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Biogeosciences
Discussions

Interactive comment on "What controls biological productivity in coastal upwelling systems? Insights from a comparative modeling study" *by* Z. Lachkar and N. Gruber

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We would like to thank this reviewer for his positive comments and suggestions that have helped to improve the quality of our manuscript. Subject to the editor's agreement, our plan is to submit a revised manuscript for publication in Biogeosciences.

Response to Reviewer's Comments:

This paper propose a comparative modeling study between the California Current System and the Canary Current System. The authors take advantage of the modeling approach to test hypothesis explaining the observed difference in primary production between the two ecosystems. Although the study is elegant and

the results are attractive, some major mechanism for primary production were not discussed. Thus, in order to improve the discussion of the paper I suggest the points listed below should be addressed.

1 - Limitation for phytoplankton growth: In the biogeochemical model used, the only possible nutrient limitation to primary production is the nitrate. However, a number of studies have shown or suggested the importance of iron or other micro-nutrients as limiting factors for primary productivity in EBUS (eg : Echevin et al., 2008; Chavez and Messié, 2009; etc...). Furthermore, it is well known in the Canary CS that Saharan dust events, carrying in particular iron over the ocean, can generate phytoplankton bloom independently from upwelling enrichment (Rijkenberg et al., 2008; Ohde and Siegel, 2010; etc...). Iron limitation was also suggested in California CS (Hutching et al., 1998). Then, if atmospheric enrichment is a specificity of the Canary CS, this should be at least discussed in your paper as another possible explanation for the more efficient use of the nutrients in the Canary CS.

Done. We now discuss in the revised manuscript the iron limitation hypothesis and we mention that it could contribute to the observed differences in NPP between the Canary CS and the California CS (see section 3.7, pages 19, 20 Introduction section, page 4, lines 4-9). However, given that a large fraction of the observed NPP contrasts could be explained in our study by physical processes alone without the need to invoke iron-limitation, we maintain our position that our (obviously limited) approach involving a relatively simple ecosystem model is fully adequate to determine the processes underlying (most of) the observed differences. This is consistent with previous findings that biogeochemical and ecological differences between different sites tend to be primarily controlled by the physical environment and depend less on ecosystem model complexity (Friedrichs et al., 2006). This point is now clearly discussed in the revised manuscript (see section 2.3, page 11, lines 11-21). See also our response to Referee 2 below.

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2 - Effect of eddies: Why should eddies reduce plankton residence time in the upwelling area? This non-intuitive result should be explained more in details. No doubt that eddies will increase the mixing of upwelled water with oceanic water, but the implication on plankton retention is not straightforward. In the literature, observations frequently report eddies as retention areas (e.g. Heywood and Priddle, 1987; see Rodriguez et al. 2004 for a review). The main source of offshore transport in the Canary CS comes from the upwelling filament structures, which generate an offshore transport significantly larger than Ekman transport (Kostianoy and Zatsepin, 1996; Navarro-PéÌArezËŻ and Barton, 1998, Pelegri et al., 2005a, Pelegri et al.. 2005b). Upwelling filaments are not eddies, but their westward movement is linked to vorticity conservation and then by removing the non-linear term in the momentum equation you may lose them as well. This experiment deserves much more description and analysis to be well understood by the reader. I suppose it is done in Gruber et al. (2011) but I could not find this reference, is it published yet? Furthermore, the effect of eddy on primary production is not neutral, and it is different between cyclonic and anticyclonic eddies (local enrichment, concentration,. . . e.g. Falkowski et al., 1991, Oschlies et Garçon, 1998, etc...). This effect might be more complex than just changing the plankton residence time in a given area, and this should be mentioned in your paper. See also Roughan et al. (2006) for a discussion on how mesoscale activity in the California CS impacts the retention of plankton inshore.

Given the complexity of the question raised by the reviewer and the variety of aspects it touches upon, we structure our response around the 4 main points invoked by the Referee:

1) - Mechanisms of the action of eddies from Gruber et al (2001):

The Gruber et al (2011) paper, which describes the mechanism of eddy-induced subduction and offshore transport of nutrients and organic matter, will be published on

October 2, 2011 by Nature Geoscience (http://www.nature.com/ngeo/index.html) (a preprint can be downloaded from: http://www.up.ethz.ch/people/ngruber/publications/gruber_natgeo_resubm_jun11.pdf.) This paper shows that mesoscale processes in EBUS substantially enhance the offshore transport in the near surface of the first ca 100 km, hence providing a mechanism explaining the shorter residence times in the coastal zone revealed in the present study. This mechanism as well as the link to water residence times is now clarified in the revised version of the manuscript (see lines 12-14, page 17, section 3.5). We also updated the Gruber et al (2011) reference with a link pointing to an online copy of the paper.

2) – Eddies or filaments?

Our analysis reveals the integrated effect of all mesoscale processes on the residence times in the coastal zone. These include eddies, filaments and the whole range of mesoscale coherent structures associated with baroclinic and frontal instabilities. For more accuracy we substituted in the revised manuscript the term “mesoscale eddies” by “mesoscale processes” or “mesoscale activity” which is inclusive of filaments.

3)- Do eddies enhance retention or increase dispersion?

The eddy-trapping effect reported in previous studies (e.g., Lobel and Robinson 1986, Lobel 1989, Logerwell and Smith, 2001, Rodriguez et al, 2004) is not in contradiction with the eddy-induced offshore transport demonstrated in Gruber et al (2011). This is because the first relates to a local reduction of relative dispersion (typically within the core of the eddy) while the second expresses an increase in the absolute dispersion, reflected in a nearshore-offshore translation of newly upwelled water.

The computation of coastal residence times constitutes a metric of “absolute” dispersion (defined as the mean square particles displacement from their starting position) (Taylor, 1921), whereas the eddy-trapping or retention effect (inversely proportional to the spreading of cloud of particles) is a proxy for relative dispersion (defined as the mean square particle relative distance or separation). The first quantifies cluster advection, the second distorsion and diffusion (Babiano, 1990).

4)- Effects of eddies are more complex than just changing residence times

We fully agree with the reviewer in that the effects of eddies are much more complex than just changing the plankton residence times. For instance, Gruber et al (2011) demonstrate that mesoscale processes, through their increase in the offshore transport of nutrients, tends to reduce the nutrient concentrations in the thermocline of the nearshore region, thereby having an overall reducing effect on primary and export production. In the present study, we focus on the role of eddies for explaining the shorter residence times that characterize the California CS in comparison to the Canary CS. This is driven by our desire to explain the difference in nutrient use efficiency between the 2 upwelling systems. This point is now being discussed in the revised manuscript (see text in section 3.7 from page 19, line 24 to page 20, line 3).

3 – Seasonality: The inter-regional comparison analysis was done between static states corresponding to the mean annual primary production. However, the upwelling seasonality is very strong in the Californian CS: during the winter the upwelling stops and a northward current, the Davidson Current, develops at the surface from the shore to 100 km offshore (Carr et al. 2008). Conversely, in the Canary CS the upwelling is permanent north of Cape Blanc (21âŮę N) (Machu et al. 2009). Comparing the annual average primary production between two regions with different upwelling seasonality can potentially lead to misinterpretation of the underlying mechanism. For example, the higher annual mean productivity in the Canary CS compared to California CS could be a consequence of its longer upwelling season. A few sentences are needed to clarify this point.

We agree with the reviewer that the upwelling seasonality varies substantially between and within these two upwelling systems. Yet, we believe that this difference is not an issue for our comparison since we analyze production in each EBUS in relation to nutrient availability, i.e. to the total inorganic nitrogen (TIN) concentration. We show, that the

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relationship of NPP to TIN is different between the two upwelling systems and that the Canary CS is substantially more productive than the California CS for a given amount of nutrients. Therefore, the differences between the two upwelling systems cannot be attributed only to the upwelling intensity or duration, but rather have to do with the nutrient use efficiency in each EBUS. These differences in the nutrient utilization efficiency between Pacific EBUS and Atlantic EBUS have already been documented in previous observational studies (e.g., Minas et 1986, Carr and Kearns, 2003, Lachkar and Gruber, 2011). This point is now discussed in the revised version of manuscript (see section 3.7). In addition, we also show now that the differences in nutrient use-efficiency between the two upwelling systems are important even when the analysis is done with monthly outputs (see our new Table 4).

Technical corrections:

P5623 line 24 : please give the range for euphotique depth in Canary and Californian CS.

Done. In the revised manuscript, we give the range of the euphotic depth variation over the first 300 km from the coast. See section 2.2, page 8, lines 2-3.

P5637 : Chavez and Messié (2009) is in your reference list but I didn't ïňĄnd it in the text.

This reference is now cited in the text. See section 3.7, page 19, line 16.

Interactive comment on Biogeosciences Discuss., 8, 5617, 2011.