Biogeosciences Discussions

Biogeosciences Discuss., referee comment RC1
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Comment on bg-2021-301

Anonymous Referee #1

Referee comment on "Acidification, deoxygenation, and nutrient and biomass declines in a warming Mediterranean Sea" by Marco Reale et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-301-RC1, 2021

The authors projected the climate change-related impacts in the marine ecosystems of the Mediterranean Sea in the middle and at the end of the 21st century using an offline coupling model combining the physical model MFS16 and the transport-reaction model OGSTM-BFM, under emission scenarios RCP4.5 and RCP8.5, focusing on the middle and the end of 21st century. Projected changes are presented for temperature, salinity, dissolved nutrients and oxygen, net primary production, respiration, organic matter, plankton and bacterial biomass, particulate organic matter, and biogeochemical parameters (DIC, pH).

The paper provides interesting projections in a changing Mediterranean Sea that is already under multiple pressures. Please check below my major and minor comments:

Major comments:

P3, L75: No, not “all” the modelling studies focused on high emissions scenarios. For example, there is Benedetti et al. (2018) who used A2, A1B and B1, and Goyet et al. (2016) who used B1 and A1F1.

- Benedetti, F., Guilhaumon, F., Adloff, F. and Ayata, S.-D. (2018), Investigating uncertainties in zooplankton composition shifts under climate change scenarios in the Mediterranean Sea. Ecography, 41: 345-360. https://doi.org/10.1111/ecog.02434
- Goyet, C., Hassoun, A., Gemayel, E., Touratier, F., Abboud-Abi Saab, M. and Guglielmi, V., 2016. Thermodynamic forecasts of the mediterranean sea acidification. Mediterranean Marine Science, 17(2), pp.508-518. Thermodynamic Forecasts of the Mediterranean Sea Acidification | GOYET | Mediterranean Marine Science (ekt.gr).

Goyet et al. (2016) is the only modelling study that it is projecting carbonate system parameters in the Mediterranean Sea so far, and the one used in MedECC (2020 ; cited by the authors to tackle OA projections in the Mediterranean). Yet, it is not mentioned at all in this work. Please check this study out and try to compare your results with theirs.

P3, L78-79: The authors mentioned that Moullec et al. (2019), under RCP8.5 emission scenario, found an increase in both phytoplankton biomass and net primary production by the end of the 21st century. However, this pattern is not homogenous in the Mediterranean since Moullec et al. (2019) have also highlighted a difference between the Eastern and Western basins with an increase in the first and a decrease in the second. Please edit accordingly.

P4, L111-113: In addition to the BOUM mesoscale experiments working on relating eddies with biogeochemical changes (BG - Influence of anticyclonic eddies on the Biogeochemistry from the Oligotrophic to the Ultraoligotrophic Mediterranean (BOUM cruise) (copernicus.org)), there are actually many modelling studies, for example:

- Ramirez-Romero E, Jordà G, Amores A, Kay S, Segura-Noguera M, Macias DM, Maynou F, Sabatés A and Catalán IA (2020) Assessment of the Skill of Coupled Physical–Biogeochemical Models in the NW Mediterranean. Front. Mar. Sci. 7:497. doi: 10.3389/fmars.2020.00497
- Guyennon, A., Baklouti, M., Diaz, F., Palmieri, J., Beuvier, J., Lebaupin-Brossier, C., Arsouze, T., Béranger, 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.
- Herrmann, M., Somot, S., Sevault, F., Estournel, C., and Déqué, M. (2008), Modeling the deep convection in the northwestern Mediterranean Sea using an eddy-permitting and an eddy-resolving model: Case study of winter 1986–1987, J. Geophys. Res., 113, C04011, doi:10.1029/2006JC003991.

Therefore, I would suggest to re-write this paragraph.

P8, L263-266: To characterize the spatial distribution and the variability of anomalies, the authors considered their horizontally averages in each sub-basin in the Western Mediterranean (WMED=(ALB+SWM+NWM+TYR)/4) and in only two sub-basins of the Eastern Mediterranean (EMED=(ION+LEV)/2). Why did you exclude the Adriatic and the Aegean Sub-basins here?

P9-10, L306-315 & Fig. 2: The authors mentioned that mean simulated values in the first 0-200 m are quite realistic in all the variables, and that biases started to show at 600 m depth. However, the vertical profiles show such discrepancies between CTRL average profiles and observational data (EMODnet) even in shallower depths, i.e. less than 50 m for phosphate in the WMed., surface waters for nitrate in the WMed., greater than 200 m

for oxygen, and so much general biases in pH. Could you please elaborate more on this?

P11, L326: Could you explain in the text the depth classification adopted in this study: 0-100 m and 200-600 m?

P12, L342-358: Is it possible to check if those differences are significant or not?

P20, L476: Please explain briefly the role of "damping effect" in controlling oxygen values at the Gibraltar Strait?

P24, L565-566: I guess you are talking here about the "projected" change not the "observed" change. In any case, I would suggest to better re-write this sentence.

P29, Fig.16: Captions on the plots should be corrected to distinguish between its different components (a-f), as well as between the locations (Med., WMed., EMed.).

In section 2, authors refer to alkalinity (ALK) in the text (i.e. L188). Do you mean by this term, the number of moles of hydrogen ions equivalent to the excess of proton acceptors (bases formed by weak acids) over proton donors (acids) in a kilogram of sample? Mostly yes, and this term should be labeled total alkalinity (DOE, 1994): TA = [HCO3-] + 2[CO32-] + [B(OH)4-] + [OH-] – [H+]. Moreover, except for figure 2 for the period 2005-2020, there is no results about ALK in the following sections. Why?

The term "tracers" is usually used for conservative elements that can be traced in function of time. It is not the appropriate term for the carbonate system parameters, such as TA, DIC or pH. Please refer to them as biogeochemical parameters/features/properties but not tracers.

Minor comments:

Please write the E and W in Eastern and Western in capital letters, and unify this in the text.

While I would suggest to add "sub-basin" to any sub-entity in the Mediterranean (i.e. Alboran Sub-basin, Levantine Sub-basin, etc.), it is OK to use "sea" instead like many other publications (i.e. Adriatic Sea, Aegean Sea). However, I would recommend the

authors to unify the terms adopted throughout the manuscript since they use "Adriatic Sea and Levantine basin", why? Also, sometimes you refer to the Gulf of Lion as Gulf of Lions (i.e. L445). Please rectify and unify this in the ms.

Please make *italic* the "a" in Chl.*a* throughout the text.

Please write "time-series" instead of "timeseries" throughout the entire manuscript (as you have already done it in L502).

Abstract:

P1, L16-18: Please write it as follows "The analysis shows significant changes in the dissolved nutrient content of the euphotic and intermediate layers of the basin, of the net primary production, phytoplankton respiration and carbon stock (including phytoplankton, zooplankton, bacterial biomass and particulate organic matter)."

P1, L20: Please avoid using personal pronouns. The sentence can be written as follows "Moreover, an acidification trend (signal) was observed in the upper water column…".

P1, L22-23: Please write it as follows "The projected changes are stronger in the Eastern Mediterranean due to the limited influence of the exchanges in the Strait of Gibraltar in that part of the basin."

Introduction:

P1, L31: These are some key references (Lascaratos, 1993; Nittis and Lascaratos, 1998) but they are old. I would suggest to also add newer ones, i.e.

- Fedele, G., Mauri, E., Notarstefano, G., and Poulain, P. M.: Characterization of the Atlantic Water and Levantine Intermediate Water in the Mediterranean Sea using Argo Float Data, Ocean Sci. Discuss. [preprint], https://doi.org/10.5194/os-2021-68, in review, 2021
- Fach, B. A., Orek, H., Yilmaz, E., Tezcan, D., Salihoglu, I., Salihoglu, B., & Latif, M. A.

(2021). Water mass variability and Levantine Intermediate Water formation in the Eastern Mediterranean between 2015 and 2017. Journal of Geophysical Research: Oceans, 126, e2020JC016472. https://doi.org/10.1029/2020JC016472

- Velaoras, D., Papadopoulos, V.P., Kontoyiannis, H., Cardin, V. and Civitarese, G., 2019. Water masses and hydrography during April and June 2016 in the cretan sea and cretan passage (Eastern Mediterranean Sea). Deep Sea Research Part II: Topical Studies in Oceanography, 164, pp.25-40.

P1-2, L41-42: These are some key references but they are old. I would suggest to also add newer ones, i.e.

- For Marine heatwaves: Ibrahim, Omneya, Bayoumy Mohamed, and Hazem Nagy. 2021. "Spatial Variability and Trends of Marine Heat Waves in the Eastern Mediterranean Sea over 39 Years" Journal of Marine Science and Engineering 9, no. 6: 643. https://doi.org/10.3390/jmse9060643
- For Med. droughts: Mathbout, Shifa, Joan A. Lopez-Bustins, Dominic Royé, and Javier Martin-Vide. 2021. "Mediterranean-Scale Drought: Regional Datasets for Exceptional Meteorological Drought Events during 1975–2019" Atmosphere 12, no. 8: 941. https://doi.org/10.3390/atmos12080941

P3, L75: Please remove “thus far”.

P3, L97: I would suggest to replace “provide” by “sustain”.

P3, L74-97: There are some missing articles in this section. For example, Howes et al. (2015) also derived the same conclusions using the RCPs 4.5 and 8.5. There is also Macias et al. (2018) who used two different global circulation models (GCMs; equivalent to RCP4.5 and RCP8.5), and other studies.

- Herrmann, M., Estournel, C., Adloff, F., and Diaz, F. (2014), Impact of climate change on the northwestern Mediterranean Sea pelagic planktonic ecosystem and associated carbon cycle, J. Geophys. Res. Oceans, 119, 5815– 5836, doi:10.1002/2014JC010016.
- Howes EL, Stemmann L, Assailly C, Irisson JO, Dima M, Bijma J, Gattuso JP (2015) Pteropod time series from the North Western Mediterranean (1967-2003): impacts of pH and climate variability. Mar Ecol Prog Ser 531:193-206. https://doi.org/10.3354/meps11322
- Macias, D., Garcia-Gorriz, E. and Stips, A. (2018), Major fertilization sources and mechanisms for Mediterranean Sea coastal ecosystems. Limnol. Oceanogr., 63: 897-914. https://doi.org/10.1002/lno.10677

P3, L99: Please write “All the above-mentioned works…” instead of “All of these previous works…”.

P4, L112: Please write “non-living” instead of “nonliving”.

Data and methods:

P6, L184: Please write “non-living” instead of “nonliving”. And edit it through the entire text.

P6, L187: Please write “physico-chemical” instead of “physical-chemical”.

P6, L191-192: Please pay attention to the subscripts throughout the manuscript, i.e. $CaCO_3$

P7-8, section 2.4: The subscripts are sometimes too small to read. Please rectify it.

Results:

P8, L284: It would be helpful to add the ranges, SDs, maybe in a table. What are the precisions of T and S derived from this model?

P10-11, L317-322, Fig. 2:

- I would recommend to add the Chl-*a* unit on the next to the bar dedicated for a & b.
- Also add the unit of the depth, on the profiles or the caption.
- You need to add in the caption that the vertical profiles are shown for the Mediterranean scale, Western Mediterranean, and Eastern Mediterranean. This was not mentioned in the corresponding text as well.
- Please write the unit appropriately for “μmol kg^{-1}” in the caption as well as throughout the ms.

P11, L338: Please add “such as…” instead of “as…”.

P12, L354-355: Please make it clearer, i.e. General freshening of the upper layers and saltening of the intermediate layers are observed over the entire basin during the MID-FUTURE period (Fig. S3 in the supplementary materials).

P13, L382: Please edit: "Only for the Aegean Sea, the changes in the winter mixed layer maximum depth are less marked, …".

P14, Fig. 4: Please correct the presentation of scenarios in the plots: RCP 4.5 and 8.5 instead of RCP 45 and 85.

P14, L404: Please delete both "the" in "the nutrients at the river mouths."

P16-17, Fig. 5-6: Please add the unit on both color bars. Please correct the presentation of scenarios: RCP 4.5 and 8.5 instead of RCP 45 and 85.

P18, L445-449: Please try to make this sentence clearer, i.e. Between 2055 and 2075, the peak in both nutrients' concentration, for RCP4.5, timely corresponds to a peak in the inflow of nutrients at the Gibraltar strait (Fig. S7). Additionally, in both scenarios the intermediate layer of the Western basin, after 2035, experiences a negative tendency in the nutrient concentration which is greater than 0.01 mmol m^{-3} for PO_4 and 0.1 mmol m^{-3} NO_3, this is related to a reduced westward transport of nutrients associated with LIW (Fig.S5).

P20, L479-80: Please add references here.

P20, L484: Please correct "in vertical processes' intensity".

P21, L489: Do you mean "in both basins"? Please correct.

P21, Fig. 9: Please correct the presentation of scenarios: RCP 4.5 and 8.5 instead of RCP 45 and 85.

P21, L498: Please remove "the" from "both the scenarios".

P21, L499: Please add a “,” after scenario.

P22, L508: Please add a “,” after scenarios.

P22, L514: Please add a “,” after scenario.

P22, L519: Please add a “,” after scenarios.

P23, L526, Fig.11: Please add the unit on both color bars. Please correct the presentation of scenarios: RCP 4.5 and 8.5 instead of RCP 45 and 85. Please unify the term “Mid-FUTURE” in the captions and the plots.

P23, L535: Please write it “parts of the Levantine basin”.

P23, L538: Please add a “,” after FUTURE.

P24, L562: Please keep either “of approximately” or “of about”.

P26, L580: Please add a “,” after FUTURE.

P27, Fig. 14: Why did you choose the abbreviation BACTC to bacterial biomass? It is not conventional. I would suggest to make it “BACT”.

P27, L592: Please remove the “,” after also, and add it before “the decline”.

P28, L616-617: The influence of the air-sea CO2 exchanges on DIC concentrations in the Mediterranean were already highlighted in multiple studies, i.e.

from models

- D'Ortenzio, F., Antoine, D. and Marullo, S., 2008. Satellite-driven modeling of the upper ocean mixed layer and air–sea CO2 flux in the Mediterranean Sea. Deep Sea Research Part I: Oceanographic Research Papers, 55(4), pp.405-434.

for observations

- Wimart-Rousseau, C., Lajaunie-Salla, K., Marrec, P., Wagener, T., Raimbault, P., Lagadec, V., Lafont, M., Garcia, N., Diaz, F., Pinazo, C. and Yohia, C., 2020. Temporal variability of the carbonate system and air-sea CO2 exchanges in a Mediterranean human-impacted coastal site. Estuarine, Coastal and Shelf Science, 236, p.106641.
- Hassoun, A.E.R., Fakhri, M., Abboud-Abi Saab, M., Gemayel, E. and De Carlo, E.H., 2019. The carbonate system of the Eastern-most Mediterranean Sea, Levantine Sub-basin: Variations and drivers. Deep Sea Research Part II: Topical Studies in Oceanography, 164, pp.54-73.
- De Carlo, E.H., Mousseau, L., Passafiume, O., Drupp, P.S. and Gattuso, J.P., 2013. Carbonate chemistry and air–sea CO 2 flux in a NW Mediterranean bay over a four-year period: 2007–2011. Aquatic geochemistry, 19(5), pp.399-442.

P28, L620: Please replace "fairly" by "equal".

P28, L621: Please replace "consistently".

P28, L625: Please remove "than in".

P30, L649: Please remove the "s" from "produces".

P30, L651: Please correct the subscript in "pCO_2".

P30, L654-655: Please re-write, i.e. "consistent with the estimates of Solidoro et al. (2021)."

P30, L657-658: Do you mean "by the end of the 21st century for RCP8.5?". Please rectify.

P31, Fig.17: Please write the unit appropriately for "µmol kg^{-1}" in the caption. Please correct the presentation of scenarios: RCP 4.5 and 8.5 instead of RCP 45 and 85.

P31, L673-674: I would recommend to also check Goyet et al. (2016), as the pattern of your results are somehow in harmony.

P31, L675: I would suggest to mention "by the end of the 21st century for RCP8.5" or "by the end of the century for RCP8.5".

P3, L682-684: Please unify the term "Mid-FUTURE" in the captions and the plots.

Discussions and conclusions:

P33, L689: Please add a "," after "In this study".

P33, L693: Please add a "," after "To the best of the authors' knowledge".

P33, L693-696: Please re-write this sentence taking into consideration the major comments above.

P33, L718: Please remove the "s" at the end of "shows".

P35, L768-769: This sentence is important for coastal ecosystems, and needs thus better elaboration, and references too.

P35, L771-772: The exchanges via the Strait of Gibraltar are surely crucial, but there are other factors that should be taken into consideration such as the difference in the ventilation period between both basins, among other factors (i.e. Pujo-Pay et al., 2011; Álvarez et al., 2014; Stöven and Tanhua, 2014; Cardin et al., 2015; Hassoun et al., 2015; Goyet et al., 2016; etc.).

- Álvarez, M., Sanleón-Bartolomé, H., Tanhua, T., Mintrop, L., Luchetta, A., Cantoni, C., Schroeder, K., and Civitarese, G.: The CO2 system in the Mediterranean Sea: a basin

wide perspective, Ocean Sci., 10, 69–92, https://doi.org/10.5194/os-10-69-2014, 2014.

- Cardin, V., Civitarese, G., Hainbucher, D., Bensi, M., and Rubino, A.: Thermohaline properties in the Eastern Mediterranean in the last three decades: is the basin returning to the pre-EMT situation?, Ocean Sci., 11, 53–66, https://doi.org/10.5194/os-11-53-2015, 2015.
- Goyet, C., Hassoun, A., Gemayel, E., Touratier, F., Abboud-Abi Saab, M. and Guglielmi, V., 2016. Thermodynamic forecasts of the mediterranean sea acidification. Mediterranean Marine Science, 17(2), pp.508-518.
- Hassoun, A.E.R., Gemayel, E., Krasakopoulou, E., Goyet, C., Abboud-Abi Saab, M., Guglielmi, V., Touratier, F. and Falco, C., 2015. Acidification of the Mediterranean Sea from anthropogenic carbon penetration. Deep Sea Research Part I: Oceanographic Research Papers, 102, pp.1-15.
- Pujo-Pay, M., Conan, P., Oriol, L., Cornet-Barthaux, V., Falco, C., Ghiglione, J.F., Goyet, C., Moutin, T. and Prieur, L., 2011. Integrated survey of elemental stoichiometry (C, N, P) from the western to eastern Mediterranean Sea. Biogeosciences, 8(4), pp.883-899.
- Stöven, T. and Tanhua, T.: Ventilation of the Mediterranean Sea constrained by multiple transient tracer measurements, Ocean Sci., 10, 439–457, https://doi.org/10.5194/os-10-439-2014, 2014.

P35, L778: Please also compare it with Mediterranean projections (i.e. Goyet et al., 2016).

P35, L790-792: Is it possible to estimate these uncertainties? It would be great to mention the level of overestimation derived from the model compared to the present conditions.

P35, L794-801: A recent study by Gazeau et al. (2021) is a good fit in this section as well, as it highlights the potential impact of aerosol deposition (dust in this case) both in present and future climate conditions in the Mediterranean.

- Gazeau, F., Ridame, C., Van Wambeke, F., Alliouane, S., Stolpe, C., Irisson, J.-O., Marro, S., Grisoni, J.-M., De Liège, G., Nunige, S., Djaoudi, K., Pulido-Villena, E., Dinasquet, J., Obernosterer, I., Catala, P., and Guieu, C.: Impact of dust addition on Mediterranean plankton communities under present and future conditions of pH and temperature: an experimental overview, Biogeosciences, 18, 5011–5034, https://doi.org/10.5194/bg-18-5011-2021, 2021.

P36, L826: Please write it “such as”.

Supplementary document:

Fig. S2: Please add the temperature unit on both color bars (°C). Please correct the presentation of scenarios: RCP 4.5 and 8.5 instead of RCP 45 and 85. Please correct "blue" instead of "blu".

Fig. S3: Please correct the presentation of scenarios: RCP 4.5 and 8.5 instead of RCP 45 and 85.

Fig. S4: Please correct the presentation of scenarios: RCP 4.5 and 8.5 instead of RCP 45 and 85. Please correct "blue line" instead of "blu line".

Fig. S8: Please add the unit on both color bars. Please correct the presentation of scenarios: RCP 4.5 and 8.5 instead of RCP 45 and 85.

Fig. S9-14: Please add the unit on both color bars. Please correct the presentation of scenarios: RCP 4.5 and 8.5 instead of RCP 45 and 85.

Fig. S14: Why are you mentioning the DIC unit in ug kg^{-1} here while it is in μmol kg^{-1} in the text? Please adopt the second one.