Response to Referee #2

We thank Referee #2 for the helpful comments. Before we respond to the individual comments, we would like to make the following remark:

The technique of using the radioactive disequilibria between parent and daughter isotopes to quantify the removal fluxes by particles in the ocean has been used for decades. The most commonly used two parent/daughter pairs to estimate particulate organic carbon (POC) export fluxes are $^{234}Th/^{238}U$ and $^{210}Po/^{210}Pb$, which integrate the changes in the water column over weeks to months, respectively. There are advantages and limitations of each radiotracer pair and the simultaneous use of both can provide more useful comparative information. During the GEOVIDE cruise, both tracers have been utilized to quantify the POC export and the companion $^{234}Th/^{238}U$ paper (Lemaitre et al., 2018) is already published in this issue. In the present study, we did the calculations and some discussions in parallel to the $^{234}Th/^{238}U$ paper. We acknowledge the technique is not perfect and we have written a manuscript that will be submitted for publication soon (Tang et al., in preparation) about when and where applying these methods are legitimate, meaning the model assumptions will be true only under specific conditions.

- This manuscript studies the export of POC from 10Po/210Pb disequilibria using a new data set acquired in the subpolar North Atlantic in 2014 during the GEOVIDE cruise. The manuscript is clearly written and could eventually be published once the authors have adequately responded to the following major comments.

We will address all changes in the revised manuscript as detailed in our responses below. The referee comments are in black and their line numbers refer to the revised manuscript. Our responses are in blue text.

- The authors used the time-averaged vertical velocity from ECCO to study vertical advection effects on 210Po export fluxes. It should be made clear in the text that it is indeed the time-averaged vertical velocity that was used. The time period when the vertical velocity was averaged should be mentioned as well.

We will clarify this on Lines 202-209 as the following:

"We selected the ECCO2 grid points closest to the station and extracted vertical velocities from the depths between z and (z + 20 m) during 30 days prior to the sampling date at each station. Because the deficit of ^{210}Po activity in the water column weighs the changes that occurred shortly prior to the sampling time more heavily than those that occurred further back in time (Verdeny et al., 2009), we chose to average the vertical velocity over one month rather than over the mean life of ^{210}Po (200 days). The 30-day averaged vertical velocity was then used to calculate vertical advective ^{210}Po export flux via Eq. (3) at each station."

We will also change the title of section 3.2. to "One-month averaged vertical velocity w_{20}" on Line 256.

- My main problem here is that, as mentioned by the authors, circulation is highly variable in the region. What is the rational for using a time-averaged vertical velocity and not the vertical velocity at the time of the cruise.

The water column inventory of ^{210}Po represents an integration of the changes over approximately the mean life of the isotope (200 days). That is why we used a time-averaged vertical velocity rather than the vertical velocity measured by the acoustic doppler current profiler (ADCP) at the sampling time. We will add the following text on Lines 181-185:

"Because the water column inventory of ^{210}Po represents an integration of the changes over approximately the mean life of the isotope, we did not use the vertical velocity measured by the acoustic doppler current profiler (ADCP) at the sampling time but a time-averaged vertical velocity from the Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2)."

In addition, we chose to average the vertical velocity between z and (z + 20 m) over one month prior to the sampling time (w_{20}) rather than over the mean life of ^{210}Po. This is because the higher range of the absolute values of w_{20} was 0.9-3.6 × 10^{-5} m s^{-1} (0.8-3 m d^{-1}, Table 1). Water masses with these velocities would travel vertically more than 20 m in a month. Moreover, the deficit of ^{210}Po activity weighs the changes that occurred shortly prior to the sampling time more heavily than those that occurred further back in time (Verdeny et al., 2009). We therefore chose to average one month rather than 200 days in order to highlight the advective impact for the depths with large monthly w_{20}.

We will add the following text on Lines 202-209:

"We selected the ECCO2 grid points closest to the station and extracted vertical velocities from the depths between z and (z + 20 m) during 30 days prior to the sampling date at each station. Because the deficit of ^{210}Po activity in the water column weighs the changes that occurred shortly prior to the sampling time more heavily than those that occurred further back in time (Verdeny et al., 2009), we chose to average the vertical velocity over one month rather than over the mean life of ^{210}Po (200 days). The 30-day averaged vertical velocity was then used to calculate vertical advective ^{210}Po export flux via Eq. (3) at each station."

- What is the variance of the vertical velocity field? How does this variance translate into a variance of the 210 Po export flux? How robust are the conclusions on the effects of vertical advection on 210Po export fluxes, given this variance?

The standard deviations of vertical velocities over one month were generally of the same order as the values of the vertical velocities themselves. Particularly large standard deviations, which exceed the typical values of the vertical velocity by a full order of magnitude, were found at station 13 (35-55 m, 110-130 m) and station 21 (110-130 m). These high standard deviations suggest that we should be careful when interpreting this data.

We will add this information on Lines 258-262 as the following:

"The standard deviations of w_{20} were generally of the same order as the values of w_{20}. Particularly large standard deviations, which exceed the typical values of the vertical velocity by a full order of magnitude, were found at stations 13 (35-55 m, 110-130 m) and station 21 (110-130 m). These high standard deviations suggest that the data of w_{20} should be used with great care."

The uncertainties of the ^{210}Po export flux calculated by Eq. (3) are obtained by using principles of error propagation. The main sources of uncertainty for ^{210}Po activity are associated with the counting of ^{210}Po and ^{209}Po by alpha spectrometry, the activity of the ^{209}Po spike, the detector background, the Pb recovery, and the uncertainty associated with ^{210}Pb activity (Rigaud et al., 2013). The final calculated uncertainty of the ^{210}Po export flux had incorporated the uncertainty of the ^{210}Po activity and the vertical velocity field. This final calculated uncertainty changed with the vertical velocity field due to the substantial variance in the velocity field. When excluding three depths at stations 13 and 21, the uncertainty of the ^{210}Po export flux was on average 2-fold larger than the value of ^{210}Po export flux. When the uncertainty propagated from all the variables mentioned above confirms that our estimates are the right order of magnitude, we feel justified in publishing the results, and confident in their contribution to our understanding of the behavior of ^{210}Po along this cruise track.

We will add the following text on Lines 347-352:

"The magnitude of the uncertainty of the ^{210}Po export flux due to vertical advection was influenced by the large variance in vertical velocity field mentioned in Sect. 3.2. When excluding the three depths at stations 13 and 21 where the monthly vertical velocity average had substantial standard deviations (an order of magnitude greater than w_{20}), the uncertainty of the ^{210}Po export flux was on average 2-fold larger than the calculated ^{210}Po export flux."

In addition, there are multiple ways to estimate sinking flux of particulate organic carbon (POC), including sediment traps and radioactive disequilibria techniques (e.g., ^{234}Th/^{238}U, ^{210}Po/^{210}Pb), but every technique has its own limitations (e.g., Buesseler et al., 2007). In the present study, we investigated how the assumption of negligible advection potentially affects the ^{210}Po export flux and POC flux estimates. We think that these estimates and their associated uncertainties are reasonable and, therefore, we believe that this data can be useful especially when combined with other data (e.g., ^{234}Th) presented in this special issue. This can provide both a greater picture of export fluxes in the North Atlantic in Spring 2014 and potentially valuable data for future studies.

- While recognizing that horizontal advection contribution can be as large as vertical advection, the authors neglects horizontal advection because they do not have the data to compute it. What I understand is that results might have been significantly different if horizontal advection could have been estimated. So what is the point of publishing results from a 1D model that everyone knows it is flawed?

We agree that a 1-D model has limitations, but we cannot fully estimate the scale of the problem in the context of this study because the horizontal sampling density along the GEOVIDE cruise did not allow it.

We realized that the original statement of "… and we must assume the horizontal advection could have influenced the ^{210}Po export flux at a similar scale" is not accurate and will remove it and add the following sentence on Lines 365-368:

"However, because our study region was characterized by distinct water masses separated by only 10s to 100s of meters in the vertical plane, but those same water masses covered huge distances (100s to 1000s of kilometer) in the horizontal plane (Fig. 4 in García-Ibáñez et al., 2018), vertical advection can result in more changes in physical and chemical parameters over the scale of our depth sampling than horizontal advection would across long distances in the horizontal plane. Because the advective ^{210}Po export flux was calculated as the product of the velocity of the water mass and the gradient of ^{210}Po activity in the corresponding direction, horizontal advection would most likely contribute a much smaller range of advective ^{210}Po flux estimates."

Overall, the influence of physical processes on ^{210}Po activity may range from relatively unimportant to dominant depending on the study area. For the future study of ^{210}Po and ^{210}Pb activity we suggest having this process incorporated into ^{210}Po export models and, therefore, planning a higher sampling resolution particularly in regions of established upwelling or ocean margins. For example, during the North Atlantic GA03 transect, Hayes et al., (2015) had examined boundary scavenging of ^{230}Th and ^{231}Pa by including zonal advection at 4 stations close to the Mauritanian margin. Unfortunately, only one station near the Mauritanian margin was sampled for ^{210}Po and ^{210}Pb activity during the same cruise and therefore zonal advection on ^{210}Po export flux could not be evaluated.

We will suggest this on Lines 372-378 as the following:

"Overall, the influence of physical advection on ^{210}Po activity may range from relatively unimportant to dominant depending on the study area. In this study, we should keep in mind that physical processes may change the ^{210}Po fluxes, in particular at stations 1 and 60. For future studies of ^{210}Po and ^{210}Pb activity in regions of established upwelling or ocean margins, we suggest designing the sampling plan so that the magnitude and variability of these processes may be incorporated into the ^{210}Po export models. At ocean margins, in particular, more water samples should be taken to improve the resolution of horizontal features."

References:

Buesseler, K. O., Antia, A. N., Chen, M., Fowler, S. W., Gardner, W. D., Gustafsson, Ö., Harada, K., Michaels, A. F., Rutgers van der Loeff, M., Sarin, M., Steinberg, D. K. and Trull, T.: An assessment of the use of sediment traps for estimating upper ocean particle fluxes, Journal of Marine Research, 65, 345-416, http://epic.awi.de/12944/, 2007.

García-Ibáñez, M. I., Pérez, F. F., Lherminier, P., Zunino, P., Mercier, H. and Tréguer, P.: Water mass distributions and transports for the 2014 GEOVIDE cruise in the North Atlantic, Biogeosciences, 15, 2075-2090, https://doi.org/10.5194/bg-15-2075-2018, 2018.

Hayes, C. T., Anderson, R. F., Fleisher, M. Q., Huang, K., Robinson, L. F., Lu, Y., Cheng, H., Edwards, R. L. and Moran, S. B.: 230Th and 231Pa on GEOTRACES GA03, the U.S. GEOTRACES North Atlantic transect, and implications for modern and paleoceanographic chemical fluxes, Deep Sea Research Part II, 116, 29-41, 2015.

Lemaitre, N., Planchon, F., Planquette, H., Dehairs, F., Batista, D. F., Roukaerts, A., Deman, F., Tang, Y., Mariez, C. and Sarthou, G.: High variability of export fluxes along the North Atlantic

GEOTRACES section GA01: Particulate organic carbon export deduced from the 234Th method, Biogeosciences, 15, 6417-6437, https://doi.org/10.5194/bg-15-6417-2018, 2018.

Rigaud, S., Puigcorbé, V., Camara-Mor, P., Casacuberta, N., Roca-Martí, M., Garcia-Orellana, J., Benitez-Nelson, C. R., Masqué, P. and Church, T.: A methods assessment and recommendations for improving calculations and reducing uncertainties in the determination of 210Po and 210Pb activities in seawater, Limnology and Oceanography Methods, 11, 561-571, 10.4319/lom.2013.11.561, 2013.

Verdeny, E., Masqué, P., Garcia-Orellana, J., Hanfland, C., Kirk Cochran, J. and Stewart, G. M.: POC export from ocean surface waters by means of 234Th/238U and 210Po/210Pb disequilibria: A review of the use of two radiotracer pairs, Deep Sea Research Part II, 56, 1502-1518, 10.1016/j.dsr2.2008.12.018, 2009.