Response to reviewer 2

We thank you very much for your constructive and relevant comments and suggestions. Below the reviews are reproduced in black font and our responses interspersed in blue and preliminary updates of the text in green.

I think that the manuscript is a useful contribution, as it applies a coupled hydrodynamic – biogeochemical model for the Gulf of Lion (NW Mediterranean) to study the current particulate organic carbon(POC) budget in this continental shelf.

The manuscript is well written and well organized. The model is clearly explained, validated, and the results and discussion are well developed (for the most part; see below). It perfectly fits within the scope of the journal, being of interest to a large group of readers.

Reply: We appreciate this overall positive assessment.

The manuscript is a significant contribution to biogeochemical modeling on continental shelves, and it has a lot of potential to predict biogeochemical – biological (production / respiration pelagic rates) conditions under future climate change scenarios. In spite of that, the authors do not explore this issue, or at least include a discussion paragraph about it in the manuscript. I think that the manuscript would greatly improve with some specific paragraph about their future modeling work, analyzing future biogeochemical consequences of climate change.

Reply: We agree with the comment of the reviewer, coupled physical/biogeochemical models are useful tools to analyse and predict the evolution of biogeochemical fluxes under climate change. The present study is a first step for further investigations of the impact of climate change on the ecosystem, biogeochemical and physical fluxes. We will extend the conclusion section to "conclusion and future works" and will add in this section a paragraph about the impact of climate change on biogeochemical implications in the Gulf of Lion and how future modelling works will help to understand those changes. The results of Herrmann et al. (2014), based on the same biogeochemical model, showed that the water warming could induce an increase in primary production at the scale of the whole northwestern Mediterranean sea under the A2 climate change scenario. Besides, Herrmann et al. (2008) showed a reduction of 90% of shelf-dense water cascading on the Gulf of Lion shelf at the end of the 21st century based on the A2 scenario, suggesting a strong decrease of POC input to the deep sea and an increase of POC transport towards the Catalan Shelf. In future works, we plan to investigate the impact of increasing temperature and stratification also predicted in more recent regional scenarios (RCP8.5 (Soto-Navarro et al., 2020) or SSP5-8.5) on the biogeochemical, physical and air-sea carbon fluxes in the shelf.

I think that the authors should contextualize their manuscript. On one hand, the authors should formulate this manuscript in the context of their own future work, as explained above. And on the other hand, the authors should put their work in the context of previous modeling efforts in the Gulf of Lion (GoL) region. I think that these two points will help to contextualize this manuscript, and to identify its novelty. As it stands right now, the manuscript could be only understood as a good modeling exercise. The authors should explain the novelty of the manuscript in the introduction section. On the other hand, the manuscript will probably benefit from integrating the modelled POC budget on the shelf with estimates from the North Western Mediterranean Open Sea obtained by previous model efforts.

Reply: We agree with the Reviewer comment that a synthesis of previous modelling studies in the Gulf of Lion was missing. We will add a paragraph on previous modelling efforts to the section "1.2 Regional settings" explaining the previous model efforts that have been made in the Gulf of Lion and point out the novelty of the present modelling study.

"Although 3D coupled physical/biogeochemical models are useful tools to analyse the POC dynamics in areas characterized by high spatial and temporal variability, studies based on those models in the Gulf of Lion at annual and shelf scale have remained scarce. Pinazo et al. (1996) investigated the influence of upwelling on primary production on the shelf under various typical wind and Northern Current conditions at a month scale, based on a model with a 4 km horizontal resolution. Tusseau et al. (1998) used a model with a resolution of 1/10° (~11 km) to estimate primary production and nitrate inputs on the shelf and in particular the shelf-slope exchanges with the open-sea, over a year. Auger et al. (2011) analysed and estimated POC deposition at the scale of the shelf over a 4-month period using a 1.5-km resolution model. Campbell et al. (2013) studied the influence of an eddy-induced upwelling on the dynamics of nutrients and phytoplankton using a realistic simulation of the year 2001 with a resolution of 3 km. Based on a coupled simulation of 17 months covering the NW Mediterranean Sea with a horizontal resolution of 1.2 km, Alekseenko et al. (2014) examined the spatial and temporal variability of the stoichiometry of the nutrients and phytoplankton in NW Mediterranean. Other high resolution (400 m) modelling studies focused on the eastern part of the shelf, in particular the Bay of Marseille, investigating the influence of Rhone river and Northern Current intrusions on nutrient and phytoplankton dynamics over the period 2007-2011 (Fraysse et al., 2013; 2014; Ross et al., 2016) and the variability of the carbonate system in 2007 (Lajaunie-Salla et al., 2021)."

Besides, as suggested by the Reviewer, we will add in the discussion section comparisons of POC fluxes on the shelf with fluxes estimated for the NW Mediterranean open-sea, in particular in the deep-convection area, in previous modelling studies (Raick et al., 2005; Herrmann et al., 2013; Ulses et al.,2016 and Kessouri et al., 2018) to discuss the fluxes on the Gulf of Lion's shelf at the scale of the western Mediterranean Sea.

Below, I make some general comments about different points of the manuscript. I believe that the manuscript will be substantially improved if the authors address those points.

GENERAL COMMENTS

It is clear that hydrodynamics processes, such as coastal upwelling, cascading, and also river input, control the POC budget in the GoL. In fact, the authors explain the seasonal variability of POC export based on these processes. Thus I would suggest that it would be interesting to include some information about the seasonality of these processes in section "1.2 Regional settings". I think that the potential reader will better understand the POC budget by indicating the seasonality of coastal upwelling, cascading, and strength of the Northern Current. On the other hand, taking into account the key role played by the Northern Current in the offshore export of POC, it would be helpful to include this current in Figure 1.

Reply: The Northern Current will be added to Figure 1. Some clarifications about the seasonality of upwelling, cascading, and flood events will be added to the section "1.2 Regional Settings".

"The Gulf of Lion is bordered on the continental slope by the Northern Current associated with the cyclonic general circulation of the western Mediterranean basin (Petrenko et al., 2008) intensified in winter (Alberola et al., 1995). The gulf is impacted by strong continental winds, which favor dense water formation and cascading events in winter (Durrieu de Madron et al., 2013), and coastal upwellings in summer (Millot, 1990; Fraysse et al., 2014). More occasionally, marine storms blowing from the east, particularly in fall and winter, induce strong along-isobath currents on the shelf, which induce powerful exports at the south-western exit of the gulf (Mikolajczak et al., 2020)."

Further details on the physical processes will be given in the new section 2.1.3 (added to answer the next question) to justify the choice of the section through which the transports are calculated.

L264- 266, Figure 7 and Figure 10. It is not completely clear which sections are considered to calculate the volume transport. How deep are the sections, only to 120m or deeper? The depth of the sections should be indicated in this part.

Reply: We will add a specific paragraph in the Method section "2.1.3 Estimation of water, nutrients and POC transport" to clarify our methodology. The flux is calculated for two layers : (1) a layer from the sea surface to 60 m corresponding roughly to the depth of the nutricline in summer (Kessouri et al., 2017) and (2) a layer from 60 m depth down to the bottom with maximum depth depending on the local bathymetry shown on Figure 1. This will be specified in the new section of the revised manuscript, as follows:

"2.1.3 Estimation of water, nutrients and POC transport

Water, nutrients and POC transport are estimated through sections that close off the Gulf of Lion shelf (see Fig. 1). The water column is each time divided into two parts, above and below 60 m corresponding roughly to the depth of the nutricline in summer (Kessouri et al., 2017). The sections are considered down to the bottom with maximum depth depending on the local bathymetry (Figure 1). The "western" section corresponds to the area known to be responsible for deep export by cascading (sometimes down to the bottom of the basin ~2500 m) during cold winters (Ulses et al., 2008c; Durrieu de Madron et al., 2013). This export is restricted to 300-400 m during mild winters and also during eastern storms, which blow predominantly in fall and produce a downwelling in the Cap de Creus Canyon (Ulses et al., 2008a; Mikolajczak et al., 2020). The other section hereafter named "eastern" for the sake of simplicity is known in the eastern part as an intrusion zone of the Northern Current (Conan et al., 1998), while in the center of the shelf, exchanges with the Northern Current have also been (more rarely) documented (Estournel et al., 2003). It is also the area where the Rhone plume most often exits the shelf under prevailing NW to N wind conditions (Gangloff et al., 2017; Many et al., 2018)."

L348 – I would indicate NEP instead of Net Ecosystem metabolism (also figure 10c).

Reply: We will replace Net Ecosystem metabolism by NEP as suggested in the manuscript and Figure 10c.

L349 - Please indicate Total Community Respiration.

Reply: "community respiration" will be replaced by "Total Community Respiration".

L 351- 353 Taking into account the important contribution of the rivers to POC delivery, I would suggest to explain the maxima of POC river fluxes of Figure 10d.

Reply: Clarification will be added to the manuscript.

"It is noticeable that while the concentration of POC in the river decreases during floods, the important volume of water delivered during such events considerably increases the input of POC to the shelf."

L343 -348 and Table 2. It is not clear the amount of remineralized organic carbon in the GoL, based on the heterotrophic respiration and the remineralization term presented in Table 2. It is not clear if this remineralization term in Table 2 only corresponds to surface sediment. In this case, it should be indicated in Table 2 legend. Besides, autotrophic and heterotrophic respiration account for more than total respiration, following Table 2. These terms must be clarified as it is kind of confusing right now.

Reply: The total respiration, i.e. 313.5 t C yr-1, in Table 2, accounts for the sum of the autotrophic respiration, i.e. 87 t C yr-1, and the heterotrophic respiration, i.e. 226.5 t C yr-1, in the water column. The remineralisation term in Table 2 corresponds to the benthic remineralisation and is not included in the total respiration. We will clarify these terms in the legend of Table 2 and detail the total respiration, by specifying autotrophic and heterotrophic respirations in Table 2 and in the revised text.

L450 "…import of nutrients on the shelf from offshore waters of 450 about 22 10^4tN yr-1 for nitrate" following Table 1, it was 22.8 10^4 tN yr-1

Reply: This error will be corrected.

L452-453 "the difference between nitrate and phosphate being explained by the very high N: P ratio in Rhone river inputs (approx. 80)". A reference of this high N:P ratio is needed here.

Reply: The value of the N:P ratio in the Rhone river inputs around 80 is based here on the in situ daily data (Mistrals-Sedoo database, http://mistrals.sedoo.fr/MOOSE/) used to force our model at the river mouth (section 2.1.2). References to previous studies (Pujo-Pay et al., 2006; Ludwig et al., 2010; Auger et al., 2011) will be added to the manuscript.

L464 -467 It is not clear the high nutrient import for the winter 2012 -13. The authors should clarify this point. This winter is not a cold winter but winter nutrient concentrations were high, and also there was an intense export of nutrients through the west.

Reply: On the Gulf of Lion's shelf the heat loss is estimated at 201 W m^{-2} for the winter 2012/13, above the average for the mean heat loss over the 5 studied years. Based on the CNRM-RCSM4 model, Somot et al. (2006) identified this winter as one of the 10 winters characterized by heat loss above average over the 33-year period 1980-2013. Moreover they found that winter 2012/13 is one of the 5 winters over the 33-year period showing high dense water formation rates in the NW Mediterranean open-sea. The intense and vertical mixing between surface water poor in nutrients and enriched deep water occurring this winter in the open-sea was responsible for a large supply of nutrients in the euphotic layer. When the deep mixing stopped in March 2013, a southeasterly storm generated a transport of nutrient-enriched offshore waters toward the Gulf of Lion's shelf. The cyclonic circulation induced by the southeasterly storm on the shelf (Ulses et al., 2008) favoured the import of those nutrients in the eastern parts in the whole water column and an export of a part of those nutrients in the western parts, as specified by the Reviewer, mainly in the deep layers. The other part of the nutrients imported during this event in the surface layer is consumed by phytoplankton. We will clarify this point in the revised manuscript.

L508: Principal components could be included in material and methods section

Reply: We understand the comment of the reviewer. However, as we use only the PC analysis shortly in the discussion and only on the NPP variability we think that it is better to describe the method in the section "5.2 Biological production".

L 543 Following Table 2, minimum POC river inputs should be 2014-15 and 2015 -16. I would say that following figure 12, minimum deposition in front of Rhone mouth should be 2014-15 and 2015 -16, and maximum 2012-13 and 2011-12.

Reply: There was an error in the main text. We apologize for this error that will be corrected in section 5.3 of the revised manuscript:

L 545 Higher anomalies of NPP were also simulated for 2012-13 (Figure 12). Could these high NPP anomalies also explain the higher POC deposition in 2012-13?

Reply: We agree with the comment of the Reviewer. The positive anomaly in NPP in 2012/13 could also explain the higher POC deposition estimated for this year. This will be mentioned in the revised manuscript.

L 600 - 601 "Rivers contribute to the POC delivery to the shelf with a mean value of 19 10^4 tC yr-1 representing 10% of the NPP, and strong changes induced by floods (72% inter-annual variability)." I would only focus on one main result here, or clarify this sentence. I would suggest to only focus on one thing, I would say the importance of POC from rivers.

Reply: We will only focus on the importance of POC from rivers vs. POC from NPP, as suggested by the Reviewer

L 564 -565 The authors indicate that the intense POC exports during winters 2011-12 and 2012-13 were favoured by the intense cascading and marine storms considering the manuscripts of Durrie de Madron et al (2013) and Bourrin et al. (2015). These references correspond to field observations collected during winter 2012 and March 2011. No other reference about the intensity of cascading and storms events are indicated for the other study years. Would it be possible to include other references with interannual data of cascading and storms events for the entire study years of this manuscript? I mean since 2011 till 2016

Reply: We agree with the comment of the reviewer. We will add a reference to the paper of Mikolajczak et al. (2020) in the manuscript as they discussed the variability of cascading and storm events over the whole period of interest, using the outputs of the meteorological model ECMWF. Based on this study, we will add a small discussion on the interannual variability of the intensity and depth of the off-shelf transport through dense shelf water cascading and storm induced circulation.

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