Seasonal dynamics and annual budget of dissolved inorganic carbon in the northwestern Mediterranean deep convection region

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Responses to the Reviewer' comments

Dear Editor,
We thank you for the consideration of the revised manuscript.
We have considered all the reviewer's comments and have addressed them point by point. Reviews are included in black font, answers in blue font and the modifications done in the revised manuscript in *italic red font*. We have also indicated the line number where the modifications have been done in the revised manuscript with track changes.

Responses to the comments of Reviewer #1

We warmly thank Reviewer #1 for his constructive comments and suggestions which help to improve the manuscript.

Review of Ulses et al. (2022): "Seasonal dynamics and annual budget of dissolved inorganic carbon in the northwestern Mediterranean deep convection region"

The new version greatly improved the ms resolving the main weak points pointed out by the reviewers. The discussion has now a wider perspective at the Mediterranean scale.
Therefore I am favourable for the publication of the ms.

We appreciate this positive general comment.

There are only a few minor points that need to be corrected or clarified:

Figure 2: Why in the scheme of the model is considered the phytoplankton deposition but not the zooplankton deposition? The zooplankton contribute to POM through faecal pellets, dead organism not only egestion why only the latter is considered? Bacteria can contribute to DOM formation through exudation, excretion, cellular lysis why these pathways are not considered in the model.

Response: The description of the dynamics of zooplankton and bacteria in the Eco3M-S model is based on the model of Anderson and Pondaven (2003), adapted in the Ligurian Sea by Raick et al. (2005). In our model, described in Auger et al. (2011), Ulses et al. (2016) and the Supplement Material in Many et al. (2021), a fraction of the food grazed by zooplankton is not assimilated, lost through messy feeding, corresponding to the breakage of preys (Anderson and Duclow, 2001) and supplies to the dissolved organic matter compartment. The term “egestion” is considered as a constant fraction of the ingested food that is released and supplied to the POM compartments; this includes faecal pellets. The flux “mortality” from the zooplankton compartment to the POM compartment (indicated by a green arrow to the left in Figure 2 diagram), corresponding to dead organisms, is also taken into account in the model.

Only particulate organic matter and micro-phytoplankton have a settling velocity. Living zooplanktons have no settling velocity as in several biogeochemical models applied in the Mediterranean Sea (for instance Levy et al., 1998; Lacroix and Grégoire, 2002; Lazzari et al., 2002; Raick et al., 2005; Palmiéri, 2014; Guyennon et al., 2015). However they indirectly contribute to POM deposition through the production of “egested” material (i.e. faecal pellets) and their mortality. Furthermore, the study of Isla et al. (2015) emphasized the importance of diel vertical migration of zooplankton in the POM export from surface to deep waters. We plan to implement this process in future works to improve the POM and zooplankton vertical distribution.

Regarding the bacteria dynamics, the excretion term in the model is a flux from bacterial to dissolved inorganic matter; cellular lysis is part of the non-grazing bacterial mortality term directed to the DOM compartment. The bacterial exudation was not taken into account in the model of Anderson and Pondaven (2003) and the adapted version by Raick et al. (2005), and was not yet added here in our model. We are conscious that the addition of this process could improve the description of the DOM dynamics and should be tested in future works.

Anderson, T.R., Ducklow, H.W.: Microbial loop carbon cycling in ocean environments studied using a simple steady-state model. Aquatic Microbial Ecology 26, 37 – 49, 2001

Anderson, T.R., Pondaven, P.: Non-redfield carbon and nitrogen cycling in the Sargasso Sea: pelagic imbalances and export flux. Deep-Sea Research I 50, 573 – 591, 2003.

Guyennon, A., Baklouti, M., Diaz, F., Palmieri, J., Beuvier, J., Lebaupin-Brossier, C., Arsouze, T., Beranger, K., Dutay, J. C., and Moutin, T.: New insights into the organic carbon export in the Mediterranean Sea from 3-D modeling, Biogeosciences, 12, 7025–7046,https://doi.org/10.5194/bg-12-7025-2015, 2015.

Isla, A., Scharek, R., Latasa, M.: Zooplankton diel vertical migration and contribution to deep active carbon flux in the NW Mediterranean, Journal of Marine Systems, 143, 86-97, https://doi.org/10.1016/j.jmarsys.2014.10.017, 2015.

Lacroix, G., Grégoire, M.: Revisited ecosystem model MODECOGeL) of the Ligurian Sea: seasonal and interannual variability due to atmospheric forcing. Journal of Marine Systems 37 (4), 229 – 258, 2002.

Levy, M., Mémery, L., and André, J. M.: Simulation of primary production and export fluxes in the Northwestern Mediterranean Sea, J. Mar. Res., 56, 197–238, 1998.

Palmiéri J.: Modélisation biogéochimique de la mer Méditerranée avec le modèle régional couplé NEMO-MED12/PISCES. Ph.D. thesis; . URL: http://www.theses.fr/2014VERS0061/document; thesis supervised by Dutay, J.-C. Bopp, L. et B., K., Sciences de l'environnement Versailles-St Quentin en Yvelines, 2014.

Raick, C., Delhez, E. J. M., Soetaert, K., and Grégoire, M.: Study of the seasonal cycle of the biogeochemical processes in the Ligurian Sea using a 1D interdisciplinary model, J. Marine Syst., 55, 177–203, 2005.

It is not clear to me the difference in the word used Transport and transfer in the figures n.7 and 11 why not to use the same transport for both vertical and horizontal exchanges?

Response: We agree with the reviewer: it is clearer to use the same term for both fluxes. "transfer" has been changed to "transport" in Figures 7 and 11.

L. 99 contribution should be "contributions"

Response: The sentence has been changed as suggested in the revised manuscript, L. 100.

L. 114. It is not clear from where the settling velocity for detritus were derived.

Response: The values of settling velocities for detritus (i.e. 1 m day^{-1} for slow sinking detritus and 90 m day^{-1} for fast sinking detritus) were based on the previous modeling studies in the northwestern Mediterranean Sea of Levy et al. (1998) (1 and 100 m day^{-1} for slow and fast sinking particles, respectively), Lacroix and Grégoire (2002) (1.5 and 95 m day^{-1} for slow and fast sinking particles, respectively), Raick et al. (2005) (1 m day^{-1} for slow sinking particles) and adapted after calibration tests. Levy et al. (1998) set the value of the settling velocity of fast sinking particles using the estimate of 92 m day^{-1} by Miquel et al. (1994) derived from sediment trap measurements in the Ligurian Sea. Their value for slow sinking particles corresponds to a medium value ranging between the settling velocity of diatoms (from 0.1 to 2.1 m day^{-1}, according to Andersen and Nival (1988)) and of small detritus (1 m day^{-1}). We have added the references in the revised manuscript, L. 115-116:

"Particulate organic detritus and micro-phytoplankton have a constant settling velocity (1 m day^{-1} for slow sinking detritus and micro-phytoplankton, and 90 m day^{-1} for fast sinking detritus, based on the modeling studies of Levy et al. (1998), Lacroix and Grégoire (2002), Raick et al. (2005) and calibration tests (Auger et al., 2011; Kessouri et al., 2017))."

Andersen, V., Nival, P.: A pelagic ecosystem model simulating production and sedimentation of biogenic particles: role of salps and copepods. Mar. Ecol. Prog. Ser., 44, 37–50, 1988.

Miquel, J.-C., Flower, S. W., La Rosa, J., Buat-Menard, P.: Dynamics of the downward flux of particles and carbon in the open Northwestern Mediterranean Sea. Deep-Sea Res., 41, 243–262, 1994.

L. 311-312. The authors should add the increase of temperature to the other factors (oligotrophy, high stratification and domination of respiration) to explain the summer drop of pHT. Moreover the authors could better explain the effect of high stratification to the variation of pH.

Response: The increase in temperature and weak vertical mixing in summer induce a high stratification that causes oligotrophy near the surface. These conditions favor a prevalence of respiration over photosynthesis, and thus a production of DIC that induces a drop in pH. We have realized that this sentence was not clear. We have modified it and, as suggested by the reviewer, we have added the increase of temperature to explain the drop of pH in summer, in line with the previous study of Hagens and Middleburg (2016) who calculated the contribution of temperature, dissolved inorganic carbon, total alkalinity and salinity in pH variation (L. 313-315):

"The pH_T seasonal variation in observations, simulation and CANYON-MED results all indicate a drop in summer, ~~reflecting a period of oligotrophy, high stratification, and domination of respiration over photosynthesis according to the study of Kessouri et al. (2018)~~ mostly due to the increase in temperature (Hagens and Middleburg, 2016)."

Hagens M., Middleburg J.J.: Attributing seasonal pH variability in surface ocean waters to governing factors", Geophysical Research Letters, 43, 12528–12537, 2016.

L.405- "physical supplies" do the authors mean "physical transport"?

Response: Yes. "physical supplies" has been replaced by "physical transport", L. 407 and also L. 31-32.

L. 417 I suggest changing vertical and horizontal exchanged transports with "vertical and horizontal exchanges" and in the following line change "transfer" with "transport"

Response: We have made the suggested modifications L. 419-420, and also L. 459.

L. 470-471. "The loss of DIC by physical fluxes resulted from a loss by lateral transport and a gain through upward transport." To make the sentence more understandable I would suggest to write "from a prevalence of the loss through lateral transport with respect to the gain through the vertical transport"

Response: The sentence has been changed as suggested L. 472-473.

L. 563. A reference about the POC:PIC ratio could be added.

Response: The reference for the mean, minimum and maximum POC:PIC ratios, Miquel et al. (2011), has been added L. 564 and 565.

L. 677-683. The huge difference of the contribution to the Mediterranean DIC outflow should be discussed.

Response: In this study we estimated a lateral DIC flux of 109 and 73 Tg C yr^{-1} in the surface (surface to 150 m) and intermediate (150 m to 800 m) layers, respectively, from the deep convection area to the surrounding area. We compared these fluxes with the DIC inflow and outflow estimates at the Gibraltar Strait by Aït-Ameur and Goyet (2006). Based on cruise DIC measurements and on previous estimates of water mass transport at the Gibraltar Strait, they obtained a DIC inflow from the Atlantic Ocean in the surface layer ranging between 660 and 1310 Tg C yr^{-1}, and a Mediterranean DIC export towards the Atlantic Ocean at the intermediate depths, ranging between 680 and 1380 Tg C yr^{-1}. The large range in their DIC flux estimates can be explained by the high discrepancies between the mass transports estimates used in their calculations. The upper range values are based on the estimates of water mass inflow and outflow by Béthoux (1979) of 1.7 Sv and 1.6 Sv, respectively. These values are twice as high as the estimates of 0.81 Sv and 0.76 Sv for the inflow and outflow, respectively, by Baschek et al. (2002), from which Aït-Ameur and Goyet (2006) derived the low values of the DIC fluxes. The review study of Jordà et al. (2017) found a mean value of the previous estimates derived from observations of 0.86 ± 0.1 Sv and 0.80 ± 0.08 Sv, closer to the lower estimates of Baschek et al. (2002).

The DIC fluxes that we estimated from the surface and intermediate layers of the deep convection area towards the adjacent area represent between 8 and 22% and between 5 and 11% of the DIC inflow and outflow at the Gibraltar Strait, respectively, estimated by Aït-Ameur and Goyet (2006). The high values of these percentages derived from the low water mass transport estimates appear more reliable according to the synthesis study of Jordà et al. (2017). As suggested by Reviewer #1, we have added a discussion on this aspect in the revised manuscript, L. 686-693:

"The large discrepancy found here in the percentages of DIC fluxes at Gibraltar Strait that DIC outflows from the deep convection area represent, is due to the large range in the DIC flux estimates at the Gibraltar Strait found by Aït-Ameur and Goyet (2006). This latter discrepancy is in turn explained by the large range in the estimates of water mass transport used in their computations, which can be attributed to the complex topography and strong tidal currents at the Strait (Jordà et al., 2017). In their synthesis study on the exchanges at the Gibraltar Strait, Jordà et al. (2017) found a mean value of the water flux estimates based on observations close to those proposed by Baschek et al. (2002), from which Aït-Ameur and Goyet (2006) derived the lower values of DIC fluxes. This suggests that the higher percentage values that we calculated would be more reliable."

Baschek, B., Send, U., Garcia-Lafuente, J., Candela, J.: Transport estimates in the Strait of Gibraltar with a tidal inverse model. Journal of Geophysical Research 106, 31033–31044, 2002.

Jordà, G., Von Schuckmann, K., Josey, S.A., Caniaux, G., García-Lafuente, J., Sammartino, S., Özsoy, E., Polcher, J., Notarstefano, G., Poulain, P.-M., Adloff, F., Salat, J., Naranjo, C., Schroeder, K., Chiggiato, J., Sannino, G, Macías, D.: The Mediterranean Sea heat and mass budgets: Estimates, uncertainties and perspectives, Progress in Oceanography, 156, 174-208,https://doi.org/10.1016/j.pocean.2017.07.001, 2017.

L. 753-755. It is confusing to compare the exchanges also with the Eastern Mediterranean, which would be the pathway of these exchanges.

Response: We agree that the sentence was confusing. We have changed this sentence L. 765-766, as well as the last sentence of the abstract L. 35-36, as follows:

"The transfer of DIC into the adjacent surface and intermediate water masses could mitigate the atmospheric CO_2 uptake also in the surrounding open sea of the sub-basin, and represent ~~contribute~~ up to 22 and 11~~0 and 220~~%, respectively, of ~~to~~ the DIC exchanges with the ~~Eastern Mediterranean and~~ Atlantic Ocean at the Strait of Gibraltar."

L. 827. In the reference of Catalano the authors should add et al. as not alL the coauthors are cited.

Response: We apologize for this oversight. We have corrected the reference, L. 840-842.

In the references check the subscripts for CO2.

Response: We have corrected the subscripts for CO_2 in the references, L. 801-1110.