Response to reviewers' comments on "Summertime episodic chlorophyll-a blooms near the east coast of Korea" by Y. -T. Son, J. -H. Park, and S.H. Nam

The authors would like to thank the editor and reviewers for careful and constructive comments. We have responded to the reviewers' comments (written in black) as below in blue.

Reviewer #1

General comments

This paper deals with summertime coastal phytoplankton blooms off eastern Korea, as measured at the ESROB fixed buoy site. The Authors show how advection of chl-rich, low salinity (due to typhoon-related heavy rainfall), water to the site triggers chl blooms, during which chl a reaches 4 ug/l and beyond. I find this paper very interesting, both in a phenomenological sense and because of the completeness of the parameters measured at ESROB, accompanied by satellite imagery. The text is well written even though it needs a little English improvement. However, I have some reserves before recommending publication, which are explained in detail below in the particular comments.

Thank you very much for the valuable comments below. We deeply appreciate the detailed suggestions and have revised the manuscript based on these comments.

To sum them up, I am mainly concerned with:

1) the fact that Total Suspended Matter (TSS) and chl a don't co-vary for chl a > 3 ug/l, so high chl may actually be due to non-chl particulate optical signature

The GOCI Chl a can be overestimated when the TSS is high as has also been shown in previous research. In the revised manuscript, we clarified this point, citing a new reference as below.

"Despite the fact that absolute value of Chl a can be overestimated at high TSS (Kim et al., 2016), this indicates ..."

However, the relative value of GOCI Chl a in this area is still useful for understanding spatial Chl a distributions and their temporal variations.

Kim, W., Moon, J. -E., Park, Y. -J., and Ishizaka, J., Evaluation of chlorophyll retrievals from Geostationary Ocean Color Imager (GOCI) for the North-East Asian region, Rem. Sens. Environ., 184, 428–495, 2016.

2) the interpretation of the dynamic situation, i.e. I have a problem with the wind re-stratifying a water column. Also, upwelling is visible in the ESROB T and S record during poleward wind events, but it is not mentioned: even though it is not relevant for blooms, it should be, to make the physical interpretation complete

We agree that the description in the original manuscript was not sufficient and could cause unnecessary confusion on the interpretation of mixing and re-stratifying dynamics. In general, i.e., with no coastal boundary, winds enhance mixing and only break stratification. However, the winds either increase or decrease the stratification near the coast owing to coastal up- and downwelling responses (with offshore and onshore Ekman transport in the upper layer) to alongshore wind, depending on its direction. The water column in the coastal area can be either re-stratified (downwelling favorable wind, Fig. R1 left) or homogenized (upwelling favorable wind, Fig. R1 right) depending on the alongshore wind. Here, we believe the mixing process is minor compared to the upwelling/downwelling response with Ekman transport.



Figure R1. Schematics of isopycnals or isotherms (dashed line) and alongshore currents at the upper layer in response to downwelling (left) and upwelling (right) favorable wind stress.

To clarify this point, we revised the sentences in Section 3.2 as below.

"... and implying the downwelling (before E01) and upwelling (after E03) in the vicinity of ESROB."

"Since typhoon KHANUN drove poleward wind stress, the strong equatorward currents (showing downwelling induced by equatorward wind stress) developed before and during the most of E04 were weakened, and SSS increased to ..."

"Two typhoons (BOLAVEN and TENBIIN) successively passed the area and poleward (equatorward) wind stress imposed by BOLAVEN (TENBIIN) induced an upwelling (downwelling) response with poleward (equatorward) and offshore (onshore) transports at the upper layer, decreasing (increasing) water temperature, and increasing (decreasing) salinity in the whole column during E06."

3) the lack of the description of the method for which the Authors find out that advection "... is primarily responsible for most (80 %) of the CF events"

We simply counted the number of events where the alongshore advection plays a primary role in changing the CF. More specifically, equatorward currents and salinity decreases were accompanied during the 8 events (E01–E06, E08–E09). The high CFs during the remaining two events (E07 and E10) were discussed in association with cross-advections. In the revised manuscript, we inserted supplementary information as "... primarily responsible for most (80%, 8 of 10) of the CF events."

4) the fact that salinity at ESROB never goes below 30 g/kg, except for E03, while SSS data indicate 27-29 g/kg for the plume in 2013. So does the plume really reach ESROB? Or maybe a mix of plume and offshore water?

Great point. We believe that what was observed at the ESROB is not pure plume water, but water mixed with offshore water. The plume water salinity increases as mixed with the saline offshore water and the modified plume water is advected equatorward to the ESROB. In the revised manuscript, we clarified the point by inserting the new sentence below in Section 4.1.

"The distribution and temporal evolution of SSS observed in July 30, 2013 implies the low salinity plume water (SSS < 29 found in the northern coastal area, Fig. 8e) is mixed with saline offshore water while advected equatorward, yielding slightly higher (> 31) SSS at ESROB."

5) the lack the suggestion for the mechanism for which the northern plume or southern chl-rich waters trigger blooms; also, why are there no other strong blooms north of ESROB? Has the nutrient load of such surface, fresh waters anything to do with bloom triggering?

As mentioned in 1), the GOCI CF can be overestimated and may not be comparable to the in-situ CF

observed at the ESROB directly. We believe the CF is higher in the northern plume water than the modified water found at the ESROB; the CF maintained or decreased while advected equatorward. The opposite case (CF increased while advected) was tested by examining the possibility of local blooms triggered by either nutrients or light availability, but not supported as discussed in Section 4.2.

Replace "summer-time" with "summertime" (hereafter "replace" will be represented as "->"). Please correct this also in the rest of the text. This has been revised throughout the manuscript.

"near east coast" -> "near the east coast" This has been corrected.

Line 23. Replace "accompanied" -> "were accompanied by". This has been corrected.

Line 37. "among others" -> "among other phenomena" Line 40. "plume-delivering" -> "plume- delivered". Line 42. "and significant" -> "and a significant". Line 43. "plume" -> "plumes". Line 44. "demonstrating localized"-> "demonstrating that localized". These have been revised.

Line 45. What do you mean by "diversion"?

We meant the change of dominant plankton species within the plume water by the "diversion." In the revised manuscript, we changed the sentence to "*a few days after the plume water discharge*" to avoid the confusion.

Line 47. "differences with respect to the plume" -> Do you mean "differences between the plume and surrounding waters"? Please clarify

No, it means differences among the local plumes. To clarify this, the sentence was revised to "... revealing large Chl a differences among the local plumes."

Line 57. "limited short-duration" -> " short-duration ". "limited" is redundant. This has been corrected.

Line 68. "The data collected includes" -> "The collected data include" Line 70-71. "vertical profile of current" -> "current vertical profiles" Line 71. "upper most" -> "uppermost". This has been revised as recommended.

Line 76. "alongshore current" -> "alongshore northward current", right? This has been revised to "*poleward alongshore current*" to make it consistent with other expressions.

Line 79. "is needed to calibrate" -> "always needs calibration". This has been revised as recommended.

Line 79. "owing to long-term sensor drift" -> "owing both to long-term sensor drift and to the fact that different chl a concentrations may yield the same fluorescence energy, i.e. the same number from the fluorimeter, because of temporal differences in phytoplankton species assemblage and of the adaptation of species to different light conditions". I should add this because, as the Authors know, this point is very important if one wants to obtain realistic chl a quantities from a fluorimeter. See for example Longhurst et al., Prog. Oceanog. VoL 22, pp. 47 - 123, 1989, but also more recent references, with which I'm sure the Authors are familiar.

Thank you for the reference. We agreed that the issues of temporal differences in species assemblage and species adaptation to different light conditions are important to obtain realistic Chl a. In the revised manuscript, we included the point as commented by citing Longhurst et al. (1989).

Line 92. "geostationary ocean color satellite" -> is this the "NASA Geostationary Ocean Color Imager (GOCI)"? If not, which satellite? By the way, if you write the acronym of the satellite you can use it in the text instead of repeating "the ocean color satellite" every time.

The GOCI is the first geostationary orbit satellite image sensor to observe an ocean color around the Korean peninsula, loaded on the Communication, Ocean, and Meteorological Satellite (COMS, launched in 2010) of South Korea. The data may also be distributed via NASA. We revised the text to use GOCI throughout the manuscript.

Line 94. "... at a grid 50 times further...". What do you mean? Please rephrase. I know that polar orbiting OC products have resolution of from 1 km onwards, so why 50 times? The 500 m grid would be 2 to 5 times finer, maybe. If "further" means "finer", that is.

The geostationary satellite was positioned 50 times higher than low altitude polar orbit ones. We corrected the sentence to avoid the confusion.

Line 95. "by the total" -> "by total". This has been corrected.

Line 98. "software modules applying a correction algorithm for the TSS and CDOM". Please cite software name and authors, as well as the reference or SW manual. These modules should be well described for anyone who might want to use them, because these corrections are very important. The software and references providing detailed descriptions were inserted into the sentence.

Line 101-102. "This indicated that Chl a can be measured regardless of the TSS both in the coastal and outer sea" -> I disagree: from Fig. 2b it seems that your Chl a measurements co-vary with TSS significantly only up to chl a = 3 ug l-1 and TSS = 2 mg m-3. This means that, up to these values, TSS is reasonably made only of phytoplankton. But when TSS is high, other particulate besides phytoplankton is present, so your satellite chl a algorithm may fail because it may mistake the light signal coming from other particulate for phytoplankton. Please comment or correct phrase. Is this issue crucial for what follows? That is, how much of the CF peaks in Fig. 4 is actually due to non-phytoplankton fluorescence? I say this because the peak values are beyond the range of chla-TSS tight covariance. So are they really phytoplankton blooms?

Suggestion: why not over-plot the in situ chl a data in Fig. 4, e.g. as asterisks or crosses? This would make sure that the peaks are real chl a.

As described in 1), the GOCI Chl a can be overestimated when the TSS is high as has also been shown in previous works. However, the overestimation issue is only for GOCI CF (Fig. 2b and 2c) and not for the ESROB WQM (Fig. 2a). Note that Fig. 4 does not show the GOCI CF but the ESROB WQM. We agree that the GOCI Chl a can be somehow affected by non-phytoplankton fluorescence when the TSS is high. This is why we limit our interpretation on the GOCI CF to relative (not absolute) values, which is still useful for understanding its spatial distributions and temporal changes although it is not directly comparable to the ESROB WQM data shown in Fig. 4. We tried to over-plot the in situ CF in Fig. 4 but decided not to replace the original as in-situ water samples were taken in very limited times having relatively wide CF ranges, which were not very useful for addressing the point above. Instead, we clarified the GOCI CF and ESROB WQM CF against the in-situ water samples in the revised manuscript.

Line 106-107. "Precipitation in unit of mm/day recorded" -> "Precipitation (mm/day) was recorded". This was revised as recommended.

Line 109. "were proxied as freshwater..." -> I think there is a piece of sentence missing. We inserted the missing part on the sentence.

Line 21. "trophic situation" -> "the trophic situation". Line 120. "upper most" -> "uppermost".

We could not find "trophic situation." The word "upper most" was revised to "uppermost."

Line 121. "summer-time" -> "summertime". This was revised as recommended.

Line 134. "over considerable period (Fig. 4, Table 1)" -> "over a considerable period, i.e. days to weeks (Fig. 4, Table 1)". This was revised as recommended.

Line 136. "when $CF > 1.0 g/l" \rightarrow I$ don't understand this third condition, given the first two. In the revised manuscript, we clarified the conditions to define the CF events as the original sentence was confusing. The event was basically defined as a period when $CF > 1.0 \mu g/l$. To avoid selecting too many temporal fluctuations as events, we use a constraint to select the 10 events using additional criterion where the duration of $CF > 2.0 \mu g/l$ was longer than 1 d.

Line 137. "three each year" -> "three in each year" Line 141. "rainfalls" -> "rainfall". For this word, usually plural not used. Pls correct also rest of manuscript. This was revised throughout the manuscript.

Line 152. "wind stress, strong" -> "wind stress, the strong". This has been revised.

Line 153. "developed before E04" -> should this not be "developed before and during most of E04"? Refer to Fig. 5.

This is correct, the sentence has been revised.

Line 157. Eliminate "both" if you use parentheses for opposing effects. This has been revised.

Line 156-159. "poleward (equatorward) wind stress re-stratified (well-mixed)" -> In my opinion, it is impossible for wind stress to re-stratify a water column, no matter its direction. So, I think that poleward (and, by the way, strong) wind stress cannot re-stratify, but mix only. Indeed, if one looks at the T and S time series of Fig. 6c and d, in correspondence of the B poleward event, the isotherms drop and the isohalines rise, but remain separated, except for the 1 and 5 m isolines. This indicates upwelling, which is consistent with the wind and coast configuration. Next, during the T (equatorward) event the isotherms rise and the isohalines drop, indicating downwelling, and after the events the isolines settle to their normal values. So mixing is not so visible, to my opinion. However, Authors are right about mixing for the M1, T and S events, all equatorward, when the 1, 5 and 20 m isolines join. In sum, it looks like during equatorward events the mixing takes place and stays there so it can be measured (Ekman transport is onshore). On the other hand, during poleward events, mixing probably takes place, but is either less intense or is not visible at ESROB, because mixed water is displaced offshore by Ekman transport, and only the "frictionless" effect of upwelling is measurable. What are the Authors' comments?

We mostly agree with you, and as mentioned in 2), believe that the water column at the ESROB is restratified and homogenized in response to downwelling and upwelling favorable winds (Fig. R1 left vs. right), assuming the mixing process plays only a minor role compared to the upwelling/downwelling response with Ekman transport.

Line 164 "did not accompany preceding heavy" -> "did not follow heavy". This was revised as recommended.

Line 176. "(Fig. 9a, b, c and d)" -> "(Fig. 8a-d)" Should this be Fig. 8, not 9? Correct. This has been revised to Fig. 8.

Line 177. "e.g. off the SP, HH, and WS," -> "e.g. off the SP, HH, and WS sites," Lines 178 - 179. "and extended" -> "while a more coastal branch extended" Line This has been revised as recommended.

179. "(Fig. 9a, b, c and d)" -> "(Fig. 8a-d)" Again should it be Fig. 8? Correct. This has been revised to Fig. 8.

Lines 179-180. "coast during the period (Fig. 9a, b, c and d) after the heavy rainfalls in July 19–24 (Fig. 7a)." -> "coast (Fig. 8a-d) after the heavy rainfalls of July 19–24 (Fig. 7a)." This has been revised as recommended.

Line 184. "(Fig. 9e and 9f)" -> "(Fig. 8e, f)". Again Fig. 8. This has been revised.

Line 188. "A pattern of" -> "The patterns of" Line 190. "within cyclonic" -> "within the cyclonic" Lines 194-195. "coastal zone" -> "coastal zone, near DH and ESROB, as well as equatorward currents just to the north". Line 196. "(as cases of many other events, see Fig. 1 or Fig. 8)" -> "(see Fig. 7, but also other similar events, as in Fig. 1 or Fig. 8)" This has been revised as recommended.

Line 203. "and is primarily responsible for most (80 %) of the CF events." Please tell how the Authors checked this, practically. Did they see if the plume could reach ESROB for each event, given the duration of the event and the equatorward current? Did they use the current at ESROB or available imagery, as in the example of Fig. 8?

As mentioned in 3), we simply counted the number of events where the equatorward currents and salinity decreases were accompanied with the CF events. The exceptions are only two events (E07 and E10) where the equatorward currents and salinity decreases are not clear just before and during the event periods (Fig. 7).

Line 205. "measured to 100 km (= dy)" -> "measured to be dy = 100 km" This has been revised as recommended.

Line 206. "with Chl a change of about 2.5 _g/l". Is this the difference between chlorophyll at the plume source and the initially oligotrophic water at ESROB? If not, between which points is this difference computed? Please specify.

Yes, it is the difference between CF at the plume source and initially oligotrophic water at ESROB as specified in the revised manuscript.

Line 207. "(Fig. 9a, b, c and d)." -> "(Fig. 8a-d)." Again Fig. 8. Correct. This has been revised to Fig. 8.

Lines 201-214. I understand the calculation and it is good that the computed advective rate of change matches local change at ESROB. However, I do notice that the maximum chl in the plume doesn't exceed 2.5 _g/l (Fig. 8), and that this is the source value at the plume's origin, which never moves south. Indeed, the water that eventually reaches ESROB has much lower chl, according to Fig. 8, i.e. max 1-1.5 _g/l. So how can E09 reach a peak of 3.5 _g/l (Fig. 7) if it is only fueled by the plume? Maybe the plume is more important as a nutrient carrier than a chl carrier, so arriving at ESROB it triggers a bloom? However, if so, why are there no other strong blooms north of ESROB in the images of Fig. 8, but only the southward-decreasing chl a plume signal? If the plume is the responsible for the blooms, then there should be even more intense blooms north of ESROB. Am I missing something? Please comment/revise in text. Also, concerning the plume investing ESROB: from ESROB and SSS cruise data in Figs. 7 and 8 one sees that S = 31.5 g/kg at ESROB at the peak of the E09 event, but the plume salinity seems much lower from Fig. 8e, i.e. S < 29. So which water reaches ESROB? It doesn't look like pure plume water; maybe it is a plume-offshore mix? I think the Authors should clarify this issue.

Great point. We tested the possibility of a local bloom triggered by nutrients advected equatorward and discussed in addition to that triggered by vertical nutrient supply in Section 4.2. However, the nutrient loading mechanisms were found to play only a minor role. Here, we have two issues using the GOCI CF data. One is that the GOCI CF cannot only overestimate but can also underestimate the Chl a when the TSS is high in the coastal area (Fig. 2b). We would limit our interpretation on the GOCI CF to relative (not absolute) values, not directly comparable to the ESROB WQM data shown in Fig. 4. Next is that the GOCI CF, unfortunately, is not available very near the coastal zone (see the blanks shown in white in Fig. 8a–8d). We believe the plume water having high (> 2.5 µg/l in GOCI CF scale) CF and low (< 29 g/kg) salinity advected equatorward very near the ESROB although slightly mixed by saline and low CF offshore water. The CF and SSS at ESROB would be ~2.0 µg/l in absolute ESROB WQM scale and ~32 g/kg, respectively. More quantitatively, we showed that the rate of CF change observed at the ESROB is comparable with that owing to equatorward advection (v times dChl/dy) in Section 4.1.

Line 224. "estimated to 0.86" -> "estimated to be 0.86" Correct. This has been revised to Fig. 8.

Lines 225-226. "demonstrating a high CF region offshore of ESROB (Fig. 9a, d)" -> "demonstrating the influence of the high CF region offshore on the ESROB site (Fig. 9a, d)". Do I understand well? Correct. This has been revised as recommended.

Line 227. "nutrient rich" -> "nutrient-rich" This has been revised as recommended.

Line 227. "accounting for half the CF change" -> "accounts for half the CF change". This has been revised as recommended.

Line 227. Question same as above: since E07's peak reaches ~ (3.5 - 1.6 = 1.7 ug/l) come from? Note that the 1.6 µg/l/d is not CF itself in a unit of µg/l but the time rate of its change at the ESROB site in a unit of µg/l/d, i.e., CF change in a day. We clarified that the time rate of CF change (up to 1.6 µg/l/d averaged over the E07 for the period when $\partial \text{Chl } a/\partial t > 0$) and the contribution of cross-shore advection (0.86 µg/l/d) are comparable.

Line 230. "significant as that of E10" -> "significant, as happens for the E10 bloom". Do I understand well?

Correct. This has been revised as recommended.

Line 244. "different each other" -> "different from each other" Line 251. "euphotic zone" -> "euphotic zone"

This has been revised as recommended.

Line 251. "was compared with others" - > "were compared with others". What do you mean by "others"? We specified the word as *"the other time-series data recorded at ESROB"* in the revised manuscript.

Line 252. "events from two PAR" -> "events, using two PAR" Line 252-3. "Basically, Zeu of 18 m averaged over E04–E10 was deeper" -> ""Basically, the average for the E04 to E10 bloom periods, Zeu = 18 m, was deeper".

This has been revised to "events, using the data collected with two PAR sensors ..." The latter was revised as recommended.

Line 255. "Zeu of 20 m averaged" -> "A Zeu of 20 m obtained by averaging". Line 265. "typhoons passed through" -> "typhoons that passed through" Line 277. "summer-time" -> "summertime". Line 296. "high surface CF enhancements" -> "high surface CF events" or "enhanced surface CF"

This was revised as recommended.

Lines 297-299. "Alongshore advection... in summer". I think that this is my main concern about the paper. That is, the Authors have demonstrated that the blooms at ESROB are not driven by local vertical nutrient supply (text relative to Fig. 10). In addition, the Authors show that chl-rich plume waters or southern waters reach ESROB. So they argue that such advection is responsible for most events. But, I ask, how? What is the biogeochemical mechanism that triggers the blooms at ESROB, after the chl-rich water hits the site? This is not clearly stated. Especially since the advected waters that arrive at ESROB have only about half of the peak chl that is measured during blooms. Why is ESROB so special about blooms, with respect to the rest of the? Or maybe other blooms are visible in other sites?

We think there was a misunderstanding possibly owing to the poor presentation of the original manuscript. Our conclusion is that there was no local bloom at ESROB, but the water having high CF was transported past the ESROB in the alongshore (equatorward) or cross-shore directions. The summertime equatorward current near the coast was the primary process accounting for the CF variability at ESROB.

I suggest that Authors should

(1) propose a mechanism for bloom generation (also tentative, that's OK);

There might be potential biogeochemical mechanisms that trigger local blooms at or nearby the ESROB. However, as discussed in Section 4.2, both nutrient loading and changing light availability at ESROB hardly accounted for the observed CF variability. Based on our results, we believe that the blooms triggered in remote places (particularly in the northern coastal area) by some mechanisms, such as advective and diffusive nutrient supplies from rivers/rainfall or changing euphotic depth, and the CFrich water are frequently transported (particularly equatorward) into the ESROB site in summer.

(2) discuss the occurrence or lack thereof of such other blooms at other sites along the coast, by showing or commenting evidence from satellite imagery (or other available data).

The GOCI CF, although the absolute values are not very useful, often shows higher CF in the northern coastal areas in summer along the east coast of North Korea where the in-situ data are not available. A typical GOCI CF image such as Fig. 1 supports such blooms occurring more frequently in the northern than southern coastal areas in summer. However, there is another source of CF-rich water originating from the southern coastal area, which may be related to frequent summertime coastal upwelling off the southeastern coast of Korea. The ESROB is located in the area affected by both sources of high CFs although the equatorward advection prevailed at and inshore of the site in the three summers.

By the way: (3) is there an image showing any of the blooms at ESROB itself, to have an idea of the bloom's extension around the site?

We hoped to find high CF at ESROB from the GOCI images for all the event and non-event periods in the three summers. However, we could not find this, as the GOCI CF data are not available very near the coast (blank area near the coast shown with white color in Fig. 8d) including the ESROB site owing to cloud cover.

Line 303. "the equatorward and cross-shore advections" -> "the equatorward and cross-shore advection". No need for plural. Line 303. "SSS plays" -> "SSS play" This was revised as recommended.

Table 1 caption. "duration in day" ->"duration in days". Line 405. Figure 1 caption. "water depth in meter" -> "water depth in meters" Line 422. Figure 4 caption. "at the ESROB" -> "at ESROB" Line 430. Figure 5 caption. "at surface" -> "at the surface" Line 431. Figure 5 caption. "at the ESROB" -> "at ESROB" Line 437. Figure 6 caption. "except for 2012 bloom events" -> "but for the 2012 bloom events" Line 442. Figure 7 caption. "except for 2013 bloom events" -> "but for the 2013 bloom events" This was revised as recommended.

Lines 446-7, Fig. 8 caption. "Surface distributions of e) salinity and f) temperature observed using a

small research vessel (ship tracks and CTD stations are remarked with dashed lines and dots)" -> "In situ surface distributions of e) salinity and f) temperature (dashed lines: ship tracks; dots: CTD stations)" This was revised to "Surface distributions of in-situ e) salinity and f) temperature (dashed lines: ship tracks; dots: CTD stations) ... "

Line 459. Figure 10 caption. "in summers" -> "in the summers" Line 460. Figure 10 caption. "A standard deviation of" -> "Standard deviations for". This was revised as recommended.

Reviewer #2

In major comments,

1) Upwelling is frequently observed in the east coastal area in the northern hemisphere under the summertime monsoonal (poleward) wind. This means that upwelling can be a major contributor for the chlorophyll a blooming event. Enhancement of vertical mixing associated with the strong wind is also an important process for the local nutrient budget. In the beginning of event E06, temperature decreased in the whole water column which is due to the passage of typhoon as described in the text. However, the authors did not mentioned it as a possible governing mechanism for the blooming event.

Thank you very much for the constructive comments. We agree that the coastal upwelling off the east coast in the northern hemisphere under the summertime monsoonal wind and intermittently enhanced vertical mixing associated with strong wind are a major driver to trigger the bloom via nutrient supply to the euphotic zone in general. In the revised manuscript, we explicitly mentioned the up- and downwelling responses to the strong alongshore wind associated with the typhoon passages. However, as discussed in Section 4.2, local blooms triggered by nutrient loading may play a minor role here in shaping the CF variability/events at ESROB.

2) The documents by the National Institute of Fisheries Science of Korea show that July 2, July 11 and July 23-29, 2013 were the period of low temperature warning in the east coast of Korea including the study area. These periods are coincident with the blooming events. Thus, it must be carefully reanalyzed for the driving mechanism by using all available data, though no clear evidence for upwelling phenomena is shown in temperature data except E07 event in Figure 7. It would be better to show analytically whether the ESROB buoy site, i.e., the distance from the coast, is suitable to monitor the summertime coastal upwelling event.

Good point. Thank you for the information. Yes, we agree that the low temperature warning in July 2013 is relevant to the coastal upwelling off the east coast of Korea. The ESROB is well located where both up- and downwelling responses to local wind can be frequently monitored as has been known for decades (most recent reference is Park and Nam [2018]). However, please note that most CF events observed in the three summers are not directly linked to the nutrient fluxes enhanced by upwelling, but the equatorward advection of CF-rich plume water in the northern coastal area.

In minor comments

Line 76. Please provide the general width of the alongshore current, if possible. The general width was inserted in the revised manuscript as recommended.

Line 105. Please provide the source for precipitation data.

The data source was inserted in the revised manuscript as recommended.

Line 144. '~ inducing strong equatorward (before E01)'. Both salinity and temperature increased sharply, especially in the lower layers just before E01 in Figure 5. This is not consistent with the effect of the equatorward flow.

Line 153. ' equatorward currents developed before E04'. Temperature increased in the whole water column before E04 under the equatorward current as well as before E01.

We understand the original manuscript may cause unnecessary confusion with this interpretation. As commented by this and another reviewer, we included the up- and downwelling responses as schematically shown in Figure R1 below. The winds either increase or decrease the stratification near the coast owing to coastal up- and downwelling responses (with offshore and onshore Ekman transport in the upper layer) to alongshore wind depending on its direction. The water column in the coastal area can be either re-stratified (downwelling favorable wind with equatorward flow, Fig. R1 left) or homogenized (upwelling favorable wind, Fig. R1 right) depending on the alongshore wind.



Figure R2. Schematics of isopycnals or isotherms (dashed line) and alongshore currents at the upper layer in response to downwelling (left) and upwelling (right) favorable wind stress.

Line 176. 'a high surface CF zone in the northern area'. Is it a general feature in summer only? Why CF is high in the northern area?

In general, the summer rainfall is much higher than that of the other seasons in the Korean peninsula and freshwater discharged from the rivers increases as previously reported (Bae et al., 2008; Kong et al., 2013). We believe that the nutrient loading associated with the river discharges in the northern coastal areas trigger blooms in summer, as often seen from relatively high GOCI CF in areas nearby river mouths (e.g., JJ, WS, SP, and HH).

Line 237. '4.2. Other mechanisms'. It would be better to add more discussion.

More discussions were added in Section 4.2 of the revised manuscript as recommended by this and other reviewers.

Lines 275, 281, 286. Check 'Park et al., 2018'. Park and Nam, 2018 ?

This has been revised as "Park and Nam (2018)".

Line 297, '80%, 8 of 10'. It may not be conclusive.

We counted the number of events where the (equatorward) alongshore advection plays a primary role in changing the CF at ESROB. More specifically, equatorward currents and salinity decreases were accompanied during the 8 events (E01–E06, E08–E09). The high CFs during the remaining two events (E07 and E10) were discussed in association with cross-advections (both onshore and offshore advections). Thus, we concluded that all the summertime CF events at ESROB could be explained by the horizontal, not vertical advection, and local blooms were not triggered by biogeochemical mechanisms (nutrient loading or light availability).

Summer-time Summertime episodic chlorophyll-a blooms near the	11	서식 있음: 글꼴: 17 pt, 굵게, 글꼴 색: 자동
east coast of Korea		서식 있음: 글꼴: 17 pt, 굵게
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Young-Tae Son, Jae-Hyoung Park, and SungHyun Nam*		서식 있음: 줄 간격: 1줄
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Abstract

. We present intensive observational data of surface chlorophyll-a bloom episodes occurring overseveral days in the summers of 2011, 2012, and 2013, accompanying the equatorward advection of low sea-surface salinity (SSS) water near the east coast of Korea. Time-series analysis of meteorological and oceanographic (physical and biochemical) parameter data, such as chlorophyll fluorescence (CF) from surface mooring, ocean color (chlorophyll a and total suspended sediment), sea surface height (satellite-derived), and serial hydrographic data (from in-situ measurements) were used to investigate the relationship between surface bloom events and changes in seawater characteristics and currents. In the summers of the three years, a total of 10 bloom events (E01-E10) were identified where the surface CF was significantly (> $2 \mu g/l$) enhanced over a relatively long (> 1 dayd) period. The bloom events in the summers of 2011 and 2012 were accompanied by low or decreasing SSS for several days to a week after heavy rainfalls rainfall at upstream stations and equatorward currents. Unlike the typical 8 of the 10 events (80 %), E07 was potentially derived from the onshore advection of high CF offshore water of southern origin into the coastal zone near the mooring, whereas E10 is likelypossibly prevailed by offshore advection of high CF plume water trapped by the coastal area. Contrasting with many coastal systems, these findings indicate that event-scale productivity near the east coast of Korea in summer is not controlled by local blooms triggered by either nutrients or light availability, but by the equatorward and cross-shore advections of high CF plume water.

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1. Introduction

Biological blooms associated with, among othersother phenomena, the horizontal advection of chlorophyll-rich+ water (often having low-salinity and high nutrients linked to heavy rain, e.g., nutrient loading), have been frequently observed in many coastal systems (e.g., Yin et al., 2004; Dai et al., 2008; Halverson and Pawlowicz, 2013; Reifel et al., 2013). Blooms stimulated by plume-deliveringdelivered nutrients and enhanced stratification were observed near and offshore of Hong Kong (Dai et al., 2008; Yin et al., 2004). During bloom events, a severalfold increase in chlorophyll a (Chl a) and significant shift in phytoplankton community structure were observed (Dai et al., 2008). The effects of effluent discharge plumeplumes on coastal phytoplankton communities were examined from the City of Los Angeles Hyperion Wastewater Treatment Plant, demonstrating that localized blooms occurred a few days after the diversion within the effluent plume water discharge (Reifel et al., 2013). The Fraser River plume affects Chl a distribution in the Strait of Georgia, British Columbia, Canada, revealing large Chl a differences with respect toamong the plumelocal plumes, despite insensitivity in the long-term average (Halverson and Pawlowicz, 2013).

There are several small river plumes potentially affecting Chl a distribution near and offshore of the east coast of Korea; yet, the effects remain poorly understood. High summer (from June to September, JJAS) precipitation often accompanying heavy rainfall around the Korean peninsula is well known and accounts for more than \geq 50% of the annual precipitation in the region. During summer, most rivers in the region become flooded and discharge large volumes of freshwater into the adjacent marginal seas, including the East Sea (Japan Sea), Yellow Sea, and East China Sea (Bae et al., 2008; Kong et al., 2013). Chl a distribution in the southwestern East Sea off the east coast of Korea has been examined, and found to be associated with physical processes at mesoscale or larger scales, including spring and fall blooms that have been detected using satellite ocean color data, data from limited short-duration ship surveys (Hyun et al., 2008; Kang et al., 2004), and time-series data collected continuously from moored buoys (Hong et al., 2013; Son et al., 2014). Despite wide range images available from geostationary and polar-orbit satellite ocean color remote sensing (Yoo and Kim, 2004; Son et al., 2014; Hyun et al., 2008; Kim et al., 2011), phytoplankton blooms observed over several days to weeks near the coast, particularly during the well-stratified summer season, have rarely been examined. Thus, we aimed to address the episodic bloom events in summer and <u>investigate_investigated</u> the effects of river plumes on Chl a distribution near and away from the east coast of Korea.

2. Data and methods

Time-series data of meteorological, physical, and biochemical parameters have been measured using a surface mooring named ESROB (East Sea Real-time monitoring Ocean Buoy), deployed in <u>a</u> water <u>atdepth of</u> 130 m depth, about 8 km off the mid-east coast of Korea (Fig. 1). The data collected <u>includesdata included</u> wind speed and direction at 2 m above the sea surface, photosynthetically active radiation (PAR) at about 2 m above the sea surface and at <u>10 ma</u> depth<u>of 10 m</u>, temperature and salinity at five depths (5-m, <u>20m</u>, <u>20</u>, 40-m, 60-m, and 110 m), <u>current</u> vertical profile of current profiles with an interval (bin size) of 4 m (upper_most bin corresponds to 5 m depth), and sea surface temperature (SST), salinity (SSS), dissolved oxygen (DO), and chlorophyll fluorescence

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(CF) measured by a Water Quality Monitor (WQM) at a depth of about 1 m-depth. Details on the technical design, improvements, and early-phase operations of ESROB have been previously described (Nam et al., 2005). In the present study, we used data collected for ~-3 years, from April, 2011 to December, 2013, with an emphasis on the three summer periods (JJAS) when the poleward alongshore current (showing a general width of up to about 40 km) averaged over 6 years reversed to an equatorward direction (Park et al., 2016).

The CF as a factory-calibrated Chl a concentration in units of $\mu g/l$ following the manufacturer's (WET Lab) instructions is needed to calibratealways needs calibration with in-situ measurements owing to long-term sensor drift- and that different Chl a concentrations may yield the same fluorescence energy (Longhurst et al., 1989). Four cruises were conducted in July and October 2011, April 2012, and July 2013 to collect in-situ water samples for Chl a and in-situ sensor measurements for water temperature and salinity near the coast. A statistically significant correlation ($r^2 = 0.76$, p < 0.001) was found between the CF sensor values and in-situ chlorophyll concentration derived from the spectrophotometer using acetone-extracted Chl a (Fig. 2a). In addition to the chlorophyll calibration, the concentrations of nitrate were analyzed simultaneously with 64 samples to determine the nitrate proxy based on the relationship between temperature and nitrate. Separately, to observe the fine-scale coastal SST and SSS distributions around the ESROB, in-situ measurements using a small research vessel equipped with a thermosalinograph (SEB21, 10 s sampling interval) were conducted on July 30, 2013, a couple of days after heavy rainfall. Since non-photochemical quenching (NPQ) has a significant influence on the CF in response to changes in ambient light (Müller et al., 2001), particularly for a single channel excitation Chl a fluorometer, the effects were corrected from the ESROB CF data following the methods described in Halverson and Pawlowicz (2013) before calibrating with in-situ water samples.

We used high-resolution daily data generated by the geostationary ocean color imager (GOCI) satellite (composited using eight images) to estimate surface Chl a distributions. The spatial resolution of the geostationary satelliteGOCI is 500 m at a gridposition 50 times further higher than previous polar orbiting ocean color satellites (Ryu et al., 2012). Chl a concentration observed from the ocean color satelliteGOCI can be easily contaminated by the total suspended sediment (TSS) and colored dissolved organic matter (CDOM) in the coastal regions (Ryu et al., 2012). Thus, the satellite-measuredGOCI Chl a was calculated through software modules of the GOCI Data Processing System (GDPS, described in Han et al., 2010 and Ryu et al., 2012) applying a correction algorithm for the TSS and CDOM, as well as by minimizing the contaminating effects of cloud, sea fog, and aerosols (level 1B). Nevertheless, relationships between the satellite-measuredGOCI Chl a and TSS in coastal and offshore areas in Fig. 1 were compared with a linear regression to determine the Chl a in the coastal region (Fig. 2b, c). Results exhibited that the higher the value, the wider the scatter. This indicatedDespite that the absolute value of Chl a can be measured regardless of the overestimated at high TSS both in(Kim et al., 2016), this indicates that the eoastal and outer sea, which supports the possibility of using the satellite-derivedGOCI Chl a in this area_is still useful for understanding the variation for spatial Chl a distribution because the horizontal pattern of Chl a is realistic. Satellite altimeter-derived sea surface height (SSH) products corrected using coastal tide-gauge sea level data along the east coast of Korea (Choi et al., 2012) were used to examine surface geostrophic currents around and offshore of the ESROB in the summer of 2013. Precipitation data (provided by Korea Meteorological Administration (KMA)) were also used to compare the bloom timings with those of heavy rainfallsrainfall in summer. Precipitation in unit of (mm/day) was recorded every 3 hours at stationsh during the summers of 2011, 2012, and 2013 at stations along the coast (SP: SinPho, HH: HamHeung, WS: WonSan, JJ: JangJun, SO: Sockcho, BGN: BukGangNeung, DH: DongHae)), and the data were proxied as freshwater discharges from several small rivers into the East Sea (Fig. 1).1) without available data for freshwater discharges along the North Korean coast.

Current and wind vectors were corrected for local magnetic deviation, decomposed into alongshore and crossshore components rotating counter-clockwise from the north by 30 degrees^o. Wind stresses have been calculated following $\vec{\tau} = \rho_a C_D |W| \vec{W}$ (ρ_a : air density, C_D : drag coefficient, \vec{W} : wind), and alongshore and cross-shore components of current (V_a and U_c) and wind stress (WS_a and WS_c) are expressed by the coordinate transformation, respectively (Large and Pond, 1981). All variables were low-pass filtered with the half power centered at 40 h.

3. Results

3.1. Climatological CF variations

Annual cycles of wind stress (WS_a, WS_c), surface CF, SST, SSS, surface DO, and surface current ((V_a, U_c) at the upper-<u>most</u> bin) observed at the ESROB were obtained by climatologically averaging monthly mean values over the three years from 2011 to 2013, which showed significant <u>summer-timesummertime</u> CF enhancements (in addition to two well-documented blooms in spring and fall), weakened wind forcing, increased SST, decreased SSS, over-saturated surface DO (though absolute DO decreased), and strengthened equatorward (V_a < 0) surface currents (Fig. 3). The <u>CF</u> enhancements of <u>CF</u>-during the summer with significantly high concentrations <u>over</u> 1 μ <u>gug</u>/l in July accompanied withby decreased SSS (abruptly decreased from June to July) and strengthened equatorward currents (maximum speed of 15 cm/s in July), implied high Chl a and low salinity water of northern

origin. Although absolute DO decreased with increasing SST, the surface water was over-saturated for most of the summer, implying a significant role of surface bioactivity. Weak poleward ($V_a > 0$ and $U_a \sim 0$) surface currents were observed throughout the year, except in summer, when strong equatorward ($V_a < 0$ and $U_a \sim 0$) currents prevailed.

3.2. CF events observed in summers of 2011, 2012, and 2013

In the summers of 2011, 2012, and 2013, 10 bloom events (E01–E10) were identified where the surface CF wassignificantly enhanced over <u>a</u> considerable period, <u>i.e.</u>, <u>days to weeks</u> (Fig. 4, Table 1). The CF bloom events were defined as follows: the peaka period of CF reached higher than $2 \ge 1.0 \text{ µg/l}$ and <u>basically</u>. Then, among the events, we selected only those where the duration when theof CF > 2.0 µg/l was longer than 1 day, when CF > 1.0 µg/ldas the final events. The summer bloom event lasted for several days to weeks, which is shorter than the typical duration of spring and fall blooms. Six events, three in each year (E01–E03 and E04–E06), were identified in the summers of 2011 and 2012, whereas four (E07–E10) occurred in 2013 (Fig. 4). The average SST, SSS, and CF for the duration of each event are listed in Table 1.

During the CF events in the summer of 2011 (E01–E03), low SSS was observed at the ESROB several days to a week after remarkable wind forcing and heavy rainfallsrainfall (maximum of 160 mm/day during E02) at upstream

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stations, accompanying enhanced equatorward currents (Fig. 5a, c, e_a and f). Two typhoons (MAON and MUIFA) yielding a maximum wind stress of 0.25 N/m² passed through the region during the CF bloom events, inducing strong equatorward (before E01) and poleward (after E03) wind stresses (arrows labeled by M1 and M2 in Fig. 5b).5b) and implying downwelling (before E01) and upwelling (after E03) in the vicinity of ESROB. Interestingly, the equatorward (poleward) wind stress may strengthen equatorward (poleward) and onshore (offshore) surface currents. Indeed, strong equatorward currents were observed up to 2 daysd after the peak wind forcing immediately before E01, whereas the equatorward currents were markedly weakened by the poleward wind stress immediately after E03 (Fig. 5b, f).

Similarly, the CF events in the summer of 2012 were also accompanied by low or decreasing SSS several days to a week after heavy rainfallsrainfall at upstream stations and equatorward currents (Fig. 6a, c, e, and f). Three (KHANUN, BOLAVEN, and TENBIIN) among the four typhoons in the summer affected the surface CF, SSS, and surface currents during the events. Since typhoon KHANUN drove poleward wind stress, the strong equatorward currents (showing downwelling induced by equatorward wind stress) developed before and during the most of E04 were weakened, and SSS increased to reduce the salinity stratification and decrease surface CF during E04 (arrow labeled by K in Fig. 6b, c, e, and f). After the typhoon passed, the surface CF increased again along with re-enhancing equatorward currents, re-stratifying salinity, and decreasing SSS during E05 (Fig. 6c, e, and f). Two typhoons (BOLAVEN and TENBIIN) successively passed the area and both poleward (equatorward) wind stress re-stratified (well-mixed)imposed by BOLAVEN (TENBIIN) induced an upwelling (downwelling) response with poleward (equatorward) and offshore (onshore) transports at the upper ocean conditionslayer, decreasing (increasing) water temperature, and increasing (decreasing) salinity in the whole column during E06. The poleward wind stress imposed by the BOLAVEN induced well-mixed conditions with high SSS, low SST, and strong poleward surface currents (arrow labeled by B in Fig. 6b, c, d, and f). However, the reversed wind stress imposed by the successive TENBIN resulted in decreasing SSS, increasing SST, weakening the poleward surface current (strengthening equatorward surface current), and rapidly increasing surface CF (peak exceeding 4.5 µgµg/l) (arrow labeled by T in Fig. 6b, c, d, e, and f).

Contrasting to the CF bloom events in the summers of 2011 and 2012, two among the four events (E07 and E10) in the summer of 2013 did not accompany precedingfollow heavy enough rainfall at the upstream stations nor equatorward currents (Fig. 7a, f). Typical heavy rainfallsrainfall and enhanced equatorward surface currents preceded low SSS and high surface CF during the other two events (E08 and E09) only (Fig. 7a, f). Unlikely with typical events, the SSS remained high and SST temporally decreased (negative anomaly) during E07 (Fig. 7c and 7dd), whereas relatively high SST and low SSS were observed during E10 (Fig. 7c, d). Contrasting with those in the other two years, winds were mild, and no typhoon passage was reported in the summer of 2013 (Fig. 7b).

3.3. Surface CF distributions

The equatorward advection of low salinity, chlorophyll-rich plume water into the ESROB area along the coast was confirmed from a series of daily composite <u>satellite measuredGOCI</u> Chl a only when clear images containing few clouds were available. One example presented here is from four images continuously available from July 24

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to 27, 2013, before E09 (Fig. 9a, b, c and 8a-d). A high surface CF zone in the northern area (e.g-, off the SP, HH, and WS_sites, Fig. 1) was separated from that in the southern area (e.g-, between the coast and UI, Fig. 1) following the poleward current—the East Korea Warm Current (EKWC)—andwhereas a more coastal branch extended equatorward with time near the coast during the period (Fig. 9a, b, c and 8a-d) after the heavy rainfalls inrainfall of July 19–24 (Fig. 7a). The high CF plume water was elongated and reached to JJ by July 24, SO by July 25–26, and farther south near the coast by July 27, yielding the E09 event from July 28 to August 1 (Table 1, Fig. 7). The SST and SSS observed using the thermosalinograph on July 30, 2013 in the vicinity of ESROB consistently demonstrated wedge-shaped patterns with low SSS and high SST water confined near the coast and reaching farther south passing BGN (Fig. 9e and 9f&e, f), confirming the equatorward advection of low-salinity and high CF surface water along the coast to ESROB. Interestingly, the satellite-based surface geostrophic currents around and offshore of the ESROB (not shown) and the alongshore currents observed at the upper depths of the ESROB (e.g-, Fig. 7f) were all equatorward during this period.

A patternThe patterns of surface CF distribution and geostrophic flow field on July 3, 2013 for E07 are shown in Fig. 9a and 9bb, where high CF was found inshore of the poleward flowing EKWC (main axis is closer to UI than the high CF area) and within the cyclonic circulation around the ESROB (area of relatively low SSH). Onshore currents prevailed between BGN and DH, associated with the cyclonic circulation (Fig. 9b), potentially yielding onshore advection of high CF offshore water of southern origin into the coastal zone near the ESROB during E07 (Fig. 9d). Similarly, although clear images were not available at that time, the geostrophic flow field on August 21, 2013 for E10 is shown in Fig. 9c, wherein offshore currents were found to prevail near the coastal zone, near DH and ESROB, as well as equatorward currents immediately to the north. The offshore advection of coastal plume water of northern origin presumably having low salinity, high temperature, and high CF (as cases of manysee in Fig. 7, but also other similar events, seeas in Fig. 1 or Fig. 8) may have enhanced the surface CF at the ESROB during E10 (Fig. 9e).

4. Discussion

4.1. Horizontal advection

The low-salinity chlorophyll-rich water originating from the northern coastal region often accompanying heavyrainfallsrainfall is advected equatorward along the coast into the coastal zone in the vicinity of the-ESROB in summer, and is primarily responsible for most ($80 \frac{96}{6}, 8 \text{ of } 10$) of the CF events. The rate of Chl a change observed at-the ESROB is comparable with the rate estimated from the spatial Chl a gradient and speed of equatorward advection. The equatorward advection distance of high Chl a water is measured to be dy = 100 km(= dy)-over 3 daysd (= dt) with Chl a change (difference between Chl a at the plume source and the initially oligotrophic water at ESROB) of about 2.5 µg/l (= dChl) from the series of four daily composites of satellitemeasuredGOCI Chl a collected in July 24 to 27, 2013 before E09 (Fig. 9a, b, c and 8a-d). With an advective speed of 0.4 m/s (= 100 km / 3 daysd), this yields a rate of Chl a change of 0.86 µg/l-/d⁺ (= $0.4 \text{ m/s} \times 2.5 µg/l / 100 \text{ km}$) owing to the alongshore advection ($v\partial$ Chl $a/\partial y$), which is consistent with the observed rate (∂ Chl $a/\partial t$ where dChl was estimated from the ESROB measurements and dt = 1 h) for E09 (µp to $1.26 µg/l-/d^{-4}$ averaged over the **서식 있음:** 글꼴 색: 자동

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period when $\partial \text{Chl } a/\partial t > 0$) and others (mean: 0.87 µg/l-/d⁻¹), supporting that the alongshore advection plays a primary role in CF variability near the coast. The distribution and temporal evolution of SSS observed in July 30, 2013 implies the low salinity plume water (SSS < 29 g/kg found in the northern coastal area, Fig. 8e) is mixed with saline offshore water while advected equatorward, yielding slightly higher (> 31 g/kg) SSS at ESROB. These findings are similar to those of bloom events with a rate of CF change (2–4 µg/l-/d⁻⁴ estimated from their Fig. 11) controlled by the advection of low SSS and high CF plume water in other coastal systems (Halverson and Pawlowicz, 2013).

In contrast to E09, the high surface CF observed during E07 is not explained by equatorward advection of lowsalinity chlorophyll-rich water originating from the northern coastal region, but potentially by the onshore advection of high CF water of southern origin advected via the EKWC. Hyun et al. (2009) demonstrated that the highest primary productivity in the southwestern East Sea is induced by the transportation of high CF water originated from upwelling of nutrient rich water along the southern east coast of Korea. The high CF water may affect the productivity near the mid-east coast of Korea as advected by the EKWC and its meanders, particularly on the western or coastal side of the front formed by the EKWC. Indeed, a rate of cross-shore Chl a change around ESROB from the surface CF distribution observed during E07 (Fig. 9a) is roughly 0.1 µg/l-/km⁺ (dChl = 1.0 µg/l and dx = 10 km) and a rate of Chl a change by cross-shore advection ($u \partial Chl a/\partial x$) is estimated to <u>be</u> 0.86 µg/l $/d^{-1}$ (= 0.1 m/s * 1.0 μ g/l / 10 km) with cross-shore velocity of 0.1 m/s (estimated from the ESROB measurements), which supports this assertion, demonstrating a the influence of the high CF region offshore of the ESROB site (Fig. 9a, d). Onshore advection of the high CF water originated from the upwelling of nutrient--rich water along the coast, accountingaccounts for half the CF change during the event (up to 1.60 µg/l-/d+ averaged over the E07 when $\partial \text{Chl} a/\partial t > 0$) observed at ESROB during E07 (Fig. 7). Conversely, offshore advection of high CF coastal plume water of northern origin may also be significant, as that of happens for the E10 bloom. Based on previous research conducted in other coastal systems, E10 is similar to results on temporal and spatial variations of CDOM, CF, and primary productivity by cross-shore (onshore and/or offshore) advection of high SST and high CF plume water associated with local circulations (Brzezinski and Washburn, 2011; Warrick et al., 2007). Thus, cross-shore advection of low SSS and high CF water associated with ambient circulation plays an equally significant role in shaping and triggering bloom events in the coastal area.-

4.2. Other mechanisms

The high CF events observed at ESROB are not local blooms triggered by either nutrients or light availability. The upward vertical flux of nitrate into the euphotic zone at Huntington Beach, southern California shows how vertical nutrient supply triggers local chlorophyll blooms (Omand et al., 2012). Omand et al. (2012) demonstrated that each episodic bloom was preceded by a vertical nitrate flux event 6–10 days earlier using nitrate concentrations estimated from a temperature proxy. Relationships between nitrate and temperature and between nitrate and salinity observed from the surveys in July and October of 2011 and April of 2012 are not significantly different from each other, and the vertical nitrate fluxes were estimated by the temperature proxy to discuss the

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potential role of nitrate in triggering the episodic blooms. However, both advective and turbulent nitrate fluxes estimated using a nitrate proxy utilized from temperature measurements (Fig. 10) did not account for the observed CF blooms (not shown). Moreover, local blooms triggered by nutrient supplied by equatorward advection is not supported by surface CF distribution (decreasing equatorward) in July 24 to 27, 2013 (Fig. 8). Although some episodic CF blooms (E01 and E06) are preceded by flux peaks with a typical time lag of 4–12 d, most events are not directly linked to the variability in vertical nitrate fluxes, suggesting only minor roles of nutrient flux in shaping CF variability observed at ESROB in summer.

Time-series of the euphotic zone depth (Z_{eu}) waswere compared with othersthe other time-series data recorded at ESROB to examine the effects of light adaptation on the bloom events-from, using the data collected with two PAR sensors available for 2012 and 2013 (Figs. 6, 7). Basically, Z_{eu} of 18 mthe averaged overfor the E04–to E10 bloom periods, $Z_{eu} = 18 \text{ m}_{x}$ was deeper than 10.5 m which is Z_{eu} averaged over the two whole summer periods (JJAS), indicating that the light environment was favorable at least for retaining and increasing of the CF bloom observed at ESROB. A Z_{eu} of 20 m averagedobtained by averaging over the three bloom events (E04–E06) in 2012 was deeper than that (Z_{eu} =15 m for E07–E10) in 2013, supporting more favorable CF bloom conditions in 2012 than 2013. Correspondingly, CF of 1.8 µg/l averaged over E04–E06 in 2012 was higher than that in 2013 (~ 1.6 µg/l for E07–E10). Our results on the deeper Z_{eu} with higher CF in 2012 than 2013 summers are consistent with those in other systems (e.g., Mississippi River coastal system) where light attenuation plays a significant role in increasing phytoplankton biomass, and productivity variation (Lehrter et al., 2009). However, the CF changes among the individual events do not necessarily follow Z_{eu} variations (Table 1), suggesting a minor role of light availability in shaping the CF variability observed at ESROB.

4.3. Inter-annual variations

The CF bloom events near the coast can vary inter-annually depending on the passage of typhoons. Five typhoonsthat passed through this area were associated with the CF bloom events for two summers (2011 and 2012) and there was no typhoon affecting the CF bloom events in 2013 summer. Both strong wind forcing and intensive rainfallsrainfall associated with typhoon passage nearby determine how the plume water is advected in and around ESROB, which varies year-to-year. In 2011, for example, the CF enhancement (E01) was accompanied by the passage of MAON (equatorward wind stress and current) through the area south of ESROB, whereas E03 ended with the passage of MUIFA (poleward wind stress and current) passing through the area north of ESROB (Fig. 5b). Similarly, surface CF decreased (increased) with the passages of typhoons KHANUN and BOLAVEN (TENBIIN) through the area north (south) of ESROB (Fig. 6b). Without any typhoon passage in the summer of 2013, only half the CF events could be explained by the alongshore advection contrasting with those in the other two years (Fig. 7b). Thus, the primary productivity in the area is possibly affected severely by inter-annual variations of typhoon-induced alongshore advection.

Remote wind forcing significantly affecting summer-timesummertime equatorward currents near the coast via equatorward propagating coastal trapped waves (CTWs) varied in the summers of 2011, 2012, and 2013 (Park et al., and Nam, 2018 submitted in revision). The CTWs generated off the Russian coast (~1,000 km from ESROB)

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changed equatorward currents at the location of ESROB to yield more equatorward advection in 2011 and 2012 summers and more poleward advection in 2013 summer, of low-salinity plume water near the coast (Park et al.,and Nam, 2018 submittedin revision). These results may be relevant to more CF bloom events explained by equatorward advection of plume water of northern origin in 2011 and 2012 summers than 2013 summer (6 among 6 events vs. 2 among 4 events). Therefore, inter-annual variations of alongshore advection and surface CF blooms near the coast are possibly affected by the CTWs propagating equatorward from the Russian coast, where wind forcing varies considerably to generate CTWs. Park et al.and Nam (2018 submittedin revision) also quantified the impact of EKWC on the alongshore current variability near the coast, which yields less EKWC impact and more equatorward currents near the coast in 2011 and 2013 summers, than 2012 summer. Although this is inconsistent with less CF bloom events explained by the equatorward advection of plume water of northern origin in 2013 summer, cross-shore advections of high CF water of either northern (E10) or southern origin (E07) are possibly associated with EKWC recirculation based on the patterns of surface geostrophic currents (Fig. 9).

5. Concluding remarks

The low-salinity chlorophyll-rich water originating from the northern coast accompanying heavy rainfallsrainfallis often advected equatorward along the coast in summer, resulting in high surface CF enhancementsevents near the mid-east coast of Korea. Alongshore advection of high CF waters is primarily responsible for most (80 %, 8 of 10) of the CF events, which confirms that the bloom events are possibly controlled by the advection of low SSS and high CF plume water in summer. In contrast to the bloom events associated with alongshore advection, the high surface CF observed during E07 is possibly explained by the onshore advection of high CF water of southern origin advected by the poleward-flowing EKWC. Similarly, offshore advection of high CF coastal plume water of northern origin may be significant, as in the case of E10. Therefore, the equatorward and cross-shore advectionsadvection of chlorophyll-rich plume water with decreasing SSS playsplay a primary role in the high productivity near the east coast of Korea in summer. Summer timeSummertime CF near the coast varies interannually as the horizontal advections vary significantly, inter-annually associated with typhoon passages nearby, CTWs generated from the Russian coast, and influence of the EKWC, which should be addressed with long time series data in the future.

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Data availability: All data are available upon request to the authors.	
Author contributions: This work was conceptualized and funding was secured by SHN and YTS. In-situ-	
measurements were designed by SHN and YTS, and performed by YTS and JHP with equipment provided by	서식 있음: 글꼴 색: 자동
SHN and YTS. Data were analyzed by YTS and JHP. The manuscript was written by YTS and SHN and edited	
by YTS, SHN, and JHP. All authors have approved the final article	서식 있음: 글꼴: 굵게, 글꼴 색: 자동
Competing interests: The authors declare that they have no conflict of interest.	
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서식 있음: 글꼴 색: 자동 **서식 있음:** 줄 간격: 1.5줄

				<u>CE</u>		
		SST	SSS	CF (start & end dates)	Duration	Z_{eu}
	E01	20.5	31.2	1.65 (<u>21.</u> Jul. <u>21–</u> 25 Jul.))	4.9	Not available
2011	E02	22.3	30.9	1.91 (26. Jul. ~ <u>26 Aug</u> 03<u>. Aug.))</u>	8.3	Not available
	E03	24.3	29.9	1.61 (05. Aug <u>05-</u> 08- Aug.)	2.5	Not available
	E04	21.4	32.9	1.67 (16. Jul. <u>16-</u>20. Jul.))	3.5	22
2012	E05	22.8	32.8	1.29 (21. Jul. <u>21-</u> 27 Jul.) <u>)</u>	5.8	20.6
	E06	18.1	33.4	2.35 (29. Aug. <u>~ 29-Sep</u> 05 . Sep.))	6.4	16.8
	E07	16.1	34.1	1.6 (01. Jul <u>.⊶_01−</u> 04 Jul.))	2.3	17.8
2013	E08	21.2	33.2	1.6 (12. Jul. <u>12</u> _16 Jul.))	4.4	15.7
	E09	25.0	32.1	1.7 (28. Jul. ~ <u>28-Aug</u>	4.3	12.7

Table 1. Sea surface temperature (SST) in °C, sea surface salinity (SSS) in g/kg, chlorophyll-a fluorescence (CF) in μ g/l, duration in <u>daydays</u>, and euphotic depth (Z_{eu}) in m during the E01–E10 observed from the surface mooring

				01 . Aug.))		
				1.4		
l	E10	26.7	31.9	(18. Aug <u> 18–</u> 23.	5.9	15.2
				<u>Aug.))</u>		



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Figure 1. a) Study area in the western part of the East Sea (Japan Sea). b) A chlorophyll a <u>(Chl a)</u> image from the geostationary ocean color satellite on September 6, 2012 in the area marked by red box in a). Black solid boxes denote the areas where the chlorophyllChl a and TSS are averaged. Locations of the rainfall station along the east coast of Korea are marked by triangles (SP: SinPho, HH: HamHeung, WS: WonSan, JJ: JangJun, SO: Sockcho, BGN: BukGangNeung, DH: DongHae, rainbow colored). The surface mooring (ESROB) is indicated by a red star in b) with bottom topography in the lower left corner where numbers denote water depth in metermeters (contour interval: 100 m). Ulleung Island (UI) is located at ~-131 °E..°E.





Figure 2. Results of cross-correlation (R²: correlation coefficient) and linear regression analyses (dash lines) between a) chlorophyll fluorescence measured by the ESROB WQM and absolute chlorophyll concentration obtained from in-situ water samples; and between TSS and <u>GOCI</u> chlorophyll a concentration for b) the areas along and near the east coast of Korea and c) area off the coast between DH and UI. The water samples (N: sample number) were collected in July and October of 2011 and April of 2012.





Figure 3. Climatology for a) alongshore and cross-shore components of wind stress, b) chlorophyll fluorescence, c) water temperature, d) salinity, e) dissolved oxygen in both ml/l and percentage saturation, and f) alongshore and cross-shore components of surface (~ 5 m) current constructed using ESROB data collected in three years from 2011 to 2013. Summer season (JJAS) is shaded.



Figure 4. Time-series of low-pass filtered (cutoff period of 40 h) chlorophyll fluorescence observed at the ESROB - during the three summers (JJAS) of a) 2011, b) 2012, and c) 2013. The episodic bloom events are green-shaded and labeled E01 to E10.





Figure 5. Time-series data collected in 2011 of a) daily rainfall amounts observed at weather stations (SP: SinPho, HH: HamHeung, WS: WonSan, JJ: JangJun, SO: Sockcho, BGN: BukGangNeung, DH: DongHae) along the east coast of Korea, and b) alongshore (solid) and cross-shore (dash) wind stresses, c) salinities, and d) water temperatures observed at <u>the</u> surface (red), 5 (cyan), 20 (blue), and 40 m (pink), e) surface CF, and f) alongshore (dashed) and cross-shore (solid) currents, observed at <u>the</u> ESROB. The bloom events are labeled by E01 to E03. In the top axis of (a), dates/times of satellite altimetry-derived surface geostrophic current map and geostationary satellite ocean color image (<u>GOCI</u>) are remarked with black diamonds and red arrow, respectively. Nearby passages of typhoons are indicated by black arrows in b) (M1: MAON, M2: MUIFA and T: TALAS).



서식 있음: 줄 간격: 1.5줄, 단락의 첫 줄이나 마지막 줄 분리 허용, 단어 잘림 허용, 한글과 영어 간격을 자동으로 조절하지 않음, 한글과 숫자 간격을 자동으로 조절하지 않음

Figure 6. Same as Figure 5, exceptbut for the 2012 bloom events labeled E04 to E06, and four typhoons (K: KHANUN, T: TENBIN, B: BOLAVEN, S: SANBA). Euphotic depth (Z_{eu}, red dots) derived from two PAR sensors attached to the ESROB are superimposed in b).



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Figure 7. Same as Figure 6 exceptbut for the 2013 bloom events labeled E07 to E10, and no typhoon occurrence.





Figure 8. a)-__d) Daily series of geostationary satellite ocean color imagesGOC1 indicating surface chlorophyll adistributions from July 24 to 27, 2013. Surface distributions of <u>in-situ</u> e) salinity and f) temperature observed using a small research vessel ((dashed lines: ship tracks-and; dots: CTD stations are remarked with dashed lines and dots) in July 30, 2013 a couple of days after heavy rainfall in the region. Two black arrows in each panel head for the same locations in the vicinity of JJ (JangJun) and SO (Sockcho).



Figure 9. Distributions of a) daily composite of chlorophyll a concentration in July 3, 2013, obtained from the geostationary satellite ocean color imager<u>GOCI</u>, and satellite altimetry-derived surface geostrophic currents in b) July 3 and c) August 21, 2013. Schematics for (d) on-shore and (e) off-shore advections of high CF surface water for July 3 (E07) and August 21 (E10), 2013.





Figure 10. A linear fit (bold line) between temperature (Temp.) and nitrate (NO₃) for Temp < $14.0 \degree C$ (NO₃=0 for Temp > 14.0 °C) to observations near the east coast of Korea in <u>the</u> summers of 2011 and 2012. A standard deviation of <u>Standard deviations for</u> nitrate and absolute salinity in g/kg are shown with vertical bars and colors (colorbar in the right), respectively.