

Interactive comment on “What drives the spatial variability of primary productivity and matter fluxes in the North-West African upwelling system? A modelling approach and box analysis” by Pierre-Amaël Auger et al.

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Summary

The paper of Auger et al. analyses in detail the North-West African upwelling region through a physical-biogeochemical model and largely contributes to a better understanding of the seasonal variability and spatial distribution of phytoplankton biomass and production for this area. It gives a good description of most processes responsible for transporting nutrients and phytoplankton, as well as an indication of the dominant processes between local phytoplankton growth, lateral transport or regenerated pro-

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duction. The used model has the advantage of allowing separation of processes that are normally difficult to detach one from another. For example, it differentiates the effect of lateral advection from that produced by the general ocean circulation or vertical mixing. Furthermore, it allows separation between local new production and lateral phytoplankton transport. When compared to satellite observations, the model gives an accurate surface ocean circulation and chlorophyll distribution, which are used to validate the model. Interestingly, they find that nutrient upwelling, despite being significant in the entire upwelling system, is not always the dominant process for sustaining primary productivity. Instead, lateral transport of nutrients and phytoplankton appear to be the dominant process in most of the studied subregions, with an important southward-alongshore and cross-shore advection off the Saharan Bank and south of Cape Blanc, respectively, as well as an intrusion of nutrient-rich waters from the offshore Guinean upwelling to the Senegalo-Mauritanian subregion.

Recommendation

This paper adds important information about relevant mechanisms influencing primary production in the North-West African upwelling region, which is one of the most productive marine ecosystem, but also poorly understood. In this regard, the paper of Auger et al. gives new insights on how and why primary productivity varies temporally and spatially in this region. The paper is well written, with clear figures and well organized. Therefore, I highly recommend it for publication in Biogeosciences, after minor corrections.

General comments

This paper has a very complete model analysis of all major processes affecting primary productivity and nutrient transport. The only major critique I have is that the authors should have made more comparisons between their model results and actual observations or other model results. I realize that there is not so much published data from this region, however, from this paper it is not always clear, especially in the discussion

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section, what is known, what is new, what was previously suggested and what was confirmed by their model results. Nevertheless, with some rephrasing and addition of visual comparison where possible, this should be easy to improve.

Major and specific comments

1) Figure 1: Why not add a figure comparing model and measured data for nitrate in, for example, surface waters? Besides chlorophyll and surface currents, there is not much comparison with observations, which would add robustness to the model results.

2) Section 3.1.1, lines 15-16: The sentences "Offshore transport of nitrate... cross-shore velocities" do not really fit this paragraph because they describe the nutrient behavior while the paragraph is about ocean circulation. They should be moved to line 23, before "Vertical (upwelling-induced) nitrate supply...". Then, remove "(see above)" and add (Fig. 3d) at the end of "cross-shore velocities".

3) I think it will be nice to indicate somewhere (for example in section 3.1.1, end of line 6) that negative velocities indicate outside transport (out of the box) while positive values indicate inward transport (inside the box). Am I correct? If this is the case, what does negative advection mean in bottom waters?

4) Section 3.1.2 (page 7 and 8): This section is a bit difficult to follow due to its structure. Why not start this paragraph with the description of Figures 3e-h and then introduce Figures 4 and 5? So mainly move "Off Cape Blanc, phytoplankton biomass...(Fig. 3d)." to the beginning of the paragraph. Then continue with "Phytoplankton biomass, averaged over ... (Fig. 3a)." and then focus on PP. In this case, I would plot figure 4c (phyto) in position 4a, figure 4a (PP) in position 4b and figure 4b (f-ratio) in position 4c. For consistency, I would also rename the title of the section as: "Phytoplankton biomass, primary production and phytoplankton fluxes". Perhaps. the paragraph will then need some rephrasing.

5) Figures 7 and 13 are very similar and it takes some time to understand their main

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differences, as well as why both are relevant. It will be good to stress out more the differences and mention why both are relevant to this work. It is also not very clear why the spring average is now more relevant than the annual average, and why spring more than other seasons (i.e. besides being the most productive, what are the advantages to show spring processes?).

Is there a way to combine these 2 figures and their respective descriptions in a summary section?

6) Section 3.2.1, line 32: What does "vertical velocities are pointing downward" mean in this context?

7) Section 3.2.2, lines 20-25: Is there any other model or measurement data also showing the strong diffusion in this region? It would be nice to compare these results to published data or at least mention how reliable these results are.

8) Section 4.1, lines 10-16 (page 14): Same as comment 7. Is there any model or measurement data to compare these results to?

9) Section 4.3, line 18 (page 17): Are the results of intrusion of nutrient-rich waters in the Senegalo-Mauritanian region in agreement with Lazaro et al., 2005 and Mittelstaedt, 1991? If so, it will be good to specify it: "originating from the Guinean upwelling. This is in agreement with previous finding of Lazaro et al., 2005 and Mittelstaedt, 1991." How do the results of Lazaro et al., 2005 and Mittelstaedt, 1991 compare to those of this paper?

10) Figure 14: Could these model parameters be compared to measurements, other model results or a theoretical average?

11) Section 3.2.2 starts with "Annual mean PP", but it should be "Spring average PP ...", I think.

12) Section "Discussion", line 11: This comment relates to point 5). Because it is not really mentioned before, I would shortly indicate, at the end of this paragraph, why

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spring processes are analyzed.

13) Section 4.1, line 22 (page 13): "Therefore it gives us confidence..." how much confidence? Some, good, very good...? I would indicate it here.

14) Section 4.1, line 23 (page 13): "For this latter purpose, we further ..." This sentence does not really explain in what way the analysis of seasonal cycles at the edge of the coastal boxes will add confidence to the model. Especially because these sensitivity results are not compared to observations or theoretical behavior. Please be more specific about the importance of this analysis.

15) Section 4.2, lines 33 (Page 14) and line 1 (page 15): Are these new results or do they include those of Barton et al., 2004, García-Muñoz et al., 2004 and Karakaş et al., 2006? Please specify which part of these results are new or used to confirm previous ones.

16) Section 4.2, line 15 (page 15): "Zooplankton excretion..." What is the explanation of the zooplankton excretion being more important for regenerated production in areas with lateral transport?

17) Section 4.3, lines 17-19 (page 15): "This supports the idea that, ..." Is this sentence in agreement or in opposition to the previous hypothesis? What do other authors say about lateral transport of organic matter in this area?

18) Section 4.3, lines 14-19 (page 16): "For this purpose, we focus...", this sentence should be briefly mentioned before as mentioned in comment 12, and here, it should be improved. Please clarify why this specific setting (maximal coastal upwelling at the Saharan Bank and maximum phytoplankton extension off Cape Blanc) is a good scenario to be tested with the model.

Minor comments/Technical corrections

1) Section "Abstract" line 29: Did you mean "lateral advection transports coastal nutri-

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ents...?"

2) Section "Introduction" line 2: "... and seasonally variable one...". I would remove "one".

3) Section "Introduction" line 29: There is a missing comma, "Here, we ...",

4) Subsection "Model validation" line 22: Are AVHRR initials? If so, they probably should be written in full, here.

5) Subsection "Model validation" line 25: To ease the understanding of Figure 1, I would replace the titles "SeaWiFS/Drifters SVP" and "ROMS" by "Observations" and "Model", respectively. I could not figure it out what SVP means. Then, add in caption "from observation given by SeaWiFS satellite data... Same for ROM-PISCES model in..."

6) Subsection "Model validation" line 6 and 7 (page 5): I would remove "see" from both "see Fig. 1" in this paragraph. I would also move the second fig. reference, line 7, to the end of the sentence: "both in the model and in the data during summer (Fig. 1)". This is, because the NECC is not entirely shown in the figure and creates some confusion if the figure reference is placed after mentioning the NECC.

7a) Subsection "Model validation" line 14 and Figure 1: If maximum values of chlorophyll in both satellite and model data go up to 10 mgChl m^{-3} , why stop at 5 mgChl m^{-3} in the color bar of Fig. 1?

7b) Figure 1: At first I could not see the 5 coastal areas. Maybe by coloring the lines in white, instead of black, the boxes will be more visible. In the caption of Figure 1, "The ten boxes" could also be replaced by "The 5 coastal and 5 offshore boxes", so it is even more clear that the 5 coastal boxes are shown in the figure.

7c) Missing figure: Please remove the sentences "Main surface currents and deep water masses over ... South Atlantic Central Water" or add the missing plot and describe it in the main text, but only if it adds relevant information to the article.

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- 8a) Section 3.1, title: To simplify, why not just call it "Meridional variability in the coastal region"?
- 8b) Section 3.1, title: Maybe add "Annual average of the meridional variability in the coastal region"
- 9) Section 3.1.1, line 7: "on the edge of coastal boxes" gives a vague description of what we are actually looking at in the figure. Maybe replace by "on each edge of the coastal boxes (i.e. North, South, West and bottom)".
- 10a) Figure 2: Are the "BOX" and the black lines needed for figure 2a and 2b? I think they do not add much information, unlike for Fig. 2c, 2d, 2e, and 2f. These plots (Fig. 2a and 2b) alone clearly represent the entire box.
- 10b) Figures 2-3: These figures are good, but they are a bit difficult to get at first (especially Fig. 2, since it is the first one of the series). To make Fig. 2 easier to understand, I would separate the main title "Wind and currents" to "Wind (m s^{-1})" and "Velocities (m s^{-1})". This will make it clear that this figure is showing 2 different things. I would write "Wind (m s^{-1})" on top of Figure 2a and 2b and "Velocities (m s^{-1})" on top of Figures 2b, 2c, 2d, 2e and 2f, as done for Fig. 3. Please use velocities instead of currents, because the word current is not as often used as velocity in the main text. Please also change the title of figure 2c to "c-Bottom (upwelling)" or "c-Bottom (vertical velocities)". The chosen title, "c-Bottom velocity" is misleading, as it suggests horizontal bottom velocities.
- 10c) Please check the sub-numbering of the figures, some do not follow a logic order.
- 11) Section 3.1.2, line 30: Please rephrase "... of PP in the boxes north and south of Cape Blanc are simulated, respectively."
- 12) Section 3.1.3, lines 26-30: This sentence is difficult to follow, maybe rephrase to "... the total rate of change of nitrate concentration and phytoplankton biomass in each coastal box are presented..."

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- 13) Section 3.1.3, line 8: replace "is not anymore" by "is no longer"
- 14) Section 3.1.3, line 13: rephrase "from the northern Saharan Bank and the Senegal-Mauritanian region, respectively."
- 15) Section 3.1.3, line 31 (page 9): remove "tentative"
- 16a) Section 3.2, title: Same as comment 8: To simplify, change it to "Meridional variability in the offshore region".
- 16b) I think, here, the title of section 3.2 should also mention that the results are now only for spring: "Spring meridional variability in the offshore region". For me this was not clear until the discussion.
- 17) Section 3.2.2, line 27: I would remove "finally".
- 18) Section 4, line 10: Please replace "we will seek to explicit" by "we explain"
- 19a) Section 4.3, line 10 (page 17): Space missing, please correct "that filaments"
- 19b) Section 4.3, line 14 (page 17): Please replace "hypothesis" by "processes". The points mentioned before are not hypotheses.
- 20) Figure 8: Same comment as 10a for Figure 2 regarding the black lines and the BOX.
- 21) Figure 11a and 11b are missing.
- 22) Figure 14: Why Fig 14c is suddenly represented with dashed lines? What do the plain and dashed lines represent in Fig. 14d?
- 23) Please check the usage of acronyms, especially in the legend of the figures. I would always use the full subregion names or always the acronyms. Personally, I would avoid the acronyms (also in the text).
- 24) Section 4.3, line 8: Please correct "2ZOLTLathuiliere2008"

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25) I would replace most "see Fig." by "Fig.", except maybe the one in line 24, page 4.

Further suggestions

1) Section 4.1, line 15-16 (page 13): Rephrase "It appears that coastal upwelling" by "However, coastal upwelling". This makes it more clear that this information comes from the literature and not the model results.

2) Section 4.1, line 20 (page 13): Replace "The simulated" by "Our simulated"

3) Section 4.2, line 4: "for 50 % of new production", please indicate if it is a model result or a general statement. Can this be seen in one of the figures? If yes, please indicate in which one.

4) Section 4.2, lines 6-8: Would it be possible to compare this with observations of mixed layer depth (MLD) off Cape Blanc? If the MLD is large there, it will give some extra validation for this result.

5) Section 4.2, lines 9-10: I would replace "Usually" by "In general", and in the following sentence, I would add "However, in our results, the water"

6) Section 4.2, line 35 (page 15): The word "provide" is maybe not the best word, here. I suggest "lead to", instead.

7) Section 4.2, lines 1-2 (page 16): To ease the reading, I would briefly re-mention why this is the case, instead of referring to the previous section. Section 4.1 mentions several points and it is not exactly clear to which one this sentence refers to. I would also remove "(see above)", it is not clear to what it is referring to.

8) Section 4.3, line 27: Please add "In our results, the vertical mixing..." and replace "Indeed" by "This is even more visible in the results for spring, where the mixed layer...".

9) Section 4.3, lines 33-34: To better differentiate between the new results and published data, please rephrase the sentence as follows: " In fact, the vertical mixing, as

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previously suggested by Huntsman and Barber 1977, is also responsible for ..."

10) Section 4.3, line 1: Maybe replace "participate to" by "partly".

11) Section 4.3, line 7: To help the reader, it would be nice to briefly mention what is the hypothesis of Lathuilère et al., 2008.

12) Section 4.3, lines 8-9: To better differentiate between the new results and published data, please add " In our results, the advection by ..." and "...off Cape Blanc, in agreement with Kostianoy and Zatspein, 1996.

13) Section 4.3, line 10: To better differentiate between the new results and published data, please add "may enhanced cross shelf transport, as also shown by satellite data in Lathuilère et al., 2008".

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