Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2020-165-AC1, 2020

Biogeosciences Discussions
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Interactive comment on "Quasi-tropical cyclone caused anomalous autumn coccolithophore bloom in the Black Sea" *by* Sergey V. Stanichny et al.

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Received and published: 22 June 2020

Response to the reviewer #1

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

General comment

G1. The structure is illogical. First, the diatom bloom began, but first the figures and text first describes the coccolithophore bloom. The Results already contain a lot of discussion. Because of this, the ultra-small Dissuasion is 1 page. It would be more logical to combine both sections into one “Results and Discussion” section.

Answer. According to Your comment, we changed the position of Fig. 2 and Fig. 4 and renamed the Section 3 as Results and Discussion.

G2. The text contains many typos and negligences (see my comment in the text). English needs to be carefully edited.

Answer. Thank You for the detailed comments. We carefully corrected all typos in the text.

G3. The presentation of the material is good. The main problem is commenting on the results and explanations. They are completely unconvincing.

Comment #1

130 “The reason for the initial increase in Rrs values was not vertical, but horizontal advection. . . . This flow was well traced in Chl maps (Fig. 4a, b, c)” This statement was not supported by any evidence. Moreover, from all possible explanations, it seems less realistic. The distance from the Danube river mouth to the south-western corner of the sea where the Chl bloom began is approximately 500 km along the coast. Fig 4b shows bloom start 4 days (or less) after the cyclone end simultaneously along the 500 km Anatolian coast. Taking the Rim Current velocity (0.3 m/s – 25 km hour) we can understand that these river waters can reach the nearest place of bloom in 20 days, and therefore cannot be the reason for this. In addition, it is obvious that within a 20-day period all ultrahigh nutrients will be consumed by phytoplankton (the graph in Fig. 3 shows well that after 2 weeks such blooms disappear on the surface).

Answer. As it is seen in Fig. 4a (in the paper) and stated on page 5: “At the beginning of September 2005, an area of high Chl (>3 mg/m3) associated with the spread of a plume of Danube was observed near the western coast to the north of 42° N (28°E) (Fig. 4a)”. At that time the south border of the plume (defined here as Chl >3 mg/m3) was already on 300 km south of the Danube mouth. We marked the plume area by the red rectangle in fig. R1a (in the response). Further up to 4 October 2005, i.e. one month after the eastern border of the plume displaced in cyclonic direction to the point 34°E (marked as the black arrow in the fig. R1b). This means that in 20 days the plume border moved on about 420 km, which is in good agreement with Your estimates, so there is no contradiction. An important fact is that before the action of the cyclone the Rim Current was weak (please, see the fig. R2a, c). The Ekman pumping caused strong onshore Ekman transport and importantly downwelling in the coastal areas, which increased the sea level gradients over the continental slope and intensified the velocity of the Rim Current up to anomalous values of 0.75 m/s. Taking into account the additional impact of strong-wind driven currents on surface transport, which may be estimated as kwd·Vwind=0.03·15=0.45 m/s the total velocity will be more than 1 m/s which is more than enough to cause the observed displacement of the plume (kwd – wind drift coefficient, Vwind – wind velocity). The impact of the Rim Current on the transport of Danube waters in the southern part of the sea was shown in several previous studies (see Yankovsky et al., 2004; Kubryakov et al., 2018).

Yankovsky, A. E., Lemeshko, E. M., & Ilyin, Y. P. (2004). The influence of shelfbreak forcing on the alongshelf penetration of the Danube buoyant water, Black Sea. Continental shelf research, 24(10), 1083-1098.

Kubryakov, A. A., Stanichny, S. V., & Zatsepin, A. G. (2018). Interannual variability of Danube waters propagation in summer period of 1992–2015 and its influence on the Black Sea ecosystem. Journal of Marine Systems, 179, 10-30.

To highlight this dynamic we will add the figures and the explanation to the text.

Comment #2

From Fig.4 it also is not follows that the high Chl from the west coast (panel a) was shifted to the east (panel b). This is just the authors' assumptions. It is strange that earlier they showed how the cyclone involved the nutrient-rich deep water to the sea surface and now they say that it is not the reason for bloom. The same mixing processes most probably entrained deep nutrients into the mixed layer on the western and south shelfs, causing an Chl increase. The most obvious explanation for the bloom in the western center is the growth of phytoplankton. At least, it is proved by uplifted deep water (Fig. 1).

Answer. We do not state that Chl from the west coast shifted to the east. We write that "Immediately after the action of an atmospheric cyclone in late September, Chl increased significantly throughout the western part of the sea and on 4 October Chl reached its maximum values (1.3 mg/m3) in the western central part of the basin (green line in Fig. 3). This fast rise of the Chl in the zone of the cyclone action was partly caused by the entrainment of phytoplankton from the layer of its subsurface maximum". We marked this zone of fast increase of Chl in the north and central-western part of the sea by a red ellipse in fig. R1b. Further on the next 8-daily map (fig. R1c) Chl in this zone decreased to the background values. This bloom can be related both to the entrainment of Chl from the subsurface maximum and also the growth of phytoplankton, which rapidly ended on 12 October. The maximum rise of Chl on this date (fig. R1c) was observed in the southwestern part of the sea (marked by the red rectangle in fig. R1c). In this area, we can see that Chl decreased from the coast to the central part of the sea, which indicates that the source is near the coast. Altimetry data (fig. R2) shows that this area is a subject of downwelling, not upwelling (sea level increases in fig. R2d). Moreover, comparing the fig. R1b and R1c we can see that from 4 to 12 October Chl near the coast (fig. R1c – in the area of the red dashed rectangle) decreased from 3 to 1.5 mg/m3, while to the north it increased to 1.5 mg/m3. This evidence about the dilution of the plume due to its horizontal mixing with offshore waters with relatively low values of Chl (Chl<0.75 mg/m3). We added a more detailed explanation to this part of the text in the paper. This gradient is the evidence of the importance of the horizontal exchange on the change of the amount of Chl.

Comment #3

145 "Part of the turbid Danube waters during this period moved across the isobates

and penetrated a considerable distance into the central part of the sea (Fig. 2c, 4c)". Again, no evidence for such a claim. The authors look at the green color in the center of the sea, which joins the shelf waters, and concludes that it came from the shelf. Why are they sure that this is not the growth of phytoplankton in the western center after the action of the cyclone?

Answer. Please see the comment above. The zone of the intense horizontal mixing is (marked by the red dashed rectangle in fig. R1c, R3c).The observed difference between the Chl map in Fig. R1b, c shows that near the coast (in the area of the red dashed rectangle) Chl decreased, while to the north it increased. This evidence about the dilution of the plume due to its horizontal mixing with offshore waters with relatively low values of Chl (Chl<0.75 mg/m3). Another evidence, which is more important to the goal of the paper is that the maximum Rrs indicating coccolithophore bloom in Fig. R3c was situated not in the area of maximum upwelling, but to the south of it in the area of downwelling. Such inconsistency can not be described by the impact of cyclone-induced vertical upwelling and also supports the importance of horizontal exchange. To highlight this effect we added a fig. R4 of daily Rrs map on 5 October 2005. In this figure, it is seen that the maximum Rrs was observed in the thin zone on the offshore periphery of the plume, which evidence about the importance of frontal mixing on the plume periphery on the growth of coccolithophores. One of the possible reasons for such growth is the inhibition of coccolithophore bloom in brackish plume waters. With the dilution of the plume, the salinity rise, and the growth of coccolithophores can begin. We added this explanation to the text.

Comment #4

170 At the velocity of 0.45 m s-1 (Fig. 1e), the particles will be transported on 1000 km in 3 weeks, which coincides well with satellite optical measurements (Fig. 2) The Fig.1f (not 1e) shows that the velocity of 0.45 m s-1 is the maximal on some areas along the western coast. 0.4 m s-1 will be a very optimistic estimate of the average current velocity. In this case 1 month is needed to distribute a bloom to the eastern part. Si-

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multaneously, fig 2c shows that bloom occupy the eastern part of Turkish shelf after 10 days after bloom 600 km eastward. Plus, fig 2c demonstrates that from approximately (because the 8-day centering) from 10 to 30 October occupy the same area, without any shifting. It is even approximately not look like as a spot of high concentration moving among poor waters in eastward direction. Moreover, the spots of high concentration are stable and only slightly shifting to the east. For example, spot of bloom at 33 longitude moved to 34 longitude, which is much more seems to be truth. Such pattern points on local slope upwelling which was intensified under action of cyclone and Rim Current activation. In any case, the explanation, that the current bears the bloom to the east is not supported by presented material.

Answer. As it is shown in fig. R3c, R4 the initial bloom was started on the whole south coast of the western part of the Black Sea in longitudes 30-37°E, which correspond to the zone of the plume mixing seen in fig. R1c. Further displacement of the bloom to the east is well seen in Fig. R3. The east border of the bloom move from 36°E in Fig. R3b, to 38°E in Fig. R3c, then to 42°E in Fig. R3d (see the red ellipse marking the eastern end of the bloom in fig. R3). This gives a velocity of the transport 150 km/8 days=0.2 m/s and 300 km/8 days. This well agrees with Your estimates of the Rim Current velocity given on the base of Fig. 1f. We should note that altimetry-derived velocities are somewhat underestimated, especially near the coast due to the mapping procedure (Fu, Cazenave, 2001). That is why, the explanation, that the current bears the bloom to the east is not supported by satellite data. We extended the explanation in the text. At the same time, we note the western border of the bloom did not move and was located exactly in the zone of the maximum upwelling (see answer below).

Comment #5

175 “The upwelling in the center of the west cyclonic gyre was a permanent source of nutrients and phytoplankton growth, from which the bloom stretched to the eastern shore “What drives this constant source of nutrients? Pure guess!

Answer. This statement is supported by the fact that the western border of the bloom (Fig. R3d, black dashed rectangle) did not move and was located exactly in the zone of the maximum upwelling, despite its eastern part moved in a cyclonic direction with the Rim Current (see comment above). This shows that the western part of the bloom with a shape well corresponded to the upwelling area was quasi-stationary, despite the Rim Current constantly transported coccolithophores from it to the east. If this source was not permanent, the process of advection would cause the decrease of Rrs in the west cyclonic gyre (advection cause losses of coccolithophores in this local zone). Therefore, there should be some process that causes the gain of coccolithophores compensating these losses. The position of this spot of bloom coincides with the area of maximal cooling. So, the most probable source of this gain is the vertical transport of nutrients, which is maximal in the zone of upwelling in the west cyclonic gyre. The prolonged action of upwelling can be related to, first, the delay between the action of Ekman pumping and upwelling and, second, the time needed for the relaxation of the upwelling after the wind action. We added a more detailed explanation in the text of the paper. So two evidences are supporting this hypothesis: The stability of the bloom in the western cyclonic gyre over more than 3 weeks despite intense cyclonic currents; The coincidence of this stable bloom with the area of maximal cooling.

Comment #6 And how does this coincide with the statement that “The reason for the initial increase in Rrs was not vertical, but horizontal advection”?

Answer. The initial growth of coccolithophores in the south coastal part was triggered by the mixing of the Danube plume with open sea waters. Further, the bloom started in the center of the western cyclonic gyre due to vertical entrainment of nutrients and its maximum displaced offshore from the coast (see fig. R3b, d).

Additional questions in the text

#7 “What is Rim Current explanation (in abstract)?”

Answer. We have expanded the mention of “Rim Current” in the abstract and added an

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explanation in the text.

#8 “types” for phytoplankton means the particular systematic information, like “genera”, ‘families’, etc. If you don’t mean this, use term “group”

Answer. Thank You, corrected.

#9 “no such references in the list”

Answer. The reference was incorrect – changed on (Kubryakov, Mikaelyan, et al., 2018).

#10 line 54: “Who and where compared these two approaches?”

Answer. (Please see the additional attached pdf file for correct display of formulas). These approaches were compared in this study. Churilova & Suslin, (2012) on the base of in-situ measurements proposed an equation for estimating the concentration of coccolithophore cells (N) in early summer using bbp(555) obtained using a regional Black Sea model of (Suslin et al., 2012): N=(160 · bbp(555) – 0.32) ·106. (1) To convert the values of bbp(555) to bbp(700), the expression (Voss et al., 1998) is used: b_bp (555)=b_bp (700)·ãĂŰ(700/555)ãĂŮˆ(-1.35). (2)

According to equation (1), (2), the values of bbp(700) corresponding to the level of bloom, i.e. the concentration of cells 1·106 cells l-1, was defined as 0.007 m-1. To determine the corresponding values of Rrs, a comparison between the Rrs values and the bbp(700) measurements was made. For this purpose, Rrs were linearly interpolated on the time and coordinates of the Bio-Argo buoy measurements, and then compared. The results show that the dependence bbp(700) at a depth of 1 m and the Rrs is close to linear: Rrs=0.7·bbp(700). (3) Thus, Rrs value equal to 0.005 sr-1 corresponds to the concentration of cells 1.2·106 cells l-1.

The equation N=0.8·109·bbp(700)1.21 and the linear relationship between Rrs(555) and bbp(700) Rrs=0.7·bbp(700) obtained on the base of comparison of Bio-Argo and satellite measurements (Kubryakov, Mikaelyan, et al., 2018) shows that Rrs value equal

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to 0.005 sr-1 corresponds to the concentration of cells 2.0·106 cells l-1.

#11 Line 98: Why is this phrase here?

Answer. It is here to highlight that the shallowness of the Black Sea nitrocline.

#12 line 115: “Fig. 3 shows that until 30 October the increase of Chl was very gradual. Therefore, during the wind-induced mixing from 25 to 29 Oct NO "fast" increase was observed, and hence, only small, not significant, addition of Chl from deep chlorophyll maximum can be expected. The fast growth started immediatelly after cyclone and was provided by phytoplankton division”.

Answer. The fast increase of Chl to the values of more than 1.3 mg/m3 was observed in the northern and western deep part of the basin after the cyclone action on 4 October We marked this zone as a red ellipse in fig. R1b for clarity. Further on 12 October Chl in this part declined again to 0.6 mg/m3 (Fig. 4c).

#13 line 135: Why maximum?

Answer. It is a misprint. Should be “area of coccolithophore bloom”. Corrected. Thank You.

Please also note the supplement to this comment:
https://www.biogeosciences-discuss.net/bg-2020-165/bg-2020-165-AC1-supplement.pdf

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2020-165, 2020.

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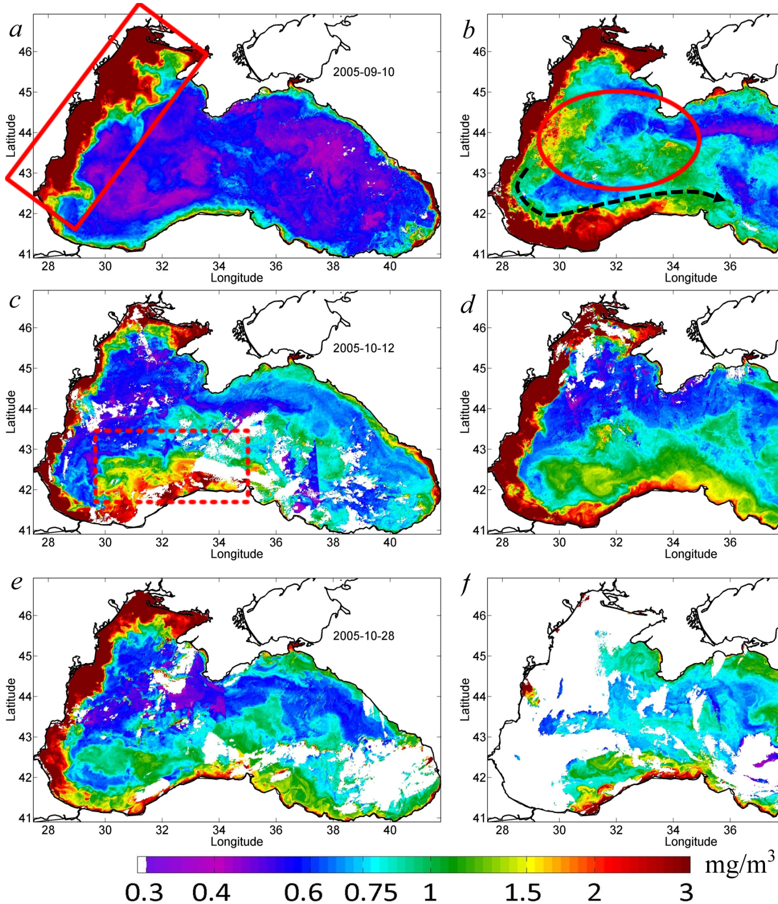

Fig. 1. Figure R1: 8-daily maps of chlorophyll-a concentration, mg m-3, centered at (a) 10 September 2005, the red rectangle (solid line) shows the Danube plume; (b) 4 October 2005, the red oval shows the phy

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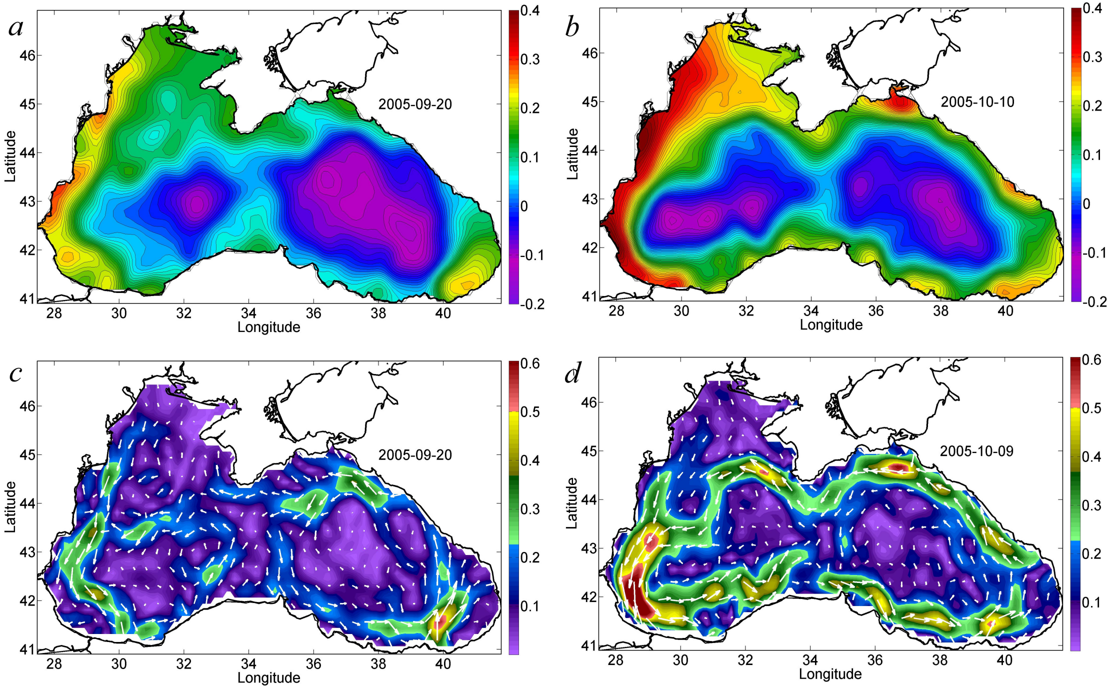

Fig. 2. Figure R2. Sea level, m: a – September 20, 2005, b – October 10, 2005; flow velocity, m/s: c – September 20, 2005, d – October 9, 2005

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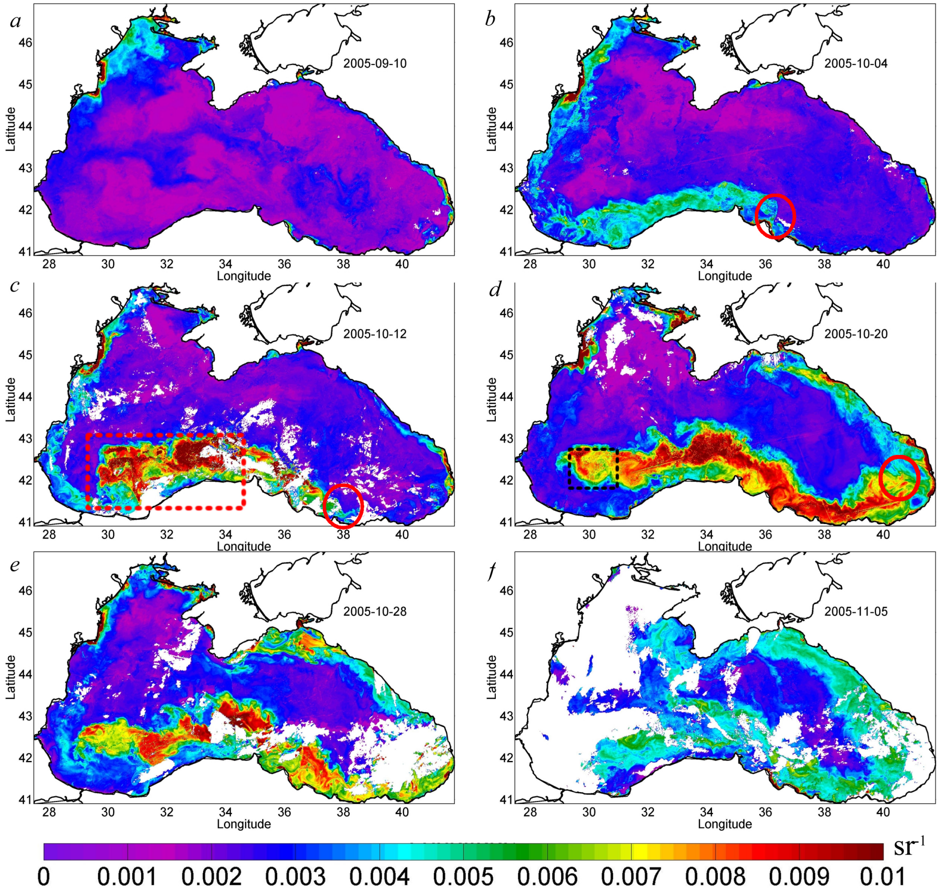

Fig. 3. Figure R3: 8-daily maps of remote sensing reflectance Rrs, sr-1, centered at (a) 10 September 2005; (b) 4 October 2005; (c) 12 October 2005, the red rectangle shows a mixing area; (d) 20 October 2005,

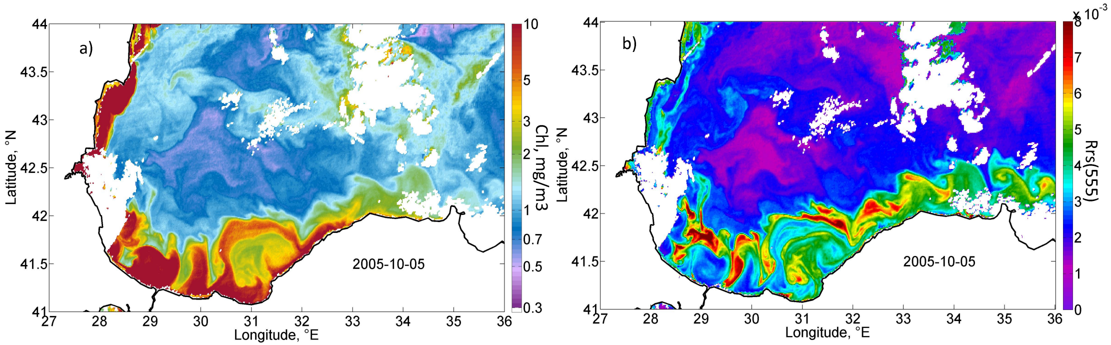

Fig. 4. Figure R4. MODIS daily map of Chl (a) and Rrs (b) for 5 October 2005 illustrating the initial growth of coccolithophores on the front of the rich in Chl plume waters

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