Manuscript Reference No.: bg-2020-457
Biogeosciences Discuss., https://doi.org/10.5194/bg-2020-457-RC1, 2021
Title: "Pelagic primary production in the coastal Mediterranean Sea: variability, trends and contribution to basin scale budgets" by Paula Maria Salgado-Hernanz et al. 2021.

==============================

Response to Interactive Discussion Referee #3. 1st revision (20-02-2021):

Dear reviewer, we would like to thank you the interest you have shown in our study and therefore consider it as suitable for publication in Biogeosciences with some modifications. We then proceed to and answer your comments:

Response to comments Referee #3:

#3.1: Lines 89-102: Are satellite data (chl, sst etc.) used at daily frequency? In the paper the authors cited monthly or 8days means but in this paragraph there is not any reference. Could you clarify?

We recognize the text was misleading regarding the resolution of the different products. We have added further details about the remote sensing data and its processing methodology in section 2.1 Remote sensing data in the Materials and Methods section.

- Surface chlorophyll (**Chl,** in mg C m^{-2}) data, was downloaded for the specific Mediterranean Sea reprocessed Level-3 surface chlorophyll concentration 1-day and 1-km product obtained from the EU Copernicus Marine Environment Monitoring Service - CMEMS (OCEANCOLOUR_MED_CHL_L3_REP_OBSERVATIONS_009_073, (http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=OCEANCOLOUR_MED_CHL_L3_REP_OBSERVATIONS_009_073 - CMEMS (copernicus.eu)). The specific dataset name was 'dataset-oc-med-chl-multi-l3-chl_1km_daily-rep-v02' and the variable used was 'mass_concentration_of_chlorophyll_a_in_sea_water (CHL)' in a NetCDF-4 Classic model file format.
- Sea Surface Temperature (**SST**, in ºC) data, we used the Level-2 SST at 1-day and 1-km from every available orbit from Moderate Resolution Imaging Spectroradiometer (MODIS) aboard satellites Terra and Aqua, downloaded from the National Aeronautics and Space Administration (NASA). Then, every orbit was averaged and projected onto the 1km^2 working grid (https://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sub=level3&per=CU&day=18693&set=10&ndx=0&mon=18659&sen=amod&rad=0&frc=0&dnm=D@M&prm=SST).
- Photosynthetically Active Radiation (**PAR**, in E m^{-2}) was obtained as a Level 3 product at 9 km, the best available resolution from the NASA archive from both MODIS and Medium Resolution Imaging Spectrometer (MERIS). Data was downloaded by the browser (https://oceancolor.gsfc.nasa.gov/l3/).

All satellite-derived variables were remapped onto a **regular 1-km spatial grid** over the Mediterranean Sea area (-6 to 37º E et 30 to 46º N) by averaging all available pixels within each grid cell. This was made at daily resolution for the time period 2002-2016. This lead to a considerable huge matrix of 529,226 grid points or pixels x 5,479 time steps. The time resolution resulted in 15 years * 365 days = 5475. As there were 4 leap years (2004, 2008, 2012, 2016), time resolution was 5479.

Further explanations regarding calculations performed to run the PP model are given in ***#3.3:***

#3.2: Line 106: "*Only values at depths exceeding 5 m depth were considered…*" is there any reference for this assumption? As you know the layer that could influence remote sensing measurements depends on the sea water bio-chemical conditions. Based on my experience I believe that satellite measurements could be influenced by the bottom seagrass also for depths greater than 5 m. Maybe the authors could investigate, in some way, in order to give to the reader an idea of how much final results could be influenced by this issue.

We considered that 5m depth was a reasonable value to avoid interference by bottom seagrasses reflectance or extreme coastal regions. We recognize that some pixels at the bottom boundary may be affected by seafloor reflectance but, in most cases, this should only represent a small fraction of the 1x1 km pixel signal.

#3.3: Line 130: Is PP estimated on daily satellite images? Graphics and images in the paper show monthly data. Could the authors describe the exact technique used? Did they average input satellite data (i.e. CHL, sst, PAR etc.) and then compute PP? Or did they computed PP on daily satellite data and then averaged PP data?

We acknowledge that this was not clear. PP calculation was performed every 7 days (starting at day 4), using the averaged Chl for a 7-day window from day-3 to day+3 and for 1 grid point out of 3. Therefore, PP model was run with 8-days resolution and for 1 pixel out of 3 pixels. Later, PP data was interpolated to 1-day 1-km grid. In some cases -e.g. Fig 6-, monthly PP data and its anomalies were derived from the above mentioned dataset to be able to correlate PP values with the climatic indices NAO and MOI, and SST values.

#3.4: Line 152-155: this point could also be investigated analyzing the mixing layer depth of the study area. Probably the chlorophyll uniform profile assumption may not be wrong in many cases, but having an idea of where this assumption is wrong could help to better understand the results of the study.

Given the variability in coastal waters, we consider that this is a better assumption that using global parameterization of the shape of the vertical profile as a function of the surface Chl obtained from deep open ocean waters. Assuming a homogeneous profile will bias the calculations in offshore boundary of the shelf, particularly during summer conditions when the contribution of the DCM is not accounted for. We state this now in the M&M section.

#3.5: Line 169-170: Please define exactly how you computed annual PP (PP). Afterwards, in the text, the authors analyze the results for ΣPP, PPannual, PPVOLannual, etc. but I cannot find any definition of these parameters. I think it is crucial to define exactly the quantities used in the analysis.

A new Table 1 has been added clarifying the different definitions of PP that we use

Table 1. Primary production acronyms used in this study, their units and definitions.

Variable	Units	Definition
P	mol C m^{-3} s^{-1}	Instantaneous production at each depth (*z*) of the water column.
PP	gC m^{-2} d^{-1}	Daily primary production per surface unit. Integration of P over depth and daylength.
PP_{annual}	gC m^{-2}	Annual mean production per surface unit.
ΣPP	GtC	Total carbon fixation per year within a basin or specific region.
PP_{VOL}	gC m^{-3}	Mean volumetric PP. Averaged form the surface to the bottom depth or productive layer
PPnew	gC m^{-2}	New production (i.e from alochtonous sources)
PPreg	gC m^{-2}	Regenerated production.

#3.6: Line 179-180: has this alongshore regionalization been done with SOM (or other technique), or has it been done by the authors observing the results of the SOM regionalization?

This alongshore regionalization in 18 zones (Z1-Z18) has been performed observing the results of the temporal patterns observed father the SOM regionalization (R1-R9). SOM aggregates the characteristic temporal patterns according to their similarities. In section 2.3 Coastal regionalization we quote, line 18-190 "*Then, 18 alongshore marine ecoregions were obtained considering the most relevant cross-shore limits of the SOM-derived regions (Z1 to Z18).*"

#3.7: Line 217-218: How did the authors deseasonalize the data?

Time series were de-seasonalized by removing the 8-days means for the original 8-days time series. It has been added to the manuscript section 2.5. Statistical analysis as ". *Time series were de-seasonalized by removing the 8-days climatological mean for the original time series".*

#3.8: Line 226: Is annual carbon fixation per surface area the PP daily average multiplied by 365? If no, how is it estimated?

That is correct. The original PP data was in day units, therefore we multiply it by 365 to obtain annual values.

#3.9: Line 237-239: from tab 1, annual carbon fixation is quite similar between eastern and western subbasins. Since the area of east shelf is about twice of west shelf, it is obvious that the eastern annual integrated PP is approximately double of the west sub-basin. On the other hand, it is not absolutely obvious why the "productivity per unit volume" of eastern compart is more than double of the western one (and even higher than the Adriatic Sea). I'm a little bit surprised…

We agree. Averages are in this case misleading because distributions are not normal. In some shallow and highly productive regions this is particularly notable. In the case of PP (gC m^{-2}; see figure 1a) this compensated by the integration depth and, thus, the weight of these pixel, although relevant, is less critical than in PP(gC m^{-3}, Fig 1b) where the influence of vertically averaging just over few surface values exacerbates the differences with overall values. As shown in Fig. 1b, due to the lack of large shallow and productive areas, there are few values above 30 (gC m^3) in the Western Med, whereas high PP is more frequent in the Adriatic (red) and in the Eastern Med (blue). If the pixels with values >30 gC m^3 are plotted (Fig 2.) it becomes evident that most of them are located in shallow waters of the Gulf of Gabes and in the Nile delta, and less so, in the northern Adriatic. To avoid these problems, we refer now to median values in Table 2, yet mean values are still provided as a reference.

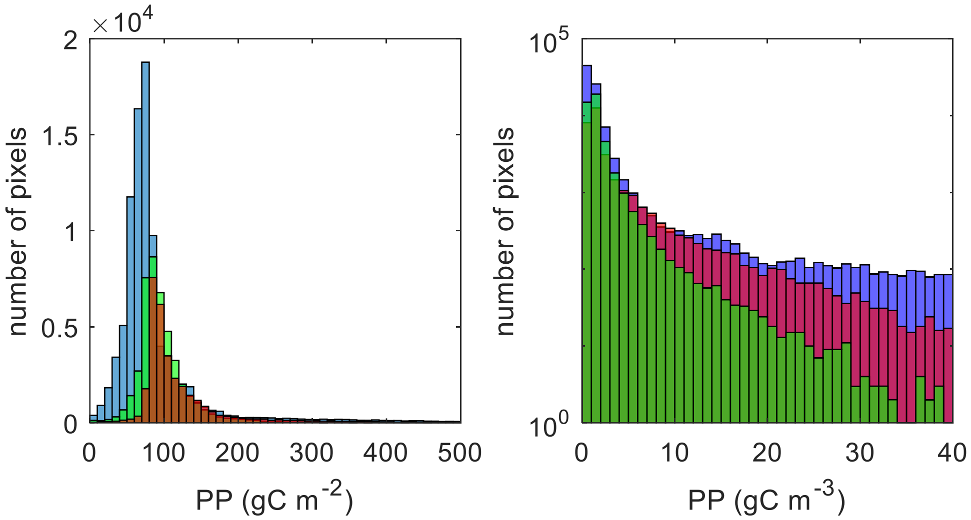

Fig. 1 Frequency histograms for a) Integrated and b) vertically averaged PP estimations. Blue (East Med.) green (West Med), red (Adriatic). Y-axis in fig 1b is logarithmic.

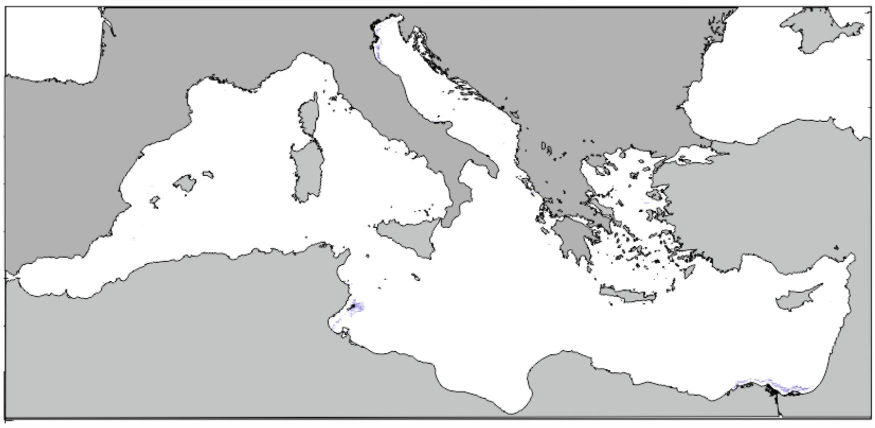

Figure 2. Map showing the location of the pixels with values >30 gC m^{-3} in blue.

#3.10: Line 239-241: I suggest starting the sentence by citing the figure you are referring to instead of citing it at the end.

This change has been performed.

#3.11: Line 243. "*…the coefficient of variation of primary production (CVPP)…*" how did you calculate this coefficient? Defining this "coefficient of variation of primary production" would also clarify why there are 2 different "coefficient of variation of primary production", one in figure 2c and another in figure 3b.

The Coefficient of Variation is a typical dispersion measurement defined as Standard Deviation / Mean.

#3.12: Tab 1: Could you please insert the exact reference (product ID as for satellite daily data described above) for the 8-days e 4km resolution data taken from CMEMS? I cannot find them. Why is *** only for “Mediterranean Sea”? shouldn’t it also be on “Open ocean waters”?

It has been added now in the manuscript the specific product ID and variable used for the analysis. In In section 2.1 – Remote sensing data, it stands: “*The dataset name was ‘dataset-oc-med-chl-multi-l3-chl_1km_daily-rep-v02’ and the variable used was ‘mass_concentration_of_chlorophyll_a_in_sea_water (Chl)’, obtainable in a NetCDF-4 file format.*”

As for the second question, we used ** for data that we took from Table 2. We used *** for data that we estimated using our coastal results added to the open waters results that we obtained in the literature. We clarify now:

*** PP estimated by averaging published satellite data shown in Table 2.*

**** ΣPP estimated adding coastal waters data from this study to open ocean waters data taken from Table 2.*

#3.13: Line 290-291: How did you estimate this interannual variability?

This value of interannual variability was calculated using the formula (PP max – PP min/ PP average) * 100. A PPtot value was calculated for every year. Then, the minimum value is subtracted from the maximum value and divided by the average.

#3.14: Line 298-299: How did you calculate the “the filtered low frequency signal” for PP and CHL?

First, we calculated the anomalies of the total monthly PP (ΣPP) for each of the 180 months between January 2002 – Dec 2015. Then, we used the *smooth* function of Matlab applying the *sgolay* filter with a span degree of 17 to the anomalies of the total PP. This sgolay filter uses the Savitzky-Golay method with the polynomial degree specified by degree. In the case of Figure 4, we were using monthly data (in total 180 time steps) for each region (a-whole Mediterranean coast, b-western coast, c-eastern coast, d- Adriatic coast) to visualize PP variability and trends. To filter the low frequency signal, we used a span degree of 17. This degree was therefore filtering about 8 months before and after every time step (about 1.5 years). Some proofs were doing using a degree of 29 (2.5 years low signal) or 59 (5 years low signal).

#3.15: Line 306-307: “Most of these regions presented declining PP trends…”. This sentence does not seem so evident observing fig 5a. The only evident negative trend is in the Gulf of Gabes as underlined by the authors. Moreover I believe that fig 5a and graphs in fig4 are quite inconsistent. In fig 4 trends are negative for Mediterranean Sea, west and east sub-basin, while for Adriatic Sea there is no evident trend. From fig 5a I’d say that on average Mediterranean Sea trend is quite positive (red areas are greater than blue ones). For west and east sub-basin the negative trend shown in fig 4a is not so evident, especially for the eastern compart. About Adriatic Sea fig 5a shows a clear positive trend. Could the authors explain this apparently discrepancy and how a reader should interpret it?

We recognize that, despite being different estimations, Figure 4 and Figure 5 could be misleading. Figure 4 showed a regional trend based on annual data (one mean value per year). This was higly influenced by the decline in PP observed in year 2012. Hence, we decided to provide only the trend obtained with the complete time series, as shown in Fig. 5. This issue was also addressed in ***#1.17***.

#3.16: Fig 6: line 324: it is not specified (here or in the text) what blue lines meaning. Are they annual PP anomalies?

This figure shows the relationship between coastal pelagic PP and SST, NAO and MOI. Blue lines indicate the global PP monthly anomalies for the whole Mediterranean Sea, whereas red lines indicate the SST monthly anomalies, NAO or MOI indices respectively. Blue lines are the same in Fig 6a-c. It has been indicated in Figure 6a caption: "*Figure 6: Relationship between coastal pelagic primary production (ΣPP anomalies, blue lines) and a) SST anomalies, b) NAO index and c) MOI index (red lines*")

#3.17: Line 327-336: R1 to R9 are represented in fig 7 as PP in gC m^{-2} d^{-1}, but in tab 3 there are mean annual PP values. Again, it should be defined how you estimate mean annual PP starting from daily PP.

The SOM analysis was performed using the original PP time series in gC m^{-2} d^{-1}. The patterns that we obtained are shown in Fig. 7. In order to provide mean values for the different regions, we give information of the mean annual values in gC m^{-2} y^{-1}. To be consistent with the rest of the analysis and to obtain mean values of PP at every area.

#3.18: Line 392: "…whereas Case-2 waters are reduced to less than 5% of the whole basin.". Is there any reference for this statement?

In the manuscript we provided some references "*Indeed, previous studies agreed that Indeed, Case-1 waters are largely predominant in the coastal Mediterranean regions whereas Case-2 waters are reduced to less than 5% of the whole basin (Antoine and André, 1995; Bosc et al., 2004; Bricaud et al., 2002). In particular, they are confined to the north Adriatic Sea, Gulf of Gabes and around Nile delta where our PP estimations may present larger uncertainties (Antoine and André, 1995).".*

We obtained that value of about 5% from the literature. Bricaud et al. (2002) *explained in section 2.1. Computation of PP: "On these maps, Case 2 waters were identified by discarding the pixels where R(555) was > 0.025 (see Bricaud & Morel, 1987), and an ''average mask'' was selected. The corresponding area was 5% of the total area of the Basin, which is close to the estimate (4%) provided by Antoine et al. (1995). Although it is acknowledged that the extension of Case 2 waters may vary throughout the year, the use of such a constant mask (instead of a temporally variable mask) allows the spatial means of chlorophyll concentration (or primary production) to be computed over a fixed area, and therefore to be comparable from month to month. The same average mask was used for".*

Bosc et al. (2004) also use this value: "*The Mediterranean is particularly well adapted to ocean color studies as the conditions of observation are optimal (low cloudiness), and also because turbid-case 2 waters, where the interpretation of ocean color is complex, are here of marginal areal extent, covering less than 5% of the whole basin [Antoine et al., 1995]."*

Antoine and André (1995) specify "*Turbid case 2 waters are particularly extensive in the Adriatic Sea, covering about 25% of the basin area. Moreover*". Also: "*This procedure also allows turbid case 2 waters to be identified and thereafter discarded (black mask in images). They cover about 3.5% of the entire eastern Mediterranean, mainly located in the north Adriatic Sea, in the Gulf of Gabes, and around the Nile delta*.". In this article, they published a Table where they provide information about the area excluding case 2 waters for the subprovinces of the Adriatic, Aegean, Ionian, North Levantine, South Levantine and Total Mediterranean Sea.

ANTOINE ET AL.: PRIMARY PRODUCTION IN THE MEDITERRANEAN SEA 16,197

Table 2. Sea Surface Covered by Each of the Five Provinces Defined in the Present Work

	Subprovince					
	Adriatic	Aegean	Ionian	North Levantine	South Levantine	Total
Area, 10^{12} m^2	0.134	0.193	0.773	0.244	0.336	1.68
Percentage of whole eastern Mediterranean	8	11.5	46	14.5	20	100*
Area excluding case 2 waters, 10^{12} m^2	0.100	0.192	0.760	0.241	0.330	1.62

*The eastern basin contributes to 67.4% of the whole Mediterranean area.

#3.10: Fig 8: Caption of the figure refers to another type of figure (seasonal PP). Fig 8a has a different color palette (and range) with respect to other 2 (b and c) images.

We apologize for the mistake. The figure caption has been corrected by "*Figure 8. a) ef-ratio in coastal waters (<200 m) of the Mediterranean Sea and estimated values of b) new (PPnew) and c) regenerated production (PPreg). Mean values for the period 2002-2016*."