous ~~taxa with lower abundances of diatoms~~phytoplankton (Odate and Fukuchi, 1995; Kopczynska et al., 2001; de Salas et al., 2011). For both years of our study, the highest annual diatom export events coincided with the onset of the biomass accumulation in the surface waters, indicating that diatoms responded rapidly to the enhanced light levels (Fig. 2a) and to the formation of a stable and shallow mixed layer (Rintoul and Trull, 2001). However, unlike the chlorophyll-*a* concentration that gradually increased throughout the spring, diatom export rapidly returned to winter values most likely caused by the depletion of the winter silicate and/or iron stocks (Lannuzel et al., 2011). This seasonal pattern is characteristic of the SAZ and other silicate-poor environments ~~at lower latitudes~~, where diatoms typically bloom at the beginning of the successional sequence and then are replaced by other functional groups ~~such as *Phaeocystis*, coccolithophores and dinoflagellates~~ (e.g. Margalef, 1978; ~~Thunell et al., 1996~~; Balch, 2004; Alvain et al., 2008; Rigual-Hernández et al., 2013). The increase in the diatom and BSi fluxes from January to early March 2001 suggests the export of a second diatom bloom that year. South of Tasmania the SAZ exhibits a complex physical structure with frequent wind mixing events (Yuan, 2004) and fronts meandering and forming eddies that can reach the trap location (Rintoul and Trull, 2001; Herraiz-Borreguero and Rintoul, 2011). Thus, it is likely that one of these mechanisms injected nutrients into the surface layer of the 47°S site fuelling diatom production and allowing the “reset” of phytoplankton succession. ~~This concept would also explain the second peak of chlorophyll-*a* registered during mid-late summer that year (Fig. 2a).~~

In terms of population dynamics, the seasonal succession of species at the 47°S site was not as clearly expressed as in station 54°S and none of the diatom species seem to play an important role in the export controls of any of the components of the flux as indicated by the results of the PCA (Fig. 6a). ~~*Fragilariopsis*~~ *F. kerguelensis* exhibited fairly constant relative abundances throughout the record suggesting little competition for resources with other diatom species. The temperate-to-warm water species ~~*Hemidiscus*~~ *H. cuneiformis* and ~~*Azpeitia*~~ *A. tabularis* showed their maximum contribution at times of maximum diatom export which suggests that these species are the first to respond to nutrient supply in the surface waters in this region. ~~Moreover, highest relative contribution of the oligotrophic *N. bicapitata* (Romero et al., 2000) registered during periods of low productivity indicates the capacity of this species to maintain relatively constant stocks in the surface waters year-round.~~

The annual export maxima of total mass and diatom valve flux at 54°S were separated into two peaks for most of the years (Figs. 5a and 7). A similar double peak feature of the particle bloom has been previously reported in the APZ ~~and AZ~~ of the ~~southwest~~ Pacific (Honjo et al., 2000; Grigorov et al., 2014) and ~~in the APZ of the south~~ Atlantic (Fischer et al., 2002). Honjo (2004) speculated that such a double peak structure may be due to a break in primary production caused by a temporary depletion of a limiting nutrient ~~macro- or micronutrients followed by a rapid replenishment of the limiting nutrient(s).~~ while Grigorov et al. (2014) attributed ~~a~~ the drop in the diatom flux between two periods of enhanced ~~diatom~~ export to a ~~strong~~ storm event that mixed the diatom biomass out of the surface layer. The lack of accompanying in situ measurements of nutrient concentration and mixed layer depth precludes the direct assessment of these possibilities. ~~Ecological factors might also play a role, for example the seasonal increase in trophic complexity may increase mesopelagic particle remineralization rates above the traps (Wassmann, 1998). Statistical funnel (i.e. the spatial domain containing the likely origins for collected sinking particles) issues related to non-uniform surface fields (Siegel and Deuser, 1997) are possible, but seem unlikely (Hamilton, 2006) based on the sparse available ocean colour observations (admittedly quite limited by cloud cover).~~

The initial diatom population size ~~(i.e. seeding stock)~~, species-specific physiological traits and selective grazing pressure are crucial factors determining which diatom species dominates or co-dominate an individual bloom (Assmy et al., 2007; Assmy et al., 2013; Boyd, 2013). The chain-forming *F. kerguelensis* is one of the most abundant diatom species in ~~the iron-limited waters of the~~ ACC waters (e.g. ~~Hart, 1934; Hasle, 1969;~~ Laubscher et al., 1993; Bathmann et al., 1997; Smetacek et al., 2002) and has been reported to represent up to 90% of the summer diatom populations in the AZ

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~~Australian sector south of the Polar Front (PF) ~~(Gall et al., 2001). The high relative contribution of *F. kerguelensis* throughout our ~~six-year time series~~record ~~-~~is consistent with these latter studies and suggests the presence of a large seeding population of this species before the onset of the ~~diatom ~~bloom. These large initial seed stocks, together with the effective mechanical protection of its robust frustule (Hamm et al., 2003) against the heavy copepod grazing pressure of the ACC (Pollard et al., 2002; McLeod et al., 2010) are most likely the main factors determining the dominance of *F. kerguelensis* during the growth season. The increase in the relative abundance of the lightly-silicified *Pseudo-nitzschia cf. lineola* and small *Fragilariopsis* species during the second part of the bloom (Fig. 5b and 7) is consistent with the observations of ~~.~~Kopczynska et al. (2001) who reported *F.~~ragilariopsis~~ pseudonana* and *P~~seudo~~-~~nitzschia ~~n. lineola* dominating the diatom assemblages in the ~~iron-limited waters of the~~ PFZ waters south of Tasmania during late summer. Assmy et al. (2007) reported large numbers of *P-n. lineola* during the last stages of the fertilization experiment EisenEx~~ in Atlantic Sector of the Southern Ocean~~, indicating the capacity of this diatom to outcompete other taxa under iron-limiting conditions. Moreover, small *Fragilariopsis* and *Pseudo-nitzschia* species are known to produce an iron-storage protein (ferritin) that allow them to undergo more cell divisions than other open-ocean diatoms under low iron concentrations (Marchetti et al., 2009). We speculate, that due to these particular physiological traits *Pseudo-nitzschia* and small-*Fragilariopsis* species may gain a competitive advantage under the environmental conditions during the last stages of the diatom bloom (i.e. low ~~-~~silica and iron~~-limiting~~ concentrations, and enhanced PAR ~~levels~~) enabling such species to escape grazing and/or outcompete other diatoms. However, this scenario does not account for our observations in 2002-3, when *Pseudo-nitzschia* and small-*Fragilariopsis* species exhibited higher relative contribution ~~to the~~ in the first seasonal export peak (Fig. 5b and 7). This exceptional seasonal flux ~~export~~ peak remained unexplained and likely due to other environmental conditions not captured by our study.

~~Maximum annual relative contribution of *Pseudo-nitzschia hemii*, the *Proboscia* group and *Thalassiothrix antarctica* were often registered between the end of the growth season and winter (Fig. 5b). As previously noted, high numbers of these species have been found in association to a subsurface chlorophyll maximum in this region during summer and autumn (Kopczynska et al., 2001; Parslow et al., 2001). We suggest that the intensification of the convective mixing and the decrease in light during this~~

~~period could have led to the sedimentation of these deep-dwellers following the conceptual scheme for the seasonal development of planktonic communities in the PFZ and POOZ (Permanently Open Ocean Zone) suggested by Quéguiner (2013).~~

5.4. Ecological flux vectors in the PFZ

The short and vigorous summer particle export, consistently observed during our six year record at the 54°S trap is characteristic of high latitude systems (e.g. Honjo et al., 2000; Fischer et al., 2002; Pilskaln et al., 2004) and can contribute up to 66% of the annual POC export to 800 m in just two months (e.g. year 1999-2000). Therefore, these large summer pulses of POC are responsible for a major proportion of the variability in carbon sequestration from the atmosphere in the PFZ. The mechanism is primarily through the increase in the overall flux, because the fractional POC content was not observed to increase during high flux periods. For example, % POC for year 1999-00 ranged between 1.2% and 3.7%, and maximum relative abundances occurred at times of relatively low fluxes (Fig. 3b).

The strong positive correlation between Factor 1 and POC fluxes at the 54°S site (Table 6) indicates an intimate association between high relative abundances of the “High-export group” species and pulses of POC export. As a specific example of this, during January 1999 and December 2000, when the highest contribution of “High-export group” was noted (55-60% of the total diatom flux; Fig 7), the PFZ sediment trap registered the largest POC fluxes of the record (up to 23 mg m^{-2} d^{-1}; Fig 7). Interestingly, these observations of elevated POC flux coincide with significantly lower summer sea surface temperatures than other years.

All the members of the “High-export group” have been previously reported as important components of both natural and iron-fertilized blooms in the Southern Ocean (Bathmann et al., 1997; ~~Bracher et al., 1999;~~ Waite and Nodder, 2001; Smetacek et al., 2002; Assmy et al., 2007; Quéguiner, 2013; Grigorov et al., 2014; ~~Sackett et al., 2014;~~ Rigual-Hernández et al., 2015). The increase in the relative abundance and fluxes of these species during the growth season indicates that they respond opportunistically to the enhanced light levels, most likely undergoing cycles of rapid biomass buildup followed by mass mortality and sinking in the form of aggregates (Smetacek et al., 2004; Green and Sambrotto, 2006; Assmy et al., 2013~~; Quéguiner, 2013; Grigorov et al., 2014~~). This concept is supported by the recent findings of_Closset et al. (2015)

~~(Closset et al., under review)~~ who documented an increase in the particle sinking speeds at the 54°S site during the summer 1999-2000 of up to at least 35 m d^{-1}, a value that falls within the range of previous estimates for marine snow sinking rates (Turner, 2002; Trull et al., 2008; Laurenceau et al., 2014). Moreover, other regionally-relevant PFZ studies (Ebersbach et al., 2011; Grigorov et al., 2014) concluded that aggregates are the principal form of particle export during the growth season. Taken together, our data and these studies strongly suggest that aggregate formation is a widespread mechanism of the summer bloom in the open-ocean waters of the ACC.

~~The aggregation and sedimentation of particles during a phytoplankton bloom is determined by the complex interaction of several factors including, the composition of the phytoplankton assemblage, biomass and particle accumulation, secretion of transparent exopolymer particles (TEP) and packaging by the zooplankton community (Passow, 2002; Turner, 2002; Grossart et al., 2006; Boyd and Trull, 2007; Burd and Jackson, 2009; Iversen and Ploug, 2010).~~ We ~~suggest~~ speculate that the massive development of “High-export group” diatoms during the growth season facilitates the formation of aggregates in the upper water column, which results in an increase in sinking rates and POC fluxes. Aggregates, and particularly diatom flocs, are rich in exopolymers that increase their effectiveness at scavenging particles they have collided with (Alldredge and McGillivary, 1991; Passow and De La Rocha, 2006). Therefore, it is possible that that the formation of aggregates during the diatom bloom facilitated the scavenging of other particles (including phytoplankton chains and cells, biominerals and detritus), leading to the co-sedimentation of the major components of the flux (i.e. calcium carbonate, silica and organic carbon). This scavenging mechanism is consistent with previous laboratory observations made by Passow and De La Rocha (2006) and can explain the increase of the sinking rates during the growth season as well as the positive correlation between Factor 1 and all bulk components of the flux (Fig. 6b; Table 6b).

Since most of the members of “High-export group” are of relatively small size and weakly silicified, it is unlikely that these species accounted for the major fraction of the BSi export during the summer bloom for most of the years. In contrast, the thick-shelled *F. kerguelensis* is a more compelling candidate to be responsible for the bulk of the BSi export, because despite the fact that its relative abundance exhibited the lowest values of the record during summer, its valve fluxes always were highest during this season. ~~In contrast, the large and thick-shelled *F. kerguelensis* is a more compelling~~

~~candidate tow be responsible for the bulk of the BSi export, because despite the fact that its lowest relative abundance always occurred during the productive season, it often represented more than 50% of the summer assemblage (Fig. 5b).~~ In terms of carbonate export, the correlation between Factor 1 and carbonate flux is not as strong as with the rest of the components of the flux but still high (Fig. 6b; Table 6b), indicating that highest relative contribution of the “High-export group” diatoms is also associated with high carbonate export. Although speculative, ~~I~~it is possible that that the formation of aggregates during the diatom bloom also facilitated the scavenging of at least the fine fraction of the carbonate (mainly coccoliths) (Ziveri et al., 2007; Iversen and Ploug, 2010) which would have led to the co-sedimentation of the BSi, POC and carbonate fractions. However, other seasonal ecological influences are also likely to be involved, given that the contribution of larger carbonate particles in the form of foraminifera tests is also increased in summer (King and Howard, 2003).

The massive sedimentation of giant diatoms characteristic of the SCM shade flora (e.g. *Thalassiothrix* and some rhizosolenids) in autumn and winter (the so-called fall dump) has been hypothesized to contribute to a substantial fraction of the annual carbon export in the PFZ (Kemp et al., 2006; Kemp and Villareal, 2013; Quéguiner, 2013). At the 54°S site, the highest fluxes and relative contribution of the deep dwellers *Thalassiothrix antarctica* and *Proboscia* were recorded between the end of the productive period and winter (Fig. 5), however their contribution to the total diatom assemblage was always low (<3.6%) and their flux pulses were not coupled with significant increases in POC export (Fig. 7). Thus, our data do not provide evidence that the sedimentation of these species was associated to a “fall dump” in the PFZ south of Tasmania. However, it has been suggested that sediment traps do not act as good samplers of large mats formed by these long diatoms (Kemp et al., 2006) and therefore their mass sedimentation during autumn and/or winter could have been missed by our sampling technique.

~~In regard to the autumn and winter months, the low particle fluxes observed during this period were overwhelmingly dominated by *F. kerguelensis* (up to 97% of the diatom assemblage) and characterized by very low settling speeds (up to less than 3 m d^{-1}; Closset et al. submitted). These observations are consistent with the findings of Grigorov et al. (2014) who reported that diatom export outside the productive period in the pelagic waters of the ACC mainly occurs in the form of single cells and chains. Small and slow sinking particles are more exposed to degradation processes (e.g. silica~~

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~~dissolution, bacterial remineralization) during settlement than larger and rapid-sinking aggregates (Trull et al., 2008). Therefore, the enrichment of the dissolution-resistant *F. kerguelensis* during this period is most likely related to the enhanced, selective dissolution of more lightly-silicified species during the non-productive season.~~

5.5. Relative importance of the SAZ and PFZ to carbon export

The depth at which the organic carbon is remineralized to CO_2 by zooplankton and bacteria determines the timescales during which carbon is sequestered from the atmosphere (Yamanaka and Tajika, 1996; Smetacek et al., 2012). In the SAZ and the PFZ, the fraction of organic carbon recycled within the winter mixed layer (>400 m in the SAZ and between 150-200 m in the PFZ; Rintoul and Bullister, 1999; Rintoul and Trull, 2001) would reequilibrate with the atmosphere within months, whereas only the comparatively smaller portion that reaches deeper layers will remain in the ocean interior for centuries or longer timescales (Trull et al., 2001a). Thus, from the perspective of carbon sequestration, the POC fluxes measured by the traps reported in this study are probably of greater importance than those remineralized at mid-depths.

Despite the fact that total mass fluxes in the PFZ at ~ 1 km were two-fold larger than those of the SAZ, the annual POC export was almost identical in both regions (Fig. 8a), implying that particles sinking out the mixed layer in the SAZ were relatively POC rich (Trull et al., 2001a; Ebersbach et al., 2011). Taking into account that gross primary production is similar in the two zones, or perhaps somewhat lower in the PFZ (Fig. 8b; Lourey and Trull, 2001; Cavagna et al., 2011; Westwood et al., 2011), our results challenge the notion that for a given similar level of production, diatom-dominated ecosystems export greater amounts of carbon to the deep ocean than ecosystems dominated by smaller, non-siliceous phytoplankton (Buesseler, 1998; Boyd and Newton, 1999; Laws et al., 2000). Trull et al. (2001) hypothesised that the similar POC export at both sites could be due to either (1) a more efficient repackaging of carbon for deep transport by the zooplankton community in the SAZ than in the PFZ or (2) to the fact that the silicate-rich particles exported in the PFZ may experience stronger loses of organic carbon at mesopelagic depths than do the carbonate-rich particles of the SAZ. Results from of the SAZ-sense programme (Bowie et al., 2011b) taken together with the data presented in this study provide key information to assess these hypotheses.

Analysis of the flux size spectra at the 47°S and 54°S sites by Ebersbach et al. (2011) during January and February 2007 revealed that the vertical export at both stations was dominated by heavily processed particles, mainly faecal aggregates with a slight shift towards smaller particles within the PFZ due to abundant chains of diatoms sinking individually or as part of unconsolidated aggregates. Although the latter study was limited to a short observational period, the results of Ebersbach et al. (2011) suggest that zooplankton grazing had a similar impact on the control of particle export at both sites, and therefore the first hypothesis seems unlikely.

On the other hand, our data shows that only a few diatom species, particularly *F. kerguelensis*, dominate the particle export in the silicate-rich and iron-limited waters of the PFZ and AZ. Most of these species are known to significantly increase their BSi:PON and BSi:POC ratios under iron deficiency resulting in the thickening of its already robust frustule (Takeda, 1998; Hoffmann et al., 2007). Furthermore, recent findings from the European Iron Fertilization Experiment (EIFEX; Smetacek et al., 2012) illustrated that the cellular content of a large fraction of the *F. kerguelensis* stock outside and inside the patch was recycled in the surface layer, resulting in the disproportional sinking of empty frustules to the deep ocean (Assmy et al., 2013). The former authors concluded that due to these particular traits, *F. kerguelensis* and other exceptionally robust diatoms, such as *Thalassiosira lentiginosa*~~,~~ and *Thalassionema nitzschioides* ~~and *Thalassiothrix antarctica*~~ preferentially sequester silicon relative to carbon in the iron-limited waters of the ACC. This concept is consistent with our findings in the open-waters of the Australian sector south of the SAF, and would help to explain the low POC content and POC:BSi ratios of the particles registered at meso- and bathypelagic depths by our PFZ and AZ traps.

Significantly, comparisons of our results (Fig. 8a) with satellite and in-situ measurements of primary production (Fig. 8b) suggest that high BSi sedimentation rates should be interpreted as a proxy for iron-limited diatom assemblages (Hutchins and Bruland, 1998; Takeda, 1998; Assmy et al., 2013) rather than for high primary production. This conclusion raises corresponding caution to previous studies that suggest that higher ~~Si~~ BSi fluxes in the past refer to a stronger biological carbon pump (Anderson et al., 2009; Sigman et al., 2010).

Conclusions

This study reports on the chemical (biogenic silica, carbonate and POC) and biological (diatoms) composition of material exported at ~1 km depth at two sites representative of two major hydrological regions of the Australian sector of the

Southern Ocean, the SAZ and PFZ. As a result of different algal communities, the composition and magnitude of the sinking particle fluxes was very different between sites, with higher and ~~biogenic silicate~~BSi-dominated fluxes in the PFZ versus lower and carbonate-dominated fluxes in the SAZ. Despite these differences, the POC export reaching the traps was indistinguishable between sites (~1 g m^{-2} yr^{-1}). Seasonality and flux magnitude was more pronounced in the PFZ. The vigorous settling of biogenic particles during summer in the PFZ accounted for a large fraction of the annual POC export. These summer pulses are a major factor responsible for the variability in carbon sequestration from the atmosphere in this region. Our results suggest that the development of a group of bloom-forming diatom species during the growth season probably led~~lead to~~ the formation of algal and/or faecal aggregates. The production and sinking of these aggregates most likely facilitated the scavenging of other particles in the water column, and thus the co-sedimentation of the all the components of the flux. *Fragilariopsis kerguelensis* dominated the diatom sinking assemblage at both sites and was considered the major biological vector decoupling the carbon and silicon cycles in the waters south the SAF. Comparisons of our data with in-situ and satellite primary production estimates lead us to conclude that high ~~biogenic silica~~BSi accumulation rates in the sedimentary record should be interpreted as a proxy for iron-limited diatom assemblages rather than for a stronger biological pump.

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Figure captions

Figure 1. Southern Ocean chlorophyll-*a* composite map (September 1997 to September 2007) from Seaviewing Wide Field-of-view Sensor with the location of the sediment trap moorings of the SAZ (47°S, 51°S, 54°S and 61°S) and AESOPS (MS-1, MS-2, MS-3, MS-4 and MS-5) experiments. Abbreviations: STF Subtropical Front, SAZ Subantarctic Zone, SAF Subantarctic Front, PFZ Polar Frontal Zone, PF Polar Front, AZ Antarctic Zone SACC Southern extent of the Antarctic Circumpolar Current, Max WSI maximum winter sea ice extent. Oceanic fronts from Orsi et al. (1995). Sea ice extent from Fetterer et al. (2002, updated 2009).

Figure 2. (a) Available mean sea surface temperature (SST), Photosynthetically Available Radiation (PAR), and Chlorophyll-*a* concentration for the 47°S site. The dashed intervals represent the studied periods. (b) Temporal variability of the total and major component fluxes, and their relative contributions to the total mass flux ~~Temporal variability of the total mass and major component fluxes and of the relative contribution of biogenic silica, carbonate, particulate organic carbon (POC), and others~~ for the < 1 mm fraction at 1000 m water depth at the 47°S site for the period July 1999 - October 2001. Biogenic silica, carbonate, and particulate organic carbon (POC) were directly measured. Other indicates uncharacterized mass contributions (organic components other than carbon and small amounts of lithogenic material; Trull et al.,

2001). Gray horizontal bars highlight the summer period (December to February) of each year.

Figure 3. (a) Available mean sea surface temperature (SST), Photosynthetically Available Radiation (PAR), and Chlorophyll-*a* concentration for the 54°S site. The dashed intervals represent the studied periods. (b) Temporal variability of the total and major component fluxes, and their relative contributions to the total mass flux ~~Temporal variability of the total mass and major component fluxes and of the relative contribution of biogenic silica, carbonate, particulate organic carbon (POC), and others~~ for the < 1 mm fraction at 800 m water depth at the 54°S site for the periods July 1999 - August 2000, November 2002 - October 2004 and December 2005 - October 2007. ~~Gray horizontal bars highlight the summer period (December to February) of each year.~~Biogenic silica, carbonate, and particulate organic carbon (POC) were directly measured. Other indicates uncharacterized mass contributions (organic components other than carbon and small amounts of lithogenic material; Trull et al., 2001). Gray horizontal bars highlight the summer period (December to February) of each year.

Figure 4. Temporal variability of (a) total diatom flux and biogenic silica and of (b) flux and relative contribution of the main diatom species at 1000 m at the 47°S site for the period July 1999 - October 2001.

Figure 5. Temporal variability of (a) total diatom flux and biogenic silica and of (b) flux and relative contribution of the main diatom species at 800 m at the 54°S site for the periods July 1999 - August 2000, November 2002 - October 2004 and December 2005 - October 2007.

Figure 6. Principal component analysis for the PFZ 47°S (a) and SAZ 54°S sites (b). Projection of the variables (diatom species or groups of species accounting for more than 1% of the integrated assemblage for the whole sampling period) on the first two PCA axes together with total mass (grey), biogenic silica (blue), carbonate (yellow) and POC (red) flux.

Figure 7. Temporal variability of the total diatom, “High export group”, *Fragilariopsis kerguelensis*, biogenic silica and POC fluxes for the six-year record at the 54°S site.

Figure 8. a. Annual mean total mass, major component, and diatom valve fluxes for the <1 mm particulate fraction for the 47°S, 54°S and 61°S sites. **b.** Annual average of

Chlorophyll-*a* concentration and two different estimates of primary productivity (standard vertically generalized production model – VGPM; and carbon-based production model - CbPM) for the 47°S, 54°S and 61°S sites from October 1997 to September 2007.

Table 1. Deployment summary of sediment traps at stations 47°S, 54°S and 61°S.

Table 2. Individual cup fluxes for the < 1 mm fraction.

Table 3. Estimated annual export fluxes of total mass flux, biogenic silica, calcium carbonate, POC and diatom valves for <1 mm fraction at the 47°S, 54°S and 61°S sites.

Table 4. List of diatom species recorded in the sediment traps of the 47°S, 54°S and 61°S (2000 m) sites along the 140°E. Relative abundances < 0.1 are represented by an asterisk (*), whereas the absence of a taxon in a given site is represented by an empty circle (○).

Table 5. Varimax loadings matrix (rotation: varimax normalized). Factor loadings for analysis on sediment trap samples using species and group of species with abundances higher than 1% of the total integrated diatom assemblage for the whole sampling period at the 47°S (a) and 54°S site (b). **Bold** print indicates the dominant species or group of species within each factor (loadings > 0.70).

Table 6. Correlation coefficients between the PCA factors and the fluxes of bulk components (total mass, carbonate, biogenic silica and POC) for the 47°S (a) and 54°S (b) sites.

Supplementary figure 1: Temporal pattern of BSi:PIC ratio at the 47°S (a) and 54°S (b) mooring sites. Dashed lines represent the average inter-annual BSi:PIC ratio.

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