

1 **Carbon export in the naturally iron-fertilized**
2 **Kerguelen area of the Southern Ocean based on**
3 **the ²³⁴Th approach**

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18

19 **Abstract**

20 This study examined upper-ocean Particulate Organic Carbon (POC) export using
21 the ^{234}Th approach as part of the second Kerguelen Ocean and Plateau compared
22 Study expedition (KEOPS2). Our aim was to characterize the spatial and the
23 temporal variability of POC export during austral spring (Oct.-Nov. 2011) in the Fe-
24 fertilized area of the Kerguelen Plateau region. POC export fluxes were estimated at
25 high productivity sites over and downstream of the plateau and compared to a High
26 Nutrient Low Chlorophyll (HNLC) area upstream of the plateau in order to assess the
27 impact of iron-induced productivity on the vertical export of carbon.

28 Deficits in ^{234}Th activities were observed at all stations in surface waters, indicating
29 early scavenging by particles in austral spring. ^{234}Th export was lowest at the
30 reference station R-2 and highest in the recirculation region (stations E) where a
31 pseudo-lagrangian survey was conducted. In comparison ^{234}Th export over the
32 central plateau and north of the Polar Front (PF) was relatively limited throughout the
33 survey. However, the ^{234}Th results support that Fe fertilization increased particle
34 export in all iron fertilized waters. The impact was greatest in the recirculation feature
35 (3 to 4 fold at 200 m depth, relative to the reference station), but more moderate over
36 the central Kerguelen plateau and in the northern plume of the Kerguelen bloom (~2-
37 fold at 200 m depth).

38 The C:Th ratio of large (>53 μm) potentially sinking particles collected via sequential
39 filtration using in situ pumping (ISP) systems was used to convert the ^{234}Th flux into a
40 POC export flux. The C:Th ratios of sinking particles were highly variable (3.1 ± 0.1 to
41 $10.5 \pm 0.2 \mu\text{mol dpm}^{-1}$) with no clear site-related trend, despite the variety of
42 ecosystem responses in the fertilized regions. C:Th ratios showed a decreasing trend
43 between 100 and 200 m depth suggesting preferential carbon loss relative to ^{234}Th

44 possibly due to heterotrophic degradation and/or grazing activity. C:Th ratios of
45 sinking particles sampled with drifting sediment traps in most cases showed a very
46 good agreement with ratios for particles collected via ISP deployments (>53 μm
47 particles).

48 Carbon export production varied between $3.5 \pm 0.9 \text{ mmol m}^{-2} \text{ d}^{-1}$ and $11.8 \pm 1.3 \text{ mmol}$
49 $\text{m}^{-2} \text{ d}^{-1}$ from the upper 100 m and between $1.8 \pm 0.9 \text{ mmol m}^{-2} \text{ d}^{-1}$ and $8.2 \pm 0.9 \text{ mmol}$
50 $\text{m}^{-2} \text{ d}^{-1}$ from the upper 200 m. Highest export production was found inside the PF
51 meander with a range of $5.3 \pm 1.0 \text{ mmol m}^{-2} \text{ d}^{-1}$ to $11.8 \pm 1.1 \text{ mmol m}^{-2} \text{ d}^{-1}$ over the
52 19-day survey period. The impact of Fe fertilization is highest inside the PF meander
53 with 2.9- up to 4.5-fold higher carbon flux at 200 m depth in comparison to the HNLC
54 control station. The impact of Fe fertilization was significantly less over the central
55 plateau (stations A3 and E-4W) and in the northern branch of the bloom (station F-L)
56 with 1.6- up to 2.0-fold higher carbon flux compared to the reference station R. Export
57 efficiencies (ratio of export to primary production and ratio of export to new
58 production) were particularly variable with relatively high values in the recirculation
59 feature (6 to 27 %, respectively) and low values (1 to 5 %, respectively) over the
60 central plateau (station A3) and north of the PF (station F-L) indicating spring
61 biomass accumulation. Comparison with KEOPS1 results indicated that carbon
62 export production is much lower during the onset of the bloom in austral spring than
63 during the peak and declining phases in late summer.

64

65 **1 Introduction**

66 Nutrient limitation is an essential control of upper-ocean productivity (Moore et al.,
67 2013) and affects the associated uptake of carbon and its transfer to the deep ocean
68 as sinking particulate organic matter. Attention has focused on iron (Fe) as a limiting
69 nutrient since the *iron hypothesis* of Martin (1990), who suggested that increased iron
70 supply to the Southern Ocean (SO) during the last glacial maximum could have
71 contributed to the drawdown of atmospheric CO₂ by stimulating the oceanic biological
72 pump. For the present-day ocean, iron limitation is now validated for several high-
73 nutrient-low-chlorophyll (HNLC) regions, including the Southern Ocean (Boyd et al.,
74 2007; Boyd et al., 2000; Coale et al., 2004; Martin et al., 1990; Martin et al., 1991;
75 Sedwick et al., 1999; Smetacek et al., 2012). However, it is still under debate whether
76 the positive growth response of phytoplankton due to iron addition results in
77 enhanced export of biogenic particles and contributes to the long-term sequestration
78 of carbon. This remains central to understanding the role of iron on the oceanic
79 carbon cycle and ultimately on the past and future climate of the Earth.

80 Mesoscale iron addition experiments have revealed no clear trend in carbon export.
81 Export fluxes estimated during SOIREE (Polar waters south of Australia), SAGE
82 (subpolar waters south of New Zealand), EisenEx (Atlantic polar waters) and
83 LOHAFEX (South-Atlantic waters) report no major differences between the Fe-
84 fertilized patch and the adjacent control site (Buesseler et al., 2004; Buesseler et al.,
85 2005; Martin et al., 2013; Nodder et al., 2001). By contrast, the experiments SOFEX-
86 South (polar waters south of New Zealand) and EIFEX (Atlantic polar waters south of
87 Africa) showed increased vertical flux of particulate organic carbon due to iron
88 addition (Buesseler et al., 2005; Jacquet et al., 2008; Smetacek et al., 2012).
89 Enhanced export appears associated with experiments carried out (1) in high silicic

90 acid waters south of the Antarctic Polar Front (PF) allowing fast-sinking, large
91 diatoms to develop under low grazing pressure and (2) over a survey period
92 sufficiently long to cover the time lag between the bloom development and the export
93 event. However, the key results obtained with purposeful iron addition still differ and
94 are difficult to scale up to regional and seasonal scales (Boyd et al., 2007).

95 Alternatives to short-term artificial experiments are the large and persistent
96 phytoplankton blooms that develop annually in the vicinity of sub-Antarctic islands
97 (Blain et al., 2007; Borrione and Schlitzer, 2013; Morris and Charette, 2013; Pollard
98 et al., 2009) and close to the Antarctic continent (Alderkamp et al., 2012; Zhou et al.,
99 2013) due to natural iron supply. These particular settings represent large scale
100 natural laboratories, where the role of Fe on ecosystems ecology, productivity,
101 structure, and associated export can be monitored over an entire seasonal cycle.
102 Two previous important field studies were carried out in natural Fe-fertilized areas,
103 the CROZet natural iron bloom and EXport experiment (CROZEX, 2004-2005)
104 (Pollard et al., 2009), and the Kerguelen Ocean and Plateau compared study
105 (KEOPS, 2005) (Blain et al., 2007). CROZEX studied the Crozet Islands region
106 located in sub-Antarctic waters of the Indian Ocean where a bloom occurs north of
107 the Islands in October/November followed by a secondary bloom in January.
108 CROZEX results confirmed that the bloom is fueled with iron from the Crozet Island
109 (Planquette et al., 2007) and that phytoplankton uptake rates are much larger in the
110 bloom area than in the HNLC control area (Lucas et al., 2007; Seeyave et al., 2007).
111 For carbon export, the primary bloom results in ~3-fold higher flux at the Fe-fertilized
112 site than at the control site, and for the secondary bloom, no substantial differences
113 are reported (Morris et al., 2007). Sinking particles collected by a neutrally buoyant
114 sediment trap (PELAGRA) were dominated by diatom cells of various species and

115 size indicating a pronounced contribution of primary producers to the export (Salter et
116 al., 2007).

117 The second study (KEOPS) focused on the high productivity area of the Kerguelen
118 Island in the Indian sector of the SO. The Kerguelen bloom has two main features, a
119 northern branch that extends northeast of the island north of the PF (also called the
120 plume), and a larger bloom covering ~45,000 km² south of the PF and largely
121 constrained to the shallow bathymetry of the Kerguelen Plateau (<1000m) (Mongin et
122 al., 2008). In austral summer 2004-2005, the bloom started in early November,
123 peaked in December and January, and then rapidly declined in February (Blain et al.,
124 2007). Fe fertilization over the plateau was demonstrated during KEOPS and
125 attributed to vertical exchanges between the surface and the deep iron-rich reservoir
126 existing above the plateau (Blain et al., 2008). The waters in the bloom showed
127 higher biomass, greater silicate depletion, and important CO₂ drawdown compared to
128 the control site (Blain et al., 2007; Jouandet et al., 2008; Mosseri et al., 2008).
129 Carbon export in the Fe-fertilized area in comparison to HNLC waters was 2-fold
130 higher as estimated using the ²³⁴Th proxy (Savoie et al., 2008), and 3-fold higher
131 based on a seasonal dissolved inorganic carbon (DIC) budget (Jouandet et al.,
132 2008). Direct observations of sinking particles using polyacrylamide gel traps
133 indicates a dominant fraction of fecal pellets and fecal aggregates and suggests a
134 strong influence of particle repackaging by grazers during the late stage of the
135 Kerguelen bloom (Ebersbach and Trull, 2008). The unprecedented results obtained
136 from CROZEX and KEOPS clearly highlight the crucial role of Fe on natural
137 ecosystems and demonstrate the stimulation of the biological carbon pump in the SO
138 resulting in an enhanced CO₂ sink and carbon export at depth.

139 The KEOPS2 project was designed to improve the spatial and temporal coverage of
140 the Kerguelen region. KEOPS2 was carried out in austral spring to document the
141 early stages of the bloom and to complement results of KEOPS1 obtained in summer
142 during the peak and decline of the bloom. The principal aims were to better constrain
143 the mechanism of Fe supply to surface waters and to determine the response of
144 ecosystems to Fe fertilization including the impact on vertical export of carbon. The
145 sampling strategy covered two distinct areas, the principal bloom already investigated
146 during KEOPS1 and located over the central plateau, and the plume downstream to
147 the east of the Island and north of the PF.

148 In this study, we report upper-ocean particulate organic carbon (POC) export
149 production estimated using the ^{234}Th -based approach (Cochran and Masqué, 2003).
150 POC fluxes at 100, 150 and 200 m depth were inferred from total ^{234}Th export fluxes
151 estimated from ^{234}Th deficit in surface waters by applying the modeling approach of
152 Savoye et al. (2006) for the ^{234}Th activity balance. ^{234}Th export fluxes were then
153 converted into POC fluxes using POC/ ^{234}Th ratio of large (>53 μm) potentially sinking
154 particles at the depth of export. Upper-ocean ^{234}Th and carbon export obtained in
155 HNLC and Fe-enriched waters were used to assess the impact of natural fertilization
156 on the vertical transfer of carbon. ^{234}Th -derived fluxes were compared to free-drifting
157 sediment and polyacrylamide gel traps data (Laurenceau-Cornec et al., 2015a).
158 Using primary production estimates (Cavagna et al., 2014) we examine spatial and
159 temporal variations in export efficiency during the survey. Finally, using KEOPS1
160 results, early and late bloom conditions are compared.

161 **2 Material and method**

162 **2.1 Study area and sampling strategy**

163 The KEOPS2 cruise took place between October and November 2011 on board the
164 *R/V Marion Dufresne*. The studied region encompasses the Kerguelen plateau
165 located between Kerguelen and Heard Island, and the deeper off-shore basin to the
166 east of the island (Figure 1). Details of the large-scale circulation in this area can be
167 found elsewhere (Park et al., 2008b). Briefly, the Kerguelen plateau represents a
168 major barrier to the eastward flow of the Antarctic Circumpolar Current (ACC). The
169 ACC is divided into two branches with the most intense flow passing to the north of
170 the island and associated with the Sub-Antarctic Front (SAF). The second branch is
171 associated with the PF and passes south of the island. When crossing the plateau
172 the southern branch turns back north and forms a large meander isolating a
173 mesoscale recirculation structure south of the PF (Figure1).

174 The sampling strategy aimed at characterizing the spatial and the temporal variability
175 of high productivity sites located on and off the plateau. The survey included two
176 transects from south to north (TNS-1 to TNS-10) and from west to east (TEW-1 to
177 TEW-8) for physics and stock parameters, and nine process stations (R-2, A3-1, A3-
178 2, E-1, E-3, E-4W, E-4E, E-5, and F-L) where more intensive sampling including
179 large volume in situ filtration and sediment trap deployments were carried out. For
180 this study, 14 stations were investigated including five transects stations (TNS-8,
181 TNS-6, TNS-1, E-2, and TEW-8) sampled for total ^{234}Th activity and nine process
182 stations where total ^{234}Th , particulate ^{234}Th and POC profiles obtained simultaneously
183 allowed to estimate POC export production. Sediment traps deployed and
184 successfully recovered at four process stations were also determined for ^{234}Th
185 activity. Process stations were carried out in four distinct areas showing different
186 characteristics (see Figure1):

187 - The reference station (R-2) was chosen in HNLC waters upstream of the island in a
188 non-Fe-fertilized area.

189 - The shallow central plateau was sampled at station A3, which corresponds to the
190 plateau bloom reference station of KEOPS1. Station A3 was sampled twice (A3-1
191 and A3-2) over a period of 27.7 days (20 Oct.-16 Nov.).

192 - The northern branch of the bloom, which develops north of the PF in the Polar Front
193 Zone (PFZ), was sampled at station F-L (6 Nov.).

194 - The recirculation feature in the PF meander (station E) received detailed attention
195 with four successive visits (E-1, E-3, E-4E, and E-5) as part of a pseudo-lagrangian
196 time-series over 19.6 days. In the same area, a highly productive station (E4W)
197 located on the western edge of the recirculation feature and close to the jet of the PF
198 was sampled but excluded from the pseudo-lagrangian study.

199 **2.2 Total ^{234}Th activities**

200 Total ^{234}Th activities were obtained from 4 L seawater samples collected from 12 L
201 Niskin bottles. For transect stations, 13 depths were sampled between the surface
202 and 20-90 m above the seafloor. For plateau station A3, samples were collected at
203 11 depths between the surface and 30-80 m above the seafloor. For deep stations
204 (R, E-1, E-3, E-4E, E-4W, E-5, F-L), 14 depths were sampled between the surface
205 and 900 m, and two deep water samples (1000-2000 m) were systematically
206 collected for calibration purposes (except at E-4W).

207 Seawater samples were processed for total ^{234}Th activity measurement following the
208 double-spike procedure developed by Pike et al. (2005) and modified as per
209 Planchon et al. (2013). Briefly, samples were acidified with nitric acid (pH 2), spiked
210 with ^{230}Th yield tracer, and left for 12 hours equilibration before co-precipitation with

211 MnO₂ (pH 8.5). Co-precipitated samples were filtered on high-purity quartz microfiber
212 filters (QMA, Sartorius; nominal pore size = 1 μm; Ø 25 mm), dried overnight and
213 mounted on nylon filter holders covered with Mylar and Al foil for beta counting.
214 Samples were counted twice on board using a low level beta counter (RISØ,
215 Denmark) and measurement was stopped when counting uncertainty was below 2%
216 (RSD). Residual beta activity was measured for each sample after a delay of six
217 ²³⁴Th half-lives (~6 months) and was subtracted from the gross counts obtained on-
218 board.

219 After background counting, all samples were processed for ²³⁴Th recovery using
220 ²²⁹Th as a second yield tracer and with a simplified procedure described elsewhere
221 (Planchon et al., 2013). Briefly, MnO₂ co-precipitates were dissolved in 10 ml of an
222 8M HNO₃/10% H₂O₂ solution, heated overnight and filtered using Acrodisc 0.2 μm
223 syringe filters. Determination of ²³⁰Th/²²⁹Th ratios was carried out on high purity water
224 diluted samples (10 to 20 times) by HR-ICP-MS (Element2, Thermo Scientific). The
225 overall precision of ²³⁰Th/²²⁹Th ratio measurements was 1.8 % (RSD) using triplicate
226 samples and multiple standards analyzed over several analytical sessions. Average
227 ²³⁴Th recovery was 88 ± 11 % (n=200). Uncertainties on total ²³⁴Th activity were
228 estimated using error propagation law and represent 0.07 dpm L⁻¹ on average.
229 Standard deviation of the mean ²³⁴Th/²³⁸U ratio obtained for deep waters (>1000 m)
230 was 0.03 dpm L⁻¹ (n=19). ²³⁸U activity (dpm L⁻¹) was calculated using the relationship
231 ²³⁸U (± 0.047) = (0.0786 ± 0.0045) × S – (0.315 ± 0.158) (Owens et al., 2011).

232 **2.3 ²³⁴Th flux**

233 ²³⁴Th export fluxes were calculated using a 1D box model, which accounts for total
234 ²³⁴Th mass balance. Detailed equations can be found elsewhere (Savoye et al.,

235 2006). ^{234}Th export flux was estimated at 100 m, 150 m, and 200 m depth in order to
236 account for (1) variations in the vertical distribution of ^{234}Th deficits, and (2) total
237 depth-integrated losses of ^{234}Th via export. This allows comparison between stations
238 at the same depth horizon, as well as with KEOPS1 study where a similar approach
239 was used (Savoie et al., 2008). At all stations, ^{234}Th flux was estimated under steady
240 state assumption (SS), i.e. considering constant total ^{234}Th activity over time and
241 neglecting advective and diffusive flux of ^{234}Th . For re-visited stations (A3 and E
242 stations), ^{234}Th flux was also estimated under non-steady state assumption (NSS). At
243 A3, the NSS model was applied for the second visit with a time delay of 27.7 days. At
244 E stations, NSS ^{234}Th export flux was estimated when the time delay was greater
245 than one week as recommended by Savoie et al. (2006). Consequently, the NSS
246 calculation was carried out only at E-4E (14.6 days) and E-5 (19.6 days). The
247 revisited stations E-2 and E-4W were not considered part of the pseudo-lagrangian
248 study at the E study site and were excluded from the NSS calculation.

249 In order to check the assumption that physical transport did not impact the ^{234}Th
250 budget, the vertical diffusive flux (V_z) was estimated using the vertical gradient of
251 ^{234}Th activity and a range of vertical diffusivity coefficients K_z between $10^{-4} \text{ m}^2 \text{ s}^{-1}$ and
252 $10^{-5} \text{ m}^2 \text{ s}^{-1}$ calculated from the Shih model (Park et al., 2014b). This range of K_z
253 values for KEOPS2 is much lower than for KEOPS1 ($4 \cdot 10^{-4} \text{ m}^2 \text{ s}^{-1}$) obtained using the
254 Osbourn model (Park et al., 2008a). V_z was calculated using total ^{234}Th activities
255 instead of the dissolved ^{234}Th (total ^{234}Th -particulate ^{234}Th) because of a poor vertical
256 resolution of particulate ^{234}Th data in the first 200 m. For all stations, the diffuse flux
257 (V_z) estimated at 100, 150, and 200 m depth was always below $50 \text{ dpm m}^2 \text{ d}^{-1}$ and
258 represents a negligible contribution to the particle-associated export flux.

259 Lateral transport may also impact the ^{234}Th budget (Savoye et al., 2006) especially
260 for stations located downstream of the Kerguelen island. From our data, this
261 contribution cannot be quantified precisely, and is only qualitatively considered.
262 Given the mean residence of surface water parcels over the plateau at station A3 (2-
263 3 months) (Park et al., 2008b) or inside the recirculation feature (0.5-1 month)
264 compared to the mean residence of ^{234}Th (~1 month), lateral contribution is likely to
265 be minimal in these areas. Circulation at the northern station F-L is more dynamic
266 and under the influence of northern Kerguelen shelf waters enriched in dFe (Qu  rou  
267 et al., 2015). Shelf waters are probably depleted in ^{234}Th relative to ^{238}U due to the
268 earlier development of the bloom in this area, as well as due to sediment
269 resuspension and deposition (Savoye et al., 2008). However, water parcel trajectory
270 calculations (d'Ovidio et al., 2015) suggest that shelf waters are transported in times
271 of less than 0.5-1 month to station F-L. This relatively short transit time still remains
272 long enough for ^{234}Th -poor waters to re-equilibrate with ^{238}U due ^{234}Th in-growth, thus
273 limiting a potential lateral component to the ^{234}Th export flux.

274 **2.4 Particulate ^{234}Th and POC**

275 Suspended particulate matter was collected at nine process stations for particulate
276 ^{234}Th and POC via large-volume (150-1000 L) in-situ filtration systems (Challenger
277 Oceanics and McLane WTS6-1-142LV pumps) equipped with 142 mm diameter filter
278 holders. Two size classes of particles (>53 μm and 1-53 μm) were collected via
279 sequential filtration across a 53 μm mesh nylon screen (SEFAR-PETEX^{  }) and a 1
280 μm pore size quartz fiber filter (QMA, Sartorius). To limit C and N blanks, the filters
281 were pre-conditioned prior to sampling. For large particles (>53 μm), the PETEX
282 screens were soaked in HCl 5%, rinsed with Milli-Q water, dried at ambient

283 temperature in a laminar flow hood and stored in clean plastic bags. QMA filters were
284 pre-combusted and acid cleaned following Bowie et al. (2010).

285 After collection, filters were subsampled under clean room conditions with acid
286 cleaned ceramic scissors for PETEX screen and a 25 mm Plexiglas punch for QMA.
287 For large particles, one fourth of the 142 mm nylon screen was dedicated to ^{234}Th
288 and POC. Particles were re-suspended in filtered seawater in a laminar flow clean
289 hood and collected on 25 mm diameter silver (Ag) filters (1.0 μm porosity). For small
290 particles, two 25 mm diameter punches were subsampled from the 142 mm QMA
291 filters. Ag and QMA filters were dried overnight and mounted on nylon filter holders
292 covered with Mylar and Al foil for beta counting. As for total ^{234}Th activity, particulate
293 samples were counted twice on board until the RSD was below 2%. The procedure
294 was similar for sediment traps samples. Sediment traps samples were re-suspended
295 in filtered seawater, collected on Ag filters, dried, and mounted on nylon filter holder.
296 Residual beta activity was measured in the home-based laboratory after six ^{234}Th
297 half-lives (~6 months) and was subtracted from the on-board measured values.

298 Following beta counting, particulate samples (QMA and Ag filters) were processed for
299 POC measurement by Elemental Analyzer - Isotope Ratio Mass Spectrometer (EA-
300 IRMS). Samples were dismounted from filters holders and fumed under HCl vapor
301 during 4 h inside a glass desiccator, to remove the carbonate phase. After overnight
302 drying at 50° C, samples were packed in silver cups and analyzed with a Carlo Erba
303 NA 1500 elemental analyzer configured for C analysis and coupled on-line via a Con-
304 Flo III interface to a Thermo-Finnigan Delta V isotope ratio mass spectrometer.
305 Acetanilide standards were used for calibration. C blanks were 1.46 μmol for Ag
306 filters and 0.52 μmol for 25 mm QMA punch. Results obtained for two size-

307 segregated POC fractions (>53 μm and 1-53 μm) are reported in Appendix 2 along
308 with particulate ^{234}Th activity measured on the same samples.

309 **3 Results**

310 **3.1 ^{234}Th activity profiles**

311 The complete dataset of total ^{234}Th ($^{234}\text{Th}_{\text{tot}}$), ^{238}U activities (dpm L^{-1}) and associated
312 $^{234}\text{Th}/^{238}\text{U}$ ratios can be found in Appendix 1. At all stations, the deficit of $^{234}\text{Th}_{\text{tot}}$
313 relative to ^{238}U was observed in surface waters ($^{234}\text{Th}/^{238}\text{U} = 0.78\text{-}0.95$). $^{234}\text{Th}_{\text{tot}}$
314 activities increased progressively with depth and were back to equilibrium with ^{238}U at
315 variable depths according to station: above 100 m at R, TNS-1 and F-L, between 100
316 and 150 m at A3-1, TEW-8, E-4E and E-4W and between 150 and 200 m at TNS-6,
317 TNS-8, E-1, E-2, E-3, E-5 and A3-2. Such a pattern is typically encountered in the
318 open-ocean (Le Moigne et al., 2013) including the Southern Ocean (Buesseler et al.,
319 2001; Cochran et al., 2000; Morris et al., 2007; Planchon et al., 2013; Rutgers van
320 der Loeff et al., 2011; Savoye et al., 2008) and indicates scavenging of ^{234}Th with
321 sinking particles. In Appendix 3, the early season trend in $^{234}\text{Th}/^{238}\text{U}$ ratios is
322 presented along the south to north transect from the central plateau (first visit to A3,
323 A3-1), on the downward slope of the plateau (TNS-8), across the E stations (TNS-6)
324 to the warmer less-saline PFZ waters north of the PF (TNS-1). Surface $^{234}\text{Th}/^{238}\text{U}$
325 ratios varied from 0.92 (A3-1) to 0.85 (TNS-8) and indicates that export of particles
326 had already occurred early at this time in the season (mid-October). Deficit was
327 higher inside the PF meander ($^{234}\text{Th}/^{238}\text{U}$ ratios of 0.85 to 0.88 at TNS-8 and TNS-6,
328 respectively) and north of the PF ($^{234}\text{Th}/^{238}\text{U} = 0.88$ at TNS-1) compared to the
329 shallow central plateau ($^{234}\text{Th}/^{238}\text{U} = 0.92$ at A3-1). Over the plateau, bottom water
330 (~50-80 m above seafloor) exhibited the lowest $^{234}\text{Th}/^{238}\text{U}$ ratios (0.75). This pattern

331 has already been documented (Savoye et al., 2008) and supports ^{234}Th removal due
332 to sediment re-suspension.

333 At process stations, $^{234}\text{Th}_{\text{tot}}$ profiles were obtained in combination with particulate
334 ^{234}Th ($^{234}\text{Th}_p$) for two size fractions (1-53 μm , >53 μm). Results obtained in the
335 different areas are shown in Figure 2 for $^{234}\text{Th}_{\text{tot}}$, $^{234}\text{Th}_p$ (sum of the two size
336 fractions), and dissolved ^{234}Th (total – particulate, $^{234}\text{Th}_d$) along with ^{238}U activity
337 (dpm L^{-1}) deduced from salinity using the equation of Owens et al (2011). The
338 average $^{234}\text{Th}_{\text{tot}}$ within the first 100 m exhibited a relatively small variability over the
339 KEOPS2 area with $2.21 \pm 0.10 \text{ dpm L}^{-1}$ ($n = 4$, $^{234}\text{Th}/^{238}\text{U} = 0.95 \pm 0.04$) at R-2, 2.18
340 $\pm 0.05 \text{ dpm L}^{-1}$ ($n = 5$, $^{234}\text{Th}/^{238}\text{U} = 0.93 \pm 0.02$) at A3-1, $2.07 \pm 0.20 \text{ dpm L}^{-1}$ ($n = 4$,
341 $^{234}\text{Th}/^{238}\text{U} = 0.89 \pm 0.08$) at F-L, and $1.98 \pm 0.03 \text{ dpm L}^{-1}$ ($n=4$, $^{234}\text{Th}/^{238}\text{U} = 0.84 \pm$
342 0.01) at E-1. In contrast, surface $^{234}\text{Th}_p$ activity, which reflects particle concentration
343 (Rutgers van der Loeff et al., 1997), was subject to larger variation. $^{234}\text{Th}_p$ activity was
344 low at R-2 (0.33 dpm L^{-1}) and at A3-1 (0.29 dpm L^{-1}), intermediate at E-1 (0.50 dpm
345 L^{-1}) and highest at F-L (0.90 dpm L^{-1}). Over the course of the survey, averaged
346 $^{234}\text{Th}_{\text{tot}}$ activity within the first 100 m remained remarkably stable over the plateau,
347 with $2.13 \pm 0.06 \text{ dpm L}^{-1}$ ($n = 3$, $^{234}\text{Th}/^{238}\text{U} = 0.90 \pm 0.03$) at A3-2 (27.7 days later),
348 and in the PF meander, with $1.91 \pm 0.07 \text{ dpm L}^{-1}$ ($n = 4$, $^{234}\text{Th}/^{238}\text{U} = 0.82 \pm 0.03$) at
349 E-3 (4.5 days later) and $1.92 \pm 0.02 \text{ dpm L}^{-1}$ ($n = 4$, $^{234}\text{Th}/^{238}\text{U} = 0.82 \pm 0.01$) at E-5
350 (19.6 days later). For the particulate phase, the situation was different. At A3, $^{234}\text{Th}_p$
351 increased from 0.29 dpm L^{-1} to 0.66 dpm L^{-1} between the two visits. At site E, $^{234}\text{Th}_p$
352 varied from 0.50 to 0.70 dpm L^{-1} between the first (E-1) and the last (E-5) visit,
353 suggesting an increase in particle concentrations in surface waters at both A3 and E
354 stations.

355 **3.2 ^{234}Th flux**

356 Total ^{234}Th activity profiles were used for estimating export fluxes based on SS and
357 NSS assumptions. Cumulated export fluxes of total ^{234}Th are presented in Figure 3.
358 Using the SS calculation, ^{234}Th export from the first 100 m ranged from 412 ± 134
359 $\text{dpm m}^{-2} \text{d}^{-1}$ at R-2 to $1326 \pm 110 \text{ dpm m}^{-2} \text{d}^{-1}$ at E-3. ^{234}Th export increased below
360 100 m depth except at station R-2 and north of the PF (stations F-L, TEW-8, and
361 TNS-1) where ^{234}Th was back to equilibrium with ^{238}U above 100 m. At 200 m depth,
362 ^{234}Th export reached $993 \pm 200 \text{ dpm m}^{-2} \text{d}^{-1}$ at A3-2, $1372 \pm 255 \text{ dpm m}^{-2} \text{d}^{-1}$ at TNS-
363 8, and between 1296 ± 193 and $1995 \pm 176 \text{ dpm m}^{-2} \text{d}^{-1}$ at E stations. At A3, the NSS
364 ^{234}Th export was $736 \pm 186 \text{ dpm m}^{-2} \text{d}^{-1}$ at 100 m and $1202 \pm 247 \text{ dpm m}^{-2} \text{d}^{-1}$ at 200
365 m and compares well with SS export. At E stations, NSS export from the first 100 m
366 were 911 ± 242 at E-4E and $1383 \pm 177 \text{ dpm m}^{-2} \text{d}^{-1}$ at E-5 and also compares well
367 with SS export. Between 100 and 200 m, NSS ^{234}Th export increased at E-5 ($2034 \pm$
368 $299 \text{ dpm m}^{-2} \text{d}^{-1}$) and decreased at E-4E ($520 \pm 402 \text{ dpm m}^{-2} \text{d}^{-1}$). In addition to
369 water-column data, export of ^{234}Th was determined from sediment traps deployed at
370 200 m depth (see Figure 3 and Table 1). Details of trap deployments carried out at E-
371 1, E-3, E-5, and A3-2 can be found elsewhere (Laurenceau-Cornec et al., 2015a).
372 Export of ^{234}Th measured in trap samples ranged from $506 \pm 21 \text{ dpm m}^{-2} \text{d}^{-1}$ at A3-2
373 to $1129 \pm 177 \text{ dpm m}^{-2} \text{d}^{-1}$ at E-3 and represented ~50 % of the SS and NSS export
374 determined from $^{234}\text{Th}_{\text{tot}}$ activity profiles.

375 **3.3 C:Th ratio of particles**

376 At process stations, particulate ^{234}Th activities and POC were obtained in two size
377 fractions of particles (1-53 μm , >53 μm). Profiles of POC to ^{234}Th ratios (C:Th) are
378 shown in Figure 4. C:Th ratios were highly variable ranging from 21.5 to 1.8 μmol
379 dpm^{-1} in 1-53 μm particles and from 12.5 to 1.0 $\mu\text{mol dpm}^{-1}$ in >53 μm particles. For
380 both size classes, C:Th ratios were high in surface waters (0-150 m) with a range of

381 9.6-6.3 $\mu\text{mol dpm}^{-1}$ at R, 13.1-6.9 at A3, and 11.4-5.7 $\mu\text{mol dpm}^{-1}$ at E stations with
382 no clear site related trend. For open-ocean stations, C:Th ratios decreased rapidly
383 with depth for the two size classes of particles and reached relatively constant values
384 in the mesopelagic zone with 2.8-4.8 $\mu\text{mol dpm}^{-1}$ at R-2, 2.6-4.5 $\mu\text{mol dpm}^{-1}$ at E
385 stations, and 1.6-2.7 $\mu\text{mol dpm}^{-1}$ at F-L. According to particle size C:Th ratios showed
386 different trends. At R-2, E-1, E-3, E-4W and E-5, C:Th ratios were comparable in
387 small and large particles. At plateau stations A3-1 and A3-2, and to a lesser extent at
388 E-4E, C:Th ratios increased with decreasing size of particles.

389 **3.4 C:Th ratio of sinking particles**

390 To estimate the POC export flux using the ^{234}Th -based approach, the C:Th ratio of
391 sinking particles needs to be determined at the depth of export (Buesseler et al.,
392 1992). Assuming the larger particle size class as representative of the sinking
393 material (Buesseler et al., 2006), we used the C:Th ratios of $>53 \mu\text{m}$ particles to
394 convert ^{234}Th fluxes into POC fluxes. C:Th ratios were estimated at fixed depths of
395 100, 150, and 200 m and results are listed in Table 1 and plotted in Figure 4. For A3-
396 1, A3-2, E-1, E-3, E-4W, and E-5, C:Th ratios of sinking particles were estimated
397 from linear interpolation of measured C:Th ratios. At R-2, the C:Th ratio at 100 m
398 represents the average ratio measured between 25 m and 110 m. At F-L, the 100 m
399 C:Th ratio was taken equal to the value at 130 m. For E-4E, C:Th of large particles
400 were measured directly at the depths of 100, 150 and 200 m and were not
401 interpolated. As illustrated in Figure 4 and in Table 1, C:Th ratios of sinking particles
402 at 200 m estimated using ISP samples showed a good agreement with sediment trap
403 data within uncertainty (3 to 6 % and 18 to 46 % RSD for ISP and trap C:Th ratios,
404 respectively) .

405 **3.5 POC export flux**

406 POC export fluxes were estimated at 100 m (EP100), 150 m (EP150), and 200 m
407 (EP200) by multiplying the corresponding ^{234}Th export flux with the C:Th ratio of
408 sinking particles at the depth of export. Results are listed in Table 1. EP100
409 estimated with the SS model were lowest at A3-1 ($3.5 \pm 0.9 \text{ mmol m}^{-2} \text{ d}^{-1}$) and at R-2
410 ($3.8 \pm 1.2 \text{ mmol m}^{-2} \text{ d}^{-1}$) and highest at E-1 with $11.8 \pm 1.3 \text{ mmol m}^{-2} \text{ d}^{-1}$. The EP100
411 at F-L was $4.1 \pm 0.6 \text{ mmol m}^{-2} \text{ d}^{-1}$ and was similar to the value for the control station
412 R-2 and the plateau station A3. In the PF meander, EP100 remained stable between
413 the two first visits (E-3) with $11.8 \pm 1.1 \text{ mmol m}^{-2} \text{ d}^{-1}$, but decreased at the third visit
414 (E-4E) to $5.4 \pm 0.7 \text{ mmol m}^{-2} \text{ d}^{-1}$ at E4-E, and increased to $7.7 \pm 0.7 \text{ mmol m}^{-2} \text{ d}^{-1}$ at
415 the last visit (E-5). Station E-4W, not included in the time series, had an EP100 of 6.7
416 $\pm 0.9 \text{ mmol m}^{-2} \text{ d}^{-1}$ very similar to E-4E on the eastern edge of the PF meander. At
417 200 m, export fluxes ranged between $1.8 \pm 0.9 \text{ mmol m}^{-2} \text{ d}^{-1}$ (R-2) and 8.2 ± 0.8
418 $\text{mmol m}^{-2} \text{ d}^{-1}$ (E-3). At the re-visited stations, carbon export was also estimated using
419 the NSS model approach. NSS EP100 varied from $4.6 \pm 1.3 \text{ mmol m}^{-2} \text{ d}^{-1}$ (E-4E) to
420 $8.4 \pm 1.1 \text{ mmol m}^{-2} \text{ d}^{-1}$ (E-5). Within uncertainty, NSS EP100 were similar (E-5 and E-
421 4E) or higher (A3) in comparison to SS EP100. EP200 determined with the ^{234}Th
422 proxy could be directly compared to fluxes estimated with sediment traps deployed at
423 the same depth (Table 1). Traps fluxes in comparison to EP200 were in very good
424 agreement within uncertainties at E-1 ($7.0 \pm 2.3 \text{ mmol m}^{-2} \text{ d}^{-1}$ and $7.7 \pm 1.0 \text{ mmol m}^{-2}$
425 d^{-1} for trap and ^{234}Th -based fluxes, respectively) and A3-2 ($2.2 \pm 0.7 \text{ mmol m}^{-2} \text{ d}^{-1}$
426 and $3.1 \pm 0.6 \text{ mmol m}^{-2} \text{ d}^{-1}$ for trap and ^{234}Th -based fluxes, respectively) , and 1.7-
427 fold and 3.3-fold lower at E-3 and E-5, respectively.

428 **4 Discussion**

429 The principal aim of this study was to estimate how natural Fe fertilization affects
430 carbon export at high productivity sites over and off plateau during the early stages of
431 the bloom. In the following sections, results obtained with the ^{234}Th -based approach
432 and summarized in Figure 5 are discussed according to the four distinct zones
433 investigated during the survey (control station R-2, North of the Polar Front station F-
434 L, Plateau station A3, and PF meander stations E). For each zone, we briefly review
435 mode and timing of iron supply, described in more details elsewhere (Trull et al.,
436 2015), deduced from dissolved and particulate iron inventories (Qu  rou   et al., 2015;
437 van der Merwe et al., 2015) as well as from iron budgets in the surface mixed-layer
438 (Bowie et al., 2015). We examine POC export efficiencies using two different metrics
439 (Table 1): (1) ThE ratio defined as the ratio of POC export to Net Primary Production
440 (NPP) (Buesseler, 1998), and (2) EP/NP ratio estimated as the ratio between POC
441 export to New Production (NP) (Joubert et al., 2011; Planchon et al., 2013). NPP and
442 NP are estimated from short-term (24h) deck board $^{13}\text{C-HCO}_3^-$, $^{15}\text{N-NO}_3^-$, $^{15}\text{N-NH}_4^+$
443 incubation experiments (Cavagna et al., 2014). NP, the fraction of C uptake
444 supported by NO_3^- assimilation is estimated from the NPP and the f-ratio (Cavagna et
445 al., 2014). NP is considered to provide an estimate of potentially “exportable
446 production” based on a number of assumptions (Sambrotto and Mace, 2000) and
447 despite several limitations (Henson et al., 2011).

448 **4.1 Reference site R-2**

449 At reference station R-2, the observed EP100 of $3.8 \pm 1.2 \text{ mmol m}^{-2} \text{ d}^{-1}$ is very small
450 and reflects mainly a small and shallow export of ^{234}Th ($412 \pm 134 \text{ dpm m}^{-2} \text{ d}^{-1}$ at 100
451 m). Low EP100 is consistent with the HNLC conditions at station R-2, where high
452 concentrations of nitrate (25 μM), silicic acid (12-13 μM) (Blain et al., 2015) and very

453 low biomass (Lasbleiz et al., 2014) are observed in surface waters. Dissolved Iron
454 (dFe) ($< 0.1 \text{ nmol L}^{-1}$) and particulate Fe (pFe) levels (0.3 nmol L^{-1}) are also very low
455 in surface waters (Qu  rou   et al., 2015; van der Merwe et al., 2015). Fluxes of dFe to
456 the surface mixed layer are estimated to be very limited ($94 \text{ nmol m}^{-2} \text{ d}^{-1}$) and
457 essentially driven by vertical supplies (Bowie et al., 2015). Biomass at station R-2
458 appears to be dominated by small size, slow growing phytoplankton (Trull et al.,
459 2015), which offers a limited potential for export. This feature is reflected in the
460 partitioning of POC and $^{234}\text{Th}_p$ with $\sim 90\%$ being associated with the small ($1\text{-}53 \mu\text{m}$)
461 size fraction between 25 and 110 m depth. C:Th ratios of particles show no variation
462 with particle size (Figure 5) and suggest that large sinking particles may be a result of
463 aggregation process (Buesseler et al., 2006). This is supported by gel trap
464 observations, revealing that phytodetrital aggregates are an important fraction of
465 sinking material between 110 and 430 m depth (Laurenceau-Cornec et al., 2015a).

466 The flux obtained at the KEOPS2 reference station is similar to results obtained
467 during the first leg of CROZEX (Nov.-Dec. 2004) at control sites M2 and M6, with
468 carbon export of $4.9 \pm 2.7 \text{ mmol m}^{-2} \text{ d}^{-1}$ and $5.8 \pm 3.9 \text{ mmol m}^{-2} \text{ d}^{-1}$, respectively
469 (Morris et al., 2007). Our value for C export is however much lower than the flux
470 obtained in summer at the KEOPS1 control site C11 ($12.2 \pm 3.3 \text{ mmol m}^{-2} \text{ d}^{-1}$) (Jan.-
471 Feb. 2005) (Savoie et al., 2008) or during the second Leg of CROZEX (Dec.2004 –
472 Jan.2005) with $18.8 \pm 3.4 \text{ mmol m}^{-2} \text{ d}^{-1}$ at M2 and $14.4 \pm 3.0 \text{ mmol m}^{-2} \text{ d}^{-1}$ at M6
473 (Morris et al., 2007).

474 For the reference station R-2, ThE and EP/NP ratios were high with 34 % and 73 %
475 respectively, and indicate a relatively efficient carbon pump despite the limited
476 magnitude of carbon export and uptake ($\text{NPP} = 11.2 \text{ mmol m}^{-2} \text{ d}^{-1}$). The ThE ratio
477 falls in the range of most literature data for the Southern Ocean, which is generally

478 elevated (>10%) in HNLC waters (Buesseler et al., 2003; Savoye et al., 2008).
479 During KEOPS1, ThE ratio as high as 58 % was observed at the reference station
480 C11 (Savoye et al., 2008). Reasons for this high efficiency can be numerous, and a
481 detailed discussion can be found elsewhere (Laurenceau-Cornec et al., 2015a).
482 Briefly, efficient scavenging of POC at the low productivity site (R-2) may be
483 mediated by fast-sinking aggregates composed of heavily-silicified diatoms. Although
484 BSi levels are low (Lasbleiz et al., 2014), this scenario is supported by the diatom
485 community found at the reference station R-2, which was dominated by the heavily-
486 silicified species *Fragilariopsis* spp. and *Thalassionema nitzschioides* (Laurenceau-
487 Cornec et al., 2015b and references therein). In addition, the limited zooplankton
488 biomass at R-2 (Carlotti et al., 2015) as well as the rarity of fecal pellets in exported
489 material (Laurenceau-Cornec et al., 2015a) suggest that attenuation/transformation
490 of the POC flux through grazing is rather limited, and thus could also partly explain
491 the high export efficiency at the reference station R-2.

492 With depth, carbon export decreased rapidly at station R-2, and more than 50 % of
493 EP100 was lost between 100 and 200 m depth. Consequently, export efficiency
494 decrease at 200 m depth to 16 % and 34 % based on the ThE and NP ratios,
495 respectively. A similar trend was deduced from gel traps (Laurenceau-Cornec et al.,
496 2015a). In our case, sharp decrease of export with depth seems to be essentially
497 driven by the C:Th ratio of sinking particles, which decreases from 9.2 $\mu\text{mol dpm}^{-1}$ to
498 4.1 $\mu\text{mol dpm}^{-1}$ between 100 and 200 m (Figure 4). Such a decrease may support a
499 preferential loss of C relative to ^{234}Th due to a partial degradation of sinking particles
500 (Buesseler et al., 2006). This feature could involve the heterotrophic bacterial activity,
501 since high content of bacteria cells ($2.9 \times 10^5 \text{ cell ml}^{-1}$) are found between 100-150 m
502 (Christaki et al., 2014).

503 **4.2 North of Polar Front site (F-L)**

504 The northern PF station (F-L) exhibits moderate dFe enrichments in surface waters
505 ($\sim 0.26 \text{ nmol L}^{-1}$) (Qu  rou   et al., 2015). Enrichments are much higher for pFe (1–2.5
506 nmol L^{-1}) presumably reflecting biological iron uptake and conversion into biogenic
507 particulate fraction (van der Merwe et al., 2015). Iron budget is not available for
508 station F-L so it is difficult to determine the mode of iron fertilization. However, dFe is
509 likely to be supplied by both vertical exchanges with the Fe-rich reservoir from below,
510 as well as by lateral advection of iron-rich coastal waters from the northern Kerguelen
511 shelf along the northern side of the PF jet (d'Ovidio et al., 2015; Park et al., 2014a;
512 Trull et al., 2015). Analysis of drifter trajectories and altimetry-based geostrophic
513 currents (d'Ovidio et al., 2015) indicate that advection of water parcels from the
514 Kerguelen shelf is relatively short to station F-L (0.5 to 1 month). However, iron-rich
515 waters rapidly disperse in this area and limit the persistence of iron fertilization (Trull
516 et al., 2015).

517 EP100 at station F-L is low ($4.1 \pm 0.6 \text{ mmol m}^{-2} \text{ d}^{-1}$) and is only 1.1-fold higher than at
518 the control station R-2. This suggests no impact of Fe fertilization on upper-ocean
519 carbon export in early bloom conditions. However, ^{234}Th export at F-L is 2.2 times
520 higher in comparison to the reference station at the same depth, and indicates a
521 more efficient scavenging of particles in the PFZ. This is supported further by the
522 similar 100-m ^{234}Th flux observed in the same area at TEW-8 ($886 \pm 162 \text{ dpm m}^{-2} \text{ d}^{-1}$,
523 see Appendix 4). It should be mentioned that EP100 at F-L may be underestimated
524 because the C:Th ratio used to convert the ^{234}Th flux into C flux was taken at 130 m
525 depth and may be lower than at 100 m depth. As an example, C:Th ratio of 1-53 μm
526 particle at station F-L is $6.0 \mu\text{mol dpm}^{-1}$ at 70 m and strongly decreases to $4.5 \mu\text{mol}$
527 dpm^{-1} at 130 m. However, considering deeper export, EP200 at F-L ($3.0 \pm 0.8 \text{ mmol}$

528 $\text{m}^{-2} \text{d}^{-1}$) appears 1.6-fold higher than EP200 at the reference station R-2 suggesting
529 an early impact of Fe fertilization on C export at this depth. In this area, EP200
530 estimated using the ^{234}Th proxy shows excellent agreement with fluxes deduced from
531 gel traps (Laurenceau-Cornec et al., 2015a).

532 The observed trend in EP drastically contrasts with the very high productivity at F-L.
533 A massive bloom rapidly developed in early November in this area as revealed by
534 satellite images (D'Ovidio, pers. comm. 2014) and station F-L was visited only a few
535 days after the start of the bloom. Phytoplankton biomass was high with total Chl-a up
536 to $5.0 \mu\text{g L}^{-1}$, total BSi up to $3.9 \mu\text{mol L}^{-1}$ and POC up to $28.2 \mu\text{mol L}^{-1}$ (Lasbleiz et al.,
537 2014), with the diatom-dominated phytoplankton community in the fast-growing
538 phase as revealed by Si (Closset et al., 2014) and C (Cavagna et al., 2014) uptake
539 rates. The phytoplankton community was composed of a broad spectrum of size and
540 taxa (Trull et al., 2015). Considering the three size fractions dominated by
541 phytoplankton (5-20 μm , 20-50 μm , 50-210 μm), 48 % and 52 % of POC was found
542 above and below 50 μm , respectively, with small species presumably originating from
543 Fe-rich waters of the northern Kerguelen shelf, and large species being characteristic
544 of low biomass waters south of the PF offshore of the island (Trull et al., 2015). It is
545 interesting to note that the high biomass content is reflected in the partitioning of
546 ^{234}Th showing very high $^{234}\text{Th}_p$ activity (0.9 dpm L^{-1} at 40 m, see Figure 2).
547 Furthermore, $^{234}\text{Th}_p$ appears to be evenly distributed among small and large particles
548 similarly to phytoplankton community structure. Between 40 and 70 m depth, 40% of
549 $^{234}\text{Th}_p$ is found with the small (1-53 μm) particles and 60 % with the large (>53 μm)
550 particles. This size spectrum of particles clearly offers higher potential for C export at
551 F-L compared to the HNLC reference station.

552 However, comparison with NPP and NP reveals that export efficiency is very low at
553 F-L with ThE and EP/NP ratios of 1 % and 2 %, respectively. The two indicators
554 clearly support an inefficient transfer of C to depth and indicate a pronounced
555 decoupling between export and production. Observed decoupling may partly result
556 from methodological miss-matches in the measurements since time and space
557 scales integrated by NPP and NP (24h incubation) differs from the ^{234}Th approach
558 (~1 month). However, very low ThE and EP/NP ratios may also indicate that biomass
559 is in an accumulation phase at station F-L and a major export event is likely to be
560 delayed until later in the season. Such an accumulation scenario is supported by the
561 small-size, fast-growing, and less-silicified phytoplankton species observed at F-L
562 (Trull et al., 2015) which are presumably less efficient at exporting carbon to depth.
563 Furthermore, high mesozooplankton biomass (4.5 gC m^{-2}) (Carlotti et al., 2015) as
564 well as the dominance of cylindrical fecal pellets in gel traps (Laurenceau-Cornec et
565 al., 2015a) supports an intense grazing activity at F-L, that may contribute to the
566 reduction of the POC flux, and to the low export efficiency.

567 Comparison with literature data shows that EP100 at F-L ($4.1 \pm 0.6 \text{ mmol m}^{-2} \text{ d}^{-1}$)
568 remains substantially lower than POC export reported during CROZEX experiment
569 both during leg 1 (range $4.9\text{-}17 \text{ mmol m}^{-2} \text{ d}^{-1}$) and leg 2 ($13\text{-}30.0 \text{ mmol m}^{-2} \text{ d}^{-1}$), even
570 though similar Fe-rich waters of the PFZ were sampled (Morris et al., 2007).

571 Attenuation of export production with depth is relatively weak at F-L, as only 25% of
572 EP100 is lost between 100 and 200 m depth. This decrease is due to the decreasing
573 C:Th ratio of sinking particles from $4.5 \text{ } \mu\text{mol dpm}^{-1}$ to $3.1 \text{ } \mu\text{mol dpm}^{-1}$ between 130
574 and 200 m. As already mentioned for the reference site, this trend may involve
575 heterotrophic degradation of sinking particles. However, bacterial production at F-L is
576 most intense in the first 60 m and decreases rapidly with depth to reach values

577 similar to the reference station below 100 m depth (Christaki et al., 2014). At F-L,
578 large particles seems to be more resistant to heterotrophic degradation and this may
579 be linked to the higher abundance of fast-sinking cylindrical fecal pellets
580 (Laurenceau-Cornec et al., 2015a).

581 **4.3 Plateau site A3**

582 Station A3 was located in iron- and silicic acid-rich waters over the central plateau
583 and was visited twice, early (20 Oct.) and late (16 Nov.) during the survey. Surface
584 mixed layer dFe levels were high at A3-1 (0.28-0.32 nmol L⁻¹) decreasing at A3-2
585 (0.14-0.18 nmol L⁻¹) probably due to biological uptake (Qu  rou   et al., 2015). Surface
586 pFe exhibits a similar trend as dFe, with higher concentrations at A3-1 compared to
587 A3-2, but with a more important biogenic fraction at A3-2 (van der Merwe et al.,
588 2015). Vertical dFe fluxes are by far the dominant sources of iron over the Plateau,
589 and fuel the surface waters during episodic deepening of the upper mixed-layer
590 (Bowie et al., 2015). Consequently, fertilization over the plateau is considered to be
591 relatively recent occurring during the maximum winter mixing period in August-
592 September (Trull et al., 2015) and persisting over 2-3 months based on the estimated
593 residence times of water parcels over the plateau (Park et al., 2008b).

594 EP100 over the plateau was very limited, with 3.5 ± 0.9 mmol m⁻² d⁻¹ and 4.6 ± 1.5
595 mmol m⁻² d⁻¹ at A3-1 and A3-2 respectively, based on the SS model. Based on the
596 NSS model, EP100 at A3-2 appears slightly higher with 7.3 ± 1.8 mmol m⁻² d⁻¹.
597 EP100 at A3 shows no difference or a maximum of 1.9-fold higher flux in comparison
598 to the HNLC reference station R-2 suggesting limited impact of Fe fertilization.
599 Interesting, the ²³⁴Th deficit follows the density structure and extends to the bottom of
600 the mixed layer at 150-200 m. This is much deeper than at stations R-2 or F-L, and

601 consequently ^{234}Th export increases to $776 \pm 171 \text{ dpm m}^{-2} \text{ d}^{-1}$ at A3-1 and to $993 \pm$
602 $200 \text{ dpm m}^{-2} \text{ d}^{-1}$ at A3-2 between 100 and 200 m depth. At A3-2, POC flux was the
603 highest at 150 m depth with EP150 of $7.1 \pm 1.5 \text{ mmol m}^{-2} \text{ d}^{-1}$ and of $8.4 \pm 1.8 \text{ mmol}$
604 $\text{m}^{-2} \text{ d}^{-1}$ based on SS and NSS model respectively, and is 2.8 to 3.4 fold-higher in
605 comparison to EP150 at the HNLC station. At 200 m, increasing ^{234}Th export is
606 cancelled by the simultaneous decrease of C:Th ratios resulting in low carbon export
607 similar to A3-1. Comparison of PPS3/3 and gel sediment traps can be conducted at
608 A3-2. First, we observe an excellent agreement between ISP and PPS3/3 trap C:Th
609 ratios (Figure 5) indicating that the choice of large ($>53 \mu\text{m}$) particles collected via
610 ISP as representative of sinking particles was appropriate. Second, EP200 estimated
611 in this study ($3.1 \pm 0.6 \text{ mmol m}^{-2} \text{ d}^{-1}$ and $3.8 \pm 0.8 \text{ mmol m}^{-2} \text{ d}^{-1}$ with SS and NSS
612 model, respectively) compare well with PPS3/3 trap flux ($2.2 \pm 0.7 \text{ mmol m}^{-2} \text{ d}^{-1}$)
613 and are smaller than gel trap-derived fluxes ($5.5 \text{ mmol m}^{-2} \text{ d}^{-1}$) (Laurenceau-Cornec
614 et al., 2015a). The low flux collected with PPS3/3 traps may indicate undertrapping,
615 but given that the trap was deployed only for one day this site is particularly
616 susceptible to temporal mismatch resulting from short-term variations in particle
617 fluxes. However, it is worth mentioning that the good agreement found between the
618 different and totally independent approaches is encouraging and tends to confirm
619 that export production over the central plateau was rather low throughout the survey.

620 Low export at A3 contrasts with the rapid biomass increase that occurred a few days
621 before the second visit as revealed by satellite images (D'Ovidio, pers. comm. 2014).
622 The phytoplankton bloom at A3 showed different characteristics compared to station
623 F-L suggesting variable biological responses to Fe fertilization. The bloom over the
624 central plateau was dominated by fast-growing, large and heavily-silicified diatoms
625 (Trull et al., 2015) showing very high Si uptake rates (Closset et al., 2014). The

626 change in biomass levels at A3 is well reproduced by $^{234}\text{Th}_p$ activity which increases
627 from 0.25 to 0.55 dpm L⁻¹ between the first and the second visit. These changes are
628 observed also in the size partitioning of $^{234}\text{Th}_p$. While at A3-1, 95% of $^{234}\text{Th}_p$ is found
629 associated with small (1-53 μm) particles, at A3-2 ~70% is found with large (>53 μm)
630 particles between 55 and 165 m depth. This clearly suggests a very high potential for
631 export at A3-2, although massive export event had not yet commenced. Delayed
632 export is suggested further by the very low ThE and EP/NP ratios at 100 m depth of 3
633 % and 5 %, respectively at A3-2, which indicates that biomass was accumulating in
634 the mixed layer.

635 Over the central plateau, EP200 during the early stages of the bloom (range: $3.1 \pm$
636 $0.6 \text{ mmol m}^{-2} \text{ d}^{-1}$ – $3.8 \pm 0.8 \text{ mmol m}^{-2} \text{ d}^{-1}$) are 4.4 to 12 times smaller than during the
637 KEOPS1 late summer condition at the same depth horizon ($13.9 \pm 5.9 \text{ mmol m}^{-2} \text{ d}^{-1}$ -
638 $37.7 \pm 13.3 \text{ mmol m}^{-2} \text{ d}^{-1}$) (Savoie et al., 2008). This difference is essentially due to
639 much higher ^{234}Th fluxes reported during KEOPS1 (range $2249 \pm 772 \text{ dpm m}^{-2} \text{ d}^{-1}$ –
640 $8016 \pm 949 \text{ dpm m}^{-2} \text{ d}^{-1}$) indicating that particle scavenging is much more intense in
641 January-February during the peak and decline of the bloom. Interestingly, the C:Th
642 ratio of sinking particles exhibits a similar range over the entire growth season, 3.1 –
643 $9.9 \mu\text{mol dpm}^{-1}$ during KEOPS1 and 4.7 – $7.7 \mu\text{mol dpm}^{-1}$ during KEOPS-2, between
644 100 and 200 m depth. This is relatively surprising because sinking particles are very
645 different between the early and late bloom period over the plateau. During KEOPS2,
646 sinking particles were dominantly composed of phytodetrital aggregates
647 (Laurenceau-Cornec et al., 2015a) and rapid aggregation of diatom cells was also
648 evidenced from underwater vision profiler observations and modeling (Jouandet et
649 al., 2014). During KEOPS1, the export process was different and the majority of the

650 particle flux (composed of fecal pellets and fecal aggregates) was processed through
651 the heterotrophic food web (Ebersbach and Trull, 2008).

652 **4.4 PF meander site E**

653 Export in the recirculation feature south of the PF (stations E) was the highest during
654 the whole survey (Figure 5). The four visits carried out as a pseudo-lagrangian
655 survey (E-1, E-3, E-4E, and E-5) revealed the short-term temporal variability of
656 carbon export over 19.6 days. Surface waters in this area shows low to moderate
657 enrichments in dFe levels relative to the reference station R-2 but with a high
658 variability (range : 0.06 – 0.38 nmol L⁻¹) (Qu  rou   et al., 2015). Mode and timing of
659 iron fertilization appears to be complex in the PF meander, and differs from over the
660 plateau. The Iron budgets suggest that lateral supplies of dFe are the dominant
661 sources of iron to the recirculation feature (4-5 fold greater than the vertical flux)
662 (Bowie et al., 2015). Based on water parcel trajectories, the recirculation region could
663 be fueled with Fe-rich waters from the northern Kerguelen shelf, similarly to the north
664 of PF region (station F-L) but delayed. Also waters derived from north-east are
665 diluted with waters derived from the south (d'Ovidio et al., 2015; Park et al., 2014a).
666 Thus, fertilization of the recirculation region is likely to be less recent and less intense
667 than at station F-L, but is probably more persistent (Trull et al., 2015).

668 EP100 was particularly elevated at the first ($11.6 \pm 1.3 \text{ mmol m}^{-2} \text{ d}^{-1}$, E-1) and at the
669 second visit ($11.8 \pm 1.1 \text{ mmol m}^{-2} \text{ d}^{-1}$, E-3), decreased at the third visit (5.4 ± 0.7
670 $\text{mmol m}^{-2} \text{ d}^{-1}$, E-4E) and then increased again during the fourth visit ($7.7 \pm 1.3 \text{ mmol}$
671 $\text{m}^{-2} \text{ d}^{-1}$, E-5). A comparison with the reference station indicates 3- to 1.4-fold
672 enhanced export (at 100 m) within the recirculation feature suggesting an early
673 impact of Fe fertilization. High EP100 appears primarily influenced by an elevated

674 100-m ^{234}Th export, ranging between $1051 \pm 121 \text{ dpm m}^{-2} \text{ d}^{-1}$ and $1326 \pm 110 \text{ dpm m}^{-2}$
675 d^{-1} . Note that high ^{234}Th export was also observed in the same area earlier in the
676 survey (21-22 Oct.) at transect stations TNS-6 and TNS-8 (see Appendix 4). These
677 results support an early export event in the PF meander that had occurred before the
678 start of the bloom and was associated with moderate biomass levels. The integrated
679 total Chl-a stocks at 200-m were relatively stable with 141 mg m^{-2} at E-1, 112 mg m^{-2}
680 at E-2, 96 mg m^{-2} at E-3, 108 mg m^{-2} at E-4E, and 126 mg m^{-2} at E-5 (Closset et al.,
681 2014). Furthermore, the relatively constant ^{234}Th flux over the 19-day period may
682 indicate that particle scavenging is at steady state, i.e. constant export (Savoye et al.,
683 2006). This is supported also by the excellent agreement found between SS and
684 NSS estimates of 100-m ^{234}Th fluxes at E-4E and E-5 (Table 1). However, local
685 variation in ^{234}Th distribution seems to exist in the PF meander as seen with the
686 smaller ^{234}Th flux recorded at station E-2 which was part of the west to east transect
687 (TEW, Appendix 4 and Figure 5). The smaller deficit at this station may have been
688 caused by lateral advection of ^{234}Th -rich (lower deficit) waters originating from the jet
689 of the PF passing to the north. The second controlling factor of EP100 was the
690 sinking particles C:Th ratio, showing elevated values at E-1 ($10.5 \pm 0.2 \mu\text{mol dpm}^{-1}$)
691 and E-3 ($8.9 \pm 0.3 \mu\text{mol dpm}^{-1}$) decreasing progressively at E-4E ($5.1 \pm 0.3 \mu\text{mol}$
692 dpm^{-1}) and increasing again at E-5 ($6.1 \pm 0.2 \mu\text{mol dpm}^{-1}$). As already mentioned,
693 such a decrease may indicate preferential loss of carbon relative to ^{234}Th (Buesseler
694 et al., 2006). This may involve food web interactions including bacterial production in
695 the mixed layer increasing from $30 \text{ nmol C L}^{-1} \text{ d}^{-1}$ (E-1) to $54.7 \text{ nmol C L}^{-1} \text{ d}^{-1}$ (E-5)
696 (Christaki et al., 2014) as well as grazing activity by zooplankton (Carlotti et al.,
697 2015).

698 EP200 was also elevated in the recirculation feature (range: $5.3 \pm 1.0 \text{ mmol m}^{-2} \text{ d}^{-1}$ to
699 $8.2 \pm 0.8 \text{ mmol m}^{-2} \text{ d}^{-1}$) but shows less temporal variability. High EP200 results from a
700 very deep ^{234}Th deficit extending down to 200 m depth, except at E-4E where the
701 export depth (depth at which ^{234}Th is to back equilibrium with ^{238}U) is shallower (~150
702 m). Consequently, important increases in ^{234}Th export (up to a factor of 2 at E-5)
703 were observed between 100 and 200 m depth. This feature is not in line with the
704 relatively shallow mixed layer depth estimated in the PF meander (range: 38 m to 74
705 m depth) and seems to follow the depth of the winter mixed layer. Note that
706 macronutrients (nitrate and silicic acid) and dissolved trace elements profiles
707 (Qu erou  et al., 2015) display similar patterns as the ^{234}Th deficit. Such a vertical
708 distribution suggests important vertical mixing in the area and tends to confirm that
709 ^{234}Th export has occurred earlier in the survey. The ^{234}Th export at 200-m displays
710 little variability over the 19.6 days of sampling and this feature is also observed in
711 sediment traps deployed at E-1, E-3 and E-5, even though the traps have collected
712 ~50% of the flux deduced from ^{234}Th deficit. The C:Th ratio in sinking particles
713 decreases sharply between 100 m and 200 m depth at E-1 and E-3 and to a lesser
714 extent at E-4E and E-5 (Figure 5). Ratios estimated from ISP show very good
715 agreement with trap C:Th ratios at E-3 and E-5 but not at E-1. The trap C:Th ratio at
716 E-1 was highly variable ($8.6 \pm 3.9 \text{ } \mu\text{mol dpm}^{-1}$) and appears closer to C:Th ratios of
717 small (1-53 μm) particles, suggesting a potential contribution of these particles to the
718 overall export. A decreasing C:Th ratio results in lower EP200 compared with EP100.
719 However, a comparison with the HNLC reference station reveals between 2.9 and
720 4.5-fold higher carbon fluxes in the PF meander at 200 m depth. This suggests a
721 strong impact of Fe fertilization in this area which is subjected to low to moderate dFe
722 inputs. The impact of Fe fertilization on carbon export at this location is higher

723 compared to the KEOPS1 study over the plateau (~2-fold higher POC flux) (Savoie
724 et al., 2008).

725 High export in the PF meander remains relatively unexpected considering the
726 temporal variation of surface phytoplankton community structure. Initially dominated
727 by small size particles including small centric and pennate diatoms, the larger
728 phytoplankton fraction increased progressively and became dominant at the end of
729 the time series (E-5) (Trull et al., 2015). This variability is also observed in $^{234}\text{Th}_p$ and
730 POC partitioning between the surface and 150 m depth. At E1, E-3, and E-4E, small
731 particles represent the dominant fraction of $^{234}\text{Th}_p$ and POC with 60% up to 80%,
732 while at E-5 small particles fraction decreases to 50%. This suggests an increasing
733 potential for export, whereas EP tends to decrease with time. The same feature is
734 observed for C (Cavagna et al., 2014) and Si uptake rates (Closset et al., 2014)
735 showing low productivity at the beginning increasing progressively during the course
736 of the survey. These inverse temporal variations between export and production are
737 supported further by the ThE and EP/NP ratios at 100 m depth, where high values
738 were observed initially (27 % and 34 %, respectively) at E-1 decreasing progressively
739 until E-5 (10 % and 14 %, respectively). The reason for this decoupling may be
740 numerous and highlights the complexity of export processes that cannot be easily
741 resolved based only on primary and new production variability. One hypothesis may
742 involve food web interactions through grazing pressure, since fecal material is one of
743 the main carriers of the POC export in the upper 200 m at the E stations
744 (Laurenceau-Cornec et al., 2015a).

745 The early bloom export in the PF meander can be compared to the late summer
746 situation reported for station A11 during KEOPS1 located in similar deep waters east
747 of Kerguelen Island (Savoie et al., 2008). POC flux at A11 in late summer (range:

748 19.4 – 26.3 mmol m⁻² d⁻¹) is substantially higher than EP100 (range: 5.4 – 11.6 mmol
749 m⁻² d⁻¹) and EP200 (5.3 – 7.7 mmol m⁻² d⁻¹) at stations E confirming that an important
750 fraction of the seasonal export was not sampled during KEOPS2. At A11, the C:Th
751 ratio was 11.0 ± 1.2 μmol dpm⁻¹ and 6.3 μmol dpm⁻¹ at 100 m and 200 m depth,
752 respectively, and appears very close to the C:Th ratios measured at E-1 and E-3, and
753 higher than the ratios measured at E-4E and E-5.

754 **5 Conclusion**

755 In the present study, we investigated upper-ocean carbon export production in the
756 naturally Fe-fertilized area adjacent to Kerguelen Island as part of the KEOPS2
757 expedition. Spatial and temporal variations in water-column total ²³⁴Th activity
758 combined with the C:Th ratios of large potentially sinking particles were used to infer
759 carbon export between 100 m and 200 m depth. Export production in the Fe-fertilized
760 area reveals large spatial variability during the early stages of bloom development
761 with low export found at high productivity sites located over the central plateau (A3
762 site) and north of the PF in deep water downstream of the island (F-L site). Highest
763 export was observed south of the permanent meander of the PF (E stations) where a
764 detailed time series was obtained as part of a pseudo-lagrangian study. The
765 comparison with the HNLC reference station located south of the PF and upstream of
766 the island, indicates that Fe fertilization increased carbon export in all iron fertilized
767 waters during the early stage of the Kerguelen bloom but at variable degrees. The
768 increase is particularly significant inside the PF meander, but more moderate over
769 the central Kerguelen plateau and in the northern plume of the Kerguelen bloom.
770 Export efficiencies were particularly low at high productivity sites over and off the
771 plateau (A3 and F-L sites) and clearly indicate that biomass was in accumulation
772 phase rather than in export phase. The varied response of ecosystems to natural iron

773 inputs results in varied phytoplankton community size structures, which in turn
774 impacts the potential for carbon export. Accordingly, station A3 over the central
775 plateau showing high biomass dominated by large-size diatoms may offer higher
776 potential for carbon export compared to F-L and E sites. Comparison with late
777 summer POC export obtained during KEOPS1 reveals a much smaller carbon export
778 during the early stages of the bloom in spring than in late summer.

779

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Table 1. ^{234}Th and POC export fluxes and C:Th ratios of sinking particles estimated at 100, 150, and 200 m depth, and carbon export efficiency (ThE and EP/NP ratios) during KEOPS2. (bold text indicates that non-steady state calculations were used).

Station	Date	Depth (m)	^{234}Th flux (dpm m ⁻² d ⁻¹)	C:Th ($\mu\text{mol dpm}^{-1}$)	POC flux (mmol m ⁻² d ⁻¹)	ThE (%)	EP/NP (%)
R-2	25-oct.	100	412 ± 134	9.2 ± 0.5	3.8 ± 1.2	34	73
R-2	25-oct.	150	448 ± 146	5.6 ± 0.4	2.5 ± 0.8	22	48
R-2	25-oct.	200	449 ± 203	4.1 ± 0.5	1.8 ± 0.9	16	35
A3-1	20-oct.	100	509 ± 127	6.9 ± 1	3.5 ± 0.9		
A3-1	20-oct.	150	666 ± 140	5.8 ± 1	3.9 ± 0.9		
A3-1	20-oct.	200	776 ± 171	4.8 ± 1	3.7 ± 0.9		
A3-2	16-nov.	100	463 ± 151	9.9 ± 0	4.6 ± 1.5	3	3
A3-2	16-nov.	150	829 ± 169	8.6 ± 0	7.1 ± 1.5	5	5
A3-2	16-nov.	200	993 ± 200	3.1 ± 0	3.1 ± 0.6	2	2
A3-2 Trap	15 nov. - 17 nov.	200	506 ± 21	4.5 ± 1.5	2.2 ± 0.7		
A3-2	20 oct.-16 nov.	100	736 ± 186	9.9 ± 0	7.3 ± 1.8	5	5
A3-2	20 oct.-16 nov.	150	975 ± 209	8.6 ± 0	8.4 ± 1.8	5	5
A3-2	20 oct.-16 nov.	200	1202 ± 247	3.1 ± 0	3.8 ± 0.8	2	2
F-L	6-nov.	100	902 ± 117	4.5 ± 0	4.1 ± 0.6	1	2
F-L	6-nov.	150	891 ± 164	4.1 ± 0	3.6 ± 0.8	1	1
F-L	6-nov.	200	973 ± 207	3.1 ± 1	3.0 ± 0.8	1	1
E-1	30-oct.	100	1111 ± 120	10.5 ± 0	11.6 ± 1.3	27	34
E-1	30-oct.	150	1504 ± 158	5.5 ± 0	8.3 ± 0.9	19	24
E-1	30-oct.	200	1665 ± 201	4.7 ± 0	7.7 ± 1.0	18	23
E-1 Trap	29 oct. - 3 nov.	200	881 ± 226	8.6 ± 3.9	7.0 ± 2.3		
E-3	3 nov.	100	1326 ± 110	8.9 ± 0	11.8 ± 1.1	21	32
E-3	3 nov.	150	1742 ± 142	6.2 ± 0	10.8 ± 0.9	19	29
E-3	3 nov.	200	1995 ± 176	4.1 ± 0	8.2 ± 0.8	14	22
E-3 Trap	5 nov. - 9 nov.	200	1129 ± 177	4.0 ± 0.7	4.9 ± 1.5		
E-4E	13 nov.	100	1051 ± 121	5.1 ± 0	5.4 ± 0.7	7	9
E-4E	13 nov.	150	1210 ± 155	3.3 ± 0	4.0 ± 0.5	5	7
E-4E	13 nov.	200	1296 ± 193	4.1 ± 0	5.3 ± 1.0	7	9
E-4E	30 oct. - 13 nov.	100	911 ± 242	5.1 ± 0	4.6 ± 1.3	6	8
E-4E	30 oct. - 13 nov.	150	726 ± 315	3.3 ± 0	2.4 ± 1.0	3	4
E-4E	30 oct. - 13 nov.	200	525 ± 402	4.1 ± 0	2.1 ± 1.7	3	4
E-5	18 nov.	100	1262 ± 116	6.1 ± 0	7.7 ± 0.7	10	14
E-5	18 nov.	150	1671 ± 153	4.2 ± 0	7.0 ± 0.7	9	12
E-5	18 nov.	200	1810 ± 190	3.7 ± 0	6.7 ± 0.8	9	12
E-5 Trap	18 nov. - 19 nov.	200	955 ± 546	2.4 ± 1.0	2.0 ± 1.0		
E-5	30 oct. - 18 nov.	100	1383 ± 177	6.1 ± 0	8.4 ± 1.1	11	15
E-5	30 oct. - 18 nov.	150	1928 ± 235	4.2 ± 0	8.1 ± 1.0	10	14
E-5	30 oct. - 18 nov.	200	2034 ± 299	3.7 ± 0	7.5 ± 1.2	10	13
E-4W	11 nov.	100	1003 ± 124	6.7 ± 0	6.7 ± 0.9	3	3
E-4W	11 nov.	150	1174 ± 168	3.9 ± 0	4.5 ± 0.7	2	2
E-4W	11 nov.	200	1068 ± 208	3.4 ± 0	3.7 ± 0.7	2	2

Figure Captions:

Figure 1: Stations map of ^{234}Th measurements during the KEOPS2 expedition. Also shown are the positions of the SubAntarctic Front (SAF) and the Polar Front (PF) adapted from Park et al (2008b).

Figure 2: Depth profiles of total ^{234}Th ($^{234}\text{Th}_{\text{tot}}$), particulate $^{234}\text{Th}_p$ (sum of the two size fractions), and dissolved ^{234}Th (total – particulate, $^{234}\text{Th}_d$) activity (dpm L^{-1}) along with ^{238}U activity (dpm L^{-1} , solid lines) deduced from salinity at HNLC reference station R, central plateau station A3 (A3-1, first visit 20-Oct.; A3-2, second visit 16-Nov.), PF meander station E (E-1, first visit 30-Oct.; E-5, fourth visit 8-Nov.), and North of PF station F-L.

Figure 3: Depth profiles of cumulated total ^{234}Th export fluxes from the surface to 250 m depth using steady state (SS) and non-steady state (NSS) models and comparison with ^{234}Th export fluxes estimated from sediment traps at 200 m.

Figure 4: POC to ^{234}Th (C:Th) ratio in size-fractionated ($1-53\ \mu\text{m}$ and $>53\ \mu\text{m}$) suspended particulate matter collected by ISP and comparison with sinking particles collected via sediment traps at 200 m depth. Also shown is a linear interpolation of C:Th ratios at 100, 150, and 200 m depth for carbon flux estimates.

Figure 5: Summary results of ^{234}Th export fluxes ($\text{dpm m}^{-2} \text{d}^{-1}$), sinking particles C:Th ratios ($\mu\text{mol dpm}^{-1}$), and POC export fluxes ($\text{mmol m}^{-2} \text{d}^{-1}$) obtained at 100 m and 200 m depth and comparison with sediment trap data obtained at 200 m depth during KEOPS2 survey.

Figure 1.

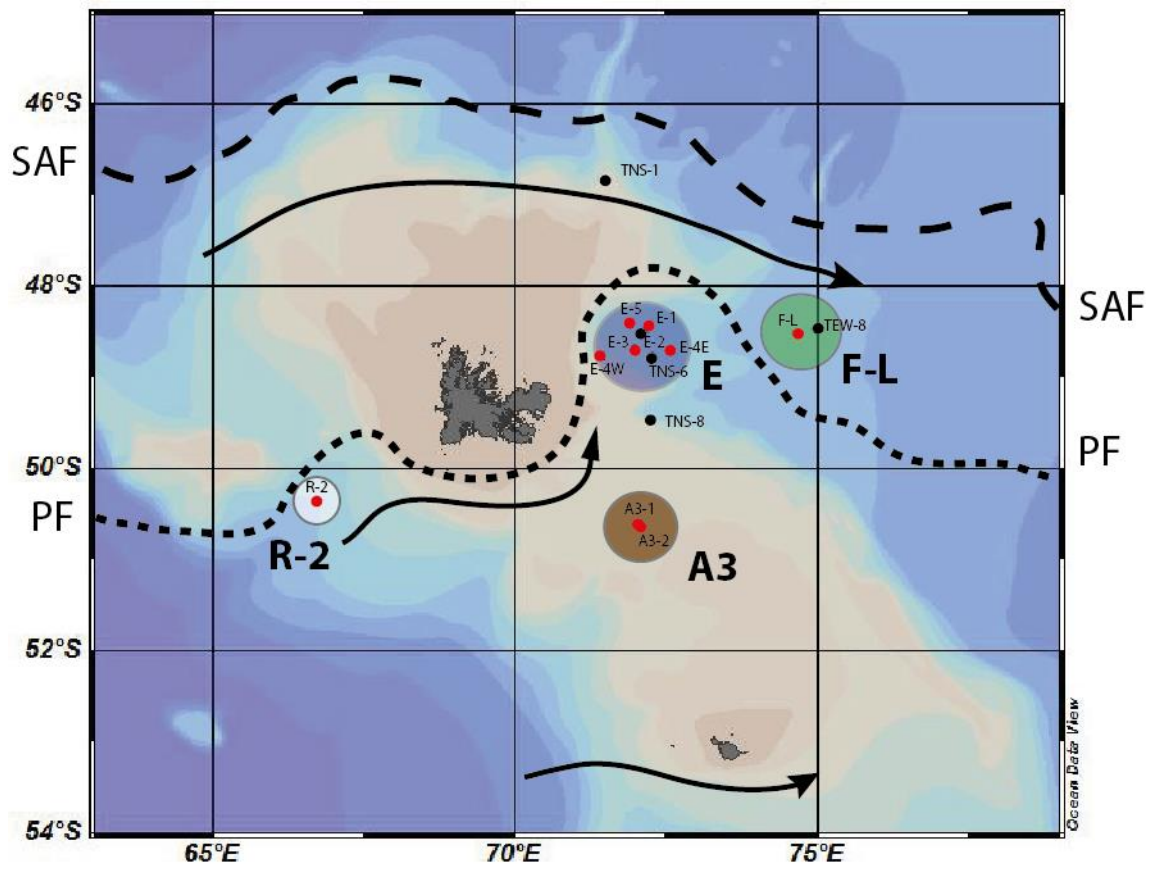


Figure 2.

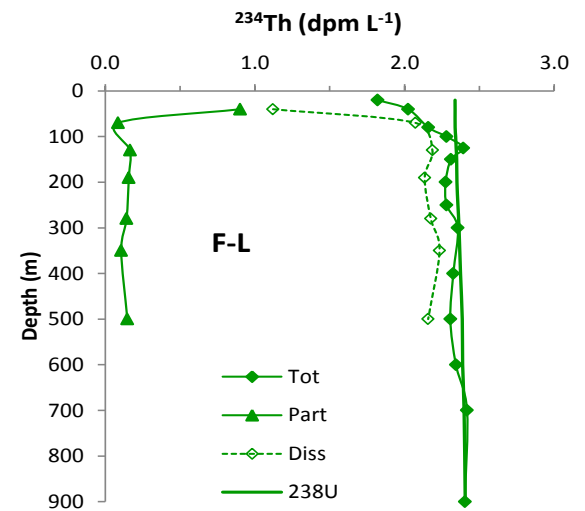
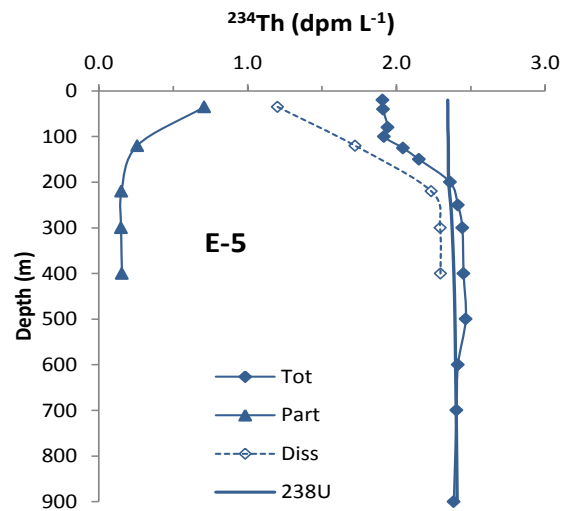
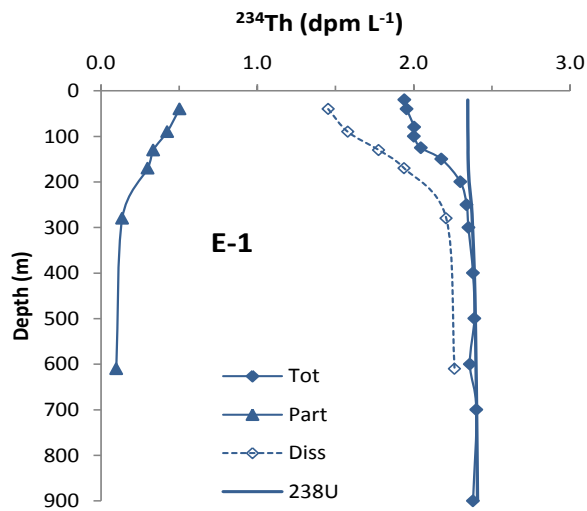
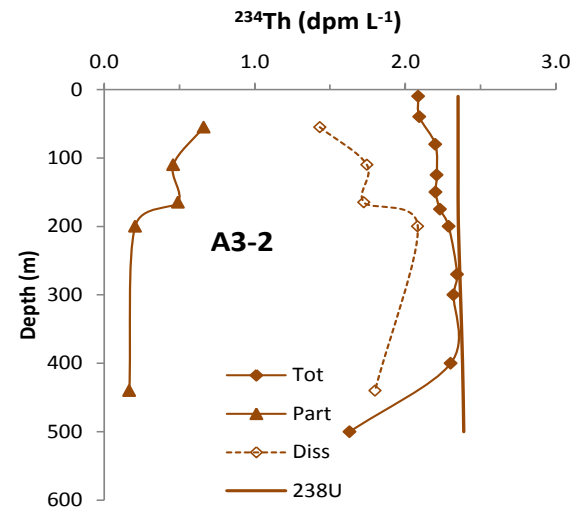
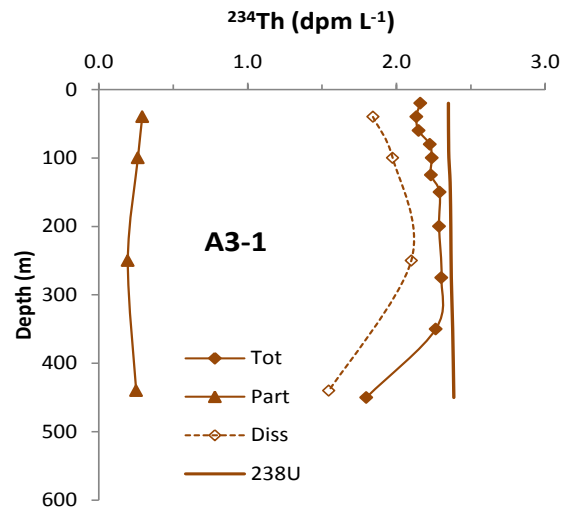
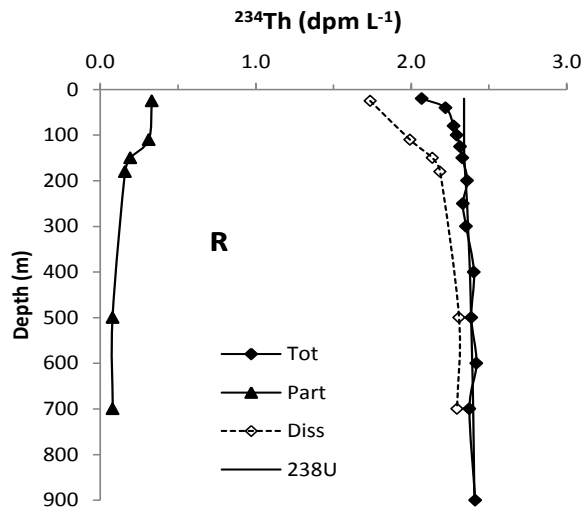


Figure 3.

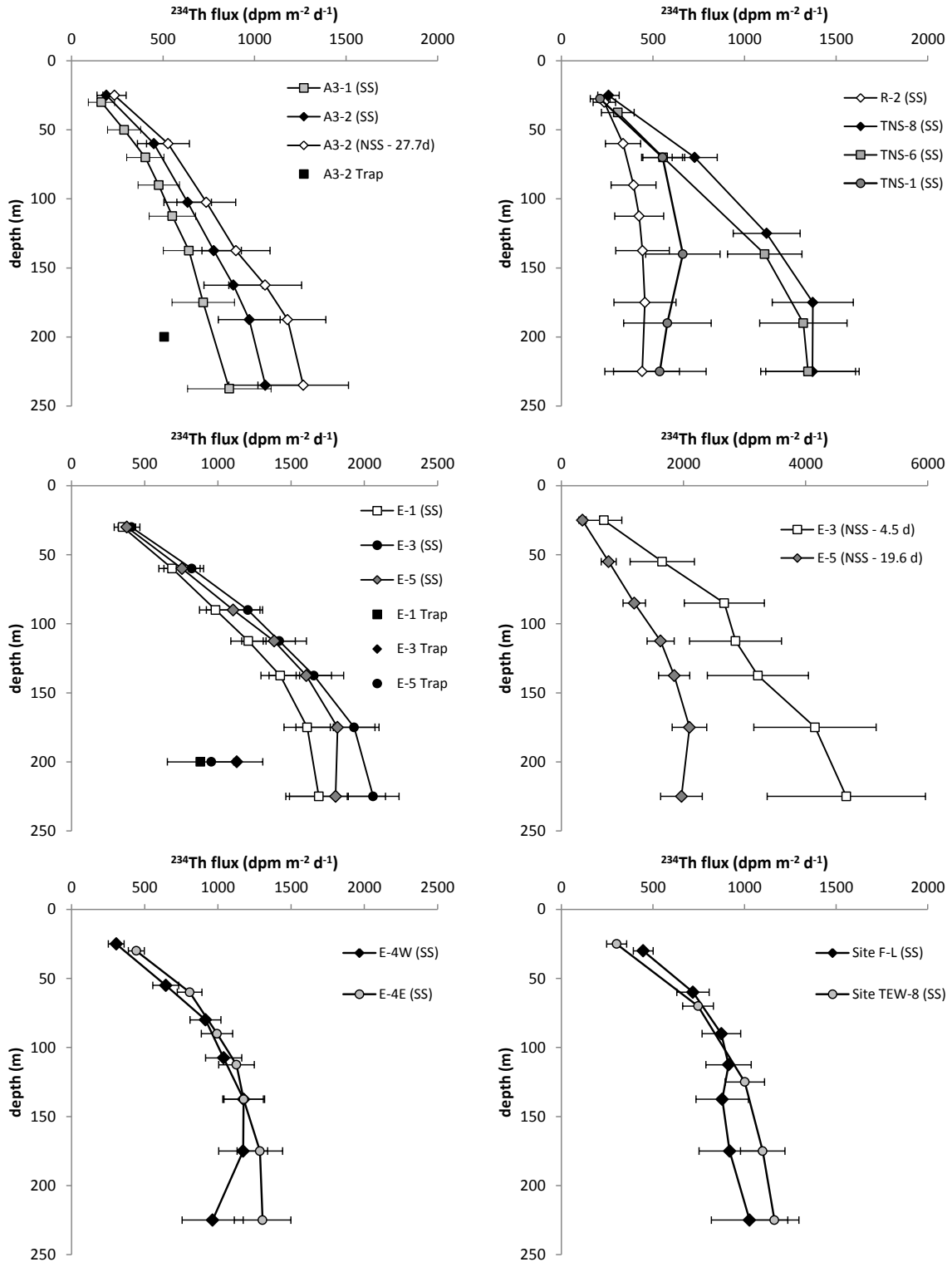


Figure 4.

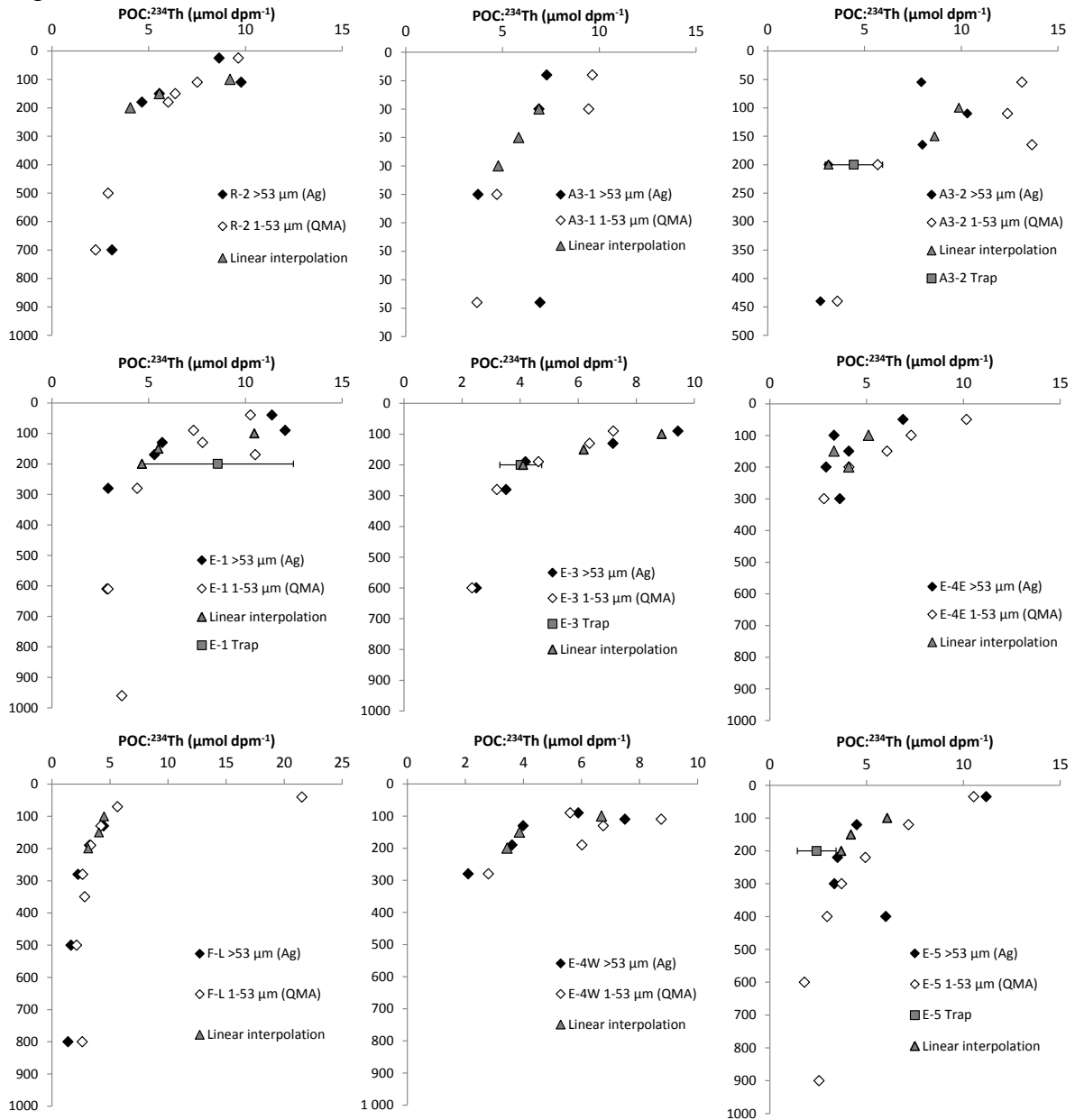


Figure 5

