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Associate Editor

Biogeosciences

Dr. Ny Riavo G. Voarintsoa

Subject: revised version of MS bg-2020-336.

Dear Dr. Voarintsoa:

We submit the revised version of your manuscript bg-2020-336. We have endeavored to deal with all the issues raised by both Anonymous Referees. Following both reviews, several changes were made to the text, figures, and tables. We have now uploaded all the final point-by-point reply to the comments of both referees, the marked-up manuscript version (changes made to text are written in red), and the revised files. In addition, we have included following major changes:

(1) Following the suggestion by Referee 1, a new table has been added (now Table 2). This table present yearly fluxes of diatoms.
(2) As part of the statistics performed, we added a new Figure (now Fig. 5=correlogram).
(3) Following Referee 2's and your own comments late Oct, we discuss the possible impact of the North Atlantic Oscillation (NOA). This is now addressed in l. 409-426.

We greatly appreciate the helpful reviewers' insights and your comments last October. We hope that this revised version will merit your positive consideration and the editorial requirements of *Biogeosciences*.

Best regards,

Oscar E. Romero
on behalf of co-authors

A two-decades (1988-2009) record of diatom fluxes in the Mauritanian coastal upwelling: Impact of low-frequency forcing and a two-step shift in the species composition (bg-2020-336)

Authors = Oscar E. Romero, Simon Ramondenc and Gerhard Fischer

Final response to Referee 1's comments

As required by BG, the response to the Referees is structured in the following sequence: (1) comments from Referee 1 (RC1) and (2) *authors' comments (AC)*.

Comments from Referee #1

RC1: Line 25: Please include AMO between brackets the first time it is mentioned in the text.
AC: This has been corrected (l. 25).

RC1: Line 91: I believe authors could go a little bit further and state that this is the longest diatom time series sediment trap record of the world's ocean.
AC: the sentence has been rephrased (l. 88-89).

RC1: Material and methods Line 105 Since there are several gaps in the sediment trap record, authors could provide the number of days sampled during the 19-year record (i.e. the proportion of days sampled versus the total number of days). This would help the reader to have a better idea of the gaps in the record.
AC: this is now mentioned in l. 104-106.

RC1: Line 108: Authors should be more specific and specify the depth range of the position of the sediment traps during their study in the text (i.e., not only in Table 1).
AC: the depth range of the traps is now included in the revised version (l. 109-110).

RC1: Line 111. While I agree with this statement, there were two mooring deployments with sediment traps deployed at 700 m and therefore their collection efficiency could have been compromised. Since the collection interval of one of these deployments coincided with an strong ENSO event, it is important that authors discuss in the text the possibility of collection efficiency issues during these intervals.
AC: This issue is now addressed in l. 465-474.

RC1: Line 156. Could authors provide annual diatom valve estimates for the years with the most complete records? Even a rough estimate of the annual fluxes at this site would be useful for the specialized reader in order to be able to compare the diatom fluxes of this site with other regions of the global ocean.
AC: this helpful suggestion of R1 is now addressed in l. 187-290. We present the new Table 2 which contains yearly fluxes of total diatoms for 13 calendar years. We believe that a table showing the yearly fluxes will be more useful for other scientists than an additional figure.

RC1: Results - Could authors provide a rough estimation, i.e. average daily and/or annual fluxes, for radiolarian and silicoflagellates fluxes? This would help the reader to understand the contribution of both groups in relation to diatoms. Also, as mentioned before, I would suggest to provide annual estimates in order to facilitate the comparison of the diatom valve fluxes of this site with other regions of the global ocean.
AC: although we agree that fluxes of silicoflagellates and radiolarians can be of interest for scientists working on marine siliceous plankton, we emphasize that the focus of our long-term trap record is on the diatom fluxes and the species-specific composition of the assemblage. There is also a methodological aspect to

consider: the use of permanent slides for diatom and silicoflagellates census does not allow the proper quantification of radiolarian skeletons. Due to the low volume used in the preparation of the permanent slides for diatom counts, the low absolute concentration of radiolarian skeletons is too low for reliable radiolarian census.

RC1: Please avoid the use of acronym TDF, i.e. write the name in full.
AC: The acronym is now avoided and the full name (=total diatom flux) is used throughout the MS.

RC1: 266 "the highest"
AC: The sentence has been rephrased and reads now: "Fluxes in spring and summer show the highest amount of above-the-average total diatom concentration." (l. 282-283).

RC1: 367 "concluded"
AC: the sentence has been corrected to: "Using observational data and model experiments, Wang and Zhang (2013) concluded…" (l. 394-395).

RC1: Line 385 Please specify/repeat when this change occurs here.
AC: the corrected sentence reads now: "An extraordinary feature of the multiyear dynamics of diatom populations at the CBmeso site is the sharp shift in the species contribution in May and 2002 (Fig. 2b)." (l. 424-425).

RC1: Line 429 "5.1.2 The occurrence of the strong 1997 ENSO and the response of the diatom community off Mauritania" The intense ENSO event registered by the traps coincides with the use of sediment trap record collected at substantially shallower depth than most of the other deployments. According to Table 1 the sediment trap from deployment "CBmeso8 upper" was placed at around 700 m while most of the traps used in the experiment were placed at > 3000 m (with some exceptions). The collection area of the shallower sediment trap and collection efficiency of the "CBmeso8 upper" could be different than the other records, and therefore it could have affected the composition of the diatom assemblage collected during this interval. Authors should discuss this point in the text.
AC: this issue is now addressed in l. 465-474. We believe that the strong resemblance in the species-specific composition of the diatom assemblage of both traps (highest contribution of diatoms associated with waters of moderate to low nutrient content), without any significant percentage shift, delivers sound evidence on the reliability of the diatom data at CB8 and CB9. Fischer et al. (2019, Global Biogeochemical Cycles, 33, 1100, https://doi.org/10.1029/2019GB006194) previously argued that the collection area of the lower CBmeso trap is larger that the one of the upper. Only when the chlorophyll filament extends further out of the Mauritanian coast, particles reach also the upper traps.

RC1: Line 455 Authors could also cite the possible impact of strong ENSO events on the Mediterranean diatom fluxes as reported by Bárcena et al. (2004) and Rigual-Hernández et al. (2013).
AC: Both articles are discussed in the revised version. (l. 506-507).

RC1: Figure 4. The graphs in this figure are too small for proper visualization. Please increase the size of the graphs.
AC: the revised version includes a larger and better resolved file of Figure 4.

A two-decades (1988-2009) record of diatom fluxes in the Mauritanian coastal upwelling: Impact of low-frequency forcing and a two-step shift in the species composition (bg-2020-336)

Authors = Oscar E. Romero, Simon Ramondenc and Gerhard Fischer

Final response to Referee 2's comments

As required by BG, the response to the Referees is structured in the following sequence: (1) comments from Referee 2 (RC2) and (2) *authors' comments (AC)*.

Comments from Referee #2

RC2: (Frankcombe et al., 2010) with the presented dataset the authors can only check on how major shifts between positive and negative states of AMO, occurred within the period of this record, affect the Canary Upwelling system, but not its fully and longterm effect on the system. However, the NAO index of atmospheric circulation over Europe has a periodicity in the order of 7-8 years (Knut Lehre Seip et al., 2019) and the work of (Yamamoto and Palter, 2016) shows a clear relation between the NAO and the AMO, with northerly winds associated to a positive state of AMO and zonal winds to a negative state of AMO. As such, it would be interesting to verify the relation of your data with NAO variability, since upwelling is indeed a response to an atmospheric process. It would also have been nice to have a comparison with the upwelling index or northerly wind strength. Maybe through another statistical approach, something like cross-correlation?

AC: We now provide an additional analytical test that supports our previous interpretations (correlogram, now Figure 5). We performed a correlation analysis with samples' score resulting from CA (Dim.1, Dim.2 and Dim. 3, which discriminates the diatom communities), climatic indexes (ENSO, NAO, AMO), diversity index (Shannon diversity) and fluxes (total diatom flux, freshwater diatom flux, Opal flux). As suggested by Reviewer 2, the correlogram shows a significant negative relationship between AMO and NAO. However, the goodness of fit between these climatic indexes was rather low (R^2 around 0.2). The correlogram also shows that the samples' score of first CA axis (Dim. 1, which discriminates the benthic from the other diatom groups) seems also impacted by the NAO, although with an exceptionally low R^2. However, the statistical tests (clustering, boxplot and the Kruskall Wallis approach) performed in the first submission do not show any relationship between diatom groups and the NAO. Conversely to the correlogram, our statistical approach analyses each community independently and does not compare one group with the others. Although both statistical approaches are correct, we believe that the correlogram method could induce some misunderstanding, leading to a certain degree of overestimation of NAO impact. We therefore conclude that AMO have a stronger impact on diatom communities off Mauritania than NAO has. However, we comment on the possible impact of NAO on the diatom community at site CBmeso and discuss the publications suggested.

RC2: On which respects the effect of warming climate on the upwelling system and its primary production, you depart from the different conclusions reached by different studies, as presented in your introduction, to the proposal that your data is a different way of approaching the question. However, you conclude that your diatom data might be instrumental in distinguishing between climate-forced and intrinsic variability of the population of primary producers.

I have trouble with this statement, intrinsic variability is related to the basic needs of the organisms, so they will most probably change in function of the changes imposed on the system both by global and regional processes that in the end will also react to climate forcing!

AC: this sentence has been rephrased as follows: Our 1988-2009 data set contributes to distinguish the impact of low-frequency climate forcings in the northeastern Atlantic and will be especially helpful for establishing the scientific basis for forecasting and modelling future states of the Canary EBUE and its decadal changes. (l. 36-39)

RC2: Furthermore, although it is important to understand the process behind your stunning increase in benthic diatoms, your record does not allow you to verify what happens in terms of the plankton production and assemblage evolution during this 20yr. Or does it? Can you deduce the effect of the benthic flux that obscures the total record, and explore the 20yr variability of the planktonic diatom flux and assemblages 'composition that reach the trap?
AC: It is true that the dramatic shift in the species-specific composition of the diatom assemblage in May 2002 does not imply any dramatic change in the absolute values of the total diatom concentration nor it translated into any significant changes of the biogenic silica (=opal) fluxes (see also Romero et al., 2017, Prog. Oceanogr. 159, 131). This observation also matches previous work at site CBmeso (Fischer et al., 2016, Biogeosciences 13, 3203).

RC2: There is a general problem with the way references are listed in the text they do not follow an alphabetical order nor the year of publication.
AC: The citation of articles and book chapters follow BG Instructions to Authors. We checked throughout and corrected when necessary.

RC2: What is the reason to use the term pelagial rather than pelagic? Although used for lakes I have not seen any paper that defends/justifies its use for the ocean environment.
AC: this has been rephrased throughout the revised MS.

RC2: The use of satellite images (composites for the n_ of years considered for each specific time interval / diatom phase) for comparison would also be important to verify the variability on the surface water and upwelling conditions.
AR: three pictures of chlorophyll a *concentration have been added to Figure 1. They depict the average concentration of chlorophyll* a *for winters 1997, 2002 and 2008, gained with SeaWIFs (for 1997) and MODIS (https://oceancolor.gsfc.nasa.gov/cgi/l3, details will be provided in the revised version of the MS). The high interannual variability is clearly seen.*

RC2: Different depths of trap deployment at some time intervals (Table 1) may influence the diatom assemblage encountered as a result of a different catching area and the different contribution of particles transported by intermediate nepheloid layers. This needs to be acknowledged and discussed especially because one of the periods coincides with the ENSO period.
AC: This issue -also raised by R1- is addressed in the replies to Referee 1's comments.

RC2: Are you assuming that the intensification of the shelf and slope poleward current favors an increase in production of the benthic community and maintenance of the means of downslope transport, or the existence of a stronger poleward current gives rise to a stronger suspension of the benthic forms and their downslope transport in higher quantities? This needs clarification and discussion.
AC: The occurrence of benthic diatoms in the hemipelagic CBmeso trap represents a lateral transport signal. It is well-known that the dynamic Mauritanian coastal waters serve as a jet for cross-shelf particle transfer and it produces sporadic particle clouds, which are advected hundred kilometers offshore within intermediate and bottom-near nepheloid layers (Nowald et al., 2015) toward the hemipelagic of the low-latitude NE Atlantic (Fischer and Karakaş, 2009). Subsurface waters (200 to 300 m depth) might be the place of mixing processes of older, laterally-advected materials from the shelf by giant filament activity, with relatively fresh material derived from the open ocean surface (Fischer et al., 2009). In addition to the nepheloid layer-mediated transport, the dynamics of water masses related to the existence of the canyon system off Mauritania might have contributed to the enhancement of transport from shallow water upon the trap site CBmeso. We speculate that the dramatic increase of benthic diatoms in the hemipelagic environment might be due to the intensification of the shelf and slope poleward transport upon deeper waters. Cross shelf particle transfer is not only restricted to the CC-EBUEs but is a general feature of these ecosystems (e.g. in the Californian EBUE, e.g. Barth et al. 2002, JGR 107)

RC2: Pg. 3, Ln. 78 – The authors suggest that a different approach for the characterization of multiyear to interdecadal upwelling intensity in EBUEs is by assessing fluxes of particulates and microorganisms as captured by continuous sediment trap experiments."

AC: a vast majority of the previous studies on the long-term variability of productivity and upwelling intensity along the north-western African margin follows different approaches than the one of our study. Approaches previously used for the characterization of interannual upwelling variations mainly are velocity and directions of winds, annual wind stress, and Ekman transport. By stating that "A different approach for the characterization of multiyear to interdecadal trends in EBUEs is assessing fluxes of particulates and microorganisms as captured by continuous sediment trap experiments" (l. 77-79)*, we emphasize the fact that observational data based on interannual trap experiments are rare and represent a different approach to the study of possible links between variability of the microorganisms community, upwelling variations and the impact of low-impact climate and oceanographic forcing.*

RC2: Although you can assume that the flux of planktonic organism blooming in surface waters as a result of upwelling intensity, we are also aware that the nutrient content of the upwelling water is determinant for the size of the blooms as well as for the type of phytoplankton community. As such, bloom size and consequently microorganism fluxes could also reflect shifts in the upwelling source water associated with latitudinal shifts for example, rather than variations in upwelling intensity.

In fact, in this study besides the physical setting it is important to also consider the chemical (nutrient) and biological setting.

AC: it is true that the occurrence of diatom populations (or those of any other organisms) at the CBmeso site is the result of the interaction of several processes acting in different timescales. The fact that the shift in the species-specific composition of the diatom assemblage in May 2002 is not paralleled by either an increase or decrease of total diatom and/or biogenic silica flux suggests that the intensity of upwelling per se did not significantly changed, nor an increase in DSi availability occurred after May 2002 in waters overlying site CBmeso.

RC2: Pg. 6, Ln. 103 – The SACW occurs in layers between 100 and 400 m depth at the Banc d'Arguin and off Mauritania.

AC: the sentence has been corrected (l. 205-206).

RC2: Pg. 8, Ln 250-252 – ENSO appears to be modulated by AMO, check Levin et al, (2017) or Chen et al., 2019 or Zhang et al., (2019).

AC: Levine et al. (2017) and Zhang et al., (2019) are discussed in the revised version.

RC2: Pg. 9. Ln. 301 – 302 – The list of species presented do correspond to marine plankton forms that although not thriving in the highly productive and colder coastal upwelling systems, and more likely to be found in warmer waters, they are also not characteristic or real oligotrophic waters.

AC: in addition to other peer-reviewed publications, we base the grouping of diatom species found in the CBmeso trap samples on our almost 20-year continuous research of the temporal dynamics of diatom populations and their biogeographical occurrence. Throughout the years, we have learnt that the species listed as 'open-ocean taxa' are typical of ocean waters of low content of dissolved silica (DSi). From this point of view, we are confident in characterizing the open-ocean diatoms (as listed in Table 3 of our MS) as typical of oligotrophic waters. Other studies along the western African margin have used the same species characterization as we do here (Nave et al., 2001; Abrantes et al., 2002; Crosta et al., 2012).

RC2: Pg. 10, Ln. 323- 324 - The impact of the environmental variables on diatom communities was investigated by simple comparison using the samples clustering and the forcing values associated (Fig 4). You are not using the forcing values, but rather the value of an index that is considered to define the

coherent mode of natural variability occurring in the north Atlantic. Changes in this mode will have an impact on the circulation at your study site and be considered a forcing factor for your specific process.
*AC: We agree with Referee 2 in that we used climate indexes, which is a proxy of the direct environmental forcing. We did not use highly-resolved environmental data (*e.g.*, DSi content) because they are not available for the complete time series.*

RC2: Pg. 10, Ln. 329 – Please specify tendency of the gradient.
AC: it has been re-phrased and reads as follows: In addition, a gradient in the Shannon diversity index of the diatom populations (Fig. 4c) is observed with predominant low values (1.7-2.5) corresponding to benthic (=group 4), intermediate values (2.7-3) for coastal planktonic (=group 3) and high values (3.1-3.45) in samples dominated by coastal upwelling and open-ocean populations (=groups 2 and 1) (pairwise Wilcoxon rank sum test; p-value<0.05). (l. 352-356)

RC2: Pg. 10, Ln. 335 – Mentioned figure should be included as a supplementary figure.
AC: Figure 3 highlights our statistical approach to define which diatom communities dominate our samples and the time series of their respective dominance instead of doing it visually. Since this figure is also causally related to Figure 4, we do believe that Figure 3 should be kept as part of the MS figures and does not need to be transferred to Supplement.

RC2: Pg. 10, Ln 337 - the benthic diatom *D. surirella* decreased the diversity, although it also seems to be promoted determined by AMO strengthening. In the same way, the second CA axis samples scores are positively correlated with TDF, which confirms that coastal upwelling diatoms seems to promote define the TDF.
AC: it has been re-phrased and reads as follows: 'Given that the first CA is positively driven by the benthic group, this confirms the outstanding dominance of the benthic diatom D. surirella *after May 2002, which also appears linked to the strengthening of AMO. In the same way, the second CA axis is positively correlated with total diatom flux also confirms that coastal upwelling diatoms deliver large numbers to the total diatom valves.' (l. 377-379)*

RC2: Pg.11, Ln 352 - Based on outstanding shifts in the species-specific composition of the diatom assemblage occurred throughout the study interval (Fig. 2b).
AC: it has been re-phrased and reads now: 'Based on outstanding shifts in the species-specific composition of the diatom assemblage occurred throughout the study interval (Fig. 2b), we propose three main intervals in the multiyear evolution of populations and discuss them in view of mayor environmental forcings:...' (l. 377-379)

RC2: Pg. , Ln. 360 - Based on the long-term trends of our data and their statistical analysis (Figs. 2-5), we suggest that the proposed intervals were the response of the diatom populations to the impact of low frequency forcing on the Canary upwelling system. To be correct, the upwelling system is the one that responds to the low frequency forcing. Diatom assemblages reflect hydrographic and nutrient availability brought up by the upwelled source waters.
AC: It is true that the upwelling in the Canary EBUE responds to low-frequency climate impact. By studying the diatom populations, we did not, however, directly characterize long-term variability of upwelling intensity off Mauritania as studies quoted in the Introduction of our first submitted version did (l. 66 th 77). Therefore, we believe that the sentence as written is correct.

RC2: Figure 4: Comparison of (a) clusters extracted from multivariate analysis with the environmental forcing variables (a1: Total diatom flux; a2: AMO; a3: Shannon diversity). Besides being too small and difficult to see, total diatom Flux and Diversity are not forcing variables. They all reflect the community adaptation to the regional conditions resulting from the forcing factor(s).

AC: it has rephrased (l. 348-350). NAO, AMO, ENSO and the diversity index Shannon-Weaver are indices while the total diatom flux is a variable. This was wrongly described in the original submission. The file resolution of Fig. 4 will be enlarged.

RC2: References
Chen, S., Song, L. & Chen, W.: Interdecadal Modulation of AMO on the Winter North Pacific Oscillation-Following Winter ENSO Relationship. Adv. Atmos. Sci. 36, 1393– 1403, 2019. https://doi.org/10.1007/s00376-019-9090-1
Frankcombe, L. M., Heydt, A. v. d., and Dijkstra, H. A.: North Atlantic Multidecadal Climate Variability: An Investigation of Dominant Time Scales and Processes, Journal of Climate, 23, 3616-3638, 2010.
Levine, A. F. Z., M. J. McPhaden, and D. M.W.Frierson: The impact of the AMO on multidecadal ENSO variability, Geophys. Res. Lett., 44, 3877–3886, 2017. doi:10.1002/ 2017GL072524.
Knut Lehre Seip, Øyvind Grøn and Hui Wang: The North Atlantic Oscillations: Cycle Times for the NAO, the AMO and the AMOC. Climate, 2019, 7, 43; doi:10.3390/cli7030043
Yamamoto, A. and Palter, J. B.: The absence of an Atlantic imprint on the multidecadal variability of wintertime European temperature, Nature Communications, 7, 10930, 2016.
Zhang, W., X. Mei, X. Geng, A. G. Turner, and F. Jin: A Nonstationary ENSO– NAO Relationship Due to AMO Modulation. J. Climate, 32, 33–43, 2019. https://doi.org/10.1175/JCLI-D-18-0365.1.
AC: we are grateful for these references. Most of these publications are now discussed in the revised version (l. 244-254 and l. 409-423).