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Biogeosciences Discussions
BGD
Interactive comment

Interactive comment on “Warmer winter causes deepening and intensification of summer subsurface bloom in the Black Sea: the role of convection and self-shading mechanism” *by* Elena A. Kubryakova and Arseny A. Kubryakov

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We would like to thank the reviewer for comments and for valuable and constructive suggestions for improving the paper.

Comment #1:

“Authors present 2-years time-series data from two Bio-Argo floats measuring temperature, salinity, Chl-a flurescence and irradiance in the Black Sea. They observed differences in deep chlorophyll maximum depth and intensity between summer 2016

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and 2017. In 2016, DCM was deeper with lower maximum Chl-a concentration than in 2017. Authors explained these differences by previous winter conditions. Authors argue that if more nutrients are supplied in surface waters during winter, they can sustain during the whole summer period via remineralisation an higher phytoplankton biomass and a shallower DCM. This paper is interesting because it raises questions about which factors control DCM. As DCM results from an equilibrium between light (impacted by phytoplankton itself) and nutrients, determining which factor determines its position and intensity remain a challenging question. However, the authors presented a theory without giving the strong proofs and arguments. In fact although they claimed in the conclusion that they have showed that "the intensity of winter convection largely controls the bio-productivity and the position of the deep maximum Chl throughout the year", no strong differences is observed in Mixed Layer Depth (MLD) between 2016 (40m) and 2017 (45m), no data are provided about nutrient distribution".

Answer #1. Unfortunately, there is no direct information about newly entrained nitrates in the upper layers in the winter season.

There are some important reasons for it. The entrained nutrients are usually rapidly consumed and then are transformed into organic form – i.e. phytoplankton, zooplankton, dissolved organic matter, etc. To account for these entrained nutrients we need to know all the compounds where e.g. nitrogen is situated, which is almost impossible nowadays. Particularly, in our institute, we made several surveys with nitrates measurements included in 2016 and 2017 in the summer and autumn periods. However, this is certainly not enough to estimate nitrates coming in the euphotic layer continuously in short-period events of winter mixing throughout all autumn-winter season.

The regular optical-based nitrates measurements of Bio-Argo buoys could be a good alternative for this task. Unfortunately, in the Black Sea data of Bio-Argo buoys is poorly consistent with information of nitrates distribution known from numerous in-situ studies. In particular, Bio-Argo buoys show the persistent presence of more than 3 μM nitrates in the upper layer of the Black Sea throughout the year (see diagram in Fig. R1-left in attached file), which is not consistent with 0.5 μM documented in many previous studies (Konovalov, Murray, 2001; Turgul et al., 2015). A possible reason for this is the complex optical characteristics of the Black Sea with a lot of dissolved organic matter, etc (see e.g. Organelle et al., 2017).

Therefore, we use indirect estimates of newly entrained nitrates.

- First, the winter of 2017 was one of the most severe in the Black Sea and this fact was already documented in several recent studies (Stanev et al., 2019; Capet et al., 2020). It was significantly colder than in warm 2016 and cause significantly stronger vertical mixing than in 2016 (Stanev et al., 2019; Capet et al., 2020). It is worth noting, that in colder winters, convection will be stronger and more nutrients will be entrained in the upper layer, than in warm winter. Please see the review in (Williams & Follows, 2003). For the Black Sea this is proven by the strong relationship between winter temperature and interannual variability of winter-early spring bloom of diatoms (Mashtakova, 1985; Sorokin 2002; Mikayelyan et al., 2018) and following the early-summer blooms of coccolithophore (Mikaelyan et al., 2015; Silkin et al., 2014, 2019), the variability of surface chlorophyll-Đř (Chl-a) (Oguz et al., 2006; Finenko et al., 2014).

In the strongly stratified Black Sea, the depth location of nutricline is tightly coupled to certain isopycnals as it is shown in many chemical studies (Tugrul et al., 1992; Konovalov et al., 2005). That is why nutricline variations in σ-coordinates are significantly less than in-depth coordinates (Tugrul et al., 1992; Konovalov et al., 2005). The multi-annual vertical profiles of nitrate (NO3) and phosphate (PO4) presented in σ-coordinates for October, the month preceding the onset of intense winter convection, are shown in Fig. R1-right. For example, the concentration of nitrates begins to gradually increase below the isopycnal of 1014 kg/m3, and increases more sharply below the isopycnal of 1014.4 kg/m3 where the upper part of nutricline is located (Konovalov, Murray, 2001). The deeper isopycnals the winter convection reaches, the more new nutrients will be entrained into the euphotic layer. The tight relation between density and the position of chemical elements (see Konovalov et al., 2005) suggests that the density of the upper mixed layer in winter can be used as a proxy, showing from which layers nutrients were entrained to the surface layer (Kubryakova et al., 2018).

At the same time, the mixed layer depth in the cold period of a year may vary significantly due to the dynamical forcing, such as eddies, large-scale circulation, etc (see in detail (Kubrykov et al., 2019)). This is related to the deepening of the density barrier – the main halocline. For example, in anticyclones, it can reach 100 m. However, if the density of the mixed layer remains low, then no new nitrates will be entrained from deep isopycnals layers.

The density of the mixed layer depends partly on the vertical uplift of isopycnals during the intensification of cyclonic circulation. The rise of cyclonic circulation on the opposite decreases mixed layer depth. Therefore, in the Black Sea the MLD is not correlated with sea surface temperature (Titov, 2004), but strongly depends on dynamic forcing (Kubryakov, Belokopytov, et al., 2019).

That is why the density rather than the depth of the mixed layer is a more robust indicator of the vertical entrainment of nutrients in winter. We use this indicator to show that in cold 2017 more nutrients are entrained in the euphotic layer than in warm 2016.

We extended the explanation in the revised version of the manuscript.

- Second, Chl-a is one of the widely-used indicators of the phytoplankton biomass, which directly depends on nutrient concentration. In 2017 Chl-a in winter and spring was higher than in 2016, which is consistent with the fact, that the winter convection and related vertical entrainment of nutrients was more intense in 2017.

We also want to underline that we are not basing on the quantitative values of nitrates, but use the above indicators to argue that in the cold winter of 2017 the vertical entrainment of nitrates was higher than in the warm winter of 2016. The increase of nutrient concentration in the Black Sea in the cold years was documented in the chemical study of (Tugrul et al., 2015).

Comment #2

"Finally, the impact of small scale structures such as fronts, eddies, etc. which are known to impact the nutrient vertical distribution and the DCM are ignored although the Argo floats trajectories indicates the presence of eddies or small gyres. Then, I recommend to reject this manuscript as it is. However, given the value of the Bio-Argo dataset in this region and the interest of the scientific community about DCM, I would recommend to the authors to resubmit later their manuscript after major modifications and improvements. I advise to the author to add information about nutrients distribution in the Black Sea, to deeply reconsider the theory which are presented in this paper and to support any new theory with arguments and data. I also suggest to the authors to avoid the monthly averaging of the data. By this way small scale events can be considered. In addition, I would like authors investigate what happens in June 2017 when DCM unexpectedly uplifts".

Answer #2. The investigation of the impact of small scale structures such as fronts, eddies on Chl-a is a very interesting and important problem. However, in this study, we are focused on the annual time scales. Particularly, Fig. 5 shows that in cold 2017 Chl-a in upper layers was higher in all seasons, while in warm 2016 it was higher in deeper layers in all seasons. This fact was observed during all investigated periods of both buoys measurements. Please see Fig. 5a, which is the main figure for this manuscript. That is, yearly average profiles of Chl-a are of main interest and they depend on the intensity of winter convection (and see Fig. R2 and R3 in the attached file).

The short-period variability of the Chl-a is out of the scope of this paper, but we briefly discuss it in the discussion part. Short period variability of the Chl-a in the summer period is related to the occasional entrainment of nutrients from nitroclyne in the euphotic zone caused by storms or dynamical forcing (studied in the Black Sea by Kubryakov, Zatsepin et al. (2019)), such as eddies horizontal and vertical advection (see e.g. Oguz et al., 2002; Shapiro et al., 2010; Kubryakov et al., 2016). After warm winters with higher water transparency, the euphotic layer is deeper and closer to the nitroclyne. Therefore, we might expect that the impact of dynamics features in summer will be more effective in years with weak winter convection.

In Fig. R2 (in the attached file) we show the diagram of 5-days averaged profiles of Chl-a for both buoys in 2016 and 2017 to demonstrate that in both years the short-period variability takes place. It is also well-seen that these two buoys were situated in different dynamic features and the Chl-a variability differs among the buoys in both years. At the same time, it is visually seen that both buoys show that in warm 2016 Chl-a subsurface maximum was deeper than in cold 2017, which is the main conclusion of the study. It is also well seen that Chl-a was higher in 2017 in the winter-spring period in upper layers and higher in summer of 2016 in deep layers (35-55 m depth) (see Fig. R2, bottom). We will add this information in the revised version of the manuscript.

Specific comments (SC)

SC1: “line 21-22, winter phytoplankton remineralisation needs reference. Same nutrients sustain spring bloom and summer DCM? You need to reference and argument”.

Answer SC1. We wrote this phrase more accurately:

“With the rise of stratification and irradiance vertically entrained nutrients during winter are further consumed by phytoplankton, which causes the early-spring bloom in the upper layers (Sverdrup, 1953; Sorokin, 2002). After the bloom, part of nutrients in organic form sinks out to the nitroclyne and another part regenerates, which can fuel the phytoplankton bloom in the warm period of the year (Williams & Follows, 2003). In the Black Sea according to (Lebedeva and Vostokov, 1984; Karl and Knauer, 1991) only a small fraction (∼10%) of particulate flux is exported to deeper anoxic part of the sea. The most intense winter-early spring bloom of diatoms (Mashtakova, 1985; Sorokin 2002; Mikayelyan et al., 2018) and following the early-summer bloom of coccolithophores (Mikaelyan et al., 2015; Silkin et al., 2014, 2019) in the Black Sea are observed after severe winters, both of which are related to the entrained in winter nutrients. Long-term analysis of in-situ data (Mikaelyan et al., 2018) showed that winter temperature significantly affects the taxonomic composition and seasonal succession of phytoplankton in the Black Sea throughout the whole warm period of the year. Several authors on the base of satellite data demonstrated that the variability of surface chlorophyll-Đř (Chl) on interannual time scales is correlated with winter sea surface temperature (Oguz et al., 2006; Finenko et al., 2014). The biomodelling study of (Kubryakova et al., 2018) also shows that the intensity of the summer deep phytoplankton maximum also depends on the winter convection".

SC2: "line 25: Strong?"

Answer SC2. Changed to most intense. There are at least two blooms of diatoms in the Black Sea – in spring and autumn.

SC3: "Line 29: "winter severity" is too general".

Answer SC3. Changed to "winter temperature".

SC4: "Line 32: DCM in the Black Sea, please provide more details".

Answer SC4. We added a short description of DCM in the Black Sea. General feature of Chl-a vertical distribution is deepening of its peak during the warm period of a year and a formation of a so-called deep chlorophyll maximum at 15-50 m depth (Sorokin, 1983; Vedernikov, Demidov, 1993), similarly as in the other areas of the World Ocean at the same latitudes. The variability of the thickness, depth, and shape of summer DCM in the Black Sea was investigated in detail by Finenko et al. (2005), Krivenko (2010).

SC5: "Lines 39-43: photo-adaptation and photo-inhibition mechanisms need to be better described".

Answer SC5. We slightly extended the description in this part of the introduction. Also, we note that the investigation of these important processes generally are not the goal of this study. The possible impact of the photoadaptation on the ratio of Chl-a and biomass is shortly addressed in the Discussion: "Deepening of the euphotic layer may also promote the growth of species adapted to low light with low biomass and high Chl content in cells (Falkowski & La Roshe, 1991; MacIntyre et al., 2002; Latasa et al., 2017). Particularly, in the Black Sea, the lower border of the euphotic zone is characterized by the domination of small flagellates and unicellular cyanobacteria (Churilova et al., 2019; Mikaelyan et al., 2020), which may have an advantage in the years with warm winters".

SC6: "Line 56: Please replace the term "winter convection" by "winter mixing". Convection implies very deep mixed layers and specific mechanisms".

Answer SC6. We partly agree with this comment and change the phrase to "winter mixing", because both wind, dynamic and cooling impact on the mixing. However, we must note that among these three factors, winter convection plays a most important role, and there are a lot of studies dedicated to the investigation of the winter convection, which is very important in the Black Sea:

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.

Stanev, E. V., Roussenov, V. M., Rachev, N. H., & Staneva, J. V. (1995). Sea response to atmospheric variability. Model study for the Black Sea. Journal of Marine Systems, 6(3), 241-267.

Staneva, J. V., & Stanev, E. V. (1997). Cold intermediate water formation in the Black Sea. Analysis on numerical model simulations. In Sensitivity to Change: Black Sea, Baltic Sea and North Sea (pp. 375-393). Springer, Dordrecht.

and others.

Convection is driven by density differences in the fluid, e.g. the sinking of cold, dense water formed in winter. It can be deep or shallow, depending on stratification, which is very strong in the Black Sea.

SC7: "A presentation of the Back Sea with water mass presentation and circulation, nutrient and phytoplankton distribution is missing".

Answer SC7. We added a short description of these features of the Black Sea in the text.

SC8: "Lines: 62-63 please give details and show data".

Answer SC8. We added the figures with the variability of both buoys in Fig. R2 (in the attached file).

SC9: "Regading Chl-a concentration data. How did you treat non photochemical quenching?"

Answer SC9. We use the standard product downloaded from ftp://ftp.ifremer.fr/ifremer/argo. The non-photochemical quenching was not corrected. We can expect that this effect will not alter the obtained result, as we focus on the differences of Chl between two years. NPQ is important in the most upper layers (0-15 m), while the differences in this study were observed in all 10-70 m layer (see Fig. 5). Also, NPQ depends primarily on the irradiance conditions on the surface, in which seasonal variability (change from summer to winter) is more or less uniform in both years. Therefore, we believe the correction of NPQ will not generally change the main results of the paper.

SC10: "Line 74: Can you better justified your 0.07 kg/m3 criteria for MLD calculation. The criteria 0.03 or 0.05 kg/m3 are more commonly used. With a criteria of 0.07, MLD may be overestimated".

Answer SC10. The criteria 0.03 is usually used globally (e.g. de Boyer Montégut et al., 2004). The criterion 0.07 used in this paper is regional and it was chosen exactly for the Black Sea. It was justified in our previous paper (Kubryakov, Belokopytov, et al., 2019), where we used composite analysis (see Fig. 1 (Kubryakov, Belokopytov, et al., 2019)) to show that this criterion is reliable for the Black Sea.

SC11: "Lines 79-86: this paragraph should be in the introduction. Please provide concentration values for nitrate and phosphate in the Black Sea".

Answer SC11 We moved this paragraph to the introduction according to Your advice.

SC12: "Line 93: "Convection" should be replaced by "mixing".

Answer SC12. Replaced.

SC13: "Line 94: what is the "cold intermediate layer"?"

Answer SC13. We added a short description of the Cold Intermediate Layer (CIL) in the Introduction. The Cold intermediate layer is the layer of minimal temperature (T<8°C) situated at 50-150 m depth. During winter convection cold waters do not penetrate through the halo-pycnocline and form the CIL with a high amount of oxygen, which is further observed during the whole year. See also

Staneva, J. V., & Stanev, E. V. (1997). Cold intermediate water formation in the Black Sea. Analysis on numerical model simulations. In Sensitivity to Change: Black Sea, Baltic Sea and North Sea (pp. 375-393). Springer, Dordrecht.

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), 35-48. And others.

SC14: "Figure 2: Please use a continuous color palette. These discontinuous colours can artificially emphasis differences in two situations which may be not so different (opposition between red and yellow colors)".

Answer SC14: We corrected the figure (see Fig. R4 in the attached file).

SC15: "Line 108: Without any data on nutrients concentration how can you argue that there is an entrainment of nutrients?"

Answer SC15. Please, see the answer to comment #1 above.

SC16: "Figure 4: Can you explain the Chl-a increase in August 2016 and the DCM uplift in June 2017?"

Answer SC16: As it is stated in the answer on Comment #2 this paper is focused on the annual time scales and shows generally that in years with weak winter convection (mixing) the DCM is situated deeper all over the year (see Fig. 5), which is related to the effect of self-shading. In Fig. R2 (in the attached file) we show a diagram of "raw" profiles Chl-a variability for both buoys in 2016 and 2017 to demonstrate that in both years the short-period variability mainly controls the Chl-a dynamics. The observed short-period oscillations of Chl-a can be caused by numerous reasons. One of them is the storm-driven mixing in the warm period of the year (see Kubryakov et al., 2019), which provides the nutrient fluxes to the deep layer in the euphotic zone. As it is discussed in the paper this process will be more effective if the euphotic zone is situated deeper, as in 2016 (due to the absence of self-shading). Another important reason for chlorophyll variability in summer is the impact of early-summer coccolithophore blooms, which are very strong in the Black Sea (Mikaelyan et al., 2015). These blooms also depend on winter convection. They, particularly, cause an intense release of DOM during their termination (see Kubryakov, Zatsepin et al., 2019), which cause significant light attenuation and shallowing of the euphotic zone. Both these effects are described in the discussion. Mesoscale or large-scale circulation also can impact on the vertical displacement of the DCM. We added this comment to the study.

SC17: "Line 118-120: Please provide evidence to support this statement: "Thus, intense entrainment of nutrients in the winter of 2017 led to an increase in biological productivity not only in winter but also in the following months as a result of their remineralization."

Answer SC17. The evidence is that the Chl-a (which is the indicator of biological productivity) was higher throughout the year in the upper layers of 2017. Additional evidence is the very intense coccolithophore blooms observed in May-July 2017 (Kubryakov, Mikaelyan, et al., 2019), which intensity also depends on winter convection, as it is shown in (Burenkov et al., 2011; Mikaelyan et al., 2011, 2015). We added the latter comment to the study.

SC18: “Figure 5: Is this figure necessary?”

Answer SC18. This is the most important figure. Please, see the answer to comment #2 above.

SC19: “line 182: Indicate to which isopycnal nitracline is related and draw it on Figure 2”.

Answer SC19. We added the graph of the nutrient distribution in the Black Sea to the paper (see Fig. R1 in the attached file). As it is seen the concentration of nitrates begins gradually increase below the isopycnal of 1014.0 kg/m3, and increases more sharply below the isopycnal of 1014.4 kg/m3 where the upper part of nutricline is located (Konovalov, Murray, 2001).

SC20: “line 185: “Further thermal stratification stabilizes the water column but keeps the same concentration of nutrients”, nutrients are generally rapidly consumed, data are needed to support this statement”.

Answer SC20. We corrected this phrase. Further thermal stratification stabilizes the water column. Entrained in winter period nutrients and the rise of the irradiance causes the following spring growth of phytoplankton.

SC21: “Line 188: Hypothesis on regeneration need to be support by strong data. In fact, regeneration generally happens in depth due to particles sedimentation”.

Answer SC21. As it is stated in the introduction the impact of the winter entrainment of nutrients on the Black Sea phytoplankton was shown in many previous studies. “After the bloom, part of nutrients in organic form sinks out to the nitroclyne and another part regenerates, which can fuel the phytoplankton bloom in the warm period of the year (Williams & Follows, 2003). In the Black Sea according to (Lebedeva and Vostokov, 1984; Karl and Knauer, 1991) only a small fraction (∼10%) of particulate flux is exported to deeper anoxic part of the sea. The most intense winter-early spring bloom of

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diatoms (Mashtakova, 1985; Sorokin 2002; Mikayelyan et al., 2018) and following the early-summer bloom of coccolithophores (Mikaelyan et al., 2015; Silkin et al., 2014, 2019) in the Black Sea are observed after severe winters, both of which are related to the entrained in winter nutrients. Long-term analysis of in-situ data (Mikaelyan et al., 2018) showed that winter temperature significantly affects the taxonomic composition and seasonal succession of phytoplankton in the Black Sea throughout the whole warm period of the year. Several authors on the base of satellite data demonstrated that the variability of surface chlorophyll-Đř (Chl) on interannual time scales is correlated with winter sea surface temperature (Oguz et al., 2006; Finenko et al., 2014). The biomodelling study of (Kubryakova et al., 2018) also shows that the intensity of the summer deep phytoplankton maximum also depends on the winter convection.

SC22: "Figure 7: This figure and the associated conclusions should be removed or at least deeply reviewed. Regarding the figure itself, it is very surprising to see a Chl-a DCM shape inside the mixed layer. In the mixed layer, one can expect homogeneous Chl-a profiles. Authors should have mentioned at least: "winter MLD" and "summer Chl-a vertical profile". Instead of the PAR arrows, it would be more accurate to indicate the position of isolumes as this information is available from Bio-Argo data".

Answer SC22: We agree and changed the Fig. 7: we added the position of euphotic zone and changed the captions on winter mixing and summer Chl-a (see Fig. R5 in the attached file).

SC23: "Regarding the theory explained in figure caption, I don't think the data presented in this paper allow to support it. Although authors didn't support with nutrient data the statement "In a cold winter, the larger amount of nutrients (grey color) is convectively entrained in the upper layer".

Answer SC23. Please see the answer to comment #1. Shortly, in cold winter the entrainment should be stronger. Chl-a is an indirect indicator of the amount of entrained nutrients.

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SC24: "... my maine concern is for the following statement about case (b) : "In the summer period with increase of PAR, light penetrates the upper layer of nitroclyne and causes intense and deep summer subsurface bloom. Therefore, the total amount of nutrients used by the phytoplankton in both year is comparable." In fact, summer light increase happens in both years and as soon as surface nutrients are consumed, DCM forms and deepens".

Answer SC24. Yes, in summer light increase and DCM deepens. Important is to answer, why in summer of warm years light penetrates deeper than in summer of cold year? In more transparent waters (modulated by the low amount of nutrients), light reaches larger depths and DCM deepens stronger.

SC25: "It seems impossible that DCM production in oligotrophic conditions can compensate additional winter production permitted by extra nutrients inputs in surface waters".

Answer SC25. The Black Sea is mesotrophic, not oligotrophic. It has several specific features – a shallow mixed layer and nitrocline, etc. That is why the discussed effects can be more prominent in the Black Sea. However, they should work in any other regions of the World Ocean, where convection reaches nitrocline. The logic is simple:

– cold winter -> more nutrients are entrained in winter -> more phytoplankton (and DOM) -> less transparent waters -> lesser penetration of light -> shallower DCM;

–warm winter ->less nutrients are entrained in winter -> less phytoplankton (and DOM) -> more transparent waters -> deeper penetration of light -> light reaches deeper layer, where nutrient concentration is higher -> deeper DCM -> DCM is closer to nitroclyne.

In this study, this compensation is confirmed by the same value of column-averaged Chl-a in the warm and cold year (Fig. R3). We also added to the manuscript figure of the average annual profile of Chl-a in 2016 and 2017 (see Fig. R3).

SC26: "In addition, authors should remind that deep DCM have generally an higher

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Chl-a/biomass ratio than shallower DCM as Chl-a per cell increases to compensate the decreasing of light".

Answer SC26. It is briefly written in the discussion at lines 247-250. Deepening of the euphotic layer may also promote the growth of species adapted to low light with low biomass and high Chl-a content in cells (Falkowski & La Roshe, 1991; MacIntyre et al., 2002; Latasa et al., 2017). Particularly, in the Black Sea, the lower border of the euphotic zone is characterized by the domination of small flagellates and unicellular cyanobacteria (Churilova et al., 2019; Mikaelyan et al., 2020), which may have an advantage in the years with warm winters.

SC27: "Line 200-207. Hypothesis on self-shading due to higher winter Chl-a concentration for explaining shallower DCM during the full summer season is doubtful. In fact, what which have been observed before is that as soon as bloom ends, DCM set up and deepens due to lower nutrient availability and higher light availability".

Answer SC27. Both of these sentences are true. But we need to explain higher light availability in a warm year. It is caused by the absence of the phytoplankton in the upper layers (no self-shading), which increases the transparency of the waters. This is directly shown in Fig. 5 and Fig. 6.

Please also note the supplement to this comment:
https://www.biogeosciences-discuss.net/bg-2020-210/bg-2020-210-AC1-supplement.pdf

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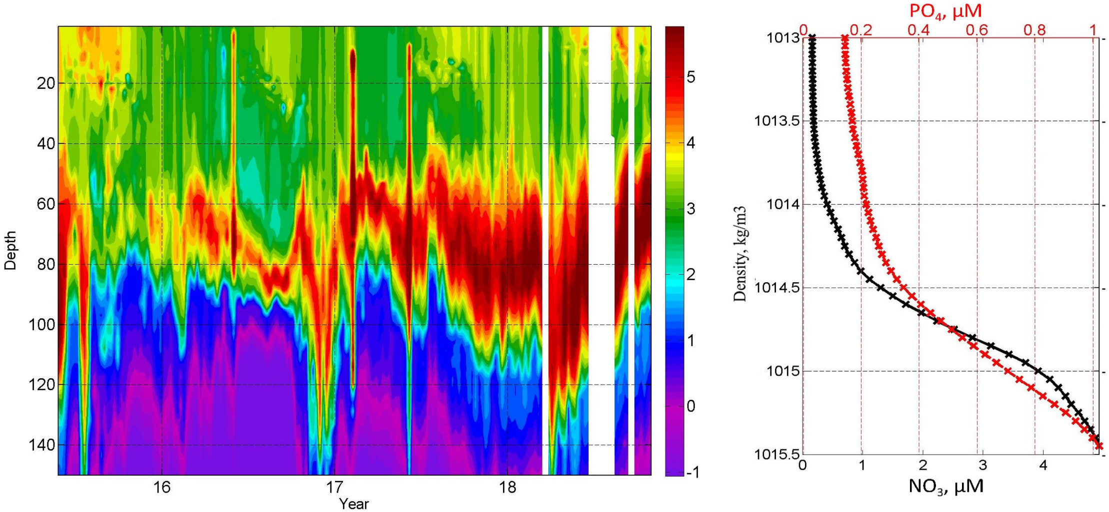

Fig. 1. Fig. R1: left– interannual diagram of NO3 (μM) measured by Bio-Argo buoy; right– multiannual averaged vertical profiles of NO3 (μM, black line) and PO4 (μM, red line) for October shown in σ-coordinate

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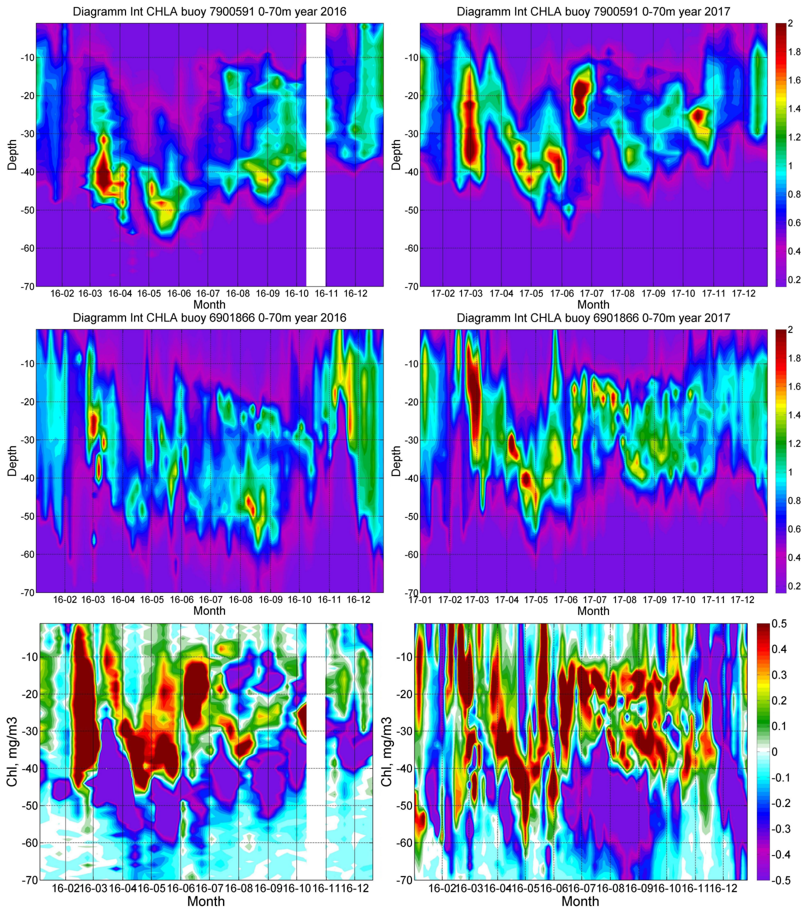

Fig. 2. R2.Time variability of Chl by Bio-Argo buoy measurements #7900591(top) and buoy #6901866(central) in 2016(left) and 2017(right).Bottom–differences between 2017,2016 by buoy #6901866(left), #7900591(ri

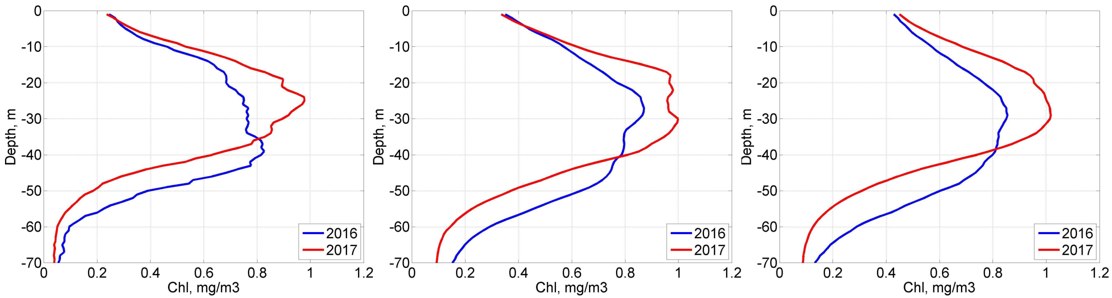

Fig. 3. Fig. R3. Average profile of Chl-a in 2016 and 2017 by the measurements of the buoy #6901866 (left) and buoy #7900591 (center) and both buoy measurements (right).

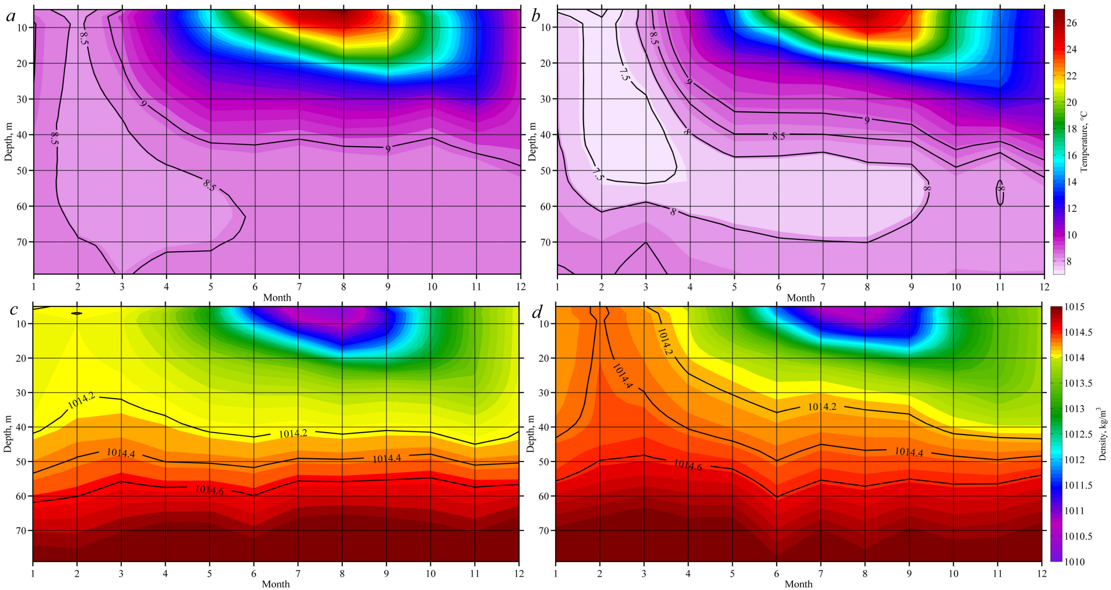

Fig. 4. Fig. R4. Seasonal variability of temperature in 2016 (a) and 2017 (b), density in 2016 (c) and 2017 (d).

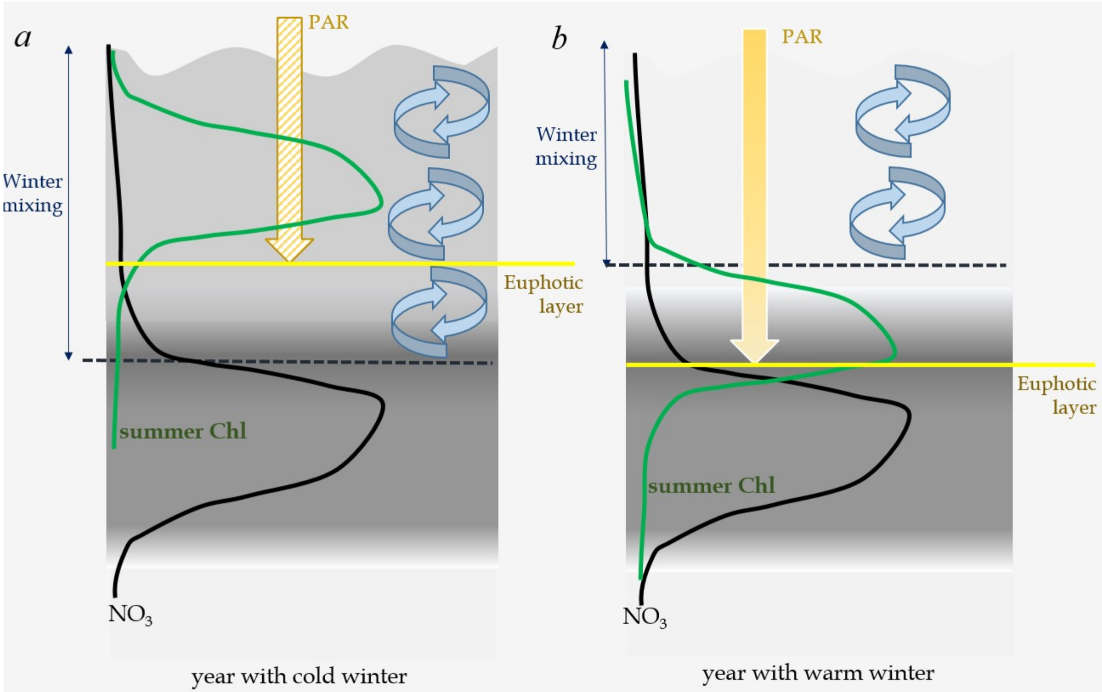

Fig. 5. R5.

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