Interactive comment on “Effects of 238 variability and physical transport on water column 234Th downward fluxes in the coastal upwelling system off Peru” by Ruifang Xie et al.

Anonymous Referee #2

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We thank the reviewer for his/her constructive comments. We’ve listed our point-by-point response in bold below.

Major comments This study evaluated the impact from the non-linearity of U-S relationship, temporal variability of 234Th and 3-D physical transport of 234Th on the estimation of downward 234Th flux. I initially read the manuscript with interest but realized finally that I need to give it up. This is an important but difficult topic that has been ignored in various 234Th studies, while the superficial description and discussion on the data by the authors keep the manuscript from further acceptance. The non-linearity between 238U and salinity is interesting and I totally agree that will induce an over- or under-estimation on the final 234Th flux. I feel very nerves that the authors attributed such non-linearity to the flooding and landslides without any obvious evidences shown in the manuscript. Meanwhile, if it was true that high uranium was transported from the coastal waters, then how was that for 234Th? I guess the 234Th activity could be low in the same water, and including the low 234Th water also elevated the 234Th flux calculation.

Response: The coastal El Niño of 2017 induced coastal precipitation as strong as the 1997-98 El Niño (Echevin et al. 2008), resulting in devastating flooding and landslides in central and northern coastal Peru. Evidence of this coastal El Niño has been presented in earlier studies cited in our manuscript. This intense flooding likely delivered large amount of fresh water, dissolved and particulate 238U, and possibly particulate 234Th. 234Th is highly particle reactive so it is unlikely that the coastal flooding has directly introduced dissolved 234Th to the coastal water. 234Th produced in-situ within the upper water column was likely scavenged quickly due to enhanced particulate input from land at this time. The addition of freshwater and riverine U may draw the datapoints up and down the conservative mixing line (as shown in Owens et al. 2011). However, this was not the case in our study where majority of the U data points fall above the S-U line defined by Owens et al. (2011). We thus agreed with the reviewer that coastal flooding is unlikely the cause of such deviations. We now have significantly modified the discussion regarding the non-linear U-salinity correlation based on both reviewers’ comments to include U remobilization induced by bottom water oxygenation

being one of the main mechanisms for enhanced water column U. We have disregarded the discussion of coastal flooding being one of the main causes of the poor U-salinity correlation.

Echevin, V. M., Colas, F., Espinoza-Morriberon, D., Anculle, T., Vasquez, L., and Gutierrez, D.: Forcings and evolution of the 2017 coastal El Niño off Northern Peru and Ecuador, Frontiers in Marine Science, 5, 367, https://doi.org/10.3389/fmars.2018.00367, 2018.

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

The authors further examine the physical transport of 234Th, but again the in-depth discussion will be required. Quite a few descriptions and explanations should be listed here: The methods on the upwelling rate estimation using wind stress and its uncertainty, the diffusivity using in situ microstructure measurements and the detail calculation for horizontal advection (the equation 3 showed in the manuscript is way too simple for this paper). I strongly recommend the authors to add these parts in the methods and discussion during the revision, and most importantly, the evaluation of the uncertainty and error should be carefully done. For example, the authors calculated the upwelling rate was on the order of 10-6 to 10-7 m s-1, those values actually were quite low compared to other upwelling sites.

Response: We have expanded the Methods section to include essential details of how upwelling rates, current velocities and diffusivities were estimated. We also include methods for error propagation in the Supplement. In the Results section, we detailed 234Th fluxes due to radioactive production and decay, advection and diffusion.

Upwelling rates off Peru estimated in our study were indeed smaller than some of the upwelling rates in other upwelling sites, but is in accord with the atmospheric and oceanic conditions off Peru at the time of sample collection. Wind stress were unusually weak off Peru beginning the last quarter of 2016 and lasted until the first half of March 2017. Toward the end of March 2017, an increase of the nearshore wind stress and a relaxation in offshore wind stress off northern Peru generated an intense wind stress curl anomaly and an associated downwelling (e.g., Echevin et al. 2008). An SST transect along 12°S off Peru showed that upwelling was restricted to the shelf and in the upper 50 m. These atmospheric and oceanic conditions were unique and resulted in very weak upwelling rates off Peru.

Lüdke, J., et al. (in review 2019). "Influence of intraseasonal eastern boundary circulation variability on hydrography and biogeochemistry off Peru." Ocean Sci. Discuss. 2019: 1-31.

In the last part of the discussion, the authors used a whole paragraph for the 234Th residence time. I did not find any wordings on the detailed calculation method for those residence time. I guess they are estimated using an 1-D steady state model, but given that the physical transport was important for some stations as the authors had pointed out, 3-D estimation for the 234Th residence time will also be needed.

Response: We now included the formulation for estimation of residence time, which was based on a 1D steady state model. Although this 1D steady state model is an oversimplification of a multi-dimensional process and should be used with caution, it provides a good first order estimate for understanding the highly dynamic nature of the 234Th residence time. It also provides a reasonable value that can be directly compared to values estimated in earlier 234Th flux studies that did not consider physical processes. We now added this discussion to the main text.

The 234Th and 238U data obtained in the region could be very interesting, the detailed description of their profiles should be more interesting.

Response: We now included a Result section that describe both 234Th and 238U profiles in detail.

I think the authors should expand their methods part, and separate the result and discussion. In addition, I found some sentences in the conclusion should also move to the discussion.

Response: We now expanded the Methods part to include detail description on how upwelling rates, current velocities and diffusivities were calculated. We also separated the Results and Discussion.

I also have quite a few detailed comments listed below. Minor comments:

The title: Effects of 238U variability and physical transport. . .. . .. It gave me an impression that the author is evaluating the 238U transport which is actually 234Th.

Response: The manuscript looks into the roles of 238U variability and physical transport on 234Th distribution and transport, and we think that the title fully reflects the goals and findings of this manuscript.

Page 3, Line 41, Add “in the upper ocean” after “export fluxes”

Response: fixed

Page 3, Line 47, Bhat et al., 1968 is not a appropriate reference, add some Santschi paper, and show the Kd values here.

Response: We disagree with the reviewer. Bhat et al. (1968) is one of the earlier field studies that have demonstrated the particle reactive nature of 234Th in the ocean. We now added the Kd values with reference to Santschi et al. (2006).

Page 3, Line 50-51, 234Th flux can be obtained even if you do not integrate with depth.

Response: It is necessary to integrate ^{234}Th activities with depth in order to estimate ^{234}Th flux.

Page 5, Methods part, Add the methods for the upwelling rate estimation, diffusivity calculation and current from ADCP.

Response: We added methods on how upwelling rates, current velocities and diffusivities were calculated

Page 6, Line 118-120, Did you just assume that 234Th had been in equilibrium with 238U or you would acidify those sample and let them stay for a year until the equilibrium would be reached. Please make that clearer.

Response: Only 238U samples were acidified. We now clarified this in the manuscript.

Page 6, Line 125, 1 dpm or 10 dpm?

Response: It is 1 dpm as stated in the text.

Page 6, Line 125, what was the volume of your sample? 4L or 2L.

Response: We now specified 4L as the sample volume.

Page 8, Line 171-172, Show the detailed calculation methods here or in the supplements. I guess here involved the simplification and manipulation of your data.

Response: We now added details in the Methods section on how upwelling velocities, current velocities, and diffusivities were calculated. We also added details on how vertical and horizontal gradients were calculated.

Page 9, Line 180-181, I have concerned on the ADCP-data which are snapshots data during the cruise, while 234Th is a chemical tracer with a time integrated information included. How do you match the different time scale between the two parameters?

Response: We appreciate the reviewer's concerned. As stated in Lines 186-189 in the original manuscript, "Zonal and meridional current velocities for each station were averaged over 5 days before and after station occupation. These current velocities were further averaged over a 10 km radian at stations closest to shore (St. 353, 428, 458, 475, 508, 904, and 907) and over a 50 km radian at the rest of the stations." In another word, the ADCP-derived current velocities were averaged over a 10-day timescale. This timescale is somewhat shorter than the residence time of 234Th. But given the short cruise timeframe, we consider this time averaged appropriate.

Page 10, Line 208, Separation between results and discussion could be better.

Response: We now separated results and discussion.

Page 11, Line 221-231, The detailed description of 234Th and 238U activities, ranges, averages, and their relationship with Chl a and oxygen will be appreciated.

Response: We added detailed descriptions in the new Results section.

Page 13, Line 265-267, How about 234Th?

Response: Unlike U, Th is not redox sensitive.

Page 13, Line 268-273, This is too superficial? Do you have any optics data here?

Response: Numerous evidence of the 2017 coastal El Niño off Peru has been published in previous studies, which were referenced in our manuscript.

Here we referenced to a figure by Echevin et al. (2018) who showed that the magnitude of precipitation in the eastern equatorial Pacific during the 2017 coastal El Niño was almost as intense as that during the 1997-98 El Niño event:

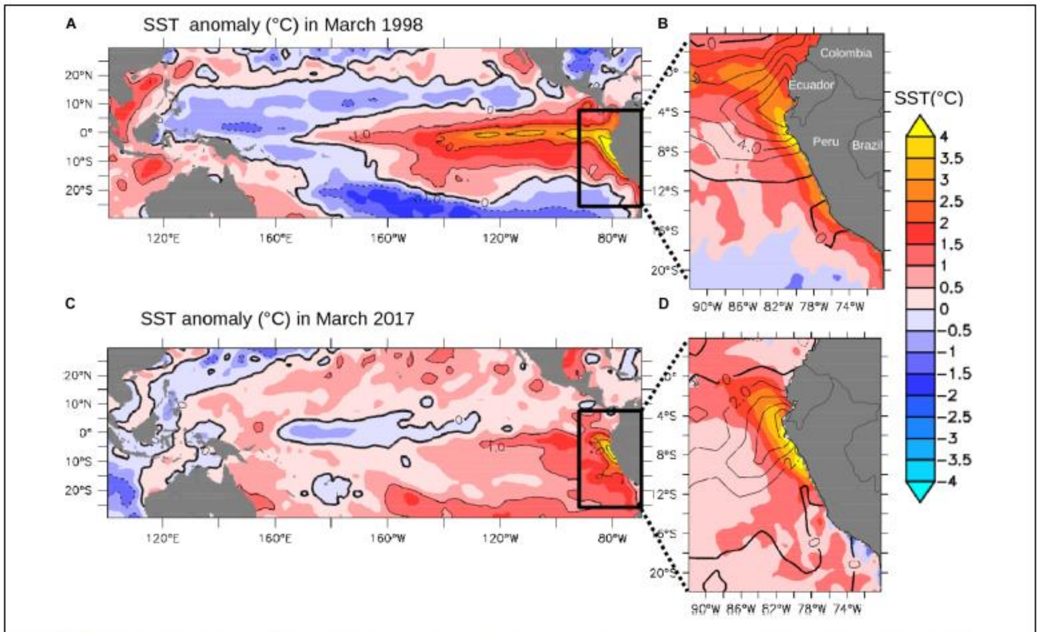

FIGURE 1 | (A) SST anomaly (in °C) and **(B)** SST anomaly (in °C, color scale) and precipitation (in mm day^{-1}, contours) during the 1997–1998 El Niño in March 1998; **(C,D)** are same as **(A,B)** during the 2017 coastal El Niño in March 2017. Anomalies were computed with respect to the 1981–2016 climatology.

Page 14, Line 290-295, Show the equation for NSS calculation. I think in the supplement you will also need to explain how you do the error propagation.

Response: We now referenced readers to Resplandy et al. (2012) and Savoye et al. (2006) for details regarding the derivation of NSS flux formulation and error propagation.

Page 14, Line 303, How reliable is your upwelling rate? I do not believe those numbers. Show the methods and put more discussion here.

Response: We now showed details in the Methods section how we calculated the upwelling rates. Please also refer to our response above in Line 53-58 in this document, which we showed that the upwelling rates estimated in our study were reliable.

Page 15, Line 318, How much is "trivial"? less than 10

Response: We now specified it as "insignificant, ranging between 1% and 10%" instead of "trivial".

Page 15, Line 325, How do you calculate the 234Th gradient?

Response: We grouped stations within a 1° by 1° grid and calculated the average 234Th for the top layer, and large scale (1° apart) horizontal 234Th gradients were calculated based on this grouping. We now added details in the Results section on how vertical and horizontal gradients were calculated.

Page 16-17, Line 353-355, The time scale for the methods is very different.

Response: Agreed. We now specified these two methods estimate upwelling rates at different timescales.

Page 17, Line 370, How do you do the calculation? 1D steady state? Or 3D steady State?

Response: Please refer to our response in Line 70-76 in this document.

Page 19, Line 411-414, not related, or move to discussion part.

Page 19, Line 417-420, Move to discussion part?

Response to both comments: Both are relevant in terms of implications for future coastal 234Th flux studies.

The references: all numbers of molecular weight for the isotopes should be in the upper case. There are quite a few errors on the references, please do the careful check.

Response: fixed

Figures: I think adding some figures here will be much helpful. Please add a transect distribution for 238U and 234Th to show the coast to offshore difference. And also add some profiles of the vertical diffusivity should be better.

Response: We now added a figure of 234Th/238U transects to show the distributions of shelf-offshore 234Th deficits (as Figure 3 in the revised manuscript). Diffusivity profiles were shown in the original supplementary file.

Figure 1: It is better to put the current field here in the map, or show it in a separate figure?

Response: We now added the current field in Figure 1.

Figure 2: Show the MLD and bottom depths here

Response: We now indicated the MLD for all stations and bottom depths for stations whose bottom depths are shallower than 600 m (scale of y-axis).

Figure 4, Can you show the profiles of 234Th for stations 458 and 508, although the surface sample was missing.

Response: We now showed the comparison between stations 458 and 508 in Figure 4 (Figure 6 in the revised manuscript).