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Interactive comment on "Warmer winters causes an increase of chlorophyll-a concentration in deeper layers: the opposite role of convection and self-shading on the example of the Black Sea" *by* Elena A. Kubryakova and Arseny A. Kubryakov

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Response to reviewer #2

Reviewer: "The authors investigate the drivers of differences in the vertical distribution of chlorophyll-a between 2016 and 2017 in the Black Sea using BGC-ARGO data. A key feature of interest in the vertical distribution is the so-called deep chlorophyll maximum (DCM), which the authors show is deeper and less intense in 2016 than in 2017. They account for this difference by arguing that cold atmospheric conditions in the winter of 2017 led to convective mixing and nutrient entrainment, thus increasing winter production. It is then argued that this increased production led to enhanced self shading in 2017, which accounts for why the DCM is shallower compared to 2016. In general, I agree with other reviewers that the hypothesis presented is interesting and could represent a significant contribution to the question of what factors control the DCM. However, I also agree that currently the authors do not present sufficient evidence to support their hypothesis. Furthermore, the methodology requires some important revisions which I explain below. I therefore recommend that the following revisions be undertaken prior to publication".

Authors: First, we would like to thank the Reviewer for comments and constructive suggestions for improving the paper.

General comments (GC).

GC1. "All monthly averaging should be removed or only added to supplement the higher frequency data. This is actually why there is little difference seen in the MLD between the 2 years - the differences have been averaged out. Below I show an example of temperature profiles for early February comparing the 2 years. Here it is clear that the MLD is deeper in 2017 by ~20 m, although if you average over the whole month you won't see much difference. This highlights that the phenomenon being investigated occurs at much higher frequency than monthly, which needs to be taken into account in more detail than is currently done".

Answer GC1 Unfortunately, we can not fully agree with the suggestion that monthly-averaged data cannot be used in the study. We agree that the short-period oscillations of Chl and the reasons for their variability is a very important task. The detailed investigation of year-to-year seasonal changes of Chl in the Black Sea in 2014-2019 was made in our recent study (Kubryakov, A. A., Mikaelyan, A. S., Stanichny, S. V., Kubryakova, E. A.: Seasonal Stages of ChlorophyllâĂŘa Vertical Distribution and Its Relation to the Light Conditions in the Black Sea from BioâĂŘArgo

Measurements, Journal of Geophysical Research: Oceans, 125, e2020JC016790, https://doi.org/10.1029/2020JC016790, 2020). We hope that we will be able to investigate the reason for even more high-frequency variability of Chl in our future studies. Particularly, one such study related to the impact of intense storm on the anomalous rise of Chl in August 2015 on the base of Bio-Argo data was carried out in (Kubryakov, A. A., Zatsepin, A. G., and Stanichny, S. V.: Anomalous summer-autumn phytoplankton bloom in 2015 in the Black Sea caused by several strong wind events, Journal of Marine Systems, 194, 11-24, https://doi.org/10.1016/j.jmarsys.2019.02.004, 2019).

However, in the present manuscript, we investigate the reasons, which can explain why DCM in one year was deeper than in another year. That is why we are focusing on annual time scales and need to average the data. The time-averaging is a typical oceanographic technique that is widely used for the investigation of processes on different time scales (see, for example, Fig. 8 and 10 in (Mignot, A., Claustre, H., Uitz, J., Poteau, A., D'Ortenzio, F., Xing, X. (2014). Understanding the seasonal dynamics of phytoplankton biomass and the deep chlorophyll maximum in oligotrophic environments: A Bio-Argo float investigation. Global Biogeochemical Cycles 28: 856-876 | DOI: 10.1002/2013gb004781).

Below, we show the examples explaining this statement, similar to the one presented by the Reviewer. In Fig. R1 You can see the data of only one float (#690186) for the February month of 2016 and 2017. In the left figure, we chose profiles, where MLD in 2016 was larger than in 2017. This figure can lead to a conclusion that MLD was higher in 2016. In the second figure, we chose profiles, where MLD in 2016 was larger than in 2017. This figure can lead to a conclusion that MLD was higher in 2017. In 2017 larger amount of profiles have higher MLD, by there were also opposite cases. This figure presents only the measurements of one float. Therefore, to understand in what years MLD was deeper, we need to average the data.

At the same time, we agree that it may be helpful for the paper to give information about maximal MLD, density, and minimum temperature observed in both years. These values more clearly define the maximum intensity of winter convection, detected by float measurements. We have added this information to the text:

lines 172-173: "Minimal temperature at 5 m depth detected by Bio-Argo floats was equal to 7.8°C in 2016 and 5.5°C in 2017."

lines 189-190: "Maximum density at 5 m depth detected by Bio-Argo floats was equal to 1014.44 kg/m3 in 2016 and 1014.70 kg/m3 in 2017."

line 202: "Maximum mixed layer depth reached 65 m in 2016 and 85 m in 2017."

GC2. "Similarly to point 1 above, the data should be presented with as little interpolation as possible. It is clear from figures 2, 4, 5 and 6 that some kind of spatiotemporal interpolation has been done to produce such highly "smoothed" plots. Below I show an example of how the chl-a data look for float 6901866 with a minimal amount of interpolation (here I only use a linear interpolation in the "depth" dimension for the missing data, and gaps of greater than 5 m are not interpolated) I suggest to change the figures to something more like this, which portrays the data more accurately.

Answer GC2. We do not use any spatiotemporal interpolation in Fig. 2, 4, 5, and 6. The Fig. 2, 4, 5 present monthly-averaged data. As it is stated in Section 2.2, we only interpolated data vertically on a 1 m grid (similar as You do). In Fig. 7, we use ten-daily averaging to obtain data on the regular time grid. This is stated in the revised text in line 262.

However, we use a different visualization technique. If it is a Matlab, we prefer to use contour plot, and we think You use "imagesc" (or "pcolor"). We try to reproduce Your code approximately and have below attached the figure of Chl variability (5-days binarization) for float #6901866 plotted with a use of "imagesc" (Fig. R2b). As You can see, Fig. R2a and R2b are very similar. For the comparison, Fig. R2c presents the same data using contour function, other colorbar, and color limits. The same data looks different when using different visualization techniques.

Both functions, "contour" and "imagesc" ("pcolor"), are widely used. Both of them use interpolation. "Imagesc" ("pcolor") use the nearest interpolation, while "contourf" use continuous one. Discrete and continuous colorbar also, of course, play their roles.

We send You the code in Matlab below. Please check if You will have the same result.

Figure

contourf(d,-z, chl,100,'lines','none')

datetick('x')

caxis([0 1])

GC3. Here it is clear that the high chl-a values seen in winter of 2017 are actually composed of 2 short periods (10-15 days) of elevated growth, one in December and another stronger one in March. Figure 2 in the current manuscript makes it seem like one long period of sustained growth. Figure 6 does actually show these 2 pulses, but since 2016 and 2017 are split into separate panels one cannot easily see the 2 distinct growth periods. The plot above also shows that the DCM is most intense (highest chl-a) in the autumn of 2018 - it might be interesting to look into why this is the case".

Answer GC3. We agree with this comment. Yes, there are two peaks in November 2016 – March 2017. Such two peaks are the usual pattern of the seasonal Chl dynamics in the Black Sea. Actually, three peaks of Chl are detected in the Black Sea throughout the year: February-March peak, summer peak, and late autumn-early winter peak in November-January. Both February-March and November-January peaks are related to the intensity of winter convection. They are separated by the minimum in February, which is related to the deepening of the mixed layer below the euphotic layer (Sverdrup, 1954). These features of the seasonal changes in Chl were in detail investigated in our recent study (Kubryakov et al., 2020). In (Kubryakov et al., 2020), we also demonstrate and discuss the year-to-year difference in Chl variability in the 2014-2019 period.

We agree that both February-March and November-January peaks were strong in the cold winter of 2016-2017. We have added this information in the revised version of the manuscript: "In addition, float #6901866 detect significantly more intense late autumn Chl bloom in November-December of 2016. This seasonal bloom is also driven by the winter mixing (see Finenko et al., 2014; Mikaelyan et al., 2017; Kubryakov et al., 2020), which was more intense in the cold season of 2016-2017." (lines 269-272).

Kubryakov, A. A., Mikaelyan, A. S., Stanichny, S. V., & Kubryakova, E. A. (2020). Seasonal Stages of ChlorophyllâĂŘa Vertical Distribution and Its Relation to the Light Conditions in the Black Sea from BioâĂŘArgo Measurements. Journal of Geophysical Research: Oceans, 125, e2020JC016790. https://doi.org/10.1029/2020JC016790

GC4. "I follow the argument that the upliftment of isopycnals is associated with a rise in the nutricline and therefore nutrient entrainment into the MLD. However, I would argue that simply referring to other literature where this relationship has been established is not sufficient to say that it has occurred in the present case. Since this entrainment of nutrients is key to the argument being made, it follows that it should be explicitly shown with data. Here I recognise that the nitrate data may be biased in these particular floats as the authors have suggested. However, the important point is that nitrate concentrations should be higher in the cold 2017 year, so biases in the concentration may not preclude the use of this data (since we look for relative differences, not absolute values). So long as the bias is properly taken into account I would argue that the data should be used to support the argument. If the data are really not appropriate, perhaps other proxies for entrainment of deep water could be used (e.g. dissolved oxygen)?"

Answer GC4. We made such a comparison to answer Your comment. The graph below shows the seasonal variability of nitrates in surface layers in different years (Fig. S1). First, we notice that it approve a higher nutrient amount in winter of 2017 than in 2016. However, we think that we can not refer to this data, as it shows completely incorrect values of NO3. Bio-Argo derived values of NO3 was in 10 times higher than the data from numerous in-situ studies (see Fig. S1a, b).

Supplementary Fig. S1: (a) the multi-annual average vertical profiles of nitrate (NO3) and phosphate (PO4) in σ-coordinates for October, the month preceding the onset of intense winter convection from in-situ MHI data archive; (b) seasonal variability of NO3 at 1 m depth in 2015-2020 according to Bio-Argo measurements.

This is the most significant problem, which does not allow to publish such data. There are some other problems: incorrect seasonal variability with maximum in summer and minimum in winter (Fig. S1b); long-term trend of NO3 (Fig. R3), which indicate the possible drift of the sensor.

Personally, our analysis of Bio-Argo optical NO3 measurements indicated that they were able to "feel" the lower boundary of nutricline, but not the proper values in upper layers. We understand that this method is experimental and hope the Bio-Argo team will be able to correct these problems in the future.

Hydrological data show that 2017 was colder than 2016. The winter convection in the Black Sea is driven by cooling, and the temperature is used as an indicator of the convection in many previous studies (please, see the comment below) Anomalously cold winter and intense convective mixing in 2017 compare to other years in the 2010-2020 period was already documented in several previous studies (Stanev et al., 2019; Capet et al., 2020). Stanev et al., 2019 showed that the cold winter of 2017 causes intense ventilation of the cold intermediate layer in 2017. A study of dissolved oxygen variability in 2017 was already done by Capet et al., 2020. Capet et al., 2020 show that oxygen content was highest in the winter of 2017 due to strong cooling and convective mixing. In our manuscript, we just confirm this already documented fact (about cold winter and strongest convection in 2017) to give an oceanographic context for the interpretation of the bio-optical properties.

We have underlined this fact in the revised manuscript at lines 206-208: "To conclude, the above analysis is used to argue that the vertical entrainment of nutrients from deep isopycnal layers was more intense in the cold winter of 2017 than in the warm winter of 2016. This fact is in agreement with recent studies based on the analysis of T, S-diagrams (Stanev et al., 2019) and oxygen variability (Capet et al., 2020) from Argo measurements."

GC5. "If convective mixing is indeed present in winter of 2017, then one should be able to see strong cooling events preceding the mixing events. For this one could perhaps use a reanalysis product or something similar. The heat flux could even be estimated for these cooling events, although it may be enough to correlate temperature anomalies with the mixing events. If there are indeed strong cooling events preceding the mixing, then this would certainly strengthen the argument".

Answer GC5. Convective mixing in the Black Sea is observed every year. It is a subject of investigations in many amount of previous studies in the basin, for example:

Staneva, J.V., Stanev, E.V.: Cold Intermediate Water Formation in the Black Sea. Analysis on Numerical Model Simulations. In: Özsoy E., Mikaelyan A. (eds) Sensitivity to Change: Black Sea, Baltic Sea and North Sea. NATO ASI Series (Series 2: Environment), 27, Springer, Dordrecht, https://doi.org/10.1007/978-94-011-5758-2_29, 1997.

Ivanov, L. I., Backhaus, J. O., Özsoy, E., & Wehde, H. (2001). Convection in the Black Sea during cold winters. Journal of marine systems, 31(1-3), 65-76.

Titov, V. B., 2004. Formation of the upper convective layer and the cold intermediate layer in the Black Sea in relation to the winter severity. Oceanology 44: 327–330.

Oguz, T., Dippner, J. W., & Kaymaz, Z. (2006). Climatic regulation of the Black Sea hydro-meteorological and ecological properties at interannual-to-decadal time scales. Journal of Marine Systems, 60(3), 235-254.

Belokopytov, V. N. (2011). Interannual variations of the renewal of waters of the cold intermediate layer in the Black Sea for the last decades. Physical Oceanography, 20(5), 347-355. Piotukh, V. B., Zatsepin, A. G., Kazmin, A. S., & Yakubenko, V. G. (2011). Impact of the Winter Cooling on the Variability of the Thermohaline Characteristics of the Active Layer in the Black Sea.Oceanology, 51(2), 221.

Korotaev, G. K., Knysh, V. V., & Kubryakov, A. I. (2014). Study of formation process of cold intermediate layer based on reanalysis of Black Sea hydrophysical fields for 1971-1993. Izvestiya. Atmospheric and Oceanic Physics, 50(1), 35.

In the major part of these studies, it is indicated that thermal conditions play the main role in the processes of ventilation of waters in the winter period. All these studies also confirm that temperature is a reliable indicator of the intensity of winter convection in the Black Sea. In this study, we do not have a goal to investigate in detail convective processes in the basin. These processes were particularly investigated in many cited studies.

Anomalously cold winter and intense convective mixing in 2017 compare to other years in the 2010-2020 period was already documented in several previous studies (Stanev et al., 2019; Capet et al., 2020). In our manuscript, we just confirm this already documented fact (about cold winter and strongest convection in 2017) to give an oceanographic context for the interpretation of the bio-optical properties.

We have added the comment to the text (lines 100-103): "The thermal conditions plays the main role in the processes of ventilation of waters in the winter period. Therefore water temperature is used as a reliable indicator of winter convection in the Black Sea (see e.g., Blatov et al., 1984; Staneva, Stanev, 1997; Ivanov et al., 2001; Belokopytov & Shokurova, 2005; Knysh et al., 2011; Piotuch et al., 2011 and many others)."

GC6. "I recommend that the authors provide a quantitative estimate of the DCM depth, so that its temporal variability be assessed objectively. I can think of various ways this could be achieved, perhaps by obtaining the mean depth of the 90th or 95th percentile of chl-a concentration for each profile. A time series of the DCM depth could then be produced for both floats and the cold/warm years compared quantitatively".

Answer GC6. Thank You for this good advice. We have added the graphs of the position of the lower boundary of DCM to the revised paper (see Fig. 3c). We subjectively defined DCM as a layer with Chl larger than 0.2 mg/m3. This graph complement our results and demonstrate that DCM in 2016 was deeper than in 2017.

GC7. "The level of English in some parts of the manuscript detracts from the value of the science being presented. I provide some suggestions for specific passages below, however, I would strongly suggest that the authors further edit the manuscript to improve clarity and the communication of the findings".

Answer GC7. According to Your comment, we have carefully checked and corrected English grammar in the revised version of the text.

Specific Comments (SC)

SC0. "All figures: The captions lack detail and in many cases are unclear. I suggest carefully reviewing them, adding additional details and rewording to avoid confusion. I give some examples below, but I suggest to revise all captions".

Answer SC0. We have improved all figures' captions in the revised version of the manuscript according to Your comment.

SC1. "Line 27 (and subsequent use): I'm not sure what is meant by "nitroclyne." Please define this."

Answer SC1. We agree and have changed this word on nutricline in the manuscript.

SC2. "Lines 58-59. Is this really true that: "The amount of Chl and related water clarity largely control the depth of the euphotic zone (Shigesada & Okubo, 1981; Morel, 1991). "What about solar angle, time of year? Non-organic particles? Time of year is mentioned earlier in the text, but here it seems like Chl is essentially the only factor. I would reword to "The amount of Chl and related water clarity strongly impact the depth of the euphotic zone . . ."

Answer SC2. Thank You. We agree and have corrected this sentence.

SC3. "Line 47. What is meant by the term "dynamic upwelling"? Please clarify in the text or reword, since this is not standard terminology".

Answer SC3. We have rewritten this phrase as "such as storms, upwellings, or vertical advection in eddies."

SC4. "Line 62 -63. What is the degree of shoaling of the euphotic zone reported in Letelier et al. (2004)? How is phytoplankton impacted and what is specifically meant by "deep layers" (i.e. how deep)?"

Answer SC4. We have added these details to the text (lines 64-66): "On seasonal time scales, Letelier et al. (2004) have shown that the winter bloom of phytoplankton in the tropical Pacific Ocean leads to the additional shoaling of the euphotic zone on about 20 m, inhibiting the development of phytoplankton in the deep layers (below 100 m depth)."

SC5. "Lines 80-82. "Due to the strong haline stratification, the position of chemical layers in the Black Sea is tightly coupled to certain isopycnals and the variations of their concentration in density coordinates are significantly less than in z-coordinates. "Do you mean that vertical variations in the concentration of certain chemicals is significantly less in density coordinates than in z-coordinates? If so, please state this more clearly since the wording is potentially ambiguous. I would also suggest briefly stating why this is important/ significant".

Answer SC5. We agree and have rephrased this sentence in the revised manuscript (lines 105-106): "That is why the variations of their concentration in isopycnic (or σ) coordinates are significantly less than in vertical z-coordinates (Konovalov et al., 2005; TuÄ§rul et al., 2014)."

SC6. "Lines 173 - 179: Do you mean here that large-scale circulation is intensified in cold years? If so, a revision of the wording is needed to make this clear. In addition, you would need to describe this phenomenon in more detail (i.e. what is the mechanism?)".

Answer SC6. Thank You. We agree with this comment and have corrected this paragraph (lines 112-116): "Usually, the most intense cyclonic circulation in the basin is observed in the cold years (Blatov et al., 1984; Oguz et al., 2006). Both cyclonic circulation and winter cooling are driven by the same atmospheric patterns – intensification of northeast winds bringing cold continental air from Eurasia (Kubryakov, Stanichny et al., 2019). The rise of cyclonic circulation causes uplift of the pycno-halocline and bring nutricline closer to the surface, but on the opposite decreases MLD (Titov, 2004)."

SC7. "Lines 223 - 229: This passage is currently very unclear. What negative anomalies are the authors referring to? Do they mean the negative values shown in Figure 6e and f? In that case, they should not be referred to as anomalies (which suggest a difference with respect to a long term mean) but as differences (higher or lower chl-a in 2017/2016) or perhaps just "negative values." I would suggest revising these lines, making clear what features the authors refer to and in which figure panels. The authors also suddenly start talking about the geographical location of the 2 floats, without any preamble or reference to Figure 1. I suggest to remind the reader of the location and trajectory of the 2 floats before discussing chl features detected by each".

Answer SC7. We agree and have changed "anomalies" on "values" in the text. We have also rephrased this paragraph (lines 283-288): "There are also noticeable differences in the float measurements, which were possibly caused by the differences in their geographical location. High Chl values measured by the float #7900591 in the central part of the basin were located in a relatively narrow layer with a thickness of 20 m (Fig. 7a, b). Chl distribution measured by the float #6901866 over the continental slope was characterized by a larger thickness of DCM in both years (Fig. 7c, d). The strongest and widest negative differences of Chl were detected by float #6901866 in the whole 35-75 m in July-September, while float #7900591 detected such values throughout the whole season in the narrower layer with a thickness of 20 m (Fig. 7e, f)".

SC8. "Line 244: What is meant by "compensational irradiance"? I suggest to clarify in the text".

Answer SC8. The compensation irradiance is the irradiance at which gross planktonic primary production equals to respiration. Below this irradiance, the demand for respiration exceeds the production by photosynthesis, Chl rapidly decreases. Phytoplankton became heterotrophic or die off (see e.g. RegaudieâĂŘdeâĂŘGioux, A., & Duarte, C. M. (2010)). Compensation irradiance for planktonic community metabolism in the ocean. Global biogeochemical cycles, 24(4), https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2009GB003639). We have rephrased this paragraph (lines 300-303): "The euphotic zone is marked in Fig. 4a, b, Fig. 5a, b as the isolume Ed=3 μmol of photons m-2 s-1 (or 0.08 mmol photons m-2 day-1). Below this isolume Chl rapidly declines in the Black Sea (Kubryakov et al., 2020). This indicates that this isolume can play a role of the compensation irradiance in the basin (the irradiance at which gross planktonic primary production equals to respiration)."

SC9. "Figure 8: I don't think it's that useful to have the NO3 depicted in both panels of the figure if the profile is exactly the same".

Answer SC9. We agree and have revised this figure to qualitatively demonstrate the changes in NO3 distribution in a warm and cold year.

Technical Comments (TC)

TC1. "Line 35: "The biomodelling study by Kubryakova et al. (2018)" → I would not use the word "biomodelling," this is definitely not a standard term that is recognised by the community. Biogeochemical or ecosystem model would be more appropriate (or just "modelling")".

Answer TC1. "Biomodelling" was replaced by "modelling".

TC2. "Line 45: "nutrients" should be nutrient."

Answer TC2. Thank You. Corrected.

TC3. "Line 54: change "documented for the Black Sea in . . . "to "which has been documented in the Black Sea (references)."

Answer TC3. This phrase is corrected.

TC4. "Throughout the manuscript please change "buoys" to floats. The use of buoys may lead to confusion since BGC-ARGO are floats".

Answer TC4. Throughout the manuscript, the word "buoys" was replaced by "floats."

TC5. "Figure 1: I suggest to only show the isobaths that are labelled (2000, 1600, 1000, 200 m), since as the figure is now there are so many that it becomes meaningless".

Answer TC5. We agree and have corrected the Fig. 1.

Figure 1: Trajectories of the floats #6901866 and #7900591 in 2016 and 2017. The colorbar shows the date of the measurements. Purple crosses – the start of the trajectories, black crosses –end of trajectories. Gray lines show the position of isobaths.

TC6. "Line 125: What is the depth of the reference density used for the MLD calculation?"

Answer TC6. The reference density was taken at 1 m depth. We have added this information to the text (line 157).

TC7. "Figure 4: Which float is the data taken from? If it is an interpolation of both then the method of interpolation must be provided. Add details to the caption".

Answer TC7. This figure shows monthly-averaged values obtained from the average data of two floats. No interpolation was used. We have added this information to the caption.

TC8. "Figure 5: State in the caption how the difference is computed, is it 2016 - 2017 or the other way around? Following this, it would also be helpful to say what positive and negative values mean, e.g. "positive values indicate the chl values are higher in

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2017".

Answer TC8. Thank You. We have added this information in the caption for Fig. 6 and 7.

TC9. "Figure 7: It is unclear what is being compared here. Are the red lines 2016 and blue 2017? Or do they represent different floats? Please clarify in the caption, and also add legends to the figures.

Answer TC9. Thank you. We have added this information to the caption: red line – 2016, blue line – 2017.

TC10. "Line 154: conventional should be convectional".

Answer TC10. Thank You. Corrected.

TC11. "Line 213: "Ten-daily diagram. . . "Change to "Fig. 6a-d shows the same features at a higher frequency of 10 days...".

Answer TC11. We have corrected this phrase.

TC12. “Line 233: “Jule-September”.

Answer TC12. We agree and have corrected the text.

TC13. "Lines 291 - 292: "Entrained in winter period nutrients and the rise of the irradiance causes the following spring growth of phytoplankton. "Reword as: "Winter entrainment of nutrients, followed by increased irradiance in spring, is known to lead to enhanced phytoplankton growth."

Answer TC13. Thank You for this advice. It is corrected.

Please also note the supplement to this comment:
https://bg.copernicus.org/preprints/bg-2020-366/bg-2020-366-AC4-supplement.pdf

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2020-366, 2020.

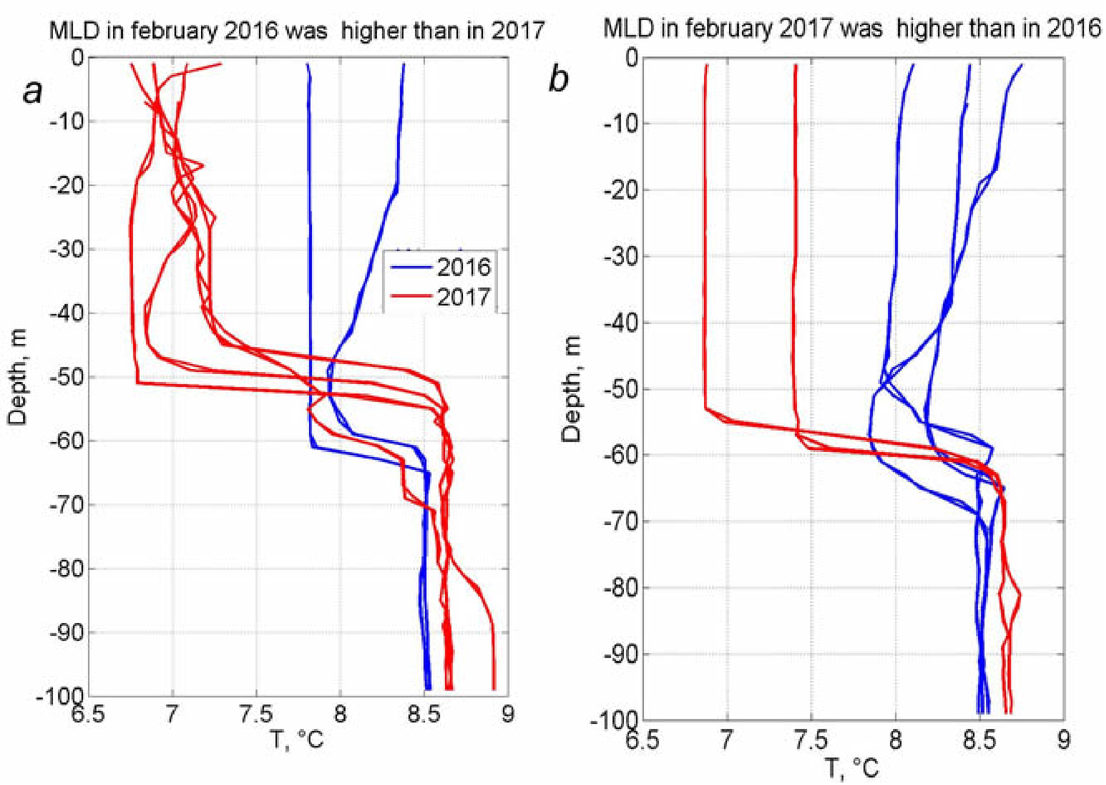

Fig. 1. Fig. R1: Profiles of float #690186 of February 2016 (blue line) and 2017 (red line): (a) – only profiles with MLD higher in 2016 than in 2017; (b) – only profiles with MLD lower in 2016 than in 2017

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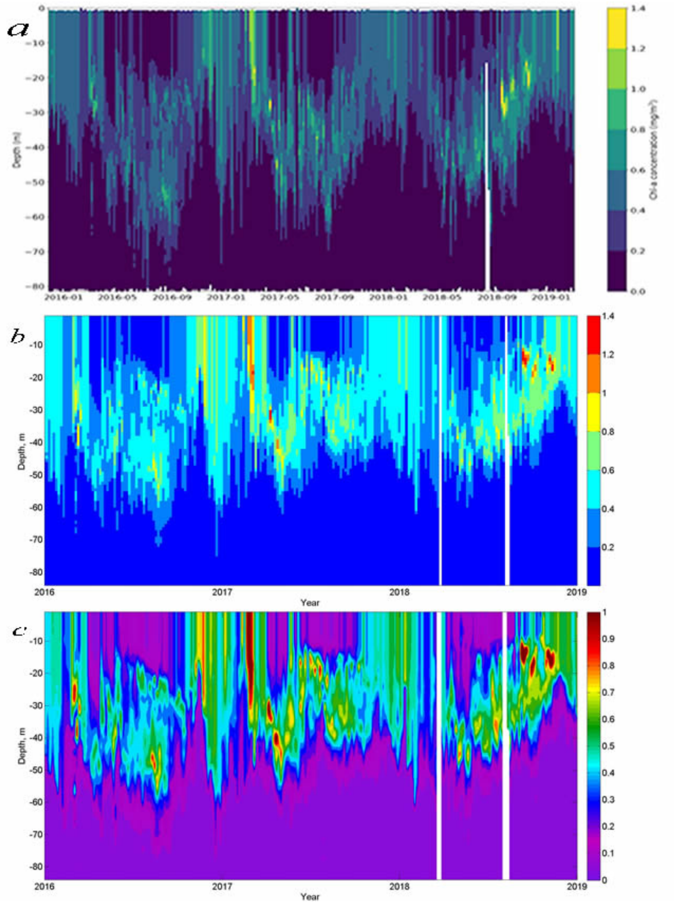

Fig. 2. Fig. R2: Variability of Chl according to Bio-Argo float #6901866: (a) – the Reviewer's image; (b) – Chl visualized using "imagesc" function; (c) – Chl visualized using "contourf" function

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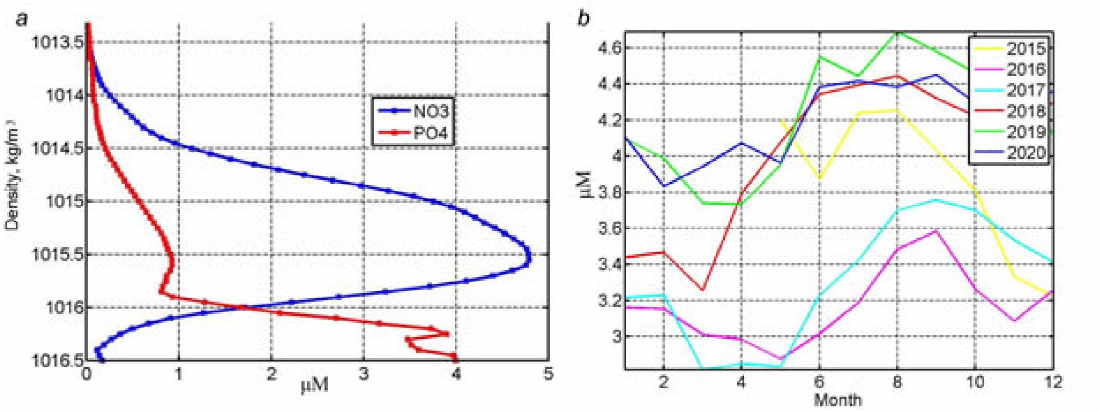

Fig. 3. Supplementary Fig. S1 (see the caption in the text, answer GC4)

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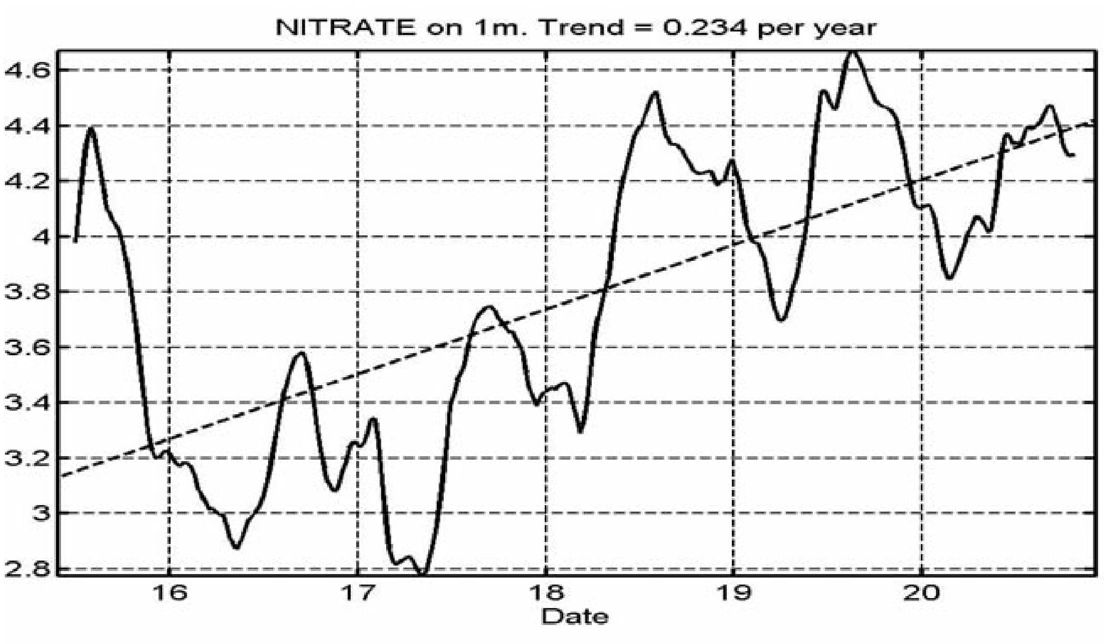

Fig. 4. Fig. R3: Interannual variability of NO3 at 1 m depth in 2015-2020 according to average data of Bio-Argo floats.

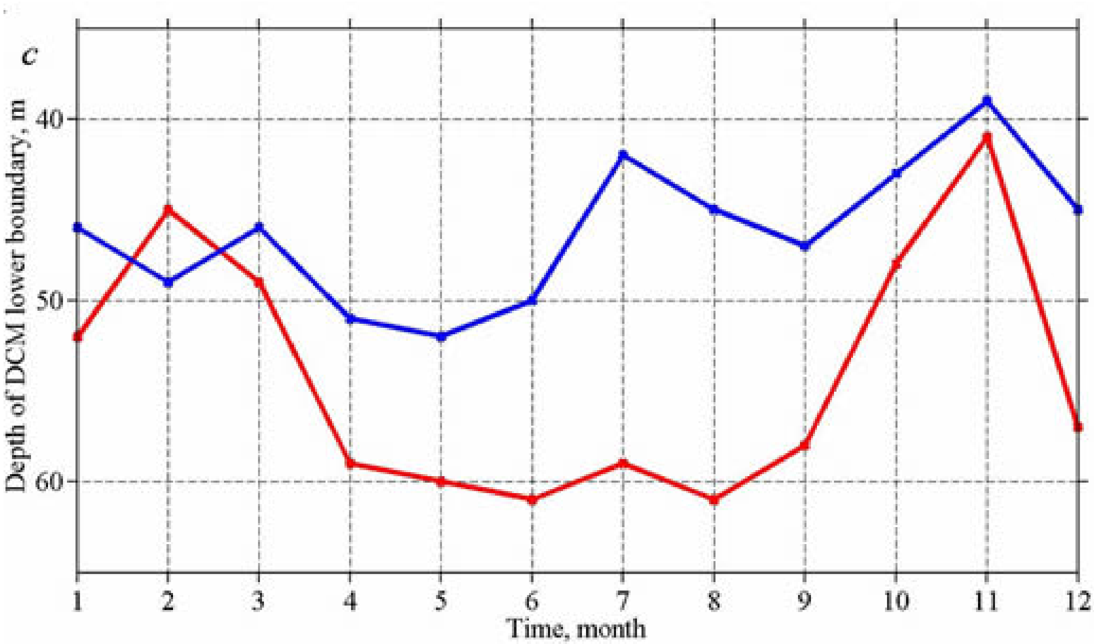

Fig. 5. Fig. 3c: Seasonal variability of the lower boundary of DCM (defined as a layer with Chl > 0.2 mg/m3) in 2016 (red line) and 2017 (blue line).

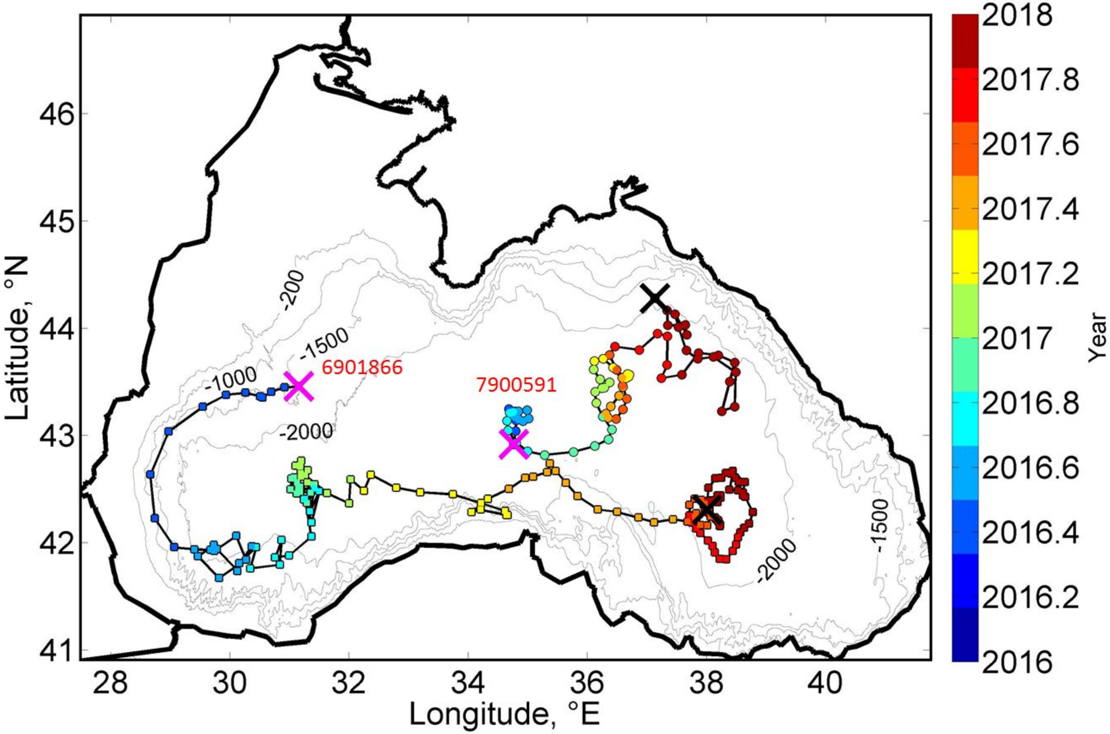

Fig. 6. Figure 1 (see the caption in the text, answer TC5)