Interactive comment on "Export fluxes in a naturally iron-fertilized area of the Southern Ocean: seasonal dynamics of particulate organic carbon export from a moored sediment trap (part 1)." by Rembauville et al.

Response to reviewer's #3 comments on the revised submission.

We thank anonymous referee #3 for the careful reading of the revised manuscript. All of the Reviewer's suggestions have been taken into account and the resulting modifications appear in a revised version of the manuscript following this answer. *R3-Cx : Referee comment*, **R3-Rx:** authors response

In the revised manuscript, the authors have significantly addressed many of the substantive issues raised in the three reviews. Most importantly they have withdrawn some of the emphasis on strong flux attenuation, since, as the referees pointed out, there is not sufficient evidence for this. They have also omitted some of the inappropriate comparisons. There is also now an appropriate emphasis on reporting the seasonal cycle as requested by the reviewers.
However, there is now inconsistency within the text on how the "flux attenuation" issue is dealt with and there remains text that does not sufficiently take account of the unanimous views of the referees and still puts an unjustified case for strong flux attenuation.
We thank Reviewer #3 for acknowledging the extensive modifications made to the manuscript. According to the Reviewer's additional suggestions, we have modified further our discussion of strong flux attenuation.

STRONG FLUX ATTENUATION considerations

R3-C1: *In the paragraph of lines 452 – 462 commencing "The annual POC export of…" the first comparison is made with the KEOPS 1 Blain et al. (2007) estimate. It would be more relevant to first compare with the other KEOPS 2 results and move the KEOPS 1 comparison to later in this paragraph.*
R3-R1: We initially decided to start with a comparison of the annual estimates before comparing the short-term estimates of KEOPS2 and KEOPS1. However following the reviewer's suggestion we now start with a comparison of the short term estimates before the annual estimate derived from KEOPS1.

R3-C2: *In lines 454 – 457 they state that: "On shorter time scales, the POC flux recorded in the moored sediment trap represents only a small fraction (3-8%) of the POC flux at the base of the mixed layer measured by the different methods during KEOPS 2 (Table 3)." In fact these other KEOPS 2 methods measure short sampling periods/ deployments and not the annual total. It would be more informative, here, to compare the individual techniques, for example the Jouandet et al (2014) values quoted in table 3 are actually very similar to the monthly values of the authors' results given in table 1. It would much improve this section if the different methods were compared, in turn.*

R3-R2: Here we indeed compare spring and summer sediment trap fluxes with short-term estimates performed at 200 m from individual techniques in spring during KEOPS2 and summer during KEOPS1. We hope the new formulation of this paragraph is clearer. Moreover, the similarity between and the Jouandet et al. (2014) values at 350 m and the sediment trap values is discussed in the next paragraph lines 453-456: *"We note that low carbon export fluxes around 300 m have been previously reported on the Kerguelen plateau. In spring 2011, UVP derived estimates of POC export at 350 m equals 0.1 to 0.3 mmol* m^{-2} d^{-1} *(Table 3), a value close to our reported value of 0.15 mmol* m^{-2} d^{-1}*."* Although a discussion of each technique is out of the scope of this paper, we added a brief description of the techniques.

MS change lines 443-466: "*We first compared the sediment trap export fluxes with short-term estimates at 200 m in spring (KEOPS2) and summer (KEOPS1). The POC flux recorded in the moored sediment trap represents only a small fraction (3-8%) of the POC flux measured at the base of the winter mixed layer (200 m) by different approaches during the srping KEOPS2 cruise (Table 3). The same conclusion can be drawn when considering the comparison with different estimates made at the end of summer during KEOPS1. Moreover, the annual POC export of ~0.1 mol* m^{-2} y^{-1} *at 289 m (Table 1) represents only 2% of the indirect estimate of POC export (5.1 mol* m^{-2} y^{-1}*) at the base of the WML (200 m) on the Kerguelen Plateau based on a seasonal DIC budget (Blain et al., 2007). The short term estimates are derived from a diverse range of methods. The* ^{234}*Th proxy is based on the* ^{234}*Th deficit relative to the* ^{238}*U due to its adsorption on particles, and it subsequent conversion to carbon fluxes using measured POC:*^{234}*Th ratios. (Coale and Bruland, 1985; Buesseler et al., 2006; Savoye et al., 2006). The UVP provides high resolution images of particles (>52 µm) and the particle size distribution is then converted to carbon fluxes using an empirical relationship (Guidi et al., 2008; Picheral et al., 2010). Drifting gel traps allows the collection, preservation and imaging of sinking particles (>71 µm) that are converted to carbon fluxes using empirical volume:carbon relationship (Ebersbach and Trull, 2008; Ebersbach et al., 2011; Laurenceau-Cornec et al., 2015). Finally, drifting sediment traps are conceptually similar to moored sediment traps but avoid most of the hydrodynamic biases associated with this technique (Buesseler et al., 2007a). The diversity of the methods and differences in depth where the POC flux was estimated render quantitative comparisons challenging. Nevertheless, POC fluxes measured at 289 m with the moored sediment trap are considerably lower than other estimates made at 200 m. This result indicates either extremely rapid attenuation of flux between 200 m and 300 m or significant sampling bias by the sediment trap."*

R3-C3: *Lines 475-476. "the scenario of strong flux attenuation…" is not well supported and this sentence should be deleted.*

R3-R3: We reformulated this sentence and deleted "the scenario of strong flux attenuation…"

MS change lines 478 - 479: "*Our calculations are thus consistent with emerging observations of significant POC flux attenuation in the Southern Ocean.*"

R3-C4: *In lines 493 – 495 they state "Therefore the low fluxes observed likely result from a combination of collection bias (hydrodynamics and swimmers) and strong attenuation of the POC flux between the base of the WML and 300 m." This should be re-written to suggest that it is currently not possible to isolate a specific explanation for low flux values.*

R3-R4: We reformulated this sentence.

MS change lines 498 - 501: "*Therefore the low fluxes observed likely result from a combined effect of collection bias (hydrodynamics and swimmers) and attenuation between the base of the WML and 300 m. However, it is not possible with the current dataset to isolate a specific explanation for low flux values*"

R3-C5: *Lines 496-497: It is incorrect to say that the moored trap had a "Low collection efficiency" with reference to the 234Th - derived flux estimates. Simply it should be stated that the methods yielded different results and this would be better discussed in the paragraph above in lines 452 – 462.*

R3-R5: We deleted this sentence. Lines 487 - 501 are dedicated to the discussion of the lower fluxes usually recorded by sediment traps compared to ^{234}Th - derived fluxes.

R3-C6: *Lines 497 – 499. "the numerous lines of evidence discussed above appear to converge on a scenario of rapid flux attenuation.". This is not justified and should be deleted.*

R3-R6: The paragraph lines 464 – 477 demonstrates from two independent measurements that attenuation coefficients (b-values) are high over the central Kerguelen Plateau and falls in the range of previously reported values for the Southern Ocean. However we followed the Reviewer's suggestion and deleted this sentence.

R3-C7: *Lines 656 – 661 in the "Conclusions" will also need to be re-written to downplay the "strong flux attenuation" emphasis.*

R3-R7: We have rewritten the last sentences of this paragraph and deleted the "strong flux attenuation".

MS change (Conclusions): *"We report the seasonal dynamics of particulate organic carbon (POC) export under the winter mixed layer (289 m) of the naturally iron fertilized and productive central Kerguelen Plateau. Annual POC flux was remarkably low (98 mmol m^{-2}) and occurred primarily during two episodic (<14 days) flux events exported with a 1 month lag following two surface chlorophyll a peaks. Analysis of the hydrological conditions and a comparison with different estimates of POC fluxes in spring and summer at the same station suggests that the sediment trap was subject to possible hydrodynamic and biological biases leading to under collection of particle flux. Nevertheless the low POC export was close to other estimates of deep (>300 m) POC export at the same station and is consistent with high attenuation coefficients reported from other methods. We invoke heterotriophic micropbial activity and mesozooplankton and mesopelagic fish activity as possible explanations for efficient carbon flux attenuation and/or transfer to higher trophic levels which results in a High Biomass, Low Export environment."*

R3-C8: *Section 4.4 "Rapid flux attenuation over the Kerguelen Plateau" should be changed to reflect a less definitive case to e.g. "Evidence for flux attenuation…"*

R3-R8: We changed the title of this section to "Evidence for significant flux attenuation over the Kerguelen Plateau".

R3-C8: *Finally, in the abstract (lines 40) "the large reduction" should be replaced with words to the effect of "a significant reduction" to achieve the appropriate nuance and line 31 "collection of only 15-30%..." should be deleted.*

R3-R8: We changed "large reduction" to "significant reduction". We also deleted the comparison with ^{234}Th fluxes in the abstract.

SECTION 4.3 Seasonal Dynamic of POC export.

R3-C9: *Line 396 "The temporal lag…"An alternative explanation is that there is a later event from which the flux originates that was not expressed in surface chlorophyll (see below). This should be discussed with reference to the Rynearson et al (2013) study.*

R3-R9: We already mentioned this potential explanation in the original version of the manuscript: lines 429 – 432: "*The temporal lag of one month measured in the present study suggest either slow sinking rates (<5 m d^{-1}) characteristic of single phytoplanktonic cells or faster sinking particles that do not originate from the peaks of surface production.*" and lines 441 – 443: "*The hypothesis of a mass production of nutrient-limited resting spores post-bloom with high settling rates explains the temporal patterns of export we observed (Rembauville et al., 2014)*".

To make this clearer we have modified that original sentence too:

MS change lines 406 – 409: "*The temporal lag of one month measured in the present study suggest either slow sinking rates (<5 m d^{-1}) characteristic of single phytoplanktonic cells or faster sinking particles that originate from sub-surface production peaks undetected by satellite.*"

R3-C10: *Line 427 "It is generally accepted that satellite detection depth is 20-50 m (Gordon and McCluney, 1975)…"The satellite detection depth is, in fact, not more than 20 m in these circumstances. See, for example, Fig. 3 of [Smith R.C. (1981) "Remote sensing and depth distribution of ocean chlorophyll" Mar. Ecol. Prog. Ser. 5, 359-361]. Since the minimum surface chorophyll indicated in Fig. 7 appears to exceed 0.2 micro-g/ L, then 20 m would be a maximum. A phytoplankton biomass would therefore only have to be deeper than 20 m to be undetected by satellite. This is significant, since the resting spores collected in traps in the North Atlantic by Rynearson et al (2013) were not part of surface samples. This paper should also be cited here in a modified discussion.*

R3-R10: We added the reference for the satellite detection depth and changed the corresponding sentence. The resting spore formation and the associated driving factors are fully discussed is the "Part 2" paper, including the Rynearson et al. (2013) reference. We choose not to discuss these points in detail in this "Part 1". Furthermore, it is entirely possible in the Rynearson dataset that the *Chaetoceros* aff. *diadema* vegetative cells were not detected in the uppermost surface samples because resting spore formation and export had already occurred at the time of sampling, as in fact suggested by their dominance as settling particles several hundred metres deep. *Chaetoceros Hyalochaete* populations are certainly present at 10 m from station A3 on the Kerguelen plateau (Armand et al., 2008).

MS change lines 409 - 412: "*It is generally accepted that satellite detection depth is 20-50 m (Gordon and McCluney, 1975), and can be less than 20 m when surface chlorophyll a exceed*

0.2 µg L^{-1} (Smith, 1981), which prevents the detection of deep phytoplanktonic biomass structures (Villareal et al., 2011)."

MINOR POINTS.

Line 208: delete :we" at end of line.
Change made.
Line 218: stop after "salts".
Change made.
Line 358: stop after (Table 2).
Change made.
Line 375: should be "Particle".
Change made.
Line 385: replace "rather than" with "in addition to".
Change made.
Line 387: "dynamics".
Change made.
Line 391: comma after "deployments".
Change made.
Line 397: should be "originate".
Change made.
Line 464: upper case Plateau; replace "equals" with "are".
Change made.
Line 466: replace "equals" with "is".
Change made.
Line 509: insert "the" after "documents".
Change made.
Lines 513, 514: "fish" not "fishes"
Change made.

REFERENCES.

Something seems to have gone wrong with Endnote: the Coale et al 2004a and 2004b are actually the same paper (Lines 767-784). Similarly: Lima et al 2014a,b Lines 948-951.
Change made.
Line 875: stray comma after date
Change made.
Line 918: Laurenceau seems now to be Laurenceau-Cornec.
Change made.

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Export fluxes in a naturally iron-fertilized area of the Southern Ocean: seasonal dynamics of particulate organic carbon export from a moored sediment trap (part 1).

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Abstract

A sediment trap moored in the naturally iron-fertilized Kerguelen plateau in the Southern Ocean provided an annual record of particulate organic carbon and nitrogen fluxes at 289 m. At the trap deployment depth current speeds were typically low (~10 cm s^{-1}) and primarily tidal-driven (M2 tidal component). Although advection was weak, the sediment trap may have been subject to hydrodynamical and biological (swimmer feeding on trap funnel) biases. ~~that could explain the collection of only 15-30 % of the ^{234}Th derived flux~~. Particulate organic carbon (POC) flux was generally low (<0.5 mmol m^{-2} d^{-1}) although two episodic export events (<14 days) of 1.5 mmol m^{-2} d^{-1} were recorded. These increases in flux occurred with a 1-month time lag from peaks in surface chlorophyll and together accounted for approximately 40 % of the annual flux budget. The annual POC flux of 98.2±4.4 mmol m^{-2} y^{-1} was low

considering the shallow deployment depth, but comparable to independent estimates made at similar depths (~300 m) over the plateau and to deep-ocean (>2 km) fluxes measured from similarly productive iron-fertilized blooms. Although undertrapping cannot be excluded in shallow moored sediment trap deployment, we hypothesize that grazing pressure, including mesozooplankton and mesopelagic fishes, may be responsible for the ~~large~~ significant reduction in POC flux beneath the base of the winter mixed layer. The importance of plankton community structure in controlling the temporal variability of export fluxes is addressed in a companion paper.

1 Introduction

The biological carbon pump is defined as the vertical transfer of biologically fixed carbon in the ocean surface to the ocean interior (Volk and Hoffert, 1985). Global estimates of Particulate Organic Carbon (POC) export cluster between 5 Pg C y^{-1} (Moore et al., 2004; Lutz et al., 2007; Honjo et al., 2008; Henson et al., 2011; Lima et al., 2014) to 10 Pg C y^{-1} (Laws et al., 2000; Schlitzer, 2004; Gehlen et al., 2006; Boyd and Trull, 2007; Dunne et al., 2007; Laws et al., 2011). The physical transfer of dissolved inorganic carbon to the ocean interior during subduction of water masses is two orders of magnitude higher (> 250 Pg C y^{-1}, Karleskind et al., 2011; Levy et al., 2013). The global ocean represents a net annual CO_2 sink of 2.5 Pg C y^{-1} (Le Quéré et al., 2013), slowing down the increase of the atmospheric CO_2 concentration resulting from anthropogenic activity. Although the Southern Ocean (south of 44°S) plays a limited role in the net air-sea CO_2 flux (Lenton et al., 2013), it is a key component of the global anthropogenic CO_2 sink representing one third the global oceanic sink (~1 Pg C y^{-1}) while covering 20 % of its surface (Gruber et al., 2009). The solubility pump is considered as the major component of this sink, whereas the biological carbon pump is considered to be inefficient in the Southern Ocean and sensitive to iron supply.

Following "the iron hypothesis" in the nineties (Martin 1990), iron limitation of high nutrient low chlorophyll (HNLC) areas, including the Southern Ocean, has been tested in bottle experiments (de Baar et al., 1990) and through *in situ* artificial fertilization experiments (de Baar et al., 2005; Boyd et al., 2007). Results from these experiments are numerous and essentially highlight that iron limits macronutrient (N, P, Si) utilization (Boyd et al., 2005; Hiscock and Millero, 2005) and primary production (Landry et al., 2000; Gall et al., 2001; Coale et al., 2004) in these vast HNLC areas of the Southern Ocean. Due to a large macronutrient repository the biological carbon pump in the Southern Ocean is considered to be inefficient in its capacity to transfer atmospheric carbon to the ocean interior (Sarmiento

66 and Gruber, 2006). In the context of micronutrient limitation, sites enriched in iron by natural
67 processes have also been studied and include the Kerguelen islands (Blain et al., 2001, 2007),
68 the Crozet islands (Pollard et al., 2007), the Scotia Sea (Tarling et al., 2012), and the Drake
69 Passage (Measures et al., 2013). Enhanced primary producer biomass in association with
70 natural iron supply (Korb and Whitehouse, 2004; Seeyave et al., 2007; Lefèvre et al., 2008)
71 strongly support trace-metal limitation. Furthermore, indirect seasonal budgets constructed
72 from studies of naturally fertilized systems have been capable of demonstrating an increase in
73 the strength of the biological carbon pump (Blain et al., 2007; Pollard et al., 2009), although
74 strong discrepancies in carbon to iron sequestration efficiency exist between systems. To date,
75 direct measurements of POC export from naturally fertilized blooms in the Southern Ocean
76 are limited to the Crozet Plateau (Pollard et al., 2009; Salter et al., 2012). The HNLC
77 Southern Ocean represents a region where changes in the strength of the biological pump may
78 have played a role in the glacial-interglacial CO_2 cycles (Bopp et al., 2003; Kohfeld et al.,
79 2005) and have some significance to future anthropogenic CO_2 uptake (Sarmiento and Le
80 Quéré, 1996). In this context, additional studies that directly measure POC export from
81 naturally iron-fertilized blooms in the Southern Ocean are necessary.

82 POC export can be estimated at short timescales (days to weeks) using the ^{234}Th proxy
83 (Coale and Bruland, 1985; Buesseler et al., 2006; Savoye et al., 2006), by optical imaging of
84 particles (e.g. Picheral et al., 2010) or by directly collecting particles into surface-tethered
85 sediment traps (e.g. Maiti et al., 2013 for a compilation in the Southern Ocean) or neutrally
86 buoyant sediment traps (e.g. Salter et al., 2007; Rynearson et al., 2013). Temporal variability
87 of flux in the Southern Ocean precludes extrapolation of discrete measurements to estimate
88 seasonal or annual carbon export. However seasonal export of POC can be derived from
89 biogeochemical budgets (Blain et al., 2007; Pollard et al., 2009) or be directly measured by
90 moored sediment traps (e.g. Salter et al., 2012). Biogeochemical budgets are capable of

integrating over large spatial and temporal scales but may incorporate certain assumptions and lack information about underlying mechanisms. Direct measurement by sediment traps rely on fewer assumptions but their performance is strongly related to prevailing hydrodynamic conditions (Buesseler et al., 2007a), which can be particularly problematic in the surface ocean. Measuring the hydrological conditions characterizing mooring deployments is therefore crucial to address issues surrounding the efficiency of sediment trap collection.

The ecological processes responsible for carbon export remain poorly characterized (Boyd and Trull, 2007). There is a strong requirement for quantitative analysis of the biological components of export to elucidate patterns in carbon and biomineral fluxes to the ocean interior (Francois et al., 2002; Salter et al., 2010; Henson et al., 2012; Le Moigne et al., 2012; Lima et al., 2014). Long-term deployment of moored sediment traps in areas of naturally iron fertilized production, where significant macro- and micro-nutrient gradients seasonally structure plankton communities, can help to establish links between ecological succession and carbon export. For example, sediment traps around the Crozet Plateau (Pollard et al., 2009) identified the significance of *Eucampia antarctica* var. *antarctica* resting spores for carbon transfer to the deep ocean, large empty diatom frustules for Si:C export stoichiometry (Salter et al., 2012), and heterotrophic calcifiers for the carbonate counter pump (Salter et al., 2014).

The increase in primary production resulting from natural fertilization might not necessarily lead to significant increases in carbon export. The concept of "High Biomass, Low Export" (HBLE) environments was first introduced in the Southern Ocean (Lam and Bishop, 2007). This concept is partly based on the idea that a strong grazer response to phytoplankton biomass leads to major fragmentation and remineralization of particles in the twilight zone, shallowing the remineralization horizon (Coale et al., 2004). In these environments, the efficient utilization and reprocessing of exported carbon by zooplankton leads to fecal pellet

dominated, low POC fluxes (Ebersbach et al., 2011). A synthesis of short-term sediment trap deployments, ^{234}Th estimates of upper ocean POC export and in situ primary production measurements in the Southern Ocean by Maiti et al. (2013) has highlighted the inverse relationship between primary production and export efficiency, verifying the HBLE status of many productive areas in the Southern Ocean. The iron fertilized bloom above the Kerguelen Plateau exhibits strong remineralization in the mixed layer compared to the mesopelagic, (Jacquet et al., 2008) and high bacterial carbon demand (Obernosterer et al., 2008), features consistent with a HBLE regime. Moreover, an inverse relationship between export efficiency and zooplankton biomass in the Kerguelen Plateau region support the key role of grazers in the HBLE scenario (Laurenceau-Cornec et al., 2015). Efficient grazer responses to phytoplankton biomass following artificial iron fertilization of HNLC regions also demonstrate increases in net community production that are not translated to an increase in export fluxes (Lam and Bishop, 2007; Tsuda et al., 2007; Martin et al., 2013; Batten and Gower, 2014).

POC flux attenuation with depth results from processes occurring in the euphotic layer (setting the particle export efficiency, Henson et al., 2012) and processes occurring in the twilight zone between the euphotic layer and ~1000 m (Buesseler and Boyd, 2009), setting the transfer efficiency (Francois et al., 2002). These processes are mainly biologically-driven (Boyd and Trull, 2007) and involve a large diversity of ecosystem components from bacteria (Rivkin and Legendre, 2001; Giering et al., 2014), protozooplankton (Barbeau et al., 1996), mesozooplankton (Dilling and Alldredge, 2000; Smetacek et al., 2004) and mesopelagic fishes (Davison et al., 2013; Hudson et al., 2014). The net effect of these processes is summarized in a power-law formulation of POC flux attenuation with depth proposed by Martin et al. (1987) that is still commonly used in data and model applications. The b-exponent in this formulation has been reported to range from 0.4 to 1.7 (Buesseler et al.,

141 2007b; Lampitt et al., 2008; Henson et al., 2012) in the global Ocean. Nevertheless, a change
142 in the upper mesopelagic community structure (Lam et al., 2011), and more precisely an
143 increasing contribution of mesozooplankton (Lam and Bishop, 2007; Ebersbach et al., 2011)
144 could lead to a shift toward higher POC flux attenuation with depth.

145 In this paper, we provide the first annual description of the POC and PON export
146 fluxes below the mixed layer within the naturally fertilized bloom of the Kerguelen Plateau
147 and we discuss the reliability of these measurements considering the hydrological and
148 biological context. A companion paper (Rembauville et al., 2014) addresses our final aim: to
149 identify the ecological vectors that explain the intensity and the stoichiometry of the fluxes.

2 Material and Methods

2.1 Trap deployment and mooring design

As part of the KEOPS2 multidisciplinary program, a mooring line was deployed at station A3 (50°38.3 S – 72°02.6 E) in the Permanently Open Ocean Zone (POOZ), south of the Polar Front (PF) (Fig. 1). The mooring line was instrumented with a Technicap PPS3 (0.125 m^2 collecting area, 4.75 aspect ratio) sediment trap and inclinometer (NKE S2IP) at a depth of 289 m (seafloor depth 527 m) (Fig. 2). A conductivity-temperature-pressure (CTD) sensor (Seabird SBE 37) and a current meter (Nortek Aquadopp) were placed on the mooring line 30 m beneath the sediment trap (319 m). The sediment trap collection period started on 21 October 2011 until 7 September 2012. The sediment trap was composed of twelve rotating sample cups (250 mL) filled with a 5 % formalin hypersaline solution buffered with sodium tetraborate at pH = 8. Rotation of the carousel was programmed to sample short intervals (10-14 days) between October and February, to optimize the temporal resolution of export from the bloom, and long intervals (99 days) between February and September. All instruments had a 1 hour recording interval. The current meter failed on the 7th April 2012.

2.3 Surface chlorophyll data

The MODIS AQUA level 3 (4 km grid resolution, 8 day averages) surface chlorophyll *a* product was extracted from the NASA website (http://oceancolor.gsfc.nasa.gov/) for sediment trap deployment period. An annual climatology of surface chlorophyll *a* concentration, based on available satellite products (1997-2013), was calculated from the multisatellite Globcolour product. The Globcolour level 3, (case 1 waters, 4.63 km resolution, 8 day averages) product merging Seawifs, MODIS and MERIS data with GSM merging model (Maritorena and Siegel, 2005) was accessed via http://www.globcolour.info. Surface chlorophyll *a* concentrations derived from Globcolour (climatology) and MODIS data

174 (deployment year) were averaged across a 100 km radius centered on the sediment trap
175 deployment location (Fig. 1).

176 **2.3 Time series analyses of hydrological parameters**

177 Fast Fourier Transform (FFT) analysis was performed on the annual time series data obtained
178 from the mooring, depth and potential density anomaly (σ_θ) that were derived from the CTD
179 sensor. Significant peaks in the power spectrum were identified by comparison to red noise, a
180 theoretical signal in which the relative variance decreases with increasing frequency (Gilman
181 et al., 1963). The red noise signal was considered as a null hypothesis and its power spectrum
182 was scaled to the 99^{th} percentile of χ^2 probability. Power peaks higher than 99 % red noise
183 values were considered to be statistically significant (Schulz and Mudelsee, 2002), enabling
184 the identification of periods of major variability in time series. In order to identify the water
185 masses surrounding the trap, temperature and salinity recorded by the mooring CTD were
186 placed in context to previous CTD casts conducted at A3 during KEOPS1 (39 profiles, 23
187 January 2005 - 13 February 2005) and KEOPS2 (12 profiles, from 15 - 17 November).

188 **2.4 Sediment trap material analyses**

189 Upon recovery of the sediment trap the pH of the supernatant was measured in every cup and
190 1 mL of 37 % formalin buffered with sodium tetraborate (pH=8) was added. After allowing
191 the particulate material to settle to the base of the sample cup (~24 hrs), 60 mL of supernatant
192 was removed with a syringe and stored separately. The samples were transported in the dark
193 at 4°C (JGOFS Sediment Trap Methods, 1994) and stored under identical conditions upon
194 arrival at the laboratory until further analysis. Nitrate, nitrite, ammonium and phosphate in the
195 supernatant were analysed colorimetrically (Aminot and Kerouel, 2007) to check for possible
196 leaching of dissolved inorganic nitrogen and phosphorus from the particulate phase.

Samples were first transferred to a petri dish and examined under stereomicroscope (Leica MZ8, x10 to x50 magnification) to determine and isolate swimmers (i.e. organisms that actively entered the cup). All swimmers were carefully sorted, cleaned (rinsed with preservative solution), enumerated and removed from the cups for further taxonomic identification. The classification of organisms as swimmers remains subjective and there is no standardized protocol. We classified zooplankton organisms as swimmers if organic material and preserved structures could be observed. Empty shells, exuvia (exoskeleton remains) and organic debris were considered part of the passive flux. Sample preservation prevented the identification of smaller swimmers (mainly copepods) but, where possible, zooplankton were identified following Boltovskoy (1999).

Following the removal of swimmers, samples were quantitatively split into eight aliquots using a Jencons peristaltic splitter. A splitting precision of 2.9 % (coefficient of variation) was determined by weighing the particulate material obtained from each of four $1/8^{th}$ aliquots (see below). Aliquots for chemical analyses were centrifuged (5 min at 3000 rpm) with the supernatant being withdrawn after this step and replaced by milliQ-grade water to remove salts. (Milli-Q rinses were compared with ammonium formate. Organic carbon content was not statistically different although nitrogen concentrations were significantly higher, consequently Milli-Q rinses were routinely performed). The rinsing step was repeated three times. The remaining pellet was freeze-dried (SGD-SERAIL, 0.05-0.1 mbar, -30 °C to 30 °C, 48h run) and weighed three times (Sartorius MC 210 P balance, precision 10^{-4} g) to calculate the total mass. The particulate material was ground to a fine powder and used for measurements of particulate constituents.

For particulate organic carbon (POC) and particulate organic nitrogen (PON) analyses, 3 to 5 mg of the freeze-dried powder was weighed directly into pre-combusted (450°C, 24h) silver cups. Samples were decarbonated by adding 20 µL of 2M analytical grade Hydrochloric

222 acid (Sigma-Aldrich). Acidification was repeated until no bubbles could be seen, ensuring all
223 particulate carbonate was dissolved (Salter et al., 2010). Samples were dried overnight at 50
224 °C. POC and PON were measured with a CHN analyzer (Perkin Elmer 2400 Series II
225 CHNS/O Elemental Analyzer) calibrated with glycine. Samples were analysed in triplicate
226 with an analytical precision of less than 0.7 %. Due to the small amount of particulate
227 material in sample cups #5 and #12, replicate analyses were not possible. Uncertainty
228 propagation for POC and PON flux was calculated as the quadratic sum of errors on mass flux
229 and POC/PON content in each sample. The annual flux (± standard deviation) was calculated
230 as the sum of the time-integrated flux.

231 **3. Results**

232 **3.1 Physical conditions around trap**

233 The sediment trap was deployed in the upper layers of Upper Circumpolar Deep Water
234 (UCDW), beneath seasonally mixed Winter Water (WW) (Fig. 2). The depth of the CTD
235 sensor varied between 318 m and 322 m (1 % and 99 % quantiles), with rare deepening to 328
236 m (Fig. 3a). Variations in tilt angle of the sediment trap were also low, mostly between 1 °
237 and 5 °, and occasionally reaching 13 ° (Fig. 3d). Current speed amplitude varied between 4
238 cm s^{-1} and 23 cm s^{-1} (1 % and 99 % quantiles) with a maximum value of 33 cm s^{-1} and a mean
239 value of 9 cm s^{-1} (Fig. 3e). Horizontal flow vectors were divided between northward and
240 southward components with strongest current speeds observed to flow northward (Fig. 3f and
241 3g).

242 The range in potential temperature and salinity was 1.85–2.23 °C and 34.12 – 34.26 (1
243 % - 99 % quantiles) (Fig. 3b and 3c). From July to September 2012, a mean increase of 0.2°C
244 in potential temperature was associated with a strong diminution of high frequency noise
245 suggesting a drift of the temperature sensor. Consequently these temperature data were

246 rejected from the time-series analysis. The potential temperature/salinity diagram is compared
247 to KEOPS1 and KEOPS2 CTD downcast at station A3 (Fig. 4). The CTD sensor recorded the
248 signature of the UCDW and no intrusion of overlying WW could be detected.

249 The power spectrum of vertical sediment trap displacements identified six significant
250 peaks corresponding to frequencies of 6.2 h, 8.2 h, 23.9 h, 25.7 h and 14 days (Fig 5a).
251 Concomitant peaks of depth, angle and current speed were also observed with a period of 14
252 days. However, spectral analysis of the potential density anomaly σ_θ revealed only one
253 significant major power peak corresponding to a frequency of 12.4 h (Fig. 5b). Isopycnal
254 displacements were driven by the unique tidal component (M2, 12.4h period) and trap
255 displacements resulted from a complex combination of multiple tidal components. The power
256 spectrum analysis suggested that a 40 hour window was relevant to filter out most of the short
257 term variability (black line in Fig 3a – 3e).

258 A pseudo-lagrangian trajectory was calculated by cumulating the instantaneous current
259 vectors (Fig 6). Over short time-scales (hours to day) the trajectory displays numerous tidal
260 ellipses. The flow direction is mainly to the South-East in October 2011 to December 2012
261 and North-East from December 2011 to April 2012. For the entire current meter record (6
262 months) the overall displacement followed a 120 km northeasterly, anticlockwise trajectory
263 with an integrated current speed of approximately 1 cm s^{-1}.

264 **3.2 Seasonality of surface chlorophyll *a* concentration above trap location**

265 The seasonal variations of surface chlorophyll *a* concentration for the sediment trap
266 deployment period differed significantly from the long-term climatology (Fig 7a). The bloom
267 started at the beginning of November 2011, ten days after the start of the sediment trap
268 deployment. Maximum surface chlorophyll *a* values of 2.5 µg L^{-1} occurred on the first week
269 of November and subsequently declined rapidly to 0.2 µg L^{-1} in late December 2011. A

second increase in surface chlorophyll *a* up to 1 µg L^{-1} occurred in January 2012 and values decreased to winter levels of 0.2 µg L^{-1} in February 2012. A short-term increase of 0.8 µg L^{-1} occurred in mid-April 2012.

3.3 Swimmer abundances

No swimmers were found in cups #3 and #5 (Table 2). Total swimmer numbers were highest in winter (1544 individuals in cup #12). When normalized to cup opening time, swimmer intrusion rates were highest between mid-December 2011 and mid-February 2012 (from 26 to 55 individuals d^{-1}) and lower than 20 individuals d^{-1} for the remainder of the year. Swimmers were numerically dominated by copepods throughout the year, but elevated amphipod and pteropod abundances were observed at the end of January and February 2012 (Table 2). There was no significant correlation between mass flux, POC and PON fluxes and total swimmer number or intrusion rate (Spearman's correlation test, p >0,01). Copepods were essentially small cyclopoid species. Amphipods were predominantly represented by the hyperidean *Cyllopus magellanicus* and *Themisto gaudichaudii*. Pteropods were represented by *Clio pyramidata*, *Limacina helicina* forma *antarctica* and *Limacina retroversa* subsp. *australis*. Euphausiids were only represented by the genus *Thysanoessa*. One *Slapa thompsoni* salp (aggregate form) was found in the last winter cup #12.

3.4 Seasonal particulate organic carbon and nitrogen fluxes

Particulate organic carbon flux ranged from 0.15 to 0.55 mmol m^{-2} d^{-1} during the productive period except during two short export events of 1.6 ± 0.04 and 1.5 ± 0.04 mmol m^{-2} d^{-1} sampled in cups #4 (2 to 12 December 2011) and #9 (25 January to 8 February 2012), respectively (Fig. 7b). The two flux events occurred with an approximate time lag of one month compared to peaks in surface chlorophyll *a* values. A modest value of 0.27±0.01 mmol m^{-2} d^{-1} was observed in autumn (cup #11, 22 February to 30 May 2012). The lowest POC flux

294 was measured during winter (0.04 mmol m^{-2} d^{-1}, cup #12, 31 May to 7 October). Assuming
295 that POC export was negligible from mid September to mid October, the annually integrated
296 POC flux was 98.2 ± 4.4 mmol m^{-2} y^{-1} (Table 1). The two short (<14 days) export events
297 accounted for 16.2±0.5 % (cup #4) and 21.0±0.6 % (cup #9) of the annual carbon export out
298 of the mixed layer (Table 1). Mass percentage of organic carbon ranged from 3.3 % to 17.4 %
299 (Fig. 7b). Values were slightly higher in autumn and winter (respectively 13.1±0.2 % and
300 11±2.1 % in cups #11 and #12) than in the summer, with the exception of cup #5 where the
301 highest value of 17.4 % was observed. PON fluxes followed the same seasonal patterns as
302 POC. This resulted in a relatively stable POC:PON ratio that varied between 6.1 to 7.4, except
303 in the autumn cup #11 were it exceeded 8.1 (Table 1).

304 **4 Discussion**

305 **4.1 Physical conditions of trap deployment**

306 Moored sediment traps can be subject to hydrodynamic biases that affect the accuracy of
307 particle collection (Buesseler et al., 2007a). The aspect ratio, tilt and horizontal flow regimes
308 are important considerations when assessing sediment trap performance. Specifically, the line
309 angle and aspect ratio of cylindrical traps can result in oversampling (Hawley, 1988).
310 Horizontal current velocities of 12 cm s^{-1} are often invoked as a critical threshold over which
311 particles are no longer quantitatively sampled (Baker et al., 1988). During the sediment trap
312 deployment period we observed generally low current speeds (mean < 10 cm s^{-1}) with 75% of
313 the recorded data lower than 12 cm s^{-1}. Despite the high aspect ratio of the PPS3 trap (4.75),
314 and the small mooring line angle deviations, it is likely that episodic increases in current
315 velocities (>12 cm s^{-1}) impacted collection efficiency. When integrated over the entire current
316 meter record (October 2011 to April 2012), the resulting flow is consistent with the annual

317 northeastward, low velocity (~ 1 cm s^{-1}) geostrophic flow previously reported over the
318 central part of the Kerguelen plateau (Park et al., 2008b).

319 The depth of the winter mixed layer (WML) on the Kerguelen Plateau is usually
320 shallower than 250 m (Park et al., 1998; Metzl et al., 2006). The sediment trap deployment
321 depth of ~300 m was selected to sample particle flux exiting the WML. The moored CTD
322 sensor did not record any evidence of a winter water incursion during the deployment period,
323 confirming the WML did not reach the trap depth. The small depth variations observed during
324 the deployment period resulted from vertical displacement of the trap. Variations of σ_θ may
325 have resulted from both vertical displacement of the CTD sensor and possible isopycnal
326 displacements due to strong internal waves that can occur with an amplitude of > 50 m at this
327 depth (Park et al., 2008a). Our measurements demonstrate that isopycnal displacements are
328 consistent with the M2 (moon 2, 12.4 h period) tidal forcing described in physical modeling
329 studies (Maraldi et al., 2009, 2011). Spectral analysis indicates that high frequency tidal
330 currents are the major circulation components. Time-integrated currents suggest that
331 advection is weak and occurs over longer timescale (months). Assuming the current flow
332 measured at the sediment trap deployment depth is representative of the prevailing current
333 under the WML, more than three months are required for particles to leave the plateau from
334 the A3 station, a timescale larger than the bloom duration itself. Therefore we consider that
335 the particles collected in the sediment trap at station A3 were produced in the surface waters
336 located above the plateau during bloom conditions.

337 **4.2 Swimmers and particle solubilization**

338 Aside from the hydrodynamic effects discussed above, other potential biases characterizing
339 sediment trap deployments, particularly those in shallow waters, is the presence of swimmers
340 and particle solubilization. Swimmers can artificially increase POC fluxes by entering the

cups and releasing particulate organic matter or decrease the flux by feeding in the trap funnel (Buesseler et al., 2007a). Some studies have focused specifically on swimmer communities collected in shallow sediment traps (Matsuno et al., 2014 and references therein) although trap collection of swimmers is probably selective and therefore not quantitative. Total swimmer intrusion rate was highest in cups #6 to #9 (December 2011 to February 2012) generally through the representation of copepods and amphipods (Table 2). The maximum swimmer intrusion rate in mid-summer as well as the copepod dominance is consistent with the fourfold increase in mesozooplankton abundance observed from winter to summer (Carlotti et al., 2014). Swimmer abundance was not correlated with mass flux, POC or PON fluxes, suggesting that their presence did not systematically affect particulate fluxes inside the cups. Nevertheless such correlations cannot rule out the possibility of swimmers feeding in the trap funnel modifying particle flux collection.

Particle solubilization in preservative solutions may also lead to an underestimation of total flux measured in sediment traps. Previous analyses from traps poisoned with mercuric chloride suggest that ~30 % of total organic carbon flux can be found in the dissolved phase and much higher values of 50 % and 90 % may be observed for nitrogen and phosphorous, respectively (Antia, 2005; O'Neill et al., 2005). Unfortunately the use of a formaldehyde-based preservative in our trap samples precludes any direct estimate of excess of dissolved organic carbon in the sample cup supernatant. Furthermore, corrections for particle leaching have been considered problematic in the presence of swimmers since a fraction of the leaching may originate from the swimmers themselves (Antia, 2005), potentially leading to over-correction. Particles solubilization may have occurred in our samples as evidenced by excess PO_4^{3-} in the supernatant. However the largest values were measured in sample cups where total swimmers were abundant (cups #8 to #12, data not shown). Consequently, it was not possible to discriminate solubilisation of P from swimmers and passively settling particles

366 and it therefore remains difficult to quantify the effect of particle leaching. However, leaching
367 of POC should be less problematic in formalin-preserved samples because aldehydes fix
368 organic matter, ~~rather than~~ in addition to poisoning microbial activity.

369 **4.3 Seasonal dynamics of POC export**

370 The sediment trap record obtained from station A3 provides the first direct estimate of POC
371 export covering an entire season over the naturally fertilized Kerguelen Plateau. We observed
372 a temporal lag of one month between the two surface chlorophyll *a* peaks and the two export
373 events. Based on a compilation of annual sediment trap deployments, Lutz et al. (2007)
374 reported that export quickly follows primary production at low latitudes whereas a time lag up
375 to two months could occur at higher latitudes. A 1-2 month lag was observed between
376 production and export in the pacific sector of the Southern Ocean (Buesseler et al., 2001), as
377 well as along 170°W (Honjo et al., 2000) and in the Australian sector of the Subantarctic
378 Zone (Rigual-Hernández et al., 2015). The temporal lag between surface production and
379 measured export in deep traps can originate~~s~~ from ecological processes in the upper ocean
380 (e.g. carbon retention in the mixed layer) as well as slow sinking velocities (Armstrong et al.,
381 2009) and one cannot differentiate the two processes from a single deep trap signal. A global-
382 scale modeling study suggests that the strongest temporal decoupling between production and
383 export (more than one month) occurs in areas characterized by a strong seasonal variability in
384 primary production (Henson et al., 2014). The study attributes this decoupling to differences
385 in phenology of phytoplankton and zooplankton and evokes zooplankton ejection products as
386 major contributors to fast sinking particles sedimenting post bloom.

387 On the Kerguelen Plateau there is evidence that a significant fraction of
388 phytoplankton biomass comprising the two chlorophyll peaks is remineralized by a highly
389 active heterotrophic microbial community (Obernosterer et al., 2008; Christaki et al., 2014).
390 Another fraction is likely ~~is~~ channeled toward higher trophic levels through the intense

391 grazing pressure that support the observed increase in zooplankton biomass (Carlotti et al.,
392 2008, 2014). Therefore an important fraction of phytoplankton biomass increases observed by
393 satellite may not contribute to export fluxes. Notably, the POC:PON ratio measured in our
394 trap material is close to values reported for marine diatoms (7.3 ± 1.2, Sarthou et al., 2005),
395 compared to the C:N ratio of zooplankton faecal pellets which is typically higher (7.3 to >15,
396 Gerber and Gerber, 1979; Checkley and Entzeroth, 1985; Morales, 1987). Simple mass
397 balance would therefore suggest a significant contribution of phytoplanktonic cells to the
398 POC export, which is indeed corroborated by detailed microscopic analysis (Rembauville et
399 al., 2014).

400 Although we observed increasing contribution of faecal pellet carbon post-bloom
401 (Rembauville et al., 2014), in line with the model output of Henson et al. (2014), differences
402 in phytoplankton and zooplankton phenology do not fully explain the seasonality of export on
403 the Kerguelen Plateau. Considering the shallow trap depth (289 m) and typical sinking speed
404 of 100 m d^{-1} for phyto-aggregates (Allredge and Gotschalk, 1988; Peterson et al., 2005; Trull
405 et al., 2008a), aggregate-driven export following bloom demise would suggest a short lag of a
406 few days between production and export peaks. The temporal lag of one month measured in
407 the present study suggest either slow sinking rates (<5 m d^{-1}) characteristic of single
408 phytoplanktonic cells or faster sinking particles that ~~do not originate from the peaks of surface~~
409 ~~production~~ originate from sub-surface production peaks undetected by satellite. It is generally
410 accepted that satellite detection depth is 20-50 m (Gordon and McCluney, 1975), and can be
411 less than 20 m when surface chlorophyll *a* exceed 0.2 µg L^{-1} (Smith, 1981), which prevents
412 the detection of deep phytoplanktonic biomass structures (Villareal et al., 2011). Although
413 subsurface chlorophyll maximum located around 100 m have been observed over the
414 Kerguelen Plateau at the end of the productive period, they have been interpreted to result
415 from the accumulation of surface production at the base of the mixed layer rather than a

subsurface productivity feature (Uitz et al., 2009). In support of this detailed taxonomic analysis of the exported material highlight diatom resting spores as major contributors to the two export fluxes rather than a composite surface community accumulated at the base of the mixed layer. The hypothesis of a mass production of nutrient-limited resting spores post-bloom with high settling rates explains the temporal patterns of export we observed (Rembauville et al., 2014). However a better knowledge of the dynamics of factors responsible for resting spore formation by diatoms remains necessary to fully validate this hypothesis.

4.4 ~~Rapid~~ Evidence for significant flux attenuation over the Kerguelen Plateau

The Kerguelen Plateau annual POC export (98.2±4.4 mmol m^{-2} y^{-1}) approaches the median global ocean POC export value comprising shallow and deep sediment traps (83 mmol m^{-2} y^{-1}, Lampitt and Antia, 1997), but is also close to values observed in HNLC areas of the POOZ (11-43 mmol m^{-2} y^{-1} at 500 m, Fischer et al., 2000). Moreover, the magnitude of annual POC export measured at ~300m on the Kerguelen Plateau is comparable to deep-ocean (>2 km) POC fluxes measured from the iron-fertilized Crozet (60 mmol m^{-2} y^{-1},Salter et al., 2012) and South Georgia blooms (180 mmol m^{-2} y^{-1}, Manno et al., 2014).

~~The annual POC export of ~0.1 mol m^{-2} y^{-1} at 289 m (Table 1) represents only 2% of the indirect estimate of POC export (5.1 mol m^{-2} y^{-1}) at the base of the WML (200 m) on the Kerguelen Plateau based on a seasonal DIC budget (Blain et al., 2007). On shorter time scales, the POC flux recorded in the moored sediment trap represents only a small fraction (3-8%) of the POC flux at the base of the winter mixed layer (200 m) measured by different methods during KEOPS2 (Table 3). The same conclusion is true when considering the comparison with different estimates made during KEOPS1. The diversity of the methods and the difference in the depth where the POC flux was estimated render quantitative comparisons challenging, but it appears the POC fluxes measured at 289 m with the moored sediment trap~

~~are considerably lower than some other estimates. This result indicates either extremely rapid attenuation of flux between 200 m and 300 m or major sampling bias by the sediment trap.~~

We first compared the sediment trap export fluxes with short-term estimates at 200 m in spring (KEOPS2) and summer (KEOPS1). The POC flux recorded in the moored sediment trap represents only a small fraction (3-8%) of the POC flux measured at the base of the winter mixed layer (200 m) by different approaches during the srping KEOPS2 cruise (Table 3). The same conclusion can be drawn when considering the comparison with different estimates made at the end of summer during KEOPS1. Moreover, the annual POC export of ~0.1 mol m^{-2} y^{-1} at 289 m (Table 1) represents only 2% of the indirect estimate of POC export (5.1 mol m^{-2} y^{-1}) at the base of the WML (200 m) on the Kerguelen Plateau based on a seasonal DIC budget (Blain et al., 2007). The short term estimates are derived from a diverse range of methods. The ^{234}Th proxy is based on the ^{234}Th deficit relative to the ^{238}U due to its adsorption on particles, and it subsequent conversion to carbon fluxes using measured POC:^{234}Th ratios. (Coale and Bruland, 1985; Buesseler et al., 2006; Savoye et al., 2006). The UVP provides high resolution images of particles (>52 µm) and the particle size distribution is then converted to carbon fluxes using an empirical relationship (Guidi et al., 2008; Picheral et al., 2010). Drifting gel traps allows the collection, preservation and imaging of sinking particles (>71 µm) that are converted to carbon fluxes using empirical volume:carbon relationship (Ebersbach and Trull, 2008; Ebersbach et al., 2011; Laurenceau-Cornec et al., 2015). Finally, drifting sediment traps are conceptually similar to moored sediment traps but avoid most of the hydrodynamic biases associated with this technique (Buesseler et al., 2007a). The diversity of the methods and differences in depth where the POC flux was estimated render quantitative comparisons challenging. Nevertheless, POC fluxes measured at 289 m with the moored sediment trap are considerably lower than other estimates made at 200

m. This result indicates either extremely rapid attenuation of flux between 200 m and 300 m or significant sampling bias by the sediment trap.

We note that low carbon export fluxes around 300 m have been previously reported on the Kerguelen ~~p~~Plateau. In spring 2011, UVP derived estimates of POC export at 350 m ~~equals~~ are 0.1 to 0.3 mmol m^{-2} d^{-1} (Table 3), a value close to our reported value of 0.15 mmol m^{-2} d^{-1}. In summer 2005, POC export at 330 m from gel trap ~~equals~~ is 0.7 mmol m^{-2} d^{-1} (Ebersbach and Trull 2008), which is also close to our value of 1.5 mmol m^{-2} d^{-1}. Using the Jouandet et al. (2014) data at 200 m (1.9 mmol m^{-2} d^{-1}) and 350 m (0.3 mmol m^{-2} d^{-1}) and the Ebersbach and Trull (2008) data at 200 m (5.2 mmol m^{-2} d^{-1}) and 330 m (0.7 mmol m^{-2} d^{-1}) leads to Martin power law exponents values of 3.3 and 4, respectively. These values are high when compared to the range of 0.4–1.7 that was initially compiled for the global ocean (Buesseler et al., 2007b). However, there is increasing evidence in support of much higher b-values in the Southern Ocean that fall in the range 0.9-3.9 (Lam and Bishop, 2007; Henson et al., 2012; Cavan et al., 2015). Our calculations are thus consistent with emerging observations of significant POC flux attenuation in the Southern Ocean. ~~and support a scenario of strong POC flux attenuation between 200 m and 350 m over the Kerguelen Plateau~~

Using the aforementioned b values (3.3 and 4) and the POC flux derived from ^{234}Th deficit at 200 m in spring (Planchon et al., 2014), we estimate POC fluxes at 289 m of 0.7 to 1.1 mmol m^{-2} d^{-1}. The flux measured in our sediment trap (0.15 mmol m^{-2} d^{-1}) data represents 14 % to 21 % of this calculated flux. Very similar percentages (21 % to 27 %) are found using the POC fluxes derived from the ^{234}Th deficit in summer (Savoye et al., 2008). Therefore we consider that the moored sediment trap collected ~15-30 % of the ^{234}Th – derived particle flux equivalent throughout the year. Trap-derived particle fluxes can represent 0.1 to >3 times the ^{234}Th-derived particles in shallow sediment traps (Buesseler, 1991; Buesseler et al., 1994; Coppola et al., 2002; Gustafsson et al., 2004) and this difference is largely attributed to the

sum of hydrodynamic biases and swimmer activities (Buesseler, 1991), although it probably also includes the effect of post-collection particle solubilisation. In the Antarctic Peninsula, ^{234}Th derived POC export was 20 times higher than the fluxes collected by a shallow, cylindrical, moored sediment trap at 170 m (Buesseler et al., 2010). The present deployment context is less extreme (depth of 289 m, mean current speed <10 cm s^{-1}, low tilt angle, high aspect ratio of the cylindrical PPS3 trap) but we consider that hydrodynamics (current speed higher than 12 cm s^{-1} during short tidal-driven events) and possible zooplankton feeding on the trap funnel are potential biases that may explain in part the low fluxes recorded by the moored sediment trap. Therefore the low fluxes observed likely result from a combined effect of ~~likely result from a combination of~~ collection bias (hydrodynamics and swimmers) and ~~strong~~ attenuation of the POC flux between the base of the WML and 300 m. However, it is not possible with the current dataset to isolate a specific explanation for low flux values.

~~Despite our conclusion that the moored sediment trap deployment was characterized by a low collection efficiency of ~15-30% with reference to ^{234}Th-derived fluxes, the numerous lines of evidence discussed above appear to converge on a scenario of rapid flux attenuation.~~ Strong POC flux attenuation over the Kerguelen Plateau compared to the open ocean is also reported by Laurenceau-Cornec et al. (2015) who associate this characteristic to a HBLE scenario and invoke the role of mesozooplankton in the carbon flux attenuation. Between October and November 2011, mesozooplankton biomass in the mixed layer doubled (Carlotti et al., 2014) and summer biomass was twofold higher still (Carlotti et al., 2008). These seasonal patterns are consistent with the maximum swimmer intrusion rate and swimmer diversity observed in summer (Table 2). It has previously been concluded that zooplankton biomass is more tightly coupled to phytoplankton biomass on the plateau compared to oceanic waters, leading to higher secondary production on the plateau (Carlotti et al., 2008, 2014). Further support linking zooplankton dynamics to HBLE environments of

iron-fertilized blooms are the findings of Cavan et al. (2015) that documents the lowest export ratio (exported production/primary production) in the most productive, naturally fertilized area downstream of South Georgia. Another important ecosystem feature associated to the HBLE environment of the Kerguelen Plateau, and likely shared by other island-fertilized blooms in the Southern Ocean, is the presence of mesopelagic fish~~es~~ (myctophid spawning and larvae foraging site, Koubbi et al., 1991, 2001). Mesopelagic fish~~es~~ can be tightly coupled to lower trophic levels (Saba and Steinberg, 2012) and can play a significant role in carbon flux attenuation (Davison et al., 2013). Although important for carbon budgets it is a compartment often neglected due to the challenge of quantitative sampling approaches. We suggest that the HBLE scenario and large attenuation of carbon flux beneath the WML at Kerguelen may represents the transfer of carbon biomass to higher and mobile trophic groups that fuel large mammal and bird populations rather than the classical remineralization-controlled vertical attenuation characterizing open ocean environments. Although technically challenging, testing this hypothesis should be a focus for future studies in this and similar regions.

5. Conclusion

We ~~have~~ report~~ed~~ the seasonal dynamics of particulate organic carbon (POC) export under the winter mixed layer (289 m) of the naturally iron fertilized and productive central Kerguelen Plateau. Annual POC flux was ~~very~~ remarkably low (98 mmol m^{-2}) and ~~most of it~~ occurred primarily during two episodic (<14 days) flux events exported with a 1 month lag following two surface chlorophyll *a* peaks. Analysis of the hydrological conditions and a comparison with different estimates of POC fluxes in spring and summer at the same station suggests that the sediment trap was subject to possible hydrodynamic and biological biases leading to under collection of particle flux. Nevertheless the low POC export was close to other estimates of deep (>300 m) POC export at the same station and is consistent with high attenuation

coefficients reported from other methods. ~~Taken together these data suggest that the low fluxes can be explained in part by strong flux attenuation between the winter mixed layer depth (~200 m) and the trap depth (~300 m). We invoke mesozooplankton and the activity of mesopelagic fishes as possible explanations for efficient carbon retention and/or transfer to higher trophic levels at the base of the mixed layer which results in a High Biomass, Low Export environment~~. We invoke heterotriophic micropbial activity and mesozooplankton and mesopelagic fish activity as possible explanations for efficient carbon flux attenuation and/or transfer to higher trophic levels which results in a High Biomass, Low Export environment.

The biogenic silicon, diatoms assemblages and faecal pellet fluxes are reported in a companion paper that identifies the primary ecological vectors regulating the magnitude of POC export and seasonal patterns in BSi:POC export (Rembauville et al., 2014).

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965

966 **Table 1:** Dynamics of carbon and nitrogen export fluxes at station A3 collected by the
967 sediment trap at 289 m.

			Fluxes (mmol m^{-2} d^{-1})			Contribution to annual export (%)	
Cup	**Start**	**Stop**	**POC**	**PON**	**POC:PON**	**POC**	**PON**
1	21/10/2011	04/11/2011	0.15±0.01	0.02±0.00	6.80±0.56	2.11±0.06	2.30±0.01
2	04/11/2011	18/11/2011	0.14 ±0.01	0.02±0.00	6.09±0.67	1.94±0.16	2.27±0.15
3	18/11/2011	02/12/2011	0.15±0.01	0.02±0.00	7.33±0.31	2.12±0.06	1.99±0.06
4	02/12/2011	12/12/2011	1.60±0.04	0.23±0.01	6.95±0.29	16.18±0.45	16.48±0.07
5	12/12/2011	22/12/2011	0.34±0.00	0.05±0.00	6.87±0.08	3.41±0.03	3.64±0.03
6	22/12/2011	01/01/2012	0.51±0.04	0.08±0.01	6.70±0.78	4.82±0.76	5.50±0.39
7	01/01/2012	11/01/2012	0.42±0.02	0.06±0.00	6.73±0.46	4.23±0.14	4.65±0.42
8	11/01/2012	25/01/2012	0.34±0.01	0.05±0.00	6.94±0.38	4.83±0.18	4.84±0.11
9	25/01/2012	08/02/2012	1.47±0.03	0.20±0.01	7.38±0.26	20.98±0.57	21.07±0.05
10	08/02/2012	22/02/2012	0.55±0.04	0.08±0.00	6.97±0.88	7.83±0.64	8.36±0.57
11	22/02/2012	31/05/2012	0.27±0.01	0.03±0.00	8.09±0.22	26.84±0.47	24.12±0.20
12	31/05/2012	07/09/2012	0.04±0.00	0.01±0.00	6.06±0.17	4.71±0.90	4.78±0.09
Annual export (mmol m^{-2} y^{-1})			98.24±4.35	13.59±0.30			

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Table 2: Number of swimmer individuals found in each cup and swimmer intrusion rate (number d^{-1}, *bold italic* numbers) for each taxa and for the total swimmers.

Cup	Copepod	Pteropod	Euphausiid	Ostracod	Amphipod	Cnidarian	Polychaete	Ctenophore	Siphonophore	Salp	Total
1	166	13	1	2	1	0	0	0	0	0	183
	12	***1***	***< 1***	***< 1***	***< 1***	***0***	***0***	***0***	***0***	***0***	***13***
2	55	0	0	0	0	0	0	0	0	0	55
	4	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***4***
3	0	0	0	0	0	0	0	0	0	0	0
	0	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
4	113	0	0	0	0	0	0	0	0	0	113
	11	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***11***
5	0	0	0	0	0	0	0	0	0	0	0
	0	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
6	540	0	1	0	2	5	1	4	1	0	554
	54	***0***	***< 1***	***0***	***< 1***	***< 1***	***0***	***0***	***0***	***0***	***55***
7	583	0	0	0	0	2	2	3	0	0	590
	58	***0***	***0***	***0***	***0***	***< 1***	***< 1***	***< 1***	***0***	***0***	***58***
8	686	33	2	2	8	5	1	4	0	0	741
	49	***2***	***< 1***	***< 1***	***1***	***< 1***	***< 1***	***< 1***	***0***	***0***	***52***
9	392	14	4	3	121	4	2	0	0	0	540
	28	***1***	***< 1***	***< 1***	***9***	***< 1***	***< 1***	***0***	***0***	***0***	***38***
10	264	69	1	2	18	11	0	2	0	0	367
	19	***5***	***< 1***	***< 1***	***1***	***1***	***0***	***< 1***	***0***	***0***	***26***
11	54	0	0	0	29	4	1	0	0	0	88
	1	***0***	***0***	***0***	***< 1***	***< 1***	***< 1***	***0***	***0***	***0***	***1***
12	1481	44	5	7	2	3	2	0	0	1	1544
	15	***< 1***	***< 1***	***< 1***	***< 1***	***< 1***	***< 1***	***0***	***0***	***< 1***	***15***

974 **Table 3:** Synthesis of estimates of POC fluxes at the base of, or under, the mixed layer at
975 station A3 from the KEOPS 1 cruise.

Author	Method	Period	Depth (m)	POC flux (mmol m^{-2} d^{-1})
		KEOPS1		
Savoye et al., 2008	^{234}Th deficit	23 Jan – 12 Feb 2005	100	23 ± 3.6
			150	25.7 ± 3.6
			200	24.5 ± 6.8
Ebersbach and Trull, 2008	Drifting gel trap, optical measurements and constant C conversion factor	4 Feb 2005	200	23.9
		12 Feb 2005	100	5.3
			200	5.2
			330	0.7
			430	1
Jouandet et al., 2008	Annual DIC budget	Annual	MLD base	85
Trull et al., 2008b	Drifting sediment trap	4 Feb 2005	200	7.3-10
		12 Feb 2005		3-3.1
Jouandet et al., 2011	In situ optical measurement (UVP) and power function C conversion factor	22 Jan 2005	200	72.4
			330	27.2
			400	21.6
		23 Jan 2005	200	29.8
			330	26.8
			400	15.9
		12 Feb 2005	200	4.8
			330	5.6
			400	7.9
		KEOPS2		
Planchon et al., 2014	^{234}Th deficit, steady state model	20 Oct 2011	100	3.5 ± 0.9
			150	3.9 ± 0.9
			200	3.7 ± 0.9
		16 Nov 2011	100	4.6 ± 1.5
			150	7.1 ±1.5
			200	3.1 ± 0.6
	^{234}Th deficit, non steady state model	16 Nov 2011	100	7.3 ± 1.8
			150	8.4 ± 1.8
			200	3.8 ± 0.8
Laurenceau-Cornec et al., 2015	Drifting gel trap, optical measurement of particles	16 Nov 2011	210	5.5
	Drifting sediment trap		210	2.2
Jouandet et al., 2014	In situ optical measurement (UVP) and power function C conversion factor	21 Oct 2011	200	0.2
			350	0.1
		16 Nov 2011	200	1.9
			350	0.3

976

977 **Figures captions**

978 **Figure 1.** Localization of the Kerguelen Plateau in the Indian sector of the Southern Ocean
979 and detailed map of the satellite-derived surface chlorophyll *a* concentration (MODIS level 3
980 product) averaged over the sediment trap deployment period. Sediment trap location at the A3
981 station is represented by a black dot, whereas the black circle represents the 100 km radius
982 area used to average the surface chlorophyll *a* time series. Arrows represent surface
983 geostrophic circulation derived from the absolute dynamic topography (AVISO product).
984 Positions of the Antarctic Circumpolar Current core (AAC core), the Polar Front (PF) and the
985 Fawn Through Current (FTC) are shown by thick black arrows. Grey lines are 500 m and
986 1000 m isobaths.

987 **Figure 2.** Schematic of the instrumented mooring line against vertical temperature profiles.
988 The sediment trap and the current meter/CTD sensor location on the mooring line are shown
989 by white circles. Temperature profiles performed during the sediment trap deployment (20
990 October 2011) are represented by grey lines. Black full line is the median temperature profile
991 from 12 casts realized on the 16 November 2011. Dashed black lines are the first and third
992 quartiles from these casts. The grey rectangle represents the Kerguelen Plateau seafloor. The
993 different water masses are Antarctic Surface Water (AASW), Winter Water (WW) and Upper
994 Circumpolar Deep Water (UCDW).

995 **Figure 3.** Hydrological properties recorded by the instrument mooring at station A3. a) depth
996 of the CTD sensor, b) salinity, c) potential temperature, d) line angle, e) current speed, grey
997 lines are raw data, black lines are low-pass filtered data with a Gaussian filter (40 hour
998 window as suggested by the spectral analysis), f) direction and speed of currents represented
999 by vectors (under sampled with a 5 hours interval) and g) wind rose plot of current direction

and intensities, dotted circles are directions relatives frequencies and colors refer to current speed (m s^{-1}).

Figure 4. Potential temperature/salinity diagram at station A3. Data are from the moored CTD (black dots), KEOPS1 (blue line) and KEOPS2 (red line). Grey lines are potential density anomaly. The different water masses are Antarctic Surface Water (AASW), Winter Water (WW) and Upper Circumpolar Deep Water (UCDW).

Figure 5. Power spectrum of the spectral analysis of a) depth time series and b) potential density anomaly time series. Pure red noise (null hypothesis) is represented by red dashed lines for each variable. The period corresponding to a significant power peak (power peak higher than the red noise) is written.

Figure 6. Progressive vector diagram (integration of the current vectors all along the current meter record) calculated from current meter data at 319 m. The color scale refers to date.

Figure 7. Seasonal variations of surface chlorophyll *a* and particulate organic carbon (POC) export. a) Seasonal surface chlorophyll concentration and 16 years climatology (Globcolour) averaged in a 100 km radius around the station A3 station The black line represents the climatology calculated for the period 1997/2013, whilst the green line corresponds to the sediment trap deployment period (2011/2012). b) POC flux (grey bars) and mass percentage of POC (red dotted line). Error bars are standard deviations from triplicates, bold italic numbers refer to cup number.

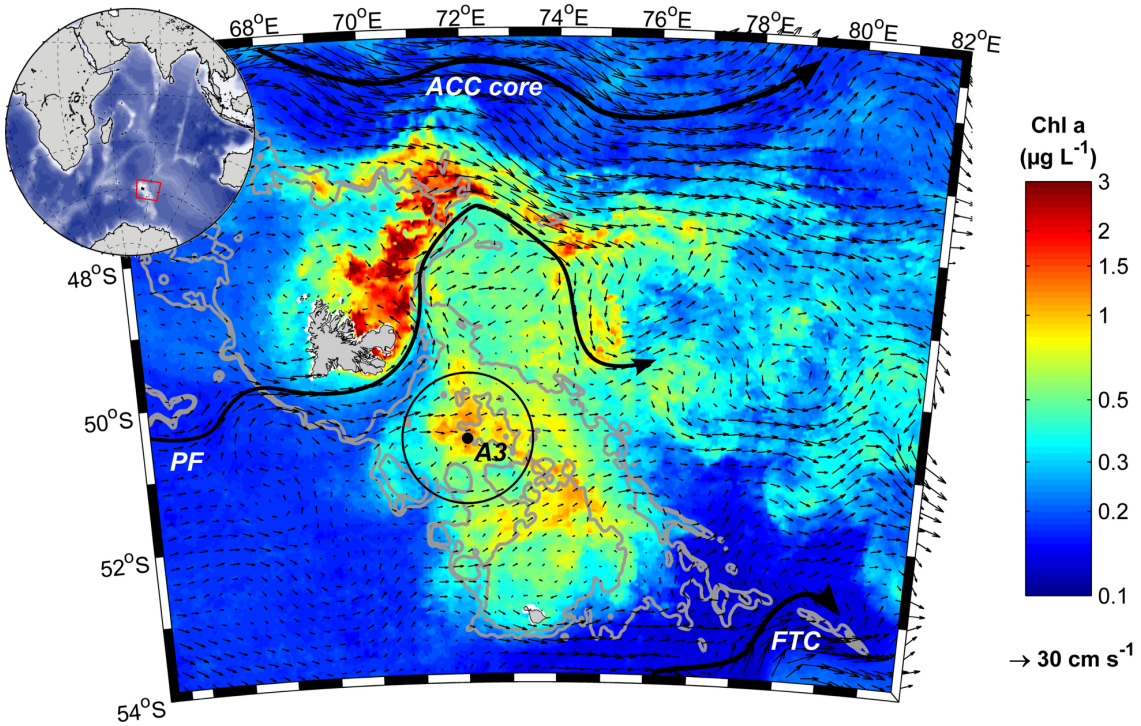
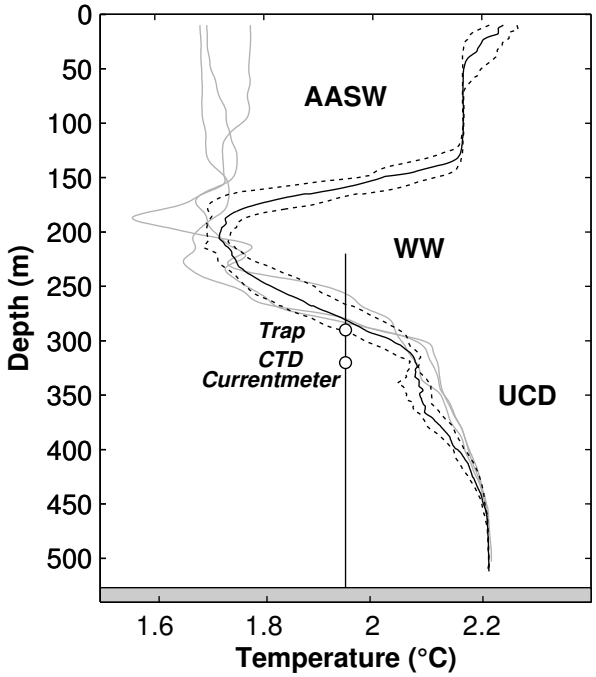


Figure 1.



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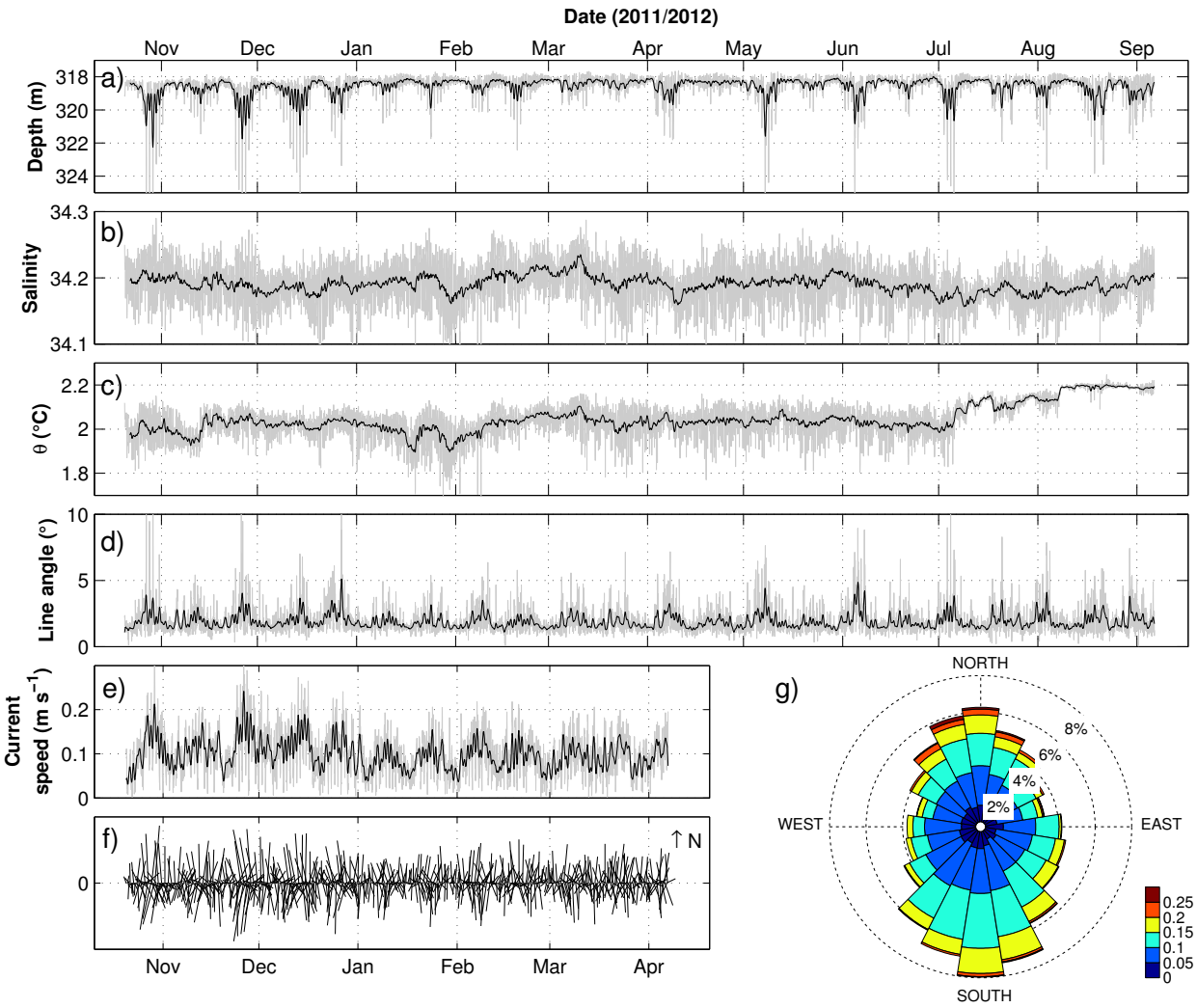
Date (2011/2012)
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
a)
Depth (m)
318
320
322
324
b)
Salinity
34.3
34.2
34.1
c)
θ (°C)
2.2
2
1.8
d)
Line angle (°)
10
5
0
e)
Current speed (m s^{-1})
0.2
0.1
0
f)
0
↑ N
Nov
Dec
Jan
Feb
Mar
Apr
g)
NORTH
8%
6%
4%
2%
WEST
EAST
SOUTH
0.25
0.2
0.15
0.1
0.05
0

Figure 3.

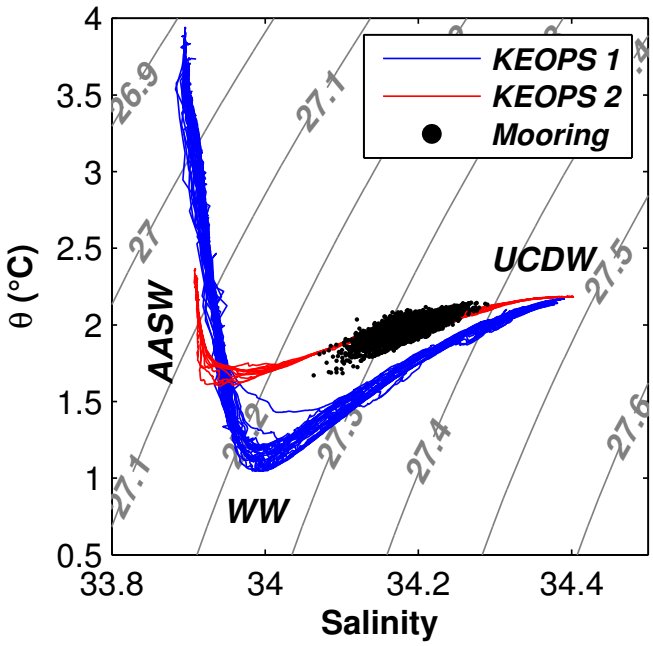

Figure 4.

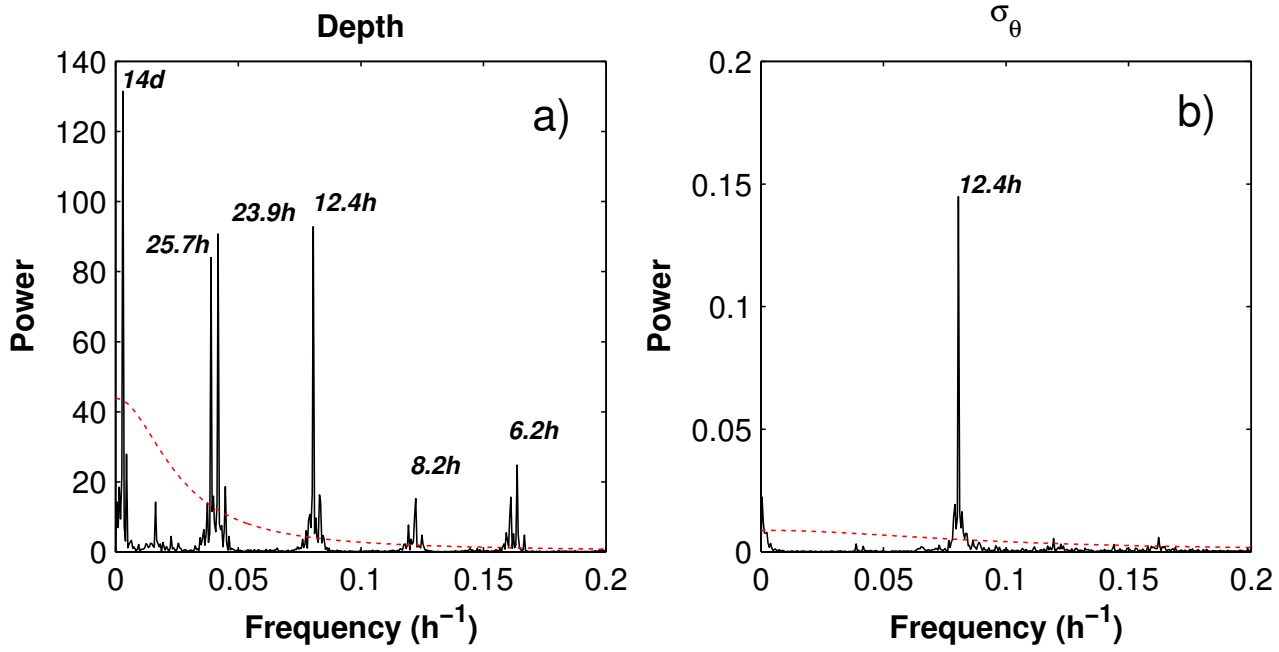

Figure 5.

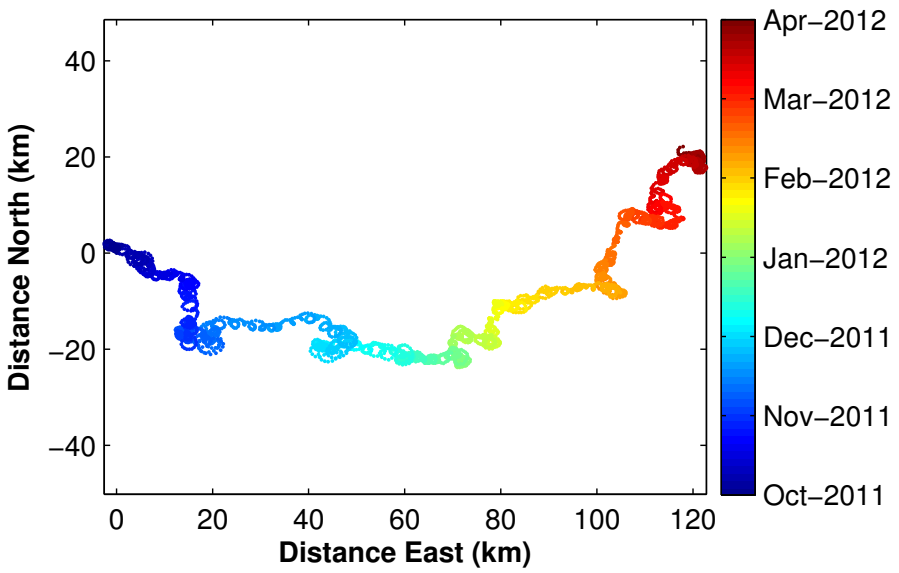

Figure 6.

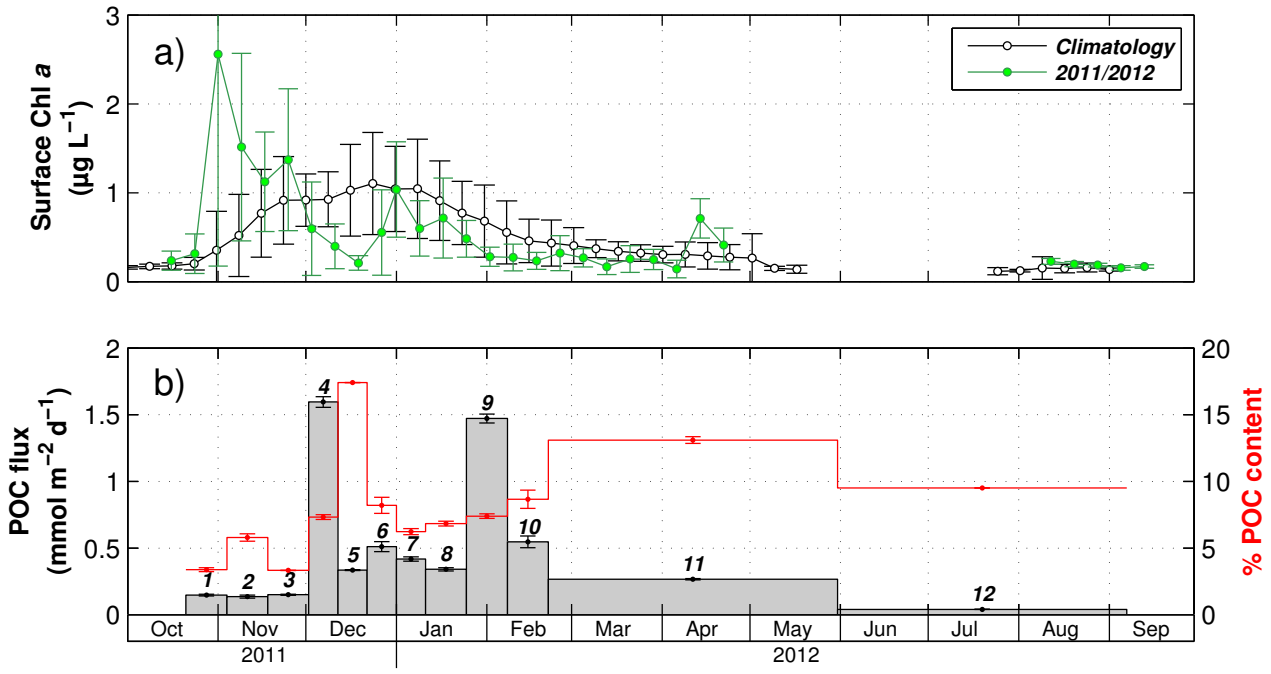

Figure 7.