Responses to reviewer 1

We thank reviewer 1 for her/his review. We have considered all the comments and revised the manuscript accordingly. Our detailed responses are listed below.

1. The number of extreme chl-a events in the study is too low to base any reliable statistical conclusion on. Also, it is not clear how many events there actually are. In the abstract, it is stated that 6 (83%) of the extreme events occur in 2016. This would imply 7 events. However, in table 4, there are only 6 events listed in total (with 3 of these in (December) 2016). So it is not clear how many events there are, but either 6 or 7 is far too small a number to base any reliable conclusions on.

Thanks for this point. In the analysed period 2010-2018, 6 extreme events of high chl-a values were found, and 5 of them (83%) correspond to 2016 (Table 3). In fact, there was an error in the abstract, and in the revised version of our work we replaced the original sentence:

'Six extreme events, corresponding to 83% of the total, were detected in the year 2016 ...',

with the following one:

'Out of six extreme events, five (83%) were detected in the year 2016…'.

We clarify that the main objective of our study is to analyse whether the synoptic-to-intraseasonal (SY-IS) environmental variability is related to the occurrence of extreme events of high chl-a in the Puyuhuapi fjord located in Chilean Patagonia (the six events listed in Table 3). In this context, extreme events of low chl-a (the six events listed in Table 4) are also included to explore whether any signs of linearity are evident between chl-a and the prevailing atmospheric conditions. This is indeed the case, as revealed in Figure 5 and discussed in subsection 3.3.

We agree that we are dealing with a very limited number of events, but this is a challenge to face in this kind of studies. The in-situ time series we analyse is unique in its nature in the context of the Chilean fjords, a fact that makes it particularly valuable for this kind of research. In most of these fjords, very scarce sampling is carried out, with a frequency up to two values per month. By definition, the extreme events we analyse correspond to values within the highest 10% SY-IS anomalies between 2010-2018 (as defined in the methodology). As shown in Fig. 6, they comprise well-defined events that show evident deviations from the long-term mean. Given the length of the available observations (2010-2018) and the definition of these extreme events according to both intensity (exceedance of the 90th percentile) and persistence (of at least 2 days), we agree that it is not possible to compute robust statistics based on these extreme events. However, we can still investigate their characteristics and analyse whether there is any similarity in the conditions before and during their occurrence, and thus establish a characteristic atmospheric configuration that is recurrent in most of the events and also suggest an associated physical mechanism. These are all valuable goals on their own. However, we agree that it is crucial to clarify to the readers the inherent restriction of our study framework. To underline this aspect of our work, we have included the following sentence to the conclusion section of the revised version of the manuscript:

'We are aware that no robust statistical conclusions can be drawn from the limited number of extreme events of chl-a that arise from the definition applied on the limited length of observations analysed here. However, our results contribute to establish an analysis framework and deliver indications for atmospheric monitoring. Therefore, we encourage revisiting our results when observations spanning a longer period become available.'

2. Of the 6 high chl-a events listed in Table 4, the MJO phases are also listed. These are, for the 6 events, MJO phases 4,6,7,2,6,5. In the abstract, it is concluded that MJO phases 6-7 tend to reinforce chl-a events. This is an incorrect conclusion. 3 out of 6 of the high chl-a events occur in MJO phases 6-7. With such a small number of events, and no prior reason to think that MJO phases 6-7 re important, this can easily happen by pure chance. Also, it is stated that ENSO is an important modulator of the high chl-a events, as 2016 is an ENSO year. The paper only analyses DJF data, and it is not clear whether the 2015/16 or 2016/17 DJF season is being discussed, which is very confusing. What is the state of ENSO in these two DJF seasons. The whole discussion here is confusing and not backed up reliably by the data.

As clarified in the previous answer, Table 4 exhibits the extreme events of low chl-a. The MJO phases registered during the extreme events of high chl-a are shown in Table 3. In this latter group of high chl-a, 4 out of 6 (67%) events correspond to active MJO phases 6/7. Building upon this fact, we analysed the corresponding trajectories (between days -20 and 0) in the Wheeler-Hendon phase diagram for each of these events (Fig. 9a; Fig. 9b exhibits the events peaking on active MJO phases 3 and 4). We found that all 4 events had similar trajectories (however, it must be noted that the events peaking on 19-Feb-2016 and 26-Feb-2016 overlap with a span of 8 days). All these trajectories developed during active MJO phases (in particular phases 4 and 5) prior to the occurrence of their associated extreme events. This result seemed as an indication for a possible relationship between the active MJO phases 6/7 and favorable atmospheric conditions for the build-up and triggering of the extreme events. From our results, there is no evidence that other active MJO phases (e.g. 1,2,8) are associated with similar conditions. Moreover, no chl-a extreme events were found during inactive MJO conditions (i.e., intensity of the Wheeler and Hendon index below 1).

To further explore this, and as a complementary analysis from the "MJO perspective" (regardless of the extreme events), we computed the mean fields of intraseasonal anomalies in the study area for each MJO active phase, which are shown in Fig. 10. We found that positive SLP anomalies and a southerly wind component predominate mainly in these active phases 6 and 7. Therefore, this suggests that active MJO phases 6/7 could reinforce, in the SY-IS time scale, the seasonal mean atmospheric conditions observed in DJF 2016 (previously shown in Fig. 2b). Taking this possible constructive interaction into account, we infer that the MJO-related anomalies seem to establish a favorable scenario for the occurrence of extreme events of high chl-a.

Correspondingly, the following comment was reformulated in the abstract:

(…) Furthermore, this work suggests that active phases 6 and 7 of the MJO might reinforce, on the SY-IS timescale, the seasonal atmospheric circulation observed in DJF 2016 (December/2015-February/2016). (…)

With respect to 2016: previous research has shown the influence of large-scale climate modes, particularly ENSO and the Southern Annular Mode (SAM), on the inter-annual variability of phytoplankton blooms in the spring-summer seasons (September/October/November-December/January/February) (Lara et al., 2016). The summer of 2016 was unusual in that a harmful algal bloom of *Pseudochattonela cf. verruculosa* wiped out about 12% of Chilean salmon production, causing the worst mass mortality of fish and shellfish ever recorded in the coastal waters of western Chilean Patagonia. This bloom occurred during a strong El Niño event and the positive phase of the Southern Annular Mode (SAM) that caused anomalies in the atmospheric circulation in southern South America and the adjacent Pacific Ocean that in turn caused dry conditions with positive radiation anomalies during those months (León-Muñoz et al., 2018).

Considering that these modes of variability, particularly ENSO, have their spectral peak in the interannual scale, they lie beyond the main focus of our research. Recall that the interannual signal was removed from our data through equation 1. Indeed, our main goal is to explore periods shorter than the interannual scale. The revised text highlights this.

Following previous ideas, the introduction was reformulated to provide a more complete context to the reader and to account for the importance of inter-annual modes of variability scale in the modulation of phytoplankton blooms, specifically in the summer of 2016. Now, this section comprises a passage that reads:

Previous research has shown the influence of large-scale climate modes acting in the inter-annual scale, such as El Niño-Southern Oscillation (ENSO) and Southern Annular Mode (SAM), on the intensity of phytoplankton biomass in the spring-summer seasons (SON-DJF) (Lara et al., 2016; Garreaud, 2018; León-Muñoz et al., 2018). The most salient recorded event occurred in DJF 2016 (December/2015-February/2016), during which a harmful algal bloom of Pseudochattonella cf. verruculosa wiped out about 12% of Chilean salmon production, causing the worst mass mortality of fish and shellfish ever recorded in the coastal waters of western Chilean Patagonia. This HAB took place during a strong El Niño event and the positive phase of SAM that induced anomalies in the atmospheric circulation in southern South America and the adjacent Pacific Ocean, which in turn caused dry conditions with positive radiation anomalies during those months (León-Muñoz et al., 2018; Garreaud, 2018).

Further relevant changes in the revised version of the manuscript

In line with our previous answers, we incorporated some discussions and clarifications in the revised version of the manuscript, with the aim of clarifying some of the ideas set out in the article that were not explicitly or obviously described but were considered in the research.

Original text in normal font; new text in italics

1 Introduction

47 ‘(...) From a climatic point of view, SY-IS variability represents high frequencies that break into the seasonal variability generating a wide range of responses on oceanographic and biological variables.the seasonal variability generating a wide range of responses on oceanographic and biological variables’.

‘(...) From a climatic point of view, SY-IS variability represents high frequencies that break into the seasonal variability generating a wide range of responses on oceanographic and biological variables. SY-IS might arise on top of seasonal variability, and both might superimpose constructively or destructively.’

66 ‘Jacques-Coper et al. (2023) found that high biomass events in Inner Sea of Chiloé occurred under the influence of a mid-latitude migratory anticyclone, inducing negative cloudiness (or increased photosynthetically active radiation: PAR) and positive SST anomalies.’

‘Jacques-Coper et al. (2023) found that high biomass events in Inner Sea of Chiloé occurred under the influence of a mid-latitude migratory anticyclone, inducing negative cloud cover anomalies leading to positive anomalies of photosynthetically active radiation (PAR) and SST. This association between atmospheric conditions and events of high chl-a in the Puyuhuapi Fjord may help to identify the synoptic configuration that may tend to favor them, by possibly forcing the marine environment. Moreover, if such configuration is modulated by climate variability modes, guidance on the predictability of their occurrence might be revealed. In any case, it should be kept in mind that SY-IS climate variability might just be one factor influencing the increase of phytoplankton biomass. Many other factors could be of relevance, for example, the availability of inorganic nutrients (from land-based activities through runoff) and the trophic interactions of the organisms present in the water column.’

4 Discussion

420 ‘(...)These caused a weakening of westerly winds (40ºS - 50ºS), from which a decrease in the frequency of storms is inferred, and therefore a decrease in precipitation in northwestern Patagonia (Garreaud, 2018).’

‘(...)These caused a weakening of westerly winds (40ºS - 50ºS), from which a decrease in the frequency of storms is inferred, and therefore a decrease in precipitation in northwestern Patagonia (Garreaud, 2018). These climate anomalies were related to a strong El Niño (ENSO) event and the positive phase of the Southern Annular Mode (SAM) (León-Muñoz et al., 2018; Garreaud, 2018). Considering that these mentioned modes of variability, mainly ENSO, belong to the interannual scale, they are not within the scope of our research, because the interannual signal was removed of our data, so no results of these are included.’

460 ‘(…)Phases 6 and 7 are the predominant phases in the 2016 events, with two events in each of these, which may be an indicator that these phases could modulate the hydrographic environment of the PF and favor the occurrence of chl-a events.’

‘(…)MJO phases 6 and 7 are the predominant phases in the 2016 events, with two events each. This may be an indicator that these phases could modulate the hydrographic environment of the PF and favor the occurrence of extreme events of high chl-a. On the other hand, 4 out of 6 (i.e., 67%) of the extreme events of low chl-a occur during non-active phases of the MJO. Of such extreme events of low chl-a, only one occurs during an active phase 6. This reinforces such a possible association.’

‘Complementarily, we analyzed the modulation of SLP, SST and wind anomalies induced by all active MJO phases (Fig. 10). Phases 6 and 7 indicate positive SLP anomalies over the entire study area, leading to negative cloud cover anomalies and an increase in PAR. This result suggests that these active MJO phases might reinforce, in the SY-IS timescale, the mean seasonal atmospheric conditions observed in DJF 2016 (Fig. 2b). Consequently, we infer that the background condition established by the annual cycle can be modified (reinforeced or weakend) by the intraseasonal variability., However, in this case, we find that the synoptic variability imposes a crucial determinant factor that can be very relevant for the occurrence of an extreme event of high chl-a.’

5. Conclusions and perspectives

490 ‘(...)Our results motivate future research that might arise based on longer time series and more frequent observations, considering also other seasons of the year, in order to gain a deeper understanding of the modulation of SY-IS on hydrographic environments, given the relevance of these phenomena and the influence they have on the processes in the fjords.’

‘We are aware that no robust statistical conclusions can be drawn from the limited length of the observations analysed here and the definition of the extreme events of chl-a. Therefore, we encourage revisiting our results when observations spanning a longer period become available. Our results motivate future research that might arise based on longer time series and more frequent observations. Future studies could also consider other seasons of the year, in order to gain a deeper understanding of the modulation of atmospheric SY-IS variability on hydrographic environments, given the relevance of these phenomena and the influence they have on the processes in the fjords. ’