Reply on RC2

Liliane Merlivat et al.

Author comment on "Physical mechanisms for biological carbon uptake during the onset of the spring phytoplankton bloom in the northwestern Mediterranean Sea (BOUSSOLE site)" by Liliane Merlivat et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-315-AC2, 2022

Reviewer: Emmanuel Boss, UMaine.

This paper focuses on the dynamics of DIC, light and chlorophyll in March and April at two sites in the Ligurian Sea, linking those dynamics to atmospheric forcing and stratification. The measurements from two buoys are also enhanced with measurements with a glider. The claim in the paper is that 'These analysis support the hypothesis that decreases in the depth of active mixing, a result of the transition from buoyancy-driven to wind-driven mixing, control the timing of the spring bloom.'

Since what is considered a bloom is not defined in this paper, it is impossible to judge whether the result support this hypothesis .

The paper is short, clear and of interest to the readers of Biogeosciences. I have, however, several comments, that if addressed will make this paper of much more interest. Since these comments are significant I suggest a major revision is necessary.

1.The concept of a 'bloom' is never defined as is that of the 'onset of the bloom'. The two competing theories you relate two (Sverdrup's and Behrenfeld's) are focused on when the depth integrated phytoplankton biomass starts accumulating. This, I believe, occurs much earlier than at March in the region in question.

It is important to distinguish blooms in surface phytoplankton from blooms in depth-integrated phytoplankton. Much of the support for the existing hypotheses is based on satellite measurements of surface biomass (e.g. Siegel et al., 2002), and often there has been little or no distinction made between blooms in the surface biomass from those in the depth-integrated biomass. Chiswell (Chiswell, 2011) and Behrenfeld (Behrenfeld, 2010), among others, showed that the annual cycles of surface and depth-integrated biomass can be driven by quite different processes and that it is important to distinguish between them.

We agree that we should have been clearer on what a bloom means in the context of this study. We actually do not define the bloom here with respect to phytoplankton biomass, either as a surface concentration or an integrated quantity. We simply consider that the decrease of DIC in the mixed layer, when corrected for possible contributions from air-sea exchange and mixing, is the

indication that significant net phytoplankton growth occurs, whatever may happen with the phytoplankton biomass. For instance, a passive accumulation of phytoplankton in the mixed layer caused by physical mechanisms but without significant phytoplankton growth would not have a signature on DIC and would not be considered a bloom here. On the contrary, a strong phytoplankton growth paralleled by a significantly redistribution of biomass in a deepening mixed layer could still be identified by a drawdown in DIC while there would likely be no observable increase in phytoplankton concentration.

In this study, we do not define the bloom in terms of phytoplankton biomass accumulation. We focus on the onset of the decrease of DIC in the mixed layer when biological processes are prevalent. We observe that the DIC decrease is paralleled by an increase of surface and depth- integrated chlorophyll concentration (cf the attached figure and the figure 2 in the manuscript).

 2.For surface concentration to accumulate, mixing with phytoplankton deplete waters needs to cease, which requires a change in heat flux. This indeed happens around March-April as described here, though it is not, typically, a smooth process but rather involves passages of storms.

For the 4 years, we observe that the initial decrease of DIC takes place after a storm (figures 2 and 3).

It is also a period of very rapid phytoplankton accumulation as stratification drives higher phytoplankton growth rates. For this to be the bloom initiation, one needs to define the bloom based on accumulation rate of surface concentrations being above a certain threshold.

We examine the contribution of atmospheric processes that control the decrease in DIC in the mixed layer as a response to high phytoplankton growth rates. The decrease of surface DIC is simultaneous of surface Chla increase as shown on the figure below. The maximum increase of surface Chla and depth-integrated accumulation occurs 13 days later (cf fig 2 of the manuscript). A similar observation was reported in Pelicherro et al, 2020, fig 3d and S7.

3.In todays ocean DIC dynamics are driven primarily by the solubility pump (which keeps increasing as anthropogenic CO2 is put in the atmosphere) and to a significantly lesser degree by ocean biology. Be good to provide the relative strength of each and hence the sensitivity of the DIC measurements to NPP.

Air-Sea exchange of CO_2 at the atmosphere - ocean interface controls the uptake of anthropogenic atmospheric CO_2 by the ocean. The air-sea flux depends on wind speed, gas solubility and the pCO_2 gradient between the atmosphere (pCO_2 air) and seawater (pCO_2 SW) at the ocean surface. The seasonal cycle of pCO_2 SW depends on the SST (4.2% per degree) and the biological consumption of carbon by photosynthesis (seasonal variability of the DIC). pCO_2 SW normalized at constant temperature is a proxy of DIC. It is therefore important to be able to disentangle the physical and biological factors that control the seasonal cycle of pCO_2 SW in order to constrain the implementation of these factors in models and forecasts of the evolution of anthropogenic carbon uptake by the ocean.

4.The neglect of advective effect is justified on longer time scales rather than short scales (as claimed here) as spatio-temporal scales tend to correlate in the ocean. While ML deepening is often well described as a 1-D process, restratification is most often a 2-3D process driven by horizontal gradients (e.g. papers from the MLML experiment in the N.

Atlantic, and many papers trying to use PWP model to study upper ocean dynamics). To convince one that indeed here 1D dynamics control restratification locally, such an exercise needs to be shown (e.g. PWP modeling showing that the density structure is consistent with local forcing only).

We isolated times when local physical processes were largely one dimensional to study changes in biological and chemical parameters that occurred during rapid transitions from deep mixing to intermittent stratification. In 2016, over a four-day period, March 18-21, the diurnal cycle of DIC values characterized by a maximum in the morning followed by a minimum at the end of the day indicates the onset of organic matter formation. On March 18, the decrease in DIC is accompanied by an increase of the concentration of the glider surface Chla and an increase in the average mixing layer irradiance .It is worth to underline that the surface Chla maximum does not occur until March 31, 13 days after the initial decrease in DIC. This maximum is likely to be the one detected by the satellite measurements with a binning period of 8 days.

.Figure. From March 6 to April 5, (a) DIC and Chla, (b) PAR and average mixing layer irradiance. The vertical dotted black line indicates the onset of the bloom on March 18. On (a), the purple line indicates the 3 days biological diurnal DIC changes during the period considered to compute NCP. The blue and orange lines indicate the surface Chla when the glider was at a distance of less than 5 km (blue) and less than 20 km (orange) respectively from the Boussole buoy.

5.The abstract ends with 'We estimate net daily community production in the mixing layer over periods of 3 days between 2016 and 2019 as between 38 mmol C m−2 and 191 mmol C m−2. These results have important implications on the oceanic carbon cycle and biological productivity estimates in the Mediterranean Sea in a scenario of climate-driven changes of the wind regimes.' – there no discussion of climate-driven changes of the wind regimes or the importance of the specific values reported anywhere else in the paper.

The 2nd sentence will be deleted in the abstract. We will outline that in our paper, we want to focus on the role of physical drivers to control the start of DIC decrease, and the concomitant surface phytoplankton growth which develop in shallow weak stratification of the mixed layer that appears once deep-mixing ceases.

Given given the above major issues, I am not providing minor comments (e.g. significant digits in DIC values, etc'). Those could be dealt with in future iterations.

RC3: 'Reply on RC2', Emmanuel Boss, 28 Dec 2021 reply

I would like to add that it would be very helpful, as a diagnosis, to see a time series of dDIC/dt and NCP, and, in general, time series spanning a year where possible (or at least from Nov. to May).

In our paper (Merlivat et al, 2018), we report the carbon data measured at the Boussole buoy over the period 2013-2015. We show in figure 2f the annual variation of pCO2@ 13°C which is a proxy for DIC. We observe for the years 2013-2015, that the initial spring decrease in DIC occurs in March-April, which is

in agreement with the results for the years 2016-2019.

There have been several paper comparing NCP from chemistry and from optics (e.g. from the NABE and EXPORTS experiments) and it may be useful to compare with those.

We have confined ourselves to stating the NCP values estimated at the nearby Dyfamed station based on oxygen or carbon-14 measurements at time scales of the order of months. At the present stage, we do not intend to extend the analysis of our findings by comparison with the results of experiments carried out in other oceanic environments.

Also, the labels on the left-hand side of Fig. 3 are cut

This has been corrected

Please also note the supplement to this comment:
https://bg.copernicus.org/preprints/bg-2021-315/bg-2021-315-AC2-supplement.pdf