The authors are grateful for the thoughtful comments given by the two anonymous referees on our paper. Below, we respond to each point raised by the reviewers and explain the changes we've made to the manuscript accordingly. The reviewers' comments are shown below in italics writing while our response is indicated in a red font.

Anonymous Referee #1

Received and published: 4 March 2020

We are grateful for the first referee's efforts in reviewing the manuscript. We believe our paper has significantly improved as a result of his/her comments. Below, we highlight our responses to the general and specific comments and explain the revisions we've made to the paper accordingly.

General comments

The paper by Hailegeorgis et al. examined upwelling and transport patterns in the Canary Current System using a Lagrangian modeling approach. The authors identified latitudinal variability in water and nitrogen export, determined transit time of water parcels from the coast to the oligotrophic oceanic region, examined the role of major capes as drivers of upwelling and offshore transport, and quantified the coastal upwelling contribution to the nitrogen stock in the North Atlantic Tropical Gyral and the North Atlantic Subtropical Gyral East. Overall, I think that the paper does an interesting contribution to the understanding of nitrogen export patterns in the Canary Current System. However, important changes need to be made in order to recommend publication.

My main concerns are two:

1) The paper is not easy reading:

There are a lot of results and figures with multiple panels and supplement figures, which made fuzzy the paper's main points. There is some redundancy in the reported results. Subregional patterns not always showed important differences, so not sure if you always need reporting all subregional results in the paper main body (you can move some Figure's panels to the Supplement).

In order to solve the redundancy and lengthiness issues in the main paper, we will merge some subsections as well as remove figures/panels (some of which will be moved to the supplementary). More specifically:

- We will move the model validation (including Fig1, Fig 2 and Fig3) into the Supplementary section following the reviewer comment 6.
- We will merge subsections 3.1 and 3.2 so there is now no subsection in Section 3.
- We will merge Figure 5 and Figure 6 in one single figure and move some of their sub-panels to the supplementary.

- We will merge and consolidate subsections 4.4 and 4.5 into one subsection 4.4 titled "Structure of offshore transport", which includes results on depth structure and horizontal structure of the offshore transport.
- Figure 9 will be moved to the supplementary as suggested by the reviewer (see below)
- Figure 10 panels c-h will be moved to the supplementary
- We will merge Figure 10 (panels a-b) and Fig 11 in one figure.

2) The manuscript length could be reduced, trying a better integration of the paper results. Results and discussion were mixed, which did not help to get the present study contribution.

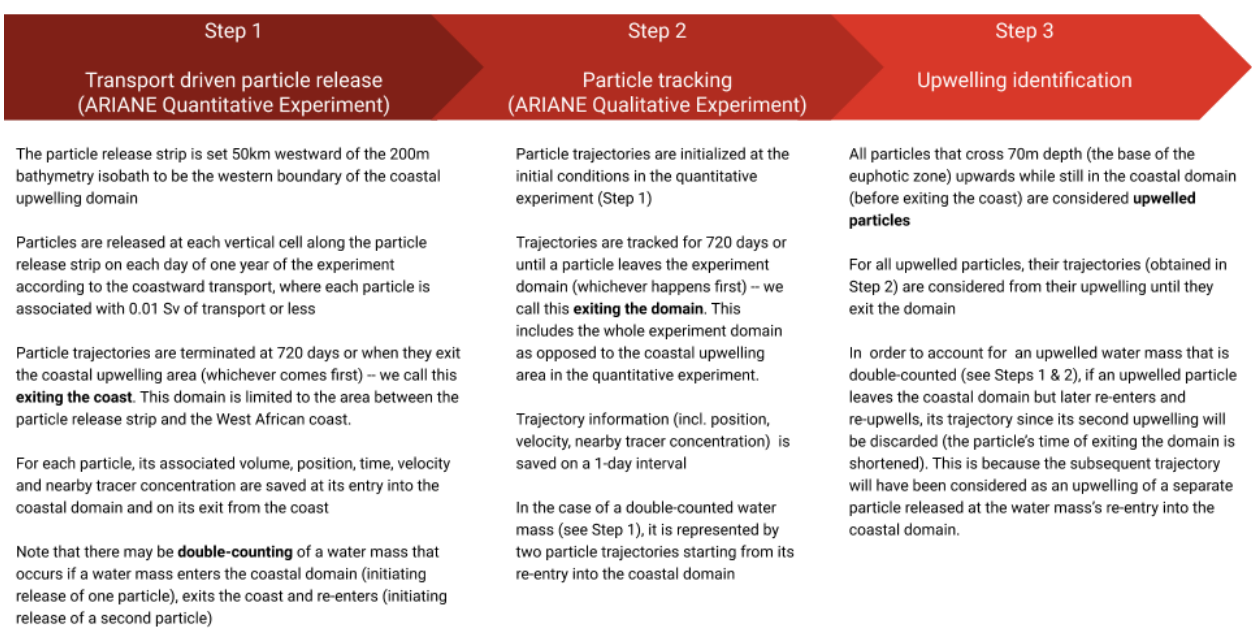
We will significantly shorten the paper and consolidate multiple sections (please see our response to previous comment).

I am not an English native speaker, but below (specific comments) I made a series of suggestions to help making sentences more concise and clear.

3) The authors need explaining much clearly how all the Lagrangian patterns were calculated in the Method section.

We will move some important details of the Lagrangian experiment from the supplementary text into Section 2.2.

We will also improve the description of the Lagrangian experiment by adding a schematic that summarizes the different steps followed to quantify the Lagrangian offshore transport (shown below).



We then will add details on ARIANE's quantitative and qualitative experiments from what used to be in the supplementary text. As part of the quantitative experiment, we explain how we save the initial condition (including associated volume) of a particle release and keep track of particle recirculation in and out of the coastal upwelling area. Many important details are mentioned here including the particle release period of one year, the release of particles over all the cells vertically along the particle release strip, the maximum volume associated with particles, etc. As part of the qualitative experiment, we explain details including the maximum length of trajectories and the frequency at which they are saved, the information saved about each particle along its trajectory and the portion of particles that leave the experiment domain early.
We also indicate in this subsection that (1) ARIANE neglects vertical mixing in its computation of particle trajectories and (2) although the validity of the assumption of incompressibility of ocean water conserves the water flow in and out of streamtubes, ARIANE doesn't have a stochastic noise term to model diffusion along particle trajectories, although diffusion is included in the model.

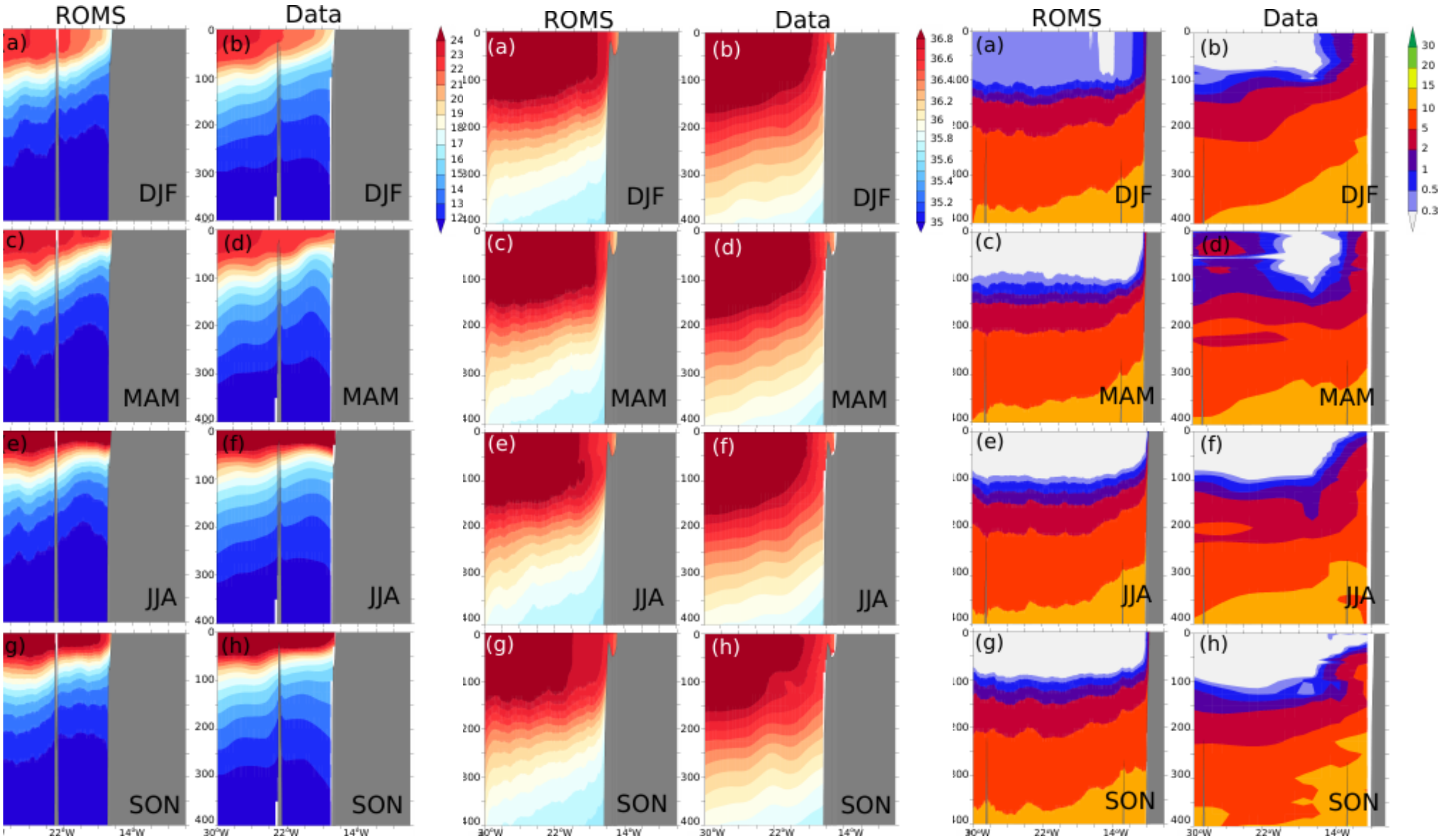
4) Model validation:

The authors need to include vertical sections and vertical profiles from the modeled variables and compare them with observations (WOA sections would be OK). I would like to see whether the vertical patterns in the model outputs have any significant bias. Is the nutricline depth consistent with observed patterns across the model domain? Is the model reproducing well the seasonal variability in vertical patterns? It is not enough the correlation analysis in Fig. 1 from the Supplement, since well-correlated variables can have important differences in terms of magnitude.

We agree with the reviewer. We have produced validations of vertical cross sections of temperature, salinity and nitrate (WOA) for each subregion and for each season.

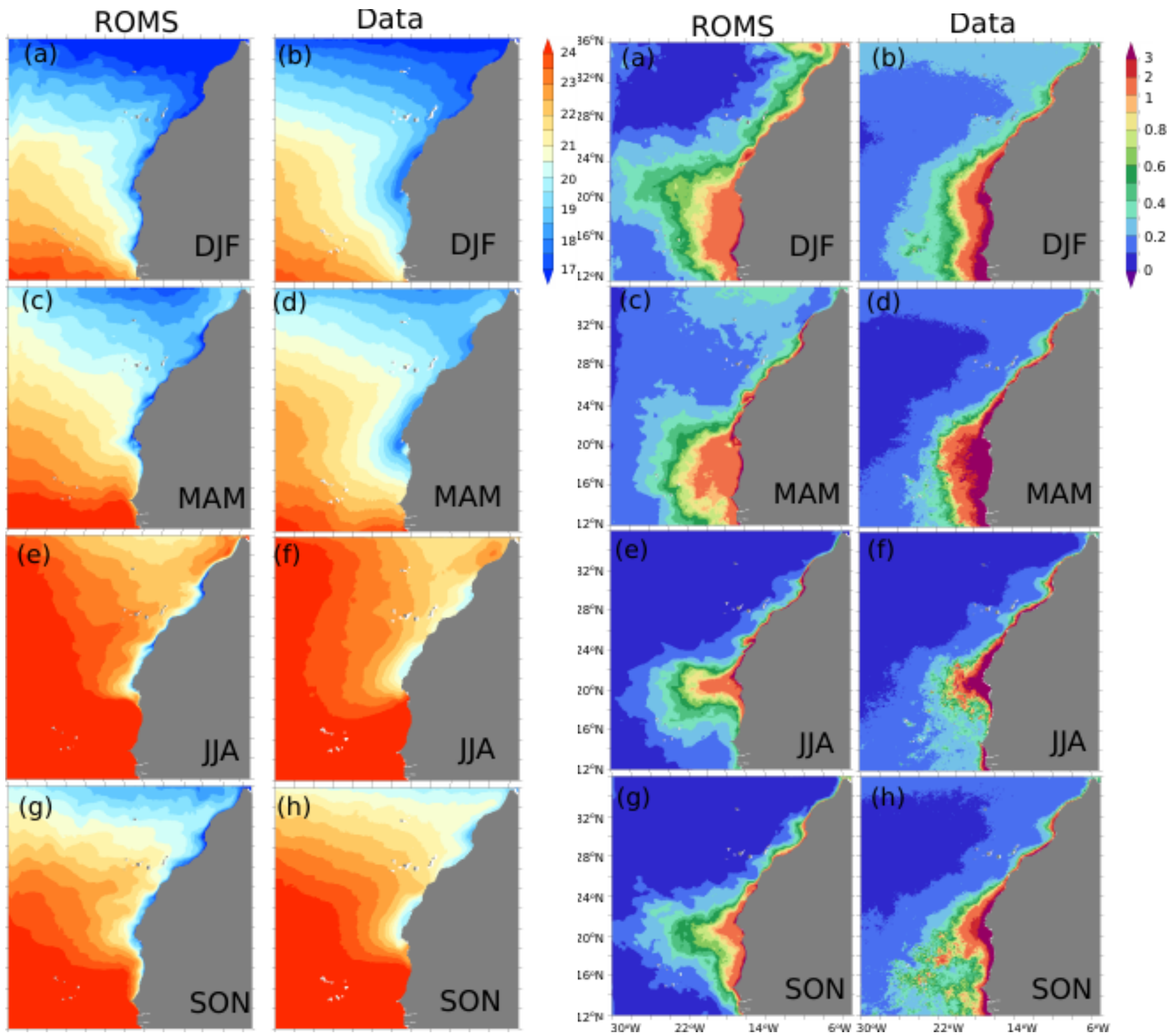
The model generally does a good job in reproducing the vertical variability in observations for all three variables across the different seasons. We present our evaluation with more detail under Model Evaluation which will be presented in the supplementary material.

As examples, the figures below show seasonal validations of vertical cross sections of (from left to right) temperature at 16N, salinity at 25N and nitrate at 30N. Each of these sample plots is taken from a distinct subregion in our experiment.



5) Since a correlation analysis per se does not show a potential bias in the simulated variables, besides the annual mean patterns shown in Fig. 2. I would like to see a comparison for mean seasonal patterns of SST and surface chlorophyll.

We have produced seasonal validation maps of SST (Pathfinder) and chlorophyll (SeaWIFS) (shown below, in that order)



Furthermore, we have added a comparison of modeled mixed layer depth (MLD) to observations in all seasons (please see our response to comment #20)

6) To reduce paper length, I recommend including the model validation as an independent section in the Supplement.

Following the reviewer's suggestion, we will move the model validation to the supplementary.

Specific comments:

7) Please, refer to the supplement figures as Figure S1, Figure S2, etc. It was confusing when a paper and supplement figures were mentioned at the same time. As example, *instead of using (Fig. 7 and Fig. 8, SI), use (Fig. 7 and Fig. S8).*

We will make these changes.

8) Abstract
Pag.1, L11: "Our model analysis suggests that the vast majority of the upwelled waters originate from offshore and below the euphotic zone (70m depth), and once upwelled remain in the top 100m". I understand what you mean, but the statement is not clear. Consider that you defined upwelling as a water parcel crossing the 70 m depth level.

We agree with the referee. We will change this statement to:
"Our model analysis suggests that the vast majority of the upwelled waters remain in the top 100m."

9) Introduction
Pag.2, L13-14: The sentence "leading to substantial modifications of the biogeochemical cycles there" is ambiguous. You could delete it.

The sentence will be deleted.

10) Pag.2, L20: delete "potentially"

The correction will be made.

11) Pag.2, L32: delete "potentially"

The correction will be made.

12) Pag.3, L10: "surface jet associated with the upwelling flowing equatorward" => "surface jet associated with the coastal upwelling front, which flows equatorward"

The correction will be made.

13) Pag.4, L6: "and therefore did not estimate" => "so did not estimate".

The correction will be made.

14) Pag.4, L8-10: These sentences need additional work. Explain better but concise.

When it comes to the quantification of the contribution of the Canary upwelling to the open ocean nitrogen budget, the Lagrangian approach presents a couple of advantages relative to the Eulerian approach. Because of its focus on water particle trajectories, Lagrangian tracking of water masses is better suited for the analysis of connectivity between the coastal and the open ocean regions. Furthermore, the Lagrangian method can be used to derive conditional statistics where subsets of particles that fulfill certain criteria are analyzed. This is useful for instance to restrict the analysis of offshore transport to upwelling particles only.

This will be better explained in the revised manuscript.

15) Pag.4, L13: What do you mean with "quantify the reach"

We will modify this to 'quantify the offshore reach'.

16) Pag.4, L13: "the spatial structure and the dominant timescales"

We will make this change.

17) Pag.4, L23-24: and quantifying the offshore export

We will make this change.

18) Pag.4, L24: "We also investigate"

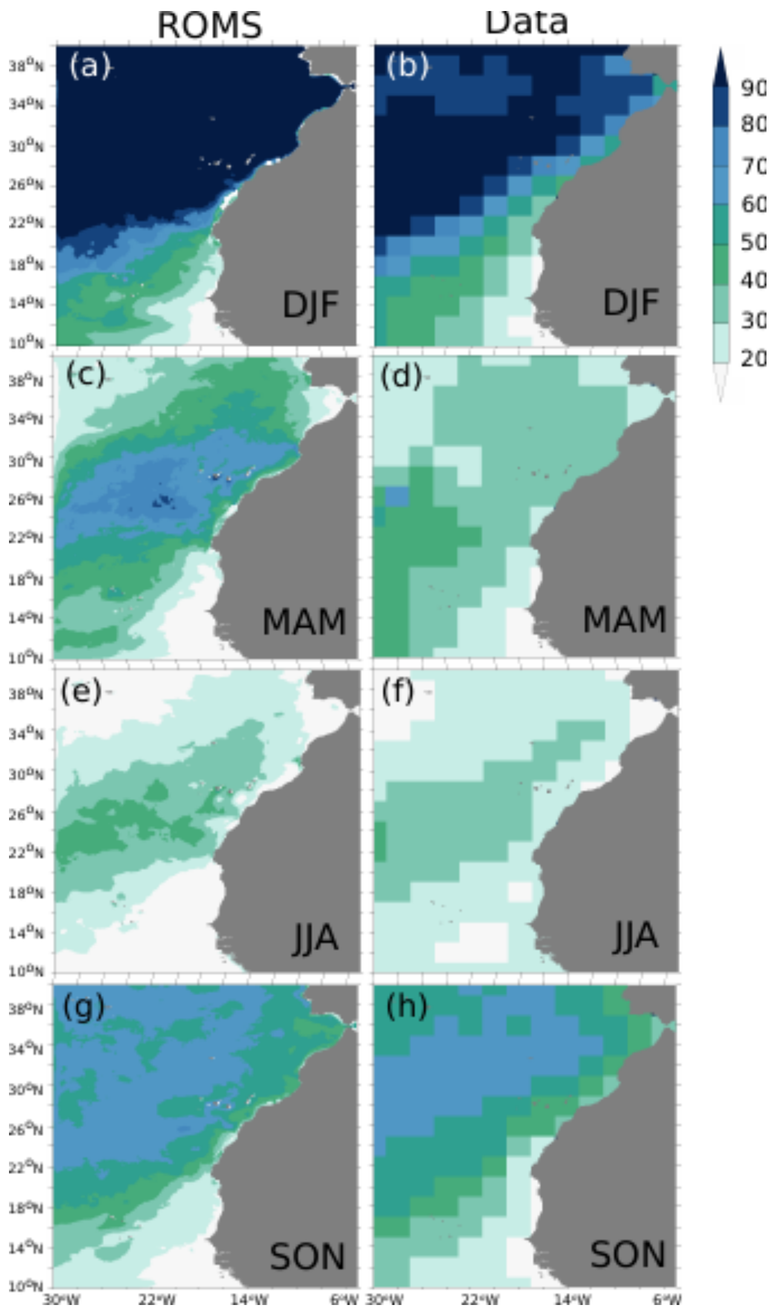
We will make this change.

19) Methods
Pag.5, L2: Was bottom remineralization included in the model? This is a relevant source of nitrogen, which can largely influence inorganic nitrogen patterns on the shelf. If it was not considered, you should mention it as another limitation in the study.

Yes, the sinking particulate organic matter that reaches the seafloor is remineralized back into ammonium at a slower rate (0.003 d^{-1}) than in the water column (0.03 d^{-1} for small detritus and 0.01 d^{-1} for large detritus). We will add that explanation and a reference to Gruber et al. (2006).

20) Pag.5, L14-15: Did you use a monthly climatology for wind stress? If this is the case, vertical mixing was probably underestimated. Did you compare the simulated mixed layer depth with observations?

We used a monthly wind climatology (QuickSCAT SCOW). We have added a comparison of the modeled mixed layer depth (MLD) with observations (will be shown in supplementary materials) for all seasons. Using a monthly climatology forcing likely contributes to the underestimation of EKE shown in Fig 1. However, much of the spatial and seasonal variability in upper ocean mixing is still captured by the model as can be seen in the figure below. This is particularly true in the summer and fall when the simulated MLD agrees the most with observations. This will be explicitly discussed in the revised manuscript.

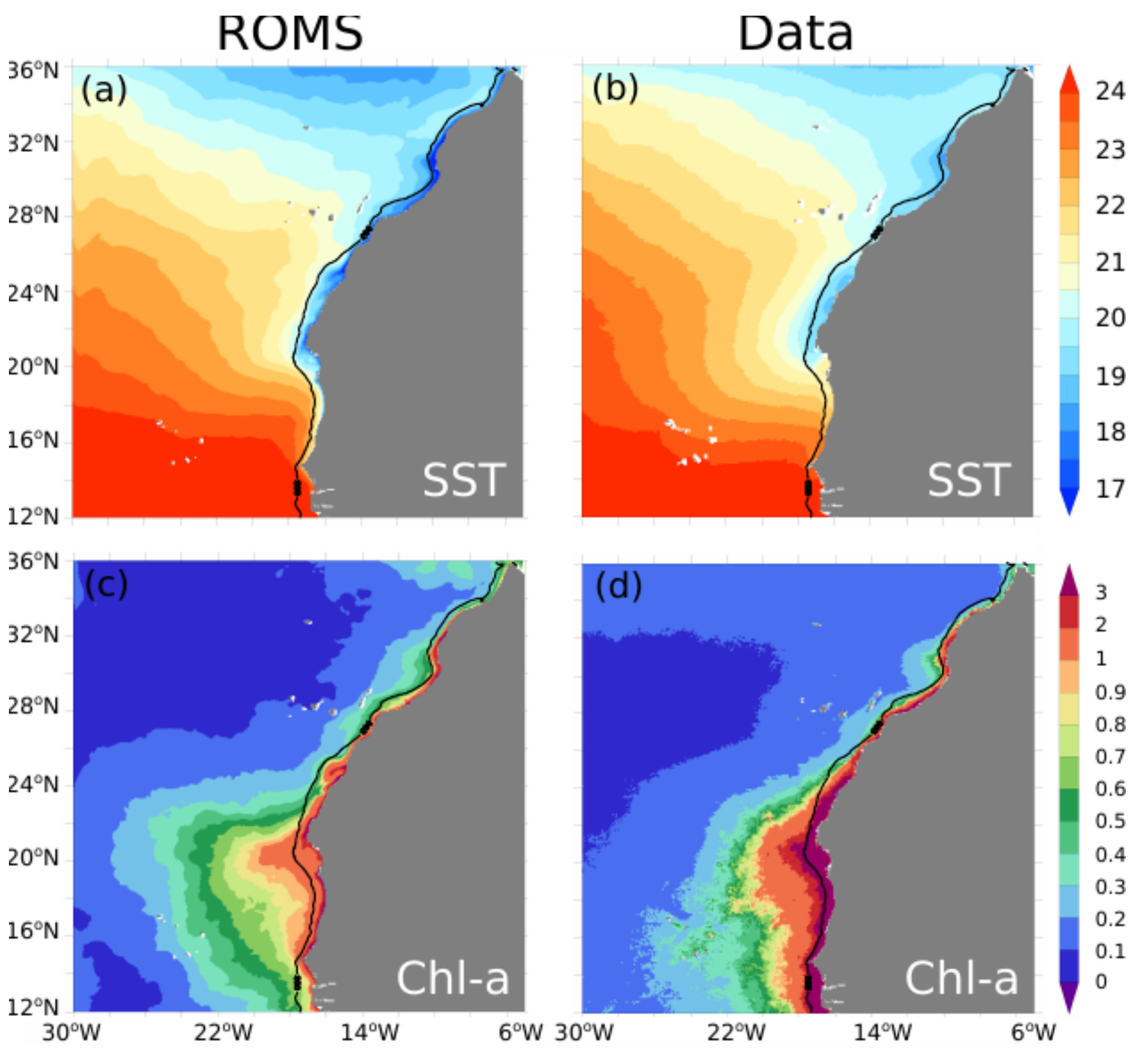


21) Pag.5, L17-18: It was mentioned that the model was spun up by 12 years, and the study was based in simulation years 10 to 12. So does it mean that you used the last 3 years of your model spin up for the analysis? If this is the case, you have to report that the model was spun up by 9 years.

Yes, we did spin up for 9 years then used years 10-12 to run the experiment. This correction will be made.

22) Figures 1 and 2: I suggest including the 200 m isobath (shelf break) as a contour line on the maps.

This change has been made as can be seen in the reproduction of Figure 2 below.



23) Pag.9, L2: It is Figure 2 not 1.

We will make this change.

24) Pag.9, L14: Indicate that vertical mixing is not considered in the Lagrangian analysis

This will be clarified.

25) Pag.9, L25: Since the dominant circulation pattern in the CanCS appears to be along-shore, I am wondering why only oceanic particles were considered in the Lagrangian experiment. I would expect that upwelled particles also come from the northern and southern boundaries. Could the poleward undercurrent be a source for upwelled waters?

It is true that potential upwelling driven by waters entering the coastal zone at 14N and 35N were not included. We acknowledge this among the study's caveats.

Our choice to only allow open ocean particle releases was dictated by technical constraints in Ariane that prevent individual segments to be considered simultaneously as entry and exit sections. Yet, in order to quantify the potential error associated with our simplification we have run a separate experiment where particles were allowed to enter the coastal ocean from the southern and northern boundaries of the upwelling strip. Our analysis reveals that we are missing only a very small amount of water by our choice, i.e., only about 1% and 3% of the total volume tracked in this study come through the northern and southern boundaries , respectively.

Furthermore, given the high rate of recirculation near the coast, a vast proportion of the particles that may have entered the coast alongshore, once upwelled and exported offshore, are likely to return to the coast from the open ocean, in which case they would be sampled in our particle release.

We conclude that discarding particles entering the coastal ocean from the southern and northern boundaries of the upwelling strip is likely to cause only a limited error in our quantification of the offshore transport.

We will further highlight this caveat and discuss its potential implications in the revised manuscript based on the arguments developed above.

26) Results
Pag.13 L7: "onshore-offshore contrast" => "cross-shore differences"

We will make this change.

27) Pag.13 L9: "followed by a second one at around 50 km from the shore" => "and a secondary maximum around 50 km"

We will make this change.

28) Pag.13, L20. Shallow regions should also show upwelling because a distance of 50 km from the shelf break was considered for the analysis. Right? Clarify.

The reason there is no upwelling at the very coast in these regions is that the bathymetry is shallower than 70m, therefore making it impossible to meet our criteria for upwelling where a particle crosses the 70m depth. The minimum bathymetry allowed by the model is 50 m and that will be added to the model's description in section 2.1.1 as Reviewer 2 has also requested (see below). However, as mentioned by the referee we sample upwelling further offshore in these locations. Therefore, for more clarity we will change the statement to: "our experiment identifies limited coastal upwelling south of Cape Blanc and between Capes Barbas and Bojador because their bathymetry is shallower than the 70 m upwelling depth criterion used here".

29) Pag.13, L25: what is the range considered for the upwelling zonal integration in Figure 6a (same for Figure 5a).

We integrate zonally across the coastal stripe (Between the coast and 50 km westward of the 200m bathymetry). We will add this clarification to the captions of Fig5 and Fig6.

30) Pag.13, L26-28: Wondering if the shallow nutricline is linked to the high-nutrient SACW or not.

No. The shallow nutricline is a consequence of the shallow thermocline which is caused by the stronger stratification in the tropics in comparison with the high latitudes.

31) Pag13, L28-29: "The central subregion has a moderate nitrogen flux associated with upwelling while the northern subregion has the weakest upwelling flux of nitrogen" => "The weakest upwelling-driven nitrogen flux was in the northern subregion"

We will make this change.

32) Pag.13, L30: "disproportionately lower" => "much lower"

We prefer to use the statement "disproportionately lower" to better highlight the fact that the ratio of upwelled nitrogen to upwelled water volume is higher near the coast than it is further offshore as suggested by Figures 5 & 6.

33) Pag.15: It is important to note that a water parcel released in region A can be upwelled in subregion B or C. Beside, a water parcel upwelled in region A can be transported away to region B or C. Consequently, the parcel transport not necessarily depends on the oceanographic conditions in region A. If I'm right, I suggest revisiting all sentences describing subregional offshore transport results. As example, I would modify "the offshore transport is fastest in the central subregion and slowest in the northern subregion" by "the particle upwelled in the central and northern subregions displayed the fastest and slowest offshore transport, respectively". Besides, I would change "At larger distances from the coast (beyond 400 km), the offshore transport becomes faster in the southern subregion" by "The fastest water parcels beyond 400 km from the coast are those upwelled in the southern subregion"

We will follow this suggestion and correct the way we express transport from each subregion accordingly.

34) Pag.15, L3: define "transit time".

We will add the transit time definition from the caption of Table 2 here.

35) Pag.15, L15-16: Why is this maximum at 150 km? Does it mean that a greater fraction of water parcels remains around this distance? Is this linked to patterns in alongshore circulation?

In the revised manuscript we explain that the distance of maximum transport corresponds to the distance reached by most sampled upwelled water (nitrogen). It is around 150km (that roughly corresponds to the width of the upwelling stripe) because at closer distances to the coast (<100-150km), upwelled volume is only partially sampled. Farther distances (>100-150km) are never reached by a proportion of particles because of recirculation retaining them close to the coast and alongshore transport exporting some particles out of the model domain.

36) Pag.15: L22: "This is because of its low offshore transport efficiency and the relatively low volume of upwelling" => ''Reduced coastal upwelling and low offshore transport efficiency explain this pattern."

We will make this change.

37) Pag.15, L22: Define transport efficiency.

Transport efficiency (the ratio of net offshore transport at a given distance to upwelling volume or nitrogen amount) will be defined in the Lagrangian experiment details (Section 2.2).

38) Table 2: It may be informative reporting the standard deviation for transit time.

We will replace Table 2 with a graph of transit times featuring error bars.

39) Pag.16, L3-5: "At close to 150 km from the coast (corresponding to the edge of the coastal upwelling stripe), the offshore transport of nitrogen reaches its maximum, reaching values as large as 500 Gmol yr−1. Thereafter, the offshore transport decreases exponentially" => "Around 150 km from the coast, the nitrogen transport reaches values as large as 500 Gmol yr-1 at 200 km, decreasing exponentially further offshore"

We will make this change.

40) Pag.16, L7: "In spite of having the lowest offshore transport of water, the southern subregion exports the highest amount of nitrogen offshore at 200 km" => "Although offshore water transport was minima in the southern CanCS, this subregion has the greatest offshore export of nitrogen."

We will make this change.

41) Pag.16, L9: "At larger distances from the coast, the situation reverses." => "This pattern reverses further offshore"

We will make this change.

42) Pag.18, L2-4: I disagree with this statement: "so that beyond the nearshore 50 km region, inorganic nitrogen in the form of nitrate dominates the nitrogen pool at all distances from the coast". NO3 dominates almost everywhere, and its contribution to total nitrogen is actually much larger in the coastal region than in the oceanic region.

We agree with the referee that NO_3^- dominates nearly everywhere. Yet, in the nearshore 50km region, the sum of all organic nitrogen (in both plankton and detritus forms) can exceed that of nitrate as shown by the fraction of organic N in the offshore transport (red dashed curve) in Figure 8.

43) Pag.18, L21-34: It would be nice having a brief introductory explanation for the motivation of the analysis in this subsection. As example, evaluate the impact of subduction on transit time, impact of subduction on nutrient fluxes or nutrient cycling.

We will add introductory statements in the beginning of this subsection on the potential impact of vertical structure of offshore transport (subduction) on transit times and offshore transport efficiency to serve as motivation for the depth structure analysis. At the end of the subsection, these potential links are revisited based on the analysis that has just been presented. In general, subduction increases transit times (slows down offshore transport) since velocities deeper in the water column are smaller. However, subduction can also increase the efficiency of offshore transport by minimizing the depletion of nitrogen in surface waters.

Elsewhere in the original draft, we've also related subduction of water particles with filament activity (same subsection on page 18) and with nitrogen offshore transport efficiency (Pg 31, Sec 8, Par 3 & Pg 32, Sec 9, Par 1).

44) Pag.18, L21: "Upwelling particles that..." => "Upwelled particles that..."

We will make this change.

45) Pag.18, L22: How do patterns in Fig. 8a,b from the supplement were calculated?

To make Figure 8 a (or b), we first considered all downward (or upward) movements of all particles across the horizontal plane at 50m depth. After finely binning the horizontal surface across the model, we added the associated volumes of all particles that crossed this depth downward (or upward) for each binned area throughout the 2 year particle trajectory experiment. We will add more detail to the caption of Fig. 8S to show this more clearly.

Although Fig. 8c gives the dominant vertical transport (upward or downward) in the modeled region, panels (a) and (b) also complement this information by giving the full picture of where the upward and downward transport occurs during the whole 2 year experiment. Panels (a) and (b), for example, show that although the coast is dominated by an upwelling flux, it also features significant downwelling.

46) Pag.18, L24: I cannot see the secondary upwelling in the open ocean. Describe better.

It is true that Figure 10d doesn't show significant upwelling flux for particles upwelled in the southern subregion except for a subsurface upward transport maxima in the first 300km from coast. So we will only cite Figure 8S(c), which does show strong net upward transport (upwelling) in the open ocean in the southern CanCS, which has significant overlap with the trajectory of the upwelling from this subregion.

47) Pag.18, L30: It is not evident for me why persistent filaments contribute to enhanced subduction. Explain.

Here, we are referring to the role of filaments in squirting cold upwelled water offshore and the subsequent subduction of this cold water due to its high density compared to the open ocean's warmer surface water. We will add a sentence stating this fact including a reference to Lovecchio et al. (2018), who found filaments to cause subduction of organic nitrogen, for example, to depths larger than 100m.

48) Figure 9: I recommend include this figure in the Supplement.

We will make this change.

49) Pag.20. Indicate what the positive/negative values in Fig. 10 represent

We will make this change.

50) Pag.21. Indicate what the positive/negative values in Fig. 11 represent

We will make this change.

51) Pag.22, L26: "offshore transport of upwelled particles"

We will make this change.

52) Pag.22, L30: I am not sure whether remotely upwelled water is a good term. I would prefer describing the results in terms of local and non-local upwelling.

We will change all references to remote upwelling to non-local upwelling.

53) Pag. 22, L32: "water upwelled"

We will make this change.

54) Pag. 23: L1: "Corresponding enhancement in local nitrogen upwelling and export is seen only in" => "Increased offshore transport of nitrogen due to increased local upwelling is seen only in"

We will make this change.

55) Caption of Figure 12: "Transport by water upwelling locally" => "Transport associated with locally upwelled water"
"Transport by particles that leave the coastal upwelling region at each cape or non-cape area but upwell remotely" => "Transport associated with remotely upwelled water"

We will make these changes.("Transport associated with remotely upwelled water at each cape or non-cape area").

56) Pag.24, L1-2: "The offshore transport of nitrogen by remote upwelling exported by all capes constitutes more than 30% of the total offshore transport of upwelling" => "Remotely upwelled waters that are transported offshore around major capes represent more than 30% of the total transport"

We will make this change.

57) Pag.24, L4-5: "In fact, all capes source the majority of water and nitrogen they export from remote upwelling (Table 3). All capes also source more of their export from remote upwelling compared to the rest of the coast." => "Indeed, most of the water and nitrogen exported offshore around major capes is non-locally upwelled (Table 3)"

The second sentence is meant to show the high export of non-local upwelling that occurs at capes compared to the non-cape coast. But the phrasing was unclear so we will modify it slightly.

58) Pag.27, L10: For consistency use CanCS

We will make this change.

59) Pag.27, L21-29: I did not understand. Please, explain better how did you estimate the CanCS contribution to the NATR and NASE provinces.

We have added a brief clarification of our calculation. Briefly, it is as follows.

We explain that whenever a particle enters a province within the top 100m, the nitrogen it carries into the province is added to the particle's source subregion's contribution to the province. On the contrary, when a particle from a given subregion leaves a province within the top 100m, the nitrogen it carries with it when it leaves the province is subtracted from the contribution of the subregion of the particle to the province.

We use precise Longhurst province boundaries for our analysis. Analysis of crossing into and out of a province is determined based on a daily resolution of particle positions since that is the resolution of our Lagrangian trajectories.