***Interactive comment on* "Global database of oceanic particulate organic carbon to ^{234}Th ratios: Improving estimates of the biological carbon pump" *by* Viena Puigcorbé et al.**

Response to reviewers

We greatly appreciate the comments of the Reviewers as they both consider the value of this paper for future use and modeling. Their constructive comments have helped us to improve the manuscript. We have expanded the dataset to include 2 studies that have been published between mid 2019 and March 2020 and an additional unpublished work from the authors, adding a total of 208 extra data points. We have edited the text to avoid repetitions and to simplify its reading and we have also modified some of the figures based on the reviewers' suggestions. Please find below the detailed responses to the reviewers' comments.

***RC1* Erin Black (Referee)**

eblack@dal.ca
Received and published: 5 March 2020

Introduction and Methods: Good introduction and justification for this study. The data will be very useful for future modeling. Sufficient detail given in the methods and database setup section.

Line 70+: 'While uranium is conservative and proportional to salinity in well oxygenated seawater (Chen et al., 1986; Ku et al., 1977; Owens et al., 2011), thorium is not soluble in seawater it is scavenged by particles as they form and/or sink along the water column.' Should there be a comma after 'in seawater, it is scavenged'?

R: Thanks, we have changed it accordingly.

Lines 89-95: 'The determination. . .oligotrophic regions'. This sentence is rather long and might be easier to read if broken up.

R: We have split the sentence in two. It now reads as: (L88-94) "*The determination of the POC/Th ratio has been historically attained by assuming that sinking carbon is driven by large particles, generally >50 μm in size (researchers also use 51, 53 or 70 μm, depending on the mesh supplier) whereas organic carbon within small particles is assumed to remain suspended and therefore not contribute to the export flux (Bishop et al., 1977; Fowler and Knauer, 1986). However, recent studies have shown that small particles can be significant players in the particle export and should not be disregarded (Alonso-González et al., 2010; Durkin et al., 2015; Le Gland et al., 2019; Puigcorbé et al., 2015; Richardson, 2019), particularly in oligotrophic regions.´´*

Lines 194-197: 'These high ratios. . .'. Should there be a comma before the 'but' in this sentence?

R: We have added a comma as suggested.

Lines 200-204: Another rather long sentence. I would suggests breaking it up for clarity, but this is only personal preference and the authors should do what they think is best.

R: We have left this sentence as it was: (L200-204) "*High POC/Th ratios are usually associated to the presence of large phytoplankton groups, such as diatoms, which are dominant in high latitude areas with no nutrient limitations, or where zooplankton populations are large and there is a significant input of fecal pellets, which should have also high POC/Th ratios.*"

Lines 206-207, Lines 216-217: Suggested comma before 'but'.

R: We have added a comma as suggested.

Lines 214-215: This sentence needs an ending. 'compared it to three different satellite-derived export'. . .export what? Models? Estimates?

R: Thanks. We have added the missing word, "models".

Lines 220-221: Is the citation format ok here? I would think it should be 'as done by Henson et al (2011)'.

R: Indeed. We have corrected it.

Section 3.4: Remove period from after recommendations since there isn't a period after other section titles.

R: Done.

Line 231: Either use 'we recommend that' or say something like 'it would be beneficial for future efforts to obtain data. . .'. Saying 'it would be recommended' is a bit awkwardly phrased.

R: We have edited the sentence as suggested and now it reads as: (L230) "It would be beneficial for future efforts to obtain data…."

Figure 1: where you say 'see main text for details' please put the Section number where you mention these definitions.

R: We have added "section 3.1 Data classification" in the caption of Figure 1.

Figure 2: It's a bit hard to see the variability in A-C. Since this is a database presentation, the readers can plot the data themselves and don't need additional figures in the manuscript. However, I wish some of these figures were log scale and/or bigger.

R: We concur and we have modified Figure 2 to have a maximum ratio of 100 µm/dpm so that the variability can be clearly seen. The modified Figure 2 is this one:

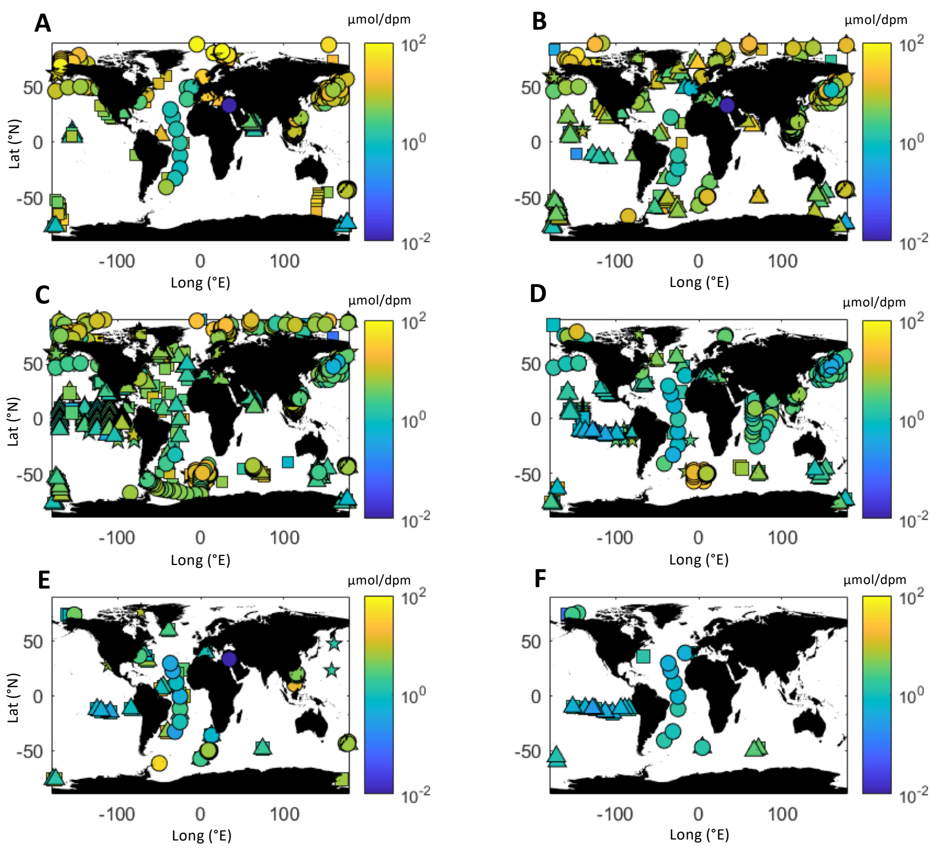


Figure 5: Does log-scale look any different or provide more information to the reader? Only a thought, not a suggestion.

R: No, not really. The aim of this figure is to show the magnitude of the ratios along the latitudinal range where they were collected. We believe Fig. 5 shows what is meant to show and the log-scale does not provide more information to the reader.

Database use comments: Locating the files was easy. Generally, the data is presented in a usable format. I would recommend that the authors note when actual dates and lat/long were not available for each location (and midpoints were used as noted in the text). It would be helpful for the data users to know which dates and locations are exact and which are not. If this was already done and indicated, I didn't see it and the authors should point clearly to this identifier in the text.

R: We agree that is important to know which dates and locations are exact and which ones are midpoint. In order to simplify the initial dataset we were recommended to have the data in one spreadsheet and the comments related to that dataset in another. Therefore two additional datasets are found in the main page for the dataset in https://doi.pangaea.de/10.1594/PANGAEA.911424, one with the actual data and the other with the comments (see screenshot below):

Datasets listed in this publication series

1. **Puigcorbé, V (2019):** Global database of oceanic particulate organic carbon to particulate ^{234}Th ratios: Comments. https://doi.pangaea.de/10.1594/PANGAEA.902103
2. **Puigcorbé, V (2019):** Global database of oceanic particulate organic carbon to particulate ^{234}Th ratios: Data. https://doi.pangaea.de/10.1594/PANGAEA.911423

In order to clarify this aspect, we have added the link to the "comments" of the dataset in the main text (see L148-149): "*(see details in the comments related to the dataset; https://doi.pangaea.de/10.1594/PANGAEA.902103; Puigcorbé, 2019).*"

The data may not be intended for use in Microsoft excel, however, I opened the file in a tab-delimited format and some odd symbols showed up. For instance, 'POC/234Th [Âµmol/dpm] (C/Th ST)' has an odd A in the heading. The actual data (numbers) are not impacted, so this issue is extremely minor. I can clearly understand and use the data as is. It may only be possible to post the data in a few formats and it seems like the website indicates which formats these are.

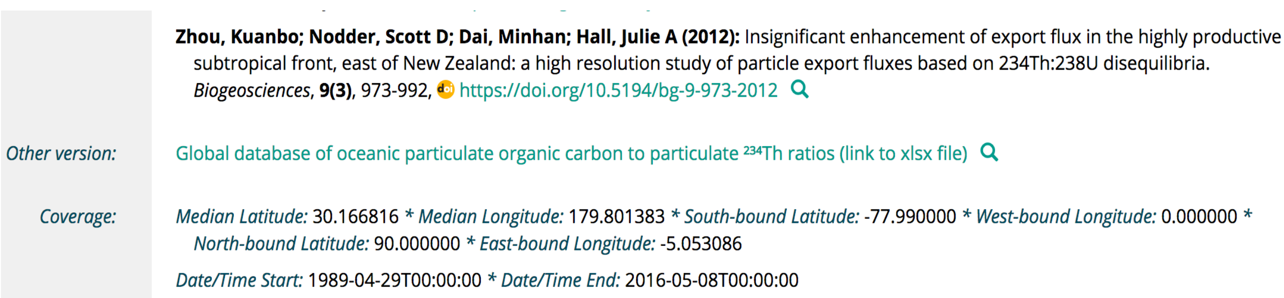
R: We have experienced that same issue and discussed it with the PANGAEA Data Archiving & Publication team. The issue is related to the way the file it is opened. Their response was:

"When you download the file from PANGAEA, you can select encoding. For us standard is UTF-8. If I want to get both issues right (names and ranges not in date format), I open a new sheet first, then go to tab Data and select Import from Text. Then I find the Tab file stored on the computer (need to specify "all" formats, .tab doesn't show automatically in my version). Then comes:

1. *a dialog, in which you can choose how to import the data, so first select "separated" and encoding UTF-8*
2. *tab as delimiter,*
3. *and the difficult part in the next step, finding the column that should not be date and change the format to Text. This is not trivial in such a complicated table, off course.*

This is really an unpleasant way if you want to get the table into excel, but then some people do not use excel and this .tab format which we use as an export format for the tabular data in the database is machine readable and also better suited for starting to work with it in R or Python. For better visualization adding another version in Excel like you did is probably a good compromise between human and machine readability."

To avoid this problem for Excel users we provided the dataset in an Excel file that can be downloaded directly and it should not have the problem with the odd symbols. The Excel file can be found just after the list of references under "Other version" section (see screenshot below).


Zhou, Kuanbo; Nodder, Scott D; Dai, Minhan; Hall, Julie A (2012): Insignificant enhancement of export flux in the highly productive subtropical front, east of New Zealand: a high resolution study of particle export fluxes based on 234Th:238U disequilibria. *Biogeosciences*, **9(3)**, 973-992, https://doi.org/10.5194/bg-9-973-2012

Other version: Global database of oceanic particulate organic carbon to particulate ^{234}Th ratios (link to xlsx file)

Coverage: *Median Latitude:* 30.166816 * *Median Longitude:* 179.801383 * *South-bound Latitude:* -77.990000 * *West-bound Longitude:* 0.000000 * *North-bound Latitude:* 90.000000 * *East-bound Longitude:* -5.053086

Date/Time Start: 1989-04-29T00:00:00 * *Date/Time End:* 2016-05-08T00:00:00

RC2 Anonymous Referee #2

Received and published: 11 March 2020

Global database of oceanic particulate organic carbon to 234Th ratios: Improving estimates of the biological carbon pump by Viena Puigcorbé, Pere Masqué, Frédéric A. C. Le Moigne

General comments

Overall, this data description paper is straightforward and generally well-written. The data compilation has the potential to further the reuse of the extensive dataset and be useful for future interpretations and models. However, as it should contain all data available, it would be necessary and reasonable to extend the dataset to 2018 (at least). In addition, some sections are redundant and the conclusion section is too similar to the abstract.

R: The dataset submitted covered studies published until mid 2019. The sampling for those studies took place between 1989 and 2016. Since mid 2019 until March 2020 we have found 2 more publications reporting POC/Th ratios, which have now been included, increasing the dataset with 129 additional data points. The overall message of the manuscript does not change with the addition of these two new studies.

We have rephrased the introduction and conclusion sections to avoid similarities with the abstract and tried to shorten and simplify the text to minimize long sentences and redundancies.

Specific comments

Lines 29-32: However, quantifying the magnitude of the biological carbon pump at both the regional and global scales is challenging and current assessments vary widely, with estimates ranging from 5 to 20 GtC y-1 being exported below the euphotic zone or the mixed layer depth (Guidi et al., 2015; Henson et al., 2011; Laws et al., 2011).

Are the wide ranges of estimates due to the challenges of quantifying the magnitude of the biological carbon pump, or do they simply accurately reflect the actual spatial and temporal variations? Please clarify the statement.

R: We believe this range largely reflects the paucity of estimates and methods used. Variability at spatial scale is large, and of course also seasonally. In some case, even if estimates are reported as annual values, the calculations are made assuming a number of considerations, hence significant uncertainty applies. And models, no matter how sophisticated, are known not to be perfect.

Lines 85-87: The sinking particles from which the ratio is measured should, ideally, be collected at the depth where the export has been estimated and represent the pool of particles that is driving the export of organic carbon.

It would be informative to highlight these 'ideal' datasets in the table; future users may want to focus on these data only. It would also be interesting to verify if the same trends reported here would be observed when using these data only.

R: That depth will change depending on the study. Traditionally a 100-150 m depth is been used (see compilation by Le Moigne et al. (2013), Global database of surface ocean particulate organic carbon export fluxes diagnosed from the ^{234}Th technique, ESSD). Recent studies have highlighted the importance of using different depths based on depth of the euphotic zone, or more recently, the depth of the primary production zone (e.g., Owens et al. 2015, Puigcorbé et al. 2017) or the equilibrium depth (e.g., Thomalla et al. 2006, Puigcorbé et al. 2017). We do not have this information available for many of the studies compiled in this dataset and it goes beyond its scope, but modelling efforts could use records of mixed layer depth or euphotic zone depths to assess what that ideal depth would be in each case.

Lines 149-150: The database consists of 9110 measurements of POC/Th ratios in the ocean. Particles were collected using in situ pumps (ISP), water collection bottles (CB) and sediment traps (ST). Could you provide the amount of measurements for each method in the text?

R: Table 1 contains the number of measurements classified as "small particles", "large particles", "bulk particles" and "sediment traps". We refer to that table in L162 at the end of that paragraph.

Other points to discuss:
1- POC flux composition

Lines 201-206: High POC/Th ratios are usually associated to the presence of large phytoplankton groups, such as diatoms, which are dominant in high latitude areas with no nutrient limitations, or where zooplankton populations are large and there is a significant input of fecal pellets, which should have also high POC/Th ratios. Low ratios, on the other hand, are commonly observed in warm oligotrophic areas where productivity is limited and the main phytoplanktonic groups are picoplankton (see Buesseler et al., 2006 and references therein).

While the influence of the composition of the POC flux is mentioned, it is possible that this is the main factor influencing POC/Th ratios. Seasonal, regional and depth variations may actually simply reflect variations in the composition of the fluxes. Could the authors further discuss this important aspect? Determining the composition of the POC flux is critical to better understand variations in POC/Th ratios and in the magnitude of the POC flux and this should be emphasized.

R: We concur. Unfortunately, not all the studies included in this dataset have a detailed POC flux composition description so we cannot provide additional information in that sense. However, the final goal of compiling this dataset is to use it in combination with other major datasets and satellite-derived tools in order to contribute to decipher this type of questions and be able to model the variability of the POC/Th in the global ocean.

2-Timescale

What about the difficulty of comparing POC/Th ratios (timescale of weeks) to global patterns of surface productivity, phytoplankton composition, zooplankton abundance, mixed layer depth, dust inputs to the surface ocean, and ice cover; all measurements with shorter timescales? Please address this issue.

R: The POC/Th ratio at a certain location and at a certain time is not integrating over weeks (the ^{234}Th export flux is). We can then put that information (POC/Th ratio) together with other data, such as the one mentioned, obtained at the same time and location, without necessarily using different time scales. If needed, surface productivity can be integrated over different time scales from satellite-products, and similarly it can be done with some of other of the parameters mentioned where data is available from time-series studies. No action taken.

3-Lateral advection

Could the export of small particles reflect lateral advection instead of downward export?

R: Each study has its particularities based on the location and the currents in the area. Advection is not commonly assessed in ^{234}Th-derived POC export studies and it tends to be considered negligible. This is likely a valid approach in the open ocean. Small particles that might sink slow are potentially more affected by lateral movements than particles that sink fast. Still, small does not necessary imply slow sinking and therefore, lateral advection may or may not have an impact on small particles. However, this discussion is beyond the scope of this paper, which is primarily intended for publishing a dataset, and could be addressed in a more specific study by assessing the hydrography of the study area and the sinking velocities of the particles. We do not have this information for the dataset provided here.

Technical corrections

-The first sentences of the introduction are the exact same sentences than the abstract - Please modify.

R: That sentence has been modified and now it reads as: "The vertical export of photosynthetically produced particulate organic carbon, from the surface waters to the deep ocean (i.e. biological carbon pump; Eppley and Peterson, 1979), has a strong impact in the global carbon cycle."

-While Lepore and Moran (2007) is listed in Pangaea, it is not listed in the reference list and in the table. Was it included in the analysis? - Please revise the reference list.

R: Thanks for noticing it. Lepore and Moran (2007) should not be listed in PANGAEA, Lepore et al. (2007) Seasonal and interannual changes in particulate organic carbon export and deposition in the Chukchi Sea, should be the reference used instead. It is correctly cited in the manuscript but not in the online repository. The mistake has been corrected.

-Some sentences are much too long - Please revise throughout the text.

R: We have revised the text and shortened those sentences that were unnecessarily long.

-Please do not use language such as: . . .is presented in Figure 4; Figure 3 shows. . . ; . . .are shown in Figure 4. Simply refer to the figure at the end of the sentence.

R: We do not find that change necessary and we have not modified the text in that sense.

-Figure 2: Could you adjust the color scales (log?) so that it is possible to see a gradient? It appears all or nothing as it is.

R: We concur and we have modified the figure to show the colour scale in log format. See new Fig 2 in response to comments from reviewer #1 above.

-Figure 4 would benefit from larger fonts.

R: We have increased the size of the fonts as much as space permits.

Global database of oceanic particulate organic carbon to ^{234}Th ratios: Improving estimates of the biological carbon pump

Viena Puigcorbé[1], Pere Masqué[1,2], Frédéric A. C. Le Moigne[3]

[1] School of Science, Centre for Marine Ecosystems Research, Edith Cowan University, Joondalup WA 6027, Australia.
[2] Institut de Ciència i Tecnologia Ambientals and Departament de Física, Universitat Autònoma de Barcelona, 08193 Cerdanyola del Vallès, Spain.
[3] Mediterranean Institute of Oceanography, UM110 CNRS, Aix-Marseille Université, IRD, 13288 Marseille, France.

Correspondance to : Viena Puigcorbé (viena.puigcorbe@outlook.com)

Abstract

The ocean's biological carbon pump (BCP) plays a major role in the global carbon cycle. A fraction of the photosynthetically fixed organic carbon produced in surface waters is exported below the sunlit layer as settling particles (e.g. marine snow). Since the seminal works on the BCP, global estimates of the global strength of the BCP have improved but large uncertainties remain (from 5 to 20 GtC yr^{-1} exported below the euphotic zone or mixed layer depth). The ^{234}Th technique is widely used to measure the downward export of particulate organic carbon (POC). This technique has the advantage to allow a downward flux to be determined by integrating the deficit of ^{234}Th in the upper water column and coupling it the POC/^{234}Th ratio in sinking particles. However, the factors controlling the regional, temporal and depth variations of POC/^{234}Th ratios are poorly understood. We present a database of 9318 measurements of the POC/^{234}Th ratio in the ocean, from the surface down to >5500 m, sampled on three size fractions (~>0.7 µm, ~1-50 µm, ~>50 µm), collected with *in situ* pumps and bottles, and also from bulk particles collected with sediment traps. The dataset is archived on the data repository PANGAEA® (www.pangaea.de) under https://doi.pangaea.de/10.1594/PANGAEA.911424 (Puigcorbé, 2019). The samples presented in this dataset were collected between 1989 and 2018 and the data have been obtained from published papers and open datasets available online. Unpublished data has also been included. Multiple measurements can be found in most of the open ocean provinces. However, there is an uneven distribution of the data, with some areas highly sampled (e.g, China Sea, Bermuda Atlantic Time Series station) compared to some others that are not well represented, such as the southeastern Atlantic, the south Pacific and the south Indian oceans. Some coastal areas, although in a much smaller number, are also included in this global compilation. Globally, based on different depths horizons and climate zones, the median POC/^{234}Th ratios have a wide range, from 0.6 to 18 µmol dpm^{-1}.

Deleted: 110

Deleted: 6

1 Introduction

The vertical export of photosynthetically produced particulate organic carbon, from the surface waters to the deep ocean (i.e. biological carbon pump; Eppley and Peterson, 1979), has a strong impact in the global carbon cycle. Through this process, the ocean stores carbon dioxide (CO_2) away from the atmosphere and buffers the global climate system (Kwon et al., 2009). Indeed, estimates suggest that atmospheric CO_2 levels would be 200 ppm

Deleted: The ocean's biological carbon pump (Eppley and Peterson, 1979) plays a major role in the global carbon cycle. A fraction of the photosynthetically produced organic carbon is exported from the surface waters below the sunlit layer as settling particles (e.g. marine snow).

higher than current concentrations without the biological carbon pump (Parekh et al., 2006). However, quantifying the magnitude of the biological carbon pump at both the regional and global scales is challenging and current assessments vary widely, with estimates ranging from 5 to 20 GtC y^{-1} being exported below the euphotic zone or the mixed layer depth (Guidi et al., 2015; Henson et al., 2011; Laws et al., 2011).

Downward export fluxes of organic carbon can be estimated using: (i) indirect approaches derived from nutrient uptake (Le Moigne et al., 2013a; Pondaven et al., 2000; Sanders et al., 2005), radioisotopes (Cochran and Masqué, 2003), satellite empirical algorithms (Dunne et al., 2007; Henson et al., 2011; Laws et al., 2011), underwater video systems (Guidi et al., 2008) or (ii) direct measurements using various designs of sediment traps (Buesseler et al., 2007; Engel et al., 2017; Lampitt et al., 2008; Owens et al., 2013) or marine snow catchers (Cavan et al., 2015; Riley et al., 2012).

Here we focus on the use of radioisotopes, specifically, ^{234}Th. The ^{234}Th approach allows to quantify an export flux from i) a water profile of ^{234}Th to obtain its deficit relative to ^{238}U combined with ii) an estimate of the POC concentration to ^{234}Th activity (POC/Th ratio) in sinking matter (Buesseler et al., 1992). In reviewing POC/Th ratios variability using the data available at the time, (Buesseler et al., 2006) found that the POC/Th ratios i) increase or remain constant with increasing particle size and ii) decrease with depth. Regionally, the POC/Th ratios vary largely between oceanic provinces and regimes (Puigcorbé et al., 2017a). The study of the biogeochemical behavior of ^{234}Th with regards to marine particles has received significant attention (Maiti et al., 2010; Le Moigne et al., 2013b; Puigcorbé et al., 2015; Rosengard et al., 2015; Santschi et al., 2006), and the availability of ^{234}Th related data has been enhanced thanks to international and national programs such as GEOTRACES (Mawji et al., 2015; Schlitzer et al., 2018) JGOFS (Joint Global Ocean Flux Study) (Buesseler et al., 1998, 1995, 2001) or VERTIGO (Buesseler et al., 2008b), yet the factors controlling the variations of the POC/Th ratio as function of region, time, particle size/type and water column depth remain poorly understood. Assessing the influence of such factors on the POC/Th ratios will contribute to improve our modelling efforts and our capacity to predict the export and fate of the organic carbon produced in the surface layers. Indeed, the necessity to constrain the variability of the POC/Th was discussed and considered a priority at the technical meeting "The Application of Radionuclides in Studies of the Carbon Cycle and the Impact of Ocean Acidification" held at the International Atomic Energy Agency (IAEA) Environment Laboratories in Monaco in October 2016 (Morris et al., 2017).

Therefore, we compiled a database that comprises 9318 POC/Th ratios collected between 1989 to 2018 covering most oceanic provinces at depths ranging from 0 to >5500 m deep. The particles were collected using collection bottles (i.e., Niskin), *in situ* pumps or sediment traps, and include bulk and size fractionated samples. This database increases significantly the pool of POC/Th ratio data available at the time of (Buesseler et al., 2006) and enables to test the influence of various factors on the variability of POC/Th ratios. Among other information, the influence of biogeochemical characteristics of the area (e.g, nutrient concentrations) together with the surface productivity levels, phytoplankton compositions, zooplankton abundance could be examined through satellites products and/or global databases (e.g., Buitenhuis et al., 2013; Moriarty et al., 2013; Moriarty and O'Brien, 2013).

Deleted: 110

Deleted: 6

2 Data

2.1 The ^{234}Th approach

The short-lived radionuclide thorium-234 (^{234}Th, $t_{1/2}$ = 24.1 d) is widely used to estimate the magnitude of the POC that escapes the upper ocean layers (e.g., the euphotic zone) (Waples et al., 2006). ^{234}Th is the decay product of uranium-238 (^{238}U, $t_{1/2}$ = 4.47·10^{9} y). While uranium is conservative and proportional to salinity in well oxygenated seawater (Chen et al., 1986; Ku et al., 1977; Owens et al., 2011), thorium is not soluble in seawater and it is scavenged by particles as they form and/or sink along the water column. As a consequence, a radioactive disequilibrium between ^{238}U and ^{234}Th can be observed, mainly in the upper layers of the water column, which in first approximation, is proportional to the amount of particles exported and hence can be used to estimate particle and elemental export fluxes.

One-box scavenging model (see review by Savoye et al. (2006) and references therein) is commonly applied to calculate ^{234}Th export rates. Steady state (SS) or non-steady state conditions (NSS) are assumed depending on the conditions at the sampling time and the possibility to reoccupy locations within an adequate timescale. Le Moigne et al. (2013c) reported ^{234}Th fluxes from both types of models in their database with flux integration depths spanning from the surface down to 300 m, although the most common integration depths were between 100 and 150 m. The choice of export depth when using the ^{234}Th technique is not trivial. Rosengard et al. (2015) provide recommendations to the various manners of choosing the export depth in order to integrate the ^{234}Th fluxes. Once the ^{234}Th export flux is estimated it is multiplied by the ratio of POC to particulate ^{234}Th activity in sinking particles to obtain the POC flux. The sinking particles from which the ratio is measured should, ideally, be collected at the depth where the export has been estimated and represent the pool of particles that is driving the export of organic carbon.

2.2 The crux of the ^{234}Th approach: POC/Th ratios of sinking particles

The determination of the POC/Th ratio has been historically attained by assuming that sinking carbon is driven by large particles, generally >50 µm in size (researchers also use 51, 53 or 70 µm, depending on the mesh supplier) whereas organic carbon within small particles is assumed to remain suspended and therefore not contribute to the export flux (Bishop et al., 1977; Fowler and Knauer, 1986). However, recent studies have shown that small particles can be significant players in the particle export and should not be disregarded (Alonso-González et al., 2010; Durkin et al., 2015; Le Gland et al., 2019; Puigcorbé et al., 2015; Richardson, 2019), particularly in oligotrophic regions. The most common methods to obtain the particulate fraction to measure the POC/Th ratio are i) *in situ* pumps (ISP), which can allow for sampling different particle sizes, ii) collection bottles (CB) such as Niskin bottles, providing bulk particles, i.e., >0.7 or 1 µm particles, iii) sediment traps (ST) and although less common iv) marine snow catchers. In some instance various methods have been used in combination (Cai et al., 2010; Maiti et al., 2016; Puigcorbé et al., 2015).

Different sampling devices have been shown to provide differences in POC/Th ratios, usually within a factor of 2 to 4 (Buesseler et al., 2006). The differences can be related to the collection of different particles pools and/or the enhanced presence of swimmers. ST collect sinking particles and may suffer from hydrodynamicdiscrimination and undersample slow sinking particles (Gustafsson et al., 2004), while CB sample both, sinking and suspended

Deleted: ,

Deleted: ,

Deleted: although

Deleted: r

particle, similar to ISP. ISP filter large volumes of water and have been suggested to potentially undersample some of the fast sinking particles (Lepore et al., 2009) and sample neutrally buoyant C-rich aggregates (i.e., non-sinking but with high POC/Th ratios) (Lalande et al., 2008). Biases due to washout of large particles when using ISP (Bishop et al., 2012) or aggregates collapse induced by their high cross-filter pressure (Gardner et al., 2003) may further enhance these differences. The presence of swimmers can also be an important bias of POC/Th ratios when not thoroughly removed, since they skew measurements towards higher values because of their high POC proportion compared to ^{234}Th (Buesseler et al., 1994; Coale, 1990).

2.3 POC/^{234}Th ratio variability

Despite the significant body of literature available on POC/Th ratios, more than 10 years after the review by (Buesseler et al., 2006) we still cannot explain the variability of the POC/Th ratios with depth, time, particle type, size or sinking velocity easily nor at a global level. Changes with size and depth have been the most extensively examined. The relation between POC/Th ratio and particle size have been assessed before with results suggesting that there is not a direct relationship. Previous studies have reported increasing ratios with increasing particle size (Benitez-Nelson et al., 2001; Buesseler et al., 1998; Cochran et al., 2000), which has been interpreted as an effect of the volume to surface area ratio of the particles, due to ^{234}Th being surface bound whereas C would be contained within the particles (Buesseler et al., 2006). Yet, a number of studies have reported the opposite trend (i.e., decreasing ratio with increasing particle size; (Bacon et al., 1996; Hung et al., 2010; Planchon et al., 2013; Puigcorbé et al., 2015) or no clear change with size (Hung and Gong, 2010; Lepore et al., 2009; Speicher et al., 2006). Depth is another factor that has been considered when assessing the variability of POC/Th, since particles are produced in the surface layer and are remineralized on their transit along the water column (Martin et al., 1987). POC/Th ratios have been found to be attenuated with depth (Jacquet et al., 2011; Planchon et al., 2015; Puigcorbé et al., 2015). This is due to (in no order or importance) decreasing autotrophic production with increasing water depth, preferential C loss compared to ^{234}Th through remineralization processes, changes in superficial binding ligands along the water column, and/or scavenging of ^{234}Th during particle sinking resulting in enhanced particulate ^{234}Th activities (Buesseler et al., 2006; Rutgers van der Loeff et al., 2002); leading to significant variability in the attenuation rates. Theoretically, high sinking velocities may limit the variations of POC/Th ratios with depth, owing to shorter residence times limiting the impacts of biotic and abiotic processes. However, using specifically design ST that segregate particles according to their *in situ* sinking velocities, (Szlosek et al., 2009) observed no consistent trend between POC/Th ratios and sinking velocities.

The truth is that numerous processes can impact the POC/Th ratios apart from particle size or depth, such as particle composition or aggregation/disaggregation processes mediated by physical or biological activity (Buesseler and Boyd, 2009; Burd et al., 2010; Maiti et al., 2010; Szlosek et al., 2009) which adds a level of complexity to the prediction of their variability in the ocean. Yet, due to the significance of the POC/Th ratios for the accuracy of the ^{234}Th flux method, the effort should be made to constrain the factors that will impact its variability and a number of environmental and biogeochemical parameters can be assessed with that goal at a global scale. Among others, surface productivity, phytoplankton composition, zooplankton abundance, mixed layer depth, dust inputs to the surface ocean and ice cover (Buitenhuis et al., 2013; Mahowald et al., 2009; Moriarty et al., 2013; Moriarty and O'Brien, 2013) are all potential candidates to test their global patterns against POC/Th ratios variability.

3 Results and discussion

3.1 Data classification

Our dataset is archived on the data repository PANGAEA® (www.pangaea.de), https://doi.pangaea.de/10.1594/PANGAEA.911424 (Puigcorbé, 2019). Latitude, longitude and sampling dates are reported. When dates of the individual stations were not reported in the original publications, we allocated the midpoint of the sampling period as the sampling date (see details in the comments related to the dataset; https://doi.pangaea.de/10.1594/PANGAEA.902103; Puigcorbé, 2019). The same was done when the specific sampling coordinates were not available. The database consists of 9318 measurements of POC/Th ratios in the ocean. Particles were collected using *in situ* pumps (ISP), water collection bottles (CB) and sediment traps (ST). We refer to "bulk" (BU) for particles sampled using CB and ISP with a pore size filter of 0.2-1 µm. For this group of samples, particles >0.7 µm were collected using GFF filters and >1 µm using QMA filters. In some particular cases other types of filters, with a different pore size (e.g., 0.2 µm, 0.45 µm or 0.6 µm) might have been used (see database for details). Hereafter, we use >1 µm for the bulk particles. We refer to "small particles" (SP) for particles usually collected using ISP on a 1-50 µm mesh size and "large particles" (LP) for particles usually collected using ISP on mesh size >50 µm (see details on other size ranges also used in the database). Finally, some POC/Th ratios were measured in sinking particles sampled using sediment traps (ST). Figure 1 shows the global distribution of POC/Th ratios grouped by these four categories: BU, LP, SP and ST. The POC/Th ratios were obtained from particles collected at various depths from surface to >5500 m deep (Figure 2). All the information on locations, dates, depth, size fractions/device (BU, SP, LP and ST) and references are included as metadata in the online database and presented in Table 1.

Our database covers POC/Th measurements sampled between 1989 and 2018, including unpublished data from our laboratories or graciously made available to us by colleagues and data available in online databases. Figure 3 shows the number of POC/Th measurements available per year. In years 1997, 2004, 2005, 2008, 2010, 2011 and 2013, the number of POC/Th measurements was >500. This highlights dedicated carbon export programs such as the Joint Global Ocean Flux Study (JGOFS) (Buesseler et al., 1998, 1992, 1995, 2001; Murray et al., 1996, 2005), the VERTIGO (Vertical Transport in the Global Ocean) voyages in the Pacific Ocean (Buesseler et al., 2008b), and the GEOTRACES program (Mawji et al., 2015; Schlitzer et al., 2018), as well as the maintained effort of the Time Series Stations (Kawakami et al., 2004, 2010, 2015; Kawakami and Honda, 2007). Sampling effort also varied depending on the month of the year (Fig. 3B), with late spring-summer months being the most highly sampled in both hemispheres. The northern hemisphere has been largely sampled in September, May and June (49, 10 and 5 times more data than in the southern hemisphere, respectively), whereas the southern hemisphere has been more sampled in December and February (5 and 4 times more data than the northern hemisphere, respectively), with no data available for the months of July and August and only 5 data points in September (austral winter). For the rest of the months, the northern hemisphere presents 1.4-1.8 times more data than the southern hemisphere. In the equatorial region (taken as the latitudes between -10° and 10° N) major sampling efforts took place in May, with no data collected in January and just 8 data points available from December. The monthly distribution is, therefore, globally biased towards the warmer and more productive seasons, leaving the winter months largely undersampled, particularly in the southern hemisphere.

Deleted: 110

Deleted: 6

3.2 Global variability: climate zones and depth horizons

The global variability of POC/Th ratios looking at six different depths horizons (50, 100, 200, 500, 1000 and >1000 m) and grouped by climatic zones (Polar >66.5°, Subpolar 66.5°-50°, Temperate 50°-35°, Subtropical 35°-23.5° and Tropical 23.5°N-23.5°S) is presented in Figure 4. A PERMANOVA analysis was conducted to examine the data and the results indicate that all the depths horizons defined here were significantly different ($p<0.05$). Significant differences were also found between climatic zones, except between the Temperate and Subtropical zones and between the Subtropical and the Tropical zones, when considering all the data together. Statistical differences between zones within a certain depth range are shown in Figure 4.

In general, we observe a reduction in POC/Th ratios with depth, previously reported by others (Buesseler et al., 2006), and likely mainly due to the remineralization of carbon along the water column. The decrease is particularly marked in the upper 200 m, where biological processes affecting the ratios are more intense, and then it smoothes below that depth horizon as the strength of these processes is more limited below the euphotic zone. It is worth noticing that some studies, particularly in coastal areas, presented extremely large POC/Th ratios (> 100 µmol dpm^{-1}, not included in Figure 4). These high ratios are not always discussed in the publications, but the presence of live zooplankton (Buesseler et al., 2009; Savoye et al., 2008; Trull et al., 2008) especially in BU, ST and LP fractions when not picked out can be the cause for those high values and should be considered with caution.

Regarding the climate zones, there is significant variability but, in general, large POC/Th ratios occur more often in productive and high latitude regions relative to low latitude tropical areas, particularly in the upper 200 m (Figure 4). When looking at the different types of sampling methods, the link between latitude and magnitude of the ratio seems to be clear for ST and BU but quite variable for LP and SP (Figure 5). High POC/Th ratios are usually associated to the presence of large phytoplankton groups, such as diatoms, which are dominant in high latitude areas with no nutrient limitations, or where zooplankton populations are large and there is a significant input of fecal pellets, which should have also high POC/Th ratios. Low ratios, on the other hand, are commonly observed in warm oligotrophic areas where productivity is limited and the main phytoplanktonic groups are picoplankton (Buesseler et al., 2006). Exceptions do exist, but they are usually found in coastal areas where other factors could be influencing the planktonic community (e.g., seasonal upwelling, continental influence, river inputs).

3.3 Contributing to global POC export estimates

The ^{234}Th approach has been used to derive an export model at global scale that uses sea surface temperatures and net primary productivity from satellite products (Henson et al., 2011). The parametrization for this model has large uncertainties in the cold regions (low sea surface temperature), which lead to a reduced estimate of the global biological carbon pump (~5 GtC y^{-1}) compared to other satellite-derived export models (9-13 GtC y^{-1}; (Dunne et al., 2007; Laws et al., 2011). A recent study by (Puigcorbé et al., 2017a) estimated POC export fluxes in the North Atlantic using *in situ* data for the ^{234}Th method and compared it to three different satellite-derived export models; Dunne et al., 2007; Henson et al., 2011 and Laws et al., 2011. The conclusion was that, overall, the geographical trends were captured by all the approaches, but the absolute values between them could reach important

Deleted: ,
Deleted: (
Deleted: ;
Deleted:)

discrepancies. In that study, the authors advised for a revision of the parametrization of the models going beyond sea surface temperatures in order to adjust to specific ocean bioregions. This database sets a strong background to develop that parametrization and contribute to similar modeling efforts to constrain the global carbon export fluxes as done by Henson et al., (2011).

Deleted: (

3.4 Significant gaps and recommendations

Deleted: .

This database provides the global POC/Th ratios sampled from all the oceans up until 2018. The sampling coverage is significant but it is not evenly distributed. Areas such as the China Sea, Arabian Sea, North Western Mediterranean Sea, Central Pacific and high latitudes of the Atlantic Ocean are well represented, whereas other areas, such as the oligotrophic gyres, West Pacific or the Southern Ocean, present important gaps. The data is not evenly distributed between seasons either, with most of the sampling taking place during spring and summer in both hemispheres, which is also when the export fluxes are expected to be larger. High seasonality in under sampled areas could potentially bias our global view of the POC/Th ratios and have an impact on the Th-derived carbon export fluxes estimates.

Deleted: 6

It would be beneficial for future efforts to obtain data for those undersampled areas with high seasonality to better characterize the expected variability in the ratios within those areas and to cover a larger span of seasons in order to better understand the seasonality of POC/Th and thus be able to translate it more accurately to the global POC export estimates.

Deleted: It would be

Deleted: recommend

Deleted: ed

4 Conclusion

Here we provide a global database of 9318 estimates of POC/Th ratio collected between 1989 and 2018 at various depths from below the surface to >5500 m deep using *in situ* pumps, Niskin® bottles and sediment traps. The observed pattern of POC/Th ratios reflects a decrease with depth and a link with the latitude, with higher ratios usually observed in high latitudes areas. Some noteworthy gaps in the dataset are the Benguela system, the Mauritanian upwelling, the western and south Pacific, and the Southern Indian Ocean. The fall-winter months in both hemispheres are also underrepresented. The temporal and spatial undersampling of some areas could bias the global view of the POC/Th ratios. Despite the gaps, this database is the largest compilation POC/Th ratios up to date and could be used to better understand the factors controlling the variation of ratios on a global scale. This will help revising and providing improved estimates of the ocean's biological carbon pump.

Deleted: 110

Deleted: s

Deleted: obtained

Deleted: 6

Deleted: . POC/Th ratios were sampled on three size fractions (~>0.7 µm, ~0.7-50 µm, ~>50 µm) or on the bulk of particles

Data availability

Our dataset is archived on the data repository PANGAEA® (www.pangaea.de), under the following doi: https://doi.pangaea.de/10.1594/PANGAEA.911424 (Puigcorbé, 2019).

Authors contribution

VP and FACLM compiled the dataset and prepared and reviewed the manuscript. All the authors contributed to the review of the manuscript.

Competing interests

The authors declare that they have no conflict of interest

Acknowledgements

We are very grateful to all of those that have provided data for this global database, specially to those authors that have provided unpublished data to make this database as complete as possible. We would like to thank also Elena Ceballos and Sian McNamara who helped during the preparation of the database. Also thanks to Daniela Ransby, from the PANGAEA Data Archiving & Publication team, for her support and efficiency during the data submission process. VP received funding from the School of Science at Edith Cowan University to compile the dataset and facilitate the collaboration with FACLM. Funding was provided to PM by the Generalitat de Catalunya (Grant 2017 SGR-1588). This work is contributing to the ICTA 'Unit of Excellence' (MinECo, MDM2015-0552). Thanks also to the Radioecology Laboratory of the IAEA for hosting the technical meeting "The Application of Radionuclides in Studies of the Carbon Cycle and the Impact of Ocean Acidification", in particular to Stephanie Morris and all the participants for the fruitful discussions.

References

Alkalay, R., Zlatkin, O., Katz, T., Herut, B., Halicz, L., Berman-Frank, I. and Weinstein, Y.: Carbon export and drivers in the southeastern Levantine Basin, Deep Sea Res. Part II Top. Stud. Oceanogr., 171, 104713, doi:https://doi.org/10.1016/j.dsr2.2019.104713, 2020.

Alonso-González, I. J., Arístegui, J., Lee, C., Sanchez-Vidal, A., Calafat, A., Fabrés, J., Sangrá, P., Masqué, P., Hernández-Guerra, A. and Benítez-Barrios, V.: Role of slowly settling particles in the ocean carbon cycle, Geophys. Res. Lett., 37(13), L13608, doi:10.1029/2010GL043827, 2010.

Amiel, D. and Cochran, J. K.: Terrestrial and marine POC fluxes derived from 234Th distributions and $δ$13C measurements on the Mackenzie Shelf, J. Geophys. Res. Ocean., 113(C3), doi:10.1029/2007JC004260, 2008.

Amiel, D., Cochran, J. K. and Hirschberg, D. J.: < sup> 234</sup> Th/< sup> 238</sup> U disequilibrium as an indicator of the seasonal export flux of particulate organic carbon in the North Water, Deep Sea Res. Part II Top. Stud. Oceanogr., 49(22), 5191–5209, 2002.

Anand, S. S., Rengarajan, R., Sarma, V. V. S. S., Sudheer, A. K., Bhushan, R. and Singh, S. K.: Spatial variability of upper ocean POC export in the Bay of Bengal and the Indian Ocean determined using particle-reactive 234Th, J. Geophys. Res. Ocean., 122(5), 3753–3770, doi:10.1002/2016JC012639, 2017.

Anand, S. S., Rengarajan, R. and Sarma, V. V. S. S.: 234Th-Based Carbon Export Flux Along the Indian GEOTRACES GI02 Section in the Arabian Sea and the Indian Ocean, Global Biogeochem. Cycles, doi:10.1002/2017GB005847, 2018a.

Anand, S. S., Rengarajan, R., Shenoy, D., Gauns, M. and Naqvi, S. W. A.: POC export fluxes in the Arabian Sea and the Bay of Bengal: A simultaneous 234Th/238U and 210Po/210Pb study, Mar. Chem., 198, 70–87, doi:https://doi.org/10.1016/j.marchem.2017.11.005, 2018b.

Aono, T., Yamada, M., Kudo, I., Imai, K., Nojiri, Y. and Tsuda, A.: Export fluxes of particulate organic carbon estimated from 234Th/238U disequilibrium during the Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study (SEEDS 2001), Prog. Oceanogr., 64(2–4), 263–282, doi:10.1016/j.pocean.2005.02.013, 2005.

Bacon, M. P., Cochran, J. K., Hirschberg, D., Hammar, T. R. and Fleer, A. P.: Export flux of carbon at the equator during the EqPac time-series cruises estimated from 234Th measurements, Deep Sea Res. Part II Top. Stud. Oceanogr., 43(4–6), 1133–1153, doi:10.1016/0967-0645(96)00016-1, 1996.

Baskaran, M., Swarzenski, P. W. and Porcelli, D.: Role of colloidal material in the removal of 234Th in the Canada basin of the Arctic Ocean, Deep Sea Res. Part I Oceanogr. Res. Pap., 50(10–11), 1353–1373, doi:http://dx.doi.org/10.1016/S0967-0637(03)00140-7, 2003.

Baumann, M. S., Moran, S. B., Lomas, M. W., Kelly, R. P. and Bell, D. W.: Seasonal decoupling of particulate organic carbon export and net primary production in relation to sea-ice at the shelf break of the eastern Bering Sea: Implications for off-shelf carbon export, J. Geophys. Res. Ocean., 118, 1–19, doi:10.1002/jgrc.20366, 2013.

Benitez-Nelson, C., Buesseler, K. O., Karl, D. M. and Andrews, J.: A time-series study of particulate matter export in the North Pacific Subtropical Gyre based on 234Th: 238U disequilibrium, Deep Sea Res. Part I Oceanogr. Res. Pap., 48(12), 2595–2611, doi:10.1016/S0967-0637(01)00032-2, 2001.

Benitez-Nelson, C. R., Buesseler, K. O. and Crossin, G.: Upper ocean carbon export, horizontal transport, and vertical eddy diffusivity in the southwestern Gulf of Maine, Cont. Shelf Res., 20(6), 707–736, doi:http://dx.doi.org/10.1016/S0278-4343(99)00093-X, 2000.

Bishop, J. K. B., Edmond, J. M., Ketten, D. R., Bacon, M. P. and Silker, W. B.: The chemistry, biology, and vertical flux of particulate matter from the upper 400 m of the equatorial Atlantic Ocean, Deep Sea Res., 24(6), 511–548, doi:10.1016/0146-6291(77)90526-4, 1977.

Bishop, J. K. B., Lam, P. J. and Wood, T. J.: Getting good particles: Accurate sampling of particles by large volume in-situ filtration, Limnol. Oceanogr. Methods, 10, 681–710, doi:/10.4319/lom.2012.10.681, 2012.

Black, E. E., Buesseler, K. O., Pike, S. M. and Lam, P. J.: 234Th as a tracer of particulate export and remineralization in the southeastern tropical Pacific, Mar. Chem., 201, 35–50, doi:10.1016/J.MARCHEM.2017.06.009, 2018.

Brew, H. S., Moran, S. B., Lomas, M. W. and Burd, A. B.: Plankton community composition, organic carbon and thorium-234 particle size distributions, and particle export in the Sargasso Sea, J. Mar. Res., 67(6), 845–868, doi:10.1357/002224009792006124, 2009.

Buesseler, K., Ball, L., Andrews, J., Benitez-Nelson, C., Belastock, R., Chai, F. and Chao, Y.: Upper ocean export of particulate organic carbon in the Arabian Sea derived from thorium-234, Deep. Res. Part II, 45(10–11), 2461–2487, doi:10.1016/S0967-0645(98)80022-2, 1998.

Buesseler, K. O. and Boyd, P. W.: Shedding light on processes that control particle export and flux attenuation in the twilight zone of the open ocean, Limnol. Oceanogr., 54(4), 1210–1232, doi:10.4319/lo.2009.54.4.1210, 2009.

Buesseler, K. O., Bacon, M. P., Cochran, J. K. and Livingston, H. D.: Carbon and nitrogen export during the JGOFS North Atlantic Bloom Experiment estimated from 234Th: 238U disequilibria, Deep Sea Res. Part A.Oceanographic Res. Pap., 39(7–8), 1115–1137, doi:10.1016/0198-0149(92)90060-7, 1992.

Buesseler, K. O., Michaels, A. F., Siegel, D. A. and Knap, A. H.: A three dimensional time-dependent approach to calibrating sediment trap fluxes, Global Biogeochem. Cycles, 8(2), 179–193, doi:10.1029/94GB00207, 1994.

Buesseler, K. O., Andrews, J. A., Hartman, M. C., Belastock, R. and Chai, F.: Regional estimates of the export flux of particulate organic carbon derived from thorium-234 during the JGOFS EqPac program, Deep Sea Res. Part II Top. Stud. Oceanogr., 42(2–3), 777–791, doi:10.1016/0967-0645(95)00043-P, 1995.

Buesseler, K. O., Steinberg, D. K., Michaels, A. F., Johnson, R. J., Andrews, J. E., Valdes, J. R. and Price, J. F.: A comparison of the quantity and composition of material caught in a neutrally buoyant versus surface-tethered sediment trap, Deep Sea Res. Part I Oceanogr. Res. Pap., 47(2), 277–294, doi:10.1016/S0967-0637(99)00056-4, 2000.

Buesseler, K. O., Ball, L., Andrews, J., Cochran, J. K., Hirschberg, D. J., Bacon, M. P., Fleer, A. and Brzezinski, M.: Upper ocean export of particulate organic carbon and biogenic silica in the Southern Ocean along 170 W, Deep Sea Res. Part II Top. Stud. Oceanogr., 48(19–20), 4275–4297, doi:10.1016/S0967-0645(01)00089-3, 2001.

Buesseler, K. O., Andrews, J. E., Pike, S. M., Charette, M. A., Goldson, L. E., Brzezinski, M. A. and Lance, V. P.: Particle export during the Southern Ocean Iron Experiment (SOFeX), Limnol. Oceanogr., 50, 311–327, 2005.

Buesseler, K. O., Benitez-Nelson, C. R., Moran, S. B., Burd, A., Charette, M., Cochran, J. K., Coppola, L., Fisher, N. S., Fowler, S. W. and Gardner, W. D.: An assessment of particulate organic carbon to thorium-234 ratios in the ocean and their impact on the application of 234Th as a POC flux proxy, Mar. Chem., 100(3–4), 213–233, doi:10.1016/j.marchem.2005.10.013, 2006.

Buesseler, K. O., Antia, A. N., Chen, M., Fowler, S. W., Gardner, W. D., Gustafsson, O., Harada, K., Michaels, A. F., Rutgers van der Loeff, M. and Sarin, M.: An assessment of the use of sediment traps for estimating upper ocean particle fuxes, J. Mar. Res., 65, 345–416, 2007.

Buesseler, K. O., Lamborg, C., Cai, P., Escoube, R., Johnson, R., Pike, S., Masque, P., McGillicuddy, D. and Verdeny, E.: Particle fluxes associated with mesoscale eddies in the Sargasso Sea, Deep Sea Res. Part II Top. Stud. Oceanogr., 55(10–13), 1426–1444, doi:10.1016/j.dsr2.2008.02.007, 2008a.

Buesseler, K. O., Trull, T. W., Steinberg, D. K., Silver, M. W., Siegel, D. A., Saitoh, S.-I., Lamborg, C. H., Lam, P. J., Karl, D. M., Jiao, N. Z., Honda, M. C., Elskens, M., Dehairs, F., Brown, S. L., Boyd, P. W., Bishop, J. K. B. and Bidigare, R. R.: VERTIGO (VERtical Transport In the Global Ocean): A study of particle sources and flux attenuation in the North Pacific, Deep Sea Res. Part II Top. Stud. Oceanogr., 55(14–15), 1522–1539, doi:http://dx.doi.org/10.1016/j.dsr2.2008.04.024, 2008b.

Buesseler, K. O., Pike, S., Maiti, K., Lamborg, C. H., Siegel, D. A. and Trull, T. W.: Thorium-234 as a tracer of spatial, temporal and vertical variability in particle flux in the North Pacific, Deep Sea Res. Part I Oceanogr. Res. Pap., 56(7), 1143–1167, doi:10.1016/j.dsr.2009.04.001, 2009.

Buesseler, K. O., McDonnell, A. M. P., Schofield, O. M. E., Steinberg, D. K. and Ducklow, H. W.: High particle export over the continental shelf of the west Antarctic Peninsula, Geophys. Res. Lett., 37(22), doi:10.1029/2010GL045448, 2010.

Buitenhuis, E., Vogt, M., Moriarty, R., Bednarsek, N., Doney, S. C., Leblanc, K., Le Quéré, C., Luo, Y.-W., O'Brien, C., O'Brien, T., Peloquin, J., Schiebel, R. and Swan, C.: MAREDAT: towards a world atlas of MARine Ecosystem DATa, Earth Syst. Sci. Data, 5, 227–239, doi:10.1594/PANGAEA.779970, 2013.

Burd, A. B., Hansell, D. a., Steinberg, D. K., Anderson, T. R., Arístegui, J., Baltar, F., Beaupré, S. R., Buesseler, K. O., DeHairs, F., Jackson, G. a., Kadko, D. C., Koppelmann, R., Lampitt, R. S., Nagata, T., Reinthaler, T., Robinson, C., Robison, B. H., Tamburini, C. and Tanaka, T.: Assessing the apparent imbalance between geochemical and biochemical indicators of meso- and bathypelagic biological activity: What the @$♯! is wrong with present calculations of carbon budgets?, Deep Sea Res. Part II Top. Stud. Oceanogr., 57(16), 1557–1571, doi:10.1016/j.dsr2.2010.02.022, 2010.

Cai, P., Huang, Y., Chen, M., Liu, G. and Qiu, Y.: Export of particulate organic carbon estimated from 234Th-238U disequilibria and its temporal variation in the South China Sea, Chinese Sci. Bull., 46(20), 1722–1726, doi:10.1007/BF02900660, 2001.

Cai, P., Dai, M., Chen, W., Tang, T. and Zhou, K.: On the importance of the decay of 234Th in determining size-fractionated C/234Th ratio on marine particles, Geophys. Res. Lett., 33(23), L23602, doi:10.1029/2006GL027792, 2006.

Cai, P., Chen, W., Dai, M., Wan, Z., Wang, D., Li, Q., Tang, T. and Lv, D.: A high-resolution study of particle export in the southern South China Sea based on 234Th:238U disequilibrium, J. Geophys. Res. Ocean., 113(C4), doi:10.1029/2007JC004268, 2008.

Cai, P., Rutgers van der Loeff, M., Stimac, I., Nöthig, E. M., Lepore, K. and Moran, S. B.: Low export flux of particulate organic carbon in the central Arctic Ocean as revealed by 234Th: 238U disequilibrium, J. Geophys. Res., 115(C10), C10037, doi:10.1029/2009JC005595, 2010.

Cai, P., Zhao, D., Wang, L., Huang, B. and Dai, M.: Role of particle stock and phytoplankton community structure in regulating particulate organic carbon export in a large marginal sea, J. Geophys. Res. Ocean., 120(3), 2063–2095, doi:10.1002/2014JC010432, 2015.

Cavan, E. L., Le Moigne, F. A. C., Poulton, A. J., Tarling, G. A., Ward, P., Daniels, C. J., Fragoso, G. and Sanders, R. J.: Attenuation of particulate organic carbon flux in the Scotia Sea, Southern Ocean, is controlled by zooplankton fecal pellets, Geophys. Res. Lett., 42, 821–830, doi:10.1002/2014GL062744, 2015.

Ceballos-Romero, E., Le Moigne, F. A. C., Henson, S., Marsay, C. M., Sanders, R. J., García-Tenorio, R. and Villa-Alfageme, M.: Influence of bloom dynamics on Particle Export Efficiency in the North Atlantic: a comparative study of radioanalytical techniques and sediment traps, Mar. Chem., 186, 198–210, doi:http://dx.doi.org/10.1016/j.marchem.2016.10.001, 2016.

Charette, M. A. and Moran, S. B.: Rates of particle scavenging and particulate organic carbon export estimated using 234Th as a tracer in the subtropical and equatorial Atlantic Ocean, Deep. Res. Part II, 46(5), 885–906, doi:10.1016/S0967-0645(99)00006-5, 1999.

Charette, M. A., Moran, S. B. and Bishop, J. K. B.: 234Th as a tracer of particulate organic carbon export in the subarctic northeast Pacific Ocean, Deep. Res. Part II, 46, 2833–2861, doi:10.1016/S0967-0645(99)00085-5, 1999.

Charette, M. A., Moran, S. B., Pike, S. M. and Smith, J. N.: Investigating the carbon cycle in the Gulf of Maine using the natural tracer thorium 234, J. Geophys. Res. Ocean., 106(C6), 11553–11579, doi:10.1029/1999JC000277, 2001.

Chen, J. H., Lawrence Edwards, R. and Wasserburg, G. J.: 238U, 234U and 232Th in seawater, Earth Planet. Sci. Lett., 80, 241–251, doi:10.1016/0012-821X(86)90108-1, 1986.

Chen, M., Huang, Y., Cai, P. and Guo, L.: Particulate organic carbon export fluxes in the Canada Basin and Bering Sea as derived from 234Th/238U disequilibria, Arctic, 56(1), 32, 2003.

Chen, W., Cai, P., Dai, M. and Wei, J.: 234Th/238U disequilibrium and particulate organic carbon export in the northern South China Sea, J. Oceanogr., 64(3), 417–428, doi:10.1007/s10872-008-0035-z, 2008.

Coale, K. H.: Labyrinth of doom: A device to minimize the" swimmer" component in sediment trap collections, Limnol. Oceanogr., 35, 1376–1381, doi:10.4319/lo.1990.35.6.1376, 1990.

Cochran, J. K. and Masqué, P.: Short-lived U/Th series radionuclides in the ocean: tracers for scavenging rates, export fluxes and particle dynamics, Rev. Mineral. Geochemistry, 52(1), 461–492, doi:10.2113/0520461, 2003.

Cochran, J. K., Barnes, C., Achman, D. and Hirschberg, D. J.: Thorium-234/uranium-238 disequilibrium as an indicator of scavenging rates and participate organic carbon fluxes in the Northeast Water Polynya, Greenland, J. Geophys. Res. Ocean., 100(C3), 4399–4410, doi:10.1029/94JC01954, 1995.

Cochran, J. K., Buesseler, K. O., Bacon, M. P., Wang, H. W., Hirschberg, D. J., Ball, L., Andrews, J., Crossin, G. and Fleer, A.: Short-lived thorium isotopes (234Th, 228Th) as indicators of POC export and particle cycling in the Ross Sea, Southern Ocean, Deep Sea Res. Part II Top. Stud. Oceanogr., 47(15–16), 3451–3490, doi:10.1016/S0967-0645(00)00075-8, 2000.

Coppola, L., Roy-Barman, M., Wassmann, P., Mulsow, S. and Jeandel, C.: Calibration of sediment traps and particulate organic carbon export using 234Th in the Barents Sea, Mar. Chem., 80(1), 11–26, doi:10.1016/S0304-4203(02)00071-3, 2002.

Coppola, L., Roy-Barman, M., Mulsow, S., Povinec, P. and Jeandel, C.: Low particulate organic carbon export in the frontal zone of the Southern Ocean (Indian sector) revealed by 234Th, Deep Sea Res. Part I Oceanogr. Res. Pap., 52(1), 51–68, doi:10.1016/j.dsr.2004.07.020, 2005.

Dai, M. H. and Benitez-Nelson, C. R.: Colloidal organic carbon and 234Th in the Gulf of Maine, Mar. Chem., 74(2–3), 181–196, doi:http://dx.doi.org/10.1016/S0304-4203(01)00012-3, 2001.

Dunne, J. P., Sarmiento, J. L. and Gnanadesikan, A.: A synthesis of global particle export from the surface ocean and cycling through the ocean interior and on the seafloor, Glob. Biogeochem.Cycles, 21(4), doi:10.1029/2006GB002907, 2007.

Durkin, C. A., Estapa, M. L. and Buesseler, K. O.: Observations of carbon export by small sinking particles in the upper mesopelagic, Mar. Chem., 175, 72–81, doi:10.1016/j.marchem.2015.02.011, 2015.

Engel, A., Wagner, H., Le Moigne, F. A. C. and Wilson, S. T.: Particle export fluxes to the oxygen minimum zone of the eastern tropical North Atlantic, Biogeosciences, 14(7), 1825–1838, doi:10.5194/bg-14-1825-2017, 2017.

Eppley, R. W. and Peterson, B. J.: Particulate organic matter flux and planktonic new production in the deep ocean, Nature, 282, 677–680, doi:10.1038/282677a0, 1979.

Evangeliou, N., Florou, H. and Psomiadou, C.: Size-fractionated particulate organic carbon (POC) export fluxes estimated using 234Th-238U disequilibria in the Saronikos Gulf (Greece) during winter bloom, Fresenius Environ. Bull., 22(7a), 1951–1961, 2013.

Foster, J. M. and Shimmield, G. B.: 234Th as a tracer of particle flux and POC export in the northern North Sea during a coccolithophore bloom, Deep Sea Res. Part II Top. Stud. Oceanogr., 49(15), 2965–2977, doi:10.1016/S0967-0645(02)00066-8, 2002.

Fowler, S. W. and Knauer, G. A.: Role of large particles in the transport of elements and organic compounds through the oceanic water column, Prog. Oceanogr., 16(3), 147–194, doi:http://dx.doi.org/10.1016/0079-6611(86)90032-7, 1986.

Friedrich, J. and Rutgers van der Loeff, M.: A two-tracer (210Po-234Th) approach to distinguish organic carbon and biogenic silica export flux in the Antarctic Circumpolar Current, Deep Sea Res. Part I Oceanogr. Res. Pap., 49(1), 101–120, doi:10.1016/S0967-0637(01)00045-0, 2002.

Gardner, W. D., Richardson, M. J., Carlson, C. A., Hansell, D. and Mishonov, A. V: Determining true particulate organic carbon: bottles, pumps and methodologies, Deep Sea Res. Part II Top. Stud. Oceanogr., 50(3), 655–674, doi:10.1016/S0967-0645(02)00589-1, 2003.

Giuliani, S., Radakovitch, O., Frignani, M. and Bellucci, L. G.: Short time scale variations of 234Th/238U disequilibrium related to mesoscale variability on the continental slope of the Gulf of Lions (France), Mar. Chem., 106(3), 403–418, doi:https://doi.org/10.1016/j.marchem.2007.03.007, 2007.

Le Gland, G., Aumont, O. and Mémery, L.: An Estimate of Thorium 234 Partition Coefficients Through Global Inverse Modeling, J. Geophys. Res. Ocean., 124(6), 3575–3606, doi:10.1029/2018JC014668, 2019.

Guidi, L., Jackson, G. A., Stemmann, L., Miquel, J. C., Picheral, M. and Gorsky, G.: Relationship between particle size distribution and flux in the mesopelagic zone, Deep Sea Res. Part I Oceanogr. Res. Pap., 55(10), 1364–1374, doi:10.1016/j.dsr.2008.05.014, 2008.

Guidi, L., Legendre, L., Reygondeau, G., Uitz, J., Stemmann, L. and Henson, S. A.: A new look at ocean carbon remineralization for estimating deepwater sequestration, Global Biogeochem. Cycles, 29(7), 1044–1059, doi:10.1002/2014GB005063, 2015.

Guo, L., Hung, C. C., Santschi, P. H. and Walsh, I. D.: 234 Th scavenging and its relationship to acid polysaccharide abundance in the Gulf of Mexico, Mar. Chem., 78(2), 103–119, doi:10.1016/S0304-4203(02)00012-9, 2002.

Gustafsson, Ö. and Andersson, P. S.: 234Th-derived surface export fluxes of POC from the Northern Barents Sea and the Eurasian sector of the Central Arctic Ocean, Deep Sea Res. Part I Oceanogr. Res. Pap., doi:10.1016/j.dsr.2012.05.014, 2012.

Gustafsson, Ö., Gschwend, P. M. and Buesseler, K. O.: Using 234Th disequilibria to estimate the vertical removal rates of polycyclic aromatic hydrocarbons from the surface ocean, Mar. Chem., 57(1–2), 11–23, doi:10.1016/S0304-4203(97)00011-X, 1997.

Gustafsson, Ö., Andersson, P., Roos, P., Kukulska, Z., Broman, D., Larsson, U., Hajdu, S. and Ingri, J.: Evaluation of the collection efficiency of upper ocean sub-photic-layer sediment traps: a 24-month in situ calibration in the open Baltic Sea using 234Th, Limnol.Oceanogr.Methods, 2, 62–74, doi:10.4319/lom.2004.2.62, 2004.

Gustafsson, Ö., Larsson, J., Andersson, P. and Ingri, J.: The POC/234Th ratio of settling particles isolated using split flow-thin cell fractionation (SPLITT), Mar. Chem., 100(3), 314–322, doi:10.1016/j.marchem.2005.10.018, 2006.

Hall, I. R., Schmidt, S., McCave, I. N. and Reyss, J. L.: Particulate matter distribution and disequilibrium along the Northern Iberian Margin: implications for particulate organic carbon export, Deep Sea Res. Part I Oceanogr. Res. Pap., 47(4), 557–582, doi:10.1016/S0967-0637(99)00065-5, 2000.

Haskell II, W. Z., Berelson, W. M., Hammond, D. E. and Capone, D. G.: Particle sinking dynamics and POC fluxes in the Eastern Tropical South Pacific based on 234 Th budgets and sediment trap deployments, Deep Sea Res. Part I Oceanogr. Res. Pap., doi:10.1016/j.dsr.2013.07.001, 2013.

Henson, S. A., Sanders, R., Madsen, E., Morris, P. J., Le Moigne, F. and Quartly, G. D.: A reduced estimate of the strength of the ocean's biological carbon pump, Geophys. Res. Lett., 38(4), L04606, doi:10.1029/2011GL046735, 2011.

Hung, C.-C. and Gong, G.-C.: Export flux of POC in the main stream of the Kuroshio, Geophys. Res. Lett., 34(18), L18606, doi:10.1029/2007GL030236, 2007.

Hung, C. C. and Gong, G. C.: POC/234Th ratios in particles collected in sediment traps in the northern South China Sea, Estuar. Coast. Shelf Sci., 88(3), 303–310, doi:10.1016/j.ecss.2010.04.008, 2010.

Hung, C. C., Guo, L., Roberts, K. A. and Santschi, P. H.: Upper ocean carbon flux determined by the 234Th approach and sediment traps using size-fractionated POC and 234Th data from the Gulf of Mexico, Geochem. J., 38(6), 601–611, doi:10.2343/geochemj.38.601, 2004.

Hung, C. C., Xu, C., Santschi, P. H., Zhang, S. J., Schwehr, K. A., Quigg, A., Guo, L., Gong, G. C., Pinckney, J. L. and Long, R. A.: Comparative evaluation of sediment trap and 234Th-derived POC fluxes from the upper oligotrophic waters of the Gulf of Mexico and the subtropical northwestern Pacific Ocean, Mar. Chem., 121(1), 132–144, doi:10.1016/j.marchem.2010.03.011, 2010.

Hung, C. C., Gong, G. C. and Santschi, P. H.: 234Th in different size classes of sediment trap collected particles from the Northwestern Pacific Ocean, Geochim. Cosmochim. Acta, 91, 60–74, doi:10.1016/j.gca.2012.05.017, 2012.

Jacquet, S. H. M., Lam, P. J., Trull, T. W. and Dehairs, F.: Carbon export production in the subantarctic zone and polar front zone south of Tasmania, Deep Sea Res. Part II Top. Stud. Oceanogr., 58(21–22), 2277–2292, doi:/10.1016/j.dsr2.2011.05.035, 2011.

Kawakami, H.: Scanvenging of 210Po and 234Th by particulate organic carbon in the surfaca layer of the northwestern North Pacific Ocean, Far East J. Ocean Res., 2(2), 67–82, 2009.

Kawakami, H. and Honda, M. C.: Time-series observation of POC fluxes estimated from 234Th in the northwestern North Pacific, Deep Sea Res. Part I Oceanogr. Res. Pap., 54(7), 1070–1090, doi:10.1016/j.dsr.2007.04.005, 2007.

Kawakami, H., Yang, Y.-L., Honda, M. C. and Kusakabe, M.: Particulate organic carbon fluxes estimated from ^{234}Th deficiency in winters and springs in the northwestern North Pacific, Geochem. J., 38(6), 581–592, doi:10.2343/geochemj.38.581, 2004.

Kawakami, H., Honda, M. C., Matsumoto, K., Fujiki, T. and Watanabe, S.: East-west distribution of POC fluxes estimated from 234Th in the northern North Pacific in autumn, J. Oceanogr., 66(1), 71–83, doi:10.1007/s10872-010-0006-z, 2010.

Kawakami, H., Honda, M. C., Matsumoto, K., Wakita, M., Kitamura, M., Fujiki, T. and Watanabe, S.: POC fluxes estimated from 234Th in late spring–early summer in the western subarctic North Pacific, J. Oceanogr., 71(3), 311–324, doi:10.1007/s10872-015-0290-8, 2015.

Kim, D., Choi, M.-S., Oh, H.-Y., Song, Y.-H., Noh, J.-H. and Kim, K. H.: Seasonal export fluxes of particulate organic carbon from 234Th/238U disequilibrium measurements in the Ulleung Basin1 (Tsushima Basin) of the East Sea1 (Sea of Japan), J. Oceanogr., 67(5), 577, doi:10.1007/s10872-011-0058-8, 2011.

Kim, G. and Church, T. M.: Seasonal biogeochemical fluxes of 234Th and 210Po in the upper Sargasso Sea: Influence from atmospheric iron deposition, Glob. Biogeochem.Cycles, 15(3), 651–661, doi:10.1029/2000GB001313, 2001.

Ku, T.-L., Knauss, K. G. and Mathieu, G. G.: Uranium in open ocean: concentration and isotopic composition, Deep Sea Res., 24(11), 1005–1017, doi:10.1016/0146-6291(77)90571-9, 1977.

Kwon, E. Y., Primeau, F. and Sarmiento, J. L.: The impact of remineralization depth on the air–sea carbon balance, Nat. Geosci., 2, 630, doi:10.1038/ngeo612, 2009.

Lalande, C., Lepore, K., Cooper, L. W., Grebmeier, J. M. and Moran, S. B.: Export fluxes of particulate organic carbon in the Chukchi Sea: A comparative study using< sup> 234</sup> Th/< sup> 238</sup> U disequilibria and drifting sediment traps, Mar. Chem., 103(1), 185–196, 2007.

Lalande, C., Moran, S. B., Wassmann, P., Grebmeier, J. M. and Cooper, L. W.: 234Th-derived particulate organic carbon fluxes in the northern Barents Sea with comparison to drifting sediment trap fluxes, J. Mar. Syst., 73(1), 103–113, doi:10.1016/j.jmarsys.2007.09.004, 2008.

Lamborg, C. H., Buesseler, K. O., Valdes, J., Bertrand, C. H., Bidigare, R., Manganini, S., Pike, S., Steinberg, D., Trull, T. and Wilson, S.: The flux of bio- and lithogenic material associated with sinking particles in the mesopelagic “twilight zone” of the northwest and North Central Pacific Ocean, Deep Sea Res. Part II Top. Stud. Oceanogr., 55(14–15), 1540–1563, doi:10.1016/j.dsr2.2008.04.011, 2008.

Lampitt, R. S., Boorman, B., Brown, L., Lucas, M., Salter, I., Sanders, R., Saw, K., Seeyave, S., Thomalla, S. J. and Turnewitsch, R.: Particle export from the euphotic zone: Estimates using a novel drifting sediment trap, 234Th and new production, Deep Sea Res. Part I Oceanogr. Res. Pap., 55(11), 1484–1502, doi:10.1016/j.dsr.2008.07.002, 2008.

Laws, E. A., D’Sa, E. and Naik, P.: Simple equations to estimate ratios of new or export production to total production from satellite-derived estimates of sea surface temperature and primary production, Limnol. Oceanogr. Methods, 9(12), 593–601, doi:10.4319/lom.2011.9.593, 2011.

Lemaitre, N., Planchon, F., Planquette, H., Dehairs, F., Fonseca-Batista, D., Roukaerts, A., Deman, F., Tang, Y., Mariez, C. and Sarthou, G.: High variability of particulate organic carbon export along the North Atlantic GEOTRACES section GA01 as deduced from ^{234}Th fluxes, Biogeosciences, 15(21), 6417–6437, doi:10.5194/bg-15-6417-2018, 2018.

Lepore, K., Moran, S. B., Grebmeier, J. M., Cooper, L. W., Lalande, C., Maslowski, W., Hill, V., Bates, N. R., Hansell, D. A., Mathis, J. T. and Kelly, R. P.: Seasonal and interannual changes in particulate organic carbon export and deposition in the Chukchi Sea, J. Geophys. Res. Ocean., 112(C10), doi:10.1029/2006JC003555, 2007.

Lepore, K., Moran, S. B., Burd, A. B., Jackson, G. A., Smith, J. N., Kelly, R. P., Kaberi, H., Stavrakakis, S. and Assimakopoulou, G.: Sediment trap and in-situ pump size-fractionated POC/234Th ratios in the Mediterranean Sea and Northwest Atlantic: Implications for POC export, Deep Sea Res. Part I Oceanogr. Res. Pap., 56(4), 599–613, doi:10.1016/j.dsr.2008.11.004, 2009.

Luo, Y., Miller, L. A., Baere, B. De, Soon, M. and Francois, R.: POC fluxes measured by sediment traps and 234Th:238U disequilibrium in Saanich Inlet, British Columbia, Mar. Chem., 162, 19–29, doi:10.1016/j.marchem.2014.03.001, 2014.

Ma, Q., Chen, M., Qiu, Y. and Li, Y.: Regional estimates of POC export flux derived from thorium-234 in the western Arctic Ocean, Acta Oceanol. Sin., 24(6), 97–108, 2005.

Mahowald, N. M., Engelstaedter, S., Luo, C., Sealy, A., Artaxo, P., Benitez-Nelson, C., Bonnet, S., Chen, Y., Chuang, P. Y., Cohen, D. D., Dulac, F., Herut, B., Johansen, A. M., Kubilay, N., Losno, R., Maenhaut, W., Paytan, A., Prospero, J. M., Shank, L. M. and Siefert, R. L.: Atmospheric Iron Deposition: Global Distribution, Variability, and Human Perturbations, Ann. Rev. Mar. Sci., 1(1), 245–278, doi:10.1146/annurev.marine.010908.163727, 2009.

Maiti, K., Benitez-Nelson, C. R., Rii, Y. and Bidigare, R.: The influence of a mature cyclonic eddy on particle export in the lee of Hawaii, Deep Sea Res. Part II Top. Stud. Oceanogr., 55(10), 1445–1460, 2008.

Maiti, K., Benitez-Nelson, C. R., Lomas, M. W. and Krause, J. W.: Biogeochemical responses to late-winter storms in the Sargasso Sea, III--Estimates of export production using 234Th: 238U disequilibria and sediment traps, Deep Sea Res. Part I Oceanogr. Res. Pap., 56(6), 875–891, doi:10.1016/j.dsr.2009.01.008, 2009.

Maiti, K., Benitez-Nelson, C. R. and Buesseler, K. O.: Insights into particle formation and remineralization using the short-lived radionuclide, Thoruim-234, Geophys. Res. Lett., 37(15), L15608, doi:10.1029/2010GL044063, 2010.

Maiti, K., Bosu, S., D'Sa, E. J., Adhikari, P. L., Sutor, M. and Longnecker, K.: Export fluxes in northern Gulf of Mexico - Comparative evaluation of direct, indirect and satellite-based estimates, Mar. Chem., 184, 60–77, doi:10.1016/j.marchem.2016.06.001, 2016.

Martin, J. H., Knauer, G. A., Karl, D. M. and Broenkow, W. W.: VERTEX: carbon cycling in the northeast Pacific, Deep Sea Res. Part A. Oceanogr. Res. Pap., 34(2), 267–285, doi:10.1016/0198-0149(87)90086-0, 1987.

Martin, P., Lampitt, R. S., Jane Perry, M., Sanders, R., Lee, C. and D'Asaro, E.: Export and mesopelagic particle flux during a North Atlantic spring diatom bloom, Deep Sea Res. Part I Oceanogr. Res. Pap., 58, 338–349, doi:10.1016/j.dsr.2011.01.006, 2011.

Martin, P., van der Loeff, M. R., Cassar, N., Vandromme, P., D'Ovidio, F., Stemmann, L., Rengarajan, R., Soares, M., González, H. E., Ebersbach, F., Lampitt, R. S., Sanders, R., Barnett, B. A., Smetacek, V. and Naqvi, S. W. A.: Iron fertilization enhanced net community production but not downward particle flux during the Southern Ocean iron fertilization experiment LOHAFEX, Global Biogeochem. Cycles, 27(3), 871–881, doi:10.1002/gbc.20077, 2013.

Mawji, E., Schlitzer, R., Masferrer, E., Abadie, C., Abouchami, W., Anderson, R. F., Baars, O., Bakker, K., Baskaran, M., Bates, N. R., Bluhm, K., Bowie, A., Bown, J., Boye, M., Boyle, E. A., Branekkec, P., Bruland, K. W., Brzezinski, M. A., Bucciarelli, E., Buesseler, K., Butler, E., Cai, P., Cardinal, D., Casciotti, K., Chaves, J., Cheng, H., Chever, F., Church, T. M., Colman, A. S., Conway, T. M., Croot, P. L., Cutter, G. A., de Baar, H. J. W., de Souza, G. F., Dehairs, F., Deng, F., Thi Dieu, H., Dulaquais, G., Echegoyen-Sanz, Y., Edwards, R. L., Fahrbach, E., Fitzsimmons, J., Fleisher, M., Frank, M., Friedrich, J., Fripiat, F., Galer, S. J. G., Gamo, T., Garcia-Solsona, E., Gerringa, L. J. A., Godoy, J. M., Gonzalez, S., Grossteffan, E., Hatta, M., Hayes, C. T., Heller, M. I., Henderson, G., Huang, K.-F., Jeandel, C., Jenkins, W. J., John, S., Kenna, T. C., Klunder, M., Kretschmer, S., Kumamoto, Y., Laan, P., Labatut, M., Lacan, F., Lam, P. J., Lannuzel, D., Le Moigne, F., Lechtenfeld, O., Lohan, M. C., Lu, Y., Masqué, P., McClain, C. R., Measures, C., Middag, R., Moffett, J., Navidad, A., Nishioka, J., Noble, A., Obata, H., Ohnemus, D. C., Owens, S., Planchon, F., Pradoux, C., Puigcorbé, V., Quay, P., Radic, A., Rehkämper, M., Remenyi, T., Rijkenberg, M. J. A., Rintoul, S., Robinson, L. F., Roeske, T., Rosenberg, M., Rutgers van der Loeff, M., Ryabenko, E., et al.: The GEOTRACES Intermediate Data Product 2014, Mar. Chem., (177), 1–8, doi:10.1016/j.marchem.2015.04.005, 2015.

Le Moigne, F. A. C., Sanders, R. J., Villa-Alfageme, M., Martin, A. P., Pabortsava, K., Planquette, H., Morris, P. J. and Thomalla, S. J.: On the proportion of ballast versus non-ballast associated carbon export in the surface ocean, Geophys. Res. Lett., 39(15), L15610, doi:10.1029/2012GL052980, 2012.

Le Moigne, F. A. C., Boye, M., Masson, A., Corvaisier, R., Grossteffan, E., Guéneugues, A. and Pondaven, P.: Description of the biogeochemical features of the subtropical southeastern Atlantic and the Southern Ocean south of South Africa during the austral summer of the International Polar Year, Biogeosciences, 10(1), 281–295, doi:10.5194/bg-10-281-2013, 2013a.

Le Moigne, F. A. C., Villa-Alfageme, M., Sanders, R. J., Marsay, C., Henson, S. and García-Tenorio, R.: Export of organic carbon and biominerals derived from< sup> 234</sup> Th and< sup> 210</sup> Po at the Porcupine Abyssal Plain, Deep Sea Res. Part I Oceanogr. Res. Pap., 72, 88–101, 2013b.

Le Moigne, F. A. C., Henson, S. A., Sanders, R. J. and Madsen, E.: Global database of surface ocean particulate organic carbon export fluxes diagnosed from the 234Th technique, Earth Syst. Sci. Data, 5(2), 295–304, doi:10.5194/essd-5-295-2013, 2013c.

Le Moigne, F. A. C., Poulton, A. J., Henson, S. A., Daniels, C. J., Fragoso, G. M., Mitchell, E., Richier, S., Russell, B. C., Smith, H. E. K., Tarling, G. A. and Zubkov, M.: Carbon export efficiency and phytoplankton community composition in the Atlantic sector of the Arctic Ocean, J. Geophys. Res. Ocean., doi:10.1002/2015JC010700, 2015.

Le Moigne, F. A. C., Henson, S. A., Cavan, E., Georges, C., Pabortsava, K., Achterberg, E. P., Ceballos-Romero, E., Zubkov, M. and Sanders, R. J.: What causes the inverse relationship between primary production and export efficiency in the Southern Ocean?, Geophys. Res. Lett., 43(9), 4457–4466, doi:10.1002/2016GL068480, 2016.

Moran, S. B. and Buesseler, K. O.: Size-fractionated 234Th in continental shelf waters off New England: Implications for the role of colloids in oceanic trace metal scavenging, J. Mar. Res., 51(4), 893–922, doi:10.1357/0022240933223936, 1993.

Moran, S. B. and Smith, J. N.: 234Th as a tracer of scavenging and particle export in the Beaufort Sea, Cont. Shelf Res., 20(2), 153–167, doi:10.1016/S0278-4343(99)00065-5, 2000.

Moran, S. B., Ellis, K. M. and Smith, J. N.: 234Th/238U disequilibrium in the central Arctic Ocean: implications for particulate organic carbon export, Deep Sea Res. Part II Top. Stud. Oceanogr., 44(8), 1593–1606, doi:10.1016/S0967-0645(97)00049-0, 1997.

Moran, S. B., Weinstein, S. E., Edmonds, H. N., Smith, J. N., Kelly, R. P., Pilson, M. E. Q. and Harrison, W. G.: Does 234Th/238U disequilibrium provide an accurate record of the export flux of particulate organic carbon from the upper ocean?, Limnol. Oceanogr., 48(3), 1018–1029, doi:10.4319/lo.2003.48.3.1018, 2003.

Moran, S. B., Kelly, R. P., Hagstrom, K., Smith, J. N., Grebmeier, J. M., Cooper, L. W., Cota, G. F., Walsh, J. J., Bates, N. R. and Hansell, D. A.: Seasonal changes in POC export flux in the Chukchi Sea and implications for water column-benthic coupling in Arctic shelves, Deep Sea Res. Part II Top. Stud. Oceanogr., 52(24–26), 3427–3451, doi:10.1016/j.dsr2.2005.09.011, 2005.

Moran, S. B., Lomas, M. W., Kelly, R. P., Gradinger, R., Iken, K. and Mathis, J. T.: Seasonal succession of net primary productivity, particulate organic carbon export, and autotrophic community composition in the eastern Bering Sea, Deep Sea Res. Part II Top. Stud. Oceanogr., doi:10.1016/j.dsr2.2012.02.011, 2012.

Moriarty, R. and O'Brien, T. D.: Distribution of mesozooplankton biomass in the global ocean, Earth Syst. Sci. Data, 5(1), 45–55, doi:10.5194/essd-5-45-2013, 2013.

Moriarty, R., Buitenhuis, E. T., Le Quéré, C. and Gosselin, M.-P.: Distribution of known macrozooplankton abundance and biomass in the global ocean, Earth Syst. Sci. Data, 5(2), 241–257, doi:10.5194/essd-5-241-2013, 2013.

Morris, P. J., Sanders, R., Turnewitsch, R. and Thomalla, S.: 234Th-derived particulate organic carbon export from an island-induced phytoplankton bloom in the Southern Ocean, Deep Sea Res. Part II Top. Stud. Oceanogr., 54(18–20), 2208–2232, doi:10.1016/j.dsr2.2007.06.002, 2007.

Morris, S. A., Hansman, R. L. and Miquel, J.-C.: Tracing carbon's fate in the ocean, Eos (Washington. DC)., 98, doi:10.1029/2017EO076681, 2017.

Murray, J. W., Young, J., Newton, J., Dunne, J., Chapin, T., Paul, B. and McCarthy, J. J.: Export flux of particulate organic carbon from the central equatorial Pacific determined using a combined drifting trap-234Th approach, Deep Sea Res. Part II Top. Stud. Oceanogr., 43(4–6), 1095–1132, doi:10.1016/0967-0645(96)00036-7, 1996.

Murray, J. W., Paul, B., Dunne, J. P. and Chapin, T.: 234Th, 210Pb, 210Po and stable Pb in the central equatorial Pacific: Tracers for particle cycling, Deep Sea Res. Part I Oceanogr. Res. Pap., 52(11), 2109–2139, doi:10.1016/j.dsr.2005.06.016, 2005.

Owens, S. A., Buesseler, K. O. and Sims, K. W. W.: Re-evaluating the 238U-salinity relationship in seawater: Implications for the 238U-234Th disequilibrium method, Mar. Chem., 127, 31–39, doi:10.1016/j.marchem.2011.07.005, 2011.

Owens, S. A., Buesseler, K. O., Lamborg, C. H., Valdes, J., Lomas, M. W., Johnson, R. J., Steinberg, D. K. and D.A, S.: A new time series of particle export from neutrally buoyant sediments traps at the Bermuda Atlantic Time-series Study site, Deep Sea Res. Part I Oceanogr. Res. Pap., 72(0), 34–47, doi:10.1016/j.dsr.2012.10.011, 2013.

Owens, S. A., Pike, S. and Buesseler, K. O.: Thorium-234 as a tracer of particle dynamics and upper ocean export in the Atlantic Ocean, Deep Sea Res. Part II Top. Stud. Oceanogr., 116, 42–59, doi:10.1016/j.dsr2.2014.11.010, 2015.

Pabortsava, K.: Downward particle export and sequestration fluxes in the oligotrophic Atlantic Ocean, University of Southampton. [online] Available from: https://eprints.soton.ac.uk/id/eprint/372493, 2014.

Parekh, P., Dutkiewicz, S., Follows, M. J. and Ito, T.: Atmospheric carbon dioxide in a less dusty world, Geophys. Res. Lett., 33(3), L03610, doi:10.1029/2005GL025098, 2006.

Planchon, F., Cavagna, A.-J., Cardinal, D., André, L. and Dehairs, F.: Late summer particulate organic carbon export and twilight zone remineralisation in the Atlantic sector of the Southern Ocean, Biogeosciences, 10(2), 803–820, doi:10.5194/bg-10-803-2013, 2013.

Planchon, F., Ballas, D., Cavagna, A.-J., Bowie, A. R., Davies, D., Trull, T., Laurenceau-Cornec, E. C., Van Der Merwe, P. and Dehairs, F.: Carbon export in the naturally iron-fertilized Kerguelen area of the Southern Ocean based on the 234Th approach, Biogeosciences, 12(12), 3831–3848, doi:10.5194/bg-12-3831-2015, 2015.

Pondaven, P., Ragueneau, O., Tréguer, P., Hauvespre, A., Dezileau, L. and Reyss, J. L.: Resolving the 'opal paradox' in the Southern Ocean, Nature, 405(6783), 168–172, 2000.

Puigcorbé, V., Benitez-Nelson, C. R., Masqué, P., Verdeny, E., White, A. E., Popp, B. N., Prahl, F. G. and Lam, P. J.: Small phytoplankton drive high summertime carbon and nutrient export in the Gulf of California and Eastern Tropical North Pacific, Global Biogeochem. Cycles, 29(8), 1309–1332, doi:10.1002/2015GB005134, 2015.

Puigcorbé, V., Roca-Martí, M., Masqué, P., Benitez-Nelson, C., Rutgers van der Loeff, M., Bracher, A. and Moreau, S.: Latitudinal distributions of particulate carbon export across the North Western Atlantic Ocean, Deep. Res. Part I Oceanogr. Res. Pap., 129, doi:10.1016/j.dsr.2017.08.016, 2017a.

Puigcorbé, V., Roca-Martí, M., Masqué, P., Benitez-Nelson, C. R., Rutgers v. d. Loeff, M., Laglera, L. M., Bracher, A., Cheah, W., Strass, V. H., Hoppema, M., Santos-Echeandía, J., Hunt, B. P. V., Pakhomov, E. A. and Klaas, C.: Particulate organic carbon export across the Antarctic Circumpolar Current at 10°E: Differences between north and south of the Antarctic Polar Front, Deep Sea Res. Part II Top. Stud. Oceanogr., 138, 86–101, doi:10.1016/j.dsr2.2016.05.016, 2017b.

Radakovitch, O., Frignani, M., Giuliani, S. and Montanari, R.: Temporal variations of dissolved and particulate< sup> 234</sup> Th at a coastal station of the northern Adriatic Sea, Estuar. Coast. Shelf Sci., 58(4), 813–824, 2003.

Richardson, T. L.: Mechanisms and Pathways of Small-Phytoplankton Export from the Surface Ocean, Ann. Rev. Mar. Sci., 11(1), 57–74, doi:10.1146/annurev-marine-121916-063627, 2019.

Riley, J. S., Sanders, R., Marsay, C., Le Moigne, F. A. C., Achterberg, E. P. and Poulton, A. J.: The relative contribution of fast and slow sinking particles to ocean carbon export, Global Biogeochem. Cycles, 26(1), n/a--n/a, doi:10.1029/2011GB004085, 2012.

Roca-Martí, M., Puigcorbé, V., Rutgers van der Loeff, M. M., Katlein, C., Fernández-Méndez, M., Peeken, I. and Masqué, P.: Carbon export fluxes and export efficiency in the central Arctic during the record sea-ice minimum in 2012: a joint ^{234}Th/ ^{238}U and ^{210}Po/ ^{210}Pb study, J. Geophys. Res. Ocean., 121(7), 5030–5049, doi:10.1002/2016JC011816, 2016.

Roca-Martí, M., Puigcorbé, V., Iversen, M. H., van der Loeff, M. R., Klaas, C., Cheah, W., Bracher, A. and Masqué, P.: High particulate organic carbon export during the decline of a vast diatom bloom in the Atlantic sector of the Southern Ocean, Deep Sea Res. Part II Top. Stud. Oceanogr., 138, 102–115, doi:10.1016/j.dsr2.2015.12.007, 2017.

Rodriguez-Baena, Y., Alessia, M., Boudjenoun, R., Fowler, S. W., Miquel, J. C., Masqué, P., Sanchez-Cabeza, J. A. and Warnau, M.: 234Th-based carbon export during an ice-edge bloom: Sea-ice algae as a likely bias in data interpretation, Earth Planet. Sci. Lett., 269, 596–604, doi:10.1016/j.epsl.2008.03.020, 2008.

Rosengard, S. Z., Lam, P. J., Balch, W. M., Auro, M. E., Pike, S., Drapeau, D. and Bowler, B.: Carbon export and transfer to depth across the Southern Ocean Great Calcite Belt, Biogeosciences, 12(13), 3953–3971, doi:10.5194/bg-12-3953-2015, 2015.

Rutgers van der Loeff, M., Cai, P., Stimac, I., Bracher, A., Middag, R., Klunder, M. and van Heuven, S.: 234Th in surface waters: distribution of particle export flux across the Antarctic Circumpolar Current and in the Weddell Sea during the GEOTRACES expedition ZERO and DRAKE, Deep Sea Res. Part II Top. Stud. Oceanogr., 58, 2749–2766, doi:10.1016/j.dsr2.2011.02.004, 2011.

Rutgers van der Loeff, M. M., Friedrich, J. and Bathmann, U. V: Carbon export during the spring bloom at the Antarctic Polar Front, determined with the natural tracer 234Th, Deep Sea Res. Part II Top. Stud. Oceanogr., 44(1–2), 457–478, doi:10.1016/S0967-0645(96)00067-7, 1997.

Rutgers van der Loeff, M. M., Buesseler, K., Bathmann, U., Hense, I. and Andrews, J.: Comparison of carbon and opal export rates between summer and spring bloom periods in the region of the Antarctic Polar Front, SE Atlantic, Deep Sea Res. Part II Top. Stud. Oceanogr., 49(18), 3849–3869, doi:10.1016/S0967-0645(02)00114-5, 2002.

Sanders, R., Brown, L., Henson, S. and Lucas, M.: New production in the Irminger Basin during 2002, J. Mar. Syst., 55(3–4), 291–310, doi:10.1016/j.jmarsys.2004.09.002, 2005.

Sanders, R., Morris, P. J., Poulton, A. J., Stinchcombe, M. C., Charalampopoulou, A., Lucas, M. I. and

Thomalla, S. J.: Does a ballast effect occur in the surface ocean?, Geophys. Res. Lett., 37(8), L08602, doi:10.1029/2010GL042574, 2010.

Santschi, P. H., Guo, L., Walsh, I. D., Quigley, M. S. and Baskaran, M.: Boundary exchange and scavenging of radionuclides in continental margin waters of the Middle Atlantic Bight: implications for organic carbon fluxes, Cont. Shelf Res., 19(5), 609–636, doi:10.1016/S0278-4343(98)00103-4, 1999.

Santschi, P. H., Murray, J. W., Baskaran, M., Benitez-Nelson, C. R., Guo, L. D., Hung, C. C., Lamborg, C., Moran, S. B., Passow, U. and Roy-Barman, M.: Thorium speciation in seawater, Mar. Chem., 100(3), 250–268, doi:10.1016/j.marchem.2005.10.024, 2006.

Savoye, N., Benitez-Nelson, C., Burd, A. B., Cochran, J. K., Charette, M., Buesseler, K. O., Jackson, G. A., Roy-Barman, M., Schmidt, S. and Elskens, M.: 234Th sorption and export models in the water column: a review, Mar. Chem., 100(3–4), 234–249, doi:10.1016/j.marchem.2005.10.014, 2006.

Savoye, N., Trull, T. W., Jacquet, S. H. M., Navez, J. and Dehairs, F.: 234Th-based export fluxes during a natural iron fertilization experiment in the Southern Ocean (KEOPS), Deep Sea Res. Part II Top. Stud. Oceanogr., 55(5–7), 841–855, doi:10.1016/j.dsr2.2007.12.036, 2008.

Schlitzer, R., Anderson, R. F., Dodas, E. M., Lohan, M., Geibert, W., Tagliabue, A., Bowie, A., Jeandel, C., Maldonado, M. T., Landing, W. M., Cockwell, D., Abadie, C., Abouchami, W., Achterberg, E. P., Agather, A., Aguliar-Islas, A., van Aken, H. M., Andersen, M., Archer, C., Auro, M., de Baar, H. J., Baars, O., Baker, A. R., Bakker, K., Basak, C., Baskaran, M., Bates, N. R., Bauch, D., van Beek, P., Behrens, M. K., Black, E., Bluhm, K., Bopp, L., Bouman, H., Bowman, K., Bown, J., Boyd, P., Boye, M., Boyle, E. A., Branellec, P., Bridgestock, L., Brissebrat, G., Browning, T., Bruland, K. W., Brumsack, H.-J., Brzezinski, M., Buck, C. S., Buck, K. N., Buesseler, K., Bull, A., Butler, E., Cai, P., Mor, P. C., Cardinal, D., Carlson, C., Carrasco, G., Casacuberta, N., Casciotti, K. L., Castrillejo, M., Chamizo, E., Chance, R., Charette, M. A., Chaves, J. E., Cheng, H., Chever, F., Christl, M., Church, T. M., Closset, I., Colman, A., Conway, T. M., Cossa, D., Croot, P., Cullen, J. T., Cutter, G. A., Daniels, C., Dehairs, F., Deng, F., Dieu, H. T., Duggan, B., Dulaquais, G., Dumousseaud, C., Echegoyen-Sanz, Y., Edwards, R. L., Ellwood, M., Fahrbach, E., Fitzsimmons, J. N., Russell Flegal, A., Fleisher, M. Q., van de Flierdt, T., Frank, M., Friedrich, J., Fripiat, F., Fröllje, H., Galer, S. J. G., Gamo, T., Ganeshram, R. S., Garcia-Orellana, J., Garcia-Solsona, E., Gault-Ringold, M., et al.: The GEOTRACES Intermediate Data Product 2017, Chem. Geol., 493, doi:10.1016/j.chemgeo.2018.05.040, 2018.

Schmidt, S., Chou, L. and Hall, I. R.: Particle residence times in surface waters over the north-western Iberian Margin: comparison of pre-upwelling and winter periods, J. Mar. Syst., 32(1), 3–11, doi:10.1016/S0924-7963(02)00027-1, 2002a.

Schmidt, S., Andersen, V., Belviso, S. and Marty, J.-C.: Strong seasonality in particle dynamics of north-western Mediterranean surface waters as revealed by 234Th/238U, Deep Sea Res. Part I Oceanogr. Res. Pap., 49(8), 1507–1518, doi:10.1016/S0967-0637(02)00039-0, 2002b.

Schmidt, S., Goutx, M., Raimbault, P., Garcia, N., Guibert, P. and Andersen, V.: 234 Th measured particle export from surface waters in north-western Mediterranean: comparison of spring and autumn periods, Biogeosciences Discuss., 6, 143–161, 2009.

Schmidt, S., Harlay, J., Borges, A. V, Groom, S., Delille, B., Roevros, N., Christodoulou, S. and Chou, L.: Particle export during a bloom of Emiliania huxleyi in the North-West European continental margin, J. Mar. Syst., 109–110, S182-- S190, doi:10.1016/j.jmarsys.2011.12.005, 2013.

Shaw, T. J., Smith, K. L., Hexel, C. R., Dudgeon, R., Sherman, A. D., Vernet, M. and Kaufmann, R. S.: 234Th-Based Carbon Export around Free-Drifting Icebergs in the Southern Ocean, Deep Sea Res. Part II Top. Stud. Oceanogr., 58(11), 1384–1391, doi:10.1016/j.dsr2.2010.11.019, 2011.

Shimmield, G. B., Ritchie, G. D. and Fileman, T. W.: The impact of marginal ice zone processes on the distribution of 210Pb, 210Po and 234Th and implications for new production in the Bellingshausen Sea, Antarctica, Deep Sea Res. Part II Top. Stud. Oceanogr., 42(4–5), 1313–1335, doi:10.1016/0967-0645(95)00071-W, 1995.

Smetacek, V., Klaas, C., Strass, V. H., Assmy, P., Montresor, M., Cisewski, B., Savoye, N., Webb, A., D'Ovidio, F., Arrieta, J. M. and Others: Deep carbon export from a Southern Ocean iron-fertilized diatom bloom, Nature, 487(7407), 313–319, doi:10.1038/nature11229, 2012.

Smoak, J. M., Moore, W. S., Thunell, R. C. and Shaw, T. J.: Comparison of 234Th, 228Th, and 210Pb fluxes with fluxes of major sediment components in the Guaymas Basin, Gulf of California, Mar. Chem., 65(3), 177–194, doi:10.1016/S0304-4203(98)00095-4, 1999.

Speicher, E. A., Moran, S. B., Burd, A. B., Delfanti, R., Kaberi, H., Kelly, R. P., Papucci, C., Smith, J. N., Stavrakakis, S. and Torricelli, L.: Particulate organic carbon export fluxes and size-fractionated POC/234Th ratios in the Ligurian, Tyrrhenian and Aegean Seas, Deep Sea Res. Part I Oceanogr. Res. Pap., 53(11), 1810–1830, doi:10.1016/j.dsr.2006.08.005, 2006.

Stewart, G., Cochran, J. K., Miquel, J. C., Masqué, P., Szlosek, J., Rodriguez y Baena, A. M., Fowler, S. W., Gasser, B. and Hirschberg, D. J.: Comparing POC export from 234Th/238U and 210Po/210Pb disequilibria with estimates from sediment traps in the northwest Mediterranean, Deep Sea Res. Part I Oceanogr. Res. Pap., 54(9), 1549–1570, doi:10.1016/j.dsr.2007.06.005, 2007.

Stewart, G., Moran, S. B., Lomas, M. W. and Kelly, R. P.: Direct comparison of 210Po, 234Th and POC particle-size distributions and export fluxes at the Bermuda Atlantic Time-series Study (BATS) site, J. Environ. Radioact., 102(5), 479–489, doi:10.1016/j.jenvrad.2010.09.011, 2011.

Stukel, M. R., Landry, M. R., Benitez-Nelson, C. R. and Goerickea, R.: Trophic cycling and carbon export relationships in the California Current Ecosystem, Limnol.Oceanogr, 56(5), 1866–1878, doi:10.4319/lo.2011.56.5.1866, 2011.

Stukel, M. R., Kahru, M., Benitez-Nelson, C. R., Décima, M., Goericke, R., Landry, M. R. and Ohman, M. D.: Using Lagrangian-based process studies to test satellite algorithms of vertical carbon flux in the eastern North Pacific Ocean, J. Geophys. Res. Ocean., 120(11), 7208–7222, doi:10.1002/2015JC011264, 2015.

Stukel, M. R., Benitez-Nelson, C. R., Décima, M., Taylor, A. G., Buchwald, C. and Landry, M. R.: The biological pump in the Costa Rica Dome: an open-ocean upwelling system with high new production and low export, J. Plankton Res., 38(2), 348–365, doi:10.1093/plankt/fbv097, 2016.

Stukel, M. R., Aluwihare, L. I., Barbeau, K. A., Chekalyuk, A. M., Goericke, R., Miller, A. J., Ohman, M. D., Ruacho, A., Song, H., Stephens, B. M. and Landry, M. R.: Mesoscale ocean fronts enhance carbon export due to gravitational sinking and subduction, Proc. Natl. Acad. Sci., 114(6), 1252–1257, doi:10.1073/pnas.1609435114, 2017.

Stukel, M. R., Kelly, T. B., Aluwihare, L. I., Barbeau, K. A., Goericke, R., Krause, J. W., Landry, M. R. and Ohman, M. D.: The Carbon:234Thorium ratios of sinking particles in the California current ecosystem 1: relationships with plankton ecosystem dynamics, Mar. Chem., doi:10.1016/j.marchem.2019.01.003, 2019.

Szlosek, J., Cochran, J. K., Miquel, J. C., Masqué, P., Armstrong, R. A., Fowler, S. W., Gasser, B. and Hirschberg, D. J.: Particulate organic carbon–234Th relationships in particles separated by settling velocity in the northwest Mediterranean Sea, Deep Sea Res. Part II Top. Stud. Oceanogr., 56(18), 1519–1532, doi:10.1016/j.dsr2.2008.12.017, 2009.

Thomalla, S. J., Turnewitsch, R., Lucas, M. and Poulton, A.: Particulate organic carbon export from the North and South Atlantic gyres: The 234Th/238U disequilibrium approach, Deep Sea Res. Part II Top. Stud. Oceanogr., 53(14–16), 1629–1648, doi:10.1016/j.dsr2.2006.05.018, 2006.

Trimble, S. M. and Baskaran, M.: The role of suspended particulate matter in 234Th scavenging and 234Th-derived export fluxes of POC in the Canada Basin of the Arctic Ocean, Mar. Chem., 96(1–2), 1–19, doi:10.1016/j.marchem.2004.10.003, 2005.

Trull, T. W., Bray, S. G., Buesseler, K. O., Lamborg, C. H., Manganini, S., Moy, C. and Valdes, J.: In situ measurement of mesopelagic particle sinking rates and the control of carbon transfer to the ocean interior during the Vertical Flux in the Global Ocean (VERTIGO) voyages in the North Pacific, Deep Sea Res. Part II Top. Stud. Oceanogr., 55(14), 1684–1695, doi:10.1016/j.dsr2.2008.04.021, 2008.

Turnewitsch, R., Dumont, M., Kiriakoulakis, K., Legg, S., Mohn, C., Peine, F. and Wolff, G.: Tidal influence on particulate organic carbon export fluxes around a tall seamount, Prog. Oceanogr., 149, 189–213, doi:10.1016/j.pocean.2016.10.009, 2016.

Umhau, B. P., Benitez-Nelson, C. R., Close, H. G., Hannides, C. C. S., Motta, L., Popp, B. N., Blum, J. D. and Drazen, J. C.: Seasonal and spatial changes in carbon and nitrogen fluxes estimated using 234Th:238U disequilibria in the North Pacific tropical and subtropical gyre, Mar. Chem., 217, 103705, doi:10.1016/j.marchem.2019.103705, 2019.

Waples, J. T., Benitez-Nelson, C., Savoye, N., Rutgers van der Loeff, M., Baskaran, M. and Gustafsson, Ö.: An introduction to the application and future use of 234Th in aquatic systems, Mar. Chem., 100(3–4), 166–189, doi:10.1016/j.marchem.2005.10.011, 2006.

Wei, C. L., Chou, L. H., Tsai, J. R., Wen, L. S. and Pai, S. C.: Comparative geochemistry of 234Th, 210Pb, and 210Po: A case study in the Hung-Tsai Trough off southwestern Taiwan, Terr. Atmos. Ocean. Sci., 20(2), 411–423, doi:10.3319/TAO.2008.01.09.01(Oc), 2009.

Wei, C. L., Lin, S. Y., Sheu, D. D. D., Chou, W. C., Yi, M. C., Santschi, P. H. and Wen, L. S.: Particle-reactive radionuclides (234 Th, 210 Pb, 210 Po) as tracers for the estimation of export production in the South China Sea, Biogeosciences, 8(12), 3793–3808, doi:10.5194/bg-8-3793-2011, 2011.

Yu, W., Chen, L., Cheng, J., He, J., Yin, M. and Zeng, Z.: 234Th-derived particulate organic carbon export flux in the western Arctic Ocean, Chinese J. Oceanol. Limnol., 28(6), 1146–1151, doi:10.1007/s00343-010-9933-1, 2010.

Yu, W., He, J., Li, Y., Lin, W. and Chen, L.: Particulate organic carbon export fluxes and validation of steady state model of 234Th export in the Chukchi Sea, Deep Sea Res. Part II Top. Stud. Oceanogr., doi:10.1016/j.dsr2.2012.03.003, 2012.

Zhou, K., Nodder, S. D., Dai, M. and Hall, J. A.: Insignificant enhancement of export flux in the highly productive subtropical front, east of New Zealand: a high resolution study of particle export fluxes based on 234Th: 238U disequilibria, Biogeosciences, 9(3), 973–992, doi:10.5194/bg-9-973-2012, 2012.

Zhou, K., Dai, M., Kao, S.-J., Wang, L., Xiu, P., Chai, F., Tian, J. and Liu, Y.: Apparent enhancement of 234Th-based particle export associated with anticyclonic eddies, Earth Planet. Sci. Lett., 381, 198–209, doi:10.1016/j.epsl.2013.07.039, 2013.

Zhou, K., Maiti, K., Dai, M., Kao, S.-J. and Buesseler, K.: Does adsorption of dissolved organic carbon and thorium onto membrane filters affect the carbon to thorium ratios, a primary parameter in estimating export carbon flux?, Mar. Chem., 184, 1–10, doi:10.1016/j.marchem.2016.06.004, 2016.

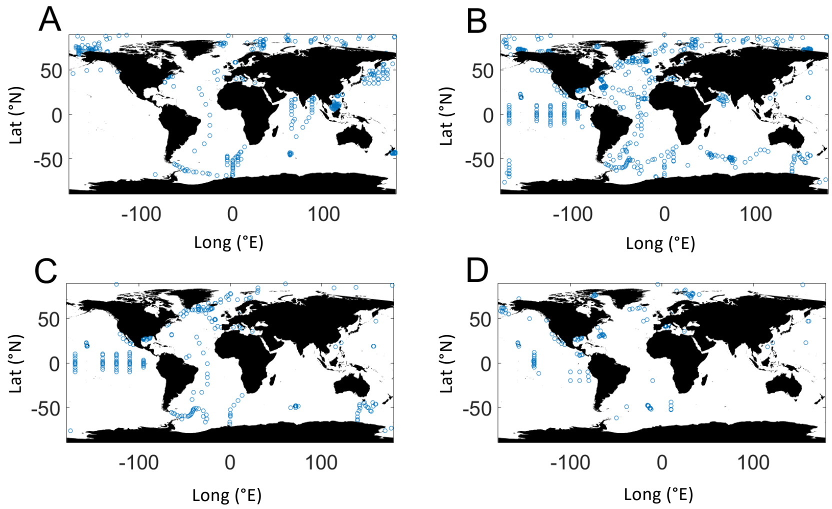


Figure 1: Maps showing the distribution of POC/Th ratios measured on (A) bulk particles, (B) large particles, (C) small particles, and (D) particles from sediment traps. See main text for details, section 3.1 Data classification.

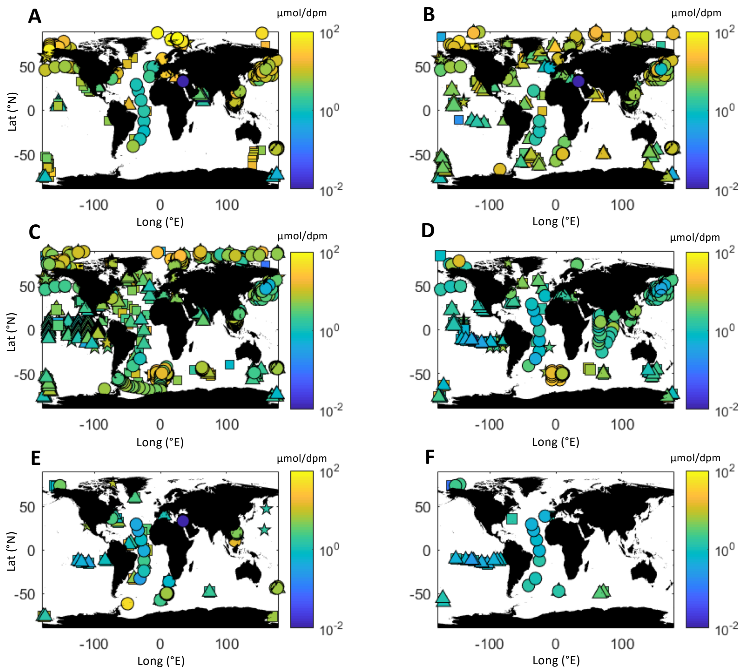


Figure 2: Global distribution of the POC/Th ratios (>100 µmol/dpm) (A) in surface, (B) at 50 m, (C) at 100 m, (D) at 200 m, (E) at 500 m and (F) at 1000 m. Circles represent BU, squares represent LP, triangles represent SP and stars represent ST (see main text for details, section 3.1 Data classification.). Data corresponds to samples collected at depths at +/- 5 meters the nominal depth for all cases, except for panel F (+/- 50 meters).

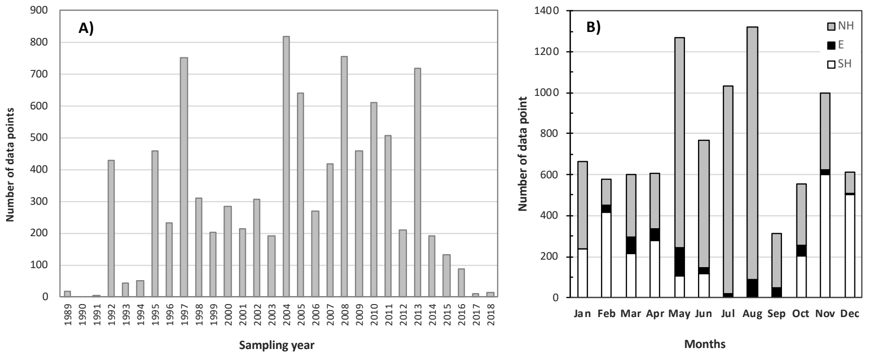


Figure 3: A) Histogram of data sampled between 1989 and 2016. See Table 1 for details. B) Number of samples per month of the year grouped as per samples collected in the Northern Hemisphere (NH; grey), Southern Hemisphere (SH; white) or Equator (E; -10° to 10°N; black).

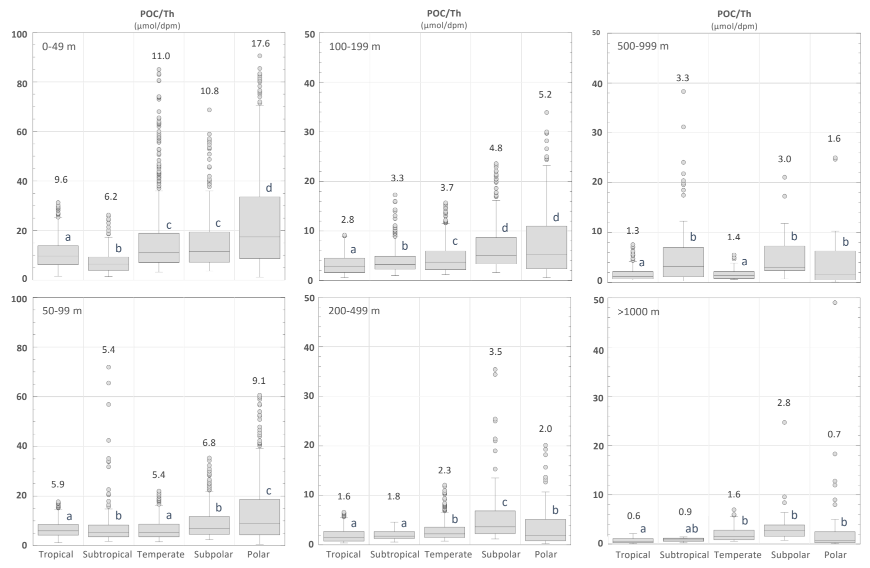


Figure 4: POC/Th ratios variability (box whisker plots) of 90% of the data sorted by climate zones and depth. The values shown on top of each box represent their median. Box plots within the same depth range (e.g, 0-49 m) sharing a letter are not significantly different. Note the different scale used between the 0 to 99 m and the 100 to >1000 m plots.

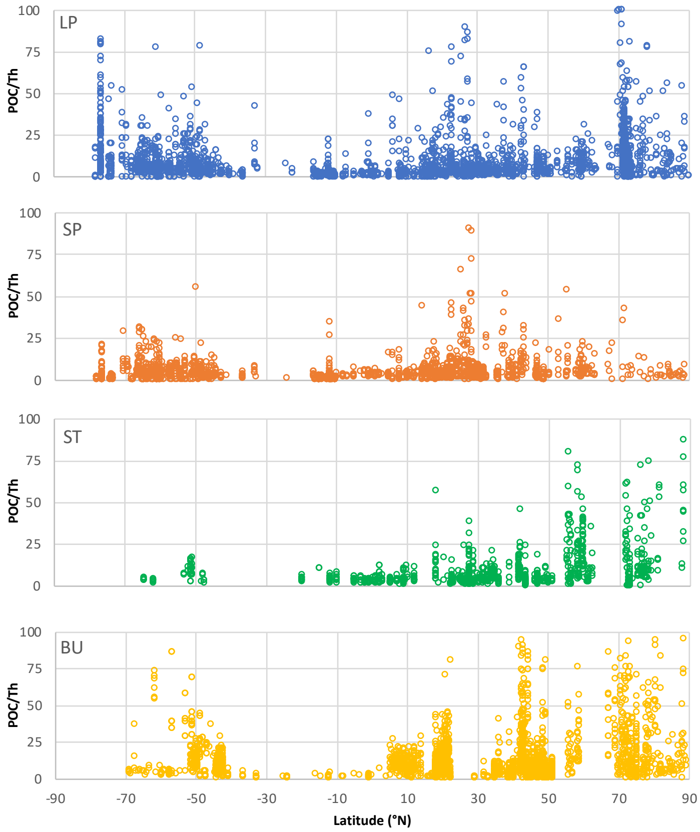


Figure 5: Latitudinal variability of the POC/Th ratios (<100 µmol/dpm) grouped by large particles (LP), small particles (SP), sediment trap particles (ST) and bulk particles (BU).

Sampling year	Area	LP n	SP n	ST n	BU n	Reference/Investigator
1989	North Atlantic	-	-	6	12	Buesseler et al. (1992)
1991-1992	Buzzards Bay	-	-	-	7	Moran and Buesseler (1993)
1992	Equatorial Pacific	80	-	-	-	Bacon et al. (1996)
1992	Sargasso Sea	-	-	2	-	Buesseler et al. (1994)
1992	Equatorial Pacific	71	78	-	-	Buesseler et al. (1995)
1992	Atlantic sector of the Southern Ocean	-	-	-	31	Friedrich and Rutgers van der Loeff (2002)
1992	Central Equatorial Pacific	-	-	124	-	Murray US JGOFS EqPac (Murray et al., 1996 and Murray et al., 2005)
1992	Atlantic Sector Southern Ocean	-	-	-	32	Rutgers van der Loeff et al. (1997)
1992	Bellingshausen Sea, Antarctica	-	-	-	3	Shimmield et al. (1995)
1992-1993	Northeast Water Polynya Greenland	-	-	-	11	Cochran et al. (1995)
1993	Middle Atlantic Bight	-	-	-	30	Santschi et al. (1999)
1993-1994	Station BATS, North Atlantic, and Gulf of Maine	-	-	-	4	Gustafsson et al. (1997)
1993-1996	Guaymas Basin	-	-	58	-	Smoak et al. (1999)
1994	Central Arctic Ocean	28	-	-	-	Moran et al. (1997)
1995	Arabian Sea	123	148	-	-	Buesseler JGOFS dataset Arabian Sea
1995	Wilkinson Basin and Jordan Basin	20	20	-	-	Charette et al. (2001)
1995	Beaufort Sea	-	-	-	22	Moran and Smith (2000)
1995	Atlantic Sector Southern Ocean	-	-	-	80	Rutgers van der Loeff et al. (2002)
1995	NW Mediterranean Sea	-	-	3	15	Schmidt et al. (2002a)
1996	Subtropical and ropical Atlantic Ocean	25	22	-	-	Charette and Moran (1999)
1996-1997	Northeast Pacific Ocean	-	-	4	144	Charette et al. (1999)
1996-1997	Ross Sea	82	79	-	-	Cochran et al. (2000)
1996-1997	Gulf of Maine	-	-	-	7	Dai and Benitez-Nelson (2001)
1996-1997	Sargasso Sea	-	-	-	6	Kim and Church (2001)
1996-1998	Ross-Sea	291	271	-	-	Buesseler JGOFS dataset Southern Ocean
1997	Southwestern Gulf of Maine	-	-	-	64	Benitez-Nelson et al. (2000)
1997	Sargasso Sea	-	-	3	-	Buesseler et al. (2000)
1997	Gulf of Lions	-	-	-	33	Giuliani et al. (2007)
1997	Northern Iberian Margin	-	-	-	22	Hall et al. (2000)
1997	Northern Adriatic Sea	-	-	-	23	Radakovitch et al. (2003)
1997-2000, 2002-2008	NW North Pacific	92	-	48	664	Kawakami North Pacific Time Series
1998	Arctic Ocean	-	-	-	19	Baskaran et al. (2003)
1998	Western Iberian Margin	-	-	-	12	Schmidt et al. (2002b)
1998-1999	Polynya North Water	15	-	45	-	Amiel et al. (2002)
1999	South China Sea	-	-	-	20	Cai et al. (2001)
1999	Canada Basin, Bering Sea	-	-	-	27	Chen et al. (2003)
1999	Barents Sea	-	-	5	25	Coppola et al. (2002)
1999	Crozet Basin	-	-	-	8	Coppola et al. (2005)
1999	Northern North Sea	-	-	-	24	Foster and Shimmield (2002)
1999	Labrador Sea	8	3	-	-	Moran et al. (2003)
1999-2000	North Pacific Subtropical Gyre	5	5	9	-	Benitez-Nelson et al. (2001)
2000	Gulf of Mexico	15	15	-	-	Guo et al. (2002)
2000	Canada Basin Arctic Ocean	-	-	-	25	Trimble and Baskaran (2005)
2000-2001	Gulf of Mexico	21	21	4	-	Hung et al. (2004)
2000-2002	Northern South China Sea	-	-	-	44	Chen et al. (2008)
2001	Subarctic Pacific	-	-	6	19	Aono et al. (2005)
2001	Gullmar fjord, Sweden	-	-	7	8	Gustafsson et al. (2006)
2001	Arctic Ocean (Marginal Ice Zone)	-	-	17	46	Gustafsson and Andersson (2012)
2001	Southern Ocean	38	36	-	-	Trull and Buesseler (unpublished)

2002	Southern Ocean/ South of the ACCF	39	40	-	-	Buesseler et al. (2005)
2002	Chukchi Sea	171	-	-	-	Moran et al. (2005)
2002	Bay of Biscay to Celtic Sea	-	-	-	24	Schmidt et al. (2013)
2003	Western Arctic Ocean	-	-	-	18	Ma et al. (2005)
2003	Southern Ocean	6	-	-	-	Rodriguez-Baena et al. (2008)
2003	NW Mediterranean Sea	4	-	20	-	Stewart et al. (2007)
2003	Western Arctic Ocean	-	-	-	32	Yu et al. (2010)
2003, 2005	Northern Barents Sea	24	-	24	-	Lalande et al. (2008)
2003-2006	Porcupine Abyssal Plain	7	-	5	-	Lampitt et al. (2008)
2004	Canadian Arctic Shelf	24	-	-	-	Amiel and Cochran (2008)
2004	South China Sea	-	-	-	169	Cai et al. (2008)
2004	Western Arctic Shelf-Basin	38	-	45	-	Lalande et al. (2007)
2004	Western Arctic Ocean	206	-	-	-	Lepore et al. (2007)
2004	Sargasso Sea	-	-	2	-	Maiti et al. (2009)
2004	NW Mediterranean Sea	-	-	3	-	Schmidt et al. (2009)
2004	Southern Ocean	-	-	-	1	Smetacek et al. (2012)
2004	Eastern Mediterranean Sea	26	26	-	-	Speicher et al. (2006)
2004-2005	Tropical North Pacific (Hawaii)	103	115	8	-	Buesseler et al. (2008a)
2004-2005	North Pacific (ALOHA and K2)	35	97	-	-	Buesseler et al. (2009)
2004-2005	North Pacific Ocean	-	-	36	-	Lamborg et al. (2008)
2004-2005	Southern Ocean	20	-	-	-	Morris et al. (2007)
2005	South China Sea	16	15	-	-	Cai et al. (2006)
2005	Mediterranean Sea and NW Atlantic	37	32	15	-	Lepore et al. (2009)
2005	Tropical North Pacific (Hawaii)	13	13	2	-	Maiti et al. (2008)
2005	Kerguelen Plateau, Southern Ocean	26	-	-	-	Savoye et al. (2008)
2005	Ligurian Sea, NW Mediterranean Sea	-	-	22	-	Szlosek et al. (2009)
2005	Falkland Island and Great Britain	10	10	-	82	Thomalla et al. (2006)
2005-2006, 2009	NW Gulf of Mexico and NW Pacific	35	34	25	-	Hung et al. (2010)
2006	Kuroshio Current	6	6	4	-	Hung and Gong (2007)
2006	Hung-Tsai Trough, southwestern Taiwan	-	-	-	30	Wei et al. (2009)
2006-2007	Sargasso Sea	20	20	12	-	Brew et al. (2009)
2006-2007	Sargasso Sea	9	9	9	-	Stewart et al. (2011)
2006-2008	Tsushima Basin, East Japan Sea	-	-	-	12	Kim et al. (2011)
2006-2008	South China Sea	-	-	17	-	Wei et al. (2011)
2006-09, 2011-12, 2014, 2016	California Current	47	-	60	-	Stukel et al. CCE
2007	Arctic Ocean	14	14	-	36	Cai et al. (2010)
2007	Southern Ocean	77	75	-	2	Jacquet et al. (2011)
2007	North Atlantic Ocean	20	-	-	-	Sanders et al. (2010)
2007	South China Sea	-	-	-	85	Zhou et al. (2013)
2008	Northwest Pacific	-	-	13	-	Hung et al. (2012)
2008	South China Sea	-	-	9	-	Hung and Gong (2010)
2008	Icleand Basin	-	-	9	-	Martin et al. (2011)
2008	Eastern Bering Sea	-	-	35	-	Moran et al. (2012)
2008	Southern Ocean	46	49	-	45	Planchon et al. (2013)
2008	Gulf of California and Easter Tropical Pacific	83	83	8	-	Puigcorbé et al. (2015)
2008	Atlantic Sector Southern Ocean	12	12	-	27	Rutgers van der Loeff et al. (2011)
2008	Chukchi Sea	-	-	-	79	Yu et al. (2012)
2008	Southern Ocean	-	-	-	146	Zhou et al. (2012)
2008-2009	West Antarctic Peninsula	1	1	4	-	Buesseler et al. (2010)
2008-2009	Southern Ocean and Sargasso Sea	-	26	-	-	Zhou et al. (2016)
2009	Porcupine Abyssal Plain	20	13	-	-	Le Moigne et al. (2013b)
2009	Southern Ocean	-	-	6	-	Martin et al. (2013)

2009	NW Mediterranean Sea	-	-	42	-	Puigcorbé et al (unpublished)-FAMOSO
2009	Powell Basin of the Weddell Sea	-	-	5	6	Shaw et al. (2011)
2009	Cape Verde Archipelago	14	-	-	-	Turnewitsch et al. (2016)
2009-2010	Eastern Bering Sea	-	-	89	-	Baumann et al. (2013)
2009-2011	South China Sea	-	-	-	777	Cai et al. (2015)
2009-2011	Saanich Inlet	-	-	-	76	Luo et al. (2014)
2010	Irminger Basin and Iceland Basin	-	-	8	-	Ceballos-Romero et al. (2016)
2010	Saronikos Gulf	10	10	-	-	Evangeliou et al. (2013)
2010	North Atlantic Ocean	39	39	-	-	Le Moigne et al. (2012)
2010	NW Atlantic	11	-	-	-	Puigcorbé et al. (2017a)
2010	Costa Rica upwelling Dome	13	-	10	-	Stukel et al. CRD
2010-2011	Southeastern Pacific	-	-	16	-	Haskell II et al. (2013)
2010-2011	Atlantic Ocean	189	-	-	-	Owens et al. (2015)
2011	Tropical Atlantic	15	-	-	-	Pabortsava (2014)
2011	Kerguelen Plateau, Southern Ocean	48	52	-	-	Planchon et al. (2015)
2011-2012	Southern Ocean (Atlantic and Indian Sectors)	27	-	-	-	Rosengard et al. (2015)
2012	Arctic Ocean	13	10	-	-	Le Moigne et al. (2015)
2012	Southeast of the Mississippi delta	39	38	11	-	Maiti et al. (2016)
2012	Atlantic Sector Southern Ocean	8	-	2	-	Puigcorbé et al. (2017b)
2012	Eurasian Basin of the central Arctic	25	-	-	-	Roca-Martí et al. (2016)
2012	Atlantic Sector Southern Ocean	19	-	22	-	Roca-Martí et al. (2017)
2013	Southeastern Tropical Pacific	339	339	-	-	Black et al. (2018)
2013	Southern Ocean (South Georgia)	10	9	-	-	Ceballos-Romero et al. unpublished
2013	Southern Ocean	12	8	-	-	Le Moigne et al. (2016)
2013-2014	Arabian Sea and Bay of Bengal	-	-	-	4	Anand et al. (2018b)
2014	Bay of Bengal	-	-	-	13	Anand et al. (2017)
2014	Southern Indian Ocean to Arabian Sea	-	-	-	11	Anand et al. (2018a)
2014	North Atlantic Ocean	56	58	-	-	Lemaitre et al. (2018)
2014-2015	Tropical and Subtropical North Pacific	53	49	5	-	Umhau et al. (2019)
2015	Arctic Ocean	17	17	-	28	Puigcorbé et al. (unpublished)-PS94
2016	Southern Ocean	21	22	-	36	Puigcorbé et al. (unpublished)-GP-Pr11
2017-2018	Levantine Basin (Mediterranean Sea)	-	-	3	19	Alkalay et al. (2020)
	Totals	**3087**	**2039**	**947**	**3245**	**9318**

Table 1: Sampling year, area, the number of samples for large particles (LP), small particles (SP), bulk particles (BU) and particles collected with sediment trap (ST) and reference of studies used in the database. Note the following reference refer to data published in several papers: Stukel et al. CCE refers to data published in Stukel et al. (2011, 2015, 2017, 2019); Stukel et al. CRD refers to data from Stukel et al. (2015, 2016). Buesseler JGOFS dataset Arabian Sea refers to data published in (Buesseler et al., 1998) and also available at https://www.bco-dmo.org/project/2043. Buesseler JGOFS dataset Southern Ocean refers to data published in (Buesseler et al., 2001) and also available at https://www.bco-dmo.org/project/2044. Kawakami North Pacific Time Series data is available at http://www.jamstec.go.jp/res/ress/kawakami/234Th.html and has also been published in Kawakami (2009), Kawakami et al. (2004, 2010, 2015), Kawakami and Honda (2007) and Yang et al. (2004). Further details regarding particle size specifications or sampling device can be found in the database file https://doi.pangaea.de/10.1594/PANGAEA.902103