

Biogeosciences Discuss., author comment AC1
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Reply on RC1

Emilia Trudnowska et al.

Author comment on "Cells of matter and life – towards understanding the structuring of particles and plankton patchiness in the Arctic fjords" by Emilia Trudnowska et al., Biogeosciences Discuss., <https://doi.org/10.5194/bg-2021-98-AC1>, 2021

Review for Trudnowska et al. Biogeosciences

General Comments:

The authors present a study in an Arctic fjord that classifies different types of plankton patches and attempts to understand the drivers of these shape changes and the plankton size composition of the patches. While the study topic is certainly valuable, and some of the attempted analyses are new, most of the main findings do not appear to add much to our understanding of the causes of patchiness, and often it is unclear how the data you collected are supporting your conclusions.

REPLY: We would like to thank the reviewer for constructive criticism and valuable suggestions for article's improvements. We did our best to improve it considerably according to the issues raised in the reviews. We agree that the results of our study do not provide the absolute answer to all questions regarding patchiness, however we do uphold the thesis that our study brings a new perspective to the issue, including the 'typology' of the patches and the more ecological 'frame' of their occurrence, which is new to such science. The phenomenon of patchiness is a derivative of the interaction of many process, therefore it is very difficult to explicitly conclude about all the processes that govern it, but we think that proposed by us typology of the patch shapes, sizes and internal structuring is an useful approach for further generalisations.

We think we are fairly admitting it in the paper:, e.g.: *"Even though we extended our comprehension of patchiness phenomenon by analysing thoroughly 94 patches of various size fractions of particles and plankton that existed in comparable environmental conditions (two Arctic fjords) over several years of the study, it still remains an ambiguous matter when, why, and which of the mechanisms (physical vs. biological) prevails in shaping the patterns of particles and plankton distribution. Since no explicit conclusions could be made, this study rather opens up new perspectives for further research by providing a proposition how to categorize the types of structuring of those 'cells of matter and life' in a water column as a potentially additional aspect to be considered for understanding their short term and local variability."*

At no point do the authors actually show the pathway of the towed vehicle, so it is possible that interpolation has an effect on what patch types are detected.

REPLY: We agree that the issue of interpolation can be of concern in other studies, but we assure that it was not the case in our research, as the resolution of measurements in our study was really high. In the supplementary material to this review we present the examples of temperature plots without any interpolation, i.e., with dots of real, input data from Kongsfjorden from 2014, 2017 (1st row) and 2019 (left in 2nd row) years, as well as from the Isfjorden transect from 2017 (right in 2nd row). As you can see the number of data points is tremendous, thus it would make the figure invisible if we were to add black dots of data points on it.

For the plots of the patches vs. oceanographic variables, it is unclear how you assign a particular value to a patch that might cross a range of temperatures and salinities, for example. And certain patch types are more likely to have this happen (i.e., ones that are vertical).

REPLY: Those density plots were done to relate the occurrence of specific types of the patches in specific values of environmental variables in order to decipher if some ranges of the variables are more favourable ('inhabited' more frequently). We agree that the averaged values per patch sometimes do not reflect the reality (e.g. as indicated by the reviewer in the case of the vertical ones). Therefore we think we should not present such relationships in the form of density plots of occurrence. We will remove this analysis and figure from the manuscript.

The authors need to re-evaluate how they are explaining their methods and revisit the figures they chose because I cannot tell exactly what was done, and the data are often presented in a confusing or redundant manner (see figure comments).

REPLY: Thank you very much for pointing it out. We definitely fully agree that the methods should be explained more elaborately. We will pay a detailed attention to improve the method description. We refer to this general comment in the section of the specific comments below.

The writing is somewhat disorganized, as many paragraphs have abrupt topic shifts and vague language.

REPLY: We have to admit that after a few months of break with this text, we can also see some problematic parts, where the flow of the concept is not that straightforward, so we will improve them accordingly.

The authors should strive to use examples and numbers whenever they make general statements because otherwise it can come across as non scientific.

REPLY: We will add them whenever possible.

Many parts use fairly informal language compared to most scientific papers, and there is an over-use of first person. The disorganized writing makes it very difficult to follow a train of thought, which makes the discussion less valuable.

REPLY: We agree and we would like to correct the Discussion accordingly (avoiding first person, stick to one issue at a time, better organise the sequence of topics and strengthen the way of reasoning).

The authors need to completely re-evaluate the visuals they use and pick the ones that most clearly demonstrate their main points. We cannot just take their word for it, as many of the figures I do not see showing the data they use to drive the main points of the paper. The data may be valuable, but the presentation is so difficult to follow that this is not close to being publication ready.

REPLY: We refer to this comment below, responding to specific points regarding figures and data presentation. In brief, we will totally redo Figure 4, delete Figure 7, supplement Figure 9 with RDA model, and improve the other figures according to the reviewers suggestions.

Specific Comments:

L11 – I do not know what you mean by “multi-fraction forms” – do you mean multiple size classes? Aren't all plankton patches going to be composed of different size classes?

REPLY: Yes, you understood properly what it means. We will specify it accordingly, as ‘multi-size-fraction’ ones. Indeed, we observed that sometimes the parcel of water is highly ‘populated’ by many size fractions (multi-size-fraction), but sometimes, there is an accumulation zone of mostly one, or two, or a few specific size fractions. That is why we thought it is an interesting aspect to raise.

L12 – It is an overstatement to say your work is “completely novel insight”, as many studies have looked at patch structure on multiple scales. This may be the first attempt to categorize them based on specific range of shapes, but that isn't novel insight in my view.

REPLY: We agree that we exaggerated this and we should specify that we mean mostly the ‘typology’ of patches based on their shape and internal structure. It will be changed accordingly.

L14 – A common issue throughout is that the authors are using “role” to mean “abundance,” as in if the abundance of a particular size class is increasing, you are saying it has an “increasing role.” It is better to stick to what you measured (abundance) rather than commenting on the role of a particular size class, which implies you are measuring something about its place or function within the food web.

REPLY: By the ‘role’ we meant relative role, which affects size spectra (L. 14, 376), percentage (L. 239), or the proportion (L. 384). Those are the only cases of using this word instead of its typical meaning.

L15 – There is no logical connection between size class changes and Atlantic waters, and it is unclear what you mean in terms of “temporal scale” here.

REPLY: We agree that this reasoning was not clearly explained in the manuscript. The connection between Atlantic water inflow and the increasing role of the smallest particles will be better explained in discussion, as e.g.,

L329-331: *“However, as both fjords are opened and prone to intensive Atlantic water advection, which definitely re-shapes plankton communities (Basedow et al., 2004; Kubiszyn et al., 2014; Skogseth et al., 2020; Trudnowska et al., 2020b), mostly in favour of smaller species, this large scale oceanic circulation process is of importance in both studied regions.”*

L376-379: *“The trend of an increasing role of the smallest size fractions (steepening size spectra slopes) over years was consistent in the two studied regions, at least until 2018. Such shift in plankton size structure towards the proliferating importance of Pico fraction is now a widely recognized effect of the progressing climate warming in the Arctic related to the increased advection of Atlantic waters (Li et al., 2009; Metfies et al., 2016; Nöthig et al., 2015).”*

“Temporal scale” means that this trend was observed over time: *“The observed increasing role of the smallest size fractions (steepening size spectra slopes) over years implies that*

proliferating Atlantic water advection played the crucial role on compositional dynamics on temporal scale."

L18 – It is better to show us how knowledge has been extended rather than state it. I still do not see what has been found besides distinguishing different patch type categories.

L19-21 – Many, many people have concluded that plankton are not passive particles, so this is not a new finding. You do not mention anything about the sampling equipment in the abstract, but you are using a LOPC, which is giving you snapshots of the distribution of plankton (and only size information – no taxonomic distinction). How would that even tell you if the plankton are moving passively or actively (unless you follow a patch through time)?

REPLY: We agree that the ending of an abstract was too vague. Therefore we will change it towards something more relevant to our results, e.g. *"Since no explicit conclusions could be made on the mechanisms governing the distribution patterns of particles and plankton assessed via Laser Optical Plankton Counter, this study opens up new perspectives for further research by providing a proposition how to categorize the types of their structuring in a water column as a potentially additional aspect to be considered for understanding their short term and local variability"*

L26-27 – It is inaccurate to say that plankton patchiness is "hardly recognized and documented" – many studies have documented patchiness for various size classes.

REPLY: We agree that such a statement was too strong and inadequate. It will be changed as e.g., *"but in fact it is still not recognized and documented sufficiently"*

L31 – I do not think Woodson et al. 2007 is an appropriate reference for sampling methods detecting different size classes because that paper was mostly about copepod behavior in experimental setups.

REPLY: Yes, we agree that it should not correspond to the designating methods, thus we will modify it towards: *"However, in most cases the patches of only one type or fraction of particles or plankton could be studied"*

Because the experiments are one among many possible methods to understand the mechanisms governing the patchiness, and this article:

'demonstrates that behavioral response to cues associated with fine-scale oceanographic gradients and biological patchiness is functionally important and prevalent among copepods and likely has significant impacts on larger-scale distributional patterns.'

but it was limited to several copepods, so it is impossible to perform such experiment for multiple species and size fractions.

L36 – Do not say something is "extremely interesting" – better to show the reader why it is interesting rather than state it.

REPLY: Agree. It will be re-phrased as follows: *"The studies of existence of mono- vs. multi-fraction patches may assist the exploration, if those are randomly or physically gathered objects, or rather the biologically rich hotspots that accumulated together in an active way"*.

L47-49 – This is not true. There are many papers about the mechanisms favoring patch generation (e.g., Stacey et al. 2007) in different physical contexts.

REPLY: We agree that the literature about thin plankton layers is much more extensive, and we refer to them:

"While the horizontal thin layers (up to few meters thickness and horizontal extensions over many kilometres) are among the best studied patchy forms (McManus et al., 2005; Stacey et al., 2007), typically containing densities far greater than those above or below the layer (Deksheniaks et al., 2001; Durham and Stocker, 2012)"

Moreover, we list several studies that contributed to our knowledge about patchiness in relation to various mechanisms:

"The attempts to study patchiness patterns of particles and plankton patchiness together with underlying physical and biophysical fields suggested that the observed heterogeneity at different spatial and temporal scales can be interpreted as the interactions between ocean turbulence and predator-prey encounter rates (Lovejoy et al., 2001; Schmitt and Seuront, 2008; Seuront et al., 2001), or can be strictly related to such physical features as ocean fronts and eddies (Durham and Stocker, 2012; Greer et al., 2016; Trudnowska et al., 2016), vertical thermal stratification (Greer et al., 2013; McManus et al., 2005; Steinbuck et al., 2009), river input (Ehn et al., 2019; Matsuoka et al., 2012), or the contact with sea ice (Trudnowska et al., 2018)."

But we think that still this issue needs further recognition, thus this statement will be re-phrased as e.g.: *"Despite those numerous studies still the mechanisms favouring generation of patches, and the processes underlying plankton distribution within patches, need further recognition (Menden-Deuer, 2012)."*

L51 – Currie et al. 1998 specifically looked at the internal structures of the patches in 1D, and also examined the patch size. There are also numerous studies that have used acoustics and nets to look at patch structure and composition.

REPLY: We agree that this statement was too rigorous, it should be smoothed towards e.g. *"To date, empirical measurements of particles and plankton patch structures are still challenging, as they require in-depth exploration with various dedicated techniques and sophisticated approaches."*

Moreover, we refer to Currie et al. 1998 several times in the manuscript, and we broadened the patch-related literature by another positions, e.g., Stacey et al. 2007, Kotliar et al. 1990; McGillicuddy and Franks, 2019; Prairie et al. 2012), but according to our knowledge the literature about the internal structure of patches is really scarce.

L65 – what does it mean to "answer the call for the insight studies" – very informal language overall and excessive use of first person.

REPLY: We agree that this phrasing was informal and weird. It will be re-phrased into e.g. *"This study addresses a recognized requirement for new insight studies at the interactions between ocean physics and ecology in structuring marine ecosystems (Lévy et al., 2018). It was addressed by following the patterns of patchiness of a wide spectrum of particles and plankton via the high resolution technology (laser counter), which were tested over several summer seasons in two Arctic fjords."*

L81 – What do you mean by these sites being treated as "natural laboratories" in the context of this study?

REPLY: Not only. The concept that the Spitsbergen fjords function as local indicators for climate change has been used for decades of studies (Wiencke and Hop, 2016; <https://geographyandyou.com/inter-seasonal-variabilities-in-an-arctic-fjord-the-kongsfjorden->

system-as-a-natural-laboratory-for-climate-change/). This common approach assumes that the fjord is a relatively small system that can be fully analysed/covered by sampling and that reflects clearly the response of an ecosystem to the processes (e.g., increased water temperatures, changes in an ice cap, increased Atlantic water advection) in a natural environment. Moreover, the two studied by us fjords are the best studied fjords on Svalbard, with the long-term monitoring programmes of several nations, thus providing unique background information of any kind as well as the long-term perspective.

L100 – Hard to tell what exactly is being done in the methods. What do you mean when you say “individual patches were selected from each other by the hierarchical clustering...”? You need to be clear about exactly what you are doing.

REPLY: We agree that the Method section needs more details on the calculations that had been performed. It will be considerably better specified.

L106 – Bez 2000 would be a good paper to reference because it talks about how these patchiness metrics can be used or misused. The Lloyd’s patchiness index is not the same as the ratio of variance to mean.

REPLY: Thank you very much for indicating this interesting article. The problem raised by this author is caused by the influence of 0 values when calculating densities (when doing arithmetic average), but it is not the case in our calculations. We applied the calculations of those indexes only to the data points that were assigned as patches, which means that in principle they had higher densities than the specific threshold.

L108 – you have not indicated what kind of correlation coefficient was used.

REPLY: It was Pearson correlation, which will be indicated in the better description of the calculations.

L117 – the package is “ggplot2” and it has a function called ggplot() – you should cite the package since the graphs were made with it.

REPLY: Yes, thank you very much for pointing this mistake in the name of the package. It will be corrected.

L134-135 – This is not that surprising if large phytoplankton and marine snow aggregates are present, as they can be ~1cm large or more and often fluoresce (see Timmermann et al. 2014)

REPLY: Yes, we agree, thus we will delete word “Interestingly...” . Thank you for suggesting this alternative interpretation, it will be incorporated in Discussion as e.g. *“Because only the concentrations of the Large size fraction correlated significantly with chlorophyll just in Isfjorden, this indicates that in general the concentration hotspots of smaller size fractions did not consist of actively fluorescent particles or plankton, and that rather large sized phytoplankton or fluorescent aggregates (Timmerman et al., 2014), or alternatively the relationship between herbivorous grazers (as the Large fraction is mostly represented by Calanus copepods (Balazy et al., 2018, 2019)) and food availability (expressed as high chlorophyll levels) could be observed.”*

L174 – But aren’t you using the concentrations to determine if they are within or outside patches? Why is this relevant? Just to say that some patches were more concentrated than others? There are no significance tests, so the reader cannot tell if these differences are meaningful or not.

REPLY: Yes, the idea was to check if some patches are extremely abundant or rather on

the border of being selected as 'patches'. We did not compare it statistically because the difference is too subtle, therefore it was described as "slightly greater", but of course we can just say how it was without comparing.

L180 – What do you mean their location was not repetitive?

REPLY: That the Pico fraction was always confined to the upper 10m layer vertically, but horizontally in each year those patches were found in different parts of the transect. At some point we expected that maybe there could be a physical mechanism that will induce the patch formation in always the same/similar location.

L247-250 – You also calculated Lloyd's patchiness index and mean crowding, but do not mention these in the results. If they add nothing to the study, then you don't need the extra graphs.

REPLY: We refer to them as "values of indices of spatial heterogeneity" (L.247-248), as they are introduced as such in Methods (L. 103). However we agree that we can add the names of the indices in a bracket so as to be more precise what is meant.

L288-290 – This does not make sense. Can you remind us how you are determining this? Does this mean that the patch category explains the given plankton concentrations?

REPLY: We agree that this sentence could be misleading. The statistics were based on the concentrations within size fractions (Pico, Nano, Micro, Small, Medium, Large) and the factors (explanatory variables) that are listed in Methods (L111-L114). This can be re-phrased as follows:

"In both regions approximately half of the variation in particle and plankton concentrations in all the distinguished patches was explained by the analysed by the model explanatory variables (51% in Kongsfjorden and 45% in Isfjorden)(Fig. 9)."

L295 – This is really confusing. I don't understand what you are talking about, so you need to use examples or numbers to supplement the text.

REPLY: We agree that this statement was confusing and actually redundant, thus it will be deleted. It is explained more thoroughly in Discussion (*"In the case of the patches analysed in this study, the local environmental variables were the most crucial in the case of the fjord, where smaller spatial scale was investigated (Isfjorden), whereas the spatial effect was privileged when the larger distance and thus wider spectrum of environments was considered (Kongsfjorden)."*)

L305 – This is a misleading statement. For smaller plankton, they are typically reproduced in a given area because their swimming ability is poor. Maybe only really large plankton are capable of "getting" to a place.

REPLY: By the statement *"the plankton organism and/or a particle has somehow get to the place"*, we were not thinking about its active swimming behaviour, but rather that "somehow" means a great variability of various mechanisms (mostly physical). However, after consideration we agree that it should be more straightforward, so we propose to add an example into the bracket "(e.g., by ocean currents)"

L312 – You need to define what and "overlaid effect" is because it is not clear from the text.

REPLY: We meant overlapping, as the fact that the influence of various forces are not acting independently, but in synergistic way. This will be clarified.

L316 – Do you mean physical or biological mechanisms? There can be ecological mechanisms, so I don't think it is appropriate to have "mechanistic vs. ecological" since they are not mutually exclusive.

REPLY: Yes, we meant "physical or biological mechanisms" and this will be changed accordingly.

L317 – What are the "new gates" that are being opened up? There is too much unclear and informal language for a scientific paper.

REPLY: We agree that this statement was unclear and constructed in rather informal matter. This will be re-phrased as e.g., *"Since no explicit conclusions could be made, this study rather opens up new perspectives for further research by providing a proposition how to categorize the types of their structuring in a water column as a potentially additional aspect to be considered for understanding their short term and local variability."*

L320-338 – This paragraph has many topic shifts and is very disorganized, so it is tough to follow the main points. L323- one example of many – this can be much more simply stated: larger scale patches are dominated by physical processes.

REPLY: We agree and we will try to shorten the paragraph by making it more straightforward according to your suggestion, e.g., as follows:

"Because the physical processes act naturally at different spatial and time scales than plankton growth and activity (Mahadevan, 2016; Prairie et al., 2012), they mostly shape large scale patches, while the relative importance of the biotic processes increases inversely with scale (Pinel-Alloul, 1995), Therefore it is important to realize which processes operate on local and which on oceanic scale when trying to decipher patterns in particles and plankton distributions (Kuhn et al., 2019; Prairie et al., 2012). In the case of the patches analysed in this study, the local environmental variables were the most crucial in the case of the fjord, where smaller spatial scale was investigated (Isfjorden), whereas the large scale spatial effect was privileged when the larger distance and thus wider spectrum of environments was considered (Kongsfjorden). However, as both fjords are opened and prone to intensive Atlantic water advection, which definitely re-shapes plankton communities (Basedow et al., 2004; Kubiszyn et al., 2014; Skogseth et al., 2020; Trudnowska et al., 2020b), mostly in favour of smaller species, this large scale oceanic circulation process has also be regarded as of high importance. Whereas melting glaciers were clearly recognized as the dominating local process, resulting in the recurring high particles and plankton accumulations in the innermost glacial bays, which is typical for the summer melting period (D'Angelo et al., 2018; Kanna et al., 2018; Meire et al., 2017; Szeligowska et al., 2020; Trudnowska et al., 2020a). Since the summertime in the Arctic is also a time of intense biological production and plankton activity (Kubiszyn et al., 2017; Svensen et al., 2019; Trudnowska et al., 2014), the local ecological selection must have also been acting, playing important role in shaping the observed patchy distribution patterns and high concentrations of plankton."

L355-360 – Chlorophyll is not the same as phytoplankton because of photoquenching and time of day can affect chlorophyll even though phytoplankton abundance is not changing.

REPLY: We agree. This sentence will be modified as follows: *"Because only the concentrations of the Large size fraction correlated significantly with chlorophyll just in Isfjorden, this indicates that in general the concentration hotspots of smaller size fractions of particles and plankton were not actively fluorescent"*

L376 – Do you mean their abundance? This isn't really a "role" unless you are defining it in a different way (in which case you need to state what you mean by "role").

REPLY: Actually it is explained in a bracket, i.e.: "*The trend of an increasing role of the smallest size fractions (steepening size spectra slopes)*", because the slope of the spectra is driven by the abundance of smaller size fractions in relation to the abundance of the larger ones. If there is a high ratio between small and large ones, then the slope is steep, whereas when the ratio is low, then the slope is flat.

L385 – You have 2 years of data, so you can't really say much about climate change. This is beyond the scope of your study. It would be best to stick to what you can actually demonstrate with your data.

REPLY: To be accurate, we present 6 years from Kongsfjorden and 5 years from Isfjorden. Of course we agree that it is not a time frame to say anything about the climate change, if we regard only our results. But if we put our results on the scene of the long term monitoring programs and literature from the same region, then this study brings new observations that may support the results and conclusions concerning the effects of climate change in Svalbard archipelago. Actually, in the cited by the reviewer line there is no indication about the climate change... the only one in this part of the Discussion is in L.378: "*Such shift in plankton size structure towards the proliferating importance of Pico fraction is now a widely recognized effect of the progressing climate warming in the Arctic (Li et al., 2009; Metfies et al., 2016; Nöthig et al., 2015).*", which in our opinion only sets our results in agreement with the trends observed in other studies.

L405-417 – Many parts of this paragraph do not make sense. There are many abrupt topic shifts that make it hard to read any flow to the discussion.

REPLY: We propose to shorten this paragraph considerably and focus only on the considerations about the possible biological content of the patches, e.g.: "*As shown by the very first studies of patchiness, the abundance patch does not necessarily coincide with the same compositional patch, as it may be formed either by a bloom of a specific species or a group of species (Mackas, 1984), resulting in a taxonomically heterogeneous patches (Greer et al., 2016). We may only assume that the observed by us patches differed compositionally, basing on variations in size spectra of particles and plankton within the patches, and our general ecological knowledge of the plankton composition observed during summer in studied regions. Even though the planktonic dominants representing the particular size fractions may vary in both studied regions depending on the year and season, typically dinoflagellates (Bhaskar et al., 2020) or diatoms (Piwosz et al., 2009) dominate the summer community structures of protists in Kongsfjord, while *Phaeocystis pouchetii* dominate in Isfjord (Kubiszyn et al., 2017), together with *Cryptophytes* and *Ciliates* (Szeligowska et al., 2020). Zooplankton in turn is mainly dominated in both fjords by copepods, such as *Oithona* and *Calanus* (Gluchowska et al., 2016; Hop and Wiencke, 2019; Szeligowska et al., 2020; Trudnowska et al., 2020b).*"

L422 – I do not agree that patchiness is "well-resolved." Many in situ technologies have only been deployed in particular environments and specific times of the year. Our descriptions of patchiness are getting better but still quite limited.

REPLY: Agree, this will be changed accordingly.

L426 – This is not true – we do know about the internal structures of patches in some instances. There is lots of thin layer research about the structure of patches, and acoustics has shown how patches can change in response to oceanography.

REPLY: First of all this controversial sentence will be smoothed into a more realistic one, e.g. : "*Hence, so far our knowledge about the internal structure of the patches is fairly limited and ecologists tend to perceive patches in a simplistic way.*" Moreover, we agree that thin layers are much better recognized, which is indicated in L338-440 ("*While the*

horizontal thin layers (up to few meters thickness and horizontal extensions overs many kilometres) are among the best studied patchy forms (McManus et al., 2005; Stacey et al., 2007), typically containing densities far greater than those above or below the layer (Deksheniaks et al., 2001; Durham and Stocker, 2012)"), but they are not the structures we found and studied.

L439 – You previously said we don't know anything about the structure of patches...

REPLY: The answer to the previous point is about this point. I think the problem is that we treat thin plankton layers as something a little bit apart from patchiness. It is something well recognized and we think that it is now quite well understood what kind of physical water structuring and biology must have stand behind their formation. But, if we look at patchiness that occur in more variable way, then the story starts to be complicated and this is the scope of our study to focus on those other than thin layer patches of plankton.

L442 – How do you know these results are specific to waters near glacial fronts?

REPLY: Because they were mostly and repeatably found near the glacier fronts, and also that we know from our Arctic experience from other studies that the glacier runoff is observed in such a form, as the material is upwelled from the bottom and at the same time it is brought with the melting waters at surface.

Also, don't you think others have reported on the patch shapes you have described? They just might not have used the same terms you are using. It would be good for you to give some credit to researchers that have found something similar in terms of patch shapes.

REPLY: We totally agree. We did again the research in literature, which resulted in a few new citations, but still we haven't found anything going deep into the topic of patch internal structure, or variability in shapes. Maybe it is a problem of the terms used, so we would be extremely grateful if the reviewer could suggest to what we can refer to.

Figures:

Figure 2- There are no indication of the units for the different size classes. It would be useful to put the track of the tow-yo on at least one of the plots, so the reader can see what was interpolated.

REPLY: The units will be added. As indicated in general comment, we are afraid that adding the data points will cover the panel drastically.

Figure 3 – Color of the boxes and the x axis are redundant – you don't need color for this figure.

REPLY: Yes we agree that they are redundant per subfigure, but we thought that this colouration will make it much easier to follow the specific years among the panels (regions and subregions).

Figure 4 – you should not use the name of an R function in the figure caption. You need to state in mathematical terms what the shapes are enclosing. The patterns are quite messy, and it is really hard to tell what the figure is showing overall. Is this really the best way to show differences in the patches among years and size classes?

REPLY: We have to admit that it is tricky to present almost 100 patches designated in a one cohesive Figure. So, if the reviewer think that it is too busy, we propose that we can

select some exemplary patches and present them in a more interesting way, as exemplified in a supplement.

Figure 5 – I am not convinced you can determine all of these types with a tow-yo sampling pattern. It is possible that some patch shapes will be less likely to be detected given the sampling pattern? Could this also be dependent on the background abundance of a given particle size? This is why you need to show the path of the sampler in at least 1 figure so this can be evaluated.

REPLY: We think that maybe the other way of presenting patches (as proposed above) will enable to present how the structures of the patches may look like, Of course this scheme is a very simplified version, but we do think it is important to present the 'idea' standing behind the selection of each type.

Figure 6 – Again your fill and x axis are redundant. Color is not needed, and all of these graphs essentially show the same thing.

REPLY: We agree. This will be unified.

Figure 7 – Density usually just implies where the patch was. So how do you account for patch types that are likely to crossing multiple environments. I would think this would be much more likely with certain patch shapes, so how do you realistically standardize this kind of plot. Also, does this account for the time spent by the tow-yo in the different values of the x variable? I cannot tell how this was done (or if it was done) in the methods.

REPLY: This Figure and analysis will be deleted in a new version of the manuscript.

Figure 8 – the size of the dots are changing, but there is no legend to indicate what this means. How can some white squares be significant, but many of the blue dots are not?

REPLY: The Figure caption will be improved, as well as the description of colour coding of the color bar.

Figure 9 – unclear what this is showing – no legend to show what the size of the dots mean. Why would this not be more clearly expressed in a table?

REPLY: This Figure will be supplemented by the RDA plot and all the necessary details.

Please also note the supplement to this comment:

<https://bg.copernicus.org/preprints/bg-2021-98/bg-2021-98-AC1-supplement.pdf>