Dear Editor and Referees,

We first would like to thank the Editor and both referees who provided useful comments to improve our paper entitled "High variability of particulate organic carbon export along the North Atlantic GEOTRACES section GA01 as deduced from $^{234}$Th fluxes".

Please see below our detailed answers to the Referees and to the Editor, including corresponding lines of the revised manuscript. We copied the comments in this document in italics, followed by our answers in black font. The new text that we propose to add in the revised manuscript is in red font.

We hope that you will find the manuscript suitable for publication,

Kind regards,

Nolwenn Lemaitre and co-authors.

## Anonymous Referee 1

Received and published: 15 June 2018

*General comments: Apart from that, the manuscript is nicely written and it contains a valuable dataset that will contribute to the body of literature using $^{234}$Th to derive POC export fluxes to help characterize the strength and efficiency of the biological carbon pump, particularly in the North Atlantic. With some minor revisions and a bit more of discussion in certain aspects, this manuscript will be a good fit for publication in Biogeosciences.*

We would like to thank the referee for these very positive comments. All suggestions have been taken into account and are detailed below.

- *Lines 46-49: There are two sentences that are repeated.*

The introduction section has changed quite a lot, and the repeated sentence has been deleted.

- *Method: I understand that Chl-a, phytoplankton community and nutrients (macro and micro) data are obtained from other studies, properly cited within the manuscript. However, I would have liked to see a small paragraph summarizing the methods used to obtain those datasets, particularly considering that there is a full section (2.1) (which is not really methods but more of a description of the study area), where all these nutrient, phytoplankton and chlorophyll-a data is used. Adding a few lines would make the reader's life easier by not needing to look for those papers. Also, a large part of the information included in 2.1 is also mentioned in the discussion, so the authors might want to consider deleting that section, then no needing to include the methods for those analyses.*

As suggested, section 2.1 has been deleted and has been integrated to the Introduction section where we describe now the different biogeochemical basins. Many details of the section 2.1 have been deleted and for that reason, we decided not to describe the methods to acquire the nutrient concentrations or the pigment data. We are citing publications describing the methods though (nutrient and pigment analyses according to Aminot and Kerouel (2007) and Ras et al. (2008), respectively).

Lines 50-70: The low nutrient availabilities (surface nitrate and silicate concentrations < 1 µmol L$^{-1}$; nutrient analyses according to Aminot and Kérouel, 2007) in the Iberian basin limits the biomass development giving the opportunity to pico-phytoplankton, such as cyanobacteria, to grow (~ 35% of the total Chl-*a* at Station 13; Tonnard et al., in prep.; pigment analyses according to Ras et al., 2008), a situation which is typical for the North Atlantic subtropical gyre (Moore et al., 2008; Zehr and Ward, 2002). The Iberian basin can also be influenced by a local upwelling, close to the Iberian margin (Costa Goela et al., 2016; Zúñiga et al., 2016; http://marine.copernicus.eu/) and potentially fueling the area with nutrient-rich, but upwelling was not active during GEOVIDE (Shelley et al., 2016).

In the subpolar region, in the Irminger and Labrador basins, phytoplankton growth is strongly light-limited seasonally (Riley, 1957) and the key parameter for alleviating these limitations is the progressive shoaling of the mixed layer. There, micro-phytoplankton, such as diatoms, dominate the phytoplankton bloom (≥ 50% of the total Chl-*a*; Tonnard et al., in prep.). Both basins were influenced by strong hydrodynamic features, such as the Irminger gyre, the Eastern Greenland Current (EGC), the Western Greenland Current (WGC), the Labrador Current (LC; Zunino et al., 2017) and the subduction of the Labrador Seawater (LSW) which was particularly intense (1700 m-deep convection) during the winter 2013-2014 (Kieke and Yashayaev, 2015).

Between the subtropical and subpolar regions, the west European and Icelandic basins represent a transition zone where nutrients and/or light can limit primary production (Henson et al., 2009). During GEOVIDE the silicic acid stock was low (≤ 1 µmol $L^{-1}$) leading to the growth of nano-phytoplankton, such as haptophytes including coccolithophorids (between 45 and 80% of the total Chl-*a*; Tonnard et al., in prep.). This region is influenced by the Eastern Reykjanes Ridge Current (ERRC) and by the North Atlantic Current (NAC) with the southernmost sub-branch evolving in a cyclonic eddy and the sub-arctic front (SAF). SAF separates cold and fresh waters from the subpolar region and the warm and salty waters from the subtropical region (Zunino et al., 2017).

- *Line 87-88: This statement is a bit vague, hard to quantify. Nanophytoplankton species seem to dominate but in the next sentence the emphasis is on picophytoplankton. Also, what do the authors consider when they say "dominate"? How much higher is the percentage of nanophytoplankton to consider that they are dominant? Above 50%?*

The general phytoplankton communities observed along the transect are presented in the Introduction Section. The percentage of the phytoplankton communities relative to the total chlorophyll-a concentration are now stated in the Introduction section. By "dominant community", we mean the most represented community (characterized by the highest percentage relative to the total Chl-a).

Lines 50-54: The low nutrient availabilities (surface nitrate and silicate concentrations < 1 µmol $L^{-1}$; nutrient analyses according to Aminot and Kérouel, 2007) in the Iberian basin limits the biomass development giving the opportunity to pico-phytoplankton, such as cyanobacteria, to grow (~ 35% of the total Chl-*a* at Station 13; Tonnard et al., in prep.; pigment analyses according to Ras et al., 2008), a situation which is typical for the North Atlantic subtropical gyre (Moore et al., 2008; Zehr and Ward, 2002).

Lines 59-60: There, micro-phytoplankton, such as diatoms, dominate the phytoplankton bloom (≥ 50% of the total Chl-*a*; Tonnard et al., in prep.).

Lines 65-67: During GEOVIDE the silicic acid stock was low (≤ 1 µmol $L^{-1}$) leading to the growth of nano-phytoplankton, such as haptophytes including coccolithophorids (between 45 and 80% of the total Chl-*a*; Tonnard et al., in prep.).

The new section 4.3 makes the connection between POC export fluxes and phytoplankton size and community structure, and presents thus more details on the phytoplankton communities observed at each station. For instance, the differences observed within the Iberian basin, between Stations 1 and 13, are clearly stated.

Lines 509-510: Within the Iberian basin, the highest abundance of pico-phytoplankton was observed at Station 13 (Tonnard et al., in prep.). These conditions are typical of the subtropical and oligotrophic waters (Dortch and Packard, 1989).

Lines 514-517: However, Station 1 was characterized by a greater POC export that could be related to the mixed proportion of micro-, nano- and pico-phytoplankton and thus to the greater proportion of larger cells such as diatoms or haptophytes, increasing the particle sinking velocity.

- *Lines 94-95: "Moderate $NO_3^-$" and then writing ≥1 µM, which does not have an upper limit, might not be appropriate.*

Most of the details on nutrient concentrations have been deleted; but when specified in the Introduction section, the upper limits are stated.

Lines 50-51: The low nutrient availabilities (surface nitrate and silicate concentrations < 1 µmol $L^{-1}$; nutrient analyses according to Aminot and Kérouel, 2007) in the Iberian basin…

Lines 65-66: During GEOVIDE the silicic acid stock was low (≤ 1 µmol $L^{-1}$) leading to the growth of nano-phytoplankton …

- *Lines 128: How good was the agreement between the deep $^{234}$Th samples and the $^{238}$U concentrations derived from salinity at those depths?*

The $^{234}$Th/$^{238}$U ratio averaged 1.00 in deep samples, and on 15 deep samples, the standard deviation was about 0.02, highlighting the perfect equilibrium between both radionuclides. Details have been added in Section 2.1.

Lines 106-109: Deep samples (between 1000 and 3500 m) were taken for the calibration of the low level beta counting (Rutgers van der Loeff et al., 2006) based on the knowledge that $^{234}$Th and $^{238}$U are generally in secular equilibrium at such depths (in this study, the deep ocean average $^{234}$Th/$^{238}$U ratio = 1.00 ± 0.02; n=15).

- *Lines 131 (and elsewhere in this section): I appreciate the detail in providing the volumes of the spikes and carriers added, however, without the concentrations of those solutions, the information about the volumes added is not really necessary.*

This is very true. As suggested by reviewer 2, many details, such as the volumes, have been deleted in order to get this manuscript less tedious to read.

- *Line 190: "only 10% of the surface value", should be "10% of its maximum value".*

OK. This has been modified.

Lines 171-172: … as well as for z representing the base of the primary production zone (PPZ), i.e. the depth where in-situ fluorescence was only 10% of its maximum value (Owens et al., 2014).

- *2.5 Scavenging fluxes of $^{234}$Th: I am a bit concerned about the assumptions taken for the scavenging fluxes. In this section, the authors present the equations that have been used to obtain those scavenging fluxes but I think there is information lacking. It is not explained how the dissolved and particulate fractions are obtained: How did the authors obtained the dissolved fraction? Did they subtract the particulate fraction from the total to get the dissolved fraction? Which particulate fraction did they use, the sum of the small and the large particles from the in situ pumps? All this information should be included. Section 4.3 discusses export and scavenging fluxes but my doubts still persist.*
  *I am concerned about the potential limitations because, unless I missed something, the total $^{234}$Th was collected from the CTD rosette, and the particulate $^{234}$Th fraction came from in situ pumps. These are two different sampling methods that could lead to differences when looking at the particulate fraction.*

Right, thank you for notifying this. We included the missing information and hopefully the section is clearer now.
To get the dissolved fraction, we subtracted the particulate from the total fraction. The particulate fraction was the sum of the small and large size particulate fractions (SSF+LSF).
The total and particulate fractions were not obtained by the same sampling method. It would be indeed ideal to have both fractions from the same device. However, particulate $^{234}$Th cannot be obtained accurately on low volume samples (i.e., 4L) because of the adsorption of dissolved $^{234}$Th on filter for example (Buesseler et al., 2006).

Lines 195-199: To estimate the rate of removal of $^{234}$Th from the dissolved to the particulate form, i.e., the scavenging flux of $^{234}$Th (Coale and Bruland, 1985), we deduced the dissolved $^{234}$Th activities by subtracting the particulate (SSF+LSF) from the total $^{234}$Th activities, keeping in mind, though, that the sampling method for the total and particulate phases differed. Because the sampling resolution was different, total $^{234}$Th data were averaged at the sampling depth of particulate $^{234}$Th.

> *Did the authors calculated the scavenging fluxes using both equations, 8 and 9? In L281 looks like they did but for equation 9 the authors can use the particulate $^{234}$Th, obtained directly from the in situ pumps, but for equation 8, again unless I am missing something, they should subtract that particulate fraction from the total $^{234}$Th to obtain the dissolved fraction of $^{234}$Th.*

The four equations, presented in the previous manuscript were describing the dissolved and particulate activities with a 2-box model. To calculate the scavenging fluxes, we actually use only 2 equations (Eq. 6 and 7, below). In order to get this section clearer and again in order to get a manuscript less tedious to read, we kept the essential equations.

Lines 200-209: The mass balance equation for dissolved $^{234}$Th can be written as follows:

$$\frac{dA_{Thd}}{dt} = \lambda A_U - \lambda A_{Thd} - J + V \qquad (6)$$

where $A_{Thd}$ is the activity of dissolved $^{234}$Th in dpm $L^{-1}$; $A_U$ and λ are defined in Eq. 2; J is the net removal flux from the dissolved to the particulate form (scavenging flux) in dpm $L^{-1}$ $d^{-1}$; and V is the sum of the advective and diffusive fluxes in dpm $L^{-1}$ $d^{-1}$.
Using again the steady state assumption (dissolved $^{234}$Th activities remain constant over time) and ignoring the physical terms (V), Eq. 6 becomes:

$$J = \lambda \int_0^z (A_U - A_{Thd}) dz \qquad (7)$$

where J in dpm $m^{-2}$ $d^{-1}$ is the net flux of scavenging integrated to the depth z. In our case, the calculation was performed at the Eq depth for comparison with the $^{234}$Th export flux (P in Eq. 3).

> *In summary, I think this section should provide more information to fully understand the calculations done and assess their robustness.*
>
> *Some small details also from this section:*
> *Eq. 6: The term V has been explained in eq. 2, and even though is quite obvious, maybe point out the fact that the subscript d refers to dissolved (same for the subscript p referring to particulate)*

As both particulate and dissolved fractions are now described in two different sections (2.3 and 2.4), the subscripts have been deleted.

- *Line 214: "Equation 5 becomes" it should be "Equation 6 becomes"*

OK. This has been modified.

- *Line 225-226: Could the authors provide the depths for the 0.2% of surface PAR to get an idea about down to what depth is the PP being estimated? Is it more or less close to the depth where the $^{234}$Th fluxes are being calculated?*

OK. This has been added in section 2.6.

Lines 237-239: Daily PP was then estimated by integrating the uptake rates from the surface down to 0.2% of surface PAR, which was located between 48 and 116 m depending on the station. The 0.2% of surface PAR depth was roughly corresponding to the Eq depth although, at few stations, a 42 m difference was observed.

- *Line 245: Could you provide more information regarding "the whole productive period"? How was it defined?*

OK. This has been added in section 2.7.

Lines 252-253: The whole productive period is the period between the bloom start (defined by a PP increase of 30% above the winter value) and the sampling date (Fig. 5).

- *Line 263: At St 26 the Eq depth in Fig 2 is placed at 100 m but it looks like the deficits goes further down and it reaches equilibrium at about 200 m, but there is lower vertical resolution. Table 1 caption mentions Station 26 has a fixed depth, maybe do the same for the caption of Figure 2.*

OK. The caption of Figure 2 has been modified.

Figure 2: Profiles of the total $^{234}$Th (closed circles), total $^{238}$U (black dotted vertical line) and particulate $^{234}$Th activities for the small size fraction (SSF; 1-53 µm; open diamonds) and for the large size fraction (LSF; >53 µm; closed triangles). All activities are expressed in dpm L$^{-1}$. The horizontal black line is the Eq depth (depth where $^{234}$Th returns to equilibrium with $^{238}$U), and the horizontal green line is the depth of the PPZ (primary production zone). Error bars are plotted but may be smaller than the size of the symbols. Note that the Eq depth at Station 26 is fixed at 100 m because of the lower sampling vertical resolution.

- *Line 264: In this line, the definition of PPZ is correct, mentioning its maximum and not the surface value, as done in line 190, however citing Owens et al., 2015 would probably be more appropriate since the work by Marra et al., 2014 does not use the term Primary Production Zone, as used in this manuscript, although they show that in fact, 1% light level (common definition of the euphotic zone depth) might not be deep enough to reach the compensation depth.*

Right, the citation has been changed. Moreover, the definition of the PPZ depth is now given only in section 2.3.

Lines 169-176: Eq. 3 has been solved for z taken as the depth (Eq) at the base of the $^{234}$Th deficit zone (Eq = depth where $^{234}$Th activity is back to secular equilibrium with $^{238}$U) as well as for z representing the base of the primary production zone (PPZ), i.e. the depth where in-situ fluorescence was only 10% of its maximum value (Owens et al., 2014). The Eq depth matched relatively well with the PPZ depth, and on average, difference between both was only 16 m, with the largest difference (~ 60 m) at Stations 1, 32 and 51 (Fig. 2). Considering that there can be export (or remineralisation) below or above the PPZ depth, only the export fluxes at the Eq depth will be discussed as they represent the fully-integrated depletion of $^{234}$Th in the upper waters and thus the maximal export.

- *Figure 2: Check Eq depth for St 26 or add explanation in the caption (see comment L263). Both, $^{238}$U and $^{234}$Th symbols (or line, for U) are quite thick and it is hard to see the uncertainties. I am assuming that they are there, just within the width of the symbol, right? Linked to that aspect, $^{238}$U activities range from 2.19 to 2.53 dpm L$^{-1}$, but it is really hard to tell from Figure 2. Minor thing, the $^{238}$U line for St 77 seems to be clearer than the rest. It could be useful to color code the labels of the stations to match the colors in Fig 1, or to group them by basins, or indicate to which basin they belong to.*

Following your suggestions, we modified the figure and its caption. Indeed, all the errors are indicated but may be hidden by the symbols.

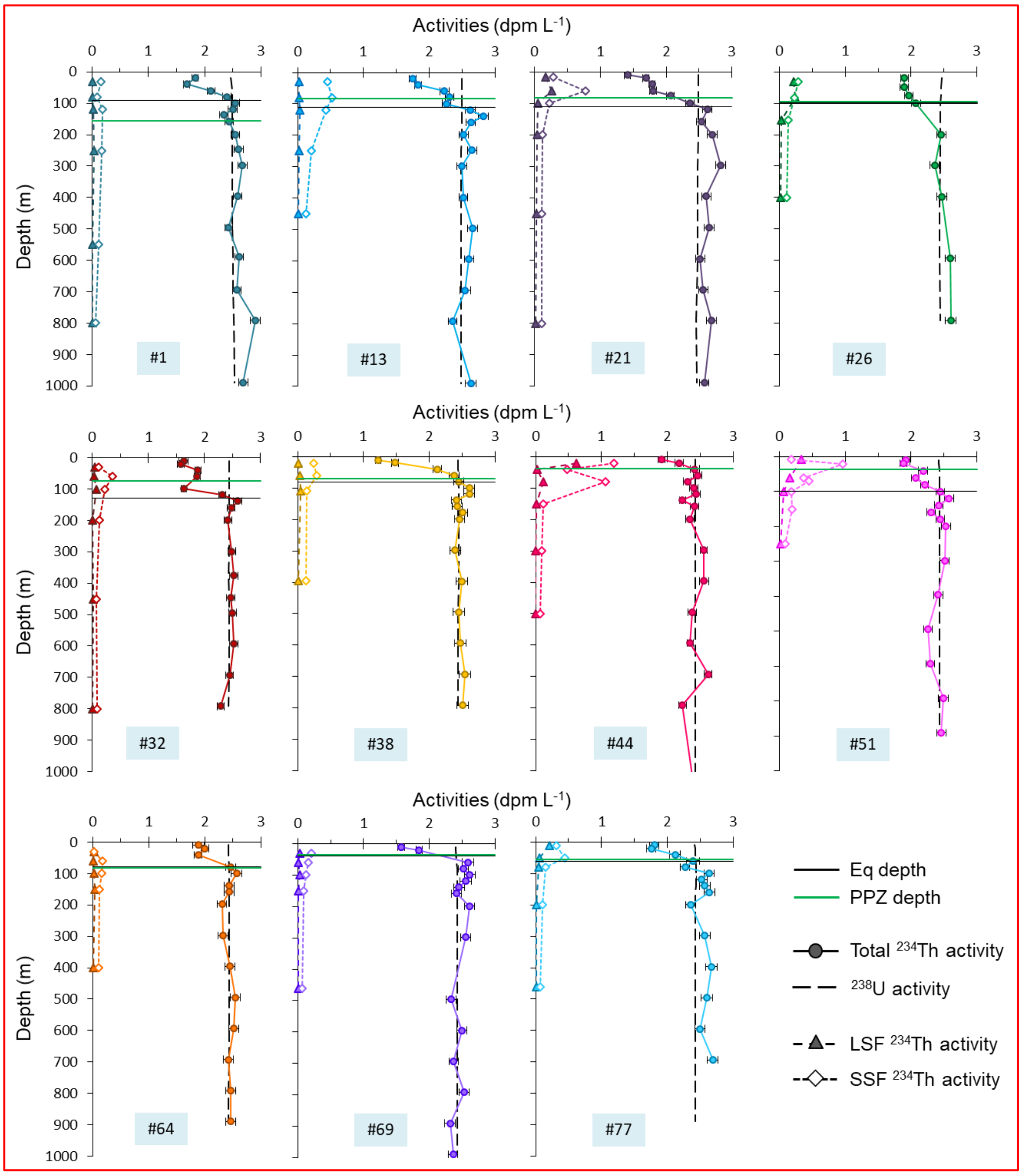


Figure 1: Profiles of the total $^{234}$Th (closed circles), total $^{238}$U (black dotted vertical line) and particulate $^{234}$Th activities for the small size fraction (SSF; 1-53 µm; open diamonds) and for the large size fraction (LSF; >53 µm; closed triangles). All activities are expressed in dpm L$^{-1}$. The horizontal black line is the Eq depth (depth where $^{234}$Th returns to equilibrium with $^{238}$U), and the horizontal green line is the depth of the PPZ (primary production zone). Error bars are plotted but may be smaller than the size of the symbols. Note that the Eq depth at Station 26 is fixed at 100 m because of the lower sampling vertical resolution.

- *Line 265: Maybe add "e.g." when citing those two studies where they integrate the Th deficits to the PPZ since there are a few more published studies that have used that same approach.*

This sentence has been removed from the Result section.

- *Figure 3: The uncertainties of the POC to $^{234}$Th ratios are not shown on the graph but there are uncertainties reported for POC and $^{234}$Th separately in Table S2. It looks like the uncertainties have not been considered in the fitting curve. What would the uncertainties of the ratios at Eq. depth be if those uncertainties on the POC and $^{234}$Th content were taken into account when doing the fitting?*

The figure and its caption have been modified. Errors of POC to $^{234}$Th ratios are shown and even if the size of the symbols has been reduced, they may not be visible. In the caption, we now give the median percentage of these errors relative to the value of the ratio.

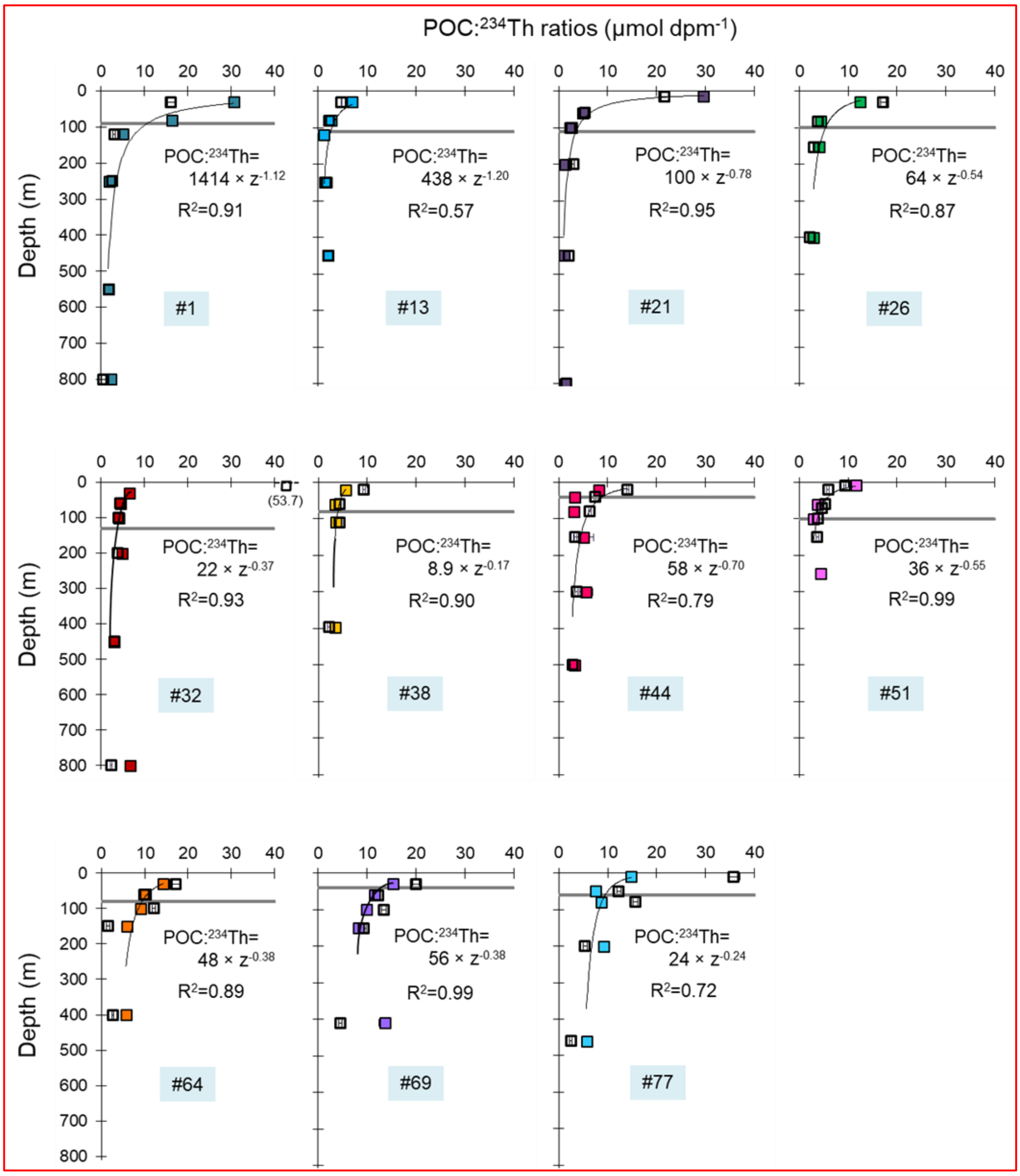


Figure 2: Profiles of the POC:$^{234}$Th ratios (µmol dpm$^{-1}$) in the SSF (open symbols) and LSF (closed symbols). The Eq depth, where $^{234}$Th is back to equilibrium with $^{238}$U, is indicated with the grey horizontal line. The thin black line represents the power law fit (POC:$^{234}$Th=a×Z$^{-b}$) of the LSF. The median percentage errors on POC:$^{234}$Th ratios are respectively representing 5 and 6% of the value for the SSF and the LSF. Error bars are plotted but may be smaller than the size of the symbols.

The uncertainty of the extrapolated ratio at the Eq depth is deduced from the fit and not from the analytical uncertainties of both POC concentrations and particulate $^{234}$Th activities. The error deduced from the fit is much larger than the one from the analytical error. This has been specified within the manuscript, section 2.5.

Lines 216-221: We estimated POC export fluxes by multiplying the $^{234}$Th export flux with the POC:$^{234}$Th ratio, both determined at the Eq depth. A power law fit was used to determine the POC:$^{234}$Th ratios at Eq (Fig. 3). Errors of the POC:$^{234}$Th ratios extrapolated at the Eq depth are deduced from the power law fit, using a root sum of square method. This error is much larger than analytical errors of both POC concentrations and particulate $^{234}$Th activities. POC fluxes were determined by using the POC:$^{234}$Th ratios of the LSF (> 53 µm) as well as the SSF (1-53 µm) samples, and both estimations were compared (Table 2).

- *Line 349: The compilations by Le Moigne et al 2013 (global) or Puigcorbe et al 2017 (North Atlantic) include most of the papers cited and will make the citation shorter.*

Right, this has been modified.

Lines 225-228: As large and rapidly sinking particles usually drive most of the export (Lampitt et al., 2001; Villa-Alfageme et al., 2016), most of the studies dedicated to POC export fluxes in the North Atlantic used the POC:$^{234}$Th ratios from the LSF (see Le Moigne et al., 2013b; Puigcorbé et al., 2017).

- *Line 358: Maybe delete “and argued”. Argued is used when one wants to make a point but my guessing is that the authors mean that there is another paper that provides more information. Also in this line, “details” should be singular (same in L571).*

OK.

- *Line 360: Delete “the” (…PP varied by a factor of…).*

OK.

- *Line 360-369: In some cases PP are presented with uncertainties and sometimes without).*

OK, we removed the uncertainties in the text. They are written in Table 3.

- *Line 380-381: Briefly define “productive period” (Is it starting with the PP increase of 30% above winter value mentioned in L449?).*

OK. This sentence has been removed from the Discussion section and the productive period is defined in section 2.7.

Lines 252-253: The whole productive period is the period between the bloom start (defined by a PP increase of 30% above the winter value) and the sampling date (Fig. 5).

- *Line 405-411: The Irminger Basin in spring is a really patchy and dynamic area, as shown by Le Moigne et al (2012) and Puigcorbe et al (2017). The exercise of trying to quantify the impact* *of physical processes is interesting, however it is a bit of a stretch with just two stations that are also relatively distant. The reference to the Artic and Greenland shelf waters helps to support the author's argument but I think the patchiness (bloom patchiness) during the productive season should also be mentioned (somehow done later on when discussing the bloom stage during the sampling period).*

This is right, thank you for your comment. The patchiness of the bloom within the Irminger basin is now mentioned when talking about impact of the physical processes.

Lines 415-419: The Irminger basin in spring is a really patchy and dynamic area (Ceballos-romero et al., 2016; Le Moigne et al., 2012; Puigcorbé et al., 2017) but the relatively high variability of the $^{234}$Th fluxes found at these two stations (321 and 922 dpm $m^{-2}$ $d^{-1}$, respectively) may also indicate a potential influence of lateral advection. The higher export flux at Station 51 could reflect an input of $^{234}$Th depleted waters originating from the Arctic and/or the Greenland shelf.

- *Line 417: I do not understand the need of the sentence "The vertical advection can also impact the distribution of $^{234}$Th" when previously (L414) there is a sentence that reads as: "the vertical transport of $^{234}$Th associated with small-scale structures could represent up to 20%", it seems redundant.*

Right, the sentence has been deleted.

- *Line 487: Maybe reduce the number of references.*

Right, this sentence is now in the Introduction section.

Lines 92-94: In the subsurface waters any excess of $^{234}$Th relative to $^{238}$U, is taken to reflect particle break-up and remineralisation by heterotrophic bacteria and/or zooplankton (Buesseler et al., 2008; Maiti et al., 2010; Savoye et al., 2004).

- *Line 495: Similar remineralization although one study was conducted in the tropical Pacific and the other in the North Atlantic Ocean. If the authors want to provide that comparison it might be interesting to discuss a bit the similarities and differences between the studies that lead to comparable values (although some higher values were reported in the tropical Pacific) since one could expect different planktonic communities in both regions, leading to different remineralization intensities.*

Right, thank you. Given the fact that both studied areas (the North Atlantic and the oxygen minimum zone of the tropical Pacific ocean) are very different, we preferred to remove this comparison. However, as Black et al. (2017) were presenting R100 values for the first time (to my knowledge), we kept citing their work when presenting the calculation of the R100 values.

Lines 188-193: To estimate the intensity of shallow remineralization, export flux was also calculated for the Eq+100 m depth horizon. In case of any $^{234}$Th excess below Eq due to remineralisation, export fluxes integrated until Eq+100 m will be less than when integrated until Eq. Following Black et al. (2017) the reduction of the $^{234}$Th flux, R100, is expressed as:

$$\mathrm{R100} = \mathrm{P_{Eq}} - \mathrm{P_{Eq+100}} \qquad (5)$$

where R100 is the flux reduction in dpm m$^{-2}$ d$^{-1}$ and P is the $^{234}$Th export flux estimated at Eq or Eq+100.

- *Line 509: Stipulate in the following "section".*

OK. This has been checked and modified in the entire manuscript.

- *Line 583: Maybe specify that the extrapolation curves from Fig 3 were used to obtain the deep POC to $^{234}$Th ratios.*

OK.

Lines 534-537: Note that the POC export flux at Eq+100 (Table 3) was calculated by multiplying the $^{234}$Th flux at Eq+100 by the POC to $^{234}$Th ratio of large particles for the same depth. The POC:$^{234}$Th ratio at Eq+100 was deduced from a power law fit (Fig. 3).

- *Lines 642-644 (and previously mentioned too): Could the authors provide a potential cause of that enhanced remineralization in the cold waters of the Labrador Sea, especially since the biogenic Ba$_{xs}$ also shows signs of remineralization. Is it also due to bacterial activity? For how it is written it looks like the authors believe is not due to bacterial activity.*

Right, the potential cause of the enhanced remineralization in the Labrador Sea proposed in Lemaitre et al. (2018) has been added in Section 4.4.

Lines 585-590: This is also in agreement with the highest R100 and carbon remineralisation flux determined with the Ba$_{xs}$ proxy (Lemaitre et al., 2018). The central Labrador basin, in proximity of Station 69, was characterized by strong subduction of the LSW during the winter preceding the GEOVIDE cruise. This downwelling could have promoted an important organic matter export leading to important prokaryotic heterotrophic activity in mesopelagic waters. This enhanced remineralisation was still observed during GEOVIDE as traced by a large mesopelagic Ba$_{xs}$ content (Lemaitre et al., 2018).

- *Line 651: This statement is not strictly quantitatively proven and although the authors provide the date of the peak of the bloom and PP values, they do not refer to the intensity of the bloom (intensity meaning magnitude of PP? Duration of the bloom? Duration of the bloom with sustained high PP values?).*

This is a very good point as the intensity of the bloom can be defined in different ways: at sampling time (illustrated by the *in-situ* PP), as the maximal PP intensity along the season or as an average PP intensity along the season.
In Section 4.2, we propose explanations for the magnitude of the POC exports according to these different definitions. The low seasonal PP average at Station 13 is suggested to explain the low POC export there.

Lines 474-476: One of the lowest POC export flux was determined at Station 13 in the Iberian basin, where the intensity of the bloom remained rather low along the season (seasonal VGPM-PP=81 mmol m$^{-2}$ d$^{-1}$, Fig. 5) due to oligotrophic conditions (depleted nutrients; Fonseca-Batista et al., 2018).

The maximal PP intensity (highest PP peak along the season) observed just before the sampling in the west European basin might explain the high POC export there.

Lines 483-484: PP appeared maximal just before the sampling in the west European basin (Fig. 4 and 5) and could have promoted these high POC export.

The high *in-situ* PP intensity in the Irminger basin indicates that the bloom is reaching its maximum and that export did not yet start at sampling time.

Lines 490-493: Indeed, this area had the highest *in-situ* PP, a high proportion of particulate $^{234}$Th in surface waters (reaching 94% of the total $^{234}$Th activity at Station 44) and a very low P/J ratio, indicating that $^{234}$Th was retained in the upper waters rather than being exported (Fig. 6; Table 1).

> *The authors discuss the temporality of the bloom with respect to the sampling time, which has been done in previous studies, but it could be interesting to produce a figure or correlation between the stage of the bloom (and/or intensity of the bloom, if defined) and the magnitude of the POC to support this statement in a more quantitative manner to be able to say that they are, in fact, directly related.*

Thank you very much for this great suggestion. In Figure 8, we attempt to illustrate the impact of the intensity of the bloom at sampling time (using the *in-situ* PP values), the stage of the bloom (using the percentage of the *in-situ* PP relative to the maximal VGPM-PP along the season) and the different phytoplankton communities on the POC export fluxes. A significant negative correlation is found between the stage of the bloom and the POC export when not considering the stations sampled between two PP peaks (or before the PP peak: Stations 26, 32, 38). In this figure, we can also see that the stations sampled close to the bloom maximum (%max seasonal PP > 80% and with a high *in-situ* PP intensity) are characterized by low POC exports.

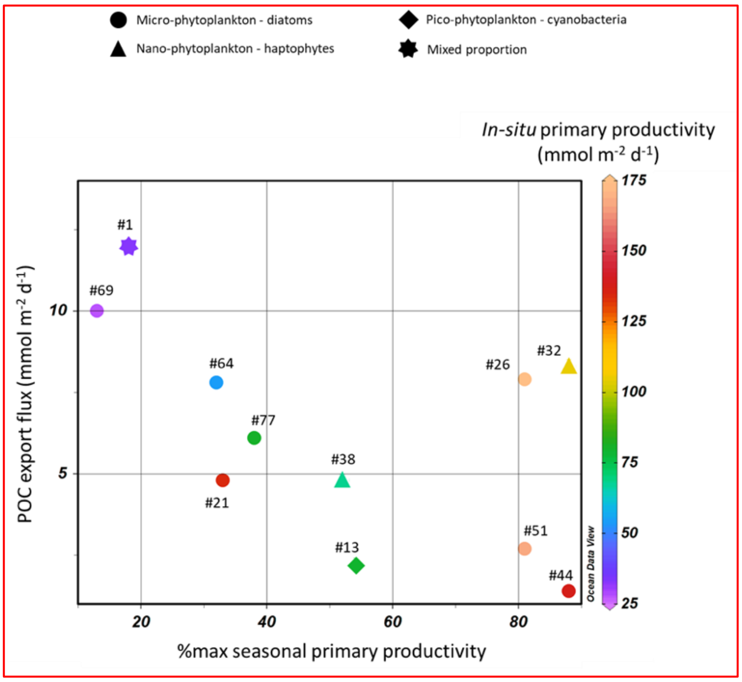


Figure 8: Percentage of the *in-situ* primary productivity (PP) relative to the maximal VGPM-PP along the season (%max seasonal primary productivity) in function of the POC export fluxes

determined at the Eq depth. The %max seasonal primary productivity illustrates the stage of the bloom (i.e., a %max seasonal primary productivity equalling 100% corresponds to a sampling time at the bloom peak). This relationship is significant when not taking into account the stations sampled between two PP peaks (Stations 26, 32 and 38, see Fig. 4): $R^2=0.77$ and p-value<0.01. The *in-situ* PP measured at sampling time is indicated with the colours in order to indicate the bloom intensity. The dominating phytoplankton community is also indicated, with circles indicating micro-phytoplankton dominance (with a majority of diatoms), triangles nano-phytoplankton dominance (with a majority of haptophytes) and diamonds pico-phytoplankton dominance (with a majority of cyanobacteria). Note that Station 1 is represented by a star because of the mixed proportion of micro-, nano- and pico-phytoplankton.

- *Line 660: I would delete the first sentence of the point iii) of the conclusions because that is not something that has been studied in this manuscript, it is probably going to be done in the coming Lemaitre et al. in prep. manuscript.*

Right, details on this future paper has been removed, especially the potential impact of the lithogenic particles. However, the potential impact of the particle density related to the presence of diatoms or coccolithophorids on export is still reported.

Lines 598-603: The magnitude of the fluxes seems also to be related to the phytoplankton size and community structure. One of the lowest POC export fluxes was found at the stations where pico-phytoplankton dominated the community. In contrast, the areas composed by micro- and nano-phytoplankton were characterized by high POC export fluxes. These areas were dominated by diatoms or coccolithophorids, known to strongly ballast the POC export fluxes. This suggests that the size as well as the composition and density of the particles likely play an important role on the particulate sinking velocities and thus on the magnitude of the POC export fluxes.

**Anonymous Referee 2**
Received and published: 16 July 2018

- *General comment: However the manuscript is missing clear motivations and objectives (see comment 1). This shortcoming has an impact throughout the manuscript, which is tedious to read and not as informative as it could be (see comment #2). The manuscript is long but new results advertised in the abstract are not clearly highlighted and discussed in the main text (e.g. control from phytoplankton size structure and the stage of the bloom). The result section is a very descriptive listing of all measured parameters and the discussion ressembles a result section (comments #3 and #4). I recommend major revisions to improve the readability and strengthen the main points.*

We thank the referee for all the suggestions on how to improve our manuscript. We paid special attention to the definition of our objectives, limiting the redundancy and improving our conclusions. To do so, the structure of the manuscript substantially changed. As you suggested, the Introduction section points out more clearly the question we try to address with this dataset, the Result section is now organized by biogeochemical basins and the sub sections of the Discussion are now based on the different factors influencing the magnitude of the POC exports (stage and intensity of the bloom, phytoplankton size and community structure). We hope that you will be satisfied with our detailed answers below.

- *Major comment 1: The manuscript lacks a clear objective. In Line 61, "According to the impact of these biogeochemical factors [. . .], the efficiency of the NAtl to transfer POC .. can be questioned. In this context, we investigated the . . . export using Thorium." How is the state-of-the-art presented between L32 to 60 questioning the transfert efficiency established in previous studies? After presenting the state-of-the-art, I strongly encourage the authors to present what open question or inconsistency they are trying to address with their dataset. Possible avenues are: What is missing in previous studies? How is this dataset complementary or inconsistent with previous data? I suggest following the traditional structure: 1_ Previous studies showed that X . . .. 2_ However, Y is still unknown (or this is inconsistent with Z); 3_ Here, we examine/show/leverage. . .. This objective should also guide the reader in the result and discussion section (see comment 2).*

Thank you for your great help, this comment is useful for this manuscript but will also be useful for the next ones. As suggested, the introduction section has been re written in order to clarify the importance of our study: 1) Carbon export in the North Atlantic has been well studied but, a substantial range of carbon export efficiencies has been reported by earlier studies at different locations of the North Atlantic. This is directly questioning about how carbon export efficiency varies at a trans-Atlantic scale and what are the controlling factors 2) The North Atlantic is characterized by different biogeochemical basins, defined by different trophic states, phytoplankton communities and hydrodynamic processes These distinct biogeochemical factors impact strongly the POC export magnitude. 3) Therefore, we examine here the impact of the stage and intensity of the bloom and the phytoplankton structure on POC export fluxes, before to evaluate the export and transfer efficiency of the high latitude North Atlantic basin.

Lines 35-101: Introduction

Through the sinking of particulate biogenic material, the biological carbon pump (BCP) plays a major role on the sequestration of carbon-rich particles in the ocean interior. The North Atlantic harbors one of the most productive spring phytoplankton bloom of the world's ocean (Esaias et al., 1986; Longhurst, 2010), generating an important pulse of biogenic sinking particles (Buesseler et al., 1992; Honjo and Manganini, 1993; Le Moigne et al., 2013a), which accounts up to 18% of the global BCP (Sanders et al., 2014). Yet, a substantial range of carbon export efficiencies (1-47%) has been reported by earlier studies at different locations of the North Atlantic (Buesseler et al., 1992; Buesseler and Boyd, 2009; Ceballos-romero et al., 2016; Herndl and Reinthaler, 2013; Lampitt et al., 2008; Moran et al., 2003; Mouw et al., 2016; Thomalla et al., 2008), directly questioning about how carbon export efficiency varies at a trans-Atlantic scale and what are the controlling factors.

The international GEOTRACES program aims to measure trace elements and isotopes along full-depth ocean sections through each of the major ocean basins in order to provide maximum scientific rewards on a global scale (GEOTRACES, 2006). The GEOVIDE GA01 section in the high-latitude North Atlantic (15 May - 30 June 2014; R/V Pourquoi Pas?), was a French contribution to this global survey. The studied area crossed five basins differentiated by their distinct biogeochemical and hydrodynamic characteristics: the Iberian basin, the west European basin, the Icelandic basin, the Irminger basin and the Labrador basin (Fig.1).

The low nutrient availabilities (surface nitrate and silicate concentrations < 1 µmol $L^{-1}$; nutrient analyses according to Aminot and Kérouel, 2007) in the Iberian basin limits the biomass development giving the opportunity to pico-phytoplankton, such as cyanobacteria, to grow (~ 35% of the total Chl-*a* at Station 13; Tonnard et al., in prep.; pigment analyses according to Ras et al., 2008), a situation which is typical for the North Atlantic subtropical gyre (Moore et al., 2008; Zehr and Ward, 2002). The Iberian basin can also be influenced by a local upwelling, close to the Iberian margin (Costa Goela et al., 2016; Zúñiga et al., 2016; http://marine.copernicus.eu/) and potentially fueling the area with nutrient-rich, but upwelling was not active during GEOVIDE (Shelley et al., 2016).

In the subpolar region, in the Irminger and Labrador basins, phytoplankton growth is strongly light-limited seasonally (Riley, 1957) and the key parameter for alleviating these limitations is the progressive shoaling of the mixed layer. There, micro-phytoplankton, such as diatoms, dominate the phytoplankton bloom (≥ 50% of the total Chl-*a*; Tonnard et al., in prep.). Both basins were influenced by strong hydrodynamic features, such as the Irminger gyre, the Eastern Greenland Current (EGC), the Western Greenland Current (WGC), the Labrador Current (LC; Zunino et al., 2017) and the subduction of the Labrador Seawater (LSW) which was particularly intense (1700 m-deep convection) during the winter 2013-2014 (Kieke and Yashayaev, 2015).

Between the subtropical and subpolar regions, the west European and Icelandic basins represent a transition zone where nutrients and/or light can limit primary production (Henson et al., 2009). During GEOVIDE, the silicic acid stock was low (≤ 1 µmol $L^{-1}$) leading to the growth of nano-phytoplankton, such as haptophytes including coccolithophorids (between 45 and 80% of the total Chl-*a*; Tonnard et al., in prep.). This region is influenced by the Eastern Reykjanes Ridge Current (ERRC) and by the North Atlantic Current (NAC) with the southernmost sub-branch evolving in a cyclonic eddy and the sub-arctic front (SAF). SAF separates cold and fresh waters from the subpolar region and the warm and salty waters from the subtropical region (Zunino et al., 2017).

The North Atlantic is thus a heterogeneous basin in terms of nutrient status, phytoplankton communities and hydrodynamic features.

This is of a crucial importance as ecosystem structure is thought to play an important role on the BCP. Guidi et al. (2009) suggested that phytoplankton composition explained 68% of the variance in POC flux at 400 m. High export efficiencies are reported in productive regions where diatoms dominate, but the exported material is relatively labile and prone to remineralisation leading to low transfer efficiency and low deep export flux (Guidi et al., 2009). Conversely, in oligotrophic regions, where diatoms are largely absent, primary production is low and mostly regenerated. Consequently, export efficiencies are low but the eventual exported material is likely less prone to dissolution - remineralisation, resulting in high transfer efficiencies (Henson et al., 2012; Lam et al., 2011; Lima et al., 2014; Marsay et al., 2015). Phytoplankton size structure has also been shown to be an important factor in controlling the POC export fluxes. Guidi et al. (2015) highlighted that the exported POC was more refractory and the remineralisation depth was deeper when the fraction of micro-phytoplankton decreased or the fraction of pico-phytoplankton increased.

Due to the complex impact of these biogeochemical factors on the POC export and according to the distinct features of each biogeochemical basin, the efficiency of the North Atlantic to transfer POC to the deep ocean deserves more study.

In this context, we investigated POC export fluxes derived from the Thorium-234 ($^{234}$Th) approach along a transect in the high-latitude North Atlantic, from the Iberian margin to the sub-arctic Irminger and Labrador Seas. $^{234}$Th, a highly particle reactive element with a short half-life (24.1 d), is widely used to explore particle export over short time events such as phytoplankton blooms (Bhat et al., 1969; Buesseler et al., 1992; Coale and Bruland, 1985; Cochran and Masqué, 2003). A deficit of $^{234}$Th with respect to its radioactive parent $^{238}$U (conservative in seawater) is usually observed in the upper water column where particles sink. In the subsurface waters any excess of $^{234}$Th relative to $^{238}$U, is taken to reflect particle break-up and remineralisation by heterotrophic bacteria and/or zooplankton (Buesseler et al., 2008; Maiti et al., 2010; Savoye et al., 2004). A $^{234}$Th flux can be converted into a POC flux by using the POC:$^{234}$Th ratio of sinking particles at the depth of export (Buesseler et al., 2006).

In this study, we discuss carbon export fluxes determined at the base of the deficit zone according to the biogeochemical properties found in each basins, with special emphasis on the stage and intensity of the bloom as well as on the phytoplankton community structure. Using estimates of primary production from shipboard incubations and satellite-derived Chl-*a*, we explore surface export efficiencies at different time scales over the studied area. In addition and using deep carbon export, we investigate POC transfer efficiency in the upper mesopelagic.

- *Major comment 2: The result section appears as a long list of parameters (e.g. 3.3- Particulate Th and POC distribution, 3.4- POC:Th ratios, 3.5-POC export; 3.6- PP), and include too many methodological details. For example: L 287 to 292 "LSF particles are collected on silver GF/F filters . . ."; L329-332; L377 "Using the 8-day average data, PP was estimated for the preceding month and the whole productive period. . . ". The result section should be re-worked to emphasize the important connections between the different measured parameters (export, PP, planktonic composition etc.). One option would be to present the results per biogeochemical province and make these links. Another option would be to organise the result section based on processes and/or novel findings (for example: Control by phytoplankton size structure, Modulation by stage of the bloom . . . or Flux attenuation in mesopelagic zone, which is now in the discussion but would fit better in as a result section- see comment #4). Please move methodological details to method section or remove when it is duplicated.*

Thank you for your help. As suggested, the Result section has been re written to describe each biogeochemical basin individually. Many details have been deleted or moved to the Method section.

Lines 255-393: Results

## 3.1. The Iberian basin (Stations 1 and 13)

Stations 1 and 13 were sampled 10 to 12 weeks after the start of the bloom (Fig. 4). At these stations, PP increased very early in the year (early to mid-March) and collapsed rapidly (end of March to mid-April). Within the Iberian basin, low *in-situ* PP were determined (Table 3), with one of the lowest values measured at Station 1 (33 mmol $m^{-2}$ $d^{-1}$) and a moderate PP at Station 13 (79 mmol $m^{-2}$ $d^{-1}$; Fonseca-Batista et al., 2018; this issue).

In line with low *in-situ* PP, low POC concentrations and particulate $^{234}$Th activities were determined in the Iberian basin (Table S2). POC:$^{234}$Th ratios were low in both size fractions at Station 13, while Station 1 had high ratios, reaching 31 µmol $dpm^{-1}$ in surface for the LSF (Fig. 3). Similarly, Station 13 had the lowest LSF POC:$^{234}$Th ratio extrapolated at Eq whereas Station 1 had one of the highest ratios (Table 3).

The $^{234}$Th/$^{238}$U ratios were in the median of the range observed along the transect and reached minima of 0.68 and 0.70 in the upper 40 m at Stations 1 and 13, respectively (Fig. 2). Interestingly, these two stations vary also in their total particulate $^{234}$Th (sum of the SFF and LSF) over total $^{234}$Th ratios with only 9% of the $^{234}$Th in the particulate phase at Station 1 and 28% at Station 13 (in the median of those observed elsewhere along the transect). At both stations, the $^{234}$Th export fluxes at the Eq depth were slightly higher than the median value observed along the transect (1135 dpm $m^{-2}$ $d^{-1}$, n=11), reaching 1264 and 1418 dpm $m^{-2}$ $d^{-1}$ at Stations 1 and 13, respectively (Table 1). Compared to Station 1, the $^{234}$Th scavenging flux was ~ 2 fold higher at Station 13 (1509 and 2898 dpm $m^{-2}$ $d^{-1}$, respectively; Table 1). Consequently, the export ratio (P/J) was higher at Station 1, reaching 0.84, compared to Station 13 (P/J ratio=0.49; Fig. 6). This indicates a balanced situation between P and J fluxes at Station 13 and a more efficient export of $^{234}$Th by sinking particles at Station 1.

Below Eq, significant excesses of $^{234}$Th relative to $^{238}$U (i.e., $^{234}$Th/$^{238}$U ratio > 1.1) were observed at both stations, indicating particle degradation (Fig. 2). However, significant shallow remineralisation was only observed at Station 13 for which the R100 value was above uncertainty, reaching 410 ± 218 dpm $m^{-2}$ $d^{-1}$ (Table 1). This represents a flux reduction of 30% relative to the surface export flux.

Similarly, POC export fluxes varied between both stations with the highest (albeit the strong associated error; 12 mmol $m^{-2}$ $d^{-1}$ at Station 1) and one of the lowest (2.2 mmol $m^{-2}$ $d^{-1}$ at Station 13) fluxes along the transect observed within this basin.

## 3.2. The west European basin (Stations 21 and 26)

Along the year 2014, the west European basin was the most productive with the highest PP peak observed at Station 21 (403 mmol $m^{-2}$ $d^{-1}$), 13 days before the sampling. At Station 26, the sampling took place during a secondary PP increase (Fig. 4 and 5). At sampling time, during the bloom development, the basin was very productive with *in-situ* PP reaching 135 and 174 mmol $m^{-2}$ $d^{-1}$ at Stations 21 and 26, respectively (Table 3).

Along with the high PP, relatively high surface POC concentrations and particulate $^{234}$Th activities were measured averaging 3.7 µmol $L^{-1}$ and 0.2 dpm $L^{-1}$ for the LSF and, 5.4 µmol $L^{-1}$ and 0.5 dpm $L^{-1}$ for the SSF (Table S2). For both size fractions, POC:$^{234}$Th ratios were high in the upper water column, reaching a maximum of 30 µmol $dpm^{-1}$ for the LSF in surface waters at Station 21 (Fig. 3). At the Eq depth, the

POC:$^{234}$Th ratios for the LSF were in the median of those determined along the transect (4.4 µmol dpm$^{-1}$, n=11) with nevertheless a lower ratio at Station 21 (2.6 µmol dpm$^{-1}$; Table 3).

The lowest $^{234}$Th/$^{238}$U ratios were observed in the surface waters of the west European basin reaching minima of 0.57 and 0.77 at Stations 21 and 26, respectively (Fig. 2). Moreover, these low ratios were observed deeper in the water column compared to the other basins. The integration of the $^{234}$Th deficit from the surface to the Eq depth led thus to high $^{234}$Th export fluxes at both stations. The $^{234}$Th export flux at Station 21 was one of the highest observed along the transect, reaching 1873 dpm m$^{-2}$ d$^{-1}$ (Table 1). The $^{234}$Th scavenging fluxes were also among the highest observed along the transect, reaching 3917 and 2839 dpm m$^{-2}$ d$^{-1}$ at Stations 21 and 26, respectively (Table 1). The resulting export ratio (P/J) was about 0.5 for both stations, indicating a balanced situation between export and scavenging fluxes.

Excess of $^{234}$Th relative to $^{238}$U below Eq, was observed at both stations, with $^{234}$Th/$^{238}$U ratios reaching 1.14 at 300 m for Station 21 (Fig. 2; Table S1). Consequently, the R100 value at this station was significant (360 ± 255 dpm m$^{-2}$ d$^{-1}$; Table 1), representing a 20% $^{234}$Th flux reduction.

Relatively high POC export fluxes at Eq were observed in the west European basin, reaching respectively 4.8 and 7.9 mmol m$^{-2}$ d$^{-1}$ at Stations 21 and 26. For the same area, other studies reported similar POC export fluxes during May (Thomalla et al., 2008), and July-August (Lampitt et al., 2008; Le Moigne et al., 2013). However, Buesseler et al. (1992) report much higher POC fluxes (up to 41 mmol m$^{-2}$ d$^{-1}$) for April-May during the North Atlantic Bloom Experiment, highlighting an important temporal variability of POC export flux in this basin (Fig. 7).

### 3.3. The Icelandic basin (Stations 32 and 38)

In general, the different fluxes in the Icelandic basin were similar to those in the west European basin. The bloom period started in May, one month before the sampling and the bloom maximum occurred after the cruise (Fig. 4). Nevertheless, the basin was highly productive at Station 32 with *in-situ* PP reaching 105 mmol m$^{-2}$ d$^{-1}$ and was relatively productive at Station 38 (68 mmol m$^{-2}$ d$^{-1}$; Table 3 and Fig. 4 and 5).

POC concentrations and particulate $^{234}$Th activities were relatively high, but unlike the west European basin the highest concentrations and activities were found in the SSF, reaching 5.8 µmol L$^{-1}$ and 0.4 dpm L$^{-1}$, respectively at Station 32 (Table S2). For surface waters of both stations, POC:$^{234}$Th ratios in the SSF exceeded those in the LSF (Fig. 3) but ratios were similar between both size fractions at Eq depth (difference less than a factor of 1.1). The ratios extrapolated to Eq for the LSF were 3.6 and 4.2 µmol dpm$^{-1}$ at Stations 32 and 38, respectively and were in the median of the range along the transect (Table 3).

As for the west European basin, $^{234}$Th/$^{238}$U ratios were low with station 38 having the lowest value for the whole transect (0.50 in the surface; Fig. 2). Low ratios were also observed deeper in the water column and the combination yielded the highest $^{234}$Th export fluxes at Eq, reaching 2282 ± 119 dpm m$^{-2}$ d$^{-1}$ at Station 32 (Table 1). While the $^{234}$Th scavenging flux was high at Station 32, reaching 3690 dpm m$^{-2}$ d$^{-1}$, it was much lower at Station 38 (1495 dpm m$^{-2}$ d$^{-1}$; Table 1). The export ratios (P/J) slightly exceeded the median value along the transect, reaching 0.62 and 0.76 at Stations 32 and 38, respectively. Despite similarities with the west European basin, the Icelandic basin appeared more efficient to export $^{234}$Th by sinking particles.

Below the Eq depth, there was no significant excess of $^{234}$Th relative to $^{238}$U, resulting in R100 values being close or below uncertainty and indicating absence of significant shallow remineralisation.

One of the highest POC export fluxes along the transect was determined at Station 32, reaching 8.3 mmol m$^{-2}$ d$^{-1}$ while the POC flux at Station 38 was lower (4.8 mmol m$^{-2}$ d$^{-1}$). Such POC export fluxes are lower than values reported in earlier studies, ranging from 0.8 to up to 52 mmol m$^{-2}$ d$^{-1}$; Ceballos-romero et al., 2016; Giering et al., 2016; Martin et al., 2011; Sanders et al., 2010; Fig. 7).

### 3.4. The Irminger basin (Stations 44 and 51)

The ship crossed the Irminger basin one month after the beginning of the bloom and sampling occurred just 1 week (Station 44) to 3 weeks (Station 51) after the peak of the bloom (Fig. 4). At sampling time, the *in-situ* PP was amongst the highest observed along the whole section, reaching respectively 137 and 166 mmol m$^{-2}$ d$^{-1}$ at Stations 44 and 51. Such high values, in line with the satellite data, suggest that the bloom was still ongoing when visiting these two stations (Table 3 and Fig. 4 and 5).

POC concentrations and particulate $^{234}$Th activities were overall highest at these two stations, reaching 17 µmol L$^{-1}$ and 1.2 dpm L$^{-1}$ for the SSF and 4.0 µmol L$^{-1}$ and 0.5 dpm L$^{-1}$ for the LSF at Station 44, respectively (Table S2). POC:$^{234}$Th ratios were moderate for both size fractions, reaching 14 µmol dpm$^{-1}$ for the SSF at Station 44 and 12 µmol dpm$^{-1}$ at Station 51 in the surface waters (Fig. 3). At the Eq depth, the extrapolated POC:$^{234}$Th ratios were similar between both size fractions at Station 51 but were 1.7 fold higher in the SSF at Station 44. The POC:$^{234}$Th ratio at Eq in the LSF at Station 44 fitted the median of the ranges determined along the transect, while the ratio at Station 51 was relatively lower (2.9 µmol dpm$^{-1}$, Table 3).

The $^{234}$Th/$^{238}$U ratios in the surface waters were higher than at other stations, reaching minima of 0.79 and 0.78 at Stations 44 and 51, respectively. These low $^{234}$Th deficits were also restricted to the upper layer, especially at Station 44 where the Eq depth was 40 m (Fig. 2).The particulate $^{234}$Th (sum of the SFF and LSF) contribution to total $^{234}$Th ratios varied widely, from 27% at Station 51 (in the median of those observed elsewhere along the transect) to 94% at Station 44. The extremely high fraction of particulate $^{234}$Th at Station 44 reflects an important particle concentration in surface waters. This high particulate fraction in the upper layer did not induce a high export fluxes, since Station 44 had the lowest $^{234}$Th export flux (321 ± 66 dpm m$^{-2}$ d$^{-1}$; Table 1) of all stations. As a result, scavenging fluxes were much higher in this basin, reaching respectively 1802 and 2189 dpm m$^{-2}$ d$^{-1}$ at Stations 44 and 51. This leads to very low P/J ratios in the Irminger basin (as low as 0.2 at Station 44), suggesting that export of $^{234}$Th is particularly inefficient in this basin, in agreement with the low export flux and the high particulate fraction in the upper layer.

Below the Eq depth, there was no significant excess of $^{234}$Th relative to $^{238}$U, reflecting no evidence for significant shallow remineralisation, with R100 values being either negative or below uncertainty.

The Irminger basin was characterized by low POC export fluxes (1.4 and 2.7 mmol m$^{-2}$ d$^{-1}$ at Stations 44 and 51, respectively). In the literature, a relatively large range of POC export fluxes has been reported for this basin. Puigcorbé et al. (2017) observed POC export fluxes ranging from 1.5 to 43 mmol m$^{-2}$ d$^{-1}$. Ceballos-Romero et al. (2016) also determined much higher POC fluxes compared to those observed in the present study, with differences reaching factors of 27 and 19 the month before and after our sampling, respectively (Fig. 7).

### 3.5. The Labrador basin (Stations 64, 69 and 77)

Stations of the Labrador basin were sampled approximatively one month after the beginning of the bloom. Station 64 was sampled just after a second peak of the bloom while Stations 69 and 77 were sampled one week after this peak (Fig. 4). At sampling time, the *in-situ* PP was low in the Labrador basin, ranging from 27 to 80 mmol m$^{-2}$ d$^{-1}$ at Stations 69 and 77, respectively (Table 3). In agreement with the satellite data shown in Fig. 4, this indicates that the decline of the bloom was ongoing in the Labrador basin.

POC concentrations and particulate $^{234}$Th activities were moderate to low, except at Station 77 where values were higher in the surface, reaching 11 µmol L$^{-1}$ and 0.45 dpm L$^{-1}$ for the SSF, and, 3.0 µmol L$^{-1}$ and 0.20 dpm L$^{-1}$ for the LSF, respectively. Moderate POC:$^{234}$Th ratios were observed in both size fractions, except in the upper layer at station 77 where SSF POC:$^{234}$Th ratios were high (Fig. 3). At the Eq depth, POC:$^{234}$Th ratios in both size fractions were similar and reached 9.2, 14 and 8.8 µmol dpm$^{-1}$ at Stations 64, 69 and 77, respectively. Interestingly, these ratios are higher than the median ratio determined along the transect.

The surface $^{234}$Th/$^{238}$U ratios were in the median of those observed along the transect (0.74 ± 0.06, n=8) with minima of 0.78, 0.66 and 0.73 at Stations 64, 69 and 77, respectively. These $^{234}$Th deficits were nevertheless observed in a relatively shallow layer (Eq depths between 40 and 80 m in this basin; Fig. 2). Stations 64 and 69 were also characterized by a low particulate $^{234}$Th activity (combined LSF and SSF) accounting for 10 and 15% of the total $^{234}$Th activity in agreement with relatively low POC concentrations observed at these stations. The $^{234}$Th export flux at Station 64 was slightly greater than those of Stations 69 and 77 but, in general, the $^{234}$Th export fluxes of the Labrador basin were moderate, averaging 758 dpm m$^{-2}$ d$^{-1}$ (Table 1). $^{234}$Th scavenging fluxes were also generally low in the Labrador basin, but with again, a slightly lower scavenging flux at Station 64 (Table 1). A higher export ratio was thus estimated at Station 64 (P/J ratio = 0.75), suggesting a more efficient export close to the Greenland margin compared to Stations 69 and 77 (Fig. 6).

Below Eq, there was a significant excess of $^{234}$Th relative to $^{238}$U at Stations 69 and 77, reaching respectively 1.08 and 1.11. Evidence for shallow remineralisation was also clear from the R100 values exceeding uncertainties (Station 69, R100=401 ± 159 dpm m$^{-2}$ d$^{-1}$ and Station 77, R100=252 ± 165 dpm m$^{-2}$ d$^{-1}$, Table 1). The flux reductions due to remineralisation below Eq were 50 and 40% of the fluxes at Eq, respectively.

High POC exports were observed within the Labrador basin and in particular at Station 69 where POC export flux reached 10 mmol m$^{-2}$ d$^{-1}$. As for the Irminger basin, Puigcorbé et al. (2017) determined a low POC export (0.7 mmol m$^{-2}$ d$^{-1}$) in May, one month before our sampling period, while Moran et al. (2003) observed higher fluxes reaching 47 mmol m$^{-2}$ d$^{-1}$ in July, one month after our sampling period (Fig. 7).

- *Major comment 3: The discussion of uncertainty opens the discussion (sections 4.1 and 4.2 NSS and physical transport). While I value this discussion, it is not novel and has been discussed in previous studies. I suggest to move it to the end of the manuscript. Please start with what is new and motivating before discussing the limitations of the method.*

It is a very good point. However, we think that it is easier for the reader to know about the potential bias of the $^{234}$Th method before reading the sections explaining the flux estimates. If the potential limitations were discussed at the end of the manuscript, the reader would have to re consider the explanations that have been previously stated. We thus decided to keep this section at the beginning of the Discussion, as it is the case in other papers about the POC exports using by the $^{234}$Th-based approach (e.g., Black et al., 2017; Owens et al., 2015). We nevertheless decided to group both sections in one named "Validity of the export estimations", which is hopefully more motivating for the reader.

- *Major comment 4: Large part of the discussion pertains to the result section (sections 4.3, 4.4 and 4.5) and could help organise the results (see comment #2). There are also many methodological details in the discussion section that should be (re)moved (e.g. L446, L462, L483), in particular when these details are stated several times. For example, L483 explains what thorium deficit is, even though this explanation is already included in the introduction, the method and the result sections. The discussion should emphasize what this study brings to existing studies and discuss the limitations.*

Thank you for noticing all these methodological details. Many parts of the discussion have been moved to the Introduction, Method or Result sections. We also decided to re organize the discussion section based on the different processes influencing the magnitude of the POC exports, as suggested in your major comment n°2.

Lines 394-590: Discussion

In the following section, we first discuss the potential impact of the physics and the non-steady state conditions on the $^{234}$Th export flux estimations. Then, temporal and regional variations of the carbon export fluxes are discussed with regards to the intensity and stage of the bloom, the phytoplankton size structure and the phytoplankton community. Finally, we examine carbon export and transfer efficiencies along the transect.

4.1. Validity of the export estimations

4.1.1. $^{234}$Th export fluxes under the potential influence of physical conditions

The GEOVIDE section sampled a diversity of dynamic regimes (Zunino et al., 2017) including continental margins affected by strong zonal surface currents (LC, WGC and EGC; Mercier et al., 2015; Reverdin et al., 2003), local and seasonal upwelling (close to the Iberian Margin), as well as deep convection zone in the Labrador Sea. In such conditions, Eq. 3, which assumes negligible lateral and vertical advective and diffusive fluxes, may not always be appropriate (Savoye et al., 2006). Whenever possible, we explore quantitatively or qualitatively, the potential errors arising from neglecting physical transport in our calculation.
Lateral processes associated with high velocity currents and intense mesoscale activity are known to affect the $^{234}$Th distribution (Benitez-Nelson et al., 2000; Resplandy et al., 2012; Roca-Marti et al., 2016b; Savoye et al., 2006). In our case, this may concern several stations located at or close to margins such as Stations 51 and 64, which were respectively subject to the powerful East and West Greenland Currents at the Greenland Margin, Station 77 under influence of the LC on the Newfoundland Margin and Station 1 under influence of the Portugal Current at the Iberian Margin (Fig. 1). However, the impact of the lateral advection cannot be quantified from our dataset, as the possible horizontal gradients of $^{234}$Th cannot be resolved at sufficient resolution. As an alternative, we compare stations close to each other such as Stations 44 and 51, both located in the Irminger Basin where surface currents are strong. The Irminger basin in spring is a really patchy and dynamic area (Ceballos-romero et al., 2016; Le Moigne et al., 2012; Puigcorbé et al., 2017) but the relatively high variability of the $^{234}$Th fluxes found at these two stations (321 and 922 dpm m$^{-2}$ d$^{-1}$, respectively) may also indicate a potential influence of lateral advection. The higher export flux at Station 51 could reflect an input of $^{234}$Th depleted waters originating from the Arctic and/or the Greenland shelf. However, Arctic (Cai et al., 2010; Roca-Marti et al., 2016a) and Greenland shelf waters (Station 53, see

Table S1) reveal very limited depletions of $^{234}$Th relative to $^{238}$U. Thus, it is reasonable to consider that the $^{234}$Th deficit at Station 51 was essentially driven by vertical rather than horizontal processes.

The impact of hydrodynamic processes concerns also the open ocean sites, such as stations within the west European and Icelandic basins (Stations 26 and 32) which are subjected to mesoscale activity. An inverse modeling study carried out for the Porcupine Abyssal Plain located in the same region, suggests that the vertical transport of $^{234}$Th associated with small-scale structures could represent up to 20% of the estimated vertical export flux (Resplandy et al., 2012). This error is larger than our analytical uncertainty and should be kept in mind when considering the export flux data in this area.

In upwelling systems, the contribution of vertical advection on the $^{234}$Th distribution has been shown to be important (Buesseler, 1998; Buesseler et al., 1995). Near the Portuguese coast, the intensity of the upwelling is seasonally dependent (Costa Goela et al., 2016; Zúñiga et al., 2016) and was rather inactive at the time of the GEOVIDE cruise (http://marine.copernicus.eu/). Therefore, the input of $^{234}$Th-rich deep waters to the surface is likely to be limited, as already observed in the northern Iberian margin in early summer (Hall et al., 2000). Downwelling systems, such as the intense convection that occurred in the Labrador basin during the winter prior to our sampling (Kieke and Yashayaev, 2015), are also likely to impact the $^{234}$Th distribution. However, a strong vertical advection would homogenize the $^{234}$Th activities in the water column, which is not the case during our study (Fig. 2). Therefore, the influence of vertical advection on $^{234}$Th export fluxes was neglected.

Finally, the contribution of the vertical molecular diffusion was estimated using the vertical gradients of total $^{234}$Th activity in upper waters and a Kz value ranging between $10^{-4}$ and $10^{-5}$ $m^2$ $s^{-1}$, as observed in the upper 1000 m between Portugal and Greenland along the OVIDE transect (Ferron et al., 2014). The highest vertical diffusive flux was determined at Station 69 and reached 181 dpm $m^{-2}$ $d^{-1}$, which is in the range of the $^{234}$Th flux uncertainties. Therefore, the impact of the vertical diffusion has not been considered further.

In conclusion, hydrodynamic processes are likely to have at most a limited impact on the measured $^{234}$Th export fluxes.

#### 4.1.2. Accounting for non-steady state conditions

As the cruise sampling scheme did not allow to collect samples through a time series, it was necessary to assume steady state conditions (i.e., no variation of $^{234}$Th activity with time). However, as documented in previous studies in the west European and Icelandic basins (Buesseler et al., 1992; Martin et al., 2011), this assumption can be questioned as large variations of $^{234}$Th activity were observed at a time scale of one to three weeks along with the onset of the seasonal biological productivity. As a consequence, the SS model was shown to poorly describe the magnitude of the $^{234}$Th export flux as it underestimated fluxes by up to a factor of 3 compared to the non-steady state (NSS) model (Buesseler et al., 1992; Martin et al., 2011).

During the weeks preceding GEOVIDE, large changes in satellite-derived PP were observed (Fig. 4). In order to evaluate the potential error introduced by the SS approach, we attempted to apply a NSS model (see section 2.3; Eq. 4).

The west European and Icelandic basins had the highest NSS $^{234}$Th fluxes (3540 dpm $m^{-2}$ $d^{-1}$ at Station 32) while the Irminger basin had the lowest (516 dpm $m^{-2}$ $d^{-1}$ at Station 44; Table 1). The NSS $^{234}$Th fluxes were either larger or similar to those obtained using the SS model. This results from the fact that the NSS approach used here assumes the observed $^{234}$Th activity changes to only reflect a linear decrease from an initial $^{234}$Th activity in secular equilibrium with $^{238}$U, over the time elapsed since the onset of the bloom (Δt, see section 2.3). For stations sampled shortly after the start of the bloom such as in the Irminger, Icelandic and Labrador basins (Δt ranges from 23 to 43 days), the fluxes predicted by the NSS model are from 1.4 to 2.1 fold higher than to the SS fluxes. In the west European and Iberian basins, this difference is reduced (NSS fluxes are from 1.1 to 1.3 fold higher) due to a larger Δt, ranging from 48 to 78 days.

As a conclusion, the SS export fluxes may have underestimated $^{234}$Th export fluxes at some stations by a maximum factor of 2 such as in the Icelandic basin. Yet, we need to keep in mind that this NSS approach has limitations by assuming the equilibrium between $^{234}$Th and $^{238}$U at the bloom start and by considering only an increasing deficit of $^{234}$Th activity over a given time period (Δt)

## 4.2 Influence of the intensity and stage of the bloom on POC exports

The GEOVIDE cruise was carried out in late spring (May-June), a period during which the productivity and the carbon export can be important (Sanders et al., 2014). The $^{234}$Th proxy integrates the activity deficits over a timescale of several weeks preceding the sampling and it appears thus essential to compare the sampling time in light of the bloom development.

Apart from Stations 1 and 13, which were sampled after the bloom, the different basins were sampled during the spring bloom, but at different stages. One of the lowest POC export flux was determined at Station 13 in the Iberian basin, where the intensity of the bloom remained rather low along the season (seasonal VGPM-PP=81 mmol m$^{-2}$ d$^{-1}$, Fig. 5) due to oligotrophic conditions (depleted nutrients; Fonseca-Batista et al., 2018). In contrast, the highest POC export flux was determined at Station 1, also in the Iberian basin. Station 1 was sampled after the bloom period and satellite-data showed this station was relatively productive in the early spring (185 mmol m$^{-2}$ d$^{-1}$ in March, Fig. 4). This greater POC export observed when the bloom had already declined may be caused by an ecosystem change, as already described in the Southern Ocean with the emergence of silicified diatoms because of nutrient stress (e.g., Baines et al., 2010; Claquin et al., 2002).

High POC export fluxes were also observed for the west European and Icelandic basins sampled during the bloom. PP appeared maximal just before the sampling in the west European basin (Fig. 4 and 5) and could have promoted these high POC exports. Within the Icelandic basin, both stations were sampled during the productive period, although the peak of the bloom was not yet reached (Fig. 4), suggesting that the export maximum might have occurred later in the season. Both basins have previously been characterized by the presence of fast-sinking particles during the bloom (data from cruises in Spring 2012 and Summer 2009; Villa-Alfageme et al., 2016) promoting the high POC export fluxes.

The Irminger basin was sampled close to the bloom maximum, but unlike the west European and Icelandic basins the POC export flux was low there, probably reflecting accumulation of biomass preceding export. Indeed, this area had the highest *in-situ* PP, a high proportion of particulate $^{234}$Th in surface waters (reaching 94% of the total $^{234}$Th activity at Station 44) and a very low P/J ratio, indicating that $^{234}$Th was retained in the upper waters rather than being exported (Fig. 6; Table 1).

The Labrador Sea basin was sampled just shortly after the peak of PP and was characterized by low *in-situ* PP, low nutrient concentrations, indicating the beginning of the decline of the bloom. The combination of the important PP a few weeks before our sampling (Fig. 4 and 5) and the decline of the bloom likely triggered the high POC export fluxes, as observed elsewhere (Martin et al., 2011; Roca-Marti et al., 2016b; Stange et al., 2016).

Overall, the magnitude of the POC export appears to depend on the degree of progress of the bloom. Indeed, the negative relationship found between the POC export fluxes and the *in-situ* PP relative to the maximal VGPM-PP along the season, representing the bloom stage, highlights that highest export occurs in post bloom periods (Fig. 8), as also evidenced from deep sediment trap studies (Lampitt et al., 2010), and is driven by large and rapidly sinking aggregates (Lampitt et al., 2001; Turner and Millward, 2002).

### 4.3. Influence of the phytoplankton size and community structure on POC exports

In the North Atlantic, the phytoplankton composition varies significantly, depending on the stage of the bloom and on the evolution of environmental parameters such as micro- and macro-nutrient concentrations or stratification depth (Moore et al., 2005). Spatial variations in phytoplankton size structure are known to exert a control on the magnitude of the POC export flux (Boyd and Newton, 1999) and high POC exports are usually related to a greater size of the sinking phytoplankton cells (Alldredge and Silver, 1988; Guidi et al., 2009).

Within the Iberian basin, the highest abundance of pico-phytoplankton was observed at Station 13 (Tonnard et al., in prep.). These conditions are typical of the subtropical and oligotrophic waters (Dortch and Packard, 1989). Villa-Alfageme et al. (2016) highlighted that small cells are usually slow-sinking particles that can be easily remineralised in the upper layers. A small sinking velocity (<100 m $d^{-1}$) allows time for bacteria and zooplankton to degrade such particles, thus reducing the export flux. For the same area, Owens et al. (2014) also report a low flux later in October, confirming a lower carbon export in general in this oligotrophic area. However, Station 1 was characterized by a greater POC export that could be related to the mixed proportion of micro-, nano- and pico-phytoplankton and thus to the greater proportion of larger cells such as diatoms or haptophytes, increasing the particle sinking velocity. The greater POC export there may also be related to the proximity to the margin, where particle dynamics are intense and lithogenic particles are numerous (Gourain et al., 2018).

At higher latitudes, particle sinking velocity has been reported to be high (>100 m $d^{-1}$; Villa-Alfageme et al., 2016), as cells generally are of a larger size. Micro-phytoplankton, with dominance of diatoms, represented an important fraction of the phytoplankton community in the west European, Irminger and Labrador basins and the dense frustules of diatoms have been reported to act as ballast for the sinking organic matter (Klaas and Archer, 2002). Fast-sinking particles could have promoted the relatively high POC export fluxes in those basins. However, in the Icelandic basin, the dominance of nano-phytoplankton coincided with relatively high POC export. Both stations in the Icelandic basin were dominated by haptophytes, including coccolithophorids (Tonnard et al., in prep.). Despite their smaller size, the dense calcium carbonate shells of the latter could promote the export of POC (Francois et al., 2002; Lam et al., 2011).

Our results suggest that high POC export fluxes can be mediated through either micro- or nano-phytopkankton species, suggesting that sinking velocity is influenced by other parameters than the size, likely their composition and density (Fig. 8).

### 4.4. Export and transfer efficiencies of POC

In order to characterize the strength of the biological carbon pump, we used two parameters: the export efficiency (ThE), which is the ratio of the POC export flux at Eq over the PP (Buesseler, 1998) and the transfer efficiency (T100) which is the ratio of the POC export flux at 100 m below Eq over the POC export flux at Eq (Fig. 9). Note that the POC export flux at Eq+100 (Table 3) was calculated by multiplying the $^{234}$Th flux at Eq+100 by the POC to $^{234}$Th ratio of large particles for the same depth. The POC:$^{234}$Th ratio at Eq+100 was deduced from a power law fit (Fig. 3).

Based on *in-situ* PP values (Table 3), ThE ranged from 1 (Station 44) to 38% (Station 69) with a median value of 7% along the transect. The highest export efficiencies were determined at Stations 1 and 69 with values reaching 35 and 38%, respectively. Other stations were characterized by ThE ≤ 14% with highest values (7 – 14%) at Stations 32, 38, 64 and 77. Export efficiencies around 10% are common in the open ocean (Buesseler, 1998). A lower export efficiency can be related to important microbial and zooplankton grazing activities or to biomass accumulation in surface waters (Planchon et al., 2013, 2015). A high ThE can result from many factors such as the presence of large and/or dense and fast sinking particles, low surface remineralisation, active zooplankton migration or nutrient stress (Ceballos-romero et al., 2016; Le Moigne et al., 2016; Planchon et al., 2013). Interestingly, stations with the highest ThE were also characterized by the lowest PP (Stations 1 and 69) while stations with the lowest ThE were characterized by the highest PP (Stations 44 and 51). This inverse relationship between PP and ThE was significant for all stations of the GEOVIDE cruise (regression slope: -0.20; $r^2$=0.58; p<0.01; n=11; Fig. S2) and has been explained in the Southern Ocean by the temporal decoupling between PP and export due to biomass accumulation in surface waters (Henson et al., 2015; Planchon et al., 2013) as well as by other processes such as zooplankton grazing and bacterial activity (Maiti et al., 2013; Le Moigne et al., 2016; Roca-Marti et al., 2016a). Such particle recycling has been also observed in the North Atlantic (Collins et al., 2015; Giering et al., 2014; Marsay et al., 2015) limiting POC export to the deep ocean. A recent study in the Icelandic and Irminger basins highlights the impact of the bloom dynamics on the particle export efficiency resulting in strong seasonal variability of the ThE (Ceballos-Romero et al., 2016). Our estimates are generally in the lower range of export efficiencies reported by others for the North Atlantic with values ranging from 1 to 42% in the western European basin (Buesseler et al., 1992; Lampitt et al., 2008; Thomalla et al., 2008), from 5 to 8% in the Icelandic basin (Ceballos-romero et al., 2016), from 4 to 16% in the Irminger basin (Ceballos-romero et al., 2016) and from 4 to > 100% in the Labrador basin (Moran et al., 2003). This wide range confirms that export efficiencies are highly variable in the North Atlantic during the period of our study. The overall low export efficiency of the North Atlantic is characteristic of highly productive areas of the world ocean.

However, it should be kept in mind that the ThE calculation is based on two parameters that are integrating processes over different time scales: 24 h for *in-situ* PP and several weeks for export. Strong variability of PP in short time period could therefore have a strong impact on the outcome. Therefore, ThE ratios were also estimated using the VGPM-derived 8-day, 32-day and seasonal PP (Table 3). As seen in Section 2.7, there are no significant differences between the VGPM-PP estimates regardless of the integrations times, and thus no significant differences between the corresponding ThE values. Stations 1 and 69 are exceptions with ThE values decreasing from 35 to 12% and from 38 to 8%, respectively, due to unusually low *in-situ* PP during our study which led to over-estimated ThE.

Carbon transfer efficiencies (T100) ranged from 30 (Station 69) to 78% (Station 32). Generally, the fluxes at these greater depths were characterized by greater error bars (see Fig. 9) due to the increasing uncertainty of the $^{234}$Th fluxes with increasing depth. The highest T100 were observed within the Icelandic basin with values reaching 78 and 74% at Stations 32 and 38 respectively. On the contrary, the lowest T100 values were observed at Stations 1, 13, 21 and 69 (between 30 and 49%) highlighting greater carbon remineralisation between Eq and Eq+100 m at these latter stations, as well as confirming important regional variability of the transfer efficiency as reported also by others (Lam et al., 2011; Lutz et al., 2002). The low T100 (and high R100) values observed in the eastern part of the transect (Stations 1, 13 and, to a lesser extent Station 21) likely reflect an important bacterial activity in these warmer waters (>13°C in the upper 100 m; Iversen and Ploug, 2013; Marsay et al., 2015; Rivkin and Legendre, 2001). This efficient recycling is characteristic for regeneration-based microbial food webs in oligotrophic regimes (Karl, 1999; Thomalla et al., 2006). In the Icelandic basin, the high T100 may be related to the large abundance of coccolithophorids (Tonnard et al., in prep.) known to enhance the POC transfer due to their ballasting effect (Francois et al., 2002; Lam et al., 2011). Indeed, Bach et al. (2016) found that a bloom of coccolithophorids can increase the transfer efficiency through the mesopelagic layer by 14-24%. Finally, the Labrador and Irminger basins exhibit relatively similar T100 (between 50 and 69%), except at Station 69 where the lowest T100 was observed. This is also in agreement with the highest R100 and carbon remineralisation flux determined with the $Ba_{xs}$ proxy (Lemaitre et al., 2018). The central Labrador basin, in proximity of Station 69, was characterized by strong subduction of the LSW during the winter preceding the GEOVIDE cruise. This downwelling could have promoted an important organic matter export leading to important prokaryotic heterotrophic activity in mesopelagic waters. This enhanced remineralisation, was still observed during GEOVIDE as traced by a large mesopelagic $Ba_{xs}$ content (Lemaitre et al., 2018).

- *Major comment 5: please streamline the text. Many methodological concepts are presented and introduced in several sections (e.d. thorium deficit, PP measurements etc.).*

OK, many parts along the manuscript have been deleted or moved to the right section, and we hope the new text will be less tedious to read.

- *Lines 43-46: two sentences are repeated in the introduction. Remove one version.*

The introduction has been re written and this repeated sentence has been removed.

- *Lines 61-63: needs to be rephrased (see comments above).*

OK. This has been modified, please see our answer to your major comment n°1.

- *Method section: could be sharpened by limiting the use of “moderate” (e.g. L91, L106, L116). Please limit the use of “moderate” (e.g. L91, L106, L116), which is rather vague. The word “briefly” (L127, L137, L222) should also be avoided. Either you have described the method and you can remove “briefly", or you haven’t described enough and should include additional references or details.*

Right, many details of the Method section have been deleted and the use of words such as “briefly” have been removed. When using the word “moderate”, result values have been added in the text in order to give the order of magnitude.

Line 260: …. and a moderate PP at Station 13 (79 mmol $m^{-2}$ $d^{-1}$; Fonseca-Batista et al., 2018; this issue)

Line 341: POC:$^{234}$Th ratios were moderate for both size fractions, reaching 14 µmol $dpm^{-1}$ for the SSF at Station 44…

Lines 370-371: POC concentrations and particulate $^{234}$Th activities were moderate to low, except at Station 77 where values were higher in the surface, reaching 11 µmol $L^{-1}$ and 0.45 dpm $L^{-1}$ for the SSF…

Lines 381-382: … but, in general, the $^{234}$Th export fluxes of the Labrador basin were moderate, averaging 758 dpm $m^{-2}$ $d^{-1}$ (Table 1).

- *Line 102: associated with (not to).*

OK, this has been changed.

- *Line 235: other estimates of PP mentioned here could be added for comparison in Figure 4. This would give confidence in the author's choice and inform the reader on the uncertainty associated with these estimates.*

OK. We added the PP estimates from the Eppley-VGPM and CbPM models in Figure 4.

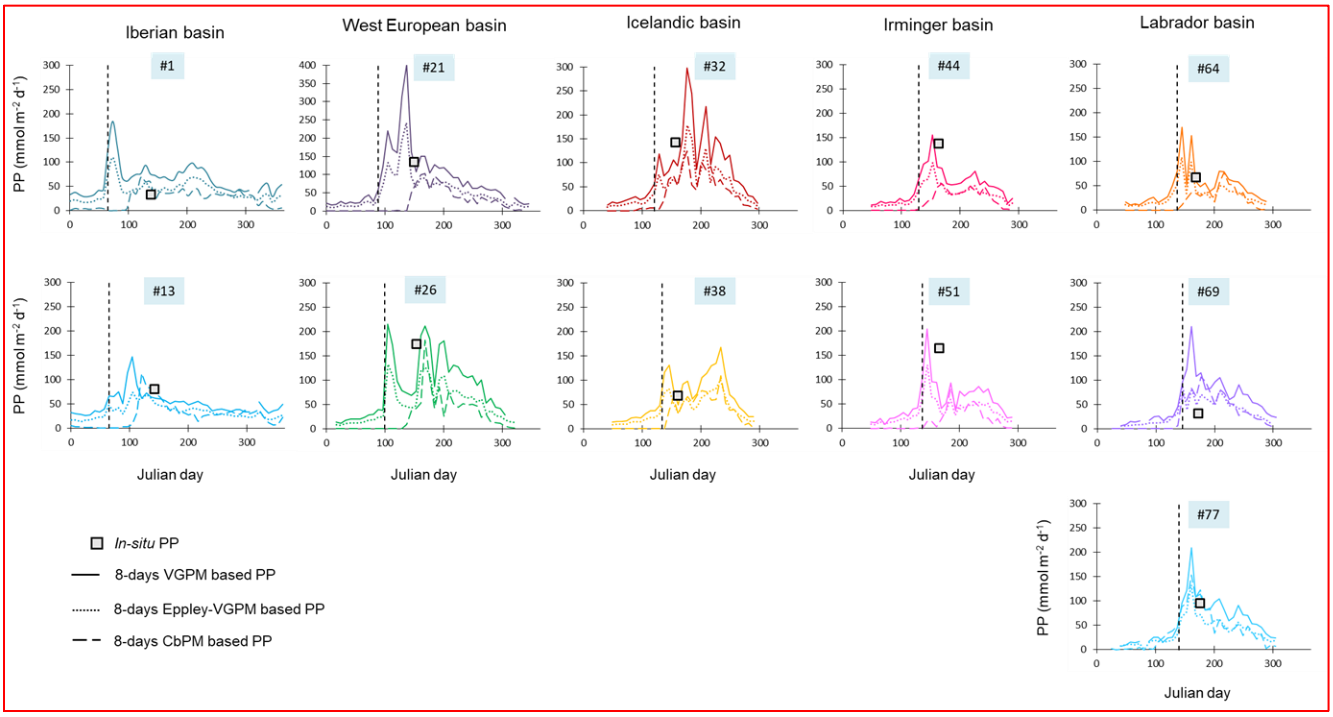


Figure 3: *In-situ* (squares) and satellite VGPM-derived (continuous lines), VGPM-Eppley-derived (dotted lines) and CbPM-derived (dashed lines) primary production (PP; in mmol $m^{-2}$ $d^{-1}$) data at the time of our sampling and along the year 2014. The start of the bloom, defined by a PP increase of 30% above the winter value, is indicated with the black vertical dashed line.

- *Lines 259-261: Move definition of PPZ above, when it is first mentioned.*

OK. This has been done.

Lines 169-172: Eq. 3 has been solved for z taken as the depth (Eq) at the base of the $^{234}$Th deficit zone (Eq = depth where $^{234}$Th activity is back to secular equilibrium with $^{238}$U) as well as for z representing the base of the primary production zone (PPZ), i.e. the depth where in-situ fluorescence was only 10% of its maximum value (Owens et al., 2014).

- *Line 110: Tonnard et al, in prep and L521 Lemaitre et al, in prep. Does the journal authorized unpublished papers?*

The citation "Lemaitre et al., in prep" and thus the details related to this manuscript have been removed. The manuscript "Tonnard et al., in prep." is going to be submitted soon, hopefully before the publication of this manuscript.

**Editor**

Received and published: 10 October 2018

*General comments: You have provided detailed replies to the reports and taken into account all the major comments received. In particular, you have considerably streamlined the paper to clarify objectives, provided more clearly the context and discussed the major results. Thus, I don't think that there is room for a second round of major revision. I have read the manuscript and have added a few comments or questions. I'd like you to take them into account and post a revised manuscript.*

We would like to thank the Editor for these very positive comments. All suggestions have been taken into account and are detailed below.

- *Line 190: Number missing*

OK, this has been changed.

Line 189: In case of any $^{234}$Th excess relative to $^{238}$U (i.e., $^{234}$Th/$^{238}$U ratio > 1) below the Eq depth…

- *Line 195: Instead of "removal", maybe use "transfer"*

OK.

Line 195: To estimate the transfer rate of $^{234}$Th from the dissolved to the particulate form…

- *Line 218: root sum of square method or root sum squared method ?*

Line 218: …using a root sum squared method…

- *Line 239: 'at few stations'? do you mean that 42 m happened at more than one station? (or is it for a specific station)?*

Lines 238-240: The 0.2% of surface PAR depth was roughly corresponding to the Eq depth (median difference between both depths: 20 ± 13 m) although, a 42 m difference was observed at Station 1.

- *Line 268: a ratio of 28%...*

Lines 267-269: Interestingly, these two stations vary also in their total particulate $^{234}$Th (sum of the SFF and LSF) over total $^{234}$Th ratios with only 9% of the $^{234}$Th in the particulate phase at Station 1 and a ratio of 28% at Station 13 (in the median of those observed elsewhere along the transect).

- *Line 279: albeit with a strong associated error..*

Okay, that has been changed (see line 280).

- *Line 283: During 2014, the ... or : before the cruise in 2014,...*

Line 284: During 2014, the west European basin..

- *Line 285: Altogether, sampling coincided with the bloom development in this basin, with in-situ PP*

Lines 286-287: Altogether, sampling coincided with the bloom development in this basin, with *in-situ* PP reaching 135 and 174 mmol m$^{-2}$ d$^{-1}$ at Stations 21 and 26, respectively (Table 3).

- *Line 287: Remove "the"*

Line 288: Along with high PP..

- *Line 299: of nearly 0.5 for both stations indicates...*

Lines 300-301: The resulting export ratio (P/J) was close to 0.5 for both stations, indicating a balanced situation between export and scavenging fluxes.

- *Line 302: was significantly positive*

Okay, see line 303.

- *Line 310: presented similar characteristics to those...*

Line 311-312: In general, the different fluxes in the Icelandic basin presented similar characteristics to those in the west European basin.

- *Line 314: but unlike for the west European basin*

Okay (see line 316).

- *Line 317: between the two size fractions*

Okay (see line 319)

- *Line 330: are lower than most values... (just after you mention values as low as 0.8, which are smaller?)*

The study of Martin et al. (2011) report a POC export flux of 0.8 mmol $m^{-2}$ $d^{-1}$ indeed, but this is an extreme minimum compared to the fluxes generally observed in this basin.

Lines 332-334: Such POC export fluxes are lower than most values reported in earlier studies, ranging from 6 to up to 52 mmol $m^{-2}$ $d^{-1}$ although Martin et al. (2011) determined a very low value of 0.8 mmol $m^{-2}$ $d^{-1}$.

- *Line 351: "On the other hand, this high..." I wondered whether this was not an issue of non-stationarity at station 44.*

Right, and the non-stationarity of Station 44, and more generally of the Irminger basin, is discussed in different sections:

Line 418: The Irminger basin in spring is a really patchy and dynamic area..

Lines 494-495: The Irminger basin was sampled close to the bloom maximum, but unlike the west European and Icelandic basins the POC export flux was low there, probably reflecting accumulation of biomass preceding export.

Lines 354: On the other hand, this high particulate fraction in the upper layer did not induce a high export flux.

- *Line 363: for the month before and after...*

Okay, see line 366.

- *Line 374: ratios were similar in the two size fractions,*

Okay, see lines 376-377.

- *Line 397: with respect to*

Okay, see line 400.

- *Line 411: under the influence*

Okay, see line 414.

- *Line 412: the impact of lateral advection*

Okay, see line 415

- *Line 422: Hydrodynamic processes could also impact open ocean sites, such as...*

Okay, see line 425.

- *Line 436: Question: and the fact that convection has ended probably more than 2 (if not 3) months ahead of the cruise, thus much longer than half life... would also be an argument against invoking it...*

That is completely correct and this has been added.

Lines 439-440: Moreover, this convection ended more than two months before our sampling, a time lag that largely exceeds the $^{234}$Th half-life thereby erasing any potential impact on the $^{234}$Th signal.

- *Line 437: this is not 'vertical molecular diffusion' that you estimate, but possible 'vertical mixing/diffusion'...*

Okay that has been changed (see line 442).

- *Line 450: I don't see why it should systematically lead to an underestimate... (as it would depend whether one samples after bloom peak or before)*

Right, the use of a SS model during the North Atlantic spring bloom (characterized by a strong PP variability) leads to a less accurate estimate of the export but not necessarily results in underestimating it.

Lines 454-456: As a consequence, the SS model was shown to poorly describe the magnitude of the $^{234}$Th export flux, leading to differences with the NSS model up to a factor of 3 (Buesseler et al., 1992; Martin et al., 2011).

- *Line 552: has also been observed...*

Okay, see line 557.

- *Line 560: replace 'the period of our study' by 'late spring' (or something else)*

Okay, see line 565.

- *Line 564: Strong variability of PP during this longer period would strongly impact the ratio.*

Lines 568-569: Strong variability of PP during this longer period would highly impact the ThE ratio.

- Line 579: could it also reflect lower particle sinking speeds?

Indeed, thank you.

Lines 581-585: The low T100 (and high R100) values observed in the eastern part of the transect (Stations 1, 13 and, to a lesser extent Station 21) likely reflect an important bacterial activity in these warmer waters (>13°C in the upper 100 m; Iversen and Ploug, 2013; Marsay et al., 2015; Rivkin and Legendre, 2001), efficiently degrading the probably slow-sinking particles. Such recycling is characteristic for regeneration-based microbial food webs in oligotrophic regimes (Karl, 1999; Thomalla et al., 2006).

- *Line 594: over a month duration or during the 1-month long cruise*

Okay, see line 599.

- *Line 594: large temporal variability*

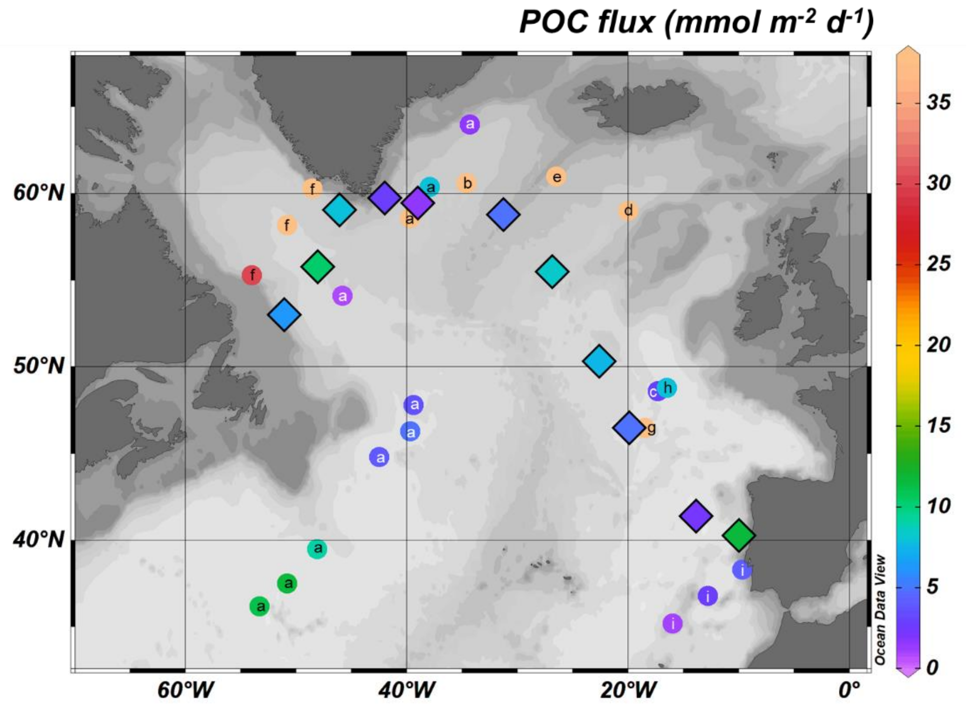
Okay, see line 599.

- *Line 598: seems also related...*

Okay, see line 603.

- *the black letters are hard to read on dark (blue or purple) circles. (maybe change them to white...)*

This is right, and we changed the colour of the numbers.



- *remove 'determined'*

Okay, see Figure 8.

- *Replaced 'determined' by 'measured on'*

Okay, see Figure S1.