

Comment on essd-2021-259

F. Planchon (Referee)

Referee comment on "Revisiting five decades of ^{234}Th data: a comprehensive global oceanic compilation" by Elena Ceballos-Romero et al., Earth Syst. Sci. Data Discuss., <https://doi.org/10.5194/essd-2021-259-RC3>, 2021

This study presents a compilation of oceanic ^{234}Th measurements made at global scale over the past 50 years (1967-2018). The dataset is composed of several parameters including total, dissolved, and particulate ^{234}Th activity, POC: ^{234}Th and PON: ^{234}Th ratios, along with ^{238}U activity, POC and PON concentrations when available. This set of parameters constitutes the basis for the use of ^{234}Th as a proxy of carbon and nitrogen export fluxes from the oceanic upper water column. The data were obtained from several sources, the vast majority from peer-reviewed articles (214) and to a lesser extent from PhD manuscripts (4), public data repositories (8), and unpublished datasets (9). The database is composed of 223 excel spreadsheets along with a compilation file hosted in PANGAEA repository. For each data set, relevant metadata (geographic location, sampling date, project, sampling and processing methodology, bloom stage, etc.) have been systematically included. The associated paper introduces the dataset, presents a global overview, and then discusses the timeline of ^{234}Th measurements according to four periods covering the last 50 years. Finally, the authors discuss gaps in the dataset and present some perspectives on its future uses.

General comments

First, I would like to acknowledge the extensive work that has gone into this very comprehensive and clear compilation of over 50 years of research on the short-lived radionuclide ^{234}Th . Such a compilation was lacking until now and represents a new important step in the use of ^{234}Th as a proxy for the export of C and other elements (N, BSi, CaCO_3 , and trace elements) from the upper water column. The database is well structured and clearly described with detailed metadata of significant importance. It also appears very exhaustive and I could only identify a few minor omissions or errors (see detailed comments below).

My first general concern is with the form, as the manuscript contains a significant number of typographical and editorial errors that would have benefited from careful review before its submission. This concerns in particular the list of bibliographic references which contains a significant number of errors (authors list, authors name, type of reference such

PhD manuscript, book chapter, research article). Still on the form, there is a surprising confusion between concentration and activity made throughout the manuscript. The ^{234}Th and ^{238}U data you report are activities not concentrations.

On the content, I was pleased to read the timeline of the Th studies which summarizes the major stages that contributed to the development of the method. For clarity to the reader, I would recommend to indicate for each period the corresponding years both in the manuscript in the subsection headings and in the figures.

About the different eras, I might have subdivided era 1 and 2 a little differently by considering the JGOFS program as the beginning of era 2. In fact, it seems more logical to me to take into account the sampling periods corresponding to different programs rather than the date of publication of the resulting studies. This is illustrated further in Table 2, where most of the studies belonging to era 2 were performed in the framework of JGOFS.

Regarding the first era, you may think to introduce the GEOSECS program earlier than L365 after the description of the Coale and Bruland papers. I think it could be relevant to mention that it was in the framework of GEOSECS that the concept of scavenging by particles has really emerged, especially for the open ocean. You may cite the seminal work of Turekian (1977) who introduced the concept of the "great particle conspiracy". Furthermore, it might be interesting to mention that during GEOSECS little attention was given to ^{234}Th in comparison to ^{228}Th and ^{230}Th for studying scavenging processes in the open ocean (Broecker and Peng, 1982). It was only later, with the papers of Coale and Bruland, that the role of ^{234}Th as a tracer of short-term particle dynamics was really highlighted.

Regarding era 4 related to the GEOTRACES program, I would set the starting year to 2008 or even 2007, which corresponds to the International Polar Year (2008) and the start of the GEOTRACES sampling program. Regarding this program, it would be relevant to include in table 2 all cruises that have been sampled for ^{234}Th so far. For consistency, I would recommend using the name of the section or process study considered as defined by GEOTRACES, you can then indicate which country has been involved in the sampling (US/UK/Netherlands/Germany/India/France). This remark is also valid for the Th_database file, the projects performed within the framework of GEOTRACES should be named in a more consistent way such as for instance GEOTRACES (section or process study number, country, and eventually project acronym).

Still on the GEOTRACES program, I think it is important to mention that not all sections analyzed for ^{234}Th are available in the 2014 and 2017 Intermediate Data Products (L367). Even if data obtained as part of GEOTRACES are published in peer-reviewed journals, their inclusion in the IDP requires some additional steps (submission and acceptance by the GDAC). Also, you may indicate that the last IDP (2021) was released very recently.

I have also some concern regarding the section 5. Significant gaps in the global dataset. It

is not clear to me what the gaps you want to discuss are. Reading the first paragraph (L696-701), it seems the gaps you want to consider are related to the current understanding of the Biological Carbon Pump. On this topic, I would recommend to include some more recent reviews (Henson et al., 2019; Boyd et al., 2019; Siegel et al., 2016), which detail some of the processes that require further consideration. Reading the following, I notice you discuss two main points, the first one is related to the spatio-temporal distribution of ^{234}Th data and the second one, too long considered from L711 until the end of the section L768, is related to the modeling approach (SS vs NSS) used for estimating the export fluxes of ^{234}Th . It is surprising to note that this entire section is mostly discussed using only two references and written by the first author of this review. In my view, this section needs to be reconsidered, first by giving more attention to the existing literature on the SS/NSS approach and the different oceanic contexts to which it has been applied (not only the North Atlantic), and second to the other numerous issues related to the ^{234}Th method. Among these, it is important to point out the role of physics (lateral and vertical advection and diffusion) (Buesseler et al., 1995; Savoye et al., 2006; Resplandy, 2012; Le Gland et al., 2019; Roca-Martí et al., 2017), the importance of the depth of integration (Buesseler et al., 2020), and finally all the other issues related to the conversion to carbon fluxes using the POC to Th ratio of sinking particles (the choice of the relevant size fraction, the interpolation methods, etc.). By following these guidelines and considering that export fluxes have not been calculated or compiled in this review, you may be able to give recommendations to future users of this database.

Finally, and still about the gaps in this dataset, there is one point that could be considered that concerns the quality of available data. I understand that it is difficult to answer this point but if we take into account the successive evolutions of the methods used for the determination of ^{234}Th , all the data are probably not of the same quality. I think this should be at least mentioned or even taken into account in the form of a quality flag assigned to each dataset.

Detailed comments

L15: the ^{234}Th - ^{238}U pair is primarily used for assessing export fluxes, to look at export efficiency you need to compare with the net primary production, which is actually not included in the dataset. Please clarify

L20: replace concentrations by activities and at all other occurrences in the manuscript for both ^{234}Th and ^{238}U .

L29: the term uptake is a bit ambiguous and not directly related to the ^{234}Th method and to export fluxes. Uptake can be used either for air-sea exchanges or biological assimilation, please clarify.

L35: correct the reference (Cochran and Masqué, 2003)

L45: remove "a" in front of ^{234}Th

L50: mean life time

L52: check the end of sentence "high scavenging"

L55: correct reference for Cochran, 1993 (Kirch is the first name)

L57-60: you may cite also the works of Lemaitre et al. (2016) for N, BSi, Fe export in the Kerguelen area (KEOPS2 project) and Lemaitre et al. (2020) for BSi, CaCO_3 , lithogenic material and trace elements along the GA01 section (GEOVIDE) in the North Atlantic.

L63-64: remove the editors list of the special issue

L88: add Th after 234

L104: ^{238}U activity

L105: you mean compiled and not "complied"

L114-115: as mentioned earlier, data obtained in the frame of GEOTRACES are not necessarily in the IDP

L124: not necessary to define supplementary material with an acronym (figure or table number is sufficient).

L129: could you provide more details on how the bloom stages were distinguished?

L145: please clarify what you mean with CHN data and how this differ from POC and PON concentrations reported in the dataset (as mentioned L104). Furthermore, CHN is not the only analytical method that can be used to determine POC and PON, EA-IRMS is also widely used for this purpose.

L151: Check sentence "Where data..."

L168: remove concentration for ^{234}Th

L169: correct units $\mu\text{mol dpm}^{-1}$ for POC and PON to ^{234}Th ratios

L172: correct $>53 \mu\text{m}$ and not $<53\mu\text{m}$

L173: was responsible instead of is

L178: check units $\mu\text{mol L}^{-1}$

L181: correct one sigma

L190: remove the _ after authors

L193: check sentence and correct "used for"?

L198: the previous compilation by Le Moigne et al. (2013) include ^{234}Th fluxes, POC:Th ratios, POC fluxes and NPP estimates.

L200: correct aspects

L201-202: check the end of the sentence

L205: remove SM

L208: correct larger

L214: put the acronym in brackets

L222: correct "on at least.."

L235: repeated occupation?

L242: Correct "the way ocean is currently..."

L275: you may include the KEOPS project (sampling in 2005) with the study of Savoye et al. (2008) and also the great Calcite Belt expedition with the study of Rosengard et al. (2015) carried out both in the Atlantic and Indian sectors of the SO.

L276: remove the # and correct "in terms"

L283: correct "field"

L284-285: what do you mean with "chemical scavenging"

L290: correct "through years"

L292: check the beginning of the sentence

L305: correct "were"

L329-333: the end of the paragraph is not related to ²³⁸U measurements but to additional metadata information (model assumption and bloom stages)

L357-358: check sentence

L364-366: I would consider the GEOSECS program earlier (see my general comment)

L387: Clarify the beginning of the sentence

L397: correct "do not"

L404: remove concentration with activity

L409: Nucleopore

L420-423: I would also mention that physical terms were not considered for solving the ^{234}Th activity balance.

L423: remove of or rephrase

L433: Clarify what kind of models were used (one or two boxes) and the corresponding fluxes (scavenging fluxes J and export fluxes P). Also check the end of the sentence.

L437: JGOFS started in 1987 according to Table 2

L441-442: correct relative to its parent nuclide or ^{238}U

L443: clarify what you mean with "response time" and also to what corresponds the second equation

L455: correct "with time"

L456: here you keep focusing on the SS vs NSS approach. You need to better account for the physical terms (according to Buesseler et al., 1995 in specific ocean settings such as upwelling regions). Furthermore, vertical diffusion can be quantified from a single ^{234}Th profile if the diffusivity coefficient is known or assumed.

L458: check sentence, you may change to "when temporal fluctuations in ^{234}Th activity can be assessed". In addition, and as mentioned by Savoye et al. (2006), NSS approach requires the same water mass to be sampled. This is another difficulty of the NSS approach that can be difficult to meet in dynamical settings.

L466: correct "0.001 < colloids..."

L471: There is a confusion, the 3-D model was not built to estimate the gradients of ^{234}Th activities but to estimate the physical components to the flux (V terms). Without these components, the sinking flux would have been largely underestimated in the equatorial upwelling region.

L482: I don't think the SEATS time-series was operated in the frame of the French JGOFS program, most probably by Taiwan.

L489: Clarify the end of the sentence "filtered"

L494: sediment traps collect sinking particles not bulk.

L505: correct "at the BATS..."

L506: replace "boxes" with areas

L508: check coordinates for the NABE experiment

L518: correct "field work"

L520: Australian

L523: correct "other major initiatives..."

L534: remove "during sampling"

L537: clarify what are the CHN data

L569: the reference Clevenger et al. (2021) is apparently missing in the reference list.

L573: clarify "234Th contraptions"

L626: Correct "Portland (USA, Oregon)" and "Numerous cruises"

L638: correct "are known..."

L664: remove "of the studies"

L666-667: check the sentence

L680: correct "emphasizes"

In the section, you may include the MOBYDICK project (Marine Ecosystem Biodiversity and Dynamics of Carbon around Kerguelen: an integrated view, 2018-2022) during which the 234Th method has been implemented.

For the APERO project, it will start in 2022 to 2026 and the cruise is planned for 2023 in the western North Atlantic.

L706: correct "gaps"

L722: correct "with time"

L777-778: correct "such as" and clarify the whole sentence

Table 1. Check start and end date (sometimes inverted). The design needs to be improved as it is very difficult to identify which parameters has been measured for each studies.

I noted a few mistakes for the studies that I know (I didn't check all entries in this table)

The study of Stewart et al. (2007) reports POC:Th ratio from in-situ pumps and sediment traps but not PON:Th ratios (check the crosses)

Thomalla studies in the Atlantic ocean was published in 2008

For Jacquet et al. (2011), PON:Th ratio were not provided but POC:Th ratio from sediments traps yes

For the Rutgers van der Loeff et al. (2011) study, underway sampling were performed and reported

Planchon et al. (2015) study does not report PN:Th ratio but C:Th ratio from sediment traps. Also dissolved Th was plotted in Figure 2. The PN:Th ratios for this cruise (KEOPS2) can be found in Lemaitre et al. (2016).

For the Lemaitre et al. (2018) study, please correct the reference as follow:

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, 6417–6437, <https://doi.org/10.5194/bg-15-6417-2018>, 2018.

The study of Maïti et al. (2016) reports total Th profiles

Table 2.

As for Table 1, the design needs some improvements. Column headings needs to be clarified and further details on the other programs than JGOFS could be included. This could be especially the case for GEOTRACES as well as EXPORTS. Furthermore, I do not

see the reason why a given program is considered a major program. For instance, the HiLATS program is indicated only for 2001

Check the start date for DYFAMED

Figure 1: use the same acronym as in the text for long-term time series (TTS)

Figure 3: check the legend "by the" written twice

Regarding the dataset, it would be worth checking if the data of Stuckel et al. (2015) and Ducklow et al. (2018) have been included.

References:

Boyd, P.W., Claustre, H., Levy, M., Siegel, D.A., Weber, T., 2019. Multi-faceted particle pumps drive carbon sequestration in the ocean. *Nature* 568, 327–335. <https://doi.org/10.1038/s41586-019-1098-2>.

Buesseler, K.O., Andrews, J.A., Hartman, M.C., Belostock, R., Chai, F., 1995. Regional estimates of the export flux of particulate organic carbon derived from thorium-234 during the JGOFS EqPac program. *Deep Sea Research Part II: Topical Studies in Oceanography* 42, 777–804. [https://doi.org/10.1016/0967-0645\(95\)00043-P](https://doi.org/10.1016/0967-0645(95)00043-P).

Buesseler, K.O., Boyd, P.W., Black, E.E., Siegel, D.A., 2020. Metrics that matter for assessing the ocean biological carbon pump. *Proc Natl Acad Sci USA* 117, 9679. <https://doi.org/10.1073/pnas.1918114117>.

Ducklow, H.W., Stukel, M.R., Eveleth, R., Doney, S.C., Jickells, T., Schofield, O., Baker, A.R., Brindle, J., Chance, R., Cassar, N., 2018. Spring–summer net community production, new production, particle export and related water column biogeochemical processes in the marginal sea ice zone of the Western Antarctic Peninsula 2012–2014. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 376, 20170177. <https://doi.org/10.1098/rsta.2017.0177>.

Henson, S., Le Moigne, F., Giering, S., 2019. Drivers of Carbon Export Efficiency in the Global Ocean. *Global Biogeochemical Cycles* 33, 891–903.

<https://doi.org/10.1029/2018gb006158>.

Le Gland, G., Aumont, O., Mémery, L., 2019. An Estimate of Thorium 234 Partition Coefficients Through Global Inverse Modeling. *Journal of Geophysical Research: Oceans* 124, 3575–3606. <https://doi.org/10.1029/2018JC014668>.

Lemaitre, N., Planquette, H., Dehairs, F., Planchon, F., Sarthou, G., Gallinari, M., Roig, S., Jeandel, C., Castrillejo, M., 2020. Particulate Trace Element Export in the North Atlantic (GEOTRACES GA01 Transect, GEOVIDE Cruise). *ACS Earth Space Chem.* 4, 2185–2204. <https://doi.org/10.1021/acsearthspacechem.0c00045>.

Lemaitre, N., Planquette, H., Dehairs, F., van der Merwe, P., Bowie, A.R., Trull, T.W., Laurenceau-Cornec, E.C., Davies, D., Bollinger, C., Le Goff, M., Grossteffan, E., Planchon, F., 2016. Impact of the natural Fe-fertilization on the magnitude, stoichiometry and efficiency of particulate biogenic silica, nitrogen and iron export fluxes. *Deep Sea Research Part I: Oceanographic Research Papers* 117, 11–27. <https://doi.org/10.1016/j.dsr.2016.09.002>.

Resplandy, L., Martin, A.P., Le Moigne, F., Martin, P., Aquilina, A., Mémery, L., Lévy, M., Sanders, R., 2012. How does dynamical spatial variability impact 234Th-derived estimates of organic export? *Deep Sea Research Part I: Oceanographic Research Papers* 68, 24–45. <https://doi.org/10.1016/j.dsr.2012.05.015>.

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

Savoie, N., Benitez-Nelson, C., Burd, A.B., Cochran, J.K., Charette, M., Buesseler, K.O., Jackson, G.A., Roy-Barman, M., Schmidt, S., Elskens, M., 2006. 234Th sorption and export models in the water column: A review. *Marine Chemistry* 100, 234–249.

Siegel, D.A., Buesseler, K.O., Behrenfeld, M.J., Benitez-Nelson, C.R., Boss, E., Brzezinski, M.A., Burd, A., Carlson, C.A., D'Asaro, E.A., Doney, S.C., 2016. Prediction of the export and fate of global ocean net primary production: the EXPORTS science plan. *Frontiers in Marine Science* 3, 22.

Stukel, M.R., Asher, E., Couto, N., Schofield, O., Strebler, S., Tortell, P., Ducklow, H.W., 2015. The imbalance of new and export production in the western Antarctic Peninsula, a

potentially “leaky” ecosystem. *Global Biogeochemical Cycles* 29, 1400–1420.
<https://doi.org/10.1002/2015GB005211>.